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STRATOSPHERIC SYNOPTIC DENSITY MAPS FOR 1964-1965 AND FOR THE WARMING EVENT OF DECEMBER 1967

by Staff, Upper Air Branch, National Meteorological Center

Weather Bureau, Environmental Science Services Administration

Hillcrest Heights, Md.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • NOVEMBER 1969

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AND FOR THE WARMING EVENT OF DECEMBER 1967

By Staff, Upper Air Branch, National
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SUMMARY

Constant-height synoptic density maps of the western portion of the Northern Hemisphere are presented for two stratospheric levels, 30 and 40 km. Temperature and pressure data are also included. The maps are for 1964-1965 and for the stratospheric warming event of December 1967-January 1968. They are at four-weekly intervals, except in January and during the stratospheric warming, for which maps at more frequent intervals are presented. A discussion is included of typical and unusual density patterns, and of interactions in the fields of pressure, temperature, and density. Density changes associated with both minor and major stratospheric warmings are described. In association with the major stratospheric warming at the end of 1967, density increases by 40% at 30 km, and by 80% at 40 km, were noted in the polar area.

INTRODUCTION

Knowledge of the horizontal density fields is useful for describing the atmospheric structure, while at the same time being required for the solution of several aerospace vehicle problems (ref. 1).

The spatial changes of the density can be shown in great detail on synoptic weather maps, if a density analysis is included. On a constant-pressure map, one needs only re-label the isotherms, since by the equation of state the density at constant pressure varies only with the temperature. Figure 1 shows the field of density, so obtained at 2 mb, on January 6, 1965. In this figure the range in density corresponding to the range in the isotherms is from 2.6 to 3.1 g m^{-3} (an increase of 20%). This is not, of course, the horizontal density change, since on the map day the height of the 2-mb surface varies over the map area by more than 4 km. Indeed, the height of the pressure surfaces can be shown to be increasingly variable (fig. 2) to about 60 km, and thus analysis at constant height is clearly necessary to represent the horizontal fields of density.

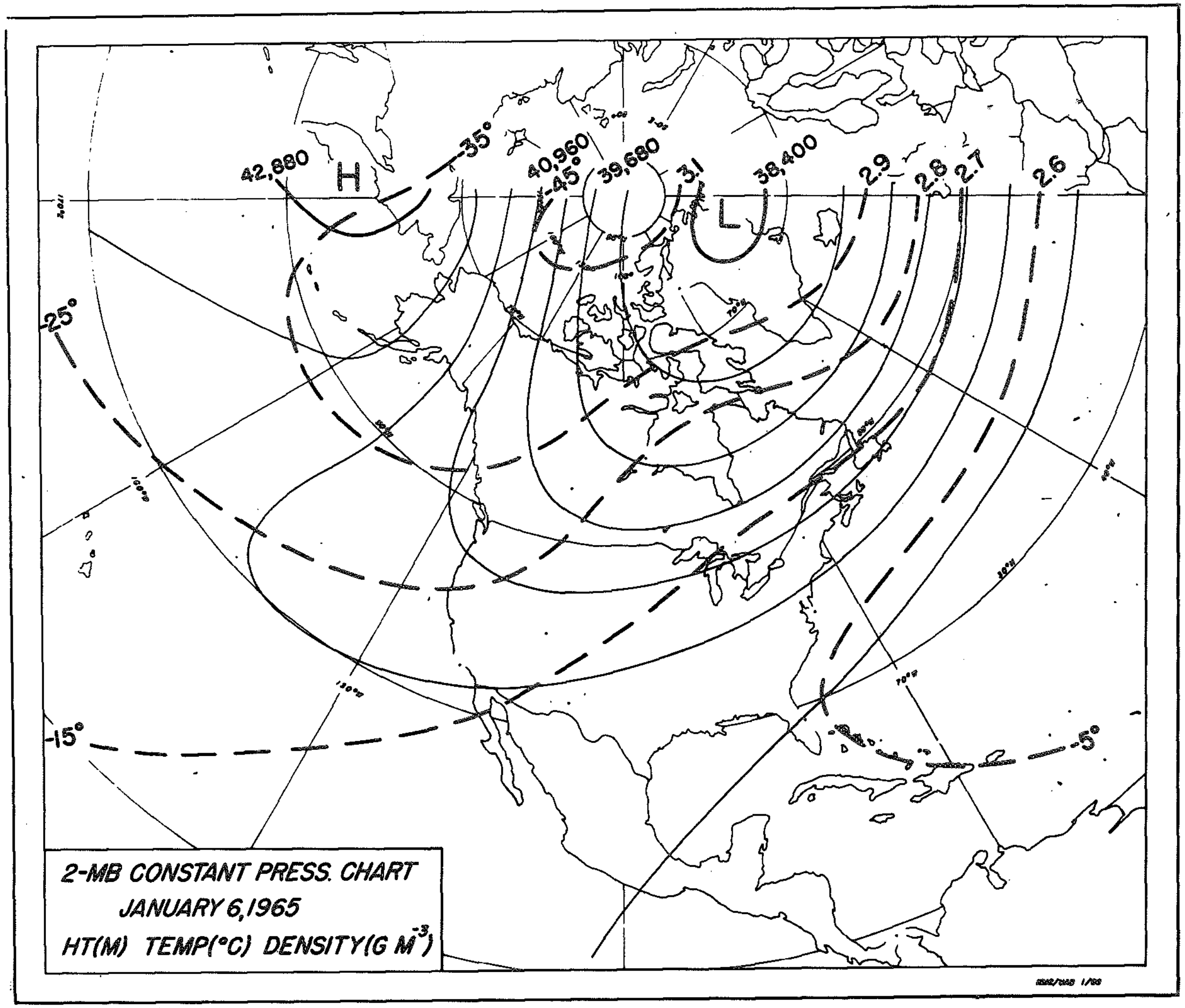

Fig. 1. Constant-pressure chart (2 mb, Jan. 6, 1965) showing a poleward density increase of 20%, from 2.6 to 3.1 g m^{-3}. (Solid lines are contours with an interval of 640 geopotential meters; dashed lines are isotherms and isopycnics with intervals of 10°C and 0.1 g m^{-3}, respectively.) For the same day, the corresponding constant-height map for 40 km indicates a density decrease poleward, with the density over Greenland 40% below the value given in the U.S. Standard Atmosphere, 1962.

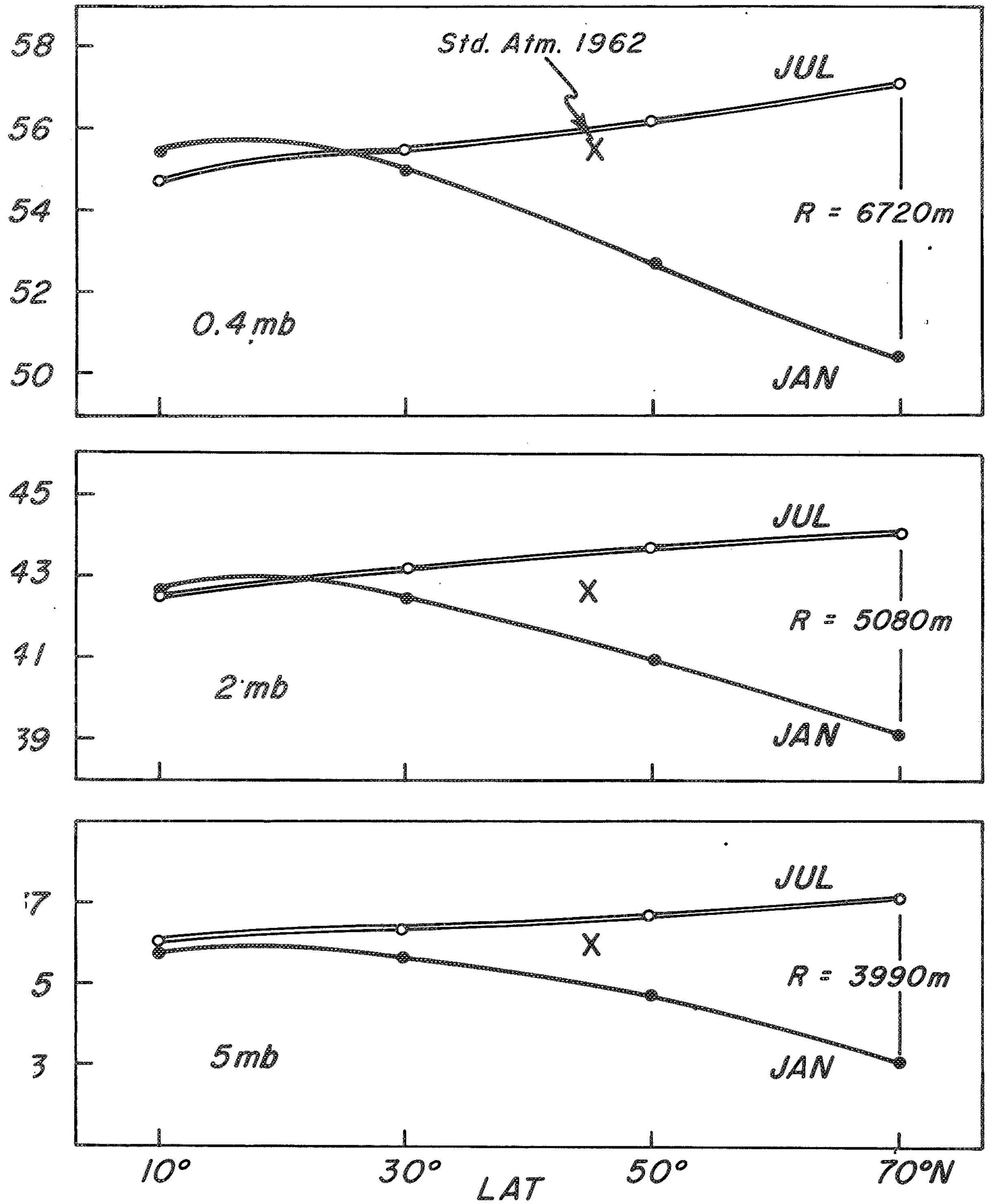

Fig. 2. Mean height of indicated pressure surfaces (based on analyzed values for 1964-65), illustrating increasing seasonal range with height in high latitudes. (From ref. 9.)

A pilot series of constant-height maps for 30 and 40 km has been constructed previously for dates in January and July of 1964-65 (ref. 1). The purpose of this report is to provide a series of such charts for all of 1964-65 and for the particularly interesting period of a major stratospheric warming in December 1967-January 1968. The analysis area of the maps is the western portion of the Northern Hemisphere. The maps are at four-weekly intervals except in January and during the stratospheric warming event, for which more frequent maps were prepared. The analysis procedure is summarized below.

PROCEDURE

The method of deriving the constant-height maps has been described previously (ref. 1). At a large number of grid points the pressure is extrapolated hydrostatically, from the altitudes indicated on a constant-pressure surface to some fixed altitude chosen for analysis. The isothermal form of the integrated hydrostatic equation has been used,

$$p=p_0 \, e^{\frac{-g\Delta z}{RT}} \tag{1}$$

Here p_o is the starting pressure and p is the pressure at constant height; the other terms have their usual meteorological meanings. Equation (1), strictly valid for an isothermal layer, may be used for non-isothermal layers with a high degree of accuracy if for $\underline{T}$ the mean layer temperature is used. With knowledge of the extrapolated pressure and the temperature at constant-height, the density is then derived from the equation of state,

For the derivation of constant-height maps of the 30- and 40-km levels, weekly constant-pressure maps of the 10-, 5-, and 2-mb surfaces were employed (refs. 2 and 3). The constant-pressure maps were analyzed according to procedures described in references 4 and 5.

Following is a list of the steps used to obtain constant-height data. A computer program was prepared for Steps 2 through 6, while the first step was executed manually.

(1) Extraction and punching of the geopotential height and temperature of the 10-, 5-, and 2-mb surfaces, at selected grid points (see below).

(2) Computation of the lapse rate (linear) between pairs of pressure levels.

(3) Conversion of geopotential to geometric height and the determination of the thickness of the layer through which the pressure is to be extrapolated.

(4) Calculation of the temperature at a given constant-height level, followed by determination of the mean temperature for the layer of extrapolation.

(5) Hydrostatic extrapolation of the pressure in accordance with eq. (1), to the nearest constant-height level (30 or 40 km).

(6) Calculation of density from the pressure and temperature at constant height.

The computations were carried out for each of 285 grid points mostly in the Western Hemisphere; the grid used has been adapted from the NMC NWP grid. Input data were provided only at alternate grid points under conditions of reduced atmospheric variability (summer, and low latitudes in winter). An error analysis indicated that the calculated density is subject to an average error of about 2%. See reference 1 for a discussion of the error sources.

CLIMATOLOGICAL TRENDS

It is anticipated that the maps presented will be most useful for making trial calculations of density gradients for use in space vehicle reentry simulations, and they should further provide theoretical meteorologists with some idea of the density variations to be encountered in the stratosphere. Also obtainable from the maps is a preliminary measure of climatological differences, from season to season and with respect to latitude and longitude. A comparison of latitudinal density means based on the maps, for January and July (ref. 1), showed good agreement with means in the U.S. Standard Atmosphere Supplements, 1966 (ref. 6). At the same time, striking longitudinal differences were noted, primarily in high latitudes. These are further illustrated in Figure 3 by traces of the actual map values at 170°E and 10°W, at 60°N; details will be discussed below.

It is emphasized that despite the good agreement of the latitudinal means with mean values in the Supplemental Atmospheres, the means for winter based on the 2-year series of maps may not be representative of other years. The stratosphere is so highly variable in winter that many years of maps would be needed to give an adequate representation of climatological values.

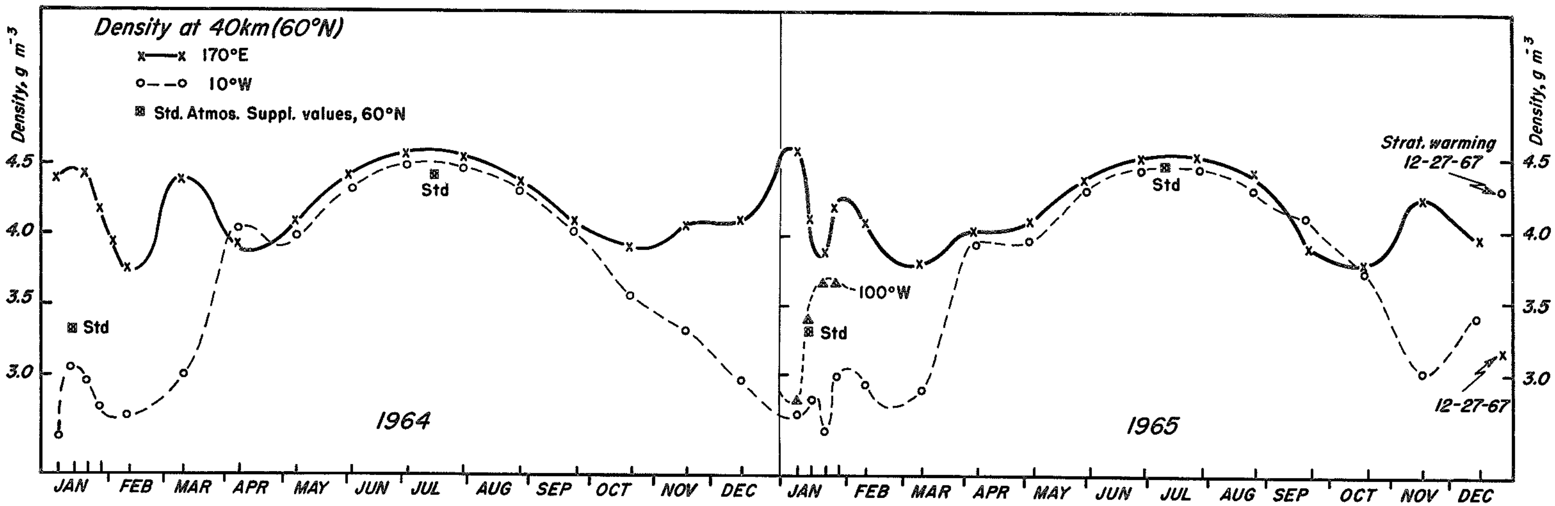

Fig. 3. The 40-km density at 60°N in 1964-65. Values from U.S. Standard Atmosphere are entered for comparison. Note large longitudinal variation in winter. The relative detail given by the weekly values in January suggests that more frequent sampling is desirable at other times of the year.

DISCUSSION OF MAP SERIES, 1964-65

The maps obtained show a number of interesting features concerning the synoptic density distributions on individual days. To provide some idea of the interaction among the fields of pressure, temperature and density (all at constant height), centers of low and high pressure and temperature have been indicated, and isotherms have been entered on most of the maps.

The situation of January 6, 1965 might be regarded as typical of mid-winter. A deep density low is situated on the Greenland side of the North Pole and a system of high density is found over the Aleutian-Kamchatka region of the North Pacific. Except in the region of the Aleutian high, there is a general decrease of density from low to high latitudes.

In mid-summer[1] (see maps for June-July 1964-65), the latitudinal density gradient is reversed and much weaker, with high density near the pole and relatively low density in the tropics.

The maps for the transitional periods April-May and September-October have generally amorphous patterns, with very weak gradients. (For operations in which it is desired to take advantage of constant-density conditions, as with the so-called constant-level balloons, these periods of the year appear to be the most favorable.)

Wintertime density fields associated with both minor and major stratospheric warmings may be radically different from the typical winter pattern described above. The consequences of the major warming of December 1967 will be described in detail in Section 5. Minor stratospheric warmings can be shown to account for some of the large density changes during winter shown in figure 3 and in the maps themselves. Examples are the large increases in February-April 1964 and November-December 1965. The developments in January 1965, as indicated in figure 3, are more readily explainable in terms of the behavior of the Aleutian anticyclone. On January 6, 1965, the constant-height density pattern is indeed the basic type of pattern observed on several of the winter maps, although the density at 170°E/60°N is about 10% higher than the average for that longitude based on all the January maps. The

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[1] Wave-like perturbations in the 30-km density fields in summer (not evident in the pressure fields) are believed to be real and explainable by corresponding variations in temperature, in accordance with the equation of state. Such perturbations are usually not found on the 40-km charts, which are based on a temperature structure subjected to considerable smoothing.

increases in density first at 170°E, then approximately two weeks later at 100°W, appear to be related to changes in the intensity and position of the Aleutian anticyclone. To illustrate the large rise in density at 100°W is nearly in phase with the eastward movement of the 10-mb anticyclone from early January to mid-month to a position over the west coast of Canada. Curiously, the temperature field on constant-pressure maps from 100 to 10 mb, except for a slight warming in late December, does not show any remarkable changes.

In contrast, the situation on December 15, 1965 provides a good illustration of the far-reaching effects directly relatable to a minor stratospheric warming. In this discussion, the reader will find it convenient to recall that by equation (1), an increase in temperature at some lower altitude implies an increase in density at the altitude of interest, as opposed to the inverse relationship in the equation of state, which applies to variables at the same altitude. In December 1965 the temperature changes at 40 km amounted to only a few degrees, yet there were drastic increases in the density at this altitude. In northwest Greenland, for example, there was an increase from 2.8 to 4.0 g m^{-3}, or a variation of 43%. Inspection of all available constant-pressure charts for the stratosphere shows that the greatest warming occurred at 100 to 50 mb (roughly 16 to 20 km) over northern Canada, although it amounted to only 20-30°C.

These results can be shown to be consistent with an equation (ref. 7) relating the density changes at altitude to changes in pressure and temperature at some lower altitude, z_o:

$$\frac{1}{\rho(z)} \frac{\partial \rho(z)}{\partial t} = \frac{1}{p_0} \frac{\partial p_0}{\partial t} + \frac{1}{H} (z-H_o) \frac{1}{T_o} \frac{\partial T_o}{\partial t} \qquad (2)$$

where H is the scale height, RT/g. For a height separation, Δz, equal to one scale-height (H_o), the temperature coefficient vanishes and the density change may be specified entirely by the pressure change. Beyond one scale-height, however, the temperature coefficient takes on increasingly positive values. Thus it is expected that a given temperature increase at, say, 50 mb (about 20 km) would account for a larger density increase at 40 km than the same amount of temperature increase occurring at some higher level.

It is interesting to note that for the case that Δz=0, equation (2) reduces to the differentiated equation of state, which in finite difference form may be written as:

$$\frac{\Delta\rho}{\rho} = \frac{\Delta p}{p} - \frac{\Delta T}{T} \qquad (3)$$

By actual calculation equation (3) may be used to examine, at the same height, the relative contribution of pressure changes and temperature changes to changes in the density, for example, from one map to the next, or from one area of the map to another. The interested reader may verify for himself that under typical, or undisturbed, mid-winter conditions, the density field is strongly linked to the pressure field, with temperature features accounting only for secondary detail in the density patterns.

In winter it is often observed that at the same altitude, centers of low temperature are nearly co-located with centers of low pressure and low density. Such a condition would seem to contradict the inference from the equation of state that high density should be associated with low temperature ($\rho = P/RT$), but is in fact a confirmation of the dominance of the pressure term in equation (3). Under certain conditions, however, for example during important stratospheric warmings and in the transitional months between summer and winter, the temperature term may have overriding importance.

STRATOSPHERIC WARMING SERIES, WINTER 1967-68

The stratospheric warming of December 1967 is of unusual interest (ref. 8). Among major warmings, none is known to have occurred so early in winter. At 10 mb an anomalous area of warm air was first observed over the North Atlantic in mid-December. The warming had a net poleward movement and by the end of the month had resulted in large temperature increases in an area centered on the Arctic Archipelago. Inspection of the constant-height charts presented here for December 6, 27, 1967 and January 10, 1968 indicates a maximum temperature increase of approximately 45°C at 30 km over north Greenland. At 40 km the maximum warming is farther west and with greater amplitude. To illustrate, the temperature increases by 65°C over northern Alaska, from -55°C on December 6 to +10°C on December 27. Unfortunately, greater precision is precluded by the time resolution of our maps.

The structural modification of the atmosphere is noteworthy. In early December we have low density over the pole, and high density south of Kamchatka peninsula. The situation then is not unlike the pattern for January 6, 1965, previously suggested as typical for mid-winter. (The temperature pattern however, is a little unusual, in view of the split system at 40 km at the pole, and suggests that a minor wave might be preceding the major warming observed later in the north. Also, there is relatively high density over the North Atlantic, in contrast to the situation on January 6, 1965.) By January 10, 1968 the density pattern is vastly changed: high density is now over the pole and the system of low density has been displaced to the northeastern Pacific. There is clear evidence of sloping axes of the high and low density system from 30 to 40 km. Horizontal density gradients are diminished, most notably at 40 km, where the maximum gradient on the map is now 0.015 g m^{-3} (deg lat)$^{-1}$, roughly one-third as great as on December 6, 1967. The largest density changes have occurred in the arctic regions: at the pole an increase of about 40% has occurred at 30 km, 80% at 40 km, from December 6 to January 10. In contrast, the northeast Pacific and western Canada have undergone density falls of 10 to 20%.

At the pole, the greater density increase at 40 km, as compared with 30 km, is noteworthy, and it is interesting to speculate concerning the depth of the layer affected by the warming. Large density increases in association with the stratospheric warming of January 1958 were noted as high as 90 km (ref. 7). The preparation of maps at levels higher than 40 km, given an adequate observational basis, would undoubtedly reveal more significant information on the structural changes of the atmosphere associated with stratospheric warmings.

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Project Leader: R. S. Quiroz

Assistant Analyst: D. Wiszneauckas

Programming Consultant: K. W. Johnson

Upper Air Branch,
National Meteorological Center, Weather Bureau, ESSA,
Hillcrest Heights, Md., June 30, 1969

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9. Quiroz, R.S., 1968: Synoptic analyses for the middle atmosphere and related research. Publication in Meteorology No. 90, McGill Univ., pp. 187-219.

MAP LEGEND

	isopycnics (lines of constant density), grams m^{-3}
	isopycnics for intermediate intervals (see notes below)
	isotherms, deg C (not entered on some January maps)
	isobars, mb (when entered)
D d	centers of high, low density, with central values in g m^{-3}
H L	centers of high, low pressure, with central values in mb
W C	centers of high (Warm), low (Cold) temperature, with central values in deg C (all temperatures negative in this series)
H L W C	areas of high, low pressure; high, low temperature (centers not definable)

Notes:

1. Basic density intervals used in the isoline analysis are 1 g m^{-3} at 30 km and 0.2 g m^{-3} at 40 km, reduced to 0.5 and 0.1, respectively, during April-September. Occasionally, smaller intervals have been introduced to depict the variability under conditions of weak gradients. The basic intervals correspond approximately to variations of 5% of the density (2.5% in April-September) at both levels, 30 and 40 km.

2. Isotherms have been drawn at intervals of 5 or 10°C.

3. Isobars, entered selectively on only a few of the maps, have been drawn at arbitrary intervals, usually with the object of drawing attention to details in the joint variation of pressure, density, and temperature. If desired, more complete pressure information can, of course, be obtained from the combined density and temperature fields, through the equation of state.

4. Centers of high and low pressure and high and low temperature have been entered to give a simple measure of the range of these variables. In some cases, an isobar has been entered to set off an area of high or low pressure. This applies especially in summer situations, when a broad belt of low pressure is common in low latitudes. In winter, a broad belt of <u>high</u> pressure is common in low latitudes, but the highest pressure is often found in the Aleutian-Siberian region.

5. For comparison with the U.S. Standard Atmosphere, 1962, the following values may be of interest.

STD. ATM., 1962

	DENSITY	PRESSURE	TEMPERATURE
30 km	18.4 g m^{-3}	12.0 mb	-47°C
40 km	4.00 g m^{-3}	2.87 mb	-23°C

LIST OF MAPS (40 AND 30 KM)

Basic series:

1964	1965
Jan. 15	Jan. 13
Feb. 12	Feb. 10
Mar. 11	Mar. 10
Apr. 8	Apr. 7
May 6	May 5
June 3	June 2
July 1	June 30
July 29	July 28
Aug. 26	Aug. 25
Sept. 23	Sept. 22
Oct. 21	Oct. 20
Nov. 18	Nov. 17
Dec. 16	Dec. 15

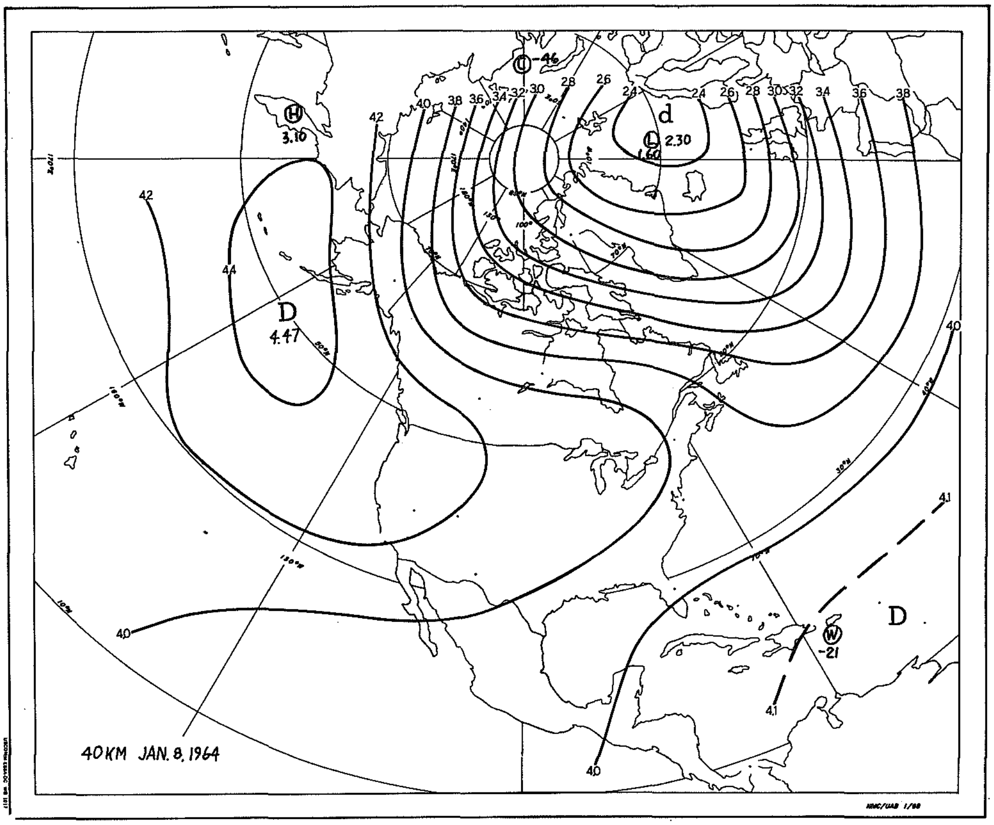
Supplementary maps (in chronological sequence with above series):

1964: Jan. 8, 22, 29

1965: Jan. 6, 20, 27

Stratospheric warming series:

Dec. 6 and 27, 1967; Jan. 10, 1968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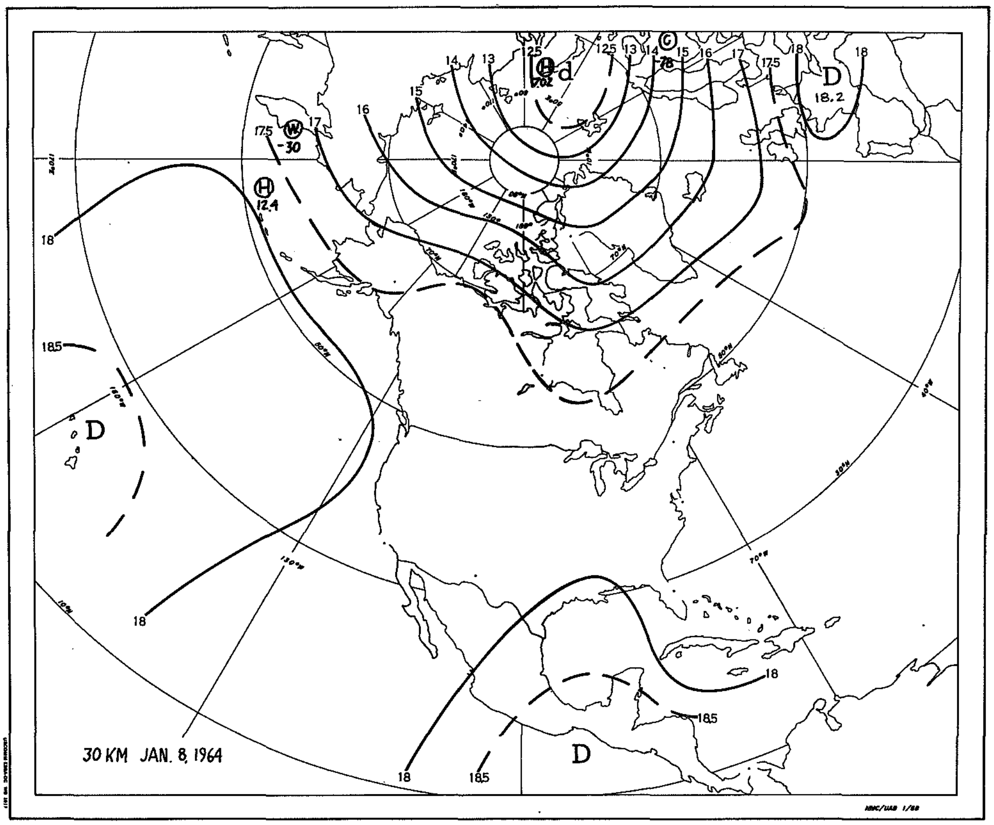
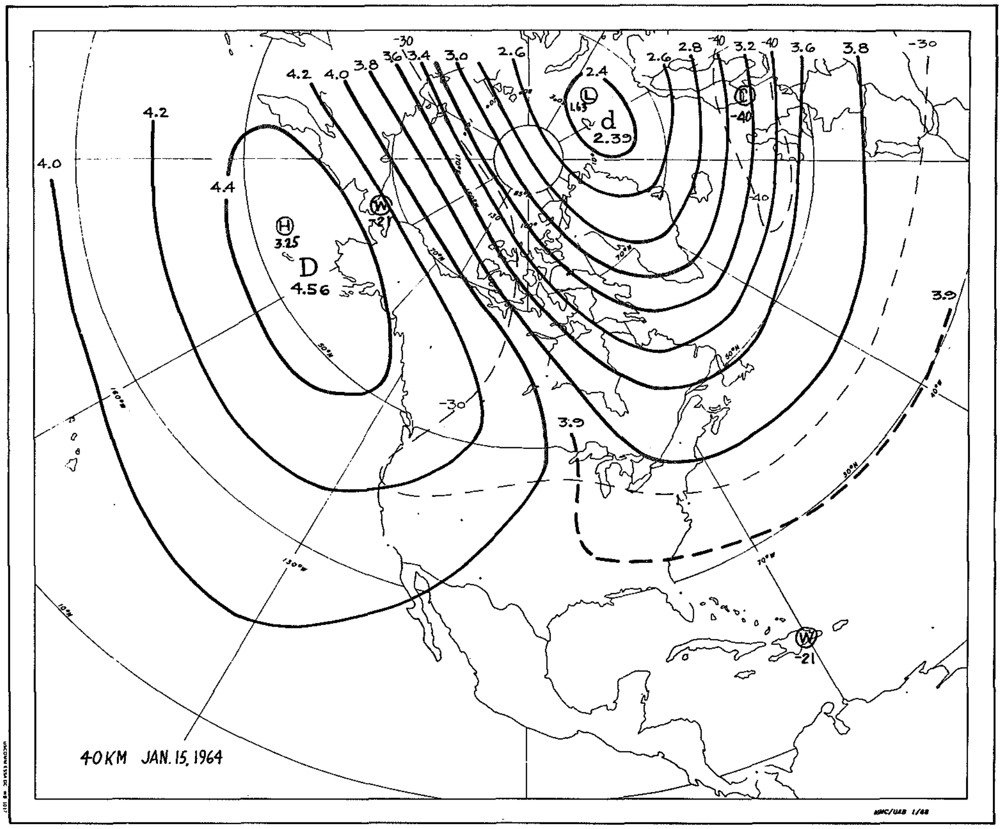
D
4.47
d
2.30
1.60
3.10
-46
-21
D


30 KM JAN. 8, 1964
D
18.2
12.4
-30
7.02
d
D
D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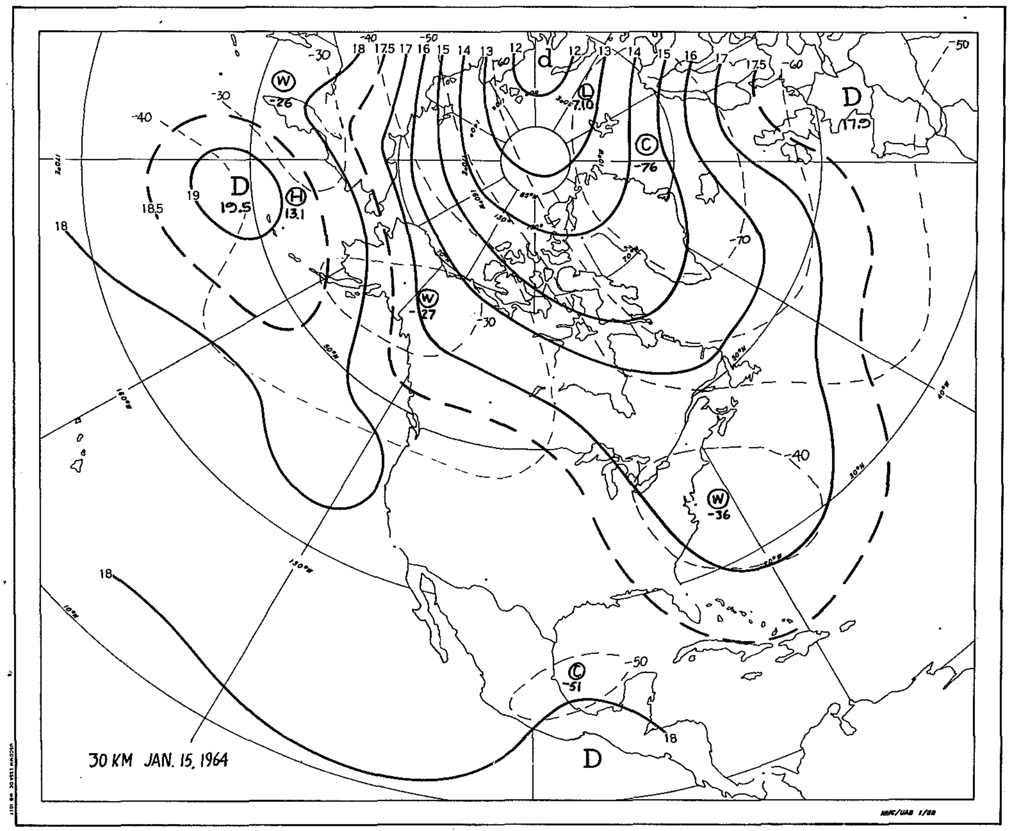
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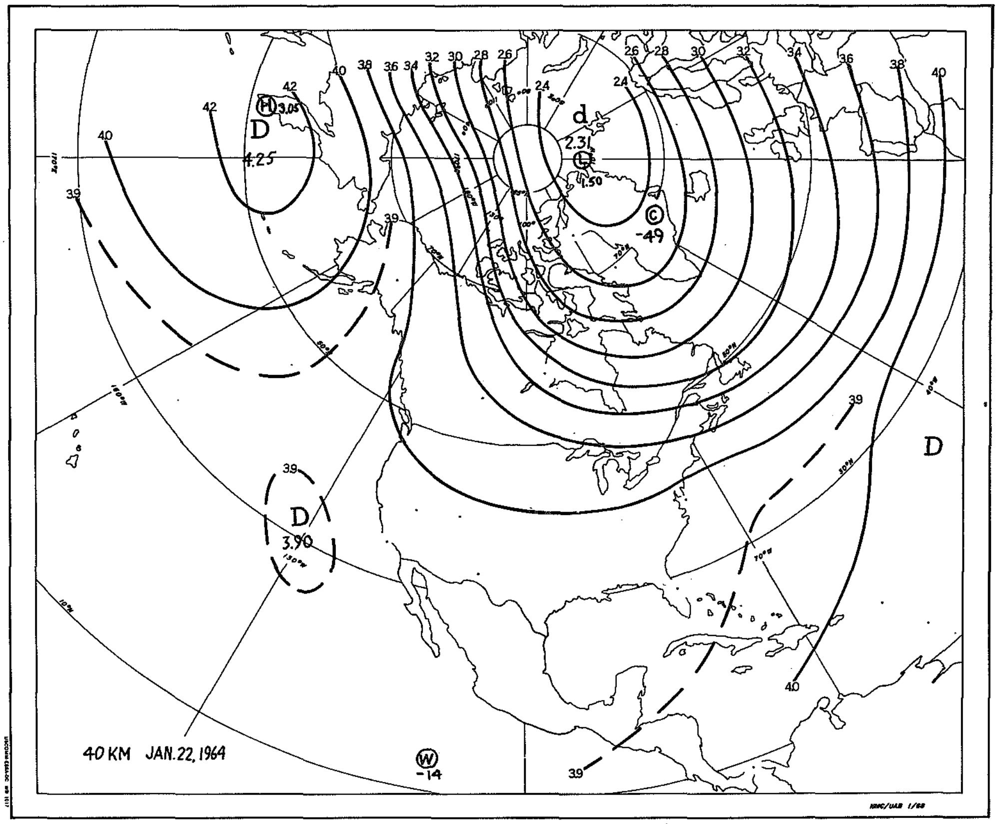
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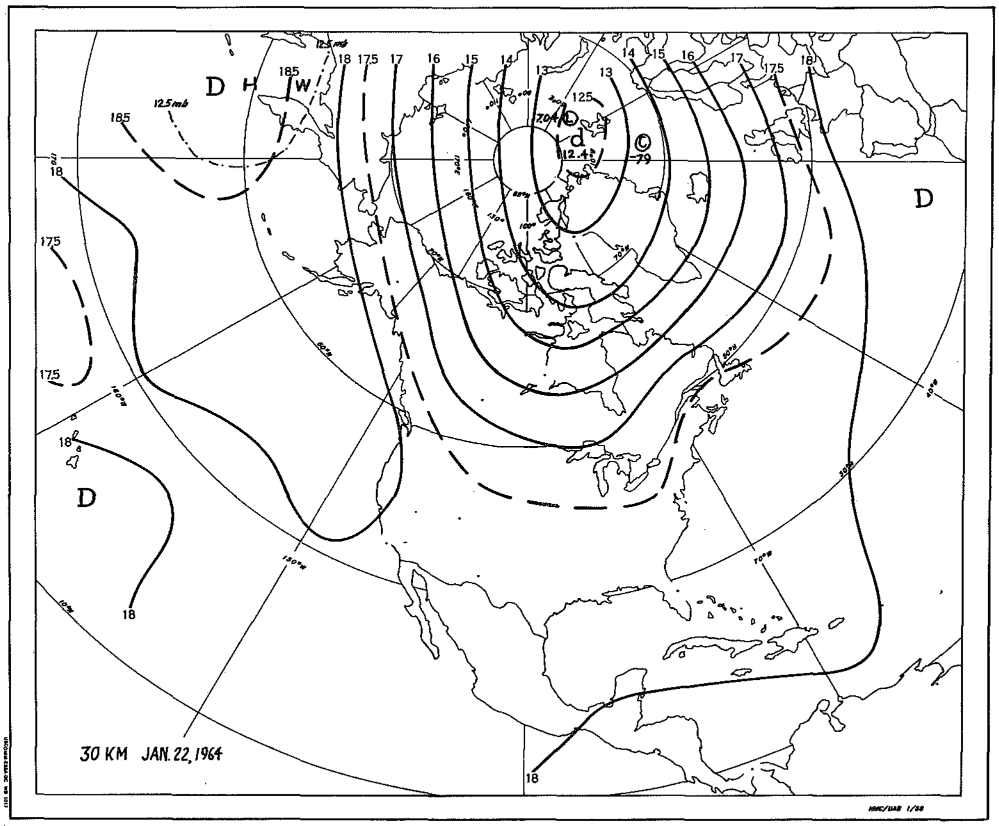
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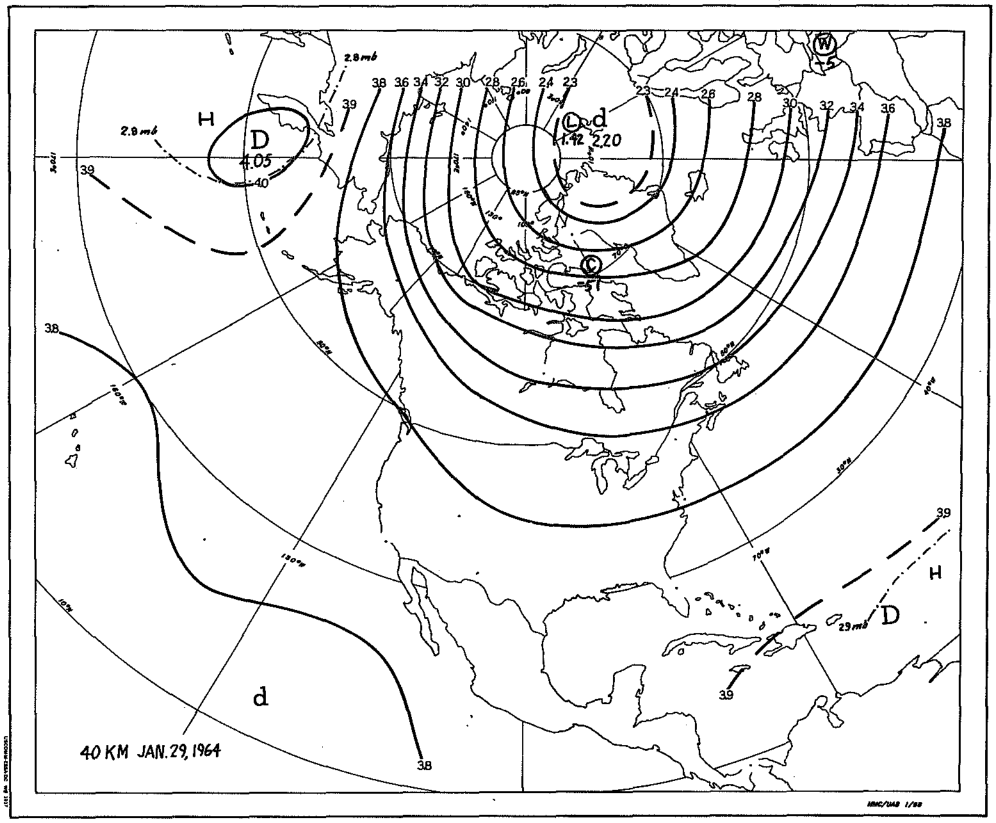
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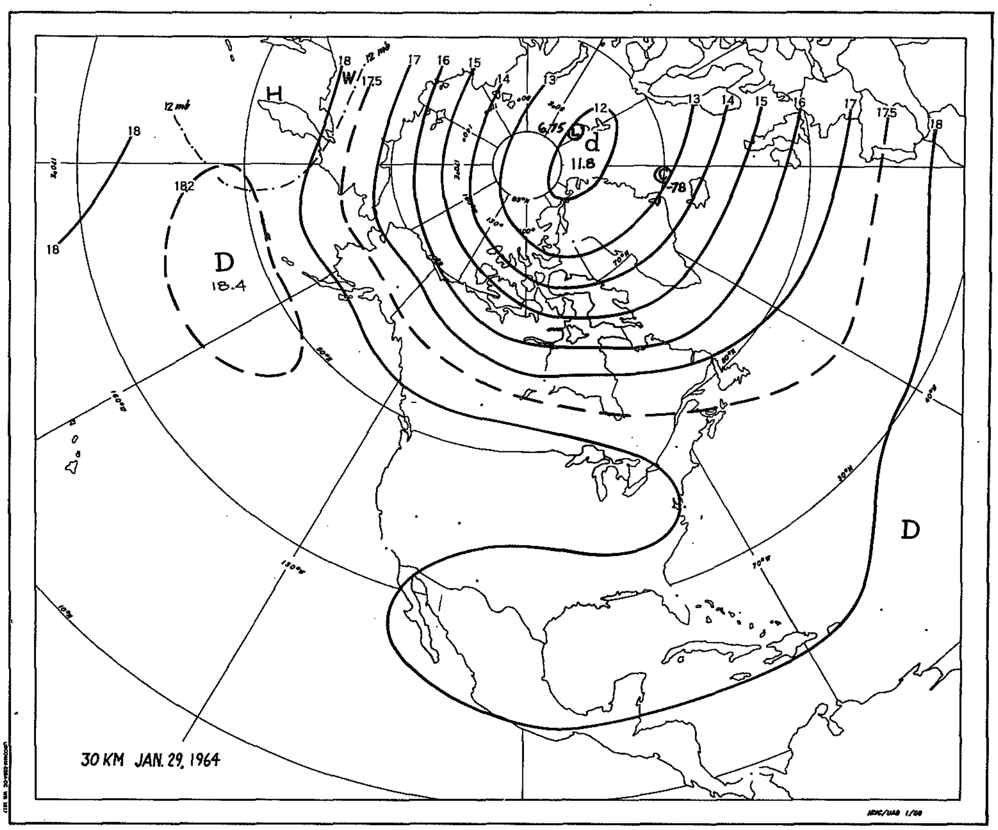
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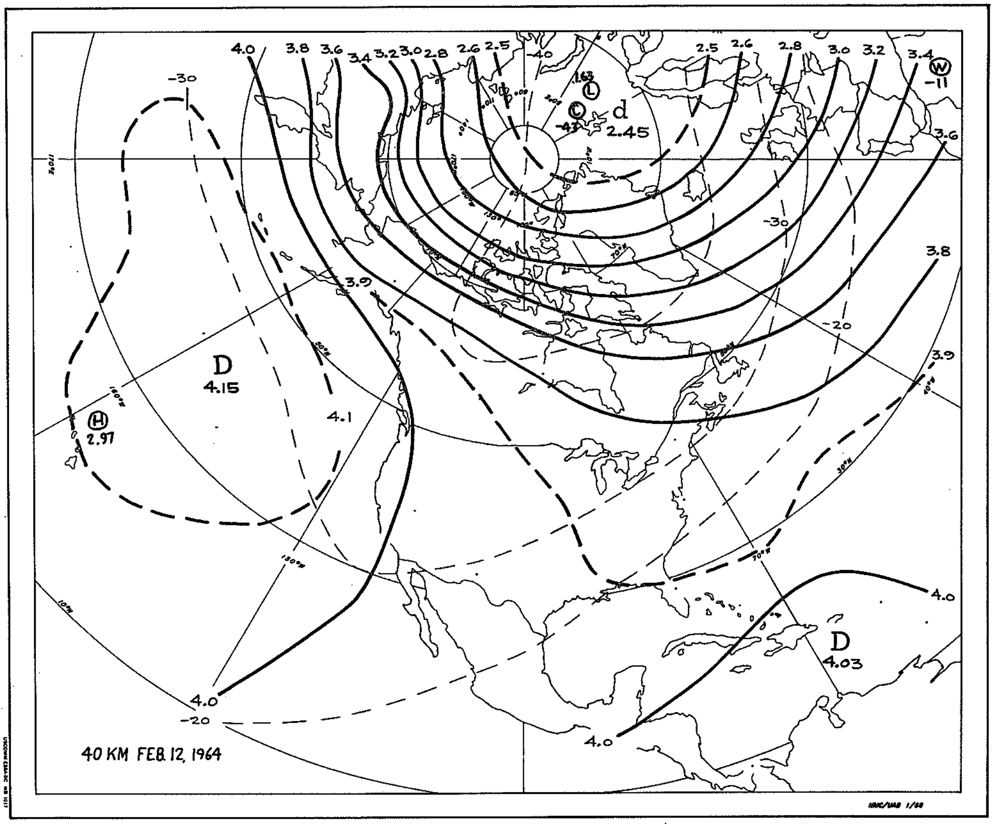
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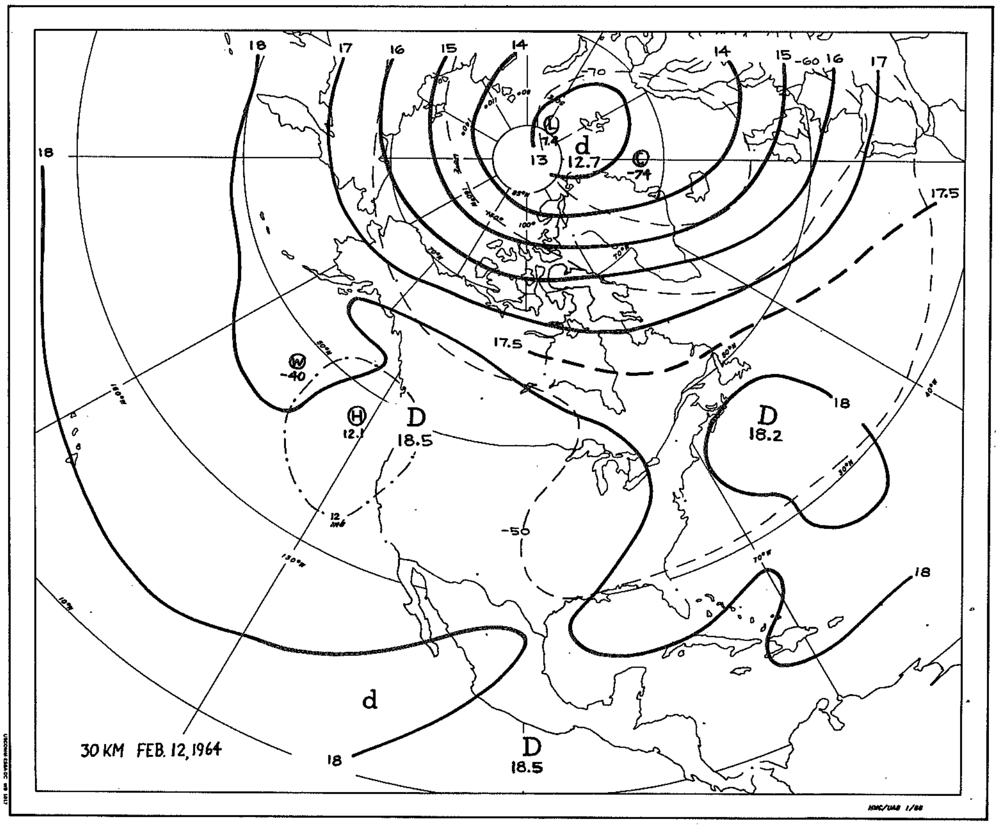
D
4.15
D
4.03
d
2.45
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.5
3.9
4.1
2.97
-30
-20
-40
-11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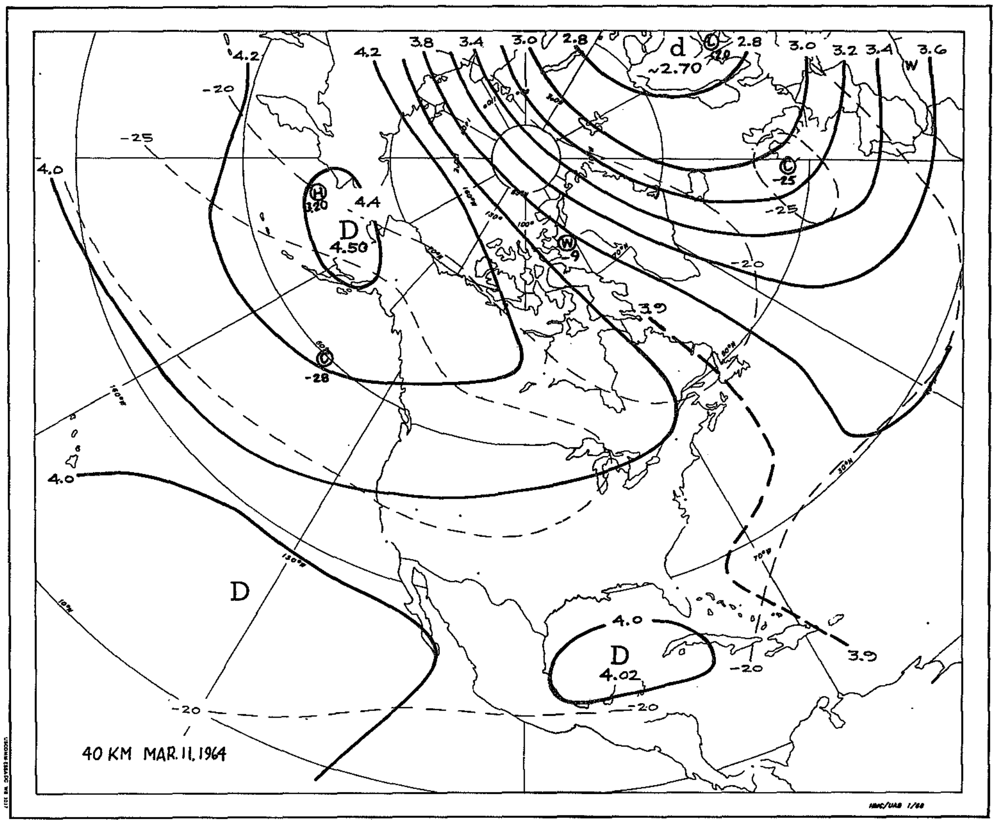
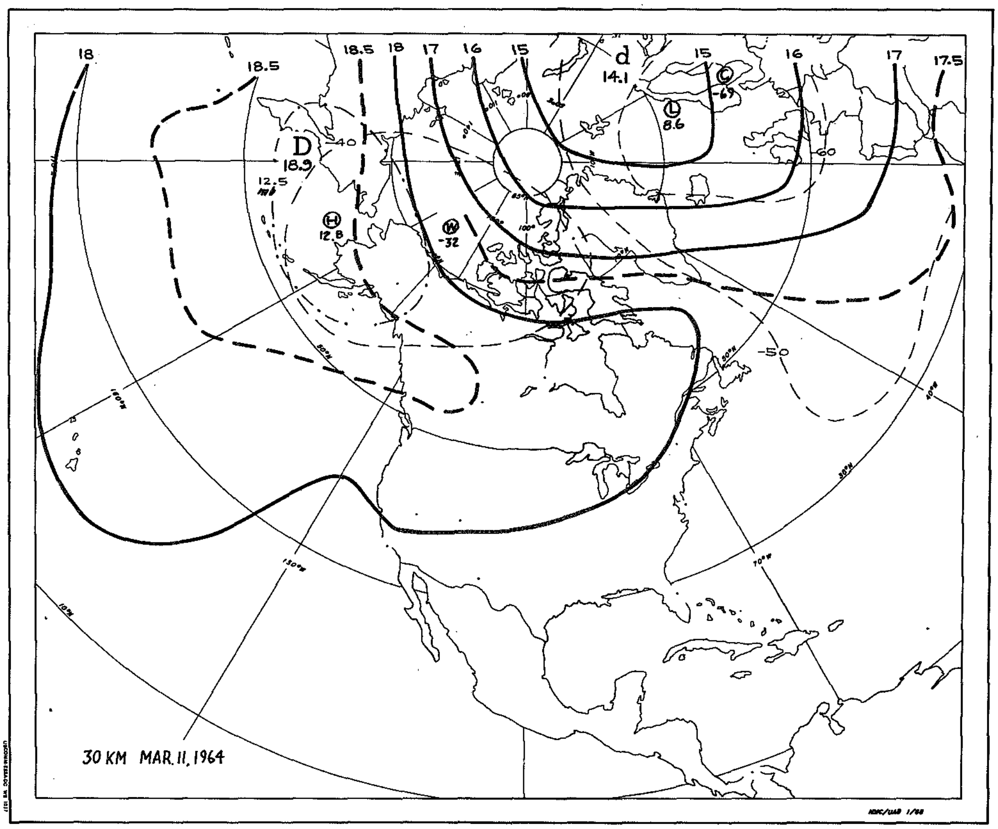
D
18.5
D
18.2
D
18.5
d
12.7
d
18
17
16
15
14
17.5
-40
-50
-60
-70
-74
13


40 KM MAR. 11, 1964
4.2
-20
-25
4.0
4.4
D
4.50
-28
3.8
3.4
3.0
2.8
d
~2.70
2.8
3.0
3.2
3.4
3.6
W
-25
-20
3.9
4.0
D
D
4.02
-20
3.9
-20
-20


30 KM MAR. 11, 1964
18
18.5
18.5
18
17
16
15
d
14.1
15
16
17
17.5
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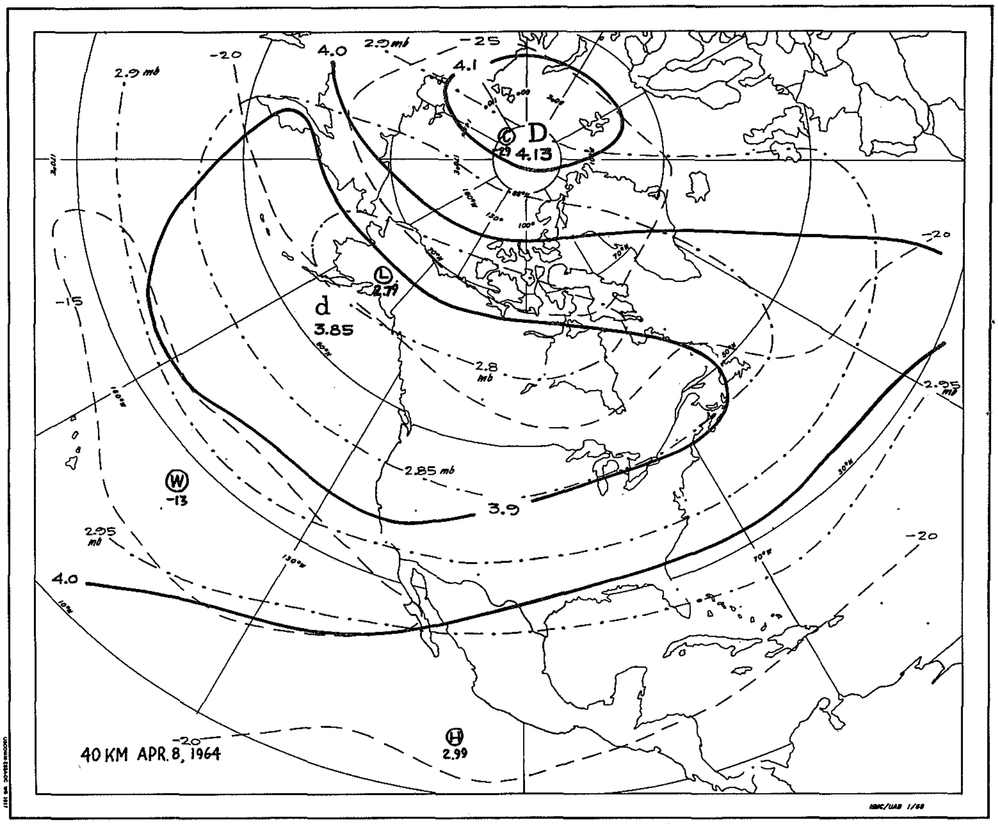
18.9
-40
12.5
12.8
-32
8.6
-67
-60
-50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D
4.13
d
3.85
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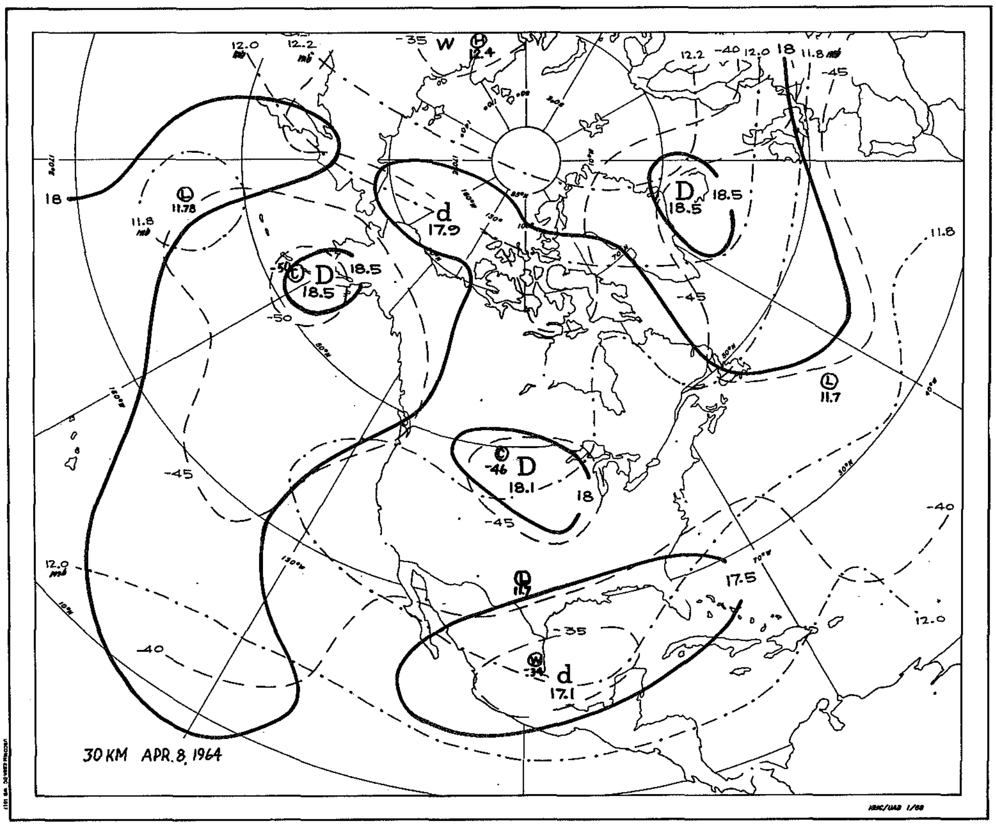
2.9 mb
2.95 mb
3.9
4.0
4.1
2.99
-13
-15
-20
-25


30 KM APR. 8, 1964
D
18.5
d
17.9
D
18.1
d
17.1
17.5
18
11.78
11.7
11.8 mb
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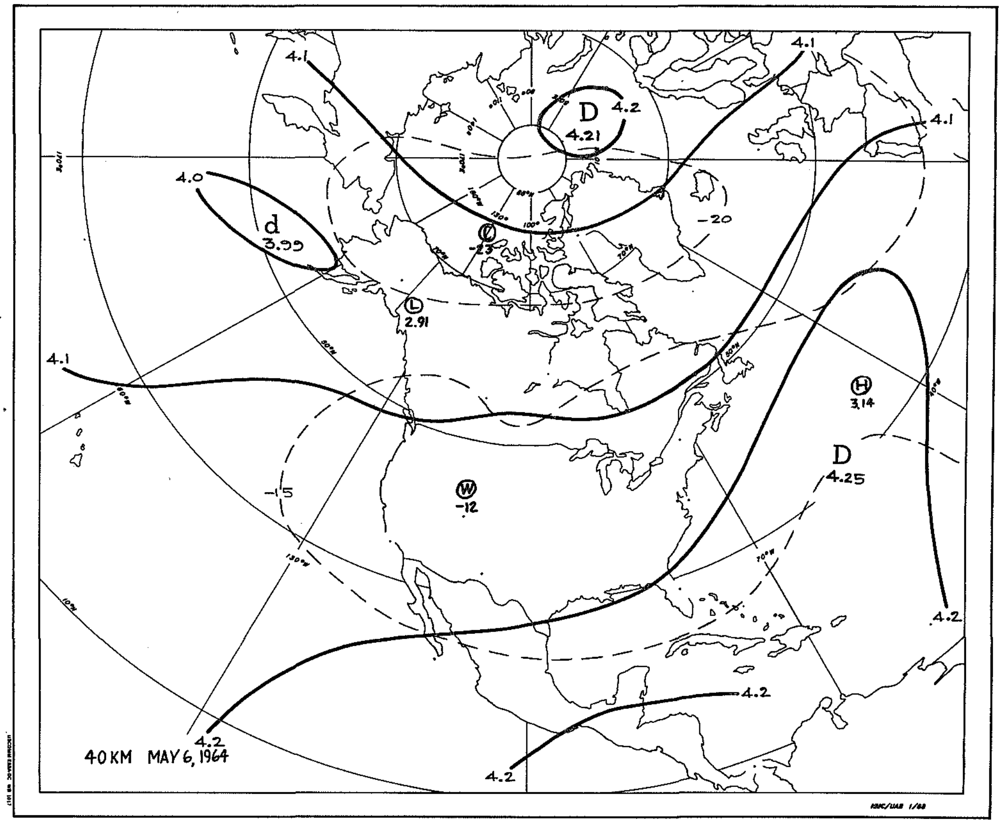
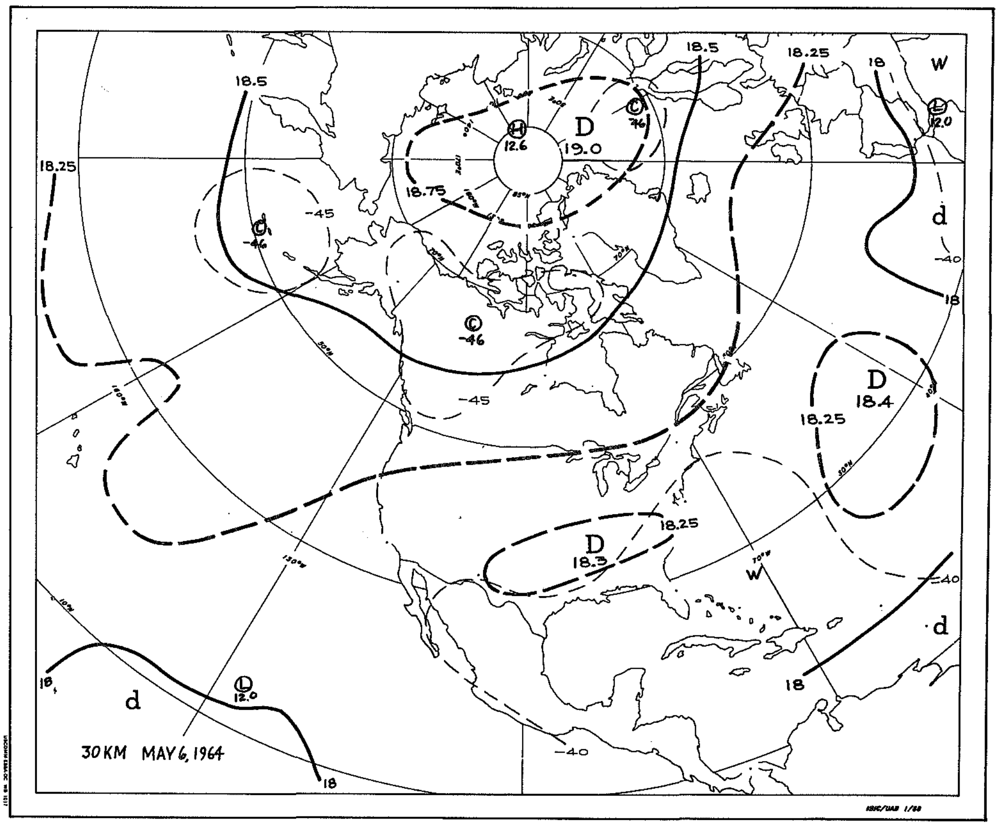
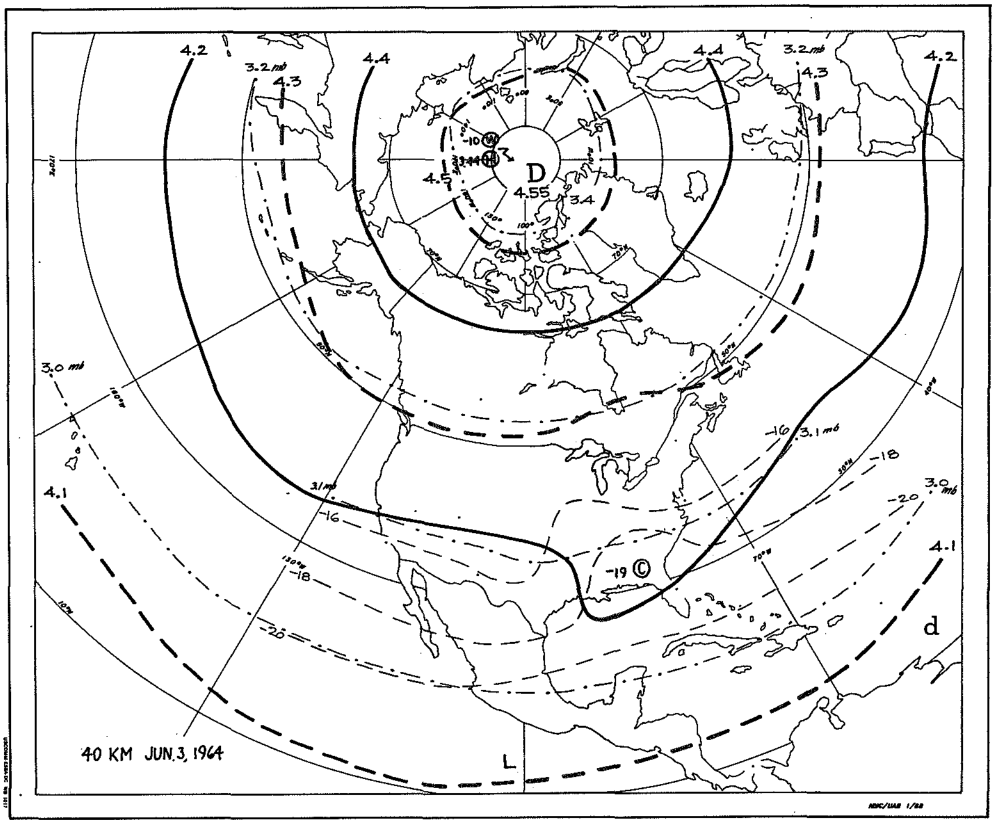
-35
-40
-45
-50

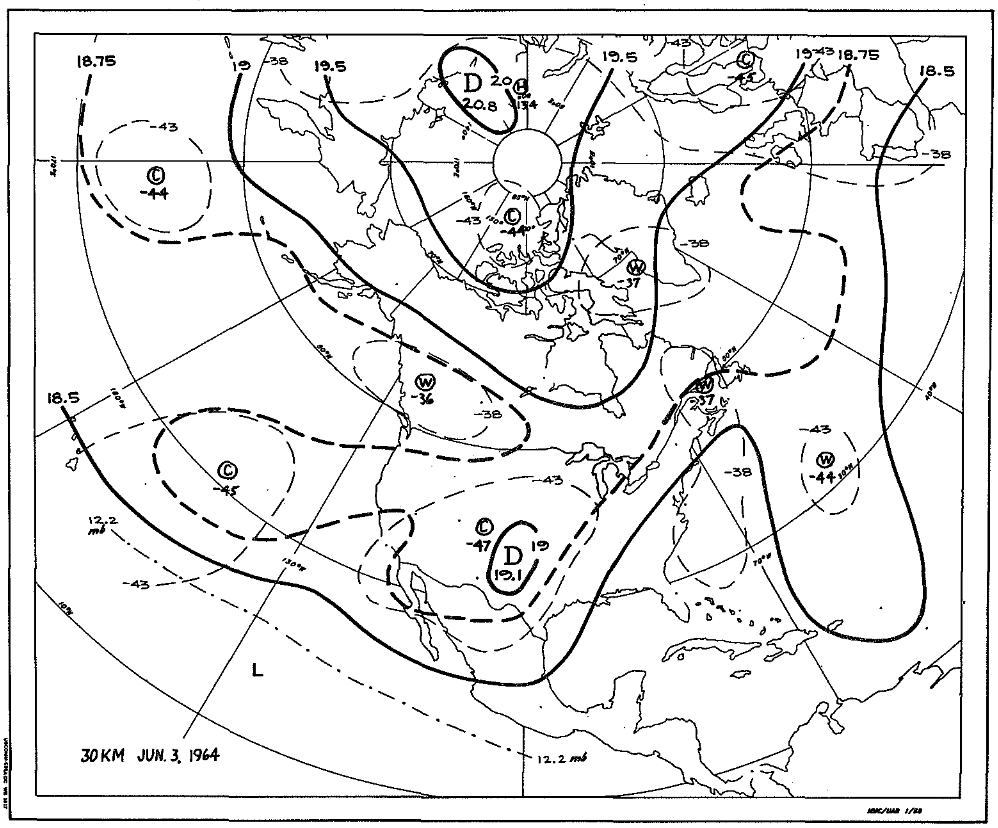


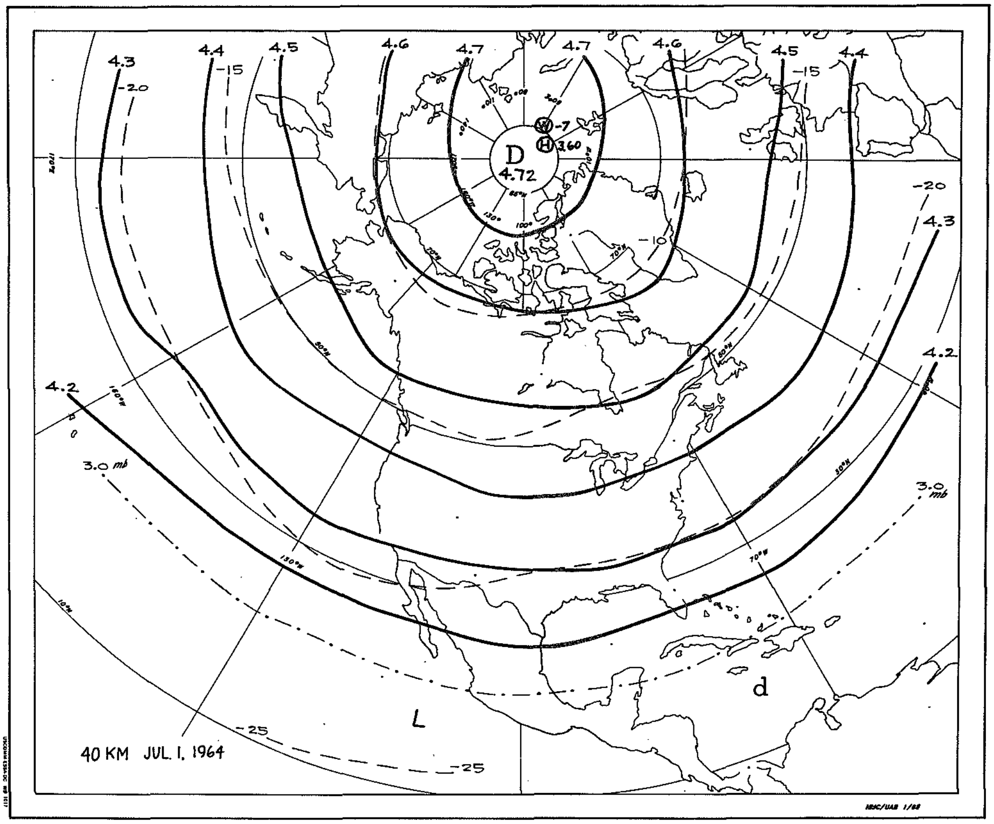
4.1
D
4.2
4.21
4.0
d
3.99
-23
-20
2.91
4.1
3.14
D
4.25
-15
-12
4.2
4.2
4.2
4.2
40 KM MAY 6, 1964

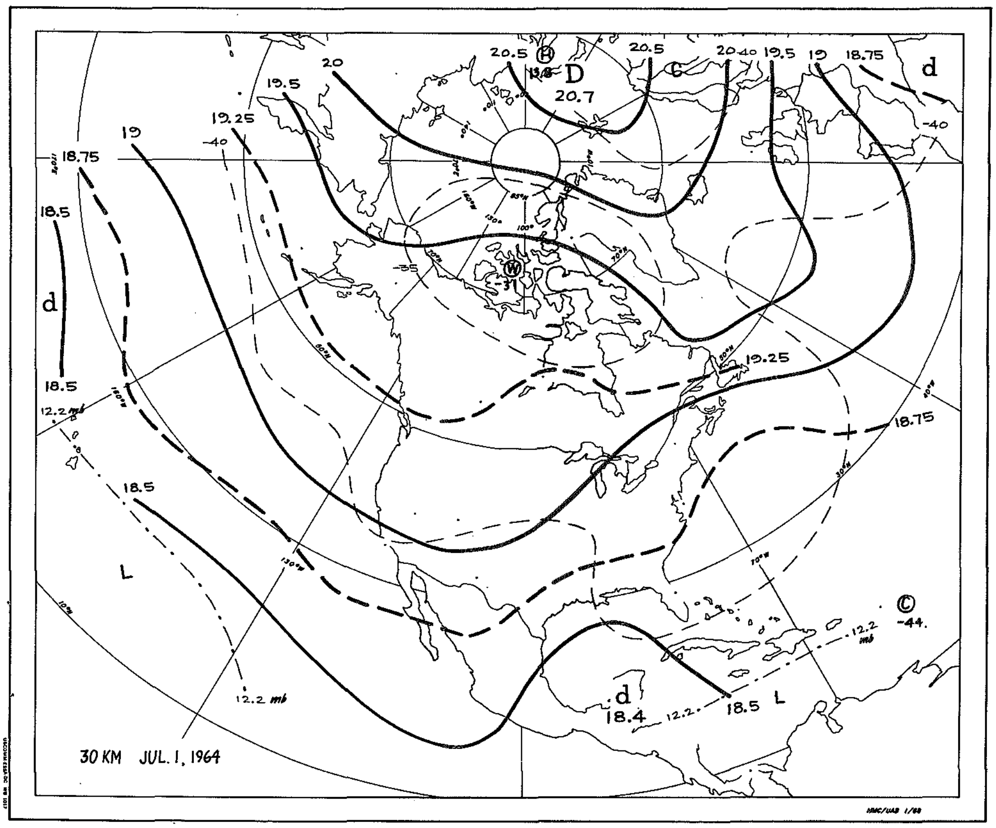


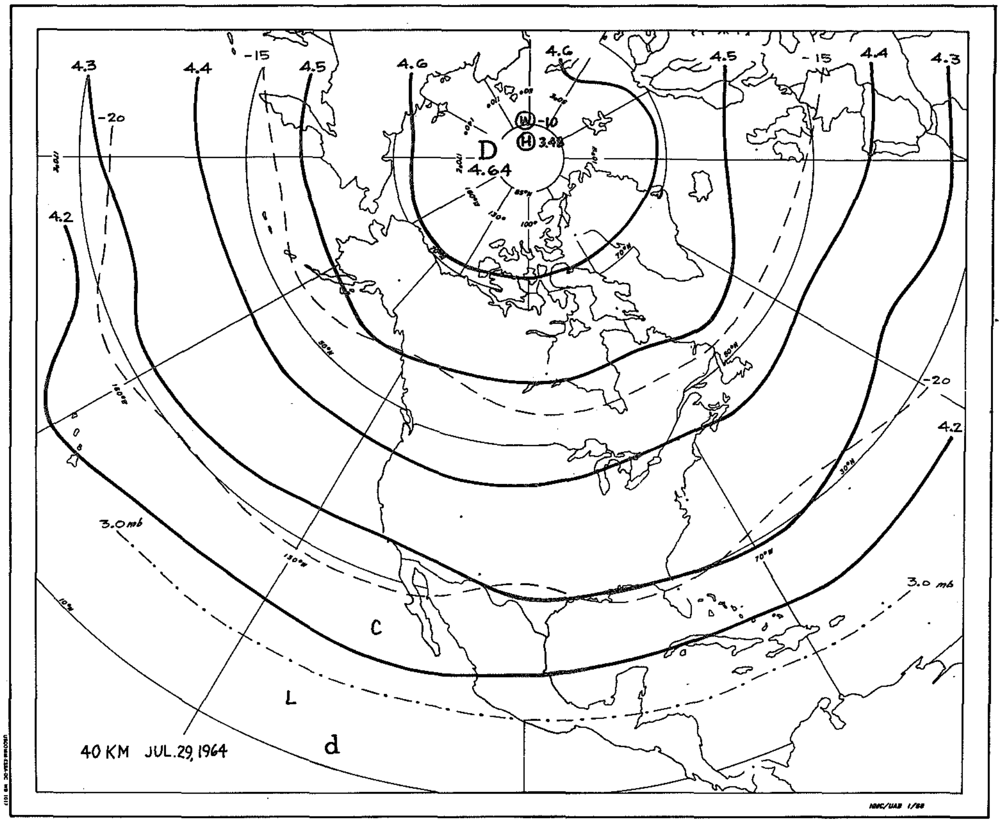
18.5
18.5
18.25
18
W
12.6
D
19.0
-46
12.0
18.25
18.75
-45
-46
d
-40
18
-46
-45
D
18.4
18.25
18.25
D
18.3
W
-40
d
18
d
12.0
18
30 KM MAY 6, 1964
-40
18

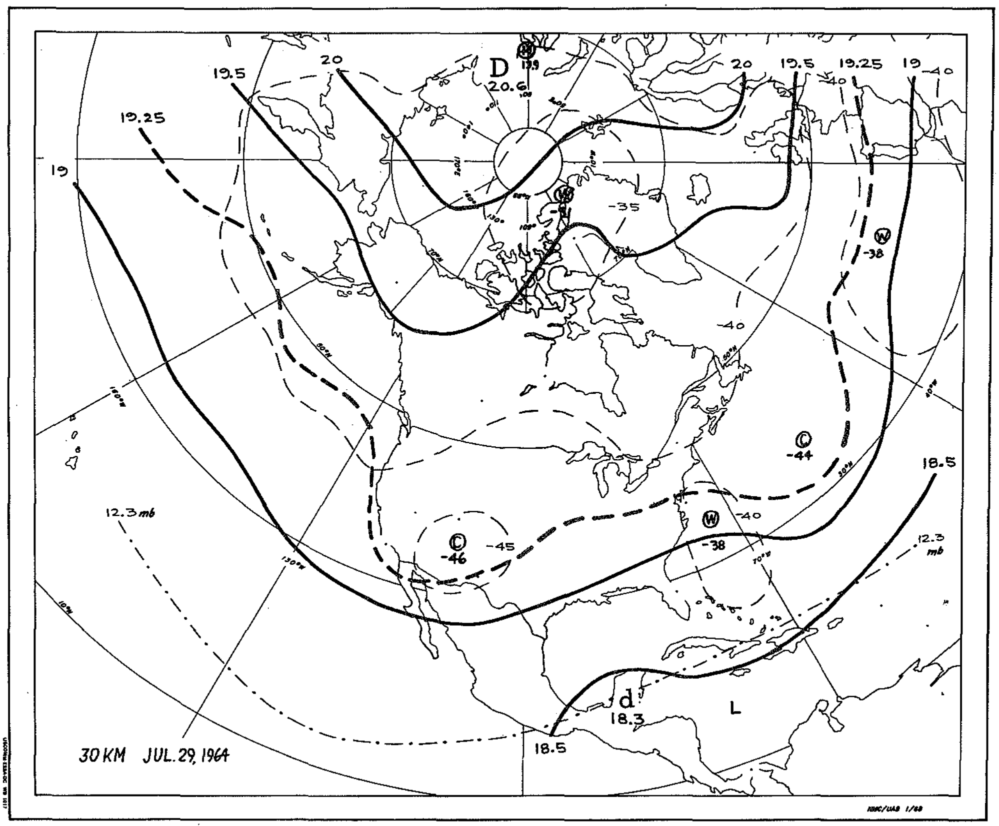

40 KM JUN. 3, 1964
D
4.55
d
L

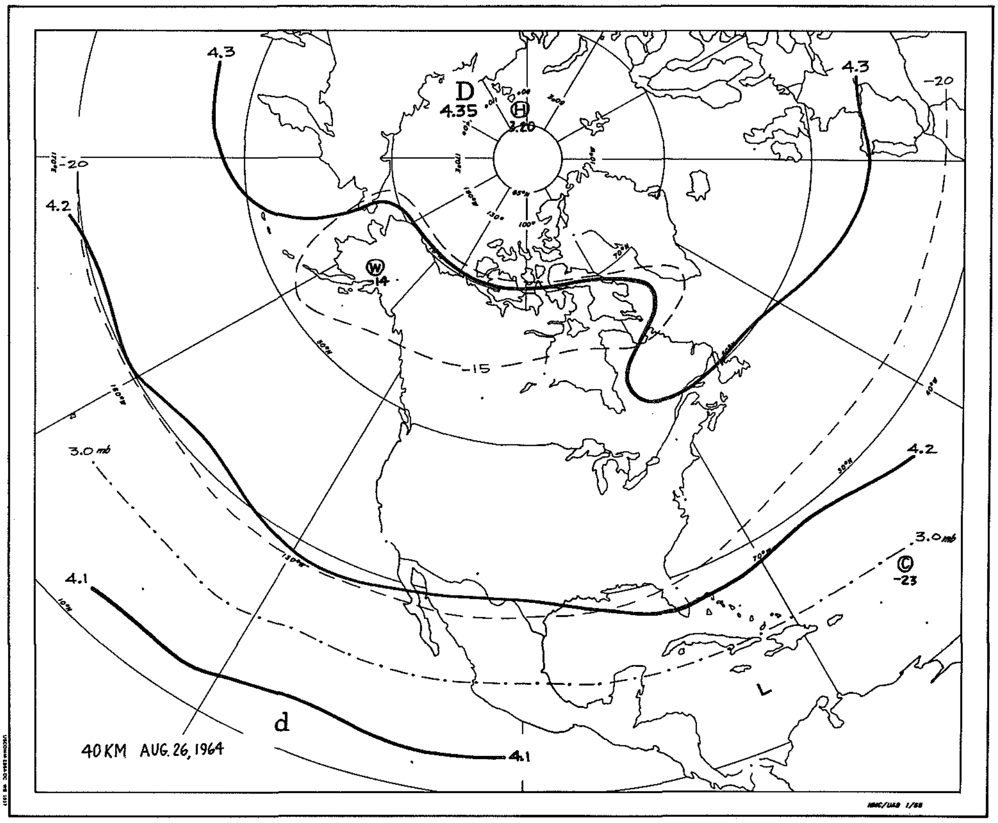

30 KM JUN. 3, 1964
L
12.2 mb


40 KM JUL. 1, 1964
D
4.72
3.0 mb
L
d

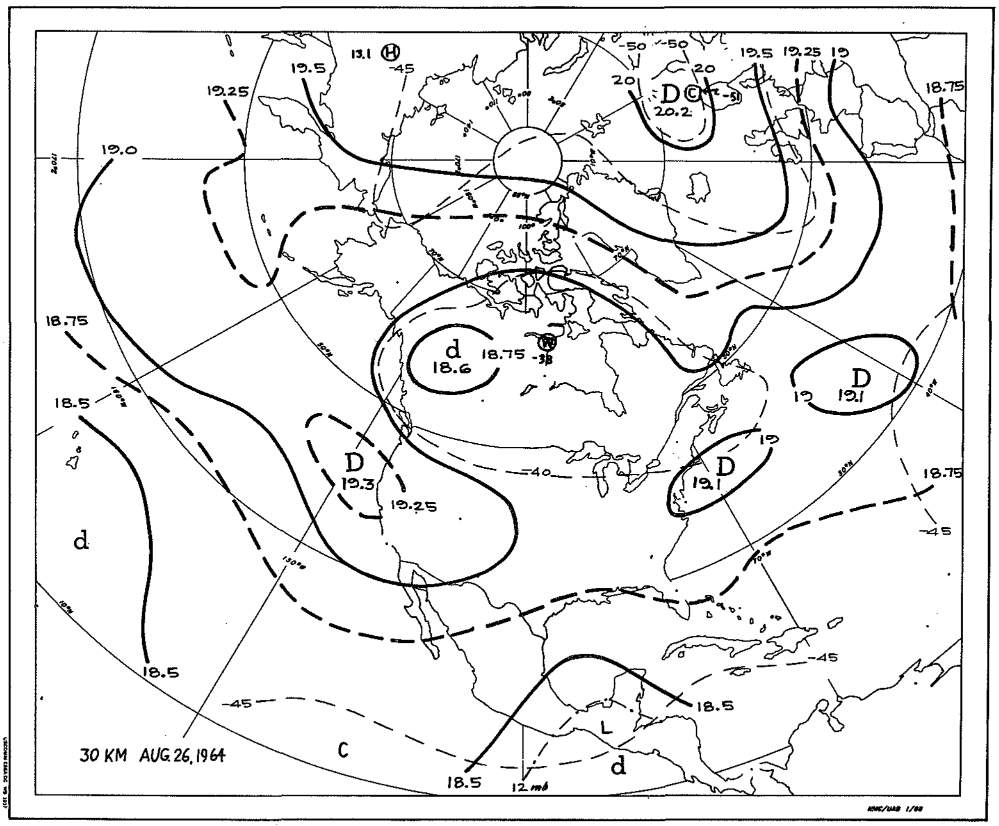

30 KM JUL. 1, 1964
D
20.7
12.2 mb
L
d


4.3
4.4
4.5
4.6
4.2
-15
-20
-10
3.48
D
4.64
3.0 mb
C
L
d
40 KM JUL. 29, 1964

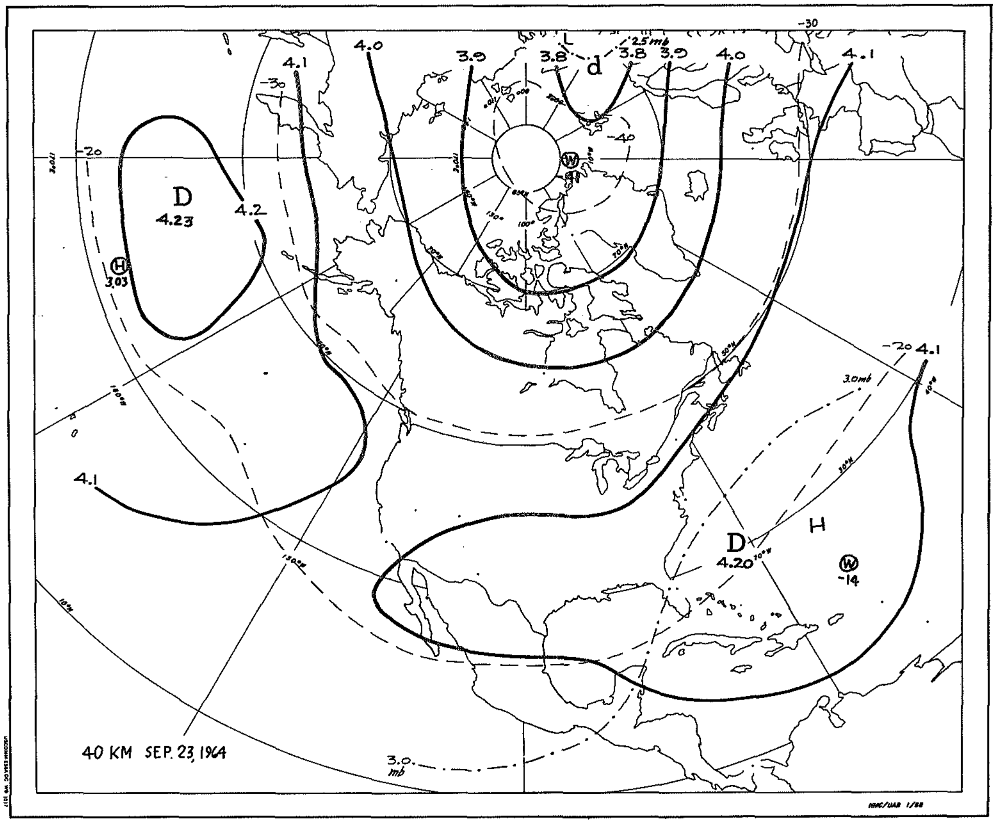

19.5
19.25
19
20
20.6
D
19.9
-35
-38
-40
-44
-45
-46
18.5
18.3
12.3 mb
L
d
30 KM JUL. 29, 1964

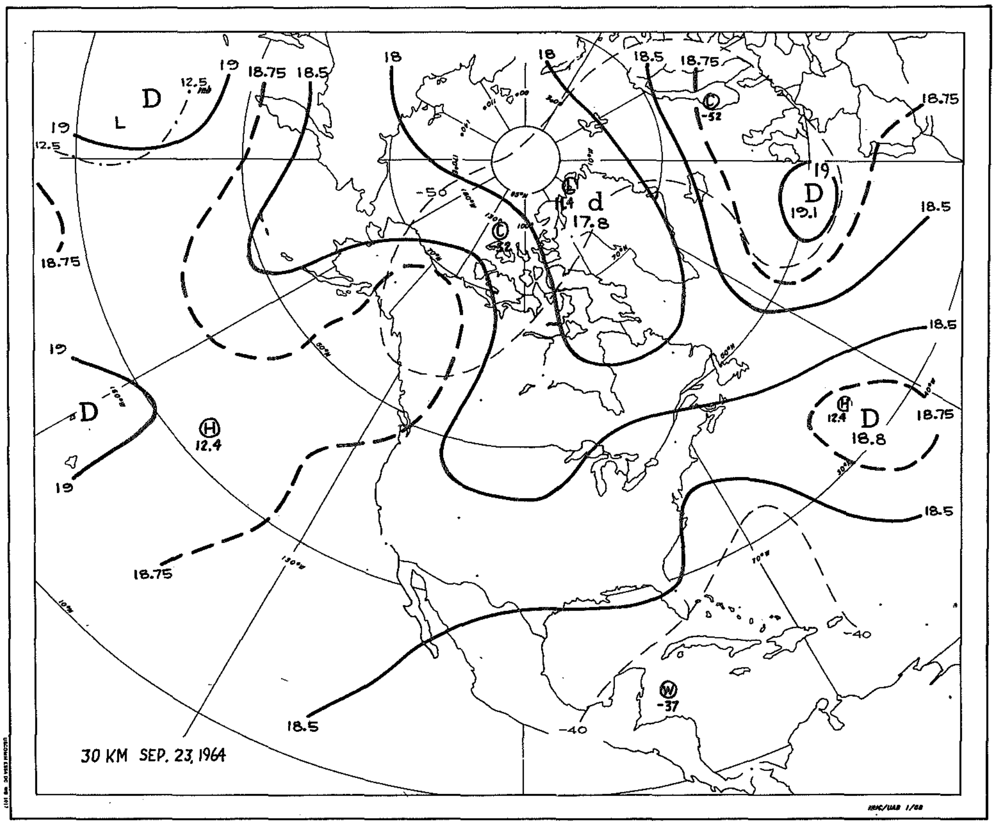


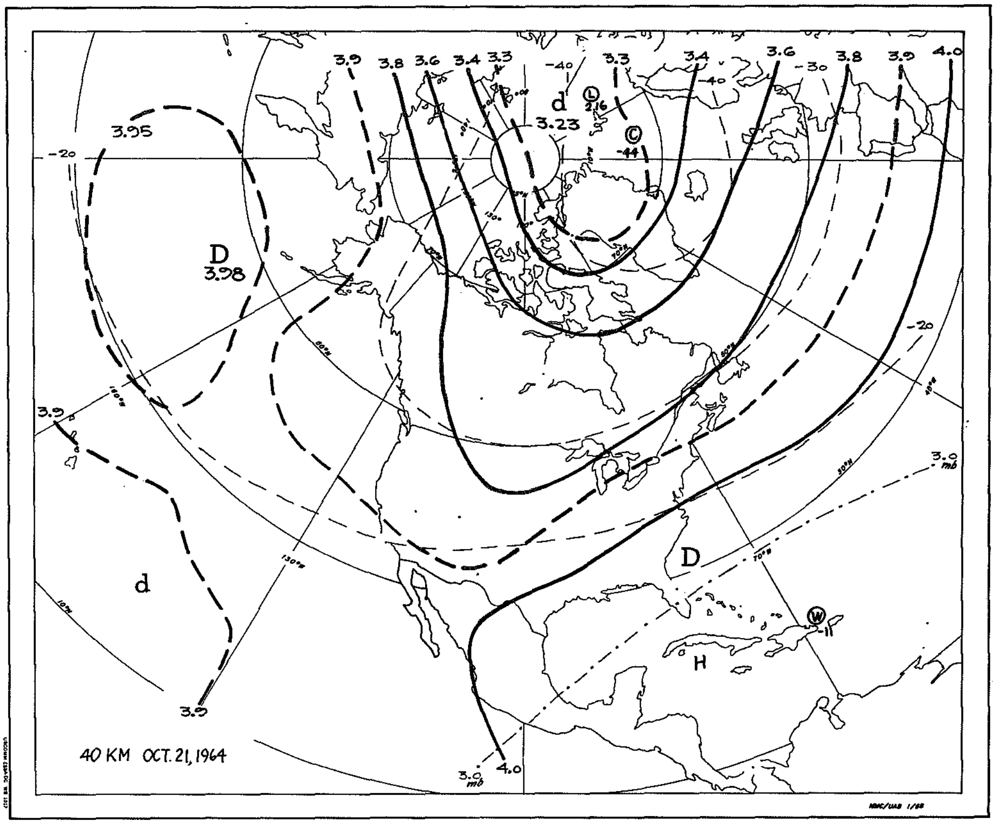
40 KM AUG. 26, 1964
3.0 mb

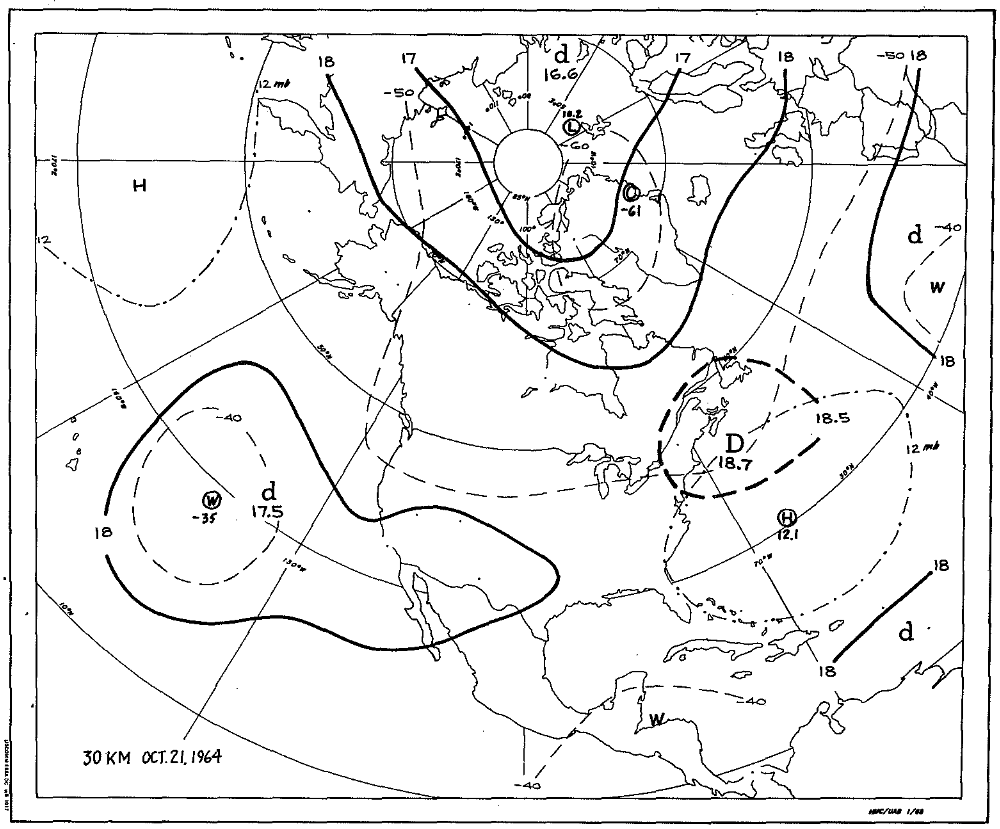


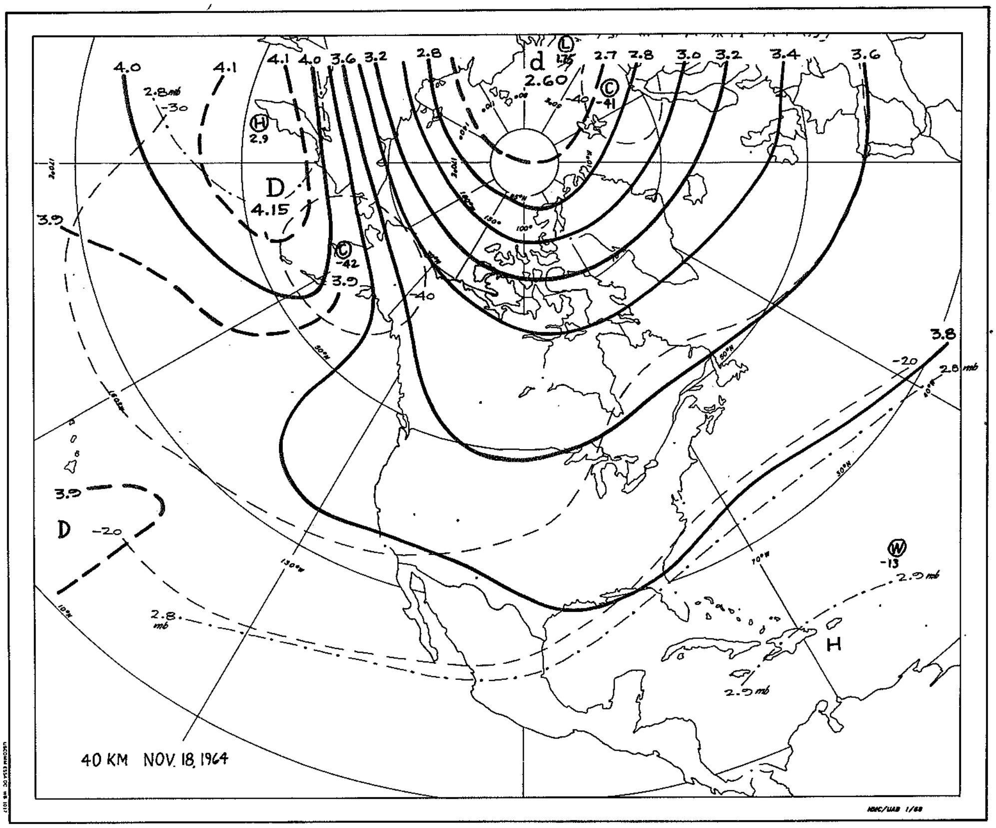
30 KM AUG. 26, 1964
12 mb

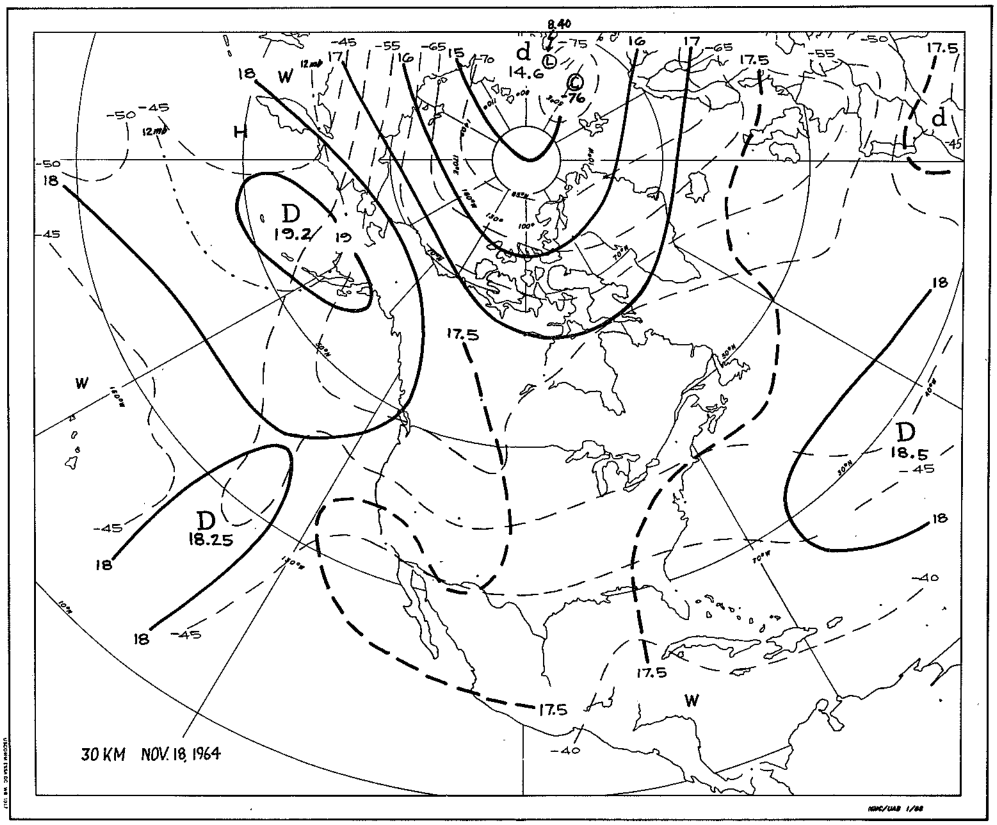

40 KM SEP. 23, 1964
D
4.23
4.2
4.1
4.0
3.9
3.8
d
2.5 mb
4.20
3.0 mb
H
-14
-20
-30
-40
3.03

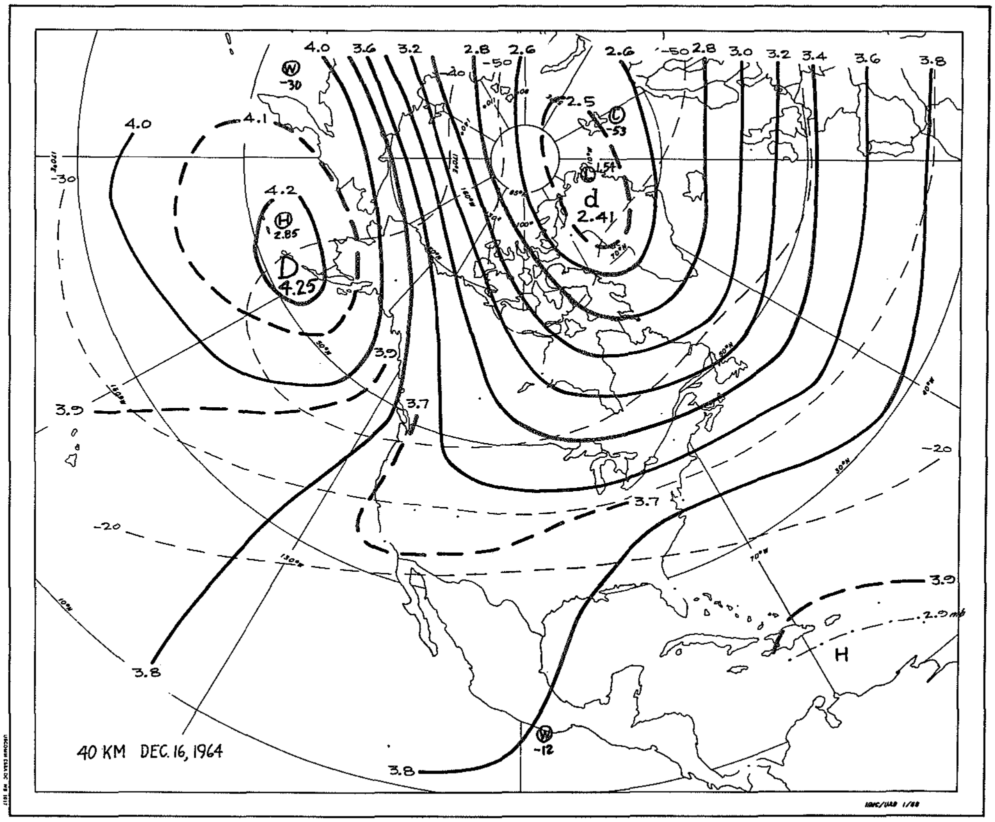

30 KM SEP. 23, 1964
D
12.5 mb
19
18.75
18.5
18
d
17.8
19.1
18.8
12.4
-52
-50
-37
-40

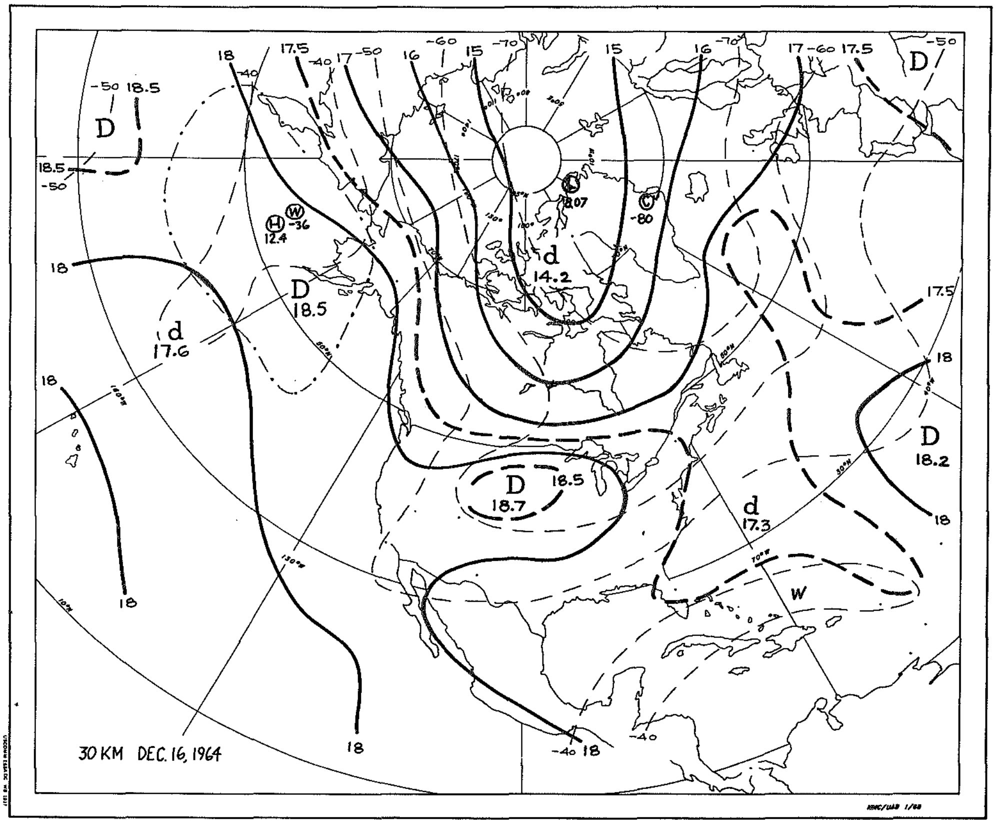

40 KM OCT. 21, 1964

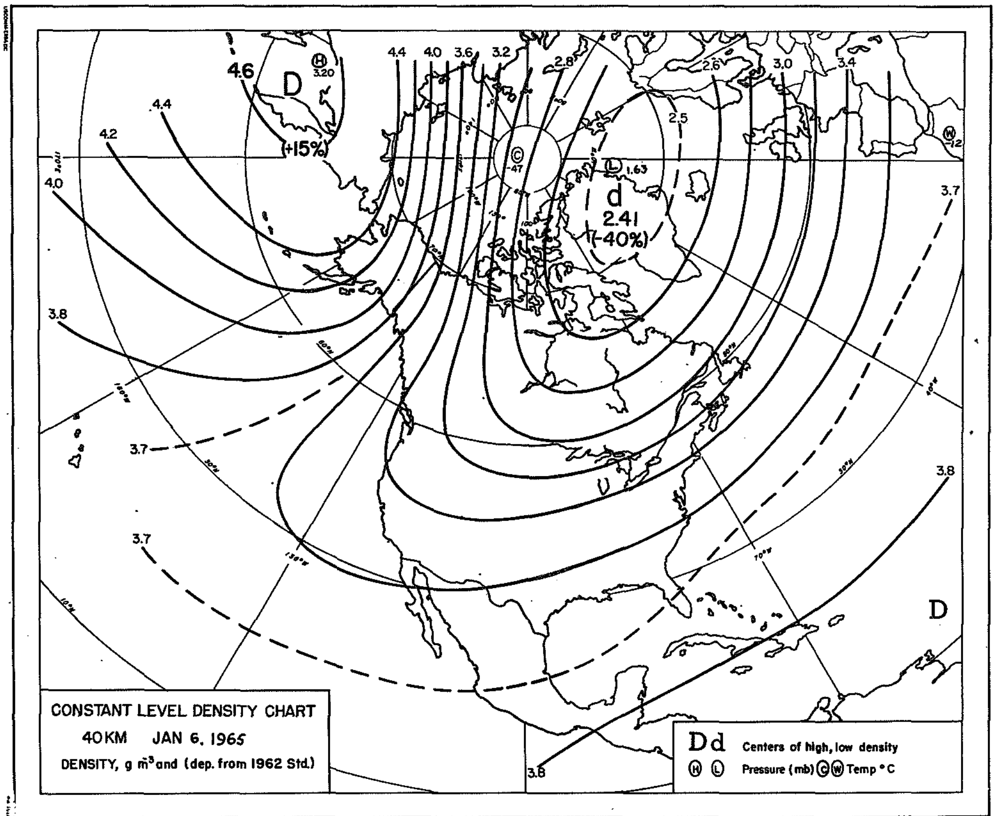

30 KM OCT. 21, 1964

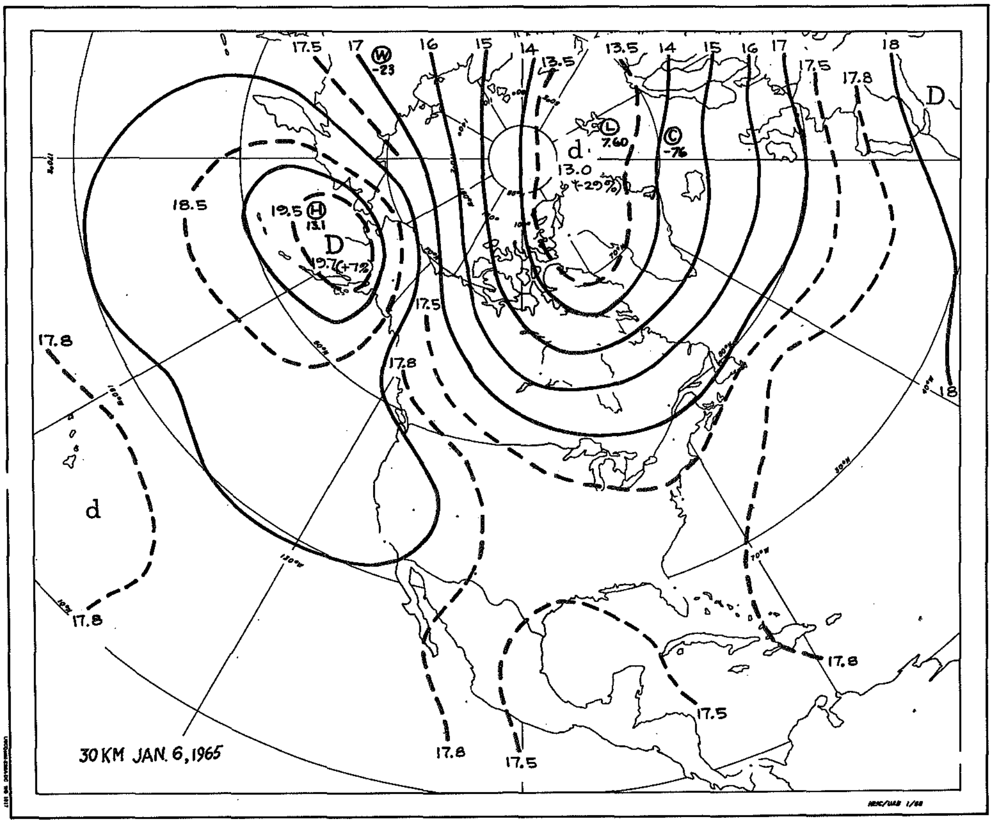

4.0
4.1
4.1
4.0
3.6
3.2
2.8
2.7
2.8
3.0
3.2
3.4
3.6
D
4.15
d
2.60
3.9
3.8
-40
-42
-41
-20
2.8 mb
2.9 mb
W
-13
H
D
40 KM NOV. 18, 1964

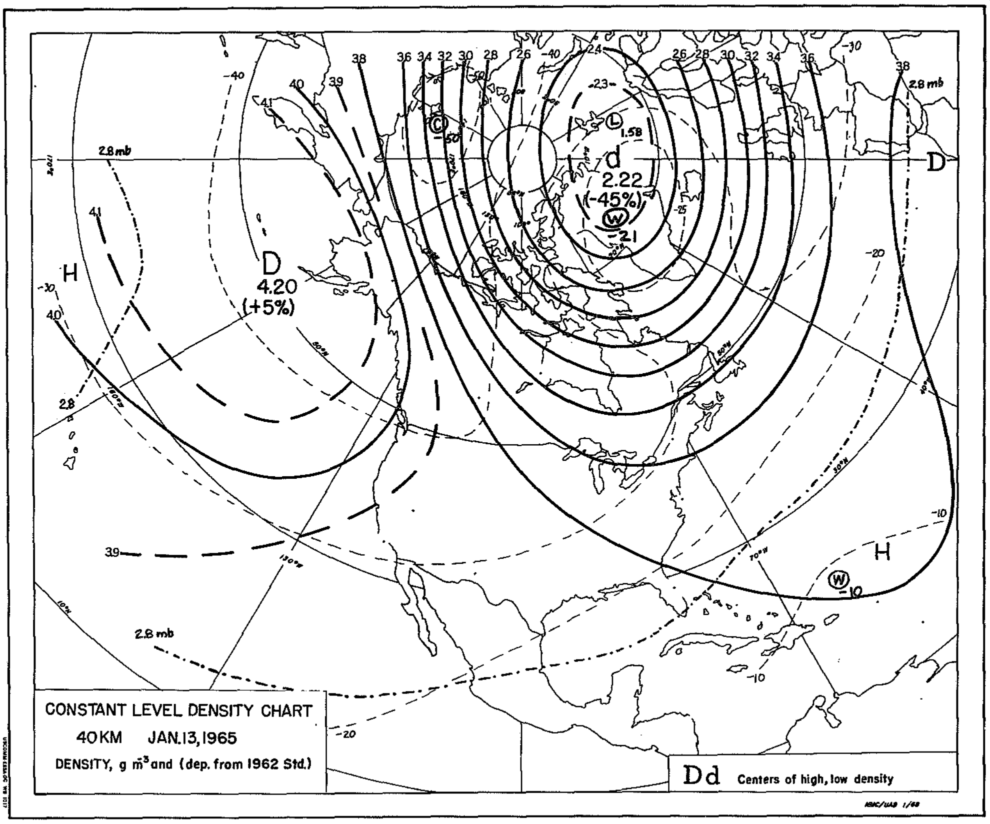

8.40
17
16
15
16
17
17.5
17.5
d
14.6
-76
D
19.2
19
D
18.25
D
18.5
18
W
H
W
d
-45
-50
-55
-65
-70
-75
-40
17.5
30 KM NOV. 18, 1964


40 KM DEC. 16, 1964

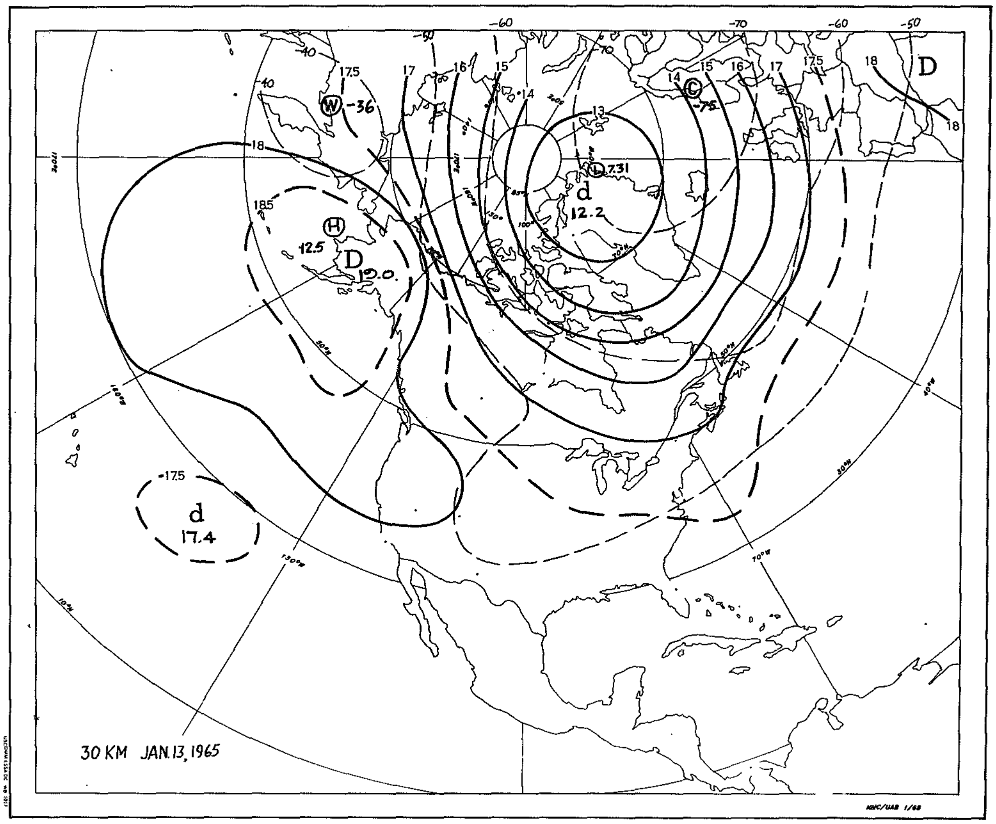

30 KM DEC. 16, 1964


CONSTANT LEVEL DENSITY CHART
40KM JAN 6, 1965
DENSITY, g m⁻³ and (dep. from 1962 Std.)
Dd Centers of high, low density
Pressure (mb) Temp °C
D
d
2.41
(-40%)
(+15%)
4.6
D

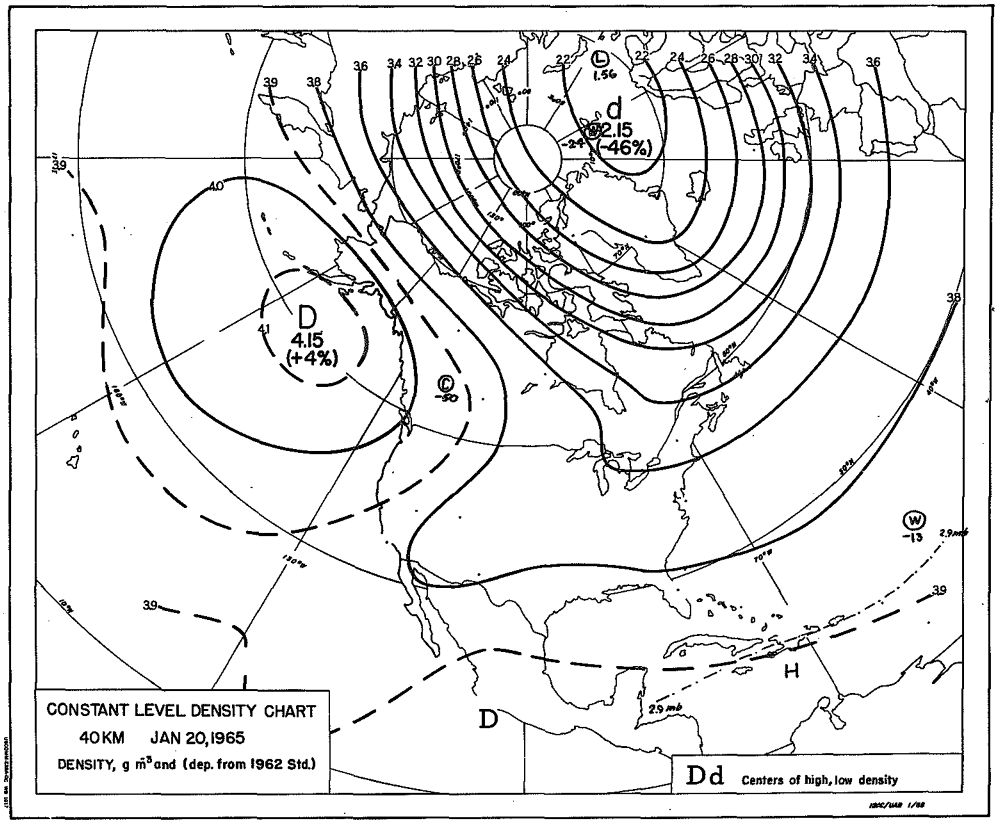

30 KM JAN. 6, 1965
D
19.7 (+7%)
d
13.0
(-29%)
d
D

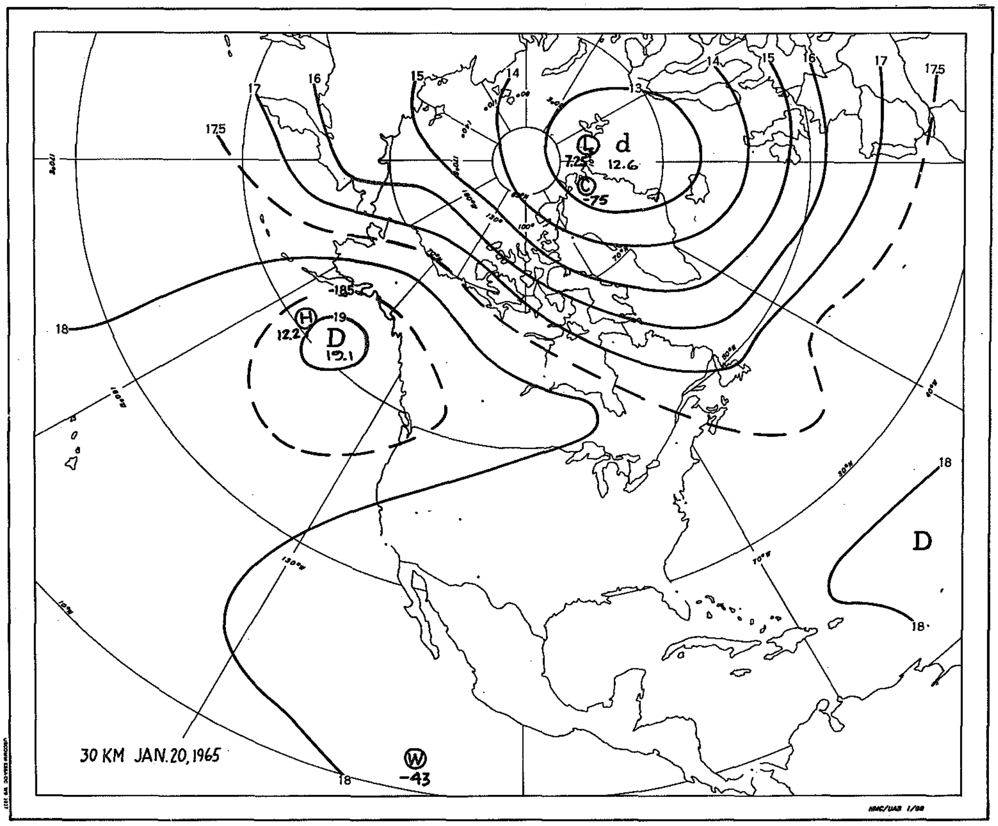


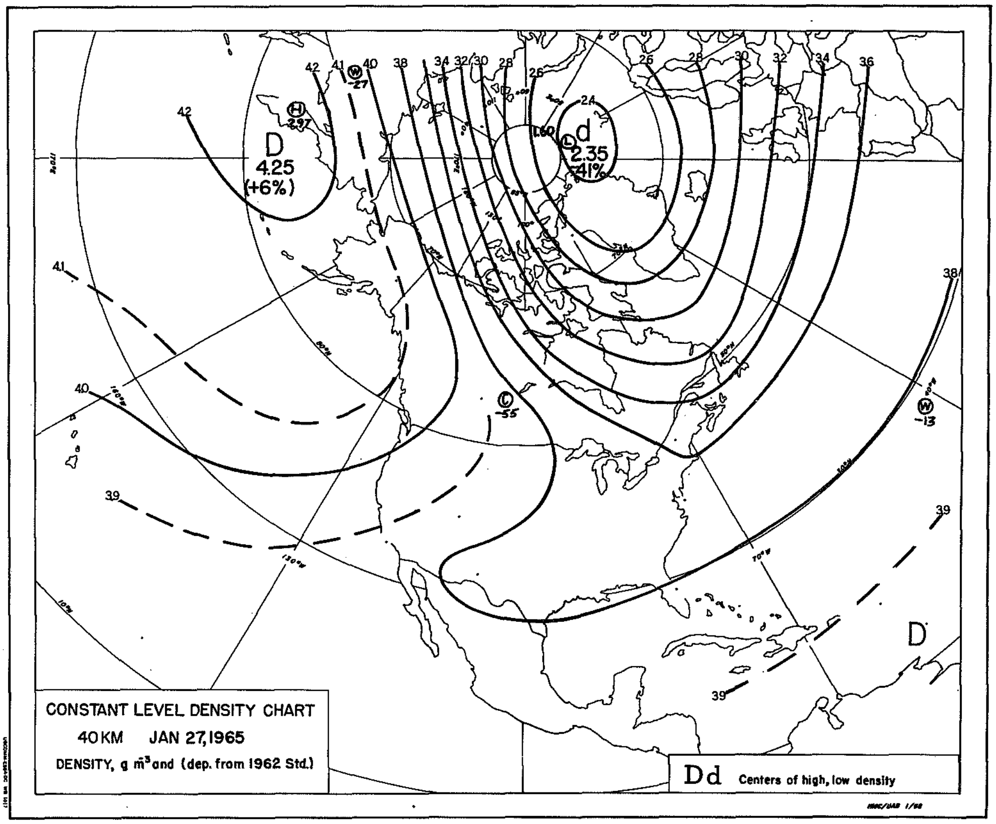
CONSTANT LEVEL DENSITY CHART
40 KM JAN.13,1965
DENSITY, g m⁻³ and (dep. from 1962 Std.)
Dd Centers of high, low density
D
4.20
(+5%)
d
2.22
(-45%)
2.8 mb
H

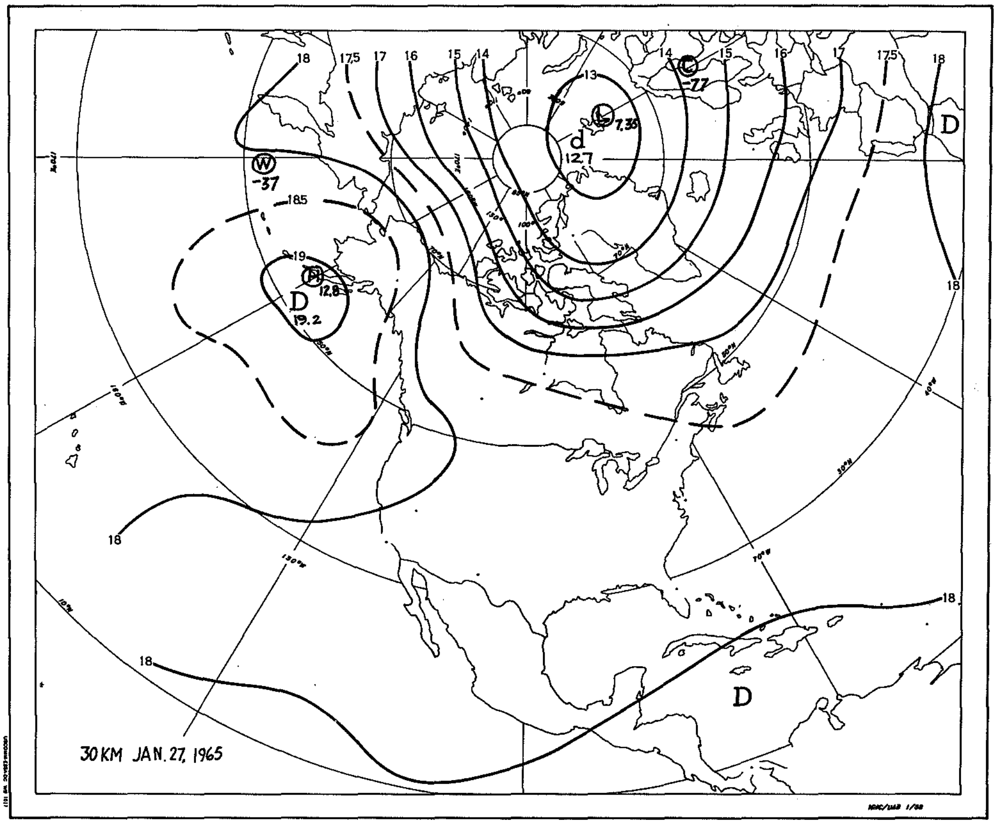


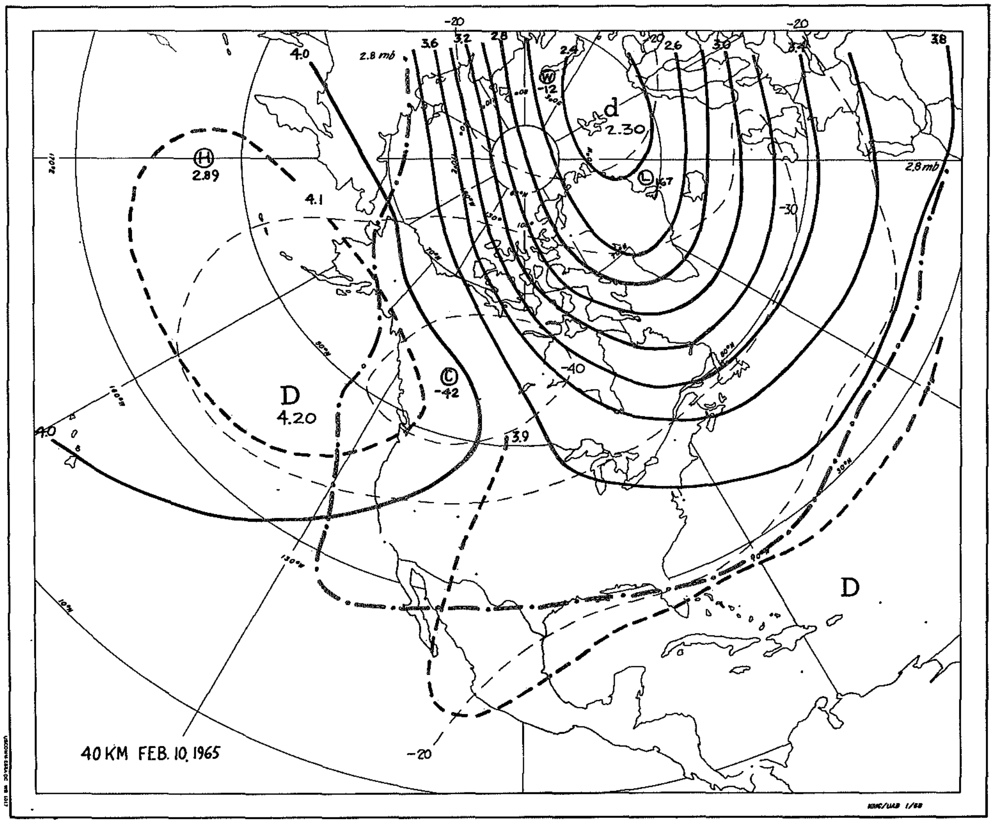
30 KM JAN.13, 1965
D
19.0
d
12.2
d
17.4
D

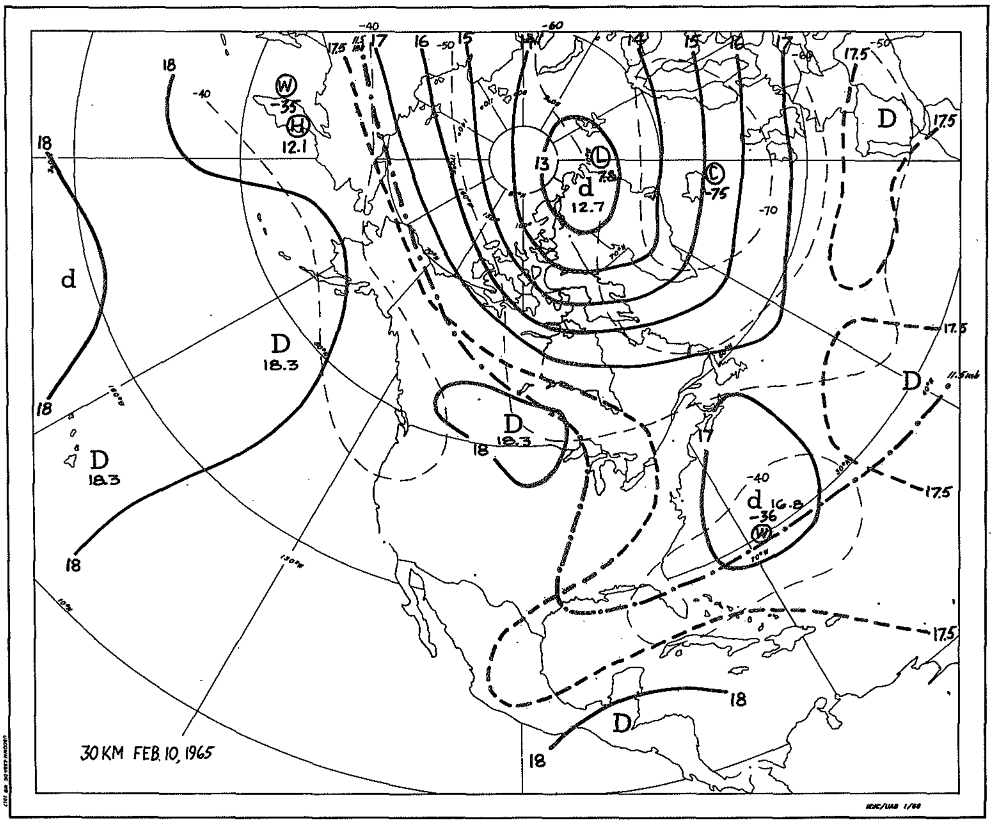

CONSTANT LEVEL DENSITY CHART
40 KM JAN 20, 1965
DENSITY, g m⁻³ and (dep. from 1962 Std.)
D
4.15
(+4%)
d
2.15
(-46%)
1.56
-50
-13
2.9 mb
H
D
Dd Centers of high, low density

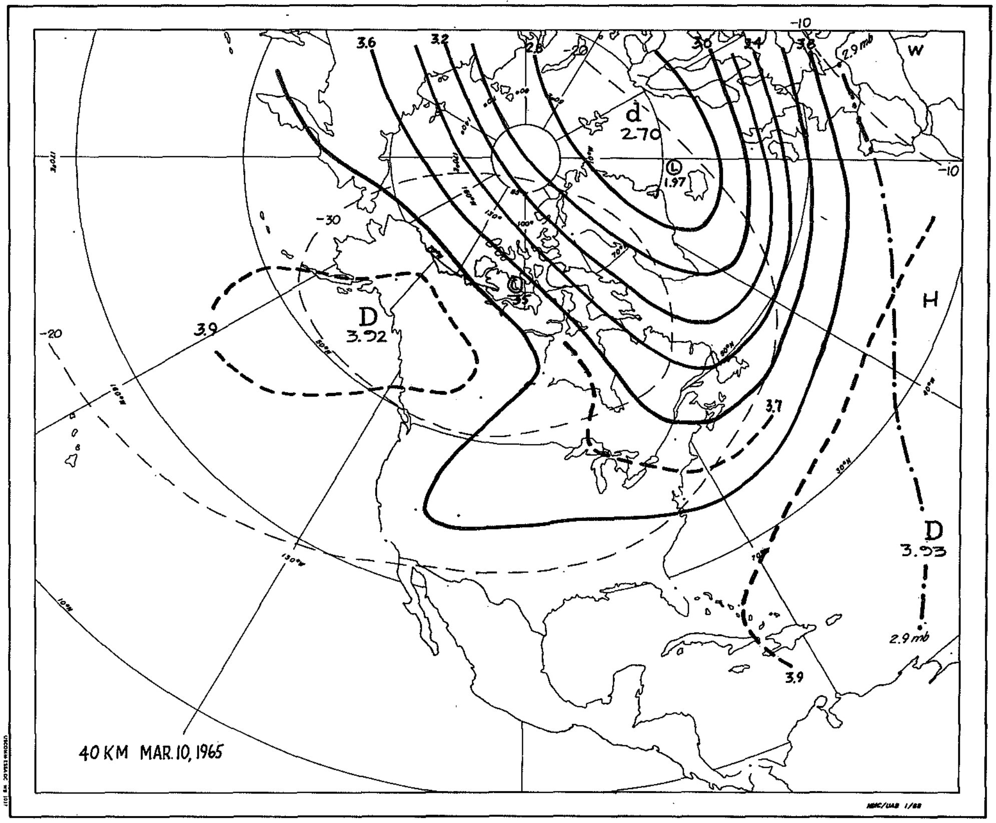

30 KM JAN. 20, 1965
d
12.6
7.25
-75
D
13.1
12.2
D
-43


CONSTANT LEVEL DENSITY CHART
40 KM JAN 27, 1965
DENSITY, g m^{-3} and (dep. from 1962 Std.)
Dd Centers of high, low density
D
4.25
(+6%)
d
2.35
-41%
D

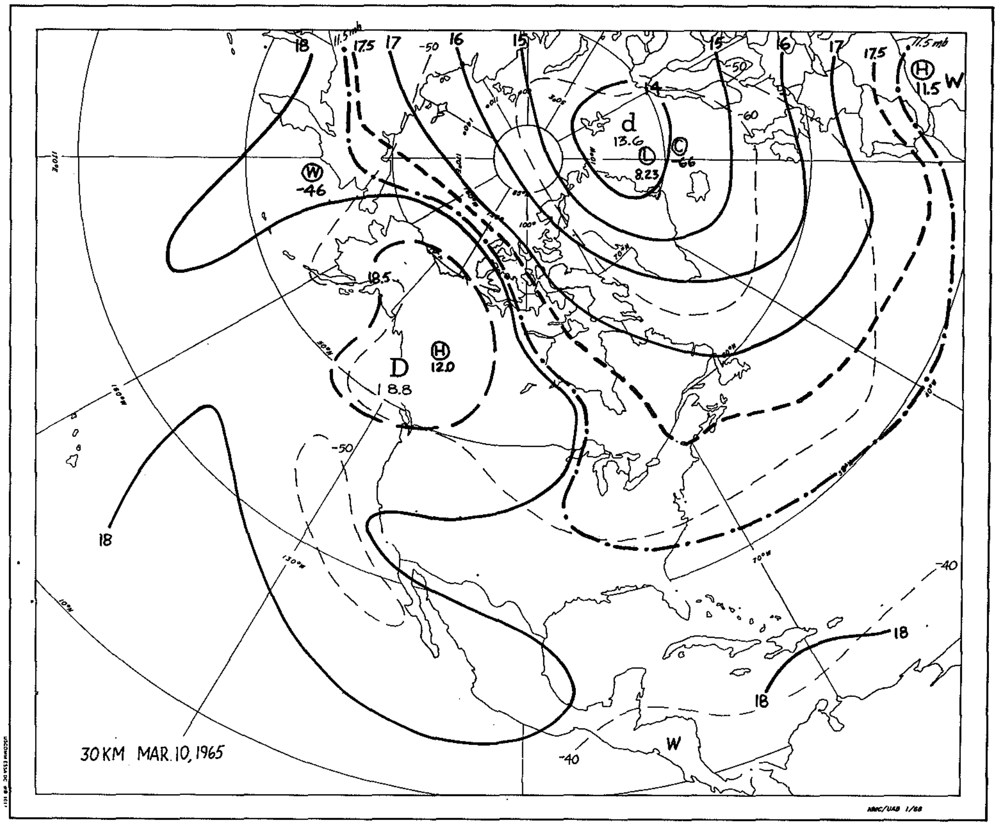

30 KM JAN. 27, 1965
d
12.7
D
19.2
D
D


40 KM FEB. 10, 1965
D
4.20
d
2.30
2.89
-42
2.8 mb
-20
-30
-40

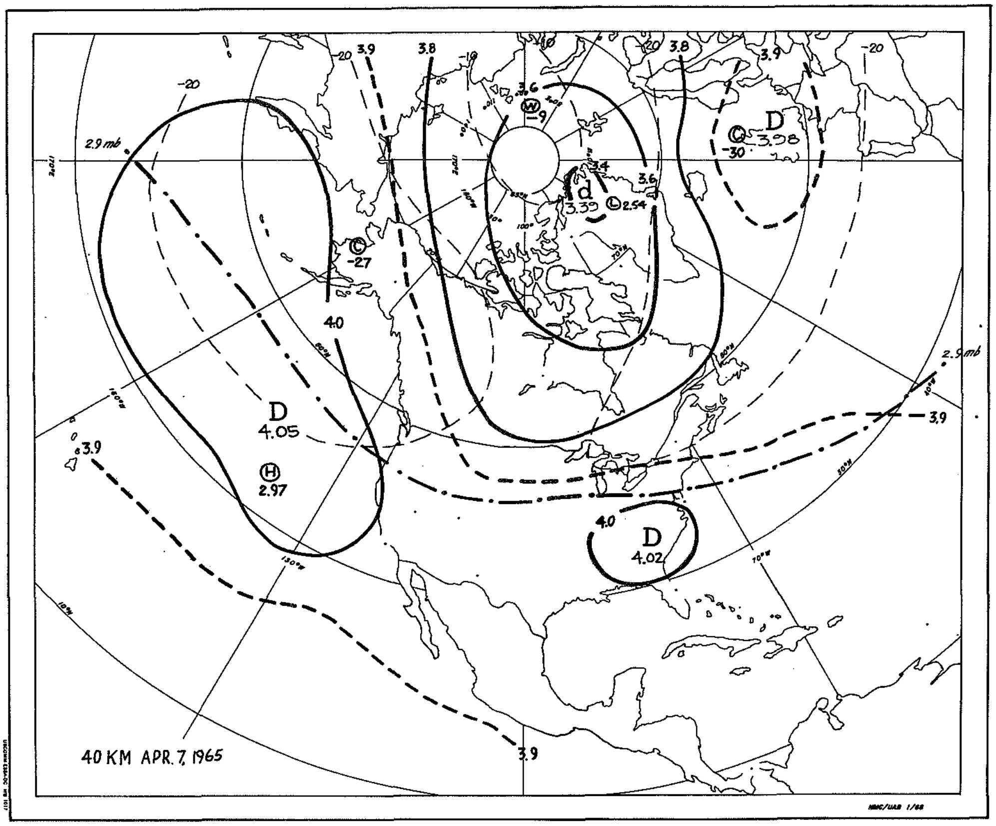

30 KM FEB. 10, 1965
D
18.3
d
12.7
16.8
12.1
-35
-75
-36
17.5
18
-40
-50
-60
-70

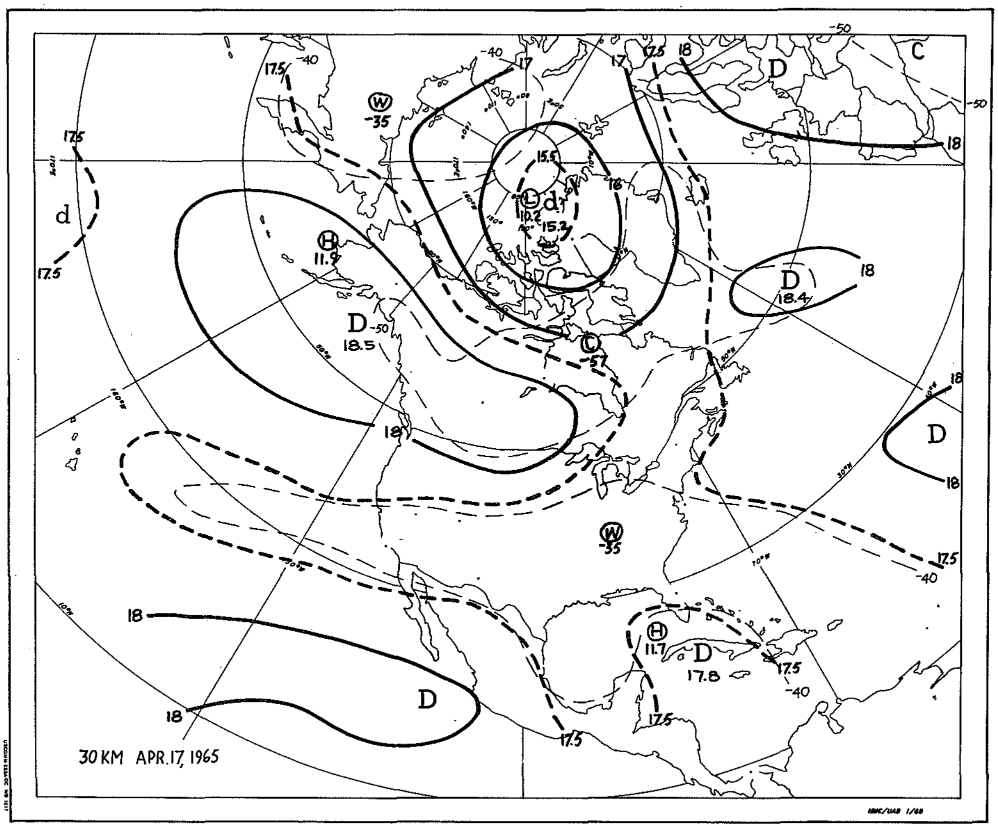


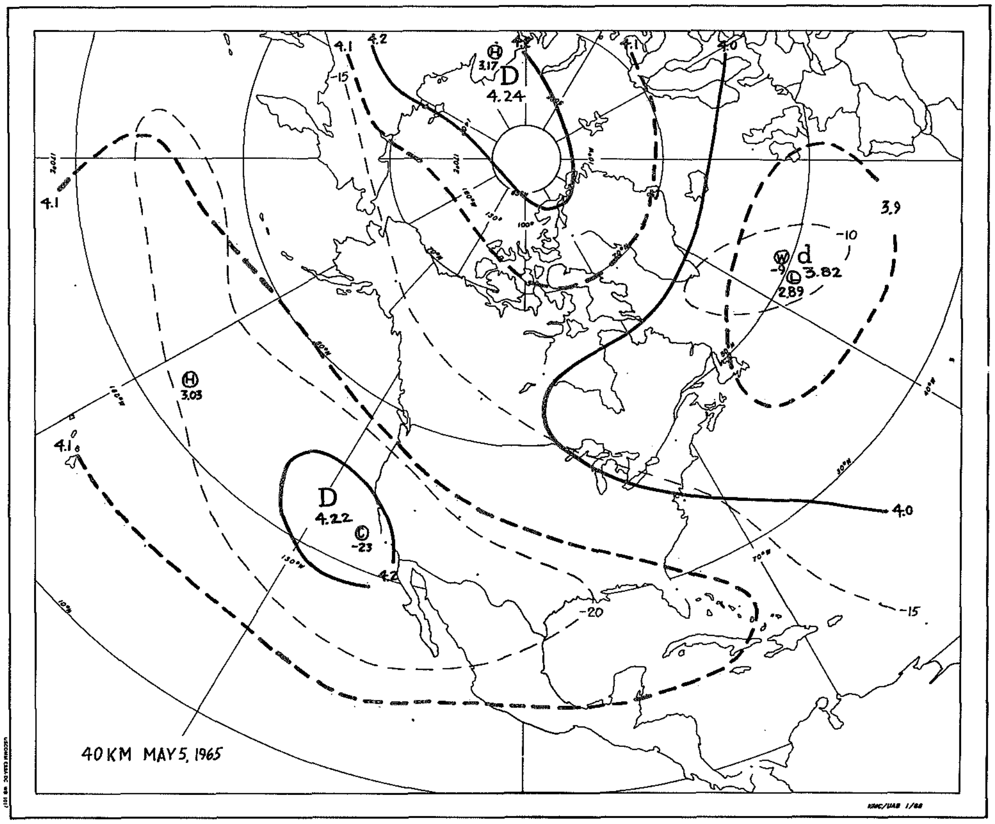
3.6
3.2
2.8
-20
3.0
3.4
3.8
-10
2.9 mb
W
d
2.70
L
1.97
-10
-30
D
3.92
3.9
-20
H
3.7
D
3.93
2.9 mb
3.9
40 KM MAR. 10, 1965



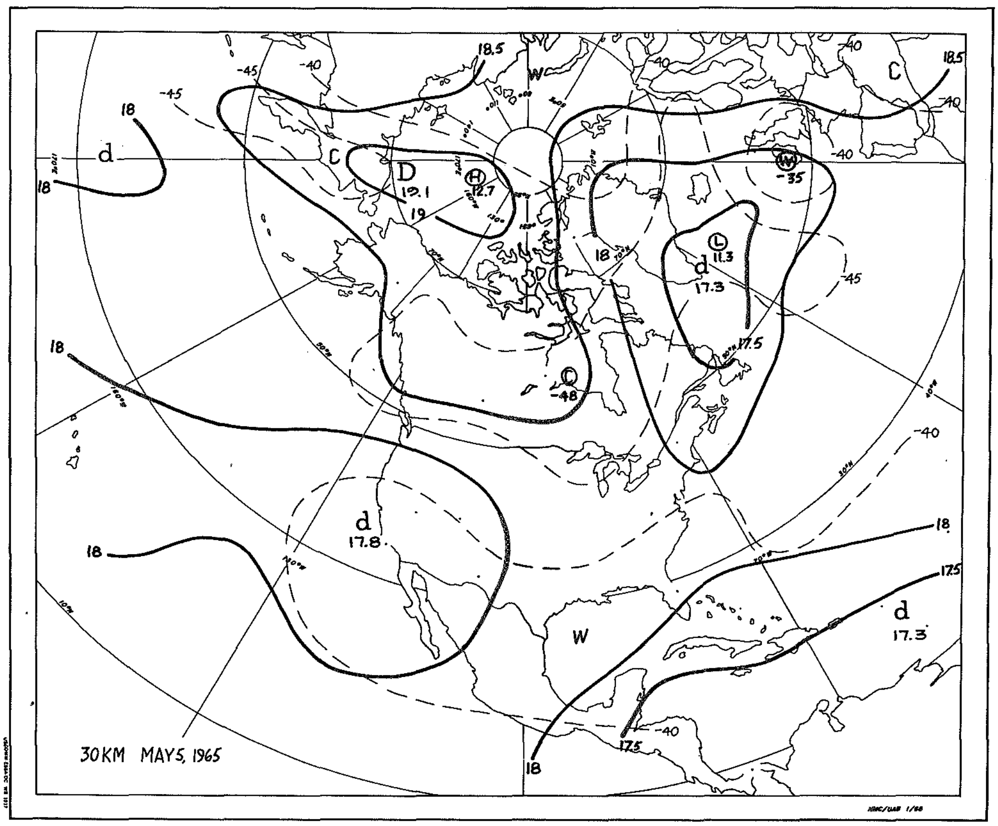
18
11.5 mb
17.5
17
-50
16
15
14
15
-50
16
17
17.5
11.5 mb
H
11.5
W
d
13.6
L
8.23
C
-66
-60
W
-46
18.5
H
12.0
D
18.8
-50
18
-40
18
18
-40
W
30 KM MAR. 10, 1965


40 KM APR. 7, 1965

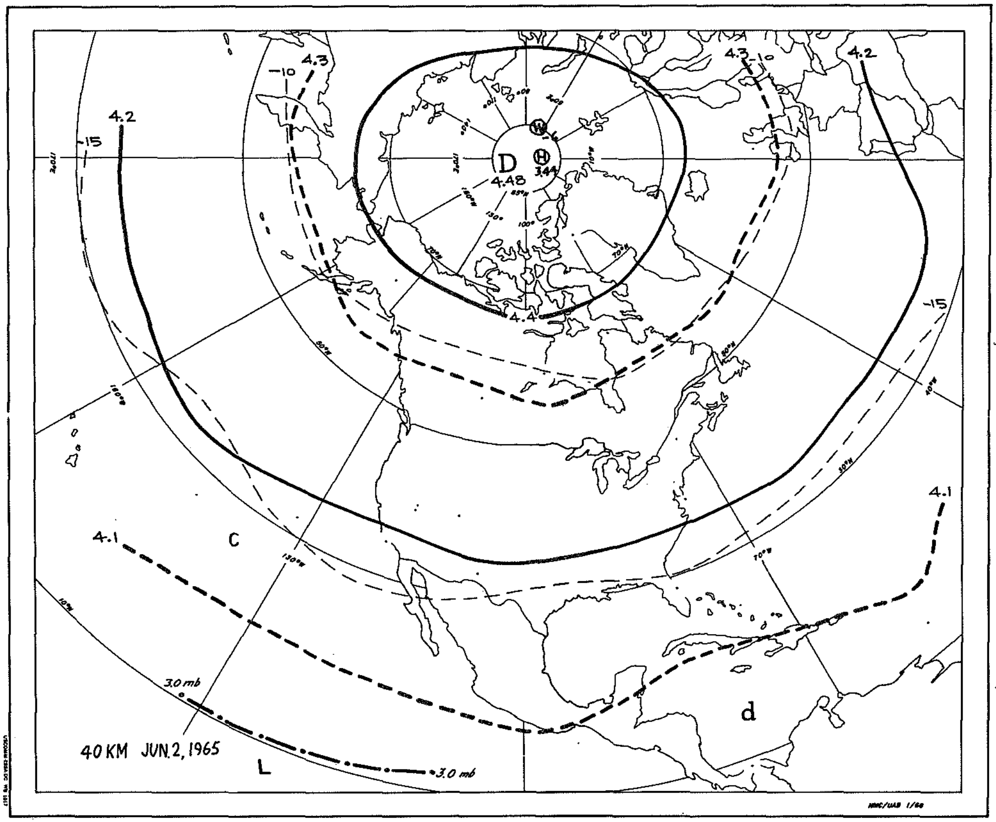

30 KM APR. 17, 1965

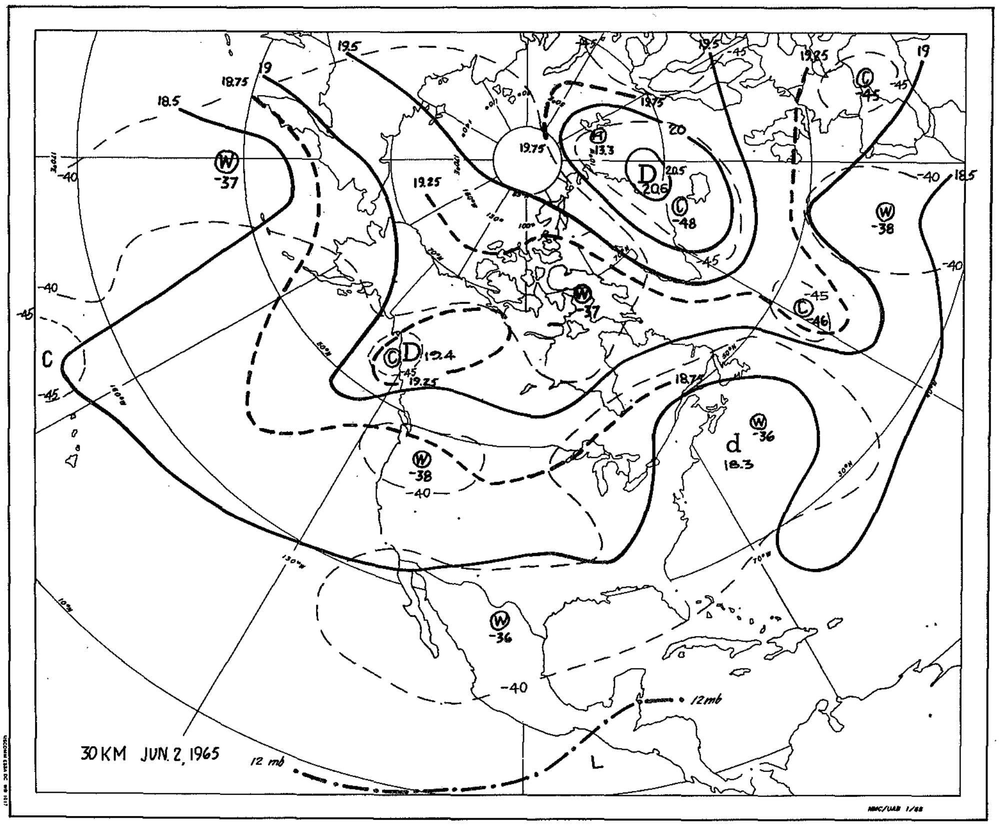


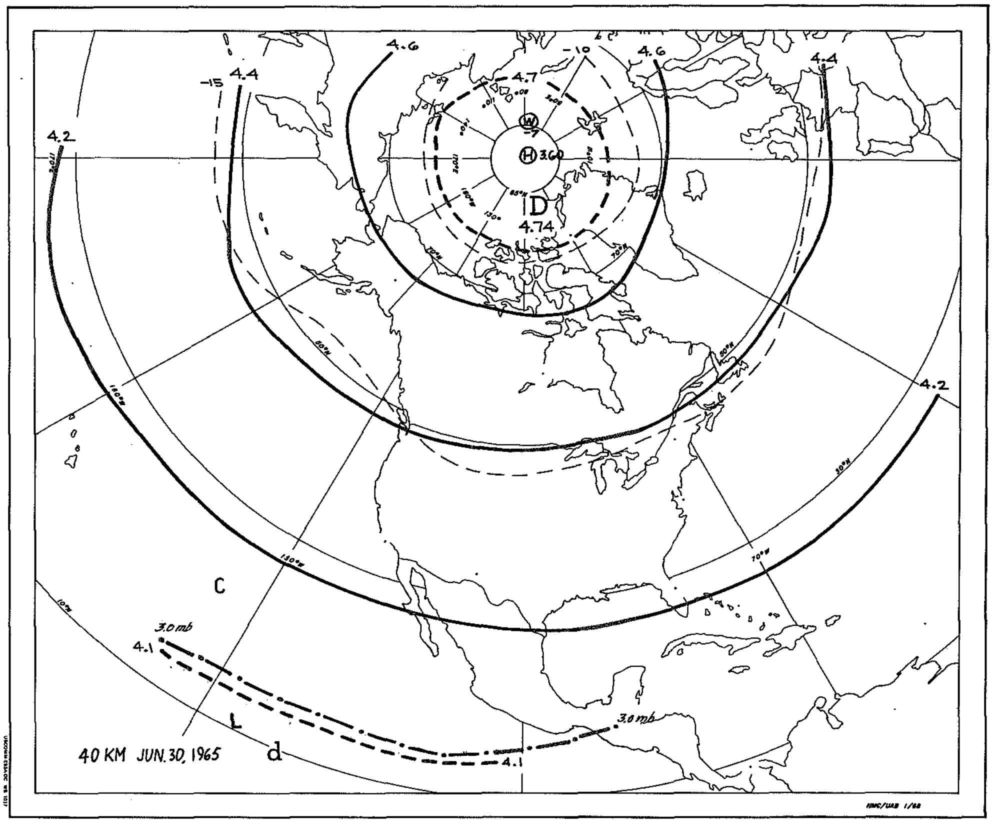
40 KM MAY 5, 1965
D
4.24
3.17
4.22
-23
3.03
3.82
2.89
4.0
3.9
4.1
4.2
-15
-20
-10

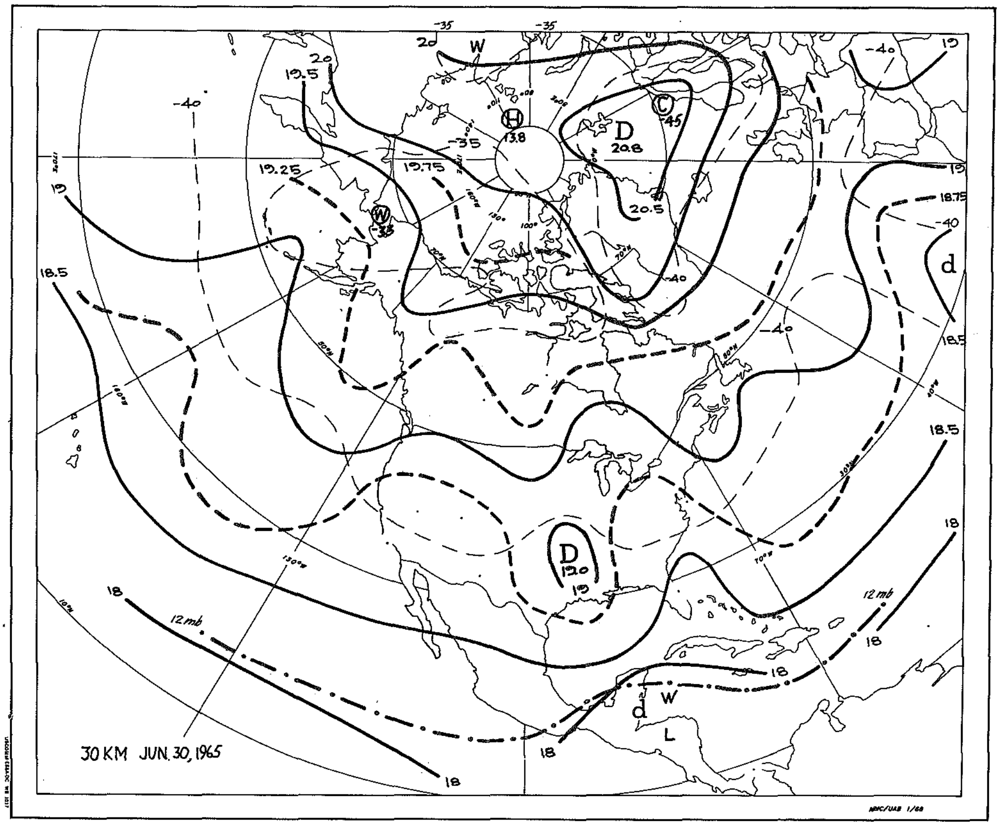


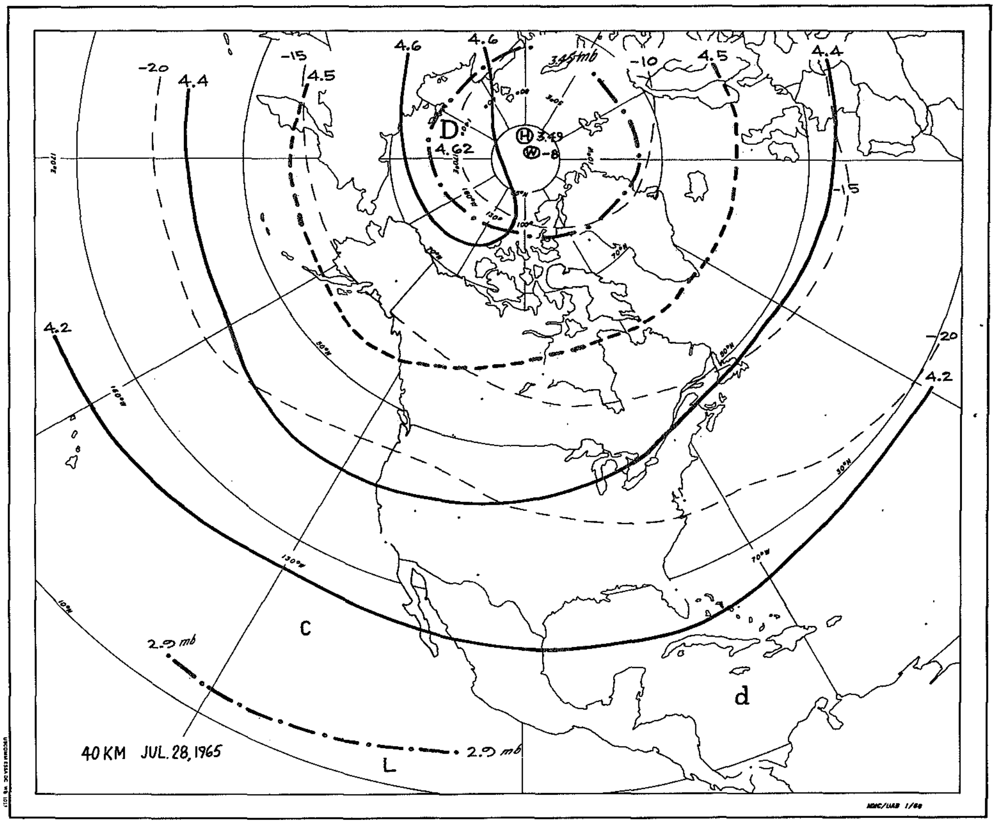
30 KM MAY 5, 1965
D
19.1
12.7
11.3
17.3
17.8
-48
-35
18.5
18
17.5
-40
-45

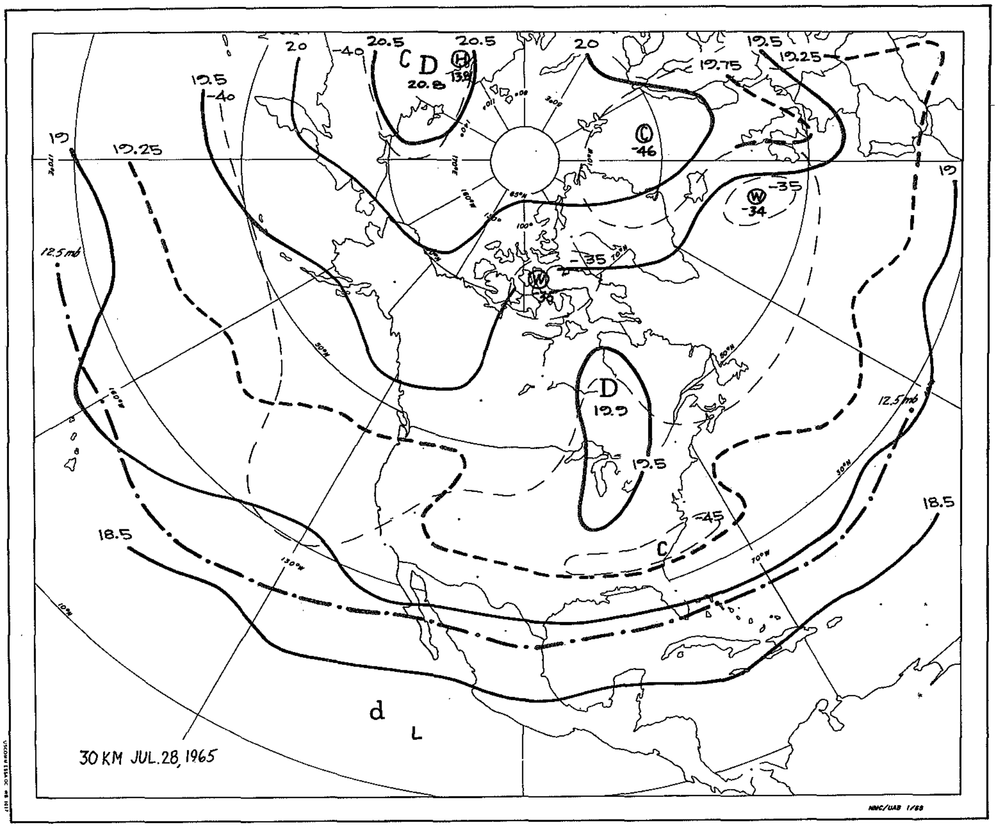

40 KM JUN. 2, 1965
3.0 mb
L
d
C
D
4.48
3.44
4.1
4.2
4.3
4.4
-10
-15

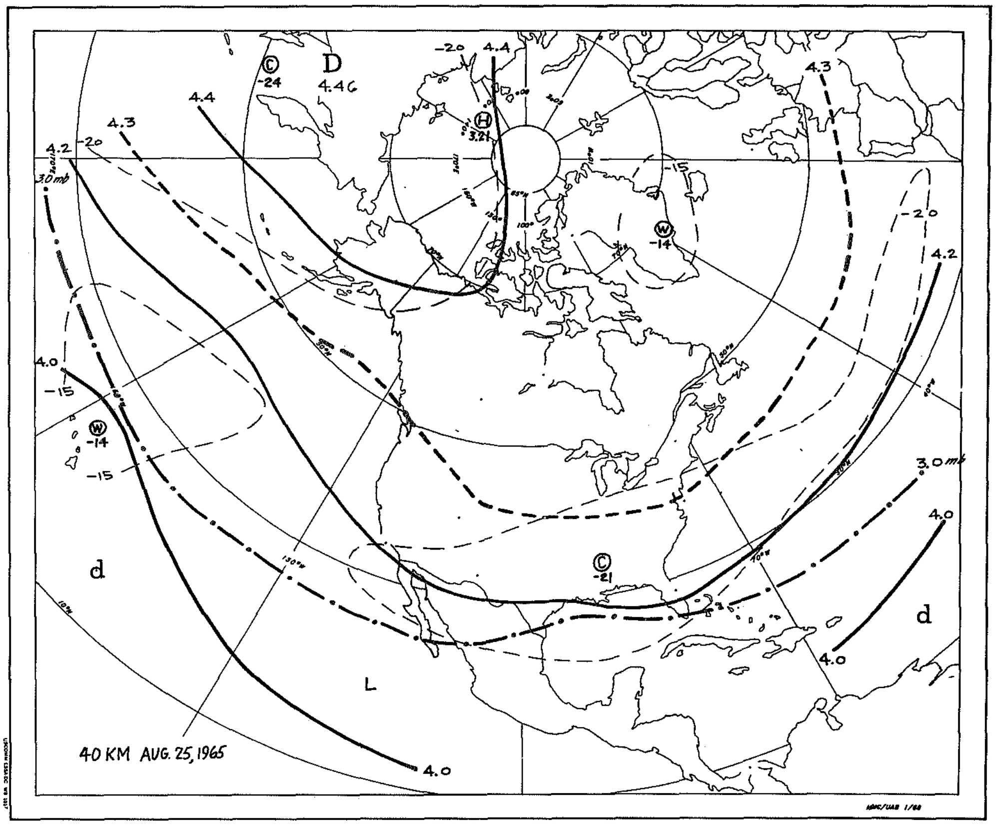

30 KM JUN. 2, 1965
12 mb
L
d
C
D
20.6
19.4
18.3
13.3
18.5
18.75
19
19.25
19.5
19.75
20
20.5
-37
-38
-36
-48
-46
-40
-45

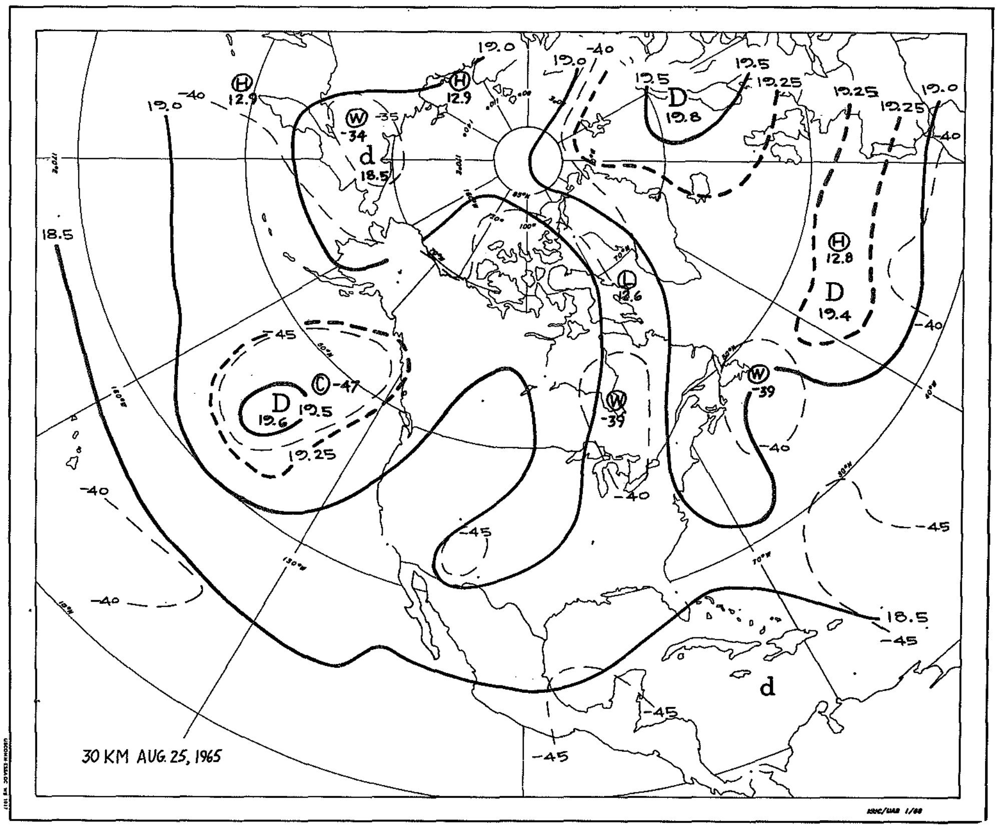

40 KM JUN. 30, 1965
3.0 mb
4.1
4.2
4.4
4.6
4.7
4.74
-15
-10
3.60
D
C
L
d

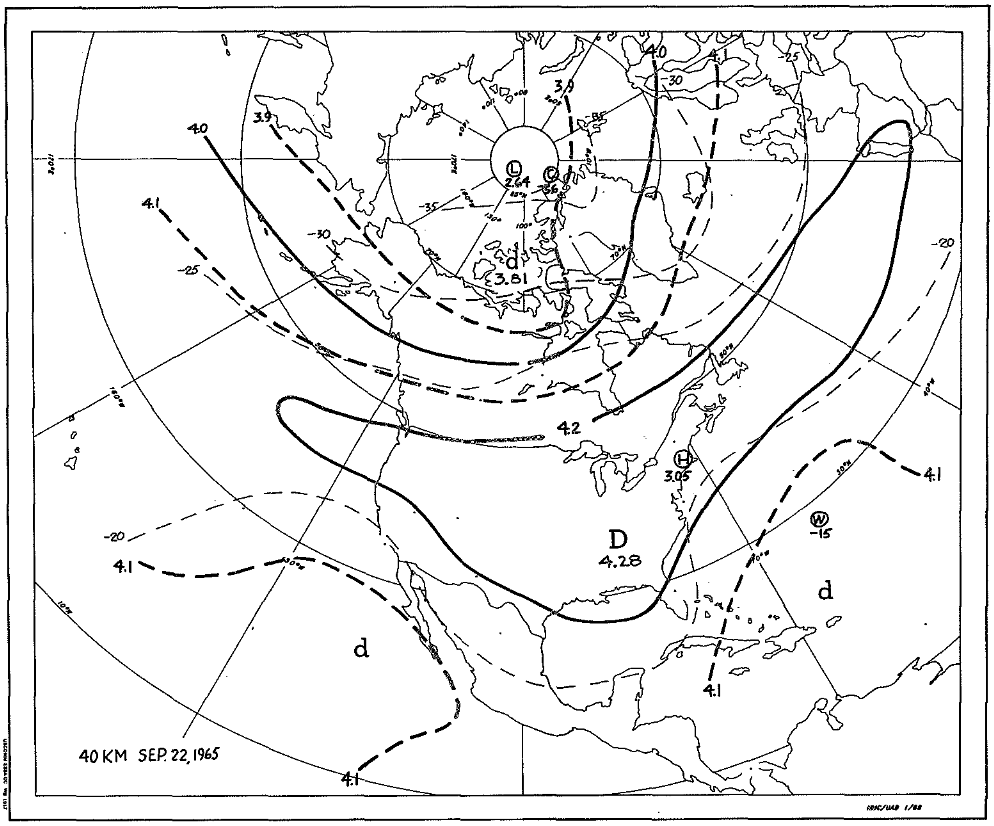

30 KM JUN. 30, 1965
12 mb
18
18.5
18.75
19
19.25
19.5
19.75
20
20.5
20.8
13.8
12.0
-35
-40
-45
D
W
C
L
d

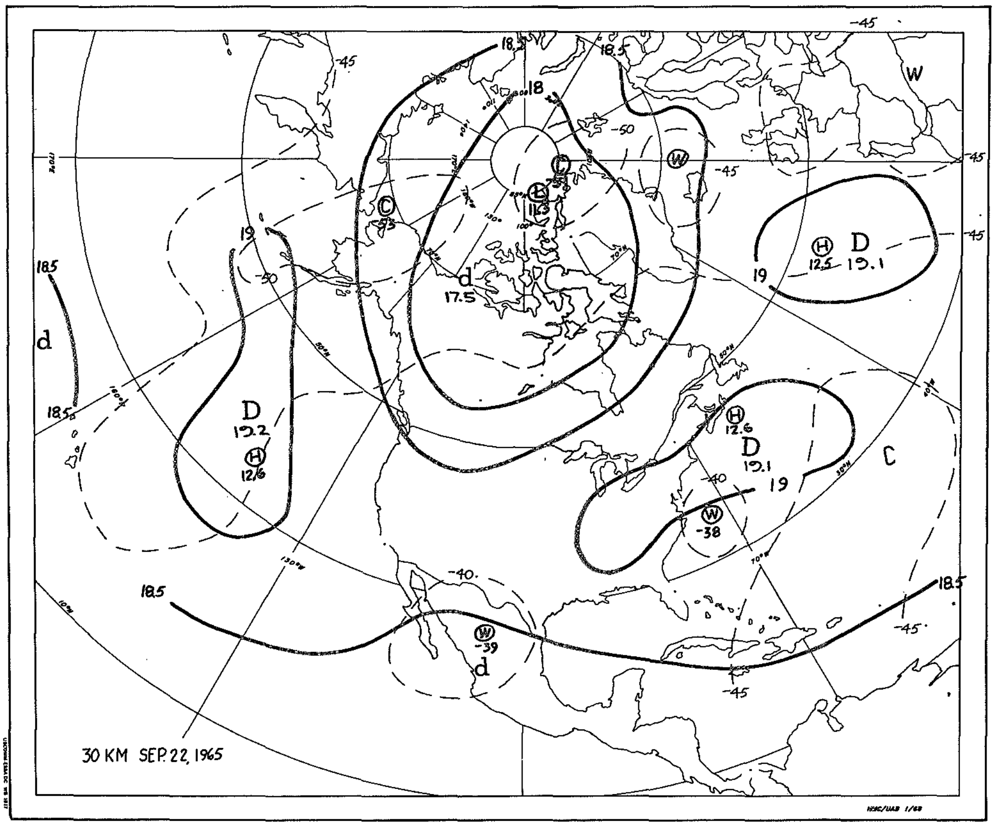

40 KM JUL. 28, 1965
3.45 mb
2.9 mb
2.9 mb
4.62
3.49
4.6
4.5
4.4
4.2
-20
-15
-10
C
d
L
D

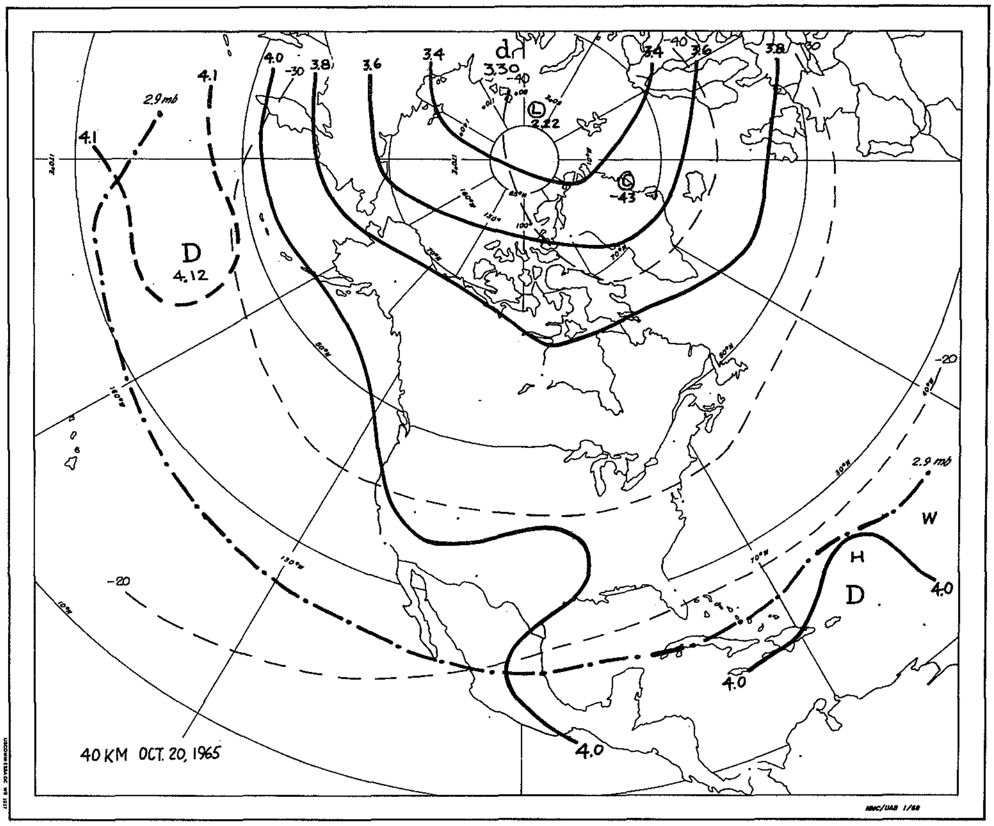

30 KM JUL. 28, 1965
12.5 mb
12.5 mb
20.8
19.9
20.5
20
19.5
19.75
19.25
19
18.5
-40
-46
-35
-34
-45
C
D
d
L

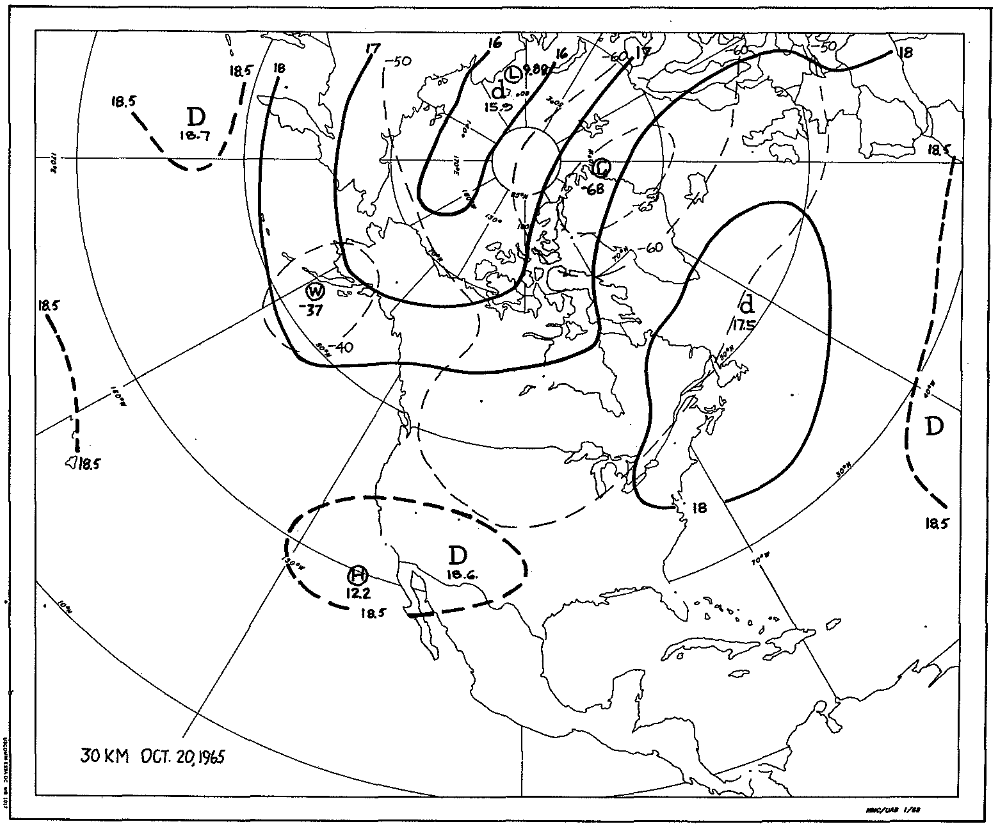

40 KM AUG. 25, 1965
3.0 mb
4.4
4.3
4.2
4.0
4.46
3.21
-24
-21
-14
-15
-20
d
L

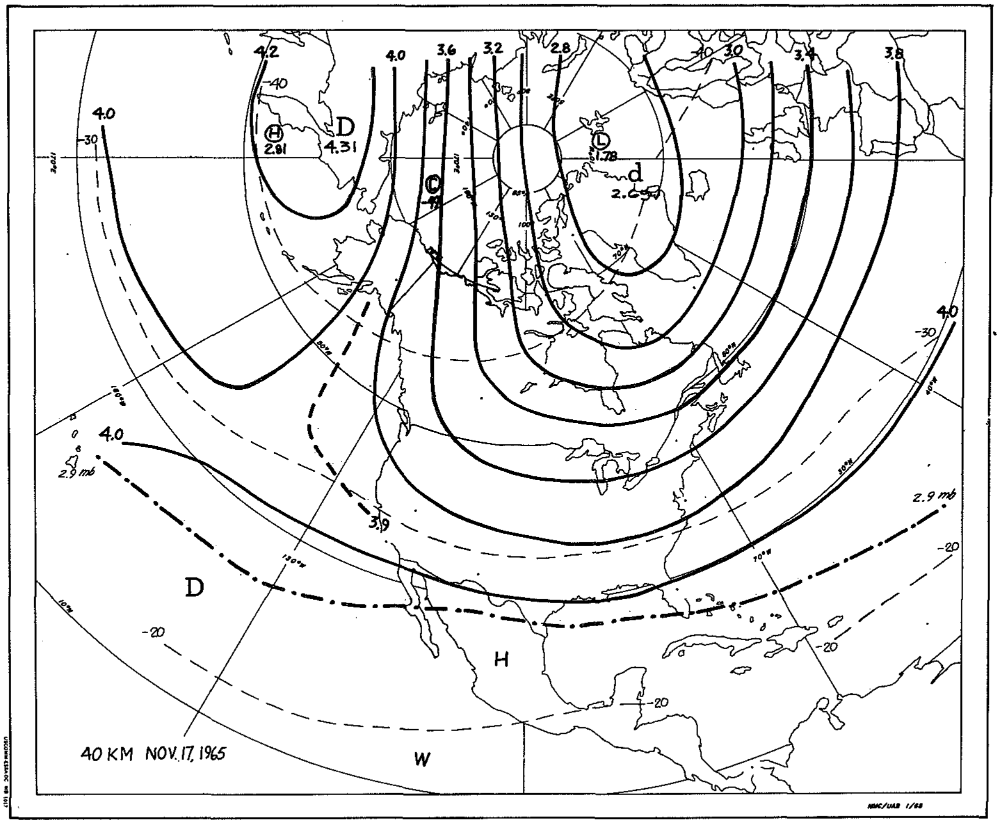

30 KM AUG. 25, 1965
19.0
19.25
19.5
18.5
12.9
12.8
12.6
19.8
19.4
19.6
18.5
-34
-35
-39
-40
-45
-47
d

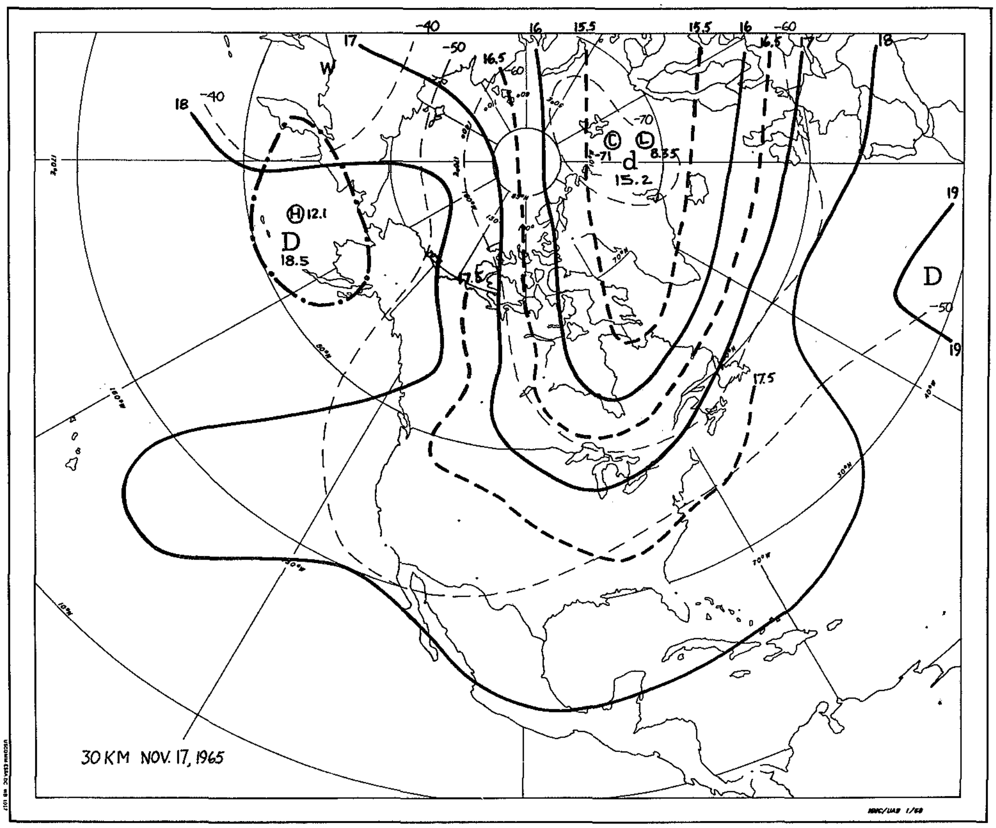

40 KM SEP. 22, 1965
D
4.28
d
3.81
d
d
2.64
3.05
-15
4.0
3.9
4.1
4.2
-20
-25
-30
-35

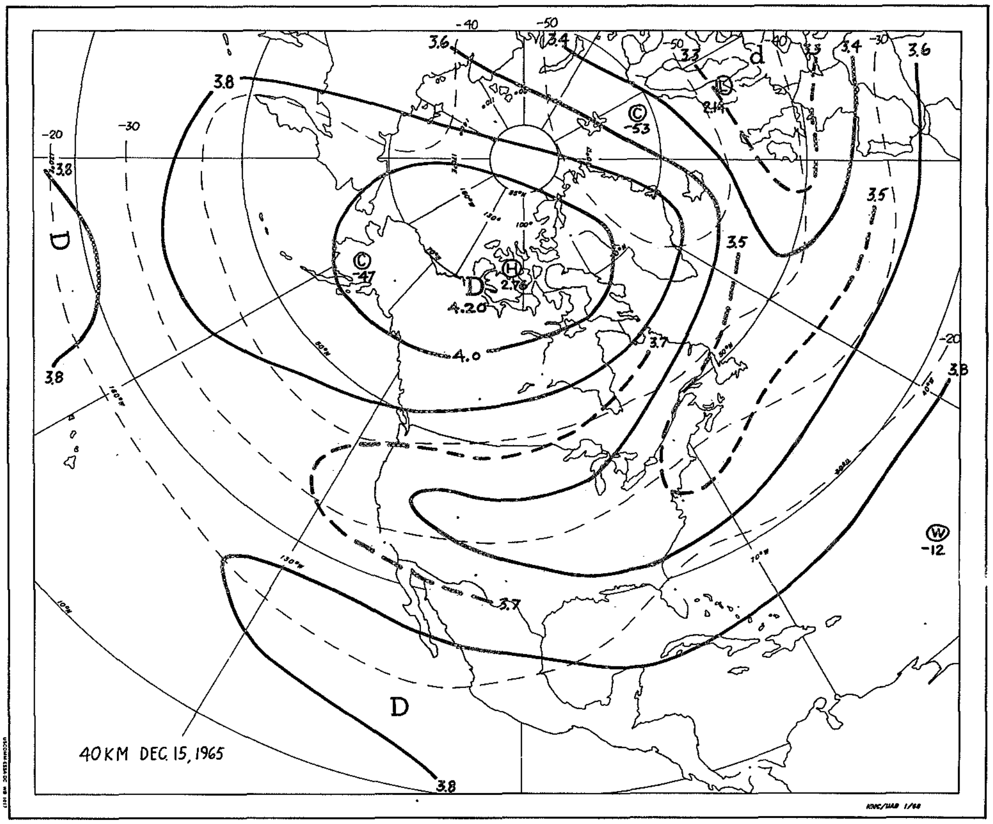

30 KM SEP. 22, 1965
D
19.2
12.6
D
19.1
12.5
D
19.1
12.6
d
17.5
d
d
-38
-39
18.5
18
19
-40
-45
-50
W
C

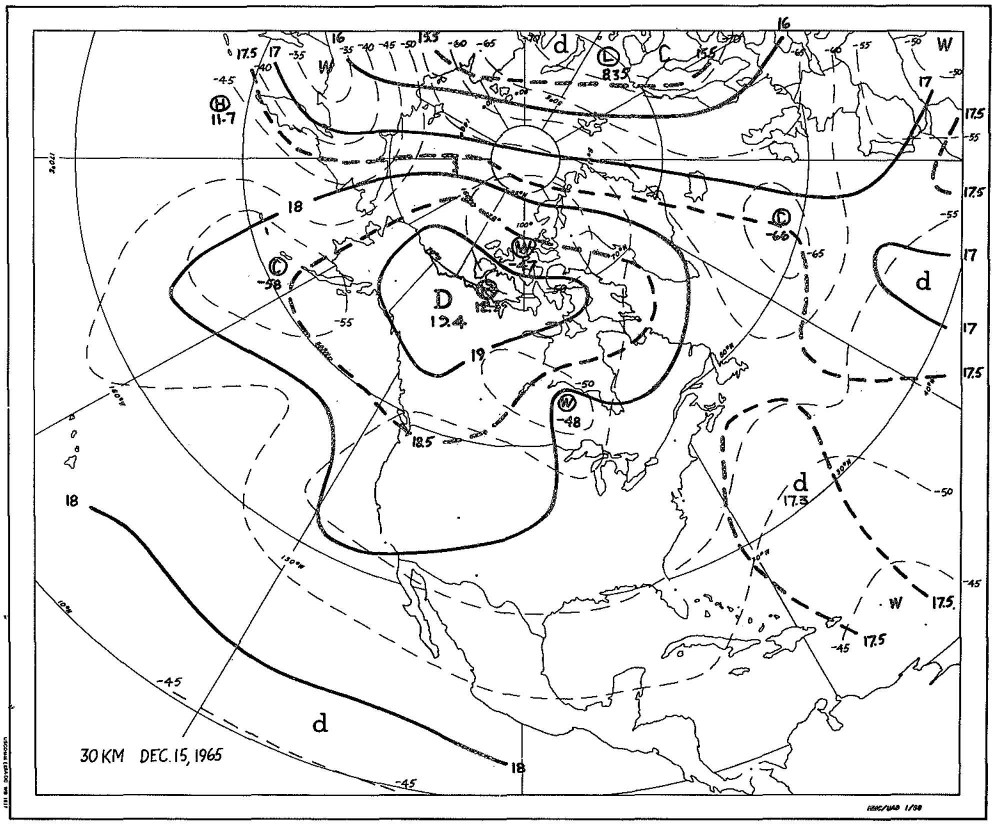

40 KM OCT. 20, 1965
2.9 mb
D
4.12
d
3.30
2.22
-43
H
W
4.0
3.8
3.6
3.4
4.1
-30
-40
-20

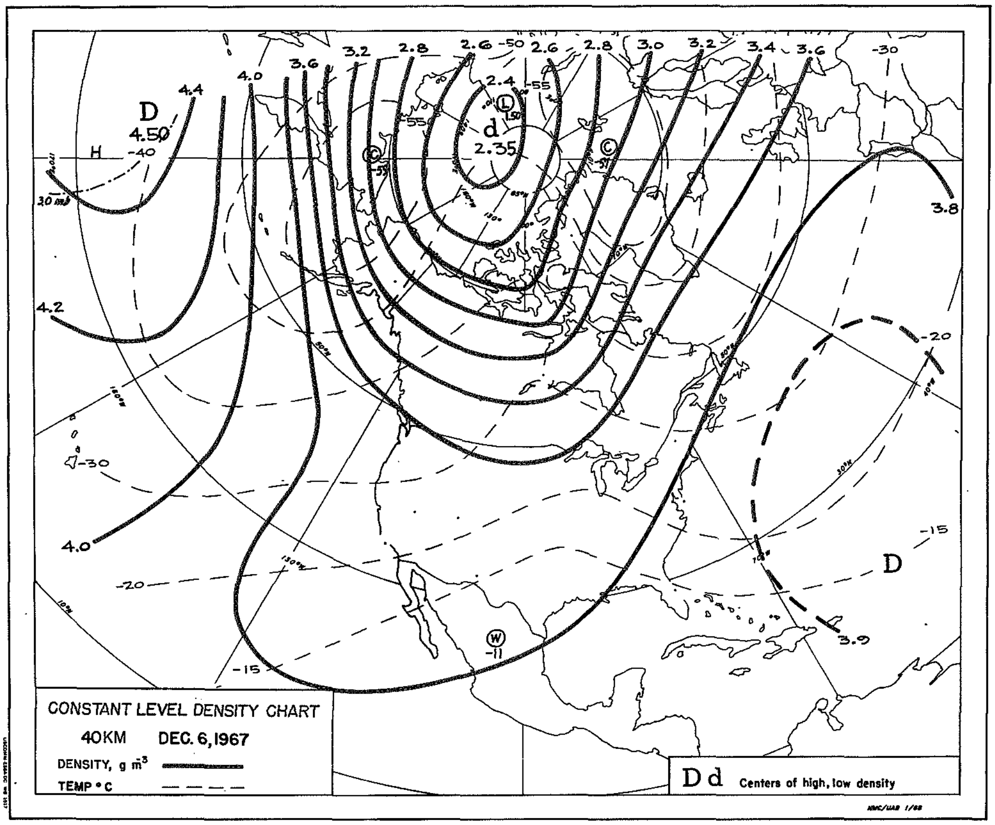

30 KM OCT. 20, 1965
D
18.7
d
15.5
-68
-37
17.5
12.2
18.6
18.5
18
17
16
-50
-60
-40

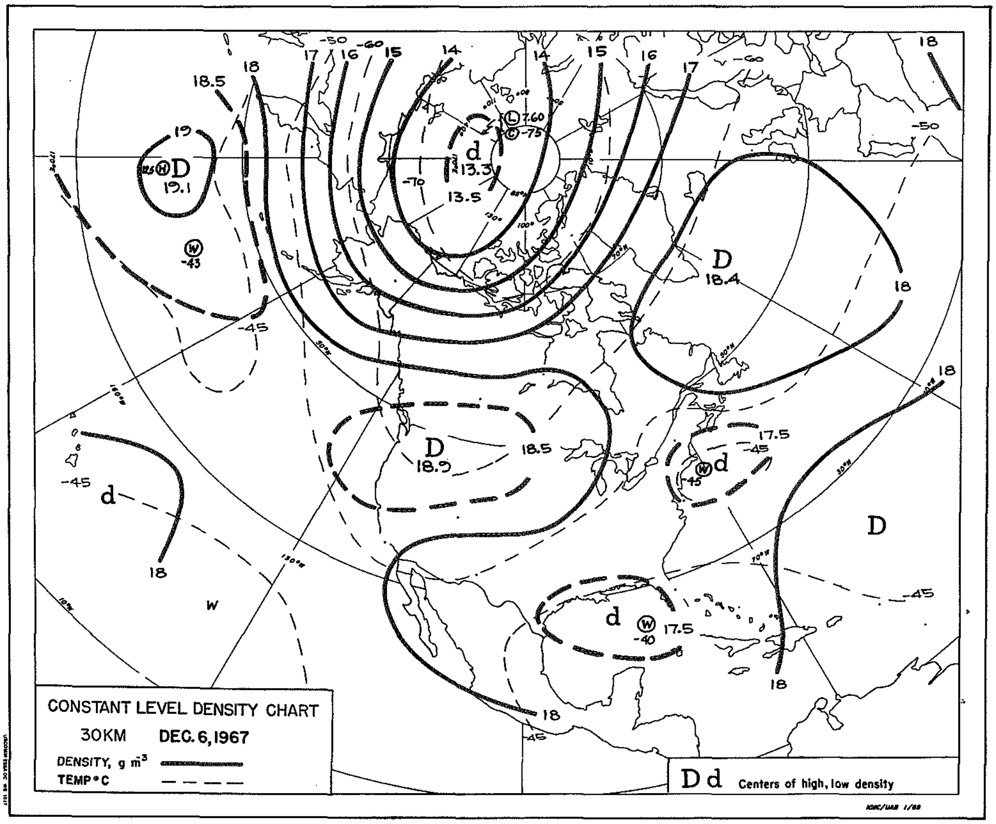

40 KM NOV. 17, 1965
4.2
4.0
3.6
3.2
2.8
3.0
3.4
3.8
D
4.31
2.81
1.78
2.6
2.9 mb
3.9
D
H
W
-20
-30
-40

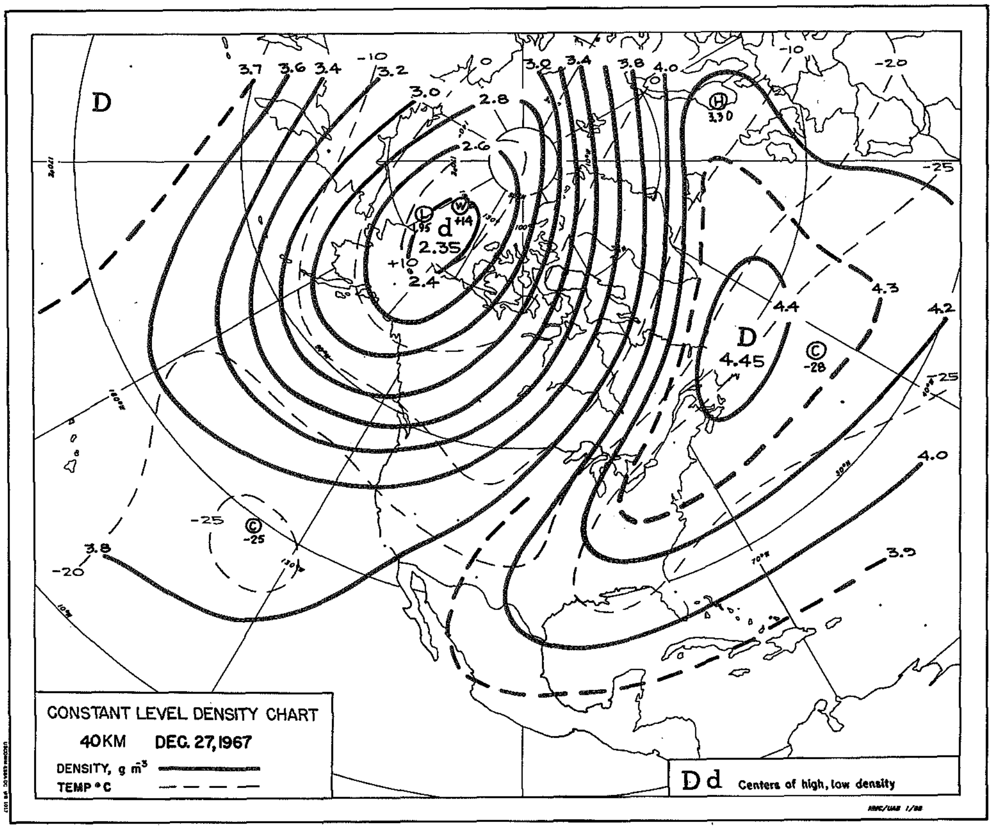

30 KM NOV. 17, 1965
17
16.5
16
15.5
18
19
12.1
D
18.5
15.2
8.35
17.5
D
W
-40
-50
-60
-70
-71

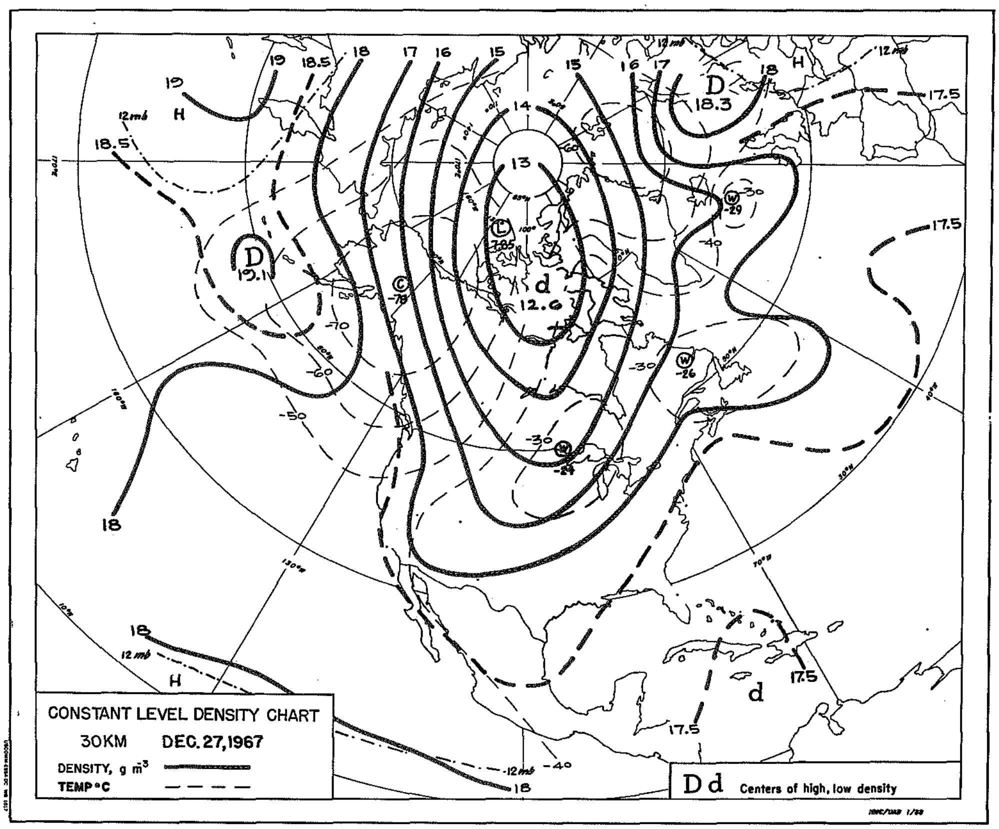

40 KM DEC. 15, 1965

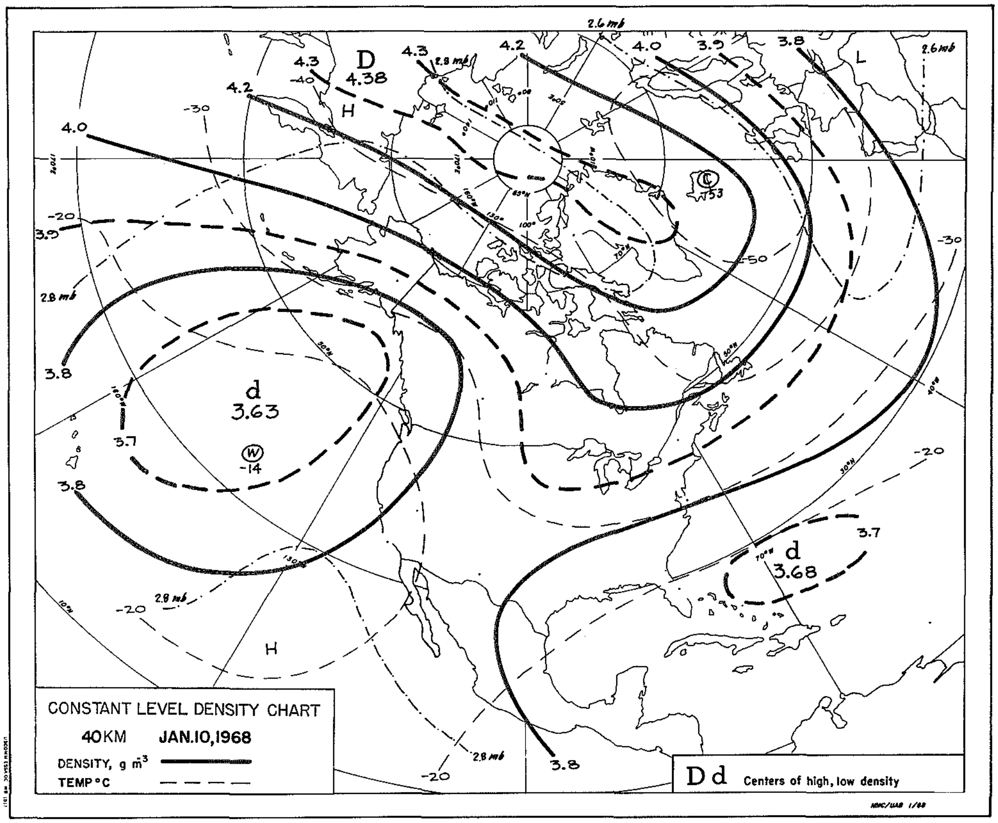

30 KM DEC. 15, 1965

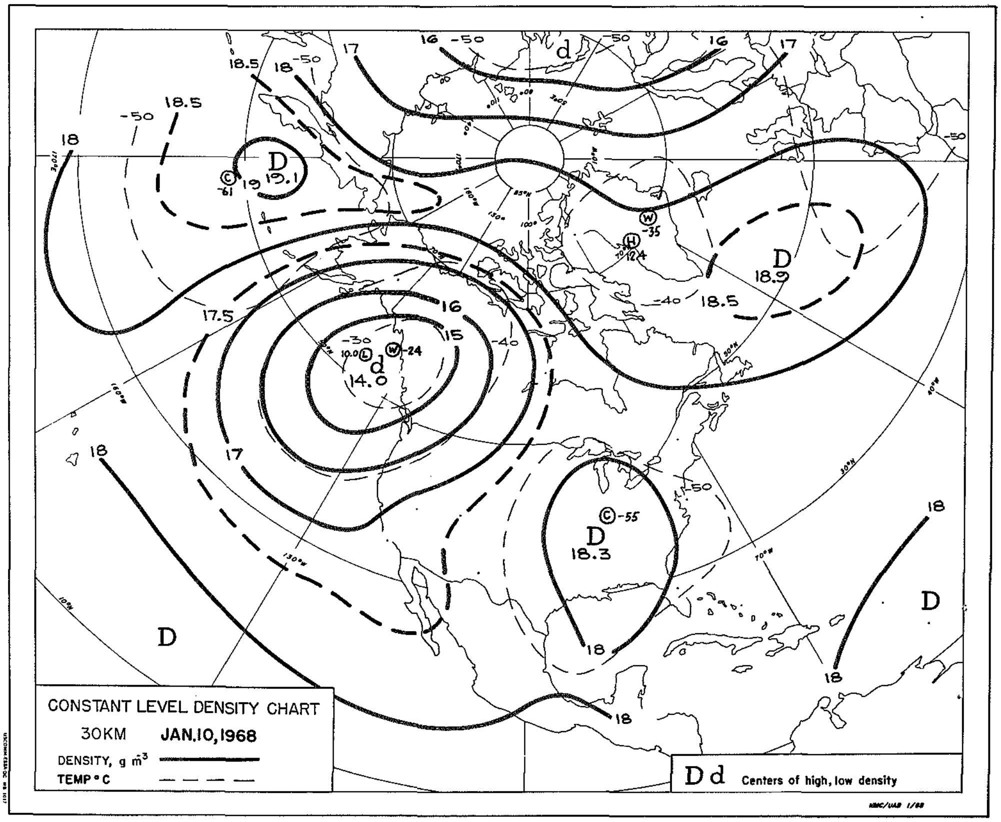

CONSTANT LEVEL DENSITY CHART
40KM DEC. 6, 1967
DENSITY, g m⁻³
TEMP °C
D d Centers of high, low density


CONSTANT LEVEL DENSITY CHART
30KM DEC. 6, 1967
DENSITY, g m⁻³
TEMP °C
D d Centers of high, low density


CONSTANT LEVEL DENSITY CHART
40KM DEC. 27, 1967
DENSITY, g m⁻³
TEMP °C
Dd Centers of high, low density


CONSTANT LEVEL DENSITY CHART
30KM DEC. 27, 1967
DENSITY, g m⁻³
TEMP °C
Dd Centers of high, low density


CONSTANT LEVEL DENSITY CHART
40KM JAN.10,1968
DENSITY, g m^-3
TEMP °C
D d Centers of high, low density
d
3.63
d
3.68
D
4.38


CONSTANT LEVEL DENSITY CHART
30KM JAN.10,1968
DENSITY, g m^-3
TEMP °C
D d Centers of high, low density
D
19.1
d
14.0
D
18.9
D
18.3

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