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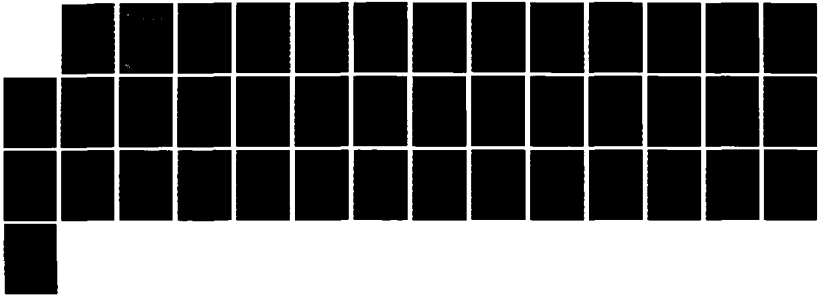

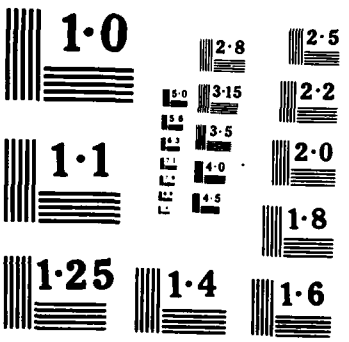
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NAVENVPREDRSCHFAC
CONTRACTOR REPORT
CR 86-03

CONVERSION OF THE NOLAPS MODEL TO THE HP9845

Philip Ardanuy

Research and Data Systems Corp.
Lanham, MD 20706

Contract No. N00228-84-D-3155

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Prepared For:
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As a first effort in developing an atmospheric predictive capability for the Tactical Environmental Support System (TESS), the model used for the Navy Operational Local Atmospheric Prediction System (NOLAPS) is converted to the HP9845B, Option 275. Three primary steps are involved in this conversion. First, the model is converted from FORTRAN to BASIC code, made to duplicate existing model results, and benchmarked for time purposes. The converted model is renamed NOWLAPS (Navy Over-Water Local Atmospheric Prediction System). Second, a user-interactive capability is developed for this desk-top system. And third, an interactive graphics package is developed to display the model results.

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1. Introduction

1.1 Summary

The purpose of this final report is to document the code conversion, testing, modification, benchmarking, and optimization of the Navy Operational Local Atmospheric Prediction System (NOLAPS), Planetary Boundary Layer (PBL), Higher Order Closure (HOC), turbulence model code for the HP9845 computer. The delivery order (QE-01) which encompasses this work is partitioned into 3 tasks, discussed in section 2 through 4, which respectively describe the code conversion procedure in full, the benchmarking procedure, and the final report.

1.2 Environment

As stated in contract N 00228-84-12-3155 "the Navy has plans to incorporate a mini-computer for environmental diagnosis and prediction onboard carriers and other selected ships and shore installations. This computer will be part of the Tactical Environmental Support System (TESS)." As a first step in developing an atmospheric prediction system for TESS, the NOLAPS turbulence model will be implemented into TESS and renamed NOWLAPS (Navy Over-Water Local Atmospheric Prediction System).* The eventual TESS computer will be a follow-on to the current-generation HP9845 A, and B option 275, shipboard microcomputers.

For this task, the NOLAPS HOC model is made operational on the current-generation HP 9845B microcomputer. Full advantage is taken in the revised model code of the capabilities of the HP machine, specifically special function key programmability, the two cassette drives, the in line printer, the graphics capabilities, and the screen-dump-to-printer feature.

1.3 Background

In an attempt to reduce the complexity of numerical models describing turbulent flow (following hypotheses of Kolmogoroff (1942), Prandt and Wieghardt (1945), Rotta (1951), and others), Mellor and Yamada (1974) of the Geophysical Fluid Dynamics Program at Princeton considered a set of systematic simplifications in the governing equations. This review led to the development of a hierarchy of

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* Companion publication -- Navy Over-Water Local Atmospheric Prediction System (NOWLAPS) Users Guide -- published separately as NAVENVPREDRSCHFAC Contractor Report CR 86-04 dated February 1986.

turbulence closure models for the planetary boundary layer, with the set of models differing due to scaling considerations based on the degree of anisotropy permitted. An intermediate, so-called "level-3" model was identified as comprising an optimal combination of reduced computational complexity (only two of the ten differential equations of the higher level-4 model are retained) and desirable solution characteristics (numerical experiments (Yamada and Mellor, 1975) indicated that both models produced practically the same results). This level-3 model was first described by Mellor (1973); Yamada and Mellor (1975) have given a full treatment of the numerical procedures involved in the time integration of the model's equations and discuss in detail comparisons of prognostic results with observations.

Following the authors' closure assumptions for the triple turbulence moments and the scaling considerations implicit in the derivation of the level-3 framework, the model requires the solution of the finite difference analogs of the partial differential equations for the total turbulent kinetic energy and potential temperature variance, mean velocity and temperature. The remaining turbulent moments are obtained through the simultaneous solution of a derived set of algebraic equations.

Using a higher-order turbulence closure model similar to the level-3 model developed by Mellor (1973) and Mellor and Yamada (1974), Burk (1977) of the National Severe Storms Laboratory at NOAA investigated the temporal behavior of moisture stratification within the diurnally-varying planetary boundary layer (PBL). Because the computation of moisture-related fluxes was of prime concern, numerical solution of the partial differential equations for the temperature-moisture covariance and the specific humidity variance, rather than the less-complex algebraic equation subsets, was incorporated into the numerical model. Application of appropriate initial and boundary conditions to this one-dimensional model then allowed the time-dependent solution of the spatial variation of the mean horizontal wind components, virtual potential temperture and specific humidity, as well as related variables. Following a linear stability analysis which showed that the finite difference expression utilized by Yamada and Mellor (1975) failed under conditions of large stability, Burk (1977) redefined the expressions for this case.

Burk and Thompson (1982), of the Naval Environmental Prediction Research Facility (NEPRF) at Monterey, took the level-3, second-moment closure turbulence model discussed in the preceeding paragraph, coupled in estimates of atmospheric refractivity characteristics (Burk, 1980), detailed cloud physics as developed by Sommeria and Deardorff (1977) and Mellor (1977), the precipitation parameterization of Barker (1977), and a detailed solution of the radiative transfer equations (both in-cloud and out) as developed by Oliver et al. (1978). The model is initialized either solely with large-scale field information (e.g., interpolations to the PBL model grid of standard-level values from the FNOC primitive equation (PE) model, or based on any designated ship sounding available from the FNOC global database. Similarity-theory solutions yield variables at the model's lower boundary; all turbulence variables are set to zero at the top of the model's grid (e.g., 3.75 km) and the wind, temperature, and moisture gradients are specified. After obtaining an initial state in the wind, temperature, and moisture fields, a dynamic initialization is effected. This "spin-up" procedure holds fixed the mean fields as the turbulence variables interactively evolve to a near-equilibrium state. At this point, the model begins its forecast and the mean fields are permitted to change. In order to incorporate into the forecast synoptic changes occuring at the location of the boundary layer forecast, total time derivatives of the large-scale variables based on the FNOC PE model forecast are interpolated to the PBL grid and added to the mean PBL equations. Through the use of altitude-dependent weights, forecasts are obtained in which the high-resolution closure model terms dominate in the boundary layer, while the 12 and 24 hour large-scale PE model forecasts are reproduced above 850 mb. The result is an operational forecast system designed to provide high-resolution boundary-layer forecasts based on any specified ship sounding, bulk air-sea differences, and large-scale wind and tendency terms (Burk and Thompson, 1982). The useful output products of this forecast system include, to name a few: fog and visibility forecasts, boundary layer winds and atmospheric refractivity characteristics.

1.4 Statement of Work

As specified in the Statement of Work for Contract N00228-84-D-3155, Delivery Order QE-01 there are three tasks:

1.4.1 Task 1

Th contractor shall become familiar with the NEPRF one-dimensional HCC model and the HP9845B, Option 275 microcomputer. If the contractor does not have access to an HP machine, off-hour and a limited amount of working hour time will be provided on the NEPRF HP9845B, Option 275. NEPRF will provide FORTRAN code for the HCC model. Because interpreted BASIC is the primary language for the HP9845, the contractor shall convert the HCC FORTRAN code into BASIC code for the HP9845. The contractor shall then segment, optimize, or otherwise manipulate this BASIC code into a program runnable on the HP9845B, Option 275. In addition, the contractor shall streamline the model's input and output into a form compatible with the HP machine. Specific goals regarding this program conversion are defined in the section entitled "Requirements." A minimum of two letter progress reports shall be submitted during this phase of work.

1.4.2 Task 2

Having converted the HCC model into BASIC code and adapted this code to the HP machine, the contractor shall run a minimum of two HP HCC (to be defined by the COTR) runs for comparison to mainframe benchmarks. The contractor shall show that the HP model results are identical to the mainframe results. A letter progress report shall follow Task 2.

1.4.3 Task 3

The contractor shall write a report detailing and documenting all of the steps necessary to achieve Tasks 1 and 2. This report shall include a specific section which describes in detail the input, running and output procedures for the converted model. Specific recommendations regarding potential additional speed enhancements shall be made in this report.

2. Task 1

2.1 Requirements

As specified in the Statement of Work for Contract N0028-84-D-3155, Delivery Order QE-01 the requirements for Task 1.1 are:

2.1.1 Code Conversion and Optimization

The benchmark running time goal for running the HDC model on the HP9845B, Option 275 is one hour for a 24 hr. forecast. This one hour running time is wall time, starting after the model is initialized with meteorological input data and ending with the forecast products output from the model. Based on CDC 6500/HP9845B, Option 275 benchmarks of comparable code, the one hour benchmark should be realizable. In the event that the contractor cannot achieve this benchmark during the course of the contract, the contractor shall detail to the contract monitor the reasons for failure, as well as extreme measures that might be taken to achieve the benchmark. Following initial conversion and running of the model on the HP machine, the contractor shall report to the contract monitor the running speed. In the event that the initial HP version results in a running time of less than or equal to one hour, the contractor shall optimize the code so as to decrease the running time 20%. In the event that the contractor cannot meet this benchmark, the same procedure as above shall be followed.

2.1.2 Code Conformance

Because the fleet HP computers are cassette-based, the HDC model shall be completely tape oriented. Optimizations to the HDC code shall be optimizations in BASIC code only (one command per one line); no assembly code is to be used. This BASIC code shall conform to the "NEPRF BASIC Code Standard" (to be published). Further, any optimizations are to be coded optimizations only; there are to be no changes in the HDC model physics, resolution, or time step.

2.1.3 Interactive Initialization

The HP HCC model will be designed to be initialized from the HP keyboard. The contractor shall design the initialization so that the user is prompted for all input data. This initialization procedure will be designed such that default data is easily utilized.

2.1.4 Standard Model Output and Restart

All standard model output will be written to CRT, and optionally to hard copy, during the course of the model's run (e.g., the output valid halfway through the run will be written at that time). The specified interval of output will be defined in the prompted initialization. In addition to this hard copy output, the program shall be designed to output data to cassette tape for restart purposes. The program shall have the capability to restart from any of these cassette output times; the model results from either a restart or a continuous run shall be identical. A header (prologue) will be displayed as the header code is loaded from tape (see Figure 1).

2.2 Code Conversion

Code conversion of the NOLAPS model was undertaken in 3 segments: (1) translation of the model dynamics from FORTRAN to BASIC; (2) development of an interactive framework for easy user interface; (3) installation of a graphics capability to facilitate user diagnosis of the forecast. The latter 2 segments are detailed in sections 2.3 - 2.5. Subject to the requirement that the model physics not be altered, and the requirement (section 3) that benchmark tests be performed and passed, care was taken to insure that an exact code translation was achieved. Whenever expedient, however, structured programming was used by taking full advantage of the structured programming ROM available in the HP9845. In addition, substantial optimization of the model code was performed at this juncture to reduce the need for later passes through the program (see section 2.7). The "Programming Guide for Shipboard Numerical Aid Programs" (Brown, 1984) was adhered to for guidance on general and detailed requirements, as well as "human factors" consideration. Some examples of this are listed below.

NAVY OVER-WATER LOCAL ATMOSPHERIC PREDICTION SYSTEM (NOWLAPS)
(A ONE DIMENSIONAL BOUNDARY LAYER PROGNOSTIC MODEL)

WRITTEN BY:
DR. STEPHEN D. BURK
AND MR. WILLIAM T. THOMPSON

ADAPTED TO THE HP9845B, OPT 275 BY:
DR. PAUL M. TAG
AND RESEARCH AND DATA SYSTEMS, CORP.

NAVAL ENVIRONMENTAL PREDICTION RESEARCH FACILITY
MONTEREY, CALIFORNIA 93943-5006
(408) 646-2927
DEVELOPED IN HP-BASIC FOR THE :
SHIPBOARD NUMERICAL AID PROGRAM

REFERENCE: THE NOWLAPS USER'S GUIDE
LAST REVISION: JANUARY 13, 1986
PROGRAM NOW LOADING

Figure 1. NOWLAPS Prologue

2.2.1 Entry-Exit Structure

Each program segment has only one entry and exit. This limitation necessitated individual functions CORWS and CORWL, unlike the FORTRAN counterparts.

2.2.2 Size

Whenever possible, the subprograms were limited to less than 100 executable statements. For clarity, however, conformance of the program structure was kept identical to the FORTRAN counterpart as much as possible. The functions of the resultant subprograms are summarized briefly in Table 1 and their flow illustrated in Figure 2.

2.2.3 Indentation

Indentation of program statements was universally applied, except for those read-from-tape statements that would then have exceeded the line length restriction and been truncated. (The structured programming ROM does truncate these statements when its indentation utility is used. The statements must then be manually restored.)

2.2.4 Naming

Naming conventions are universal throughout the model code. This is facilitated by the use of labelled common containing the global variables.

2.2.5 Constants

Constants were determined identically with the FORTRAN code in order to meet the mainframe benchmarks.

2.2.6 Significant Digits

Full precision model variables were employed throughout the program.

2.2.7 Abstracts

Detailed textual abstracts are provided at the beginning of the executable coding for the main program and each subprogram.

TABLE 1

Subprogram Names and Functions

AUTOST	This subroutine writes a prologue, loads the softkeys, and loads the program.
BCS	This subroutine inserts the upper and lower boundary conditions for the turbulence variables, calls subroutine THOMAS, and stores the newly-calculated turbulence variables. This subroutine was formerly part of the MAIN program in the FORTRAN version of program CLOSURE.
BOUND	This subroutine calculates the Louis/ECMWF drag coefficient and the Monin-Obukhov length for the stable, neutral, or unstable PBL. It then calculates the surface layer fluxes of momentum, heat, and moisture using the newly-calculated drag coefficients.
CHAREN	This subroutine accepts only single-character input from the user during an interactive session; i.e., Y or N for a yes or no query.
CLEARS	This subroutine clears the screen.
COEF	This subroutine calculates the coefficients for the general tridiagonal matrix before the boundary conditions have been inserted.
CORCR	This subroutine calculates the path integrals and then the downward transmissivities.
CORRD	This subroutine defines the radiative constants and variables used in CORCR.
DEW	This subroutine accepts numerical input for the dew point or dew point depression from the user during an interactive session.
ENTERS	This subroutine accepts numerical input from the user during an interactive session.
ESAT	This subroutine computes the saturation vapor pressure of the air using a 6th order polynomial expansion when given the temperature in degrees Kelvin.
FCST	This subroutine initiates the forecast.
FNCORWL	This subroutine calculates the total transmissivity for the longwave radiation.
FNCORWS	This subroutine calculates the total transmissivity for the shortwave radiation. This was formerly part of

CORWL in the FORTRAN version CLOSURE.

GRAPH — This subroutine produces graphical displays and diagnosis of the NOLAPS forecast.

GREEN — This subroutine accepts user entry of Greenwich Mean Time and converts to useable form.

HEADER — This subroutine determines whether a new sounding will be defined or a previously-entered sounding, stored in the header record, will be used to make a forecast.

HEIGHT — This subroutine accepts numerical input for Height, from the user during an interactive session.

HICHEK — This subroutine verifies that the data extends above the top of model grid.

HIST — This subroutine creates a history record.

HOSKEEP — This subroutine calculates the eddy momentum coefficient, the eddy heat coefficient, and the liquid-water-related variables.

INITIAL — This subroutine specifies the initial lower boundary values. It calculates factors used in computing derivatives and calculates the initial M-Y length scales. This subroutine was formerly lines 75 to 135 of the main program in the FORTRAN version of program CLOSURE.

INVAR — This subroutine sets up the initial conditions for numerous variables. INVAR was formerly subroutine INITIAL in the FORTRAN version of program CLOSURE.

ITER — This subroutine is used both for the dynamic initialization and to forecast. ITER was formerly lines 136 to 473 of the main program in the FORTRAN version of program CLOSURE.

LSCALE — This subroutine defines a weight factor that operates on the large-scale tendencies. LSCALE was formerly lines 424 to 448 of the main program in the FORTRAN version of program CLOSURE.

LSTEND — This subroutine accepts a value for the time that the next set of large scale (L/S) tendencies are to be read. It then accepts the values to be stored as the set of L/S tendencies. All values are entered by the user during an interactive session.

MAIN — Main routine which oversees the running of the NOLAPS program.

MEANS	This subroutine calculates the new U and V components for the mean wind. It then determines if radiation should be computed for this time step, and if so, calls CORRD. Finally, it computes the new mean values of the virtual potential temperature and the specific humidity.
MTAPE	This subroutine reads the header and history records from the history tape.
OUT	This subroutine prints out all the important variables of the forecast at set time intervals.
OUTP	This subroutine prints out all the data that was entered during the interactive session.
PARAM	This subroutine allows the user to select one of two predefined grids.
PRESS	This subroutine accepts numerical input for the pressure during an interactive session.
SETUP	This subroutine initalizes all the constants used throughout the program. SETUP also initializes certain string arrays with the dialogue needed for the interactive session.
SITEND	This subroutine calls subroutine ENTERS to accept numerical input from the user during an interactive session. This input is stored either in the array for the site variables or the array for the large-scale tendencies.
SOUND	This subroutine initiates the interactive session. It guides the user through each step with the aid of prompts, waits for replys, and issues error messages when appropriate. It allows the user to set up new run parameters and enter site variable, large-scale-tendencies, the temperature sounding, and the wind sounding. The user can also back up to any previous entry to make a change.
SPINUP	This subroutine initiates the dynamic initialization.
STRETCH	This subroutine calculates the grid to be used in the forecast.
TEMPS	This subroutine is the part of the interactive session which allows the user to enter data for a temperature sounding. This data consists of temperature, height, dew point or dew point depression, and pressure.

TEND	This subroutine determines which set of large scale tendencies will be interpolated to the grid and does the interpolation. TEND was formerly lines 158 through 185 of the main program of the FORTRAN version of program CLOSURE.
THOMAS	This subroutine solves the tridiagonal set of equations which includes the boundary conditions via the Thomas algorithm.
THOMASF	This subroutine solves the tridiagonal set of equations with flux boundary conditions via the Thomas algorithm.
UVCOMP	This subroutine sets up the boundary conditions and solves the tridiagonal set of equations which yield the new U or V component for the mean wind.
WINDS	This subroutine is the part of the interactive set of code which allows the user to enter data for a wind sounding. This data consists of either the U and V components of the wind, or the speed and direction.
VINTRP	This subroutine linearly interpolates or extrapolates to obtain variables at the height of the grid points using, as input, values of the points obtained from the sounding.

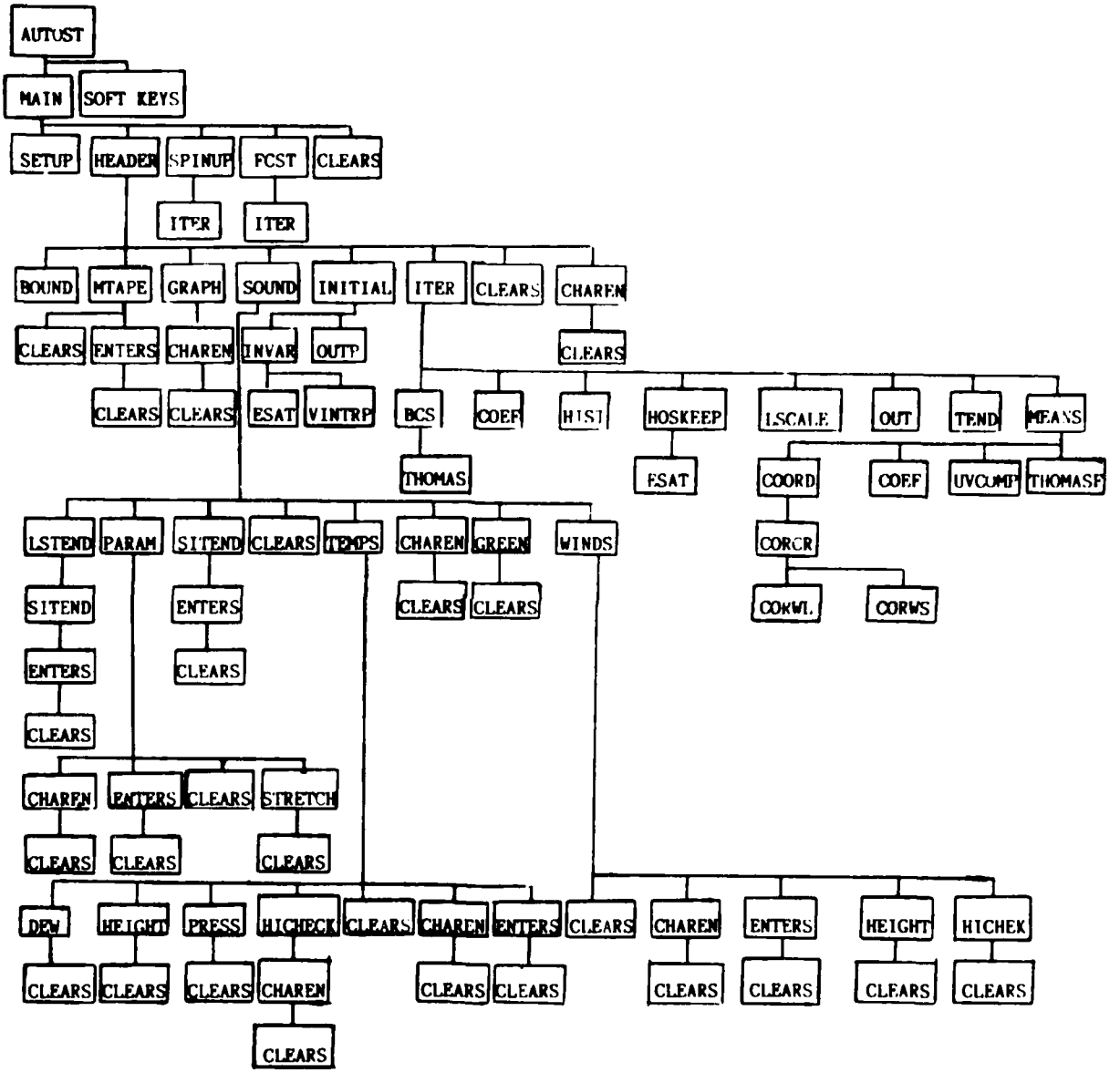

Figure 2. Hierarchy chart of the NOWLAPS subprograms.

2.2.8 Comments

Comments are used throughout the code.

2.2.9 Labels

With several exceptions, line numbers, rather than line labels, are used in program branches. One notable exception is in the OPTION branch for special function key number 1.

2.2.10 Labelled Common

Comments are used to distinguish between different common blocks. In general, variables are grouped in comon blocks labelled by that routine name within which they were first defined.

2.2.11 Data Statements

Program constants, as defined in data statements, are all now located in the static initialization portion of the code.

2.2.12 Abnormal Termination

System errors are trapped using ON ERROR statements. These conditions are possible when manipulations of the history tape files are performed. The code is designed to correct the error conditions.

2.2.13 Units

Units are generally MKS. Exceptions are made in those extensive computations for which the FORTRAN code used units other than MKS. For consistency, the unit conventions are maintained.

2.2.14 Special Function Keys

Special Function Key (SFK) definitions are consistent with the NEPRF standards (Brown, 1984).

2.2.15 Program Overlays

No program overlays are required or used.

2.2.16 Default Values

Where appropriate, default values are displayed for the convenience

of the user. To avoid the loss of data when the user is "backing up," the previous answer to the question becomes the new default.

2.2.17 Feedback

All user entries are echoed.

2.2.18 Data Entry

The data entry process guidelines are followed.

- o program displays a prompt
- o user enters information
- o program echoes the entry on the screen
- o program error checks the entry
- o program displays an error message
- o information is edited as needed
- o information is accepted

2.2.19 Prompting

As shown in the example in the User's Guide, the entry format guidelines are followed exactly.

2.2.20 Editing

The user may edit entries at more than one stage: during initial entry, after a block of related entries have been made (by "backing up"), and after the data have become part of a data base (by reading the header record on the history tape and then modifying and recreating the data).

2.3 Interactive Initialization

A comprehensive and carefully constructed capability exists to facilitate the entry or revision of the initial state for a model forecast. Defaults are displayed where appropriate, including hypsometric estimates of pressure, given height, temperature, and dewpoint temperature. The user is able to back up to revise previous answers. Upon backing up, previous answers to questions become the new default values. The user is guided, step by step, through the entire set of parameters requisite to a forecast. For flexibility, either wind

direction and speed or the U and V wind components may be entered. Similarly, either the dew point temperatures or the dew point depressions may be entered. It is possible for the user to bypass the entire block of questions regarding the large scale tendencies if none are to be specified. The User's Guide covers the details of this interactive, static initialization.

2.4 Restart Capability

The capability exists for restarting an interrupted forecast at several points in the process:

- o at the end of the static initialization, when all the initial state data has been inserted and a header record written to tape;
- o at the end of the dynamic initialization, when the model's "spin up" is completed, and the "zero'th" history record has been written to tape; and,
- o at any of the model's output intervals, when the history records have been written to tape.

The user is also given the opportunity of modifying a previous initial state (header record) if this is desired. The logic contained in the restart portion of the code is described fully in the User's Guide.

As required, the model predictions from a continuous and a restart run are identical. All variables that are not re-initialized by the model code in an interaction prior to use are stored on tape. Since full precision variables are stored exactly on tape, no loss of accuracy occurs.

2.5 Graphical Display

The interactive BASIC NOWLAPS code has the ability to diagnose the forecast for any history record written to tape. Both figures and tabular output may be obtained. The method of user access is discussed in the User's Guide. These capabilities are available to the user at any time before, during, or following model execution by simply

depressing KEY 1 to go to label OPTION, or by appropriately answering the program queries.

2.6 Timing

A timing test was performed on the translated NOLAPS model code. For these tests, a HP9845 option 175 was used. It should be noted that execution times of math floating point routines in the option 275 computer are typically 5 times faster than in the comparable 175 machine (See Table 2). The data set was the so-called CALSPAN case-3 benchmark, as provided by NEPRF (see Mack, et al., 1983). Case 3 is an 18 hr. (222 time step) fog/stratus simulation. Using the case-3 input data, the following running times (per time step) were measured:

5.4 seconds: no radiation
8.7 seconds: longwave radiation only (night)
12.9 seconds: longwave & shortwave radiation (day).

The total forecast took 48 minutes and 40 seconds. This timing included 7 output intervals, each with a write to screen time of aproximately 32 seconds and a write to tape time of approximately 20 seconds. The 7 output intervals thus consumed approximately 6 minutes and 4 seconds. By removing this time from the total time, a 24-hour forecast time can be extrapolated to be 56 minutes and 48 seconds. Because two of the output intervals are forecast requirements (at the end of the dynamic initialization and at the end of the forecast), this time must be added to the forecast time to yield an effective total forecast wall clock time length of 58 minutes and 32 seconds. This timing is consistent with the 1 hour wall clock time goal as stated in the requirements. Of course, the exact wall clock time of the forecast will depend on the number of calls to radiation (every time step when liquid water is present) and the length of the daylight portion of a 24-hour forecast.

2.7 Optimization

Further optimization of the NOWLAPS BASIC code was initiated at this time, the goal being a further reduction in the wall clock time

Table 2

Timing Comparisons for the HP9845, options 175 and 275.

	Time (ms)	
Routine[1]	Opt. 175	Opts, 275,280
Addition	0.27	0.04
Subtraction	0.33	0.06
Multiplication	0.89	0.14
Division	2.90	0.56
Raise to power	17.00	3.21
Square root	2.90	0.43
Tangent	14.00	2.41
Sine	21.00	3.68
Cosine	21.00	3.68
Arctangent	18.00	2.31
Arcsine	26.00	3.88
Arcosine	26.00	4.00
Natural log	7.50	1.39
Log base 10	9.70	1.49
e^x	6.10	1.00
Integer	0.46	0.24
Absolute value	0.13	0.03
Fraction	0.35	0.09
Random number	1.80	0.33

[1] Based on a table provided in the HP 9845 Computer Family Specifications, P2.

length of a forecast. The optimization variables were installed in a common block called /OPTIM/. Specific improvements involved precomputing a set of composite denominators relating to vertical gradients, removing data reads from the radiation package, and precomputing the spherical trigonometry/ law of cosines terms necessary for the solar zenith angle. It was verified that runs made with these changes produced identical results with the pre-optimization benchmark case-6 reference.

A retiming of the model runs following these changes showed an optimization of 4%. (This improvement is in addition to those time savings resulting from revisions already performed at the time of the original code translation.) For example, the daytime calculations took 12.3 seconds/time steps, reduced from the previous length of 12.9 seconds by approximately 4%.

Following this optimization, final timing tests were conducted. Data from the CALSPAN case-3 benchmark were utilized and two runs were made. In the first, data with a single asterisk (see Tables 3 and 4) were used to form the vertically-interpolated, 25 point, 2250 meter initial state. In the second run, data with single and double asterisks were used. Data without any asterisks were excludeed from the vertical interpolations for these comparisons only. (The benchmark accuracy comparisons with NEPRF-supplied mainframe results used all the data). The difference between the two runs is that, following the vertical interpolation in the static initialization, no cloud will exist in the former run. This comparison is important since the radiation is computed every time step when liquid water is present in the model grid, yet only every six timesteps when no liquid water is present.

As expected, the first run was substantially quicker than the second. With output intervals following only the dynamic initialization and the full 24-hour forecast, the wall clock times were:

Run	Time (minutes:seconds)
1 (no cloud)	28:52
2 (with cloud)	50:35

TABLE 3
Initializing thermodynamic data from CALSPAN case 3 benchmark

Sounding level	Pressure (mb)	Temperature (°C)	Dewpoint depression (°C)	Height (m)
		Temperature Sounding		
* 1	1012	17.6	01.3	4
**2	996	16.1	00.0	144
**3	982	15.3	00.0	265
**4	977	15.5	08.1	305
* 5	974	21.1	23.1	335
6	971	23.3	24.8	361
7	965	25.1	25.1	415
8	938	25.7	25.3	664
9	927	25.1	25.1	768
10	895	23.3	24.8	1075
11	871	21.7	24.9	1311
12	861	21.2	24.5	1411
* 13	850	20.4	24.3	1522
14	700	9.6	22.4	3151
15	500	-5.6	30.0	5875
* 16	400	-20.1	30.0	7580
17	300	-36.9	30.0	9641
18	200	-56.8	30.0	12319
* 19	100	-73.4	30.0	16494

TABLE 4
Initializing momentum data from CALSPAN case 3 benchmark

Wind Sounding

Sounding level	U component (m/sec)	V component (m/sec)	Height (m)
* 1	3.0	0.0	5
* 2	-0.1	-2.1	400
* 3	-3.9	-5.6	1500
* 4	-3.9	-5.6	3000

It is significant that the second run's timing is less than the 24 hour estimate of 56:48, which was based on an extrapolation of the 18 hour forecast to 24 hours (with a factor of 4/3). This difference relates to the 1100 GMT start time, for which the full daylight period (with correspondingly longer time steps) is contained in the first 18 hours of the forecast. It is therefore incorrect to extrapolate these daylight timesteps into what would otherwise have been night if the forecast had been allowed to continue.

3. Task 2

3.1 Requirements

As specified in the Statement of Work for Contract N00228-84-D-3155, Delivery Order QE-01, the requirements for Task 2 state:

The contractor shall ensure that the results of the HP HCC runs agree with the mainframe benchmarks to within four significant digits. This agreement shall be demonstrated for the restart capability also.

3.2 CALSPAN Case 6

The CALSPAN case 6 benchmark run used the standard model code for a (220 minute, 43 iteration) forecast. CALSPAN case 6 was a stratus lowering to Fog case over cold water (Mack et al., 1983). It was necessary to use Teten's formula of water vapor pressure for this comparison as the original polynominal expansion was not accurately evaluated in the HP 9845. This switch to Teten's formula was determined to be necessary due to the inherent inability of the HP9845 to accurately replicate vapor pressures computed on the FNOC mainframe using the polynomial method. This inability was presumably due to an accuracy requirement in the polynomial evaluation beyond the capabilities of the HP9845. When Teten's formula was substituted, consistent estimates were obtained by the two systems. This, however, is not the delivered version which instead contains the polynomial representation. With this alternative version of the vapor pressure subroutine, the requisite four significant places of accuracy in all model variables were exceeded, even for the liquid water specific humidity (QL) and the cloud fraction (RC) which have proven to be among the most sensitive parameters. Complete sets of the BASIC model and the benchmark model output for all model output intervals were provided to the COTR at the time of verification.

3.3 CALSPAN Case 3

Because the CALSPAN case 3 benchmark required revisions to the standard model code, particularly in the areas of sea surface temperature time dependence and the vertical structure of large-scale subsidence. These revisions resulted in comparison discrepencies

against the mainframe benchmark which were initially attributed, incorrectly, to errors in the model logic itself. These discrepancies did delay Task 2 until the errors were correctly trapped and removed. When the code was running properly, a successful 246 time step (20 hour) benchmark comparison was made. The results are detailed below.

The run used Teten's formula in the computation of the vapor pressure in subroutine ESAT, and was followed up with a forecast using the original polynominal expansion. For the former run, using Teten's formula, all variables agreed to a high degree of accuracy at time step 10, but the accuracy fell off slowly as time progressed. It is impossible to make any statement about error growth between timesteps 10 and 126 as we have no comparison data for that period. By time step 126, the U field is comparatively accurate to 4-5 places in the boundary layer (PBL) and to all 9 places listed above the PBL. Similarly, the V field shows an accuracy of 4 places in the boundary layer and 9+ places above, with the exception of the first layer where only 3 accurate digits are obtained. This first-layer inaccuracy is no doubt due to the fact that the wind component is relatively weak at that level and thus has the same absolute accuracy as the higher levels. The liquid water virtual potential temperature, or THL (the third prognostic variable), appears accurate to all 6 places provided in the NEPRF printout, while the total water substance specific humidity, or QW, behaves similarly in accuracy to the U component of the wind. The cloud fraction, a relatively sensitive parameter, shows an accuracy of from 3 to 4 digits, or to at least .03% in "cloud" units. By time step 246, some additional degradation in forecast accuracy is realized. For the winds, the U and V components are accurate to 5 and 4 digits, respectively, in the boundary layer, with an additional loss of 1 more digit in the V component whenever the velocity components fall an "order of magnitude" below the values (-09.692E-1 vs. -01.07916E0) of the other levels; both components have an accuracy, however, of the order of ten thousandth's of a m/sec. The variable THL is accurate to 5-6 places in the boundary later and better above, while the variable QW shows an accuracy of 4 places in the boundary layer and better above. The cloud variables QL and RC are less accurate, with the cloud amounts for example correct

only to the tenth's of a percent (eg., .058 vs. .06, .461 vs. .463, .6419 vs. .6422, .5677 vs. .5683). All the cloud layers are predicted correctly as are the layers with 100% cloud. The losses in accuracy reviewed above appear to be simply the result of nonlinear error propagation during the course of the forecast due to the precision differences between the two machines, and thus not amenable to further improvement. As with the case 6 benchmark, complete sets of BASIC model and benchmark model output for all model output intervals were provided to the COTR at the time of verification.

4. Task 3

4.1 Requirements

As specified in the Statement of Work for Contract N00228-84-D-3155, Delivery Order QE-01 the requirements for Task 3 state:

The contractor shall provide two HP cassettes, each containing the HP HCC BASIC code. The contractor shall provide one camera-ready original plus two copies of the final report. Separately, the contractor shall provide three copies of the HCC model in BASIC code. This code shall be presented in a one statement per one line format and shall include comments or other documentation detailing changes or manipulations of the original HCC FORTRAN code. The report shall include a specific section which describes in detail the input, running, and output procedures for the converted model.

4.2 Final Report

This document constitutes the final report for this delivery order.

4.3 User's Guide

A user's guide to the NOLAPS model code is included with the final report.

4.4 BASIC Code Listing

Three copies of the fully documented BASIC code listing of the NOWLAPS code are included with this final report.

5. Conclusions

As stated in the previous sections, the goals of Tasks 1, 2, and 3 have been achieved. The model code, as developed, has been demonstrated:

- o to function correctly, relative to the 2 required benchmark runs.
- o to restart correctly, relative to a continuous run.
- o to provide graphical forecast diagnosis.
- o to permit interactive static initialization.
- o to be well documented internally, and externally via a model user's guide, and
- o to be constructed in a "user-friendly" manner, so as to facilitate interaction.

6. Recommendations

6.1 Further Optimization

a) It has been demonstrated that including radiation computations adds from 61% to 139% extra wall clock time to the length of each time step (section 2.6) depending on the solar zenith angle. As such, the radiative transfer portion of the code is one area for which further optimization may significantly reduce the time length of a forecast. These optimizations could be numerical approximations, for example utilizing simple lookup tables to replace calls to exponential functions.

b) It has been demonstrated (section 2.7) that the presence of liquid water will almost double the length of wall clock time required to complete a forecast. This doubling results from radiation being called every time step when liquid water is present. This requirement may be unnecessary and should be critically examined.

c) The execution time of the model, and the amount of tape storage of the code, may be significantly reduced by stripping off the extensive internal documentation.

6.2 Enhancement of Capabilities

a) During a forecast diagnosis (sections 2.5 and 8.5) the number of variables that may be examined is somewhat less than the number included in the standard model output at each output interval. Tape length limitations restrict the amount of data written to tape at each output interval to be that minimum amount needed to perform a restart (for plotting purposes, the modified index of refraction and the dew point temperature are derived from other variables). If a full set of output is desired, the model will have to make a one time step forecast, possibly with the large-scale variables held constant as during spin up. This procedure would allow the many temporary, or diagnostic, variables to be computed; they are not written to the history tape to save space. This capability would require code changes to the existing software.

b) In the plot of the modified index of refraction, ducting layers are shown graphically. It would be possible to incorporate a similar feature, in the temperature and dew point temperature plots, to represent cloud layers.

6.3 Further Testing

a) No tests have been conducted relative to the two benchmark cases with nonzero large-scale (L/S) tendencies. A third benchmark test should be conducted in the future to check out the L/S tendency terms and logic as it exists.

7. References

The following documents are references for this project:

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