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AN EXAMINATION OF THE DETERMINATION
OF CLOUD TOP HEIGHT FROM THE SATELLITE PICTURES

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INTRODUCTION

By mid-November,1980, PWC will begin transmission of a cloud top height
chart analysis for western Canada and the northeast Pacific followed by
a 12 hour cloud top height prognosis chart for the same area.

READINGS FROM THE IR SENSOR

The cloud top heights (especially over the oceans) can be determined from
the IR pictures by calculating the cloud top temperature then converting
this temperature into a corresponding height for that particular airmass.

The IR sensor, however, has certain inaccuracies introduced into the system
itself. Due to noise interference and variations in instrument stability,
the accuracy of the reading can result in errors of $\pm$ 1,000 feet at the
3,000 foot level to $\pm$ 4,000 feet at the 33,000 foot level.

Further inaccuracies in the reading of cloud top temperature arise due to
interference of cloud temperatures from one layer to another, the resolution
of the IR sensor, size of the holes in cloud layers, the opaqueness of clouds
and the location of the cloud layer relative to the viewing angle of the
sensor.

Cirrus is semi-transparent to infra-red radiation at 11 μm. The transparency
will depend upon the thickness of the cloud layer and the concentration of
ice crystals in the cloud. The result is that the IR sensor senses both the
cold cirrus and the warmer temperatures from below, then averages these to
give a cloud top temperature for the cirrus which is too warm. Fig. 1 and 2
give a schematic representation of the degree to which the cirrus temperature
can be affected by the lower clouds or surface temperature.

Fig. 3 gives a schematic representation of the effects of the sensor
resolution, the angle of the sensor to the cloud layer, and the openess of
any holes in the cloud. The sensor measures the total long wave radiation
from the cloud.

TWXN & TUXN DATA

The estimated cloud top height in mb can be obtained from the TWXN and TUXN
satellite data. These are heights computed from the temperature of the cloud
top read by the sensor. The TWXN data is taken from the geostationary
satellite, the TUXN data is taken from a polar orbiting satellite.

Fig. 6(a) and 6(b) are hand drawn reproduction of an IR picture taken at 00Z
on September 30, 1980. Fig. 6(a) has various values for cloud top height
plotted on it from the TWXN data with values given by the TUXN data plotted
in brackets for comparison. Fig. 6(b) shows the relative degree of white
and grey shading for the clouds for the same time. If we follow a path
through the cloud area from point A to point B, the shading becomes progres-
sively darker, giving the impression the cloud tops are gradually lowering.
The visual display for the same time period actually showed that the entire
area was jet stream cirrus becoming progressively thinner from point A to
point B. As the clouds become thinner, more interference from the lower levels
was read giving progressively warmer temperature for the same cirrus cloud tops.
The cloud in area B was almost totally transparent with insignificant clouds
below it. It is quite surprising in this example to see the TWXN data has
given just about the same temperature and height for the entire cirrus shield
regardless of the amount of white or grey shading. Another point of interest
is the plot at 45N and 155W, the temperature drops to -53°C but the height cal-
culated is still near the 290-300mb level. I am not sure how this happens but
it is interesting to note from Figs. 4 and 5 which are for the same time period,
that a temperature of -38°C south of the jet and a temperature of -53°C north
of the jet would give values close to the 290-300mb level. Obviously more is
involved in determining the cloud top heights (in the TUXN and TWXN data)
than simply reading the degree of greyness. For comparison with the TWXN data,
two values taken from the TUXN data are plotted for the same time near 40N,
143W and 40N, 150W. These show higher values and seem to be a little more
consistent with the shading. My own estimate put the cloud temperature near
-45°C which would give a height of 260mb on the Salem tephigram. If we assume
the temperatures to be generally too warm, the height of 230mb given by the
TUXN is probably closest to the true height for the highest cloud top.

Some confusing cloud top readings can be given by the TUXN data as illustrated
in Fig. 7. From the IR picture it appears the cloud at point A is colder and
therefore higher than at point B which is in a mostly grey area. The TUXN
data however gives a cloud top height of 404mb for point A and 281mb for
point B.

USE OF THE LEVEL OF MAXIMUM WIND

Figs. 8 & 9 illustrate some relationships we can use to help find the upper
limit of cirrus clouds.

Fig. 8 depicts the vertical motions of the atmosphere related to the jet stream.
As seen in the diagram, there is a downward vertical motion between the level of
maximum wind and the tropopause. Below the jet stream level, the vertical motion
is upward reaching a maximum near the 500mb and gradually decreasing to zero
at the jet stream level.

Fig. 9 is a plot of the frequency of occurrence of clouds in relation to the

jet stream core. The level of maximum wind is also drawn in on either side
of the jet cone. Notice again the absence of any clouds above the level of
maximum winds, and the high percentage values from about 7 to 10 thousand
feet below the tropopause on the warm side of the jet and 11 to 15 thousand
feet on the cold side .

THE CLOUD TOP HEIGHT CHART

When composing the cloud top height chart and prognosis it will be useful to
remember the areas of possible error and inaccuracies outlined in the previous
sections. The following are just a few suggestions:

- Consult with the Shift Supervisor to determine which cloud areas should be
  considered in the analysis and prog. A layer of high thin cirrus may not
  be very important if there is a broken layer of low or middle cloud below it.

- Use a corresponding visual picture if available to determine the thickness
  of cirrus clouds and if any higher thin clouds are interfering with the IR
  reading of lower clouds.

- Try to determine from surface reports and deduce from synoptic modelling whether
  any lower clouds may be underlying higher clouds and the possible effects on
  the cloud top temperature readings.

- Remember the inherent errors of the IR sensor with respect to resolution, noise
  interference, angle of the sensor to the cloud, openess of the cloud holes,
  etc. Most errors produce temperatures that are too warm.

- Try to pick areas of cloud free from large holes and interference from other
  clouds as a representative value for the main cloud area being measured.

- Use the tephigrams whenever possible as they are the most accurate tool for
  middle and low cloud tops.

- Construct your own tephigrams from the upper level charts to get a height from
  the temperature derived over ocean areas.

- You may wish to use the TVWS prog charts to find a climatological probability
  of cloud tops from Fig. 9 and on upper limit by determining the level of
  maximum wind.

- Use the TUXN and TWXN data with caution, they seem to be inconsistent.
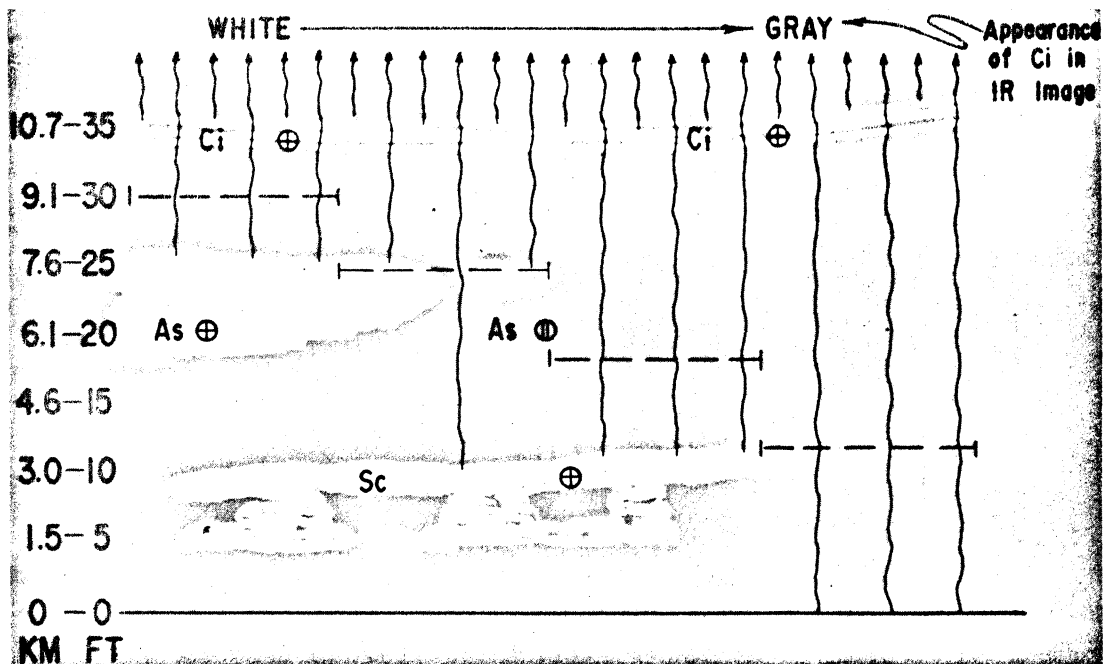
Fig. 1   This diagram shows the effect of lower cloud on radiation emitted by a uniform layer of thin cirrus. It is assumed that no large temperature inversion is present. The vertical wavy lines represent schematically the source of the radiation reaching the satellite sensor. The horizontal dashed lines represent the height of the cirrus tops computed on the basis of the integrated temperature received by the SR. The horizontal lines are of equal length and represent the smallest distance that the IR sensor can resolve. As the clouds below the cirrus become less in amount and lower, the cirrus appears progressively grayer and warmer in an IR display. The heights and gray shades shown here are for illustration purposes only, but are considered representative of changes that actually can occur. Cirrus can appear to be as low as 10,000 feet if it is almost transparent, and occurs where the surface below is sufficiently warm.
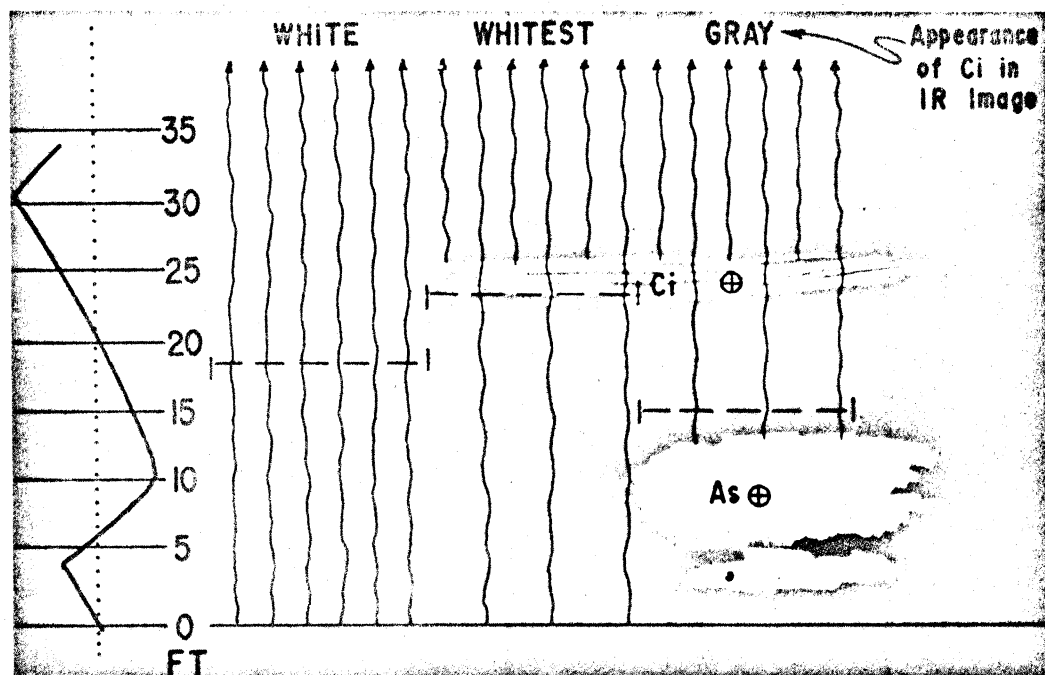

Fig. 2   This diagram shows a uniform, thin cirrus layer over a cloud layer that is warmer than the earth's surface. The dashed horizontal cloud height lines and the schematic representation of radiation follow the same convention as in figure 6-B-1. The schematic sounding curve on the left indicates the strength of the inversion for this example. The ground temperature shown is the same as the temperature at 500-mb. In this example the cirrus over the cold ground appears whiter than the ground alone. The cirrus is now grayer when over low cloud, rather than whiter as shown in figure

Direct View
Zenith Angle = 0°

Oblique View
Zenith Angle = 60°

Thousand Feet

25
20
15
10
5
0

Ⓐ

Ⓑ

|—4 Mi—|

|——— 12 Mi ———|

Small Cloud Elements Spaced Close Together

Direct View
Zenith Angle = 0°

Oblique View
Zenith Angle = 60°

Thousand Feet

25
20
15
10
5
0

Ⓒ

Ⓓ

|—4 Mi—|

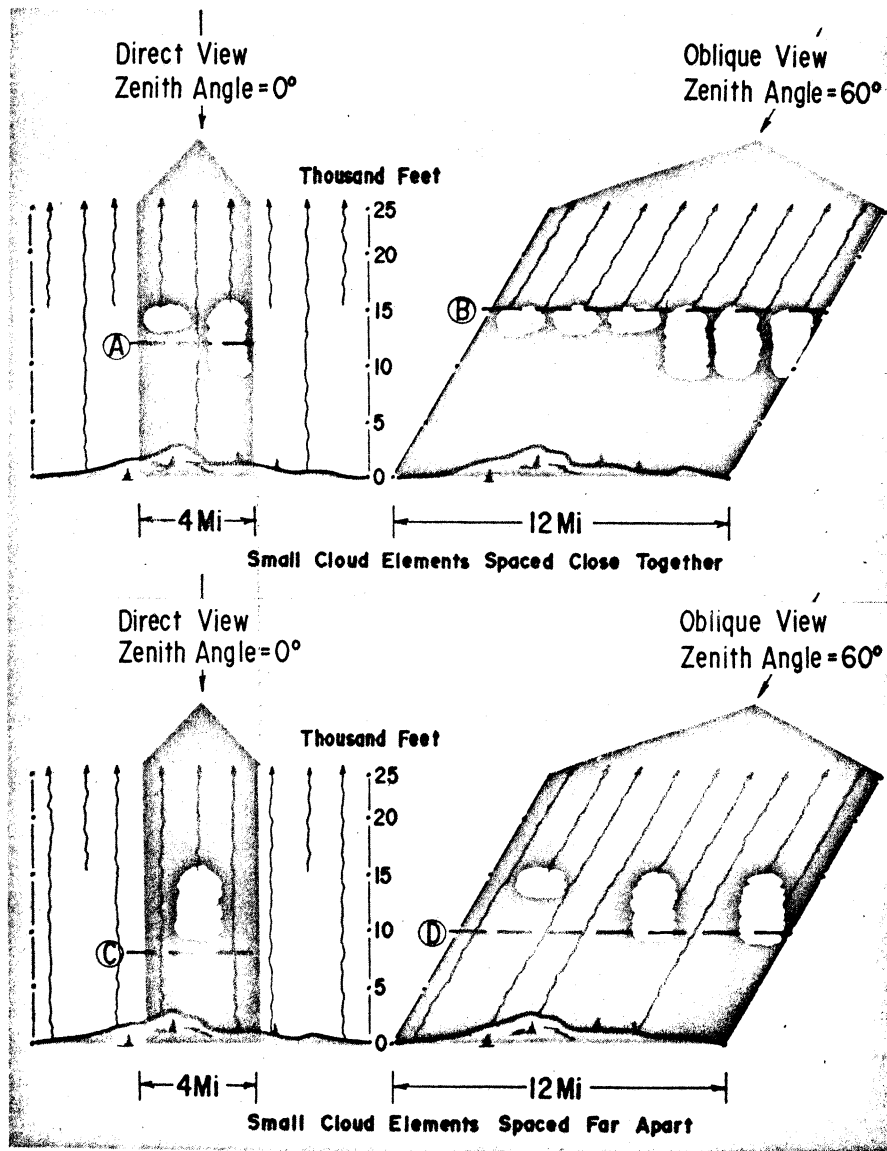|——— 12 Mi ———|

Small Cloud Elements Spaced Far Apart

Figure 3   This schematic diagram shows how cloud element size and viewing angle make clouds appear warmer and lower than they actually are. The horizontal dashed lines, identified by letters, represent the cloud-top heights as they might be derived from the two cloud fields shown. The cloud fields on the left and right-hand side of the diagram are identical. Only the viewing angle and field of view changes. The cloud-top height measurements observed for a broken cloud layer with closely spaced, thick and thin, opaque cloud elements appear at the top of the figure. When these clouds are viewed directly (nadir angle = 0), the SR measures both cloud-top and ground radiation; thus, the height of the clouds appears to be at a lower level (A). The same clouds, viewed at an oblique angle (top, right), appear to be higher (B) due to the absence of ground radiation. At the bottom of the figure, the clouds are spaced farther apart. Here the ground contributes more energy and the clouds appear warmer and lower (C, D). The numerical values for height changes shown here are for purposes of illustration only.

TÉPHIGRAMME

L'échelle de l'altitude géopotentielle en fonction de la
pression et autres constantes utilisées dans ce
Téphigramme sont conformes au Doc. 7488/2 Manuel
de l'Atmosphère Type OACI (2 ième éd., 1964).

Environnement
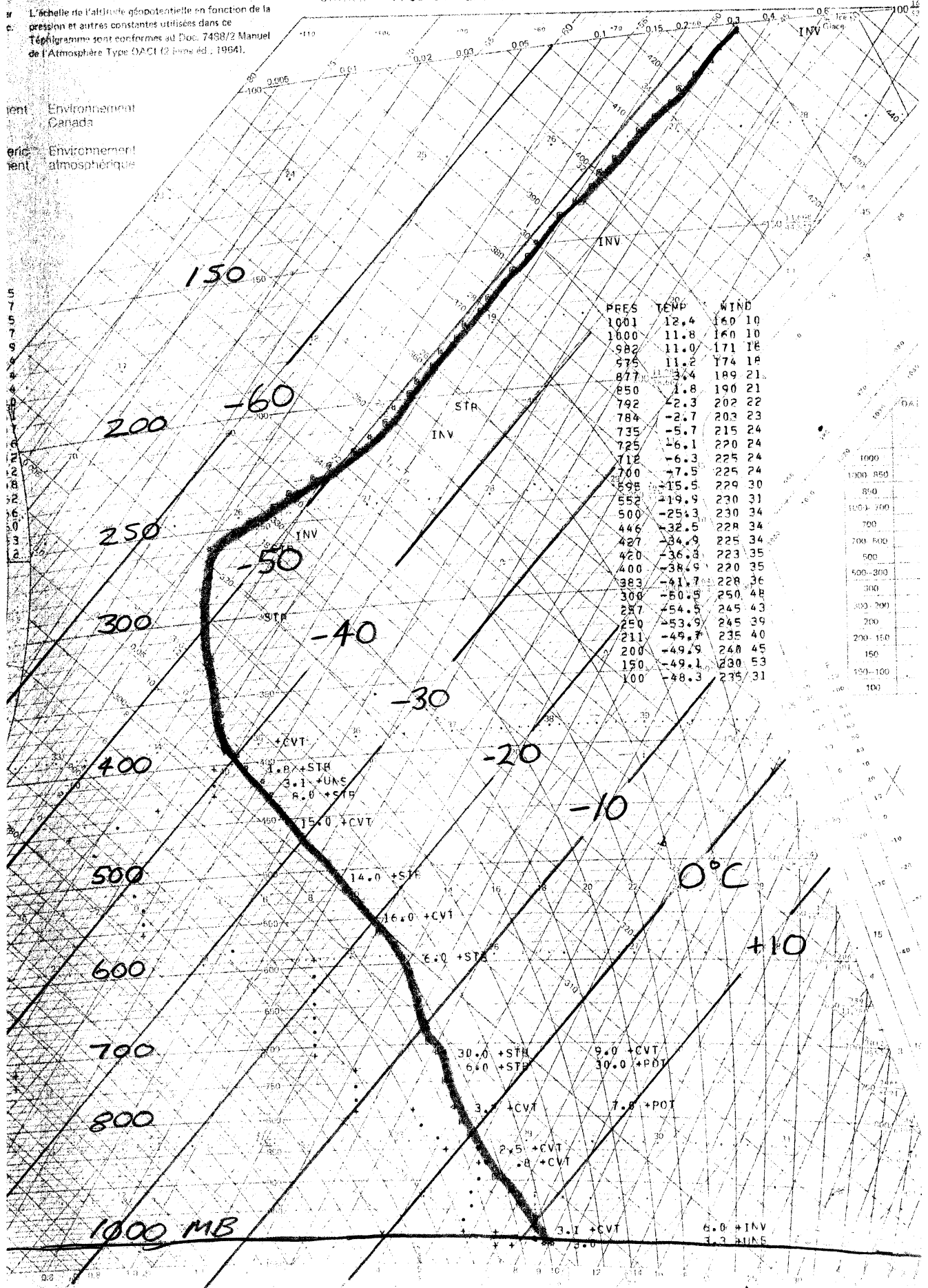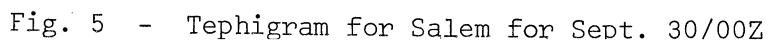Canada

Environnement
atmosphérique

PRES	TEMP	WIND	
1001	12.4	160	10
1000	11.8	160	10
982	11.0	171	18
975	11.2	174	18
877	3.4	189	21
850	1.8	190	21
792	-2.3	202	22
784	-2.7	203	23
735	-5.7	215	24
725	-6.1	220	24
718	-6.3	225	24
700	-7.5	225	24
598	-15.5	229	30
552	-19.9	230	31
500	-25.3	230	34
446	-32.5	228	34
427	-34.9	225	34
420	-36.3	223	35
400	-38.9	220	35
383	-41.7	228	36
300	-50.5	250	48
287	-54.5	245	43
259	-53.9	245	39
211	-49.7	235	40
200	-49.9	248	45
150	-49.1	230	53
100	-48.3	235	31

Fig. 4 - Tephigram for Annette for Sept. 30/00Z

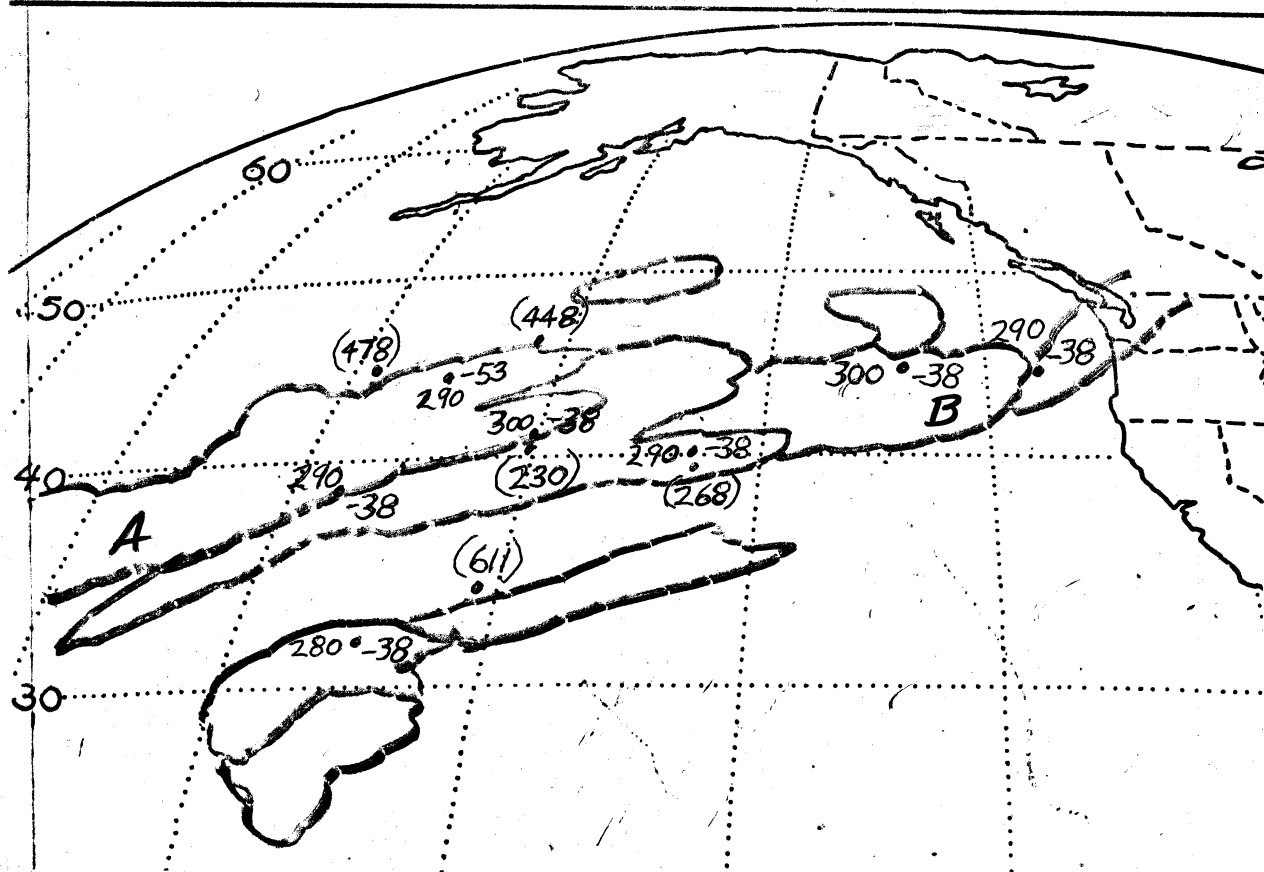Fig. 5 — Tephigram for Salem for Sept. 30/00Z

Fig. 6(a) — Reproduction of IR picture for Sept. 30/00Z with TWXN data plotted. Data in brackets taken from TUXN data.
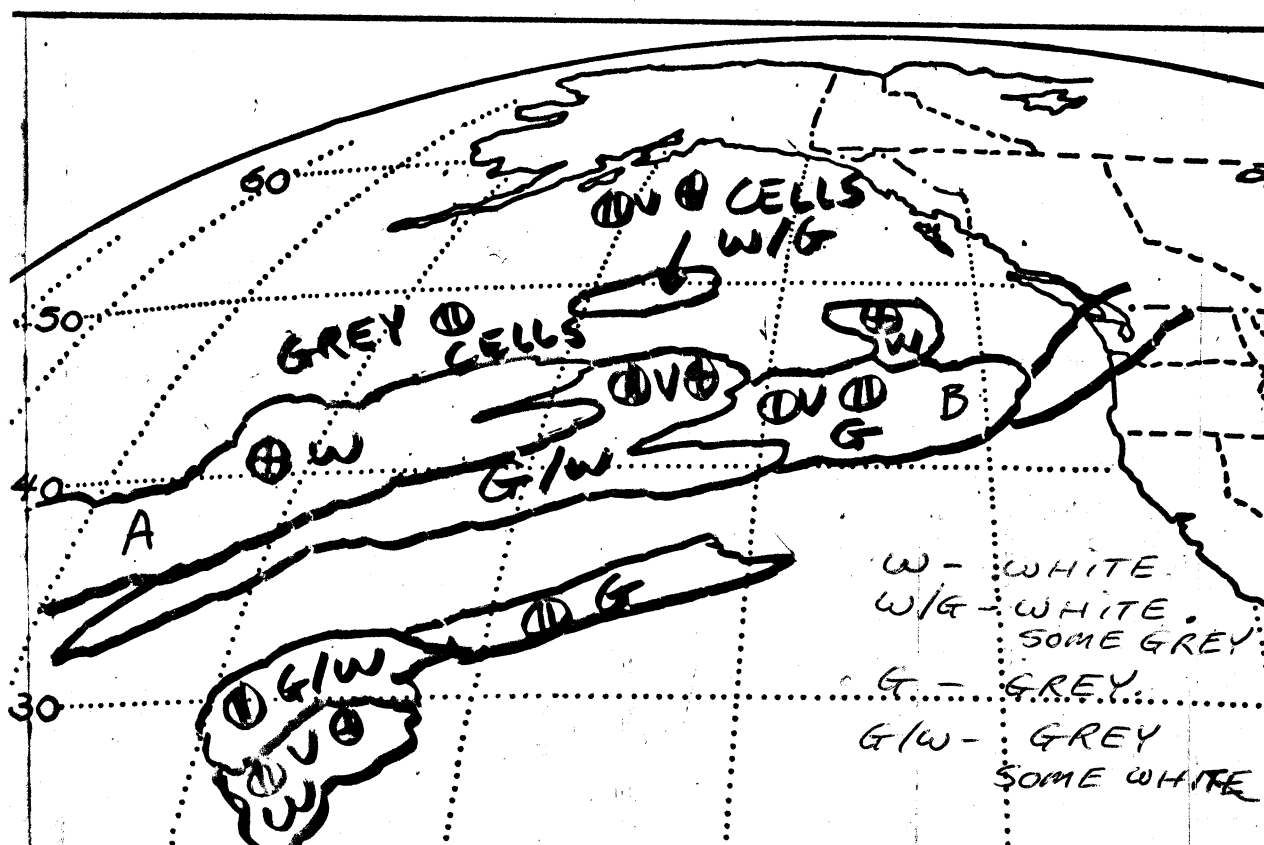

Fig. 6(b) — Reproduction of Fig. 6(a) showing relative shades of white and grey.