A Documentation of the Mintz-Araraka
Two-Level Atmospheric General Circulation Model

W. L. Gates, E. S. Batten, A. B. Kahle and A. B. Nelson

A Report prepared for
ADVANCED RESEARCH PROJECTS AGENCY
This research is supported by the Advanced Research Projects Agency under Contract No. DAHC15 67 C 0141. Views or conclusions contained in this study should not be interpreted as representing the official opinion or policy of Rand or of ARPA.
A DOCUMENTATION OF THE MINTZ-ARAKAWA TWO-LEVEL ATMOSPHERE GENERAL CIRCULATION MODEL

Summary of the physical bases of the Mintz-Arakawa two-level atmospheric model and presentation of numerical procedures and computer program for its execution. Discussion covers the physics of the model, with particular attention given to the treatment of the moisture and heat sources, including parameterization of convective processes, cloudiness, and radiation. Numerical approximations and finite-difference equations used in the numerical simulations are also given. Throughout the documentation, emphasis is on the specific details of the model in its present form, rather than on derivation or justification of its present design. To facilitate the use of this model, a complete listing of the code as written in FORTRAN language is given, together with a description of all constants and parameters used. Also included are a dictionary of FORTRAN variables and a dictionary of principal physical features. To illustrate the model's performance, samples of its solutions are given for selected variables at a specific time.
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This documentation describes the two-level Mintz-Arakawa atmospheric general circulation model developed by Professors Mintz and Arakawa of the Department of Meteorology, University of California, Los Angeles. This is the first of a series of numerical models of the global circulation being used at Rand in a research program on the dynamics of climate. Through the selective alteration of the model's initial and boundary conditions, and of the model's physical and numerical treatment of atmospheric processes, it is planned that the sensitivity and response of the world's climates to either deliberate or inadvertent modification be explored. It is the purpose of the present documentation to facilitate those modifications of the model that may be required to simulate such climatic effects. This model, which was developed at UCLA with the support of the National Science Foundation, is undergoing continuing development, particularly with respect to the parameterization of convective heating and radiative transfer. The numerical solutions shown in this report are for illustrative purposes only and should not be used to judge the model's ability to simulate climate. Although every effort has been made to ensure the accuracy of the model description used here, the responsibility for any errors or misrepresentations rests solely with the authors.

The Rand research program on climate dynamics is sponsored by the Advanced Research Projects Agency, and is directed to the systematic exploration of the structure and stability of the earth's climate. Meteorological studies suggest that technologically feasible operations might trigger substantial changes in the climate over broad regions of the globe. Depending on their character, location, and scale, these changes might be both deleterious and irreversible. If such perturbations were to occur, the results might be seriously detrimental to the welfare of this country. So that we may react rationally and effectively to any such occurrences, it is essential that we: (1) evaluate all consequences of a variety of possible
occurrences that might modify the climate, (2) detect trends in the global circulation that presage changes in the climate, either natural or artificial, and (3) determine, if possible, means to counter potentially deleterious climatic changes. Our possession of this knowledge would make incautious experimentation unnecessary. The present Report is a technical contribution to this larger study of the effects on climate of environmental perturbations.
SUMMARY

In this documentation the physical bases of the Mintz-Arakawa two-level atmospheric model are summarized, and the numerical procedures and computer program for its execution are presented in detail. The physics of the model is summarized, with particular attention given to the treatment of the moisture and heat sources, including the parameterization of convective processes, cloudiness, and radiation. The numerical approximations and finite-difference equations used in the model's numerical simulations are also given. Throughout the documentation the emphasis is on the specific details of the model in its present form, rather than on the derivation or justification of its present design.

To facilitate the use of this model, a complete listing of the code as written in FORTRAN language is given, together with a description of all constants and parameters used. A complete dictionary of FORTRAN variables, a dictionary of principal physical features, and a complete list of symbols are presented. To illustrate the model's performance, samples of its solutions for selected variables at a specific time are also given.
ACKNOWLEDGMENTS

The authors would like to acknowledge the permission given by Professors Yale Mintz and Akio Arakawa of the University of California, Los Angeles, to use their atmospheric general circulation model, and for their numerous comments and suggestions made during their review of a draft version of this Report. They would like also to thank Dr. A. Katayama, of the Meteorological Research Institute, Tokyo, for a number of suggestions that have clarified the program description, and Professor R. T. Williams of the Naval Postgraduate School for his assistance during the early stages of the preparation of the model's code description. An expression of thanks is also due our colleagues in the Rand/ARPA Climate Dynamics Program for their encouragement. Finally, we would like to acknowledge the capable and patient typing of the manuscript by Phyllis Davidson.
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One of the more widely known numerical models of the global atmospheric general circulation is that developed by Professors Mintz and Arakawa at the Department of Meteorology, UCLA. First formulated in the early 1960s, this model has undergone a series of modifications and improvements, and has been used in a number of simulations of the global climate and in tests of atmospheric predictability. Although it addresses the primary dynamical and thermal variables at only two tropospheric levels, the model is relatively sophisticated in its treatment of the physics of large-scale atmospheric motion, and the method of numerical solution is relatively complex.

It is the purpose of this Report to describe the model from a user's viewpoint, in order to facilitate its actual use in a program of climatic simulation. Although some description of the model's basic equations is necessary, it is not our present purpose to present their derivation nor to discuss the justification of the model's many physical parameterizations and numerical procedures. Instead, we have attempted to set forth several aspects of the model: its physical basis, its numerical formulation and solution, its computer code, and its typical results. These aspects are related to one another by the provision of a dictionary of selected terms and a list of physical and FORTRAN symbols. The description of the model's physics, given in Chapter II, is intended to present the basic differential equations and physical constants; the corresponding difference equations and other numerical approximations used in the program are presented in Chapter III. This is followed by a summary of the program's operating characteristics in Chapter IV, together with some typical results for selected variables, and by Chapter V, which presents a physics dictionary giving a brief summary of the treatment of certain variables and effects. As a supplement to the preceding chapters, a comprehensive list of symbols is given in Chapter VI. Finally, the model's integration and output map-routine codes as written in FORTRAN are presented in extenso in Chapter VII, followed by a FORTRAN dictionary in Chapter VIII, whose purpose is to permit ready interpretation of
specific portions of the program. It is hoped that this documentation will answer the question, "Just how are the circulation simulations made?"

A previous description of the model (in one of its earlier versions) was given by Mintz (1965, 1968), and has been supplemented by Arakawa (1970). Further details of the treatment of convection and radiation were given by Arakawa, Katayama, and Mintz (1969). An extended description of the basic model and the computational procedures used was prepared by Langlois and Kwok (1969). This latter publication has been of particular use in the preparation of the present documentation, although the present version of the model differs slightly from the version described by them. In one form or another the Mintz-Arakawa two-level model was applied to the estimation of atmospheric predictability by Charney (1966) and Jastrow and Halem (1970), and was applied to the simulation of the circulation of the Martian atmosphere by Leovy and Mintz (1969). The present version of the model is being used in a program of experimentation on the dynamics of climate at Rand, and will form the basis of future model changes and extensions.
II. MODEL DESCRIPTION — PHYSICS

In this chapter the physical and dynamical basis of the Mintz-Aракава two-level general circulation model is presented, together with a summary of the basic differential equations and boundary conditions. Particular attention has been given to the preparation of a summary of the various physical approximations in the model's treatment of radiation, moisture, and convection.

A. NOTATION AND VERTICAL LAYERING

In the first instance the present model is for the troposphere only, and divides the atmosphere beneath an assumed isobaric tropopause into two layers, as sketched in Fig. 2.1. At the center of each layer are the reference levels (1 and 3) at which the basic variables of the model are carried. At the interface between the layers (level 2), as well as at the tropopause and earth’s surface, certain additional variables and conditions are specified. For convenience, the atmosphere is divided in the vertical according to mass (or pressure), and the dimensionless vertical coordinate, \( \sigma \), is introduced

\[
\sigma = \frac{P - P_T}{P_S - P_T} \tag{2.1}
\]

where \( P \) is the pressure, \( P_T \) the (constant) tropopause pressure, and \( P_S \) the (variable) pressure at the earth’s surface. The levels 1, 2, and 3 are defined as those for \( \sigma = 1/4, 1/2, \) and \( 3/4 \), respectively, with the tropopause corresponding to \( \sigma = 0 \) and the surface always given by \( \sigma = 1 \). Thus, if the surface pressure is approximately 1000 mb and the tropopause is assumed to be at 200 mb, the levels 1 and 3 correspond approximately to the 400-mb and 800-mb levels, respectively.

Although a comprehensive list of symbols appears later in this report (see Chapter VI), it is convenient to introduce the more common variables at this point. Anticipating the use of spherical coordinates, the independent variables are:
Fig. 2.1 -- Schematic representation of the model's vertical structure.
$\phi =$ latitude, positive northward from the equator
$\lambda =$ longitude, positive eastward from Greenwich
$\sigma =$ dimensionless vertical coordinate, $0 \leq \sigma \leq 1$, increasing downward
$t =$ time

The primary dependent (prognostic) variables are:

$\mathbf{v} = (u,v)$, horizontal vector velocity
$T =$ temperature
$p = p_s - p_T$, surface pressure parameter
$q =$ mixing ratio

The other dependent (diagnostic) variables are:

$\phi =$ geopotential
$\alpha =$ specific volume
$p =$ pressure
$\dot{\sigma} = \frac{d\sigma}{dt}$, sigma vertical-velocity measure

The forcing terms are:

$\mathbf{F} =$ horizontal vector frictional force per unit mass
$\dot{H} =$ diabatic heating rate per unit mass
$\dot{Q} =$ rate of moisture addition per unit mass

The basic physical constants are:

$f = 2\Omega \sin \phi$, Coriolis parameter
$\Omega =$ earth's rotation rate
$a =$ earth's radius
$\mathbf{k} =$ vertical unit vector
$c_p =$ specific heat (for dry air) at constant pressure
$R =$ specific gas constant (for dry air)
g =$ acceleration of gravity
B. DIFFERENTIAL EQUATIONS

The vector equation of horizontal motion (in σ coordinates) may be written

\[
\frac{\partial}{\partial t} (\pi \mathbf{V}) + (\mathbf{V} \cdot \pi \mathbf{V}) \mathbf{V} + \frac{\partial}{\partial \sigma} (\pi \mathbf{\phi}) + f \mathbf{k} \times \pi \mathbf{V} + \pi \mathbf{\phi} + \sigma \pi \mathbf{\phi} = \pi \mathbf{F}
\]

(2.2)

where

\[
\mathbf{V} \cdot \mathbf{A} = \frac{1}{a \cos \varphi} \left[ \frac{\partial A_\lambda}{\partial \lambda} + \frac{\partial}{\partial \varphi} (A_\varphi \cos \varphi) \right]
\]

(2.3)

for a vector \( \mathbf{A} = (A_\lambda, A_\varphi) \).

The thermodynamic energy equation (in σ coordinates) is written

\[
\frac{\partial}{\partial t} (\pi c_p T) + \mathbf{V} \cdot (\pi c_p \mathbf{T} \mathbf{V}) + \frac{\partial}{\partial \sigma} (\pi c_p \mathbf{T} \mathbf{\sigma}) = \pi \mathbf{H}
\]

(2.4)

The mass continuity equation is

\[
\frac{\partial \pi}{\partial t} + \mathbf{V} \cdot (\pi \mathbf{V}) + \frac{\partial}{\partial \sigma} (\pi \mathbf{\sigma}) = 0
\]

(2.5)

The moisture continuity equation is

\[
\frac{\partial}{\partial t} (\pi q) + \mathbf{V} \cdot (\pi q \mathbf{V}) + \frac{\partial}{\partial \sigma} (\pi q \mathbf{\sigma}) = \pi \mathbf{Q}
\]

(2.6)

The equations (2.2) and (2.4) to (2.6) are the prognostic equations for the dependent variables \( \mathbf{V}, T, \pi, \) and \( q \). The specification of the frictional force \( \mathbf{F} \), the heating rate \( \mathbf{H} \), and the moisture-addition...
rate \( \dot{Q} \), or the right-hand sides of these equations is considered in subsequent sections. Supplementing these equations are the diagnostic equation of state,

\begin{equation}
\alpha = \frac{RT}{p}
\end{equation}

and the hydrostatic equation,

\begin{equation}
\frac{\partial \phi}{\partial \sigma} + \pi \sigma = 0
\end{equation}

These complete the dynamical system in \( \sigma \) coordinates, with \( \sigma \) itself given by \( \sigma = (p - p_T)/\pi \), where \( p_T \) is a constant (tropopause) pressure.

C. BOUNDARY CONDITIONS

Accompanying the dynamical system, Eqs. (2.2) to (2.8), are physical boundary conditions at only the earth's surface and the tropopause, as there are no lateral boundaries in the \( \sigma \) system for the global atmosphere. At the earth's surface we require zero (air) mass flux normal to the earth's surface and either a zero heat flux or a specified surface temperature, depending upon the surface character. Thus, we write at the earth's surface:

\begin{align*}
\dot{\sigma} &= 0 \\
\phi &= \phi_s(\lambda, \varphi) \\
F_H &= 0 \\
\delta &= 0 \\
\varphi &= 0 \\
T &= T_s(\lambda, \varphi)
\end{align*}

at \( \sigma = 1 \) over land (2.8a)

at \( \sigma = 1 \) over ocean (2.8b)
Here \( \phi_4(\lambda, \varphi) \) denotes the fixed distribution of the geopotential of the earth's land (or ice) surface, \( F_H \) is the vertical heat flux at the surface, and \( T_a(\lambda, \varphi) \) the fixed distribution of the sea-surface temperature.

At the assumed isobaric tropopause \( p = p_t \) we require the free-surface condition \( \frac{dp}{dt} = 0 \), or

\[
\dot{\sigma} = 0, \quad \text{at} \quad \sigma = 0 \tag{2.8c}
\]

Although they are not strictly boundary conditions, we may regard the specification of the surface drag coefficient which contributes to the horizontal frictional force, \( \vec{F}_f \), in Eq. (2.2) as fixing the vertical momentum transfer at the surface, and similarly regard the specification of the surface evaporation (minus the surface precipitation and runoff) as determining the moisture available for the source \( \dot{Q} \) in Eq. (2.6). The determination of these transfers in terms of the model is described below. We might also regard the solar radiation at the top of the atmospheric model at \( \sigma = 0 \) as a boundary condition. Here this flux is assumed to be given by the solar constant, modified as described below by the eccentricity of the earth's orbit and by the zenith angle of the sun.

D. VERTICALLY DIFFERENCED EQUATIONS

1. Vector Form

As an introduction to the presentation of the complete difference equations (including the horizontal and time finite-difference forms), the model's dynamical equations are here first stated in terms of the variables at specific model levels (which statement constitutes the vertical differencing in \( \sigma \) coordinates), and then given in terms of the horizontal (rectangular) map coordinates actually used in the computations. The dependent variables are computed at the several levels as shown below:
Table 2.1
DISPOSITION OF THE DEPENDENT VARIABLES

<table>
<thead>
<tr>
<th>Level</th>
<th>$\sigma$</th>
<th>$\delta$</th>
<th>$\phi$</th>
<th>$p$</th>
<th>$T$</th>
<th>$\vec{v}$</th>
<th>$q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>...</td>
<td>$p_T$</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>1</td>
<td>$\frac{1}{4}$</td>
<td>...</td>
<td>$\phi_1$</td>
<td>$p_1$</td>
<td>$T_1$</td>
<td>$\vec{v}_1$</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>$\frac{1}{2}$</td>
<td>$\delta_2$</td>
<td>...</td>
<td>$p_2$</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>3</td>
<td>$\frac{3}{4}$</td>
<td>$\phi_3$</td>
<td>$p_3$</td>
<td>$T_3$</td>
<td>$\vec{v}_3$</td>
<td>$q_3$</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0</td>
<td>...</td>
<td>$p_T + \pi$</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

We note that the mixing ratio, $q$, is carried only at level 3, and that the surface pressure is computed by means of $\pi$. At the midlevel 2, only the $\sigma$ vertical velocity $\delta_2$ is independently computed, although it is sometime useful to regard the wind and temperature at level 2 in terms of values interpolated between levels 1 and 3.

The equation of horizontal motion, Eq. (2.2), is now written for levels 1 and 3 (with corresponding subscripts) as

$$\frac{3}{\delta t} (\pi \vec{v}_1) + (\vec{v} \cdot \pi \vec{v}_1) \vec{v}_1 + \pi \delta_2 (\vec{v}_1 + \vec{v}_3) + \pi f \vec{k} \times \vec{v}_1$$

$$+ \pi \nabla \phi_1 + \sigma_1 \pi a_1 \nabla \pi = \pi \dot{F}_1$$

(2.9)
where vertical finite differences between $\sigma = 0$ and $\sigma = 1/2$ and between $\sigma = 1/2$ and $\sigma = 1$ have been taken, and the conditions $\partial = 0$ at $\sigma = 0, 1$ and $\hat{\mathbf{v}}_2 = 1/2(\hat{\mathbf{v}}_1 + \hat{\mathbf{v}}_3)$ used.

The thermal energy equation (2.4) may be similarly written for levels 1 and 3 as

\[
\frac{3}{\partial t} (\pi T_1) + \nabla \cdot (\pi T_1 \hat{\mathbf{v}}_1) + \left(\frac{p_1}{p_o}\right) \pi \partial_2 (\theta_1 + \theta_3) \\
- \frac{\pi \alpha_1 \sigma_1}{c_p} \left(\frac{\partial p}{\partial t} + \hat{\mathbf{v}}_1 \cdot \nabla \pi\right) = \frac{\pi \dot{\mathbf{H}}_1}{c_p} \tag{2.11}
\]

\[
\frac{3}{\partial t} (\pi T_3) + \nabla \cdot (\pi T_3 \hat{\mathbf{v}}_3) - \left(\frac{p_3}{p_o}\right) \pi \partial_2 (\theta_1 + \theta_3) \\
- \frac{\pi \alpha_3 \sigma_3}{c_p} \left(\frac{\partial p}{\partial t} + \hat{\mathbf{v}}_3 \cdot \nabla \pi\right) = \frac{\pi \dot{\mathbf{H}}_3}{c_p} \tag{2.12}
\]

where the condition $\theta_2 = 1/2(\theta_1 + \theta_3)$ has been used with the potential temperature, $\theta$, given by

\[
\theta = T(p_o/p)^\kappa
\]

with $p_o = 1000$ mb, a reference pressure, and $\kappa = R/c_p = 0.286$.

Manipulation of the mass continuity equation (2.5) applied at levels 1 and 3 with the conditions $\partial = 0$ at $\sigma = 0, 1$ leads to the relations

\[
\frac{\partial \pi}{\partial t} = -\frac{1}{2} \nabla \cdot \left[\pi (\hat{\mathbf{v}}_1 + \hat{\mathbf{v}}_3)\right] \tag{2.13}
\]
for the prediction of the surface pressure and the computation of the midtropospheric vertical motion field.

The moisture continuity equation (2.6) is applied only at the (lower) level 3, giving

\[ \frac{3}{3t} (\pi q_3) + v \cdot [\pi (\dot{\varphi}_3 - \dot{\varphi}_1)] = 2g(E - C) \]  

where the conditions \( \dot{\varphi} = 0 \) at \( \sigma = 1 \) and \( q = 0 \) at \( \sigma = 1/2 \) have been used, and the wind at level 3 (\( \sigma = 3/4 \)) is replaced by a wind at \( \sigma = 7/8 \) found by linear extrapolation from \( \dot{\varphi}_1 \) and \( \dot{\varphi}_3 \). The moisture source term, \( 2g(E - C) \), represents the net rate of vapor addition as a result of the evaporation rate, \( E \), and condensation rate, \( C \), into the air column of unit cross section between \( \sigma = 1 \) and \( \sigma = 1/2 \).

The hydrostatic equation (2.8) is integrated from the surface to the levels 1 and 3, yielding the relations

\[ \phi_1 = \phi_4 + \frac{1}{2} c_p \theta_2 \left[ \left( \frac{p_3}{p_0} \right)^k - \left( \frac{p_1}{p_0} \right)^k \right] + \frac{\pi}{2} (\sigma_3 a_3 + \sigma_1 a_1) \]  

\[ \phi_3 = \phi_4 - \frac{1}{2} c_p \theta_2 \left[ \left( \frac{p_3}{p_0} \right)^k - \left( \frac{p_1}{p_0} \right)^k \right] + \frac{\pi}{2} (\sigma_3 a_3 + \sigma_1 a_1) \]  

where \( \phi_4 \) is the (fixed) geopotential of the earth's surface, and where \( \theta \) has been assumed linear in \( p^k \) space from \( \sigma_1 = 1/4 \) to the ground \( \sigma = 1 \).

2. Rectangular (Map) Coordinates

As a final transformation prior to the consideration of the difference equations used in the computations, it is convenient to present the vertically differenced equations (2.9) to (2.17) in terms of
the rectangular (or map) coordinates $x$ and $y$. The grid-scale distances $m$ and $n$, defined as

$$m = a\Delta\lambda \cos \varphi$$

$$n = a\Delta\varphi$$

represent the longitudinal and latitudinal distances between grid points separated by $\Delta\lambda$ and $\Delta\varphi$, respectively. The dimensionless map coordinates $x$ and $y$ may then be defined as

$$x = m^{-1}a\lambda \cos \varphi$$

$$y = n^{-1}a\varphi$$

so that a rectangular grid-point array is generated with unit distance between points. The reciprocals $m^{-1}$ and $n^{-1}$ are the conventional map-scale or magnification factors.

We also introduce the new area-weighted variables

$$\Pi = mn\pi$$

$$\dot{S} = 2mn\pi\delta_2$$

$$F = mnf - u \frac{dm}{dy}$$

and the weighted mass fluxes

$$u^* = \Pi u$$

$$v^* = \Pi v$$

at both levels 1 and 3.
Upon multiplication by mn, the equations of motion, Eqs. (2.9) and (2.10), may thus be written:

\[
\frac{\partial}{\partial t} (\Pi u_1) + \frac{\partial}{\partial x} (u_1^* u_1) + \frac{\partial}{\partial y} (v_1^* u_1) + \dot{\Sigma} \left( \frac{u_1 + u_3}{2} \right) \\
+ n \left( \Gamma \frac{\partial \phi}{\partial x} + \sigma_1 \pi \alpha \frac{\partial \pi}{\partial x} \right) - F_{\Pi v_1} = \Pi \dot{F}_1^x \tag{2.27}
\]

\[
\frac{\partial}{\partial t} (\Pi v_1) + \frac{\partial}{\partial x} (u_1^* v_1) + \frac{\partial}{\partial y} (v_1^* v_1) + \dot{\Sigma} \left( \frac{v_1 + v_3}{2} \right) \\
+ m \left( \Gamma \frac{\partial \phi}{\partial y} + \sigma_1 \pi \alpha \frac{\partial \pi}{\partial y} \right) + F_{\Pi u_1} = \Pi \dot{F}_1^y \tag{2.28}
\]

\[
\frac{\partial}{\partial t} (\Pi u_3) + \frac{\partial}{\partial x} (u_3^* u_3) + \frac{\partial}{\partial y} (v_3^* u_3) - \dot{\Sigma} \left( \frac{u_1 + u_3}{2} \right) \\
+ n \left( \Gamma \frac{\partial \phi}{\partial x} + \sigma_1 \pi \alpha \frac{\partial \pi}{\partial x} \right) - F_{\Pi v_3} = \Pi \dot{F}_3^x \tag{2.29}
\]

\[
\frac{\partial}{\partial t} (\Pi v_3) + \frac{\partial}{\partial x} (u_3^* v_3) + \frac{\partial}{\partial y} (v_3^* v_3) - \dot{\Sigma} \left( \frac{v_1 + v_3}{2} \right) \\
+ m \left( \Gamma \frac{\partial \phi}{\partial y} + \sigma_1 \pi \alpha \frac{\partial \pi}{\partial y} \right) + F_{\Pi u_3} = \Pi \dot{F}_3^y \tag{2.30}
\]

where the frictional force \( \vec{F} = (F^x, F^y) \) at levels 1 or 3.

The thermodynamic equations (2.11) and (2.12) may be similarly written as

\[
\frac{\partial}{\partial t} (\Pi T_1) + \frac{\partial}{\partial x} (u_1^* T_1) + \frac{\partial}{\partial y} (v_1^* T_1) + \left( \frac{p_1}{p_o} \right)^\kappa \left( \frac{\theta_1 + \theta_3}{2} \right) \dot{\Sigma} \\
- \frac{\sigma_1 \pi}{c_p} \left( \Gamma \frac{\partial \pi}{\partial t} + u_1^* \frac{\partial \pi}{\partial x} + v_1^* \frac{\partial \pi}{\partial y} \right) = \frac{\Pi \dot{H}_1}{c_p} \tag{2.31}
\]
The mass and moisture continuity equations (2.13) to (2.15) may also now be written as

$$\frac{\partial}{\partial t} (\Pi_3) + \frac{\partial}{\partial x} (u_3^* T_3) + \frac{\partial}{\partial y} (v_3^* T_3) - \left( \frac{p_3}{p_0} \right)^x \left( \frac{\theta_1 + \theta_3}{2} \right) \dot{s}$$

$$- \frac{\sigma_3 \theta_3}{c_p} \left( \frac{\partial}{\partial t} u_3^* + u_3^* \frac{\partial}{\partial x} + v_3^* \frac{\partial}{\partial y} \right) = \frac{\Pi H_3}{c_p} \tag{2.32}$$

E. FRICTION TERMS

The frictional terms $F_1$ and $F_3$ in the equations of horizontal motion (2.9) and (2.10) are given by relations of the form

$$\dot{F}_1 = -\nu \left( \frac{\partial \nabla}{\partial z} \right) \frac{2g}{\pi} = -\nu \left( \frac{\dot{v}_1 - \dot{v}_3}{z_1 - z_3} \right) \frac{2g}{\pi} \tag{2.36}$$

$$\dot{F}_3 = -\dot{F}_1 - C_f \rho_4 \dot{v}_s (|\dot{v}_s| + C) \frac{2g}{\pi} \tag{2.37}$$
where \( u \) is an empirical coefficient for the vertical shear stress, and the factor \( 2g/\pi \) represents the mass per unit area in each of the two model layers. Here \( z_1 - z_3 \) is the height difference between the levels 1 and 3, \( C_D \) is the surface drag coefficient, \( \rho_4 \) the surface air density, \( \bar{v}_s \) a measure of the surface wind (\( = 0.7 \bar{v}_4 \), with \( \bar{v}_4 \) an extrapolated wind at level 4), and \( G \) an empirical correction for gustiness.

The frictional force \( \mathbf{F}_1 \) thus represents the internal downward transfer of momentum between the levels due to the vertical shear of the horizontal wind, whereas the force \( \mathbf{F}_3 \) also includes the effects of surface skin friction.

F. MOISTURE, CONVECTION, AND CLOUDS

The purpose of this section is to describe the physics of the hydrologic cycle used in the model and to develop the expressions used to evaluate the moisture-source term, \( 2 \frac{p}{\pi} (E - C) \), on the right-hand side of the moisture-balance equation for the atmosphere [Eq. (2.35)]. The moisture source for the atmosphere is evaporation from the surface, \( E \), and the moisture sink is precipitation, \( C \). All the moisture condensed in the model atmosphere is assumed to fall to the surface as precipitation. Thus the moisture sink for the atmosphere, \( C \), is specified by large-scale, convective, and surface condensation. The variables specifying the amount of moisture in the atmosphere and in the ground are \( q_3 \), the lower-level mixing ratio, and \( GW \), the ground-wetness parameter. While \( q_3 \) is determined in part by horizontal advection and is thus modified every time step, \( GW \), \( E \), \( C \), and that part of the change of \( q_3 \) due to \( E \) and \( C \) are computed every fifth time step (see Chapter III, Section A).

Clearly, the amount of evaporation, condensation, and convection depend on the thermal state of the atmosphere, which is in turn a function of the exchange of heat taking place during these processes. Instead of obtaining a simultaneous solution for the moisture and thermal states of the atmosphere, the model evaluates the evaporation and the components of the condensation in a sequence. At each step
of the sequence the thermal state of the atmosphere is modified, and the new values of temperature are used in the next step.

In the following subsections each process is discussed in the sequence in which it is evaluated in the FORTRAN program. First, the temperature lapse rate between \( \sigma = 3/4 \) and \( \sigma = 1/4 \) is adjusted to the dry-adiabatic lapse rate if it is found to be dry-adiabatically unstable; this convective adjustment is discussed in Subsection F.1. Second, if the air is supersaturated at \( \sigma = 3/4 \), large-scale condensation occurs and the temperature and mixing ratios at \( \sigma = 3/4 \) are adjusted (see Subsection F.2). Third, the temperature lapse rates between levels and the humidity are tested to determine the existence of moist convective instability. If there is instability, convective condensation occurs and the temperatures and mixing ratios are adjusted according to the three types of convection permitted:

(a) Middle-level convection, which occurs if the layer between \( \sigma = 3/4 \) and \( \sigma = 1/4 \) is unstable (for moist convection).

(b) Penet rate convection, which occurs if the layer from \( \sigma = 3/4 \) to \( \sigma = 1/4 \) is stable but the layer from the surface to \( \sigma = 3/4 \) is unstable and, in the mean, unstable from the surface to \( \sigma = 1/4 \).

(c) Low-level convection, which occurs if the atmosphere is unstable only between the surface and \( \sigma = 3/4 \).

To determine the existence of convection types (b) and (c), one needs the temperature and mixing ratios at the top of the surface boundary layer. All three forms of convective condensation and the physics of the boundary layer are discussed in Subsection F.3. Fourth, the quantities needed to evaluate the evaporation from the surface are discussed in Subsection F.4, and the moisture balance at the surface and in the atmosphere is discussed in Subsection F.5.

The final two subsections are devoted to parameters which are related to the moisture content of the atmosphere and are used in the radiation balance calculation in Section G. In Subsection F.6, the cloud types and cloud amounts produced by the various forms of condensation are discussed, and in Subsection F.7, equations for the effective water-vapor content of the atmosphere are derived.
1. Convective Adjustment

If, as a result of the changes due to advection, the atmosphere is found to be dry-adiabatically unstable ($\theta_1 \leq \theta_3$) at the beginning of the heating and moisture-balance calculations, then a "convective adjustment" is made. This consists of setting both $\theta_1$ and $\theta_3$ equal to an average $\theta$, which is calculated from

$$\theta = \frac{1}{2} \left[ \frac{1}{2} \left( p_1^\kappa + p_3^\kappa \right) \right]^{-1}$$

assuming that

$$\bar{T} = \frac{1}{2} (T_1 + T_3)$$

Thus, the convective adjustment consists of setting

$$\frac{\theta_1}{p_0^\kappa} = \frac{\theta_3}{p_0^\kappa} = \frac{\theta_2}{p_0^\kappa} = \frac{T_1 + T_3}{p_1^\kappa + p_3^\kappa} \quad (2.38)$$

from which the temperatures are accordingly recalculated as

$$T_1 = \frac{\theta_1}{p_0^\kappa} p_3^\kappa$$

$$T_3 = \frac{\theta_3}{p_0^\kappa} p_3^\kappa \quad (2.39)$$

After this convective adjustment, the model proceeds as usual to the moisture and convection calculations.

2. Large-Scale Condensation

Large-scale condensation occurs if the lower-level grid cell is supersaturated at the beginning of the moisture-balance calculation.
The saturation mixing ratio is given by

\[ q_s(T) = \frac{M_w e_s(T)}{M_d p - e_s(T)} \]  \hspace{1cm} (2.40)

where \( M_w \) and \( M_d \) are the mean molecular weights of water vapor and dry air, respectively \((M_w/M_d = 0.622)\), and where the saturation vapor pressure is given by the equation

\[ e_s(T) = e_o \exp(A_e - B_e/T) \]  \hspace{1cm} (2.41)

with \( e_o = 1 \) mb, \( A_e = 21.656 \), and \( B_e = 5418 \) deg K.

If it is then determined that \( q_3 > q_s(T_3) \) as a result of the computed solution of the moisture continuity equation (2.35), large-scale condensation is allowed to occur. This condensation will remove moisture from the atmosphere and will also warm the atmosphere by releasing latent heat, with the warming in turn modifying the saturation mixing ratio \( q_s(T_3) \). The condensation proceeds until \( q_3 = q_s(T) \) at the new (warmed) temperature. If the original temperature and mixing ratio at level 3 are written as \( T_o \) and \( q_o \), the new temperature \( T \) satisfies

\[ c_p(T - T_o) = L[q_o - q_s(T)] \]  \hspace{1cm} (2.42)

In view of the dependence of \( q_s \) on \( T \), as given by Eqs. (2.40) and (2.41), we seek the approximate value of \( T \) when

\[ F(T) = T - T_o + \left( \frac{L}{c_p} \right)[q_s(T) - q_o] = 0 \]  \hspace{1cm} (2.43)

Using the Newton-Raphson method, the first-order approximation of \( T \) becomes

\[ T \approx T_o - \frac{F(T_o)}{F'(T_o)} \]  \hspace{1cm} (2.44)
where

\[ F(T_0) = - \frac{L}{c_p} [q_o - q_s(T_o)] \tag{2.45} \]

and

\[ F'(T_0) = \frac{dF}{dT} (T_0) = 1 + \frac{L}{c_p} q_s(T_o) \frac{B e}{T_o^2} \left[ 1 + \frac{M_d}{M_w} q_s(T_o) \right] \tag{2.46} \]

Substituting Eqs. (2.45) and (2.46) into (2.44) and neglecting \((M_d/M_w)q_s(T_o)\) in comparison with 1, the change in temperature at level 3 as a result of large-scale condensation becomes

\[ (\Delta T_3)_L = T - T_0 = \frac{\frac{L}{c_p} [q_o - q_s(T_o)]}{1 + \frac{L}{c_p} q_s(T_o) \frac{B e}{T_o^2}} \tag{2.47} \]

The change in moisture content due to this large-scale condensation is found from

\[ (\Delta q_3)_L = \frac{c_p}{L} (T_3)_L \tag{2.48} \]

and the new \(q_3\) is given by

\[ q_3 = q_{3o} - (\Delta q_3)_L \tag{2.49} \]

Since the amount of precipitation is assumed to be equal to the condensation, the large-scale precipitation rate becomes

\[ P_{LS} = (\pi/2g_w)(\Delta q_3)_L \tag{2.50} \]
where \((\pi/2g)/\rho v\) is a conversion factor used to obtain the precipitation rate from the condensation rate (see Chapter IV, Large-Scale Precipitation Rate: Map 9). Finally, the large-scale condensation produces type-2 clouds (see Subsection F.6).

3. Convective Condensation

To determine the possibility of convection, suitable stability criteria must first be defined. The equivalent potential temperature, defined as

\[
\theta_E = \theta_d \exp \left( \frac{Lq}{c_p T} \right)
\]  

(2.51)

where

\[
\theta_d = T \left( \frac{P_0}{P - e} \right)^k
\]

(2.52)

is conservative in both unsaturated-adiabatic and saturated-adiabatic processes. A more convenient parameter for our purposes is given by the approximation

\[
\frac{c_p T}{\theta_E} d\theta_E \approx dh
\]

(2.53)

Here

\[
h = c_p T + gz + Lq
\]

(2.54)

shall be referred to as the static energy; it is the sum of the enthalpy, the potential energy, and the latent energy of a parcel of air. The static energy is very nearly conservative in both unsaturated and saturated adiabatic processes, and thus can be used in the analysis of convective phenomena. For example, following the argument
of Arakawa et al. (1969), if we assume that the air in the clouds at level 1 is saturated, then the static energy in the cloud at level 1 becomes

\[ h_c = c_p T_{cl1} + g z_1 + L q_s(T_{cl}) \]  

(2.55)

where \( q_s(T_{cl}) \) is the saturation mixing ratio at the cloud temperature \( T_{cl} \). For convenience we define the quantity

\[ h_1^* = c_p T_1 + g z_1 + L q_s(T_1) \]  

(2.56)

where \( T_1 \) is the temperature of the air surrounding the clouds at level 1. Eliminating \( g z_1 \) from Eqs. (2.55) and (2.56), the temperature difference between the clouds and the surrounding air at level 1 becomes

\[ T_{cl1} - T_1 = \frac{1}{1 + \gamma_1} \frac{h_c - h_1^*}{c_p} \]  

(2.57)

where

\[ \gamma_1 = \frac{L}{c_p} \left( \frac{\partial q_s}{\partial T} \right)_1 = \frac{L}{c_p} \frac{q_s(T_{cl}) - q_s(T_1)}{T_{cl} - T_1} \]  

(2.58)

Thus it can be seen from Eq. (2.57) that when \( h_c > h_1^* \) the temperature in the clouds at level 1 is warmer than that in the surroundings, and any convection that has been initiated will tend to continue.

We now seek to determine the value of \( h_c \) in terms of the Mintz-Arakawa two-level model's parameters. To do this we assume that all the entrainment takes place at level 3, and thus the vertical mass flux (\( M \)) through the cloud above level 3 becomes

\[ M = M_0 \eta \]  

(2.59)
where $M_b$ is the vertical mass flux through the bottom of the cloud and $n$ is the entrainment factor. When there is entrainment, $n > 1$, and the static energy in the cloud is a mixture of the static energy entering the base of the cloud, $h_b$, and that of the surrounding air, $h_3$. Thus we have

$$h_c = h_3 + \frac{1}{n} (h_b - h_3)$$

(2.60)

What is assumed for the amount of entrainment will therefore determine the value of $h_c$ in Eq. (2.57) and thus the existence of stability in the model.

In the following subsections, the value of $n$ for each type of convection will be discussed and the stability criteria derived. The criteria will then be used to determine the temperature and moisture changes resulting from the convection.

a. Middle-Level Convection. In middle-level convection we assume that the entrainment at level 3 is much larger than the mass flux through the bottom of the cloud. Mathematically, it can be represented by setting $\frac{1}{n} = 0$ while leaving $nM_b$ finite. Thus from Eq. (2.60) we have $h_c = h_3$, and from Eq. (2.57) the condition for middle-level convection becomes $h_3 > h^* _1$. The parameters $h_3$ and $h^*_1$, rewritten in terms of the potential temperatures and mixing ratios at levels 1 and 3, are

$$\frac{h^*_1}{c_p} = \theta_3 \left( \frac{p_s}{p_o} \right)^\kappa + \left( \theta_1 - \theta_3 \right) \left( \frac{p_2}{p_o} \right)^\kappa + \frac{L}{c_p} q_s (T_1)$$

(2.61)

$$\frac{h_3}{c_p} = \theta_3 \left( \frac{p_s}{p_o} \right)^\kappa + \frac{L}{c_p} q_3$$

(2.62)
To determine the temperature change at levels 1 and 3 due to this convection, we introduce the concept of "dry" static energy, $S$, where

$$ S = c_p T + gz $$

(2.65)

Considering convection only, the continuity equation for $S$ at level 1 is

$$ \frac{\partial p S_1}{\partial t} = - \frac{\partial (\rho M_b S_1)}{\partial z} $$

(2.66)

which may be approximated by

$$ \frac{\Delta p}{g} \frac{\partial S_1}{\partial t} = \rho M_b (S_{c1} - S_2) $$

(2.67)

Neglecting the time change of the geopotential and using Eq. (2.57) we may write Eq. (2.67) as

$$ \frac{\partial T_1}{\partial t} = \frac{g}{c_p} \rho M_b \left[ \frac{1}{1 + \gamma_1} (h_3 - h_1^*) + (S_{c1} - S_2) \right] $$

(2.68)
With similar approximations, the temperature change at level 3 is given by

\[ \frac{\partial T_3}{\partial t} = \frac{R}{\Delta p} \frac{nM_b}{c_p} (S_2 - S_3) \]  

(2.69)

Equations for the mixing ratios at levels 1 and 3 can be derived in a similar fashion. However, in the model all the moisture is assumed to be carried at level 3, and thus the change of \( q_3 \) due to convection becomes:

\[ \frac{\partial q_3}{\partial t} = \frac{R}{\Delta p} nM_b [q_s(T_{c1}) - q_3] \\
- \frac{R}{\Delta p} nM_b [q_s(T_1) - q_3 + \frac{\gamma_1}{1 + \gamma_1} \frac{1}{L} (h_3 - h_1^*)] \]  

(2.70)

Here, Eq. (2.57) has been used to eliminate \( q_b(T_{c1}) \).

To eliminate the unknown mass flux in Eqs. (2.68) to (2.70), we relate \( nM_b \) to the relaxation time, \( \tau_r \), of free cumulus convection. As a result of convection, the instability of the layer diminishes and \( h_3 + h_1^* \). The time rate of change of \( (h_3 - h_1^*) \) is given by

\[ \frac{\partial}{\partial t} (h_3 - h_1^*) = \frac{\partial}{\partial t} (S_3 - S_1) + L \frac{\partial q_3}{\partial t} - L \frac{\partial q_s(T_1)}{\partial T_1} \frac{\partial T_1}{\partial t} \\
= - \frac{R}{\Delta p} nM_b \left( \frac{2 + \gamma_1}{1 + \gamma_1} [(h_3 - h_1^*) + \frac{1}{2} (1 + \gamma_1)(S_1 - S_3)] \right) \]  

(2.71)

If the instability diminishes exponentially with e-folding time \( \tau_r \), then

\[ nM_b = \frac{1}{\tau_r} \frac{\Delta p}{2 + \gamma_1} \left( \frac{h_3 - h_1^*}{h_3 - h_1^* + \frac{1}{2} (1 + \gamma_1)(S_1 - S_3)} \right) \]  

(2.72)
When Eq. (2.72) is combined with (2.68) and (2.69), the change in temperature at levels 1 and 3 [over the time interval (5\Delta t) between heating calculations] due to the release of latent heat is given by

\[
(\Delta T_1)_{CM} = \frac{h_3 - h_1}{c_p (2 + \gamma_1) \tau_r} 5\Delta t
\]

\[
(\Delta T_3)_{CM} = \frac{(\Delta T_1)_{CM} (1 + \gamma_1) \text{LR}/2}{(h_3 - h_1^*)/c_p + (1 + \gamma_1) \text{LR}/2}
\]

where \( \gamma_1 = (L/c_p) 5418\deg q_s(T_1)T_1^{-2} \) and \( \text{LR} = (\rho_1 - \rho_3)/(\rho_2/\rho_0)X \) is a "nominal lapse rate." In this model, the relaxation time, \( \tau_r \), is taken to be 1 hour. From Eqs. (2.70) and (2.73) the change in moisture at level 3 is given by

\[
(\Delta q_3)_{CM} = \frac{c_p}{L} \left[ (\Delta T_1)_{CM} + (\Delta T_3)_{CM} \right]
\]

As in Eq. (2.50), the precipitation rate due to middle-level convection is given by

\[
P_{CM} = (\pi/2g_\omega)(\Delta q_3)_{CM}
\]

Type-1 clouds may be produced by this middle-level convection (see Subsection F.6), and the associated convective precipitation rate is illustrated in Map 13, Chapter IV.

b. Boundary-Layer Temperature and Moisture. If middle-level convection does not occur, either "penetrating convection" or "low-level convection" may. Since both of these convection types originate at the air/ground interface, it is convenient to discuss first the computation of the moisture, \( q_4 \), and air temperature, \( T_4 \), at the surface along with other air/ground interaction parameters. A thin
boundary layer is assumed at the air/ground interface, with the subscript "4" referring to values at the top of the boundary layer and the subscript "g" referring to values at the bottom of the layer, just above the ground or water surface.

We assume that the flux of static energy [see Eq. (2.54)] from the surface into the bottom of the boundary layer is equal to the flux out the top. We neglect horizontal convergence in this thin boundary layer and also assume negligible geopotential difference between its top and bottom. Thus the flux of static energy from the surface may be approximated by

\[
\Gamma_h = \rho_4 C_D W (h_g - h_4)
\]  
(2.77)

where

\[
W = | \vec{V}_s |^n + G
\]  
(2.78)

is a surface-wind parameter corrected for gustiness and \( C_D \) is the drag coefficient. Implied in Eq. (2.77) are the assumptions that the eddy-diffusion coefficient for the static energy can be approximated by that for momentum, and that a constant transfer coefficient may be used in the boundary layer. Equating (2.77) to the flux through the top of the boundary layer, we obtain

\[
\rho_4 C_D W (h_g - h_4) = \rho_4 A_v \frac{h_4 - h_3}{z_3}
\]  
(2.79)

where \( A_v \) is the vertical eddy-diffusion coefficient. Solving Eq. (2.79) for \( h_4 \) we obtain

\[
h_4 = (EDR) h_3 + (1 - EDR) h_g
\]  
(2.80)
where $h_3$ is given by Eq. (2.62), $h_g$ is given by

$$
\frac{h_g}{c_p} = T_g + \frac{L}{c_p} q_g
\quad (2.81)
$$

and

$$
EDR = \frac{A_v/z_3}{A_v/z_3 + C_p W}
\quad (2.82)
$$

In the present version of the model it is assumed that $A_v = 1/\vec{v}_s^2 \text{ m}^2 \text{ sec}^{-1}$, where the surface wind $\vec{v}_s$ is in m sec$^{-1}$.

In order to obtain the surface moisture, $q_4$, and temperature, $T_4$, we now write the parameter $h_4$ from Eq. (2.54) as

$$
\frac{h_4}{c_p} = T_4 + \frac{L}{c_p} q_4
\quad (2.83)
$$

By defining the values of $q_g$ and $q_4$, one may solve Eqs. (2.80) and (2.83) for $T_4$ in terms of the surface parameters $T_g$ and $GW$ and the static energy at level 3. In general the ground temperature, $T_g$, and the ground wetness, $GW (0 \leq GW \leq 1)$, are available from the previous time step, along with the level-3 temperature and moisture. From these data, the relative humidities at levels 3 and 4 may be determined from

$$
RH_3 = \frac{q_3}{q_g(T_3)}
\quad (2.84)
$$

and

$$
RH_4 = \frac{(2GW)(RH_3)}{GW + RH_3}
\quad (2.85)
$$
where \( RH_3 \) is the harmonic mean of \( RH_1 \), the relative humidity at level 3, and the ground wetness, \( GW \). The ground-level mixing ratio is assumed to be directly proportional to the ground wetness. Hence

\[
q_g = GW q_s(T_g) \tag{2.86}
\]

where \( q_s(T_g) \) is calculated from \( T_g \) in the usual fashion [see Eq. (2.40)],

\[
q_s(T_g) = \frac{0.622 e_s(T_g)}{p_4 - e_s(T_g)} \tag{2.87}
\]

and the ground-level saturation vapor pressure is given by

\[
e_s(T_g) = \min[e_0 \exp(A - B/T_g), p_4/16.62] \tag{2.88}
\]

The mixing ratio at level 4 can now be obtained from Eq. (2.85) and an extrapolation of \( q_s(T_g) \) to level 4. Thus

\[
q_4 = RH_4 \left[ q_s(T_g) + \Delta z \frac{dq_s(T_g)}{dT} \right]
= RH_4 \left[ q_s(T_g) + \frac{c_p}{L} \gamma_g (T_4 - T_g) \right] \tag{2.89}
\]

where \( \gamma_g \) is evaluated from

\[
\gamma_g = \frac{L}{c_p} \frac{dq_s(T_g)}{dT} = \frac{L}{c_p} 5418 \deg \frac{q_s(T_g)}{T_g^2} \tag{2.90}
\]

Using Eqs. (2.83), (2.89), and (2.80), the temperature at level 4 becomes finally
\[ T_4 = \begin{cases} \hfill \frac{\tilde{h}_4}{c_p} - \frac{\text{RH}_4}{1 + \text{RH}_4 \gamma g} \left[ \frac{L}{c_p} \frac{q_s(T_4) - \gamma T}{g} \right], & \text{if } T_4 \left( \frac{p_o}{p_4} \right)^{\kappa} \leq \theta_3 \\ \theta_3 \left( \frac{p_4}{p_o} \right)^{\kappa}, & \text{otherwise} \end{cases} \] (2.91)

where \( \tilde{h}_4 \) is the value of the static energy at level 4 as given by Eq. (2.80). The condition on \( T_4 \) given by Eq. (2.91) is invoked to prevent a super-adiabatic lapse rate between levels 4 and 3. From the quantities \( T_4 \) and \( q_4 \) given by Eqs. (2.89) and (2.91) the convection parameter \( h_4 \) defined by Eq. (2.83) may then be evaluated, although the quantities \( T^* \) and \( q_4 \) will be redefined later if penetrating or low-level convection occurs [see Eqs. (2.96) and (2.97) below].

c. Penetrating and Low-Level Convection. In the model, both penetrating convection and low-level convection are mutually exclusive with middle-level convection. Thus, the first criterion to be met is that the layer between level 3 and level 1 be stable, i.e., that \( h_3 < h_1^* \). A second criterion, similar to Eq. (2.57) for middle-level convection, is obtained from instability conditions for the layer between levels 4 and 3. Thus we first write

\[ T_{c3} - T_3 = \frac{1}{1 + \gamma_3} \frac{h_c - h_3^*}{c_p} \] (2.92)

where \( T_{c3} \) is the temperature of the rising air in the clouds at level 3,

\[ \gamma_3 = \frac{L}{c_p} \frac{dq_s(T_3)}{dT} = \frac{5418 \text{deg}}{c_p} \frac{q_s(T_3)}{T_3^2} \] (2.93)

and

\[ \frac{h_3^*}{c_p} = \theta_3 \left( \frac{p_s}{p_o} \right)^{\kappa} + \frac{L}{c_p} q_s(T_3) \] (2.94)
For penetrating and low-level convection we assume that there is no entrainment at level 3 \((n = 1)\), and from Eq. (2.60) we then find \(h_c = h_b\). Further, we take the static energy at the base of the cloud, \(h_b^*\), to be equal to its value at the top of the boundary layer, \(h_4\). Therefore the second criterion for penetrating and low-level convection becomes \(h_4 > h_3^*\), along with the primary criterion \(h_3 < h_1^*\). When these two conditions are met, we may then discriminate between penetrating and low-level convection. From Eq. (2.57) with \(h_c = h_4\) we see that if \(h_4 > h_1^*\), convection can penetrate into the stable layer above level 3 and reach all the way to level 1. This is therefore the distinguishing condition for penetrating convection. If, on the other hand, \(h_4 < h_1^*\), the convection stops at level 3. This is therefore the condition for low-level convection.

In the case of low-level convection, it is assumed that \(h_4\) is modified to \(h_3^*\), because of the process of transporting static energy out of the boundary layer. This is equivalent to assuming that static energy in the cloud becomes \(h_3^*\). Low-level convection may produce type-3 clouds (see Subsection F.6), and condensation and precipitation are not allowed to occur; all the moisture transported as clouds is assumed to evaporate again within the same layer with no release of latent heat. The effect of this type of convection is thus felt only in the vertical transport of sensible heat and in surface evaporation, where it alters the surface moisture and temperature.

Indicating by primes the values prior to modification by low-level convection, we may write

\[
h_4 = h_4' - (h_4' - h_3^*)
\]  (2.95)

Substituting the definitions of \(h_4\) and \(h_4'\) into Eq. (2.95) and using Eq. (2.89) for the old and new mixing ratios at level 4, the surface temperature and mixing ratios are given, after convection, as

\[
T_4 = T_4' - \frac{(h_4' - h_3^*)/c_P}{1 + RH_4 Y_g}
\]  (2.96)
The temperature and mixing-ratio adjustments at level 4 given by Eqs. (2.96) and (2.97) also occur in the case of penetrating convection. To find the change in the temperature and mixing ratios at levels 3 and 1 in this case we continue to assume modification of $h_4$ to $h_3^*$ and follow the same procedure used in middle-level convection. Thus, as in Eqs. (2.68) and (2.69) and using $h_3^*$ as the static energy in the cloud, we obtain

$$\frac{dT_1}{\Delta t} = \frac{g}{c_p \Delta p} \frac{M_b}{1 + \gamma_1} \left( h_3^* - h_1^* \right) + \frac{S_1 - S_2}{c_p}$$  \hspace{1cm} (2.98)$$

and

$$\frac{dT_3}{\Delta t} = \frac{g}{c_p \Delta p} \frac{M_b}{1 + \gamma_1} \left( h_3^* - h_4^* \right)$$  \hspace{1cm} (2.99)$$

To determine the value of the mass flux, $M_b$, we assume, as in the case of middle-level convection, that the penetrating convection decays with a relaxation time $\tau_r$. Here $M_b$ is determined by the time required to remove the instability in the layer from level 4 to level 3, i.e., the time required for $h_4^*$ to approach $h_3^*$. With this assumption, the mass flux becomes

$$M_b = \frac{1}{\tau_r} \frac{\Delta p}{\Delta \rho} \left( \frac{h_4^* - h_3^*}{EDH} \right) \left( h_3^* - h_1^* \right) + \frac{S_1 - S_2}{c_p} \left( 1 + \gamma_3 \right) (S_2 - S_4)$$  \hspace{1cm} (2.100)$$

Using Eqs. (2.98), (2.99), and (2.100), the temperature changes at the levels 1 and 3 due to penetrating convection over the time interval $\Delta t$ are given by
\[
(\Delta T_1)_{CP} = \frac{h_4 - h_3^*}{c_p \tau} \tau_1 \frac{5\Delta t}{\tau_r}
\]

\[
(\Delta T_3)_{CP} = \frac{h_4 - h_3^*}{c_p \tau} \tau_2 \frac{5\Delta t}{\tau_r}
\]

where

\[
\tau_1 = \frac{h_3^* - h_1^*}{(1 + \gamma_1)c_p} + \frac{LR}{2}
\]

\[
\tau_2 = \left(\frac{LR}{2}\right) + \theta_3 \left(\frac{P_4}{P_0}\right)^\kappa - T_4
\]

\[
\tau = \begin{cases} 
\text{EDR} \tau_1 + (1 + \gamma_3)\tau_2, & \text{if } \tau \geq 0.001 \\
0.001 & \text{otherwise}
\end{cases}
\]

and \(\tau_r\) is the convection relaxation time as before. As with the middle-level convection, all the moisture condensed (and hence precipitated) is assumed to originate in the lower layer, so that the level-3 moisture change due to penetrating convection is given by

\[
(\Delta q_3)_{CP} = \frac{c_p}{L} \left[ (\Delta T_1)_{CP} + (\Delta T_3)_{CP} \right]
\]

Type-1 clouds may be produced by this convection (see Subsection F.6), and the precipitation rate due to penetrating convection is given by

\[
P_{CP} = \left(\pi/2g\omega\right)(\Delta q_3)_{CP}
\]
This contributes to the total convective precipitation rate illustrated in Map 13, Chapter IV.

4. Evaporation

The evaporation rate per unit area from the surface is approximated by an equation similar to (2.77) for the flux of static energy from the surface. Thus

\[ E = \rho_4 C_D W (q_g - q_4) \]  \hspace{1cm} (2.108)

where \( \rho_4 = p_g (RT_g)^{-1} \) with \( R \) the gas constant, \( p_g \), the surface (level-4) pressure, and \( T_4 \) and \( q_4 \) are given by Eqs. (2.96) and (2.97) if penetrating or low-level convection exists, and otherwise by Eqs. (2.91) and (2.89). The ground-level value of the mixing ratio is given by

\[ q_g = GW q_{se}(T_{gr}) \]  \hspace{1cm} (2.109)

where \( q_{se}(T_{gr}) \) is the effective saturation mixing ratio at the bottom of the boundary layer after a correction to include the effects of the radiation balance at the surface on the ground-level temperature (see Subsection G.3). Thus

\[ q_{se} = q_s(T_g) + \frac{d q_s(T_g)}{dt}(T_{gr} - T_g) \]  \hspace{1cm} (2.110)

where \( T_{gr} \) is the new value of \( T_g \) calculated to include the radiation.

The evaporation thus calculated can be either positive or negative, and is available as a separate output from the program (see Map 14, Chapter IV). The moisture at level 3 will be changed in direct proportion to this evaporation. Thus, over the time interval \( 5\Delta t \), the contribution by evaporation to the total moisture balance at level 3 (see following subsection) is given by

\[ (\Delta q_3)_E = \frac{2R}{n} \cdot E \cdot 5\Delta t \]  \hspace{1cm} (2.111)
5. Moisture Balance and Ground Water

Moisture balance is maintained both in the form of moisture at level 3 and as the ground water on the land. The ocean, ice, and snow are considered both as infinite sources (for evaporation) and infinite sinks (for precipitation, negative evaporation, and runoff). Although the upper-level moisture is calculated as a function of lower-level moisture for radiation purposes, the total amount at the upper level is otherwise considered to be negligible, as is any transport between the upper and lower layers of the model.

The level-3 moisture balance is calculated from

$$q_3^{\text{new}} = q_3^{\text{old}} + (\Delta q_3)^{\text{TOTAL}}$$

where \((\Delta q_3)^{\text{TOTAL}}\) is the sum of the level-3 moisture changes due to middle-level convection, \(CM\), or penetrating convection, \(CP\), large-scale condensation, \(LS\), and evaporation, \(E\). Thus the expression for the moisture-source term of Eq. (2.35) becomes

$$2mg(E - C) = \frac{n}{5\Delta t} \ (\Delta q_3)^{\text{TOTAL}}$$

$$= \frac{n}{5\Delta t} \left[ (\Delta q_3)^{E} - (\Delta q_3)^{LS} - (\Delta q_3)^{CM} - (\Delta q_3)^{CP} \right]$$

The ground water is carried as the variable \(GW\), which varies between 0 for dry ground and 1 for saturated ground. For ocean, ice, or snow, \(GW\) is always considered to be 1. This quantity is used in the determination of ground temperature and evaporation, and is recalculated (for land) after the level-3 moisture balance has been determined. If \((\Delta q_3)^{\text{TOTAL}}\) is negative (a decrease in level-3 moisture), enough precipitation occurs for runoff to be calculated. If the ground is not saturated (\(GW < 1\)) then the runoff is taken as \(0.5 \ GW\); if the ground is saturated, the runoff is taken as unity. The new ground wetness is then given by
\[ (GW)_{\text{new}} = (GW)_{\text{old}} + (1 - \text{runoff})(\Delta q_3) \]
\[ \frac{1}{GWM} \frac{\pi}{2g} \]

(2.114)

where \( GWM \) is the maximum mass of water per unit area which the ground can absorb (here assumed to be 30 g/cm\(^2\)), and the factor \( \pi/2g \) is the air mass in a vertical column of unit area in the lower model layer. If \( (\Delta q_3) \) is not negative, because evaporation is greater than precipitation, the runoff is zero and Eq. (2.114) represents the net decrease of moisture at the ground. If \( (GW)_{\text{new}} < 0 \) then \( (GW)_{\text{new}} \) is set to zero, and if \( (GW)_{\text{new}} > 1 \) it is set to 1.

6. Clouds

The type of clouds present in the model depends upon which condensation and/or convection processes have occurred. The amount of cloud cover depends upon the relative humidity at level 3, \( RH_3 \), for convective clouds, whereas a complete overcast is assumed for clouds caused by large-scale condensation. Figure 2.2 shows the assumed physical dimensions of the various cloud types. Although the clouds are only parameterized entities as far as the moisture is concerned, they must have physical dimensions for the radiation calculations. In the present version of the program, type-1 clouds cannot coexist with other types in any given grid cell; types 2 and 3 may coexist.

Type-1 clouds may be described as towering cumulus, having their bases at level 3 and their tops at level 1. They exist if either middle-level or penetrating convection occurs. The amount of cloud cover (given as the fraction of the sky covered with clouds) is defined by \( CL = -1.3 + 2.6 \times RH_3 \). If \( CL \leq 0 \) the sky is defined to be clear. This convection therefore does not create clouds unless the relative humidity at level 3 is greater than 50 percent. If \( CL > 1 \) it is reset to 1, implying a completely cloudy sky.

Type-2 clouds may be described as a heavy overcast with base at level 3 and top at level 2. They exist if large-scale condensation takes place (as described in Subsection F.2 above), and if type-1 clouds do not exist (since strong convection would destroy these clouds).
Fig. 2.2 -- Schematic representation of convective cloud types. Type-1 cloud represents either penetrating or middle-level convection and is assumed to extend from level $\sigma_0$ to $\sigma_1$, type-2 cloud represents large-scale condensation and is assumed to extend from level $\sigma_0$ to $\sigma_2$, and type-3 cloud represents low-level cumulus convection and is assumed to be confined to level $\sigma_3$ itself.
When type-2 clouds are present they always form a completely overcast sky -- i.e., CL = 1 or 0.

Type-3 clouds may be described as shallow cumulus with bases and tops both at level 3. They exist if there is low-level convection but no penetrating convection. The cloud amount is again defined as

\[ \text{CL} = -1.3 + 2.6 \text{RH}_3 \]

with CL reset to 1 if CL > 1 and with CL ≤ 0 meaning a clear sky. This cloud type could possibly coexist with type 2, but if so it would not affect the radiation, since cloud type 2 is a complete overcast in the same region.

7. Effective Water-Vapor Content

To determine the effect of the moisture on radiation we must estimate the entire vertical profile of q from the single value \( q_3 \). The \( q_3 \) value used here is a revised one, including the effects of large-scale condensation, but not including changes due to convective condensation or evaporation. If \( q_3 < 10^{-5} \) it is set equal to \( 10^{-5} \). Above 120 mb the vapor pressure is assumed to be constant with height, with the value 0.3316 dynes/cm² corresponding to the frost-point temperature 190 deg K, as suggested by Murgatroyd (1960). Thus

\[
q = 0.622 \left( \frac{0.3316}{p_{\text{cgs}}} \right) = \frac{206255}{p_{\text{cgs}}} , \quad p < 120 \text{ mb}
\]  

(2.115)

where \( p_{\text{cgs}} \) is pressure in cgs units (dynes/cm²). Below 120 mb it is assumed that

\[
\frac{q}{q_3} = \left( \frac{p}{p_3} \right)^K(p_3, q_3) , \quad p \geq 120 \text{ mb}
\]  

(2.116)

where \( K(p_3, q_3) \) is evaluated by matching \( q \) from Eqs. (2.115) and (2.116) at the 120-mb level

\[
K(p_3, q_3) = \frac{\ln (q_3/1.7188 \times 10^{-6})}{\ln (p_3/120 \text{ mb})}
\]  

(2.117)
The effective water-vapor amount per unit area in a vertical column below a given level, \( n \), with a pressure-broadening correction term included, is defined to be

\[
\nu_n^* = \int_{z_4}^{z_n} \rho \left( \frac{P}{P_o} \right) q \, dz = \frac{1}{g} \int_{p_n}^{p_4} \left( \frac{P}{P_o} \right) q \, dp
\]  

(2.118)

Combined with the values of \( q \) defined above, this becomes, for level \( n \),

\[
\nu_n^* = \frac{q_3(p_3)^2}{8P_o(2+K)} \left[ \left( \frac{p_4}{p_3} \right)^{2+K} - \left( \frac{p_n}{p_3} \right)^{2+K} \right]
\]

(2.119)

and for the entire atmospheric column, including the stratosphere, the effective water-vapor content becomes

\[
\nu_{\infty}^* = \frac{q_3(p_3)^2}{8P_o(2+K)} \left[ \left( \frac{p_4}{p_3} \right)^{2+K} - \left( \frac{p(120 \text{ mb})}{p_3} \right)^{2+K} \right] + 2.526 \times 10^{-5}
\]

(2.120)

where the additive term is the effective vapor amount above 120 mb, and where \( q_3 \) is set equal to \( 10^{-5} \) if it is \( < 10^{-5} \). The effective vapor content of clouds is described in the following section.

G. RADIATION AND HEAT BALANCE

In this section the heat budget of the earth/atmosphere system is discussed and the expressions which are used to evaluate the diabatic-heating terms in the thermodynamic equations, (2.31) and (2.32), are developed, together with those expressions used to determine the surface temperature over land and over ice-covered oceans.

In addition to being partly determined by the release of latent heat during convection (see Subsection F.3), the net heating rate at level \( 1 (\sigma = 1/4) \) is also determined by the amount of solar radiation absorbed by, and the long-wave radiation emitted from, the layer \( \sigma = 0 \)
to $\sigma = 1/2$. The heating rate at level 3 ($\sigma = 3/4$) is determined by the flux of sensible heat from the surface and the release of latent heat in large-scale condensation (Subsection F.2), in addition to the absorbed and emitted radiation and the convective latent heating in the layer $\sigma = 1/2$ to $\sigma = 1$. The treatment of the short-wave (solar) radiation and the long-wave (terrestrial) radiation used in the model follows the discussion of Arakawa, Katayama, and Mintz (1969). The so-called short-wave radiation includes all the solar radiation, regardless of wavelength, and the parameterization for the attenuation of this radiation by Rayleigh scattering, for its reflection from the earth's surface and from clouds, and for its absorption in the atmosphere and in clouds is given in Subsection G.1. The treatment of the flux of long-wave radiation, which includes all that which is emitted by the atmosphere, clouds, and the earth's surface, is given in Subsection G.2.

The ground temperature, $T_{gr}$, needed to evaluate the evaporation, the sensible heat flux from the surface, and the net long-wave surface radiation is determined from the heat balance at the earth's surface in Subsection G.3, and in Subsection G.4 a discussion of the heat balance in the atmosphere and the expressions for the temperature change due to diabatic heating are given.

1. Short-Wave Radiation

The incoming solar radiation is immediately divided into two parts, that of wavelength $\lambda < 0.9\mu$, which is assumed to be subject to Rayleigh scattering only, and that of wavelength $\lambda \geq 0.9\mu$, which, in a clear atmosphere, is assumed to be subject to absorption only. The actual wavelength does not again enter into the model's treatment of radiation. The two parts of the radiation are designated $S^S_o$ (part subject to scattering) and $S^A_o$ (part subject to atmospheric absorption), and are approximated as

$$S^S_o = 0.651 S_o \cos \zeta$$  \hspace{1cm} (2.121)

$$S^A_o = 0.349 S_o \cos \zeta$$  \hspace{1cm} (2.122)
where $S_o$ is the solar constant (adjusted for the earth/sun distance), and $\zeta$ is the zenith angle of the sun. The rationale for this partitioning is described by Joseph (1966). A summary of the disposition of these components of the short-wave radiation for both clear and cloudy skies is given in Figs. 2.3 and 2.4, and is described in detail in the following paragraphs.

**a. Albedo.** The albedo of the clear atmosphere for the portion of the radiation assumed subject to (Rayleigh) scattering is given by

$$
\alpha_o = \min \{1, 0.085 - 0.247 \log_{10}\left[\frac{(p_g/p_o) \cos \zeta}{(p_g/p_o) \cos \zeta}\right]\}
$$

(2.123)

as deduced by Katayama using the estimate of Joseph (1966). For an overcast atmosphere, the albedo for the scattered part of the radiation is composed of the contributions of Rayleigh scattering (by atmospheric molecules) and of Mie scattering (by cloud drops). The simplest useful formulation adopted by Katayama is

$$
\alpha_{ac} = 1 - (1 - \alpha_o)(1 - \alpha_{c1})
$$

(2.124)

where $\alpha_{c1}$ is the cloud albedo (for both $S_A$ and $S_S$), which is assumed to be given by

$$
\alpha_{c1} = 0.7 \quad \text{for cloud type 1}
$$

$$
\alpha_{c2} = 0.6 \quad \text{for cloud type 2}
$$

(2.125)

$$
\alpha_{c3} = 0.6 \quad \text{for cloud type 3}
$$

The various cloud types are discussed in Subsection F.6 below.

---

In the program, the expression $p_g/p_o$ in Eq. (2.128) was inadvertently coded as $(p_g/p_o)(p_o/p_T)^{-1}$; see instruction 10450 in COMP 3 in the listing of Chapter VII. This error, which is not thought to be serious, was brought to our attention by A. Katayama.
Fig. 2.3 -- Short-wave radiation in a clear atmosphere. The solid arrows indicate the path of radiative flux, while the dashed lines indicate a region of the atmosphere in which interaction occurs or in which a diffuse path is followed. The absorbed radiation $A_1 = S^A_T - S^A_2$ and $A_3 = S^A_2 - S^A_4$, according to (2.136). The program (FORTRAN) symbols are given in parentheses following certain of the physical symbols.
Fig. 2.4 -- Short-wave radiation in an overcast atmosphere, illustrated for cloud type 1. The absorbed radiation $A_1 = S^A_T - S^A_2 - S^A_1 c_1$ according to (2.141), and

$A_3 = S^A_2 - S^A_4$ according to (2.136). See also Fig. 2.3.
The ground albedo $a_g$ (again for both $S_o^A$ and $S_o^S$) is taken as

$$a_g = 0.07 \quad \text{for ocean}$$
$$= 0.14 \quad \text{for land}$$

$$= 0.45\left[1 + (\text{CLAT} - 10)^2/[(\text{CLAT} - 30)^2 + (\text{CLAT} - 10)^2]\right] \quad (2.126)$$
for south-polar ice and snow

$$= 0.40\left[1 + (\text{CLAT} - 5)^2/[(\text{CLAT} - 45)^2 + (\text{CLAT} - 5)^2]\right]$$
for north-polar ice and snow

These values for land, ice, and snow were developed by Katayama (1969) as approximations to the data of Posey and Clapp (1964). In the expressions for polar ice and snow, CLAT is the number of degrees poleward from the assumed northern or southern snowline (as appropriate) given by the functions $\text{SN0WN}$ and $\text{SN0WS}$. The expression for north-polar ice and snow applies also for ice at latitudes between the two snow lines, with $\text{CLAT} = 0$.

b. The Radiation Subject to Scattering ($S_o^S$). The part of the solar radiation which is assumed to be scattered does not interact with the atmosphere, except to be partly scattered back to space. Thus the only part with which we are concerned is that amount which reaches, and is absorbed by, the earth's surface. This is given by the expressions

$$S_{o'}^S = S_o^S(1 - a_g)(1 - a_o)/(1 - a_o a_g)$$
for clear sky

$$S_{o''}^S = S_o^S(1 - a_g)(1 - a_{ac})/(1 - a_{ac} a_g) \quad (2.127)$$
for overcast sky

Multiple reflections between sky and ground or between cloud base and

*These expressions are coded incorrectly in the program; see instructions 23720 and 23760, Chapter VII.
ground are accounted for by the terms in the denominators (see Joseph, 1966). For partly cloudy conditions (neither clear nor overcast) the scattered radiation absorbed at the earth's surface is

\[ S'_g = \text{CL} S''_g + (1 - \text{CL}) S'_{g} \]  

(2.128)

where CL is the fractional cloudiness of the sky (see Subsection F.6). The absorption of this radiation by the ground affects the ground temperature, and subsequently affects the long-wave emission from the ground and the ground-level heat balance (see Figs. 2.3 and 2.4).

c. The Radiation Subject to Absorption \( (S^A_o) \). The solar radiation subject to absorption is distributed as heat to the various layers in the atmosphere and to the earth's surface. The absorption is assumed to depend only upon the effective water-vapor content \( (u^*) \) in a layer -- a quantity calculated from the model as previously outlined (see Subsection F.7). The absorptivity of a layer is given by the empirical formula

\[ A(u^*, \zeta) = 0.271(u^* \sec \zeta)^{0.303} \]  

(2.129)

Here the (dimensionless) coefficient 0.271 has been found by increasing the (dimensional) coefficient 0.172 ly min\(^{-1}\) of the Mürge-Müller absorption formula by 10 percent, as suggested by Manabe and Müller (1961), and then dividing by the total radiative flux subject to absorption, which is given by 0.349\( S_o \) = 0.698 ly min\(^{-1}\) according to Eq. (2.122).

For clear sky the flux of \( S^A_o \) transmitted to a level \( n \) is given by

\[ S^A_n = S^A_o[1 - A(u^* - u^*_n, \zeta)] \]  

(2.130)

and the flux absorbed in a layer between an upper level, \( i \), and a lower level, \( j \), is given by

\[ A_{i+\frac{1}{2}} = S^A_{i} - S^A_{j} \]  

(2.131)
For a cloudy sky the absorption in a cloud is calculated by assuming an equivalent water-vapor content which will absorb the same amount of radiation as would the cloud itself. These amounts are assumed in the present version of the model to be

\[ u_{c_1}^* = 65.3 \text{ g/cm}^2 \quad \text{for cloud type 1} \]

\[ u_{c_2}^* = 65.3 \text{ g/cm}^2 \quad \text{for cloud type 2} \quad (2.132) \]

\[ u_{c_3}^* = 7.6 \text{ g/cm}^2 \quad \text{for cloud type 3} \]

The incoming beam becomes diffuse in the cloud, and its path is assumed to be 1.66 times the vertical thickness of the cloud. Below the cloud the beam is still diffuse, and the factor 1.66 for path length is retained. Therefore we have the following expressions for the downward flux at various levels.

\[ S''_1 = S'_0 \left[ 1 - A(u_m^* - u_{c_1}^*, c) \right] \]

above the cloud at level 1

\[ S''_m = S'_0 (1 - \alpha_c) \left[ 1 - A \left( \left( u_m^* - u_{c_1}^* \right) \sec \zeta + 1.66 \frac{\Delta p_m}{\Delta p_c} u_c^* \right) \right] \]

inside a cloud at level m

\[ S''_j = S'_0 (1 - \alpha_c) \left[ 1 - A \left( \left( u_m^* - u_{c_1}^* \right) \sec \zeta + 1.66(u_c^* + u_{c_1}^* - u_j^*) \right) \right] \]

below a cloud at level j

\[ (2.133) \quad (2.134) \quad (2.135) \]

The fraction \( \Delta p_m / \Delta p_c \), which is equal to 1/2 when \( m = 2 \) and type-1 clouds are present, has been inadvertently omitted from the model's present FORTRAN program.
where subscripts CT and CB refer to the cloud top and cloud bottom, respectively, $\Delta p_c$ is total pressure thickness of the cloud, and $\Delta p_m$ is the pressure thickness of the cloud above level $m$. The factor $(1 - \alpha_c)$ accounts for reflection from the cloud top.

The flux absorbed in a layer in a cloudy sky will, in general, be $A_{i+1/2}^A = S_{i}^A'' - S_{j}^A''$, in a fashion similar to Eq. (2.131) for clear sky. If there is a cloud top anywhere within a layer, however, the flux absorbed by that layer will not be just the flux difference at the levels above and below the layer, since there will be a flux reflected from the cloud top and therefore lost. Thus, for the layer between levels $i$ and $j$, the absorbed radiation is given by

$$A_{i+1}^A = S_{i}^A'' - S_{j}^A'' - S_{CT}^A c$$

(2.136)

where the last term is the flux reflected from the cloud top. When the sky is partly cloudy, the total flux at level $i$ is given by a weighted average of the clear and overcast fluxes:

$$S_i^A = CL S_i^A'' + (1 - CL) S_i^A'$$

(2.137)

That part of the flux subject to absorption which is actually absorbed by the ground is given by

$$(1 - \alpha_g) S_4^A' = S_4^A'$$

(2.138)

for clear sky, and by

$$\frac{(1 - \alpha_g) S_4^A''}{1 - \alpha_c g} = S_4^A''$$

(2.139)
for completely cloudy (overcast) sky, where the factor $1/(1 - a_{cg})$ again accounts for multiple reflections between the ground and cloud base. For partly cloudy skies, the radiation absorbed by the ground is the sum

$$S_g^A = CL S_g^{A''} + (1 - CL) S_g^{A'}$$

(2.140)

The total solar radiation absorbed by the ground will be the sum of that part of the solar radiation subject to (atmospheric) absorption that is absorbed instead by the ground and that part subject to scattering (atmospheric) that is absorbed by the ground. Thus, from Eqs. (2.128) and (2.140), we have

$$S_g = S_g^A + S_g^S$$

(2.141)

2. Long-Wave Radiation

The calculation of the long-wave radiation, like that of the short-wave radiation, is based on an empirical transmission function depending primarily upon the amount of water vapor. The net upward long-wave radiation at a level $i$ can be expressed as the sum of three terms

$$R_i = R_A + R_B + C_i$$

(2.142)

where $R_A$ is the radiative flux downward from the atmosphere above the level $i$, and $R_B$ is the flux from below. The term $C_i$ was intended to be a correction term accounting for a possible large temperature difference between the level-4 air temperature, $T_A$, and the ground surface temperature, $T_g$. However, in the early stages of evolution of the Mintz-Arakawa program the two temperatures were assumed to be equal, and both were designated in the program with the same symbol. At the time the program was modified to calculate the two separately, a programming error was made whereby the terms were not changed consistently. In several statements the ground temperature, $T_g$, is used
in place of the air temperature $T_4$, and in the ground temperature correction term, $C_1$, the values of ground temperatures before and after the heating cycle ($T_g, T_{gr}$) are used in place of $T_4$ and $T_{gr}$.

In this Report we have described what the program actually does, rather than what was intended. Those equations in which $T_g$ was used in place of $T_4$ are indicated throughout Subsections G.2 and G.3 by the symbol -. In future work, the program will be corrected and the effects of this error will be investigated.

The term $C_1$ in Eq. (2.142) is thus now apparently a "correction" involving the change in the ground temperature during the heating time interval. This term depends upon all the various heat-exchange mechanisms in the program, including the other terms involving long-wave radiation. Therefore $R_A + R_B$ is calculated first and the $C_1$ term is left until later (see Subsection G.3). A schematic overview of the long-wave radiation balance is given in Fig. 2.5.

The fluxes at level 1 are given by the expressions

$$R_A = \sigma T_1^4 \tau_A$$

$$R_B = (\sigma T_1^4 - \sigma T_4^4) \tau_B$$

where $\sigma$ is here the Stefan-Boltzman constant, and the empirical transmission functions are given by

$$\tau_A = \tau(u_\infty - u_1)$$

$$\tau_B = \frac{1 + \tau(u_1^*)}{2}$$

with

$$\tau(u_1^*) = \frac{1}{(1 + 1.75u_1^*^{0.416})}$$
Fig. 2.5 -- Long-wave radiation in a clear atmosphere. See also Fig. 2.3.
as found by Katayama for the Callendar water-vapor transmission function. Here \( u^* \) is the effective vapor content defined in Subsection F.7. For a clear sky, if we define \( R'_1 = R'_A + R'_B \), we have at the three levels
\[ \sigma = 0 \ (i = 0), \ \sigma = 1/2 \ (i = 2), \ \text{and} \ \sigma = 1 \ (i = 4), \]
where radiation is determined by:
\[
R'_0 = \sigma T_0^4 \tau (u^*_\infty - u^*_0) + (\sigma T_0^4 - \sigma T_0^4) \frac{1 + \tau (u^*_0)}{2} \tag{2.148} \\
R'_2 = \sigma T_2^4 \tau (u^*_\infty - u^*_2) + (\sigma T_2^4 - \sigma T_2^4) \frac{1 + \tau (u^*_2)}{2} \tag{2.149} \\
R'_4 = \sigma T_4^4 \tau (u^*_\infty) \tag{2.150}
\]

Here the primes indicate a clear sky. To account for the absorption by CO\(_2\), which is not included in the above expressions, the model incorporates a number of empirical modifications [due to Katayama (1969)] of the long-wave fluxes. We thus redefine the clear-sky fluxes given above as
\[
R'_0 = 0.820R'_0 \tag{2.151} \\
R'_2 = 0.736R'_2 \tag{2.152} \\
R'_4 = \sigma T_4^4 \left[ 0.6 \sqrt{\tau (u^*_\infty)} - 0.1 \right] \tag{2.153}
\]
which are the clear-sky expressions used in the program. The expression for \( R'_4 \) is similar to Brunt's formula.

Clouds are treated as opaque black bodies, and the cloud cover may consist of any of the model's three cloud types. Including empirical corrections, one uses the following expressions for the radiation in
completely overcast skies. For cloud type 1 (top at level 1, bottom at level 3)

\[ R''_0 = 0.820 \left[ \sigma T_0^4 (u^*_0 - u^*_1) + (\sigma T_1^4 - \sigma T_0^4) \frac{1 + \tau (u^*_0 - u^*_1)}{2} \right] \]  
(2.154)

\[ R''_2 = 0 \]  
(2.155)

\[ R''_4 = 0.85 (\sigma T_0^4 - \sigma T^4_3) \left[ 1 + 3 \tau (u^*_3) \right] / 4 \]  
(2.156)*

where the double primes indicate an overcast sky and \( R''_1 \equiv R_A + R_B \). For cloud type 2 (top of cloud at level 2, bottom at level 3),

\[ R''_0 = 0.820 \left[ \sigma T_0^4 (u^*_0 - u^*_1) + (\sigma T_1^4 - \sigma T_0^4) \frac{1 + \tau (u^*_0 - u^*_1)}{2} \right] \]  
(2.157)

\[ R''_2 = [0.736 \sigma T_2^4 (u^*_0 - u^*_2)] / 2^+ \]  
(2.158)

\[ R''_4 = \text{same as for cloud 1 [Eq. (2.156)]} \]

For cloud type 3 (top and bottom at level 3):

\[ R''_0 = 0.820 \left[ \sigma T_0^4 (u^*_0 - u^*_1) + (\sigma T_3^4 - \sigma T_0^4) \frac{1 + \tau (u^*_0 - u^*_3)}{2} \right] \]  
(2.159)

\[ R''_2 = 0.736 \left[ \sigma T_2^4 (u^*_0 - u^*_2) + (\sigma T_3^4 - \sigma T_2^4) \frac{1 + \tau (u^*_0 - u^*_3)}{2} \right] \]  
(2.160)

\[ R''_4 = \text{same as for cloud type 1 [Eq. (2.156)]} \]

*This \( R''_2 \) is divided by 2 because the cloud top is assumed to be an irregular surface lying half-above, half-below level 2.
If we now define $\tilde{R}_1$ as the net upward long-wave radiation for partly cloudy skies prior to the ground-temperature correction, $R'_1$ and $R''_1$ combine to give

$$\tilde{R}_1 = (1 - CL)R'_1 + (CL)R''_1$$

(2.161)

where $CL$ is the fractional cloudiness (see Subsection F.6).

Finally, after the ground temperature has been determined using $\tilde{R}_1$ and the calculated short-wave radiation (among other quantities, as described in Subsection G.3 below), the long-wave radiation is calculated in its complete form $R_1$ by applying the correction $(C)$ given at level 4 by

$$C_4 = 4\sigma T^3_{gr} - T_g$$

(2.162)

where $4\sigma T^3_{gr} - T_g$ is an approximation to $\sigma(T^4_{gr} - T^4_g)$. The complete long-wave flux at level 4 is thus given, according to Eq. (2.96), by

$$R_4 = \tilde{R}_4 + C_4 = (1 - CL)R'_4 + (CL)R''_4 + 4\sigma T^3_{gr} - T_g$$

(2.163)

At levels 2 and 0 the complete long-wave flux is similarly given by

$$R_2 = \tilde{R}_2 + C_2 = \tilde{R}_2 + 0.8(1 - CL)C_4^2 u^*$$

(2.164)

$$R_0 = \tilde{R}_0 + C_0 = \tilde{R}_0 + 0.8(1 - CL)C_4^2 u^*$$

(2.165)

where $\tilde{R}$ is given by Eq. (2.161) and $C_4$ by (2.162), and where the coefficient 0.8 is the correction factor for $CO_2$ absorption. These are the long-wave radiation fluxes calculated in the program as the net transfers at the levels 4, 2, and 0, and are used in the preparation of the
long-wave radiative budgets for the layers 0 to 2 and 2 to 4 as well as for the surface (level-4) radiation budget in the output programs (see Chapter IV). The various components of these long-wave fluxes are summarized in Fig. 2.6.

3. Heat Balance at the Ground

The ground temperature, $T_{gr}$, as corrected for surface radiation and as used to find the evaporation, is itself obtained from the heat balance at the ground. The treatment of the heating of the ground depends first of all upon the character of the ground or underlying surface.

If the surface is ice-free ocean, it is considered to be an infinite heat reservoir whose surface temperature, $T_s$, is a specified function of position and does not change during the heating time interval ($5\Delta t$). The new ground temperature, $T_{gr}$, is set equal to the old $T_s$.

Where the surface is bare land, snow-covered land, or ice-covered land, the ground is considered to be a perfect insulator with zero heat capacity. For these types of ground, the total flux of heat across the air/ground interface must be zero, according to

$$R_4 + \Gamma + H_E - S_g = 0$$  \hspace{1cm} (2.166)

where $R_4$ is the long-wave radiation emitted from the surface, $\Gamma$ is the sensible heat flux from the surface, $H_E$ is the flux of latent heat due to evaporation from the surface, and $S_g$ is the solar radiation absorbed by the ground.

For ice-covered ocean, the surface heat balance is modified to include conduction of heat through the ice, $\tilde{B}$, in which case Eq. (2.166) is changed to read

$$R_4 + \Gamma + H_E - S_g - \tilde{B} = B(T_o - T_{gr})$$  \hspace{1cm} (2.167)
Fig. 2.6 -- Long-wave radiation in an overcast atmosphere (cloud types 1, 2, or 3). See also Fig. 2.3.
where $T_0$ equals the freezing point of seawater (273.1 deg K). Equation (2.167) is applicable to the land, snow- and ice-covered land surfaces too, if we define $B = 0$ for these locations; for sea ice the conduction coefficient $B$ is equal to 1.44 ly day$^{-1}$ deg$^{-1}$, found from an assumed thermal conductivity of 0.005 ly cm sec$^{-1}$ deg$^{-1}$ and an ice thickness of 300 cm. Note that, except for the solar radiation, these heating terms depend upon the as-yet-undetermined new value of the ground temperature, $T_{gr}$, as well as upon the old value, $T_g$, upon the temperature of the air, $T_4$, or upon the freezing point of seawater, $T_0$.

The heating terms are given by

$$R_4 = \tilde{R}_4 + \sigma(T^4_{gr} - T^4_g)$$  \hspace{1cm} (2.168)

where $\tilde{R}$ is the long-wave radiation without the ground-temperature correction as given by Eq. (2.161) and $\sigma(T^4_{gr} - T^4_g)$ is the "correction" term. (See, however, Subsection G.2.) The sensible (turbulent) heat flux, $\Gamma$, is given by

$$\Gamma = C_T(T_{gr} - T_4)$$  \hspace{1cm} (2.169)

where

$$C_T = \rho_A C_p C_D W$$  \hspace{1cm} (2.170)

where $W$ is the surface wind speed, as corrected for gustiness in Eq. (2.78). The latent heat flux is given by

$$H_E = LE = C_T L C_p \left\{ GW \left[ q_s(T_g) + \frac{dq_s}{dT} \frac{dT_g}{dT} (T_{gr} - T_g) \right] - q_4 \right\}$$  \hspace{1cm} (2.171)
where Eqs. (2.108) and (2.109) have been used to evaluate the evaporation.

Substituting Eqs. (2.168), (2.169), and (2.171) for $R_4$, $r$, and $H_E$ into the heat-balance equation, (2.167), and approximating

$$\sigma(T_{gr}^4 - T_g^4)$$

by $4\alpha T_g^3(T_{gr} - T_g)$, we can solve for the unknown ground temperature $T_{gr}$. Thus, we have

$$T_{gr} = \frac{C_T \left( T_4 + \frac{L}{c_p} \left\{ q_4 + GW \left( \frac{dq_s(T_g)}{dT} T_g - q_s(T_{gr}) \right) \right\} \right)}{C_T \left[ 1 + \frac{L}{c_p} \frac{dq_s(T_g)}{dT} GW \right] + 4\sigma T_g^3 + B}$$

(2.172)

Having found $T_{gr}$, we can complete the calculation of the individual radiation and heating terms $R_4$ (and $R_2$, $R_0$ as in Subsection C.2), $r$ and $H_E$ from Eqs. (2.167) to (2.171), and the surface evaporation, $E$, from Eq. (2.108). The equations are applicable to an ocean surface as well as to land, ice, and snow: for oceans, $T_{gr} = T_g$, some of the terms will be zero, and there will be no correction terms for the long-wave radiation; for ice and snow, if the calculated value of $T_{gr}$ is greater than $T_o$ (= 273.1 deg K) it is set equal to $T_o$.

4. Heat Budget of the Atmosphere

The heat balance is maintained at the ground through the calculated ground temperature (see previous section), and at the levels 3 and 1 by means of the diabatic heating terms on the right-hand sides of Eqs. (2.31) and (2.32). After the temperature changes due to convective adjustment (see Subsection F.1), no further change is made until the end of all the radiation- and moisture-balance calculations. Then the change in temperature over the interval $5\Delta t$ at levels 3 and 1 is given by

$$H_3 = 5\Delta t \hat{H}_3$$

$$= (A_3 + R_4 - R_2 + r) \left( \frac{2g}{\pi c_p} \right) 5\Delta t + (\Delta T_3)_{CM} + (\Delta T_3)_{CP} + (\Delta T_3)_{LS}$$
\[ H_1 = 5 \Delta t \hat{H}_1 \]
\[ = (A_1 + R_2 - R_0)(2g/c_p)5\Delta t + (\Delta T_{CM}) + (\Delta T_{CP}) \]  
\[ (2.174) \]

Here \( A_1 \) and \( A_3 \) are the net absorption of solar radiation at the levels 1 and 3 (see Subsection G.1), \( R_4 - R_2 \) and \( R_2 - R_0 \) are the long-wave radiation absorbed in the layers 4-2 and 2-0 (see Subsections G.2 and G.3), and \( \Gamma \) is the sensible heat flux (see Subsection G.3). The \((\Delta T)\) terms are the latent heat released during large-scale condensation (LS) [Eq. (2.17)], middle-level convection (CM) [Eqs. (2.73) and (2.74)], and penetrating convection (CP) [Eqs. (2.101) and (2.102)] (see Subsections F.2 and F.3). The factor \( 5\Delta t \) is the time interval between heating calculations, and together with the factor \( 2g/c_p \) converts the heating rate to the layers' temperature change.

There is some smoothing of the heating as given by Eqs. (2.173) and (2.174) in both the vertical and horizontal directions before the temperatures \( T_1 \) and \( T_3 \) are redefined at the end of the time interval. The average heating, \( \bar{H} = 1/2(\hat{H}_1 + \hat{H}_3) \), is first weighted according to the area of the grid cell surrounding the \( \pi \) point, and is then subjected to a 9-point areal smoothing with the central heating value weighted by 1/4, the four values to the north, south, east, and west each weighted by 1/8, and the four values to the northeast, northwest, southeast, and southwest each weighted by 1/16. If we denote the result of this smoothing operation on \( \bar{H} \) by \( \bar{H}^A \), the final temperatures, after correction for diabatic heating at levels 1 and 3, are determined from

\[ T_1 = T_1' + \frac{H_1}{2} - \frac{H_3}{2} + \bar{H}^A \]  
\[ T_3 = T_3' + \frac{H_3}{2} - \frac{H_1}{2} + \bar{H}^A \]  
\[ (2.175) \]
\[ (2.176) \]

where \( T_1' \) and \( T_3' \) are the temperatures at levels 1 and 3 before the correction for diabatic heating.
Equations (2.27) to (2.33) and Eq. (2.35) form a set of eight prognostic equations for the eight dependent variables \( u_1, v_1, u_3, v_3, T_1, T_3, \pi, \) and \( q_3 \). The time-extrapolation method and the horizontal finite-difference schemes used to solve these equations were developed by Professor Arakawa at UCLA and are discussed in the following sections. For convenience, Eqs. (2.27) to (2.33) and Eq. (2.35) have been restated in Tables 3.1 to 3.4 and Table 3.6, where the sub-sections describing the numerical treatment of each term are indicated, along with the location in the FORTRAN program where each term is evaluated. The diagnostic equation for the vertical velocity [Eq. (2.34)] is given a similar treatment in Table 3.5. In the present chapter, particular attention has been given to the preparation of a systematic statement of the precise finite-difference approximations actually used in the programmed numerical solution of the model. The smoothing procedures, provisions for global mass conservation, and the various parameters and constants used in the model are also summarized here.

A. TIME FINITE DIFFERENCES

1. The General Scheme of Time Extrapolation

From the equations in Tables 3.1 to 3.4 and Table 3.6, we can obtain expressions for the tendencies of the dependent variables \( \psi = u_1, v_1, \ldots \) at the point \( ij \) in the general form

\[
\left[ \frac{\partial \psi}{\partial t} \right]_{ij} = D\psi + S\psi
\] (3.1)

while the pressure-tendency equation is written in the form

\[
\left[ \frac{\partial \pi}{\partial t} \right]_{ij} = D\pi
\] (3.2)
Table 3.1

DESCRIPTION OF THE ZONAL (u) MOMENTUM EQUATIONS

<table>
<thead>
<tr>
<th></th>
<th>u Momentum Tendency</th>
<th>Horizontal Advection of u Momentum</th>
<th>Vertical Advection of u Momentum</th>
<th>Coriolis Force</th>
<th>Pressure-Gradient Force</th>
<th>Friction Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eq. (2.27): (\frac{3}{3} (\frac{\partial u}{\partial t})) =</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(- \frac{3}{3} x (u_1 u_1) - \frac{3}{3} y (v_1 u_1)) - (\frac{3}{3} u_2) (\lambda v F) - (n\left[\frac{3}{3} \lambda \frac{3}{3} x \frac{3}{3} y\right]) + (\lambda F_F)</td>
<td></td>
<td>(\lambda v F)</td>
<td></td>
<td>(n\left[\frac{3}{3} \lambda \frac{3}{3} x \frac{3}{3} y\right]) + (\lambda F_F)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Eq. (2.29): \(\frac{3}{3} (\frac{\partial u}{\partial t})\) = |                          |                                    |                                 |                |                        |               |
| \(- \frac{3}{3} x (u_3 u_3) - \frac{3}{3} y (v_3 u_3)\) + \(\frac{3}{3} u_2\) \(\lambda v F\) - \(n\left[\frac{3}{3} \lambda \frac{3}{3} x \frac{3}{3} y\right]\) + \(\lambda F_F\) | | \(\lambda v F\) | | \(n\left[\frac{3}{3} \lambda \frac{3}{3} x \frac{3}{3} y\right]\) + \(\lambda F_F\) |

<table>
<thead>
<tr>
<th>Program Reference</th>
<th>STEP (1850-2280)</th>
<th>COMP 1 (3750-4120)</th>
<th>COMP 1 (4690-4830)</th>
<th>COMP 2 (5010-5200)</th>
<th>COMP 2 (5450-5690)</th>
<th>COMP 2 (5710-6050)</th>
<th>COMP 3 (11500-11620)</th>
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</thead>
<tbody>
<tr>
<td>Text Reference</td>
<td>III.A.(1-3)</td>
<td>III.C.3</td>
<td>III.C.4</td>
<td>III.C.5</td>
<td>III.C.6</td>
<td>III.C.10</td>
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</tbody>
</table>
**Table 3.2**  
**DESCRIPTION OF THE MERIDIONAL (v) MOMENTUM EQUATIONS**

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<tr>
<th>v Momentum Tendency</th>
<th>Horizontal Advection of v Momentum</th>
<th>Vertical Advection of v Momentum</th>
<th>Coriolis Force</th>
<th>Pressure-Gradient Force</th>
<th>Friction Term</th>
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</thead>
<tbody>
<tr>
<td>Eq. (2.28): $\frac{\partial (\nabla v)}{\partial t} = -\frac{\partial}{\partial x} (u^1 v_1) - \frac{\partial}{\partial y} (v_1^* v_1) - \frac{\partial}{\partial y} v_2 - \pi u_1 F - m \left[ \frac{\partial \theta}{\partial y} + \sigma_1 \pi \alpha \frac{\partial \pi}{\partial y} \right] + \Pi F_1^Y$</td>
<td></td>
<td></td>
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<tr>
<td>Eq. (2.30): $\frac{\partial (\nabla v_3)}{\partial t} = -\frac{\partial}{\partial x} (u_3 v_3) - \frac{\partial}{\partial y} (v_3^* v_3) + \frac{\partial}{\partial y} v_2 - \pi u_3 F - m \left[ \frac{\partial \theta}{\partial y} + \sigma_3 \pi \alpha \frac{\partial \pi}{\partial y} \right] + \Pi F_3^Y$</td>
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<table>
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<th>COMP 3 (11500-11620)</th>
</tr>
</thead>
<tbody>
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<td>III.A.(1-4)</td>
<td>III.C.3</td>
<td>III.C.4</td>
<td>III.C.5</td>
<td>III.C.6</td>
<td>III.C.10</td>
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</tbody>
</table>
Table 3.3
DESCRIPTION OF THE THERMODYNAMIC ENERGY EQUATION

<table>
<thead>
<tr>
<th>Temperature Tendency</th>
<th>Horizontal Advection of Temperature</th>
<th>Energy Conversion Terms</th>
<th>Diabatic Heating Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eq. (2.31): [ \frac{3}{\tau} (\nabla T_1) = -\frac{3}{\tau} (u_1^* T_1) - \frac{3}{\tau} (v_1^* T_1) - \left( \frac{p_1}{p_0} \right)^k a_2 \frac{\sigma}{c_p} \nabla T_1 + \frac{\sigma_1 a_1}{c_p} \frac{\partial \pi}{\partial \tau} + \frac{\sigma_1 a_1}{c_p} \left[ u_1^* \frac{\partial \pi}{\partial x} + v_1^* \frac{\partial \pi}{\partial y} \right] + \frac{\hat{H}_1}{c_p} ]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eq. (2.32): [ \frac{3}{\tau} (\nabla T_2) = -\frac{3}{\tau} (u_3^* T_3) - \frac{3}{\tau} (v_3^* T_3) + \left( \frac{p_3}{p_0} \right)^k a_2 \frac{\sigma_3 a_3}{c_p} \nabla T_3 + \frac{\sigma_2 a_3}{c_p} \frac{\partial \pi}{\partial \tau} + \frac{\sigma_2 a_3}{c_p} \left[ u_3^* \frac{\partial \pi}{\partial x} + v_3^* \frac{\partial \pi}{\partial y} \right] + \frac{\hat{H}_3}{c_p} ]</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Program Reference
- STEP (1850-2280)
- COMP 1 (3250-3730)
- COMP 1 (4560-4670)
- COMP 2 (6070-6370)
- COMP 3 (11280-11480)

Text Reference
- III.A.(1-4)
- III.C.7
- III.C.8
- III.C.12
Table 3.4

DESCRIPTION OF THE PRESSURE-TENDENCY EQUATION

<table>
<thead>
<tr>
<th></th>
<th>Pressure Tendency</th>
<th>Mass Convergence at the Upper Level</th>
<th>Mass Convergence at the Lower Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eq. (2.33):</td>
<td>( \frac{\partial \Pi}{\partial t} = )</td>
<td>(- \frac{1}{2} \left( \frac{\partial}{\partial x} u_1^* + \frac{\partial}{\partial y} v_1^* \right) )</td>
<td>(- \frac{1}{2} \left( \frac{\partial}{\partial x} u_3^* + \frac{\partial}{\partial y} v_3^* \right) )</td>
</tr>
<tr>
<td>Program Reference</td>
<td>STEP (1850-2280)</td>
<td>COMP 1 (4130-4540)</td>
<td></td>
</tr>
<tr>
<td>Text Reference</td>
<td>III.A.(1-4)</td>
<td></td>
<td>III.C.2</td>
</tr>
</tbody>
</table>
Table 3.5
DESCRIPTION OF THE VERTICAL VELOCITY EQUATION

<table>
<thead>
<tr>
<th>Vertical Velocity</th>
<th>Mass Convergence at Upper Level</th>
<th>Mass Convergence at Lower Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eq. (2.34): ( \dot{S} = + \frac{1}{2} \left( \frac{\partial}{\partial x} u_3^* + \frac{\partial}{\partial y} v_3^* \right) - \frac{1}{2} \left( \frac{\partial}{\partial x} u_1^* + \frac{\partial}{\partial y} v_1^* \right) )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Program Reference</td>
<td>COMP 1 (4530)</td>
<td>COMP 1 (4130-4540)</td>
</tr>
<tr>
<td>Text Reference</td>
<td>III.C.2</td>
<td>III.C.2</td>
</tr>
</tbody>
</table>
### Table 3.6
Description of the Moisture-Balance Equation

<table>
<thead>
<tr>
<th>Moisture Tendency</th>
<th>Horizontal Advection of Moisture</th>
<th>Moisture-Source Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eq. (2.35): [\frac{3}{\delta t}(\Pi q_3) = -\frac{3}{\delta x}\left[q_3\left(\frac{5}{4} u_3^* - \frac{1}{4} u_1^*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table><p>ight)\right] - \frac{3}{\delta y}\left[q_3\left(\frac{5}{4} v_3^* - \frac{1}{4} v_1^*ight)\right] + 2\mu g(E - C)] |                                                                      |                                        |</p>

<table>
<thead>
<tr>
<th>Program Reference</th>
<th>Reference</th>
<th>Stage</th>
<th>Reference</th>
<th>Stage</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEP (1850-2280)</td>
<td>COMP 1 (3250-3730)</td>
<td>COMP 3 (11280-11480)</td>
<td>III.A.(1-4)</td>
<td>III.C.9</td>
<td>III.C.11</td>
</tr>
</tbody>
</table>
The expression $S_\psi$ represents the friction terms in the momentum equations, the diabatic heating term in the energy equation, or the moisture source term in the moisture equation. These terms will be referred to collectively as the "source terms." All the other terms are included in the expression $D_\psi$. Both $D_\psi$ and $S_\psi$ are complicated finite-difference expressions involving the independent variables and the dependent variables at $ij$ and neighboring points.

In the time-extrapolation method used in this model, the source terms are evaluated every fifth time step. The remaining terms ($D_\psi$) are evaluated each time step by means of a sequence of uncentered and centered horizontal differences. Thus, the time extrapolation proceeds in a repeated sequence of five individual time steps of $\Delta t$ each. The first four time steps consist of two substeps each, and the fifth time step consists of three substeps. The first substage, which is identical in all five time steps, provides a preliminary estimate of the dependent variables for time $\tau + n$ by evaluating $D_\psi$ using values of the dependent variables at time $\tau + (n - 1)$. The second substage obtains a final estimate of the dependent variables using the preliminary estimates to evaluate $D_\psi$ with the horizontal-difference scheme appropriate to the position in the five-step sequence. The special third substage in the fifth time step consists of evaluating the source terms using values of the dependent variables obtained from the second substage. An outline of this procedure is shown in Fig. 3.1, and each substage of the time step is described below.

2. Preliminary Estimate of the Dependent Variables (All Time Steps)

The preliminary estimate (identified in the FORTRAN code by the flag MRCH=1) is obtained using a forward time step and evaluating $D_\psi$ by a centered horizontal difference. However, the horizontal and vertical advection terms and the Coriolis force term of $D_\psi$ are advanced only a half time step, while the remaining terms are advanced a full time step ($\Delta t$). Thus, from Eq. (3.1) for the momentum, energy, and moisture equations we have, upon omitting the source terms,
Fig. 3.1 -- Sequence of time steps and substages in the time-integration procedure.
\[
(\hat{\psi}_j^{T+1}) = (\psi_j^T) + \frac{\Delta t}{2} A_\psi(\pi^T, u^T, \ldots)_{ij} + \Delta t R_\psi(\pi^T, u^T, \ldots)_{ij}
\]

where \( A_\psi \) represents the advection terms in \( D_\psi \), \( R_\psi = D_\psi - A_\psi \) represents the remaining terms of \( D_\psi \), the superscript \( T \) refers to values at time \( T \), and the caret is used to indicate the preliminary estimate of a quantity. Similarly, the pressure-tendency equation (3.2) becomes

\[
(\hat{\eta}^{T+1})_{ij} = (\eta^T)_{ij} + \Delta t D_\eta(\hat{n}, \hat{u}, \ldots)_{ij}
\]

The first estimate of the dependent variables \( \psi \) is therefore given by Eqs. (3.3) and (3.4) as

\[
\hat{\psi}^{T+1} = \frac{(\hat{\psi})^{T+1}_{ij}}{(\hat{n})^{T+1}_{ij}}
\]

which serves to remove the \( \Pi \) weighting of the variables. As noted previously, this procedure is used as a preliminary estimate in each time step of the numerical integration.

3. Final Estimate of the Dependent Variables (Time Steps 1 to 4)

Using the preliminary estimates given above, the final estimates of the dependent variables at the nth time step of the sequence \( n = 1, 2, 3, 4 \) become

\[
(\Pi \psi)^{T+n}_{ij} = (\Pi \psi)^{T+(n-1)}_{ij} + \Delta t D_\psi(\hat{n}, \hat{u}, \ldots)_{ij}
\]

\[
\eta^{T+n}_{ij} = \eta^{T+(n-1)}_{ij} + \Delta t D_\eta(\hat{n}, \hat{u}, \ldots)_{ij}
\]

from which we calculate
When \( n = 1 \) an up-right uncentered horizontal space difference is used (identified by the flag MRCH=3); when \( n = 2 \), a down-left uncentered horizontal space difference is used (identified by the flag MRCH=4), and when \( n = 3 \) or 4, a centered horizontal space difference is used (identified by the flag MRCH=2). The case for \( n = 5 \) is considered below.

4. Final Estimate of the Dependent Variables (Time Step 5)

The first two substages of the fifth time step \( (n = 5) \) are performed as described above by Eqs. (3.6) to (3.8). If we represent the variables at the end of the second substage of the fifth time step by a tilde, \( \tilde{\psi} \), the final estimates become

\[
\tilde{\psi}_{i,j}^{n+5} = \tilde{\psi}_{i,j}^{n+5} + 5\Delta t \frac{S_{\psi}(\tilde{\psi}_{i,j}^{n+5}, u^{n+5}, \ldots)_{i,j} - \tilde{\psi}_{i,j}^{n+5}}{\nabla \tilde{\psi}_{i,j}^{n+5}}
\]

The final estimate at every fifth time step thus introduces the source terms (as evaluated in subroutines COMP 3 and COMP 4), and weights them for the full \( 5\Delta t \) time interval. Because the continuity (or pressure-tendency) equation (3.2) is source free, the value of \( \tilde{\psi}_{i,j}^{n+5} \) is given directly by the final estimate [Eq. (3.7)] for \( n = 5 \).

Upon the completion of this time step, the sequence of five steps begins again. The flow of this time-integration procedure is controlled by subroutine STEP (steps 1850 to 2280). The horizontal finite-difference expressions used in the determination of the terms \( S_\psi, D_\psi, \) and \( R_\psi \) are given below.
B. HORIZONTAL FINITE DIFFERENCES

1. The Horizontal Finite-Difference Grid

The earth's surface is represented in the numerical calculations by a rectangular grid of points extending from pole to pole, an arbitrary point of which is designated \(ij\) and identified by \((J,I)\) in the code. The 180th meridian is represented by the set of points \((1,j)\), the longitude 175W by the points \((2,j)\), etc., the South Pole by \((1,1)\), and the North Pole by \((1,J)\); the equator is not a member of this grid, but corresponds to the value \(j = 23^{\circ}\). This set of primary grid points can be regarded as the centers of the network of rectangular cells outlined by dashed lines in Fig. (3.2). The velocity variables \(u\) and \(v\) are carried at the corners of the cells (designated by + in the figure), the west/east mass flux \(u^*\) at the midpoints of the vertical sides (designated >), and the south/north mass flux \(v^*\) at the midpoint of the horizontal sides (designated \(\wedge\)). All other quantities are carried at the midpoint of the cells (designated o). The values of \(u\) and \(v\) at the lower right-hand corner of the cell \((i,j)\) are denoted by \(u_{ij}\) and \(v_{ij}\), the value of \(u^*\) on the right-hand side of the cell by \(u_{ij}^*\) and the value of \(v^*\) on the lower side of the cell by \(v_{ij}^*\). In the remainder of the text, the points o, +, >, and \(\wedge\) will be referred to as "\(\pi\) points," "\(u,v\) points," "\(u^*\) points," and "\(v^*\) points," respectively. It may be noted that the poles are "\(\pi\) points," while the points at the equator are "\(u,v\) points."

The grid-point separation factors \(m\) and \(n\) represent the geographical distance between grid points, and are defined by Eqs. (2.18) and (2.19). The factors \(m,n\) and the area \((mn)\) of the cells surrounding the \(\pi\) points are computed in subroutine MAGFAC (steps 14360 to 14850), where the following quantities are defined:

For purposes of computational efficiency, the notation \((J,I)\), listing the y-index \(J\) first, is used in the FORTRAN code in lieu of the more conventional \((I,J)\) notation. When reproducing specific FORTRAN statements this \((J,I)\) notation, where \(J = 1, 2, \ldots, JM\) and \(I = 1, 2, \ldots, IM\), will be used. Elsewhere, the notation \((i,j)\), where \(i = 1, 2, \ldots, I\) and \(j = 1, 2, \ldots, J\), will be used.
Fig. 3.2 -- The horizontal finite-difference grid with zonal index $i$ and meridional index $j$. Here the open circles (o) represent grid points of the primary or $T$ grid at which $T$, $q$, and $\phi$ are carried, while the plus (+) signs represent points at which $u$ and $v$ are carried (the $u,v$ grid). The carets ($\wedge$ and $\triangleright$) denote points of supplementary grids at which the northward and eastward mass fluxes $v^*$ and $u^*$ are determined.
LAT(j) = \psi_j = \Delta \psi(j - \frac{J + 1}{2}) \quad 1 \leq j \leq J \quad (3.10)

DXP(j) = a\Delta \lambda \cos \phi_j \quad 1 \leq j \leq J \quad (3.11)

DXU(j) = a\Delta \lambda \frac{1}{2} (\cos \phi_j + \cos \phi_{j-1})
\quad = \frac{1}{2} [DXP(j) + DXP(j-1)] \quad 1 \leq j \leq J

DYU(j) = a(\psi_j - \psi_{j-1}) \quad j \geq 2 \quad (3.13)

DYU(1) = DYU(2)

DYP(j) = a\Delta \lambda (\phi_{j+1} - \phi_j)
\quad = \frac{1}{2} [DYU(j+1) + DYU(j)] \quad 2 \leq j \leq J

DYP(1) = DYU(2)

DYP(J) = DYU(J)

DXYP(j) = DYP(j) \frac{[DXU(j+1) + DXU(j)]}{2} \quad 2 \leq j \leq J \quad (3.15)

DXYP(1) = \frac{1}{2} DXU(2) \frac{DYP(1)}{2}

DXYP(J) = \frac{1}{2} DXU(J) \frac{DYP(J)}{2}

These quantities are illustrated in Figs. 3.3 to 3.5. From Fig. 3.2 we see that \pi and u* are carried at the same latitudes, whereas u, v, v* are carried at intermediate latitudes. Thus, the factors m,n centered at \pi or u* points are given by DXP and DYP, whereas those centered at u, v, or v* points are given by DXU and DYU. In this scheme the pressure (\pi) is thus given at the poles but not at the equator, whereas the velocity (u,v) is given at the equator but not at the poles.
Fig. 3.3 -- The map metric $n$, the meridional distance between grid points. At latitude $\varphi_j$, $n = DYP$ is the north/south distance between points of the $u,v$ grid (and between points of the $v^*$ grid), while $n = DYU$ gives the corresponding distance between points of the $\pi$ grid (and between points of the $u^*$ grid).

Fig. 3.4 -- The map metric $m$, the zonal distance between grid points. At latitude $\varphi_j$, $m = DXP$ is the east/west distance between points of the $\pi$ grid (and between points of the $u^*$ grid), while $m = DXU$ gives the corresponding distance between points of the $u,v$ grid (and between points of the $v^*$ grid).
Fig. 3.5 -- The area $mn = DXYP$ surrounding a point of the $\pi$ grid (a). At the north and south poles ($j=J$ and $j=1$) this area is identified as the shaded regions shown in (b) and (c), respectively.
2. Finite-Difference Notation

The \([J,I]\) indexing used in the FORTRAN code is identical for each of the four grid networks described above. That is, \(u_{JI}, v_{JI}, u_{*JI}\), and \(v_{*JI}\) all have the same index, \((J,I)\), but each of these is carried and computed at different points in the horizontal finite-difference grid. It is convenient, therefore, to define \(u, v, u^*,\) and \(v^*\)-centered notations to be used in formulating the finite-difference expressions. These notations are illustrated in Figs. 3.6 to 3.9. Here the index used for the finite-difference expressions is given below each point, and the \([J,I]\) index used in the FORTRAN code is given above each point. These figures facilitate the transformation of the finite-difference expressions given below into the equivalent FORTRAN statements found in the program itself (see Chapter VII).

It is also convenient to introduce a notation for the grid-point separation factors (the horizontal distances between grid points on the surface of the earth). For each of the \(u, v, u^*,\) and \(v^*\)-centered notations (see Figs. 3.6 to 3.9), \(m_{-1}, m_0,\) and \(m_1\) will denote the distance from \(-20\) to \(00\), from \(-10\) to \(10\), and from \(00\) to \(22\), respectively. Similarly, \(n_{-1}, n_0,\) and \(n_1\) will denote the distance from \(-2\) to \(00\), from \(-1\) to \(1\), and from \(00\) to \(2\), respectively. The numerical values of \(m_0, n_0,\) etc. are given in Eqs. (3.11) to (3.15). For example, when \(u\)- or \(u^*\)-centered notation is used, \(m_0\) and \(m_{-1}\) are given by \(\text{DXP}(J)\), \(n_0\) by \(\text{DYP}(J)\), \(n_{-1}\) by \(\text{DYU}(J)\), and \(n_1\) by \(\text{DYU}(J+1)\), whereas when \(v, v^*\)- or \(v^*\)-centered notation is used, \(m_0\) and \(m_{-1}\) are given by \(\text{DXU}(J)\), \(n_0\) by \(\text{DYU}(J)\), \(n_{-1}\) by \(\text{DYP}(J-1)\), and \(n_1\) by \(\text{DYP}(J)\).

In the following subsections, variables at the two vertical levels will be indicated by the subscript \(\ell\), with \(\ell = 1\) denoting the (upper) level \(\sigma_1\) and \(\ell = 3\) denoting the (lower) level \(\sigma_3\). In the FORTRAN code the index \(L\) is used to indicate the levels, with \(L = 1\) denoting the level \(\sigma_1\) and \(L = 2\) denoting the level \(\sigma_3\).

3. Preparation for Time Extrapolation

At the beginning of each time step the dependent variables are transformed into a set of pressure-area-weighted variables. This trans-
Fig. 3.6 -- The schematic finite-difference grid in $\pi$-centered notation. The symbols above each point are the FORTRAN J,I index, and those below each point are the finite-difference subscript notation relative to the origin 00 or relative to the poles (p). The open circles (o) are points of the $\pi$ grid, the plus signs (+) are points of the u,v grid, and the carets ($\wedge$ and $>$) are points of the v* and u* grids, respectively.
Fig. 3.7 — The schematic finite-difference grid in u,v-centered notation. See Fig. 3.6 for symbol identification.
Fig. 3.8 -- The schematic finite-difference grid in $u^*$-centered notation. See Fig. 3.6 for symbol identification.
Fig. 3.9 -- The schematic finite-difference grid in $v^*$-centered notation. See Fig. 3.6 for symbol identification.
formation is performed at the beginning of subroutine COMP 1 (steps 2500 to 2680). For the quantities carried at \( \pi \) points (\( \pi \), \( \Pi \), \( T_3 \), and \( q_3 \)) the transformation is straightforward, and is given by

\[ \Pi_{00} = (mn)_{00}^{\pi} \quad (3.16) \]

\[ (\Pi l)_{00} = (mn)_{00}^{\pi} T_l \quad (3.17) \]

\[ (\Pi q)_{3,00} = (mn)_{00}^{\pi} q_{3,00} \quad (3.18) \]

where \((mn)_{00}^{\pi}\) is the \( \pi \)-centered area \( \text{DXYP}(J) \) (see Fig. 3.5).

For the transformation of the velocity components we similarly write (in u,v-centered notation)

\[ (\Pi u)_{00} = \Pi_{00}^{u} + l,00 \quad (3.19) \]

\[ (\Pi v)_{00} = \Pi_{00}^{v} l,00 \]

where the u,v-centered area-weighted \( \Pi \) is defined in u,v-centered notation as

\[ \Pi_{00}^{u} = \frac{1}{4} \left[ (mn)_{-1,1}^{\pi} + (mn)_{1,1}^{\pi} + (mn)_{-1,-1}^{\pi} + (mn)_{1,-1}^{\pi} \right] \]

for \( 2 < j \leq J - 1 \) \quad (3.20)

with the polar expressions

\[ \Pi_{0,p+1}^{u} = \frac{1}{4} \left[ (mn)_{-1,1}^{p+2} + (mn)_{1,1}^{p+2} \right] + (mn)_{1,1}^{\pi_{1,1}} \quad (3.21) \]

\[ \Pi_{0,p-1}^{u} = \frac{1}{4} \left[ (mn)_{-1,1}^{p-2} + (mn)_{1,1}^{p-2} \right] + (mn)_{1,1}^{\pi_{1,1}} \quad (3.22) \]
where \( p \) denotes the South or North Pole, and where

\[
\bar{\tau}_{i,1} = \frac{1}{I} \sum_{i=1}^{I} \tau_{i,1}
\]  

(3.23)

and

\[
\bar{\tau}_{i,J} = \frac{1}{I} \sum_{i=1}^{I} \tau_{i,J}
\]  

(3.24)

The quantities given by Eqs. (3.20) to (3.24) are illustrated in Fig. 3.10. Note that since the poles are mapped into \( I \) grid points, Eqs. (3.23) and (3.24) provide unique values of \( \tau \) for all \( I \) grid points of the South and North Poles. The other dependent variables carried at the poles (\( T_1, T_3, \) and \( q_3 \)) and quantities computed at the poles, such as the mass convergence discussed in the next section, are similarly averaged. The polar adjustment of \( \tau, T_1, T_3, \) and \( q_3 \) is performed in subroutine COMP 2 (steps 6410 to 6560).

C. Solution of the Difference Equations

1. The Mass Flux

The west/east and south/north mass fluxes are defined by Eqs. (2.25) and (2.26). These quantities require three finite-difference approximations corresponding to the three space-difference schemes (the upright, down-left, and centered) used during the cycle of the time integration. Furthermore, \( u^* \) is given a longitudinal smoothing to avoid computational instability resulting from the decrease in the longitudinal spacing as the poles are approached. The mass-flux parameters are computed in subroutine COMP 1 (steps 2710 to 2950) and the longitudinal smoothing of \( u^* \) is performed in subroutine AVRX(K).

In the \( v^* \)-centered notation (see Fig. 3.9), the south/north mass flux \( v^* \) at the level \( i \) becomes
Fig. 3.10 — Illustration of the area-pressure weighting function $\Pi U$ centered at $u,v$ points. At non-polar points, $\Pi U$ is the sum of the four shaded areas shown in (a), each weighted by its adjacent value of $\pi$; at polar points, $\Pi U$ is given by the sum of the three shaded areas shown in (b) weighted by the indicated values of $\pi$. 
The west/east mass flux \( u^* \) is computed in three stages. First, \((nu)\) at the level \( k \) is computed according to

\[
(nu)_{k,01} = \begin{cases} 
\frac{n_1 u_{k,01} + n_{-1} u_{k,0-1}}{2} & \text{when } MRCH = 1 \text{ or } 2 \\
n_1 u_{k,01} & \text{when } MRCH = 3 \\
n_{-1} u_{k,0-1} & \text{when } MRCH = 4 
\end{cases}
\] (3.26)

where \( u^* \)-centered notation has been used (see Fig. 3.8). Second, the values of \((nu)_{k,00}\) are smoothed in subroutine AVRX(K) using a three-point zonal smoothing routine that may be represented by

\[
(nu)_{k,00} = \lambda_0 (nu)_{k,-10} + (1 - 2\lambda_0) (nu)_{k,00} + \lambda_0 (nu)_{k,10}
\] (3.27)

where \( \lambda_0 \) is the weighting factor of the smoothing routine. This smoothing procedure is described further in Section D below. After this calculation, the west/east mass flux \( u^* \) at the level \( k \) is finally computed from

\[
u^*_{k,00} = (nu)_{k,00}^N_0 \frac{(\pi_{-10} + \pi_{10})}{2}
\] (3.28)

where the superscript \( N_0 \) denotes the smoothed result after application of the subroutine AVRX(K) \( N_0 \) times (see Section D).
At this point it should be noted that \( u^* \) at the poles (\( u^*_{1,1} \) and \( u^*_{1J} \)) has no meaning. However, to determine the advection of momentum in the polar caps, an equivalent \( u^* \) at the poles is defined. The routine used to compute this equivalent polar \( u^* \) is described in Subsection C.3 below.

2. Continuity Equation

The prognostic equation (2.33) for the pressure tendency and the diagnostic equation (2.34) for the vertical-velocity term may be rewritten in terms of the mass convergence at levels 1 and 3. Thus,

\[
\frac{\partial \Pi}{\partial t} = -\frac{1}{2} \left( \frac{\partial u^*_1}{\partial x} + \frac{\partial v^*_1}{\partial y} \right) - \frac{1}{2} \left( \frac{\partial u^*_3}{\partial x} + \frac{\partial v^*_3}{\partial y} \right) 
\]

\[
\tilde{s} = -\frac{1}{2} \left( \frac{\partial u^*_1}{\partial x} + \frac{\partial v^*_1}{\partial y} \right) + \frac{1}{2} \left( \frac{\partial u^*_3}{\partial x} + \frac{\partial v^*_3}{\partial y} \right) 
\]

In the \( \pi \)-centered notation (see Fig. 3.6), the mass convergence at all grid points, except the poles, is given by

\[
\left( \frac{\partial u^*_k}{\partial x} + \frac{\partial v^*_k}{\partial y} \right)_{k,00} = \text{CONV}_{k,00} 
\]

\[
= (u^*_{k,10} - u^*_{k,-10}) + (v^*_{k,01} - v^*_{k,0-1}) 
\]

\[
2 \leq j \leq J - 1 
\]

Only the south/north mass flux \( (v^*) \) contributes to the total mass convergence within the polar cap. The total mass convergence at the South and North Poles is therefore given by

\[
\text{CONV}_{k,1} = \sum_{i=1}^{I} v^*_{k,i,p+1} 
\]
while the mass convergence attributed to each of the I sectors of the polar caps is given by

\[ \text{CONV}_{\lambda,1} = -\frac{1}{I} \sum_{i=1}^{I} \mathbf{v}_{\lambda,i,p-1}^* \]  

(3.33)

Thus, Eqs. (3.29) and (3.30) may be written in the computational forms

\[ \left( \frac{3\pi}{\partial t} \right)_{00} = -\frac{1}{2} (\text{CONV}_{1,00} + \text{CONV}_{3,00}) \]  

(3.36)

\[ \dot{s}_{00} = \frac{1}{2} (\text{CONV}_{3,00} - \text{CONV}_{1,00}) \]  

(3.37)

for an arbitrary point outside the polar cap,

\[ \left( \frac{3\pi}{\partial t} \right)_{1,1} = -\frac{1}{2} (\text{CONV}_{1,1,1} + \text{CONV}_{3,1,1}) \]  

(3.38)

\[ \dot{s}_{1,1} = \frac{1}{2} (\text{CONV}_{3,1,1} - \text{CONV}_{1,1,1}) \]  

(3.39)

at the South Pole, and

\[ \left( \frac{3\pi}{\partial t} \right)_{1,J} = -\frac{1}{2} (\text{CONV}_{1,i,J} + \text{CONV}_{3,i,J}) \]  

(3.40)

\[ \dot{s}_{1,J} = \frac{1}{2} (\text{CONV}_{3,i,J} - \text{CONV}_{1,i,J}) \]  

(3.41)

at the North Pole.
3. Horizontal Advection of Momentum

The horizontal advection of momentum at the \(u,v\)-grid point \(i,j\) and at the level \(l\) is approximated in the equations of motion (2.27) to (2.30) by

\[
\left[ \frac{\partial}{\partial x} (u^* u) + \frac{\partial}{\partial y} (v^* u) \right] \approx \int_{\Gamma} u^* \mathbf{U} \cdot \hat{N} d\Gamma
\]

(3.42)

and

\[
\left[ \frac{\partial}{\partial x} (u^* v) + \frac{\partial}{\partial y} (v^* v) \right] \approx \int_{\Gamma} v^* \mathbf{U} \cdot \hat{N} d\Gamma
\]

(3.43)

where \(\mathbf{U}^*\) is a vector in the \(x,y\) plane with \(u^*\) and \(v^*\) as its \(x\) and \(y\) components, and \(\hat{N}\) is the outward unit vector normal to the contour \(\Gamma\) of the rectangular grid defined by the four \(\pi\) points surrounding the \(u\)-grid point \(i,j\) (see Fig. 3.11).

To evaluate the integrals in Eqs. (3.42) and (3.43) the contour \(\Gamma\) is divided into eight segments. Along each of the eight segments, \(\mathbf{U}^* \cdot \hat{N}\) is defined (using \(u,v\)-centered notation) as

- \(U_{10} = \frac{2}{3} \cdot \frac{1}{4} [u^*_{01} + u^*_{21} + u^*_{2-1} + u^*_{0-1}],\) along \(ab\)
- \(\tilde{U}_{11} = \frac{1}{6} \cdot \frac{1}{2} [v^*_{01} + v^*_{21}] + \frac{1}{6} \cdot \frac{1}{2} [v^*_{10} + v^*_{12}],\) along \(bc\)
- \(V_{01} = \frac{2}{3} \cdot \frac{1}{4} [v^*_{10} + v^*_{12} + v^*_{-12} + v^*_{-10}],\) along \(cd\)
- \(\tilde{V}_{-11} = \frac{1}{6} \cdot \frac{1}{2} [v^*_{-10} + v^*_{-12}] - \frac{1}{6} \cdot \frac{1}{2} [u^*_{01} + u^*_{-21}],\) along \(de\)
- \(-U_{-10} = -\frac{2}{3} \cdot \frac{1}{4} [u^*_{01} + u^*_{-21} + u^*_{-2-1} + u^*_{0-1}],\) along \(ef\)
- \(-\tilde{U}_{-11} = -\frac{1}{6} \cdot \frac{1}{2} [u^*_{-10} + u^*_{-2-1}] - \frac{1}{6} \cdot \frac{1}{2} [v^*_{-10} + v^*_{-1-2}],\) along \(fg\)
- \(-V_{0-1} = -\frac{2}{3} \cdot \frac{1}{4} [v^*_{10} + v^*_{1-2} + v^*_{-1-2} + v^*_{-10}],\) along \(gh\)
- \(-\tilde{V}_{1-1} = -\frac{1}{6} \cdot \frac{1}{2} [v^*_{10} + v^*_{1-2}] + \frac{1}{6} \cdot \frac{1}{2} [u^*_{0-1} + u^*_{2-1}],\) along \(ha\)
Fig. 3.11 -- Schematic representation of the fluxes $U,V$ and $\tilde{U},\tilde{V}$ on the grid cell surrounding a point of the $u,v$ grid (identified by 00 in $u,v$ notation; see Fig. 3.7).
With these definitions, Eqs. (3.42) and (3.43) become

\[
\left[ \frac{3}{3x} (u^* u) + \frac{3}{3y} (v^* u) \right]_{00} = \frac{1}{2} \left[ u_{10} (u_{00} + u_{20}) - u_{-10} (u_{-20} + u_{00}) + v_{01} (u_{00} + u_{02}) - v_{0-1} (u_{0-2} + u_{00}) + \tilde{u}_{11} (u_{00} + u_{20}) - \tilde{u}_{-1-1} (u_{-2-2} + u_{00}) + \tilde{v}_{-11} (u_{00} + u_{-22}) - \tilde{v}_{1-1} (u_{2-2} + u_{00}) \right] (3.45)
\]

\[
\left[ \frac{3}{3x} (u^* v) + \frac{3}{3y} (v^* v) \right]_{00} = \frac{1}{2} \left[ u_{10} (v_{00} + v_{20}) - u_{10} (v_{-20} + v_{00}) + v_{01} (v_{00} + v_{02}) - v_{0-1} (v_{0-2} + v_{00}) + \tilde{v}_{11} (v_{00} + v_{20}) - \tilde{v}_{-1-1} (v_{-2-2} + v_{00}) + \tilde{v}_{-11} (v_{00} + v_{-22}) - \tilde{v}_{1-1} (v_{2-2} + v_{00}) \right] (3.46)
\]

at all points outside the polar cap. In Eqs. (3.44) to (3.46) the subscript \(i\) has been dropped, and it should be understood that these expressions for the horizontal advection are valid for \(i = 1\) and 3.

The momentum advection within the polar cap requires special treatment. In Fig. 3.11 it can be seen that when the unit square represents a north polar sector, the fluxes \(\tilde{v}_{-11}, v_{01}\), and \(\tilde{u}_{11}\) represent advection across the pole. Physically, advection can occur across the pole only from a single sector to that sector separated by 180 deg of longitude. Thus, transpolar advection is not calculated and \(\tilde{v}_{-11}, v_{01}\) and \(\tilde{u}_{11}\) are not defined. However, the fluxes \(u_{-10}\) and \(u_{10}\) represent advection between adjacent sectors within the polar cap, but the definitions for these fluxes [Eq. (3.44)] break down since \(u^*\) is not defined at the poles. To circumvent this, a polar \(u^*\) is determined in subroutine COMP 1 (steps 2790 to 3230) so that the near-polar \(U\) are given by

\[
U_{\pm 1, p-1} = \frac{1}{6} \left( u^*_{0, J} + u^*_{\pm 2, J} + u^*_{0, p-2} + u^*_{\pm 2, p-2} \right) (3.47)
\]
and the continuity equation

\[ \frac{3}{\beta t} (u_{0,p-1}^u + u_{1,p-1} - u_{-1,p-1} - v_{0,p-2}) \]

\[ - \tilde{U}_{-1,p-2} - \tilde{V}_{1,p-2} - s_{0,p-1}^u = 0 \] (3.48)

is satisfied for each of the north polar sectors. Here u,v-centered notation has been used, and the definition of \( s_{0,p-1}^u \) is given in the next subsection.

It is shown by Langlois and Kwok (1969) that under the above conditions \( u^* \) at a polar grid point \( i,J \) is given by

\[ u_{i,J}^* = 3 \left( \psi_i - \frac{1}{I} \sum_{i=1}^I \psi_i \right) \] (3.49)

where \( \psi_i \) is given by

\[ \psi_1 = 0, \psi_2 = v_{3/2}^*, \psi_3 = v_{3/2}^* + v_{5/2}^*, \ldots, \psi_I = \sum_{k=1}^{i-1} v_{k+1/2}^* \]

\[ i = 2, 3, \ldots, I \] (3.50)

and

\[ v_{i+1/2}^* = v_{i+1/2,p-1}^* - \frac{1}{I} \sum_{i=0}^{I-1} v_{i+1/2,p-1}^* \] (3.51)

In Eqs. (3.50) and (3.51) the fractional values of the index \( i \) are used to denote the \( v^* \)-grid points to the right of the \( u,v \)-grid point \((1,p-1)\). Similar expressions can be derived for the South Pole.

If we use Eqs. (3.49) to (3.51) to determine the values of \( u_{0,J}^* \) and \( u_{1,J}^* \) in Eq. (3.47), the polar horizontal advection of momentum in \( u,v \)-centered notation becomes
\[
\left[ \frac{\partial}{\partial x} (u^* u) + \frac{\partial}{\partial y} (v^* u) \right]_{0,p+1} = \frac{1}{2} \left[ u_{1,p+1}(u_{0,p+1} + u_{2,p+1}) \\
- u_{-1,p+1}(u_{-2,p+1} + u_{0,p-1}) + v_{0,p+2}(u_{0,p+1} + u_{0,p+3}) \\
+ \tilde{u}_{1,p+2}(u_{0,p+1} + u_{2,p+3}) + \tilde{v}_{-1,p+2}(u_{0,p+1} + u_{-2,p+3}) \right] (3.52)
\]

and

\[
\left[ \frac{\partial}{\partial x} (u^* v) + \frac{\partial}{\partial y} (v^* v) \right]_{0,p+1} = \frac{1}{2} \left[ u_{1,p+1}(v_{0,p+1} + v_{2,p+1}) \\
- u_{-1,p+1}(v_{-2,p+1} + v_{0,p-1}) + v_{0,p+2}(v_{0,p+1} + v_{0,p+3}) \\
+ \tilde{u}_{1,p+2}(v_{0,p+1} + v_{2,p+3}) + \tilde{v}_{-1,p+2}(v_{0,p+1} + v_{-2,p+3}) \right] (3.53)
\]

at the South Pole, and

\[
\left[ \frac{\partial}{\partial x} (u^* u) + \frac{\partial}{\partial y} (v^* u) \right]_{0,p-1} = \frac{1}{2} \left[ u_{1,p-1}(u_{0,p-1} + u_{2,p-1}) \\
- u_{-1,p-1}(u_{-2,p-1} + u_{0,p-1}) - v_{0,p-2}(u_{0,p-3} + u_{0,p-1}) \\
- \tilde{u}_{1,p-2}(u_{-2,p-3} + u_{0,p-1}) - \tilde{v}_{1,p-2}(u_{2,p-3} + u_{0,p-1}) \right] (3.54)
\]

and

\[
\left[ \frac{\partial}{\partial x} (u^* v) + \frac{\partial}{\partial y} (v^* v) \right]_{0,p-1} = \frac{1}{2} \left[ u_{1,p-1}(v_{0,p-1} + v_{2,p-1}) \\
- u_{-1,p-1}(v_{-2,p-1} + v_{0,p-1}) - v_{0,p-2}(v_{0,p-3} + v_{0,p-1}) \\
- \tilde{u}_{1,p-2}(v_{-2,p-3} + v_{0,p-1}) - \tilde{v}_{1,p-2}(v_{2,p-3} + v_{0,p-1}) \right] (3.55)
\]

at the North Pole.
4. Vertical Advection of Momentum

In Subsection C.2 the vertical velocity parameter \( \dot{S} \) is defined at \( \pi \)-grid points [Eqs. (3.37), (3.39), and (3.41)]. However, for use in the momentum equations, a \( \dot{S}^u \), analogous to \( \Pi^u \) [Eqs. (3.20) to (3.24)] must be defined at \( u,v \)-grid points. Thus, at \( u,v \) points outside the polar cap the vertical advection term in \( u,v \)-centered notation is given by

\[
\frac{(u_{1,0} + u_{3,0})}{2} \dot{S}^u_{00} = u_{2,0} \frac{1}{4}(\dot{S}_{11} + \dot{S}_{11} + \dot{S}_{1-1} + \dot{S}_{-1-1})
\]  

(3.56)

and at the poles by

\[
\frac{(u_{1,0,p+1} + u_{3,0,p+1})}{2} \dot{S}^u_{0,p+1} = u_{2,0,p+1} \left[ \frac{1}{4}(\dot{S}_{-1,p+2} + \dot{S}_{1,p+2} + \dot{S}_{1,1}) \right]
\]  

(3.57)

and

\[
\frac{(u_{1,0,p-1} + u_{3,0,p-1})}{2} \dot{S}^u_{0,p-1} = u_{2,0,p-1} \left[ \frac{1}{4}(\dot{S}_{-1,p-2} + \dot{S}_{1,p-2} + \dot{S}_{1,1}) \right]
\]  

(3.58)

where

\[
\ddot{S}_{1,1} = \frac{1}{I} \sum_{i=1}^{I} \dot{S}_{1,1}
\]  

(3.59)

and

\[
\ddot{S}_{1,J} = \frac{1}{I} \sum_{i=1}^{I} \dot{S}_{1,J}
\]  

(3.60)
5. Coriolis Force

To evaluate the Coriolis force term in the momentum equations, the parameter $F$ [Eq. (2.24)] and the Coriolis parameter $f = 2\Omega \sin \varphi$ are the first obtained at the $\pi$-grid points. The Coriolis parameter is computed in subroutine MAGFAC (steps 14710 to 14750). In terms of $\pi$-centered notation it is defined as

$$f_{00} = \Omega \frac{a}{2(mn)_{00}} \left[ (\cos \varphi_{-2} + \cos \varphi_{0})m_{-1} - (\cos \varphi_{0} + \cos \varphi_{2})m_{1} \right]$$

Equation (3.61) can be reduced to

$$f_{00} = -2\Omega \frac{\cos \varphi_{2} - \cos \varphi_{-2}}{\varphi_{2} - \varphi_{-2}}$$

which is a finite-difference analog of

$$f = 2\Omega \sin \varphi = -2\Omega \frac{\partial (\cos \varphi)}{\partial \varphi}$$

At the poles $f$ is given by

$$f_{J} = \Omega \frac{a}{(mn)_{J}} \left[ (\cos \varphi_{J} + \cos \varphi_{J-1})m_{J} \right]$$

and

$$f_{1} = -f_{J}$$
With the Coriolis parameter defined by Eqs. (3.61) to (3.63), the finite-difference form of Eq. (2.24) in \( \pi \)-centered notation becomes

\[
F_{00} = (mn)_{00} f_{00} - \frac{1}{4} (u_{-11} + u_{11} + u_{1-1} + u_{-1-1})(m_{1} - m_{-1}) \tag{3.64}
\]

Finally, the Coriolis term at a \( u,v \)-grid point is represented in terms of \( F \) at the four surrounding \( \pi \) points by

\[
(u\pi F)_{k,00} = \frac{1}{2} \left[ \frac{(\pi_{11} + \pi_{1-1})}{2} \left( \frac{F_{11} + F_{1-1}}{2} \right) \\
+ \frac{(\pi_{-11} + \pi_{-1-1})}{2} \left( \frac{F_{-11} + F_{1-1}}{2} \right) \right] u_{k,00} \tag{3.65}
\]

\[
(v\pi F)_{k,00} = \frac{1}{2} \left[ \frac{(\pi_{11} + \pi_{1-1})}{2} \left( \frac{F_{11} + F_{1-1}}{2} \right) \\
+ \frac{(\pi_{-11} + \pi_{-1-1})}{2} \left( \frac{F_{-11} + F_{1-1}}{2} \right) \right] v_{k,00} \tag{3.66}
\]

where \( u,v \)-centered notation has been used.

6. Pressure-Gradient Force

The pressure-gradient force terms require a treatment analogous to that for the mass flux discussed in Subsection C.1. That is, they require three finite-difference approximations corresponding to the three space-difference schemes used during the cycle of the time integration, and the pressure-gradient terms of the \( u \)-momentum equation are smoothed using subroutine \( \text{AVRX(K)} \), as discussed in Subsection C.1.

In \( u,v \)-centered notation, the pressure-gradient force in the \( u \)-momentum equation [Eqs. (2.27) and (2.29)] is given by
\[
  n_0 \left( \frac{\partial \phi}{\partial x} + \sigma_k^\pi a_k \frac{\partial \pi}{\partial x} \right)_{\ell,00}
\]

\[
  = \frac{n_0}{4} \left[ \left( \pi_{-11} + \pi_{11} \right) \left( \phi_{\ell,11} - \phi_{\ell,-11} \right) + \left( \sigma_k^\pi a_k \right)_{-11} + \left( \sigma_k^\pi a_k \right)_{11} \right] \left( \pi_{11} - \pi_{-11} \right)_{N_0}
  + \frac{n_0}{4} \left[ \left( \pi_{-1-1} + \pi_{1-1} \right) \left( \phi_{\ell,1-1} - \phi_{\ell,-1-1} \right) + \left( \sigma_k^\pi a_k \right)_{-1-1} + \left( \sigma_k^\pi a_k \right)_{1-1} \right] \left( \pi_{1-1} - \pi_{-1-1} \right)_{N_0}
\]

when \( MRCH = 1 \) or 2

\[
  = \frac{n_0}{2} \left[ \left( \pi_{-11} + \pi_{11} \right) \left( \phi_{\ell,11} - \phi_{\ell,-11} \right) + \left( \sigma_k^\pi a_k \right)_{-11} + \left( \sigma_k^\pi a_k \right)_{11} \right] \left( \pi_{11} - \pi_{-11} \right)_{N_0}
\]

when \( MRCH = 3 \)

\[
  = \frac{n_0}{2} \left[ \left( \pi_{-1-1} + \pi_{1-1} \right) \left( \phi_{\ell,1-1} - \phi_{\ell,-1-1} \right) + \left( \sigma_k^\pi a_k \right)_{-1-1} + \left( \sigma_k^\pi a_k \right)_{1-1} \right] \left( \pi_{1-1} - \pi_{-1-1} \right)_{N_0}
\]

when \( MRCH = 4 \)

\[
(3.67)
\]

where \( (\quad)^{N_0} \) indicates the smoothing procedure in subroutine AVRX(K) and \( \phi_{\ell} \) is the geopotential at the levels \( \ell = 1 \) and 3 defined by Eqs. (2.16) and (2.17). The geopotential is evaluated at \( \pi \) points in subroutine COMP 2 (steps 5260 to 5430).

For the \( v \)-momentum equations [Eqs. (2.28) and (2.30)] the pressure-gradient force is given by
\[ m_0 \left( \frac{\partial \phi_z}{\partial y} + \sigma_z \frac{\partial \phi_z}{\partial y} \right) \]

\[ = m_0 \left[ \frac{1}{2} \left( \phi_{z,11} - \phi_{z,-1-1} + \frac{\pi_{11} + \pi_{1-1}}{2} \phi_{z,11} - \phi_{z,1-1} \right) \right] \]

\[ + \frac{1}{2} \left[ \frac{(\sigma_z \pi_{z11})_{11} + (\sigma_z \pi_{z11})_{1-1}}{2} (\pi_{11} - \pi_{1-1}) \right] \]

\[ + \frac{(\sigma_z \pi_{z11})_{11} + (\sigma_z \pi_{z11})_{1-1}}{2} (\pi_{11} - \pi_{1-1}) \]

when MRCH = 1 or 2

\[ = m_0 \left[ \frac{\pi_{11} + \pi_{1-1}}{2} \left( \phi_{z,11} - \phi_{z,1-1} \right) + \frac{(\sigma_z \pi_{z11})_{11} + (\sigma_z \pi_{z11})_{1-1}}{2} (\pi_{11} - \pi_{1-1}) \right] \]

when MRCH = 3

\[ = m_0 \left[ \frac{\pi_{11} + \pi_{1-1}}{2} \left( \phi_{z,-11} - \phi_{z,-1-1} \right) + \frac{(\sigma_z \pi_{z11})_{11} + (\sigma_z \pi_{z11})_{1-1}}{2} (\pi_{11} - \pi_{1-1}) \right] \]

when MRCH = 4

\[ (3.68) \]

7. Horizontal Advection of Temperature

The horizontal advection of temperature at the level \( z \) and for an arbitrary \( \pi \) point at the latitudes from \( \psi_3 \) to \( \psi_{-2} \) is given in \( \pi \)-centered notation as

\[ \left[ \frac{\partial}{\partial x} (u^* T) + \frac{\partial}{\partial y} (v^* T) \right]_{z,0} = (u^* T)_{z,10} - (u^* T)_{z,-10} \]

\[ + (v^* T)_{z,01} - (v^* T)_{z,0-1} \]

\[ (3.69) \]
where
\[
(u^* T)_{\ell, \pm 10} = u^*_{\ell, \pm 10} \frac{1}{2} (T_{\ell, 00} + T_{\ell, 0\pm 2})
\]  
(3.70)

and
\[
(v^* T)_{\ell, 0\pm 1} = v^*_{\ell, 0\pm 1} \frac{1}{2} (T_{\ell, 00} + T_{\ell, 0\pm 2})
\]  
(3.71)

At the poles only the south/north mass flux contributes to the advection of temperature. Thus, for the South Pole, Eq. (3.69) reduces to
\[
\left[ \frac{\partial}{\partial x} (u^* T) + \frac{\partial}{\partial y} (v^* T) \right]_{\ell, 0, 0} = (v^* T)_{\ell, 0, p+1}
\]  
(3.72)

where
\[
(v^* T)_{\ell, 0, p+1} = v^*_{\ell, 0, p+1} \begin{cases} T_{\ell, 0, 0} & \text{if } v^*_{\ell, 0, p+1} \leq 0 \\ T_{\ell, 0, p+2} & \text{if } v^*_{\ell, 0, p+1} > 0 \end{cases}
\]  
(3.73)

while at the North Pole it reduces to
\[
\left[ \frac{\partial}{\partial x} (u^* T) + \frac{\partial}{\partial y} (v^* T) \right]_{\ell, 0, 0} = (v^* T)_{\ell, 0, p-1}
\]  
(3.74)

where
\[
(v^* T)_{\ell, 0, p-1} = v^*_{\ell, 0, p-1} \begin{cases} T_{\ell, 0, 0} & \text{if } v^*_{\ell, 0, p-1} \leq 0 \\ T_{\ell, 0, p-2} & \text{if } v^*_{\ell, 0, p-1} > 0 \end{cases}
\]  
(3.75)
At the latitudes $\varphi_2$ and $\varphi_{J-1}$ [the points $(i, p=\pm 1)$ in $n$-centered notation] the west/east advection term $\left(\frac{3}{a_n} u_i^* T\right)$ is given a special treatment. The form of the total advection term, analogous to Eq. (3.69), is given at these latitudes by

\[
\left[\frac{3}{a_n} (u_i^* T) + \frac{2}{a_n} (v_j^* T)\right]_{k,0,p=\pm 2} = (u_i^* T)_{k,1,p=\pm 2} - (u_i^* T)_{k,-1,p=\pm 2}
\]

\[
\pm (v_j^* T)_{k,0,p=\pm 3} - (v_j^* T)_{k,0,p=\pm 1}
\]

(3.76)

with $(v_j^* T)_{k,0,p=\pm 1}$ given by Eqs. (3.73) and (3.75), and with

\[
(v_j^* T)_{k,0,p=\pm 3} = v_j^*_{k,0,p=\pm 3} \frac{1}{2} (T_{k,0,p=\pm 2} + T_{k,0,p=\pm 4})
\]

(3.77)

\[
(u_i^* T)_{k,1,p=\pm 2} = u_i^*_{k,1,p=\pm 2} \begin{cases} 
&T_{k,2,p=\pm 2} \\
&T_{k,0,p=\pm 2}
\end{cases} \quad \text{if} \quad u_i^*_{k,1,p=\pm 2} \begin{cases} 
<& 0 \\
> 0
\end{cases}
\]

(3.78)

\[
(u_i^* T)_{k,-1,p=\pm 2} = u_i^*_{k,-1,p=\pm 2} \begin{cases} 
&T_{k,-2,p=\pm 2} \\
&T_{k,0,p=\pm 2}
\end{cases} \quad \text{if} \quad u_i^*_{k,-1,p=\pm 2} \begin{cases} 
<& 0 \\
> 0
\end{cases}
\]

(3.79)

8. Energy-Conversion Terms

The first two energy-conversion terms in the thermodynamic energy equations (see Table 3.3) do not require horizontal finite-difference expressions. They are evaluated at $n$ points in subroutine COMP 1 (steps 4560 to 4660) from the equations

\[
\left[ \left(\frac{p_i^k}{p_0^k}\right)^{\frac{\theta_1 + \theta_3}{2}} \phi \right]_{i,0,0} = p_i^k \frac{1}{2} \left(\frac{T_{i,1,0,0}^k}{p_1^k} + \frac{T_{i,3,0,0}^k}{p_3^k}\right) \phi_{0,0} 
\]

(3.80)
\[
\left( \frac{\partial u}{\partial x}, \frac{\partial v}{\partial y} \right)_{l,00} = \sigma_k \pi_0 \frac{K_T}{\rho_{l,00}} \left( \frac{\partial n}{\partial t} \right)_{00}
\]

where \( \sigma \) and \( \partial n/\partial t \) are evaluated at \( \tau \) points using Eqs. (3.36) to (3.41), and the pressure at level \( \tau \) is given by

\[
p_{\tau} = p_{\tau} + \sigma_k \pi
\]

In Eq. (3.80) the definition

\[
\theta_{l} = T_{l} (\frac{p_{0}}{p_{l}})^{\kappa}
\]

has been used to eliminate the potential temperature, and in Eq. (3.81) the equation of state in the form

\[
\sigma_{l} = c_{p} \kappa \frac{T_{l}}{p_{l}}
\]

has been used to eliminate the specific volume.

The remaining energy-conversion terms at the level \( \tau \) are evaluated from the expression

\[
\left[ \frac{\sigma u}{c_{p}} \left( u \frac{\partial \kappa}{\partial x} + v \frac{\partial \kappa}{\partial y} \right) \right]_{l,00} = \frac{1}{c_{p}} \frac{1}{2} \left[ (\sigma u) \frac{\partial n}{\partial x} \right]_{l,-10} + (\sigma u) \frac{\partial \kappa}{\partial x} \right]_{l,10} + (\sigma v) \frac{\partial \kappa}{\partial y} \right]_{l,0-1} + (\sigma v) \frac{\partial \kappa}{\partial y} \right]_{l,01} \]

where \( \pi \)-centered notation has been used, and where
\[
\left( \sigma u \frac{\partial \alpha}{\partial x} \right)_{x, \pm 1, 0} = \left( \pm \pi_{0 \pm 20} + \pi_{00} \right) \left( (\sigma u)_{x, \pm 20} + (\sigma u)_{x, 00} \right)/2
\]

\[
\times \begin{cases} 
\frac{n_1 u_{x, \pm 11} + n_{-1} u_{x, \pm 1-1}}{2} & \text{if } MRCH = 1 \text{ or } 2 \\
(n_1 u_{x, 11})^N_0 & \text{if } MRCH = 3 \\
(n_{-1} u_{x, \pm 1-1})^N_0 & \text{if } MRCH = 4
\end{cases}
\]

\[
\left( \sigma v \frac{\partial \alpha}{\partial y} \right)_{x, 0\pm 1} = \left( \pm \pi_{0 \pm 2} + \pi_{00} \right) \left( (\sigma v)_{x, 0\pm 2} + (\sigma v)_{x, 00} \right)/2
\]

\[
\times \begin{cases} 
\frac{m_1 v_{x, \pm 11} + m_{-1} v_{x, \pm 1-1}}{2} & \text{if } MRCH = 1 \text{ or } 2 \\
m_1 v_{x, \pm 11} & \text{if } MRCH = 3 \\
m_{-1} v_{x, \pm 1-1} & \text{if } MRCH = 4
\end{cases}
\]

In Eq. (3.84), \( (\text{---})^N_0 \) denotes the zonal smoothing routine in subroutine AVRXY(6) (see Chapter III, Subsection C.1).

9. Horizontal Advection of Moisture

As discussed in Chapter II, moisture is carried only at the level \( \ell = 3 \). Furthermore, the moisture is considered to be advected by the average wind in the layer between \( \ell = 3 \) and the surface. By linear extrapolation to the surface of the winds at levels \( \ell = 1 \) and \( \ell = 3 \), the average pressure-area-weighted wind in this layer is given by the equations
\[
\frac{u_{3}^* + u_{4}^*}{2} = \frac{5}{4} u_{3}^* - \frac{1}{4} u_{1}^* \\
\frac{v_{3}^* + v_{4}^*}{2} = \frac{5}{4} v_{3}^* - \frac{1}{4} v_{1}^*
\]

(3.86)

Using Eqs. (3.86) for the advecting wind, the expressions for the west/east and south/north moisture advection at \(\pi\) points outside the poles are given in \(\pi\)-centered notation by

\[
\left\{ \frac{\partial}{\partial x} \left[ q_{3} \left( \frac{5}{4} u_{3}^* - \frac{1}{4} u_{1}^* \right) \right] \right\}_{3,00} = \frac{5}{4} \left[ \left( q_{3} u_{3}^* \right)_{3,10} - \left( q_{3} u_{3}^* \right)_{3,-10} \right] \\
- \frac{1}{4} \left[ \left( q_{3} u_{1}^* \right)_{3,10} - \left( q_{3} u_{1}^* \right)_{3,-10} \right] 
\]

(3.87)

and

\[
\left\{ \frac{\partial}{\partial y} \left[ q_{3} \left( \frac{5}{4} v_{3}^* - \frac{1}{4} v_{1}^* \right) \right] \right\}_{3,00} = \frac{5}{4} \left[ \left( q_{3} v_{3}^* \right)_{3,01} - \left( q_{3} v_{3}^* \right)_{3,0-1} \right] \\
- \frac{1}{4} \left[ \left( q_{3} v_{1}^* \right)_{3,01} - \left( q_{3} v_{1}^* \right)_{3,0-1} \right] 
\]

(3.88)

Physically the moisture parameter \(q\) is a non-negative quantity. Therefore, the fluxes \(\left( q_{3} u_{3}^* \right)_{3,01}\), etc. on the right-hand sides of Eqs. (3.87) and (3.88) must be defined in such a way that when a grid cell becomes "dry," advection to neighboring cells will be prevented. With this restriction, the moisture fluxes in \(\pi\)-centered notation are given by
\[
\begin{align*}
\begin{cases}
\{ q_{3,10}^* \}^{3,10} \times \begin{bmatrix} u_{3,10}^* \\ u_{1,10}^* \end{bmatrix} \\
\{ q_{3,10}^* \}^{3,10} \times \begin{bmatrix} u_{3,10}^* \\ u_{1,10}^* \end{bmatrix}
\end{cases} & \begin{cases}
q_{3,00} + q_{3,20} \\
q_{3,00} + q_{3,20}
\end{cases} \quad \text{if } (q_{3,00} + q_{3,20}) < 10^{-10} \\
0 & \begin{cases}
q_{3,00} < q_{3,20} \quad \text{and} \quad u_{3,10}^* > 0 \\
q_{3,00} < q_{3,20} \quad \text{and} \quad u_{3,10}^* < 0 \\
q_{3,00} > q_{3,20} \quad \text{and} \quad u_{3,10}^* > 0 \\
q_{3,00} > q_{3,20} \quad \text{and} \quad u_{3,10}^* < 0 \\
q_{3,00} + q_{3,20} \\
q_{3,00} + q_{3,20}
\end{cases} \quad \text{otherwise}
\end{align*}
\]

\[(3.89)\]

\[
\begin{align*}
\begin{cases}
\{ q_{3,10}^* \}^{3,-10} \times \begin{bmatrix} u_{3,10}^* \\ u_{1,10}^* \end{bmatrix} \\
\{ q_{3,10}^* \}^{3,-10} \times \begin{bmatrix} u_{3,10}^* \\ u_{1,10}^* \end{bmatrix}
\end{cases} & \begin{cases}
q_{3,00} + q_{3,20} \\
q_{3,00} + q_{3,20}
\end{cases} \quad \text{if } (q_{4,00} + q_{4,0-2}) < 10^{-10} \\
0 & \begin{cases}
q_{3,00} < q_{3,20} \quad \text{and} \quad u_{3,10}^* > 0 \\
q_{3,00} < q_{3,20} \quad \text{and} \quad u_{3,10}^* < 0 \\
q_{3,00} > q_{3,20} \quad \text{and} \quad u_{3,10}^* > 0 \\
q_{3,00} > q_{3,20} \quad \text{and} \quad u_{3,10}^* < 0 \\
q_{3,00} + q_{3,20} \\
q_{3,00} + q_{3,20}
\end{cases} \quad \text{otherwise}
\end{align*}
\]

\[(3.90)\]

\[
\begin{align*}
\begin{cases}
\{ q_{3,10}^* \}^{1,01} \times \begin{bmatrix} u_{3,10}^* \\ u_{1,10}^* \end{bmatrix} \\
\{ q_{3,10}^* \}^{1,01} \times \begin{bmatrix} u_{3,10}^* \\ u_{1,10}^* \end{bmatrix}
\end{cases} & \begin{cases}
q_{3,00} + q_{3,20} \\
q_{3,00} + q_{3,20}
\end{cases} \quad \text{if } (q_{4,00} + q_{4,0-2}) < 10^{-10} \\
0 & \begin{cases}
q_{3,00} < q_{3,20} \quad \text{and} \quad u_{3,10}^* > 0 \\
q_{3,00} < q_{3,20} \quad \text{and} \quad u_{3,10}^* < 0 \\
q_{3,00} > q_{3,20} \quad \text{and} \quad u_{3,10}^* > 0 \\
q_{3,00} > q_{3,20} \quad \text{and} \quad u_{3,10}^* < 0 \\
q_{3,00} + q_{3,20} \\
q_{3,00} + q_{3,20}
\end{cases} \quad \text{otherwise}
\end{align*}
\]

\[(3.91)\]

\[
\begin{align*}
\begin{cases}
\{ q_{3,10}^* \}^{1,0-1} \times \begin{bmatrix} u_{3,10}^* \\ u_{1,10}^* \end{bmatrix} \\
\{ q_{3,10}^* \}^{1,0-1} \times \begin{bmatrix} u_{3,10}^* \\ u_{1,10}^* \end{bmatrix}
\end{cases} & \begin{cases}
q_{3,00} + q_{3,20} \\
q_{3,00} + q_{3,20}
\end{cases} \quad \text{if } (q_{4,00} + q_{4,0-2}) < 10^{-10} \\
0 & \begin{cases}
q_{3,00} < q_{3,20} \quad \text{and} \quad u_{3,10}^* > 0 \\
q_{3,00} < q_{3,20} \quad \text{and} \quad u_{3,10}^* < 0 \\
q_{3,00} > q_{3,20} \quad \text{and} \quad u_{3,10}^* > 0 \\
q_{3,00} > q_{3,20} \quad \text{and} \quad u_{3,10}^* < 0 \\
q_{3,00} + q_{3,20} \\
q_{3,00} + q_{3,20}
\end{cases} \quad \text{otherwise}
\end{align*}
\]

\[(3.92)\]
In the polar caps only the south/north advection terms given by Eq. (3.88) contribute to the advection of moisture. In $\pi$-centered polar notation, Eq. (3.88) at the South Pole becomes

$$\left\{ \frac{3}{3} \left[ q_3 \left( \frac{5}{4} v_3^* - \frac{1}{4} v_1^* \right) \right] \right\}_{3,01} = \frac{5}{4} \left( q_3 v_3^* \right)_{3,0,p+1} - \frac{1}{4} \left( q_3 v_3^* \right)_{3,0,p+1} \quad (3.93)$$

and at the North Pole

$$\left\{ \frac{3}{3} \left[ q_3 \left( \frac{5}{4} v_3^* - \frac{1}{4} v_1^* \right) \right] \right\}_{3,0J} = -\frac{5}{4} \left( q_3 v_3^* \right)_{3,0,p-1} + \frac{1}{4} \left( q_3 v_1^* \right)_{3,0,p-1} \quad (3.94)$$

where the fluxes on the right-hand side of Eq. (3.93) are given by Eq. (3.91) and those on the right-hand side of Eq. (3.94) are given by Eq. (3.92).

10. Horizontally Differenced Friction Terms

The friction terms $F_1^x, F_1^y$ and $F_3^x, F_3^y$ appearing in the equations of motion (2.27) to (2.30) are given in horizontally differenced form in $u,v$ notation by

$$F_{1,00}^x = -R^x(u_{1,00} - u_{3,00})(\pi_{00}^u)^{-2} \quad (3.95)$$

$$F_{1,00}^y = -g^x(v_{1,00} - v_{3,00})(\pi_{00}^u)^{-2} \quad (3.96)$$

$$F_{3,00}^x = g^x(u_{1,00} - u_{3,00})(\pi_{00}^u)^{-2}$$

$$-\frac{2g}{\pi_{00}^u} C_D \frac{p_T}{\eta_{00}} \frac{\pi_{00}^u + p_T}{R T_{4,00}} \left( |\vec{v}_s|_{00}^\pi + G \right) (0.7) u_{4,00} \quad (3.97)$$
These forms rest upon the approximation of the height difference \((z_1 - z_3)\) in Eq. (2.36) by \(\Delta z(h/t)\), where \(\Delta z(\approx 5400 \text{ m})\) and \(h(\approx 900 \text{ mb})\) are standard values of \((z_1 - z_3)\) and \(h\), respectively. The coefficient \(\beta\) thus becomes \(\beta = 2\tau_s \Delta z^{-1}\), and is taken as 0.13 mb\(^2\) sec\(^{-1}\), corresponding to \(v = 0.44 \text{ mb sec}\).

In Eqs. (3.97) and (3.98) the surface wind speed \(|\mathbf{V}_s|^n\) is given (in \(u,v\) notation) by

\[
|\mathbf{V}_s|^n = \frac{1}{2} \left( |\mathbf{V}_s|^2_{00} + |\mathbf{V}_s|^2_{20} + |\mathbf{V}_s|^2_{02} + |\mathbf{V}_s|^2_{22} \right)^{1/2}
\]

where \(\mathbf{V}_s = 0.7\mathbf{V}_4\) and where \(\mathbf{V}_4 = \frac{3}{2} \mathbf{V}_3 - \frac{1}{2} \mathbf{V}_1 = (u_4,v_4)\) is the wind extrapolated to level 4. Here the subscripts refer to the \(u,v\) grid (see Fig. 3.7). The gustiness term is given by the constant \(G = 2.0 \text{ m sec}^{-1}\). The surface drag coefficient is given by the relations

\[
C_D = \begin{cases} 
\min \left[ \left( 1.0 + 0.07 |\mathbf{V}_s|^n \right) 10^{-3}, 0.0025 \right], & \text{if ocean} \\
0.002 + 0.006(z_4/5000 \text{ m}), & \text{otherwise}
\end{cases}
\]

where \(z_4\) is the elevation of the surface of the ground. Hence \(C_D\) varies between 0.001 and 0.0025 over the ocean, while over either bare land or ice, \(C_D\) is independent of the wind speed and varies between 0.002 over lowlands and sea ice to about 0.007 over the higher mountains. This increase of the drag coefficient with \(z_4\) is an attempt to simulate the increased roughness or ruggedness of the terrain in higher elevations, as suggested by the work of Cressman (1960).
As elsewhere in this section, the subscript 00 (in u,v-centered notation) denotes an arbitrary point of the u,v grid, and the superscript u denotes the average of the four surrounding points of the \( \pi \) (or primary) grid. Hence

\[
\pi_{00}^u = \frac{1}{4} \left( \pi_{-11} + \pi_{11} + \pi_{-1-1} + \pi_{1-1} \right)
\]  

recalling that the \( \pi \) grid is displaced upward and to the left of the u,v grid (see Fig. 3.2). The factor \((\pi_{00}^u + p_T)(R\pi_{00}^u)^{-1}\) in Eqs. (3.97) and (3.98) is thus the surface air density \( \rho_4 \). This averaging serves to "center" the pressure and temperature on the local velocity point. Note, however, that \( \pi_{00}^u \) also involves a 4-point averaging; although this is unnecessary for a point of the u,v grid, it is consistent with the calculation of the surface evaporation and sensible heat flux at points of the \( \pi \) grid (where averaging over velocity points is necessary).

In the program the frictional terms (3.95) to (3.98) are computed every fifth time step as part of the COMP 3 subroutine (instructions 9700 to 9920), and directly give the frictionally induced speed change in m sec\(^{-1}\) for the \( 5\Delta t = 30 \) min interval. The factor \( \Pi \) in Eqs. (2.27) to (2.30) is effectively divided out in the finite-difference computations.

11. Moisture-Source Terms

The source term \( 2mng(E - C) \) in the moisture equation (2.35) may be written in differenced form as

\[
2mng(E - C) = 2(mn)_{00}g(E - C)_{00}
\]

\[
= \frac{\Pi_{00}}{5\Delta t} \left[ (\Delta q_3)_E - (\Delta q_3)_L + (\Delta q_3)_C - (\Delta q_3)_P \right]_{00}
\]  

(3.102)

where the subscript 00 denotes (in \( \pi \)-centered notation) an arbitrary point of the \( \pi \) grid (see Fig. 3.6). This source computation is carried out for level 3 every five time steps in subroutine COMP 3, instructions
Here the level-3 moisture change (in 5Δt) due to evaporation is given by

\[ \Delta q_3 = \frac{2E}{E_0} E_0 5\Delta t \]  

(3.103)

according to Eq. (2.111), where \( E_0 \) is the local evaporation rate itself. The level-3 moisture change due to large-scale condensation is given by

\[ \Delta q_3 = \frac{c}{L} (\Delta T_3) \]  

(3.104)

where \( (\Delta T_3) \) is the local temperature change (over 5Δt) at level 3 due to the large-scale latent-heat release, as given by Eq. (2.47).

The level-3 moisture change due to middle-level convection is given by

\[ \Delta q_3 = \frac{c}{L} \left[ (\Delta T_1) + (\Delta T_3) \right] \]  

(3.105)

where \( (\Delta T_1) \) and \( (\Delta T_3) \) are the temperature changes (over 5Δt) at levels 1 and 3 due to the latent-heat release in middle-level convective condensation, as given by Eqs. (2.73) and (2.74), respectively.

Finally, the moisture change at level 3 due to penetrating convection is given by

\[ \Delta q_3 = \frac{c}{L} \left[ (\Delta T_1) + (\Delta T_3) \right] \]  

(3.106)

where \( (\Delta T_1) \) and \( (\Delta T_3) \) are the temperature changes (over 5Δt) at levels 1 and 3 due to the release of latent heat in penetrating convective condensation, as given by Eqs. (2.101) and (2.102), respectively.
The three moisture-change terms, Eqs. (3.104) to (3.106), collectively constitute the total moisture sink due to condensation, which we may then write as

\[
\left[ (\Delta q_3)_{LS} + (\Delta q_3)_{CM} + (\Delta q_3)_{CP} \right]_{00} = \frac{2g}{\nu} c^{00} \Delta t \quad (3.107)
\]

in analogy with (3.103) for the evaporation. Since all condensed water vapor is assumed to fall out as precipitation, we may also rewrite Eq. (3.107) in the form

\[
c^{00} = (P_{LS} + P_{CM} + P_{CP})_{00} \quad (3.108)
\]

where \( P_{LS} \), \( P_{CM} \), and \( P_{CP} \) are the precipitation rates resulting from large-scale condensation, middle-level convection, and penetrating convection, as given by Eqs. (2.50), (2.76), and (2.107), respectively.

12. Diabatic Heating Terms

The heating terms \( \Pi_{1/c_p} \) and \( \Pi_{3/c_p} \) in Eqs. (2.31) and (2.32) may be written in differenced form as

\[
\Pi_{00} \dot{H}_{1,00}/c_p \quad (3.109)
\]

\[
\Pi_{00} \dot{H}_{3,00}/c_p \quad (3.110)
\]

where the subscript 00 (in \( \pi \)-centered notation) denotes an arbitrary point of the \( \pi \) grid. These terms are computed every fifth time step in the subroutine COMP 3. Here the diabatic heating rates at levels 1 and 3 are given by
According to Eqs. (2.173) and (2.174), where $A_1$ and $A_3$ are the net short-wave radiation absorbed at levels 1 and 3, and $R_2 - R_0$ and $R_4 - R_2$ are the net long-wave radiation absorbed at the two levels. These terms in Eqs. (3.111) and (3.112) therefore constitute the radiative portions of the diabatic heating. The lower-level heating also contains a contribution from the vertical sensible heat flux from the surface $\Gamma_{00}$. The terms in $(\Delta T_1)$ and $(\Delta T_3)$ are the temperature changes due to convective effects, with the subscript CM denoting midlevel convection and CP denoting penetrating or deep convection. Together with the term in the level-3 temperature change due to large-scale condensation, LS, these terms constitute the portions of the diabatic heating due to the release of the latent heat of condensation, as considered in Eqs. (3.104) to (3.106). The total diabatic heating is illustrated in Map 8, Chapter IV.

D. SMOOTHING

Aside from the smoothing built into the time finite-difference approximations themselves, relatively little explicit smoothing is performed in the present version of the program. The subroutine AVRX(K), which performs a three-point ronal averaging, is employed in the main subroutines COMP 1 and COMP 2 principally for the mass-flux variables $u_1^*$ and $u_3^*$, as described in Subsection C.1 above. The only other use of AVRX(K) is with the zonal-pressure force terms $\left(\frac{\partial f_1}{\partial x} + \alpha_1 \frac{\partial u_1}{\partial x}\right)$ and $\left(\frac{\partial f_3}{\partial x} + \alpha_3 \frac{\partial u_3}{\partial x}\right)$ in the momentum equations, as described in
Subsection C.6 above. The effect of the use of subroutine AVRX(K) is to introduce a multiple-point zonal difference for higher latitudes to help avoid computational instability; the variables such as $u_1^*$ are not themselves smoothed.

This selective zonal averaging subroutine is called every time step, with the number of smoothing passes made at each step (as well as the smoothing weighting factor) increasing with latitude. Denoting $\bar{()}$ the smoothed value of a variable $()$, the zonal smoothing subroutine AVRX(K) may be described by

$$
\bar{()}_{00} = \lambda_0()_{-10} + (1 - 2\lambda_0)()_{00} + \lambda_0()_{10}
$$

where the subscripts denote identity points in the (1,j) grid array, and where the weighting or smoothing factor $\lambda_0$ is given by

$$
\lambda_0 = \begin{cases} 
0, & \text{for } N_0 < 1 \\
[1/8(n_e/m_0 - 1)]/N_0, & \text{for } N_0 \geq 1
\end{cases}
$$

Here $n_e$ is the latitudinal separation of grid points at the equator, $m_0$ is the longitudinal separation of $\pi$ points at the latitude of the smoothing, and $N_0$ is the integer part of $(n_e/m_0)$. The smoothing is applied $N_0$ times at each latitude, as shown in Table 5.7. Note that the number of applications of the smoothing operator increases from zero between the equator and $\pm 34$ deg latitude to 11 near the poles. The strength of the smoothing as given by $\lambda_0$ is also seen to vary with latitude.

An explicit smoothing occurs in the subroutine COMP 3, where the heating rates $\hat{H}_1$ and $\hat{H}_3$ for the two model layers [as in Eqs. (2.31) and (2.32)] are first averaged together, area weighted, and then subjected to a 9-point horizontal averaging prior to their final incorporation into the temperature-change computation at each level. This smoothing is described as part of the subroutine COMP 3 (see Chapter II, Subsection G.4).
Table 3.7

SMOOTHING PARAMETERS USED IN SUBROUTINE AVRX(K)

Here $\lambda_0$ is the three-point smoothing weighting factor [as in Eq. (3.27)] and $N_0$ is the number of times the smoothing is repeated at each latitude.

<table>
<thead>
<tr>
<th>$\varphi$, deg (LAT)</th>
<th>$N_0$ (NM)</th>
<th>$\lambda_0$ (ALPHA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-34 to +34</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>+38</td>
<td>1</td>
<td>$1.90 \times 10^{-3}$</td>
</tr>
<tr>
<td>+42</td>
<td>1</td>
<td>$9.56 \times 10^{-3}$</td>
</tr>
<tr>
<td>+46</td>
<td>1</td>
<td>$1.90 \times 10^{-2}$</td>
</tr>
<tr>
<td>+50</td>
<td>1</td>
<td>$3.06 \times 10^{-2}$</td>
</tr>
<tr>
<td>+54</td>
<td>1</td>
<td>$4.51 \times 10^{-2}$</td>
</tr>
<tr>
<td>+58</td>
<td>1</td>
<td>$6.37 \times 10^{-2}$</td>
</tr>
<tr>
<td>+62</td>
<td>1</td>
<td>$8.80 \times 10^{-2}$</td>
</tr>
<tr>
<td>+66</td>
<td>1</td>
<td>$1.21 \times 10^{-1}$</td>
</tr>
<tr>
<td>+70</td>
<td>2</td>
<td>$8.37 \times 10^{-2}$</td>
</tr>
<tr>
<td>+74</td>
<td>2</td>
<td>$1.19 \times 10^{-1}$</td>
</tr>
<tr>
<td>+78</td>
<td>3</td>
<td>$1.19 \times 10^{-1}$</td>
</tr>
<tr>
<td>+82</td>
<td>5</td>
<td>$1.19 \times 10^{-1}$</td>
</tr>
<tr>
<td>+86</td>
<td>11</td>
<td>$1.19 \times 10^{-1}$</td>
</tr>
</tbody>
</table>
The remaining smoothing operations are performed on the lapse rate in the subroutine COMP 4, which is called every 5 time steps. Here the temperature at levels 1 and 3 is smoothed according to

\[ T_1 = \frac{1}{2} (T_3 + T_1) - \pi [TD + \frac{1}{48} (\overline{TD} - TD)] \quad (3.113) \]

\[ T_3 = \frac{1}{2} (T_3 + T_1) + \pi [TD + \frac{1}{48} (\overline{TD} - TD)] \quad (3.114) \]

where the temperature difference (or lapse rate) TD is given by

\[ TD = \frac{1}{\pi} \left( \frac{T_3 - T_1}{2} \right) \quad (3.115) \]

and \( \overline{TD} \) denotes the 9-point horizontal average about a point 00 of the \( \pi \) grid, given in \( \pi \)-centered notation by

\[ \overline{TD}_{00} = \frac{1}{16} (TD_{-22} + 2TD_{02} + TD_{22} + 2TD_{-20} + 4TD_{00} + 2TD_{20} + TD_{-2-2} + 2TD_{0-2} + TD_{2-2}) \quad (3.116) \]

Since the first terms of Eqs. (3.113) and (3.114) are a form of vertical averaging, this subroutine may be regarded as a three-dimensional smoothing operation, wherein the temperature at levels 1 and 3 is altered in proportion to the departure of the local lapse rate from the 9-point averaged lapse rate. If TD = \( \overline{TD} \), for example, \( T_1 \) and \( T_3 \) remain unaltered by this smoothing. Viewed in another fashion, from Eqs. (3.113) and (3.114) we have

\[ \frac{T_3 - T_1}{2\pi} = TD_{\text{smoothed}} = TD + \frac{1}{48} (\overline{TD} - TD) \quad (3.117) \]

and the averaging may be regarded as a local smoothing of the lapse rate.
Another part of the subroutine COMP 4 (instructions 12270 to 12680) provides for the smoothing of the local velocity change through the simulation of a horizontal diffusion of momentum. This portion is omitted in the present version of the code through the assignment of a zero lateral-diffusion coefficient.

E. GLOBAL MASS CONSERVATION

Although the continuity equation (2.33) is solved at each (mass) point of the grid at each time step (see Chapter III, Subsection C.2), a small loss of mass over the globe still occurs because of the truncation caused by the retention of at most 7 decimal digits in the single-precision calculation (which does not round) of the surface pressure on the IBM 360/91 computer. Over the globe this amounts to approximately a 0.0028 percent \((2.8 \times 10^{-5})\) loss of mass per day of simulated time. To correct for this effect, the subroutine CMP is used once every 24 hours; in CMP the local value of the surface pressure parameter, \(\tau\), is increased (at every point) by the amount 
\[984 \text{ mb} - \bar{p}_s\],
where \(\bar{p}_s\) is the global average surface pressure determined each day (as the sum of the global average of the current \(\tau\) distribution and the constant tropopause pressure \(p_T = 200 \text{ mb}\)). Here the constant 984 mb is used to represent the observed global average surface pressure, and is read into the program as the loaded constant PSF. In the present version of the program this correction at each \(\tau\)-grid point thus amounts to approximately 0.028 mb per day.

F. CONSTANTS AND PARAMETERS

1. Numerical Data List

Although a number of the constants and parameters used in the model integration are given elsewhere [see particularly the chapters on model performance (IV), the list of symbols (VI), and the FORTRAN dictionary (VIII)], it is useful to collect them here for easy reference.

\[\text{Presumably this loss would be reduced by the use of double-precision arithmetic.}\]
Those symbols with an asterisk (*) are defined within the subroutines COMP 3 or INPUT, with the others loaded via data cards (see Chapter IV, Section A).

<table>
<thead>
<tr>
<th><strong>Constant</strong></th>
<th><strong>Symbol</strong></th>
<th><strong>Value and Units</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>ratio of latent heat of condensation to specific heat at constant pressure, $L/c_p$</td>
<td>CLH*</td>
<td>580/0.24 deg</td>
</tr>
<tr>
<td>length of day</td>
<td>DAY</td>
<td>86,400 sec</td>
</tr>
<tr>
<td>days per year</td>
<td>DAYPYR*</td>
<td>365 days</td>
</tr>
<tr>
<td>maximum solar declination</td>
<td>DECMAX*</td>
<td>$23.5\pi/180$ radians</td>
</tr>
<tr>
<td>north/south grid-point spacing</td>
<td>DLAT</td>
<td>4 deg</td>
</tr>
<tr>
<td>east/west grid-point spacing</td>
<td>DLØN*</td>
<td>$2\pi/IM$ radians ($= 5$ deg)</td>
</tr>
<tr>
<td>time step, $\Delta t$</td>
<td>DT*</td>
<td>360 sec</td>
</tr>
<tr>
<td>time step, $\Delta t$</td>
<td>DTM</td>
<td>6 min</td>
</tr>
<tr>
<td>standard value of vertical eddy mixing coefficient</td>
<td>ED</td>
<td>$10 \text{ m}^2 \text{ sec}^{-1}$</td>
</tr>
<tr>
<td>gravity, $g$</td>
<td>GRAV</td>
<td>$9.81 \text{ m sec}^{-2}$</td>
</tr>
<tr>
<td>vertical shear-stress coefficient ($\times 10^{-5}$)</td>
<td>FMX</td>
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<td>grid points in meridional direction</td>
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<td>grid points in zonal direction</td>
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<td>frequency of source-term calculation</td>
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<td>Constant</td>
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<td>Value and Units</td>
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<tr>
<td>earth's radius, (a)</td>
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<td>(6.3750 \times 10^6) m</td>
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<tr>
<td>dry-air gas constant, (R)</td>
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<td>(287.0 , \text{m}^2 , \text{deg}^{-1} , \text{sec}^{-2})</td>
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<tr>
<td>solar rotation period</td>
<td>R0TPER</td>
<td>(24 , \text{hr})</td>
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<tr>
<td>upper model level, (\sigma_1)</td>
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<td>(0.25)</td>
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<td>lower model level, (\sigma_3)</td>
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<td>(0.75)</td>
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<td>solar constant (normalized)</td>
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<td>(2880 , \text{ly} , \text{day}^{-1} (= 2 , \text{ly} , \text{min}^{-1}))</td>
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<tr>
<td>freezing temperature</td>
<td>TICE*</td>
<td>(273.1 , \text{deg K})</td>
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### 2. Geographical Finite-Difference Grid

The specific geographical position of the points of the 46 by 72 grid is shown in Fig. 3.12. Here the grid points of the primary or \(v\) grid are given over the oceans every 4 deg latitude and 5 deg longitude, together with the outlines of the continents and islands resolved by the interlocking points of the \(u,v\) grid. The left-hand and right-hand columns of grid points are at 180 deg longitude; the top and bottom rows are at the North and South Poles, respectively, with the latitude identification on the right of the figure. The finite-difference indices \(i\) and \(j\) are shown on the bottom and left side of the figure, respectively. This map is on the same scale as that used to show the land elevations and sea-surface temperatures in Figs. 3.13 and 3.14, and is the same as that used for the selected variables produced by the map-generation program in the figures of Chapter IV.

### 3. Surface Topography (Elevation, Sea-Surface Temperature, Ice, and Snow Cover)

During the course of a numerical simulation, the land surface elevation and the ocean surface temperature are held fixed, and thus serve as physical surface boundary conditions. Although these data may conceivably be changed from one simulation to another, their normal distributions are shown in Figs. 3.13 and 3.14 in the form of the programmed Map 5 output (see Map Routine Listing, Chapter VII), and
Fig. 3.12 -- The geographical grid and land-mass outlines. The points shown over water surfaces are those of the primary or \( \tau \) grid every 4° latitude and 5° longitude (90S, ..., 6S, 2S, 2N, 6N, ..., 90N; 180W, 175W, ...). The continental and major island outlines are formed by zonal and meridional lines connecting points of the \( u,v \) grid (88S, ..., 4S, 0, 4N, ..., 88N; 177.5W, 172.5W, ...). The latitude is shown on the right, and the longitude of both the left-hand and right-hand columns is 180°W. The grid indexes \( i \) and \( j \) (for the \( \tau \) grid) are shown on the bottom and left, respectively. This map is on the same scale as those of Figs. 3.13, 3.14, and 4.1 to 4.31.
Fig. 3.13 -- The distribution of surface elevation, with isolines every $10^3$ ft and the 3000-ft contour dashed. The overprinted symbol I denotes ice-covered land. The grid-point elevation data themselves are given in Table 3.8.
Fig. 3.14 -- The distribution of sea-surface temperature, with isolines every 2 deg C and the 20°C isotherm dashed. The overprinted symbol I denotes ice-covered ocean. The grid-point temperature data themselves are given in Table 3.10.
the corresponding global grid-point values are given every 5 deg longitude and 4 deg latitude (at the points of the \( \pi \) grid) in the tabulation following the maps.

The land elevations shown in Fig. 3.13 are based upon the values at points of the 4 deg latitude, 5 deg longitude grid (see data tabulation), which were themselves obtained from the subjective interpolation of topographic maps. These data resemble (but are not identical to) the data given by Berkofsky and Bertoni (1955), and are tabulated in Table 3.8. In Fig. 3.13 the overprinted symbol I designates those grid points at which the land is ice covered; in the data tabulation, the elevation of these points is given separately in Table 3.9, where 0 denotes the locations of sea ice. In the present version of the model, the ice-covered points are not permitted to change their surface cover during the course of the simulation.

The ocean surface temperatures shown in Fig. 3.14 are based upon the values at points of the 4 deg latitude, 5 deg longitude grid (see data tabulation) which were obtained from the average annual sea-surface temperature data given by Dietrich (1963). These data resemble (but are not identical to) the mean of the average February and August distributions given by Sverdrup (1943), and are tabulated in Table 3.10. In Fig. 3.14 the overprinted symbol I here designates those \( \pi \)-grid points at which sea ice is prescribed (and held intact throughout the simulation); in the data tabulation these sea-ice points may be identified by the assigned constant temperature 0 deg C (see Table 3.9). Because the ocean's surface temperature is not allowed to change, even though there are evaporation, radiative transfer, and sensible-heat fluxes at the surface, the ocean has effectively been assumed to be of infinite thermal capacity. The surface temperatures of the sea ice, land ice, snow-covered land, and bare land, on the other hand, are allowed to change, and are separately computed (see COMP 3 in the Program Listing, Chapter VII).

All land grid points north of a seasonally varying northern snowline (SN\( \text{\textsc{w}} \)) are considered to be snow covered. Snow does not cover either ice-covered land or sea ice. The northern snowline has a 15-deg sinusoidal seasonal variation around 60 deg north latitude given by
SNOWN = 60 deg - 15 deg cos \left[ \frac{2\pi}{365} \left( \text{day} - 24.6 \right) \right]

where "day" is the number of the day of the year, with day 0 corresponding to 1 January. A constant southern snowline (SNOWS) is defined at 60 deg south latitude. Although the value of this southern snowline is required by the program for the surface-albedo calculation (see Chapter III, Section H), it actually has no function in defining snow cover, since all land south of 60 deg is permanently ice covered (see Fig. 3.13).
Table 3.8

LAND ELEVATION (100 FT)

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|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0   | 5F  | 10F | 15F | 20F | 25E | 30E | 35F | 40F | 45F | 50E | 55E | 60E | 65E | 70E | 75E | 80E | 85E |
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Notes:
- The table lists elevation values in feet (ft) for various locations.
- The column headings indicate west (W) and south (S) directions.
- Values in the table represent the elevation difference in feet between two points.
Table 3.9 (cont.)

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*Note: Additional data not shown in this partial view.*
Table 3.10 (cont.)

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Table 3.10 (cont.)

SFA-SURFACE TEMPERATURE (DEG C)
IV. MODEL PERFORMANCE

A. OPERATING CHARACTERISTICS

1. Integration Program

The Mintz-Arakawa two-level model is written in IBM FORTRAN IV (see program listing, Chapter VII). The core size, central processing unit (CPU) time, and the input/output (I/O) requirements are based on experience with the FORTRAN H compiler on an IBM 360/91 at UCLA for a 46-by-72 array. The model uses about 400,000 bytes of core memory, and each simulated day requires about 25 minutes of CPU time and about 1000 I/O requests. All calculations are performed with single-precision arithmetic.

The program in its present form is expected to start from nonzero initial data, and the history-restart tape is used to provide the initial values for continuing the calculations. The time to restart is specified by the parameters TAUID and TAUIH (see the control-card sequence below). The tape is read until the last record is reached or until TAU from tape (expressed in hours) is less than or equal to TAUIH + 24·TAUID. If the last record on the tape (identified by -TAU) is reached before the specified time to restart, the last set of data will be used. This allows automatic continuation of the calculation from the last time data were stored on the tape.

The input parameters TRST and TERM control the disposition of the old and new sets of data. If TRST = 0, the newly computed data will be written on the old history-restart tape as if no interruption had occurred; otherwise, the new data are written at the beginning of a different tape. If TRST ≠ 0, the parameter TERM determines whether the old history-restart tape is to be terminated after the restart data are read from it. If TERM = 0, the old tape is not terminated. The data-set reference number of the tape to be written is always 11. If TRST ≠ 0, the initial data is read from data-set reference number 10.

Various control parameters and constants in the program are read from cards, although several of the parameters that are read in the
The model's present version no longer influence the program. The topography deck following card number fourteen (MARK) is read only if a change is desired in sea-surface temperature, land elevation, or the assigned distribution of ice. All numerical values follow the standard FORTRAN convention except KAPA, which is a real number. Only the constants NCYCLE, NC3, JM, IM, MARK, LDAY, LLYR, and the sequence numbers in the topography deck are in integer format. The control-card sequence and layout are as follows:

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<td>DTM</td>
<td>1-10</td>
<td>min</td>
<td>Time step</td>
</tr>
<tr>
<td>4</td>
<td>NCYCLE</td>
<td>11-15</td>
<td>IS(1)</td>
<td>Time extrapolation control parameter</td>
</tr>
<tr>
<td>4</td>
<td>NC3</td>
<td>16-20</td>
<td>IS(1)</td>
<td>Frequency to call COMP 4 and COMP 3</td>
</tr>
<tr>
<td>5</td>
<td>JM</td>
<td>1-5</td>
<td>--</td>
<td>Number of N-S grid points (in η grid)</td>
</tr>
<tr>
<td>5</td>
<td>IM</td>
<td>6-10</td>
<td>--</td>
<td>Number of E-W grid points (in η grid)</td>
</tr>
<tr>
<td>5</td>
<td>DLAT</td>
<td>11-20</td>
<td>deg</td>
<td>Distance between N-S grid points</td>
</tr>
<tr>
<td>6</td>
<td>AX</td>
<td>1-10</td>
<td>--</td>
<td>Diffusion coefficient (not used)</td>
</tr>
</tbody>
</table>

(1) The IS unit is one integration time step.
<table>
<thead>
<tr>
<th>Card Number</th>
<th>Name</th>
<th>Card Columns</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>FMM</td>
<td>1-10</td>
<td>$10^{-5} \text{ sec}^{-1}$</td>
<td>Shear-stress coefficient</td>
</tr>
<tr>
<td>7</td>
<td>ED</td>
<td>11-20</td>
<td>m</td>
<td>Constant used in air/ground interaction</td>
</tr>
<tr>
<td>7</td>
<td>TCNV</td>
<td>21-30</td>
<td>sec</td>
<td>Relaxation time for cumulus convection</td>
</tr>
<tr>
<td>8</td>
<td>RAD</td>
<td>1-10</td>
<td>km</td>
<td>Earth radius, $a$</td>
</tr>
<tr>
<td>8</td>
<td>GRAV</td>
<td>11-20</td>
<td>m sec$^{-2}$</td>
<td>Gravitational acceleration, $g$</td>
</tr>
<tr>
<td>8</td>
<td>DAY</td>
<td>21-30</td>
<td>hour</td>
<td>Length of day</td>
</tr>
<tr>
<td>9</td>
<td>RGAS</td>
<td>1-10</td>
<td>$m^2 \text{deg}^{-1} \text{sec}^{-2}$</td>
<td>Gas constant, $R$</td>
</tr>
<tr>
<td>9</td>
<td>KAPA</td>
<td>11-20</td>
<td>--</td>
<td>Thermodynamic coefficient, $\kappa$</td>
</tr>
<tr>
<td>10</td>
<td>PSL</td>
<td>1-10</td>
<td>mb</td>
<td>Sea-level pressure</td>
</tr>
<tr>
<td>10</td>
<td>PTP</td>
<td>11-20</td>
<td>mb</td>
<td>Tropospheric pressure, $p_T$</td>
</tr>
<tr>
<td>11</td>
<td>PSF</td>
<td>1-10</td>
<td>mb</td>
<td>Surface pressure, $p_s$</td>
</tr>
<tr>
<td>12</td>
<td>DLIC</td>
<td>1-10</td>
<td>--</td>
<td>Not used</td>
</tr>
<tr>
<td>13</td>
<td>KSET</td>
<td>1-10</td>
<td>--</td>
<td>Not used</td>
</tr>
<tr>
<td>14</td>
<td>MARK</td>
<td>1-3</td>
<td>--</td>
<td>Flag indicating presence of topography deck (sea-surface temperature and land elevation) and number of sets of cards to be read. In 46-by-72 grid version, MARK = 72.</td>
</tr>
</tbody>
</table>

15-376 Topography Deck -- see description below.

377 CLKSW 1-4 -- If the characters OFF are punched in columns 1 to 3 with column 4 blank, the solar declination will remain fixed.

377 RSETSW 11-14 -- If the characters RESE are punched in columns 1 to 4, the day and year counters (SDEDY and SDEYR) will be set to LDAY and LYR.

377 LDAY 21-23 day Day of year if time is reset

377 LYR 31-34 year Year if time is reset

The topography deck is read only if MARK ≠ 0. The deck contains $2 + 5 \cdot \text{MARK}$ cards and is read in subroutine INIT 2. The topography deck card layout is as follows:
<table>
<thead>
<tr>
<th>Number of Cards</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TEMSCL</td>
<td>Four characters in columns 1 to 4. Indicates temperature scale of sea-surface temperature: FAHR = Fahrenheit, CENT = centigrade.</td>
</tr>
<tr>
<td>3·MARK</td>
<td>Sea-surface temperature</td>
<td>'MARK' is the number of three-card sets that define the ocean temperature for each longitude, beginning at the south pole and extending north. For the 46-by-72 grid, the numbers each take four columns (a decimal point is implicit between the third and fourth columns), with fifteen numbers on the first and second cards and sixteen numbers on the third card. The longitude grid number (i = 1-72) is in columns 79 and 80 of each card of a set, and must be sequential. Special numbers indicate points that are not open ocean: -640 for land without ice, and -960 for land ice or sea ice.</td>
</tr>
<tr>
<td>1</td>
<td>HSCL</td>
<td>Four characters in columns 1 to 4. Indicates distance scale of land elevation: FEET = feet/100, METE = meters/10.</td>
</tr>
<tr>
<td>2·MARK</td>
<td>Land elevation</td>
<td>'MARK' is here the number of two-card sets that define the land elevation for each longitude, beginning at the south pole and extending north. For the 46-by-72 grid, the numbers each take three columns (a decimal point is implicit following the third column), with twenty-five numbers on the first card and twenty-one numbers on the second card. The longitude grid number (i = 1-72) is in columns 79 and 80 of each card of a set, and must be sequential. The elevations must be in either hundreds of feet or tens of meters. The entries in this deck corresponding to sea surface must be zero or blank.</td>
</tr>
</tbody>
</table>

The principal output of the model is written on magnetic tape, and a history-restart tape is written at specified intervals. Eighteen logical records are written with a frequency of TAUI: TAU and C, P, U, V, T, Q3, T0P0G, PT, GW, TS, GT, SN, Tt, Q3T, SD, H, TD, -TAU and C. These arrays contain all constants and current variables, and in addition, several arrays of packed data generated in subroutine COMP 3. [Note
that TS is equivalent to UT(1,1,2) and SN is equivalent to VT(1,1,2) in the data from subroutine COMP 3.\footnote{In the present version of the model these records are written on tape every 6 hours (= TAUH). The last logical record (-TAU,C) is identified as the last record written on the tape, and will be written over the next time the tape is written; hence, only seventeen records are saved every TAUH. A test is made before writing the tape to determine if it is properly positioned. About sixty sets of seventeen logical records can be saved on a 2400-ft reel of tape. The automatically printed output consists of the input parameters, the time at each integration step, and the amount of pressure added at each grid point every twenty-four hours of simulated time in the subroutine GMP.}

2. Map-Generation Program

The map-generation program for use with the model uses about 520,000 bytes of core, and averages about 0.2 seconds of CPU time and about 5 I/O requests for each map generated. This program reads the data produced by the model and processes them to form arrays of data in map form. The source of the basic data may be tape or disk.

The tape input format is the same as the tape output from the model: TAU and \(C, P, U, V, T, Q3, T0P0G, PT, GW, TS, GT, SN, TT, Q3T, SD, H, TD\). The first logical record on a disk is always T0P0G, which does not change during a run. The subsequent logical records for each time step that was saved are TAU and \(C, P, U, V, T, Q3, PT, GW, TS, GT, SN, TT, Q3T, SD\).

The card input to the map-generation program consists of an interval and data-source control card, followed by as many as ninety-nine map selection cards. The end of the map selection card deck is indicated by a blank card. The interval and data-source control card contains \(T0\) (the time, in days, to start generating the map arrays), TEND (the time, in days, to stop generating the map arrays), and TAPIN (the data-source indicator). The card layout is as follows:

\footnote{Some arrays may be referred to by different names. For example, \(Q(J,I,K)\) contains \(\pi, U_1, U_3, V_1, V_3, T_1, T_3,\) and \(Q3\) for \(K = 1\) through 8. See the common and equivalence block in Chapter VII for more detail.}
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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Card</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Theta$</td>
<td></td>
<td>1-10</td>
</tr>
<tr>
<td>TEND</td>
<td></td>
<td>11-20</td>
</tr>
<tr>
<td>TAPIN</td>
<td></td>
<td>21-24</td>
</tr>
</tbody>
</table>

The desired maps will be generated for $\Theta$, TEND, and for each intermediate time available from the data source. If the characters TAPE are punched in columns 21 to 24 (TAPIN), the data source is a tape; otherwise the source is assumed to be a disk.

The map selection cards contain MAPN$\Theta$ (the map number) and SURF (the $\sigma$ surface, $< 2.0$, or the pressure level, in millibars, at which the map is to be calculated). The card layout is as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Card</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAPN$\Theta$</td>
<td></td>
<td>1-2</td>
</tr>
<tr>
<td>SURF</td>
<td></td>
<td>3-12</td>
</tr>
</tbody>
</table>

Some values of SURF are not valid for certain maps, and in some cases the following convention has been used:

- **topography maps**: SURF $< 2.0$ for ocean temperature
- SURF $\geq 2.0$ for surface elevation
- **cloudiness maps**: SURF $\leq 0.5$ for high cloudiness
- SURF $= 1.0$ for low cloudiness
- $0.5 <$ SURF $\neq 1.0$ for middle cloudiness
- SURF $> 1.0$ for cloudiness (maximum)

The processed data representing each requested map array are written on tape along with various other data, and the tape may be used for further processing and map displays. The map array is dimensioned ($JM$, $IM$), where $JM$ is the total number of north/south grid points and $IM$ is the total number of east/west grid points. One logical
record is written for each map, and contains the following data:

<table>
<thead>
<tr>
<th>Name and Dimension</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAU (1)</td>
<td>Time in hours</td>
</tr>
<tr>
<td>ID (1)</td>
<td>Four-character identification from the model</td>
</tr>
<tr>
<td>MAPN0 (1)</td>
<td>Map number</td>
</tr>
<tr>
<td>NAME (13)</td>
<td>Map title</td>
</tr>
<tr>
<td>SURF (1)</td>
<td>Sigma surface or pressure level for which the map is generated</td>
</tr>
<tr>
<td>STAGI (1)</td>
<td>Logical variables indicating whether the maps are staggered (offset) in the I and J directions</td>
</tr>
<tr>
<td>STAGJ (1)</td>
<td></td>
</tr>
<tr>
<td>SINT (1)</td>
<td>Not used in the present version</td>
</tr>
<tr>
<td>WORK2 (JM,IM)</td>
<td>Map array</td>
</tr>
<tr>
<td>ZM (JM)</td>
<td>Zonal mean</td>
</tr>
<tr>
<td>ZN2 (JM)</td>
<td>Zonal mean, excluding points on land or ice</td>
</tr>
<tr>
<td>ZMM (1)</td>
<td>Global mean</td>
</tr>
</tbody>
</table>

The printed output consists of the input parameters, along with the map time, number, surface or level, and map title of each record as written on the tape.

B. SAMPLE MODEL OUTPUT

1. Maps of Selected Variables

To illustrate the general nature and structure of the solutions of the circulation model, a series of programmed map outputs for selected variables has been developed (see Map Routine Listing in Chapter VII). Presented here are samples of this output for the primary dependent variables $p_s$, $u_1$, $u_3$, $v_1$, $v_3$, $T_1$, $T_3$, and $q_3$ (as represented by the relative humidity), and for the geopotential heights. A selection of variables related to the heat and water balance in the model layers and at the surface is also given. These data are for day 400 (28 January, hour 0 GMT) of a basic or control simulation of
northern-hemisphere winter, with the program as listed in Chapter VII and with the fixed sea-surface temperature and ice distributions as shown in Chapter III.

For each of the maps shown below, a brief identification and description of the mapped quantity is given on the facing page, while the values of the minimum and dashed isolines and of the isoline interval are given at the upper right of each map's label. The symbols H and L designate locations of local maxima and minima, respectively, that are not resolved by the selected isoline interval. A rectangular map representation of the spherical grid has been used for convenience, with the points of the \( \pi \) grid and continental outlines shown as in Fig. 3.12. For each map the designation S/P denotes the \( \sigma \) level of the map, with S/P = 1 for those maps without a level designation as well as for the surface. The velocity, temperature, and geopotential heights may be generated for any \( 0 \leq \sigma \leq 1 \) by extrapolation and interpolation from the solutions at \( \sigma = 1/4 \) and \( \sigma = 3/4 \), and may also be displayed for any pressure surface \( p_T \leq p \leq p_s \) (see Map Routine Listing, Chapter VII). The complete list of available maps is given in Chapter VII just before the map code listings.

Those maps listed in Table 4.1 are given in \( \sigma \) coordinates, with the exception of the geopotential height in Map 6, which is given for both \( \sigma \) and \( p \) surfaces.
<table>
<thead>
<tr>
<th>Map</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Smoothed sea-level pressure ($\sigma = 1$)</td>
</tr>
<tr>
<td>2</td>
<td>Zonal (west/east) wind component ($\sigma = 1/4, 3/4$)</td>
</tr>
<tr>
<td>3</td>
<td>Meridional (south/north) wind component ($\sigma = 1/4, 3/4$)</td>
</tr>
<tr>
<td>4</td>
<td>Temperature ($\sigma = 1/4, 3/4$)</td>
</tr>
<tr>
<td>5</td>
<td>Geopotential height ($\sigma = 1/4, 3/4; p = 400, 800$ mb)</td>
</tr>
<tr>
<td>6</td>
<td>Total diabatic heating ($\sigma = 1/4, 3/4$)</td>
</tr>
<tr>
<td>7</td>
<td>Large-scale precipitation rate</td>
</tr>
<tr>
<td>8</td>
<td>Sigma vertical velocity ($\sigma = 1/2$)</td>
</tr>
<tr>
<td>9</td>
<td>Relative humidity ($\sigma = 3/4$)</td>
</tr>
<tr>
<td>10</td>
<td>Precipitable water</td>
</tr>
<tr>
<td>11</td>
<td>Convective precipitation rate</td>
</tr>
<tr>
<td>12</td>
<td>Evaporation rate ($\sigma = 1$)</td>
</tr>
<tr>
<td>13</td>
<td>Sensible heat flux ($\sigma = 1$)</td>
</tr>
<tr>
<td>14</td>
<td>Lowest-level convection ($\sigma = 1$)</td>
</tr>
<tr>
<td>15</td>
<td>Long-wave heating in layers ($\sigma = 0$ to $1/2, \sigma = 1/2$ to $1$)</td>
</tr>
<tr>
<td>16</td>
<td>Short-wave absorption (heating) in layers ($\sigma = 0$ to $1/2, \sigma = 1/2$ to $1$)</td>
</tr>
<tr>
<td>17</td>
<td>Surface short-wave absorption ($\sigma = 1$)</td>
</tr>
<tr>
<td>18</td>
<td>Surface air temperature ($\sigma = 1$)</td>
</tr>
<tr>
<td>19</td>
<td>Ground temperature ($\sigma = 1$)</td>
</tr>
<tr>
<td>20</td>
<td>Ground wetness ($\sigma = 1$)</td>
</tr>
<tr>
<td>21</td>
<td>Cloudiness (high, middle, low)</td>
</tr>
<tr>
<td>22</td>
<td>Total convective heating in layers ($\sigma = 0$ to $1/2, \sigma = 1/2$ to $1$)</td>
</tr>
<tr>
<td>23</td>
<td>Latent heating ($\sigma = 1/2$ to $1$)</td>
</tr>
<tr>
<td>24</td>
<td>Surface long-wave cooling ($\sigma = 1$)</td>
</tr>
<tr>
<td>25</td>
<td>Surface heat balance ($\sigma = 1$)</td>
</tr>
</tbody>
</table>
Fig. 4.1. Smoothed Sea-Level Pressure (Map 1) (mb - 1000 mb)

This map is calculated from the expression

\[ p_s \exp \left( \frac{\phi_4}{RT} \right) - 1000 \text{ mb} \]

where \( p_s \) is the surface pressure, \( \phi_4 \) is the geopotential at the ground, \( R \) is the dry-air gas constant, and \( \bar{T} \) is the average temperature between level 4 and sea level, given by

\[ \bar{T} = T_4 + \frac{1}{2} \frac{\gamma \phi_4}{g} \]

Here \( T_4 = \frac{3}{2} T_3 - \frac{1}{2} T_1 \) is the air temperature extrapolated to the surface, \( g \) is acceleration of gravity, and \( \gamma \) is an assumed constant lapse rate in the hypothetical layer between the earth's surface and sea level, taken here as \( \gamma = 0.6 \) deg C/100 m. The resulting sea-level pressures are then averaged over the local 9 points at which pressure is computed. At nonpolar points this smoothing operator is

\[ (\cdot)_{00}, \text{smoothed} = \frac{1}{16} \left[ (\cdot)_{-22} + 2(\cdot)_{02} \right. \]

\[ + (\cdot)_{22} + 2(\cdot)_{-20} + 4(\cdot)_{00} + 2(\cdot)_{20} \]

\[ + (\cdot)_{-2-2} + 2(\cdot)_{0-2} + (\cdot)_{2-2} \]

where the subscripts (in \( \pi \)-centered notation) refer to adjacent points of the \( \pi \) grid (see Fig. 3.6).
Fig. 4.2. Zonal (West/East) Wind Component (Map 2)  
(m sec$^{-1}$)

This map is calculated from the expression

$$ u = 2 \left[ u_3 \left( \sigma - \frac{1}{4} \right) + u_1 \left( \frac{3}{4} - \sigma \right) \right] $$

with $0 \leq \sigma \leq 1$ an arbitrary $\sigma$ surface. For $\sigma = 1/4$ and $\sigma = 3/4$ this reduces to the primary variables $u_1$ and $u_3$, respectively, and for other $\sigma$ represents a linear extrapolation and interpolation of $u$ in $\sigma$ (or $p$) space. The zonal wind component may also be generated for an arbitrary pressure surface $p$, in which case $\sigma$ in the above expression is replaced by $(p - p_T)/(\overline{\pi}^u)$, where $\overline{\pi}^u$ is the average of $\pi$ at the four $\pi$ points surrounding each $u,v$ point. The symbols E and W designate locations of local maxima of positive (eastward) and negative (westward) zonal wind speed, respectively, which are not resolved by the selected isoline interval.

Level shown in map at right: $\sigma = 1/4$. 
Fig. 4.2 -- Zonal (u) wind speed at $\beta = 1/4$. The dashed line is 0 and the isoline interval is 5 m sec$^{-1}$. 
Fig. 4.3. Zonal (West/East) Wind Component (Map 2) 

\( \text{(m sec}^{-1}\text{)} \)

This map is calculated from the expression

\[
  u = 2 \left[ u_3 \left( \sigma - \frac{1}{4} \right) + u_1 \left( \frac{3}{4} - \sigma \right) \right]
\]

with \( 0 \leq \sigma \leq 1 \) an arbitrary \( \sigma \) surface. For \( \sigma = 1/4 \) and \( \sigma = 3/4 \), this reduces to the primary variables \( u_1 \) and \( u_3 \), respectively, and for other \( \sigma \) represents a linear extrapolation and interpolation of \( u \) in \( \sigma \) (or \( p \)) space. The zonal wind component may also be generated for an arbitrary pressure surface \( p \), in which case \( \sigma \) in the above expression is replaced by \( (p - p_T)/(\pi^u) \), where \( \pi^u \) is the average of \( \pi \) at the four \( \pi \) points surrounding each \( u,v \) point. The symbols E and W designate locations of local maxima of positive (eastward) and negative (westward) zonal wind speed, respectively, which are not resolved by the selected isoline interval.

Level shown in map at right: \( \sigma = 3/4 \).
Fig. 4.3 -- Zonal (u) wind speed at $z = 3/4$. The dashed line is 0 and the isoline interval is 5 m sec$^{-1}$. 
Fig. 4.4. Meridional (South/North) Wind Component (Map 3) (m sec$^{-1}$)

The map is calculated from the expression

$$v = 2 \left[ v_3 \left( \sigma - \frac{1}{4} \right) + v_1 \left( \frac{3}{4} - \sigma \right) \right]$$

with $0 \leq \sigma \leq 1$ an arbitrary $\sigma$ surface. For $\sigma = 1/4$ and $\sigma = 3/4$, this reduces to the primary variables $v_1$ and $v_3$, respectively, and for other $\sigma$ represents a linear extrapolation and interpolation of $v$ in $\sigma$ (or $p$) space. The meridional wind component may also be generated for an arbitrary pressure surface $p$, in which case $\sigma$ in the above expression is replaced by $(p - p_T)/(\pi^u)$, where $\pi^u$ is the average of $\pi$ at the four $\pi$ points surrounding each $u,v$ point. The symbols $N$ and $S$ designate locations of local maxima of positive (northward) and negative (southward) meridional wind speed, respectively, which are not resolved by the selected isoline interval.

Level shown in map at right: $\sigma = 1/4$. 
Fig. 4.4: Meridional \((v)\) wind speed at \(\sigma = 1/4\). The dashed line is 0 and the isoline interval is 5 m sec\(^{-1}\).
Fig. 4.5. Meridional (South/North) Wind Component (Map 3) (m sec\(^{-1}\))

This map is calculated from the expression

\[ v = 2 \left[ v_3 \left( \sigma - \frac{1}{4} \right) + v_1 \left( \frac{3}{4} - \sigma \right) \right] \]

with \(0 \leq \sigma \leq 1\) an arbitrary \(\sigma\) surface. For \(\sigma = 1/4\) and \(\sigma = 3/4\), this reduces to the primary variables \(v_1\) and \(v_3\), respectively, and for other \(\sigma\) represents a linear extrapolation and interpolation of \(v\) in \(\sigma\) (or \(p\)) space. The meridional wind component may also be generated for an arbitrary pressure surface \(p\), in which case \(\sigma\) in the above expression is replaced by \((p - p_T)/(\pi^u)\), where \(\pi^u\) is the average of \(\pi\) at the four \(\pi\) points surrounding each \(u, v\) point. The symbols \(N\) and \(S\) designate locations of local maxima of positive (northward) and negative (southward) meridional wind speed, respectively, which are not resolved by the selected isoline interval.

Level shown in map at right: \(\sigma = 3/4\).
Fig. 4.5 — Meridional (y) wind speed at \( z = 3/4 \). The dashed line is 0 and the isoline interval is 5 m sec\(^{-1}\).
Fig. 4.6. Temperature (Map 4) (deg C)

This map is calculated from the expression

\[ T = \frac{(\sigma \pi + p_T)^\kappa}{p_3 - p_1} \left\{ \frac{T_1}{p_1} \left[ p_3^\kappa - (\sigma \pi + p_T)^\kappa \right] \right. \\
+ \left. \frac{T_3}{p_3^\kappa} \left[ (\sigma \pi + p_T)^\kappa - p_1^\kappa \right] \right\} - 273.1 \text{ deg} \]

with \( 0 \leq \sigma \leq 1 \) an arbitrary \( \sigma \) surface. This represents the linear interpolation and extrapolation of the potential temperature \( \theta = T(p_0/p)^\kappa \) in \( p^\kappa \) space. For \( \sigma = 1/4 \) and \( \sigma = 3/4 \), this reduces to the primary variables \( T_1 \) and \( T_3 \), respectively. Here \( p_T \) is the tropopause pressure (= 200 mb) and \( \kappa = 0.286 \). The temperature may also be obtained at an arbitrary pressure surface \( p_T \leq p \leq p_s = \pi + p_T \) by replacing \( (\sigma \pi + p_T) \) in the above expression by \( p \).

Level shown in map at right: \( \sigma = 1/4 \).
Fig. 4.6 -- Temperature at $t = 1/4$. The dashed line is -20°C and the isoline interval is 5 deg C.
This map is calculated from the expression

\[ T = \frac{(\sigma \pi + p_T)^\kappa}{p_3^\kappa - p_1^\kappa} \left\{ \frac{T_1^\kappa}{p_1^\kappa} \left[ p_3^\kappa - (\sigma \pi + p_T)^\kappa \right] \right\} + \frac{T_3^\kappa}{p_3^\kappa} \left[ (\sigma \pi + p_T)^\kappa - p_1^\kappa \right] \}

- 273.1 deg

with \( 0 \leq \sigma \leq 1 \) an arbitrary \( \sigma \) surface. This represents the linear interpolation and extrapolation of the potential temperature \( \theta = T(p_o/p)^\kappa \) in \( p^\kappa \) space. For \( \sigma = 1/4 \) and \( \sigma = 3/4 \), this reduces to the primary variables \( T_1 \) and \( T_3 \), respectively. Here \( p_T \) is the tropopause pressure (\( \approx 200 \) mb), and \( \kappa = 0.286 \). The temperature may also be obtained at an arbitrary pressure surface \( p_T \leq p \leq p_s = \pi + p_T \) by replacing \( (\sigma \pi + p_T) \) in the above expression by \( p \).

Level shown in map at right: \( \sigma = 3/4 \).
Fig. 4.7 -- Temperature at $\tau = 3/4$. The dashed line is $0^\circ$C and the isoline interval is 5 deg C.
Fig. 4.8. Geopotential Height of $\sigma$ Surface (Map 6)

(100 m)

This map is calculated from the expression

$$z = \frac{\phi + \phi_4}{10^2 g}$$

where $\phi_4$ is the geopotential of the earth's surface, $g$ is the acceleration of gravity, and where the geopotential $\phi$ of an arbitrary $\sigma$ surface is given by

$$\phi = \frac{R}{2} \left\{ T_1 \left[ \frac{p_1 - p_T}{p_1} + \frac{2\kappa - p_1}{p_3 - p_1} + 2\kappa p_1 p_3 - 4(\sigma \pi + p_T) \kappa p_3 + 2(\sigma \pi + p_T)^{2\kappa} }{2\kappa p_1 (p_3 - p_1)} \right] + T_3 \left[ \frac{p_3 - p_T}{p_3} + \frac{2\kappa - p_1}{p_3 - p_1} - 2\kappa p_3 + 4(\sigma \pi + p_T) \kappa p_3 - 2(\sigma \pi + p_T)^{2\kappa} }{2\kappa p_3 (p_3 - p_1)} \right] \right\}$$

Here $p_T$ is the tropopause pressure (= 200 mb), $\kappa = 0.286$, and $R$ is the dry-air gas constant. For $\sigma = 1/4$ and $\sigma = 3/4$, this reduces to $\phi_1$ and $\phi_3$, respectively, while for other $\sigma$ it represents a linear interpolation and extrapolation of the potential temperature in $p^\kappa$ space. The geopotential height of an arbitrary pressure surface $p_T \leq p \leq \pi + p_T$ may also be obtained by replacing $(\sigma \pi + p_T)$ in the above expression by $p$ (see Figs. 4.8a and 4.9a).

Level shown in map at right: $\sigma = 1/4$. 
Fig. 4.8 -- Geopotential height at $\sigma = 1/4$. The dashed line is 7000 m and the isoline interval is 100 m.
Fig. 4.8a. Geopotential Height of Pressure Surface (Map 6) (100 m)

This map is calculated from the expression

\[ z = \frac{\phi + \phi_4}{10^2 g} \]

where \( \phi_4 \) is the geopotential of the earth's surface, \( g \) is the acceleration of gravity, and where the geopotential \( \phi \) of an arbitrary \( p \) surface is given by

\[ \phi = \frac{R}{2} \left\{ \frac{p_1 - p_T}{p_1} + \frac{p_3^2 - p_1^2}{2p_1} \right\} + \frac{2\kappa}{p_3^2 - p_1^2} \left\{ \frac{\kappa}{p_3^2 - p_1^2} \right\} \]

Here \( p_T \) is the tropopause pressure (= 200 mb), \( \kappa = 0.286 \), and \( R \) is the dry-air gas constant. For \( p = p_1 \) and \( p = p_3 \), this reduces to the height of the 400-mb and 800-mb surfaces, respectively, while for other \( p \) it represents a linear interpolation and extrapolation of the potential temperature in \( p^K \) space. The geopotential height of an arbitrary \( \sigma \) surface \( 0 \leq \sigma \leq 1 \) may also be obtained by replacing \( p \) in the above expression by \( (\sigma p + p_T) \) (see Figs. 4.8 and 4.9).

Level shown in map at right: \( p = 400 \) mb.
Fig. 4.8a -- Geopotential height at p = 400 mb. The dashed line is 7000 m and the isoline interval is 100 m.
Fig. 9. Geopotential Height of \( \sigma \) Surface (Map 6) (100 m)

This map is calculated from the expression

\[
\frac{\phi + \phi_4}{10^2} = \frac{z}{g}
\]

where \( \phi_4 \) is the geopotential of the earth's surface, \( g \) is the acceleration of gravity, and where the geopotential \( \phi \) of an arbitrary \( \sigma \) surface is given by

\[
\phi = \frac{R}{2} \left\{ T_1 \left[ \frac{p_1 - p_T}{p_1} + \frac{2\kappa}{p_3} - \frac{2\kappa}{p_1} + 2p_1^\kappa p_3^\kappa - 4(\sigma \pi + p_T)^K p_3^\kappa + 2(\sigma \pi + p_T)^2K}{2\kappa p_1^\kappa p_3^\kappa} \right] + T_3 \left[ \frac{p_3 - p_T}{p_3} + \frac{2\kappa}{p_3} - \frac{2\kappa}{p_1} - 2p_1^\kappa p_3^\kappa + 4(\sigma \pi + p_T)^K p_1^\kappa - 2(\sigma \pi + p_T)^2K}{2\kappa p_3^\kappa (p_3 - p_1^\kappa)} \right] \right\}
\]

Here \( p_T \) is the tropopause pressure (= 200 mb), \( \kappa = 0.286 \), and \( R \) is the dry-air gas constant. For \( \sigma = 1/4 \) and \( \sigma = 3/4 \), this reduces to \( \phi_1 \) and \( \phi_3 \), respectively, while for other \( \sigma \) it represents a linear interpolation and extrapolation of the potential temperature in \( p^K \) space.

The geopotential height of an arbitrary pressure surface \( p_T \leq p \leq \pi + p_T \) may also be obtained by replacing \( \pi + p_T \) in the above expression by \( p \) (see Figs. 4.8a and 4.9a).

Level shown in map at right: \( \sigma = 3/4 \).
Fig. 4.9 -- Geopotential height at $\sigma = 3/4$. The dashed line is 2500 m and the isoline interval is 250 m.
Fig. 4.9a. Geopotential Height of Pressure Surface (Map 6)

(100 m)

This map is calculated from the expression

\[ z = \frac{\phi + \phi_4}{10^2 g} \]

where \( \phi_4 \) is the geopotential of the earth's surface, \( g \) is the acceleration of gravity, and where the geopotential \( \phi \) of an arbitrary \( p \) surface is given by

\[ \phi = \frac{R}{2} \left\{ T_1 \left[ \frac{p_1 - p_T}{p_1} + \frac{2\kappa - p_1^{2\kappa} + 2p_1^{2\kappa} - 4p_1^{2\kappa}p_3^{2\kappa} + 2p^{2\kappa}}{2\kappa p_1^{2\kappa}(p_3^{2\kappa} - p_1^{2\kappa})} \right] \right. \\
+ T_3 \left[ \frac{p_3 - p_T}{p_3} + \frac{2\kappa - p_3^{2\kappa} - 2p_3^{2\kappa}p_1^{2\kappa} + 4p_1^{2\kappa}p_3^{2\kappa} - 2p^{2\kappa}}{2\kappa p_3^{2\kappa}(p_3^{2\kappa} - p_1^{2\kappa})} \right] \right\} \]

Here \( p_T \) is the tropopause pressure (= 200 mb), \( \kappa = 0.286 \), and \( R \) is the dry-air gas constant. For \( p = p_1 \) and \( p = p_3 \), this reduces to the height of the 400-mb and 800-mb surfaces, respectively, while for other \( p \) it represents a linear interpolation and extrapolation of the potential temperature in \( p^\kappa \) space. The geopotential height of an arbitrary \( \sigma \) surface \( 0 \leq \sigma \leq 1 \) may also be obtained by replacing \( p \) in the above expression by \( (\sigma T + p_T) \) (see Figs. 4.8 and 4.9).

Level shown in map at right: \( p = 800 \) mb.
Fig. 1.9a -- Geopotential height at p = 800 mb. The dashed line is 2300 m and the isoline interval is 100 m.
This map is calculated from the expression

\[ H = 2 \left[ H_1 \left( \frac{3}{4} - \sigma \right) + H_3 \left( \sigma - \frac{1}{4} \right) \right] 48 \]

where \( H_1 \) and \( H_3 \) are the net temperature changes in the upper and lower layers, respectively, over a time interval \( 5\Delta t \) (the time interval over which the heating is calculated by means of the subroutine COMP 3). Here

\[ H_1 = (\Delta T_1)_{CM} + (\Delta T_1)_{CP} + \left( \frac{A_1 + R_2 - R_0}{c_p} \cdot \frac{2g}{\pi} \cdot \frac{1}{48} \right) \]

\[ H_3 = (\Delta T_3)_{CM} + (\Delta T_3)_{CP} + \frac{L}{c_p} \cdot \text{PREC} + \left( \frac{A_3 + R_4 - R_2 + F_4}{c_p} \cdot \frac{2g}{\pi} \cdot \frac{1}{48} \right) \]

where \((\Delta T_1)_{CM}\) and \((\Delta T_1)_{CP}\) are the temperature changes (over \( 5\Delta t \)) due to middle-level and penetrating convective heating in the upper layer, respectively [with \((\Delta T_3)_{CM}\) and \((\Delta T_3)_{CP}\) similarly defined for the lower layer], \( A_1 \) and \( A_3 \) are the net rates of short-wave radiant-energy absorption in the two layers, \( R_0, R_2, \) and \( R_4 \) are the upward long-wave radiative flux at each level, \( F_4 \) is the upward flux of sensible heat from the surface, \( L \) is the latent heat of condensation, and PREC is the large-scale condensation or precipitation rate. The factor \((2g/\pi)^{-1}\) represents the mass in each layer (per unit area), and the factor 48 (the number of times in a day the heating is calculated) converts to the desired units (see Chapter II, Sections F and G, and instructions 11410 to 11490, COMP 3, for further details).

For \( \sigma = 1/4 \) and \( \sigma = 3/4 \), this expression reduces to the net heat-induced temperature changes in the upper and lower layers, \( H_1 \) and \( H_3 \), respectively. For other \( 0 \leq \sigma \leq 1 \) it represents the assignment of the layer's temperature change to its midpoint, and the subsequent linear interpolation and extrapolation in \( \sigma \) (or \( p \)) space. This representation of the diabatic heating may also be generated for an arbitrary pressure, \( p \), by replacing \( \sigma \) in the above expression by \( (p - p_T)/\pi \).

Level shown in map at right: \( \sigma = 1/4 \).
Fig. 4.10 - Total diabatic heating rate at $t = 1/4$. The dashed line is 0 and the isoline interval is 5 deg/day.
This map is calculated from the expression

\[ H = 2 \left[ H_1 \left( \frac{3}{4} - \sigma \right) + H_3 \left( \sigma - \frac{1}{4} \right) \right] 48 \]

where \( H_1 \) and \( H_3 \) are the net temperature changes in the upper and lower layers, respectively, over a time interval \( 5\Delta t \) (the time interval over which the heating is calculated by means of the subroutine COMP 3). Here

\[ H_1 = (\Delta T_1)_{CM} + (\Delta T_1)_{CP} + \left( \frac{A_1 + R_2 - R_0}{c_p} \right) \left( \frac{2\pi}{48} \right) \]

\[ H_3 = (\Delta T_3)_{CM} + (\Delta T_3)_{CP} + \frac{L}{c_p} \text{ PREC} + \left( \frac{A_3 + R_4 - R_2 + F_4}{c_p} \right) \left( \frac{2\pi}{48} \right) \]

where \((\Delta T_1)_{CM}\) and \((\Delta T_1)_{CP}\) are the temperature changes (over \( 5\Delta t \)) due to middle-level and penetrating convective heating in the upper layer, respectively [with \((\Delta T_3)_{CM}\) and \((\Delta T_3)_{CP}\) similarly defined for the lower layer], \( A_1 \) and \( A_3 \) are the net rates of short-wave radiant-energy absorption in the two layers, \( R_0, R_2, \) and \( R_4 \) are the upward long-wave radiative flux at each level, \( F_4 \) is the upward flux of sensible heat from the surface, \( L \) is the latent heat of condensation, and \( \text{PREC} \) is the large-scale condensation or precipitation rate. The factor \((2\pi/48)^{-1}\) represents the mass in each layer (per unit area), and the factor 48 (the number of times in a day the heating is calculated) converts to the desired units (see Chapter II, Sections F and G, and instructions 11410 to 11490, COMP 3, for further details).

For \( \sigma = 1/4 \) and \( \sigma = 3/4 \), this expression reduces to the net heat-induced temperature changes in the upper and lower layers, \( H_1 \) and \( H_3 \), respectively. For other \( 0 < \sigma < 1 \) it represents the assignment of the layer's temperature change to its midpoint, and the subsequent linear interpolation and extrapolation in \( \sigma \) (or \( p \)) space. This representation of the diabatic heating may also be generated for an arbitrary pressure, \( p \), by replacing \( \sigma \) in the above expression by \( (p - p_0)/\pi \).

Level shown in map at right: \( \sigma = 3/4 \).
**Fig. 4.12. Large-Scale Precipitation Rate (Map 9)**

This map is calculated from the expression

\[
\text{PREC} \left( \frac{\pi}{2g} \right) 48 \frac{10^2}{\rho_w}
\]

where the large-scale precipitation rate (PREC) is taken equal to the rate of generation of water vapor in excess of saturation (i.e., the condensation rate) in the lower layer, and is given by

\[
\text{PREC} = \begin{cases} 
[q_3 - q_s(T_3)](1 + \gamma_3)^{-1}, & q_3 > q_s(T_3) \\
0, & \text{otherwise}
\end{cases}
\]

where \(q_3\) is the water-vapor mixing ratio at level 3, \(q_s(T_3)\) is the saturated mixing ratio at the ambient level-3 temperature \(T_3\) (see Fig. 4.14), and the parameter \(\gamma_3 = L q_s(T_3) (c_p T_3^2)^{-1} 5418\) deg, with \(L\) the latent heat of condensation and \(c_p\) the dry-air specific heat at constant pressure. The factor \(\pi/2g\) represents the mass (per unit area) in the lower-layer air column (\(\sigma = 1\) to \(\sigma = 1/2\)). The factor 48 (the ratio of 1 day to \(5\Delta t\)) represents the number of times per day the precipitation (PREC) is computed by means of the subroutine COMP 3. Together with the density of water, \(\rho_w = 1\) g cm\(^{-3}\), the factor \(10^2\) converts to the desired units. See Chapter II, Section F and instructions 8610 to 8690, COMP 3, for further details.
Fig. 4.12 -- Large-scale precipitation rate. The dashed line is 4 mm day⁻¹ and the isoline interval is 2 mm day⁻¹.
This map is calculated from the expression

$$\pi = \frac{\dot{S}}{2mn}$$

where $\dot{\sigma} = \dot{\sigma}_2 = d\sigma/dt$ at level 2 and $\dot{S}$ is a measure of the difference in horizontal mass convergence between levels 1 and 3, given by Eq. (2.34), Chapter II, as

$$\dot{S} = \frac{1}{2} \left[ \left( \frac{\partial u^*}{\partial x} + \frac{\partial v^*}{\partial y} \right) - \left( \frac{\partial u^*_1}{\partial x} + \frac{\partial v^*_1}{\partial y} \right) \right]$$

where $u^* = n\pi u$ and $v^* = m\pi v$ are weighted mass fluxes at the levels 1 or 3, and $n$ and $m$ are the meridional distance ($y$) and zonal distance ($x$) between $u,v$ grid points. The sigma vertical velocity may also be written $\pi = \pi - \sigma^*$, where $\sigma$ = dp/dt is the isobaric vertical velocity and $\pi = dp_s/dt$, with $p_s$ the surface pressure. See Chapter II for further details of $\dot{S}$, representing an integration of the equation of continuity. See Instructions 4130 to 4550, COMP 1, for further details.
Fig. 4.13 -- Sigma vertical velocity. The dashed line is 0 and the isoline interval is 10 mb hr⁻¹.
This map is calculated from the expression

\[ q_3 \frac{10^2}{q_s(T_3)} \]

where \( q_3 \) is the water-vapor mixing ratio at level 3 and \( q_s(T_3) \) is the saturation mixing ratio at the ambient level-3 air temperature \( T_3 \). Here \( q_s(T_3) \) is given by

\[ q_s(T_3) = \frac{0.622 e_s(T_3)}{0.1 p_3 - e_s(T_3)} \]

where \( p_3 \) is the (total) pressure at level 3, and the saturation vapor pressure \( e_s(T_3) \) is given by the semi-empirical formula

\[ e_s(T_3) = 10 \exp(8.4051 - 2753 \text{ deg}/T_3) \]

Both \( p_3 \) and \( e_s \) here are in the units cb (centibar = \( 10^{-2} \) bar = 10 mb). These relationships permit a supersaturation of a few percent in very moist air.

All of the atmospheric humidity is carried in the model at level 3 (i.e., \( q_1 = 0 \)), so that Map 11 is always for the level \( \sigma = 3/4 \).
Fig. 2.1: Relative humidity at \( t = \frac{1}{2} t \). The dashed line is 60 percent and the isoline interval is 20 percent.
This map is calculated from the expression

$$q_3 \frac{\pi}{2g} \frac{10}{\rho_w}$$

where $q_3$, the mixing ratio at level 3, is interpreted as the average mixing ratio between the surface ($\sigma = 1$) and level 2 ($\sigma = 1/2$), and where the density of water, $\rho_w$, is taken as 1 g cm$^{-3}$, which together with the factor 10 serves to give the desired units. The factor $\pi/2g$ represents the mass (per unit area) in the lower half of the air column ($\sigma = 1$ to $\sigma = 1/2$), and results from the vertical integration of the water-vapor distribution.
Fig. 4.15 -- Total precipitable water in column from $r = 1$ to $r = 1/2$. The dashed line is 1 cm and the isoline interval is 1 cm.
This map is calculated from the expression

\[
\frac{(\Delta T_1^\text{CM}) + (\Delta T_1^\text{CP}) + (\Delta T_3^\text{CM}) + (\Delta T_3^\text{CP})}{L/c_p^*} \cdot \frac{48 \cdot 10^2}{\rho_w^{\frac{\pi}{2g}}}
\]

where \((\Delta T_1^\text{CM})\) and \((\Delta T_1^\text{CP})\) are the temperature changes (over 5\(\Delta t\)) due to middle-level and penetrating convective heat transport in the upper layer, respectively [with \((\Delta T_3^\text{CM})\) and \((\Delta T_3^\text{CP})\) similarly defined for the lower layer], \(L\) is the latent heat of condensation, \(c_p\) is the specific heat at constant pressure, \(\rho_w = 1\ \text{g cm}^{-3}\) is the density of water, the factor \(\pi/2g\) represents the mass in each layer (per unit area), and the factor 48 (the number of 5\(\Delta t\) intervals in one day) together with the factor 10\(^2\) serves to convert to the desired units. The quantity

\[
\left[\frac{(\Delta T_1^\text{CM}) + (\Delta T_1^\text{CP}) + (\Delta T_3^\text{CM}) + (\Delta T_3^\text{CP})}{L/c_p^*}\right] \cdot \frac{1}{10^2} = C1 + PC1 + C3 + PC3
\]

in FORTRAN notation, and corresponds to the quantity PREC in Map 9 for the large-scale precipitation rate.

In the map shown on the right, the convective precipitation rate has a maximum of approximately 244 mm day\(^{-1}\). This rate, however, lasts for a relatively short time, and, due to the nature of the computed convective heating, characteristically occurs at isolated grid points.

See instructions 8700 to 8890, 9140 to 9390, COMP 3, and Chapter II, Subsection F.3, for further details.
Fig. 4.6 -- Convective precipitation rate. The dashed line is 100 mm day⁻¹, and the isoline interval is 50 mm day⁻¹.
This map is calculated from the expression

\[
\frac{E_4}{\rho_w} \cdot 10 \ \text{D}\text{AY} = \frac{C_D}{\rho_w} \left( |\mathbf{v}_s|_{00} + 2.0 \text{ m sec}^{-1} \right) \left[ \text{WET} \cdot q_s(T_g) + \text{WET} \cdot \frac{5418. \text{deg} q_s(T_g)}{T_g^2} (TGR - T_g) - Q_4 \right] 10^3 \ \text{D}\text{AY}
\]

where \(E_4\) is the evaporation in \(\text{g cm}^{-2} \text{ sec}^{-1}\), \(\rho_4\) is the surface air density, \(\rho_w = 1 \text{ g cm}^{-3}\) the density of water, WET a (calculated) ground wetness parameter, \(q_s(T_g)\) the saturated mixing ratio at the (computed) ground temperature \(T_g\), TGR a (computed) ground temperature parameter including the effects of radiation, and \(Q_4\) a measure of the mixing ratio at level 4. The surface drag coefficient \(C_D\) is given by

\[
C_D = \begin{cases} 
\min \left[ \left(1.0 + 0.07 |\mathbf{v}_s|^\pi \right) 10^{-3}, 0.0025 \right], & \text{if ocean} \\
0.002 + 0.006 \ (z_4/5000 \text{ m}), & \text{otherwise}
\end{cases}
\]

with \(z_4\) the elevation of the surface. Here \(|\mathbf{v}_s|^\pi\) is given in terms of the wind speeds at the four velocity points surrounding a pressure (or temperature) point by the expression (in \(\pi\)-centered notation)

\[
|\mathbf{v}_s|_{00} = \frac{1}{2} \left[ |\mathbf{v}_s|_{11}^2 + |\mathbf{v}_s|_{-11}^2 + |\mathbf{v}_s|_{-1-1}^2 + |\mathbf{v}_s|_{1-1}^2 \right]^{1/2}
\]

where \(\mathbf{v}_s = 0.7|\mathbf{v}_4|\) and \(\mathbf{v}_4 = \frac{3}{2} \mathbf{v}_{-3} - \frac{1}{2} \mathbf{v}_1\) (the wind extrapolated to level 4). The additive term 2.0 m sec\(^{-1}\) is an empirical correction for gustiness, and the factors 10, 10\(^3\), and D\text{AY} (= 86,400) convert to the desired units.

The term \(Q_4\) is interpreted as the effective moisture just above the surface, and the terms in WET represent the effective surface moisture. The entire term \(\left[ \left(1.0 + 0.07 |\mathbf{v}_s|^\pi \right) 10^{-3}, 0.0025 \right]\) thus represents the vertical moisture gradient near the earth's surface. As shown in the map on the right, most of the evaporation occurs over the ocean where \(TGR - T_g\) is zero, although the evaporation is occasionally negative elsewhere (representing condensation on the surface). See instructions 11220 to 11290, COMP 3, and Chapter II, Subsection F.6, for further details.
Fig. 4.7 -- Surface evaporation rate. The dashed line is 10 mm day⁻¹ and the isoline interval is 5 mm day⁻¹.
This map is calculated from the expression

\[ C_D \rho_4 c_p \left( |\vec{V}_s|_0^n + 2.0 \text{ m sec}^{-1} \right) (T_g - T_4) \text{ 10 DAY} \]

where \( \rho_4 \) is the surface air density, \( c_p \) the specific heat at constant pressure, \( T_g \) the (computed) ground temperature (or an assigned ice or ocean surface temperature), and \( T_4 \) is the air surface temperature. The surface drag coefficient \( C_D \) is given by

\[ C_D = \begin{cases} \min \left[ \left( 1.0 + 0.07 |\vec{V}_s|_0^n \right) 10^{-3}, 0.0025 \right], & \text{if ocean} \\ 0.002 + 0.006(z_4/5000 \text{ m}), & \text{otherwise} \end{cases} \]

with \( z_4 \) the elevation of the surface. Here \( |\vec{V}_s|_0^n \) is given in terms of the wind speeds at the four velocity points surrounding a pressure (or temperature) point by the expression (in \( n \)-centered notation)

\[ |\vec{V}_s|_0^n = \frac{1}{2} \left[ |\vec{V}_s|_{11}^2 + |\vec{V}_s|_{-11}^2 + |\vec{V}_s|_{-1-1}^2 + |\vec{V}_s|_{1-1}^2 \right]^{1/4} \]

where \( \vec{V}_s = 0.7|\vec{V}_3| \) and \( \vec{V}_4 = \frac{3}{2} \vec{V}_3 - \frac{1}{2} \vec{V}_1 \) (the wind extrapolated to level 4). The additive term 2.0 m sec\(^{-1}\) is an empirical correction for gustiness, and the factor 10 DAY (= 10 \( \times \) 86,400) converts to the desired units. The sensible heat flux (\( F4 \) in the FORTRAN code) is positive when ground temperature is greater than surface air temperature \( (T_g > T_4) \), representing a heat flux from the ground to the air. As shown in the map on the right, however, this flux is often negative. See instructions 11220 to 11290, COMP 3, and Chapter II, Subsection C.3, for further details.
Fig. 4.13 -- Surface sensible heat flux. The dashed line is 0 and the Isoline interval is 100 by day-1.
This map is calculated from the expression

\[
\text{EX} = \begin{cases} 
  h_4 - h_3^*, & \text{if } h_4 > h_3^* \text{ and } h_3 < h_1^* \\
  0, & \text{otherwise}
\end{cases}
\]

where the static-energy parameters are given by

\[
h_1^* = T_1 + \frac{\phi_1}{c_p} + \frac{L}{c_p} q_s(T_1)
\]

\[
h_3 = T_3 + \frac{\phi_3}{c_p} + \frac{L}{c_p} q_3
\]

\[
h_3^* = T_3 + \frac{\phi_3}{c_p} + \frac{L}{c_p} q_s(T_3)
\]

\[
h_4 = T_4 + \frac{L}{c_p} q_4
\]

where \( \phi = gz \) is the geopotential and \( q_s \) is the saturation mixing ratio. The condition \( h_4 > h_3^* \) thus ensures instability between levels 4 and 3, while the condition \( h_3 < h_1^* \) ensures stability between levels 3 and 1 (i.e., there is no middle-level convection). Hence \( \text{EX} > 0 \), and represents the adjustment of the level-4 temperature due to convection. If \( h_4 < h_1^* \) the computed value of \( \text{EX} \) is regarded as due to low-level convection, and is used to modify both the lowest-level temperature \( (T_4) \) and lowest-level heating \( (Q_4) \). If \( h_4 > h_1^* \) the computed value of \( \text{EX} \) is regarded as due to penetrating convection, and is used to modify not only \( T_4 \) and \( Q_4 \) but the heating in the upper and lower layer as well. See Chapter II, Subsection F.3, and instructions 8700 to 9350, COMP 3, for further details.
Fig. 4.18a — Lowest-level convection. The dashed line is 10.0 deg and the isoline interval is 2.0 deg.
Fig. 4.19. Long-Wave Heating in Layers (Map 19)
(deg day$^{-1}$)

This map is calculated from the expressions

$$(R2 - R0) \left(\frac{2g}{\pi}\right) \frac{1}{c_p} \quad \text{if} \quad 0 \leq \sigma < 0.5$$

$$(R4 - R2) \left(\frac{2g}{\pi}\right) \frac{1}{c_p} \quad \text{if} \quad 0.5 \leq \sigma \leq 1$$

for an arbitrary $\sigma$ surface, where $R0$, $R2$, $R4$ are the upward long-wave radiation fluxes at the levels $\sigma = 0$, $1/2$, $1$, respectively. The difference $(R2 - R0)$ is thus the net long-wave radiation absorbed in the upper layer $\sigma = 0$ to $\sigma = 1/2$, and $(R4 - R2)$ is the net long-wave radiation absorbed in the lower layer $\sigma = 1/2$ to $\sigma = 1$. Usually this heating is negative, representing a net long-wave cooling. The factor $(2g/\pi)^{-1}$ represents the air mass in either the upper or lower layer (per unit area), and $c_p$ is the air’s specific heat at constant pressure. Thus, depending upon whether $\sigma < 1/2$ or $\sigma \geq 1/2$, either one of two versions of this map is produced. See Chapter II, Section G, and instructions 9750 to 10230, COMP 3, for further details.

Layer shown in map at right: upper layer.
Fig. 4.19 -- Long-wave radiative heating rate in upper layer ($\sigma = 0$ to $\sigma = 1/2$). The dashed line is $-2.0 \text{ deg day}^{-1}$ and the isoline interval is $0.5 \text{ deg day}^{-1}$. 
This map is calculated from the expressions

\[(R_2 - R_0) \left( \frac{2g}{\pi} \right) \frac{1}{c_p} \quad \text{if} \quad 0 \leq \sigma < 0.5\]

\[(R_4 - R_2) \left( \frac{2g}{\pi} \right) \frac{1}{c_p} \quad \text{if} \quad 0.5 \leq \sigma \leq 1\]

for an arbitrary \( \sigma \) surface, where \( R_0, R_2, R_4 \) are the upward long-wave radiation fluxes at the levels \( \sigma = 0, 1/2, 1 \), respectively. The difference \((R_2 - R_0)\) is thus the net long-wave radiation absorbed in the upper layer \( \sigma = 0 \) to \( \sigma = 1/2 \), and \((R_4 - R_2)\) is the net long-wave radiation absorbed in the lower layer \( \sigma = 1/2 \) to \( \sigma = 1 \). Usually this heating is negative, representing a net long-wave cooling. The factor \( (2g/\pi)^{-1} \) represents the air mass in either the upper or lower layer (per unit area), and \( c_p \) is the air's specific heat at constant pressure. Thus, depending upon whether \( \sigma < 1/2 \) or \( \sigma \geq 1/2 \), either one of two versions of this map is produced. See Chapter II, Section G, and instructions 9750 to 10230, COMP 3, for further details.

Layer shown in map at right: lower layer.
Fig. 4.20 -- Long-wave radiative heating rate in lower layer ($\zeta = 1/2$ to $\zeta = 1$). The dashed line is -2.0 deg day$^{-1}$ and the isoline interval is 0.5 deg day$^{-1}$. 
This map is calculated from the expressions

\[ A_1 \left( \frac{2g}{\pi} \right) \frac{1}{c_p} \quad \text{if} \quad 0 \leq \sigma \leq 0.5 \]

\[ A_3 \left( \frac{2g}{\pi} \right) \frac{1}{c_p} \quad \text{if} \quad 0.5 < \sigma \leq 1 \]

if the cosine of the sun's zenith angle exceeds 0.01. These expressions are replaced by zero if the cosine of the sun's zenith angle is less than or equal to 0.01. Here \( A_1 \) and \( A_3 \) are the absorbed short-wave radiation in the upper layer (\( \sigma = 0 \) to \( \sigma = 1/2 \)) and lower layer (\( \sigma = 1/2 \) to \( \sigma = 1 \)), respectively, the factor \( \left( \frac{2g}{\pi} \right)^{-1} \) represents the mass (per unit area) in each layer, and \( c_p \) is the specific heat at constant pressure. Thus, depending upon whether the arbitrary value of \( \sigma \) is \( \leq 1/2 \) or \( > 1/2 \), either one of two versions of this map is produced. The value of \( A_1 \) is the difference between the incoming solar radiation (that part subject to absorption) at the level \( \sigma = 0 \) and the downward short-wave flux at the level \( \sigma = 1/2 \). Similarly, \( A_3 \) is the difference between the downward fluxes at the levels \( \sigma = 1/2 \) and \( \sigma = 1 \). In either version, the short-wave absorption is always positive (or zero) and represents the net short-wave heating within the layers. See Chapter II, Section G, and instructions 10430 to 11010, COMP 3, for further details.

Layer shown in map at right: upper layer.
Fig. 4.21 -- Short-wave radiative heating rate in upper layer ($\sigma = 0$ to $\sigma = 1/2$). The dashed line is 2 deg day$^{-1}$ and the isoline interval is 0.5 deg day$^{-1}$.
This map is calculated from the expressions

\[ A_1 \left( \frac{2g}{\pi} \right) \frac{1}{c_p} \quad \text{if} \quad 0 \leq \sigma \leq 0.5 \]

\[ A_3 \left( \frac{2g}{\pi} \right) \frac{1}{c_p} \quad \text{if} \quad 0.5 < \sigma \leq 1 \]

if the cosine of the sun's zenith angle exceeds 0.01. These expressions are replaced by zero if the cosine of the sun's zenith angle is less than or equal to 0.01. Here \( A_1 \) and \( A_3 \) are the absorbed short-wave radiation in the upper layer (\( \sigma = 0 \) to \( \sigma = 1/2 \)) and lower layer (\( \sigma = 1/2 \) to \( \sigma = 1 \)), respectively, the factor \( (2g/\pi)^{-1} \) represents the mass (per unit area) in each layer, and \( c_p \) is the specific heat at constant pressure. Thus, depending upon whether the arbitrary value of \( \sigma \) is \( \leq 1/2 \) or \( > 1/2 \), either one of two versions of this map is produced. The value of \( A_1 \) is the difference between the incoming solar radiation (that part subject to absorption) at the level \( \sigma = 0 \) and the downward short-wave flux at the level \( \sigma = 1/2 \). Similarly, \( A_3 \) is the difference between the downward fluxes at the levels \( \sigma = 1/2 \) and \( \sigma = 1 \). In either version, the short-wave absorption is always positive (or zero) and represents the net short-wave heating within the layers. See Chapter II, Section G, and instructions 10430 to 11010, COMP 3, for further details.

Layer shown in map at right: lower layer.
Fig. 4.22 -- Short-wave radiative heating rate in lower layer ($c = 1/2$ to $c = 1$). The dashed line is 2 deg day$^{-1}$ and the isoline interval is 0.5 deg day$^{-1}$. 
This map is calculated from the expression

\[ \frac{S_4}{100} \]

if the cosine of the sun's zenith angle is greater than 0.01, and is set equal to zero if the cosine of the sun's zenith angle is less than or equal to 0.01. Here \( S_4 \) is the short-wave radiation absorbed at the surface (or level 4). The effects of surface albedo, atmospheric moisture, and cloudiness are taken into account. The surface short-wave heating is always positive (or zero), and represents the net absorption of insolation at the surface. See Chapter II, Section G, and instructions 10430 to 11010, COMP 3, for further details.
This map is calculated from the expression

\[ T_4 - 273.1 \text{ deg} \]

where \( T_4 \) is the air temperature at the surface (level 4). Since \( T_4 \), like other dependent temperature variables, is in deg K, this expression serves simply to convert the surface air temperature into the units deg C. The value of \( T_4 \) resembles the extrapolated value \( \frac{3}{2} T_3 - \frac{1}{2} T_1 \) (where \( T_3 \) and \( T_1 \) are the air temperatures at levels 3 and 1, respectively), but also incorporates the surface air temperature adjustments introduced by low-level convection and latent heating. See Chapter II, Section G, and instructions 8970 to 9130 in subroutine COMP 3 for further details.
Fig. 4.24 -- Surface air temperature. The dashed line is 0 deg C and the isoline interval is 5 deg C.
This map is calculated from the ground-temperature ($T_{gr}$) dependence of the terms in the surface heat-balance equation, assuming the ground to be a perfect insulator of zero heat capacity:

$$R_4 + \Gamma + H_E - S_g = 0$$

Here the surface long-wave cooling $R_4$ is given by $\tilde{R}_4 + \sigma(T_{gr}^4 - T_g^4)$, the surface sensible heat flux $\Gamma$ by $C_p(T_{gr} - T_g)$, the latent heat flux from surface evaporation $H_E$ by $C_p(q_{se} - q_g) L/c_p$, and $S_g$ is the solar radiation absorbed at the surface. Here $\tilde{R}_4$ is a preliminary determination of the surface long-wave cooling, and $T_{gr}$ is a revised or improved value of the ground temperature $T_g$. For further details, see Chapter II, Subsection G.3.

Over ice- or snow-covered land and over sea ice, $T_{gr}$ is not allowed to exceed $T_o (= 273.1^oK)$. Over sea ice this balance is altered to include a heat flux into the sea ice given by $-B(T_{gr} - T_o)$, where $B$ is an assumed ice conduction coefficient. Over open ocean the ground temperature $T_{gr}$ is taken equal to the assigned sea-surface temperature $T_g = T_{GOO}$ (see Fig. 3.14), and there is thus no ground-temperature correction to either the surface long-wave radiation ($R_4 = \tilde{R}_4$) or to the surface saturated mixing ratio ($q_{se} = q_s$).
Fig. 4.25 -- Ground temperature. The dashed line is 0 deg C and the isoline interval is 5 deg C.
Fig. 4.26. Ground Wetness (Map 25)
(dimensionless)

This map is calculated from the expression \( GW = 10 \ WET \), where
\( WET \) is assigned the value 1.0 (saturated) over ocean, ice, and snow
surfaces, and is calculated over (bare) land surfaces according to

\[
WET = (GW)_{\text{new}} = (GW)_{\text{old}} + (1 - \text{runoff})(\Delta q_3)_{\text{TOTAL}} \frac{1}{GWM 2g'}\]

in which the old or previous value of \( GW \) is altered according to the
surface water balance. Here \( (\Delta q_3)_{\text{TOTAL}} = (E - C)(2g/\pi)5\Delta t \) is the
total moisture change (over 5\( \Delta t \)) including the effects of evaporation
and both large-scale and convective condensation, and \( GWM \) is an as-
sumed constant ground-water mass (\( = 30 \text{ g cm}^{-2} \)). The runoff factor
varies between 0 and 1, and is taken as 0.5\( (GW)_{\text{old}} \) if \( (GW)_{\text{old}} < 1 \)
(unsaturated surface), and as unity if \( (GW)_{\text{old}} = 1 \) (saturated), pro-
vided \( (\Delta q_3)_{\text{TOTAL}} > 0 \) in either case. If \( (\Delta q_3)_{\text{TOTAL}} < 0 \), representing
an increase in level-3 moisture and a decrease of surface moisture,
then the runoff is taken as zero. See Chapter II, Subsection F.5,
for further details.

If \( (GW)_{\text{new}} < 0 \) it is set to zero, and if \( (GW)_{\text{new}} > 1 \) it is set
to unity. The resulting wetness is then multiplied by 10 in order to
scale the final \( GW \) from 0 to 10.
Fig. 4.26. -- Ground wetness, scaled 0 to 10. The dashed line is 6.0 and the isoline interval is 2.0.
This version of Map 26 is calculated from the expression

$$CL_1 = \min(-1.3 + 2.6RH_3, 1)$$

where RH$_3$ is the level-3 relative humidity (as in Map 11). If CL $\leq$ 0 the sky is assumed to be clear and CL is reset to zero; otherwise CL$_1$ is taken as the fraction of the sky covered with high or type-1 clouds. This cloudiness measure may be identified with towering cumulus between the levels 3 and 1, and is associated with either middle-level or penetrating convection. If there is no such convection, there is no type-1 or high cloudiness (CL$_1 = 0$). For identification, this cloudiness is assigned the index $c = 1/4$ in the map-generating program in Chapter VII. See Chapter II, Subsection F.6, for further details.
Fig. 4.27 — High cloudiness, scaled ≥ 1. The dashed line is 0.5 and the isoline interval is 0.3.
This version of Map 26 is calculated on the basis of $CL_2 = 1$ if there is large-scale precipitation (and if there is no penetrating convection or high cloudiness, $CL_1 = 0$). Under all other conditions $CL_2 = 0$. Thus this measure of cloudiness is either 0 or 1 at all points. We may regard $CL_2$ as the fraction of the sky covered by type-2 clouds, which are identified as heavy overcast between levels 3 and 2. For identification, this cloudiness is assigned the index $\sigma = 3/4$ in the map-generating program in Chapter VII. See Chapter II, Subsection F.6, for further details.
Fig. 4.28 -- Middle cloudiness, scaled 0 or 1. The dashed line is 0.5 and the isoline interval is 0.3.
This version of Map 26 is calculated from the expression

$$\text{CL3} = \min(-1.3 + 2.6\text{RH}_3, 1)$$

where \(\text{RH}_3\) is the level-3 relative humidity (as in Map 11). If \(\text{CL3} \leq 0\) the sky is assumed to be clear and \(\text{CL3}\) is reset to zero; otherwise \(\text{CL3}\) is taken as the fraction of the sky covered with low or type-3 clouds. This cloudiness measure may be identified with shallow cumulus at level 3, and is associated with low-level convection. If there is no low-level convection, there is no low cloudiness (\(\text{CL3} = 0\)); there is also no low cloudiness if there is any high cloudiness (as in Fig. 4.27). For identification, this cloudiness is assigned the index \(\sigma = 1\) in the map-generating program in Chapter VII. See Chapter II, Subsection F.6, for further details.
Fig. 4.29 -- Low cloudiness, scaled ≤ 1. The dashed line is 0.5 and the isoline interval is 0.3.
This map is calculated from the expression

\[ 2 \left\{ \left( \Delta T_1 \right)_{CM} + \left( \Delta T_1 \right)_{CP} \right\} \frac{3}{4} - \sigma \left[ \left( \Delta T_3 \right)_{CM} + \left( \Delta T_3 \right)_{CP} \right] (\sigma - \frac{1}{4}) \right\} 48 \]

where \( \left( \Delta T_1 \right)_{CM} \) and \( \left( \Delta T_1 \right)_{CP} \) are the temperature changes (over 5\( \Delta t \)) due to middle-level and penetrating convective heating, respectively, in the upper layer [with \( \left( \Delta T_3 \right)_{CM} \) and \( \left( \Delta T_3 \right)_{CP} \) similarly defined for the lower layer]. The factor 48 converts to the desired units, and the factor 2 represents \( \left( \sigma_3 - \sigma_1 \right)^{-1} \). For \( \sigma \) other than \( \sigma_1 (= 1/4) \) and \( \sigma_3 (= 3/4) \), this map thus generates the convective heating rate by linear interpolation and extrapolation in \( \sigma \) (or \( p \)) space. If a \( p \) surface is requested, \( \sigma \) in the above expression is replaced by \( (p - p_T)/\pi \). See Chapter II, Section F, and instructions 11410 to 11490, COMP 3, for further details.

Layer shown in map at right: upper layer.
Fig. 4.29a. -- Total convective heating in the upper layer (c = 0 to c = 1/2). The dashed line is 0.2 deg day.
This map is calculated from the expression

\[
2 \left\{ \left[ \frac{(\Delta T_1)}{CM} + \frac{(\Delta T_1)}{CP} \right] \left( \frac{3}{4} - \sigma \right) + \left[ \frac{(\Delta T_3)}{CM} + \frac{(\Delta T_3)}{CP} \right] \frac{1}{4} \right\} 48
\]

where \((\Delta T_1)\) and \((\Delta T_1)\) are the temperature changes (over 5\(\Delta t\)) due to middle-level and penetrating convective heating, respectively, in the upper layer [with \((\Delta T_3)\) and \((\Delta T_3)\) similarly defined for the lower layer]. The factor 48 converts to the desired units, and the factor 2 represents \((\sigma_3 - \sigma_1)^{-1}\). For \(\sigma\) other than \(\sigma_1 (= 1/4)\) and \(\sigma_3 (= 3/4)\), this map thus generates the convective heating rate by linear interpolation and extrapolation in \(\sigma\) (or \(p\)) space. If a \(p\) surface is requested, \(\sigma\) in the above expression is replaced by \((p - p_T)/\pi\). See Chapter II, Section F, and instructions 11410 to 11490, COMP 3, for further details.

Layer shown in map at right: lower layer.
Fig. 4.29b -- Total convective heating in the lower layer ($\sigma = 1/2$ to $\sigma = 1$). The dashed line is 0 and the isoline interval is 0.2 deg day$^{-1}$. 
This map is calculated from the expression

\[ \frac{L}{c_p} \text{(PREC)} \times 48 \]

where PREC is the large-scale condensation (or precipitation) rate (as in Map 9), \( L \) is the latent heat of condensation, and \( c_p \) is the air's specific heat at constant pressure. The factor 48 converts to the desired units. This latent heating applies to the lower layer only, as represented by level 3. See Chapter II, Subsection F.2, and instructions 8610 to 8690, COMP 3, for further details.
Fig. 4.29c -- Latent heating in the lower layer ($\sigma = 1/2$ to $\sigma = 1$). The dashed line is 1.0 deg day$^{-1}$ and the isoline interval is 0.5 deg day$^{-1}$. 
This map is calculated from the expression

\[ \frac{R_4}{100} \]

where \( R_4 \) is the net upward long-wave radiation at the earth's surface. See Chapter II, Subsection G.2, and instructions 10430 to 11010, COMP 3, for further details.
Fig. 4.30 -- Long-wave radiative flux at the surface. The dashed line is 100 ly day$^{-1}$ and the isoline interval is 50 ly day$^{-1}$. 
This map is calculated from the expression

\[(S_4 - R_4 - F_4)10^{-2} - (L_0 \rho_w E_4)10^{-3}\]

where \(S_4\) is the short-wave radiation absorbed at the surface (as in Map 22), \(R_4\) is the net upward long-wave radiation at the surface (as in Map 30), \(F_4\) is the upward sensible heat flux from the surface (as in Map 15), and \(E_4\) is the heat expended in evaporation from the surface (as in Map 14). Here \(L\) is the latent heat of evaporation, \(\rho_w\) is the density of water, and the factors \(10^{-2}\) and \(10^{-3}\) serve to convert to the desired units. A positive balance indicates a net downward energy flux at the surface. Since the ground temperature over land (and ice) itself determined from the condition of a zero surface heat balance, the small but nonzero values for the heat balance seen here over the continents are the result of the use of spatially averaged temperatures in those portions of the subroutine COMP 3 that have been incorporated into the program for Map 30 (see Map Program Listing, Chapter VII, Section B). This imbalance is here less than 10 ly/day, or approximately one percent of the separate heat-balance components. The relatively small heat flux through the ice at the (fixed) locations of ice-covered ocean has also been neglected in producing this map. See Chapter II, Subsection G.3, for further details.
Fig. 4.31 -- Total heat balance at the surface. The dashed line is 0 and the isoline interval is 200 ly day⁻¹.
2. **Surface-Pressure Sequence**

To illustrate the typical time behavior of the circulation simulated by the model, a 10-day sequence of the solution for sea-level pressure is presented in Fig. 4.32. These maps are from the same control experiment as those shown in Subsection A.1 above, and constitute a time series starting with Map 1 of Fig. 4.1. These maps show the sea-level pressure isolines at 5-mb intervals, with an additive 1000 mb understood. It is characteristic of the model’s solutions that the sea-level pressure distribution maintains a synoptic-like structure as successive cyclone families are formed in the middle latitudes.
Fig. 4.32 -- Daily sequence of smoothed sea-level pressure. The dashed line is 1000 mb and the isoline interval is 5 mb (see Fig. 4.1).
Fig. 4.32 -- Continued.
Fig. 4.32 -- Continued.
Fig. 4.32 -- Continued.
V. PHYSICS DICTIONARY

PURPOSE

This list of terms permits easy entry into the model's physics and its numerical procedures without prior knowledge of specific mathematical or FORTRAN symbols. In this sense it complements the list of symbols and FORTRAN dictionary given in Chapter VIII. This list, of course, is by no means a complete one, but the authors have included those terms commonly associated with the numerical simulation of the general atmospheric circulation. For each term a brief description (and location) of its treatment in the model is given, together with any appropriate symbols, values, units, FORTRAN representations, and program locations.

LIST OF TERMS

Albedo

The albedo of the earth's surface, α_e (ALS), is assumed constant for two types of surface topography: 0.14 for bare land, 0.07 for ocean. The albedo of ice and of snow-covered land varies from about 0.40 to 0.90 and is dependent upon latitude and time of year (see instructions 10240 to 10410 in the FORTRAN listing), but does not depend in the present version upon the simulated circulation. The albedo of clouds, α_c (ALAC), used in the treatment of radiation varies between 0.6 and 0.7, depending upon the simulated clouds (see instructions 7620 to 7640 in the FORTRAN listing). The value of the albedo of the cloudless atmosphere for (Rayleigh) scattering, α_o (ALA0, instruction 10450), is a function of pressure and solar zenith angle, while for an overcast sky, α_c, it depends upon both α_o and α_c (see instructions 10650, 10750, 10880). See Chapter II, Section G, for further details.

Boundary Conditions

At the earth's surface (σ = 1) and at the assumed isobaric tropopause (σ = 0) the condition σ = dσ/dt = 0 is imposed. This ensures no
motion through the surface \( p = p_s \) at the ground (kinematic boundary condition), and no motion through the surface \( p = p_T \) (free surface condition), where \( p_T (= 200 \text{ mb}) \) is the assumed tropopause pressure.

There are no lateral boundary conditions in the global model, although there are some computational adjustments at the poles (see Chapter III). Over a water surface (ocean or lake) the surface temperature is fixed at a climatological mean value, whereas over a snow or ice surface (sea ice or glacier) the surface ground temperature, although in general calculated by the model, is not allowed to warm above 0 deg C.

**Clouds**

Clouds are simulated in the model both through large-scale condensation and through convection. The degree of cloudiness affects the short-wave radiation by reflection (with an assumed cloud albedo) and by partial absorption within the cloud by means of a fictitious water-vapor amount \( u_c^* \). The cloudiness also affects the long-wave radiation balance (see Chapter II and subroutine COMP 3, instructions 9400 to 10230 and 10540 to 11200). The cloudiness parameters CL1, CL2, and CL3 represent: (1) either penetrating or midlevel convection, (2) large-scale condensation, and (3) low-level convection, respectively. These are combined into the total or effective cloudiness measure CL, which is the fraction of sky assumed to be cloud-covered \((0 \leq CL \leq 1)\). The measures CL1 and CL3 also depend upon the humidity at level 3. See Chapter II, Subsection F.4, for further details and Figs. 4.27 to 4.29, Chapter IV, for typical distributions.

**Condensation**

Large-scale condensation (PREC) occurs mainly as a result of the lifting of saturated air; the model's only atmospheric moisture, \( q_3 \), is at the level \( \sigma = 3/4 \) and this is assumed representative of the average moisture in the layer \( \sigma = 1/2 \) to 1. Convective condensation (Cl, C3, PC1, PC3) is parameterized in both the upper and lower levels, although moisture continues to be carried only at the level 3. Condensation (dew deposit) may also occasionally occur on the surface as
negative evaporation (E4). Since no cloud liquid-water content is
carried, condensation is equivalent to precipitation in the model (see
subroutine COMP 3, instructions 8620 to 8800, 9140 to 9360). See also
Chapter II, Subsections F.2 and F.3, for further details; and Figs.
4.12 and 4.16, Chapter IV, for typical distributions.

Convection

Low-level convection is simulated under unstable conditions by
altering the surface air temperature (level 4) by an amount necessary
to restore the vertical lapse rate between levels 3 and 4 to a stable
configuration. If the lapse rate between the surface and the upper
level 1 is unstable, a penetrating convective heating is introduced
in the heat budget of both the upper and lower layer, as well as at
the surface, so as to restore stability. See Chapter II, Section F;
and subroutine COMP 3, instructions 8700 to 8880, 8960 to 9390, for
further details.

Convective Adjustment

As a result of advective temperature changes and diabatic heat-
ing at the levels 1 and 3, the vertical temperature lapse rate may
become dry-adiabatically unstable. This is checked in a test for
dry-adiabatic instability every 30 minutes, or every 5 time steps
(before the heating), in subroutine COMP 3 (instructions 8180 to 8320),
wherein the potential temperatures \( \theta_1 \) and \( \theta_3 \) are both set equal to the
value \( (T_1 + T_3)/(p_1^K + p_3^K) \), if prior to the adjustment \( \theta_3 > \theta_1 \). See
Chapter II, Subsection F.1, for further details.

Coriolis Force

The Coriolis force (per unit mass), \( f = 2\Omega \sin \varphi \), is computed for
each latitude by means of a finite-difference approximation to the
equality \( \sin \varphi = -\frac{\partial \cos^2 \varphi}{2 \cos \varphi} \). This is performed in the subroutine
MAGFAC (see instructions 14700 to 14750), wherein \( F(J) \) is the Coriolis
parameter. See Chapter III, Subsection C.5, for further details.
Diffusion Coefficient

The coefficient of lateral eddy diffusion is set equal to zero in the present version of the model. However, provision has been made for including a diffusion of horizontal momentum in the subroutine COMP 4 (see instructions 12270 to 12680), with horizontal diffusion coefficients dependent upon the local mesh sizes.

Drag Coefficient

Over the oceans the drag coefficient $C_D$ is a function of the surface wind speed, $\vec{V}_s$, and is given by $1.0 + 0.07|\vec{V}_s|10^{-3}$ or 0.0025, whichever is smaller. Over land (and ice or snow) $C_D$ is given by $0.002 + 0.006(z/z_{5000} \text{ m})$, where $z_{5000}$ is the height of the surface. This is computed as $C_D$ in subroutine COMP 3 (see instructions 7910 to 7980). See Chapter III, Subsection C.10, for further details.

Evaporation

The surface evaporation rate, $E$, is locally computed every five time steps over both ocean and land as $E4$ in the subroutine COMP 3 (see instruction 11240). The evaporation is dependent upon the local surface wind speed and drag coefficient, the local surface air density and temperature, and the low-level vertical moisture gradient. The evaporation distribution is illustrated in Fig. 4.17, Chapter IV. See Chapter II, Subsection F.4, for further details.

Finite-Difference Grid

The present model's primary or $\pi$ grid consists of points spaced 5 deg longitude and 4 deg latitude over the globe, and is illustrated by the symbol (o) in Fig. 3.2. At the set of such points including the poles (but not the equator) the variables $\pi$, $T$, $\phi$, and $q$ are determined, while at the set of points 4 deg latitude apart including the equator (but not the poles) and displaced eastward 2-1/2 deg longitude relative to the $\pi$ grid, the horizontal speeds $u$ and $v$ are determined [the $u,v$ grid, illustrated by the symbol (+) in Fig. 3.2]. The
complete grid therefore consists of 6552 distinct data points at each of two levels, with additional information stored for the \( \tau \) grid at the surface. For computational convenience additional subgrids are defined in Chapter III (see Fig. 3.2).

**Friction**

The internal frictional force arising from the vertical shear stress of the horizontal wind between levels 1 and 3 is written

\[
\mu (\nabla \cdot \mathbf{V}) (z_1 - z_3)^{-1}(2g/\pi),
\]

where \( \mu = 0.44 \text{ mb sec} \) is an empirical shear-stress coefficient. This frictional force is applied with opposite signs in the equations of motion at levels 1 and 3. The frictional force at the earth's surface (which affects level 3 only) is written

\[
C_D \nabla \cdot \mathbf{V} (\nabla \cdot \mathbf{V}) + G(2g/\pi),
\]

where \( C_D \) is the drag coefficient, \( \nabla \cdot \mathbf{V} \) the (extrapolated) surface wind, and \( G = 2.0 \text{ m sec}^{-1} \) an empirical correction for gustiness. These frictional forces are computed every fifth time step in subroutine COMP 3 (see instructions 11500 to 11620). See Chapter II, Section E, and Chapter III, Subsection C.10, for further details.

**Geopotential**

The geopotential, \( \phi \), of the sigma surfaces is used in the subroutine COMP 2 to compute a portion of the horizontal pressure gradient force (see instructions 5210 to 5700). The geopotential computation is based upon the assumption that the potential temperature is linear in \( p^k \) space; it is illustrated in Figs. 4.8 and 4.9, Chapter IV.

The geopotential of constant-pressure surfaces may also be calculated for interpretive purposes, as shown in Figs. 4.8a and 4.9a, Chapter IV.

**Grid-Point Separation**

The zonal (west/east) distance between grid points, \( \Delta \lambda \), is equal to 5 deg longitude (FORTRAN symbol DLON), for which the actual distance varies with latitude as given by the map metric \( m \) (FORTRAN symbols DXU, DXP, in Fig. 3.4). The meridional (south/north) distance between grid
points, \( \Delta \phi \), is equal to 4 deg latitude (FORTRAN symbol DLAT), with the equivalent distance given by the map metric \( n \) (FORTRAN symbols DYU, DYP in Fig. 3.3). These variables are computed in the subroutine MAGFAC (see instructions 14360 to 14850). See Chapter III, Section B, for further details.

**Ground Temperature**

The temperature of the ground at the earth's surface (FORTRAN symbol TG) is computed in subroutine COMP 3 (instructions 11010 to 11200) as a function of the surface radiation balance (short-wave absorption minus net long-wave emission), evaporation, and vertical sensible heat flux. This is done under the assumption of no heat transfer into the ground (zero heat capacity for bare land, snow-covered land, or ice-covered land). Over an ice-covered ocean the surface temperature is computed as for bare land, except that heat flux through the ice is permitted. Ice- and snow-covered surfaces are not allowed to become warmer than 0 deg C. Over water surfaces the temperature is held at the assigned sea-surface temperature distribution (FORTRAN symbol TG00). See Chapter II, Section G, for further details; and Fig. 4.25, Chapter IV, for a typical distribution.

**Ground Wetness**

The degree of wetness of the ground surface is measured by a dimensionless parameter (FORTRAN symbols WET and GW) varying between 0 and 1. This is computed in subroutine COMP 3 (instructions 11280 to 11390) as a function of the surface-moisture budget (precipitation, evaporation, and runoff). Ice-, snow-, and water-covered surfaces have a ground-wetness parameter equal to 1 (saturation). See Chapter II, Subsection F.7, for further details; and Fig. 4.26, Chapter IV, for a typical distribution.

**Heat Balance**

A net heating or cooling may occur in either the upper or lower layers of the model from the absorption of short-wave (solar) radiation,
net long-wave radiation, the convective heating, and (in the lower layer only) through large-scale condensation and the surface flux of sensible heat. The sum of these effects may be termed the heat balance, which on the long-term average over the global domain should be approximately zero. At the earth's surface (over bare land or snow- or ice-covered land) a heat balance is assumed among the fluxes of short- and long-wave radiation, the upward sensible heat flux, and the latent heat used for surface evaporation. This balance is used to determine the ground temperature, and corresponds to a zero land heat capacity. A similar balance is assumed over ice-covered ocean surfaces, except that heat flux through the ice is permitted (snow and ice temperatures may not exceed 0 deg C). Over water surfaces there is no surface heat balance in the model because the water's surface temperature is fixed. The surface heat balance is illustrated in Fig. 4.31, Chapter IV. See Chapter II, Section G, for further details.

**Heating**

Diabatic heating occurs in the upper and lower layers of the model as a result of the radiation (both short- and long-wave) and the convective heating. In the lower layer there is also heating by large-scale condensation (PREC) and by the vertical (turbulent) flux of sensible heat (P4). These heat sources are computed every 5 time steps (= 30 min) in subroutine COMP 3 (instructions 11170 to 11310), and are used to change the temperature at levels 1 and 3. The total heating (in layers), surface sensible heat flux, long-wave heating (in layers), short-wave heating (in layers), surface short-wave absorption, and the surface long-wave cooling are illustrated in Figs. 4.10 and 4.11, 4.18, 4.19 and 4.20, 4.21 and 4.22, 4.23, and 4.30, respectively, of Chapter IV. See Chapter II, Section G, for further details.

**Ice**

The distribution of surface ice is prescribed in the present version of the model, and is shown in Figs. 3.13 and 3.14 for land ice and sea ice by the overprinted symbol I. The elevation of the land ice
is also shown in Fig. 3.13, while the sea ice is assumed to be at sea level. These ice locations are identified in the topography input deck (TOPG) in subroutine INIT 2 by the values \( \leq -10^5 \), with the amount below \(-10^5\) equal to the ice surface’s elevation above sea level (in \(10^2\) ft). In the computation of the heat balance over sea ice, the ice is assumed to be 300 cm thick (HICE) and to have a thermal conductivity (CTI) \(= 0.005 \text{ ly cm sec}^{-1} \text{ deg}^{-1}\), and is not allowed to be warmer than 0 deg C (TICE). Except for its albedo (and not being allowed to warm above 0 deg C), land ice is treated in the same manner as bare land with \(GW = 1\).

**Long-Wave Radiation**

The upward long-wave radiative flux is computed at the tropopause (R0), at the level 2 (R2), and at the ground (R4), taking into account the atmospheric emissivity, transmissivity, and the presence of clouds. This is performed every 5 time steps in subroutine COMP 3 (instructions 9750 to 10220, 11040 to 11200). The net fluxes \(R_2 - R_0\) and \(R_4 - R_2\) contribute to the change of air temperature at levels 1 and 3, while the surface flux \(R_4\) contributes to the change of ground temperature and to the surface heat balance. These fields are illustrated in Figs. 4.19, 4.20, and 4.30 of Chapter IV. See Chapter II, Subsection G.2, for further details.

**Low-Level Convection**

The effect of relatively shallow or low-level convection on the surface temperature and moisture is parameterized in the model in terms of a generalized convection measure. There is no low-level convection unless the lapse rate is unstable between levels 3 and 4 (as measured by the temperature parameters HH4 and HH3S). In addition, the atmosphere must be stable between levels 1 and 3. Under these conditions the surface temperature (T4) and moisture (Q4) are adjusted to simulate low-level convective transports every 5 time steps in subroutine COMP 3 (see instructions 8700 to 8790, 9140 to 9350). See Chapter II, Section F, for further details.
Middle-Level Convection

This form of convection occurs if the atmosphere is unstable between levels 1 and 3, and alters the heat and moisture distribution at these levels. Midlevel clouds will be created if the level-3 relative humidity exceeds 50 percent. See subroutine COMP 3 (instructions 8810 to 8880) and Chapter II, Section F, for further details.

Moisture

The mixing ratio ($Q_3$) is computed at the lower level 3 in the model at the points of the $\pi$ grid in the subroutine COMP 1 (instructions 3520 to 3740), and the moisture sources and sinks due to evaporation and condensation are computed every 5 time steps in subroutine COMP 3 (instructions 8330 to 8450). The upper model level 1 is considered dry, and the moisture advects are such that total moisture is conserved in the absence of sources and sinks. The surface moisture balance is computed in subroutine COMP 3 (instructions 8540 to 8590, 8970 to 9120, 11280 to 11410), and includes the effects of evaporation (E4), precipitation (PREC), ground wetness (GW), and runoff. The moisture distribution is illustrated in the form of the relative humidity at level 3 in Fig. 4.14, Chapter IV, and the total precipitable water is illustrated in Fig. 4.15, Chapter IV. See Chapter II, Section F, and Chapter III, Subsection C.9, for further details.

Momentum Advection

The horizontal advection of momentum is computed in subroutine COMP 1 (instructions 3750 to 4120) in a way which ensures momentum conservation and the conservation of kinetic energy and the square of relative vorticity (in the absence of sources and sinks). This is accomplished by keeping track of the momentum fluxes ($PU, PV, FLUXU, FLUXV$) between neighboring u,v-grid cells, and with special adjustment near the poles. The vertical advection of momentum is also computed in subroutine COMP 1 (instructions 4690 to 4860), and represents a momentum exchange between levels 1 and 3 through the large-scale vertical velocity (SD). See Chapter III, Subsections C.3 and C.4, for further details.
Penetrating Convection

Like low-level convection, penetrating or deep convection is parameterized by a convection measure. For penetrating convection to occur, the atmosphere must be unstable between levels 3 and 4 and between levels 1 and 4, but stable between levels 1 and 3. Under these conditions the temperatures at levels 1 and 3 are changed to reflect the vertical convective heat transport (see subroutine COMP 3, instructions 8700 to 8790, 9140 to 9350) with the surface temperature ($T_4$) and moisture ($Q_4$) also changed every 5 time steps. This convection ($PC_1, PC_3$) also contributes to the precipitation, although it is assumed that no moisture is carried to the upper level 1. See Chapter II, Subsection F.3, for further details.

Potential Temperature

The potential temperature $\Theta = T(p_o/p)^K$ (FORTRAN symbol TETA) is computed at various levels in the model for use in vertical stability tests and in the vertical interpolation in $p^\sigma$ space for the temperature and geopotential heights at $\sigma$ (or $p$) surfaces. Here $p_o = 1000$ mb and $K = 0.286$.

Precipitation

The large-scale precipitation rate ($PREC$) is computed every 5 time steps in the subroutine COMP 3 (instructions 8610 to 8690) as a result of the indicated supersaturation at level 3. The temperature at level 3 is also altered by the corresponding release of latent heat. An additional precipitation rate ($CP$) is due to middle-level and penetrative convective processes ($C_1, C_3, PC_1, PC_3$), which also result in the latent heating of the upper and lower layers (COMP 3, instructions 9140 to 9320, 11430 to 11480). The large-scale and convective precipitation rates are illustrated in Figs. 4.12 and 4.16, Chapter IV. See Chapter II, Subsections F.2 and F.3, for further details.
Pressure

The atmospheric pressure (PL) is computed at various levels in the model at the points of the pi grid, and is widely used in the numerical integrations (see subroutine COMP 3, instructions 8020 to 8160). The pressure of the earth's surface, p_s, (FORTRAN symbol P4) is carried as a dependent variable through the parameter π (FORTRAN symbol P) = p_s - p_T, where p_T = 200 mb is the assumed tropopause pressure. The sea-level pressure (illustrated in Fig. 4.1, Chapter IV) is computed on the basis of an assumed lapse rate of 0.6 deg C/100 m between the surface and sea level. Other pressure parameters used are an average surface pressure (PSF = 984 mb), and a reference pressure (PSL = 1000 mb). The surface pressure tendency (FORTRAN symbol PT) is computed each time step in subroutine COMP 1 (instructions 4130 to 4540) as a result of the solution of the mass-continuity equation.

Pressure-Gradient Force

The pressure force terms in the equations of horizontal motion are calculated in subroutine COMP 2 (instructions 5210 to 6050) as a combination of the gradients of the geopotential, φ, and the surface-pressure parameter, π. These computations use finite differences centered at the velocity points and are performed each time step. See Chapter III, Subsection C.6, for further details.

Radiation

The net radiative flux of both long- and short-wave radiation is computed for the levels 0, 2, and 4 bounding the upper and lower layers of the model, as well as at the ground. These fluxes depend upon atmospheric moisture (in the lower layer), cloudiness, scattering, reflection (from both the earth's surface and from clouds), the solar zenith angle, and absorption, and are computed every 5 time steps in subroutine COMP 3 (instructions 9750 to 11000). The radiation contributes to the temperature change at levels 1 and 3, as well as to the change of surface temperature. See Chapter II, Section G, for further details.
Sea-Surface Temperature

The temperature at the sea surface is prescribed in the present version of the model. The data shown in Fig. 3.14, Chapter III, approximate the annual mean sea-surface temperature, and have been used in most applications of the model. Any net energy from the radiation exchange and the fluxes of latent and sensible heat at the ocean surface is absorbed by the sea without changing the surface temperature. The sea-surface temperature is read by subprogram INIT 2 (instructions 16020 to 16530) as part of the topography data (FORTRAN symbol TG00), and may be in either deg C or deg F (but not both).

Sensible Heat Flux

The (turbulent) flux of sensible heat at the earth's surface (FORTRAN symbol F4) is computed every 5 time steps in subroutine COMP 3 (instruction 11250) as a function of the surface wind speed and the low-level vertical temperature gradient (as measured by the difference between the ground, ocean, or ice temperature and the surface air temperature). This flux is illustrated in Fig. 4.18, Chapter IV, and is seen to be frequently negative, representing a sensible heat flux from the air to the ground. See Chapter II, Subsection G.3, for further details.

Short-Wave Radiation

The incoming short-wave or solar radiation is partitioned into a portion subject to scattering $S^S_o$ and a portion subject to absorption $S^A_o$. The latter component may be absorbed in each of the two model layers, depending upon the moisture and cloudiness, and the net absorbed short-wave radiation (FORTRAN symbols AS1 and AS3) is determined every fifth time step in subroutine COMP 3 (instructions 10430 to 11000); this is part of the diabatic temperature change at levels 1 and 3, as illustrated in Map 20, Chapter IV. The short-wave radiation reaching the surface is partly reflected (depending upon the albedo), and partly absorbed. The net surface insolation absorbed (FORTRAN symbol S4) is illustrated in Fig. 4.23, Chapter IV, and
contributes to the surface heat balance. See Chapter II, Subsection G.1, for further details.

**Smoothing**

There is relatively little explicit smoothing in the present version of the model, although there is considerable averaging in the finite-difference formulations. The subroutine AVRX is used to perform an effective zonal averaging of certain quantities at higher latitudes in subroutines COMP 1 and COMP 2. There is also a 9-point spatial smoothing of the diabatic heating at levels 1 and 3 which is performed in subroutine COMP 3 (instructions 11850 to 12020), and a similar smoothing of the temperature lapse rate in subroutine COMP 4 (instructions 12700 to 12860). See Chapter III, Section D, for further smoothing details, and Subsection C.1 for a discussion of the subroutine AVRX.

**Snow Cover**

In the present version of the model the snow cover on the earth's surface is prescribed. In the northern hemisphere, all land surfaces (except ice-covered land) north of the latitude defined by the parameter SN0WN (see instruction 7460 in subroutine COMP 3) are assumed to be covered by snow. The southern boundary of this snow line averages at 60 deg N but varies in time with a period of one year and with an amplitude of 15 deg latitude, with maximum extent on January 25. In the southern hemisphere, a constant snowline SN0WS (see instruction 7470 in subroutine COMP 3) prescribes snow-covered land south of 60 deg S, but this is overridden in the model's present version, because all points south of 60 deg S are either ocean, sea ice, or land ice.

**Solar Constant**

The value of the solar constant is taken to be $2 \text{ ly min}^{-1} = 2880 \text{ ly day}^{-1}$. This value is modified in subroutine COMP 3 (instruction 7610) to take account of the seasonal variation of the earth/sun
distance in the calculation of the FORTRAN variable SO (see instruction 15520 in subroutine SDET).

Temperature

The air temperature \( T \) is computed each time step in the model for levels 1 and 3 at the points of the \( \pi \) grid, and is widely used in the numerical integration (see instructions 8180 to 8310, subroutine COMP 3). A number of interpolations and extrapolations are made in \( p^x \) space for the temperatures and potential temperatures for use in the radiation and convection calculations. The surface air temperature \( T_4 \) is computed as a result of the surface heat and moisture balance (instructions 8960 to 9120, 9340, subroutine COMP 3), while the ground temperature itself \( T_G \) is separately computed. The temperature at levels 1 and 3 is illustrated in Figs. 4.6 and 4.7, Chapter IV, and the surface air temperature is illustrated in Fig. 4.24, Chapter IV.

Time

Time is measured with respect to hour 0 for midnight at the Greenwich meridian (0 deg longitude), with day 400 corresponding to the 28 January declination of the sun.

Time Step

In the main integration of the model, the time step \( \Delta t \) is 6 minutes. The friction, heating, evaporation, and condensation source terms, however, are computed only every fifth time step (every 30 minutes) in the subroutine COMP 3. In each step of the 5-step sequence, a preliminary estimate of the new values of the dependent variables is first obtained, then followed by a final estimate in a modified backward-difference scheme. See Chapter III, Section A, for further details, and subroutine STEP (instructions 1850 to 2280). Once each day the total global mass is adjusted in subroutine GMP, and the solar declination and earth/sun distance are recalculated. In the present
version of the model, the output or history tape of the primary dependent variables is written every 6 hours.

Topography

The topography (TGOO) of the earth's surface is prescribed as either water (with a fixed surface temperature), ice (with a maximum temperature of 0 deg C), or land (which may be snow-covered, depending upon the latitude and time of year). The elevation of all land points is prescribed (whether ice-covered, snow-covered, or bare), and is shown in Fig. 3.13, Chapter III; the assigned sea-surface and lake temperatures and ice locations are shown in Fig. 3.14, Chapter III. The topography is read into the program by the subroutine INIT 2, and the land elevation data is decoded in subroutine VPHI4.

Transmission Function

The transmission function for short-wave radiation (FORTRAN symbol TRSW; see subroutine COMP 3, instructions 10460 to 11000) is given by the empirical expression $1 - 0.271(x)^{0.303}$, where $(x)$ is the effective water vapor concentration in a vertical atmospheric column (see subroutine COMP 3, instructions 9750 to 10230). The transmission function for long-wave radiation (FORTRAN symbol TRANS; see subroutine COMP 3, instructions 9910 to 10220) is given by the expression $[1 + 1.75(x)^{0.416}]^{-1}$. See Chapter II, Section G, for further details.

Tropopause

The tropopause in the model is assumed to be always at the pressure $p_T = 200$ mb (FORTRAN symbol PTRØP), and is used in the definition of the tropospheric $\sigma$-coordinate system. At this level the boundary condition $\delta = 0$ is applied.

Vertical Velocity

The $\sigma$-vertical velocity $\tilde{\sigma}_v = \frac{\hat{z}}{2mn}$ (FORTRAN symbol SD = $\hat{z}$) is computed in the model for the middle level 2 from the equation of
continuity as a result of the net horizontal mass convergence (see subroutine COMP 1, instructions 4320 to 4540). The vertical velocity is used to effect the vertical advection of momentum and temperature, and to determine the large-scale precipitation rate; it is illustrated in Fig. 4.13, Chapter IV. See Chapter III, Subsections C.1, C.2, and C.8, for further details.

Wind Velocity

The horizontal zonal and meridional wind speeds (FORTRAN symbols U and V) are computed each time step in the model at the points of the u,v grid, and are widely used in the program. These fields are illustrated in Figs. 4.2 to 4.5 in Chapter IV. In the subroutine COMP 1 a number of spatially averaged speeds and fluxes are defined for use in the horizontal advections of momentum, mass, heat, and moisture. The wind velocity at the earth's surface (US, VS) is found by linear extrapolation in p from levels 1 and 3 (see subroutine COMP 3, instructions 7490 to 7570), and is used in the determination of the surface friction, evaporation, and sensible heat flux. See Chapter III, Section C, for further details.
VI. LIST OF SYMBOLS

PURPOSE

In order to provide a complement to the physics dictionary presented in Chapter V, a comprehensive alphabetical listing and identification of all the symbols used in the discussion of the model's physics and numerics is given here. For each symbol a brief identification, typical value, units, and FORTRAN symbol (if any) is given. Those symbols which occur at more than one level in the model (as designated by the subscripts 1, 2, 3, or 4) are listed following the primary variable. Not separately listed are those symbols which occur with the superscripts τ or n (denoting evaluation at time steps), those symbols which occur with the subscripts i and/or j, those symbols with various combinations of numerical subscripts (denoting grid-point locations), or those symbols representing a local specialization of a previously defined symbol. In general, symbols which occur only in FORTRAN notation are also not listed here (see Chapter VIII).
<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>MEANING</th>
<th>UNITS (and value for constants)</th>
<th>FORTRAN SYMBOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>specific volume</td>
<td>(\text{cm}^3 \text{g}^{-1})</td>
<td>--</td>
</tr>
<tr>
<td>(a_1)</td>
<td>albedo of cloudy atmosphere</td>
<td>--</td>
<td>ALAC</td>
</tr>
<tr>
<td>(a_3)</td>
<td>cloud albedo (subscripted by cloud type)</td>
<td>--</td>
<td>(ALC1, ALC2, ALC3)</td>
</tr>
<tr>
<td>(a_g)</td>
<td>albedo of earth's surface</td>
<td>--</td>
<td>ALS</td>
</tr>
<tr>
<td>(a_o)</td>
<td>albedo of clear atmosphere</td>
<td>--</td>
<td>ALAO</td>
</tr>
<tr>
<td>(\beta)</td>
<td>vertical shear stress parameter</td>
<td>(0.13 \text{mb sec}^{-1} \text{m}^{-1})</td>
<td>--</td>
</tr>
<tr>
<td>(\Gamma)</td>
<td>surface sensible heat flux</td>
<td>(1 \text{ly day}^{-1})</td>
<td>F4</td>
</tr>
<tr>
<td>(\Gamma_h)</td>
<td>surface flux of static energy</td>
<td>(1 \text{ly sec}^{-1})</td>
<td>--</td>
</tr>
<tr>
<td>(\gamma)</td>
<td>temperature lapse rate near surface</td>
<td>(0.6 \text{deg/100 m})</td>
<td>--</td>
</tr>
<tr>
<td>(\gamma_1)</td>
<td>latent heating parameter</td>
<td>--</td>
<td>GAM</td>
</tr>
<tr>
<td>(\gamma_3)</td>
<td>(= LQ_s (c_p T^2)^{-1} \times 5418 \text{deg})</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>(\zeta)</td>
<td>sun's zenith angle</td>
<td>radians</td>
<td>ØSZ ((= \cos \zeta))</td>
</tr>
<tr>
<td>(\eta)</td>
<td>entrainment factor</td>
<td>--</td>
<td>ETA</td>
</tr>
<tr>
<td>(\theta)</td>
<td>potential temperature</td>
<td>(\text{deg K})</td>
<td>TETA</td>
</tr>
</tbody>
</table>

\(^1\) The multiple listing is for symbols occurring with the subscripts 1, 2, 3, or 4; these denote evaluation at the respective model levels \(\sigma = 1/4, 1/2, 3/4, \text{or } 1 \text{(surface)}\). The subscripts \(g\) and \(o\) also sometimes denote the ground or surface level.
<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>MEANING</th>
<th>UNITS (and value for constants)</th>
<th>FORTRAN SYMBOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{\theta}$</td>
<td>an average potential temperature</td>
<td>deg K</td>
<td>--</td>
</tr>
<tr>
<td>$\theta_d$</td>
<td>partial potential temperature</td>
<td>deg K</td>
<td>--</td>
</tr>
<tr>
<td>$\theta_E$</td>
<td>equivalent potential temperature</td>
<td>deg K</td>
<td>--</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>thermodynamic ratio $R/c_p$</td>
<td>0.286</td>
<td>KAPA</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>longitude, positive eastward from Greenwich</td>
<td>radians</td>
<td>--</td>
</tr>
<tr>
<td>$\Delta \lambda$</td>
<td>longitudinal spacing between grid points</td>
<td>$\pi/36$ radians ($= 5$ deg)</td>
<td>DLGN</td>
</tr>
<tr>
<td>$\mu$</td>
<td>vertical shear stress parameter</td>
<td>0.44 mb sec</td>
<td>--</td>
</tr>
<tr>
<td>$\Pi$</td>
<td>pressure area weighting = $\Pi m$</td>
<td>$m^2$ mb</td>
<td>FD(J,I)</td>
</tr>
<tr>
<td>$\Pi_u$</td>
<td>local four-point average of $\Pi$ centered on u,v grid points</td>
<td>$m^2$ mb</td>
<td>FDU(J,I)</td>
</tr>
<tr>
<td>$\pi$</td>
<td>(1) surface pressure parameter $= p_s - p_T$ (2) constant</td>
<td>mb</td>
<td>SP,P(J,I)</td>
</tr>
<tr>
<td>$\dot{\pi}$</td>
<td>surface pressure change $= \frac{dp_s}{dt}$</td>
<td>mb sec$^{-1}$</td>
<td>PI</td>
</tr>
<tr>
<td>$\pi_s$</td>
<td>standard value of $\pi$</td>
<td>800 mb</td>
<td>PT</td>
</tr>
<tr>
<td>$\pi_u$</td>
<td>local four-point average of $\pi$ centered on u,v grid points</td>
<td>mb</td>
<td>PM</td>
</tr>
<tr>
<td>$\rho$</td>
<td>air density</td>
<td>g cm$^{-3}$</td>
<td>RH\emptyset, R\emptyset4</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>MEANING</td>
<td>UNITS (and value for constants)</td>
<td>FORTRAN SYMBOL</td>
</tr>
<tr>
<td>--------</td>
<td>---------</td>
<td>--------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>( \rho_w )</td>
<td>water density</td>
<td>( 1 \text{ g cm}^{-3} )</td>
<td>--</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>Stefan-Boltzman constant</td>
<td>( 1.171 \times 10^{-7} ) ( \text{ly day}^{-1} \text{deg}^{-4} )</td>
<td>STBØ</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>vertical coordinate</td>
<td>--</td>
<td>SIG</td>
</tr>
<tr>
<td>( \sigma_1 ) ( \sigma_3 )</td>
<td>( = \frac{(p - p_T)}{(p_s - p_T)} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \phi ) ( \phi_2 )</td>
<td>sigma vertical velocity = ( \frac{d\sigma}{dt} )</td>
<td>( \text{sec}^{-1} )</td>
<td>SD</td>
</tr>
<tr>
<td>( \tau )</td>
<td>time-step index</td>
<td>--</td>
<td>TAU</td>
</tr>
<tr>
<td>( \tau_1 ) ( \tau_2 )</td>
<td>intermediate variables in penetrating convection</td>
<td>( \text{deg K} )</td>
<td>TEMP</td>
</tr>
<tr>
<td>( \tau_r )</td>
<td>relaxation time for cumulus convection</td>
<td>( 3600 \text{ sec} )</td>
<td>TCVN</td>
</tr>
<tr>
<td>( \tau(u^*) )</td>
<td>long-wave transmission function</td>
<td>--</td>
<td>TRANS(X)</td>
</tr>
<tr>
<td>( \tau_A ) ( \tau_B )</td>
<td>long-wave transmission above and below a given level</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>( \phi ) ( \phi_1 ) ( \phi_3 )</td>
<td>geopotential of sigma surface</td>
<td>( \text{m}^2\text{sec}^{-2} )</td>
<td>PHI</td>
</tr>
<tr>
<td>( \phi_4 )</td>
<td>geopotential of ( \sigma = 4 ) surface</td>
<td>( \text{m}^2\text{sec}^{-2} )</td>
<td>( \text{VPHI4} )</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>MEANING</td>
<td>UNITS (and value for constants)</td>
<td>FORTRAN SYMBOL</td>
</tr>
<tr>
<td>--------</td>
<td>---------</td>
<td>--------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Φ</td>
<td>latitude, positive northward from equator</td>
<td>radians</td>
<td>LAT(J)</td>
</tr>
<tr>
<td>ΔΦ</td>
<td>latitudinal spacing between grid points</td>
<td>π/45 radians (= 4 deg)</td>
<td>DLAT</td>
</tr>
<tr>
<td>ψ</td>
<td>arbitrary variable</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Ω</td>
<td>earth's rotation rate</td>
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<td>A₁, A₃</td>
<td>absorbed short-wave radiation in upper and lower layers</td>
<td>1y day⁻¹</td>
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<td>Aᵥ</td>
<td>eddy diffusion coefficient</td>
<td>m² sec⁻¹</td>
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<td>Λ</td>
<td>arbitrary vector, whose latitudinal and longitudinal components are AΦ and A₉</td>
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<td>Ae</td>
<td>saturation vapor pressure constant</td>
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<td>A(u*,z)</td>
<td>short-wave absorption function</td>
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<td>Aₚ</td>
<td>general representation for advection terms</td>
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<td>$C_i$</td>
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<td>CLAT</td>
<td>degrees poleward of snowline</td>
<td>deg latitude</td>
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<td>$E$</td>
<td>surface evaporation rate</td>
<td>g cm$^{-2}$sec$^{-1}$</td>
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<td>$e_s$</td>
<td>saturation vapor pressure</td>
<td>cb</td>
<td>ES, EG</td>
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</table>
| $F$    | modified Coriolis parameter  
\[ = mnf - udm/dy \]  | $m^2$sec$^{-1}$ | FD(J,I) |
<p>| $\bar{F}$ | horizontal vector frictional force (per unit mass) | -- | -- |
| $F_x'$ | eastward component of frictional force | -- | -- |
| $F_y'$ | northward component of frictional force | -- | -- |</p>
<table>
<thead>
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<td>( F_4 )</td>
<td>upward sensible heat flux from surface</td>
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<td>( F_H )</td>
<td>vertical heat flux at surface</td>
<td>1 ly day(^{-1} )</td>
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<td>Coriolis parameter = 2( \Omega ) ( \sin \varphi )</td>
<td>( \text{sec}^{-1} )</td>
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<td>( G )</td>
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<td>2 m sec(^{-1} )</td>
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<td>30 g cm(^{-2} )</td>
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<td>gravity</td>
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<td>( h/c_p )</td>
<td>static energy</td>
<td>deg K</td>
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<tr>
<td>( h_3/c_p )</td>
<td>static energy at level 3</td>
<td>deg K</td>
<td>HH3</td>
</tr>
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<td>( h_4/c_p )</td>
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<td>HH4 HH4P</td>
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<td>( \tilde{h}_4/c_p )</td>
<td>intermediate stability parameter</td>
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<td>diabatic heating rate (per unit mass)</td>
<td>cal g(^{-1} ) sec(^{-1} )</td>
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<td>( H_1 )</td>
<td>diabatic temperature change (over 5( \Delta t )) in layer</td>
<td>deg</td>
<td>H1</td>
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<tr>
<td>( H_3 )</td>
<td>diabatic temperature change (over 5( \Delta t )) in layer</td>
<td>deg</td>
<td>H3</td>
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<td>( \bar{H} )</td>
<td>average of ( H_1 ), ( H_3 )</td>
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<td>( H_E )</td>
<td>surface latent heat flux</td>
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<td>$h_1^*/c_p$</td>
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<td>deg K</td>
<td>HH1S</td>
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<td>$K$</td>
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<td>$\hat{k}$</td>
<td>vertical unit vector</td>
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<td>580 cal g$^{-1}$</td>
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<td>$\ell$</td>
<td>level index = 1 at $\sigma_1$, = 3 at $\sigma_3$</td>
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<td>L</td>
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<td>$LR$</td>
<td>nominal lapse rate</td>
<td>deg K</td>
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<tr>
<td></td>
<td>$= (\theta_1 - \theta_3)(p_2/p_0)^{\ell}$</td>
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<tr>
<td>$M$</td>
<td>vertical mass flux in cloud</td>
<td>g cm$^{-2}$ sec$^{-1}$</td>
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<td>$M_b$</td>
<td>ratio of the molecular weight of water vapor to dry air</td>
<td>0.622</td>
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<td>$m$</td>
<td>map metric or zonal distance between grid points $= a\Delta \lambda \cos \varphi$</td>
<td>m</td>
<td>DXU</td>
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<td>$n$</td>
<td>(1) map metric or meridional distance between grid points $= a\Delta \varphi$</td>
<td>m</td>
<td>DYU</td>
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<td>(2) arbitrary time step</td>
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<tr>
<td>( p )</td>
<td>(1) pressure</td>
<td>mb</td>
<td>PL</td>
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<td>( p_1 )</td>
<td>(2) polar grid-point index</td>
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<td>( p_3 )</td>
<td>reference pressure</td>
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<td>PSL</td>
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<td>( P_{CM} )</td>
<td>precipitation rate from middle-level convection</td>
<td>mm day(^{-1})</td>
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<tr>
<td>( P_{CP} )</td>
<td>precipitation rate from penetrating convection</td>
<td>mm day(^{-1})</td>
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<td>( P_{LS} )</td>
<td>large-scale precipitation rate</td>
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<td>( p_s )</td>
<td>surface pressure</td>
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<td>( p_T )</td>
<td>tropopause pressure</td>
<td>200 mb</td>
<td>PTR Hàng P</td>
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<td>( Q )</td>
<td>rate of moisture addition (per unit mass)</td>
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<td>( q_g )</td>
<td>mixing ratio at ground</td>
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<td>QG</td>
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<td>( \Delta q_3 )</td>
<td>mixing ratio change (at level 3)</td>
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<td>$q_s$</td>
<td>saturated mixing ratio</td>
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<td>$q_{se}$</td>
<td>effective ground saturation mixing ratio</td>
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<td>$R$</td>
<td>dry air specific gas constant</td>
<td>$287 \text{ m}^2 \text{ deg}^{-1} \text{ sec}^{-2}$</td>
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<td>$R_\psi$</td>
<td>general representation for non-advective, non-source terms = $D_\psi - A_\psi$</td>
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<td>$R'_n$</td>
<td>clear sky long-wave radiation at level $n$</td>
<td>$1 \text{ y day}^{-1}$</td>
<td>$\text{ R00}$</td>
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<td>$R''_n$</td>
<td>overcast sky long-wave radiation at level $n$</td>
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<td>$\tilde{R}_n$</td>
<td>weighted sum of $R'_n$, $R''_n$</td>
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<td>$R_0$</td>
<td>upward long-wave radiation flux at level $0 (\sigma = 0)$</td>
<td>$1 \text{ y day}^{-1}$</td>
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<td>$R_2$</td>
<td>upward long-wave radiation flux at level 2</td>
<td>$1 \text{ y day}^{-1}$</td>
<td>$\text{ R2C}$</td>
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<td>$R_4$</td>
<td>upward long-wave radiation flux at level 4 (surface)</td>
<td>$1 \text{ y day}^{-1}$</td>
<td>$\text{ R4C}$</td>
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<td>$\text{RH}_3$</td>
<td>relative humidity (scaled 0 to 1)</td>
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<td>$\dot{S}$</td>
<td>vertical velocity measure = $2 \text{ mm mb sec}^{-1}$</td>
<td>$\text{ m mb sec}^{-1}$</td>
<td>$\text{ SD(J,I)}$</td>
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<tr>
<td>( (S_A^i) )</td>
<td>flux of ( S_A ) at level ( i ) in clear sky</td>
<td>( 1 \text{ y day}^{-1} )</td>
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<td>( (S_A^i)'' )</td>
<td>flux of ( S_A ) at level ( i ) in overcast sky</td>
<td>( 1 \text{ y day}^{-1} )</td>
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<tr>
<td>( (S_A^{CT_i})'' )</td>
<td>flux of ( S_A ) reflected from top of cloud type ( i )</td>
<td>( 1 \text{ y day}^{-1} )</td>
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<td>( S_u^L )</td>
<td>local four-point average of ( S ) centered on ( u,v ) grid points</td>
<td>( 2 \text{ m mb sec}^{-1} )</td>
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<td>( S_o )</td>
<td>solar constant (after modification for earth-sun distance)</td>
<td>( \sim 2880 \text{ y day}^{-1} )</td>
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<tr>
<td>( S_o^g )</td>
<td>solar radiation subject to scattering</td>
<td>( 1 \text{ y day}^{-1} )</td>
<td>SS</td>
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<td>( S_o^A )</td>
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<td>( S_g )</td>
<td>total solar radiation absorbed at ground</td>
<td>( 1 \text{ y day}^{-1} )</td>
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<td>( S_g^A )</td>
<td>flux of ( S_o^A ) absorbed by ground</td>
<td>( 1 \text{ y day}^{-1} )</td>
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<tr>
<td>( S_g^A )</td>
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<td>( T_3 )</td>
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<td>$T_0$</td>
<td>tropopause temperature</td>
<td>deg K</td>
<td>TTRP</td>
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<td>$T_4$</td>
<td>air temperature at level 4 (surface)</td>
<td>deg K</td>
<td>T4</td>
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<td>$T_{c1}$</td>
<td>air temperature in cloud</td>
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<td>--</td>
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<td>$T_{c3}$</td>
<td>temperature change (of layer)</td>
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<td>$\Delta T_1$</td>
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<td>GT(J,I)</td>
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<td>GT(J,I)</td>
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<td>an average temperature</td>
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<td>deg mb⁻¹</td>
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<tr>
<td>t</td>
<td>time</td>
<td>sec, min, hr, or days</td>
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<tr>
<td>Δt</td>
<td>time step</td>
<td>6 min</td>
<td>DTM</td>
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<tr>
<td>U</td>
<td>west/east advective flux</td>
<td>m² mb sec⁻¹</td>
<td></td>
</tr>
<tr>
<td>Ũ</td>
<td>southwest/northeast advective flux</td>
<td>m² mb sec⁻¹</td>
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</tr>
<tr>
<td>u</td>
<td>zonal (eastward) wind speed</td>
<td>m sec⁻¹</td>
<td>U</td>
</tr>
<tr>
<td>u₁</td>
<td>** effective water vapor content in column (to level n) **</td>
<td>g cm⁻²</td>
<td>EFV</td>
</tr>
<tr>
<td>u₄</td>
<td>** effective water vapor content in column (entire atmosphere) **</td>
<td>g cm⁻²</td>
<td>EFVO</td>
</tr>
<tr>
<td>u</td>
<td>zonal mass flux = nπu</td>
<td>m² mb sec⁻¹</td>
<td>PU(J, I)</td>
</tr>
<tr>
<td>u₁</td>
<td>** cloud water vapor equivalent **</td>
<td>65.3 g cm⁻²</td>
<td>EFVC1</td>
</tr>
<tr>
<td>u₄</td>
<td></td>
<td></td>
<td>EFVC2</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>MEANING</td>
<td>UNITS (and value for constants)</td>
<td>FORTRAN SYMBOL</td>
</tr>
<tr>
<td>----------</td>
<td>----------------------------------------------</td>
<td>---------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>$u_{c_3}$</td>
<td>cloud water vapor equivalent</td>
<td>7.6 g cm$^{-2}$</td>
<td>EFVC3</td>
</tr>
<tr>
<td>$v$</td>
<td>south/north advective flux</td>
<td>m$^{-2}$ mb sec$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>$\tilde{v}$</td>
<td>southeast/northwest advective flux</td>
<td>m$^{-2}$ mb sec$^{-1}$</td>
<td>--</td>
</tr>
<tr>
<td>$\hat{v}$</td>
<td>horizontal velocity vector</td>
<td>m sec$^{-1}$</td>
<td>--</td>
</tr>
<tr>
<td>$\hat{v}_1$</td>
<td></td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>$\hat{v}_2$</td>
<td></td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>$\hat{v}_3$</td>
<td></td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>$\hat{v}_4$</td>
<td></td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>$\hat{v}_s$</td>
<td>surface wind vector, $= 0.7\hat{v}_4$</td>
<td>m sec$^{-1}$</td>
<td>US, VS</td>
</tr>
<tr>
<td>$\sqrt{\hat{v}_s}$</td>
<td>local four-point root-mean-square surface wind speed centered at $\pi$ points</td>
<td>m sec$^{-1}$</td>
<td>WMAG</td>
</tr>
<tr>
<td>$v$</td>
<td>meridional (northward) wind speed</td>
<td>m sec$^{-1}$</td>
<td>V</td>
</tr>
<tr>
<td>$v_1$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$v_3$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$v_{1*}$</td>
<td>meridional mass flux $= \text{mmbv}$</td>
<td>m$^{-2}$ mb sec$^{-1}$</td>
<td>PV(J, I)</td>
</tr>
<tr>
<td>$v_{3*}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$v_{4*}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$w$</td>
<td>surface wind speed with gustiness correction</td>
<td>m sec$^{-1}$</td>
<td>WINDF</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>MEANING</td>
<td>UNITS (and value for constants)</td>
<td>FORTRAN SYMBOL</td>
</tr>
<tr>
<td>--------</td>
<td>---------</td>
<td>--------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>x</td>
<td>eastward coordinate (on rectangular projection)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>y</td>
<td>northward coordinate (on rectangular projection)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>z</td>
<td>height of sigma surface</td>
<td>m</td>
<td>ZZZ</td>
</tr>
<tr>
<td>z&lt;sub&gt;1&lt;/sub&gt;</td>
<td>standard value of z&lt;sub&gt;1&lt;/sub&gt; - z&lt;sub&gt;3&lt;/sub&gt;</td>
<td>5400 m</td>
<td>--</td>
</tr>
<tr>
<td>z&lt;sub&gt;3&lt;/sub&gt;</td>
<td>designation for preliminary estimate in time integration</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>z&lt;sub&gt;4&lt;/sub&gt;</td>
<td>designation for provisional value prior to incorporation of source terms in time integration</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Δz</td>
<td>a smoothing operator denoting a horizontally averaged value</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>(\h)</td>
<td>an operator denoting the three-point longitudinal smoothing routine in AVRX(K), which is automatically applied N&lt;sub&gt;o&lt;/sub&gt; times</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
VII. THE FORTRAN PROGRAM

A listing of the computer program actually used in the numerical simulations is perhaps the most important part of the documentation. In the FORTRAN program listing given in Section A below the sequential numbering of all cards in the program deck is reproduced on the right-hand side of the listing to permit easy identification of specific instructions. Following the listing of the integration program and the common block, the program listing for the map routines is presented in Section B with a separate instruction card numbering.

A. INTEGRATION PROGRAM LISTING

1. Subprograms

The integration program itself is divided into a main or control routine and a number of subroutines. In the order of their appearance in the program, these subroutines (and an indication of their functions and initial program instruction numbers) follow:

- COMMON -- lists variables' common and equivalence assignments
- CONTROL -- controls program execution (0120)
- OUTAPE -- reads and writes history tape (0800)
- GMP -- calculates global average surface pressure, and adjusts pressure for mass conservation (1250)
- VPHI4 -- decodes land elevation (1510)
- IPK -- packs data for output (1610)
- KEY -- logical key control (1770)
- STEP -- controls sequence of time steps, and readies data for execution of subroutines COMP 1, COMP 2, COMP 3, and COMP 4 (1850)
- COMP 1 -- calculates mass flux and convergence; horizontal advection of momentum, heat, and moisture; vertical advection of momentum and heat (2290)
- COMP 2 -- calculates Coriolis and pressure-gradient forces (4880)
- AVRX -- performs zonal smoothing (6780)
- COMP 3 -- calculates radiative heating, convection, precipitation, surface and ground temperature, surface evaporation and sensible heat flux, surface friction; calculates selected data for output (7070)
COMP 4 -- calculates diffusion of momentum (suppressed in the present version); performs areal smoothing of the temperature lapse rate (12040)

INPUT -- reads input data and controls generation of selected constants (12880)

MAGFAC -- calculates map scale factors and Coriolis parameter (14350)

INSDET -- adjusts day, month, and seasonal sun position

SDET -- calculates solar zenith angle and related parameters (15190)

INIT 1 -- prepares for cold-start initial conditions (inoperative in the present version) (15620)

INIT 2 -- reads and encodes surface topography data (sea-surface temperature and land elevation) (15770)

2. Guide to the Main Computational Subroutines

The bulk of the computations involved in the solution of the main dynamical equations of the model, Eqs. (2.27) to (2.35), are performed in the subroutines COMP 1, COMP 2, COMP 3, and COMP 4. An outline of these calculations is given below in the sequence performed each time step in the program by the subroutines COMP 1 and COMP 2, followed by an outline for subroutines COMP 3 and COMP 4 which are performed every five time steps. The initial instruction location is cited for each major program subdivision.

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Initial Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMP 1</td>
<td></td>
</tr>
<tr>
<td>Formation of area-pressure-weighted variables</td>
<td>2540</td>
</tr>
<tr>
<td>Horizontal mass flux</td>
<td>2710</td>
</tr>
<tr>
<td>Zonal smoothing (AVRX)</td>
<td>2830</td>
</tr>
<tr>
<td>Horizontal polar mass flux</td>
<td>2970</td>
</tr>
<tr>
<td>Horizontal temperature advection</td>
<td>3260</td>
</tr>
<tr>
<td>Horizontal moisture advection</td>
<td>3390</td>
</tr>
<tr>
<td>Horizontal momentum advection</td>
<td>3770</td>
</tr>
<tr>
<td>Continuity equation (vertical velocity and surface pressure tendency)</td>
<td>4130</td>
</tr>
<tr>
<td>Calculation</td>
<td>Initial Instruction</td>
</tr>
<tr>
<td>-------------------------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td><strong>COMP 1</strong></td>
<td></td>
</tr>
<tr>
<td>Vertical temperature advection</td>
<td>4560</td>
</tr>
<tr>
<td>Vertical momentum advection</td>
<td>4690</td>
</tr>
<tr>
<td><strong>COMP 2</strong></td>
<td></td>
</tr>
<tr>
<td>Coriolis force</td>
<td>5010</td>
</tr>
<tr>
<td>Pressure-gradient force</td>
<td>5220</td>
</tr>
<tr>
<td>Zonal smoothing (AVRX)</td>
<td>5970</td>
</tr>
<tr>
<td>Thermodynamic energy conversion</td>
<td>6070</td>
</tr>
<tr>
<td>Zonal smoothing (AVRX)</td>
<td>6210</td>
</tr>
<tr>
<td>Polar adjustment</td>
<td>6410</td>
</tr>
<tr>
<td>Return to unweighted variables</td>
<td>6580</td>
</tr>
<tr>
<td><strong>COMP 3</strong></td>
<td></td>
</tr>
<tr>
<td>Radiation and heating functions</td>
<td>7150</td>
</tr>
<tr>
<td>Surface wind magnitude</td>
<td>7490</td>
</tr>
<tr>
<td>Radiation constants</td>
<td>7590</td>
</tr>
<tr>
<td>Solar declination</td>
<td>7740</td>
</tr>
<tr>
<td>Surface topography (ocean, ice, bare land, snow-covered land)</td>
<td>7820</td>
</tr>
<tr>
<td>Pressure variables</td>
<td>8030</td>
</tr>
<tr>
<td>Temperature and moisture variables, and test for dry-adiabatic instability</td>
<td>8180</td>
</tr>
<tr>
<td>Ground temperature and wetness</td>
<td>8540</td>
</tr>
<tr>
<td>Large-scale precipitation</td>
<td>8610</td>
</tr>
<tr>
<td>Middle-level convection</td>
<td>8700</td>
</tr>
<tr>
<td>Preparation for air/earth interaction</td>
<td>8900</td>
</tr>
<tr>
<td>Surface temperature</td>
<td>8970</td>
</tr>
<tr>
<td>Penetrating and low-level convection</td>
<td>9140</td>
</tr>
<tr>
<td>Cloudiness</td>
<td>9400</td>
</tr>
<tr>
<td>Long-wave radiation</td>
<td>9750</td>
</tr>
<tr>
<td>Surface albedo</td>
<td>10240</td>
</tr>
</tbody>
</table>
3. Common and Equivalence Statements

Most of the variables and constants of the program are communicated between the subprograms via a common block, stored in the single array BC0MN. The following equivalents should be noted:

BC0MN(1)--BC0MN(800) equivalent to C(1)--C(800)

where C(K) is defined to be equivalent to all the constants and one-dimensional arrays [and MAPLST(3, 40)],

BC0MN(801)--BC0MN(67040) equivalent to QT0T(1,1,1)--QT0T(46,72,20)

where QT0T is equivalent to all the two- and three-dimensional arrays,

QT0T(1,1,1)--QT0T(46,72,9) equivalent to Q(1,1,1)--Q(46,72,9)

QT0T(1,1,10)--QT0T(46,72,20) equivalent to QT(1,1,1)--QT(46,72,11)
and

\begin{align*}
Q(J, I, 1) & \text{ equivalent to } P(J, I) & \text{ surface pressure (π)} \\
Q(J, I, 2) & \text{ equivalent to } U(J, I, 1) & \text{ level 1 zonal wind (u₁)} \\
Q(J, I, 3) & \text{ equivalent to } U(J, I, 2) & \text{ level 3 zonal wind (u₃)} \\
Q(J, I, 4) & \text{ equivalent to } V(J, I, 1) & \text{ level 1 meridional wind (v₁)} \\
Q(J, I, 5) & \text{ equivalent to } V(J, I, 2) & \text{ level 3 meridional wind (v₃)} \\
Q(J, I, 6) & \text{ equivalent to } T(J, I, 1) & \text{ level 1 temperature (T₁)} \\
Q(J, I, 7) & \text{ equivalent to } T(J, I, 2) & \text{ level 3 temperature (T₃)} \\
Q(J, I, 8) & \text{ equivalent to } Q₃(J, I) & \text{ moisture (q₃)} \\
Q(J, I, 9) & \text{ equivalent to } TΩPΩG(J, I) & \text{ surface elevation and ocean temperature}
\end{align*}

The array QT(J, I, K) for K = 1 to 8 is similarly equivalent to all the temporary and intermediate values of the above quantities, i.e., PT(J, I), UT(J, I, K), etc. Occasionally Q and QT are used in the program rather than the original variables, especially in the time steps where all Q quantities are treated at once (see, for example, instructions 1960 to 220). The array QT is also equivalent to all other two- and three-dimensional arrays in the program not requiring permanent storage. The common, dimension, and equivalence statements are given on the immediately following pages.
COMMON BLOCK FOR MINTZ-ARAKAWA TWO-LEVEL GENERAL CIRCULATION MODEL

COMMON GW,GT

* COMMON BLOCK

* DIMENSION

* BCDMN

* BCDMN(67040), C(800), QTOT(46,72,20), Q(46,72,9), QT(46,72,11) 00000140

* P(46,72), U(46,72,2), V(46,72,2), T(46,72,2), Q3(46,72) 00000150

* PT(46,72), UT(46,72,2), VT(46,72,2), T3T(46,72,2), Q3T(46,72) 00000160

* FD(46,72), H(46,72,2), PIH(46,72), TD(46,72) 00000170

* PH(46,72), W(46,72), TOPDG(46,72) 00000180

* CONV(46,72), PV(46,72), SD(46,72) 00000190

* GW(46,72), GT(46,72), QD(46,72,9) 00000200

* WORK1(46,72), WORK2(46,72) 00000210

* TS(46,72), SN(46,72) 00000220

* D11 and D1V ARE INTERM VARIABLES ONLY

* LAT(46), DXU(46), DXP(46), DUY(46), DYP(46) 00000240

* S1N(46), COSL(46), AXU(46), AXV(46), AYU(46), AYV(46) 00000250

* DXP(46), F(46), SIG(2), AMONTH(3), XLABL(9), MAPLIST(3,40) 00000260

* DXV(46), DYV(46) 00000270

* EQUIVALENCE

* (QTOT(1),Q(1)), (QTOT(29809),QT(1)), (BCDMN1,C(1)) 00000290

* (BCDMN(801),QTOT(1)), (Q11.P(1)), (Q1112,U(1)) 00000300

* (Q1114,V(1)), (Q1116,T(1)), (Q1118,T3(1)) 00000310

* (Q1119,TOPDG(1)), (QT(1),QD(1),PT(1)) 00000320

* (QT112,UT11,WORK11) 00000330

* (QT113,TS11) 00000340

* (QT114,VT11,WORK211) 00000350

* (QT115,SN11) 00000360

* (QT116,TT11), (Q1118,QT3(1)) 00000370

* (QT119,CONV11,SD(1)) 00000380

* (QT1110,H11,PV11,PHI11,W11) 00000390

* (QT1111,PU11,FD11,TD11) 00000400

* EQUIVALENCE

* (C11,JM), (C21,IM), (C31,JTP), (C41,KTP), (C51,LTP) 00000410

* (C61,MTP), (C71,NDOUT), (C81,RESTRT), (C91,TAU) 00000420

* (C101,TAU1), (C111,TAUD), (C121,TAUD), (C131,TACE) 00000430

* (C141,TAUH), (C151,TAUC), (C161,ID), (C171,DT) 00000440

* (C181,DLAT), (C191,DLON), (C201,RAI), (C211,RSOST) 00000450

* (C221,DCLK), (C231,SOI), (C241,COSD), (C251,TODAY) 00000460

* (C261,MNTHDY), (C271,NAPYR), (C281,ROPER), (C291,SOEDY) 00000470

* (C301,SKYR), (C311,ENCY), (C321,APHEL), (C331,DECMAX) 00000480

* (C341,ECNN), (C351,DAY), (C361,GRAV), (C371,RAGAS) 00000490

* (C381,KAPA), (C391,SF), (C401,PTRDP), (C411,PSL) 00000500

* (C421,TENV), (C441,A), (C451,NCLG) 00000510

* (C461,NC3), (C471,FM), (C481,ED) 00000520

* (C571,PL1), (C581,ZM) 00000530

* (C591,SPOL), (C601,STG), (C611,MRCH), (C621,STAGJ) 00000540

* (C631,NE1), (C641,SPD), (C651,SL), (C661,MTCH), (C671,STAGJ) 00000550

* (C681,NC2), (C691,SM), (C701,STG), (C711,MRCH), (C721,STAGJ) 00000560
* (C(63),STAG), (C(64),SIG(1)), (C(66),AMONTH(1))
* (C(69),XLABL(1)), (C(78),LAT(1)), (C(124),OXU(1))
* (C(170),OXP(1)), (C(216),OYU(1)), (C(262),OYP(1))
* (C(304),OXYP(1)), (C(354),F(1)), (C(400),SINL(1))
* (C(446),COSL(1)), (C(492),AXU(1)), (C(538),AXV(1))
* (C(584),AYU(1)), (C(630),AYV(1)), (C(676),MAPLST(1))
* (C(797),NSTEP), (C(798),DLC)
* (C(799),TREADY), (SINT,ISINT)
* (DXV(1),DXP(1)), (DYV(1),OYP(1))

REAL LAT, KAPA, NPOL
LOGICAL KEYS(1),BIT,MAPGEN,RESTR,KEY,TREADY
COMMON /VKEYV/ KEYS(32)
INTEGER SOEDY,SDEYR
MINTZ-ARAKAWA TWO-LEVEL ATMOSPHERIC GENERAL CIRCULATION MODEL

**CONTROL**

// DD DISP=OLD, DSN=MES727.ABN.COMMON
// DD *  
LOGICAL EVENT, CHECK, PASS2, EVNTH, NOOUT, VIVA
DIMENSION CXXX(800)
EVENT(XTAU)=MOD(NSTEP, IFIX(XTAU*3600./DT+0.1)) .EQ. 0
PASS2=.FALSE.,
DO 100 J=1,32
100 KEYS(J)=.FALSE.,
200 KNT=.FALSE.,
RESTR=.TRUE.,
VIVA=.TRUE.,
CALL INPUT

NSTEP=TAU*3600./DT+0.1
RESTR=.FALSE.,

MAIN COMPUTATIONAL CONTROL

310 NSTEP=NSTEP+1
TAU=FLOAT(NSTEP)*ABS(DT)/3600.*1.E-3
IF (TAU.GT.TAUE) GO TO 1200
TOFDAY=MOD(TAU, ROTPER)
NOOUT=.NOT.(EVENT(TAU) .OR. KEYS(8))
IF (NOOUT .OR. MOD(NSTEP, NC3) .EQ. 0) GO TO 320
NOOUT=.TRUE.
KEYS(8)=.TRUE.,
320 CONTINUE

CALL STEP
IF (EVENT(24.)) CALL GMP
VARIOUS CHECKING AND HISTORY OPTIONS

630 IF (EVENT(TAUD)) CALL SOFT
   IDAY=TAU/ROTHER
   IF (EVENT(TAUD)) GO TO 1000
   GO TO 310
1000 CONTINUE
   READ (KTP) TAU
   IF (TAUX.GT.0.0) GO TO 1100
   IF (ABS(TAUH+TAUX).GT.0.01) GO TO 1100
1001 CONTINUE
   BACKSPACE KTP
   WRITE (KTP) TAU, C
   CALL OUTAPE(KTP,?)
   PRINT 1005,TAU
1005 FORMAT (1X,'WRITE TAPE ',F8.2)
   GO TO 310
1100 WRITE (MTP,1110) TAU,TAUX
1110 FORMAT (1X, 'SOME MESS ON TAPE',1X,E12.5,1X,I8)
   CALL EXIT
1200 WRITE (MTP,1210) TAU
1210 FORMAT (1X,'TERMINATING AS REQUIRED AT TAU= ',F8.2)
   STOP

C
9200 FORMAT (1 WMSG020, MINTZ-ARAKAWA GLOBAL WEATHER MODEL NOW RUNNING)
9670 FORMAT (1 WMSG040, 'A4', 'SWITCHING FROM TAPE ', I2, ' TO TAPE ', I2)
   2 ON DAY ',F7.3)
9690 FORMAT (1 WMSG035, 'SIM TIME IS DAY ',I4,' HOUR ',F7.3)
9715 FORMAT (1 WMSG036, 'A4', 'HAS STOPPED AT DAY ',I4,' / HOUR ',
   2 F7.3)

C
END

C
SUBROUTINE OUTAPE(K, I)

// DD DISP=OLD, DSN=MESS727.ANH.COMMON

IF (I.EQ.2) GO TO 20
READ (K) P
READ (K) U
READ (K) V
READ (K) T
READ (K) Q3
READ (K) TDPOG
READ (K) PT
READ (K) GW
READ (K) TS
READ (K) GT
READ (K) SN
READ (K) TT
READ (K) Q3T
READ (K) SD
READ (K) H
READ (K) TD
RETURN

CONTINUE
WRITE (K) P
WRITE (K) U
WRITE (K) V
WRITE (K) T
WRITE (K) Q3
WRITE (K) TDPOG
WRITE (K) PT
WRITE (K) GW
WRITE (K) TS
WRITE (K) GT
WRITE (K) SN
WRITE (K) TT
WRITE (K) Q3T
WRITE (K) SD
WRITE (K) H
WRITE (K) TD
RETURN

TAUX = ABS(TAU)
WRITE (K) TAUX, C
BACKSPACE K
C THE NEGATIVE RECORD PREVENTS NOISE, MISSING RECORDS,
C AND MISSING TRAILER LABELS.
RETURN
END
SUBROUTINE

GM

// DD DISP=OLD,DSN=MFS727,ABN,COMMON
//
DIMENSION ZM(46)
FIM=IM
DO 135 J=1,JM
ZM(J)=0.0
DO 136 I=1,IM
135 ZM(J)=ZM(J)+P(J,I)
136 ZM(J)=ZM(J)/FIM
WTH=0.0
ZMM=0.0
DO 137 J=1,JM
WTH=WTH+ARS(DXYP(J))
137 ZMM=ZMM+ZM(J)*ARS(DXYP(J))
ZMM=ZMM/WTH+PTRNP
DELTAP=PSF-ZMM
DO 301 J=1,IM
DO 301 J=1,IM
301 P(J,I)=P(J,I)+DELTAP
WRITE(6,138) DELTAP
138 FORMAT(* PRESSURE ADDED = F8.15,F6.0)
RETURN
END
FUNCTION VPH14 (J, I)
C
" */
// DD DISP=OLD, DSN=MES727.ARN.COMMIN
// DD
// VPH14=0.
// IF (TOP1G(J, I).LT. 1.0) VPH14=AMOD(-TOP1G(J, I), 10.E5)
C
RETURN
END

FUNCTION IPK(IL, IR)
INTEGER IHALF=2(2)
EQUIVALENCE (IHALF(1), IWD)
IHALF(1)=IL
IHALF(2)=IR
IPK=IWD
RETURN
ENTRY IRHM(IPKWD)
IWD=IPKWD
IRH=IHALF(2)
RETURN
ENTRY ILHM(IPKWD)
IWD=IPKWD
ILH=IHALF(1)
RETURN
END

LOGICAL FUNCTION KEY(M)
LOGICAL KEYS(32)
COMMON /KEYV/ KEYS
N=ABS(M)
KEY=KEYS(N)
IF (M .LT. 0) KEYS(N)=FALSE.
RETURN
END
SUBROUTINE STEP

// DD DISP=OLD, DSN=MES727.ABN, COMM
// DD *
C
C MAIN LOOP OF INTEGRATION
C FORWARD STEP (CENTERED IN SPACE)
C
MRCH=1
DO 310 K=1,R
DO 310 I=1,IM
DO 310 J=1,JM
310 QT(J,I,K)=Q(J,I,K)
THRP=TAH/24*
PRINT 9999,TAH,THRP
9999 FORMAT (1X,TIMEs1,2X,FR.2,2X,F9.4)
CALL COMPl
CALL COMPl
DO 360 K=1,R
DO 360 I=1,IM
DO 360 J=1,JM
TEMP=Q(J,I,K)
Q(J,I,K)=QT(J,I,K)
360 QT(J,I,K)=TEMP
C
C BACKWARD STEP
C
NS=MOD(NSTFP,NCYLFL)
MRCH=2
IF(NS.EQ.1) MRCH=3
IF(NS.EQ.2) MRCH=4
CALL COMPl
CALL COMPl
DO 380 K=1,R
DO 380 I=1,IM
DO 380 J=1,JM
TFMP=Q(J,I,K)
Q(J,I,K)=QT(J,I,K)
380 QT(J,I,K)=TEMP
C
IF(MOD(NSTFP,NC3).NE.0) GO TO 400
CALL COMPl4
CALL COMPl3
400 RETURN
END
SUBROUTINE COMPL

/*
// DD DISP=MES727.AHN.COMMON
// DD =
// JMM1=JM-1
// IMM2=IM-2
// FIM=IM
// SIG1=SIG(1)
// SIG3=SIG(2)
C C
C MRCH=1 CENTERED IN SPACE AND FORWARD IN TIME
C MRCH=2 CENTERED IN SPACE AND BACKWARD IN TIME
C MRCH=3 UP-RIGHT UNCENTERED IN SPACE AND BACKWARD IN TIME
C MRCH=4 DOWN-LEFT UNCENTERED IN SPACE AND BACKWARD IN TIME
C
C TIME EXTRAPOLATION INTERVAL FOR ADVECTION TERMS
C
TEXCO=DT
IF(MRCH.EQ.1) TEXCO=0.5*DT
C
C PREPARATION FOR TIME EXTRAPOLATION
C
TRANSFORMATION TO AREA-PRESSURE WEIGHTED VARIABLES
C
QT CONTAINS VARIABLES TO WHICH TENDENCIES ARE TO BE ADDED
C
DO 2100 I=1,IM
DO 2100 J=1,JM
FD(J,1)=PT(J,1)*DXYP(J)
2100 Q3T(J,1)=Q3T(J,1)+FD(J,1)
DO 2120 L=1,2
DO 2120 I=1,IM
IP1=MOD(I,IM)+1
DO 2110 J=1,JM
2110 TT(J,I,L)=TT(J,I,L)+FD(J,1)
DO 2120 J=2,JM
FDU=0.25*(FD(J,1)+FD(J,IP1)+FD(J-1,1)+FD(J-1,IP1))
IF (J .EQ. 2) FDU=0.25*(FD(2,1)+FD(2,IP1)+FD(1,1))
IF (J .EQ. JM) FDU=0.25*(FD(JM-1,1)+FD(JM-1,IP1)+FD(JM,1))
UT(J,I,L)=UT(J,I,L)+FDU
2120 VT(J,I,L)=VT(J,I,L)+FDU
C
COMPUTING MASS FLUX P PU *
P * PV UV *

L=1

DO 2160 I=1,IM

IPI=MOD(I,1,IM)+1

DO 2160 J=2,JMM1

IF(MRCH .LE. 2) PU(J,1) = 0.25*(DYU(J)*U(J,1,L)+DYU(J+1)*U(J+1,1,L))

IF(MRCH .EQ. 3) PU(J,1) = 0.5*DYY(J)*U(J,1,L)

IF(MRCH .EQ. 4) PU(J,1) = 0.5*DYY(J)*U(J,1,L)

2160 CONTINUE

CALL AVRXX(11)

DO 2180 I=1,IM

IP1=MOD(I,1,IM)+1

IM1=MOD(I+1,MM2)+1

DO 2170 J=2,JMM1

PU(J,1) = PU(J,1)*(P(J,1)+P(J,1))

DO 2180 J=2,JM

IF(MRCH .LE. 2) PV(J,1) = 0.25*DUXU(J)*(V(J,1,L)+V(J,1,M1,L))

IF(MRCH .EQ. 3) PV(J,1) = 0.5*DUXU(J)*(V(J,1,L)*P(J,1)+P(J,1))

IF(MRCH .EQ. 4) PV(J,1) = 0.5*DUXU(J)*(V(J,1,L)*P(J,1)+P(J,1))

2180 CONTINUE

VM1=0.0

VM2=0.0

DO 2185 I=1,IM

VM1=VM1+PV(2,1)

VM2=VM2+PV(2,1)

2185 VM2=VM2+PV(JM+1)

VM1=VM1/FIM

VM2=VM2/FIM

PV(1,1)=0.0

DO 2190 I=2,IM

2190 PV(1,1)=PV(1,1-1)+(PV(2,1)-VM1)

VM1=0.0

DO 2192 I=2,IM

VM1=VM1+PV(1,1)

VM1=VM1/FIM

2192 VM1=VM1+PV(1,1)

DO 2195 I=1,IM

2195 PU(1,1)=-(PV(1,1)-VM1)*3.0

PV(1,1)=0.0

DO 2200 I=2,IM

2200 PV(1,1)=PV(1,1-1)+(PV(JM+1)-VM2)

VM2=0.0

DO 2202 I=1,IM

2202 VM2=VM2+PV(1,1)

VM2=VM2/FIM

2205 PU(JM+1)=(PV(1,1-VM2)*3.0

C
C HORIZONTAL ADVECTION OF THERMODYNAMIC ENERGY AND MOISTURE EQUATIONS

FXCO=0.5*TEXCO
DO 2220 I=1,IM
IP1=MOD(I,IM)+1
DO 2210 J=2,JM1
FLUX=FXCO*P(JJ(I))
FLUX=FLUX*(T(J,J1,L)+T(J,J1,L))
IF (J.EQ.2.OR.J.EQ.JM1) AND. FLUX.LT.0.)
* FLUX=FLUX2.*T(J,J1,L)
IF (J.EQ.2.OR.J.EQ.JM1) AND. FLUX.GT.0.)
* FLUX=FLUX2.*T(J,J1,L)
TT(J,J1,L)=TT(J,J1,L)+FLUX
TT(J,J1,L)=TT(J,J1,L)+FLUX
IF (L.EQ.1) FLUX=-0.25*FLUX
IF (L.EQ.2) FLUX=1.25*FLUX
Q3M=Q3(J,J1)+Q3(J,J1)
IF (Q3M.LT.0.1) GO TO 2210
2210 CONTINUE
DO 2220 J=2,JM
FLUX=FXCO*P(JJ(I))
FLUX=FLUX*(T(J,J1,L)+T(J,J1,L))
IF (J.EQ.2) AND. FLUX.LT.0.) FLUX=FLUX2.*T(J,J1,L)
IF (J.EQ.2) AND. FLUX.GT.0.) FLUX=FLUX2.*T(J,J1,L)
IF (J.EQ.JM) AND. FLUX.LT.0.) FLUX=FLUX2.*T(J,J1,L)
IF (J.EQ.JM) AND. FLUX.GT.0.) FLUX=FLUX2.*T(J,J1,L)
TT(J,J1,L)=TT(J,J1,L)+FLUX
TT(J,J1,L)=TT(J,J1,L)+FLUX
IF (L.EQ.1) FLUX=-0.25*FLUX
IF (L.EQ.2) FLUX=1.25*FLUX
Q3M=Q3(J,J1)+Q3(J,J1)
IF (Q3M.LT.0.1) GO TO 2220
2220 CONTINUE
10, E-10 IS A RELATIVELY SMALL NUMBER
FLUXO=FLUX*Q3M
IF (Q3J,J1).LT.Q3(J,J1) AND. FLUXG.T.O.)
* FLUXO=FLUX*Q3(J,J1)/Q3M
IF (Q3J,J1).LT.Q3(J,J1) AND. FLUX.LT.0.)
* FLUXO=FLUX*Q3(J,J1)/Q3M
Q3T(J,J1)=Q3T(J,J1)-FLUXO
Q3T(J,J1)=Q3T(J,J1)+FLUXO
2210 CONTINUE
DO 2220 J=2,JM
FLUX=FXCO*P(JJ(I))
FLUX=FLUX*(T(J,J1,L)+T(J,J1,L))
IF (J.EQ.2) AND. FLUX.LT.0.) FLUX=FLUX2.*T(J,J1,L)
IF (J.EQ.2) AND. FLUX.GT.0.) FLUX=FLUX2.*T(J,J1,L)
IF (J.EQ.JM) AND. FLUX.LT.0.) FLUX=FLUX2.*T(J,J1,L)
IF (J.EQ.JM) AND. FLUX.GT.0.) FLUX=FLUX2.*T(J,J1,L)
TT(J,J1,L)=TT(J,J1,L)+FLUX
TT(J,J1,L)=TT(J,J1,L)+FLUX
IF (L.EQ.1) FLUX=-0.25*FLUX
IF (L.EQ.2) FLUX=1.25*FLUX
Q3M=Q3(J,J1)+Q3(J,J1)
IF (Q3M.LT.0.1) GO TO 2220
2220 CONTINUE
11, E-10 IS AN ARBITRARY LOWER LIMIT
FLUXO=FLUX*Q3M
IF (Q3J,J1).LT.Q3(J,J1) AND. FLUXG.T.O.)
* FLUXO=FLUX*Q3(J,J1)/Q3M
IF (Q3J,J1).LT.Q3(J,J1) AND. FLUX.LT.0.)
* FLUXO=FLUX*Q3(J,J1)/Q3M
Q3T(J,J1)=Q3T(J,J1)+FLUXO
Q3T(J,J1)=Q3T(J,J1)+FLUXO
2220 CONTINUE
HORIZONTAL ADVECTION OF EQUATION OF MOTION

FXCO=TEXCO/12.
FXCO1=TEXCO/24.
DO 2320 I=1,IM
   IP1=MOD(I,IM)+1
   IMI=MOD(I+1,IM)+1
DO 2310 J=2,JM
   FLUX=FXCO*(PU(J,1)+PU(J-1,1)+PU(J,IM1)+PU(J-1,IM1))
   FLUXU=FLUX*(U(J,1)+U(J,IM1))
   UT(J,1,1)=UT(J+1,1,1)+FLUXU
   UT(J,IM1,1)=UT(J+1,IM1,1)-FLUXU
   FLUXV=FLUX*(-V(J,1)+V(J,IM1))
   UT(J,1,1)=UT(J,1,1)+FLUXV
   2310 VT(J,IM1,1)=VT(J,1,1)-FLUXV
   DO 2320 J=2,JM1
   FLUX=FXCO*(PV(J,1)+PV(J,IP1)+PV(J+1,1)+PV(J+1,IP1))
   FLUXU=FLUX*(U(J,1)+U(J+1,1))
   UT(J,1,1)=UT(J,1,1)+FLUXU
   UT(J,IP1,1)=UT(J+1,IP1,1)-FLUXU
   FLUXV=FLUX*(-V(J,1)+V(J,IP1))
   VT(J,1,1)=VT(J,1,1)+FLUXV
   2320 VT(J,1,1)=VT(J+1,1,1)-FLUXV
CONTINUITY EQUATION

DO 2400 I=1,IM
  IM1=MOD(I+1,IM)+1
DO 2400 J=1,JM
  IF (J.EQ.1) CONVM=-PV(J,1)+PV(J,2)*0.5
  IF (J.EQ.JM) CONVM=PV(J,JM)+PV(J,JM+1)*0.5
  IF (J.LT.JM) CONVM=-CONVM-
    +PV(J,JM+1)-PV(J,1)*0.5
  IF (L.EQ.1) CONV(J,1)=CONVM
  IF (L.EQ.2) PV(J,1)=CONVM
  IF (L.EQ.2) GO TO 2410
  L=2
  GO TO 2150
2400 CONTINUE
  IF (L.EQ.2) GO TO 2410
  L=2
2410 CONTINUE

CONV IS MASS CONVERGENCE AT L=1 AND PV IS THAT AT L=2.

2411 PB1=0.0
  PB2=0.0
  PB3=0.0
  PB4=0.0
  DO 2402 I=1,IM
    PR1=PB1+CONV(I,1)
    PB2=PB2+CONV(JM,1)
    PB3=PB3+PV(1,1)
2402 PB4=PB4+PV(JM,1)
    PR1=PR1/FIM
    PR2=PR2/FIM
    PR3=PR3/FIM
    PR4=PR4/FIM
    DO 2405 I=1,IM
      CONV(JM,1)=PH1
      CONV(JM,1)=PH2
      PV(JM,1)=PB3
2405 PV(JM,1)=PB4
  DO 2420 I=1,IM
  DO 2420 J=1,JM
    PT=CONV(J,1)+PV(J,1)
    SD(J,1)=CONV(J,1)-PV(J,1)
    PT(J,1)=PT(J,1)+DV*PT/DXY(J)
ENERGY CONVERSION TERM IN THERMODYNAMIC ENERGY EQUATION

PL1 = PTROP + SIG1 * P(J,1)
PL3 = PTROP + SIG3 * P(J,1)
PK1 = PL1 * KAPA
PK3 = PL3 * KAPA
TETAM = 0.5 * (T(J,1,1) / PK1 + T(J,1,1) / PK3)

TT(J,1,1) = T(J,1,1) + DT * (SIG1 * KAPA * P(J,1) * T(J,1,1) * PIT / PL1
* - SD(J,1) * TETAM * PK1)
TT(J,1,2) = T(J,1,2) + DT * (SIG3 * KAPA * P(J,1) * T(J,1,2) * PIT / PL3
* + SD(J,1) * TETAM * PK3)
2420 CONTINUE

VERTICAL ADEPTION OF MOMENTUM

FXCO = 0.5 * TEXCO
DO 2510 I = 1, IM
IP1 = MOD(I, IM) + 1
DO 2510 J = 2, JM
SDU = 0.25 * (SD(J,1) + SD(J,IP1) + SD(J-1,1) + SD(J-1,IP1))
IF (J .LT. JM) SDU = 0.25 * (SD(JM,1) + SD(J-1,1) + SD(JM-1,IP1) + SD(JM,IP1))
VAD = FXCO * SDU * U(J,1,1) + U(J,1,2)
UT(J,1,2) = UT(J,1,2) + VAD
UT(J,1,1) = UT(J,1,1) - VAD
VAD = FXCO * SDU * V(J,1,1) + V(J,1,2)
VT(J,1,2) = VT(J,1,2) + VAD
VT(J,1,1) = VT(J,1,1) - VAD
2510 CONTINUE
RETURN
END
SUBROUTINE COMP2

DO 3140 J=1,IMM1
    DO 3140 I=1,IM
        FD(J,I)=FXCO*(J+0.125)*TEXCO
        DO 3110 J=1,IM
            DO 3110 I=1,IM
                FD(J,I)=FD(J,I)+0.0
            ENDDO
        ENDDO
    ENDDO
    DO 3110 J=2,JMM1
        FD(J,I)=FD(J,I)+0.0
    ENDDO
    IF(MRCH.EQ.1) FD(J,I)=FD(J,I)*TEXCO*0.5**DT
    IF (KEY(31)) FD(J,I)=FD(J,I)*TEXCO*DT
    HRGAS=RGAS/2.
C      CIRCULUS FORCE
C
    FXCO=0.125*TEXCO
    DO 3140 L=1,2
        DO 3110 I=1,IM
            IM1=MOD(I+1,IM)+1
            FD(1,1)=0.0
            FD(JM,1)=0.0
        ENDDO
    ENDDO
    DO 3140 J=2,JMM1
        DO 3140 I=1,IM
            IM1=MOD(I+1,IM)+1
        ENDDO
    ENDDO
    ALPHA=FXCO*(P(J,1)+P(J-1,1))*FD(J,1)*FD(J-1,1)
    UT(J,1,L)=UT(J,1,L)+ALPHA*V(J,1,L)
    UT(J,IM1,L)=UT(J,IM1,L)+ALPHA*V(J,IM1,L)
    VT(J,1,L)=VT(J,1,L)-ALPHA*U(J,1,L)
    VT(J,IM1,L)=VT(J,IM1,L)-ALPHA*U(J,IM1,L)
PRESSURE GRADIENT

DO 3340 L=1,2

COMPUTATION OF PHI

DO 3210 I=1,IM
DO 3210 J=1,JM
PHI4=VPHI4(J,I)
VPS1= P(J,I)*0.25/(P(J,I)*0.25 + PTROP)
VPS2= P(J,I)*0.75/(P(J,I)*0.75 + PTROP)
VPS3=-(P(J,I)*0.25+PTROP)/(P(J,I)*0.75+PTROP))**KAPA
VPS4=VP3/VPK1
IF(L,F0.2) GO TO 3205
COE1=(VPS1+0.5*(VPS3-1.)/KAPA)*HRGAS
COE2=(VPS3+0.5*(1.-VPK1)/KAPA)*HRGAS
PHI(J,I)=COE1*T(J,J,1)+COE2*T(J,J,2)+PHI4
GO TO 3210

3205 COE3=(VPS1-0.5*(VPS3-1.)/KAPA)*HRGAS
COE4=(VPS3-0.5*(1.-VPK1)/KAPA)*HRGAS
PHI(J,I)=COE3*T(J,J,1)+COE4*T(J,J,2)+PHI4

CONTINUE

GRADIENT OF PHI

FXC(I)=0.25*DI
FXC(I)=0.5*DI
DO 3220 J=1,IM
PU(I,J)=0.
DO 3250 J=1,IM
IF(J-I)=MOD(J,I)+1
IM1=MOD(I+IMM2,1)+1
DO 3250 J=2,IM
TEMP1=P(J,I)+P(J,I)*PHIJ(J,1) - PHIJ(J,1))/2
PHIJ(J,1)=TEMP1
TEMP2=P(J,I)+P(J-1,1) - PHIJ(J,1) + PHIJ(J-1,1))/2
IF(MACH=EQ.1) GO TO 3250
IF(MACH=EQ.4) GO TO 3250

3230 IF(MACH=1 OR 2, CENTERFII IN SPACE)
VT(J,J,I,L)=VT(J,J,I,L)-FXC(I)*TEMP2
VT(J,J,I,M,L)=VT(J,J,I,M,L)-FXC(I)*TEMP2
GO TO 3250

3240 IF(MACH=3, UP-RIGHT UNCENTERED)
VT(J,J,I,M,L)=VT(J,J,I,M,L)-FXC(I)*TEMP2
GO TO 3250

3250 CONTINUE

3250 CONTINUE
GRADIENT OF P
SIGMA*P*ALPHA IS STORED AT PHI

DO 3260 I=1,IM
DO 3280 J=1,JM
3260 PHI(J,I)=SIG(L)*P(J,I)*R*G*S*T(J,I)*L/(PTROP*S*IG(L)*P(J,I))
DO 3290 I=1,IM
IP1=MOD(I-IM)+1
IM1=MOD(I+IM2+IM)+1
DO 3290 J=2,JM
TEMPI=(PHI(J,IP1)+PHI(J,IM1))*P(J,IP1)-P(J,IM1)
PU(J,IP1)=TEMPI+PU(J,IP1)
TEMP2=(PHI(J,IP1)+PHI(J-1,IM1))*P(J,IP1)-P(J-1,IM1)
PU(J,IM1)=TEMP2+PU(J,IM1)
IF(MRCH.EQ.3) GO TO 3270
IF(MRCH.EQ.4) GO TO 3290
3260 CONTINUE
MRCH=1 OR 2.

VT(J,I,L)=VT(J,I,L)-FXCO*TEMP
VT(J,IM1,L)=VT(J,IM1,L)-FXCO*TEMP
GO TO 3290

MRCH=3, UP-RIGHT UNCENTERED
3270 VT(J,I,L)=VT(J,I,L)-FXCO*TEMP
GO TO 3290

MRCH=4, DOWN-LEFT UNCENTERED
3290 CONTINUE

CALL AVRX(11)

DO 3300 I=1,IM
DO 3300 J=2,JM
3300 CONTINUE
C ENERGY CONVERSION TERM IN THERMODYNAMIC EQUATION.
C SIGMA*P*ALPHA IS NOW STORED AT PHI.
C
3310 FXCO=0.125*DT*KAPA/RGAS
FXCO1=0.25*DT*KAPA/RGAS
C
3320 DO 3320 J=1,IM
[1]=MOD([1],IM)+1
DO 3320 J=2,JMM1
IF(MRCH.LT.2) TEMP=FXCO*(U(J*I+1,L)+DYU(J+1)*U(J*I+1,L)+DYU(J+1))
IF(MRCH.EQ.3) TEMP=FXCO*U(J*I+1,L)+DYU(J+1)
IF(MRCH.EQ.4) TEMP=FXCO1*U(J*I+1,L)+DYU(J+1)
3320 P(J,J)=TEMP
C
3330 DO 3330 J=1,IM
[1]=MOD([1],IM)+1
IM1=MOD([1]+IM2,IM)+1
DO 3330 J=2,JMM1
PU(J+1)=PU(J+1)*(PHI(J+1)+PHI(J+1))*(P(J+1)=P(J+1))
TT(J+1)=TT(J+1)+PU(J+1)
3330 TT(J+1)=TT(J+1)+PHI(J+1)
C
3340 CONTINUE
C
THIS IS THE END OF FORWARD OR CENTRED TYPE OF TIME EXTRAPOLATION.
ADJUSTMENT AT THE POLES

DO 3415 L=1,8
IF(L.GT.1.AND.L.LT.A) GO TO 3415
PB1=0,
PB2=0.
DO 3405 I=1,IM
PH1=PB1+QT(I,L,L)
PH2=PB2+QT(JM,I,L)
PBC=PB1/FIM
PH2=PB2/FIM
DO 3410 I=1,IM
QT(I,L,L)=PB1
3410 CONTINUE
3430 Q3T(JM,L)=PB2
C
RETURN TO UNWEIGHTED VARIABLES
C
DO 3460 I=1,IM
DO 3460 J=1,JM
FD(J,I)=PT(I,J)*DFI(J,I)
3460 Q3T(J,I)=Q3T(J,I)/FD(J,I)
DO 3470 L=1,2
DO 3470 I=1,IM
IPI=MCI(I,IM)+1
DO 3465 J=1,JM
3465 TT(J,I,L)=TT(J,I,L)/FD(J,I)
DO 3470 J=2,JM
FDU=0.25*(FD(J,I)+FD(J,P1)+FD(J-1,I)+FD(J-1,P1))
IF (J .EQ. 2) FDU=0.25*(FD(2,I)+FD(2,P1)+FD(1,I))
IF (J .EQ. JM) FDU=0.25*(FD(JM-1,I)+FD(JM-1,P1)+FD(JM,I))
UT(J,I,L)=UT(J,I,L)/FDU
3470 VT(J,I,L)=VT(J,I,L)/FDU
RETURN
C
END
SUBROUTINE

*AVRX(IN)

/*
// DD DISPR=ILD, DSN=MFS727, ARN, COMM
// DD =
C THIS SUBROUTINE USES UT(I,J,1) AS A WORKING SPACE
C
JMM1=JM-1
JMM2=JM-2
JF=JM/2+1
OFF=DRP(JF)
DO 150 J=2,JMM1
DRAT=OFF/DRP(J)
IF (DRAT .LT. 1.) GO TO 150
ALP=0.,125*(DRAT-1.)
NM=DRAT
FNM=NM
ALPHA=ALP/FNM
DO 150 N=1,NM
DO 120 I=1,M1
[I]=MOD(I,IM)+1
[MM]=MOD(I,MM)+1
120 UT(I,J,1)=QT(J,I,K)*ALPHA*QT(J+1,I,K)+QT(J+1,I,K)*2.*QT(J+1,K)
DO 150 I=1,M1
130 QT(J+1,K)=UT(I,J,1)
150 CONTINUE
C
RETURN
END
SUBROUTINE COMP3

C

// DD DISP=OLD, DSN=MESS27, ABN, COMMON
// DD *


C EQUIVALENCE (KKK, XXX)
LOGICAL NOOUT, ICE, LAND, OCEAN, SNOW, KEY

C TRANS(X)=1.0/(1.+1.75*X**7.416)
TRSW(X)=1.0-271.X**1.303

C JMM1=JM-1
JMM2=JM-2
JMM3=JM+1
I=IM/2+1
FIM=IM
SIG1=SIG(1)
SIG2=SIG(2)
DSIG=SIG3-SIG1

C GWM=30.
DTC3=FLOAT(MC3)*DT
RCNV=DTC3/TCNV
CLH=580./P24
PIOK=1000.*KAPA
CTI=.005
CTID=8.664E4*CTI
MICE=300.
TICE=273.1

C PM=PSL-PTROP
COE=GRAV*100./(0.5*PM=1000.*0.24)
CDE1=COE*DTC3/(124.*3600.)
SCALEU=COE*100.
TSPD=DAY/DTC3
SCALEP=TSPD*.5*(10./GRAV)*100.
CONRAD=180./PI
CNRX=CONRAD*.01
FSDEDY=FSDE
SNOWN=(60.-15.*COS1.9863*(FSDEDY-24.66)/CONRAD)/CONRAD
SNOWS=-60./CONRAD

C SURFACE WIND MAGNITUDE

C DD 10 J=1, JM
DD 10 J=2, JM
US=2.*SIG3*U(J, 1, 2)-SIG1*U(J, 1, 1)*0.7
VS=2.*SIG3*V(J, 1, 2)-SIG1*V(J, 1, 1)*0.7
10 FD(J, 1)=US-US+VS*VS
WMAG1=SQR((FD(1, 1)+FD(1, 1)))
WMAGJM=SQR((FD(JM, 1)+FD(JM, 1)))
C RADIATION CONSTANTS
   SO=RSO2/RSO1ST
   ALC1=.7
   ALC2=.6
   ALC3=.6
   STR0=1.171E-7
   EFVC1=.65,.3
   EFVC2=.65,.3
   EFVC3=7.6
   CPART=5*1.3071E7
   ROT=TOF/OAY/ROTPER*2.0*PI
C HEATING LOOP
DO 370 I=1,IM
   IM1=MOD(I+IMM2,IM)+1
   IP1=MOD(I,IM)+1
   FIM1=I-1
   MACOS=CSOS*COS(ROT+FIM1*OLON)
   ON 360 J=1,JM
   CG1Z=SLN(J)*SINL(J)*COSL(J)*HACOS
C SURFACE CONDITION
TG00=TOPDG(J,1)
OCEAN=TG00.OST,1
ICE=TG00.0L.F=99.5
LAND=NOT.(ICE.OR.OCEAN)
SNOW=LAND.AND.(LAT(J).GE.SNOWN.OR.LAT(J).LE.SNOWS)
LAND=LAND.AND.NOT.SNOW
IF (.NOT.OCEAN) ZJZ=VPH+4(J,1)/GRAV
ORAG COEFFICIENT
IF (J.EQ.1) WMAG=WMAG1
IF (J.EQ.JM) WMAG=WMAGJM
IF (J.NE.1.AND.J.NE.JM) WMAG=SORT(.25*(FO(J,1)+FO(J+1,1))
   X +FD(J,1M1)+FO(J+1,IM1))
   CD = .002
   IF (.NOT.OCEAN) CD=CD+0.006*ZJZ/5000.
   IF (OCEAN) CD = AMIN1(1.0+.07*WMAG)*.001+.0025)
   CS = CD*100.
   CSa = .24*CS*24*.3600.
   FK1 = CD*(10.*GRAV)/(DSIG*PM)
PRESSURES
SP=P(J,I)
COLMR=PM/SP
P4=SP+PTR0P
P4*K=P*KAPA
PL1=SIG1*SP+PTR0P
PL2=.5*SP+PTR0P
PL3=SIG3*SP+PTR0P
PL1K=PL1**KAPA
PL3K=PL3**KAPA
PL2K=PL2**KAPA
PTRK=PTR0P**KAPA
DPLK=PL3K-PL1K

TEMPERATURES AND TEST FOR DRY-ADIABATIC INSTABILITY
T1=T(J,I,1)
T3=T(J,I,2)
THL1=T1/PL1K
THL3=T3/PL3K
IF (THL1 .GT. THL3) GO TO 310
XX1=(T1+T3)/(PL1K+PL3K)
T1=XX1*PL1K
T3=XX1*PL3K
T(J,I,1)=T1
T(J,I,2)=T3
THL1=T1/PL1K
THL3=T3/PL3K

MOISTURE VARIABLES
310 ES1=10.0**((8.4051-2353.0/T1)
ES3=10.0**((8.4051-2353.0/T3)
P1CB=.1*PL1
P3CB=.1*PL3
P4CB=.1*P4
Q51=.622*ES1/(P1CB-ES1)
Q53=.622*ES3/(P3CB-ES3)
GAM1=CLH*Q51+.5*Q51/T1**2
GAM3=CLH*Q53+.5*Q53/T3**2
Q3R=Q3(J,I)
RH3=Q3R/Q53

TEMPERATURE EXTRAPOLATION AND INTERPOLATION FOR RADIATION
ATEM=(THL3-THL1)/DPLK
ATEM=(THL1*PL3K-THL3*PL1K)/DPLK
T2=(ATEM+PTR0K+BTEM)*PTR0K
T2=(ATEM+PPL2K+BTEM)*PPL2K
GROUND TEMPERATURE AND WETNESS

TG=7600
WET=1.0
IF (NOT OCEAN) TG=GT(J,I)
IF (LAND) WET=GW(J,I)

LARGE SCALE PRECIPITATION

PREC=0.0
IF (Q3R .LE. 0.03) GO TO 1060
PREC=(Q3R-0.03)/(1.0+GAM3)
T3=T3+CLH*PREC
THL3=T3/PL3K
Q3R=Q3R-PREC

CONVECTION

1060 TETA1=THL1*P10K
TETA3=THL3*P10K
SS3 = TETA3*P4K/P10K
SS2 = SS3 + 0.5*(TETA1-TETA3)*PL2K/P10K
SS1 = SS2 + 0.5*(TETA1-TETA3)*PL2K/P10K
HH3 = SS3 + CLH*Q3R
HH3S = SS3 + CLH*QS3
HH1S = SS1 + CLH*QS1

MIDDLE LEVEL CONVECTION

C1 = 0.0
C3 = 0.0
EX = HH3 - HH1S
IF (EX .LE. 0.0) GO TO 1065
C1 = RCNV*EX/(2.0+GAM1)
C3 = C1*(1.0+GAM1)*(SS2-SS3)/(EX*(1.0+GAM1)*(SS1-SS2))

PREPARATION FOR AIR-EARTH INTERACTION

1065 ZL3 = 2000.0
WINDF=2.0+WMAG
DRAW=CD*WINDF
EDV=ED/ZL3*WMAG/10.0
DETERMINATION OF SURFACE TEMPERATURE

1070  RH4=Z*(WET*RH3/(WET*RH3))
      EG=10**((0.4051-2353.*/TG))
      EG= AMIN1(EG,P4CB/1.662)
      QG=622*EG/(P4CB-EG)
      DOG=5418.*OG/TG**2
      HMG=TG+CLH*OG*WET
      EDR=EDV/EDV+DRAW
      HM4=EDR*HM3+(1.0-EDR)*HMG
      GAGM=CLH*DOG
      T4=(HM4-RH4*CLH*OG-GAMG*TG)/(1.0+RH4*GAMG)
      IF (T4*PI0K/P4K*GT*TETA3) T4=TETA3*P4K/PI0K
      Q4=RH4*(OG+DOG*(T4-TG))
      HM4=T4+CLH*Q4

PENETRATING AND LOW-LEVEL CONVECTION

PC1=0.
PC3=0.
EX=0.
IF (HM4.LT.WH3S) GO TO 1077
IF (HM3.GT.HH1S) GO TO 1077
EX = HM4-HH3S
MH4 = HM4
MH4 = HM3S
IF (HM4P.LT.HH1S) GO TO 1076
ETA = 1.
TEMP1 = ETA*(HM3S-HH1S)/(1.0+GAM1)*SS1-SS2)
TEMP2 = ETA*(SS2-SS3) + (SS3-T4)
TEMP = EDR*TEMP1*(1.0+GAM3)*TEMP2
IF (TEMP.LT.001) TEMP=.001
CONVP = RCNV*EX/TEMP
PC1 = CONVP*TEMP1
PC3 = CONVP * TEMP2

1076  T4=T4-EX/(1.0+RH4*GAMG)
      Q4=(HM4-T4)/CLH

1077  R04=P4CB/(RGAS*T4)
      CSEN=CS4*R04*WINDF
      CEVA=CS5*R04*WINDF
C C CLOUDINESS

ICLOUD=1
CL=0.0
CL1=0.0
CL2=0.0
CL3=0.0
CLT=0.0
CL=AMAX1(-1.3+2.6*RH3,1.)
IF (CL1.GT.0.0) OR (PC1.GT.0.) CL1=CL
IF (PREC.GT.0.0) AND (CL1.EQ.0.) CL2=1.0
IF (EX.EQ.0.) AND (PC1.EQ.0.) CL3=CL

CL1

CL2

CL3

CL=AMAX1(CL1,CL2,CL3)
IF (CL .GE. 1.0) ICLoud=3
IF (CL .LT. 1.0) AND (CL1 .GT. 0.0) ICLoud=2

ICLOUD=1 CLEAR, ICLoud=2 PARTLY CLOUDY, ICLoud=3 OVERCAST
C LONG WAVE RADIATION

1080 Q3RB=AMAX1(Q>2*1.E-5)
VAK=2.*ALOG(1.71886-6/Q3RB)/ALOG(120./PL3)
TEM1=0.00102*PL3**2*Q3RB/VAK
TEM2=TEM1*(P4/PL3)**VAK
EFV3=TEM2-TEM1
EFV2=TEM2-TEM1*(PL2/PL3)**VAK
EFV1=TEM2-TEM1*(PL1/PL3)**VAK
EFVT=TEM2-TEM1*(PTROP/PL3)**VAK
EFV0=TEM2-TEM1*(120./PL3)**VAK+2.526E-5
BLT=STBO*TROP**4
BL1=STBO*T1**4
BL2=STBO*T2**4
BL3=STBO*T3**4
BL4=STBO*TG**4
C LONG WAVE RADIATION

1090 R00=0.82*(URT*(BL4-BLT)*(1.+TRANS(FFVT-EFVT)))/2.*
R20=0.736*(UR2*(R14-RL2)*(1.+TRANS(FFVT-EFVT)))/2.*
R40=BL4*(0.6+SORT(TRANS(FFV0)-0.1))
IF (ICLOUD .EQ. 1) GO TO 2015
2000 IF (CL2 .LE. 0.) GO TO 2004
CLT=CL2
ROC=0.82*(URT*(BL2-BLT)*(1.+TRANS(FFVT-EFVT)))/2.*CLT
R2C=0.736*UR2*CLT
R2C=0.5*R2C
GO TO 2006
2004 IF (CL3 .LE. 0.) GO TO 2006
CLT=CL3
ROC=0.82*(URT*(BL3-HLT)*(1.+TRANS(FFVT-EFVT)))/2.*CLT
R2C=0.736*UR2*(RBL3-RL2)*(1.+TRANS(FFVT-FFV3))/2.*CLT
2006 IF (CL1 .LE. 0.) GO TO 2010
CLM=AMAX1(CL2-CL1+0.5)
C IN PRESENT VERSION, CLM AND THIS TEM ARE ALWAYS ZERO

2010 ROC=0.85*(BL4-RL3)*TRANS(FFV3)*BL4-RL3+CL
2015 ROC=ROC+11.-CL)R00
R2=R2+(11.-CL)*R20
R4=R4+(11.-CL)*R40
DIRAD=4.*STBO*TG**3
C SURFACE ALFRED
C IF (COSZ * LF. * 0.01) GO TO 340
SCOSZ=SF*COSZ
ALS=0.07
IF (OCEAN) GO TO 335
ALS=0.14
IF (LAT(J) * LT. SNOWN) GO TO 327
CLAT=(LAT(J)-SNOWN)*CONRAD
GO TO 330
327 IF (LAT(J) * GT. SNOWS) GO TO 328
CLAT=(SNOWS-LAT(J))*CONRAD
ALS=45*(1+((CLAT-10.)*2)/(CLAT-30.)*2+(CLAT-10.)*2)
GO TO 335
328 IF (LAND) GO TO 335
CLAT=0.0
ALS=4*(1+((CLAT-5.)*2))/((CLAT-45.)*2+(CLAT-5.)*2)
330 IF (LAND) GO TO 335
CLAT=0.0
ALS=4*(1+((CLAT-5.)*2))/((CLAT-45.)*2+(CLAT-5.)*2)
C SOLAR RADIATION
C
335 ALO=AMIN1(1.05-2.247*ALNG10(COSZ/COSM))
SA=349*SCOSZ
SS=SCOSZ-SA
ASOT=SA*TRSW((FV0-FFVT)/COSZ)
AS2T=SA*TRSW((FV0-FFVT2)/COSZ)
FS2C=0.
FS4C=0.
S4C=0.
GO TO (336,336,337). IC.01T1
C CLEAR

FS20=AS2T
FS40=SA*TRSW(EFV0/COSZ)
S40=(1.-ALS)*(FS40*(1.-ALAO)/(1.-ALAO*ALS)*SS)
IF (ICLOUD .EQ. 1) GO TO 341

C LARGE SCALE CLOUD

IF (CL2 .LE. 0.) GO TO 331
CLT=CL2
FS2C=AS2T*CLT
TEMU*(1.-ALC2)*TRSW(EFV0-EFV2)/COSZ+1.66*(EFVC2*EFV3))
FS4C=(TEMS+ALC2*AS2T)*CLT
ALAC=ALC2+ALAO-ALC2*ALAO
S4C=(1.-ALS)*(TEMS/(1.-ALC2*ALS)+(1.-ALC)/1.-(ALAC*ALS))SS)*CLT
GO TO 339

C LOW LEVEL CLOUD

IF (CL3 .LE. 0.) GO TO 339
CLT=CL3
FS2C=AS2T*CLT
TEMU=(EFV0-EFV3)/COSZ
TEMS=SA*(1.-ALC3)*TRSW(TEMU+1.66*(EFVC3*EFV3))
FS4C=(TEMS+ALC3*SA*TRSW(TEMU))/CLT
ALAC=ALC3+ALAO-ALC3*ALAO
S4C=(1.-ALS)*(TEMS/(1.-ALC3*ALS)+(1.-ALC)/1.-(ALAC*ALS))SS)*CLT

C THICK CLOUD

IF (CL1 .LE. 0.) GO TO 341
CLH=AMAX1(CL1,0.)

C IN PRESENT VERSION, CLM AND THIS TEM ARE ALWAYS ZERO

IF (CLT .GT. 0.) TEM=CLM/CLT
TEMU=(EFV0-EFV1)/COSZ
TEMB=(1.-ALC1)*TRSW(TEMU)/SA*CL1
FS2C=SA*(1.-ALC1)*TRSW(TEMU+1.66*(EFVC1*EFV3))
FS4C=(TEMS+ALC1*SA*TRSW(TEMU))/CLT
TENM=SA*(1.-ALC1)*TRSW(TEMB+1.66*(EFVC1*EFV3))
FS4C=TEM+FS2C*TEM
ALAC=ALC1+ALAO-ALC1*ALAO
S4C=(1.-ALS)*(TEMS/(1.-ALC1*ALS)
X=(1.-ALC)/1.-(ALAC*ALS)*SS)*CL1+S4C*TEM

C MEAN CONDITION

FS2=FS2C+(1.-CL)*FS20
FS4=FS4C+(1.-CL)*FS40
S4=S4C+(1.-CL)*S40
AS1=AS0T*FS2
AS3=FS2+FS4
GO TO 349

340 S4=0.0
AS3=0.0
AS1=0.0
COMPUTATION OF GROUND TEMPERATURE

345 TGR=TG
IF (OCEAN) GO TO 347
BRAD*S4-R4
TEM=0
IF (ICE .AND. ZEZ.LT.0.1) TEM=CTD/HICE
A1=CSEN*(T1+CLH*(Q4*WET*(DG*TG-QG)))
A2=BRAD+S4*BL4*TEM*TICE
B1=CSEN*1*CLH*DG*WET
B2=DIRAD*TEM
TGR=(A1+A2)/(B1+B2)
IF (LAND.OR.TGR.LT.TICE) GO TO 346
TGR=TICE

346 DR4=DIRAD*(TGR-TG)
R4=R4+DR4
R2=R2+.R*(1.-CL)*TRANS(EVF2)*DR4
RO=RO+.8*(1.-CL)*TRANS(EFVT)*DR4

347 GT(J,J)=TGR

SENSIBLE HEAT (LY/DAY) AND EVAPORATION (GM/CM**2/SEC)
E4=CEVA*(WET*(DG+DG*(TGR-TG)))-04
F4=CSEN*(TGR-T4)
FK=RD4*FK4*WINDF

TOTAL HEATING AND MOISTURE BUDGET
QN=(C1+C3+PC1+PC3)/CLH*P*PC2-2.0*ETC3*GRAV/(SP*10.)
O3(V,J)=O3(J,J)-ON
IF (.NOT.LAND) GO TO 350
RUNOFF=0.
IF (QN.GT.0. .AND. WET.LT.1.) RUNOFF=.5*WET
IF (QN.GT.0. .AND. WET.GE.1.) RUNOFF=1.
WET = GW(J,J)+(1.-RUNOFF)*DN5*SP/GRAV/GWM
IF (WET.GT.1.) WET = 1.
IF (WET.LT.0.) WET = 0.

350 GW(J,J) = WET

IF (O3(J,J).LT.0.) O3(J,J)=0.
IF (KEY(31)) GO TO 360

351 H1=(AS1+R2-R0)*COE1*COLMR+C1*PC1
H3=(AS3+R4+R2+FA)*COE1*COLMR+C3*PC3+PRE*CLH
W(J,J)=0.5*(H1+H3)
TFM=0.5*(H1-H3)
T(J,J)=T(J,J)+TFM
T(J,J)=T(J,J)-TEMP
SURFACE FRICTION

352 IF (JNEQ0 1) GO TO 358
C
J=IPJ+1

DO 355 K=1,2
K1=K+1

Q(J,K1)=Q(J,K1)-FM*TEMP*COLMR*2*DTC3
Q(J,K2)=Q(J,K2)+(FM*TEMP*COLMR*FK(Q(J,K1)-5*TEMP)*S)

355 CONTINUE

358 IF (INDOUT) GO TO 360

PACK FOR OUTPUT

370 CONTINUE

375 DO 377 L=1,IM
DN 377 J=1,JM

377 H(J+1,1)=H(J,1)+DXYP(J)

DO 390 L=1,IM

1=MOD(L,1)+1
IM=MOD(L,1)+1

DO 380 L=1,JMM

TEMP=(M+H(J,L,1)+2) .* (H(J,L,1)+H(J,L,1)+H(J,L,1)+H(J,L,1))

T(J,L)=T(J,L,1)+DXYP(J)

380 CONTINUE

400 RETURN

END
* SUBROUTINE
* COMP4
*/
DO DISP=OLD, DSN=MFS727.AHN.COMMON
!
C DO 20 I=1,IM
DO 25 J=2, JM
20 PV(J, I) = DXYP(J) * P(J, I)
25 PV(1, I) = DXYP(1) * P(1, I)
C C DIFFUSION OF MOMENTUM
C DO 30 I=1, IM
1P1 = MOD(I, 1M) + 1
DO 30 J=2, JM
30 PV(J, I) = 0.25 * (PV(J, I) + PV(J-1, I) + PV(J, I1) + PV(J-1, I1))
DO 90 K=2,5
K1 = MOD(K, 2)
FL = MOD(K, 2) * 2 + 1
SIGG0 = FL / 2.
DO 40 I=1, IM
1P1 = MOD(I, 1M) + 1
DO 40 J=2, JM
40 PV(J, I) = SIGG0 * (IPJ[1]P1) + P(J-1, I1) - P(J, I1) - P(J-1, 11)
! / (P(J, I1) + P(J-1, I1) + P(J, I) + P(J-1, I1))
/ *(Q(J, I, K1) - Q(J, I, K1+1))
DO 50 I = 1, IM
IM = MOD(I, IM2) + 1
DO 50 J = 2, JM
TEMP = DTC3 * (P(J, I) + P(J, I - 1)) * DXU(J) / DUY(J) * 0.5
* *(Q(J, I, K) - Q(J, I, M1, K) + PV(J, I) + PV(J, I))
Q(J, I, K) = Q(J, I, K) - TEMP / PU(J, I)
50
Q(J, IM1, K) = Q(J, IM1, K) * TEMP / PU(J, IM1)
DO 60 I = 1, IM
I1 = MOD(I, IM) + 1
DO 60 J = 2, JM
PV(J, I) = SIGMA * (P(J, I) + P(J, I) - P(J - 1, I) - P(J - 1, I))
* / (P(J, I) + P(J, I) + P(J - 1, I) + P(J - 1, I))
* *(Q(J, I, K) - Q(J, I, K))
60
DO 80 I = 1, IM
I1 = MOD(I, IM) + 1
DO 70 J = 2, JM
TEMP = DTC3 * (P(J, I) + P(J, I)) * DXU(J) / DUY(J) * 0.5
* *(Q(J, J, K) - PV(J, I, K) - PV(J, I))
Q(J, J, K) = Q(J, J, K) - TEMP / PU(J, I) * DXU(J)
70
Q(J, IM, K) = Q(J, IM, K) * TEMP / PU(J, IM)
TEMP = DTC3 * (P(J, I) * DXU(J) / DUY(J) * (Q(J, J, K)) - PV(J, I))
Q(JM, I, K) = Q(JM, I, K) - TEMP / PU(J, IM)
TEMP = DTC3 * (P(J, I) * DXU(J) / DUY(J) * Q(JM, I, K) - PV(J, I))
80
Q(J, IM, K) = Q(J, IM, K) - TEMP / PU(J, IM)
90 CONTINUE
90 CONTINUE
CONTINUE
C
92
C
SMOOTHING LAPSE RATE
C
99
DO 100 I = 1, IM
100 CONTINUE
DO 100 J = 1, JM
100 CONTINUE
100 TD(J, I) = (T(J, I, 2) - T(J, I, 1)) / 5 / P(J, I)
DO 110 I = 1, IM
I1 = MOD(I, IM2) + 1
I1 = MOD(I, IM) + 1
DO 110 J = 2, JM
TDBAR = (TD(J, I, IM1) + 2 * TD(J, I, I) + TD(J, I, I)) / 16
* 4
TD(J, I, 1) = TD(J, I, 1) + 2 * TD(J, I, 1)
3
TD(J, I, 1) = TD(J, I, 1) + 2 * TD(J, I, 1)
16
TDSM = (TD(J, I) + (TDBAR - TD(J, I)) / TSDM) * P(J, I)
110
T(J, I, 2) = T(J, I, 2) + T(J, I, 1) * 5
T(J, I, 1) = TBAR + TDSM
RETURN
END
SUBROUTINE

* INPUT

C IF (KEY(11) .OR. KEY(12)) GO TO 751
P1=3.1415926
SIG(1)=.25
SIG(2)=.75
DAYPRR=365.
DECMAK=23.5/180.0*P1
ROTPER=24.0
EONX=173.0
APHEL=183.0
ECCN=0.0178
C HISTORY FILE
    KTP=11
C CHECKPOINT FILE
    LTP=1
C DATA CARD IMAGE FILE
    INU=5
C OUTPUT (MAP) STREAM
    MTP=6
C (1)
READ (INU,50) ID,XLABL
C (2)
C (3)
READ (INU,RO) TAU0,TAUD,TMP,TRST,TFRM
IF (TRST.NE.0.0) KTP=10
TAU1=TAU0+24.0*TAUH
C (4)
READ (INU,RO) TAU0,TAUD,TAF0,TAUF,TAUC
TAUC=24.0*TAUH
C (5)
READ (INU,RO) DTM,NCYCLE,NC3
C (6)
READ (INU,RO) JM,IM,OLAT
C (7)
READ (INU,RO) FMX,ED,TCNV
C (9) READ (INU,80) RAO, GRAV, OAY
C (10) READ (INU,80) RGAS, K&'A
C (11) READ (INU,80) PSL, PTROP
C (12) READ (INU,80) PSF
C (13) FOR POLAR MAPS, LATITUDE OF INSCRIBED CIRCLE
C (14) READ (INU.85) KSET
DO 40 J=1,32
   KEY$J=KSET$J..NE.BLANK
   OT=DTH*60.0
   ATX=1.05
   TIN=IN
   DLAT=DLAT*PI/180.0
   DLON=DLON*PI/F1N
   FM=FMX*0.00001
   RAO=RAD*1000.0
   OAY=OAY*3600.0
   C(20) CALL M GLfloat
   READ (INU,1199) MARK
   123 TRFAO=?..TRUE.
   125 READ (KTP) TAU$X, C1
   IF (TAUX .LT. 0.0) GO TO 135
   TAU$X=TAUX
   TAUX=FIX(TAUX/24.0)
   TAU$X=TAUX-24.*TAU$X
   IF (KEY$9) WRITE (MTP,9120) TAU$X, TAU$X
   C(22) = C1(22)
   SDEY = ICI(29)
   SDEY = ICI(30)
   CALL OUTAPE(KTP,1)
   IF (TAUX-<TAUX) 125, 190, 190
   135 BACKSPACE KTP
   190 CONTINUE
   IF ((TRST, EQ, 1).AND.(TERM, EQ, 0)) GO TO 195
   WRITE (KTP) TAU$X, C1
   BACKSPACE KTP
   195 CONTINUE
   IF ((TRST, EQ, 0.0)) GO TO 202
   REWIND KTP
   KTP=11
   WRITE (KTP) TAU$X
   CALL OUTAPE(KTP,2)
   202 JUMP=..FALSE.
205 CALL INIT2(MARK) 00013940
206 CALL INSNET 00013950
  IF (JUMP) GO TO 300 00013960
250 CONTINUE 00013970

C  

IF (KEY1-201) TAU=24.
C
TAU=TAU
WRITE (MTP,1200) ID,XLARL 00014010
WRITE (MTP,1201) TAU10,TAU1N,TRST,TAU1 00014020
WRITE (MTP,1201) TAU0,TAH0,TAH1,TAU0,TAU1 00014030
WRITE (MTP,1201) DTM,DLAT,AX,FMX,FO,TCNV 00014040
WRITE (MTP,1201) RAD,GRV,DAY,RGAS,KAPA,PSL,PTROP,PSF,DLIC 00014050
WRITE (MTP,1202) JM,IM,NCYCLE,NC3 00014060
WRITE (MTP,1197) AX 00014070
WRITE (MTP,1195) FD,TCNV 00014080
WRITE (MTP,1196) FMX 00014090

C  

300 TOTDAYS=MOD(TAU,R(TPFR)) 00014100
C  

WRITE (2) GM,GT,TS,SN 00014120
C  

REWIND 2 00014130
RETURN 00014140

C  

10 FORMAT (215,F10.0) 00014160
50 FORMAT (10A4) 00014180
57 FORMAT (12,AA1,2F10.0,MA4) 00014190
A2 FORMAT (F10.0,2%5) 00014200
80 FORMAT (5F10.0) 00014210
85 FORMAT (32A1) 00014220
1195 FORMAT (6HO,FR=FS,FS,F10.0,*HCNV=FS,FS) 00014230
1194 FORMAT (6HO,FM=F4,2,RAH=1.0,0001) 00014240
1197 FORMAT (6HO,AS,F4,2,9H=E10.0000,0) 00014250
1199 FORMAT (213) 00014260
9120 FORMAT (1X,2F10.2) 00014270
9731 FORMAT ('ITAPE',14,A) 00014280
97FL FORMAT ('OSWITCHING FROM TAPE ',14,A) 00014290
1200 FORMAT (1M1,AA,A2,2A4) 00014300
1201 FORMAT (9(1X,E12.5)) 00014310
1202 FORMAT (10(1X,15)) 00014320
END 00014330
**SUBROUTINE**  

```c
// Do 01SP=0,0.OSN=ME5727.ARN.COMMON
// Do 2

* C

EQUAL LATITUDE DISTANCE PROJECTION

JMM1=JMM-1
FJM=JM
FJE=FJM/2.0*0.5
ON 410 J=2,JMM1
FJ=J

410 LAT(1)=DLAT*(FJ-FJE)
LAT(10)=P1/2.0
LAT(JM)=P1/2.0

420 DXP(J)=RAO*COS(LAT(1))*(DLAT

ON 430 J=2,JMM1
ON 440 J=2,JMM1

450 FJM=2.0*PI/DAY*(RAO/DXP(J))*(COS(LAT(1)))*COS(LAT(J))+DXU(J)

ON 445 J=2,JMM1
ON 450 J=2,JMM1

480 FJM=2.0*PI/DAY*(RAO/DXP(JM))*(COS(LAT(JM)))*COS(LAT(JM))

C

USED IN COMP* ONLY

EXP1=4.0/3.0

42 J=1,JM

42 AXU(J)=AXU(J)/3.0*EXP1

42 AXU(J)=AXU(J)/3.0*EXP1

42 AXU(J)=AXU(J)/3.0*EXP1

42 AXU(J)=AXU(J)/3.0*EXP1

42 AXU(J)=AXU(J)/3.0*EXP1

RETURN

END
```
SUBROUTINE INSSET

* 

DO 10 DISP=OLD, DSN=MON, A$a, COMMON

DO 10 * 

LOGICAL DCLK

DO 411 J=1, JM 

SIN(L(J)) = SIN(LAT(J))

COS(L(J)) = COS(LAT(J))

411 IF (KEY(11), OR, KEY(12)) GO TO 15

C IF (KEY(11), OR, KEY(12)) GO TO 15

C 10 IMU=5 

READ (IMU, 7) CLKSW, RSETSW, LDAY, LRY

31 IF (RSETSW .NE. RESET) GO TO 14

SDEY=LDAY 

SDEY=LYR

DCLK = .FALSE. 

CALL SOET

14 IF (CLKSW .NE. OFF) DCLK = .TRUE.

RETURN

C 15 OCLK=.FALSE. 

CALL SOET

RETURN

C 7 FORMAT (A4, 6X, A4, 6X, 13, 7X, 14)

C DATA RESET/4MRESF/, OFF/4MHOFF /

END
SUBROUTINE SDEI
/
// Disp=ODS,OSN=mes727,Arn,Common
// DD *
C
DIMENSION ZMONTH(3,12), MONTH(12)
LOGICAL DCLK
MAXDAY=DAYPR+1.E-2
IF (DCLK) SOEDY=SOEDY+1
IF (SOEDY .LE. MAXDAY) Go TO 211
SOEDY=SOEDY-MAXDAY
SOEVR=SOEVR+1
211 J0YACC=0
DO 251 L=1,24
    JDYACC=JOYACC+MONTH(L)
    IF (SOEDY .LE. JOYACC) Go TO 241
251 CONTINUE
L=12
241 MATHY=MONTH(L)-JOYACC-SOEDY
    AMOUTH(1)=ZMONTH(1,L)
    AMOUTH(2)=ZMONTH(2,L)
    AMOUTH(3)=ZMONTH(3,L)
    DY=SOEDY
    SEASON=(DY-EONX)/DAYPR
    DIST=(DY-APHFL)/DAYPR
C
EONX = JUNE 22
APHELION = JULY 1
ECCN= ORBITAL ECCENTRICITY
C
DEC=DFCMA*COS(2*0*PI*SEASON)
RDIST=(1.0+ECCN*COS(2.0*PI*DIST1)**2
SIND=SIND*DEC)
COSD=COSD*DEC)
C
DATA ZMONTH/ * JANUARY FEBRUARY MARCH APRIL */
X MAY JUNE JULY AUGUST SEPTEMBER OCTOBER
XER NOVEMBER DECEMBER */
RETURN
END
* SUBROUTINE
  * INIT
  
  // DD DISP=OLD,DSN=MES727,ARIN,COMMUN
  // DD *

  THIS ROUTINE IS FOR COLD START INITIAL CONDITION.

  RETURN

  END

* SUBROUTINE
  * INIT2 (MARK1)
  
  // DD DISP=OLD,DSN=MES727,ARIN,COMMUN
  // DD *

  REAL METER
  DIMENSION HEIGHT (46)
  LOGICAL FAH

  INU = 5
  IF (MARK1 .EQ. 0) GO TO 71

  READ UNIT CARD FOR GEOGRAPHY

  75 READ (INU,110) TEMSCL
     IF (TEMSCL .EQ. FARREN) GO TO 16
     IF (TEMSCL .EQ. CENTIG) GO TO 46
     STOP 19121
  86 FAH=.TRUE.
     GO TO 97
  46 FAH=.FALSE.
     GO TO 97
  19 WRITE (6,76)
     STOP
  97 CONTINUE
C READ GEOGRAPHY DECK
     0016020
C OCEAN: SEA SURFACE TEMPERATURE
     0016030
C LAND: -64
     0016040
C SEA ICE OR LAND ICE: -96
     0016050
C
    0016060
ON 15 IL=1,MARK1      0016070
READ (INU,102) (TOPD(J,IL),J=1,15),IL1,(TOPD(J,IL),J=16,30),IL2
     0016090
X,(TOPD(J,IL),J=31,46),IL3
     0016100
IF (IL1.NE.IL2.OR.IL2.NE.IL3.OR.IL1.NE.IL) GO TO 19
     0016110
15 CONTINUE
     0016120
DO 23 IL=1,IM      0016130
DO 23 JL=1,JM      0016140
IF (TOPD(JL,IL),LE. -64.0) GO TO 23
     0016150
IF (FAM) TOPD(JL,IL)=(TOPD(JL,IL)-32.0)*5./9.
     0016160
TOPD(JL,IL)=TOPD(JL,IL)+273.0
     0016170
23 CONTINUE
     0016180
CNST=GRAV=30.48
     0016190
HCST=1.
     0016200
C READ UNIT CARO FOR TOPOGRAPHY
     0016210
C READ (INU,110) MSCL
     0016220
IF (MSCL .EQ. FEET .AND. MSCL .NE. METER) GO TO 78
     0016230
IF (MSCL .EQ. METER)HCST=39.37/120.
     0016240
CNST=CNST*HCST
     0016250
DO 10 I=1,MARK1
     0016260
C READ TOPOGRAPHY DECK
     0016270
READ (INU,101) (HEIGHT(J),J=1,25),IL1,(HEIGHT(J),J=26,JM),IL2
     0016280
IF (IL1.NE.IL2.OR.IL1.NE.IL2) GO TO 19
     0016290
DO 20 J=1,JM
     0016300
IF (TOPD(JL,IL),LE. -64.0) 60,50,20
     0016310
50 TOPD(JL,IL)=-(HEIGHT(J)+CNST)
     0016320
GO TO 20
     0016330
60 TOPD(JL,IL)=-(HEIGHT(J)+CNST*10,F5)
     0016340
20 CONTINUE
     0016350
10 CONTINUE
     0016360
71 WRITE (6,112) MSCL
     0016370
STOP 19122
     0016380
C 101 FORMAT (2SF3.0,1X,14/2SF3.0,13X,14)
     0016390
102 FORMAT ('SF4.1,1AX,12/1SF4.1,1AX,12/1SF4.1,1AX,12)
     0016400
110 FORMAT (A4)
     0016410
111 FORMAT (I4,I6X,2A6,4OH NOT RECOGNIZED AS TEMPERATURE CONTROL.
     0016420
112 FORMAT (I4,I6X,2A6,3OH NOT RECOGNIZED AS HEIGHT CONTROL.
     0016430
76 FORMAT(///6OH GEOGRAPHY DATA SEQUENCE ERROR, RELOAD GEOGRAPHY DECK
     0016440
9 AND PUSH START,///)     0016450
    0016460
C DATA FAREN/4HFAMR//CENTIG/4HCENI//FEET/4HFEET/ METER/4HMETER/
     0016470
     0016480
C END
     0016490
     0016500
MAP PROGRAM LISTING

To facilitate the output of the primary dependent variables and auxiliary physical quantities, a number of routines for the production of analyzed maps have been prepared. Examples of these maps have been given in Chapters III and IV. The FORTRAN listing of the complete set of map routines is given below, with the cards in the program numbered sequentially for easy reference. Each of the map subroutines automatically computes the zonal average at each grid latitude, as well as the global average. The maps 2, 3, 4, 6, 8, 17, 18, 21, 27, and 28 may be produced for an arbitrary tropospheric o or p surface by interpolation or extrapolation of the solutions at the basic levels o = 1/4 and o = 3/4, while the other maps refer only to fixed levels, layers, or quantities.

It may be noted from the model description (see Chapter III) that while the primary dependent variables are computed each time step, the source or forcing terms (such as the diabatic heating) are computed every fifth time step. In order that any of the maps, whether involving a dependent variable and/or forcing term, may be prepared at any time selected for map output, portions of the subroutines OUTAPE, VPHI4, AVRX, and COMP 1 have been made part of the map program, a new subroutine MAPGEN has been written, and a substantial portion of the subroutine COMP 3 has also been incorporated. In this way those maps involving heating or precipitation, for example, are explicitly computed from the data at the time requested for map output.

The complete list of maps and the levels associated with their output (in o coordinates) is shown below; examples of those maps marked by an asterisk (*) are given in Chapter IV, with Map 5 given in Chapter III, Section F.

* Map 1: Smoothed sea-level pressure (σ = 1)
* Map 2: Zonal wind component (0 ≤ σ ≤ 1)
* Map 3: Meridional wind component (0 ≤ σ ≤ 1)
* Map 4: Temperature (0 ≤ σ ≤ 1)
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*Map 5: Topography (sea-surface temperature, land elevation, ice distribution)

*Map 6: Geopotential height (0 ≤ σ ≤ 1)

Map 7: Unsmoothed sea-level pressure (σ = 1)

*Map 8: Total diabatic heating (0 ≤ σ ≤ 1)

*Map 9: Large-scale precipitation rate

*Map 10: Sigma vertical velocity (σ = 1/2)

*Map 11: Relative humidity (σ = 3/4)

*Map 12: Precipitable water

*Map 13: Convective precipitation rate

*Map 14: Evaporation rate (σ = 1)

*Map 15: Sensible heat flux (σ = 1)

*Map 16: Lowest-level convection (σ = 1)

Map 17: Wind direction angle (0 ≤ σ ≤ 1)

Map 18: Wind direction vectors (0 ≤ σ ≤ 1)

*Map 19: Long-wave heating in layers (σ = 0 to 1/2, c = 1/2 to 1)

*Map 20: Short-wave absorption (heating) in layers (σ = 0 to 1/2, σ = 1/2 to 1)

Map 21: Wind magnitude (0 ≤ σ ≤ 1)

*Map 22: Surface short-wave absorption (heating) (σ = 1)

*Map 23: Surface air temperature (σ = 1)

*Map 24: Ground temperature (σ = 1)

*Map 25: Ground wetness (σ = 1)

*Map 26: Cloudiness (high, middle, low)

Map 27: Pressure at sigma surfaces (0 ≤ σ ≤ 1)

*Map 28: Total convective heating in layers (σ = 0 - 1/2, σ = 1/2 - 1)
Map 29: Latent heating ($\sigma = 1/2$ to 1)

Map 30: Surface long-wave cooling ($\sigma = 1$)

Map 31: Surface heat balance ($\sigma = 1$)
MAP LIST FOR MINTZ-ARAKAWA TWO-LEVEL GENERAL CIRCULATION MODEL

// DD DISP=OLD,DSN=KES727,AN,COMMON
// DD 
 COMMON/COUT/ZM(46),SURF,LEV,ISL,NAME(ID)
 COMMON/COT/TAPIN
 DIMENSION MAP(99),SRF(99),SNT(99),ZM2(46)
 DATA JH/LK/4H  / 
 DATA HCTP/TAPE*/
 100 FORMAT (5F10.0) 
 101 FORMAT (12,2E10.0,13A4) 
 102 FORMAT (5I1X,FR,3)) 
 103 FORMAT (1X,12,2(1X,FR,3)) 
 104 FORMAT (1X,FR,2,2X,ISL,FR,2,2X,ISL,FR,2,2X,FR,2,2X,ISL,FR,2,2X,F13,5) 
 105 FORMAT (2E10.0,4A4) 
 106 FORMAT (1X,FR,3,1X,FR,3,2X,A4) 
 107 FORMAT (1H1) 
 READ (5,105) TO,TEND,TAPIN 
 WRITE (4,106) TO,TEND,TAPIN 
 TIPDG(1,1)=-1.0 
 IF (TAPIN.NF.HCTP) READ (R) TIPDG 
 TSA=TIPDG(1,1) 
 TO=24.*T0 
 TEND=24.*TEND 
 DAY=24.*3600. 
 EJECT=0.0 
 I=0
 200 READ (5,101) MAPNI,SURF 
 WRITE (6,103) MAPNI,SURF 
 I=I+1 
 MAP(I)=MAPNI 
 IF (MAPNI.EQ.0) GO TO 230 
 SRF(I)=SRF 
 SNT(I)=SNT 
 GO TO 200 
 230 CONTINUE 
 TI=0.0 
 250 READ (R) TAU,C 
 DAY=DAY+1 
 IF (TAU.EQ.TSA) GO TO 250 
 NONUT=0 
 T2=TAU/24. 
 IF (EJECT.NE.0) EJECT=EJECT+1.0 
 IF (EJECT.EQ.2.0) PRINT 107 
 WRITE (6,102) TAU,T2 
 IF (TAU,LT,0.0) GO TO 250 
 CALL OUTAPE 
 IF (TAU,LT,0.0) GO TO 250 
 IF (TAU,GT,TEND) CALL EXIT
IF (TAU LE T1) GO TO 250
T1=TAU
I=1
IF (EJECT, NE, 0.0) GO TO 270
CALL COMP3
PRINT 107
EJECT=1.0
270 MAPNO=MAP(I)
IF (MAPNO, EQ, 0.0) GO TO 250
SURF=SRF(I)
SINT=SNT(I)
DO 275 J=1, L3
275 NAME(J)=JBLK
CALL MOPGEN (MAPNO)
DO 290 J=1, JM
ZM2(J)=0.0
FCNT=0.0
DO 280 K=1, IM
IF (TOPOG(J,K), LT, 1.0) GO TO 280
ZM2(J)=ZM2(J)+WORK2(J,K)
FCNT=FCNT+.0
280 CONTINUE
IF (FCNT, NE, 0.0) ZM2(J)=ZM2(J)/FCNT
290 CONTINUE
WRITE(9) TAU, 10, MAPNO, NAME, SURF, STAG1, STAGJ, SINT, WORK2, ZM, ZM2, ZMM
PRINT 104, T2, MAPNO, SURF, NAME
I=1
GO TO 270
END
SUBROUTINE OUTAPE
// 00 DSP=OLD,DSN=MESS727,ABN.COMMON
//
OD *
COMMON /CDT/TAPIN
DATA BCPT/*TAPE*/,
K=8
READ (K) P
READ (K) U
READ (K) V
READ (K) T
READ (K) Q3
IF (TAPIN,NX,BCPT) READ (8) T0PNG
READ (K) PT
READ (K) GW
READ (K) TS
READ (K) GT
READ (K) SN
READ (K) TT
READ (K) Q3T
READ (K) SD
IF (TAPIN,NX,BCPT) RETURN
READ (K) H
READ (K) TD
RETURN
END
SUBROUTINE MAPGEN (MAPNO)

/ * DISP=O, OSN=, WES727.ABN.COMMON
 DD *
 COMMON /SC11/ RCTL(2), ICTL(10)
 COMMON /CUIT/ ZM(46), SURF, LEV, ISL, NAME(13)
 EQUIVALENCE (LEVEL, SURF)
 LOGICAL LEV
 MAPGEN=.TRUE.,
 LEV=.FALSE.,
 IF (SURF.LT.2.0) LEV=.TRUE.,
 C
 GO TO (301, 302, 303, 304, 305, 306, 307, 308, 309, 310)
 + (311, 312, 313, 314, 315, 316, 317, 318, 319, 320)
 + (321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331), MAPNO
 C
 301 CALL MAP1
 GO TO 410
 302 CALL MAP2
 GO TO 410
 303 CALL MAP3
 GO TO 410
 304 CALL MAP4
 GO TO 410
 305 IF (KEY(18)) MAPGEN=.FALSE.,
 CALL MAP 5
 GO TO 410
 306 CALL MAP 6
 GO TO 410
 307 CALL MAP 7
 GO TO 410
 308 IF (NONOUT.EQ.0) CALL COMP3
 NONOUT=1
 CALL MAP8
 GO TO 410
 309 IF (NONOUT.EQ.0) CALL COMP3
 NONOUT=1
 CALL MAP9
 GO TO 410
 310 CALL MAP10
 GO TO 410
 311 CALL MAP11
 GO TO 410
 312 CALL MAP12
 GO TO 410
313 IF (NODUT.EQ.0) CALL COMP3
    NODUT=1
    CALL MAP13
    GO TO 410
314 IF (NODUT.EQ.0) CALL COMP3
    NODUT=1
    CALL MAP14
    GO TO 410
315 IF (NODUT.EQ.0) CALL COMP3
    NODUT=1
    CALL MAP15
    GO TO 410
316 IF (NODUT.EQ.0) CALL COMP3
    NODUT=1
    CALL MAP16
    GO TO 410
317 CALL MAP 2
    DO 3175 I=1,IM
    DO 3175 J=1,JM
3175 WORK(I,J)=WORK2(I,J)
    CALL MAP 3
    CALL MAP 17
    GO TO 410
318 CALL MAP 2
    DO 3185 I=1,IM
    DO 3185 J=1,JM
3185 WORK(I,J)=WORK2(I,J)
    CALL MAP 3
    CALL MAP 18
    GO TO 410
319 IF (NODUT.EQ.0) CALL COMP3
    NODUT=1
    CALL MAP19
    GO TO 410
320 IF (NODUT.EQ.0) CALL COMP3
    NODUT=1
    CALL MAP20
    GO TO 410
321 CALL MAP 2
    DO 3215 I=1,IM
    DO 3215 J=1,JM
3215 WORK(I,J)=WORK2(I,J)
    CALL MAP 3
    CALL MAP 21
    GO TO 410
322 IF (NODUT.EQ.0) CALL COMP3
    NODUT=1
    CALL MAP22
    GO TO 410
323 IF (NONOUT.EQ.0) CALL COMP3
    NONOUT=1
    CALL MAP23
    GO TO 410
324 CALL MAP24
    GO TO 410
325 CALL MAP25
    GO TO 410
326 IF (NONOUT.EQ.0) CALL COMP3
    NONOUT=1
    CALL MAP26
    GO TO 410
327 CALL MAP27
    GO TO 410
328 IF (NONOUT.EQ.0) CALL COMP3
    NONOUT=1
    CALL MAP28
    GO TO 410
329 IF (NONOUT.EQ.0) CALL COMP3
    NONOUT=1
    CALL MAP29
    GO TO 410
330 IF (NONOUT.EQ.0) CALL COMP3
    NONOUT=1
    CALL MAP30
    GO TO 410
331 IF (NONOUT.EQ.0) CALL COMP3
    NONOUT=1
    CALL MAP31
    GO TO 410
410 RETURN
C
END

00002060
00002070
00002080
00002090
00002100
00002110
00002120
00002130
00002140
00002150
00002160
00002170
00002180
00002190
00002200
00002210
00002220
00002230
00002240
00002250
00002260
00002270
00002280
00002290
00002300
00002310
00002320
00002330
00002340
00002350
00002360
00002370
00002380
FUNCTION IPK(I,L,R)
  INTEGER IHALF(2)
  EQUIVALENCE (IHALF(1)=1L)
  IHALF(2)=IR
  IPK=IWD
  RETURN
  ENTRY IMH(IPKWD)
  IWD=IPKWD
  IMH=IHALF(2)
  RETURN
  ENTRY IMH(IPKWD)
  IWD=IPKWD
  IMH=IHALF(1)
  RETURN
END  

FUNCTION VPHI4(J,I)  
C */
// DO DISPMOD,DSN=KES727,ABN,COMMON  
DO *  
VPHI4=0  
IF (TOPOL(J,I),LT,1.0) VPHI4=AMOD1-(TOPOL(J,I),10,ES)  
C RETURN
END  

LOGICAL FUNCTION KEVM(N)
LOGICAL KEYS*1(32)
COMMON /VEKV/ KEYS
N=IARS(M)
KEY=KEYS(N)
IF (M,LT,0) KEYS(N)=.FALSE.
RETURN
END

SUBROUTINE MAP1
/*
// DD DISP=OLD,DSN=MES727,AHN.COMMON
// DD *
COMMOM /COUT/, ZM(46),SURF, LEV, I$L, NAME(13)
LOGICAL LEV, STAGJ, STAGI, I$L
DIMENSION NAME(13)
C
C SEA LEVEL PRESSURE, MAP TYPE 1
L1=1
LC=2
C
F0M=1M
IM2=1M-2
JMM1=JM-1
STAGJ=.FALSE.
STAGI=.FALSE.
SIG1=SIG(1)
SIG3=SIG(2)
FLR=5.0*1R28/130.4**G(NAV)
C
DU 110 I=1,NL
NAME(I)=NAME(I)
C
DU 11A J=1,JM
11A ZM(J)=0.0
C
DU 128 I=1,IM
DU 12R J=1,JM
P0H4=VPH4(JJ,1)
PJJ=PP(JJ)
C
T14=IHM03T(JJ,11)
C
T4=T4/10.
C
EXTRAPOLATED SURFACE AIR TEMPERATURE
T1=T1(JJ,11)
T3=T(JJ,1L2)
T4=T1*3+T3-0.5*T1
ZT=Z(JJ)+PHI4
ACC=(PJJ+PT(JJ))*EXP(PHI4/RTM)-PSL
ZM(J)=ZM(J)+ACC
12R WORK(JJ,11)=ACC
*/
000002730
000002760
000002770
000002780
000002790
000002800
000002810
000002820
000002830
000002840
000002850
000002860
000002870
000002880
000002890
000002900
000002910
000002920
000002930
000002940
000002950
000002960
000002970
000002980
000002990
000003000
000003010
000003020
000003030
000003040
000003050
000003060
000003070
000003080
000003090
000003100
000003110
000003120
000003130
000003140
C
DO 148 J=1,IM
IP1=MOD(J,IM)+1
IM1=MOD(J,IM2)+1
WORK2(JM+1)=WORK1(JM+1)
WORK2(J+1)=WORK1(J+1)
DO 148 J=2,IM1
148 WORK2(J+1)= ( WORK1(J+1,IM1)+2.*WORK1(J+1,1) + WORK1(J+1,IP1)
                      +2.*WORK1(J,IM1) +4.*WORK1(J,1) +2.*WORK1(J,IP1)
                      + WORK1(J-1,IM1)+2.*WORK1(J-1,1) + WORK1(J-1,IP1))/16.
C
ZMM=0.0
WTM=0.0
DO 150 J=1,JM
WTM=WTM+ABS(DXYP(J))
ZM(J)=ZM(J)/WTM
150 ZM=ZMM+ZM(J)*ABS(DXYP(J))
ZMM=ZMM/WTM
SPOL=ZM(J)
NPOL=ZM(JM)
C
DATA NAME,"SEA LEVEL PRESSURE SMOOTHED (MB-1000.)"          00003350
DATA NL/13/          00003360
RETURN          00003370
C
ENO          00003380
SUBROUTINE MAP2

DIMSCALE
!
LOGICAL LEV, STAGJ, STAG1, ISL
COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMF(13)
EQUIVALENCE (SURF,STIGL)
DIMENSION NAMEL(13)
!
EAST-WEST (II) WIND COMPONENT, MAP TYPE 2
!
S1 = 1
STAGJ = .TRUE.
STAG1 = .TRUE.
!
ON 110 I=1,NL
110 NAME(I) = NAMEL(I)
!
210 L1=1
L2=2
SIGL1=SIG(L1)
SIGL2=SIG(L2)
OSIG=1./(SIGL2-SIGL1)
!
IF (LEV) GO TO 310
!
PS=4.*(SURF-PTROP)
!
ON 220 J=1,1M
!
WORK2(I,J) = 0.
IPI=MOO(I,1M)+1
!
ON 220 J=2,1M
!
SIGPS = PS/(PI(J,1) + PI(J,1P) + PI(J-1,1) + PI(J-1,1P))
!
220 WORK2(J,1) = DSIG*(SIGPS-SIGL1)*(J+L2)+(SIGL2-SIGPS)*(J+L1))
!
GO TO 410
!
310 OSIG1 = (SIGL1-SIGL1)*DSIG
OSIG2 = (SIGL2-SIGL1)*DSIG
!
ON 320 J=1,1M
!
WORK2(I,J) = 0.
!
ON 320 J=2,1M
!
320 WORK2(J,1) = DSIG1*(J+L2)+(J+L1)*DSIG2
C 410 ZMM=0.0
    WTM=0.0
    ZM(1)=0.0
    DO 430 J=2, JM
        SUM=0.0
    DO 420 I=1,JM
        SUM=SUM+M(I,J)
        CLAT=ABS(COS(.5*(LAT(J-1)+LAT(J))))
        ZM(J)=SUM/FIM
    WTM=WTS+CLAT
430 ZMM=ZMM+ZM(J)*CLAT
    ZMM=ZMM/WTM
    SPOL=ZM(J)
    NPOL=ZM(JM)
C DATA NAME='EAST-WEST (II) WIND COMPONENT (M/SEC)
C     DATA NL/13/
C     RETURN
C C END
SUBROUTINE MAP3

// DD USP=ILD, USN=MES727, ABN.COMMON
// DD *
LOGICAL LEV, STAJ, STAG, ISL
COMMON /COUT/ ZM(46), SURF, LEV, ISL, NAME(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAME(13)

C NORTH-SOUTH (V) WIND COMPONENT, MAP TYPE 3

C DIM=S1M
STAJ=.TRUE.
STAG=.TRUE.

C DO 110 I=1, NL
110 NAME(I)=NAME(L)

C DO 210 J=1, JM
210 SIG1=SIG(J, 1)
SIG2=SIG(J, 2)
USIG=1./(SIG2-SIG1)

C IF (LEV) GO TO 310

C PS=4.*SURF-PTRIIP
DO 220 I=1, IM
IP1=MIND(I, IM+1)
DO 220 J=1, JM
SIGPS=PS/(P(J, I) + P(J, IP1) + P(J-1, I) + P(J-1, IP1))
220 WORK2(J, I)=SIG*(((SIGPS-SIG1)*V(J, I+L2) + (SIGL2-SIGPS)*V(J, I-L1))
GO TO 410

00004050
00004060
00004070
00004080
00004090
00004100
00004110
00004120
00004130
00004140
00004150
00004160
00004170
00004180
00004190
00004200
00004210
00004220
00004230
00004240
00004250
00004260
00004270
00004280
00004290
00004300
00004310
00004320
00004330
00004340
00004350
00004360
00004370
C
310 DSIG1=(SIGL-SIGL1)*SIG
DSIG2=(SIGL2-SIGL1)*SIG
DO 320 I=1,1M
DO 320 J=1,1M
320 WORK2(J,I)=DSIG1*V(J,I,L2) + V(J,I,L1)*DSIG2
C
410 ZM=M0.0
WTM=0.0
DO 430 J=1,1M
SUM=0.0
DO 420 I=1,1M
420 SUM=SUM+WORK2(J,I)
CLAT=ARSICOS(LAT(J))
ZM(J)=SUM/FIM
WTM=WTM+CLAT
430 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WTM
SPDL=ZM(I)
NPDL=ZM(JM)
C
C
DATA NAMEL/*NORTH-SOUTH (V) WIND COMPONENT (M/SEC)
DATA NL/13/
C
RETURN
END
SUBROUTINE MAPA

// DD DISRL, DSN=MES727, ABN.COMMON
// DD C
LOGICAL LEV, STAGJ, STAGI, ISL
COMMON /COUT/, ZM(46), SURF, LEV, ISL, NAME(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAMEL(13)

C TEMPERATURE, MAP TYPE 4
C VERTICAL INTERPOLATION IS WITH POTENTIAL TEMPERATURE
C IN P-KAPPA SPACE.

FIM=IM
STAGJ=.FALSE.
STAGI=.FALSE.

DO 110 I=1, NL
110 NAME(I)=NAMEL(I)

C DO 220 J=1, JM
220 WORKZ(J, I)=PSK/(PL2K-PL1K) * (TPOTL1*PL2K-PSK) * (PSK-PL1K)*TPOTL2 + TKEL

00004650 00004650
00004660 00004670
00004680 00004680
00004690 00004700
00004710 00004720
00004730 00004740
00004750 00004760
00004770 00004780
00004790 00004800
00004810 00004820
00004830 00004840
00004850 00004860
00004870 00004880
00004890 00004900
00004910 00004920
00004930 00004940
00004950 00004960
00004970 00004980
00004990 00005000
C
C
410  ZMM=0.0
     WTM=0.0
     DO 430 J=1,JM
     SUM=0.0
     DO 420 I=1,IM
420  SUM=SUM+WORK2(J,I)
     CLAT=ABS(DXYP(J))
     ZM(J)=SUM/FIM
     WTM=WTM+CLAT
     ZMM=ZMM+ZM(J)*CLAT
     ZMM=ZMM/WTM
     NPOL=ZM(JM)
     SPOL=ZM(I)
C
C
     DATA NAMEL/'TEMPERATURE (DEGREES CENTIGRADE)
     DATA NL/13/
     DATA TKFL/-273.1/
C
RETURN
END
SUBROUTINE MAPS

// 00 DISP=OL,0,0SN=MES727,ABN,COMMON
// 00 *
C
LOGICAL LEV, STAGI, STAGJ, ISL
COMMON /COUT/, ZM(46), SURF, LEV, ISL, NAME(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAME1(13), NAME2(13)
C
GEOGRAPHY, MAP TYPE 5

C FJM = IM
FJM = JM
STAGI= .FALSE.
STAGJ= .FALSE.
CNST= 30, 48, GKA
C
00 110 I=1,NL
NAME(I)=NAME1(I)
110 IF (.NOT.LEV) NAME(I)=NAME2(I)

C DO 220 I=1,IM
DO 220 J=1,JM
TG=TPOG(J,I)
IF (.NOT.LEV) GO TO 215
IF (TG LT 1.0) GO TO 205
TG=TG/273.
GO TO 220

205 IF (TG+10.ES.0,0) GO TO 220
210 TG=10.ES
GO TO 220

215 IF (TG GT 1.0) GO TO 210
TG=TG
IF (TG GT 9.ES) GO TO 218
TG=TG/CNST
GO TO 220

218 IF (TG EQ 10.ES) GO TO 220
TG=(10.ES+TG-10.ES)/CNST
GO TO 220

220 WORK2(J,I)=TG

C 410 WS=0.0
WN=0.0
DO 415 I=1,IM
WS=WS+WORK2(I,I)
415 WN=WN+WORK2(I,JM,I)
WS=WS/FIM
WN=WN/FIM
DO 420 I=1,IM
WORK2(I,I)=WS
420 WORK2(I,JM,I)=WN
C
ZMM=0.0
WTM=0.0
DO 450 J=1,JM
SUM=0.0
CI=0.0
ZM(J)=0.0
DO 430 I=1,IM
W2=WORK2(J,I)
IF (.NOT.LEV) GO TO 425
IF (W2.GE.10.E5) GO TO 430
CI=CI+1.0
IF (W2.LT.0.0) GO TO 430
SUM=SUM+W2
GO TO 430
425 CI=CI+1.0
IF (W2.GE.10.E5) GO TO 430
IF (W2+10.E5.LE.0.0) W2=-W2+10.E5
SUM=SUM+W2
430 CONTINUE
CLAT=ABS(COS(LAT(J))
IF (CI.GT.0.0) ZM(J)=SUM/CI
ZM(J)=SUM/FIM
WTM=WTM+CLAT
450 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WTM
SPOL=ZM(1)
NPOL=ZM(JM)
C
DATA NAME1/TOPOGRAPHY (OCEAN TEMP, DEG CENT) /* 00006040
DATA NAME2/TOPOGRAPHY (SURFACE ELEVATION, HECTOFEET) */ 00006050
DATA NL/13/
RETURN
END
SUBROUTINE MAPA

// DD DISP=OLD,DSN=MES727,AMN,GIMMOM
// DD *
LOGICAL LEV, STAGJ, STAGI, ISL
COMMON /COUT/ IM(46), SURF, LEV, ISL, NAMF(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAMEL(13)
C
C GENOPOTENTIAL HEIGHT SURFACE,
C MAP TYPE 6
C
IM2=IM-2
JM1=JM-1
STAGI=.FALSE.
STAGJ=.FALSE.
L1=1
L2=2
PSK=SURF**KAPA
HR=RGAS/2.
IMM2=IM-2
SIGL1=SIG(L1)
SIGL2=SIG(L2)
DO 110 I=1,NL
110 NAME(I)=NAMEL(I)
DO 220 I=1,IM
IF MOD(I,IM)+1
IM=MOD(I+IM)+1
DO 220 J=1,JN
SP=PI(J,1)
PL1=(SIGL1*SP*PTR(IP))
PL1K=PL1**KAPA
PL2=(SIGL2*SP*PTR(IP))
PL2K=PL2**KAPA
PS2=(PL2*PTR(IP))/PL2
IF (LEV) PSK=(SIGL*SP*PTR(IP)**KAPA
PKDTK=KAPA*(PL2K-PL1K)*2.
PLIKS=PL1K**2
PL2KS=PL2K**2
PSKS=PSK**2
PTLTP2=PL1K*PL2K**2.
XT2=PS2+(PLZKS-PTTP2-PLIKS-2.*PSKS+4.)*PLIK*PSK /PKDTK/PL2K
XT2=PS2+(PLZKS+PTTP2-PLIKS-4.)*PL2K*PSK+2.*PSKS /PKDTK/PL1K
WORK2(J,1)=XT1*XT(J,1,L1)+XT2*XT(J,1,L2)*HR+VPW1(J,1)/GRAV

C 410 ZMM=0.0
    WTM=0.0
    DO 430 J=1,JM
    SUM=0.0
    CLAT=AHS(DXYP(IJ))
    (II) 420 I=1,IM
        ZM(I,J)=SUM/FIM
        WTM=WTM+CLAT
    430 ZMM=ZMM+ZM(I,J)*CLAT
        ZMM=ZMM/WTM
        SPDL=ZM(1)
        NWDL=ZM(JM)
C DATA NAMEL/"GEOPOTENTIAL HEIGHT (HECTIMETERS)"
-data NL/13/
RETURN
END
SUBROUTINE MAP

// DD DISP=OLD, DSN=HS727., ARR, COMM
// DD *
C
COMMON /COUT/ ZM(46), SURFLEVEL, ISL, NAMEF(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(131)
C
SURFACEPRESSURE, MAP TYPE 7
L1=1
L2=2
C
FIM=1M
IMM2=1M-2
JMM1=JM-1
STAGJ=.FALSE.
STAGI=.FALSE.
SIG1=SIG(1)
SIG3=SIG(12)
FLR=.5, 1R2/(130.4*GRAV)
C
DO 110 I=1,NL
110 NAMEF(II)=NAMEF(II)
C
II M=0,0
DO 118 J=1,JM
118 ZM(J)=0,0
C
DO 128 I=1,IM
1M=MNI(1*IMH2, IM)+1
1P=MNI(1, IM)+1
DO 128 J=1,JM
PH14=VPH14(J, 1)
PJI=P(J, 1)
C
T14=1LM(03T(J, 1))
C
T4=TT4/10.
C
EXTRAPOLATED SURFACE AIR TEMPERATURE
T1=T(J, 1, L1)
T3=T(J, 1, L2)
T4=1.5*T3-0.5*T1
RTM=RGAS*(T4+FLR*PH14)
ACC=(PJI+PTNP)*EXP(PHI4/H1M)-PSL
ZM(J)=ZM(J)+ACC
128 WINEK/P(J, 1)=ACC
C

MTM=0.0
DO 150 J=1,JM
   ZM(J)=ZM(J)/FIN
   MTM=MTM + ABS(DXYP(J))
150 ZMM=ZMM+ZM(J)*ARS(DXYP(J))
C ZMM IS GLOBAL MEAN SURFACE PRESSURE
   ZMM=ZMM/WTM
   SPOL=WORK2(1,1)
   NPOL=WORK2(JM,1)
C
   DATA NAMEL/'SFA LEVEL PRESSURE UNSMOOTHED (MR-1000.) 
   DATA NL/13/
   RETURN
C
   END

00007190
00007200
00007210
00007220
00007230
00007240
00007250
00007260
00007270
00007280
00007290
00007300
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00007320
00007330
00007340
00007350
SUBROUTINE MAPZ

// DD D1SR=OLD, D2N=NEST727, ARN.COMMON
// DD *
// COMMON /COUT/ ZM(16), SURFLEFVEIL, NAME(13)
// LOGICAL LEV, STAGJ, STAGI, ISL
// EQUIVALENCE (SIGL, SURF)
// DIMENSION NAMEL(13)
C TOTAL HEATING, MAP TYPE A
C DIMENSION MZ1(100), MZ3(100)
FIM=IM
C
C STAGJ=.,FALSE,
C STAGI=.,FALSE,
L1=1
L2=2
SIGL1=SIGL(1)
SIGL2=SIGL(2)
DSIG=1.0/(SIGL2-SIGL1)
SURFMT=SURF-PTRO
IF (LEV) SIGX=SIGL
C
C DD 110 I=1,NL
C NAME(I)=NAMEL(I)
C
C DD 220 J=1,JM
C IF (.NOT.LEV) SIGX=SURFMT/P(J,1)
C H1=IM(PT(J,1))
C H1=H1/100.
C H3=IM(PT(J,1))
C H3=H3/100.
C IF (J,NE,1) GO TO 220
C MZ1(J)=H1
C MZ3(J)=H3
C 220 WORK2(J,1)=DSIG*(SIGL2-SIGX)*H1 + (SIGX-SIGL1)*H3

00007200
00007310
00007320
00007330
00007340
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00007360
00007370
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00007600
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00007630
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00007650
00007660
00007670
00007680
00007690
00007700
00007710
00007720
C
   DO 118 J=1,JM
118  ZM(J)=0.0
C
   ZMM=0.0
   WTM=0.0
   DO 430 J=1,JM
   SUM=0.0
   CLAT=ABS(DXYP(J))
   DO 420 1=1,IM
420  SUM=SUM+WORK2(J+1)
   ZM(J)=SUM/FIM
   WTM=WTM+CLAT
430  ZMM=ZMM+ZM(J)*CLAT
   ZMM=ZMM/WTM
   SPOL=ZM(J)
   NPOL=ZM(JM)
C
   DATA NAMEL/"TOTAL HEATING (DEG CENT/DAY)"
   DATA NL/13/
   RETURN
C
   END
SUBROUTINE MAPS

// 00 DISP=OLD,DSN=MEST727,AKN,COMMON
// (M) C
LOGICAL LEV, STAG1, STAGJ, ISL
DIMENSION NAME(13)
COMMON /COUT/, ZM(44), SURF, LEV, ISL, NAME(13)
EQUVALENCE (SURF, SIGL)

C LARGE SCALE PRECIPITATION, MAP TYPE 9
C
FIM = 1M
FJM = JM
STAG1 = FALSE.
STAGJ = FALSE.

C DO 110 IM=1, NL
110 NAME(IM)=NAME(IM)
C
C DO 220 J=1, JM
220 WORK2(J, 11)=PLSC/10.
C
ZMM=0.0
WM=0.0
DO 450 J=1, JM
450 SUM=SUM+WORK2(J, 1)
CLAT=ABS(DXP(J))
ZM(J)=SUM/FIM
WM=WM+CLAT
450
ZMM=ZMM*ZM(J)*CLAT
ZMM=ZMM/WM
SPIL=ZM(J)
NPIL=ZM(J)
C
DATA NAMEL/LARGE SCALE PRECIPITATION (MM/DAY)
DATA NL/13/
RETURN
FMI

C 00007960
C 00007970
C 00007980
C 00007990
C 00008000
C 00008010
C 00008020
C 00008030
C 00008040
C 00008050
C 00008060
C 00008070
C 00008080
C 00008090
C 00008100
C 00008110
C 00008120
C 00008130
C 00008140
C 00008150
C 00008160
C 00008170
C 00008180
C 00008190
C 00008200
C 00008210
C 00008220
C 00008230
C 00008240
C 00008250
C 00008260
C 00008270
C 00008280
C 00008290
C 00008300
C 00008310
C 00008320
C 00008330
C 00008340
C 00008350
C 00008360
C 00008370
C 00008380
SUBROUTINE MAP1Q

C // 00 DISP=OLD,DSN=H5EST27,ABM,COMMON
// 00 DO * 0
C // LOGICAL LEV, STAGJ, STAGI, ISL
COMMON /COUT/ IM(46),SURF,LEV,ISL,NAME(13)
EQUIVALENCE (SURF,STGL)
DIMENSION NAME(13)
DIMENSION COMMON(46,2)
C
C VERTICAL VELOCITY, MAP TYPE 10
C
C FIN=IM
IM2=IM-2
JMM1=JM-1
STAGJ=.FALSE.
STAGI=.FALSE.
C
ON 110 1=1,NL
110 NAME(I)=NAME(I)
C
2149 L=1
2150 DO 2160 I=1,IM
IP1=MOD(I,IM)+1
DO 2160 J=2,JMM1
PU(I,J)=0.25*(OU(J)*U(I,J,L)+OU(J+1)*U(I,J+1,L))
2160 CONTINUE
C
CALL AVRX(I1)
C
2170 DO 2180 I=1,IM
IP1=MOD(I,IM)+1
IM1=MOD(I+1,IM)+1
ON 2170 J=2,JMM1
2170 PU(I,J)=PU(J,I)*(P(J,I)+P(J,IP1))
2180 CONTINUE
C
C EQUIVALENT PU AT POLES. PV(1,1) IS USED AS A WORKING SPACE.
C
VM1=0.0
VM2=0.0
ON 2185 I=1,IM
VM1=VM1+PV(2,I)
2185 VM2=VM2+PV(IM,J)
VM1=VM1/FIN
VM2=VM2/FIN
PV(1,1)=0.0
DO 2190 I=2, IM

2190 PV(1, I)=PV(1, I-1)+(PV(2, I)-VM1)
VM1=0.0
DO 2192 I=1, IM

2192 VM1=VM1+PV(1, I)
VM1=VM1/FIM
DO 2195 I=1, IM

2195 PV(1, I)=(PV(1, I)-VM1)*3.0
PV(1, I)=0.0
DO 2200 I=2, IM

2200 PV(1, I)=PV(1, I-1)+(PV(JM, I)-VM2)
VM2=0.0
DO 2202 I=1, IM

2202 VM2=VM2+PV(1, I)
VM2=VM2/FIM
DO 2205 I=1, IM

2205 PV(JM, I)=(PV(1, I)-VM2)*3.0
DO 2400 I=1, IM
IM1=MOD(I+1,IM2+1)+1
DO 2400 J=1, JM
IF (J, EQ, 1) CONVM=PV(2, I)*0.5
IF (J, EQ, JM) CONVM=PV(JM, I)*0.5
IF (J, GT, 1, AND, J, LT, JM) CONVM=-(PV(J, I) - PV(J, IM1) + PV(J+1, I) - PV(J, I))*0.5
IF (L, EQ, 1) CONVM(J, I)=CONVM
IF (L, EQ, 2) PV(J, I)=CONVM

2400 CONTINUE
IF (L, EQ, 2) GO TO 2410
L=2
GO TO 2150

2410 CONTINUE
CONM IS MASS CONVERGENCE AT L=1 AND PV IS THAT AT L=2.

```
2411    PH1=0.0
         PH2=0.0
         PH3=0.0
         PH4=0.0
      DO 2402 1=1,1M
         PR1=PR1+CONM(1,1)
         PR2=PR2+CONM(JM,1)
         PR3=PR3+PV(1,1)
      END
2402    PB4=PB4+PV(JM,1)
         PB1=PR1/FIM
         PB2=PR2/FIM
         PB3=PR3/FIM
         PB4=PR4/FIM
      DO 2405 1=1,1M
         CONM(1,1)=PH1
         CONM(JM,1)=PR2
         PV(1,1)=PB3
      END
2405    PV(JM,1)=PB4
      DO 2420 1=1,1M
      DO 2420 J=1,1M
         WW=CONM(J,1)-PV(J,1)
         WORK2(J,1)=3600.*WW/12.0*DXYPJ(J)
      END
2420    CONTINUE
```

```
410    ZMM=0.0
         WTM=0.0
      DO 430 J=1,1M
         SUM=0.0
      DO 420 1=1,1M
        SUM=SUM+WORK2(J,1)
        CLAT=ABS(DXYPJ(J))
        ZMJ=SUM/FIM
        WTM=WTM+CLAT
      END
430    ZMM=ZMM+ZMJ*CLAT
         ZMM=ZMM/WTM
         NPDL=ZMJ
         SPOIL=ZMJ
```

```
C DATA NAMEL/"SIGMA VERTICAL VELOCITY (MM/H)
DATA NL/13/
RETURN
END
```
SUBROUTINE AVRX(K)

* THIS SUBROUTINE USES UT(1,1,1) AS A WORKING SPACE

JMM1=JM-1
JM2=JM-2
JE=JM/2+1
OEFF=DYP(JE)
DO 150 J=2,JMM1
ORAT=OEFF/DXP(J)
IF (ORAT .LT. 1.) GO TO 150
ALP=0.125*(ORAT-1.)
NM=ORAT
FNM=NM
ALPHA=ALP/FNM
DO 150 N=1,NM
DO 120 I=1,IM
IP1=MOD(I,IM)+1
IM=MOD(1+JM2,IM)+1
120 UT(1,1,1)=CT(J,1,K)+ALPHA*(CT(J,1P1,K)+CT(J,1M1,K)-2.*CT(J,1,K))
DO 130 I=1,IM
130 QT(J,1,K)=UT(1,1,1)
150 CONTINUE

RETURN

END
SUBROUTINE MAP11
// DO DSP=OLD, OSN=MESS72, AHN.COMMON
// DO *
LOGICAL LEV, STAGI, STAGJ, ISL
COMMON /COUT /ZM(46), SURF, LEV, ISL, NAME(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAME(13)
C
C RELATIVE HUMIDITY, MAP TYPE 11
FIM = IM
FJN = JM
STAGI=FALSE.
STAGJ=FALSE.
C
DO 110 I=1, NL
110 NAME(I)=NAMEJ(I)
C
DO 220 J=1, JM
220 WORK2(J, I) = RH3*100.
C
410 WS=0.0
WN=0.0
DO 415 J=1, JM
415 WS=WS+WORK2(J, I)
415 WN=WN+WS/FIM
WS=WN/FIM
DO 420 I=1, NL
420 WORK2(JM, I)=WN
C
C
ZMM=0.0
WTM=0.0
00 450 J=1, JM
SUM=0.0
00 430 I=1, IM
430 SUM=SUM + WORK2(J, I)
   CLAT=ARS(DXYP(J))
   ZM(J)=SUM/FIM
   WTM=WTM+CLAT
450 ZMM=ZMM+ZM(J)*CLAT
   ZMM=ZMM/WTM
   SPOL=ZM(1)
   NPOL=ZM(JM)
C
DATA NAMEL/'RELATIVE HUMIDITY (PERCENT)'/
DATA NL/13/
RETURN
END
SUBROUTINE MAP12

* DD DISP=OLD,DSN=MES27.ARN.COMMON
  DD *
  LOGICAL LEV, STAGI,STAGJ, ISL
  COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)
  EQUIVALENCE (SURF,SIGL)
  DIMENSION NAMEL(13)

C PRINCIPITABLE WATER IN CM, MAP TYPE 12
C
FIM = IM
STAGI=.FALSE.
STAGJ=.FALSE.

C DO 110 I=1,NL
110 NAME(I)=NAMEL(I)
C
C DO 220 J=1,JM
DO 220 J=1,JM
220 WORK2(J,1) = 03(J,1)*P(J,1)*0.5*(10.0/GRAV)
C
C DO 410 I=1,IM
DO 410 I=1,IM
410 WS=0.0
WS=WS+WORK2(I,1)
415 WN=WS/FIM
WN=WN/FIM
DO 420 I=1,IM
420 WORK2(I,1)=WN
C
C ZMM=0.0
ZMM=0.0
C DATA NAMEL/*PRINCIPITABLE WATER (CM)
DATA NL/13/
RETURN
END
SUBROUTINE MAP13
/
// DD DISP=D00,DSN=MES727,ARN,COMMON
// DD *
// LOGICAL LEV, STAGI,STAGJ, ISL
COMMON /COUT/, ZM(44), SURF, LEV, ISL, NAMF(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAMEF(13)
C
C CONVECTIVE PRECIPITATION (MM/DAY) MAP TYPEF 13
C
STAGI=.FALSE.*
STAGJ=.FALSE.*
F1M = 1M
C
DO 110 I=1, NL
NAMEF(I)=NAMF(I)
C
DO 250 I=1, 1M
DO 250 J=1, JM
CP=IKM(U(1,J,1,2))
250 WORK2(I,J)=CP/10.
C
410 WS=0.0
WN=0.0
DO 415 I=1, 1M
WS=WS+WORK2(I,1)
415 WN=WN+WORK2(JM, I)
WS=WS/F1M
WN=WN/F1M
DO 420 I=1, 1M
WORK2(I,1)=WS
420 WORK2(I,JM)=WN
C
ZMM=0.0
WTM=0.0
DO 430 J=1, JM
SUM=0.0
DO 430 I=1, 1M
SUM=SUM+WORK2(J, I)
430 CLAT=ARSN(DXPY(J))
ZM(J)=SUM/F1M
WTM=WTM+CLAT
ZMM=ZMM+ZM(J)=CLAT
ZMM=ZMM/WTM
SPOL=ZM(1)
NPOL=ZM(JM)
C
DATA NAMF='CONVECTIVE PRECIPITATION (MM/DAY)' NAMF NL/13/ RETURN
END
SUBROUTINE MAP14

C LOGICAL LEV, STAG1, STAG2, ISL,
C COMM/N /COUT/ ZM(46), SURF+LEV+SL, NAME(16)
C EQUIVALENCE (SURF+SIGL)
C DIMENSION NAMEL(16)

C EVAPORATION (E4 IN MM/DAY), MAP TYPE 14

C STAG1=FALSE
C FIM=IM
C STAG2=FALSE
C IMM1=IM-1
C IMM2=IM+2
C JMM1=JM-1
C JMM2=JM+2
C DO 110 I=1,IM
C NAME(I)=NAMEL(I)

C UN 250 I=1,IM
C DO 250 J=1,JM
C F4=IM(N(J+1,2))

C WS=0.0
C WN=0.0
C UN 410 I=1,IM
C WS=WS+WORK2(I,1)
C 410 WN=WN+WORK2(JM,1)
C WS=WS/FIM
C WN=WN/FIM
C UN 420 I=1,IM
C WORK2(I,JM)=WS
C 420 WORK2(JM,1)=WN
C
ZMM=0.0
WTM=0.0
DO 450 J=1,JM
SUM=0.0
DO 430 I=1,IM
430 SUM=SUM + WNK2(J,I)
CLAT=ABS(OXYP(J))
ZM(J)=SUM/FIM
WTM=WTM+CLAT
450 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WTM
SPOL=ZM(J)
NPOL=ZM(JM)
C
DATA NAMEL/EVAPORATION (MM/DAY)/*
DATA NL/13/
RETURN
ENO
SUBROUTINE MAP15

DIMENSION NAME1(13)
COMMON /COUT/ ZM46, SURF, LVE, ISL, NAME1(13)
COMMON LVE, STAGJ, STAG{, ISL

C

C SENSIBLE HEAT FLUX (F4 IN TENS OF CAL/CN**2/DAY) MAP 15

C STAGJ, FALSF
C STAGJ, FALSF
C FL=1M
C IMM1=1M-1
C IMM2=1M-2
C JMM1=JM-1
C JMM2=JM-2
C ON 110 I=1, NL
C NAME1(1)*NAME1(1)
C ON 350 I=1, IM
C ON 350 J=1, JM
C F4=1LHMTT(JM, 1, 2)
C 350 WORK2(JM, 1)=F4/10.

C

C 410 WS=0.0
C WN=0.0
C ON 415 I=1,IM
C WS=WS+WORK2(I, 1)
C 415 WN=WN+WORK2(I, 1, 1)
C WS=WS/F1M
C WN=WN/F1M
C ON 420 I=1, IM
C WORK2(I, 1)=WS
C WORK2(I, JM, 1)=WN

C

C 420

C 430 SUM=SUM + WORK2(JM, 1)
C CLAT=ANSM(DXYP, J)
C JMJ1=SUM/F1M
C WM=WM+CLAT
C 430 SUM=MJM+CLAT
C WM=MJM/WM
C 430

C DATA NAME1, "SENSIBLE HEAT FLUX (10 CAL/CN**2/DAY)"
C DATA NL/13/
C RETURN

C
SUBROUTINE MAP 16

// DD DISP=OLD, DSN=MES272, ABN=COMMON
// DO 0
LOGICAL LEV, STAGJ, STAGL, ISL
COMMON /CNUT/ ZM(14), SURF,LEV,ISL,NAME(13)
EQUIVALENCE (SURF,STGL)
DIMENSION NAMEL(13)

C
LOW LEVEL CONVECTION (DEG) MAP TYPE 16

C
FIM=1M
STAGJ=.FALSE.
STAGL=.FALSE.

C
DO 110 I=1,NL
NAME(I)=NAMEL(I)

C
DO 220 J=1,IM
FLSC=ILHM(I,J,1,21)
220 WORK2(I,J,1)=FLSC/10.

C
410 ZMM=0.0
WMN=0.0
DO 430 J=1,IM
SUM=0.0
DO 420 I=1,IM
SUM=SUM+WORK2(I,J,1)
CLAT=ABS(DXYP(I,J))
ZM(J)=SUM/FIM
WMN=WMN+CLAT
430 ZMM=ZMM*ZM(J)+CLAT
ZMM=ZMM/WMN
NPOL=ZM(JM)
SPOL=ZM(J)

C
DATA NAMEL/* LOW LEVEL CONVECTION (DEG, CNT)
DATA NL/13/
RETURN

C
END
SUBROUTINE

* MAP 17

// 00 0ISP*OLO*OSN=MES727*ABN.COMMON
// DD *
LOGICAL LEV, STAGJ, STAGI, ISL
COMMON /COUT/ ZM(I46), SURF, LEV, ISL, NAMF(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAMEL(I3), DIRECTION, MAP TYPE 17

C WIND DIRECTION, MAP TYPE 17
C (NORMALLY POLAR PROJECTED)
C
PID2=PI/2
PID2T3=PID2*3.
PT2=PT2.
RPI35=35./PT2

C
JN 220 I=1,I M
ON 220 J=1, J M
WU=WORK1(J, I)
WV=WORK2(J, I)
K=1
IF (WU.GE. 0.) K=K+1
IF (WV.GE. 0.) GO TO (103, 104), K
IF (WU.GE. 0.) K=K+2
IF (WV.GE. 0.) K=K+4
ANG=ATAN(WU/WV)
GO TO 1220, 101, 102, 102, 101, 101, 102, 102), K

101 ANG=ANG+PT2
GO TO 220

102 ANG=ANG+PI
GO TO 220

103 ANG=PT2
GO TO 220

104 ANG=PT2T3
GO TO 220

220 WORK2(J, I)=ANG*RPI35*1.0
C
DC 110 I=1,NL
110 NAME(I)=NAMEL(I)
   STAGJ*=TRUE.
   STAG1*=TRUE.
   FIM=1M
C
410 ZMM=0.0
   WTM=0.0
   DO 430 J=1,JM
   SUM=0.0
   DO 420 I=1,IM
420 SUM=SUM+WORK2(J,I)
   CLAT=ABS(COS(LAT(J))
   ZM(J)=SUM/FIM
   WTM=WTM+CLAT
430 ZMM=ZMM+ZM(J)*CLAT
   ZMM=ZMM/WTM
   SPOL=ZM(JM)
   NPOL=ZM(JM)
C
DATA NAMEL/*WIND DIRECTION
DATA NL/13/
RETURN
C
C
END
SUBROUTINE MAP 1A
  // 00013780
  // 00013790
  // 00013800
  // 00013810
  // 00013820
  // 00013830
  // 00013840
  // 00013850
  // 00013860
  // 00013870
  // 00013880
  // 00013890
  // 00013900
  // 00013910
  // 00013920
  // 00013930
  // 00013940
  // 00013950
  // 00013960
  // 00013970
  // 00013980
  // 00013990
  // 00014000
  // 00014010
  // 00014020
  // 00014030
  // 00014040
  // 00014050
  // 00014060
  // 00014070
  // 00014080
  // 00014090
  // 00014100
  // 00014110
  // 00014120
  // 00014130
  // 00014140
  // 00014150
  // 00014160
  // 00014170
  // 00014180
  // 00014190
  // 00014200
  // 00014210
  // 00014220
  // 00014230
  // 00014240
  // 00014250
  // 00014260
  // 00014270
  // 00014280
  // 00014290
  // 00014300

  MAP 1A
  LOGICAL LEV, STAGJ, STAGI, ILS
  COMMON /COUT/, ZM(46), SURF.SIGL, ISL, NAME(13)
  EQUVALENCE (SURF.SIGL)
  DIMENSION NAME(13)

  MAP WIND DIRECTION, MAP TYPE 1A
  (MEANINGFUL ON CYLINDRICAL PROJECTION ONLY)

  P102*P1*5,
P1023=P102*3,
P102=P1*2,
  PDI1=1A/P1

  DO 220 1=1,IM
  DO 220 J=1,JM
  WU=WORK(J,1)/DXU(J)
  WY=WORK2(J,1)/DYY(J)
  IF (WU .EQ. 0. .AND. WY .EQ. 0.) WY=1.
  ANG=ATAN2(WU,WY)
  IF (ANG .LT. 0.) ANG=ANG+PI12
  WORK(J,1)=ANMD(ANG*PDTM+1A,36)

  DO 110 J=1,NL
  NAME(I)=NAMEL(I)
  NIN=IM
  STAGJ=TRUE
  STAGI=TRUE

  ZMM=0.0
  WTM=0.0
  DO 430 J=1,JM
  SUM=0.0
  DO 420 I=1,IM
  SUM=SUM+WORK2(I,J)
  CLAT=ABS(COS(LAT(I)))
  ZM(J)=SUM/F1M
  WMM=WTM+CLAT
  ZMM=ZMM+ZM(J)
  ZMM=WMM/WTM
  SPOL=ZM(1)
  NPOL=ZM(JM)

  DATA NAMEL/MAP WIND DIRECTION
  DATA NL/13/
  RETURN

  END
* S U R R O U T I N E  *

// MAP10
// OD OISP=OLO, OSN=RES727, ABN.COMMON
// OD *
COMMON /COUT/, ZX(I,1), SURF, LRV, ISL, NAME(I)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(I)
LOGICAL LHLF
C
LONG WAVE COOLING. MAP TYPE 19
C
FIM=0,M
STAGJ=., FALSE.
STAGI=., FALSE.
C
LHLF= SURF .LT. 0.5
ON 110 IF=1,ML
110 NAME(I)=NAME(I)
ON 118 J=1,MJ
118 ZM(J)=0.0
C
ON 150 I=1,IM
ON 150 J=1,JM
IF (LHLF) GO TO 125
ACC=LMVT(J=1,2)
ACC=ACC/100.
GO TO 140
125 ACC=LMVT(J=1,2)
ACC=ACC/100.
140 ZM(J)=ZM(J)+ACC
150 WTM2(J=1)=ACC
C
ZMM=0.
WTM=0.0
ON 155 J=1, JM
WTM=WTM + ABS (DXY(J):)
ZM(J)=ZM(J)+FIM
155 ZMM=ZMM+ZM(J)+ABS (DXY(J))
ZMM=ZMM/WTM
SPOL=ZM(1)
NPOL=ZM(J)
C
DATA NAMEF/10. LONG WAVE HEATING IN LAYERS (DEG CENT/DAY) /
DATA ML/10/
RETURN
C
END
SUBROUTINE MAP20
// OD OISP=OLD.OSN=MES72,FABN.COMMON
// OD 
COMMON /CDUT/ ZM(44),SURF,LEV,ISL,NAME(13)
C ABSORPTION OF INSOLATION, MAP TYPE 20
LOGICAL LEV, STAGJ, STAG1, ISL
DIMENSION NAMEL(13)
LOGICAL LHLF
C
FIN=IM
STAGJ=.FALSE.
STAG1=.FALSE.
C
LHLF=.SURF,GT,5
OD 110 I=1,NL
110 NAME(I)=NAME(1)
C
OD 110 J=1,JM
110 ZM(J)=O.
C
DD 150 I=1,IM
DD 150 J=1,JM
IF (LHLF) GO TO 125
ACC=1LMT{TIIJ,J*111})
ACC=ACC/100.
GO TO 140
125 ACC=1M(TII,J,1,1))
ACC=ACC/100.
140 ZM(J)=ZM(J)+ACC
150 WORKZ(J,1)+ACC
C
ZMM=0.0
WMM=0.0
OD 150 J=1,JM
WMM=WMM+ABS(DXP(J))
ZM(J)=ZM(J)/FIN
150 ZMM=ZMM+ZM(J)+ABS(DXP(J))
ZMM=ZMM/WMM
SPDL=ZM(1)
NPD=ZM(JM)
C
DATA NAMEL/"ABSORPTION OF INSOLATION IN LAYERS (DEG CENT/DAY) "/
DATA NL/13/
RETURN
C
END
**SUBROUTINE MAP21**

// DD DISP=OLD,DSN=MEST727,ARN,COMM/N
// DD *
LOGICAL LEV, STAGJ, STAGI, ISL
COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)
EQUIVALENCE (SURF,SIGL)
DIMENSION NAMEL(13)
C
C WIND SPEED, MAP TYPE 21
C
1MM2=1MM-2
JMM1=JMM-1
C
DO 110 I=1,NL
110 NAME(I)=NAMEL(I)
C
STAGJ=.TRUE.,
STAGI=.TRUE.,
C
DO 330 J=1,IM
DO 330 J=2,IM
WIND=WORK2(J,1)**2+WORK1(J,1)**2
330 WORK2(J,1)=SORT(WIND)
C
FIM=1M
ZMM=0,0
WIM=0,0
DO 430 J=2,IM
SUM=0,0
420 SUM=SUM+WORK2(J,1)
CLAT=ARCCOS(
*ZM(J)+LAT(J-1)+LAT(J))/FIM
ZM(J)=SUM/FIM
WIM=WIM+CLAT
430 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WIM
SPOL=ZM(J)
NPOL=ZM(J)
C
DATA NAMEL/MAGNITUDE OF THE VECTOR WIND (M/SFC)/
DATA NL/13/ RETURN
C
END
SUBROUTINE MAP22

DIMENSION NAMEL(13)

COMMON /COUT/ ZM(146), SURFLEV, ISL, NAME(13)
LOGICAL LEV, STAGJ, STAGI, ISL

SURFACE INSOLATION MAP TYPE 22

FLM=IM
STAGJ=.FALSE.
STAGI=.FALSE.

DO 110 J=1, NL
110 NAME(J)=NAMEL(J)

DO 150 J=1, JM
150 ZM(J)=0.0

DO 275 J=1, JM
275 ACC=AM(SDI(J))

ZMIJ=ZMIJ+ACC

WORK2(J)=ACC

ZMM=0.0
WTM=0.0

DO 158 J=1, JM
158 WTM=WTM + ARS(DXY(J))

ZM(J)=ZM(J)/WTM

ZMM=ZMM+ZMIJ*ARS(DXY(J))

SPOL=ZM(J)
NPSL=NPSL ZM(J)

DATA NAMEL/"SURFACE INSOLATION ABSORPTION (100 CAL/CM**2/DAY) */
DATA NL/13/

RETURN

END
SUBROUTINE MAP 23

// DD *
LOGICAL LEV, STAGJ, STAGI, ISL
COMMON /COUT/ ZM(46), SURF.LEV, ISL, NAMEL(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAMEL(13)
C
SURFACE AIR TEMPERATURE, MAP TYPE 23
C
DIMENSION NAMEL(13)
C
C
DO 110 I=1, NL
110 NAME(I)=NAMEL(I)
C
DO 220 J=1, JM
220 WORK2(J,I)=TT4/10. - TICE
C
SUM=SUM+WORK2(J,I)
C
ZMM=ZMM+SUM/FIM
C
ZMM=ZMM/WTM
C
DATA TICE/273.1/
DATA NAMEL/'SURFACE AIR TEMPERATURE (DEG CENT)'
DATA NL/13/
C
RETURN
END

SUBROUTINE MAP24

COMMON /CDUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /CDUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

 COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMEL(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

RETURN
END
SUBROUTINE MAP25

// DO DISP=OLD,DSN=MESS727,ABN,COMMON
// DO =
// COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMES(13)
// LOGICAL LEV, STAGJ, STAGI, ISL
// DIMENSION NAMEL(13)
C
C WETNESS, MAP TYPE 25
C
FIM=IM
JIM2=IM-2
JMM1=JM-1
STAGJ=.FALSE.
STAGI=.FALSE.
C
DO 110 I=1,NL
110 NAME(I)=NAMEL(I)
C
ZMM=0.0
DO 118 J=1,JM
118 ZM(J)=0.0
C
DO 128 I=1,IM
DO 128 J=1,JM
ACC=GW(J,1)*10.
ZMIJ=ZM(J)+ACC
C
128 WORK2(J,1)=ACC
C
WTM=0.0
DO 15A J=1,JM
WTM=WTM+ARS(DXYP(J))
ZM(J)=ZM(J)/FIM
15A ZMM=ZMM+ZM(J)*ARS(DXYP(J))
ZMM=ZMM/WTM
SPOL=ZM(1)
NPOL=ZM(JM)
C
DATA NAMEL/'GROUND WETNESS (SCALES) ZERO TO TEN'
DATA NL/13/
C
RETURN
C
END
SUBROUTINE MF

// DD DISP=XLN,DSN=MF5727,ARN,COMMON
// DD *
COMMON /COUT/ ZM(46),SURF,LEV,SL,NAMF(I,13)
LOGICAL LEV, STAGJ, STAGI, ISL
COMMON /EXCM/CC(46,72,4),CPC1(46,72),CPC3(46,72),
* PRCLH(46,72),SR4(46,72)
DIMENSION NAME(1,13),NAMF(1,13),NAMF3(I,13)
C
C
FIM=JM
STAGJ=FALSE
STAGI=FALSE
C
K=1
IF (SURF.GT.0.5) K=2
IF (SURF.EQ.1.0) K=3
IF (SURF.GT.1.0) K=4
ON 110 I=1, NL
NAME(I)=NAMF1(I)
IF (K.EQ.2) NAME(I)=NAMF2(I)
IF (K.EQ.3) NAME(I)=NAMF4(I)
ON 110 I=1, NL
NAME(I)=NAMF3(I)
C
ON 150 J=1, JM
150 ZM(J)=0.0
C
ON 275 I=1,1M
ON 275 J=1, JM
ACC=CC(J,I,K)
IF (ACC.LT.0.0) ACC=0.0
ZM(J)=ZM(J)+ACC
275 WORK2(J,I)=ACC
C
JMM=0.0
WTM=0.0
ON 15A J=1, JM
WTM=WTM + AHS(XXXP(J))
ZM(J)=ZM(J)/FIM
15A ZMM=ZMM+ZM(J)*AR3I(XXXP(J))
ZMM=2M/MM/WTM
NDOL=ZM(J)
C
DATA NAME1/*HIGH CLOUDINESS* / 00017840
DATA NAME2/*MIDDLE CLOUDINESS* / 00017850
DATA NAME3/*LOW CLOUDINESS* / 00017860
DATA NAME4/*CLOUDINESS* / 00017870
DATA NL/13/ 00017880
RETURN
C
FND
00017900
SUBROUTINE MAP27

COMMON /COIN/ ZM(46), SURF, LEV, ISL, NAMF(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMF(13)

C
F1M=1M
C
STAGJ=.FALSE.,
STAGI=.FALSE.,
C
DO 110 I=1, NL
NAME(I)=NAMFL(I)
C
DO 220 J=1, JM
DO 220 1=1, IM
220 WORK2(J, 1)+P1NP+SURF*P(J, 1)
C
DO 118 J=1, JM
ZM(J)=0.0
C
ZMM=0.0,
WTM=0.0,
DO 420 J=1, JM
SUM=0.0,
CLAT=AHM(NXJMP(J)),
DO 420 1=1, IM
420 SUM=SUM+WORK2(J, 1)
ZMJ=SUM/FIM
WTM=WTM*CLAT
430 ZMM=ZMM/ZMJ*CLAT
ZM=ZMM/WTM
SPNL=ZM(1)
NPNL=ZM(JM)
C
DATA NAMFL/ 'PRESSURF AT SIGMA SURFACE /
DATA NL/ 13/
RETURN
C
FIN
**SUBROUTINE**

* MAPZB

// DD DISP=MLB, DSN=MR5727.AHN.COMMIN

// DD * COMMON /CMIT/ ZM1461, SURF, LEV, I & NAMFL(13)
LOGICAL LEV, STAGJ, STAGI, I &
EQUIVALENCE (SIGL, SURF1)
COMMON /EXCMN/ CC(46,72), CPC(146,72), CPC3(46,72),
* PRCLM(46,72), SR4(46,72)

**DIMENSION NAMEFL(13)**

C FIM=1

C STAGJ=FALSE
STAGI=FALSE
L1=1
L2=2
SIGL1=SIGL1
SIGL2=SIGL2
OSIG=1, SIGL2-SIGL1
SURFMT=SURF-PTRNP
IF (LEV) SIGX=SIGL

C DD 110 J=1, NL

110 NAME(11)=NAMEFL(11)

C DD 220 J=1, JM

220 WORKJ=1, INDG1=SIGL2-SIGX1*H1 + (SIGX-SIGL1)*H3

C DD 118 J=1, JM

118 ZMJ=0, 0

C DD 430 J=1, JM

430 SUM=0, CLAT=ARS(IXYPJ1)

C DD 420 I=1, IM

420 SUM=SUM+WKZ(J, 11)

C DD 410 J=1, JN

410 ZMJ=SUM/FIM

C DD 330 J=1, JM

330 ZMJ=ZMJ/WTM

C DATA NAMEFL, 'TOTAL CONVECTIVE HEATING (HEG CENT/MAY)
DATA NL/13/ RETURN

C END
SUBROUTINE MAP20

// DO DS=OLD,DSN=HESTM717,AHN=COMMON
// DO #
COMMON /COUT/ ZM1461,SURF,LEV,ISL,NAMF1131
LOGICAL LEV, STAGJ, STAGI, ISL
EQUIVALENCE (SIGL,SURF1)
COMMON /EXCM/CC(46,72,41,CPC1(46,72),CPC3(46,72),
* PRCLH(46,72),SR4(46,72)
DIMENSION NAME(1131)
C
F1=1
C
STAGJ=FALSF,
STAGI=FALSF,
LI=1
L2=2
SIGL1=SIG(L1)
SIGL2=SIG(L2)
DSIG1=(SIGL2-SIGL1)
SURFMT=SURF-PTROP
IF (LEV) SIGX=SIGL
C
DO 110 J=1,NL
110 NAME(I)=NAMFL(I)
C
DO 220 J=1,JK
IF (.NOT.LEV) SIGX=SURFMT/J(J,1)
H1=0.0
H3=PRCLH(J,1)
220 WORK2(J,1)=DSIG1*(DSIG1*H1 + (SIGX-SIGL1)*H3)
C
DO 118 J=1,LM
118 ZM(J)=0.0
C
ZMM=0.0
WMM=0.0
DO 430 J=1,LM
SUM=0.0
CLAT=AH5DXYP(J,1)
DO 420 I=1,IM
420 SUM=SUM+WORK2(J,I)
ZM(J)=SUM/FJM
WMM=WMM+CLAT
430 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WMM
SPOL=ZM(1)
NPIL=ZM(1)
C
DATA NAMFL/'LATENT HEATING IN LAYER (DFG CFNT/DAY)'
DATA NL/13/
RETURN
C
END
SUBROUTINE MAP30
!
DO 0150 ISN=MES727,ANN+COMMON
!
C
COMMON /COUT/ ZM(4A),SURF,LEV,ISL,NAME(13)
LOGICAL LEV, STAGJ, STAGI, ISL
COMMON /FXCOM/CC(46,72,41),CPC1(46,72),CPC3(4A,72),
! PRCLM(46,72),SR4(4A,72)
!
DIMENSION NAMEL(13)

C
!
F1M=JM
STAGJ=FALSE
STAGI=FALSE
!

00 110 J=1,NL
110 NAMEI(N)=NAME(1)
!
00 150 J=1,JM
150 ZM(J)=0.0
!
00 275 J=1,IM
00 275 J=1,JM
ACC=01*SR4(J,J)
ZM(J)=ZM(J)+ACC
!
275 WORK2(J,J)+ACC
!
ZMM=0.0
WTM=0.0
!
15A J=1,JM
WTM=WTM+AHSM(0XVP(J))
ZM(J)=ZM(J)/WM

!
15A ZMM=ZMM+ZM(J)=AHSM(0XVP(J))
! ZMM=ZMM/WTM
SPOL=ZM(1)
NPOL=ZM(JM)
!
C
DATA NAMEL/*SURFACE LONG-WAVE CIRCLING (100 CAL/CM**2/DAY)*/
DATA NL/13/
RETURN
!
C
END
SUBROUTINE MAP31

// DO DISP=HLD,ISN=MES727,ABN,COMM1N

// DO
// COMMON /COUT/ ZM(46),SURF,LFV,ISL,NAMF(13)
LOGICAL LFV,STAGI,STAGJ,ISL
COMMON /FXCIM/CL(46,72,4),CPCL1(46,72),CPCL3(46,72),
PRCLH(46,72),SR1(46,72)
DIMENSION NAMFL(13)

C
FJM=1M
STAGJ=.FALSE.
STAGI=.FALSE.
C
CALL MAP 22
ON 275 I=1,IM
ON 275 J=1,JM
275 WORK2(J,I)=WORK2(J,I)
CALL MAP 30
ON 280 I=1,IM
ON 280 J=1,JM
280 WORK1(J,I)=WORK1(J,I)-WORK2(J,I)
CALL MAP 15
ON 285 I=1,IM
ON 285 J=1,JM
285 WORK1(J,I)=WORK1(J,I)-0.1*WORK2(J,I)
CALL MAP 14
ON 290 I=1,IM
ON 290 J=1,JM
290 WORK2(J,I)=WORK1(J,I)-0.5*WORK2(J,I)
ON 300 J=1,JM
150 ZM(J)=0.0
ON 305 I=1,IM
ON 300 J=1,JM
300 ZM(J)=2*ZM(J)+WORK2(J,I)
C
ZMM=0.0
WTM=0.0
ON 155 J=1,JM
WTM=WTM + AHS2(0XYP(J))
ZMJ=ZMJ/FJM
155 ZMM=ZMM/WTM
SPNL=ZM(11)
NPNL=ZM(JM)
ON 110 I=1,NI
110 NAME(1)=NAMFL(1)
C
DATA NAMFL/Y SURFACE HEAT BALANCE (100 CAL/CM**2/DAY)
DATA NL/13/
RETURN
C
* "SUBROUTINE C M P 3秆
/*
// O I S P = O L O , D S N = M E S 7 2 7 . A R N , C O M M O N
//
// EQUIVALENCE ( K K K , X X X )
// LOGICAL I C F , L A N D , N C F A N , S N O W , K F Y
// COMMON / E X C N M / C C ( 4 8 , 7 2 , 4 ) , C P C I ( 4 8 , 7 2 ) , C P C 3 ( 4 8 , 7 2 ) ,
// * P R C L H ( 4 8 , 7 2 ) , S R 4 ( 4 8 , 7 2 )
* C
TRANS(X)=1./((1. + 1. 7 5 * X X X * 4 1 6 )
TRSW(X)=-2 7 1 * X X X , 3 0 3
* C
J M M 1 = J M - 1
J M M 2 = J M - 2
J M M 2 = J M - 2
J H = I M / 2 + 1
F I M = I M ( SIG1=SIG11)
SIG3=SIG12)
SIG3=SIG13=SIG14
* C
G M = 3 0 .
D T C 3 * F L O A T ( N C 3 ) * N T
R C N V = D T C 3 / T C N V
C L H = P S L * 0 . 2 4
P I O K = 1 0 0 0 . 0 0 K A P A
C T I = 0 . 0 5
C T I 0 = 0 . 6 4 * C T I
M I C E = 3 0 0 .
T I G E = 2 7 3 . 1
* C
P M = P S L - P T R N P
C N E = G R A V * 1 0 0 , / ( 0 . 5 * P M * 1 0 0 0 . * 0 . 2 4 )
C N E 1 = C N E * D T C 3 / 1 2 4 . * 3 6 0 0 . 1
SC A L F = C N F * 1 0 0 .
T S P D = N A V / D T C 3
S CA L E P = T S P D * 5 *( 1 0 . / G R A V ) * 1 0 0 .
C N R A D = 1 8 0 . / P I
C N R X = C N R A D * 0 . 0 1
F S D E D = S F D F Y
S N W N = 1 8 0 . - 1 5 . * G N S 1 . 9 A B 3 *( F S D F D Y - 2 4 . 6 8 A ) / ( C N R A D ) ) / C N R A D
S N W N S = - 4 0 . / C N R A D
* C
C
S U R F A C E W I N D M A G N I T U D E
* C
D O 1 0 1 = 1 . 1 M
D O 1 0 J = 2 . J M
U S = 2 . * ( S I G 3 * W I ( J + 1 . 2 ) - S I G 1 * W I ( J + 1 ) ) * 0 . 7
V S = 2 . * ( S I G 3 * W I ( J + 1 . 2 ) - S I G 1 * W I ( J + 1 ) ) * 0 . 7
F D I ( J , 1 ) = U S * U S + V S * V S
W M A G 1 = S O R T ( 1 . 5 *( F D I ( 2 , 1 ) )
W M A G J M = S O R T ( 1 . 5 *( F D I ( J M , 1 ) )
W M A G = S O R T ( 1 . 5 *( F D I ( J M , 1 ) + F D I ( J M , 1 ) )
W M A G J M = S O R T ( 1 . 5 *( F D I ( J M , 1 ) + F D I ( J M , 1 ) )
W M A G = S O R T ( 1 . 5 *( F D I ( J M , 1 ) + F D I ( J M , 1 ) )
W M A G J M = S O R T ( 1 . 5 *( F D I ( J M , 1 ) + F D I ( J M , 1 ) )
W M A G = S O R T ( 1 . 5 *( F D I ( J M , 1 ) + F D I ( J M , 1 ) )
C RADIATION CONSTANTS

SO=2800./RSNIST
ALC1=.7
ALC2=.6
ALC3=.6
STRT=1.17E-7
EFVC1=65.3
EFVC2=65.3
EFVC3=7.6
CPART=5*1.3071E7

C ROT = T06DAY/R0TPE*2.0*PI

C HEATING LOOP

DO 370 J=1,1M
IM=M0D(I+IM2,IM)+1
IP=M0D(I+IM),I+
FIM1=-1
MACOS=C0S(N*COS(RMT+F1M1*DL/

DO 360 J=1,JM
COS2=SIN(IJ)*SIND*COS(IJ)*MACOS

C SURFACE CONDITION

TGOO=TOPOG(I,J)
OCEAN=TGOO,G1,T.
ICE=TGOO,F,.9,9F4
LAND=NOT.(ICF,FH,OCEAN)
SNOW=LAND.AND.(LAT(I,J),GF,SN OW,1K,LAT(I,J),GF,SN OW)
LAND=LAND.AND.,*NOT,SNOW
IF (,NOT, OCEAN) ZZV=VPH4(J,11)/GRAV

C DRAG COEFFICIENT

IF (J,JQ,1) WMAG=WMAG
IF (J,JQ,1) WMAG=WMAG
IF (J,JQ,JM) WMAG=WMAG
IF (J,JN,1) AND.(J,JF,JM) WMAG=SORT(.25+(FD(J,J),FD(J+1,J))
X =FD(J,J)+FD(J+1,J)))
CD = .002
IF (,NOT, OCEAN) CD=CD+0.006*ZZV/5000.
IF (OCEAN) CD = AMIN(1.1,0.07*WMAG1,0.01,0.025)
CS = CD+100.
CS4 = .24*CS*74.*3600.
FK1 = CO*10.*GRAV)/(INSIG*PM)
C
C
PRESURES

SP=P(J+1)
CMLMR=PM/SP
P4=SP+PTRN
P4K=P4***KAPA
PL1=SIG1*SP*PTRN
PL2=SIG2*SP*PTRN
PL3=SIG3*SP*PTRN
PL1K=PL1***KAPA
PL2K=PL2***KAPA
PTRK=PTRN***KAPA
NPLK=PL3K-PL1K

C
C
TEMPERATURES AND TEST FOR DRY-ADIABATIC INSTABILITY

T1=T(J,1,1)
T3=T(J,1,2)
THL1=TI/PL1K
THL3=T3/PL3K
IF (THL1 .GT. THL3) GO TO 310
X1=(T1+T3)/(PL1K+PL3K)
T1=XX1*PL1K
T3=XX1*PL3K
THL1=TI/PL1K
THL3=T3/PL3K

C
C
MOISTURE VARIABLES

310 FS1=10.0**((R.4051-2353.0)/T1)
FS3=10.0**((R.4051-2353.0)/T3)
P1CB=.1*PL1
P3CB=.1*PL3
Q5=.62*FS1/(P1CB-FS1)
Q3=.62*FS3/(P3CB-FS3)
GM1=CLH*OS1*541.1/T1**2
GM3=CLH*OS3*541.1/T3**2
Q3R=Q3(J,1)
RH3=Q3R/OS3

C
C
TEMPERATURE EXTRAPOLATION AND INTERPOLATION FOR RADIATION

ATFM=(THL3-THL1)/NPLK
RTFM=(THL1*PL3K-THL3*PL1K)/NPLK
TTRNP=(ATFM*PTRK+RTFM)*PTRK
T2=(ATFM*PL2K+BTFM)*PL2K
GROUND TEMPERATURE AND WETNESS

TG = TG00
WFT = 1.0
IF (.NOT.(OCFAN)) TG = GT(J,1)
IF (LAND) WFT = GW(J,1)

LARGE SCALE PRECIPITATION

PRECF = 0.
IF (O3R * LE.0.53) GO TO 1060
PRECF = (O3R - 0.53) / (1.0 * GAM3)
T3 = T3 + CLH * PRECF
THL3 = T3 / PL3K
O3R = O3R - PRECF

CONVECTION

1060 TFTA1 = THTL1 * PI0K
TFTA3 = THTL3 * PI0K
SS3 = TFTA3 / PL3K / PI0K
SS2 = SS3 + 0.5 * (TFTA1 - TFTA3) / PL2K / PI0K
SS1 = SS2 + 0.5 * (TFTA1 - TFTA3) / PL2K / PI0K
MH3 = SS3 + CLH * O3R
MH95 = SS3 + CLH * O3R
MH15 = SS1 + CLH * O3R

MIDLEVEL CONVECTION

C1 = 0.9
C3 = 0.9
FX = MH3 = MH15
IF (FX LE.0.5) GO TO 1064
C1 = RCNV*FX / (2.0 + GAM1)
C3 = C1 * (1.0+GAM1) * (SS2 - SS3) / (FX * (1.0+GAM1) * (SS1 - SS2))

PREPARATION FOR AIR-EARTH INTERACTION

1064 ZL3 = 2000.
WINDF = 2.0 * WMAG
URAW = CDI * WINDF
F0V = FD / ZL3 * WMAG / 10.

...
DETERMINATION OF SURFACE TEMPERATURE

1070 RH4 = 2.0 * WET * RH3 / (WET + RH3)
      EG = 10.0 * (R*405 - 2353) / TG
      EG = AMN1(EQ, P4CR, 1.662)
      QG = 0.22 * EG / (P4CR + FG)
      QG = 541 * EQ / (TG * 2)
      HMG = TG + CLH * QG / WET
      EDV = EDV / (EDV + TRAW)

      HH4 = EDV / (1.0 - EDV) * HMG
      GAMG = CLH * QG
      T4 = (HH4 - RH4) * (CLH + QG - GAMG) / (1.0 + RH4 * GAMG)
      IF (T4 > P1OK / P4K / CT / TETA3) T4 = TFTA3 * P4K / P1OK
      Q4 = RH4 * (QG + DOG * (T4 - TG))
      HH4 = T4 + CLH / 04

PENETRATING AND LOW-LEVEL CONVECTION

PC1 = 0.0
PC3 = 0.0
PC2 = 0.0
EX = 0.0
IF (HH* <= LF) HH3S GO TO 1077
IF (HH* > GT) HH1S GO TO 1077
EX = HH4 - HH3S
HH4P = HH4
HH4 = HH3S
IF (HH4P < LT) HH1S GO TO 1076
ETA = 1.0
TEMP1 = ETA * ((HH3S - HH1S) / (1.0 + GAM1) * SS1 - SS2)
TEMP2 = ETA * (SS2 - SS3) + (SS3 - T4)
TEMP = EDV * TEMP1 + (1.0 + GAM3) * TEMP2
IF (TEMP < LT + 001) TEMP = 001
CONVP = RCNV * EXP / TEMP
PC1 = CONVP * TEMP1
PC3 = CONVP * TEMP2

1076 T4 = T4 - EX / (1.0 + RH4 * GAMG)
      Q4 = (HH4 - T4) / CLH

1077 R04 = P4CR / (RGAS * T4)
CSE = CS4 * R04 * WNOF
CEVA = CS4 * R04 * WNOF
C
C CLOUDINESS
C
ICLOUD=1
CL=0.
CL1=0.
CL2=0.
CL3=0.
CLT=0.
CL=AMIN1(-1.3+2.6*RH3,1.)
IF (CL < GT, 0., PR, CL1, GT, 0.) CL1=CL
IF (PRF, GT, 0., AND, CL1, EQ, 0.) CL2=1.
IF (EX, GT, 0., AND, PC1, EQ, 0.) CL3=CL
CL = AMAX1(CL1, CL2, CL3)
IF (CL GT 1.) CL=0.
IF (CL LT 1. AND, CL GT 0.) CL=0.
CLFAR, ICLOUD=3

LONG WAVE RADIATION

VAK = 2.*ALNG(1.71*RE-6/3R3)/ALNG(120./PL3)
TE1 = 0.0102*PL3**2*3R3/VAK
TE2 = TEM1*(PR/PL3)**VAK
EFV3 = TEM2-TEM1
EEV2 = TEM2-TEM1*(PL2/PL3)**VAK
FFV1 = TEM2-TEM1*(PL1/PL3)**VAK
FFV3 = TEM2-TEM1*(PTOP/PL3)**VAK
FFV0 = TEM2-TEM1*(120./PL3)**VAK+2.52*6**5
BLT = STN0*TRP**4
BL1 = STN0*T1**4
BL2 = STN0*T2**4
BL3 = STN0*T3**4
BL4 = STN0*T4**4

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LONG WAVE RADIATION

R0C=0.
R2C=0.
R4C=0.
URT=4LT*TRANS(EFV0-FFVT)
UR2=RL2*TRANS(EFV0-FFV2)
GO TO (1090,1090,2000), ICL(HU)

1090 R0O=0.R2*(4RT+(RL4-4LT)*(1.+TRANS(FFVT1/2.))
R20=0.736*(UR2+(RL4-RL2)*(1.+TRANS(FFV2/FFV3)))
R40=RL4*0.4*SORT(TRANS(FFV0)-0.1)
IF (ICLN(HD) .EQ. 1) GO TO 2015

2000 IF (CL2 .LE. 0.) GO TO 2004
CLT=CL2
R0C=0.R2*(URT+(RL2-RL1)*(1.+TRANS(FFVT-FFV2)/2.))*CLT
R2C=0.736*UR2*CLT
R2C=.5*R2C
GO TO 2006

2004 IF (CL3 .LE. 0.) GO TO 2006
CLT=CL3
R0C=0.R2*(URT+(RL3-RL1)*(1.+TRANS(FFVT-FFV3)/2.))*CLT
R2C=0.736*(UR2+(RL3-RL2)*(1.+TRANS(FFV2-FFV3)/2.))*CLT

2006 IF (CL1 .LE. 0.) GO TO 2010
CLM=AMAX1(CL1,0.)

C IN PRESENT VERSION, CLM AND THIS TFM ARF ALWAYS /=R0

TEM=0.
IF (CLT .GT. 0.001) TEM=CLM/CLT
R0C=0.R2*(URT+(RL1-RLT)*(1.+TRANS(FFVT-FFV1)/2.))*CL1+ROC*TEM
R2C=R2C*TEM

2010 R4C=0.5*(.25+.75*TRANS(FFV3))*(RL4-RL3)*CL

2015 R0=ROC+11.-CL)*R00
R2=R2C+11.-CL)*R20
R4=R4C+11.-CL)*R40
01RAD=4.*STB0**3

C

SURFACE ALBFDN

C

IF (GCSZ .LE. .01) GO TO 340
SCOSZ=50.*GCSZ
ALS=10.

IF (OCEAN) GO TO 335

ALS=14.
IF (LAT(J) .LT. SNOWN) GO TO 327

CLAT=(LAT(J)-SNOWN)*CONRAD
GO TO 330

327 IF (LAT(J) .GT. SNOWS) GO TO 328

CLAT=(SNOWS-LAT(J))*CONRAD

ALS=65*(1.+CLAT-10.)*2/((CLAT-30.)*2+((CLAT-10.)*2)
GO TO 335

328 IF (LAND) GO TO 335

CLAT=0.

ALS=4*(1.+CLAT-5.)*2/((CLAT-45.)*2+((CLAT-5.)*2))

00023720
C          SOLAR RADIATION
C
335   ALAO=MIN(1.05,0.247*ALOG10(COSZ/COSZ))
SA=.3495*COSZ
SS=COSZ-5A
ASOT=SA*TRSW((FFV0-FFV1)/COSZ)
ASST=SA*TRSW((FFV0-FFV2)/COSZ)
FS2C=0.
FS4C=0.
SGC=0.
GO TO (336,336,337), ICLUD
C
CLEAR
336   FS20=AS2T
   FS40=SA*TRSW((FFV0/COSZ)
   S40=(1.05-ALS)*FS40*(1.05-ALAO)/(1.05-ALAO*ALS)*SS)
IF (ICL(HH) .EQ. 1) GO TO 341
C
LARGE SCALE CLOUD
337   IF (CLZ .LE. 0.) GO TO 338
   CLT=CLZ
   FS2C=AS2T*CLT
   TFMS=SA*(1.05-ALC2)*TRSW((FFV0-FFV2)/COSZ+1.66*(FFVC2+FFV3))
   FS4C=(TFMS+ALC2*AS2T)*CLT
   ALAC=ALC2+ALC2*ALC2
   SAC=(1.05-ALS)*(TFMS(1.05-ALC2*ALS)+(1.05-ALAC)/(1.05-ALAC*ALS)*SS)*CLT
GO TO 339
C
LOW LEVEL CLOUD
338   IF (CL3 .LE. 0.) GO TO 339
   CLT=CL3
   FS2C=AS2T*CLT
   TFMS=SA*(1.05-ALC3)*TRSW((FFV0-FFV3)/COSZ)
   TFmur=1.05*TFM(1.05-ALC3)*SA*TRSW((FFV0-FFV3))/COSZ
   FS4C=(TFMS+ALC3*AS2T)*CLT
   ALAC=ALC3+ALC2*ALC2
   SAC=(1.05-ALS)*(TFMS(1.05-ALC3*ALS)+(1.05-ALAC)/(1.05-ALAC*ALS)*SS)*CLT
GO TO 334
C
THICK CLOUD
339   IF (CL1 .LE. 0.) GO TO 341
   CLM=MAX(1.05,CL1,0.1)
C
!PRESENT VERSION CLM AND THIS TF MAT ALWAYS ZERO)
   TFM=0.0
   IF (CLT .LT. 0.0) TEM=CLM/CLT
   TFM=FFVO-FFV1)/COSZ
   TFmur=1.05*TFM(1.05-ALC1)*SA*CLT
   FS2C=SA*(1.05-ALC1)*TRSW((TFM+1.66*(FFVC1+FFV3))/CL1+TFM)*FS2C*TFM
   FS4C=TFMS*CL1+TEM*FSAC*TFM
   ALAC=ALC1+ALC1*ALC1
   SAC=(1.05-ALS)*(TFMS(1.05-ALC1*ALS)
   X+(1.05-ALAC)/(1.05-ALAC*ALS)*SS)*CL1+SCC*TFM
   GO TO 342
C MEAN CONDITION
341 FS2 = FS2C + (1 - CL) * FS20
    FS4 = FS4C + (1 - CL) * FS40
    S4 = S4C + (1 - CL) * S40
    AS1 = AS0T - FS2
    AS3 = FS2 - FS4
    G0 TO 345
340 S4 = 0, 0
    AS3 = 0, 0
    AS1 = 0, 0
COMPUTATION OF GROUND TEMPERATURE

345 TGR=T6R
    IF (NCFAN) GO TO 347
    BRAO=S4-R4
    TFM=0.
    IF (ICE.AND.ZZZ.LT.0.1) TFM=CTID/HICE
    A1=CSEN*T4+CLH*(O4+WET*(DGG*T6-R-0.1))
    A2=BRAO+4.*PL4*TFM*TFIC
    B1=CSEN*T1+CLH*(DGG*WET)
    B2=DIFAD+TEM
    TGR=(A1+A2)/(B1+B2)
    IF (LAND.OR.TGR.LT.TICF) GO TO 346
    TGR=TFIC

346 DR=DIRAD*(TGR-T6R)
    R4=R4+DR
    R2=R2+R*(1.-CL)*TRANS(WFV2)*DR
    R0=R0+R*(1.-CL)*TRANS(WFT)*DR
    CONTINUE

351 H1=(A51+R2+R0)*C0E1*COLMR+C1+PC1
    H3=(A53+R4+R0)*C0E1*COLMR+C3+PC3+PFC*CLH
    TFMP=0.5*(H1+H3)

CONTINUE

SFNSIBLE HEAT (LY/DAY) AND EVAPORATION (GM/CMM**2/SEC)

E4=CFV6*WET*(TG+DGG+(TGR-T6R))-0.4
F4=CSFN*(TGR-T4)
FK=RO4*FK1*WINDF

TOTAL HEATING AND MOISTURE BUDGFT

QN=(C1+C3+PC1+PC3)/CLH+PFC=2.*E4+DTC3*GRAV/(SP*1.0)
    IF (NOT.LAND) GO TO 350
    RUNOFF=0.
    IF (QN.GT.0. AND. WFT.LT.1.) RUNOFF=5.*WET
    IF (QN.GT.0. AND. WFT.GF.1.) RUNOFF=1.
    WET = GW(J,I)+(1.-RUNOFF)*QN5.*SP/GRAV/GWM
    IF (WET.GT.1.1) WFT = 1.
    IF (WET.LT.0.1) WFT = 0.
    CONTINUE

SURFACE FRICTION

CONTINUE

CONTINUE

CONTINUE
C PACK FOR OUTPUT

WW=0.0
CC(J+1,1)=CL1
CC(J+1,2)=CL2
CC(J+1,3)=CL3
CC(J+1,4)=CL
CPC1(J,1)=(C1+PC1)*DAY/DTC3
CPC3(J,1)=(C3+PC3)*DAY/DTC3
CPC1(J,1)=C1+PC1
CPC3(J,1)=C3+PC3
PRCLH(J,1)=PRFC*CLH*DAY/DTC3
SCALE=SCALF*CDLMR
KKK=IPK(IFIX(AS1*SCALF),IFIX(AS3*SCALF))
TT(J,1,1)=XXX
KKK=IPK(IFIX((R2-R0)*SCALF),IFIX((R4-R2)*SCALF))
VT(J,1,2)=XXX
KKK=IPK(IFIX(F4),IFIX(E4*100.*3600.*24.))
TT(J,1,2)=XXX
KKK=IPK(IFIX(T4*10.),IFIX(PRFC*SCALFP*SP))
Q3T(J,1)=XXX
KKK=IPK(IFIX(EX*10.),IFIX((C1+C3+PC1+PC3)*SP*SCALFP/CLH))
UT(J,1,2)=XXX
KKK=IPK(IFIX(H1*100.*DAY/DTC3),IFIX(H3=100.*DAY/DTC3))
PT(J,1)=XXX
KKK=IPK(IFIX(S4/10.),IFIX(WW=100.))
SD(J,1)=XXX
360 CONTINUE
370 CONTINUE
375 CONTINUE
377 CONTINUE
380 CONTINUE
400 RETURN
FND
VIII. FORTRAN DICTIONARY

PURPOSE

In order to permit the efficient reading of the FORTRAN program and map routine listings, all of the FORTRAN variables used in the code are collected below. For each FORTRAN term a brief identification or meaning is given, together with the term's units (if any) and the location of its first appearance or definition in the program. The locations are not given for certain symbols of widespread use, and those FORTRAN symbols used only in the output map routines of Chapter VII, Section B, are not listed. Conventional FORTRAN notation has been used, with the equivalence in terms of the physical symbols of the model also given where appropriate.
### TERM LIST

<table>
<thead>
<tr>
<th>FORTRAN Symbol</th>
<th>Meaning</th>
<th>Units</th>
<th>Program Location</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
<td>$AX \times 10^5$, horizontal momentum diffusion coefficient (zero in present version)</td>
<td>$m^2 \text{sec}^{-1}$</td>
<td>13570 INPUT</td>
</tr>
<tr>
<td><strong>ALAC</strong></td>
<td>$\alpha_c = \alpha_{c_1} + \alpha_0 - \alpha_{c_1} \alpha_0$, albedo of cloudy atmosphere for Rayleigh scattering</td>
<td>--</td>
<td>10650 COMP 3</td>
</tr>
<tr>
<td><strong>ALAO</strong></td>
<td>$\alpha_0$, albedo of clear sky for Rayleigh scattering</td>
<td>--</td>
<td>10450 COMP 3</td>
</tr>
<tr>
<td><strong>ALC1</strong></td>
<td>$\alpha_{c_1}$, albedo of type 1 (penetrating convective) cloud, $= 0.7$</td>
<td>--</td>
<td>7610 COMP 3</td>
</tr>
<tr>
<td><strong>ALC2</strong></td>
<td>$\alpha_{c_2}$, albedo of type 2 (middle-level overcast) cloud, $= 0.6$</td>
<td>--</td>
<td>7620 COMP 3</td>
</tr>
<tr>
<td><strong>ALC3</strong></td>
<td>$\alpha_{c_3}$, albedo of type 3 (low-level convective) cloud, $= 0.6$</td>
<td>--</td>
<td>7630 COMP 3</td>
</tr>
<tr>
<td><strong>ALP</strong></td>
<td>$(m/n - 1)/8$, longitudinal smoothing parameter</td>
<td>--</td>
<td>6920 AVRX</td>
</tr>
<tr>
<td><strong>ALPH(8)</strong></td>
<td>identification parameter (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>ALPHA</strong></td>
<td>(1) $FXCO*(P(J,I)+P(J-1,I))*(FD(J,I)+FD(J-1,I))$ Coriolis force parameter</td>
<td>$m^2 \text{mb}$</td>
<td>5160 COMP 2</td>
</tr>
<tr>
<td></td>
<td>(2) $ALP/FNM$, longitudinal smoothing weighting factor</td>
<td>--</td>
<td>6950 AVRX</td>
</tr>
<tr>
<td><strong>ALS</strong></td>
<td>$\alpha$, surface albedo (0.07 for ocean, 0.14 for bare land, a defined function of latitude for ice and snow)</td>
<td>--</td>
<td>10290-10410 COMP 3</td>
</tr>
<tr>
<td><strong>AMONTH(3)</strong></td>
<td>name of month</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>APHEL</strong></td>
<td>aphelion, 1 July ($= 183.0$)</td>
<td>day</td>
<td>13110 INPUT</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
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<td>---------</td>
<td>-------</td>
<td>------------------</td>
</tr>
<tr>
<td>ASOT</td>
<td>$S_T^A$, flux at tropopause of solar radiation subject to absorption</td>
<td>1y day$^{-1}$</td>
<td>10480 COMP 3</td>
</tr>
<tr>
<td>AS1</td>
<td>$A_1$, insolation absorbed by upper layer ($= 0$ if $\cos \zeta \leq 0.01$)</td>
<td>1y day$^{-1}$</td>
<td>10950 COMP 3</td>
</tr>
<tr>
<td>AS2T</td>
<td>$(s_2^A)^T$, flux at level 2 of solar radiation subject to absorption ($= F S 20$)</td>
<td>1y day$^{-1}$</td>
<td>10490 COMP 3</td>
</tr>
<tr>
<td>AS3</td>
<td>$A_3$, insolation absorbed by lower layer ($= 0$ if $\cos \zeta \leq 0.01$)</td>
<td>1y day$^{-1}$</td>
<td>10960 COMP 3</td>
</tr>
<tr>
<td>ATEM</td>
<td>$(\theta_3 - \theta_1)/(p_3^K - p_1^K)$, temperature interpolation parameter</td>
<td>$\text{deg}(\text{mb})^{-2}$</td>
<td>8490 COMP 3</td>
</tr>
<tr>
<td>AX</td>
<td>horizontal momentum diffusion coefficient ($= 0$ in present version)</td>
<td>m$^2$ sec$^{-1}$</td>
<td>13380 INPUT</td>
</tr>
<tr>
<td>AXU(J)</td>
<td>$A(DXU(J)/300 \text{ km})^{4/3}$, zonal momentum diffusion coefficient (not used)</td>
<td>m$^2$ sec$^{-1}$</td>
<td>14800 MAGFAC</td>
</tr>
<tr>
<td>AXV(J)</td>
<td>$A(DXP(J)/300 \text{ km})^{4/3}$, zonal momentum diffusion coefficient (not used)</td>
<td>m$^2$ sec$^{-1}$</td>
<td>14810 MAGFAC</td>
</tr>
<tr>
<td>AYU(J)</td>
<td>$A(DYU(J)/300 \text{ km})^{4/3}$, meridional momentum diffusion coefficient (not used)</td>
<td>m$^2$ sec$^{-1}$</td>
<td>14820 MAGFAC</td>
</tr>
<tr>
<td>AYV(J)</td>
<td>$A(DYP(J)/300 \text{ km})^{4/3}$, meridional momentum diffusion coefficient (not used)</td>
<td>m$^2$ sec$^{-1}$</td>
<td>14830 MAGFAC</td>
</tr>
<tr>
<td>Al</td>
<td>$C_T \left( T_4 + \frac{L}{c_p} \left( q_4 + \text{WET} \left[ T_2 \left( \frac{d q_4(T)}{dT} - q_s(T) \right) \right] \right) \right)$</td>
<td>1y day$^{-1}$</td>
<td>11090 COMP 3</td>
</tr>
</tbody>
</table>

ground temperature parameter
<table>
<thead>
<tr>
<th>FORTRAN Symbol</th>
<th>Meaning</th>
<th>Units</th>
<th>Program Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2</td>
<td>$S_4 - \sim R_4 + 4\sigma T^4_g + \sim T_o$, ground temperature parameter</td>
<td>1y day$^{-1}$</td>
<td>11100 COMP 3</td>
</tr>
<tr>
<td>BCØMN (67040)</td>
<td>common block (see Chapter VII, Subsection A.3)</td>
<td>(various)</td>
<td>0140 COMMON</td>
</tr>
<tr>
<td>BIT</td>
<td>control parameter (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>BLANK</td>
<td>logical variable control</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>BLT</td>
<td>$\sigma T^4_T$, long-wave radiation parameter at tropopause</td>
<td>1y day$^{-1}$</td>
<td>9860 COMP 3</td>
</tr>
<tr>
<td>BL1</td>
<td>$\sigma T^4_1$, long-wave radiation parameter at level 1</td>
<td>1y day$^{-1}$</td>
<td>9870 COMP 3</td>
</tr>
<tr>
<td>BL2</td>
<td>$\sigma T^4_2$, long-wave radiation parameter at level 2</td>
<td>1y day$^{-1}$</td>
<td>9880 COMP 3</td>
</tr>
<tr>
<td>BL3</td>
<td>$\sigma T^4_3$, long-wave radiation parameter at level 3</td>
<td>1y day$^{-1}$</td>
<td>9890 COMP 3</td>
</tr>
<tr>
<td>BL4</td>
<td>$\sigma T^4_8$, long-wave radiation parameter at ground level</td>
<td>1y day$^{-1}$</td>
<td>9900 COMP 3</td>
</tr>
<tr>
<td>BRAD</td>
<td>$S_4 - \sim R_4$, ground radiation balance (uncorrected for $T_g$)</td>
<td>1y day$^{-1}$</td>
<td>11060 COMP 3</td>
</tr>
<tr>
<td>BTEM</td>
<td>$(\theta_{p_3}^K - \theta_{p_1}^K)/(p_3^K - p_1^K)$, temperature interpolation parameter</td>
<td>deg(mb)$^{-K}$</td>
<td>8500 COMP 3</td>
</tr>
<tr>
<td>BL1</td>
<td>$C_T(1 + \gamma_{g \text{WET}})$, ground temperature parameter</td>
<td>1y day$^{-1}$ deg$^{-1}$</td>
<td>11110 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
<td>----------------</td>
<td>------------------</td>
</tr>
<tr>
<td>B2</td>
<td>$4\sigma T^2 + \bar{B}$, ground temperature parameter ($\bar{B} = 0$ unless over ice)</td>
<td>1 year day$^{-1}$ deg$^{-1}$</td>
<td>11120 COMP 3</td>
</tr>
<tr>
<td>C(K)</td>
<td>equivalence array (see Chapter VII, Subsection A.3)</td>
<td>(various)</td>
<td>0430 COMMON</td>
</tr>
<tr>
<td>CD</td>
<td>$C_D$, surface drag coefficient</td>
<td>--</td>
<td>7970-7980 COMP 3</td>
</tr>
<tr>
<td>CENTIG</td>
<td>identification for sea-surface temperature</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>CEVA</td>
<td>$100 \ C_D \rho_4 (</td>
<td>\bar{v}_g</td>
<td>^n + G)$, surface evaporation parameter</td>
</tr>
<tr>
<td>CHECK</td>
<td>data control parameter (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>CL</td>
<td>max(CL1, CL2, CL3), fraction of sky covered by cloud</td>
<td>--</td>
<td>9700 COMP 3</td>
</tr>
<tr>
<td>CLAT</td>
<td>degrees poleward of snowline, used in surface albedo calculation $(\varphi_j - \text{SNWON,SNWS-} \varphi_j) \times \text{CONDAD}$ for (northern, southern) hemisphere</td>
<td>deg lat</td>
<td>10330, 10360 COMP 3</td>
</tr>
<tr>
<td>CLH</td>
<td>$L/c_p$, latent heat to specific heat ratio</td>
<td>deg</td>
<td>7300 COMP 3</td>
</tr>
<tr>
<td>CLSW</td>
<td>input identification</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>CLM</td>
<td>$\max(\text{CLT} - \text{CL1}, 0)$, cloud parameter (not used)</td>
<td>--</td>
<td>10130 COMP 3</td>
</tr>
<tr>
<td>CLT</td>
<td>$\text{CL1}$ or $\text{CL3}$, cloud parameter (not used)</td>
<td>--</td>
<td>10030 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------------------------------------------------------------------</td>
<td>-------</td>
<td>------------------</td>
</tr>
<tr>
<td>CL1</td>
<td>min(-1.3 + 2.6RH3, 1), fraction of sky covered by type 1 (penetrative convective) cloud</td>
<td>--</td>
<td>9500 COMP 3</td>
</tr>
<tr>
<td>CL2</td>
<td>fraction of sky covered by type 2 (large-scale condensation) cloud (either 0 or 1)</td>
<td>--</td>
<td>9510 COMP 3</td>
</tr>
<tr>
<td>CL3</td>
<td>min(-1.3 + 2.6RH3, 1), fraction of sky covered by type 3 (low-level convective) cloud</td>
<td>--</td>
<td>9520 COMP 3</td>
</tr>
<tr>
<td>CNRX</td>
<td>0.01*C(\text{CNRAD}), unit conversion factor (not used)</td>
<td>deg/radian</td>
<td>7440 COMP 3</td>
</tr>
<tr>
<td>CNST</td>
<td>GRAV<em>30.48</em>HCST, unit conversion factor for surface elevation</td>
<td>--</td>
<td>16200, 16270 INIT 2</td>
</tr>
<tr>
<td>C(\text{&amp;})E</td>
<td>200g/c(p_o - p_T)(10^3), heat capacity of 1/2 unit column</td>
<td>deg ly(^{-1})</td>
<td>7380 COMP 3</td>
</tr>
<tr>
<td>C(\text{&amp;})E1</td>
<td>(1) C(\text{&amp;})E<em>DTC3/24</em>3600, unit conversion factor for heating terms</td>
<td>deg day ly(^{-1})</td>
<td>7390 COMP 3</td>
</tr>
<tr>
<td></td>
<td>(2) (\sigma_1 \gamma_1 / 2T_1 + (c_p \theta_1 / 4T_1) \cdot [(p_3 / p_o)^{K} - (p_1 / p_o)^{K}]), (1) geopotential parameter</td>
<td>m(^2) sec(^{-2}) deg(^{-1})</td>
<td>5360 COMP 2</td>
</tr>
<tr>
<td>C(\text{&amp;})E2</td>
<td>(\sigma_3 \gamma_3 / 2T_3 + (c_p \theta_3 / 4T_1) \cdot [(p_3 / p_o)^{K} - (p_1 / p_o)^{K}]), (3) geopotential parameter</td>
<td>m(^2) sec(^{-2}) deg(^{-1})</td>
<td>5370 COMP 2</td>
</tr>
<tr>
<td>C(\text{&amp;})E3</td>
<td>(\sigma_1 \gamma_1 / 2T_1 - (c_p \theta_1 / 4T_1) \cdot [(p_3 / p_o)^{K} - (p_1 / p_o)^{K}]), (3) geopotential parameter</td>
<td>m(^2) sec(^{-2}) deg(^{-1})</td>
<td>5400 COMP 2</td>
</tr>
<tr>
<td>C(\text{&amp;})E4</td>
<td>(\sigma_3 \gamma_3 / 2T_3 - (c_p \theta_3 / 4T_3) \cdot [(p_3 / p_o)^{K} - (p_1 / p_o)^{K}]), (3) geopotential parameter</td>
<td>m(^2) sec(^{-2}) deg(^{-1})</td>
<td>5410 COMP 2</td>
</tr>
<tr>
<td>C(\text{&amp;})LMR</td>
<td>((p_o - p_T) / (p_s - p_T)), column mass ratio (also redefined in 11530, COMP 3 with average (p_s - p_T))</td>
<td>--</td>
<td>8060 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
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<td>----------------</td>
<td>-------------------------------------------------------------------------</td>
<td>---------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>CØNRA D</td>
<td>180/PI, unit conversion factor</td>
<td>deg/radian</td>
<td>7430 7440</td>
</tr>
<tr>
<td>CØNVM</td>
<td>CØNVM, mass convergence at level 1</td>
<td>m$^2$ sec$^{-1}$mb</td>
<td>4220 4210</td>
</tr>
<tr>
<td>CØNVM</td>
<td>-(mn/2)$\vec{v}$ - m$^+$, net mass convergence into cell surrounding $\pi$ point (defined for poles in 4560, 4580 COMP 1)</td>
<td>m$^2$ sec$^{-1}$mb</td>
<td>4180-4210 4180</td>
</tr>
<tr>
<td>CØNVP</td>
<td>$(h_4 - h_3^*)5\Delta t(\tau_1)^{-1}$, penetrating convection parameter</td>
<td>--</td>
<td>9300 9300</td>
</tr>
<tr>
<td>CØSD</td>
<td>cos $\tau$, cosine of solar declination</td>
<td>--</td>
<td>15540 15540</td>
</tr>
<tr>
<td>CØSL(J)</td>
<td>cos $\varphi_j$, cosine of latitude</td>
<td>--</td>
<td>14960 14960</td>
</tr>
<tr>
<td>CØSZ</td>
<td>cos $\tau$, cosine of solar zenith angle</td>
<td>--</td>
<td>7800 7800</td>
</tr>
<tr>
<td>CPART</td>
<td>0.5<em>1.3071</em>10$^7$, a constant (not used)</td>
<td>--</td>
<td>7690 7690</td>
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<tr>
<td>CS</td>
<td>$10^2C_D$, unit conversion factor</td>
<td>cm m$^{-1}$</td>
<td>7990 7990</td>
</tr>
<tr>
<td>CSEN</td>
<td>$C_T = 10^2c_p C_D^p_4 (</td>
<td>\vec{v}_s</td>
<td>^2 + G)$ DAY, surface sensible heat flux parameter</td>
</tr>
<tr>
<td>CS4</td>
<td>$10^2c_p C_D$ DAY, surface sensible heat flux parameter</td>
<td>cm m$^{-1}$cal g$^{-1}$</td>
<td>8000 8000</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------------------------------------------------------------------</td>
<td>------------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>CTI</td>
<td>thermal conductivity of ice (= 0.005)</td>
<td>ly sec$^{-1}$ cm deg$^{-1}$</td>
<td>7320 COMP 3</td>
</tr>
<tr>
<td>CTID</td>
<td>thermal conductivity of ice (= 432)</td>
<td>ly day$^{-1}$ cm deg$^{-1}$</td>
<td>7330 COMP 3</td>
</tr>
<tr>
<td>CXXX(800)</td>
<td>data control parameter (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Cl</td>
<td>$(\Delta T_1) = (h_3 - h_1^*)(2 + \gamma_1)^{-1}5\Delta t$, level 1</td>
<td>deg</td>
<td>8870 COMP 3</td>
</tr>
<tr>
<td></td>
<td>temperature change due to mid-level convective latent heating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl(800)</td>
<td>array identification</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Cl(800)</td>
<td>array identification</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>C3</td>
<td>$(\Delta T_3) = (\Delta T_1) (1 + \gamma_1)(LR/2)$</td>
<td>deg</td>
<td>8880 COMP 3</td>
</tr>
<tr>
<td></td>
<td>$(h_3 - h_1^*) + (1 + \gamma_1)(LR/2))^{-1}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>level-3 temperature change due to mid-level convective latent heating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAY</td>
<td>hours in day (= 24), or sec in day (= 86,400)</td>
<td>hr, sec</td>
<td>13420, 13650 INPUT</td>
</tr>
<tr>
<td>DAYPYR</td>
<td>days in year (= 365)</td>
<td>day</td>
<td>13070 INPUT</td>
</tr>
<tr>
<td>DCLK</td>
<td>logical variable for day counter SDEDY</td>
<td>--</td>
<td>15050 INSDET</td>
</tr>
<tr>
<td>DEC</td>
<td>$(23.5\pi/180)\cos[2\pi(DY-173.0)/365]$, solar declination</td>
<td>radians</td>
<td>15510 SDET</td>
</tr>
<tr>
<td>DECMAX</td>
<td>$23.5\pi/180$, maximum solar declination</td>
<td>radians</td>
<td>13080 INPUT</td>
</tr>
<tr>
<td>DEFF</td>
<td>$n = \Delta y$, equatorial meridional mesh length</td>
<td>m</td>
<td>6880 AVRX</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
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<td>----------------</td>
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<td>-----------------</td>
</tr>
<tr>
<td>DELTAP</td>
<td>correction for atmospheric mass loss (= PSF - ZMM)</td>
<td>mb</td>
<td>1430 GMP</td>
</tr>
<tr>
<td>DIRAD</td>
<td>$4\sigma T_g^3$, long-wave radiation parameter at ground</td>
<td>ly day$^{-1}$deg$^{-1}$</td>
<td>10230 COMP 3</td>
</tr>
<tr>
<td>DIST</td>
<td>$(DY - 183.0)/365$, day of year parameter</td>
<td>--</td>
<td>15450 SDET</td>
</tr>
<tr>
<td>DLAT</td>
<td>$\Delta \varphi$, north/south grid-point separation (= 4 deg) (changed to radians in 13590, INPUT)</td>
<td>deg</td>
<td>13360 INPUT</td>
</tr>
<tr>
<td>DLIC</td>
<td>input card identification (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>DLON</td>
<td>$\Delta \lambda = 2\pi/72$, east/west grid-point separation (= 5 deg)</td>
<td>radians</td>
<td>13610 INPUT</td>
</tr>
<tr>
<td>DPLK</td>
<td>$\rho_3 - \rho_1$</td>
<td>$(\text{mb})^\kappa$</td>
<td>8160 COMP 3</td>
</tr>
<tr>
<td>DQG</td>
<td>$B e^{q_g(T_g)} T_g^{2} = \gamma c_p/L$, approximate change of $q_s$ with temperature, $\frac{dq_s(T_g)}{dT}$</td>
<td>deg$^{-1}$</td>
<td>9040 COMP 3</td>
</tr>
<tr>
<td>DRAT</td>
<td>n/m, grid scale ratio</td>
<td>--</td>
<td>6900 AVRXX</td>
</tr>
<tr>
<td>DRAW</td>
<td>$C_D (</td>
<td>\mathbf{\hat{V}}_g</td>
<td>+ G)$, surface wind drag parameter</td>
</tr>
<tr>
<td>DR4</td>
<td>$4\sigma T_g^3(T_g - T_g) = R_4 - \frac{R_4}{C_4}$, surface long-wave radiation parameter</td>
<td>ly day$^{-1}$</td>
<td>11160 COMP 3</td>
</tr>
<tr>
<td>DSIG</td>
<td>$\sigma_3 - \sigma_1$, model sigma increment (= 1/2)</td>
<td>--</td>
<td>7250 COMP 3</td>
</tr>
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<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
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<td>------------------</td>
</tr>
<tr>
<td>DT</td>
<td>Δt in sec (= 360)</td>
<td>sec</td>
<td>13560 INPUT</td>
</tr>
<tr>
<td>DTC3</td>
<td>5Δt, time interval between heating steps in COMP 3 (= 1800)</td>
<td>sec</td>
<td>7280 COMP 3</td>
</tr>
<tr>
<td>DTM</td>
<td>Δt in min (= 6)</td>
<td>min</td>
<td>13340 INPUT</td>
</tr>
<tr>
<td>DXP(J)</td>
<td>m = aΔλ cos ϑ_j, east/west distance between π (or u*) points</td>
<td>m</td>
<td>14570 MAGFAC</td>
</tr>
<tr>
<td>DXU(J)</td>
<td>m = aΔλ(cos ϑ_j + cos ϑ_j-1)/2, east/west distance between u,v (or v*) points</td>
<td>m</td>
<td>14610 MAGFAC</td>
</tr>
<tr>
<td>DXV(J,I)</td>
<td>zonal distance between π points (= DXP)</td>
<td>m</td>
<td>--</td>
</tr>
<tr>
<td>DXYP(J)</td>
<td>m^2, area of grid cell around π point (defined for polar points in 14680, 14690 MAGFAC)</td>
<td>m^2</td>
<td>14670 MAGFAC</td>
</tr>
<tr>
<td>DY</td>
<td>t, day counter (= SDEDY)</td>
<td>day</td>
<td>14530 SDET</td>
</tr>
<tr>
<td>DYP(J)</td>
<td>n = (ϑ_j+1 - ϑ_j-1)a/2, north/south distance between u,v (or v*) grid points (defined for polar points in 14640, 14650 MAGFAC)</td>
<td>m</td>
<td>14630 MAGFAC</td>
</tr>
<tr>
<td>DYU(J)</td>
<td>n = a(ϑ_j - ϑ_j-1), north/south distance between π (or u*) grid points</td>
<td>m</td>
<td>14540 MAGFAC</td>
</tr>
<tr>
<td>DYV(J,I)</td>
<td>meridional distance between u,v points (= DYP)</td>
<td>m</td>
<td>--</td>
</tr>
<tr>
<td>ECCW</td>
<td>orbital eccentricity (= 0.0178)</td>
<td>--</td>
<td>13120 INPUT</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
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<tr>
<td>----------------</td>
<td>-------------------------------------------------------------------------</td>
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<td>------------------</td>
</tr>
<tr>
<td>ED</td>
<td>constant used in air/ground interaction (= 10.0)</td>
<td>m</td>
<td>13400 INPUT</td>
</tr>
<tr>
<td>EDR</td>
<td>$\left( \left</td>
<td>\frac{\hat{V}_s}{1000} \right</td>
<td>\left[ \left</td>
</tr>
<tr>
<td>EDV</td>
<td>$\left</td>
<td>\frac{\hat{V}_s}{1000} \right</td>
<td>$, air/ground interaction parameter</td>
</tr>
<tr>
<td>EFVC1</td>
<td>$u_c^1$, effective water vapor for type 1 clouds (= 65.3)</td>
<td>g cm$^{-2}$</td>
<td>7660 COMP 3</td>
</tr>
<tr>
<td>EFVC2</td>
<td>$u_c^2$, effective water vapor for type 2 clouds (= 65.3)</td>
<td>g cm$^{-2}$</td>
<td>7670 COMP 3</td>
</tr>
<tr>
<td>EFVC3</td>
<td>$u_c^3$, effective water vapor for type 3 clouds (= 7.6)</td>
<td>g cm$^{-2}$</td>
<td>7680 COMP 3</td>
</tr>
<tr>
<td>EFVT</td>
<td>$u_{x}^* = p_3 q_3 g^{-1}(2 + k)^{-1}\left[ (p_4/p_3)^{2+K} - (p_7/p_3)^{2+K} \right]$, effective water vapor in air column below tropopause</td>
<td>g cm$^{-2}$</td>
<td>9840 COMP 3</td>
</tr>
<tr>
<td>EFVO1</td>
<td>$u_1^* = p_3 q_3 g^{-1}(2 + k)^{-1}\left[ (p_4/p_3)^{2+K} - (p_1/p_3)^{2+K} \right]$, effective water vapor in air column below level 1</td>
<td>g cm$^{-2}$</td>
<td>9830 COMP 3</td>
</tr>
<tr>
<td>EFVO2</td>
<td>$u_2^* = p_3 q_3 g^{-1}(2 + k)^{-1}\left[ (p_4/p_3)^{2+K} - (p_2/p_3)^{2+K} \right]$, effective water vapor in air column below level 2</td>
<td>g cm$^{-2}$</td>
<td>9820 COMP 3</td>
</tr>
<tr>
<td>EFVO3</td>
<td>$u_3^* = p_3 q_3 g^{-1}(2 + k)^{-1}\left[ (p_4/p_3)^{2+K} - (p_3/p_3)^{2+K} \right]$, effective water vapor in entire atmospheric column</td>
<td>g cm$^{-2}$</td>
<td>9850 COMP 3</td>
</tr>
</tbody>
</table>

**Units:**
- m: meters
- g cm$^{-2}$: grams per square centimeter
- m sec$^{-1}$: meters per second
- 10$^{-5}$: 10 to the power of -5

**Program Location:**
- INPUT
- COMP 3
<table>
<thead>
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<th>Units</th>
<th>Program Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>EFV3</td>
<td>$u_3^* = p_3^2 q_3 g^{-1} (2 + K)^{-1} [(p_4/p_3)^{2+K} - 1]$, effective water vapor in air column below level 3</td>
<td>g cm^-2</td>
<td>9810 COMP 3</td>
</tr>
<tr>
<td>EG</td>
<td>$e_s(T_g)$, saturation vapor pressure at ground temperature</td>
<td>cb</td>
<td>9020 COMP 3</td>
</tr>
<tr>
<td>EQNX</td>
<td>equinox, 22 June (= 173.0)</td>
<td>day</td>
<td>13100 INPUT</td>
</tr>
<tr>
<td>ES1</td>
<td>$e_s(T_1)$, saturation vapor pressure at level 1</td>
<td>cb</td>
<td>8350 COMP 3</td>
</tr>
<tr>
<td>ES3</td>
<td>$e_s(T_3)$, saturation vapor pressure at level 3</td>
<td>cb</td>
<td>8360 COMP 3</td>
</tr>
<tr>
<td>ETA</td>
<td>entrainment factor (= 1)</td>
<td>--</td>
<td>9250 COMP 3</td>
</tr>
<tr>
<td>EVENT</td>
<td>program control parameter</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>EVNTH</td>
<td>data control parameter (not used)</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
| EX             | (1) $h_3 - h_1^* = HH3 - HH1S$  
<pre><code>           |       | deg   | 8850 COMP 3 |
</code></pre>
<p>|               | = $(L/c_p)[q_3 - q_s(T_1)] - LRc_p/L$, stability parameter for middle-level convection |       | |
|               | (2) $h_4 - h_3^* = HH4 - HH3S$, stability parameter for low-level convection | deg   | 9210 COMP 3 |
| EXP1           | empirical coefficient = 4/3 | --      | 14780 MAGFAC |
| E4             | $E = D_4 C_D (|\ddot{V}_s|^n + G)(q_g - q_4)$, surface evaporation rate | g cm^-2 sec^-1 | 11240 COMP 3 |</p>
<table>
<thead>
<tr>
<th>FORTRAN Symbol</th>
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</thead>
<tbody>
<tr>
<td>F(J)</td>
<td>$f = -2\Omega \beta (\cos \phi_j)/\beta$, Coriolis parameter (defined for poles in 14740-14750 MAGFAC)</td>
<td>sec$^{-1}$</td>
<td>14710-14730 MAGFAC</td>
</tr>
<tr>
<td>FAH</td>
<td>logical variable for temperature input</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FAREN</td>
<td>identification for sea-surface temperature</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FD(J,I)</td>
<td>(1) $\Pi = \text{mm}$, area-weighted pressure (about $\pi$ point)</td>
<td>m mb</td>
<td>2560 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(2) $v^2$, square of surface wind speed</td>
<td>m sec$^{-2}$</td>
<td>7550 COMP 3</td>
</tr>
<tr>
<td></td>
<td>(3) $F = \text{mm}f - u \beta m/\beta y$, weighted Coriolis force (at $\pi$-points)</td>
<td>m sec$^{-1}$</td>
<td>5070-5120 COMP 2</td>
</tr>
<tr>
<td>FDU</td>
<td>$\Pi^u = \text{average mm}$ at $u,v$ points (defined for polar caps in 2650-2660 COMP 1)</td>
<td>m mb</td>
<td>2640 COMP 1</td>
</tr>
<tr>
<td>FEET</td>
<td>identification for topographic height</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FIM</td>
<td>IM, maximum number of longitudinal grid points (= 72)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FIM1</td>
<td>I-1=i-1, longitudinal grid-point variable</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FJ</td>
<td>J=j, longitudinal grid-point index</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FJE</td>
<td>J index for equator (= 23½)</td>
<td>--</td>
<td>14460 MAGFAC</td>
</tr>
<tr>
<td>FJM</td>
<td>JM, maximum number of latitudinal grid points (= 46)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FK</td>
<td>$\rho_0 C_D g (</td>
<td>\vec{v}_g</td>
<td>^n + G)(\sigma_3 - \sigma_1)^{-1}(p_0 - p_T)^{-1}$, surface friction parameter</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
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<td>Units</td>
<td>Program Location</td>
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<tr>
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</tr>
<tr>
<td>FK1</td>
<td>$g C_D (\sigma_3 - \sigma_1)^{-1} (p_o - p_T)^{-1}$, surface friction parameter</td>
<td>$cm^2 g^{-1}$</td>
<td>8010 COMP 3</td>
</tr>
<tr>
<td>FL</td>
<td>2MOD(K,2)+1, indicator for u,v data at levels 1 and 3</td>
<td>--</td>
<td>12350 COMP 4</td>
</tr>
<tr>
<td>FLUX</td>
<td>(1) $^* u \Delta t$, $^* v \Delta t$, mass flux parameters</td>
<td>$m^2 mb$</td>
<td>3310, 3520 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(2) $-^* u \Delta t/4$, $-^* v \Delta t/4$, mass flux parameters at level 1</td>
<td>$m^2 mb$</td>
<td>3390, 3610 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(3) $5^* u \Delta t/4$, $5^* v \Delta t/4$, mass flux parameters at level 3</td>
<td>$m^2 mb$</td>
<td>3610, 3620 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(4) various momentum flux parameters</td>
<td>$m^2 mb$</td>
<td>3830, 3910, 3980, 4050 COMP 1</td>
</tr>
<tr>
<td>FLUXQ</td>
<td>FLUX*Q3M (and other definitions), moisture flux parameters</td>
<td>$m^2 mb$</td>
<td>3480, 3660 COMP 1</td>
</tr>
<tr>
<td>FLUXT</td>
<td>FLUX*(T(J,1,L)+T(J,IP1,L)) (and other definitions), temperature advection parameters</td>
<td>$m^2 mb deg$</td>
<td>3320-3580 COMP 1</td>
</tr>
<tr>
<td>FLUXU</td>
<td>FLUX*(U(J,1,L)+U(J,IM1,L)) (and other definitions), u-momentum advection parameters</td>
<td>$m^2 sec^{-1} mb$</td>
<td>3840-4060 COMP 1</td>
</tr>
<tr>
<td>FLUXV</td>
<td>FLUX*(V(J,1,L)+V(J,IM1,L)) (and other definitions), v-momentum advection parameters</td>
<td>$m^2 sec^{-1} mb$</td>
<td>3870-4090 COMP 1</td>
</tr>
<tr>
<td>FN</td>
<td>FM$\times 10^{-5}$, a constant</td>
<td>--</td>
<td>13610 INPUT</td>
</tr>
<tr>
<td>FNX</td>
<td>constant (= 0.2)</td>
<td>--</td>
<td>13400 INPUT</td>
</tr>
<tr>
<td>FNM</td>
<td>NM, the integer part of DRAT</td>
<td>--</td>
<td>6940 AVRX</td>
</tr>
<tr>
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<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
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<td>---------</td>
<td>-------</td>
<td>------------------</td>
</tr>
<tr>
<td>FSDEDY</td>
<td>( t ), day of year (= SDEDY)</td>
<td>day</td>
<td>7450 COMP 3</td>
</tr>
<tr>
<td>FS2</td>
<td>( S_2^A + CL \alpha c_{i_1} \left( S_{CT_i}^A \right)^{''} ), total flux of ( S_2^A ) at level 2 (plus reflected flux from type 1 cloud top)</td>
<td>1y day(^{-1})</td>
<td>10920 COMP 3</td>
</tr>
<tr>
<td>FS2C</td>
<td>(1) ( AS2T*CLT ), clear sky flux at level 2, times type 2 or 3 cloudiness</td>
<td>1y day(^{-1})</td>
<td>10620, 10710 COMP 3</td>
</tr>
<tr>
<td>FS2C</td>
<td>(2) ( CL \left[ \left( S_2^A \right)^{''} + \alpha c_{i_1} \left( S_{CT_i}^A \right)^{''} \right] ) flux of ( S_2^A ) at level 2 (plus flux reflected from cloud top) times type 1 cloudiness</td>
<td>1y day(^{-1})</td>
<td>10850 COMP 3</td>
</tr>
<tr>
<td>FS20</td>
<td>( S_2^A ), flux of ( S_2^A ) at level 2 for clear sky</td>
<td>1y day(^{-1})</td>
<td>10550 COMP 3</td>
</tr>
<tr>
<td>FS4</td>
<td>( S_4^A + CL \alpha c_{i_1} \left( S_{CT_i}^A \right)^{''} ), total flux of ( S_4^A ) at level 4 (plus reflected flux from cloud top)</td>
<td>1y day(^{-1})</td>
<td>10930 COMP 3</td>
</tr>
<tr>
<td>FS4C</td>
<td>( CL \left[ \left( S_4^A \right)^{''} + \alpha c_{i_1} \left( S_{CT_i}^A \right)^{''} \right] ), flux of ( S_4^A ) reaching level 4 (plus flux reflected from cloud top)</td>
<td>1y day(^{-1})</td>
<td>10640, 10740, 10870 COMP 3</td>
</tr>
<tr>
<td>FS40</td>
<td>( S_4^A ), flux of ( S_4^A ) at level 4 for clear sky</td>
<td>1y day(^{-1})</td>
<td>10560 COMP 3</td>
</tr>
<tr>
<td>FXC0</td>
<td>(1) ( TEXC0/2 ), time-step factor for advection (other definitions in 3770, 5030 COMP 1)</td>
<td>sec</td>
<td>3270, 4710 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(2) ( DT/4 ), time-step factor for pressure force</td>
<td>sec</td>
<td>5470 COMP 2</td>
</tr>
<tr>
<td></td>
<td>(3) ( \Delta t/8c_p ), time-step factor in thermodynamic energy equation</td>
<td>m(^{-2})sec(^{-3})deg</td>
<td>6100 COMP 2</td>
</tr>
<tr>
<td>Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
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<td>------------------</td>
</tr>
<tr>
<td>FXC¥1</td>
<td>(1) TEXC¥/24, time-step factor for advection</td>
<td>sec</td>
<td>3780 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(2) DT/2, time-step factor for pressure force</td>
<td>sec</td>
<td>5480 COMP 2</td>
</tr>
<tr>
<td></td>
<td>(3) $\Delta t/4 c_p$, time-step factor in thermodynamic energy equation</td>
<td>m$^{-2}$ sec$^3$ deg</td>
<td>6110 COMP 2</td>
</tr>
<tr>
<td>F4</td>
<td>$\Gamma = C_p (T_g - T_s)$, surface sensible heat flux</td>
<td>lyr day$^{-1}$</td>
<td>11250 COMP 3</td>
</tr>
<tr>
<td>GAMG</td>
<td>$\gamma_g = (L/c_p) B e^q g (T_g) T_g^{-2}$, latent heat parameter</td>
<td>--</td>
<td>9080 COMP 3</td>
</tr>
<tr>
<td>GAM1</td>
<td>$\gamma_1 = (L/c_p) B e^q g (T_1) T_1^{-2}$, latent heat parameter</td>
<td>--</td>
<td>8420 COMP 3</td>
</tr>
<tr>
<td>GAM3</td>
<td>$\gamma_3 = (L/c_p) B e^q g (T_3) T_3^{-2}$, latent heat parameter</td>
<td>--</td>
<td>8430 COMP 3</td>
</tr>
<tr>
<td>GRAV</td>
<td>$g$, acceleration of gravity (= 9.81)</td>
<td>m sec$^{-2}$</td>
<td>13420 INPUT</td>
</tr>
<tr>
<td>GT(J,I)</td>
<td>$T_g$, ground temperature (= $T_{gr}$ after radiation correction)</td>
<td>deg</td>
<td>11200 COMP 3</td>
</tr>
<tr>
<td>GW(J,I)</td>
<td>GW = WET, ground wetness (0 &lt; GW &lt; 1)</td>
<td>--</td>
<td>11360 COMP 3</td>
</tr>
<tr>
<td>GWM</td>
<td>ground water mass (= 30)</td>
<td>g cm$^{-2}$</td>
<td>7270 COMP 3</td>
</tr>
<tr>
<td>H(J,I,1)</td>
<td>(1) $(H1 + H3)/2$, average heating</td>
<td>deg</td>
<td>11450 COMP 3</td>
</tr>
<tr>
<td></td>
<td>(2) $(H1 + H3)mn/2$, area-weighted average heating</td>
<td>deg m$^2$</td>
<td>11870 COMP 3</td>
</tr>
</tbody>
</table>

[Note: $H(J,I,2)$ not used.]
<table>
<thead>
<tr>
<th>FORTRAN Symbol</th>
<th>Meaning</th>
<th>Units</th>
<th>Program Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>HACØS</td>
<td>( \cos d \cos (t + \lambda) ), solar zenith angle parameter</td>
<td>--</td>
<td>7780 COMP 3</td>
</tr>
<tr>
<td>HCS</td>
<td>unit conversion factor for surface elevation</td>
<td>--</td>
<td>16200, 16260 INIT 2</td>
</tr>
<tr>
<td>HEIGHT(J)</td>
<td>surface height data</td>
<td>h ft, dm</td>
<td>16310 INIT 2</td>
</tr>
<tr>
<td>HHG</td>
<td>( T_g + (L/c_p)q_g ), WET, ground equivalent temperature</td>
<td>deg</td>
<td>9050 COMP 3</td>
</tr>
<tr>
<td>HH1S</td>
<td>( h_1^* = \theta_3 (p_s/p_o)^\alpha + (\theta_3 - \theta_3)(p_2/p_o)^\alpha + (L/c_p)q_s(T_1) ), level 1 stability parameter</td>
<td>deg</td>
<td>8790 COMP 3</td>
</tr>
<tr>
<td>HH3</td>
<td>( h_3 = \theta_3 (p_s/p_o)^\alpha + (L/c_p)q_3 ), level 3 stability parameter</td>
<td>deg</td>
<td>8770 COMP 3</td>
</tr>
<tr>
<td>HH3S</td>
<td>( h_3^* = \theta_3 (p_s/p_o)^\alpha + (L/c_p)q_3(T_3) ), level 3 stability parameter</td>
<td>deg</td>
<td>8780 COMP 3</td>
</tr>
<tr>
<td>HH4</td>
<td>(1) ( h_4 ), low-level temperature parameter</td>
<td>deg</td>
<td>9070 COMP 3</td>
</tr>
<tr>
<td></td>
<td>(2) ( h_4 = T_4 + (L/c_p)q_4 ), level 4 stability parameter</td>
<td>deg</td>
<td>9230 COMP 3</td>
</tr>
<tr>
<td></td>
<td>(3) ( h_3^* ), level 3 stability parameter</td>
<td>deg</td>
<td>9252 COMP 3</td>
</tr>
<tr>
<td>HH4P</td>
<td>( h_4 = HH4 ), level 4 stability parameter</td>
<td>deg</td>
<td>9220 COMP 3</td>
</tr>
<tr>
<td>HICE</td>
<td>effective ice thickness (( = 300 ))</td>
<td>cm</td>
<td>7340 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
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<td>----------------</td>
<td>---------</td>
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<td>------------------</td>
</tr>
<tr>
<td>HRGAS</td>
<td>R/2, one-half the dry air gas constant</td>
<td>$\text{m}^2\text{sec}^{-2}\text{deg}^{-1}$</td>
<td>4990 COMP 2</td>
</tr>
<tr>
<td>HSCL</td>
<td>unit indicator for surface height</td>
<td>--</td>
<td>16240 INIT 2</td>
</tr>
<tr>
<td>H1</td>
<td>$H_1 = (A_1 + R_2 - R_0)(2g/\pi c_p)\Delta t + (\Delta T_1)^\text{CM} + (\Delta T_1)^\text{CP}$, total heating at level 1 (over 5\Delta t interval)</td>
<td>deg</td>
<td>11430 COMP 3</td>
</tr>
<tr>
<td>H3</td>
<td>$H_3 = (A_3 + R_4 - R_2 + R)(2g/\pi c_p)\Delta t + (\Delta T_3)^\text{CM}$ + (\Delta T_3)^\text{CP} + (\Delta T_3)^\text{LS}$, total heating at level 3 (over 5\Delta t interval)</td>
<td>deg</td>
<td>11440 COMP 3</td>
</tr>
<tr>
<td>I</td>
<td>$i$, longitude grid-point index ((i = 1 \text{ is } \lambda = 0 \text{ at } 180 \text{ deg W})$</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>IC(800)</td>
<td>integer array (= C)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>ICE</td>
<td>ice-cover location indicator</td>
<td>--</td>
<td>7860 COMP 3</td>
</tr>
<tr>
<td>IC1(800)</td>
<td>array identification (alternate to C)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>ICLUD</td>
<td>cloud parameter (= 1 for clear, = 2 for partly cloudy, = 3 for overcast)</td>
<td>--</td>
<td>9430, 9710, 9720 COMP 3</td>
</tr>
<tr>
<td>ID</td>
<td>identification on input data card</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>IDAY</td>
<td>day number (= TAU/R0TPER)</td>
<td>--</td>
<td>0500 CONTROL</td>
</tr>
<tr>
<td>IH</td>
<td>IM/2 + 1, longitudinal grid-point parameter (= 37)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FORTRAN Program</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------</td>
<td>-------</td>
<td>-----------------</td>
</tr>
<tr>
<td>IHALF(2)</td>
<td>two half words that form IWD</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>IL</td>
<td>(1) card identifier for topography</td>
<td>--</td>
<td>16320 INIT 2</td>
</tr>
<tr>
<td></td>
<td>(2) left half word in packed data</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>(3) index counter</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>ILEV</td>
<td>level identification parameter (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>ILH</td>
<td>entry point for left half word in IPKWD</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>IL1</td>
<td>temporary identification of topography cards</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>IL2</td>
<td>temporary identification of topography cards</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>IL3</td>
<td>temporary identification of topography cards</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>IM</td>
<td>maximum number of east/west grid points (= 72)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>IMM2</td>
<td>IM-2, longitudinal grid-point index</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>IM1</td>
<td>I-1, longitudinal grid-point index</td>
<td>--</td>
<td>--</td>
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<tr>
<td>INU</td>
<td>identification for card reader input</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>IPKWD</td>
<td>pack data word (argument for ILH, IRH)</td>
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<tr>
<td>IP1</td>
<td>I+1, longitudinal grid-point index</td>
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<tr>
<td>IR</td>
<td>right half word in packed data</td>
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<td>IRH</td>
<td>entry point for right half word in IPKWD</td>
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<td>control parameter (not used)</td>
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<tr>
<td>IWD</td>
<td>word containing two half words</td>
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<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
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<td>----------------</td>
<td>-------------------------------------------------------------------------</td>
<td>-------</td>
<td>------------------</td>
</tr>
<tr>
<td>J</td>
<td>j, latitudinal grid-point index</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>JDYACC</td>
<td>variable for day of month determination</td>
<td>--</td>
<td>15350</td>
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<td></td>
<td></td>
<td></td>
<td>SDET</td>
</tr>
<tr>
<td>JE</td>
<td>JM/2 + 1, latitudinal grid-point index (= 24)</td>
<td>--</td>
<td>6870</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>AVRX</td>
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<tr>
<td>JL</td>
<td>index counter</td>
<td>--</td>
<td>--</td>
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<tr>
<td>JM</td>
<td>maximum number of north/south grid points (= 46)</td>
<td>--</td>
<td>--</td>
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<tr>
<td>JMM1</td>
<td>JM - 1, latitudinal grid-point index</td>
<td>--</td>
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</tr>
<tr>
<td>JMM2</td>
<td>JM - 2, latitudinal grid-point index</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>JTP</td>
<td>variable input/output identification (not used)</td>
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<td>--</td>
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<tr>
<td>JUMP</td>
<td>control parameter (not used)</td>
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<td>--</td>
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<tr>
<td>K</td>
<td>level or variable indicator (in friction calculation K = 1 or 2)</td>
<td>--</td>
<td>--</td>
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<tr>
<td>KAPA</td>
<td>$\kappa = R/c_p$, thermodynamic ratio (= 0.286)</td>
<td>--</td>
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<tr>
<td>KEYS(J)</td>
<td>logical control parameters (not used)</td>
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<td>--</td>
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<td>KKK</td>
<td>packed data location in COMP 3</td>
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<td>11690</td>
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<tr>
<td>KNT</td>
<td>variable input/output identification (not used)</td>
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<td>--</td>
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<tr>
<td>KSET</td>
<td>array for KEY control characters (not used)</td>
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<tr>
<td>KTP</td>
<td>variable identification for history tape</td>
<td>--</td>
<td>--</td>
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<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
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<td>----------------</td>
<td>------------------------------------------------------------------------</td>
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<tr>
<td>K1</td>
<td>2K, identifier for u₁ or v₁</td>
<td>--</td>
<td>11550</td>
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<td>COMP 3</td>
</tr>
<tr>
<td>K2</td>
<td>2K + 1, identifier for u₃ or v₃</td>
<td>--</td>
<td>11560</td>
</tr>
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<td></td>
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<td></td>
<td>COMP 3</td>
</tr>
<tr>
<td>L</td>
<td>level indicator (L = 1 for level 1, L = 2 for level 3)</td>
<td>--</td>
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<tr>
<td>LAND</td>
<td>land location indicator</td>
<td>--</td>
<td>7870</td>
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<td>COMP 3</td>
</tr>
<tr>
<td>LAT(J)</td>
<td>ϕ₃, latitude of grid point</td>
<td>radians</td>
<td>14490</td>
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<td>MAGFAC</td>
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<tr>
<td>LDAY</td>
<td>t, day numbering origin (= 0)</td>
<td>day</td>
<td>15010</td>
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<td>INSDET</td>
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<td>LTP</td>
<td>variable input/output identification (not used)</td>
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<td>--</td>
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<tr>
<td>LYR</td>
<td>year (if reset from input)</td>
<td>year</td>
<td>15040</td>
</tr>
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<td>INSDET</td>
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<tr>
<td>M</td>
<td>logical KEY function argument</td>
<td>--</td>
<td>--</td>
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<tr>
<td>MARK</td>
<td>MARK 1, control number in topography deck (= 0 if deck not read)</td>
<td>--</td>
<td>13680</td>
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<tr>
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<td></td>
<td></td>
<td>INPUT</td>
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<tr>
<td>MAPGEN</td>
<td>map generation identification</td>
<td>--</td>
<td>--</td>
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<tr>
<td>MAPLST (3,40)</td>
<td>map list identification (not used)</td>
<td>--</td>
<td>--</td>
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<tr>
<td>MAXDAY</td>
<td>DAYPYR + 10⁻², maximum allowed day in year (= 365.01)</td>
<td>day</td>
<td>15280</td>
</tr>
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<td></td>
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<td>SDET</td>
</tr>
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<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
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<td>----------------</td>
<td>--------------------------------------------------------------</td>
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<td>------------------</td>
</tr>
<tr>
<td>METER</td>
<td>identification for topographic height</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>MNTHDY</td>
<td>identification for day of month</td>
<td>day</td>
<td>--</td>
</tr>
<tr>
<td>MONTH(12)</td>
<td>days in each month (beginning with January)</td>
<td>day</td>
<td>--</td>
</tr>
<tr>
<td>MRCH</td>
<td>identifier for steps in time integration (= 1, 2, 3, or 4)</td>
<td>--</td>
<td>1920, 2120-2140</td>
</tr>
<tr>
<td>MTP</td>
<td>variable identification for printed output</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>N</td>
<td>logical variable in KEYS array</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>NCYCLE</td>
<td>control parameter for MRCH (= 5)</td>
<td>--</td>
<td>13340 INPUT</td>
</tr>
<tr>
<td>NC3</td>
<td>number of time steps between uses of subroutine</td>
<td>--</td>
<td>13340 INPUT</td>
</tr>
<tr>
<td></td>
<td>COMP 3 (= 5)</td>
<td></td>
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</tr>
<tr>
<td>NM</td>
<td>integer part of DRAT</td>
<td>--</td>
<td>6930 AVRX</td>
</tr>
<tr>
<td>NOUT</td>
<td>map generation output parameter</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>NPOL</td>
<td>zonal mean at north pole</td>
<td>(various)</td>
<td>--</td>
</tr>
<tr>
<td>NS</td>
<td>control parameter for time integration</td>
<td>--</td>
<td>2110 STEP</td>
</tr>
<tr>
<td>NSTEP</td>
<td>control parameter for time integration</td>
<td>--</td>
<td>0280 CONTROL</td>
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<tr>
<td>OCEAN</td>
<td>ocean location indicator</td>
<td>--</td>
<td>7850 COMP 3</td>
</tr>
<tr>
<td>OFF</td>
<td>solar declination control parameter</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
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<td>----------------</td>
<td>---------</td>
<td>-------</td>
<td>------------------</td>
</tr>
<tr>
<td>P(J,I)</td>
<td>$\pi = p_s - p_T$, surface pressure parameter</td>
<td>mb</td>
<td>--</td>
</tr>
<tr>
<td>PASS2</td>
<td>data control parameter (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>PB1</td>
<td>(1) $\text{CONV}(1,I)$, parameter for south pole mass convergence</td>
<td>$m^2 \text{sec}^{-1} \text{mb}$</td>
<td>4320-4410 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(2) $\text{QT}(1,I,L)$, parameter for south pole calculations</td>
<td>(various)</td>
<td>6450-6500 COMP 2</td>
</tr>
<tr>
<td>PB2</td>
<td>(1) $\text{CONV}(JM,I)$, parameter for north pole mass convergence</td>
<td>$m^2 \text{sec}^{-1} \text{mb}$</td>
<td>4330-4420 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(2) $\text{QT}(JM,I,L)$, parameter for north pole calculations</td>
<td>(various)</td>
<td>6460-6510 COMP 2</td>
</tr>
<tr>
<td>PB3</td>
<td>$\text{PV}(1,I)$, parameter for south pole mass convergence</td>
<td>$m^2 \text{sec}^{-1} \text{mb}$</td>
<td>4340-4430 COMP 1</td>
</tr>
<tr>
<td>PB4</td>
<td>$\text{PV}(JM,I)$, parameter for north pole mass convergence</td>
<td>$m^2 \text{sec}^{-1} \text{mb}$</td>
<td>4350-4440 COMP 1</td>
</tr>
<tr>
<td>PC1</td>
<td>$(\Delta T_1)_{CP} = (h_4 - h_3) \tau_1^5 \Delta t / \tau \pi$, level 1 temperature change due to penetrating convection</td>
<td>deg</td>
<td>9310 COMP 3</td>
</tr>
<tr>
<td>PC3</td>
<td>$(\Delta T_3)_{CP} = (h_4 - h_3) \tau_2^5 \Delta t / \tau \pi$, level 3 temperature change due to penetrating convection</td>
<td>deg</td>
<td>9320 COMP 3</td>
</tr>
<tr>
<td>PHI(J,I)</td>
<td>(1) $\phi_1$ or $\phi_3$, level 1 or 3 geopotential</td>
<td>$m^2 \text{sec}^{-2}$</td>
<td>5380, 5420 COMP 2</td>
</tr>
<tr>
<td></td>
<td>(2) $\sigma_1 \pi_1$ or $\sigma_3 \pi_3$, pressure gradient parameter</td>
<td>$m^2 \text{sec}^{-2}$</td>
<td>5760 COMP 2</td>
</tr>
<tr>
<td>PHI4</td>
<td>$\phi_4 = \text{VPHI4}(J,I)$, surface geopotential (0 if ocean)</td>
<td>$m^2 \text{sec}^{-2}$</td>
<td>5300 COMP 2</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
<td>-------</td>
<td>-----------------</td>
</tr>
<tr>
<td>PI</td>
<td>constant $\pi = 3.1415926$</td>
<td>--</td>
<td>13040 INPUT</td>
</tr>
<tr>
<td>PIT(J,I)</td>
<td>$-\left(\frac{mn}{2}\right)\left[\nabla \cdot \left{ \left( \mathbf{V}_1 + \mathbf{V}_3 \right) \right} \right] = \text{CONV}(J,I) + \text{PV}(J,I)$, net column mass convergence (not tendency)</td>
<td>$\text{m}^2\text{sec}^{-1}\text{mb}$</td>
<td>4520 COMP 1</td>
</tr>
<tr>
<td>PK1</td>
<td>$p_1^{K}$, upper-level pressure to kappa power</td>
<td>(mb)$^K$</td>
<td>4600 COMP 1</td>
</tr>
<tr>
<td>PK3</td>
<td>$p_3^{K}$, lower-level pressure to kappa power</td>
<td>(mb)$^K$</td>
<td>4610 COMP 1</td>
</tr>
<tr>
<td>PL1</td>
<td>$p_1 = p_T + \sigma_1^\pi$, level 1 pressure</td>
<td>mb</td>
<td>4580 COMP 1</td>
</tr>
<tr>
<td>PL1K</td>
<td>$p_1^{K}$, upper-level pressure to kappa power</td>
<td>(mb)$^K$</td>
<td>8120 COMP 3</td>
</tr>
<tr>
<td>PL2</td>
<td>$p_2 = p_T + \pi/2$, level 2 pressure</td>
<td>mb</td>
<td>8100 COMP 3</td>
</tr>
<tr>
<td>PL2K</td>
<td>$p_2^{K}$, middle-level pressure to kappa power</td>
<td>(mb)$^K$</td>
<td>8140 COMP 3</td>
</tr>
<tr>
<td>PL3</td>
<td>$p_3 = p_T + \sigma_3^\pi$, level 3 pressure</td>
<td>mb</td>
<td>4590 COMP 1</td>
</tr>
<tr>
<td>PL3K</td>
<td>$p_3^{K}$, lower-level pressure to kappa power</td>
<td>(mb)$^K$</td>
<td>8130 COMP 3</td>
</tr>
<tr>
<td>PM</td>
<td>$p_o - p_T$, standard tropospheric pressure depth (= 800)</td>
<td>mb</td>
<td>7370 COMP 3</td>
</tr>
<tr>
<td>PREC</td>
<td>$(\Delta q)_L = \left[ q_3 - q_a(T_3) \right] \cdot \left[ 1 + \left( \frac{L}{c_p} \right) \frac{B}{e_a} \frac{q_a(T_3)}{T_3} \right]^{-1}$, level 3 moisture change due to large-scale condensation</td>
<td>--</td>
<td>8650 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Location</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
<td>-------</td>
<td>-----------</td>
</tr>
<tr>
<td>PSF</td>
<td>reference global mean surface pressure (= 984)</td>
<td>mb</td>
<td>1430 COMP, 13680 INPUT</td>
</tr>
<tr>
<td>PSL</td>
<td>$p_0^*$, reference sea-level pressure (= 1000)</td>
<td>mb</td>
<td>13460 INPUT</td>
</tr>
<tr>
<td>PT(J,I)</td>
<td>$n + \Delta t \text{ PIT/mn, updated } n \text{ value}$</td>
<td>mb</td>
<td>4560 COMP 1</td>
</tr>
<tr>
<td>PTRK</td>
<td>$P_T$</td>
<td>$(\text{mb})^\kappa$</td>
<td>8150 COMP 3</td>
</tr>
<tr>
<td>PTRP</td>
<td>$p_T$, tropopause pressure (= 200)</td>
<td>mb</td>
<td>13460 INPUT</td>
</tr>
<tr>
<td>PU(J,I)</td>
<td>(1) $u^* = n \cdot u$, zonal mass flux (at $u^*$ points)</td>
<td>m$^2$ sec$^{-1}$ mb</td>
<td>2780-2890 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(2) TEMP 1, provisional pressure gradient parameter</td>
<td>m$^2$ sec$^{-2}$ mb</td>
<td>5560 COMP 2</td>
</tr>
<tr>
<td></td>
<td>(3) TEMP, provisional term in energy equation (other provisional definition in 6270 COMP 2, 12320 COMP 4)</td>
<td>sec$^2$ deg</td>
<td>6190 COMP 2</td>
</tr>
<tr>
<td>PV(J,I)</td>
<td>(1) $v^* = m \cdot v$, meridional mass flux (at $v^*$ points)</td>
<td>m$^2$ sec$^{-1}$ mb</td>
<td>2910-2940 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(2) CØNVM, mass convergence at level 2</td>
<td>m$^2$ sec$^{-1}$ mb</td>
<td>4230 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(3) polar PU equivalent (various definitions) (other definitions in COMP 4)</td>
<td>m$^2$ sec$^{-1}$ mb</td>
<td>3050-3170 COMP 1</td>
</tr>
<tr>
<td>PICB</td>
<td>$p_1/10$, level 1 pressure in centibars</td>
<td>cb</td>
<td>8370 COMP 3</td>
</tr>
<tr>
<td>PIOK</td>
<td>$p_o^\kappa$</td>
<td>$(\text{mb})^\kappa$</td>
<td>7310 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
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<td>------------------</td>
</tr>
<tr>
<td>P3CB</td>
<td>$p_3/10$, level 3 pressure in centibars</td>
<td>cb</td>
<td>8380 COMP 3</td>
</tr>
<tr>
<td>P4</td>
<td>$p_4 = p_8 = r + p_T$, surface pressure</td>
<td>mb</td>
<td>8070 COMP 3</td>
</tr>
<tr>
<td>P4CB</td>
<td>$p_4/10$, surface pressure in centibars</td>
<td>cb</td>
<td>8390 COMP 3</td>
</tr>
<tr>
<td>P4K</td>
<td>$p_4^e$</td>
<td>(mb)$^c$</td>
<td>8080 COMP 3</td>
</tr>
<tr>
<td>Q(J,I,K)</td>
<td>equivalence array ($K = 1, 2, \ldots 9$; see Chapter VII, Subsection A.3)</td>
<td>(various)</td>
<td>2060 STEP</td>
</tr>
<tr>
<td>QD(J,I,9)</td>
<td>array identification (alternate to QT)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>QG</td>
<td>$q_s(T_1)$, ground-level saturation mixing ratio</td>
<td>--</td>
<td>9030 COMP 3</td>
</tr>
<tr>
<td>QN</td>
<td>$\Delta q_3$, total level 3 mixing ratio change due to convection, condensation, evaporation</td>
<td>--</td>
<td>11300 COMP 3</td>
</tr>
<tr>
<td>QS1</td>
<td>$q_s(T_2)$, level 1 saturation mixing ratio</td>
<td>--</td>
<td>8400 COMP 3</td>
</tr>
<tr>
<td>QS3</td>
<td>$q_s(T_3)$, level 3 saturation mixing ratio</td>
<td>--</td>
<td>8410 COMP 3</td>
</tr>
<tr>
<td>QT(J,I,K)</td>
<td>equivalence array for temporary variables ($K = 1, 2, \ldots 8$; see Chapter VII, Subsection A.3)</td>
<td>(various)</td>
<td>2070 STEP</td>
</tr>
<tr>
<td>QT(J,I,20)</td>
<td>equivalence array (see Chapter VII, Subsection A.3)</td>
<td>(various)</td>
<td>0140 COMMON</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
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<td>-------------------------------------------------------------------------------------------</td>
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<td>------------------</td>
</tr>
<tr>
<td>Q3(J,I)</td>
<td>q₃, level 3 mixing ratio</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Q3M</td>
<td>level 3 moisture parameter</td>
<td>--</td>
<td>3410, 3660</td>
</tr>
<tr>
<td>Q3R</td>
<td>q₃ - (Δq₃), level 3 mixing ratio after large-scale condensation</td>
<td>--</td>
<td>8680</td>
</tr>
<tr>
<td>Q3RB</td>
<td>max(q₃, 10⁻⁵), provision to insure q₃ ≥ 10⁻⁵</td>
<td>--</td>
<td>9770</td>
</tr>
<tr>
<td>Q3T(J,I)</td>
<td>q₃′′, pressure-area-weighted level 3 mixing ratio</td>
<td>m²·mb</td>
<td>2570</td>
</tr>
<tr>
<td></td>
<td>(also moisture flux at 3710, 3720 COMP 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q4</td>
<td>(1) RH₄[q₈(T₄) + (c₉/p)γ₈(T₄ - T₈)], level 4 moisture parameter</td>
<td>--</td>
<td>9110</td>
</tr>
<tr>
<td></td>
<td>(2) q₄ = q₈(T₄) + <a href="c%E2%82%89/p">q₃(p₈/p₀)κ - T₄</a></td>
<td></td>
<td>9350</td>
</tr>
<tr>
<td>RAD</td>
<td>a, earth's radius (= 6375) (redefined in m in 13640, INPUT)</td>
<td>km</td>
<td>13420</td>
</tr>
<tr>
<td>RCNV</td>
<td>DTC₃/TGNV, = 5Δt/τ_r = 1/2</td>
<td>°r</td>
<td>7290</td>
</tr>
<tr>
<td>RESET</td>
<td>day and year control parameter</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>RGAS</td>
<td>R, gas constant for dry air (= 287)</td>
<td>m²·deg⁻¹·sec⁻²</td>
<td>13440</td>
</tr>
<tr>
<td>RH₃</td>
<td>RH₃ = q₃/q₈(T₃), relative humidity at level 3</td>
<td>--</td>
<td>8450</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
<td>-------</td>
<td>------------------</td>
</tr>
<tr>
<td>RH4</td>
<td>$RH_4 = 2RH_3 \cdot GW(RH_3 + GW)^{-1}$, ground-level humidity measure</td>
<td>--</td>
<td>9000 COMP 3</td>
</tr>
<tr>
<td>RØT</td>
<td>$t = t \cdot 2\pi/24$ hr, hour of day (converted to radians)</td>
<td>radians</td>
<td>7730 COMP 3</td>
</tr>
<tr>
<td>RØTPER</td>
<td>period of solar rotation (= 24.0)</td>
<td>hr</td>
<td>13090 INPUT</td>
</tr>
<tr>
<td>RØ4</td>
<td>$\rho_4 = p_s(RT_4)^{-1}$, air density at level 4 (surface)</td>
<td>g cm$^{-3}$</td>
<td>9370 COMP 3</td>
</tr>
<tr>
<td>RSDIST</td>
<td>square of the normalized earth/sun distance</td>
<td>--</td>
<td>15520 SDET</td>
</tr>
<tr>
<td>RSETSW</td>
<td>input identification</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>RUNØFF</td>
<td>WET/2, fraction of rainfall which runs off</td>
<td>--</td>
<td>11340 COMP 3</td>
</tr>
<tr>
<td>RØ</td>
<td>(1) $\bar{R}_o$, long-wave radiation parameter at tropopause</td>
<td>1y day$^{-1}$</td>
<td>10200 COMP 3</td>
</tr>
<tr>
<td></td>
<td>(2) $R_o = \bar{R}_o + 0.8(1 - CL)(R_4 - \bar{R}_o) \cdot \tau(u_4)$, net upward long-wave radiative flux at tropopause</td>
<td>1y day$^{-1}$</td>
<td>11190 COMP 3</td>
</tr>
<tr>
<td>ROC</td>
<td>$R_o^{\text{CL}}$, cloudy sky part of long-wave radiative flux at tropopause, times cloudiness (separately defined for cloud types 1, 2, 3)</td>
<td>1y day$^{-1}$</td>
<td>10040, 10100, 10170 COMP 3</td>
</tr>
<tr>
<td>ROØ</td>
<td>$R_o^{\text{CL}}$, clear sky part of long-wave radiative flux at tropopause</td>
<td>1y day$^{-1}$</td>
<td>9980 COMP 3</td>
</tr>
<tr>
<td>Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program location</td>
</tr>
<tr>
<td>--------</td>
<td>---------</td>
<td>-------</td>
<td>------------------</td>
</tr>
<tr>
<td>R2</td>
<td>(1) $\tilde{R}_2$, long-wave radiation parameter at level 2</td>
<td>1 y day$^{-1}$</td>
<td>10210, COMP 3</td>
</tr>
<tr>
<td></td>
<td>(2) $R_2 = \tilde{R}_2 + 0.8(1 - CL)(R_4 - \tilde{R}_4) \cdot \tau(u_2^*), \quad \text{net upward long-wave radiative flux at level 2}$</td>
<td>1 y day$^{-1}$</td>
<td>11180, COMP 3</td>
</tr>
<tr>
<td>R2C</td>
<td>$R_2^{CL}$, cloudy sky long-wave radiative flux at level 2, times cloudiness (separately defined for cloud types 1, 2, 3)</td>
<td>1 y day$^{-1}$</td>
<td>10050, 10010, 10180, COMP 3</td>
</tr>
<tr>
<td>R2O</td>
<td>$R_2^{O}$, clear sky part of long-wave radiative flux at level 2</td>
<td>1 y day$^{-1}$</td>
<td>9990, COMP 3</td>
</tr>
<tr>
<td>R4</td>
<td>(1) $\tilde{R}_4$, long-wave radiation parameter at level 4</td>
<td>1 y day$^{-1}$</td>
<td>10220, COMP 3</td>
</tr>
<tr>
<td></td>
<td>(2) $R_4 = \tilde{R}<em>4 + cT_3^3(T</em>{gr} - T_g)$, net upward long-wave radiative flux at level 4 (surface)</td>
<td>1 y day$^{-1}$</td>
<td>11170, COMP 3</td>
</tr>
<tr>
<td>R4C</td>
<td>$R_4^{CL}$, cloudy sky long-wave radiative flux at level 4 (ground), times cloudiness</td>
<td>1 y day$^{-1}$</td>
<td>10190, COMP 3</td>
</tr>
<tr>
<td>R4O</td>
<td>$R_4^{O}$, clear sky part of long-wave radiative flux at level 4 (ground)</td>
<td>1 y day$^{-1}$</td>
<td>10000, COMP 3</td>
</tr>
<tr>
<td>SA</td>
<td>$S_A = 0.349 S_o \cos \varphi$, part of incoming solar radiation subject to absorption</td>
<td>1 y day$^{-1}$</td>
<td>10460, COMP 3</td>
</tr>
<tr>
<td>SCALE</td>
<td>scale factor for layer radiative heating</td>
<td>deg 1 y$^{-1}$</td>
<td>11680, COMP 3</td>
</tr>
<tr>
<td>SCALEP</td>
<td>scale factor for layer latent heating</td>
<td>mm day$^{-1}$ mb$^{-1}$</td>
<td>7420, COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------------------------------------------------------------------</td>
<td>------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>SCALEU</td>
<td>((10/c_p)(2g/\pi)), scale factor for column heat capacity</td>
<td>deg 1y(^{-1})</td>
<td>7400</td>
</tr>
<tr>
<td>SCQSZ</td>
<td>(S_0 \cos \tau), total solar radiation at top of atmosphere</td>
<td>1y day(^{-1})</td>
<td>10280</td>
</tr>
<tr>
<td>SD(J,I)</td>
<td>(\frac{m}{2} [\nabla \cdot (\hat{V}_3 - \hat{V}_1)] = \text{CONV}(J,I) - \text{PV}(J,I)), net mass convergence ((\dot{s} = \frac{2m}{\partial} ))</td>
<td>m(^2) sec(^{-1}) mb</td>
<td>4530</td>
</tr>
<tr>
<td>SDEDY</td>
<td>day counter starting from origin LDAY</td>
<td>day</td>
<td>15030</td>
</tr>
<tr>
<td>SDU</td>
<td>(\dot{s}_u), four-point average mass convergence</td>
<td>m(^3) sec(^{-2}) mb</td>
<td>4750</td>
</tr>
<tr>
<td>SEASON</td>
<td>((\text{DY}-173.0)/365), time parameter in solar declination</td>
<td>--</td>
<td>15440</td>
</tr>
<tr>
<td>SIG1</td>
<td>(\sigma_1), upper-level (\sigma) value ((= 1/4))</td>
<td>--</td>
<td>7230</td>
</tr>
<tr>
<td>SIG3</td>
<td>(\sigma_3), lower-level (\sigma) value ((= 3/4))</td>
<td>--</td>
<td>7240</td>
</tr>
<tr>
<td>SIGCØ</td>
<td>FL/2, level designator</td>
<td>--</td>
<td>12360</td>
</tr>
<tr>
<td>SIND</td>
<td>(\sin \tau), sine of solar declination</td>
<td>--</td>
<td>15530</td>
</tr>
<tr>
<td>SINL(J)</td>
<td>(\sin \varphi_j), sine of latitude</td>
<td>--</td>
<td>14950</td>
</tr>
<tr>
<td>SINT</td>
<td>control parameter (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
<td>-------</td>
<td>------------------</td>
</tr>
<tr>
<td>SN(J,I)</td>
<td>identification for VT(1,1,2)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>SNOW</td>
<td>designator for snow-covered land</td>
<td>--</td>
<td>7880 COMP 3</td>
</tr>
<tr>
<td>SNOWA</td>
<td>snowline in northern hemisphere (varies ±15° about 60 deg N)</td>
<td>radians</td>
<td>7460 COMP 3</td>
</tr>
<tr>
<td>SNOWS</td>
<td>snowline in southern hemisphere (= 60 deg S)</td>
<td>radians</td>
<td>7470 COMP 3</td>
</tr>
<tr>
<td>SP</td>
<td>P(J,I) - π, surface pressure parameter</td>
<td>mb</td>
<td>8050 COMP 3</td>
</tr>
<tr>
<td>SPOL</td>
<td>zonal mean at south pole</td>
<td>(various)</td>
<td>--</td>
</tr>
<tr>
<td>S0</td>
<td>S0 = 0.651S0 cos ζ, part of incoming solar radiation subject to scattering</td>
<td>ly day^{-1}</td>
<td>10470 COMP 3</td>
</tr>
<tr>
<td>SS1</td>
<td>θ3(pB/p0)^K + (θ1 - θ3)(p2/p0)^K, convective stability parameter</td>
<td>deg</td>
<td>8760 COMP 3</td>
</tr>
<tr>
<td>SS2</td>
<td>θ3(pB/p0)^K + 1/2 (θ1 - θ3)(p2/p0)^K, convective stability parameter</td>
<td>deg</td>
<td>8750 COMP 3</td>
</tr>
<tr>
<td>SS3</td>
<td>θ3(pB/p0)^K, convective stability parameter</td>
<td>deg</td>
<td>8740 COMP 3</td>
</tr>
<tr>
<td>STAGI</td>
<td>logical variable for zonal map staggering</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>STAGJ</td>
<td>logical variable for meridional map staggering</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>STBÔ</td>
<td>σ, Stefan-Boltzman constant</td>
<td>ly day^{-1}deg^{-4}</td>
<td>7650 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
<td>-------</td>
<td>-----------------</td>
</tr>
<tr>
<td>S0</td>
<td>$S_0$, solar constant (modified for earth/sun distance)</td>
<td>ly day^-1</td>
<td>7610 COMP 3</td>
</tr>
<tr>
<td>S4</td>
<td>$S = (1-CL)S' + CL S''$, total flux of short-wave radiation absorbed by the ground</td>
<td>ly day^-1</td>
<td>10940 COMP 3</td>
</tr>
<tr>
<td>S4C</td>
<td>$S''$, cloudy sky part of short-wave radiation absorbed by the ground (defined separately for cloud types 1, 2, 3)</td>
<td>ly day^-1</td>
<td>10660, 10760, 10890 COMP 3</td>
</tr>
<tr>
<td>S40</td>
<td>$S'$, clear sky part of short-wave radiation absorbed by the ground</td>
<td>ly day^-1</td>
<td>10570 COMP 3</td>
</tr>
<tr>
<td>T(J,I,L)</td>
<td>level 1 or level 3 temperature (also for temperature after heating and smoothing in 11470, 11980, COMP 3); $L = 1$ denotes $T_1$, $L = 2$ denotes $T_3$</td>
<td>deg</td>
<td>8280 COMP 3</td>
</tr>
<tr>
<td>TAU</td>
<td>time in hr</td>
<td>hr</td>
<td>--</td>
</tr>
<tr>
<td>TAUC</td>
<td>input identification (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>TAUD</td>
<td>frequency of recalculation of solar declination (= 24)</td>
<td>hr</td>
<td>13310 INPUT</td>
</tr>
<tr>
<td>TAUE</td>
<td>day of integration end</td>
<td>day, hr</td>
<td>13310, 13320 INPUT</td>
</tr>
<tr>
<td>TAUH</td>
<td>frequency of history tape storage (= 6)</td>
<td>hr</td>
<td>13310 INPUT</td>
</tr>
<tr>
<td>TAU1</td>
<td>TAUD · 24 + TAUH, starting time (in hr)</td>
<td>hr</td>
<td>13290 INPUT</td>
</tr>
<tr>
<td>TAU1D</td>
<td>starting time</td>
<td>day</td>
<td>13730 INPUT</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------------------------------------------------------------------</td>
<td>-----------</td>
<td>------------------</td>
</tr>
<tr>
<td>TAUIH</td>
<td>hour of starting time</td>
<td>hr</td>
<td>13740 INPUT</td>
</tr>
<tr>
<td>TAUØ</td>
<td>output interval (= 24)</td>
<td>hr</td>
<td>13310 INPUT</td>
</tr>
<tr>
<td>TAUX</td>
<td>starting time parameter</td>
<td>hr</td>
<td>13700 INPUT</td>
</tr>
<tr>
<td>TBAR</td>
<td>$(T_1 + T_3)/2$, average temperature</td>
<td>deg</td>
<td>12830 COMP 4</td>
</tr>
<tr>
<td>TCNV</td>
<td>relaxation time for cumulus convection (= 3600)</td>
<td>sec</td>
<td>13400 INPUT</td>
</tr>
<tr>
<td>TD(J,I)</td>
<td>$(T_3 - T_1)/2^n$, vertical temperature (lapse-rate) parameter</td>
<td>deg mb⁻¹</td>
<td>12740 COMP 4</td>
</tr>
<tr>
<td>TDBAR</td>
<td>smoothed value of TD</td>
<td>deg mb⁻¹</td>
<td>12790 COMP 4</td>
</tr>
<tr>
<td>TDSM</td>
<td>weighted TD parameter</td>
<td>deg</td>
<td>12820 COMP 4</td>
</tr>
<tr>
<td>TEM</td>
<td>$\bar{h}$, conduction coefficient for ice (also defined as cloudiness parameters in COMP 3 but not used)</td>
<td>1y day⁻¹ deg⁻¹</td>
<td>11080 COMP 3</td>
</tr>
<tr>
<td>TEMB</td>
<td>short-wave radiative flux reflected from type 1 cloud top</td>
<td>1y day⁻¹</td>
<td>10840 COMP 3</td>
</tr>
<tr>
<td>TEMP</td>
<td>(1) intermediate parameter in thermodynamic energy conversion calculation</td>
<td>sec² deg</td>
<td>6160–6340 COMP 2</td>
</tr>
<tr>
<td></td>
<td>(2) $\tau$, penetrating convection parameter</td>
<td>deg</td>
<td>9280 COMP 3</td>
</tr>
<tr>
<td></td>
<td>(3) $(H_1 - H_3)/2$, heating parameter</td>
<td>deg</td>
<td>11460 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
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<tr>
<td>TEMP</td>
<td>(4) vertical wind shear ((u_1 - u_3)) or (v_1 - v_3)</td>
<td>(\text{m sec}^{-1})</td>
<td>11570 COMP 3</td>
</tr>
<tr>
<td></td>
<td>(5) (\overline{H}), averaged heating</td>
<td></td>
<td>11930-11950 COMP 3</td>
</tr>
<tr>
<td>TEMP1</td>
<td>(1) intermediate parameter in pressure gradient calculation</td>
<td>(\text{m sec}^{-2})</td>
<td>5550, 5810 COMP 2</td>
</tr>
<tr>
<td></td>
<td>(2) (\tau_1 = (h_3^* - h_1^*)(1 + \gamma_1)^{-1} + LR/2), penetrating convection parameter</td>
<td>(\text{deg})</td>
<td>9260 COMP 3</td>
</tr>
<tr>
<td>TEMP2</td>
<td>(1) intermediate parameter in pressure gradient calculation</td>
<td>(\text{m sec}^{-2})</td>
<td>5570, 5830 COMP 2</td>
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<tr>
<td></td>
<td>(2) (\tau_2 = \theta_3(p_4/p_o)^K - T_4 + LR/2), penetrating convection parameter</td>
<td>(\text{deg})</td>
<td>9270 COMP 3</td>
</tr>
<tr>
<td>TEMS</td>
<td>((S_4^A)), flux of (S_0^A) reaching level 4 through clouds (defined separately for cloud types 1, 2, 3)</td>
<td>(1 \text{ y day}^{-1})</td>
<td>10630, 10730, 10860 COMP 3</td>
</tr>
<tr>
<td>TEMSCL</td>
<td>sea-surface temperature unit indicator</td>
<td></td>
<td>15910 INIT 2</td>
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<tr>
<td>TEMU</td>
<td>((u_0^* - u_1^* or u_3^*) \text{ sec} \tau), parameter for transmission of (S_0^A) through type 1 or type 3 clouds</td>
<td>(\text{g cm}^{-2})</td>
<td>10720, 10830 COMP 3</td>
</tr>
<tr>
<td>TEM1</td>
<td>(p_3^2q_3(2 + K)^{-1}g^{-1}), water vapor parameter</td>
<td>(\text{g cm}^{-2})</td>
<td>9790 COMP 3</td>
</tr>
<tr>
<td>TEM2</td>
<td>(p_3^2q_3(2 + K)^{-1}g^{-1}(p_4/p_3)^{2+K}), water vapor parameter</td>
<td>(\text{g cm}^{-2})</td>
<td>9800 COMP 3</td>
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<tr>
<td>TEMAM</td>
<td>(\theta_2p_o^{-K}), temperature parameter</td>
<td>(\text{deg mb}^{-K})</td>
<td>4620 COMP 1</td>
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<tr>
<td>TETA1</td>
<td>$\theta_1$, level 1 potential temperature</td>
<td>deg K</td>
<td>8720 COMP 3</td>
</tr>
<tr>
<td>TETA3</td>
<td>$\theta_3$, level 3 potential temperature</td>
<td>deg K</td>
<td>8730 COMP 3</td>
</tr>
<tr>
<td>TEXCO</td>
<td>DT, time step (= 360) (also defined as DT/2 in 2480 COMP 1, 4970 COMP 2 for advective terms)</td>
<td>sec</td>
<td>2470 COMP 1, 4960 COMP 2</td>
</tr>
<tr>
<td>TG</td>
<td>$T_g$, ground temperature (original)</td>
<td>deg K</td>
<td>8560 COMP 3</td>
</tr>
<tr>
<td>TGR</td>
<td>(1) $T_{gr} = T_g$ if ocean, $T_{gr} = T_o$ if ice or snow and $T_{gr} &gt; T_o$</td>
<td>deg K</td>
<td>11040 COMP 3</td>
</tr>
<tr>
<td></td>
<td>(2) $T_{gr} = (A1 + A2)/(B1 + B2)$, ground temperature (revised)</td>
<td>deg K</td>
<td>11130 COMP 3</td>
</tr>
<tr>
<td>TGO0</td>
<td>$T_{OPG}$, ocean surface temperature or surface geopotential</td>
<td>deg or $m^2$ sec $^{-2}$</td>
<td>7840 COMP 3</td>
</tr>
<tr>
<td>THL1</td>
<td>$\theta_{1p}^{-K}$, level 1 temperature parameter</td>
<td>deg mb $^{-K}$</td>
<td>8220 COMP 3</td>
</tr>
<tr>
<td>THL3</td>
<td>$\theta_{3p}^{-K}$, level 3 temperature parameter</td>
<td>deg mb $^{-K}$</td>
<td>8230 COMP 3</td>
</tr>
<tr>
<td>THRIP</td>
<td>time in days and fractions (= TAU/24)</td>
<td>day</td>
<td>1970 STEP</td>
</tr>
<tr>
<td>TICE</td>
<td>$T_o$, melting point of ice (= 273.1)</td>
<td>deg K</td>
<td>7350 COMP 3</td>
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<tr>
<td>TDFDAY</td>
<td>$t =$ time of day counter (Greenwich hours)</td>
<td>hr</td>
<td>14120 INPUT</td>
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<tr>
<td>TØPØG(J,I)</td>
<td>surface topography indicator</td>
<td>deg or 2 m⁻² sec⁻²</td>
<td>16090 INIT 2</td>
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<tr>
<td>TRANS(X)</td>
<td>( \tau(x) = (1 + 1.75x^{0.416})^{-1} ), slab transmission function for long-wave radiation ((x = u^* \text{ in g cm}^{-2}))</td>
<td>--</td>
<td>7150 COMP 3</td>
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<td>TREADY</td>
<td>integration control parameter (not used)</td>
<td>--</td>
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<td>TRST</td>
<td>tape output control parameter</td>
<td>--</td>
<td>--</td>
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<tr>
<td>TRSW(X)</td>
<td>( 1 - 0.271x^{0.303} ), transmission function for short-wave radiation ((x = u^* \text{ in g cm}^{-2}))</td>
<td>--</td>
<td>7160 COMP 3</td>
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<tr>
<td>TS(J,I)</td>
<td>identification for UT(1,1,2)</td>
<td>--</td>
<td>--</td>
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<tr>
<td>TSPD</td>
<td>DAY/DTC3, number of source (COMP 3) calculations per day (= 48)</td>
<td>--</td>
<td>7410 COMP 3</td>
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<tr>
<td>TT(J,I,L)</td>
<td>(1) ( T ), temperature</td>
<td>deg K</td>
<td>1960 STEP</td>
</tr>
<tr>
<td></td>
<td>(2) ( T_H ), pressure-area-weighted temperature</td>
<td>( m^2 \text{ deg} \text{ cm} )</td>
<td>2620 COMP 1</td>
</tr>
<tr>
<td>TTRØP</td>
<td>( T_T ) or ( T_0 ), tropopause temperature (extrapolated from ( T_1 ) and ( T_3 ) in ( p^k ) space)</td>
<td>deg K</td>
<td>8510 COMP 3</td>
</tr>
<tr>
<td>T1</td>
<td>( T_1 ), level 1 temperature (redefined if convective adjustment occurs)</td>
<td>deg K</td>
<td>8200, 8280 COMP 3</td>
</tr>
<tr>
<td>T2</td>
<td>( T_2 ), level 2 temperature</td>
<td>deg K</td>
<td>8520 COMP 3</td>
</tr>
<tr>
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<td>Units</td>
<td>Program Location</td>
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<tr>
<td>T3</td>
<td>$T_3$, level 3 temperature (redefined if convective adjustment or large-scale condensation occurs in 8660, COMP 3)</td>
<td>deg K</td>
<td>8210, 8270 COMP 3</td>
</tr>
<tr>
<td>T4</td>
<td>$T_4$, air temperature at level 4 (redefined if convection occurs in 9340, COMP 3)</td>
<td>deg K</td>
<td>9090 COMP 3</td>
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<tr>
<td>U(J,I,L)</td>
<td>$u$, zonal wind speed ($L = 1$ designates $u_1$, $L = 2$ designates $u_3$)</td>
<td>m sec$^{-1}$</td>
<td>--</td>
</tr>
<tr>
<td>URT</td>
<td>$\sigma T_2 \tau (u_3^* - u_2^*)$, total long-wave flux at tropopause from atmosphere above tropopause</td>
<td>ly day$^{-1}$</td>
<td>9950 COMP 3</td>
</tr>
<tr>
<td>UR2</td>
<td>$\sigma T_2 \tau (u_2^* - u_2^*)$, total long-wave flux at level 2 from atmosphere above level 2</td>
<td>ly day$^{-1}$</td>
<td>9960 COMP 3</td>
</tr>
<tr>
<td>US</td>
<td>$u_s = 0.7(3u_3 - u_1)/2$, surface zonal wind speed</td>
<td>m sec$^{-1}$</td>
<td>7530 COMP 3</td>
</tr>
<tr>
<td>UT(1,1,1)</td>
<td>provisional variable during zonal smoothing</td>
<td>--</td>
<td>7000 AVRX</td>
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<tr>
<td>UT(J,I,L)</td>
<td>(1) $u^* u^n$, pressure-area-weighted zonal wind speed</td>
<td>m$^3$mb sec$^{-1}$</td>
<td>2670 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(2) $u^n$, value after Coriolis force calculation</td>
<td>m$^3$mb sec$^{-1}$</td>
<td>3170 COMP 2</td>
</tr>
<tr>
<td>V(J,I,L)</td>
<td>$v$, meridional wind speed ($L = 1$ designates $v_1$, $L = 2$ designates $v_3$)</td>
<td>m sec$^{-1}$</td>
<td>--</td>
</tr>
<tr>
<td>VAD</td>
<td>$\text{TEXCO} \cdot u_2, v_2/2$, vertical advection of $u, v$ momentum</td>
<td>m$^3$sec$^{-1}$mb</td>
<td>4780, 4810 COMP 1</td>
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<tr>
<td>VAK</td>
<td>$2 + K$, parameter for effective water amount</td>
<td>--</td>
<td>9780</td>
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<tr>
<td>VIVA</td>
<td>data control parameter (not used)</td>
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<td>VKKEYV</td>
<td>name of labeled common block (KEYS)</td>
<td>--</td>
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<tr>
<td>VM1</td>
<td>polar mass flux parameters (various definitions)</td>
<td>--</td>
<td>2990-3120</td>
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<tr>
<td>VM2</td>
<td>polar mass flux parameters (various definitions)</td>
<td>--</td>
<td>3000-3210</td>
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<tr>
<td>VPHI4(J,I)</td>
<td>$\phi_4$, surface (level 4) geopotential (* 0 if ocean)</td>
<td>$m^2 \text{sec}^{-2}$</td>
<td>1570 VPHI4</td>
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<tr>
<td>VPK1</td>
<td>$(p_1/p_3)^K$, level 1 geopotential parameter</td>
<td>--</td>
<td>5330</td>
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<tr>
<td>VPK3</td>
<td>$(p_3/p_1)^K$, level 3 geopotential parameter</td>
<td>--</td>
<td>5340</td>
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<tr>
<td>VPS1</td>
<td>$\sigma_1^p/p_1$, level 1 pressure gradient parameter</td>
<td>--</td>
<td>5310</td>
</tr>
<tr>
<td>VPS3</td>
<td>$\sigma_3^p/p_3$, level 3 pressure gradient parameter</td>
<td>--</td>
<td>5320</td>
</tr>
<tr>
<td>VS</td>
<td>$v_a = 0.7 (v_3 - v_1)/2$, surface meridional wind speed</td>
<td>m sec$^{-1}$</td>
<td>7540</td>
</tr>
<tr>
<td>VT(J,I,L)</td>
<td>(1) $v_m^u$, pressure-area-weighted meridional wind speed</td>
<td>m$^3$ sec$^{-1}$ mb</td>
<td>2680</td>
</tr>
<tr>
<td></td>
<td>(2) $v_m$, value after Coriolis force calculation</td>
<td>m$^3$ sec$^{-1}$ mb</td>
<td>5190</td>
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<tr>
<td>$W(J,I)$</td>
<td>temporary variable for $N, PV, PHI, QT$</td>
<td>(various)</td>
<td>--</td>
</tr>
<tr>
<td>WET</td>
<td>$GW$, ground wetness (scaled 0 to 1)</td>
<td>--</td>
<td>11360 COMP 3</td>
</tr>
<tr>
<td>WINDP</td>
<td>$</td>
<td>\vec{v}_s</td>
<td>^n + G$, surface wind speed with gustiness correction ($G = 2.0 \text{ m sec}^{-1}$)</td>
</tr>
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<td>WMAG</td>
<td>$</td>
<td>\vec{v}_s</td>
<td>^n$, surface wind speed (root-mean-square value)</td>
</tr>
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<td>WMAGJH</td>
<td>$</td>
<td>\vec{v}_s</td>
<td>^n$, surface wind speed for north pole</td>
</tr>
<tr>
<td>WMAGS</td>
<td>$</td>
<td>\vec{v}_s</td>
<td>^n$, surface wind speed for south pole</td>
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<tr>
<td>WORK1(J,I)</td>
<td>temporary array in map routines</td>
<td>(various)</td>
<td>1760 MAPGEN</td>
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<td>WORK2(J,I)</td>
<td>--</td>
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<tr>
<td>WTM</td>
<td>$</td>
<td>\mathfrak{m}</td>
<td>$, area weighting factor magnitude</td>
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<tr>
<td>WW</td>
<td>$2\mathfrak{m}\delta$, vertical velocity measure</td>
<td>m$^2$ mb hr$^{-1}$</td>
<td>11670 COMP 3</td>
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<td>XLABL(9)</td>
<td>input character identification</td>
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<td>level identification parameter (not used)</td>
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<td>XXI</td>
<td>$(T_1 + T_2)/(P_1^\kappa + P_2^\kappa)$, convective adjustment parameter</td>
<td>deg mb$^{-\kappa}$</td>
<td>8250 COMP 3</td>
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<td>packed data location (= KKK)</td>
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<td>ZL3</td>
<td>average height of level 3 (= 2000)</td>
<td>m</td>
<td>8920 COMP 3</td>
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<td>ZM(J)</td>
<td>zonal mean at latitude $\varphi_j$</td>
<td>(various)</td>
<td>1360 GMP</td>
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<tr>
<td>ZMM</td>
<td>global mean</td>
<td>(various)</td>
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<td>ZMONTH(3,12)</td>
<td>names of months</td>
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<tr>
<td>ZZZ</td>
<td>$\phi_g$, height of surface (level 4) (= 0 if ocean)</td>
<td>m</td>
<td>7900 COMP 3</td>
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REFERENCES


