

Environment Canada Imaging Cover Page

Report N.:



* T E C - 5 5 1 *

SKP Box Number: 672572427



DEPARTMENT OF TRANSPORT
METEOROLOGICAL BRANCH

ESTIMATES OF 1000MB-HEIGHT AND TEMPERATURE CHANGES FROM SURFACE SYNOPTIC DATA

BY

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U.D.C. 551.509.313
551.509.323.7

CIR. 4173
TEC. 551
JAN. 21, 1964

CANADA - DEPARTMENT OF TRANSPORT - METEOROLOGICAL BRANCH
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ABSTRACT

Several formulas for calculating 1000-mb height and temperature from regular synoptic reports of surface temperature and sea-level pressure are evaluated. The results indicate that a version of the hypsometric formula can be used to calculate a 1000-mb height comparable to the reported value, while application of an appropriate lapse rate to the observed surface temperature seems to be an acceptable method of estimating the corresponding 1000-mb temperature. A possible application of these results in an objective analysis scheme is discussed briefly.

ESTIMATION DE LA HAUTEUR ET DE LA TEMPÉRATURE A 1,000 MB
A L'AIDE DE DONNÉES SYNOPTIQUES DE SURFACE

par

H. B. Kruger
et
C. Marullo

RÉSUMÉ

Les auteurs évaluent plusieurs formules servant au calcul de la hauteur et de la température a 1,000 mb à partir de messages synoptiques réguliers de température de surface et de pression au niveau de la mer. Les résultats indiquent qu'une version de la formule hypsométrique peut servir à calculer, pour 1,000 mb, une hauteur comparable à la valeur signalée, alors que l'application d'un gradient vertical approprié à la température de surface observée semble être une méthode acceptable pour évaluer la température correspondante au niveau de 1,000 mb. Les auteurs commentent brièvement une application possible de ces résultats dans un schéma d'analyse objective.

ESTIMATES OF 1000-MB HEIGHT AND TEMPERATURE FROM SURFACE SYNOPTIC DATA

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1. INTRODUCTION

The generally accepted method of preparing a subjective analysis of 1000-mb heights involves two steps. First, a preliminary 1000-mb chart is prepared graphically from a surface analysis by referring to a table giving the approximate relationship of sea-level pressure and surface temperature to 1000-mb height. The tabulated values are calculated from an integrated form of the hydrostatic equation. The second step consists of making corrections to the preliminary chart so that the contours fit the reported 1000-mb heights.

Since sea-level pressure analyses are not produced by the objective analysis scheme currently in use at the Central Analysis Office (CAO), the method as described cannot be automated; however, use of the practical principle that the more numerous surface synoptic reports can be used to supplement regular 1000-mb data should be quite feasible in a computer technique. Several ways of applying this principle were investigated, and this report summarizes the results that were obtained. All computations were programmed for the Control Data G-20 computer at the CAO.

2. CALCULATION OF 1000-MB HEIGHTS

Three formulas for calculating 1000-mb heights were tested. The first is the linear equation

$$2.1. \quad Z_{10} = 8.2937(P_M - 1000),$$

where

Z_{10} = height, in meters, of the 1000-mb level above mean sea-level;

P_M = reported sea-level pressure in millibars.

This formula is in use at the National Meteorological Center of the U. S. Weather Bureau (1). It is obtainable from the hypsometric formula if the mean virtual temperature for the stratum between sea-level and 1000-mb is assumed to be 10°C.

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The second is the regression equation

$$2.2. \quad Z_{10} = Z_s + T_s (P_s - 1000) \quad [.049 - .00002(P_s - 15)]$$

where

Z_s = height, in meters, of the station above mean sea-level;

T_s = surface temperature, °K;

P_s = station pressure in millibars.

This equation is used by the Climatological Division of the Meteorological Service of Canada to check 1000-mb height calculations. Since station pressure is not available from regular synoptic reports, it was approximated from the following form of the hypsometric formula:

$$2.3. \quad P_s = P_M \exp \left(- \frac{g}{R \bar{T}_{s-M}} Z_s \right),$$

where

\bar{T}_{s-M} = mean virtual temperature for the stratum between the station and sea level, °K;

g = acceleration due to gravity (980 cm/sec^2);

R = gas constant for dry air ($2.87 \times 10^6 \text{ erg/gram} \text{ } ^\circ\text{K}$).

Assuming that the virtual temperature is identical with the ambient temperature, it is approximately true that

$$2.4. \quad T_{s-M} = T_s + \frac{\gamma_{s-M}}{2} Z_s$$

where γ_{s-M} = assumed mean temperature lapse rate in the stratum between the station and sea-level.

For the purposes of testing equation (2.2.), γ_{s-M} was assigned a value of half the dry adiabatic lapse rate ($0.49 \text{ } ^\circ\text{C}/100 \text{ meters}$), following Godson (2).

The third equation is obtained from the following form of the hypsometric formula:

$$2.5. \quad Z_{10} = Z_s + \frac{R \bar{T}_{s-10}}{g} \ln \left(\frac{P_s}{1000} \right),$$

where

\bar{T}_{s-10} = the mean (virtual) temperature of the stratum between the station and the 1000-mb level, °K.

Substitution of equation (2.3.) into (2.5.) gives

$$2.6. \quad Z_{10} = Z_s \left(1 - \frac{\bar{T}_{s-10}}{\bar{T}_{s-M}}\right) + T_{s-10} \frac{R}{g} \ln\left(\frac{P_M}{1000}\right),$$

which is the equation tested. A value for \bar{T}_{s-M} may be estimated from equation (2.4.), and a value for \bar{T}_{s-10} from:

$$2.7. \quad \bar{T}_{s-10} = T_s + \frac{\gamma_{s-10}}{2} (Z_s - Z_{10}),$$

where

γ_{s-10} = mean temperature lapse rate in the stratum between the station and the 1000-mb level;

Z_{10} = a reasonable estimate of the 1000-mb height.

For the purposes of testing equation (2.6.), it was assumed that

$\gamma_{s-10} = \gamma_{s-M} = 0.49^\circ\text{C}/100\text{m}$, and that

$$Z_{10} = \frac{RT_s}{g} \ln\left(\frac{P_M}{1000}\right).$$

The form of the integrated hydrostatic equation represented by equation (2.6.) was used (rather than the somewhat simpler form which results when the assumption is made that virtual temperature is a linear function of height) because it is anticipated that reasonably accurate values of γ_{s-10} and Z_{10} will be available under operational conditions.

3. CALCULATION OF 1000-MB TEMPERATURE

In estimating a 1000-mb temperature from the surface temperature, there is no obvious alternative to applying a reasonable lapse rate to the surface value; that is:

$$3.1. \quad T_{10} = T_s + \gamma_{s-10} (Z_s - Z_{10}).$$

To test this equation, two values for the mean lapse rate in the stratum between the surface and the 1000-mb level were used:

$$3.2. \quad \gamma_{s-10} = 0.49^\circ\text{C}/100\text{m},$$

and

$$3.3. \quad \gamma_{s-10} = 0$$

4. DATA

Data used to test the formulas were the 1200Z observations for two days, January 3, 1963 and July 3, 1963, from one hundred and twenty North American, Caribbean and Pacific stations as shown in Figure 1. The relevant data were abstracted from published tabulations (3), (4), (5), and transferred to punched cards. Stations elevations, when not given with the data, were obtained from a World Meteorological Organization document (6). There were two stations for which no 1000-mb data were available on January 3. In these cases the 1200Z data for January 2 were substituted. In both sets of data, there were several stations for which there was no record of the surface report. In these cases, the required values were estimated from the relevant surface analyses.

5. CALCULATIONS

The data area was divided into six latitudinal zones in such a way that there were twenty stations per zone (see figure 1). For each station, calculated 1000-mb heights were obtained by solving equations (2.1.), (2.2.) and (2.6.), and in each case where a 1000-mb temperature report was available for comparison, calculated values of 1000-mb temperatures were obtained from equations (3.1.), (3.2.) and (3.3.). The arithmetic means, root mean squares, and standard deviations of the departures from reported values were calculated for each of the zones and for all stations collectively for both the January and July sets of data. The results are presented in tables 1 and 2.

6. DISCUSSION OF RESULTS

In this kind of study, the possible sources of error should be kept in mind when drawing conclusions from the results. The assumptions inherent in the various equations tested are not necessarily valid in any particular situation, nor are the assumptions with regard to lapse rate and stratum mean virtual temperature used in the calculations. In the reports themselves, errors may arise during the observation, transmission and abstraction of the data, and the coarseness of the reporting units lead to uncertainties in checking the results. For example, since station pressures are recorded only to the nearest whole millibar, accurate comparisons with calculated values cannot be made. The assumptions made with respect to mean stratum temperature in 1000-mb height reports in cases where the 1000-mb level is below station level, and in sea-level pressure reports in cases where the station is not at mean sea level, are not only of indeterminable accuracy but also inconsistent with each other. According to MANUPP (7), whenever the station pressure is less than 1000 mb, the following formula is used to calculate the mean virtual temperature of the stratum between the station and the 1000-mb level:

$$T_{mv} = \frac{1}{3} (T_{-6} + 2T_0) + C,$$

where

T_0 = surface temperature at balloon release time;

T_{-6} = surface temperature six hours previous to release;

C = special factor depending on the station pressure and the value of $\frac{1}{3} (T_{-6} + 2T_0)$;

On the other hand, MANOBS (8) states that the sea-level correction is computed using the mean of the present temperature and (usually) the temperature recorded twelve hours earlier. The reduction value required is obtained from a table supplied to the station. It is computed from the established elevation of the station and the seasonal characteristics of humidity and temperature of the region.

Any difference between a station pressure calculated from equation (2.3.) and the actual value may be attributed to a difference between the mean virtual temperature of the stratum as given by equation (2.4.), and that implied by the sea-level reduction procedure followed in observing practice. Similarly, any difference between a calculated 1000-mb height and the reported value may be attributed to a difference between the mean virtual temperature of the stratum between the station and the 1000-mb level implied in the calculation, and that implied by the procedures used in computing the reported height value. In the sample selected for this study, the greatest values of the departure (Z calculated - Z reported) occurred with stations well above mean sea-level. In fact, the largest contributions to the departure statistics of table 1 for zones 4 and 5 in January come from high altitude stations.

Table 3 gives the results of some calculations for all stations having a departure of more than 15 meters in either the January or July data sample, where equation (2.6.) has been used to obtain the calculated 1000-mb height value. Even when allowances are made for the lack of precision to which actual station pressures are available, it is evident that the cause of the departure, in most cases, can be attributed to the mean temperature of the stratum between the station and mean sea-level as implied by the reported mean sea-level pressure.

In spite of this inconsistency in the data, the largest departure recorded with equations (2.2.) and (2.6.) was -63 meters. Since most of the large departures noted in this study were confined to high altitude stations, surface synoptic reports obviously can give useful supplementary data over oceans and most land areas with an accuracy comparable to that of reported values.

An examination of Table 1 shows that equation (2.1.) gives inferior results as would be expected from the far-reaching assumption involved. Equations (2.2.) and (2.6.) give comparable results; however, it was felt that equation (2.6.) would have greater application in an objective analysis scheme since more actual data could be fed into it.

7. APPLICATION TO AN OBJECTIVE ANALYSIS SCHEME

A program for the automatic processing of surface synoptic reports is under development at the CAO. From what has been accomplished on it so far, it is quite evident that surface data processing cannot be entirely divorced from objective analysis because of the apparent impossibility of unambiguously decoding surface temperature without reference to a trial temperature field.

In the objective analysis scheme (9) in operational use at the CAO, the analysis cycle begins at the 500-mb level, using a 12-hour numerical prognosis to form the trial field. Next, the 300-mb height analysis is performed, the trial field being derived from the 500-mb analysis. The analysis of heights and temperatures then proceeds stepwise downwards to the 1000-mb level, the trial field for each analysis being obtained from preceding analyses. In the case of 1000-mb height reports, the trial field for the analysis is obtained from a regression equation involving 850-mb height and temperature analyses.

The analysis scheme could be carried to this point before the final processing of surface synoptic reports need take place. The processing requirement is for a trial temperature field against which the two possible decoded values can be checked and the correct one selected. A 1000-mb temperature field derived either from the 850-mb to 1000-mb thickness and the 850-mb temperature by means of a regression equation or from persistence should be adequate for this purpose. Upon completion of the surface data processing and the initial 1000-mb height analysis, the estimation of 1000-mb height and temperature information from surface reports could begin.

It is assumed that equation (2.6.) would be used to calculate 1000-mb height values from surface reports. Note that since trial 1000-mb height values could be obtained from the earlier analysis of 1000-mb height reports it would be possible to make the necessary calculations of \bar{T}_{s-10} . The earlier analysis could also be used as the trial field in the subsequent analysis of calculated and reported 1000-mb heights.

A procedure to obtain 1000-mb analyses adjusted to surface reports might consist of the following series of steps:

- (a) Compute and store the average lapse rate from the surface to the 1000-mb level, γ_{s-10} , for each station reporting both surface and 1000-mb temperatures.
- (b) Analyse these values of γ_{s-10} , using an appropriate trial field. This might be a level field consisting, for example, of the mean of the computed values γ_{s-10} , or of half the dry adiabatic lapse rate. It might also be possible to form the trial field by allowing a subjective specification of areas in which "reported" values of γ_{s-10} are to be averaged with the mean value being assigned to each grid point in that area. These areas would presumably be specified on the basis of geography and a recent subjective analysis of surface fronts and weather. Areas in which no relevant data are received could be assigned a value either automatically or subjectively.

- (c) Calculate a 1000-mb height value for each report of sea-level pressure and surface temperature not associated with a 1000-mb height report by using equation (2.6.). Values of γ_{s-10} and Z_{10} are to be obtained from the available analyses. Assign to γ_{s-M} the same value used for γ_{s-10} .
- (d) Analyse the calculated and reported values of 1000-mb height using the earlier 1000-mb analysis as the trial field.
- (e) Calculate a 1000-mb temperature for each report of surface temperature not associated with a 1000-mb temperature report by using equation (3.1.). γ_{s-10} is to be obtained from the analyzed field.
- (f) Obtain a trial 1000-mb temperature field by using a regression equation involving the 850 to 1000-mb thickness and 850-mb temperature; then analyse the calculated and reported 1000-mb temperatures.

8.

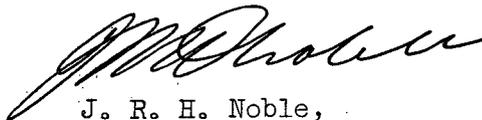
CONCLUSION

Abstraction of data for the purposes of study would have been facilitated if a surface report were included for every upper-air sounding in the data tabulations. The Arctic Summary (5) is excellent in this respect, while the Monthly Bulletin (4) contains no surface reports. The USWB publication (3) is erratic in that surface reports for some of the upper-air stations are not listed. It would also have been helpful for checking purposes if station pressures were available to the nearest tenth of a millibar rather than to the nearest whole millibar.

When the 1000-mb heights calculated from sea-level pressures and surface temperatures are compared to reported values of 1000-mb height, it becomes clear that the discrepancies noted could to a large extent be attributed to the inconsistency in the stratum mean temperatures used in the sea-level reduction procedure and the 1000-mb height report computation. The discrepancies are, however, not significant enough to cancel the usefulness of surface data in the objective construction of 1000-mb charts.

It would, nevertheless, be advantageous if observing practice could be modified to make the sea-level reduction procedure more consistent with radiosonde reporting practices, or, failing that, to make station pressure routinely available in synoptic surface reports.

APPROVED,



J. R. H. Noble,
Director.

9.

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TABLE 1. SUMMARY OF STATISTICS FOR 1000-mb HEIGHT DEPARTURES

$$\left[Z_{\text{calculated}} - Z_{\text{reported}} \right]$$

METERS

ZONE EQUATION		JANUARY 3, 1963							JULY 3, 1963						
		1	2	3	4	5	6	All zones	1	2	3	4	5	6	All zones
1 Arithmetic mean	2.1	25.6	7.1	3.0	- 9.2	- 6.2	- 4.1	2.7	4.2	4.0	1.4	1.6	- 1.6	- 7.0	0.4
	2.2	- 2.7	- 3.4	- 2.6	-17.0	-11.0	- 1.3	- 6.3	1.7	3.7	1.5	4.5	3.0	- 0.8	2.3
	2.6	- 2.6	- 3.4	- 2.7	-17.2	-10.9	- 1.2	- 6.3	1.6	3.6	1.4	4.5	3.2	- 0.6	2.3
2 RMS difference	2.1	28.3	13.2	9.7	25.2	18.3	7.0	18.6	7.6	7.1	7.3	13.1	7.3	8.7	8.8
	2.2	3.9	9.8	9.5	28.7	19.9	5.8	15.6	6.1	7.5	7.8	13.9	7.4	5.6	8.5
	2.6	3.8	9.8	9.6	28.7	19.3	5.7	15.4	6.2	7.5	8.1	14.8	7.7	5.6	8.8
3 Standard deviation	2.1	12.0	11.1	9.2	23.4	17.3	5.6	18.4	6.4	5.9	7.2	13.0	7.2	5.2	8.8
	2.2	2.8	9.2	9.1	23.1	16.5	5.6	14.2	5.9	6.5	7.7	13.2	6.7	5.5	8.2
	2.6	2.8	9.1	9.2	22.9	16.0	5.6	14.1	6.0	6.6	7.9	14.2	7.0	5.5	8.5

TABLE 2. SUMMARY OF STATISTICS FOR 1000-mb. TEMPERATURE DEPARTURES

$[T_{\text{calculated}} - T_{\text{reported}}]$ °C

EQUATION 3.1 + ZONE		JANUARY 3, 1963							JULY 3, 1963							
		1	2	3	4	5	6	All Zones	1	2	3	4	5	6	All Zones	
1	Arithmetic Mean	3.2	-2.3	-0.3	0.1	-0.2	-2.7	-0.4	-1.2	0.1	0.5	-1.4	-0.3	-0.5	0.7	0.1
		3.3	3.0	0.8	0.2	0.7	3.2	1.0	1.7	0.2	-0.1	1.9	0.6	1.1	0.0	0.4
2	RMS Difference	3.2	3.7	1.5	0.3	1.0	3.9	1.8	2.6	0.7	0.9	2.2	0.7	1.7	1.4	1.3
		3.3	4.2	1.8	0.4	1.2	4.3	2.0	3.0	0.6	0.7	2.5	0.9	1.9	1.2	1.3
3	Standard Deviation	3.2	2.9	1.5	0.2	0.9	2.7	1.8	2.4	0.7	0.8	1.7	0.6	1.6	1.2	1.3
		3.3	2.9	1.6	0.3	1.0	2.9	1.8	2.5	0.6	0.6	1.6	0.7	1.6	1.2	1.2

TABLE 3. STATIONS WITH DEPARTURES

Z_{calculated} - Z_{reported}

eq. 2.6

EXCEEDING 15 METERS.

STATION ZONE	ELEVATION (METERS)	DATE	DEPARTURE, EQN. 2.6 (METERS)	SFC TEMP °C	STATION PRESSURE (MB)		T _{s-M} , °C EQN. 2.3 given P _s , P _M	T _{s-M} , °C EQN. 2.4	T _{s-10} , °C EQN. 2.5 given P _s , Z ₁₀	COMMENTS
					OBSERVED	CALCULATED EQN. 2.3				
72964 2	700	JAN	-28.5	-28.3	917	914.1	-17.1	-26.6	-27.7	Sea-level pressure for this station was interpolated from an analysis.
		JUL	-18.2	11.1	931	932.4	9.0	12.8	16.7	
72945 2	379	JAN	-20.4	-31.7	965	962.3	-16.0	-30.7	-29.8	
		JUL	11.2	15.0	964	964.3	14.8	15.9	24.8	
72967 2	273	JAN	-15.6	-27.2	992	989.4	-7.3	-26.6	-9.7	
		JUL	3.9	12.8	985	985.6	9.7	13.4	13.7	
72768 3	696	JAN	-23.2	-7.8	931	927.0	8.7	-6.1	0.0	
		JUL	9.6	14.4	932	932.5	15.4	16.1	19.7	
72637 3	234	JAN	-16.9	-2.8	993	991.0	19.3	-2.2	-1.1	
		JUL	-3.0	10.6	991	990.8	14.6	11.1	10.1	
72572 4	1288	JAN	-60.0	-10.0	873	866.1	7.8	-6.8	-5.4	
		JUL	23.1	20.6	869	870.4	21.8	23.7	27.1	
72681 4	868	JAN	-25.0	1.1	917	913.7	14.0	3.2	5.8	
		JUL	13.6	16.7	911	911.1	19.7	18.8	24.6	

(Cont'd)

TABLE 3. STATIONS WITH DEPARTURES

 $Z_{\text{calculated}} - Z_{\text{reported}}$

eqn. 2.6

EXCEEDING 15 METERS.

STATION + ZONE	ELEVATION (METERS)	DATE	DEPARTURE, EQN. 2.6 (METERS)	SFC TEMP °C	STATION PRESSURE (MB)		T_{s-M} , °C EQN. 2.3 given P_s, P_M	T_{s-M} , °C EQN. 2.4	T_{s-10} , °C EQN. 2.5 given P_s, Z_{10}	COMMENTS
					OBSERVED	CALCULATED EQN. 2.3				
72562 4	848	JAN	-28.9	- 7.2	919	915.7	5.3	- 5.1	- 4.4	
		JUL	11.2	20.0	918	918.8	20.6	22.1	24.5	
72469 4	1611	JAN	-58.5	- 5.6	837	831.0	9.6	- 1.6	- 0.9	
		JUL	11.2	15.0	840	839.0	22.0	18.9	24.1	
72486 4	1908	JAN	-63.2	- 5.6	807	800.9	9.2	- 0.9	- 0.4	
		JUL	-33.0	5.6	809	803.3	20.5	10.2	15.5	
72476 4	1474	JAN	-59.4	- 9.4	854	849.0	3.9	- 5.8	- 7.9	
		JUL	43.8	25.0	852	855.5	22.5	28.6	31.2	
72365 5	1619	JAN	-31.6	0.0	837	833.9	10.5	4.0	4.7	
		JUL	21.8	19.4	842	842.5	23.7	23.4	27.8	
72270 5	1193	JAN	-40.8	6.7	882	878.0	20.1	9.6	29.9	
		JUL	0.1	21.7	884	883.6	26.7	24.6	26.7	
72265 5	874	JAN	-44.4	1.7	918	913.1	19.6	3.8	4.6	
		JUL	1.4	20.6	919	918.9	24.2	22.7	24.7	

(Cont'd)

TABLE 3. STATIONS WITH DEPARTURES

 Z calculated - Z reported

EQN. 2.6.

EXCEEDING 15 METERS

STATION + ZONE	ELEVATION (METERS)	DATE	DEPARTURE, EQN. 2.6 (METERS)	SFC TEMP °C	STATION PRESSURE (MB)		T_{s-M} , °C EQN. 2.3, given P_s , P_M	T_{s-M} , °C EQN. 2.4,	T_{s-10} , °C EQN. 2.5, given P_s , Z_{10}	COMMENTS
					OBSERVED	CALCULATED EQN. 2.3				
72363 5	1095	JAN	-42.5	-1.7	893	888.3	13.3	1.0	2.0	
		JUL	2.2	18.9	896	895.3	24.5	21.6	25.3	
70261 1	135	JAN	- 1.7	-22.8	986	986.2	-23.9	-22.4		
		JUL	-18.7	8.3	996	993.6	59.4	8.7	24.9	
72879 2	668	JAN	- 4.5	- 8.3	923	923.2	- 6.1	- 6.7	- 8.1	
		JUL	19.1	18.3	934	935.8	14.0	20.0	22.4	
72775 3	1123	JAN	12.8	6.7	880	880.0	10.6	9.4	14.0	
		JUL	25.4	13.3	888	887.7	18.0	16.1	25.2	
72386 5	660	JAN	- 7.3	9.4	938	937.3	15.0	11.1	11.7	
		JUL	16.6	22.2	934	934.6	22.4	23.8	30.4	

CIR-4173 UDC: 551.509.313
TEC-551 551.509.323.7
21 Jan. 65.

CANADA

DEPARTMENT OF TRANSPORT - METEOROLOGICAL BRANCH
315 Bloor Street, West - Toronto 5, Ontario

Estimates of 1000-MB Height and Temperature
Changes from Surface Synoptic Data
by H. B. Kruger and C. Marullo

14 pps. 1 fig. 3 tables. 3 eqns. 9 refs.

Subject reference: 1. Numerical Weather Prediction
2. Forecasting Upper Air Temperature.

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