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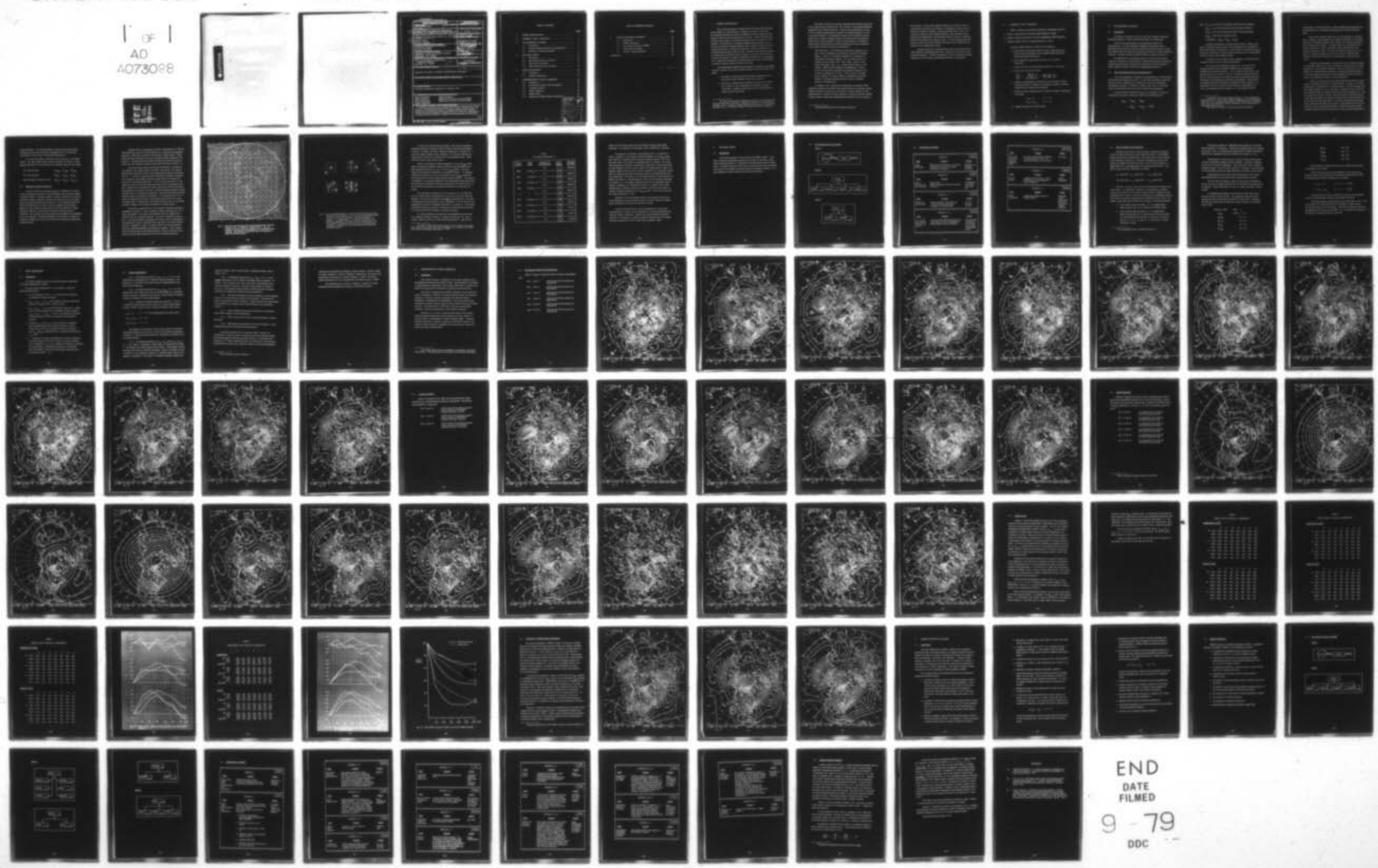

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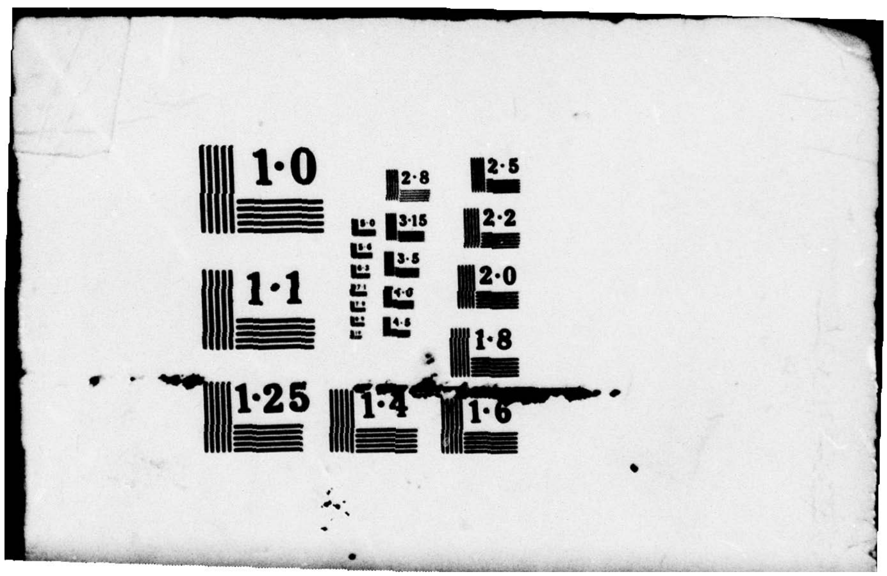
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A method is described for bit-coding meteorological analyses and forecasts in terms of specifying parameters which measure pattern characteristics. By matching the associated bit strings, an absolute measure of the similarity between forecast and analyzed synoptic fields can be obtained. Applications to numerical model verification, evaluation and development are discussed.

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1. GENERAL INTRODUCTION

At this time there exists no widely-known and established technique which enables the meteorologist to compare two fields of the same environmental parameter and obtain a meaningful objective measure of the degree of pattern similarity between the two fields. Several techniques are available which purport to provide the required measure of similarity. For example, one technique is to compute a difference field between, say, a forecast field and the verifying analysis field[1]; another technique is to use statistical methods to calculate the correlation coefficient using pairs of corresponding grid-point values as input. However such methods are based on comparisons of grid-point values, failing to recognize and/or take into account such features as isopleth orientations and gradients; these features are of comparable significance to absolute grid-point values in determining the degree of pattern similarity between two fields.

Two fundamental capabilities are required for obtaining a meaningful objective measure of the overall degree of pattern similarity between two fields:

a. An ability to recognize and assign objective measures to all those facets which combine to constitute a pattern;

b. An ability to compare these individual measures for two fields and, utilizing a pre-established and consistent scoring methodology, produce a further measure which represents the degree of pattern similarity.

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[1] The RMS of the grid-point differences provides a single measure of the error for the area of interest. However as pointed out by Somerville [1], the RMS measure "conceals meteorologically significant error information regarding, e.g., the location, shape and intensity of pressure systems".

The need for measures of synoptic similarity has long been recognized by the meteorological community but, until recently, the required fundamental capabilities have eluded formulation. There are many applications waiting for the successful development of measures of synoptic similarity--to give one obvious example[2], by comparing the results of two numerical forecast models with a common verifying analysis, the model which has performed better may be readily identified. The following quotation is informative, reflecting the current need for a pattern recognition and scoring capability in the context of model verification and evaluation:

> "The final topic...is one which has been rather neglected in the past. That is verification and objective evaluation of numerical models. There is no accepted procedure for evaluating the performance of numerical models. No one really knows, for example, how the NCAR, NMC, GISS, FNWC, AFGWC, UCLA, British Met Office, GFDL, etc., models perform relative to one another. What are their strengths and weaknesses? There is much to be learned by comparing and analyzing differences, but we have no framework to do this". (From the text of a speech by Col. Thomas W. Flattery, AFGWC, presented at the Annual Meeting of the American Meteorological Society, Savannah, Georgia, 2 February 1978.)

In February 1978, Meteorology International Incorporated (MII) submitted a proposal to the Naval Environmental Prediction Research Facility (NEPRF) pointing out that many of the basic concepts required for the establishment of a system to provide Measures of Synoptic Similarity (MOSS) already existed, having been developed and formulated by MII as parts of

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[2] Potential applications are discussed in Section 5.

other projects. The proposal offered to develop, by a series of Tasks, a comprehensive system for the evaluation of atmospheric models based on measures of synoptic similarity. The first of these Tasks, Task 1, was intended to establish a basic MOSS capability, with subsequent Tasks adding further capabilities, refinement and flexibility based on experience gained by utilization of the results of Task 1. It was considered that this approach would prove more efficient and effective than implementing an initially more-comprehensive system.

The MII proposal was accepted and this Report describes the basic MOSS capability established under Task 1 together with an outline of the underlying concepts. A System Description of a more comprehensive MOSS capability also is provided in accordance with Task 1 requirements.

2. SUMMARY OF TASK 1 OBJECTIVES

(NOTE: Terminology used below is defined in subsequent Sections.)

a. Design, program and test the basic MOSS capability, MOSS1.

b. Produce a System Description of a more comprehensive MOSS capability.

c. Produce a Report for Task 1 incorporating items a and b.

The basic MOSS capability is defined as the ability to:

a. Accept 1000-mb and 500-mb fields as input, these fields to be for the Northern Hemisphere on the standard FNWC 63x63 grid (polar stereographic projection).

b. Scale separate the input fields into their SV, SL and SD components.

c. Compute the 500-1000-mb thickness fields of SV, SL and SD.

d. Bit-code the following 18 fields:

$$\left.\begin{matrix} \text{SV} \\ \text{SL} \\ \text{SD} \end{matrix}\right\} \times \left.\begin{matrix} \text{1000 mb} \\ \text{500 mb} \\ \text{500-1000 mb} \end{matrix}\right\} \times \begin{matrix} \text{base field } (A_\tau) \\ \text{trial field } (F_\tau) \end{matrix}$$

e. Compare corresponding bit-string pairs (9) and compute a match coefficient which is a measure of the degree of synoptic similarity between the two fields being considered.

f. Repeat the above procedure so as to allow the following comparisons to be made:

$$A_{\tau+n} : A_\tau \quad , \quad n = 1 \rightarrow 8$$

$$F_{\tau+n} : A_{\tau+n} \quad , \quad n = 1 \rightarrow 8$$

g. Output the results in a tabular format.

3. THE UNDERLYING CONCEPTS

3.1 Introduction

This Section describes--in outline only--the concepts underlying the MOSS capability. Further details are provided in the References.

The first concept described, scale-and-pattern spectra and decompositions, is a well-established capability developed by MII for producing the characteristic ranges-of-scale associated with synoptic fields. This technique has long been used by FNWC and forms part of their operational jobstream. Examples of pattern separated fields are given in Section 6.4.

The methodology for assigning measures to all those facets which combine to constitute a synoptic pattern, and the methodology for determining an absolute and monotonic measure which represents the common degree of pattern similarity between two fields, is described in Section 3.3.

3.2 Scale-and-Pattern-Spectra and Decomposition

Two of the fundamental concepts in the interpretation of meteorological fields are those of pattern and scale. In 1963 MII developed an objective technique [2] for separating any geophysical field into recognizable characteristic patterns, or features, evident in the field, so that their relative contributions to the total can be quantitatively represented.

Using the 500-mb height field (D_{500}) as an example, this may be decomposed into additive component ranges-of-scale expressed by:

$$D_{500} = SD_{500} + SR_{500}$$

$$= SD_{500} + SL_{500} + SV500$$

where SD_{500} is the 500-mb Disturbance range-of-scale component,

SR_{500} is the 500-mb Residual range-of-scale component,

SL_{500} is the 500-mb Long-wave range-of-scale component,

SV_{500} is the 500-mb planetary Vortex,

by definition, $SR_{500} = SL_{500} + SV_{500}$.

It should be noted that the decomposition process, leading to the various component ranges-of-scale, can be applied to any geophysical field in any number of dimensions. It should also be noted that the original field can be reformed by a direct grid-point summation of the corresponding grid-point values of the component fields.

To appreciate the relevance of this technique to the MOSS system, a number of factors must be stated and considered.

Each of the three component fields (SD, SL, SV), which taken together represent a given synoptic situation, has a characteristic significance and dynamic behavior. The SL range-of-scale shows, for a particular level, the "centers of action" in the sense coined by de Bort[3]. The SD range-of-scale for the same level shows the inherent small-scale disturbance--the propagating cyclones and anticyclones. These exhibit the dynamic-behavior characteristic of apparently being "steered" (i.e., advected) by the SR flow pattern whose features are dominated by SL cells. The planetary-vortex component, SV, also exhibits dynamic

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[3]According to the Meteorological Glossary, a "term introduced by Teisserenc de Bort in 1881, which generally signifies an area covered by a large-scale low- or high-pressure system, which dominates the circulation, and so has a big influence on weather conditions, over a large area for a considerable period of time."
(The term has, however, been used with other meanings.)

characteristics, being dominated by dynamic instabilities (interacting with and contributing to SL changes) superimposed on a seasonal amplitude cycle.

These three ranges-of-scale (SD, SL, SV) represent the synoptic scale. However, associated with each range-of-scale there is a range-in-time; the SV component generally varies slowly, SL features more quickly, and SD features vary rapidly. To capture these time variabilities in the sense of being able to "see" a reasonably smooth transition from one synoptic situation to another, SV fields are required at intervals of 1 or 2 days, SL fields are required every 12 hours, and SD fields should be available at least every 6 hours with an interpolation capability down to 1 hour.

From the above paragraphs it can be seen that the component ranges-of-scale differ markedly as to their variability in space and time--in effect they differ as to their dynamic behavior. Since the MOSS system is to be applied to the development and evaluation of numerical/dynamic models it is clear that separate evaluation of each component range-of-scale would give a more complete assessment of model capabilities.

There is a further reason for providing separate assessment of range-of-scale components as part of the MOSS system. Consider two forecast models which, commencing with a common analysis, are each compared with the verifying analysis of, say, 3 days later. Assume that--as is often the case--neither model can cope well with small-scale variabilities (i.e., the SD scale) over a period of 3 days, but that one model is markedly superior to the other with regard to its ability to represent the centers of action (i.e., the SL field) over the same period. In these circumstances neither model would score well--the small-scale "noise" would obscure the fact that the centers of action were being well handled. Separate evaluation of each component range-of-scale would again give a more complete assessment of model capabilities. (A common drawback of previously devised scoring techniques is that they are based on the total field, not on individual consideration of each scale of atmospheric disturbance.)

It is clear that pattern separation should form part of the MOSS system. The basic MOSS system design described in Section 4 allows separate assessment of the following nine component range-of-scale fields:

The 1000-mb fields; SD_{1000} , SL_{1000} , SV_{1000}

The 500-mb fields; SD_{500} , SL_{500} , SV_{500}

The 500-1000-mb thickness fields; SD_{5-10} , SL_{5-10} , SV_{5-10} .

3.3 Measures of Synoptic Similarity

In June 1976 MII was awarded Contract No. N00228-76-C-3189 to continue with the development of a Rapid Analogue Selection System (RASS) on behalf of NEPRF. Analogue selection is based on an ability to recognize significant degrees of similarity between one selected event and all other events from recorded meteorological history. The methodology devised by MII for the RASS project not only is able to recognize similar synoptic patterns in their component ranges-of-scale but also allocates a "match coefficient" which is an absolute and monotonic measure of pattern similarity. The matching and scoring system used by MOSS is an adaptation of that used by RASS. The RASS development is the subject of a report [3] prepared for NEPRF and so only a brief outline of the pertinent features will be presented here.

Consider that a given synoptic situation is represented by a 1000-mb and 500-mb field, each on a 63x63 analysis grid, north polar stereographic projection. (These are constraints upon the basic MOSS system. These constraints may be reduced in a more comprehensive MOSS capability--see Section 7.) Consider further that these two fields have been processed to provide the nine component range-of-scale fields described in Section 3.2.

On the SD range-of-scale the Northern Hemisphere is divided into 144 modules, each module being a 4x4 array of grid points; the spacing between each grid point is equal to the standard FNWC 63x63 grid spacing--see Fig. 1. On the SL range-of-scale the Northern Hemisphere is divided into 36 modules, each being a 4x4 array of grid points with a spacing of twice that of the standard 63x63 grid. For the SV range-of-scale, 16 4x4 modules are used, the spacing being three times that of the standard 63x63 grid. Different sizes of module (in terms of the number of 63x63 grid points encompassed) are employed for the SD, SL and SV component ranges-of-scale in order to take into account the variations in resolution required by the three different scales of atmospheric disturbance. The inscribed circle on Fig. 1 shows the (approximate) location of the equator; note that the SD, SL and SV modular arrays, although each covers the same total area, do not provide complete coverage of the Northern Hemisphere in tropical regions.

The pattern in <u>each</u> module is cast in terms of seventeen parameters, designated A through Q, which measure the pattern characteristics (i.e., value and shape) of the height and thickness contours affecting that module for the given synoptic situation. This set of parameters, shown in Fig. 2, has been designed to encompass the various scales of atmospheric disturbance and contour orientations that could occur in any meteorological situation. Parameters A and B are actual values of the field parameters while the remaining parameters are measures of gradient. These gradient measures provide links to surrounding modules. Note that each grid-point value of the 4x4 module enters into two of the seventeen parameters.

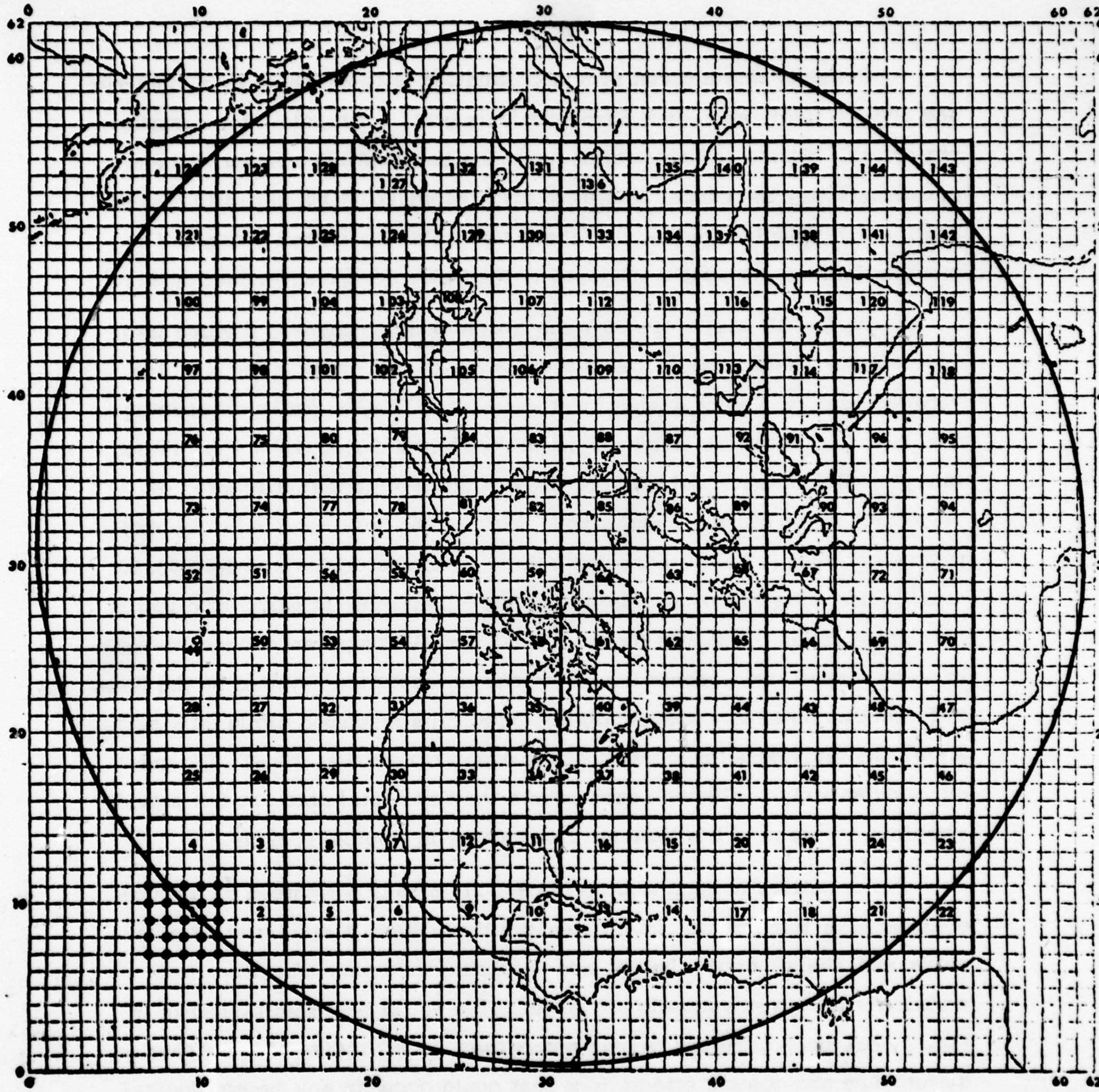

Fig. 1 Resolution and coverage for the Disturbance Scale of pattern features--the SD component range-of-scale. The 4x4 modules of the grid array are numbered for identification and ordering. The density of grid points used is illustrated in grid-array subset number 1.

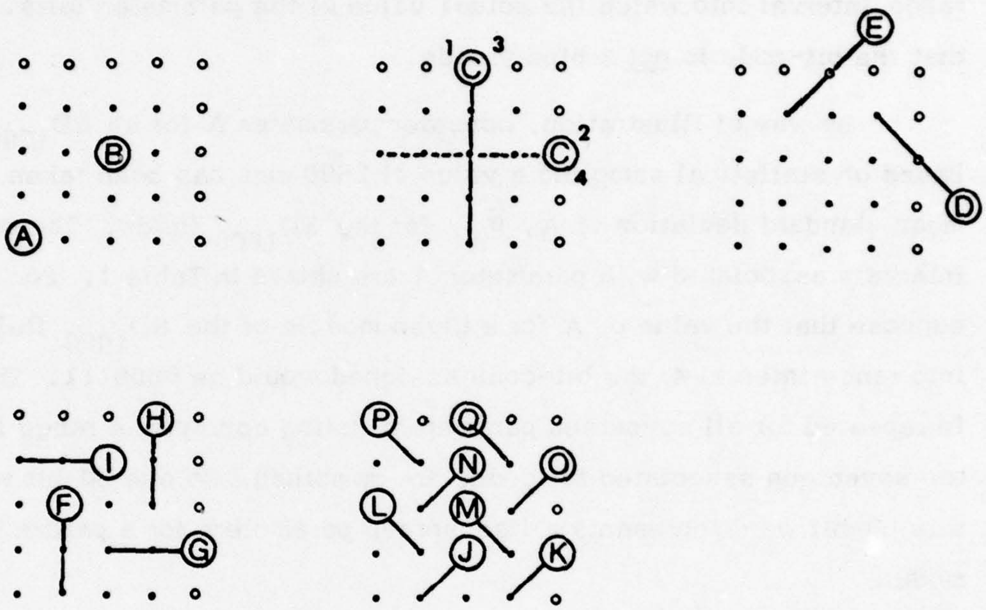

Fig. 2 The seventeen parameters for each 4x4 module of the grid array are shown in five subsets. A and B are actual parameter values at the two grid points indicated. The other parameters, C through Q, are differences. To calculate the value of any difference parameter, the value at the non-lettered end of the line segment is subtracted from the value at the lettered end. Parameter C alternates in orientation between even and odd numbered modules.

For any given meteorological situation, each of these seventeen parameters will have a numerical value of height or thickness (parameters A and B), or height or thickness difference (parameters C through Q). A bit-code is then assigned to each parameter, this bit-code defining the range interval into which the actual value of the parameter falls. (Note that the bit-code is not a binary code.)

By way of illustration, consider parameter A for an SD_{1000} field. Based on statistical sampling a value of 2600 cms has been taken as the mean standard deviation of A, $\overline{\sigma}_A$, for the SD_{1000} fields. The range intervals associated with parameter A are shown in Table 1. For example, suppose that the value of A for a given module of the SD_{1000} field falls into range interval 4; the bit-code assigned would be 0000111. This process is repeated for all seventeen parameters (using appropriate range levels) and the seventeen associated bit codes are combined into one 60-bit word--i.e., this 60-bit word represents all seventeen parameters for a particular SD module.

This procedure is repeated for all 144 modules of an SD field and the 144 60-bit words are assembled into a bit-string containing 8640 bits (60x144). This bit-string represents the pattern characteristics of the field--it encompasses not only absolute values (parameters A and B) but also the magnitude and direction of gradients (parameters C through Q). This coding methodology provides an ability to recognize and assign objective measures to all those facets which combine to constitute a pattern.

In a similar manner bit strings may be assembled for all nine fields of a particular synoptic situation--3 ranges-of-scale (SV, SL, SD) x 3 "levels" (1000 mb, 500 mb, and 500-1000-mb thickness)[4]. Note that the

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[4] In order to effect greater discrimination in the coding of the vortex (SV) range-of-scale field, the coding is applied to the anomaly of this field from a long-term (annual) mean field: $SV - \overline{SV}$.

Table 1

Bit coding for parameter A .

Value of A (cms)	Range Level	Frequency of Occurrence (%)	Range Interval	Assigned Bit Code
		4.5	1	0000000
4420	$1.700\ \bar{\sigma}_A$			
		8.0	2	0000001
2990	$1.150\ \bar{\sigma}_A$			
		12.5	3	0000011
1755	$0.675\ \bar{\sigma}_A$			
		12.5	4	0000111
832	$0.320\ \bar{\sigma}_A$			
		12.5	5	0001111
0	0			
		12.5	6	0011111
-832	$-0.320\ \bar{\sigma}_A$			
		12.5	7	0111111
-1755	$-0.675\ \bar{\sigma}_A$			
		12.5	8	1111111
-2990	$-1.150\ \bar{\sigma}_A$			
		8.0	9	1111110
-4420	$-1.700\ \bar{\sigma}_A$			
		4.5	10	1111100

length of the bit string varies with the component range-of-scale being considered. To represent all nine fields a total of 35280 bits is required.

For purposes of illustration, now consider that it is required to obtain a measure of the synoptic similarity between two SD_{1000} fields, one of which is a forecast and the other the verifying analysis. As a first step each field is bit coded as described above to produce a bit string which represents the pattern characteristics of the field. The two bit strings are then compared, bit by bit, and a count of the matching bits is made. For example suppose that the value of the A parameter for a particular module falls into range interval 4 for the analysis field but into range interval 6 for the forecast field. From Table 1 it can be seen that the bit code elements are 0000111 and 0011111. The matching bit count--for this particular parameter and module--is 5. The total matching bit count for all parameters and all modules, expressed as a percentage fraction of a perfect match (8640 matching bits), provides an absolute monotonic measure of the degree of synoptic similarity between the two SD_{1000} fields. Thus if 6912 bits match the "match coefficient" is 80%.

Similarly, all nine component fields of one synoptic situation may be matched against the corresponding fields of another situation to produce match coefficients for each of the nine pairs of fields.

It can be seen that the bit string representation of the pattern characteristics of a field, and the technique for counting matching bits and obtaining a match coefficient, together can provide absolute monotonic measures of the degree of synoptic similarity between any two synoptic situations expressed in terms of their nine component fields.

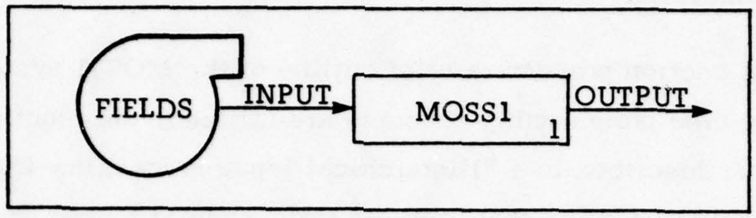
4. THE MOSS1 SYSTEM

4.1 Introduction

This Section presents a brief outline of the MOSS1 system. "Top-down" structured programming concepts are utilized, the function of each module being described in a "Hierarchical Input-Processing-Output" (HIPO) chart. It should be noted that only the main modular functions are described; each module--for example the pattern separation component (module 1.1.1)--may encompass several information-processing subroutines.

4.2 The Modular Structure of MOSS1

Level 1



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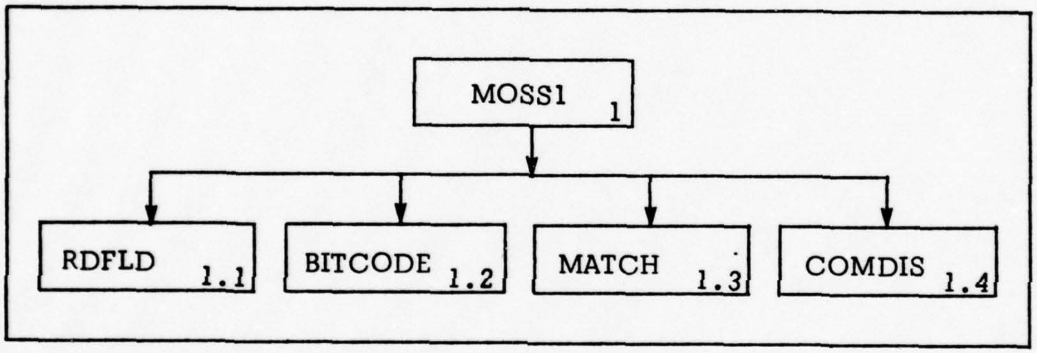

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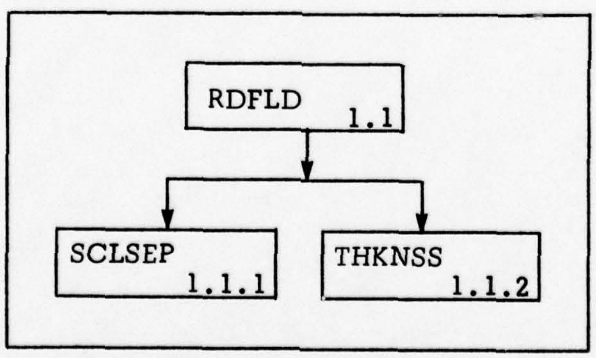

4.3 HIPO Charts for MOSS1

MOSS1

MODULE 1

Input	Process	Output
Fields (from tape)	MOSS1 is the main driver, controlling information flow and processing throughout the system.	Measures of Synoptic Similarity

RDFLD

MODULE 1.1

Input	Process	Output
Pair of 1000-mb and 500-mb fields	Reads fields. Pattern separates fields and computes thickness.	9 component fields from each input pair

SCLSEP

MODULE 1.1.1

Input	Process	Output
1000-mb or 500-mb field	Pattern separates input field into 3 range-of-scale components. Computes SV anomaly field.	SV, SV anomaly, SL, SD

THKNSS

MODULE 1.1.2

Input	Process	Output
SV, SL and SD fields for 1000 mb and 500 mb	Computes 500-1000-mb thickness for each range of scale, expressing SV field in terms of the SV anomaly.	500-1000-mb thickness of SV anomaly, and SL and SD thickness fields

BITCODE

MODULE 1.2

Input	Process	Output
One of the nine range-of-scale component fields	Bit codes each field and assembles the associated bit string. Bit strings are output to mass storage.	Bit string

MATCH

MODULE 1.3

Input	Process	Output
Two bit strings	Compares two bit strings, counts matching bits, and computes a match coefficient.	Match coefficient

COMDIS

MODULE 1.4

Input	Process	Output
Match coefficients	Prepares and outputs results in required format.	Tabulated match coefficients which are measures of synoptic similarity

4.4 System Operation and Constraints

The input must consist of pairs of fields, each pair consisting of a 1000-mb field followed by the associated 500-mb field. (The THKNSS module assumes this ordered pairing.) Each field must be on the standard FNWC hemispheric 63x63 grid, north polar stereographic projection and include the standard FNWC 20-word ident. The User must specify the total number (M) of input pairs where M cannot be greater than 20. The pairs of input fields must be ordered as follows[5]:

$$A_\tau\ (1000,500)\ ;\ A_{\tau+1}\ (1000,500)\ ;\ \ldots\ A_{\tau+n}\ (1000,500)\ ;$$

$$(F_\tau\ (1000,500));\ F_{\tau+1}\ (1000,500)\ ;\ \ldots\ F_{\tau+n}\ (1000,500)\ .$$

Normally, of course, there will be no forecast pair of fields for the initial time τ, F_τ (1000,500). However it is possible that a forecast scenario may be based on an analysis technique which is different to that employed for the A fields. In these circumstances the independent analysis from which the forecasts emanate may be considered as the F_τ field. The MOSS1 system takes this possibility into account in the following manner:

a. If the number of pairs specified, M , is an even integer, MOSS1 assumes that the F_τ field-pair has been provided.

b. If the number of pairs specified, M , is an odd integer, MOSS1 assumes that the F_τ field-pair has not been provided and will automatically utilize the A_τ field-pair in its place. Thus for n = 0, $F_\tau = A_\tau$ and $F_\tau : A_\tau$ will result in a match coefficient of 100%.

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[5] The nomenclature used is defined in Section 5.1.

Note that the number of F field-pairs must be equal to or one less than the number of A field-pairs. Normally the minimum value of M utilized will be two. (M = 1 is permissible but would result in match coefficients of 100% for all 9 component fields since MOSS1 would assume $F_\tau = A_\tau$.)

The first field--a 1000-mb field--is read in (RDFLD) and provided as input to the pattern separation module (SCLSEP). The field is separated into its SV, SL and SD components. Each component field is saved on temporary storage. The SV anomaly field also is computed. The SV anomaly, SL and SD fields are then bit coded (BITCODE) and output to mass storage.

The second field--the 500-mb field corresponding to the initially read 1000-mb field--is then read in and the same procedure followed.

The 500-1000-mb thickness fields are then computed (THKNSS) for the SV, SL and SD ranges-of-scale, the SV component being expressed as an anomaly. These three fields are then bit coded and output to mass storage.

On completing processing of the first pair of fields there will be nine bit strings on mass storage. The appropriate date-time group, acquired from the 20-word ident associated with each field, is attached. The nine bit strings and the date-time group constitute one 589-word record, thus:

Date-time group	Word	1
SV_{500}	Words	2 → 17
SV_{1000}		18 → 33
SV_{5-10}		34 → 49
SL_{500}		50 → 85
SL_{1000}		86 → 121

SL_{5-10}	122 → 157
SD_{500}	158 → 301
SD_{1000}	302 → 445
SD_{5-10}	446 → 589

This procedure is repeated until all pairs of fields have been read in, processed and bit coded.

Once all bit strings have been assembled on mass storage--one 589-word record for each input pair--the following comparisons are made automatically and the match coefficients are computed:

a. $A_{\tau+n} : A_{\tau}$, $n = 0, 1, 2 \ldots 9$ (max)

b. $F_{\tau+n} : A_{\tau+n}$, $n = 0, 1, 2 \ldots 9$ (max)

Tabulated values of match coefficients are output on a line printer. A score of 1000 represents a perfect match between two fields.

The MOSS1 system is represented by about 1000 lines of code. A run on the FNWC CDC 6500 system with 13 input-pairs of fields required $147{,}000_8$ CM and took 557 CP seconds. (The pattern separation subroutine averages about 21 seconds for each field--i.e., 42 seconds per input-pair.) The number of system seconds was about 2300.

5. MOSS1 APPLICATIONS

5.1 Introduction

This Section examines some of the potential areas of application of the basic MOSS system, MOSS1.

To avoid lengthy explanations it is convenient to adopt the following nomenclature:

a. A_τ is an analysis at time τ. A' is an analysis produced by an alternative analysis technique.

b. $A_{\tau+1}, A_{\tau+2}, \ldots A_{\tau+n}$ are subsequent analyses in the same sequence or scenario (e.g., every 12 hours).

c. $F_{\tau+1}, F_{\tau+2}, \ldots F_{\tau+n}$ are the forecasts, based on A_τ, which are to be verified against the corresponding analysis scenario $A_{\tau+1}, A_{\tau+2}, \ldots A_{\tau+n}$. F' and F" are forecasts produced by alternative numerical models or emanating from alternative analyses.

d. In general $A_{\tau+n}$ and $F_{\tau+n}$ are each assumed to encompass nine component fields--the 3 ranges-of-scale x 3 levels. If necessary a particular component field can be indicated; thus $A_{\tau+n}(SD_{500})$ represents the SD component of the 500-mb $A_{\tau+n}$ field.

e. " : " signifies the process of comparing two fields and obtaining a measure of pattern similarity in terms of a match coefficient. Thus, for example, $F_{\tau+4} : A_{\tau+4}$ indicates the process of matching the fourth forecast in a sequence against the corresponding verifying analysis, both forecast and analysis emanating from the analysis at time τ, A_τ.

5.2 Potential Applications

5.2.1 By obtaining measures of $A_{\tau+n} : A_{\tau}$, $n = 1 \rightarrow N$, the effectiveness of persistence as a "forecast" can be ascertained. This determines a "zero-skill" level against which the effectiveness of any model must be evaluated.

5.2.2 By obtaining measures of $F_{\tau+n} : A_{\tau+n}$, $n = 1 \rightarrow N$, the effectiveness of the model with time can be determined for a particular synoptic sequence. Repeating the process for a large number of sequences would give a measure of overall effectiveness.

5.2.3 Suppose two forecast models are available, F' and F" . To determine which model performs better for a given meteorological scenario, MOSS1 could be used to provide the following score series:

$A_{\tau+n} : A_{\tau}$, $n = 1 \rightarrow N$ (This determines the zero skill level.)

$F'_{\tau+n} : A_{\tau+n}$, $n = 1 \rightarrow N$

$F''_{\tau+n} : A_{\tau+n}$, $n = 1 \rightarrow N$

Any superiority of one model over the other would be revealed by significant differences in the scores. (This is the application suggested in Section 1.) Note that the two models are compared as a function of time and range-of-scale.

5.2.4 By obtaining measures of $F_{\tau+n} : A_{\tau+n}$ and $F'_{\tau+n} : A_{\tau+n}$, $n = 1 \rightarrow N$, where F' represents a model which is a modification of model F , the effects of any model change can be studied. Such changes could be relatively minor (such as algorithm refinement, tuning of constants for loss of variance in the integration process) or relatively major (such as the addition of packages to the model to incorporate diabatic heating and radiative transfer, water content/clouds, convective mixing, terrain effects, etc.).

5.2.5 By obtaining measures of $A_{\tau+n} : A'_{\tau+n}$, $n = 0 \rightarrow N$ the relative performance of two analysis techniques may be obtained. Of course, in this instance, the score series does not determine which analysis technique is the best. However it does provide an ability to test, say, a new analysis system against one which has been thoroughly evaluated in an operational context and found satisfactory.

5.2.6 The effect of different initializing analyses on the subsequent behavior of a common forecast model can be evaluated. For example the impact of new data sets can be assessed. Another application is investigation of the significance of features in the initial analysis on the subsequent forecasts.

5.2.7 Study of MOSS1 scores could reveal hitherto unsuspected model defects leading to model improvement.

5.2.8 MOSS1 scores may be used for model development, testing, and tuning.

5.2.9 Models which are ineffective will be demonstrably so, thus releasing resources for more promising developments.

It should be noted that no forecasting center, national nor international, currently is able to evaluate the results of numerical models, and perform diagnostic and bias-detecting functions, in accordance with the above list.[6] Such a potentially useful tool should find a wide variety of applications and should have a significant effect on the future development,

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[6] See the quotation given in Section 1.

evaluation and verification of numerical forecast models. However MOSS1 is a basic capability, primarily intended to demonstrate the viability and effectiveness of measures of synoptic similarity. Section 7 provides a System Description of a more comprehensive and flexible system, MOSS2.

The following Section, Section 6, presents a selection of results obtained during development and testing of the MOSS1 capability.

6. DEMONSTRATION OF MOSS1 CAPABILITIES

6.1 Introduction

This Section presents a selection of the results obtained during development and testing of the MOSS1 system. These examples are intended to demonstrate the capabilities of the system rather than to evaluate the degree of forecasting skill exhibited by a particular numerical model.

Data used to develop and test MOSS1 consisted of three scenarios--72-hour sequences of 1000-mb and 500-mb forecast fields and verifying analyses at 12-hourly intervals emanating from analyzed fields at 00Z12NOV78, 00Z13NOV78 and 00Z14NOV78. The analyzed fields were produced by the FNWC analysis system and the forecast fields by the FNWC PE model. All fields were on a 63x63 grid, north polar stereographic projection, and were produced during routine FNWC operations.

Sections 6.2, 6.3 and 6.4 present plotted fields of the synoptic situation prevailing during the period covered by the three scenarios, a forecast scenario, and examples of pattern-separated fields. However it should be noted that, in general, utilization of the MOSS1 system in the context of model evaluation, verification and tuning does not require the output and study of plotted fields.[7]

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[7] The MOSS1 system does not encompass a capability for providing plotted fields. The fields shown in this Section were produced separately.

6.2 The Synoptic Situation and Development

Figures 3 through 14 show the course of synoptic development thus:

Figs. 3 and 4:	1000-mb and 500-mb analyses for 00Z12NOV78
Figs. 5 and 6:	1000-mb and 500-mb analyses for 00Z13NOV78
Figs. 7 and 8:	1000-mb and 500-mb analyses for 00Z14NOV78
Figs. 9 and 10:	1000-mb and 500-mb analyses for 00Z15NOV78
Figs. 11 and 12:	1000-mb and 500-mb analyses for 00Z16NOV78
Figs. 13 and 14:	1000-mb and 500-mb analyses for 00Z17NOV78

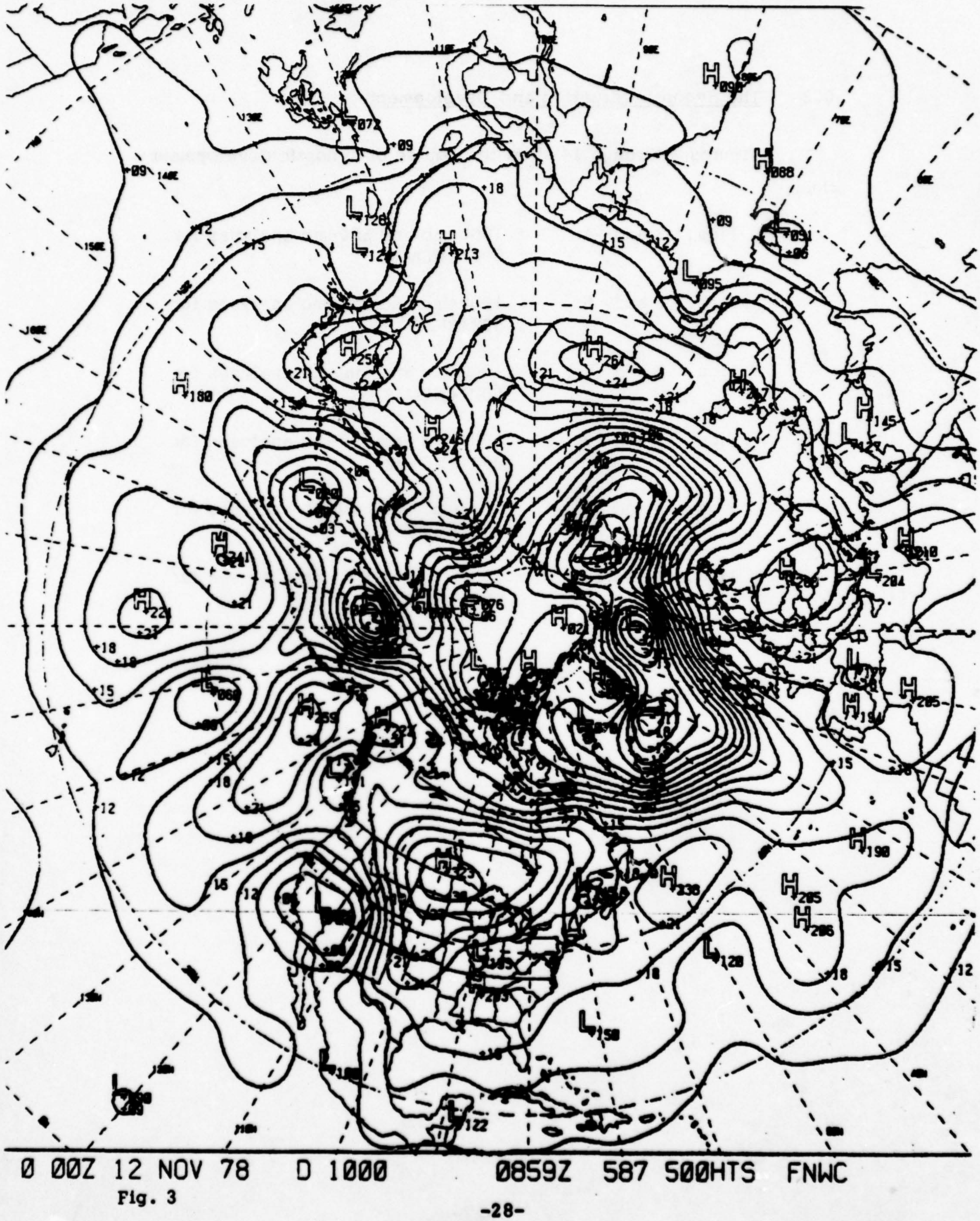


Fig. 3

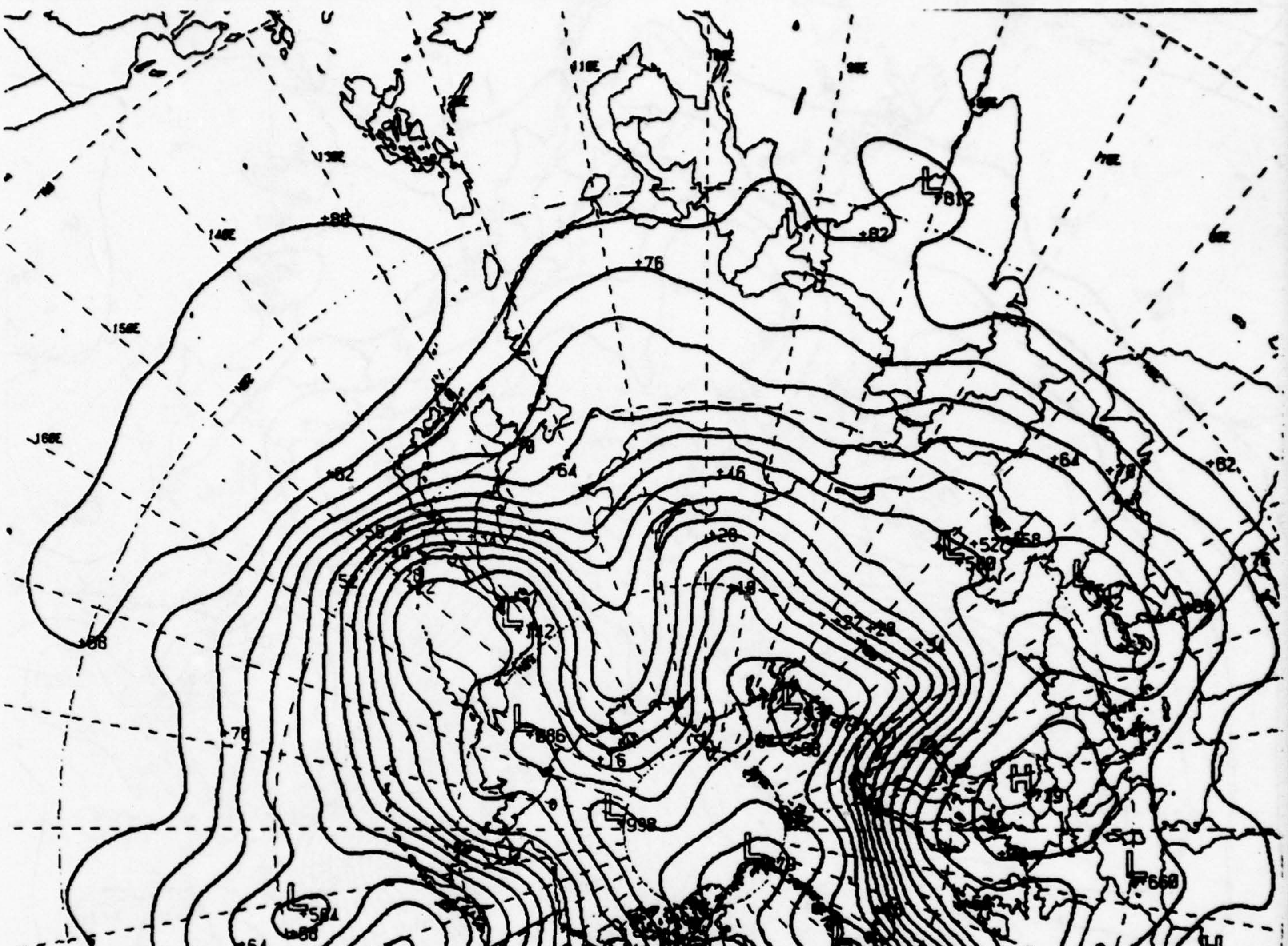


Fig. 4

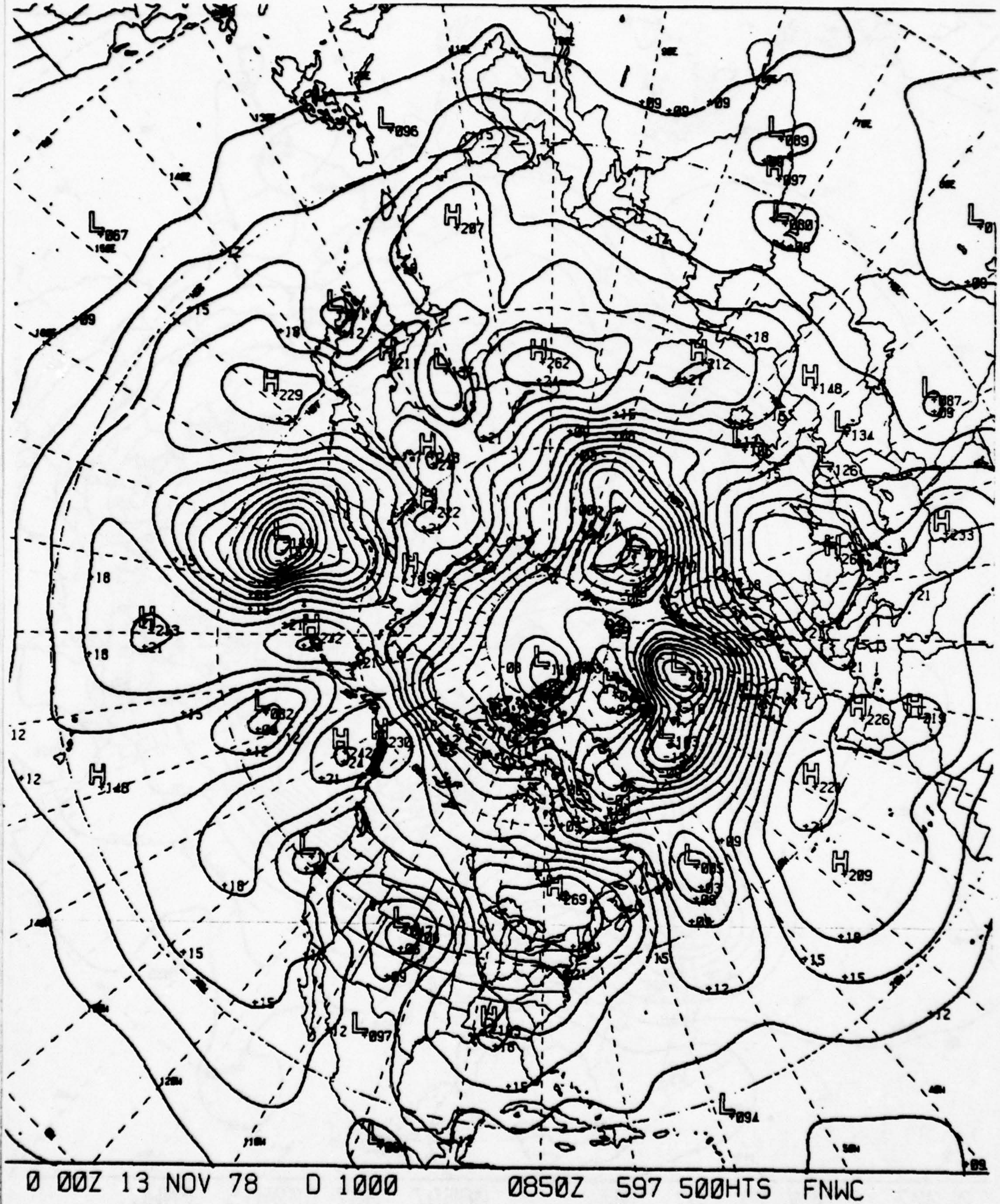


Fig. 5

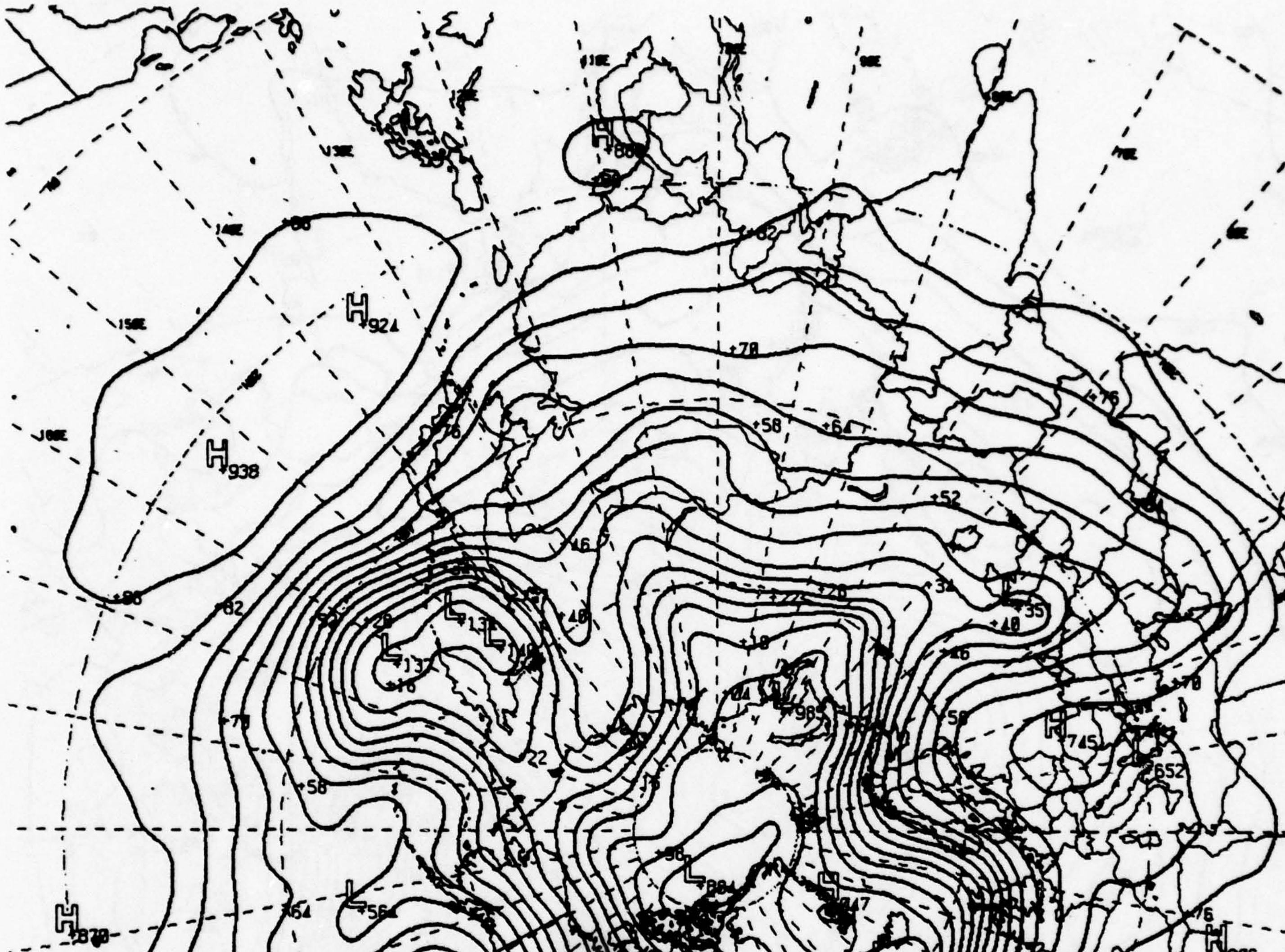
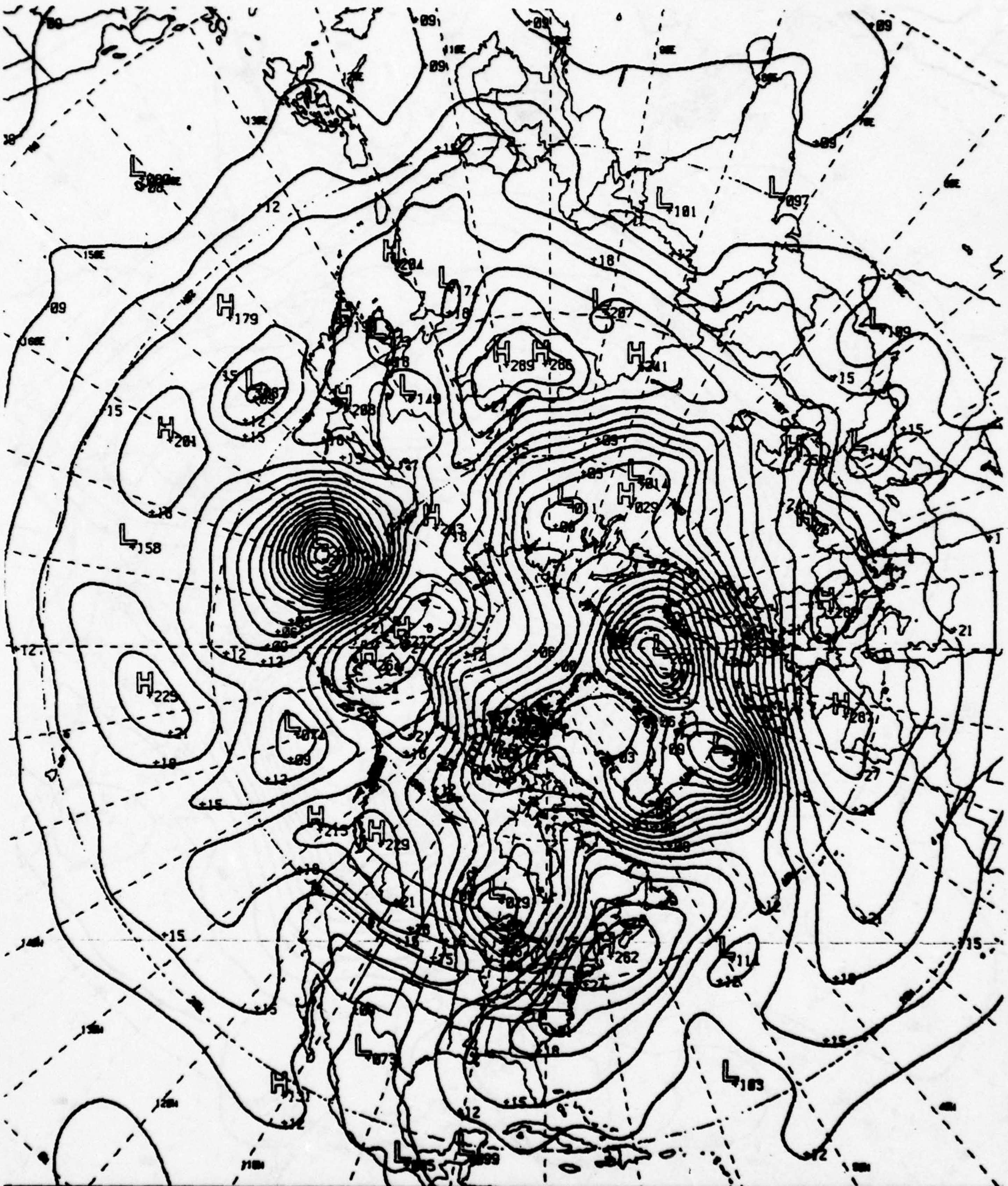


Fig. 6



0 00Z 14 NOV 78 D 1000 0902Z 611 500HTS FNWC

Fig. 7

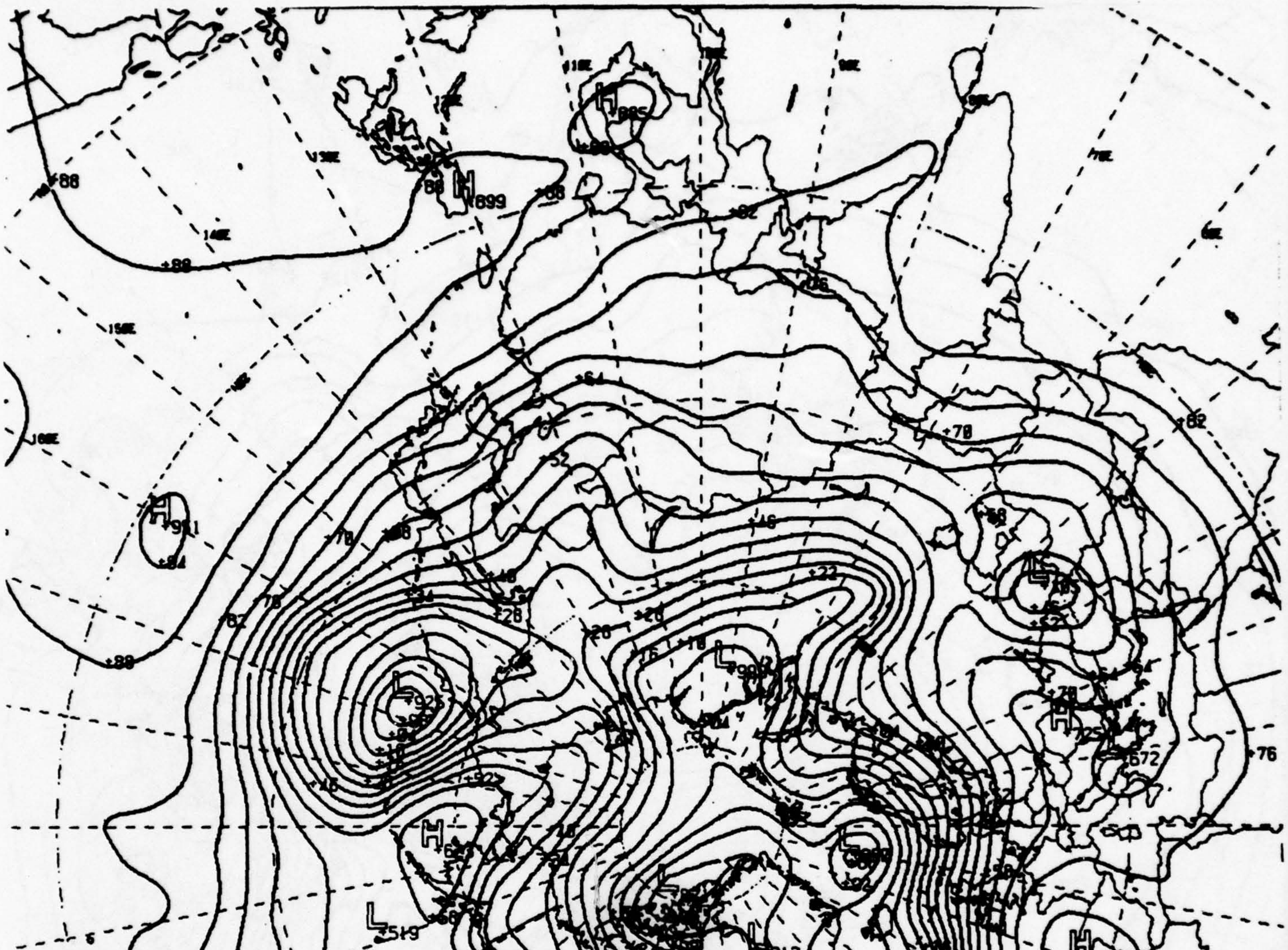
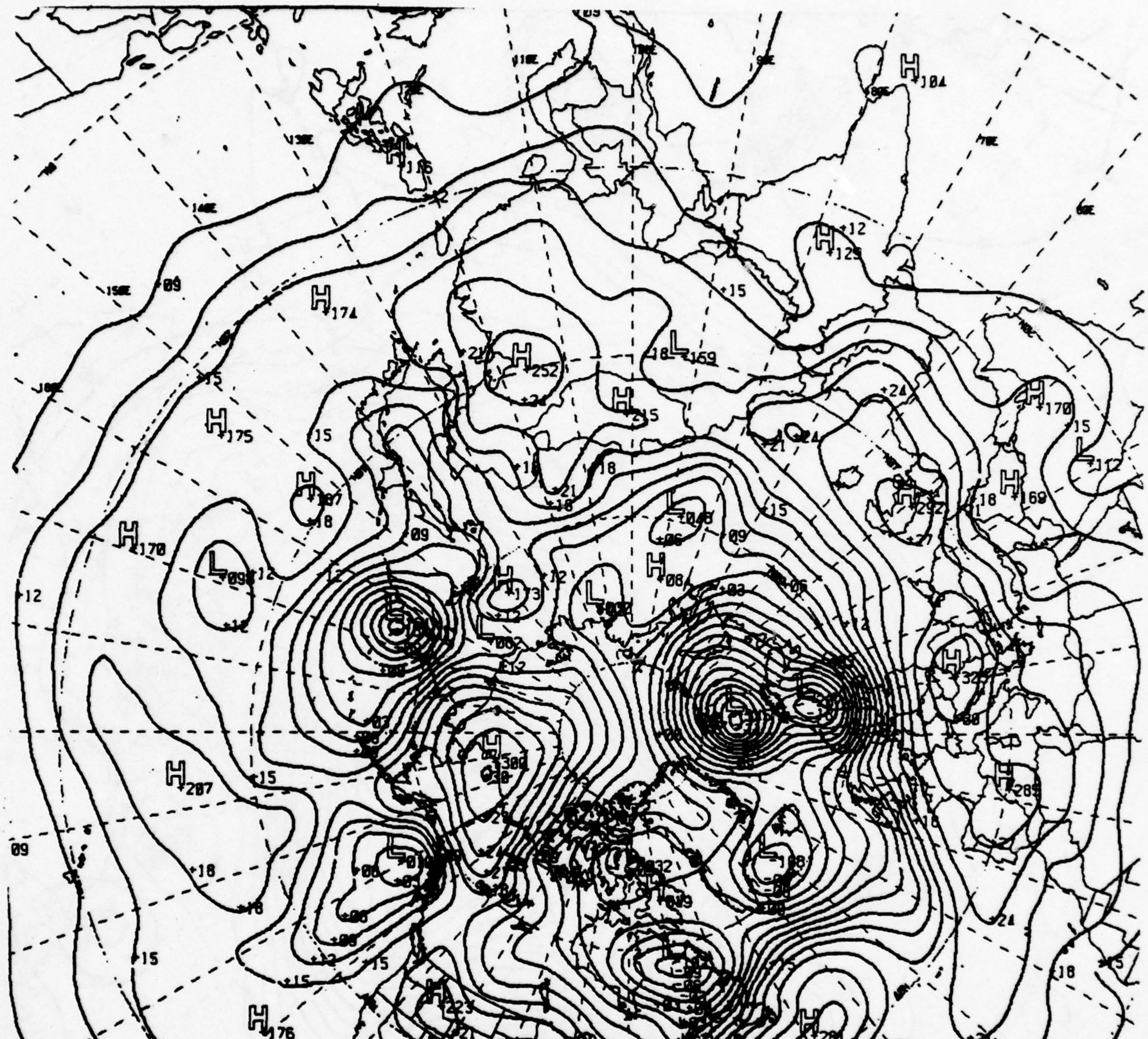


Fig. 8



0 00Z 15 NOV 78 D 1000 0357Z 535 500HTS FNWC

Fig. 9

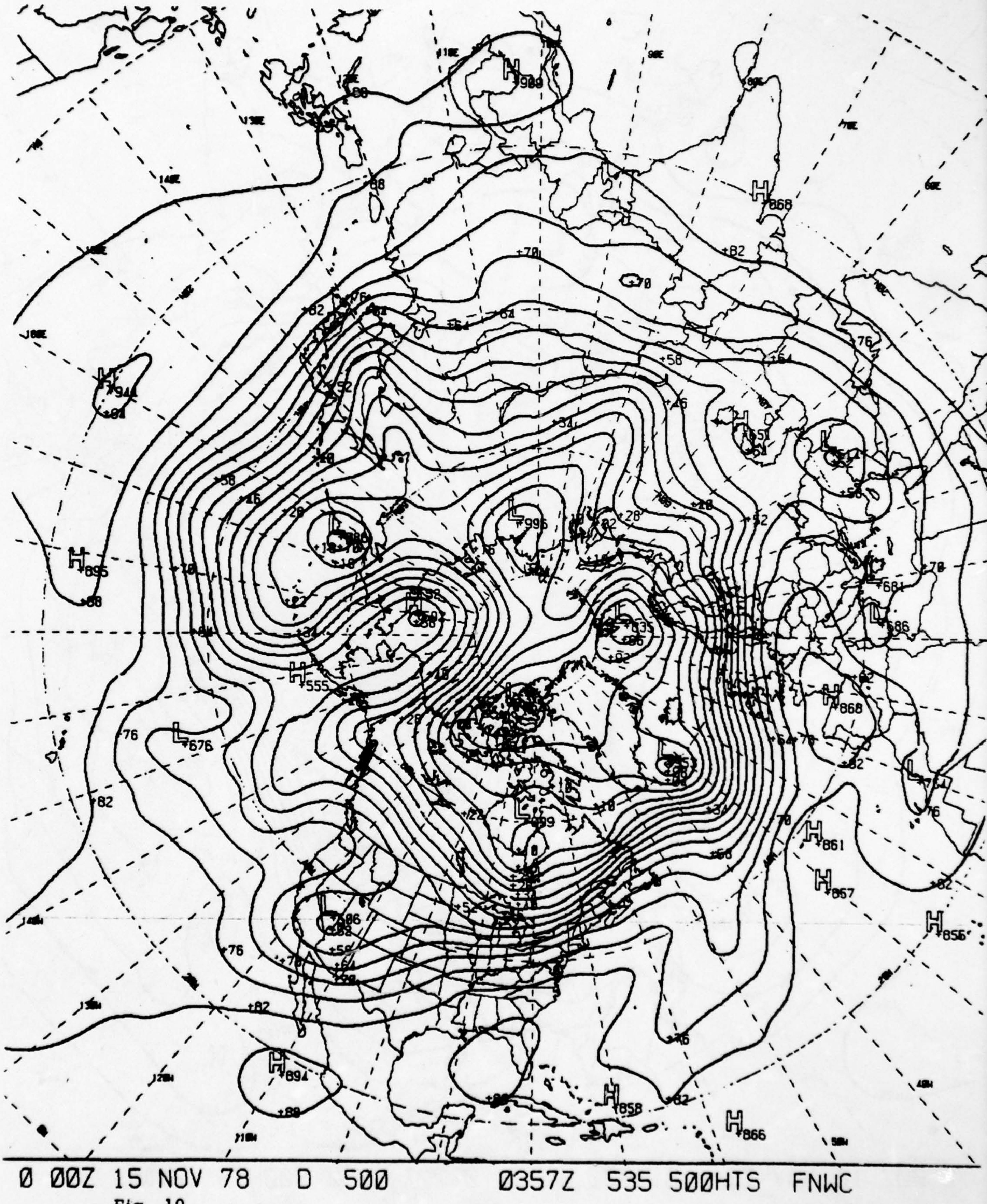
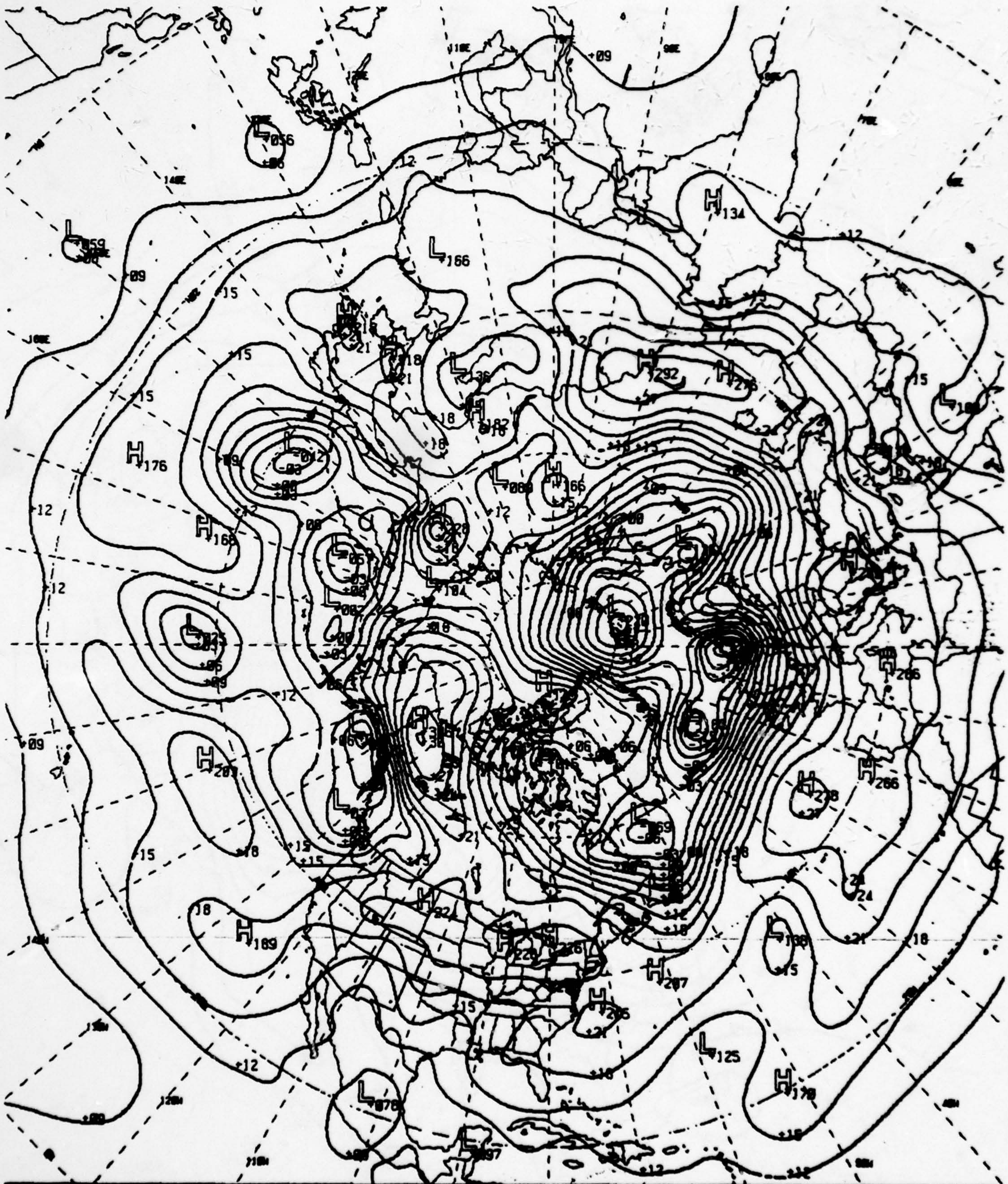
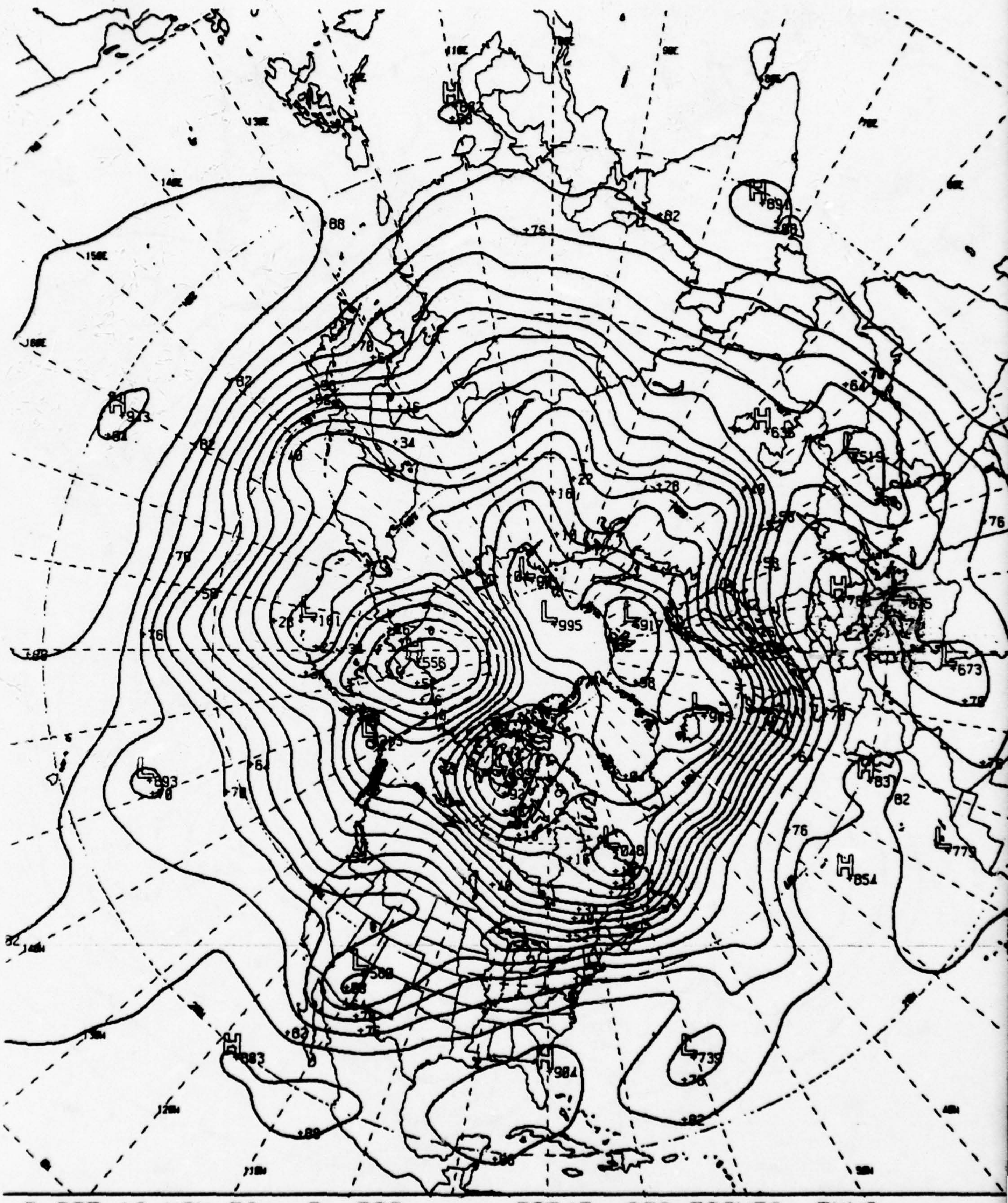


Fig. 10



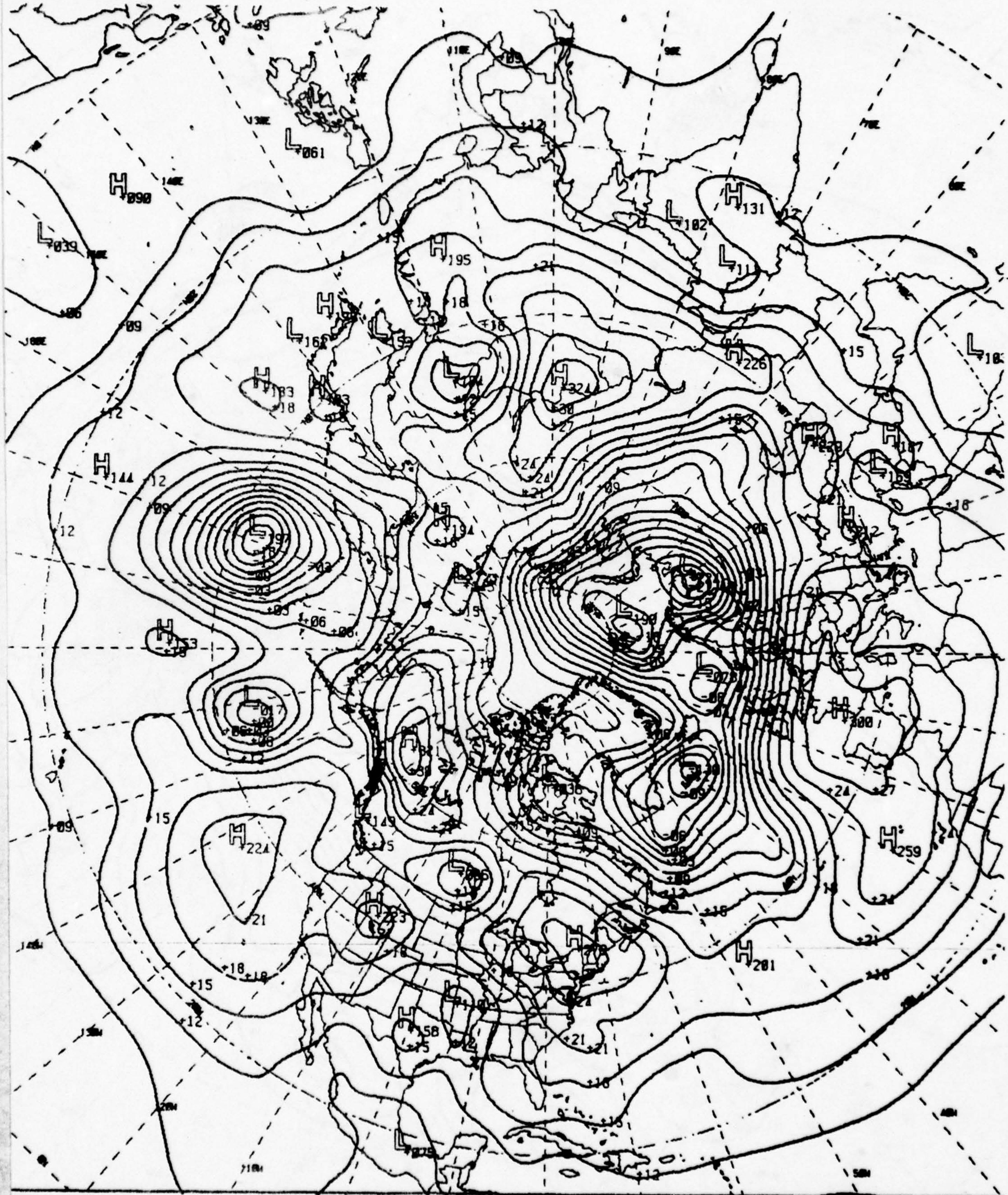
0 00Z 16 NOV 78 D 1000 0422Z 554 500HTS FNWC

Fig. 11



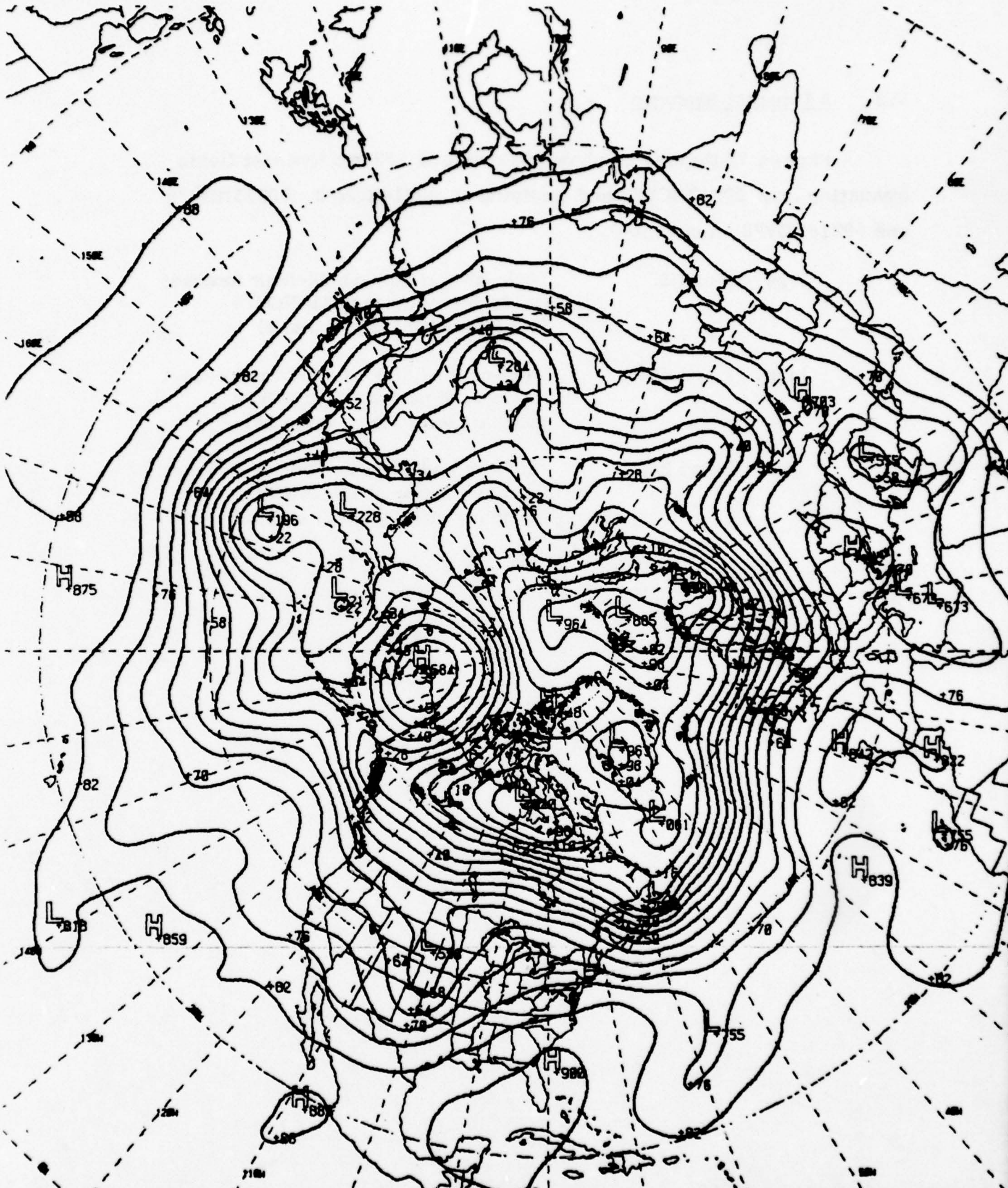
0 00Z 16 NOV 78 D 500 0854Z 603 500HTS FNWC

Fig. 12



0 00Z 17 NOV 78 D 1000 0855Z 597 500HTS FNWC

Fig. 13



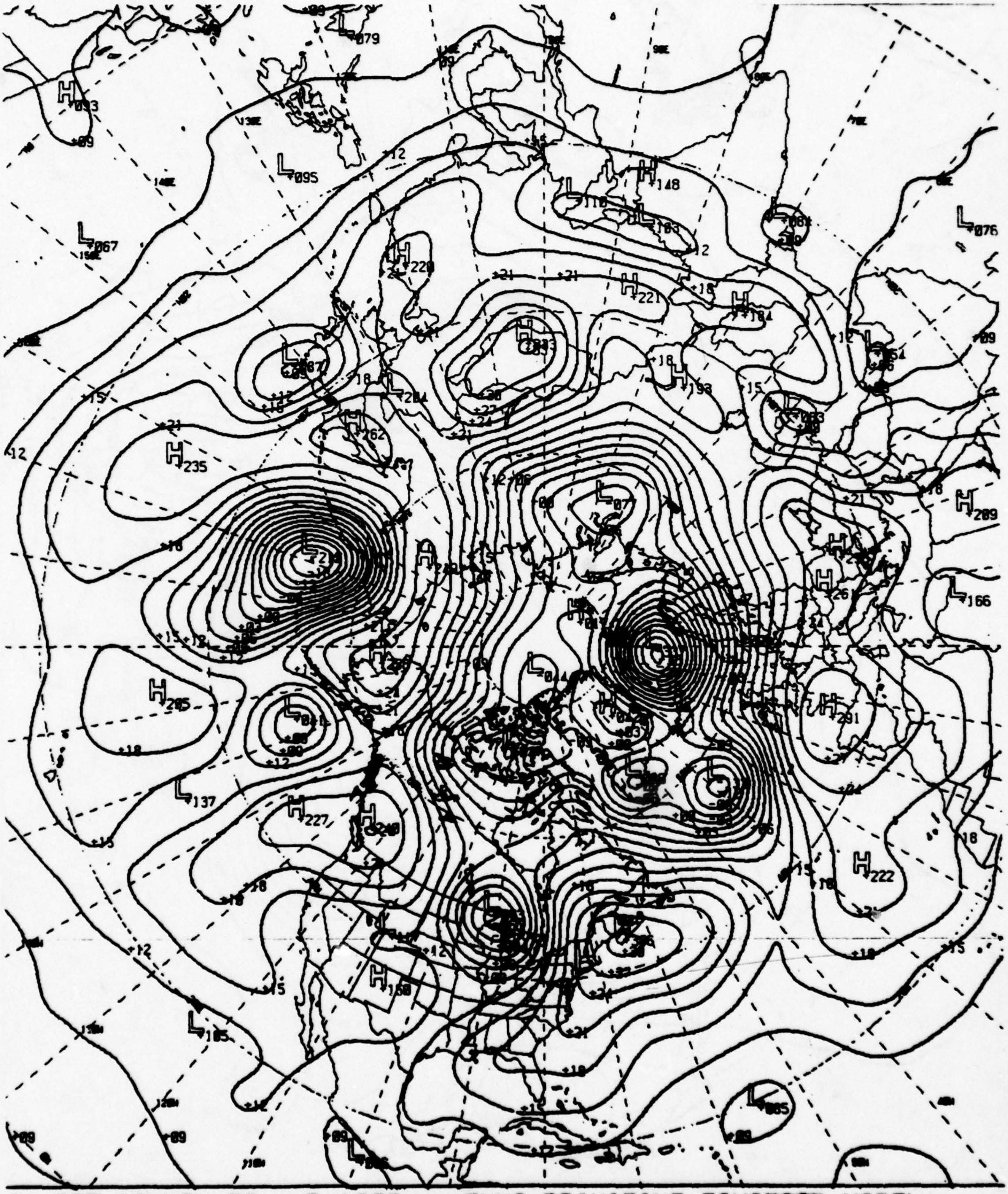
Ø ØØZ 17 NOV 78 D 5ØØ ØØ855Z 597 5ØØHTS FNWC

Fig. 14

6.3 A Forecast Scenario

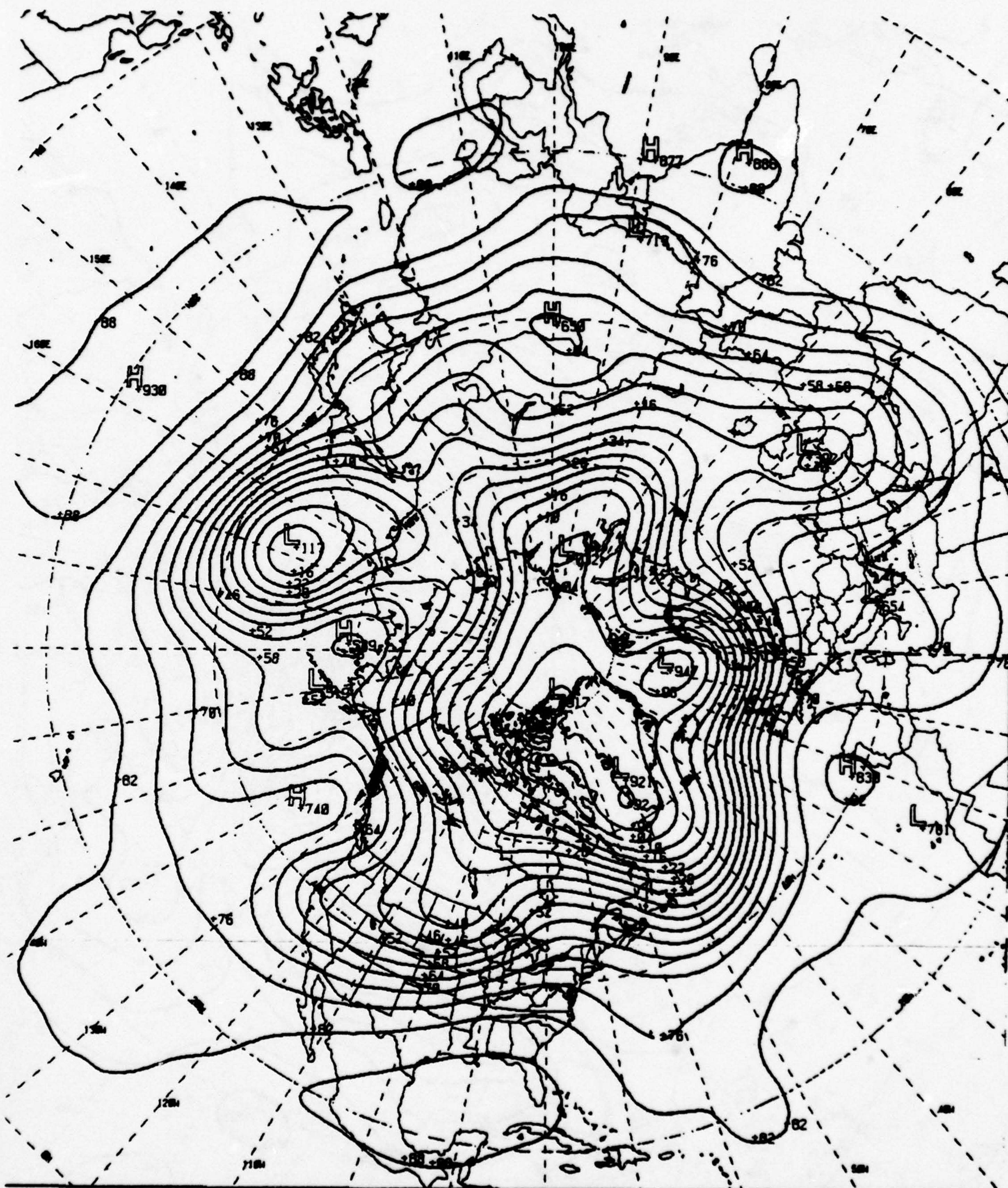
Figures 15 through 20 show 1000-mb and 500-mb forecast fields emanating from 00Z13NOV78 and verifying at 00Z14NOV78, 00Z15NOV78 and 00Z16NOV78, respectively.

Figs. 15 and 16:	1000-mb and 500-mb 24-hour forecast fields verifying at 00Z14NOV78 (compare with Figs. 7 and 8)
Figs. 17 and 18:	1000-mb and 500-mb 48-hour forecast fields verifying at 00Z15NOV78 (compare with Figs. 9 and 10)
Figs. 19 and 20:	1000-mb and 500-mb 72-hour forecast fields verifying at 00Z16NOV78 (compare with Figs. 11 and 12)



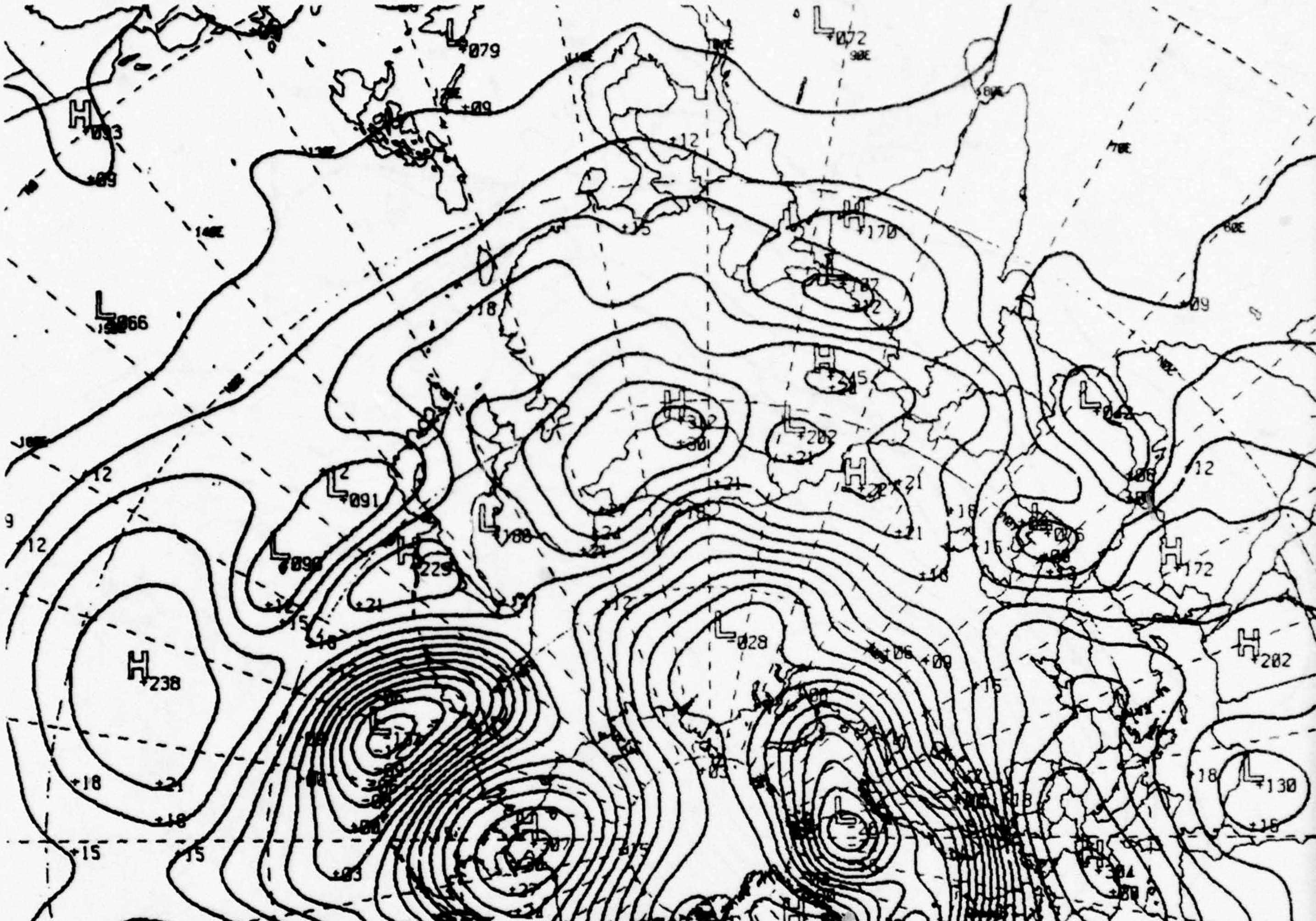
24 00Z 13 NOV 78 D 1000 FNWC PRIMITIVE EQUATION MODEL

Fig. 15



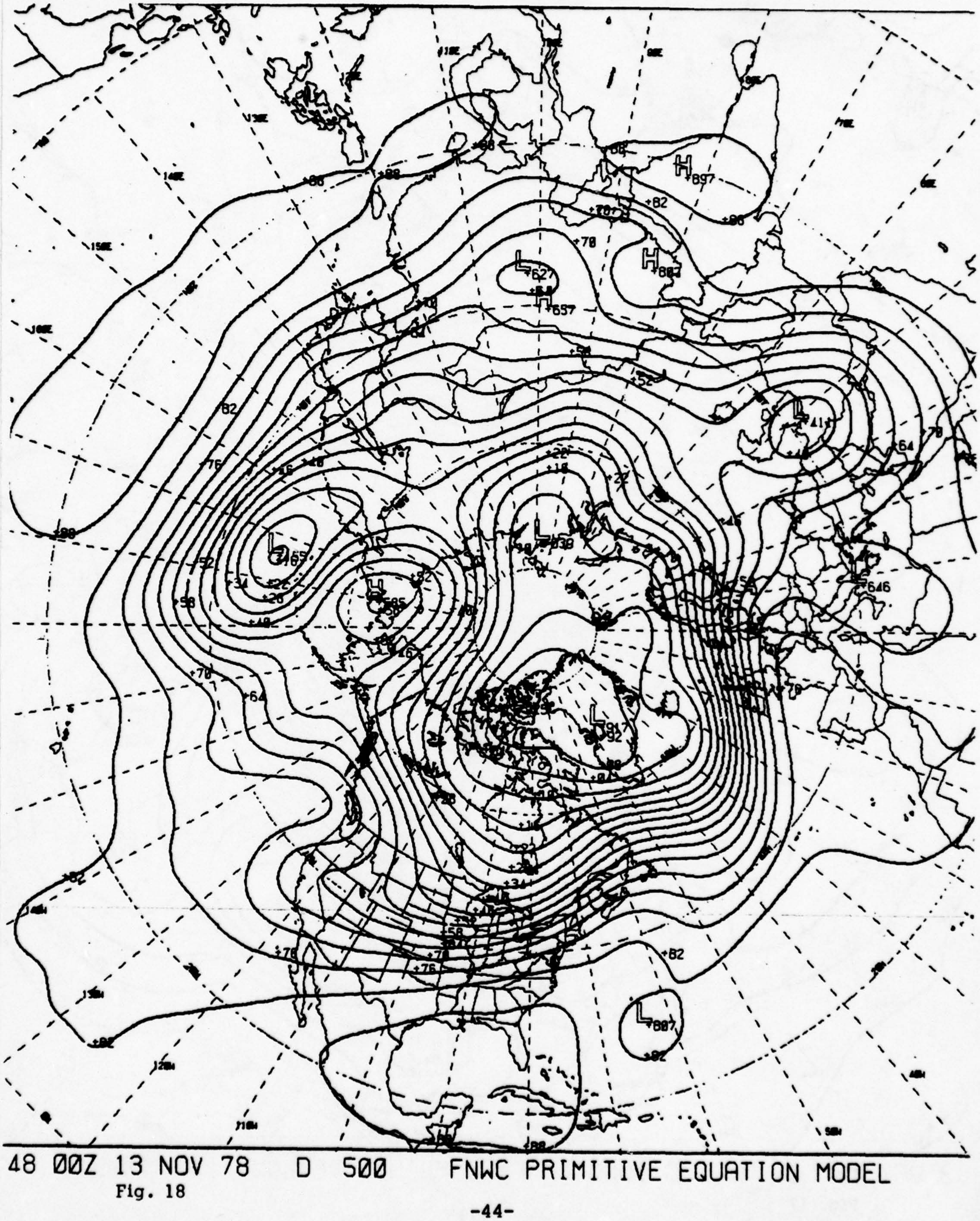
24 00Z 13 NOV 78 D 500 FNWC PRIMITIVE EQUATION MODEL

Fig. 16



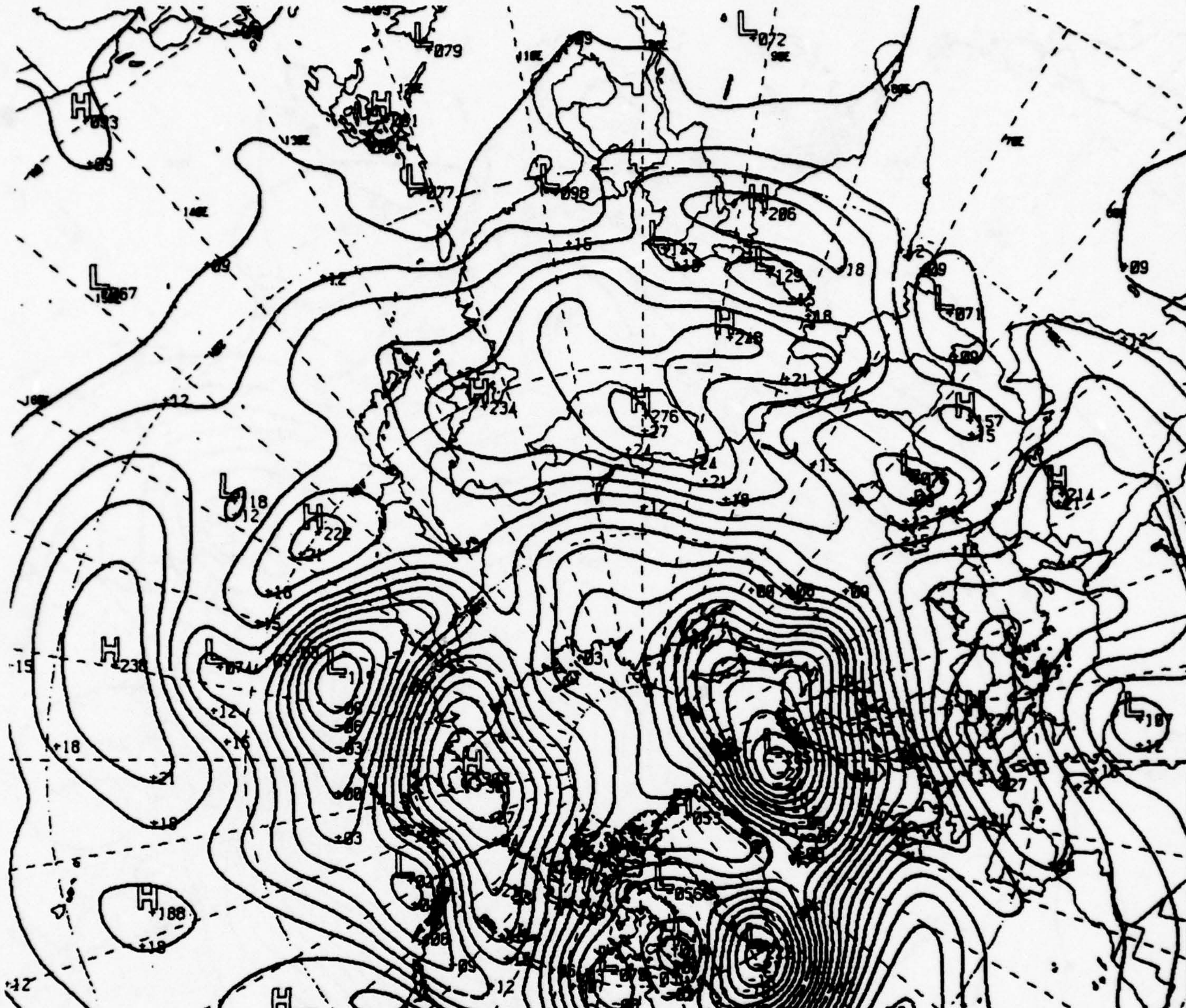
48 ØØZ 13 NOV 78 D 1ØØØ FNWC PRIMITIVE EQUATION MODEL

Fig. 17



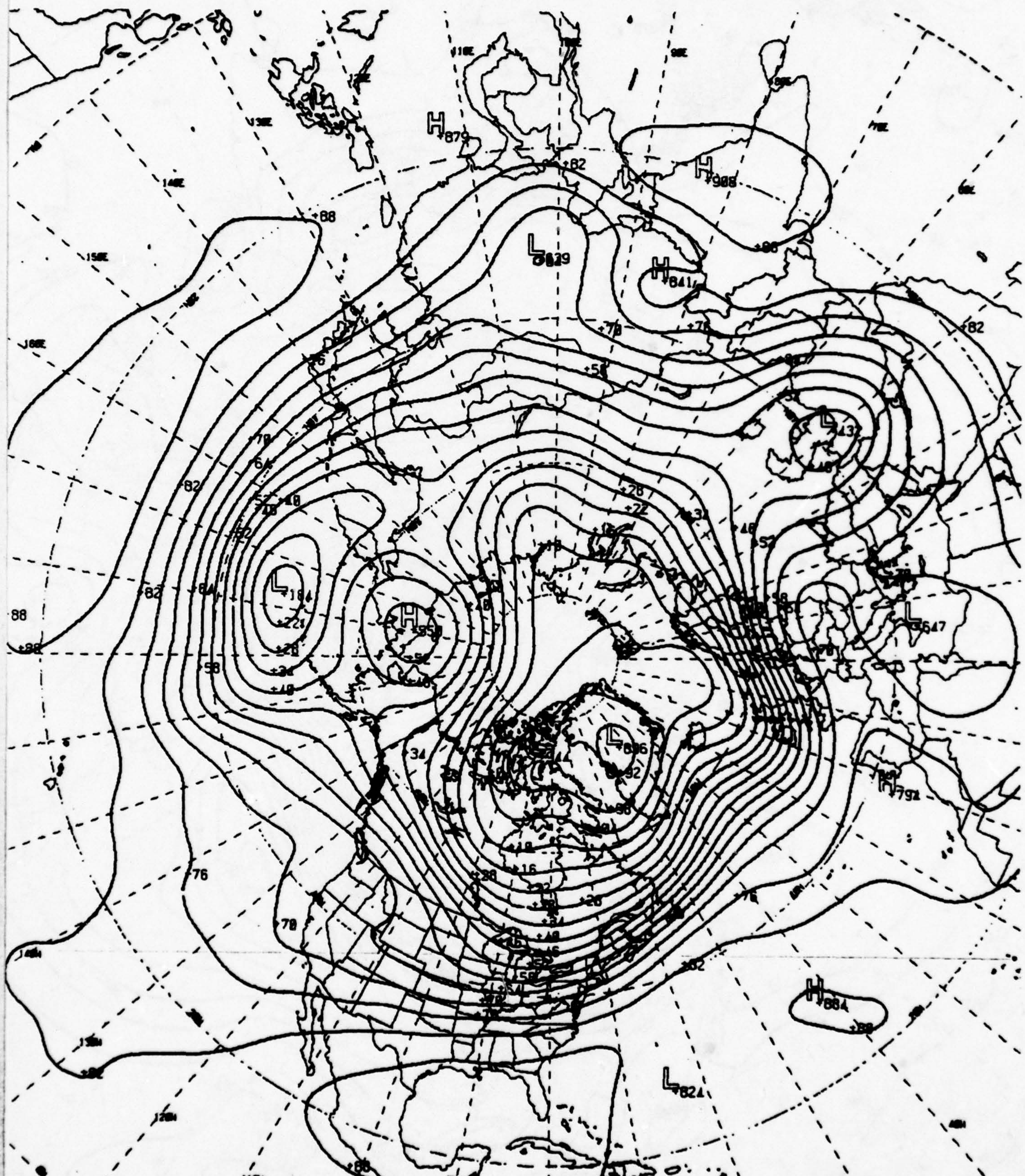
48 ØØZ 13 NOV 78 D 5ØØ FNWC PRIMITIVE EQUATION MODEL

Fig. 18



72 ØØZ 13 NOV 78 D 1ØØØ FNWC PRIMITIVE EQUATION MODEL

Fig. 19



72 00Z 13 NOV 78 D 500 FNWC PRIMITIVE EQUATION MODEL

Fig. 20

6.4 Pattern Separation

Figures 21 through 32 show the results of separating the 1000-mb and 500-mb 00Z15NOV78 analyses (Figs. 9 and 10 respectively), and the 1000-mb and 500-mb 48-hour forecast fields verifying at 0015NOV78 (Figs. 17 and 18 respectively), into their SV, SL and SD component ranges-of-scale.[8]

Figs. 21 and 22:	SV components of the 1000-mb and 500-mb analysis fields
Figs. 23 and 24:	SV components of the 1000-mb and 500-mb forecast fields
Figs. 25 and 26:	SL components of the 1000-mb and 500-mb analysis fields
Figs. 27 and 28:	SL components of the 1000-mb and 500-mb forecast fields
Figs. 29 and 30:	SD components of the 1000-mb and 500-mb analysis fields
Figs. 31 and 32:	SD components of the 1000-mb and 500-mb forecast fields

[8] Pattern separated thickness fields are not shown.

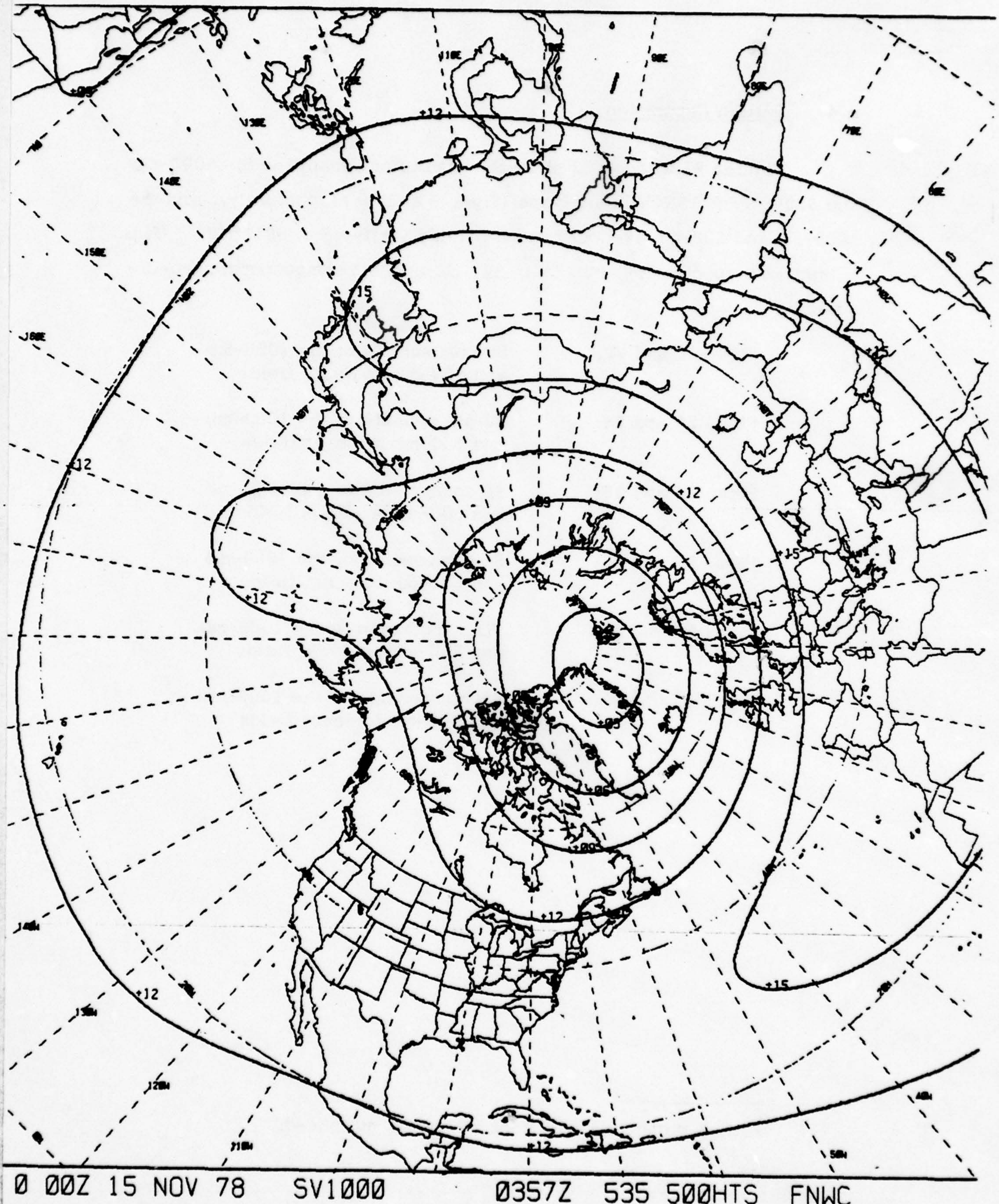
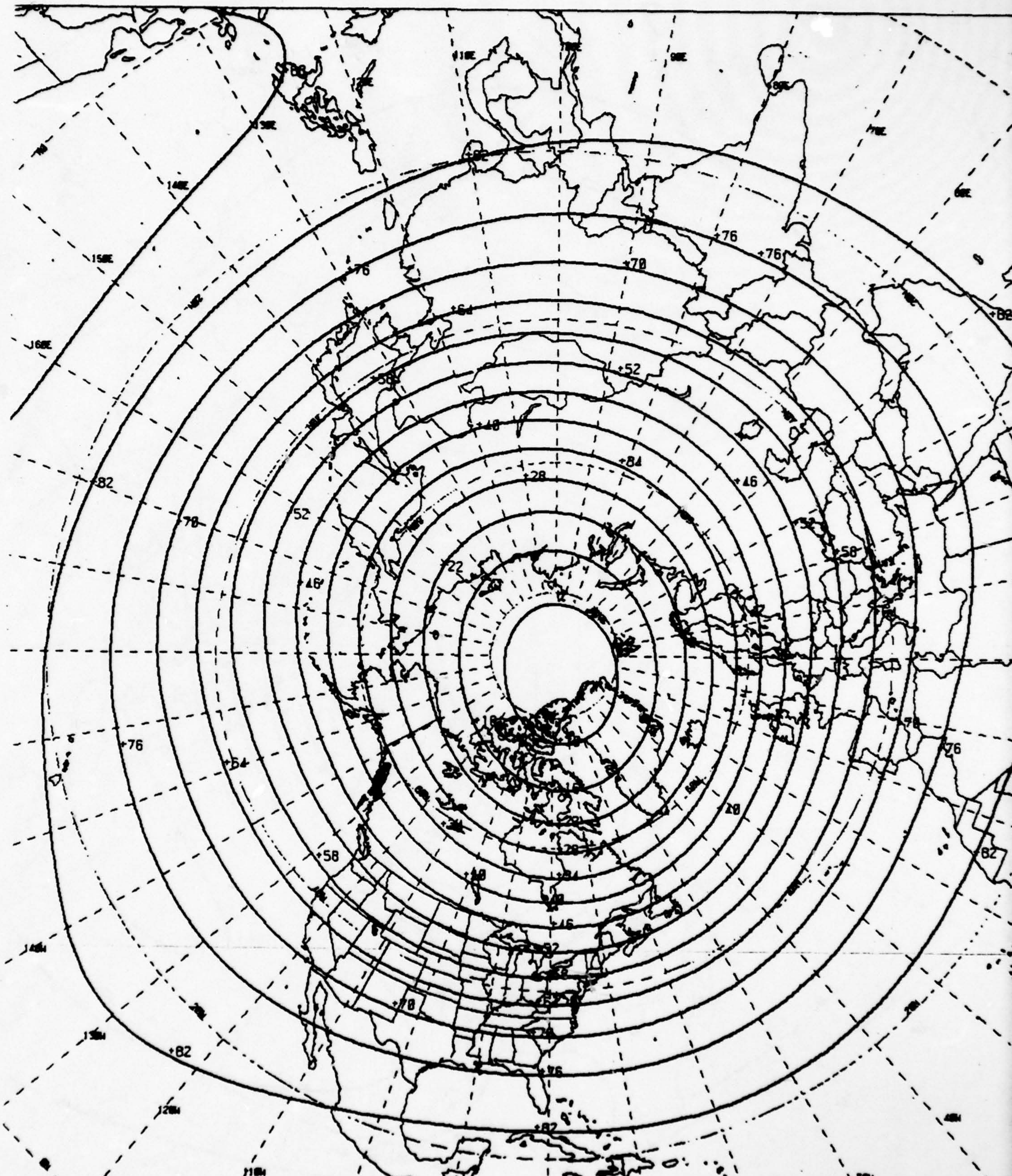
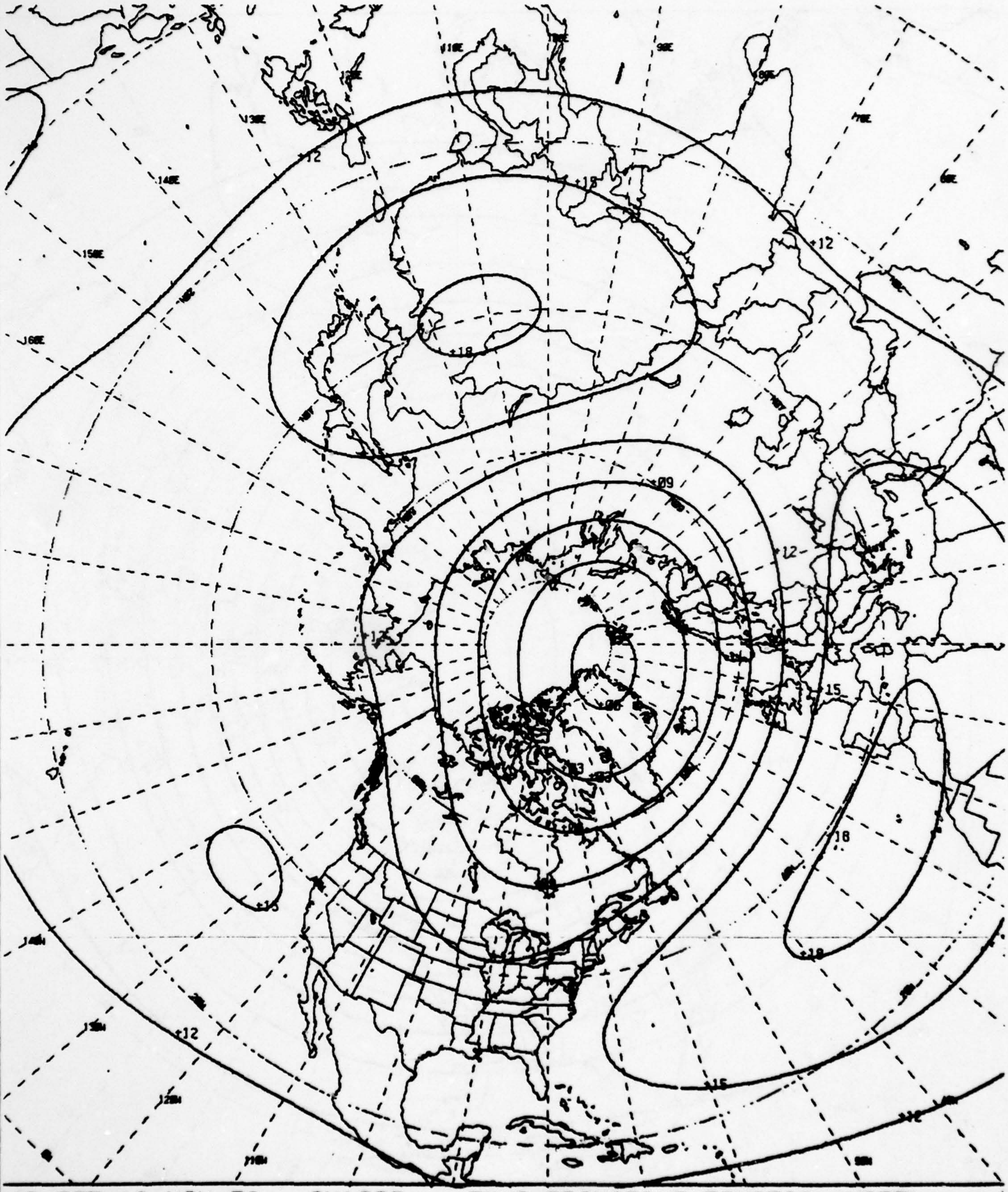


Fig. 21



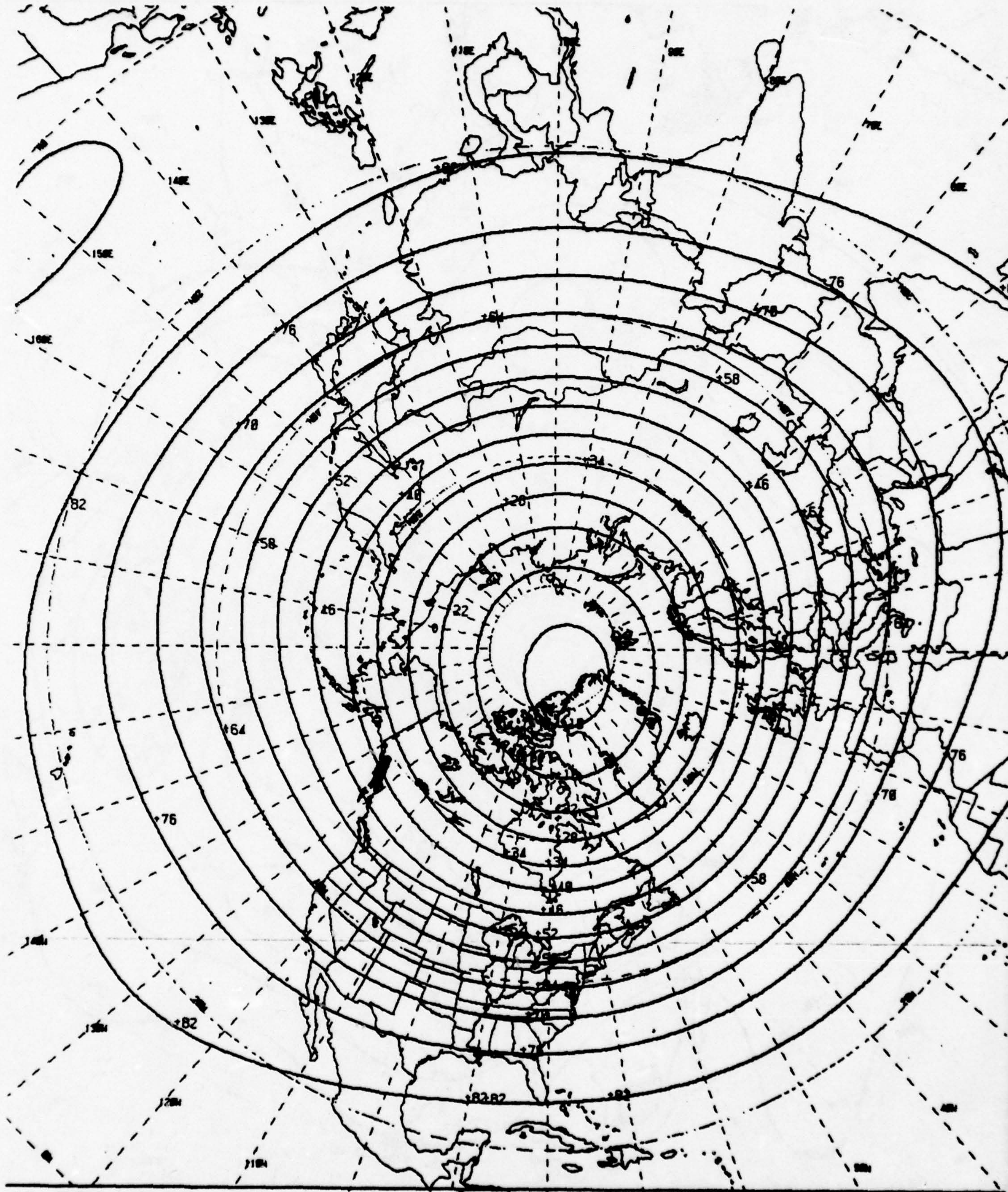
0 00Z 15 NOV 78 SV 500 0357Z 535 500HTS FNWC

Fig. 22



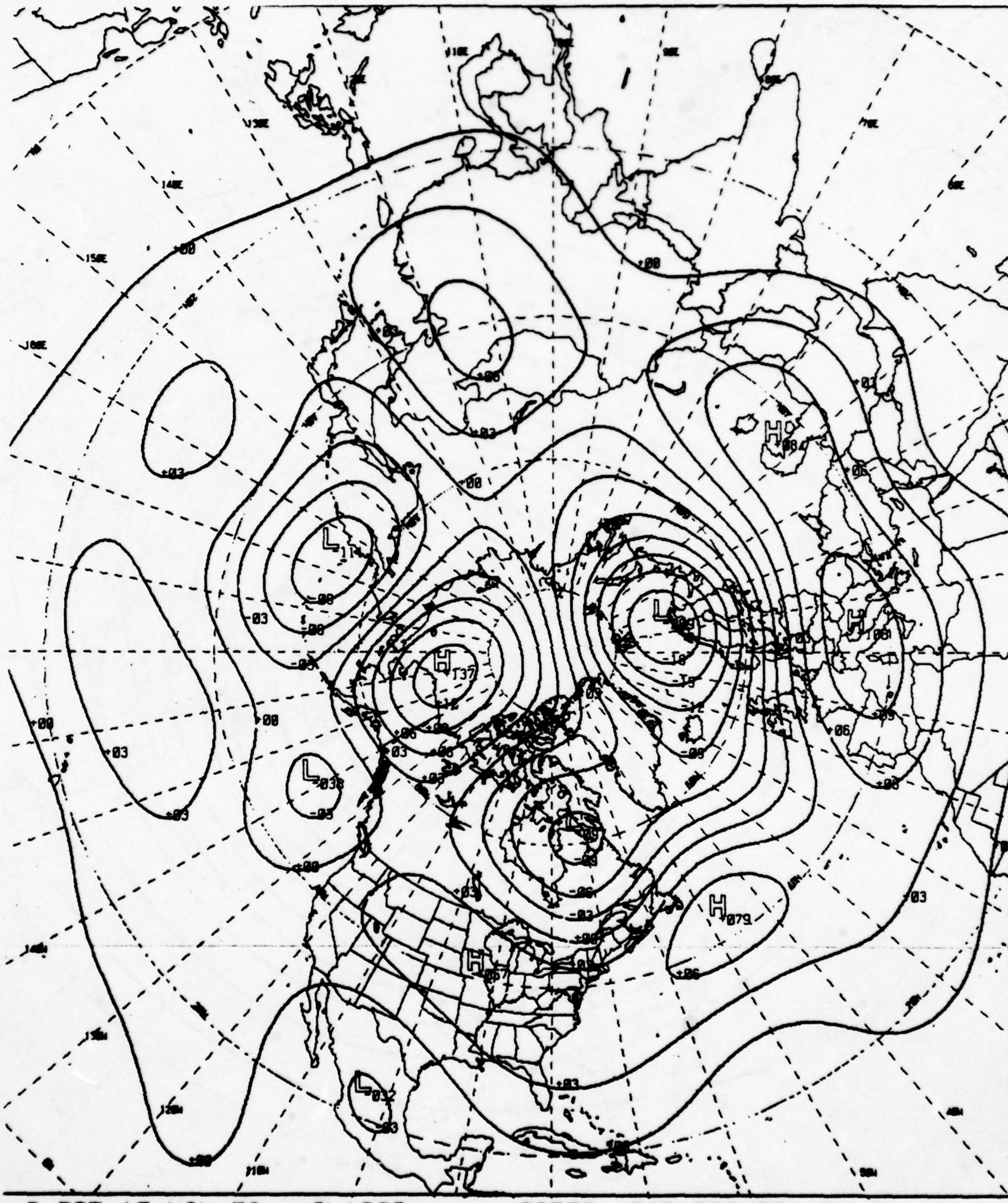
48 ØØZ 13 NOV 78 SV1ØØØ FNWC PRIMITIVE EQUATION MODEL

Fig. 23



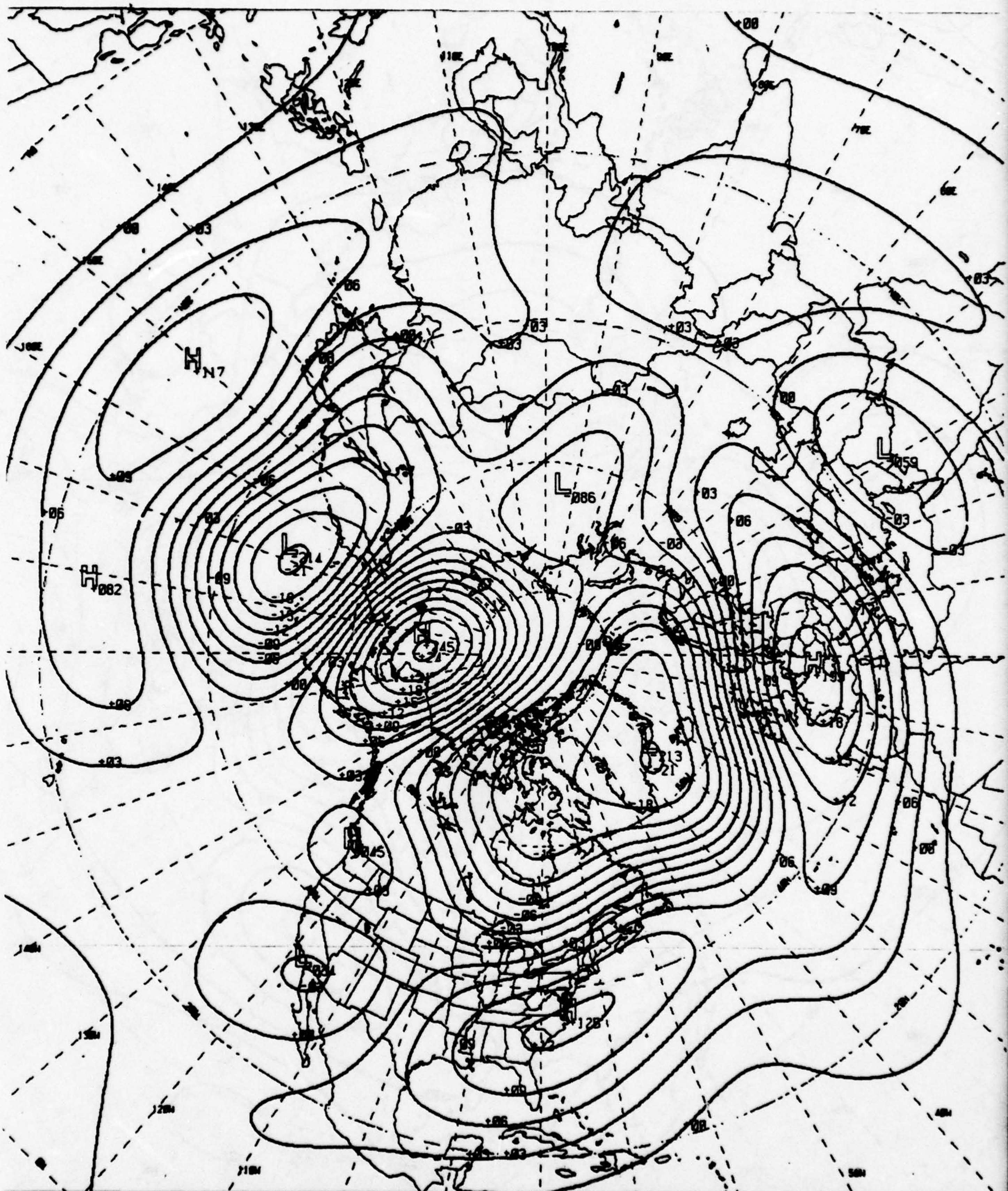
48 ØØZ 13 NOV 78 SV 5ØØ FNWC PRIMITIVE EQUATION MODEL

Fig. 24



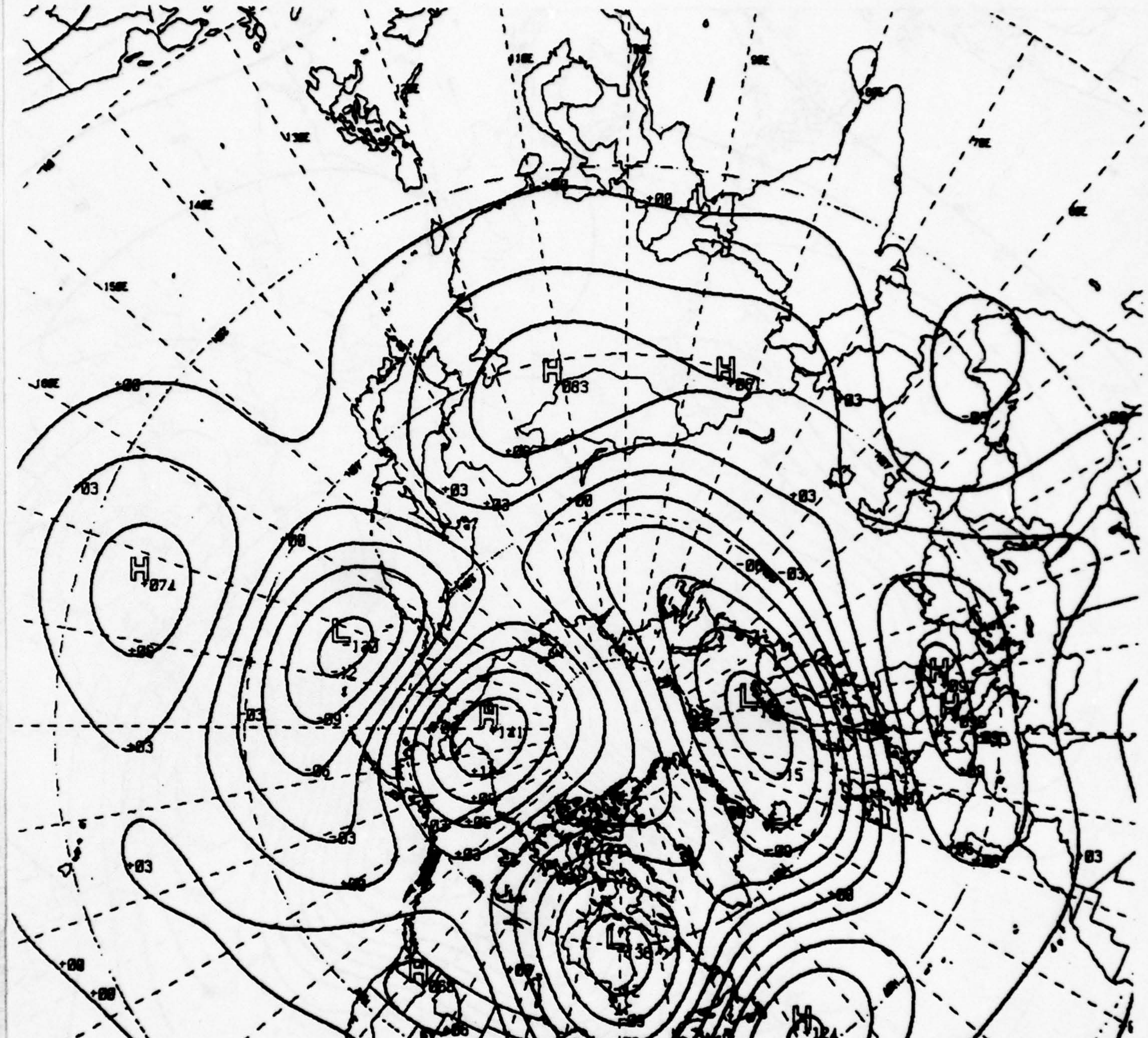
0 00Z 15 NOV 78 SL1000 0357Z 535 500HTS FNWC

Fig. 25



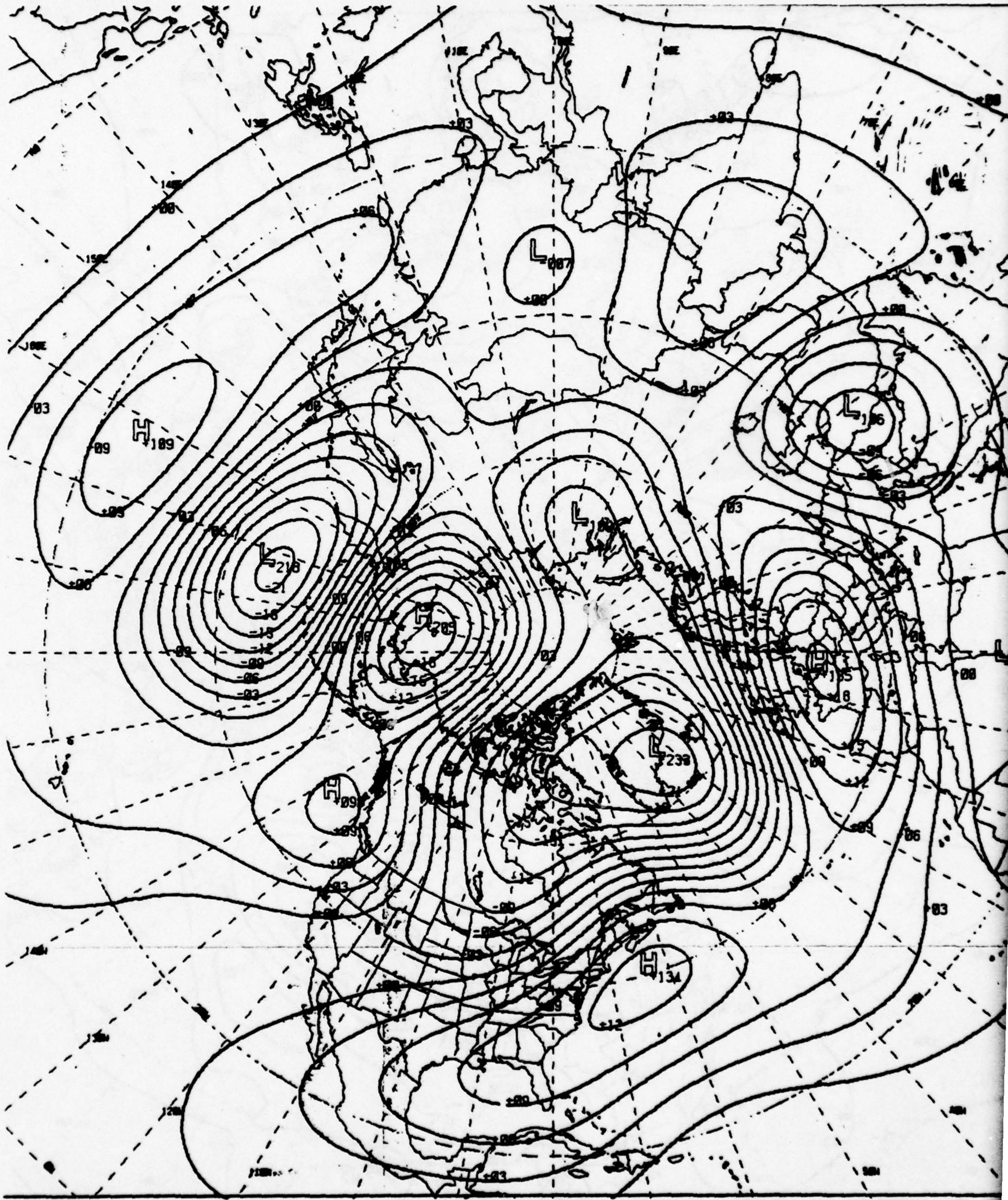
0 00Z 15 NOV 78   SL 500   0357Z 535 500HTS FNWC

Fig. 26



48 00Z 13 NOV 78 SL1000 FNWC PRIMITIVE EQUATION MODEL

Fig. 27



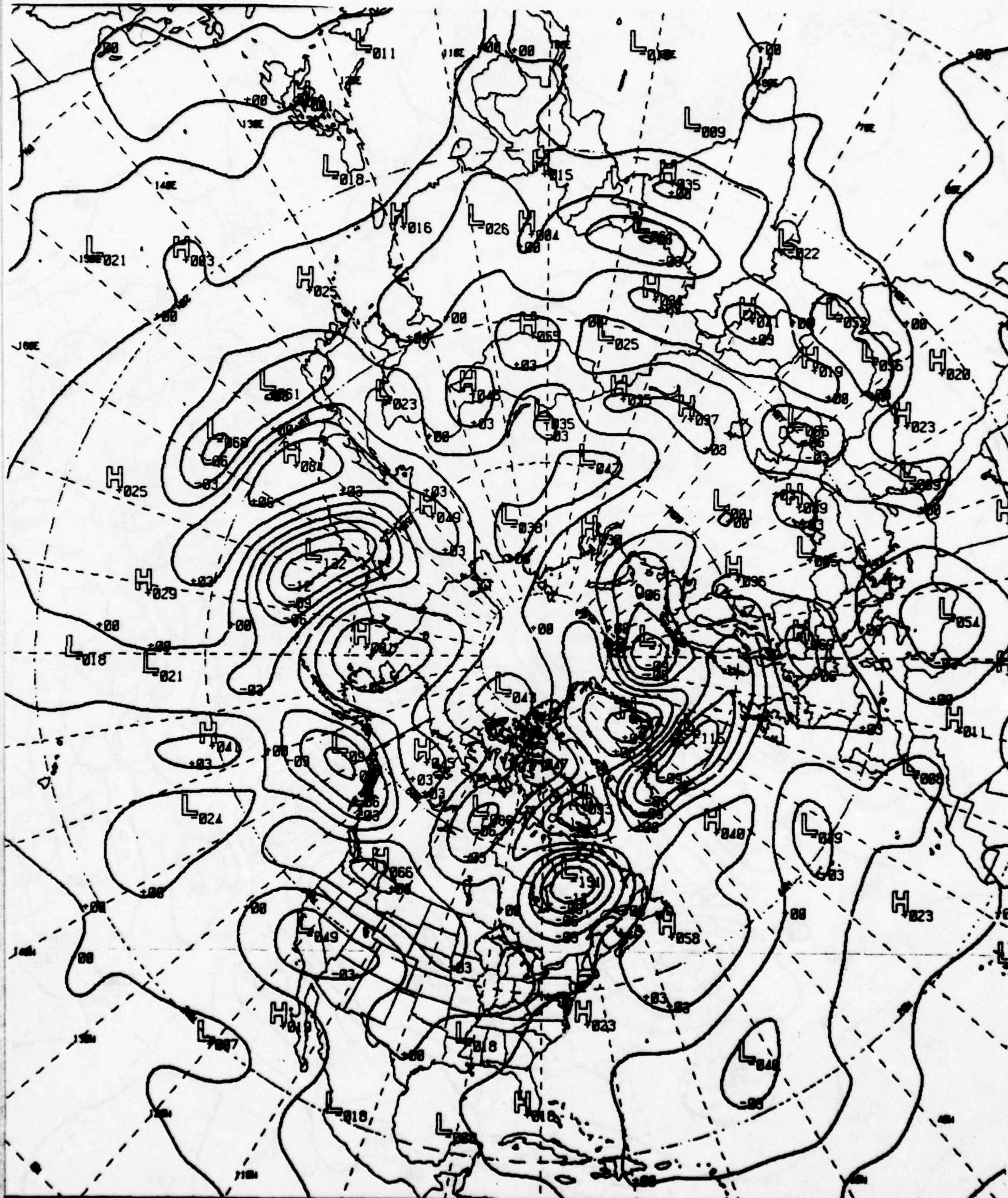
48 ØØZ 13 NOV 78 SL 5ØØ FNWC PRIMITIVE EQUATION MODEL

Fig. 28

Fig. 29

0 00Z 15 NOV 78 SD 500 0357Z 535 500HTS FNWC

Fig. 30



8 00Z 13 NOV 78 SD1000 FNWC PRIMITIVE EQUATION MODEL

Fig. 31

48 00Z 13 NOV 78 SD 500 FNWC PRIMITIVE EQUATION MODEL

Fig. 32

6.5 MOSS1 Scores

Tables 2, 3 and 4 show MOSS1 scores for the 72-hour scenarios emanating from analyses at 00Z12NOV78, 00Z13NOV78 and 00Z14NOV78. Two sets of scores are given for each scenario. The first set (headed PERSISTENCE SCORES) shows MOSS1 scores for $A_{\tau+n} : A_{\tau}$ where each increment of n (shown across the top of the table) corresponds to an increment of 12 hours. These scores show, for each level and range-of-scale, the effectiveness of persistence as a "forecast" for the ensuing 72-hour period and establish the zero skill levels for the nine component fields. The second set (headed MODEL SCORES) shows MOSS1 scores for $F_{\tau+n} : A_{\tau+n}$. In general these scores, when compared with the zero skill scores, provide a measure of the effectiveness of a model in forecasting the evolution of a given scenario over the forecast period in terms of the nine component fields.

Evaluation of the overall effectiveness of a numerical model must not be based on a case study of three scenarios covering a total period of 5 days in November 1978; a far more representative sample is required to evaluate model performance. For this reason no attempt should be made to interpret the MOSS1 scores in terms of model effectiveness. The scores given are only a demonstration of MOSS1 capabilities that could be applied to model evaluation and verification.

Figure 33 shows the difference in MOSS1 scores, $F_{\tau+n} : A_{\tau+n} - A_{\tau+n} : A_{\tau}$, $n = 0 \rightarrow 6$ ($0 \rightarrow 72$ hours) for the scenario emanating from 00Z13NOV78. Thus Fig. 33 is a plot of MOSS1 score-differences between the two sets of scores given in Table 3.

Table 5 has been compiled from Tables 2 to 4 and shows mean scores for the nine component fields. For example, the $\overline{SV}_{500}$ value of 960 directly under n = 1 was obtained from MOSS1 scores of 967 (Table 2), 950 (Table 3) and 964 (Table 4). Thus this score is a mean MOSS1 score over three scenarios for the SV_{500} component field. An overall mean score also has been computed for each range-of-scale using unweighted contributions from each level. For example the overall mean score of 959 under n = 1, the "MEAN $\overline{SV}$", was computed from the $\overline{SV}$ scores of 960, 962 and 954. Thus the overall mean is derived from nine MOSS1 scores, all equally weighted.

Figure 34 shows the difference in MOSS1 scores, $F_{\tau+n} : A_{\tau+n} - A_{\tau+n} : A_{\tau}$, $n = 0 \rightarrow 6$ ($0 \rightarrow 72$ hours) using the $\overline{SV}$, $\overline{SL}$ and $\overline{SD}$ values given in Table 5 for each level.

Figure 35 shows the mean $\overline{SV}$, $\overline{SL}$ and $\overline{SD}$ scores from Table 5 for persistence (solid line) and the model (broken line).

Table 2

MOSS1 scores for scenario 1--00Z12NOV78.

PERSISTENCE SCORES

		+0	+1	+2	+3	+4	+5	+6
SV	500:	1000	957	936	916	919	905	916
	1000:	1000	963	947	923	914	907	915
	5-10:	1000	951	955	955	950	930	936
SL	500:	1000	937	889	863	850	847	846
	1000:	1000	905	842	813	813	814	793
	5-10:	1000	938	910	889	880	875	862
SD	500:	1000	840	786	765	761	763	774
	1000:	1000	825	775	764	759	748	762
	5-10:	1000	814	760	741	758	768	775

MODEL SCORES

		+0	+1	+2	+3	+4	+5	+6
SV	500:	1000	965	946	927	894	878	864
	1000:	1000	961	946	922	909	914	910
	5-10:	1000	964	945	940	909	895	859
SL	500:	1000	951	938	924	908	890	875
	1000:	1000	931	906	865	826	804	782
	5-10:	1000	956	934	914	891	872	865
SD	500:	1000	861	839	826	808	797	794
	1000:	1000	853	817	801	774	764	751
	5-10:	1000	850	830	806	789	785	777

Table 3

MOSS1 scores for scenario 2--00Z13NOV78.

PERSISTENCE SCORES

		+0	+1	+2	+3	+4	+5	+6
SV	500:	1000	950	949	917	906	879	892
	1000:	1000	959	948	935	939	918	910
	5-10:	1000	954	959	923	925	919	915
SL	500:	1000	937	897	870	857	843	850
	1000:	1000	901	858	821	795	779	796
	5-10:	1000	931	901	872	855	844	829
SD	500:	1000	836	796	759	754	757	768
	1000:	1000	834	777	748	750	742	749
	5-10:	1000	815	764	742	747	745	762

MODEL SCORES

		+0	+1	+2	+3	+4	+5	+6
SV	500:	1000	957	936	928	911	901	891
	1000:	1000	959	949	936	920	910	911
	5-10:	1000	968	944	933	915	914	876
SL	500:	1000	962	936	920	901	883	882
	1000:	1000	934	889	852	827	801	793
	5-10:	1000	945	931	908	898	863	853
SD	500:	1000	864	844	819	806	799	789
	1000:	1000	842	814	796	778	761	742
	5-10:	1000	857	823	794	778	768	757

Table 4

MOSS1 scores for scenario 3--00Z14NOV78.

PERSISTENCE SCORES

		+0	+1	+2	+3	+4	+5	+6
SV	500:	1000	964	930	903	897	896	906
	1000:	1000	965	961	936	931	913	909
	5-10:	1000	957	951	949	939	948	938
SL	500:	1000	932	903	870	859	856	858
	1000:	1000	919	856	826	815	820	840
	5-10:	1000	924	897	875	851	851	849
SD	500:	1000	834	790	762	751	741	762
	1000:	1000	831	794	759	761	758	766
	5-10:	1000	827	781	759	744	735	745

MODEL SCORES

		+0	+1	+2	+3	+4	+5	+6
SV	500:	1000	955	950	936	932	908	901
	1000:	1000	949	947	925	916	910	907
	5-10:	1000	966	955	939	922	923	907
SL	500:	1000	961	950	931	923	894	878
	1000:	1000	933	907	880	850	831	813
	5-10:	1000	953	934	907	894	891	880
SD	500:	1000	868	841	825	802	799	795
	1000:	1000	841	822	797	781	761	752
	5-10:	1000	861	834	807	794	777	762

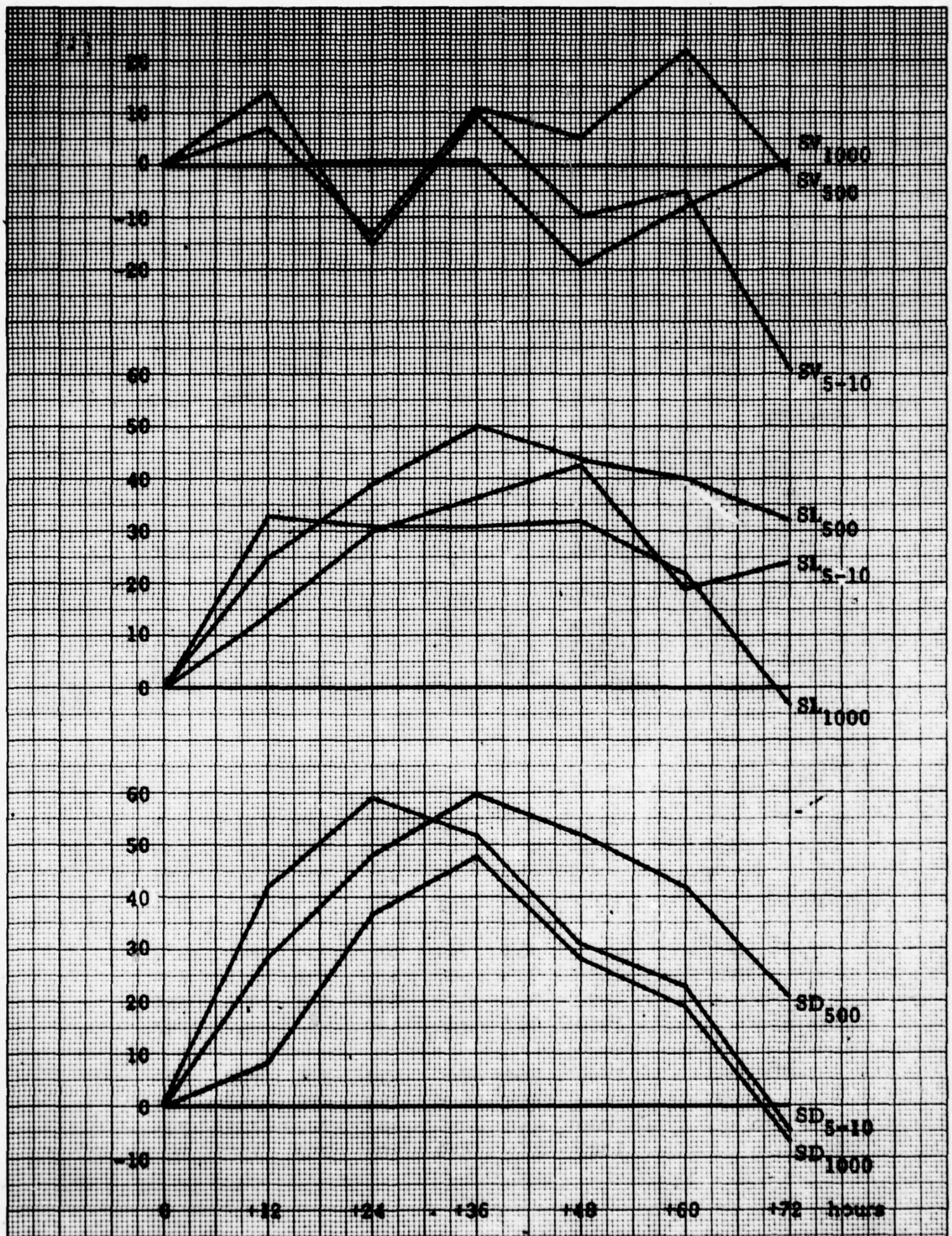
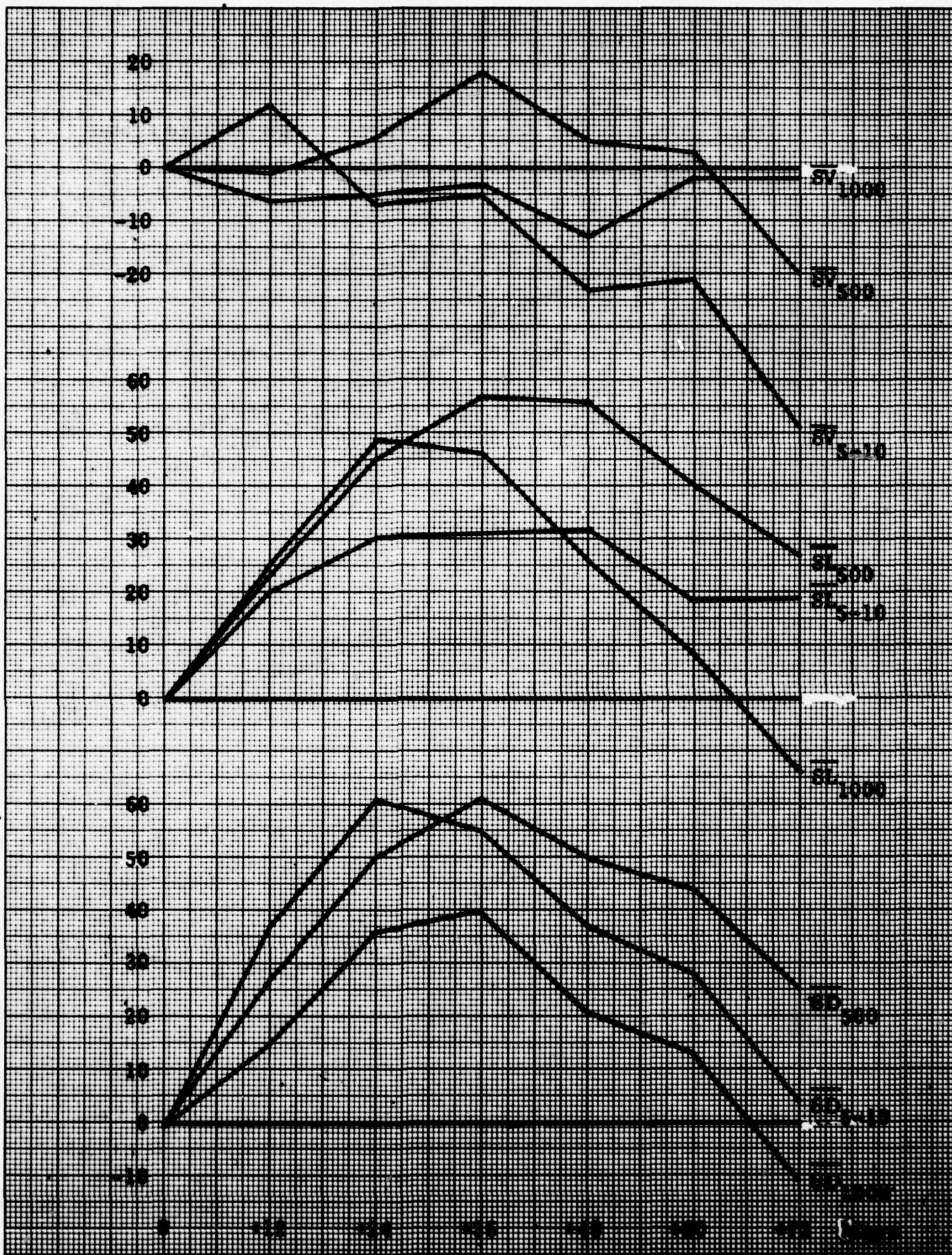


Fig. 33 Model Scores minus Persistence Scores for the 00Z13NOV78 scenario.

Table 5

Mean MOSS1 scores (see text for explanation).

		n = 0	1	2	3	4	5	6
PERSISTENCE								
$\overline{SV}$	500	1000	960	938	912	907	893	905
	1000	1000	962	952	931	928	913	911
	5-10	1000	954	955	942	938	932	930
MEAN $\overline{SV}$		1000	959	948	928	924	913	915
$\overline{SL}$	500	1000	935	896	868	855	849	851
	1000	1000	908	852	820	808	804	810
	5-10	1000	931	903	879	862	857	847
MEAN $\overline{SL}$		1000	925	884	856	842	837	836
$\overline{SD}$	500	1000	837	791	762	755	754	768
	1000	1000	830	782	758	757	749	759
	5-10	1000	819	768	747	750	749	761
MEAN $\overline{SD}$		1000	829	780	756	754	751	763
MODEL								
$\overline{SV}$	500	1000	959	944	930	912	896	885
	1000	1000	956	947	928	915	911	909
	5-10	1000	966	948	937	915	911	881
MEAN $\overline{SV}$		1000	960	946	932	914	906	892
$\overline{SL}$	500	1000	958	941	925	911	889	878
	1000	1000	933	901	866	834	812	796
	5-10	1000	951	933	910	894	875	866
MEAN $\overline{SL}$		1000	947	925	900	880	859	847
$\overline{SD}$	500	1000	864	841	823	805	798	793
	1000	1000	845	818	798	778	762	748
	5-10	1000	856	829	802	787	777	765
MEAN $\overline{SD}$		1000	855	829	808	790	779	769



20
10
0
-10
-20
SV1000
SV500
SVS-10
60
50
40
30
20
10
0
SL500
SLS-10
SL1000
60
50
40
30
20
10
0
-10
SD500
SDS-10

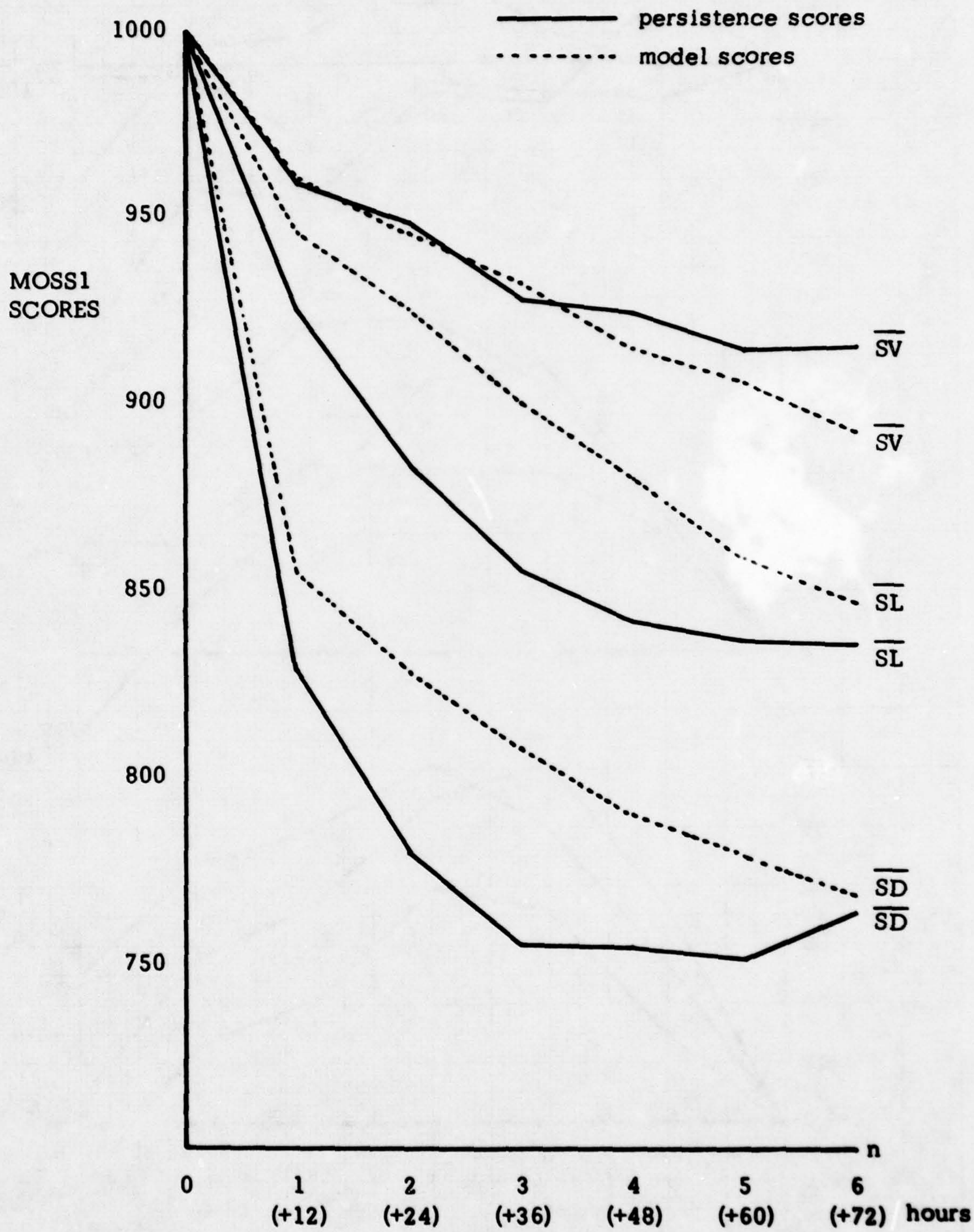


Fig. 35 Mean MOSS1 scores for the SV, SL and SD ranges-of-scale.

6.6 Discussion of MOSS1 Match Coefficients

The scores generated by MOSS1 provide an objective monotonic measure of the degree of pattern similarity between two synoptic situations expressed in terms of nine component fields. However, though monotonic, MOSS scores are not a linear measure of skill--it is more difficult to improve a score from, say, 900 to 950 than from 800 to 850. Nevertheless, if two or more appropriate patterns are each compared with a common pattern, that pattern which is most similar to the common comparison pattern will achieve the highest MOSS score. The utility of the MOSS1 system in the context of model evaluation, verification and development lies in this capability of identifying the most similar pattern in terms of an objective scoring methodology.[9]

To illustrate this capability, Figures 36 to 38 show the SL_{500} analysis for 00Z13NOV78, the 72-hour SL_{500} forecast and the verifying SL_{500} analysis at 00Z16NOV78 respectively. Using MOSS1 to score Fig. 37 against Fig. 38 produced a match coefficient of 882, and Figure 38 against Fig. 36 gave a coefficient of 850. Study of the figures--taking (subjective) account of such features as the placement and intensity of highs and lows, and gradient magnitudes and orientations--shows that Fig. 37 is more similar to Fig. 38 than is Fig. 38 to Fig. 36. In other words, for this case, the 72-hour forecast produced by the model is superior to a 72-hour forecast based on persistence and this is revealed by the MOSS1 match coefficients of 882 and 850 respectively.

(Figures 21 through 32 provide scale-separated 48-hour forecast fields together with the verifying analysis fields. The appropriate MOSS1 match coefficients are given in Table 3. Study of these figures and scores provides a subjective appreciation of the degree of pattern similarity represented by the objective MOSS1 match coefficient(s).)

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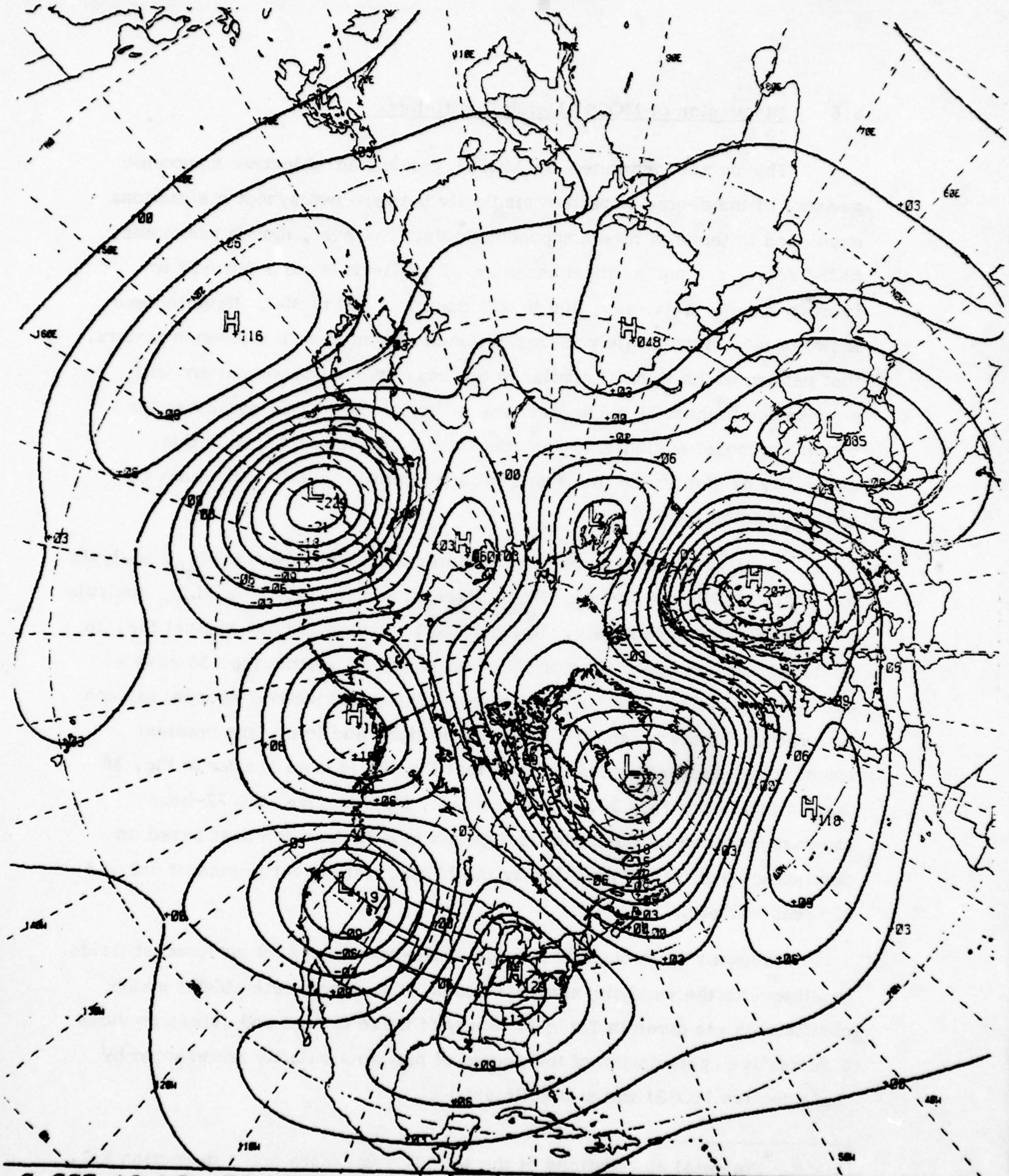
[9]Potential applications of the MOSS1 system are given in Section 5.2.



0 00Z 13 NOV 78 SL 500 0850Z 597 500HTS~ FNWC

Fig. 36

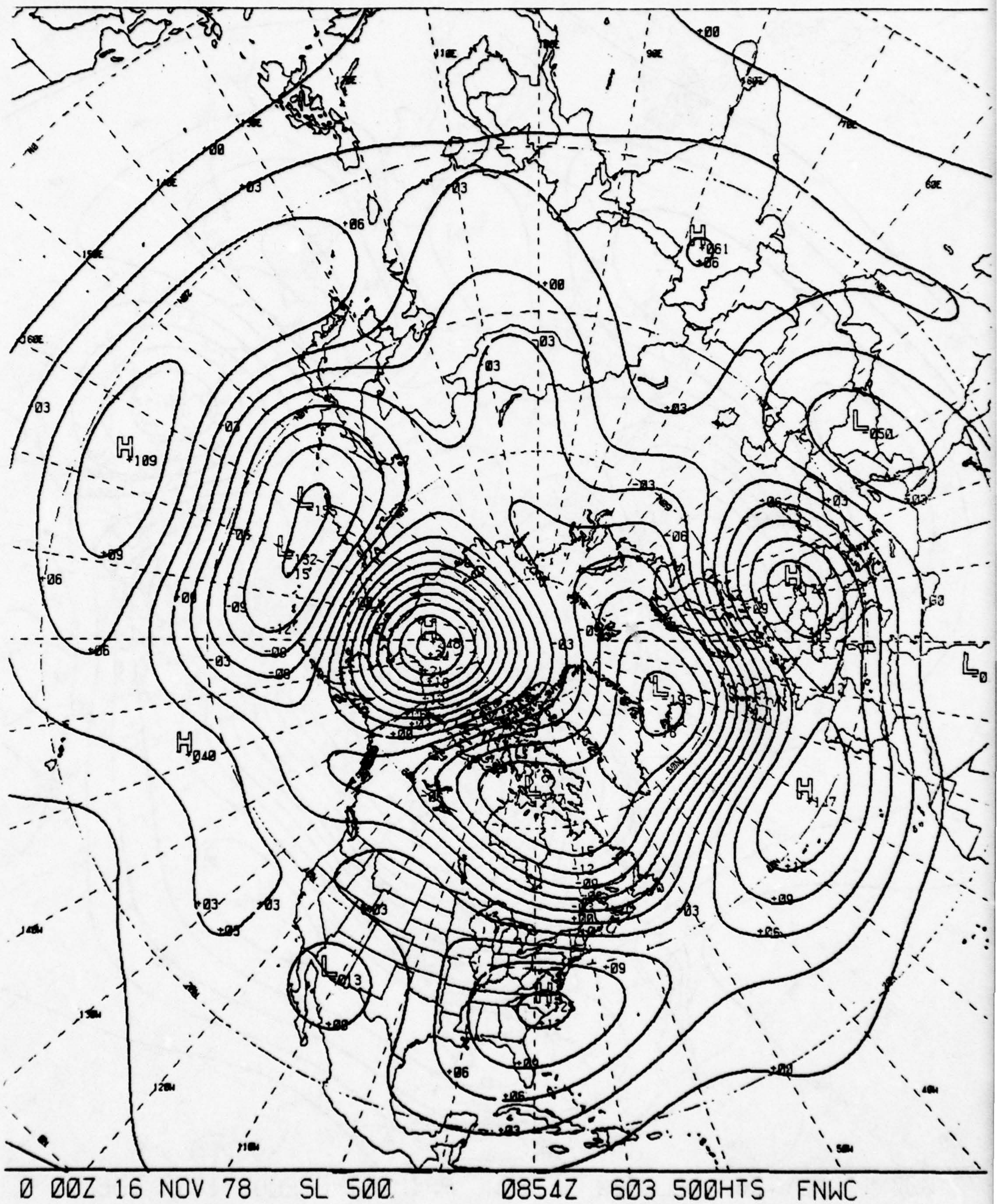
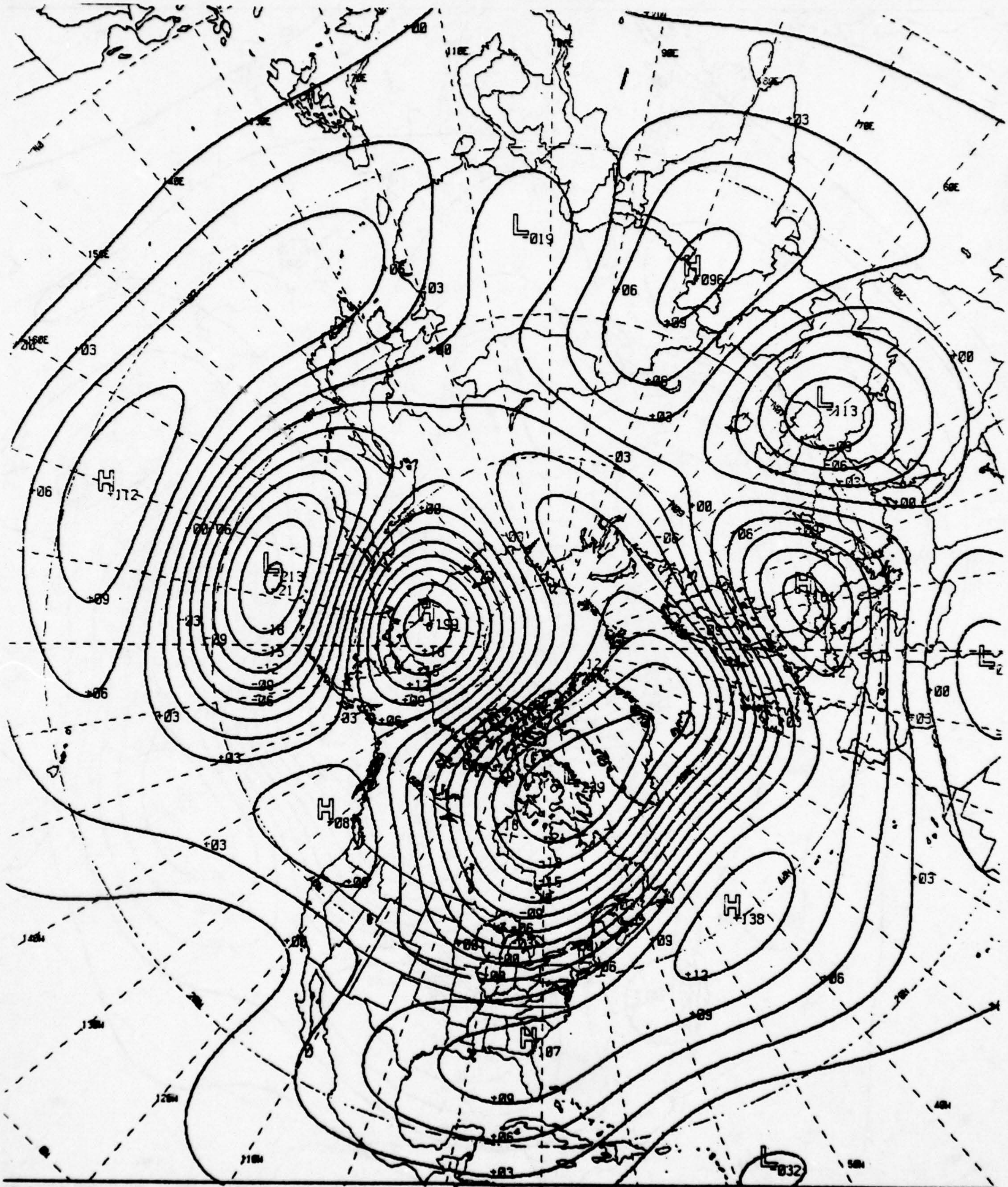


Fig. 37



72 ØØZ 13 NOV 78 SL 5ØØ FNWC PRIMITIVE EQUATION MODEL

Fig. 38

7. SYSTEM DESCRIPTION FOR MOSS2

7.1 Introduction

The basic MOSS system, MOSS1, primarily was designed to demonstrate that an objective measure of the degree of pattern similarity between two fields can indeed be obtained and utilized in the context of model development, verification and evaluation. However MOSS1, although a valuable tool in its own right, is subject to a variety of constraints. The system may be made more flexible and comprehensive thus increasing its range of application. This Section provides a System Description of a more comprehensive MOSS capability, MOSS2.

The following features and capabilities have been considered for expanding the MOSS1 system:

a. An ability to produce scores for selected geographical regions rather than a single score for a complete hemisphere. A map showing match coefficients for a large number of sub-regions covering the whole analysis/forecast area considered by MOSS would reveal areas where models F' and F" both were scoring well, and areas where one model was superior to the other.

b. An ability to weight scores from each contributing range-of-scale component (i.e., SV, SL and SD). The sum of these weighted scores will provide a measure of the overall effectiveness of, say, a forecast model in predicting a particular meteorological scenario.

c. Remove the MOSS1 constraint that input fields must be in pairs--1000 mb followed by 500 mb. For example, it might be required to match only the fields (in ranges-of-scale) for one level.

d. The ability to compare and score fields for levels other than 500 mb and 1000 mb.

e. A module to permit values of $\overline{\sigma}$ to be calculated for the 17 parameters A through Q. (This module would be needed before fields for other levels could be compared and scored--item d.)

f. A module to convert sea-level pressure fields to 1000-mb fields.

g. Addition of a module to allow alternative grid systems to be utilized.

h. Extension to provide a Southern Hemisphere capability.

i. Remove the constraint that input fields must have the standard FNWC 20-word ident. (This would facilitate evaluation of fields produced by other forecasting authorities.) An ident for specific application to MOSS should be designed and utilized.

j. Modify the system to allow applicability to fields other than hemispheric fields.

k. If a forecast model consistently moves synoptic features too rapidly or too slowly then, in effect, model time does not correspond to real time. The "Time Shift Factor" (TSF) may be estimated by comparing an analysis and forecast sequence thus:

$$F_{\tau+n\pm m} : A_{\tau+n} \; , \; n = 1 \rightarrow N$$

Design and incorporate a module to allow estimation of the TSF for each component field, and an overall TSF for a numerical model.

l. Generalize the matching module so that any appropriate pair of component fields may be compared to obtain a measure of synoptic similarity. (MOSS1 follows the matching sequence given in Section 4.4.)

m. There is a loss of variance in the time-integration process--in essence, forecast fields become progressively smoother with forecast time. The "Variance Loss Factor" (VLF) may be estimated by the following process:

$$(1 \pm \epsilon)\, F_{\tau+n} : A_{\tau+n} \qquad n = 1 \rightarrow N$$

Design and incorporate a module to allow estimation of the VLF for each component field, and an overall VLF for a numerical model.

n. Design and inclusion of appropriate statistical compilations.

o. Provide a capability for computing a measure of the analysis variability and an option to rescale scores achieved by forecast models in terms of the analysis variability.

p. An output package which provides all measures and scores needed to evaluate model performance.

q. Expanded output formats and graphics capabilities.

r. Design and incorporation of a main driver program, thus providing an automated MOSS capability.

s. Provision of an interactive terminal capability.

7.2 MOSS2 Capabilities

MOSS2 should be a reasonable expansion of MOSS1. Appropriate features to be added to MOSS1 to provide MOSS2 are seen as:

a. A capability for producing an areal distribution of match coefficients for the SV, SL and SD ranges-of-scale.

b. A capability for producing an areal distribution of match coefficients which are a User-weighted combination of the SV, SL and SD ranges-of-scale.

c. A capability for matching, in ranges-of-scale, either 1000-mb fields only or 500-mb fields only.

d. A capability for converting sea-level pressure fields to 1000-mb fields.

e. The ability to accept hemispheric fields on Mercator and lat/lon projections.

f. The ability to accept polar-stereographic hemispheric fields on a grid other than the standard 63x63 grid-point values.

g. The utilization of a field ident for specific application to MOSS.

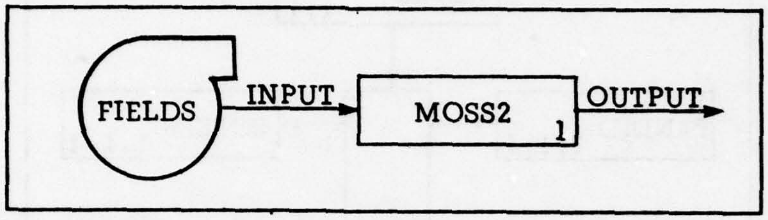
h. The estimation of time-shift factors.

i. The estimation of variance-loss factors.

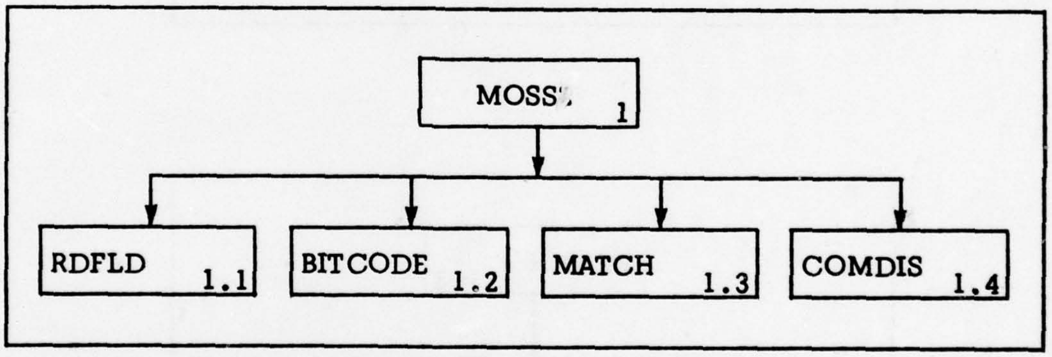
j. Extended output compilation and display capabilities.

7.3 The Modular Structure of MOSS2

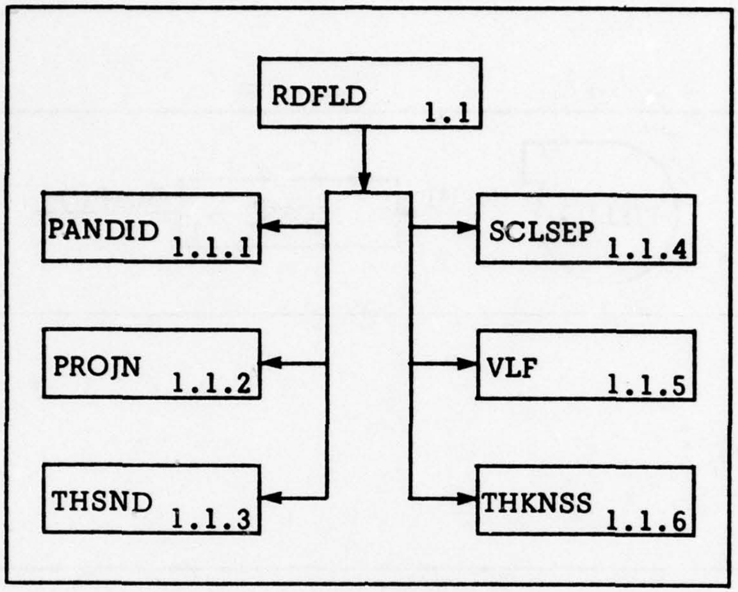
Level 1



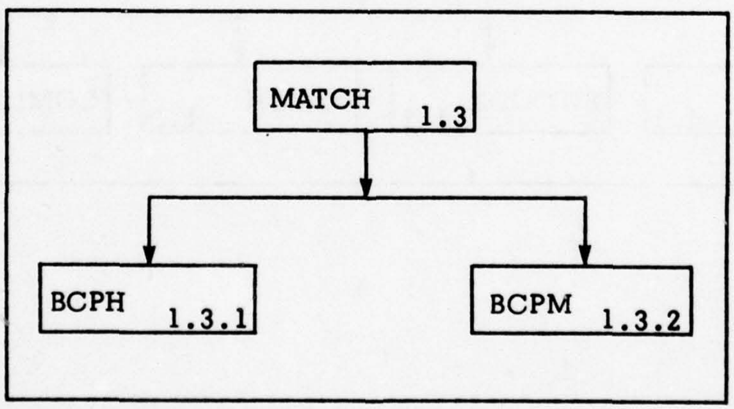
Level 2



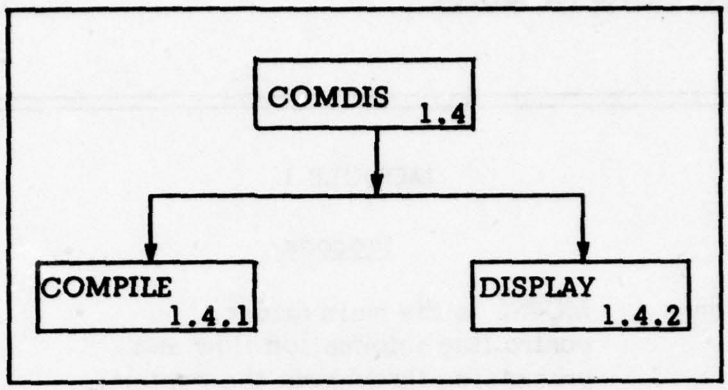
Level 3



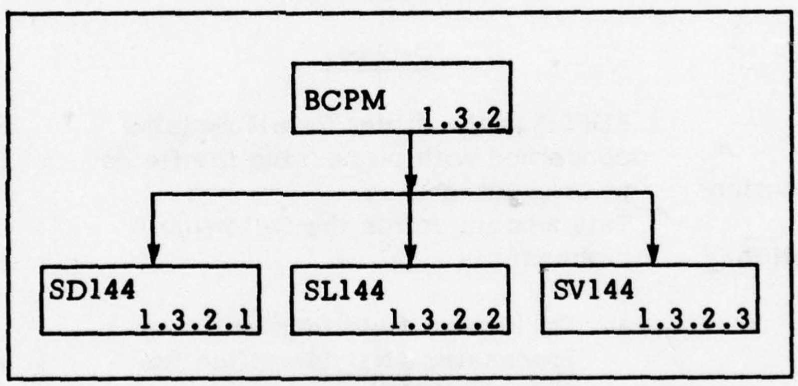
RDFLD 1.1
PANDID 1.1.1
PROJN 1.1.2
THSND 1.1.3
SCLSEP 1.1.4
VLF 1.1.5
THKNSS 1.1.6



MATCH 1.3
BCPH 1.3.1
BCPM 1.3.2


COMDIS
1.4
COMPILE
1.4.1
DISPLAY
1.4.2

Level 4


BCPM
1.3.2
SD144
1.3.2.1
SL144
1.3.2.2
SV144
1.3.2.3

7.4 HIPO Charts for MOSS2

MOSS2

MODULE 1

Input	Process	Output
Fields (from tape). User specifications and information	MOSS2 is the main driver, controlling information flow and processing throughout the system.	Measures of Synoptic Similarity

RDFLD

MODULE 1.1

Input	Process	Output
Field. User-specifications and information	RDFLD is the driver for all modules concerned with processing the fields prior to bit-coding. This module drives the following processes: a. Produces a field ident--Processing AND Identification Data (PANDID). b. Converts projection to PS, 63x63. c. Converts surface fields to 1000 mb. d. Separates a field into component ranges-of-scale. e. Computes thickness. f. Multiplies grid-point field values by $(1+\epsilon)$--the VLF.	Processed field in ranges-of-scale, with PANDID

PANDID

MODULE 1.1.1

Input	Process	Output
Field ident and User specifications	This module produces a code--PANDID--which is used to identify and control processing of the fields, and controls the User-specified matches to be made between fields. MOSS1 follows a fixed information-processing sequence; the PANDID code will provide MOSS2 with considerable flexibility.	PANDID

PROJN

MODULE 1.1.2

Input	Process	Output
Field (hemispheric)	RDFLD determines if a field is in a 63x63 PS format. If not, RDFLD calls PROJN which carries out the necessary conversion. For Task 2 acceptable projections will be Mercator, lat/lon and PS. PROJN incorporates a ZOOM capability for converting, for example, 89x89 PS to 63x63 PS.	Field, hemispheric, 63x63 PS

THSND

MODULE 1.1.3

Input	Process	Output
Surface field, 63x63 PS	Converts a surface field to a 1000-mb field.	1000-mb field

SCLSEP

MODULE 1.1.4

Input	Process	Output
1000-mb or 500-mb field	Pattern separates input field into 3 range-of-scale components. Computes SV anomaly field.	SV, SV anomaly, SL, SD

			VLF
	MODULE 1.1.5		
Input	**Process**	**Output**	
Component range-of-scale field	Multiplies each grid point value by $(1+\epsilon)$.	Component range-of-scale field with increased variance	

			THKNSS
	MODULE 1.1.6		
Input	**Process**	**Output**	
Pair of 1000-mb and 500-mb fields	Computes 500-1000-mb thickness for each range-of-scale, expressing SV in terms of the SV anomaly.	500-1000-mb thickness of SV anomaly and SL and SD fields.	

			BITCODE
	MODULE 1.2		
Input	**Process**	**Output**	
Component range-of-scale field	Bit codes the field and assembles the associated bit string.	Bit string	

			MATCH
	MODULE 1.3		
Input	**Process**	**Output**	
Two bit strings	Driver for bit code matching. If a hemispheric score is required (such as produced by MOSS1) this module calls BCPH--Bit Count Per Hemisphere. For producing an areal distribution of match coefficients module BCPM--Bit Count Per Module--is called.	Match coefficient(s)	

			BCPH
	MODULE 1.3.1		
Input	**Process**	**Output**	
Two bit strings	Compares two bit strings, each representing all modules appropriate to the range-of-scale, and computes an overall match coefficient.	Match coefficient	

			BCPM
	MODULE 1.3.2		
Input	**Process**	**Output**	
Two bit strings	Carries out bit matching and counts matching bits, module by module. Thus 144 scores would be produced for each component SD field, 36 for an SL field and 16 for an SV field. These counts provide input to modules SD144, SL144 and SV144 as appropriate.	Matching bit counts for each module	

			SD144
	MODULE 1.3.2.1		
Input	**Process**	**Output**	
Modular bit counts for SD fields	This module accumulates the results of matching SD fields. As each component-pair of SD fields are matched, module by module by BCPM, the results are stored in a 12x12 array which is map oriented using the array subscripts as map coordinates. Thus, on completion of matching a pair of component SD fields, the array provides an areal distribution of SD matching bit counts. Three 12x12 arrays are provided, one for each level (1000 mb, 500 mb and 1000-500-mb thickness).	Areal distribution of matching bit counts for pairs of SD fields	

			SL144
	MODULE 1.3.2.2		
Input	**Process**	**Output**	
Modular bit counts for SL fields	Similar in concept to module 1.3.2.1 but accumulates the results from matching SL fields. For any pair of SL fields the matching bit counts are again entered into map-oriented 12x12 arrays, a given count being entered into the appropriate 4 positions in the array. (An SL module covers 4 SD modules--see Section 3.3.)	Areal distribution of matching bit counts for pairs of SL fields	

			SV144
	MODULE 1.3.2.3		
Input	**Process**	**Output**	
Modular bit counts for SV fields	Similar in concept to modules 1.3.2.1 and 1.3.2.2. For any pair of SV fields the matching bit counts are again entered into map-oriented 12x12 arrays, a given count being entered into the 9 appropriate positions in the array.	Areal distribution of matching bit counts for pairs of SV fields	

			COMDIS
	MODULE 1.4		
Input	**Process**	**Output**	
Compilation and display information and data	This module derives the compilation and display of results.	Measures of Synoptic Similarity	

MODULE 1.4.1		COMPILE
Input	**Process**	**Output**
Match coefficients or modular bit counts	This module compiles the results of bit matching. If a hemispheric match coefficient has been computed (BCPH) the component range-of-scale scores may be weighted and summed to provide a single overall measure of synoptic similarity. If BCPM has been activated, the required scores are selected and processed. All results, after selection, compilation and processing, are formatted in accordance with display requirements.	Measures of Synoptic Similarity

MODULE 1.4.2		DISPLAY
Input	**Process**	**Output**
Measures of Synoptic Similarity	Drives display device(s) to output results.	Display of results

7.5 . Outline of System Operation

A field is read in (1.1)[10]--e.g., a sea-level pressure analysis for time τ. Based on User-entered specifications a field ident is derived which determines subsequent processing (1.1.1). If necessary the projection is converted to PS, 63x63 (1.1.2), and the field to 1000 mb (1.1.3). The field is separated into 3 component ranges-of-scale (1.1.4). (MOSS2 will be able to accept fields which have already been pattern separated; the relevant modules will automatically be by-passed). If required each of these 3 fields may be multiplied by VLF (1.1.5). The fields are then bit coded (see below). If scores for thickness fields are required the next field read in must be the 500-mb field. The 500-mb field is subjected to similar processing (apart from module 1.1.3) and the component ranges-of-scale bit coded. The thickness fields are treated similarly, thus providing 9 bit strings in a manner similar to MOSS1 operation.

However it may be required to compare, say, two series of 500-mb fields without entering the corresponding 1000-mb fields. MOSS2 will have this flexibility.

As the processing of each field is completed it is bit coded and the bit string assembled. Note that for MOSS1 each bit string represents 9 component fields and uses 589 words. In MOSS2 the 589-word bit string may represent a minimum of 1 field (e.g., SL500) to a maximum of 9.

The process is repeated until all fields, in component ranges-of-scale, have been bit coded and stored. The maximum number of fields to be stored in bit-coded format will be

$$\begin{matrix} A(10) \\ F(10) \end{matrix} \times \begin{matrix} SD \\ SL \\ SV \end{matrix} \times \begin{matrix} 500 \\ 1000 \\ 5\text{-}10 \end{matrix} = 180$$

[10]Numbers in parentheses indicate the module number.

A pair of bit strings is selected for matching (1.3). Any pair (from the maximum of 180) may be chosen--e.g., $A_{\tau} : A_{\tau+6}$, $A_{\tau} : F_{\tau}$, $A_{\tau+5} : F_{\tau+6}$, etc. If a total score over the whole field is required module BCPH (1.3.1) is utilized; this corresponds to the MOSS1 system. However if an areal distribution of coefficients is required module BCPM (1.3.2) is utilized which makes a count of the number of matching bits per module. (For each field (SV, SL, SD) the maximum number of matching bits possible is 60.) These counts are entered into map-oriented 12x12 arrays (1.3.2.1, 1.3.2.2, 1.3.2.3). Note that for SL fields a common count is entered into 4 array locations and for SV fields a common count is entered into 9 array locations. In general, if all 9 component range-of-scale fields are being used to represent a given synoptic situation, then matching any pair of bit strings will result in the filling of 9 12x12 arrays.

The results of bit-string matching are provided as input to module 1.4 and the next pair of bit strings for matching is selected.

Module 1.4 compiles the results of bit matching (1.4.1), including the production of an areal distribution of match coefficients which are a weighted combination of the SV, SL and SD ranges-of-scale.

The results are then output (1.4.2).

REFERENCES

[1] Somerville, Richard C. J.; "Pattern Recognition Techniques for Forecast Verification", Beiträge zur Physik der Atmosphäre, 50. Band, Seite 403-410, 1977.

[2] Holl, M. M.; "Scale-and-Pattern Spectra and Decompositions", Technical Memorandum No. 3, Contract N228-(62271)60550, Meteorology International Incorporated, Monterey, California, 28 pp., 1963.

[3] Caton, Francis G., Manfred M. Holl and Michael J. Cuming; "Technical Description of the Rapid Analogue Selection System including Regionalized Capabilities applied to the Mediterranean Sea", Final Report, Contract No. N00228-76-C-3189, Meteorology International Incorporated, Monterey, California, 164 pp., 1977.