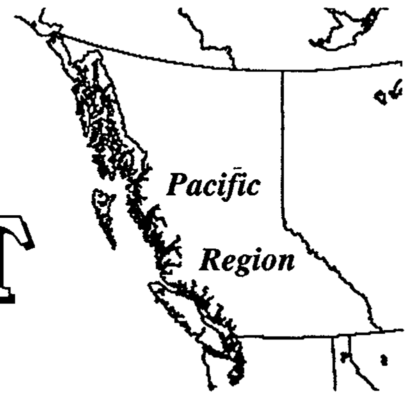
SCIENTIFIC SERVICES DIVISION

REPORT



AN EVALUATION OF BOLON/1 MESOSCALE WIND MODEL

Bill Taylor
Scientific Services Division
Atmospheric Environment Service
Pacific Region

January 22, 1992
Report PAES-92-1

ABSTRACT

An evaluation of the mesoscale wind model, BOLON/1, was conducted to determine its suitability for the Environmental Emergency Response program (EER) as well as its potential application in mesoscale forecasting. This evaluation follows an earlier report by Seaconsult Marine Research Ltd. (Dunbar, et. al., 1988) which recommended a more detailed review of BOLON/1 for its potential use by the AES.

The model was validated for three cases under three different synoptic conditions, and model output was found to be in general agreement with observed winds. Obtaining an accurate estimate of the "free atmosphere" geostrophic wind is critical to obtaining valid output from the model, yet a satisfactory method of estimating this parameter remains elusive. With this exception, other geographical and meteorological data required to initialize the model are readily available from the AES synoptic network. The execution of the model, including the collection and preparation of the input data, however, can take upwards of 30 minutes which far exceeds the five minute initial response requirement of EER.

Resolving the problem of estimating the geostrophic wind, further testing of the model and making enhancements to the user interface software are recommended before BOLON/1 becomes fully operational.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

The purpose of this report is to evaluate the Danard mesoscale wind model, BOLON/1, for utilization in the AES Environmental Emergency Response (EER) program. To be useful operationally, the model must be relatively easy to initialize and must produce results that appear physically reasonable and that are within acceptable performance limits.

Within these broad requirements, the report endeavours to answer the following questions:

(A) How readily can information be extracted from the existing synoptic observation network and guidance material for the purpose of initializing the model?

(B) How does the accuracy of the input data affect model performance?

(C) Are the modelled winds verifiable from observed surface winds?

The report includes a brief overview of the model followed by a discussion of the potential applications of the model to EER and mesoscale wind forecasting.

Procedures used to initialize the model are discussed in view of the various sources of data available to the operational meteorologist.

The model output is validated by testing wind velocity predictions against actual surface observations. Three case studies representing three different synoptic conditions are presented.

The results of a sensitivity analysis are discussed. This procedure is utilized to determine which of the input parameters are most critical to model performance. The more critical the parameter, the greater the need for an accurate input value.

The report concludes with a number of recommendations concerning further tests and applications of the model. Observations concerning the User Interface are included in the Appendix.

2. MODEL OVERVIEW

This section of the report contains a brief description of the model and explains the rationale for acquiring BOLON/1 and its potential for application within the AES.

2.1 DESCRIPTION

The main feature of BOLON/1 is its ability to diagnose the effects of terrain on surface winds. Topographically-induced circulations such as sea and land breezes and mountain and valley winds are, in general, not easily resolved on the synoptic scale. BOLON/1 is a "one-layer" mesoscale model capable of diagnosing these winds in the lowest layer of the atmosphere. The main limitation of this type of model is its inability to diagnose vertical motions or upper level flows (Dunbar, et. al., 1988).

While it is not the purpose of this report to provide a thorough explanation of the physics underlying BOLON/1, a brief description of the main characteristics of the model would be appropriate. The model has been in existence in one form or another for almost 20 years and has undergone numerous revisions over that period. For further information the reader is referred to the manual (Danard and Galbraith, 1989) which accompanies the software and the references contained therein.

The model proceeds sequentially from an initial wind field obtained from synoptic data to a final surface wind which includes the effects of topography. The sequence of the BOLON/1 program may be visualized as follows.

(A) Initial Surface Pressure and Temperature

An initial geostrophic wind field is calculated from the geostrophic wind and the temperature gradient at 850 mb. Knowledge of the temperature and height at 850 mb above the model domain is also required. Next, the free-atmosphere lapse rate is calculated based on the temperatures at 850 and 700 mb.

(B) Atmospheric Boundary Layer (ABL) Characteristics

This part of the model computes the Monin-Obukhov length, friction velocity, and height of the atmospheric boundary layer (ABL) at each grid point. The inputs required for this procedure are terrain elevations, the roughness length, the water fraction at each grid point, the water temperature, and the surface temperature of the air over land. Cross-isobar angles are then computed for the wind at each grid point.

(C) Balanced Surface Wind

The surface wind field is now modified by taking into account the surface roughness and atmospheric stability and baroclinicity as determined by the previous step. At each grid point, a three-way balance of the pressure gradient force, Coriolis force and friction force is computed. This step reduces the speed of the initial surface wind and backs it toward lower pressure.

(D) Dynamical Adjustment

The final wind field includes small scale topographical influences by taking into account the changes in the horizontal pressure gradient arising from terrain-induced adiabatic temperature changes and differential heating and cooling. It is this part of the model that determines the more complex circulations that occur due to topography and the diurnal variation in the surface temperature.

(E) Objective Analysis

Finally, the model has the option of incorporating observed winds into the wind field by means of objective analysis. The model output is thereby refined to reflect actual wind measurements within the model domain.

2.2 MODEL APPLICATIONS

BOLON/1 was acquired by the AES for the Environmental Emergency Response (EER) program as a means of providing accurate estimates of the surface wind in initializing dispersion models. One of the difficulties in emergency response is estimating the speed and direction of the wind at a spill site where direct measurement is not possible. One method is to estimate the surface wind based on measurements from the nearest observing station. To the degree that the actual wind at the spill site is different from the estimated wind introduces error into the initialization of the dispersion models. Wind models such as BOLON/1 are believed to be capable of providing better estimates of the wind velocity at a spill site than measurements taken at the nearest observation station in most cases. The AES is also required to provide an initial operational response by way of an estimate of the surface wind within five minutes of the time the spill is discovered.

Seaconsult Marine Research Ltd. recommended BOLON/1 (Dunbar et. al., 1988) in view of the AES requirements for Environmental Emergency Response but also noted that the model could potentially be used to provide operational support in mesoscale wind forecasting including marine, aviation, and forestry forecasts.

A menu-driven User Interface which utilizes X Windows on an HP9000 work-station has been developed to facilitate data entry and to display the model output. The performance of the User Interface is discussed in Appendix A.

3. METEOROLOGICAL DATA REQUIREMENTS

The validity of the model output depends to a very great extent on the accuracy of the data used to initialize it. This section of the report examines the sources of input data and the procedures involved in initializing the model.

3.1 SOURCES OF DATA

In this study, the model was tested only for the Greater Vancouver Area. Consequently the examples used in this report pertain to the Pacific Region in general and the Greater Vancouver area in particular. Selection of case studies of past weather necessitated the use of archival data including surface and upper air maps and tephigrams rather than near real-time data available to the operational meteorologist in the AES data network.

(A) Model Domain

The selection of an appropriate model domain depends largely on the major terrain features to be modelled (eg. valleys, mountains, inlets, fjords). Since model results are generally improved by incorporating observed winds through objective analysis, it is desirable to include one or more verification stations in the model domain.

The size and dimensions of the domain will depend on the degree of resolution desired. Danard (1989) recommends a maximum grid size of 100 x 100 kilometres and a grid interval of 1 to 2 kilometres.

A so-called "reference station" is chosen by the user to represent a point of interest such as the spill site in the case of EER. The reference station is chosen to be near the centre of the model domain. All meteorological input data used to initialize the model refer to this point although the reference station need not be a real meteorological observing station.

A verification station, on the other hand, will of necessity be a meteorological station or an air quality station equipped with an anemometer as a means of incorporating actual wind measurements.

A map is a useful tool in specifying the grid domain and is indispensable in editing the water fraction file (see below). Maps published by Energy, Mines and Resources Canada of various scales (1:50,000, 1:250,000, 1:500,000) are available in Pacific Region, and most weather offices will have aeronautical maps (1:500,000) or marine navigational charts published by the Canadian Hydrographic Service (various scales).

Knowledge of geographic coordinates, i.e. latitude and longitude to the closest minute, and elevation to the closest metre of the reference station, is sufficient to establish the grid domain. The latitude, longitude, and elevation of meteorological observing stations are available on the AES and other data networks.

(B) Terrain Elevation

The model utilizes the terrain database developed by the Communications Research Centre (CRC) of the federal Department of Communications. Geographic coverage of this database is limited in some regions. For instance, coverage of British Columbia extends only as far north as latitude 55N, restricting application of the model to the lower half of the Province. The horizontal resolution of the database is 1 kilometre for British Columbia. Since three data points are required to adequately resolve any feature, the smallest topographical feature that can be resolved by the model is two kilometres.

Once the grid is specified the terrain database is accessed directly by the User Interface and saved in a file along with the water fraction data.

(C) Water Fraction

The fraction of water coverage is determined automatically from the land use code in the CRC data base. This method assigns a value of one or zero to each grid point in the model domain depending on whether the surface is water or land. Increased resolution along a coastline, where land meets the water, may be obtained by laying a grid over a map of sufficient scale (ideally 1:250,000) and analyzing the water coverage to the closest tenth. The data file must then be manually edited.

(D) Land Roughness Length

A single value for roughness length is selected to represent all land use within the chosen model domain. Values range from 0.01 for soil and short grass to a maximum of 10.0 for high density, multi-story, urban development. A table of roughness lengths for several types of land use is given by Oke (1987). While it is possible to input roughness length values at each grid point, it has been found that using one value representing the average land use within the model domain is sufficient (Danard and Galbraith, 1989).

(E) State of the Water (frozen or unfrozen)

During this study, the model was not tested under conditions where the water was frozen. Presumably the only way of determining the state of the water is by direct observation.

(F) Water Temperature

Sea surface temperature (SST) data are compiled by the Meteorological and Oceanographic Centre (METOC, CFB Esquimalt) for an extremely large portion of the Pacific Ocean, but these observations are too sparse to define the finer scale SST field in the Strait of Georgia. The only known sources of this data for the Straight of Georgia are lighthouse reports, however METOC advises that sea surface temperatures off the west coast of Vancouver Island are fairly representative of those in Georgia Strait. Monthly average sea surface temperatures for outer coastal waters are available in graphical form from the Marine Climatological Atlas published by the Canadian Climate Centre and the NOAA Oceanographic Monthly Summaries.

Water temperatures of inland lakes are sometimes available from local AES weather offices. The Penticton Weather Office, for example, measures the lake temperature daily during summer months for its recreation forecasts. The Kelowna Weather Office, on the other hand, utilizes volunteers to measure the lake temperature on a weekly or biweekly basis at three locations. Temperatures may vary by two or three degrees on any particular day from one end of a large lake to the other. Daily temperature variation also depends on the amount of overturning caused by the wind. The average monthly variation in the lake temperature is also of the order of two or three degrees. The practice of measuring lake temperatures apparently varies from one area to the next depending on local needs and interests.

(G) Surface Air Temperature Over Land

The surface air temperature over land must be specified at one location, and, according to Danard and Galbraith (1989), that location does not have to be within the model domain. Danard cautions, however, that the surface air temperature over land should be at a location not affected by local lake or sea breezes. For example, he suggests using the temperature at Abbotsford for modelling the winds over the greater Vancouver area rather than the temperature at Vancouver International Airport which is very near the water. Current temperatures are observed to 0.1 °C.

(H) 850 mb Analysis

The model requires three pieces of information from the 850 mb level: temperature, height, and the temperature gradient. A Canadian Meteorological Centre (CMC) analysis is issued every twelve hours based on upper air soundings at 00Z and 12Z.

Through interpolation of plotted upper air data and visual inspection of the height contours and thickness isopleths it is possible to determine the 850 mb temperature to within 1 °C and the 850 mb height to within 10 metres at any given point. The temperature gradient, however, is generally more difficult to ascertain to any degree of accuracy by visual inspection. Resolution can be a problem since a distance of 100 kilometres corresponds to approximately three millimetres on the CMC upper air maps, and interpolation between the thickness lines is not always straight forward.

Another method for computing the temperature gradient involves applying regression analysis to upper air data. This method involves fitting the equation

$$T_{85}=T_0+\frac{\partial T}{\partial X}(x-\overline{x})+\frac{\partial T}{\partial Y}(y-\overline{y})+\frac{\partial T}{\partial Z}(z-\overline{z})$$

by least squares to a minimum of five upper air observations of the 850 mb temperature (T_{85}).

The regression coefficients yield the east and north components, respectively, of the temperature gradient.

The symbols, x and y, represent the horizontal coordinates of the upper air stations from known latitude and longitude, and z is the height of the 850 mb surface. The over-bar represents the centroid of the stations. For the Lower Mainland, data from the following upper air stations have been utilized to compute the temperature gradient at 850 mb.:

Port Hardy (YZT)	Vernon (WVK)
Quillayute (UIL)	Prince George (YXS)
Spokane (GEG)	

An alternate method that bears investigation involves working with CMC grid point data rather than the 850 mb map or observation data. An interpolation algorithm could then be developed to compute the temperature and height above the reference station. As the grid spacing on the numerical models is roughly the same scale as the model domain this technique is capable of providing much higher resolution of the height and temperature fields than is possible by visual inspection of the 850 mb map.

(I) 700 mb Analysis

Two pieces of information are needed from the 700 mb analysis: temperature and height. The same comments made above in relation to the 850 mb analysis also apply here. Temperatures are considered accurate to 1 °C and 700 mb heights to 10 metres.

(J) Geostrophic Wind

The speed, direction and height of the geostrophic wind are required to initialize the model. Danard (1989) states that the geostrophic or free-atmosphere wind is a very important variable, and he cautions that care should be taken in its calculation. He proposes three methods for computing the geostrophic wind:

(i) Sounding - Danard claims that the best way of calculating the geostrophic wind is to average winds from a nearby rawindsonde at several heights near the top of the atmospheric boundary layer (ABL). The height of the geostrophic wind then is the average of the levels used in the calculation of the speed and direction.

Upper air data is available from tephigrams twice per day at 00Z and 12Z, and some first order stations conduct pibal flights every six hours. For the lower mainland, radiosonde soundings from Port Hardy (YZT) and Quillayute (UIL) or pibal data from Vancouver International Airport (YVR) may be utilized. For the Okanagan, the radiosonde from Vernon (WVK) would be appropriate and for central B.C., it is Prince George (YXS). For more sparsely populated areas, the lack of upper air data poses more of a problem for calculating the geostrophic wind.

Identification of the top of the ABL requires experienced meteorological judgement. For the purpose of initializing the model, the top of the ABL will probably be in the lowest kilometre of the atmosphere away from the influence of frictional effects, or just beneath the top of an inversion if one exists.

The model requires the user to enter the geostrophic wind in component form. The conversion from meteorological convention (speed and the direction from which the wind blows) to vector component form is given by the following equations:

$$u = -c\sin B; \quad v = -c\cos B;$$

where u and v are the east (positive x) and north (positive y) components respectively, c is the speed and B is the direction in degrees of the geostrophic wind.

Upper air soundings give wind speeds in integer knots resulting in an uncertainty of one half of one knot, and the wind direction as determined from a hodograph may be considered accurate to within five degrees.

(ii) Regression Analysis - Danard outlines a method for computing the geostrophic wind from station observations of surface pressure, temperature and elevation using regression analysis. Data are required from at least four stations, and a statistical software package capable of performing multiple regression must be utilized. The results obtained so far using this method have been less than satisfactory due to the lack of agreement with other estimates of the geostrophic wind. Nevertheless, the technique bears further investigation.

(iii) Surface Analysis - The third method proposed by Danard is to use Pacific Weather Centre analyzed sea level pressure charts. By analyzing the pressure field at one millibar intervals, a surface geostrophic wind scale may be used to determine the wind speed and direction. This method produces reasonable results provided the pressure gradient is well defined and the reported pressures are not badly distorted by elevation in mountainous regions.

(K) Verification Stations

Objective analysis is an optional feature of BOLON/1 which incorporates observed winds into the model output. Up to five verification stations can be included. The latitude and longitude of the verification station must be known to the nearest minute along with the wind speed and direction. In the lower mainland the GVRD network may be utilized as verification stations.

3.2 UNCERTAINTY IN INPUT DATA

The degree of accuracy in the model output is directly affected by the uncertainty in the input parameter values, and it would be unreasonable to expect the model to perform better than the data used to initialize it. Thus the error in the model output arising from uncertainties in the input data must be taken into account when validating the model against observed surface winds.

PARAMETER	UNCERTAINTY	DATA SOURCE
Geostrophic Wind		Upper Air (sounding, CMC)
Speed	±0.25 m/s	or Surface Analysis
Direction	±5 degrees	
Height	±10 m	
Temperature Gradient	±0.5 °C/100 km	CMC 850 map or Upper Air
Temperature 850 mb	±1 °C	CMC 850 map or Upper Air
Height 850 mb	±10 m	" " " " "
Temperature 700 mb	±1 °C	CMC 700 map or Upper Air
Height 700 mb	±10 m	" " " " "
Temperature Air Over Land	±0.1 °C	Surface Observations
Temperature Water	±2 °C	Various Sources

TABLE 1: Uncertainties in Meteorological Input Data

The degree of uncertainty in the meteorological measurements used to initialize the model as discussed in the previous section is reflected in Table 1. The impact of measurement error on the model output is discussed in Section 5, Sensitivity Analysis.

It should be noted that this degree of accuracy will not always be achievable in practise owing to missing information or difficulty in interpreting the data. The figures in Table 1 should be regarded as the minimum amount of uncertainty in the input data.

4. MODEL VALIDATION

The ultimate test of model performance is the agreement between predicted values and actual observations. This section of the report examines model performance expectations and discusses the methods used to validate the model. The results of the validation process on the basis of three case studies are presented.

4.1 SELECTION OF CASE STUDIES

To determine the consistency of model performance under different synoptic conditions, three case studies were selected for evaluation. Two of the cases were chosen to test the ability of the model to diagnose light, thermally-driven winds on the assumption that they are more difficult to estimate than stronger, dynamically-induced winds. Accordingly, two days were selected for study based on the existence of a slack horizontal pressure gradient and associated light surface winds being observed at verification stations. In one of those cases the atmosphere was unstable. The other was an ozone episode day representing highly stable conditions. The third case is the dynamical situation where there is a tight pressure gradient and strong winds. All maps and charts used in the preparation of these case studies are included in the Appendices.

(A) Case #1 - 31AUG91 5PM - An upper trough lies off the west coast with its axis lying along 130W resulting in a southwesterly flow aloft. A cold front moved through B.C. within the past 12 hours and now extends NE to SW over the SE corner of the Province. The surface pressure gradient is slack throughout the study area. Summertime instability due to daytime heating is apparent by the presence of convective cloud (TCU) in observations and confirmed by examination of YZT and UIL tephigrams (Appendix B).

(B) Case #2 - 23JUL91 5PM - An upper ridge of high pressure dominates British Columbia and Alberta. A thermal trough pushes up from the southwestern US and is reflected in low pressure centres in Washington and Oregon. The surface horizontal pressure gradient is slack. Both UIL and YZT tephigrams display subsidence inversion characteristics with the atmosphere being absolutely stable in the lowest 50 mb. The airmass is warm and dry (Appendix C).

(C) Case #3 - 21OCT91 5PM - A major disturbance moved through the region about 12 hours earlier. A low with a central pressure of 988 mb lies on the Alberta-Saskatchewan-Montana border. A cold front trails southwesterly from the low well clear from the region of interest. A second cold front extends northwest of the low and lies to the north across the Charlottes. The upper flow is from the northwest, and the surface horizontal pressure gradient is tight. Both UIL and YZT tephigrams indicate a very cold and unstable airmass (Appendix D).

Model input data for all three cases are summarized below in Table 2 for comparison.

PARAMETER	CASE #1 31AUG91 5PM	CASE #2 23JUL91 5PM	CASE #3 21OCT91 5PM
Roughness Length for Land (m)	0.1	0.1	0.1
Ice on Water Flag (T or F)	F	F	F
Water Temperature (°C)	18	16	11
Surface Air Temperature (°C)	19.7	35.7	11.6
East Temp. Gradient (°C/m)	1.0×10^{-5}	6.0×10^{-6}	1.0×10^{-6}
North Temp. Gradient (°C/m)	-3.0×10^{-6}	-3.5×10^{-6}	-7.1×10^{-6}
Temp. of 850 mb Surface (°C)	7	21	0
Height of 850 mb Surface (m)	1490	1540	1370
Temp. of 700 mb Surface (°C)	-2	9	-9
Height of 700 mb Surface (m)	3050	3190	2900
East Geostrophic Wind (m/s)	1.15	1.88	14.00
North Geostrophic Wind (m/s)	1.64	-0.68	-3.75
Geostrophic Wind Height (m)	300	300	300

Table 2: Summary of Model Input Data For Three Cases

4.2 SELECTION OF MODEL DOMAIN

As indicated earlier, application of the model in this study has so far been restricted to the Greater Vancouver area. The grid covers an area 32 x 32 kilometres of greater Vancouver roughly centred over East Richmond. The domain includes the Burrard Inlet and North Vancouver to the north, Sturgeon Bank to the west, Boundary Bay to the south, and Surrey to the east (see Figure 1a). While the area does not display much topographical variability, the justification for its selection lies in the availability of verification data with which to validate the model. Further testing of the model under different geographical conditions remains to be undertaken.

The Reference Station data shown in Table 3 correspond to the centre of the grid.

Reference Station Latitude (° ′ ″)	49 10 00
Reference Station Longitude (° ′ ″)	123 00 00
Reference Station Elevation (m)	10
East-West Distance (km)	32
North- South Distance (km)	32
Grid Unit distance (km)	2
Grid Layout Rotation (degrees)	0

Table 3: Reference Station Data - Grid centred over East Richmond, Greater Vancouver Area

A background map (Figure 1b) showing the contours of the land is drawn by the User Interface program using the elevation data in the CRC data base. While the interface does a good job of contouring the land, it does not resolve the shoreline particularly well. Consequently, certain topographical details familiar to the user may be missing from the graphical output. In the current set of test runs for Greater Vancouver, for example, the interface was unable to resolve the Fraser River.

Scan

Figure 1a: Map of Greater Vancouver Showing Grid Domain and Location of Verification Stations

SC 1A

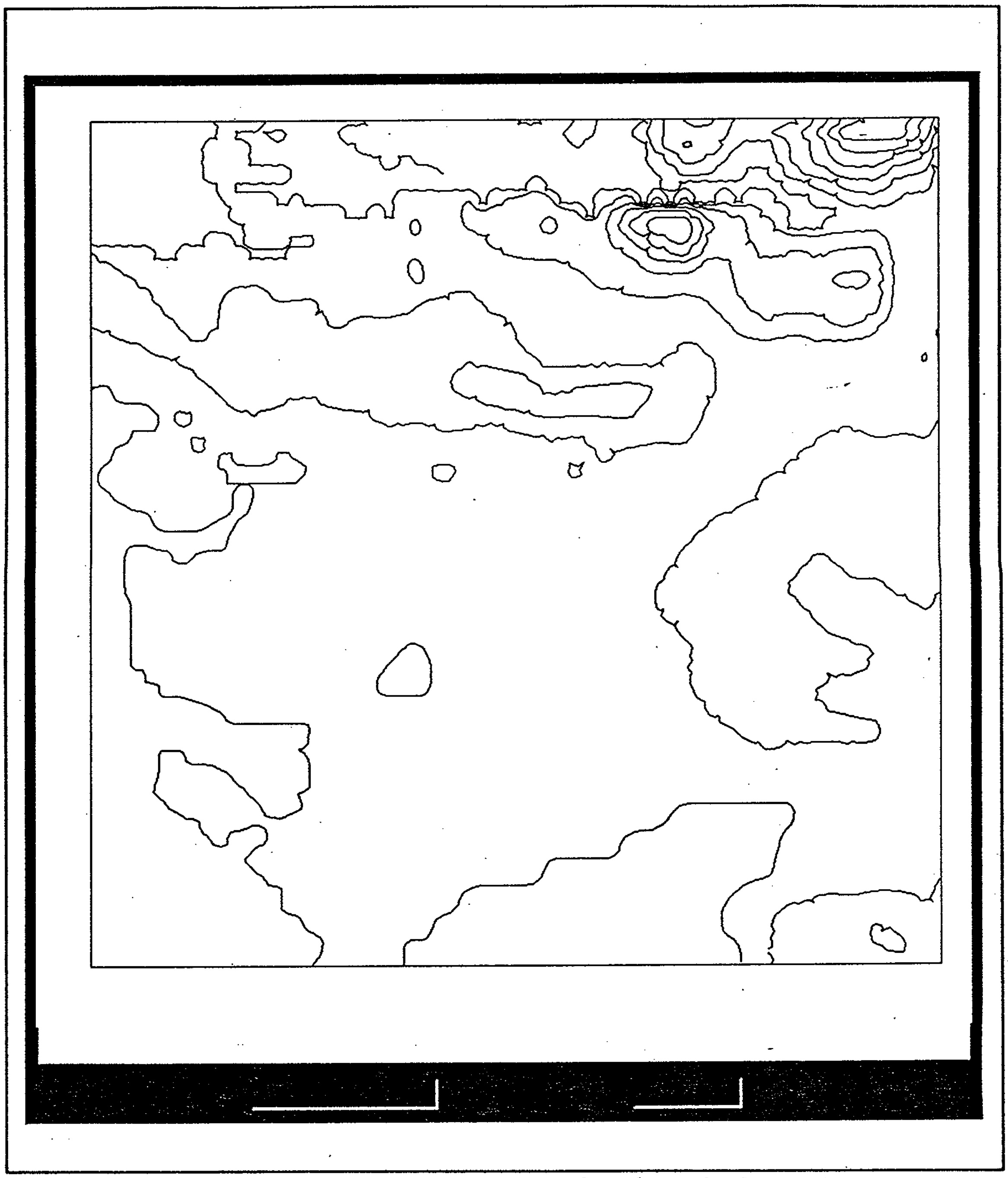


Figure 1b: Background Map drawn by User Interface from CRC Data Base

4.3 IDENTIFICATION OF VERIFICATION STATIONS

The Greater Vancouver Area provides a good basis for validating the model because of the density of the meteorological data network operated by the AES and the Greater Vancouver Regional District (GVRD). A description and a summary of the characteristics of the verification stations as identified by B.H. Levelton & Associates Ltd (Voigt et.al., 1991) are included in Table 4.

STATION	LOCATION			COMMENTS
	LAT (° ' ")	LONG (° ' ")	ELEV (metres)	
YVR INT'L AIRPORT	49 11 15	123 09 55	10	Excellent exposure.
T13 NORTH DELTA	49 09 35	122 54 00	90	Good exposure. Possible problem with uplift from side of reservoir
T14 BURNABY MTN	49 16 45	122 54 25	350	Exposure open in all directions.
T17 RICHMOND SOUTH	49 08 25	123 06 25	2	Exposure fair to good. Some sheltering from trees and homes.
T18 BURNABY SOUTH	49 12 55	122 59 00	30	Good exposure. Some influence from trees and school to east.
T19 RICHMOND EAST	49 11 05	123 02 05	5	Excellent exposure.

Table 4: Verification Stations - Location and Characteristics (see map, Figure 1)

The AES reports hourly wind speeds in knots and direction in degrees based on two minute averages. GVRD wind data are one hour averages and are reported in units of kilometres per hour and compass direction (eg. SW, NNE).

As indicated earlier, a maximum of five verification stations may be included for objective analysis. The inclusion of the objective analysis procedure, however, precludes during trial runs of the model the objective analysis procedure was omitted in favour of using verification station data as a basis for comparing model output.

4.4 OBSERVED WINDS

It should be acknowledged that model output may not always agree with observed winds. The model output represents the steady state of the wind field in relation to the input parameters. Verification station data, on the other hand, are point observations which are averages of the wind speed and direction at a particular location. The validation problem is further compounded by the fact that the model is unable to resolve features of less than one kilometre grid distance. This means that local effects that influence the wind measurement at a particular anemometer site will not be resolved by the model.

The actual winds occurring at the time of the three model runs are listed in Table 5. Wind data for Vancouver International Airport has been converted to kilometres per hour and compass sector for ease of comparison to GVRD data.

STATION	CASE #1 (31AUG91)		CASE #2 (23JUL91)		CASE #3 (21OCT91)	
	Speed(kmh)	Direction	Speed(kmh)	Direction	Speed(kmh)	Direction
YVR INT'L AIRPORT	7	WSW	5	WNW	32	W
T 13 N. DELTA	5	SW	7	WNW	17	W
T14 BURNABY MTN.	10	NW	7	NW	26	W
T17 RICHMOND S.	1	SW	7	WNW	12	W
T18 BURNABY S.	4	SW	5	SW	12	W
T19 RICHMOND E.	3	SSW	12	W	21	W

Table 5: Observed Surface Winds for Three Cases

Standard deviations in the observed winds for the three cases are as follows: Case #1, σ = 3.1 kmh; Case #2, σ = 2.6 kmh; Case #3, σ = 8.0 kmh.

4.5 PERFORMANCE STANDARDS

It is difficult to ascertain the degree of accuracy required of the model output in relation to the goals of the Environmental Emergency Response program. A previous evaluation of the Ayotte wind model by Dunbar (1989) makes no reference to specific performance levels nor do Kramer and Porch (1990) in their research into computer models used for emergency response.

Observed winds have measurement errors associated with them which may be expressed in terms of the standard deviation of the data shown in Table 5. Employing the principle that the model can not be expected to perform better than the uncertainty in the observational data, the standard deviation in the observed wind speed has been adopted as the performance standard for the wind model. The criterion for direction has been arbitrarily set at one compass sector based on 16 divisions (22.5 degrees).

The performance of the model is determined by comparing predicted and actual winds at grid points that correspond to the locations of the six verification stations.

4.6 STATISTICAL METHODS

Statistical methods for assessing and comparing model performance are the same as those utilized by Ayotte (1986) and Dunbar (1989) after a paper by Willmott (1981). These statistical indices are based on vector differences between model output and observed winds, commonly referred to as residuals, which incorporate differences in both speed and direction.

(A) Root Mean Square Error (RMSE): calculates the average difference between observed and predicted values.

$$RMSE=\sqrt{\frac{1}{N}\Sigma(d_j^2)}$$

where d_j is jth value of the predicted minus the observed values. (i.e. $d_j=p_j-o_j$)

(B) Index of Agreement (D2): used in place of a correlation coefficient with a value of 1.0 representing complete agreement and 0 representing no agreement between observed and predicted values.

$$D2=1-\frac{\sum d_j^2}{\sum(|p_j-\bar{o}|+|o_j-\bar{o}|)^2}$$

where $\bar{o}$ is the mean of the observed values.

Residual plots provide a visual means of comparing observed winds to those predicted by the model in terms of both speed and direction. The performance standard is indicated by the dotted line. Points lying outside the dotted line indicate unacceptable model performance.

Model output has been converted from metres per second to kilometres per hour and from degrees to compass sector in order to be consistent with verification data.

4.7. RESULTS

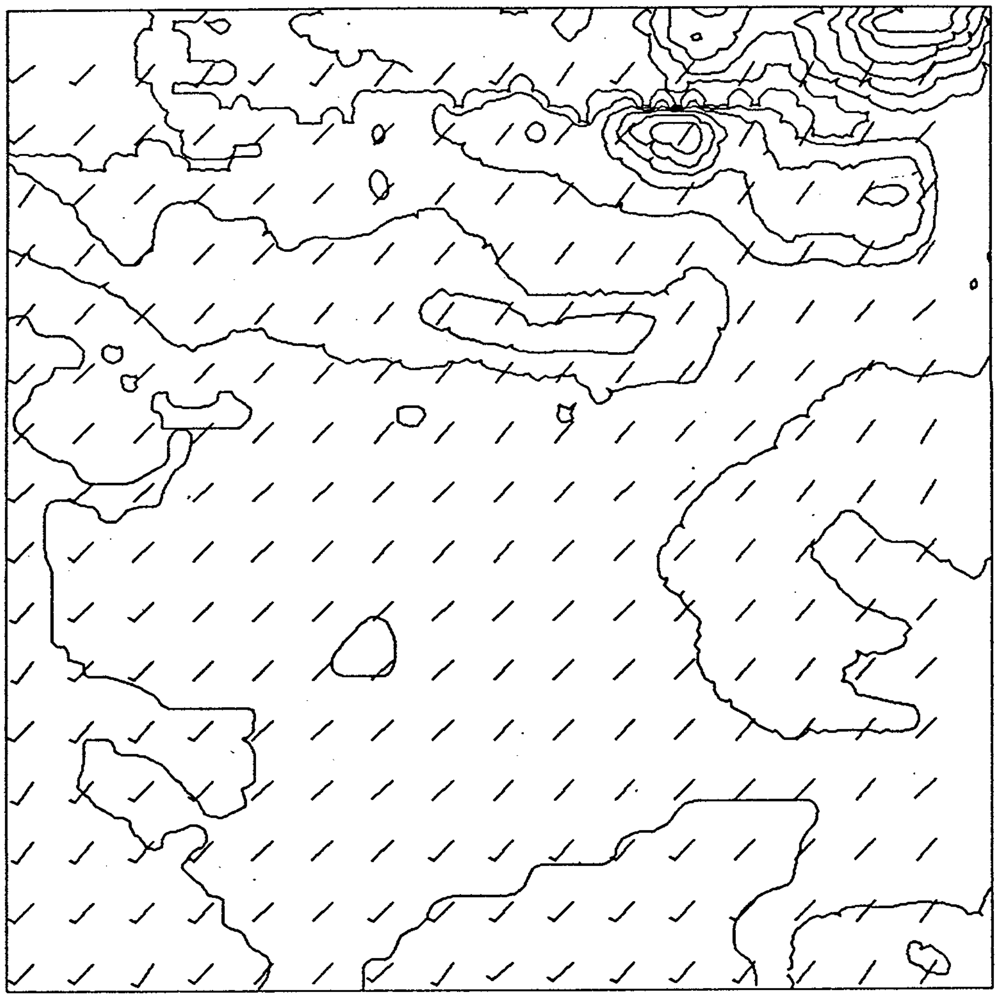
The results of the three case studies are discussed on the following pages. Model output is presented in both graphical and numerical form. In the graphical output, the wind field overlays a background map of the grid domain. Speed is indicated in knots and wind barbs follow standard meteorological convention. The numerical output displays pairs of values representing the speed (metres per second) and direction (degrees) at each grid-point. Grid coordinates are referenced by row and column numbers which form a border around the data.

Tables of predicted and observed winds are presented followed by residual plots and statistics.

DISCUSSION OF RESULTS - CASE #1

Model output for Case #1 is displayed in graphical form in Figure 2a and in numerical form in Figure 2b.

SCAN



Danard Model Output from run date 91-12-10 13:35 (wind speed in knots)

Figure 2a: Graphical Output - CASE #1 - 31AUG91

Danard Mesoscale Model Run (speeds in m/s)
91/12/10/13/35

16 Grid Rows
16 Grid Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
16	233	225	222	219	223	219	219	224	221	217	221	221	214	210	210	212	16
	1.5	1.6	.8	1.5	1.5	1.6	.7	.7	1.6	.7	1.6	.9	.9	1.0	1.2	1.2	
15	230	227	226	225	224	224	223	223	220	222	223	216	212	212	214	220	15
	1.4	1.2	1.1	1.2	1.2	1.1	1.0	1.0	1.0	1.0	1.1	1.0	.9	.9	1.0	.8	
14	217	225	226	225	225	224	223	221	220	221	218	216	216	216	214	218	14
	.8	1.0	1.0	1.1	1.1	1.0	1.0	.9	1.0	1.0	1.0	1.0	1.0	.9	.9	.8	
13	222	222	224	224	223	223	222	220	219	219	219	218	216	215	214	215	13
	.8	1.0	1.0	1.0	1.0	1.0	1.0	.9	.9	.9	.9	1.0	1.0	1.0	.9	.9	
12	219	223	224	223	222	221	220	218	218	219	219	217	216	218	219	226	12
	.8	1.1	1.1	1.1	1.0	1.0	1.0	1.0	.9	.9	.9	.9	.9	.9	.9	.8	
11	224	225	224	223	222	221	219	218	219	219	218	218	220	222	221	217	11
	1.6	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.0	.9	.9	.9	.9	.9	.9	
10	225	225	225	225	224	223	221	220	221	221	221	223	224	222	217	210	10
	.7	1.2	1.1	1.1	1.0	1.0	.9	.9	.9	.9	.9	.9	.9	.9	.9	1.0	
9	225	226	227	227	226	225	224	224	223	224	225	226	223	219	216	211	9
	1.6	1.3	1.2	1.1	1.0	.9	.9	.9	.9	.9	.9	.9	.9	.9	.9	.9	
8	226	227	228	227	227	225	224	224	224	226	226	225	222	220	219	220	8
	1.6	1.4	1.2	1.1	1.0	1.0	.9	.9	.9	.9	.9	.9	.9	.9	.9	.8	
7	222	225	226	227	226	225	225	226	226	225	225	224	222	220	219	221	7
	1.5	1.4	1.3	1.2	1.1	1.0	1.0	.9	.9	.9	1.0	1.0	.9	.9	.8	.8	
6	219	224	225	225	226	226	227	226	225	225	225	224	222	220	220	224	6
	1.8	1.5	1.4	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	.9	.8	.7	
5	225	222	223	225	227	228	227	226	225	225	224	224	223	222	221	224	5
	1.6	1.5	1.4	1.3	1.2	1.1	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.0	.9	.7	
4	216	221	224	225	227	227	227	226	225	224	224	224	224	223	221	226	4
	1.7	1.6	1.5	1.3	1.2	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.1	1.0	.9	.7	
3	219	221	223	225	227	227	226	224	224	223	223	224	226	225	223	220	3
	1.8	1.6	1.5	1.4	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.2	1.0	.9	.8	
2	225	222	222	223	226	226	224	222	224	225	224	223	224	224	221	215	2
	1.6	1.6	1.5	1.4	1.1	1.1	1.3	1.4	1.5	1.5	1.5	1.5	1.4	1.1	.9	.9	
1	225	225	215	224	222	223	227	215	230	229	222	223	218	220	215	213	1
	1.6	1.6	1.5	1.6	.7	.8	1.7	1.5	1.8	1.5	1.7	1.6	1.7	.9	.9	1.0	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	

Figure 2b: Numerical Output - CASE #1 - 31AUG91

As Table 6 indicates, winds predicted by the model tend to be much more uniform in both speed and direction than observed winds which may best be described as light and variable (1 to 10 kph and SSW to NW). Three verification stations report winds from the southwest which is consistent with the model output.

Plot No.	Grid Coords		Model Output (p)		Verif-ication Station ID	Obs Wind (o)		Difference (p-o)	
	Row	Col	Speed (kph)	Dir (sector)		Speed (kph)	Dir (sector)	Speed (kph)	Dir (sectors)
1	10	3	4	SW	YVR	7	WSW	-3	-1
2	8	12	3	SW	T13	5	SW	-2	0
3	14	12	4	SW	T14	10	NW	-6	-4
4	7	5	4	SW	T17	1	SW	3	0
5	11	9	4	SW	T18	4	SW	0	0
6	9	7	3	SW	T19	3	SSW	0	1

Table 6: Comparison of Model Output and Observed Winds - CASE #1 - 31AUG91

Statistical indices regarding the agreement between observed and modelled values are:

RMSE = 5.1 kmh D2 = 0.38 σ = 3.1 kmh

The use of Burnaby Mountain (T14) as a verification station is questionable due to the large discrepancy between the winds there and at other observing sites. This may be due to decoupling of the wind within the relatively low atmospheric boundary layer from the free atmosphere. When Burnaby Mountain is excluded from the data the following statistics are obtained.

RMSE = 2.4 kmh D2 = 0.28 σ = 2.2 kmh

The root mean square error (RMSE) is greatly improved by the rejection of Burnaby Mountain, but, curiously, the index of agreement (D2) is worse.

The standard deviation of the observed winds for Case #1 is $\sigma = 3.1$. Five of the six differences in speed fall within the acceptable range of one standard deviation as indicated by the dotted line in Figure 3a. Five of the six differences in direction are within the acceptable range of one sector (see Figure 3b). Differences in speed and direction are both positive and negative indicating no systematic error.

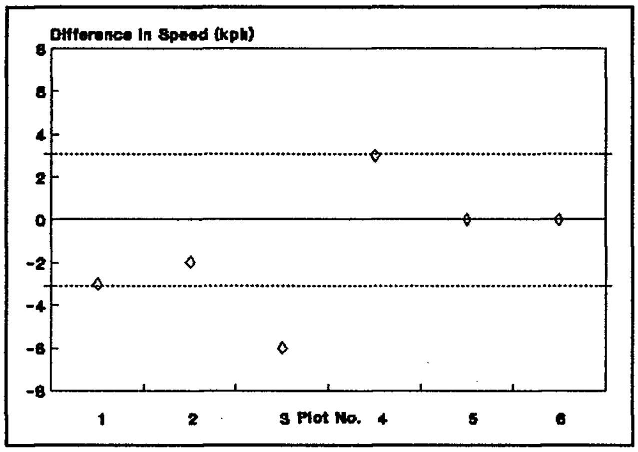


Figure 3a: Model Performance - Case #1 - Difference between model output and observed wind speeds.

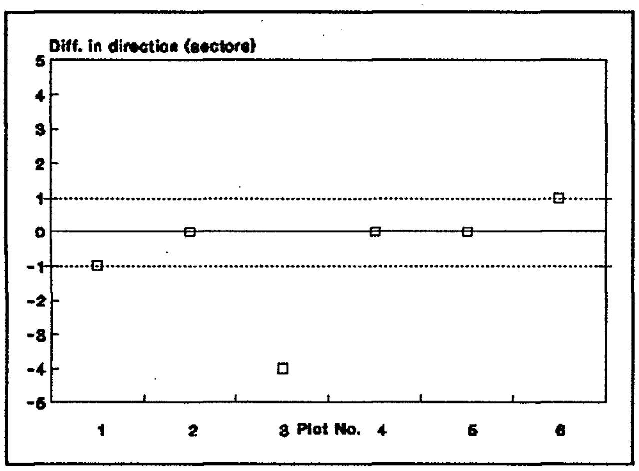


Figure 3b: Model Performance - Case #1 - Difference between model output and observed wind direction.

Using the standard deviation of the observed winds without Burnaby Mountain (σ = 2.2 kmh), only three of the five differences in speed meet the standard.

DISCUSSION OF RESULTS - CASE #2

Model output for Case #2 is displayed in graphical form in Figure 4a and in numerical form in Figure 4b.

SCAN

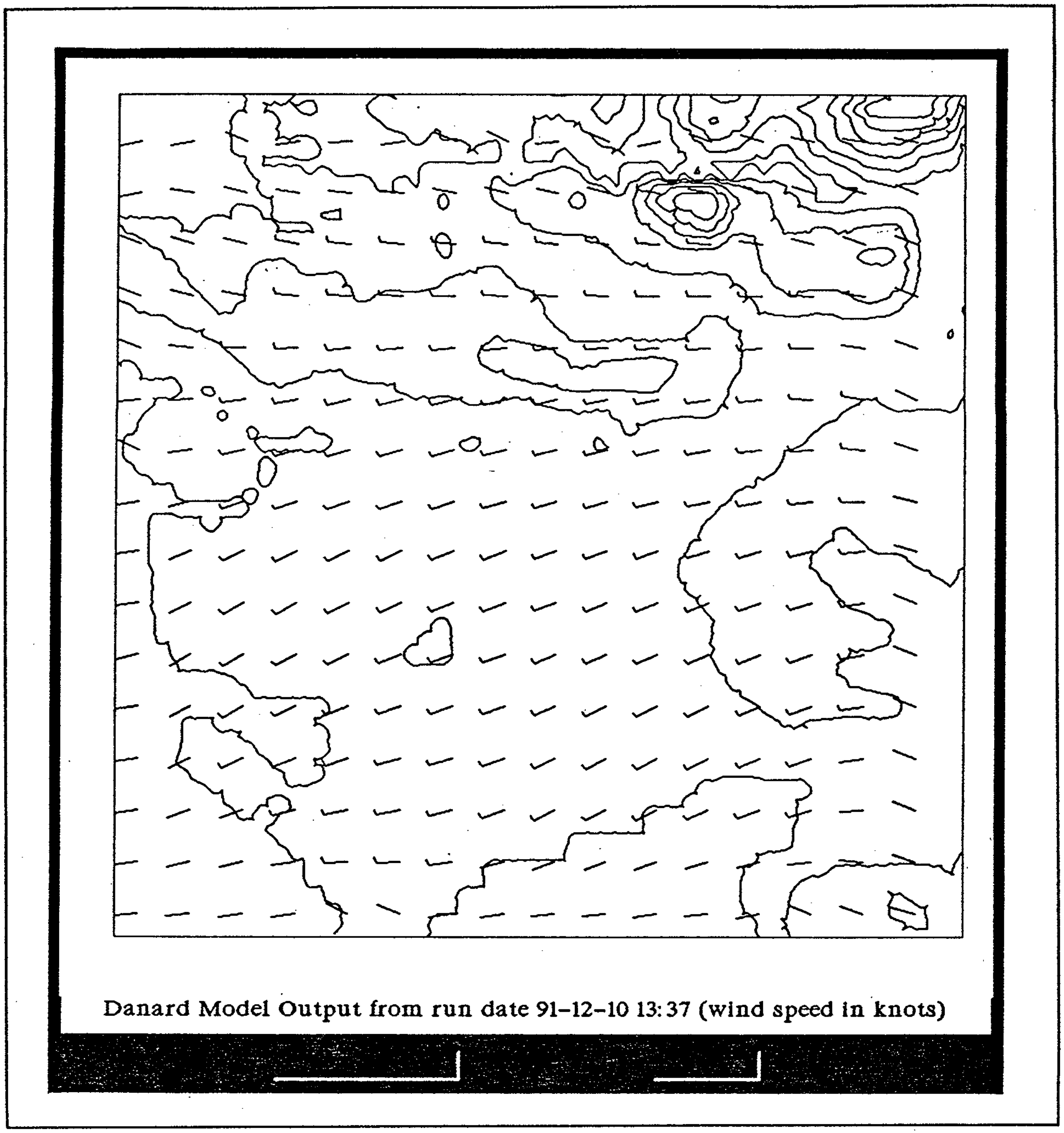


Figure 4a: Graphical Output - CASE #2 - 23JUL91

Scan

Danard Mesoscale Model Run (speeds in m/s)
91/12/10/13/37

16 Grid Rows
16 Grid Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
16	260	260	293	263	267	262	293	296	266	292	259	290	288	282	279	282	16
	.7	.7	1.1	.7	.7	.7	1.1	1.1	.7	1.2	.7	1.1	1.1	1.1	1.1	1.0	
15	260	280	283	279	275	277	282	283	282	283	280	281	288	287	284	294	15
	.7	.9	1.1	1.1	1.1	1.1	1.2	1.2	1.1	1.2	1.3	1.1	1.0	1.1	1.1	1.1	
14	291	287	284	280	277	276	277	277	277	278	273	272	278	285	289	292	14
	1.1	1.1	1.2	1.3	1.3	1.4	1.3	1.3	1.3	1.4	1.4	1.3	1.2	1.2	1.1	1.1	
13	290	285	280	276	273	272	271	272	272	272	271	270	269	272	278	293	13
	1.1	1.1	1.2	1.3	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.3	1.1	1.2	
12	290	276	271	267	265	264	263	263	264	266	266	266	265	269	277	290	12
	1.0	1.1	1.3	1.4	1.5	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.4	1.2	1.1	
11	263	267	261	259	257	257	256	256	257	258	259	260	264	271	279	296	11
	.7	1.1	1.3	1.5	1.6	1.7	1.8	1.8	1.8	1.9	1.8	1.7	1.6	1.5	1.3	1.1	
10	293	261	254	253	252	252	252	254	254	254	255	258	263	267	275	289	10
	1.1	1.1	1.4	1.6	1.7	1.8	1.8	1.8	2.0	2.0	2.0	1.9	1.8	1.6	1.4	1.2	
9	260	255	250	248	248	248	250	252	252	253	255	257	259	262	268	283	9
	.7	1.1	1.4	1.7	1.8	1.9	2.0	2.0	2.0	2.1	2.1	2.0	1.9	1.7	1.4	1.1	
8	263	249	245	244	245	246	248	250	252	252	253	254	255	258	265	289	8
	.7	1.1	1.4	1.7	1.9	2.0	2.0	2.0	2.0	2.1	2.1	2.1	1.9	1.7	1.4	1.1	
7	264	244	240	241	243	246	249	250	251	250	250	250	251	254	264	292	7
	.7	1.1	1.5	1.8	1.9	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.0	1.7	1.4	1.1	
6	258	240	238	241	244	248	250	250	249	248	247	247	248	252	261	293	6
	.7	1.1	1.5	1.8	1.9	1.9	2.1	2.1	2.1	2.1	2.1	2.0	1.9	1.7	1.4	1.1	
5	262	241	240	244	248	251	251	250	247	245	244	244	247	251	261	292	5
	.7	1.1	1.4	1.7	1.9	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.8	1.6	1.3	1.1	
4	263	245	245	249	252	254	253	250	245	242	242	243	247	251	263	293	4
	.7	1.0	1.4	1.6	1.8	1.9	1.9	1.8	1.8	1.7	1.7	1.7	1.6	1.4	1.2	1.1	
3	261	251	251	255	258	259	256	251	245	243	244	246	250	254	267	291	3
	.7	1.0	1.2	1.5	1.7	1.7	1.6	1.5	1.4	1.4	1.4	1.4	1.4	1.3	1.1	1.1	
2	261	257	257	262	267	268	262	255	251	250	251	253	256	264	276	289	2
	.7	.9	1.0	1.2	1.4	1.4	1.3	1.1	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	
1	263	263	260	261	295	291	262	262	265	263	262	263	258	292	288	286	1
	.7	.7	.7	.8	1.1	1.2	.7	.8	.7	.7	.8	.7	.8	1.1	1.0	1.1	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	

Figure 4b: Numerical Output - CASE #2 - 23JUL91

In this second light wind case, Table 7 shows more uniformity in the observed wind speeds (5 to 12 kmh) than in the first case, but directions have a fairly wide range (SW to NW). Four verification stations report winds from the west-northwest or northwest whereas the direction of the predicted wind field is mostly west-southwest.

Plot No.	Grid Coords		Model Output (p)		Verification Station ID	Obs Wind (o)		Difference (p-o)	
	Row	Col	Speed (kmh)	Dir (sector)		Speed (kmh)	Dir (sector)	Speed (kmh)	Dir (sectors)
1	10	3	5	WSW	YVR	5	WNW	0	-2
2	8	12	8	WSW	T13	7	WNW	1	-2
3	14	12	5	W	T14	7	NW	-2	-2
4	7	5	7	WSW	T17	7	WNW	0	-2
5	11	9	6	WSW	T18	5	SW	1	1
6	9	7	7	WSW	T19	12	W	-5	-1

Table 7: Comparison of Model Output and Observed Winds - CASE #2 - 23JUL91

Statistical indices are as follows:

RMSE = 4.8 kmh   D2 = 0.52

The root mean square error (RMSE) is about the same obtained for Case #1, and the index of agreement (D2) is slightly better.

In Case #1, the wind observation at Burnaby Mountain (T14) was rejected due to the large discrepancy between it and that of other stations. It was argued that the wind there was not representative of the surface wind due to the elevation of the station. In Case #2, data from this station is retained since the wind there is consistent with other observations.

The standard deviation of the observed winds for Case #2 is σ = 2.6 kmh. Five of the differences in speed fall within the acceptable limit of accuracy required of the model as shown in Figure 5a, but only two differences in direction fall within the defined limit (Figure 5b). Differences in speed are both positive and negative indicating a lack of systematic error, however the direction is systematically underestimated by about 2 sectors (45 degrees).

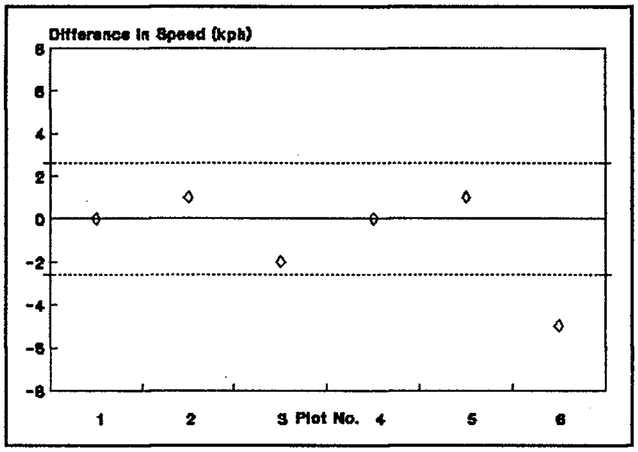


Figure 5a: Model Performance - Case #2 - Difference between model output and observed wind speeds.

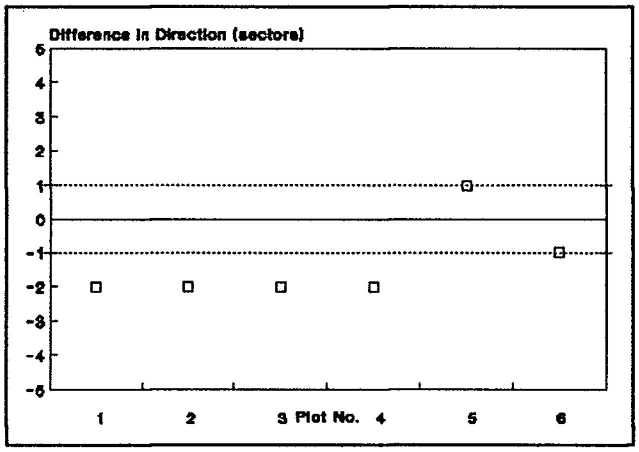


Figure 5b: Model Performance - Case #2 - Difference between model output and observed wind direction.

DISCUSSION OF RESULTS - CASE #3

Model output for Case #3 is displayed in graphical form in Figure 6a and in numerical form in Figure 6b.

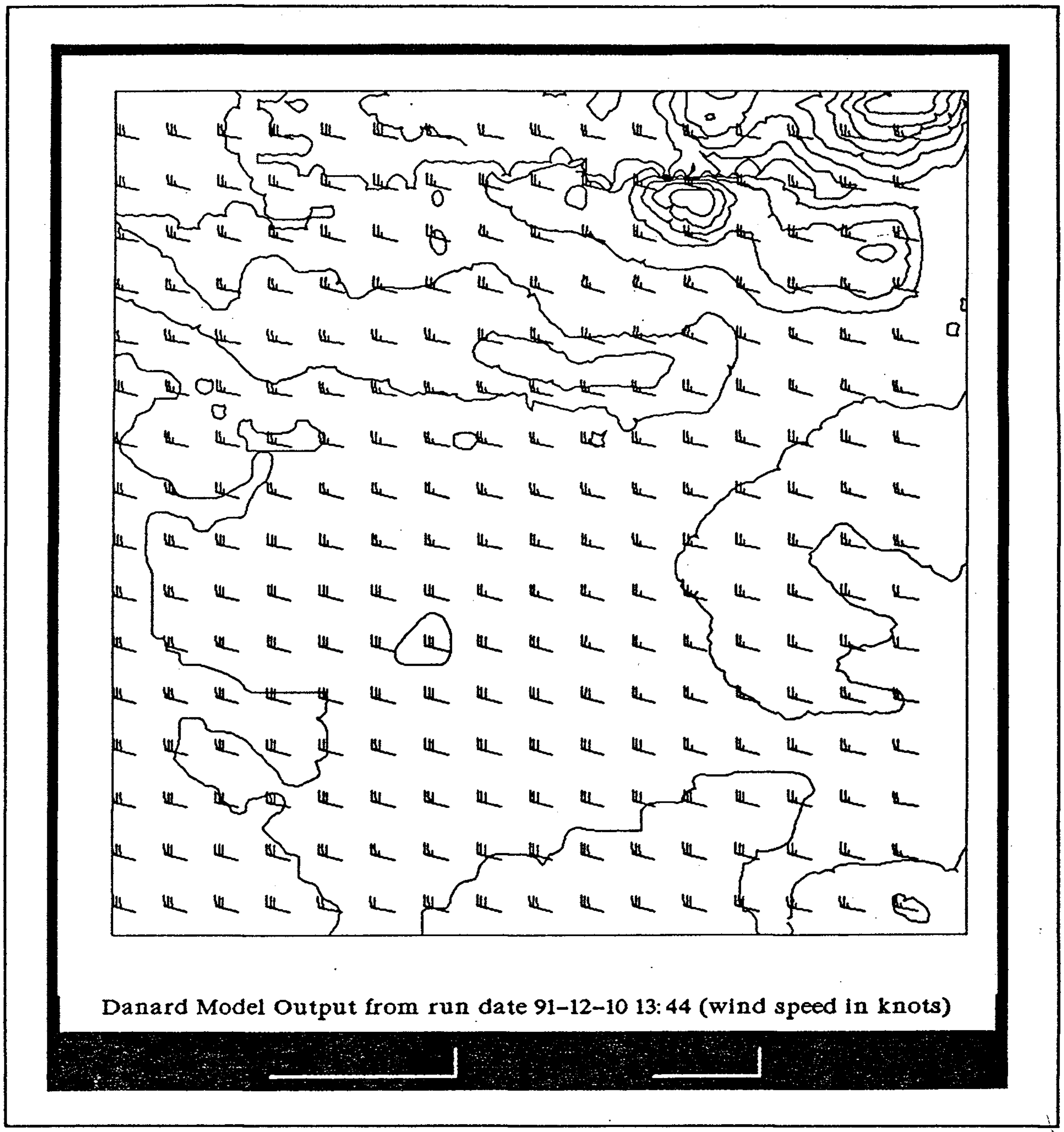


Figure 6a: Graphical Output - CASE #3 - 21OCT91

SCAN

Danard Mesoscale Model Run (speeds in m/s)
91/12/10/13/44

16 Grid Rows
16 Grid Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
16	283	283	280	283	283	282	279	280	282	280	282	279	280	280	279	279	16
	13.5	13.5	10.2	13.5	13.7	13.8	10.2	10.2	13.7	10.2	14.0	10.4	10.2	10.3	10.5	10.4	
15	282	283	282	283	284	284	284	284	284	284	285	284	284	282	280	279	15
	13.6	12.8	12.1	12.3	12.6	12.7	12.0	11.8	11.7	11.4	12.5	12.0	11.1	10.8	10.9	10.3	
14	279	282	283	283	284	284	285	286	284	286	285	283	284	284	285	280	14
	10.3	11.1	11.4	11.6	11.8	12.1	12.0	11.8	11.7	11.7	11.9	11.9	11.8	11.8	11.2	10.2	
13	280	279	280	281	283	284	284	285	286	287	287	287	285	283	281	280	13
	10.3	10.5	10.9	11.3	11.4	11.7	11.8	11.8	11.6	11.6	11.6	11.8	11.9	12.0	11.4	10.2	
12	279	278	278	279	279	280	281	282	283	285	287	288	286	285	282	280	12
	10.2	11.0	11.4	11.5	11.5	11.6	11.8	11.8	11.7	11.6	11.7	11.6	11.4	11.5	11.4	10.3	
11	283	281	280	278	278	278	278	278	279	280	281	282	284	285	285	279	11
	13.6	12.2	11.9	11.8	11.7	11.8	11.8	11.9	11.9	11.8	11.8	11.4	11.2	11.4	11.5	10.3	
10	280	281	281	280	280	280	279	279	279	279	279	280	282	283	284	279	10
	10.1	11.6	11.9	12.0	12.0	12.0	12.0	12.0	12.0	12.0	11.8	11.7	11.7	11.9	11.7	10.2	
9	282	282	282	282	282	282	282	281	281	281	281	281	283	283	283	279	9
	13.6	12.8	12.6	12.5	12.4	12.4	12.3	12.3	12.2	12.1	12.1	12.2	12.1	12.0	11.9	10.3	
8	283	283	283	283	283	283	283	283	283	283	282	282	283	283	283	279	8
	13.6	13.4	13.2	13.0	12.8	12.7	12.6	12.5	12.5	12.3	12.4	12.5	12.3	12.1	12.1	10.3	
7	282	283	283	284	284	284	284	284	284	284	284	283	283	284	284	280	7
	13.6	13.5	13.4	13.3	13.2	13.0	12.9	12.8	12.7	12.5	12.5	12.6	12.6	12.5	12.1	10.2	
6	283	283	283	284	284	284	284	284	284	285	285	284	284	284	284	280	6
	13.7	13.6	13.5	13.4	13.3	13.2	13.1	13.1	13.0	12.8	12.7	12.8	12.8	12.6	12.2	10.2	
5	283	283	283	283	283	284	284	284	284	285	285	285	284	283	283	279	5
	13.6	13.6	13.5	13.5	13.4	13.4	13.3	13.2	13.1	13.0	12.8	12.8	12.8	12.8	12.4	10.2	
4	283	282	283	283	283	283	284	284	284	284	285	285	284	284	282	280	4
	13.5	13.6	13.5	13.5	13.5	13.4	13.3	13.2	13.2	13.1	12.9	12.8	12.8	12.7	12.5	10.2	
3	282	282	282	282	283	283	283	283	284	284	284	284	284	284	284	279	3
	13.6	13.6	13.6	13.5	13.4	13.3	13.2	13.2	13.2	13.1	13.1	13.0	12.9	12.7	12.6	10.2	
2	282	282	282	282	282	282	283	283	283	283	283	283	283	284	284	279	2
	13.6	13.6	13.6	13.4	12.9	12.7	12.8	13.1	13.2	13.3	13.2	13.2	13.1	12.8	12.2	10.3	
1	283	283	283	283	280	280	283	283	282	283	282	283	282	279	279	279	1
	13.5	13.5	13.5	13.5	10.1	10.2	13.7	13.5	13.7	13.5	13.7	13.7	13.6	10.3	10.3	10.4	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	

Figure 6b: Numerical Output - CASE #3 - 21OCT91

SCAN

Observed winds in this strong wind case are uniformly from the west which is in general agreement with the model output as shown in Table 8.

Plot No.	Grid Coords		Model Output (p)		Verif-ication Station ID	Obs Wind (o)		Difference (p-o)⁻	
	Row	Col	Speed (kmh)	Dir (sector)		Speed (kmh)	Dir (sector)	Speed (kmh)	Dir (sectors)
1	10	3	43	WNW	YVR	32	W	11	1
2	8	12	45	WNW	T13	17	W	28	1
3	14	12	43	WNW	T14	26	W	17	1
4	7	5	48	WNW	T17	12	W	36	1
5	11	9	43	W	T18	12	W	31	0
6	9	7	44	WNW	T19	21	W	23	1

Table 8: Comparison of Model Output and Observed Winds - CASE #3 - 21OCT91

There is however, a large variation in the speeds (12 to 36 kilometres per hour) which is not predicted by the model. As a result there is a very large root mean square error (RMSE), and the index of agreement (D2) is low as shown below.

RMSE = 27 kmh   D2 = 0.30

The model greatly overestimates the speed of the wind by as much as three or four times the observed values. This suggests that the geostrophic wind used to initialize the model may have been poorly estimated. A comparison of the three upper air soundings tends to bear this out with Vancouver Airport reporting winds about 50% stronger than Port Hardy and Quillayute (see Appendix D). The same comment applies to a systematic error in direction which the model consistently overestimates by one sector (22.5 degrees).

The standard deviation of the observed winds for Case #3 is 8.0 kmh. As Figure 7a shows, none of the differences in speed meet the performance standard of one standard deviation (dotted line), however all of the differences in direction are within the acceptable range as indicated by Figure 7b.

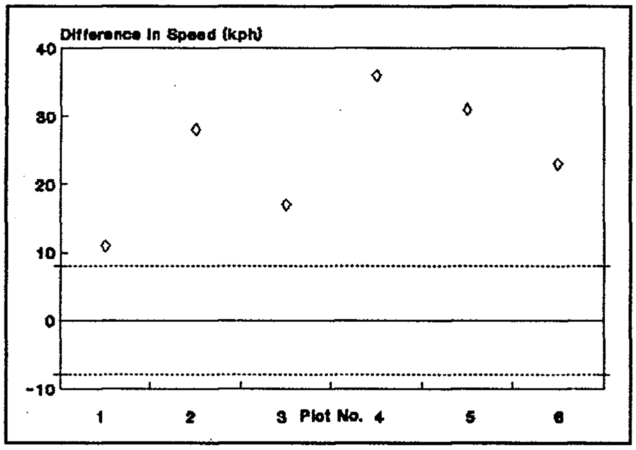


Figure 7a: Model Performance - Case #3 - Difference between model output and observed wind speeds.

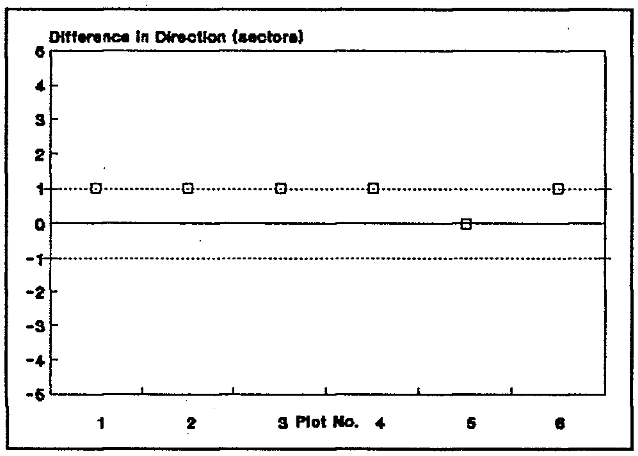


Figure 7b: Model Performance - Case #3 - Difference between model output and observed wind direction.

5. SENSITIVITY ANALYSIS

This section of the report examines which parameters are most critical to obtaining valid model output. Three factors are considered: the sensitivity of the model, the accuracy (uncertainty) of the input data, and the level of accuracy required of the model output.

5.1 SENSITIVITY

Sensitivity is a measure of how the model output is affected by changes to input parameter values (Table 9). The greater the sensitivity to a particular parameter, the greater the requirement for obtaining accurate data for model initialization.

PARAMETER	CASE #1 (Light Wind)		CASE #3 (Strong Wind)	
	MODEL SPEED (m/s)	MODEL DIRECTION (degrees)	MODEL SPEED (m/s)	MODEL DIRECTION (degrees)
Geostrophic Wind				
Speed (per m/s)	0.8	3	0.6	1
Direction (per deg)	0	1	0	1
Height (per metre)	0.005	0.1	0.005	0
Temperature Gradient (per °C/1000 km)	0.02	3	0.2	0.2
Temperature 850 mb				
Unstable (per °C)	0.1	5	2	6
Stable (per °C)	0.1	2	0.6	2
Height 850 mb (per metre)	0.001	0.01	0.002	0.01
Temperature 700 mb				
Unstable (per °C)	0.05	1	0.5	1
Stable (per °C)	0.05	2	0.3	1
Height 700 mb (per metre)	0.001	0.01	0.002	0.01
Temperature Air Over Land (per °C)	0.05	1	0.4	3
Temperature Water (per °C)	0.05	0.1	0.05	2

Table 9: Model Sensitivity - Light Wind Case (13AUG91) and Strong Wind Case (21OCT91)

The numbers in Table 9 represent changes in the model output per unit of change in input value. Using the geostrophic wind speed as an example, the table shows that for Case #1 the model output changes by 0.8 m/s in speed and 3 degrees in direction for every one metre per second change in the input value of the geostrophic wind speed.

In performing this procedure the value of one parameter is systematically varied while other parameters are held constant. The model output at a single grid point is then monitored to determine the effect of varying the value of that parameter. The relationship between the change in output and the change in input is assumed to be linear over a small range of values and is determined by means of linear regression (ie. the slope of the line of best fit through a scatter-plot of the data). The grid point (R9, C7) located near the centre of the grid and away from extreme topographical influences was chosen to represent the field.

To determine whether the sensitivity of the model might be affected by the strength of the wind, the sensitivity analysis was performed under light (Case #1) and strong (Case #3) wind conditions. For instance, it would be important to know whether the direction of the modelled wind is more sensitive to uncertainty in the temperature gradient when the wind is very light compared to when it is very strong.

The sensitivity of the model to the geostrophic wind was determined independent of the temperature gradient by setting the value of the latter to zero. In practise these two parameters are coupled through the geostrophic thermal wind equation such that errors are actually compounded. This can be especially troublesome in cases where a very sharp temperature gradient exists such that a small error in the geostrophic wind can result in either a very large error, or alternatively a cancelling effect, in the model output due to the compounding effect.

The model was found to be extremely sensitive to the 850 mb temperature where the resulting lapse rate is reduced to below the wet adiabatic lapse rate (ie. towards greater stability). When this occurs, the entire wind field, which appears uniform under unstable conditions, becomes more and more irregular and chaotic in appearance. Furthermore, as the lapse rate approaches the dry adiabatic lapse rate, dramatic changes to both the speed and direction of the modelled winds are observed but without the loss of uniformity in the wind field. A similar phenomenon occurs with the 700 mb temperature but to a lesser extent. For these reasons, the sensitivity of the model to the 850 and 700 mb temperatures is analyzed separately for stable and unstable conditions.

The model is also found to be highly sensitive to large values of the roughness length for land. Abrupt changes appear in the wind speed and direction at land-water interfaces, and sharp discontinuities to the wind field are introduced when the roughness length for land exceeds 1.0 for strong winds and 2.0 for light winds.

As was suspected, the model reacts differently to certain parameters when modelling light winds (Case #1) in comparison to modelling strong winds (Case #3). Predicted wind speeds are more sensitive in the case of strong winds to the temperature gradient, the temperature at 850 and 700 mb and the temperature of the air above land. The direction of the modelled wind is more sensitive to the geostrophic wind speed and the temperature gradient in light winds. All other parameters appear to be unaffected by the strength of the wind.

5.2 ACCURACY OF INPUT DATA

A better appreciation of which parameters are critical to model performance is obtained when the sensitivity of the model is considered in conjunction with the uncertainties in the input data. This method is completely analogous to that used in instrument calibration whereby an instrument of known sensitivity is used to measure some physical property. The resolution of the instrument is equal to the product of the sensitivity and the standard deviation (uncertainty) of the data. In the case of the model, the resolution is represented by the error in the output as shown in Table 10 and is given by the product of the sensitivity and the uncertainty as determined in an earlier section (Error = Sensitivity x Uncertainty).

PARAMETER	CASE #1 (Light Wind)			CASE #3 (Strong Wind)		
	ERROR IN MODEL SPEED		ERROR IN MODEL DIRECTION	ERROR IN MODEL SPEED		ERROR IN MODEL DIRECTION
	(m/s)	(%)	(degrees)	(m/s)	(%)	(degrees)
Geostrophic Wind						
Speed	0.2	20	1	0.2	2	0
Direction	0		5	0		1
Height	0		1	0		0
Temperature Gradient	0.1	10	15	1.0	8	1
Temperature 850 mb						
Unstable	0.1	10	5	2	15	6
Stable	0.1	10	2	0.6	5	2
Height 850 mb	0		0	0		0
Temperature 700 mb						
Unstable	0		1	0.5	4	1
Stable	0		2	0.3	2	1
Height 700 mb	0		0	0		0
Temperature Air Over Land	0		0	0		0
Temperature Water	0.1	10	0	0.1	1	4

Table 10: Error in Output Owing to Uncertainty in Input Data for Light Wind (Case #1) and Strong Wind (Case #3)

The numbers in Table 10 may be explained with the aid of the following example. Recalling from Table 1 that the uncertainty in the input geostrophic wind speed is 0.25 m/s and from Table 8 (Light Wind Case) that the sensitivity of the model to this parameter is 0.8 m/s, the resulting error in the output is (0.25 m/s) x (0.8 m/s per m/s) = 0.2 m/s. The corresponding error in the direction of modelled winds due to the uncertainty in the input geostrophic wind speed is (0.25 m/s) x (3 degrees per m/s) = 0.75 degrees, or 1 degree after rounding off to the nearest degree.

This analysis indicates that the uncertainties in the input data are likely to have a greater effect on the accuracy of the predicted speeds, in terms of relative error, in light wind situations (Case #1) than in strong winds (Case #3). For example, an uncertainty of 0.25 m/s (one half knot) in the input geostrophic wind value results in an error in the output of 0.2 m/s for both cases. This represents a relative error in the modelled speed of 20% for a 1 m/s wind as in Case #1 but only 2% for a 13 m/s wind for Case #3.

In the case of light winds, errors in the modelled speeds on the order of 20% are inherent in the input values of the geostrophic wind speed, and an error of 10% is associated with the uncertainties in the input values of the temperature gradient, the 850 mb temperature and the surface temperature of the water. The largest error (15 degrees) in the predicted direction of the light wind is associated with the uncertainty in the value of the temperature gradient. Uncertainties in the direction of the geostrophic wind and the 850 mb temperature result in errors in the direction of the modelled winds of 5 degrees.

For strong winds, the largest errors in the modelled wind speeds result from uncertainties in the input values of the temperature gradient and the 850 mb temperature. Directional errors of the order of five degrees are associated with uncertainties in the 850 mb temperature and the water surface temperature.

5.3 TOLERANCE FOR INPUT ERROR

Earlier it was established that the level of accuracy required of the model for emergency response purposes is a maximum error of one standard deviation in speed and one compass sector (22.5 degrees) in direction relative to the set of observed wind values. The question then arises as to how accurate the input data must be to ensure that the model output remains within the acceptable limits of accuracy. In other words, it is desirable to know <u>the degree of *in*accuracy the model will tolerate in the input data before the maximum acceptable error in the output is reached</u>. The requirement for accuracy in the input data (tolerance), reflected in the Table 10, is a function of the sensitivity and the level of accuracy required of the model as given by the performance standard (Tolerance = performance standard ÷ sensitivity). Note that units are indicated by rows. Uncertainties are shown in the table in order to provide a basis for comparison for the tolerance data.

PARAMETER	UNCERTAINTY INPUT DATA	CASE #1 (Light Wind)		CASE#3 (Strong Wind)	
		Tolerance for input error on		Tolerance for input error on	
		Model Speed	Model Direction	Model Speed	Model Direction
Geostrophic Wind					
Speed (m/s)	±0.25	0.75	7.5	3.7	22.5
Direction (deg)	±5	infinite	22.5	infinite	22.5
Height (m)	±10	120	225	440	infinite
Temperature Gradient (°C/1000 km)	±5	30	7.5	11	112.5
Temperature 850 mb					
Unstable (°C)	±1	6	4.5	1.1	3.75
Stable (°C)	±1	6	11.25	3.7	11.25
Height 850 mb (m)	±10	600	2250	440	2250
Temperature 700 mb					
Unstable (°C)	±1	12	22.5	4.4	22.5
Stable (°C)	±1	12	11.25	7.3	22.5
Height 700 mb (m)	±10	600	2250	1100	2250
Temp. Air Land (°C)	±0.1	12	22.5	5.5	7.5
Temp. Water (°C)	±2	12	225	44	11.25

Table 11: Model Tolerance for Error in Input Data for Light Wind (Case #1) and Strong Wind (Case #3)

An understanding of Table 11 may be facilitated by the following example using Case #1. Suppose one was interested in knowing the degree of accuracy required in the measurement of the height of the geostrophic wind.

Performance Standard (see Section 4.5)
Speed (1 standard deviation) = 2.2 kmh = 0.6 m/s (excludes T14)
Direction (1 compass sector) = 22.5 degrees

Sensitivity (see Table 9)
Speed: 0.005 m/s per metre
Direction: 0.1 degree per metre

The required degree of accuracy is defined by the tolerance.

Tolerance = performance standard ÷ sensitivity
Tolerance (speed) = (0.6 m/s) ÷ (0.005 m/s per metre) = 120 metres
Tolerance (direction) = (22.5 degrees) ÷ (0.1 degrees per metre) = 225 metres

In Table 11, the tolerance for error for each parameter is indicated by the magnitude of the values with relatively small numbers indicating low tolerance for error. Where the value is small, great care must be taken in obtaining accurate input; conversely, relatively large values suggest a much lower requirement to obtain accurate input data.

A clearer perspective on the requirement for accuracy may be obtained by comparing the tolerance values to the uncertainties inherent in the input data. Where the two values are of the same order of magnitude, the requirement for accurate data is great. Returning to the previous example, it is apparent that the tolerance for error in the height of the geostrophic wind greatly exceeds the uncertainty in the input data (uncertainty of 10 metres versus 120 metres and 225 metres tolerance for speed and direction respectively). This implies that the need for accuracy can be relaxed in estimating the height of the geostrophic wind. This is not the case, however, when computing the speed of the geostrophic wind. Note that the tolerance of the geostrophic wind speed parameter approaches the uncertainty in the data itself. This implies that there is little room for inaccuracy in computing the geostrophic wind speed beyond the inaccuracy of the measurement itself!

This discussion on the sensitivity of the model will now be concluded by the identification of the parameters considered critical to obtaining valid model output. Table 12 summarizes these findings by indicating the critical parameters according to their impact (speed vs. direction) on the predicted wind field by case (weak vs. strong winds).

CRITICAL PARAMETER	Light Winds		Strong Winds	
	Speed	Direction	Speed	Direction
Geostrophic Wind				
Speed	X		X	
Direction		X		X
Temperature Gradient		X		
Temperature 850 mb			X	

Table 12: Identification of Critical Input Parameters

A critical parameter is defined as one in which

- the uncertainty in the input data is likely to cause an error in the model output which exceeds the acceptable limit set for the model

- data may be either missing or difficult to interpret which may result in an unacceptable error in the model output.

The geostrophic wind is apparently the most sensitive parameter especially in the case of light winds. Here, the accuracy of the input data is not so much at issue as is the judgement required on the part of the user to make a reasonable estimate in the face of often conflicting data from different soundings.

The direction of the modelled wind is particulary sensitive to the temperature gradient when modelling light winds. As direction may be the more critical parameter in emergency response situations, care should be taken in calculating the temperature gradient.

For modelling strong winds, the model is very sensitive to changes to the temperature of the 850 mb surface that results in a lapse rate which becomes steeper than the wet adiabatic value. It has been found that the 850 mb temperature needs to be estimated to the closest degree.

Finally, the value of the roughness length for land should not be allowed to exceed 1.0 in view of the sudden discontinuities produced in the model output at higher values. Evidently, the use of values greater than 1.0 violates the boundary layer similarity assumptions used in the model.

6. SUMMARY AND CONCLUSIONS

The purpose of this report was to evaluate BOLON/1 for its use within the AES, particularly with regard to the Environmental Emergency Response Program. The model was tested for the Greater Vancouver area using a 32 by 32 kilometre grid with a grid mesh of two kilometres. Three cases were selected to compare model performance under different synoptic conditions. Two of the cases involved very light, thermally-driven winds, one under stable conditions and the other under unstable conditions. The third case examined model performance for dynamically-induced winds.

6.1 DATA AVAILABILITY

Meteorological data required to initialize the model are readily available from the AES synoptic data network. Much of this data may be obtained from upper air soundings or from CMC analyzed maps, specifically the 850 mb and 700 mb analyses. Once these data have been extracted, however, the user is still required to make a number of calculations to put the information into a form which can be utilized by the model. Gathering and analyzing the data may take upwards of 30 minutes, and entering the data and running the model takes about five minutes. However, this is much longer than the five minute initial response requirement set for the Environmental Emergency Response Program. It is anticipated that the only way of meeting this requirement would be to completely automate model initialization. Unfortunately, automation implies some loss of user control over the input values which in turn could jeopardize the validity of the model output.

As upper air and CMC data are issued only twice per day (00Z and 12Z), input data may not be representative of synoptic conditions at the time of the wind model run. Using BOLON/1 in a prognostic mode may be accomplished by extrapolating from synoptic data to current conditions using forecasting techniques. It should be recognized, however, that this process of estimating current input parameter values introduces uncertainty in the input data and corresponding error in the model output.

6.2 MODEL VALIDATION

Model runs were verified by comparing model output to actual winds as determined from six AES and GVRD stations. For the thermal cases, a large degree of variability existed in the observed winds which was not reflected in the model output. Nonetheless, reasonable agreement was obtained between modelled winds and observed winds for both of these cases (index of agreement = 0.38 for Case #1 and 0.52 for Case #2). For the stronger winds of the dynamical case, there was less variability in the direction of the observed winds but large variability in observed wind speeds. Consequently, the level of agreement between modelled and observed winds was good in terms of direction but not speed (index of agreement = 0.30 for Case #3). In all three cases, better agreement between modelled and observed winds was found in respect to direction than speed.

6.3 MODEL SENSITIVITY

A sensitivity analysis was conducted to determine which parameters are most critical to obtaining valid output. The speed and direction of the geostrophic wind were shown to be critically important for modelling both light and strong winds. The temperature gradient is a critical parameter with respect to direction for modelling light winds, and the temperature at 850 mb is critical to obtaining valid wind speeds in strong winds.

The main challenge to obtaining satisfactory results from the model involves exercising care and good judgement in initializing the input parameters. This is particularly true of the geostrophic wind which is the most difficult parameter to estimate. Danard suggests a variety of methods for computing the geostrophic wind, however, the results obtained using different methods may not agree. Determining the most appropriate value for the geostrophic wind is perhaps the single largest obstacle to overcome in applying the model.

The results obtained to date with BOLON/1 have been encouraging, and the model shows considerable promise with respect to its operational utility. Regardless, the issues just raised concerning the initialization process need to be addressed if the model is to perform as expected.

7. RECOMMENDATIONS

Before the model becomes fully operational, the problems identified in this report need to be addressed and further testing of the model will be necessary. Specifically, the following actions need to be taken.

(A) Test the model under different geographic conditions where the terrain effects are likely to be more profound. Potential areas for further application are the Okanagan, Barkley Sound, and Georgia Strait. Modelling of the coastal region could be done in conjunction with the PWC Marine Desk to evaluate the use of the model in marine forecasting.

(B) Test the model for its ability to simulate known mesoscale events such as outflow winds.

(C) Investigate further the different approaches outlined by Danard for computing the geostrophic wind. These include the multiple regression method and the use of analyzed sea level pressure maps referred to in Section 3.1.

(D) Determine whether climatological data can be substituted for actual measurements of the water surface temperature, and determine other procedures for estimating the water surface temperature of large bodies of water where either actual measurements or climate data may be missing.

(E) Investigate the use of CMC grid point data for determining the temperature gradient and other synoptic data at 850 mb and 700 mb.

(F) Implement the recommended changes to the User Interface (see Appendix A), and where it appears profitable to do so, correct the various software problems identified.

Once these steps have been taken it is anticipated that BOLON/1 will better serve the operational needs of the Environmental Emergency Response program and hopefully will find utility in improving the mesoscale forecasting capability of the weather centres.

REFERENCES

Ayotte, K.W., "The Development and Application of a One-Level Mesoscale Atmospheric Model Over the Lower Fraser Valley of British Columbia", Masters Thesis, University of British Columbia, 1986.

Danard, M. and Galbraith, J., " The Local Area Wind Model, BOLON1", manuscript prepared for the Atmospheric Environment Service, Pacific Region, 1989.

Dunbar, D.S., Nikleva, S. and Steyn, D., "Mesoscale Wind Models For Environmental Emergency Response", manuscript prepared by Seaconsult Marine Research Ltd. for the Atmospheric Environment Service, Pacific Region, 1988.

Dunbar, D.S., "Mesoscale Wind Models For Environmental Emergency Response", manuscript prepared by Seaconsult Marine Research Ltd. for the Atmospheric Environment Service, Pacific Region, 1989.

Kramer, M.L., and Porch, W.M. (eds) "Meteorological Aspects of Environmental Response", American Meteorological Society, Boston, MA, 1990.

Oke, T.R., "Boundary Layer Climates", Second Edition, Methuen, New York, 1987.

APPENDIX A

OBSERVATIONS CONCERNING THE USER INTERFACE

The User Interface was developed using X Windows in order to display model output both graphically and numerically on the HP9000 and to facilitate the initialization of the model. Initial trials of the wind model have provided an opportunity to evaluate the performance of the User Interface. Most of the software problems encountered have been corrected during the course of testing the model, and it may now be said with confidence that the interface is working reliably and is producing output consistent with expectations.

Most of the observations that follow pertain to gathering and entering input data to the model. Recommendations are made to make the task of initializing the model either faster or more convenient. In addition, some bugs in the X Windows software need to be corrected although these are more of a nuisance factor and do not significantly affect the performance of the model.

(A) At present the User Interface requires the user to calculate the geographic coordinates of the reference station in degree decimal form. A more convenient form for entering this data would be in terms of degrees/minutes/seconds as this is how the information normally appears.

(B) The User Interface does not provide a means of storing more than the current grid layout data file. Since the elevations, land use, and water fraction are an invariant property of any particular domain, it would be useful to be able to prepare certain grid layouts in advance and save them in a file. This would allow the user quick access to a number of predetermined geographic regions as well as avoid the necessity of manually editing the water fraction file where higher resolution is desired.

(C) Only one Reference Station screen can be saved at a time even though the output from up to 50 model runs can be saved. Without the relevant input however, the model output can be relatively meaningless. The capability of matching input and output would be a very useful enhancement to the User Interface.

(D) It should be possible to print input data screens, such as the Reference Station screen, from the User Interface. At the present time this must be done using Unix.

(E) The number of files in the Previous Output file should be indicated, and a warning message should be produced when the file is full.

(F) The model should be capable of producing output in the units of the user's choice (eg. knots, m/s, km/hr).

(G) When modelling over a large geographic area characterized by extremes in topography, the background map may appear very cluttered by the large number of contours. A better sense of the terrain could be achieved using coarser resolution by choosing fewer contours. At present, the number of contours is fixed at seven, however, having the user input the number of contours at the keyboard would provide control over the desired resolution.

(H) X Windows "bugs":

- The user is logged out of the computer when attempting to switch back and forth between graphical and numerical output (intermittent).

- The "Select Output Style" window shrinks to the size of an icon rendering interaction impossible (intermittent).

- The "Previous Output" screen goes blank during file removal if the user attempts to remove the file at the top of the list.

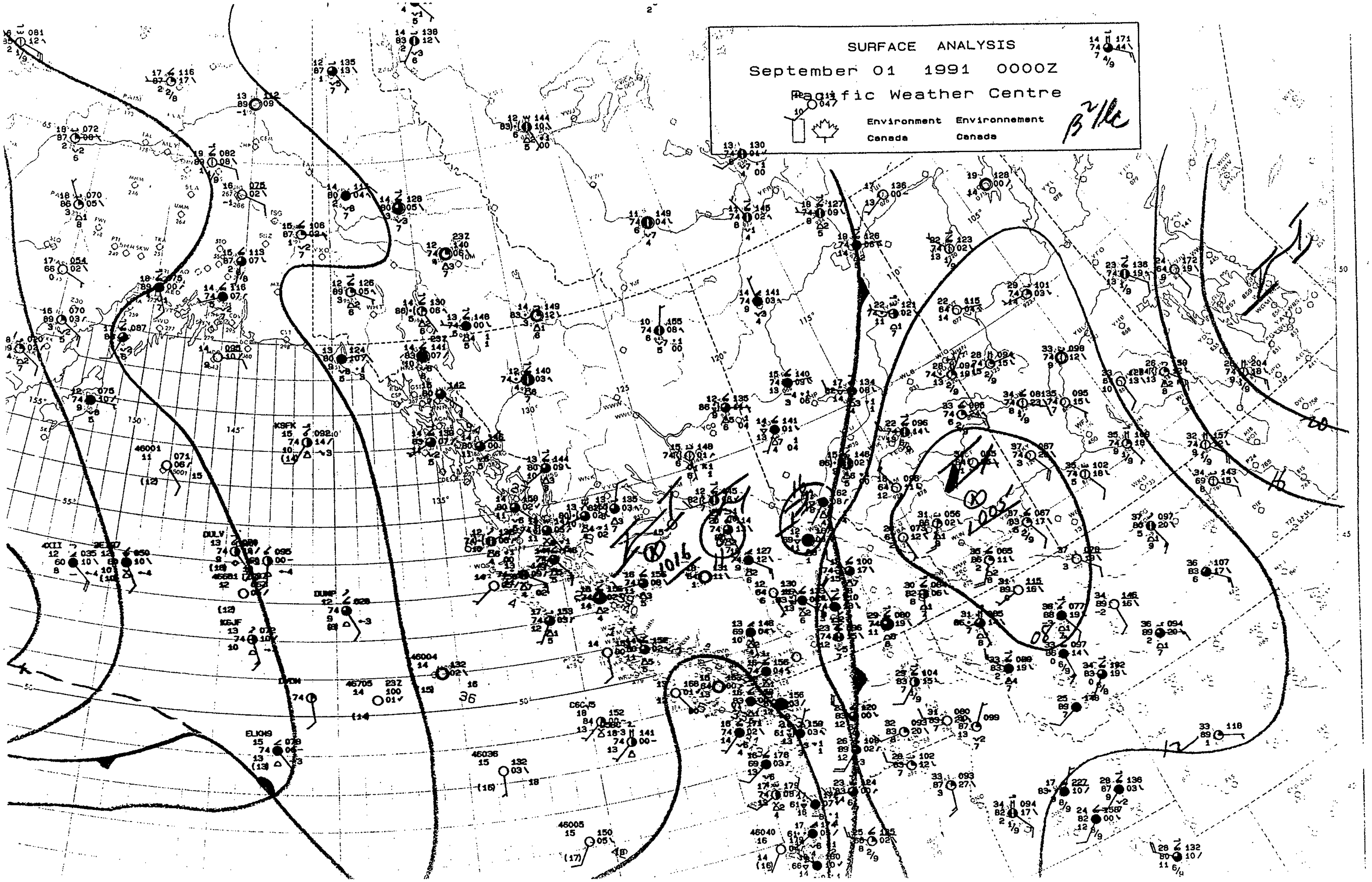
- The software slows down with continuous and repeated running of the model.

APPENDIX B

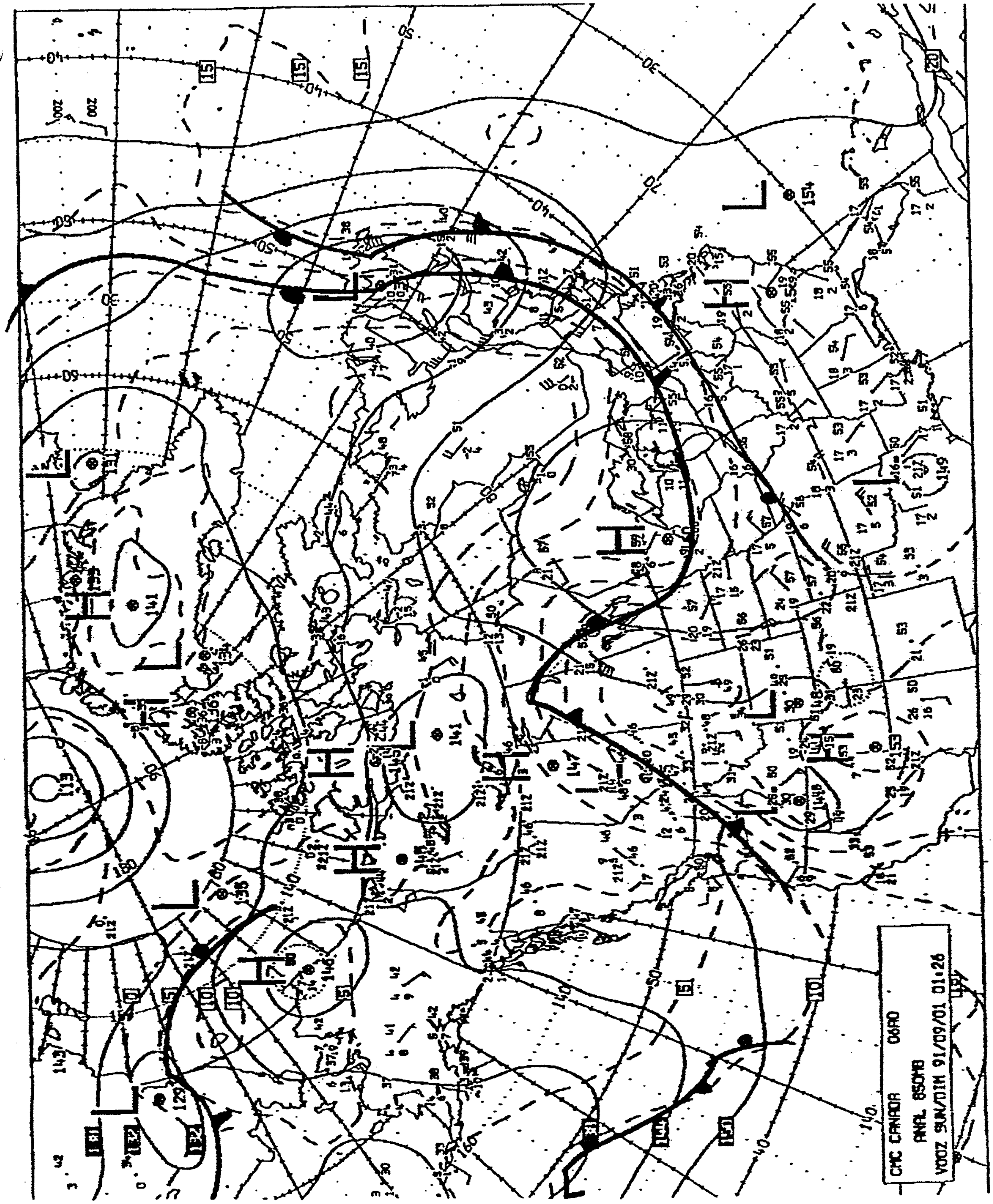
SYNOPTIC CHARTS AND WIND DATA

<u>CASE #1 - Thermally-induced Wind</u>

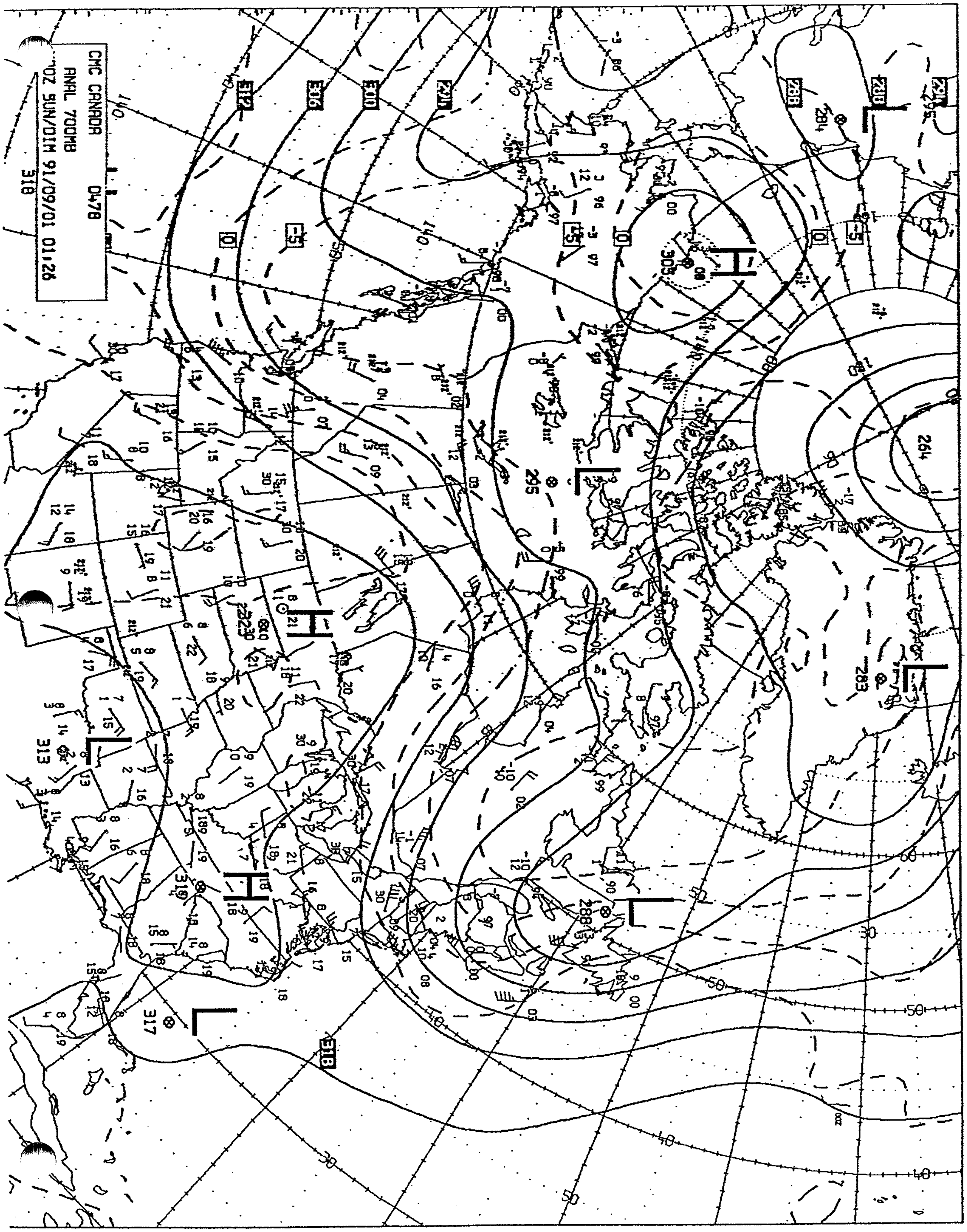
DATE: 31 AUGUST 91
TIME: 5PM (SEPT 01, 00Z)
SYNOPTIC CONDITIONS: Summertime instability
STABILITY: Unstable


SURFACE ANALYSIS
September 01 1991 0000Z
Pacific Weather Centre
Environment Canada
Environnement Canada

MAPS W0946C CMC06AO 850MB ANAL (FRONTAL ANAL) 0000Z
Printed Sun Sep 1 02:18:19 UTC 1991



MAPS A0712C CMC478 700MB ANALYSIS (OOZ)
Printed Sun Sep 1 01:45:19 UTC 1991



RAMME

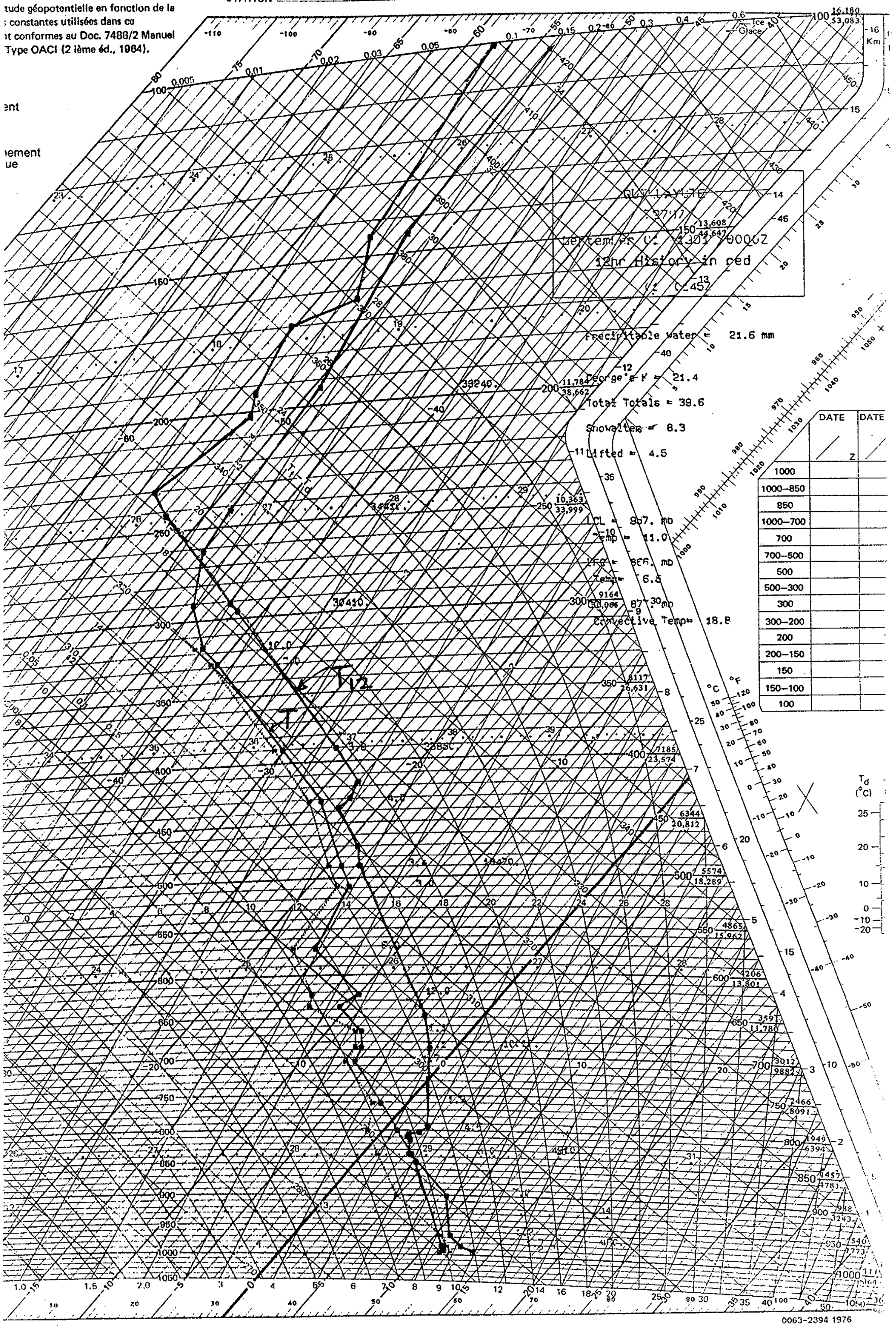
STATION ____ DATE ____

STATION ____ DATE ____

tude géopotentielle en fonction de la
s constantes utilisées dans ce
t conformes au Doc. 7488/2 Manuel
Type OACI (2 ième éd., 1964).

ent

ement
ue



	DATE	DATE
1000		
1000–850		
850		
1000–700		
700		
700–500		
500		
500–300		
300		
300–200		
200		
200–150		
150		
150–100		
100		

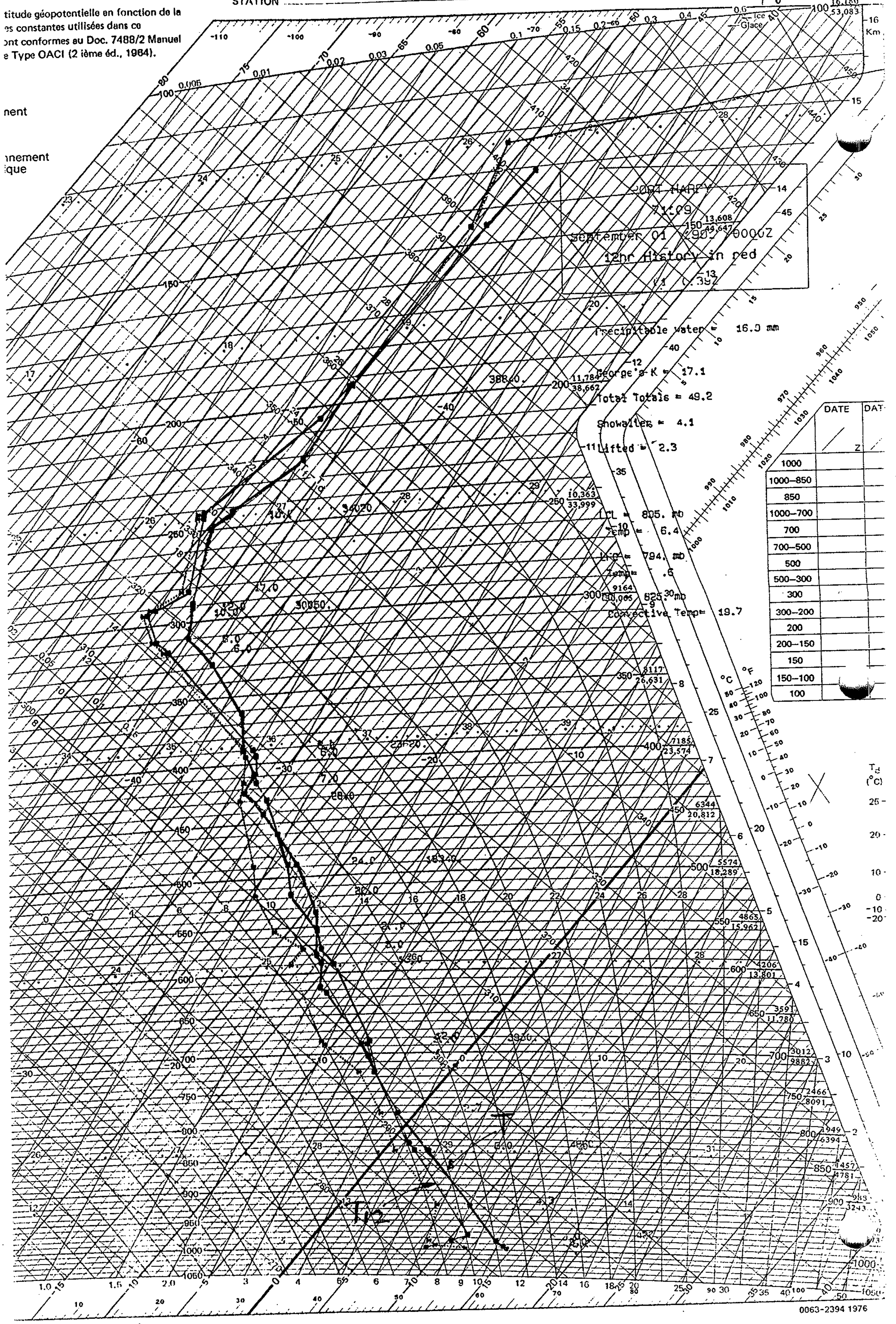
0063-2394 1976

STATION DATE 48

…titude géopotentielle en fonction de la …es constantes utilisées dans ce …ont conformes au Doc. 7488/2 Manuel …e Type OACI (2 ième éd., 1964).

…nent

…nnement …ique



0063-2394 1976

Geostrophic Wind - Wind soundings in knots from YVR, YZT and UIL for 01SEP91 00Z are given in Table B1.

HEIGHT (ft)	YVR	YZT	UIL
Surface	04/250	10/100	06/160
1000	04/215	05/150	10/185
2000	03/240	05/190	07/210
3000	06/265	07/210	06/220
4000	08/270	09/205	08/240

Table B1: Upper Air Wind Soundings - CASE #1 - 31AUG91

The disagreement among these three soundings at the surface and 1000 foot level illustrates the difficulty in choosing an appropriate source for the geostrophic wind. In spite of the short distance separating the stations (YZT lies some 350 km to the northwest of YVR and UIL is roughly 200 km to the southwest), the winds differ in both magnitude and direction across all three soundings over what would be considered a relatively small area on the synoptic scale.

YVR pibal data is chosen to compute the geostrophic wind because it represents the closest sounding to the geographic region of interest. The 1000 foot level is chosen because it is the lowest level of the sounding suitable for identifying the geostrophic wind. After converting from knots to metres per second (2 knots = 1 m/s) and feet to metres (1000 ft = 300 m), the geostrophic wind in component form becomes:

$$V_g = 2.0 \text{ m/s} @ 215; \quad u = 1.14 \text{ m/s}, v = 1.64 \text{ m/s}; \quad Z_g = 300 \text{ m}$$

Observations - YXX SA 0000Z 45 SCT 110 SCT 300 -SCT 25 220/20/9/2105/018/ TCU1AC1CI

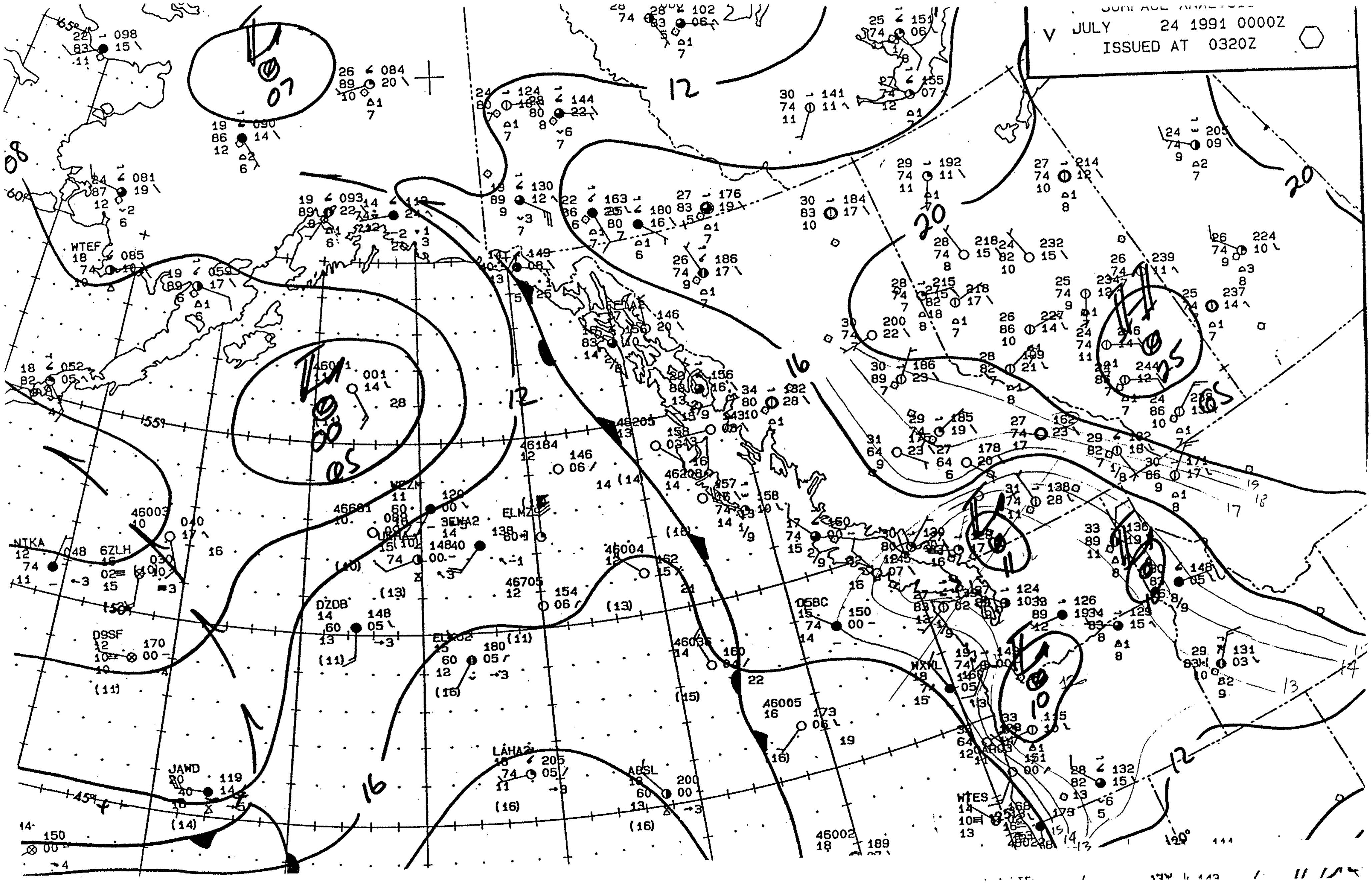
YVR SA 0000Z 30 SCT 50 SCT 100 -SCT 280 -SCT 30 224/18/11/2805/01 CU1TCU1AC1CI1

APPENDIX C

SYNOPTIC CHARTS AND WIND DATA

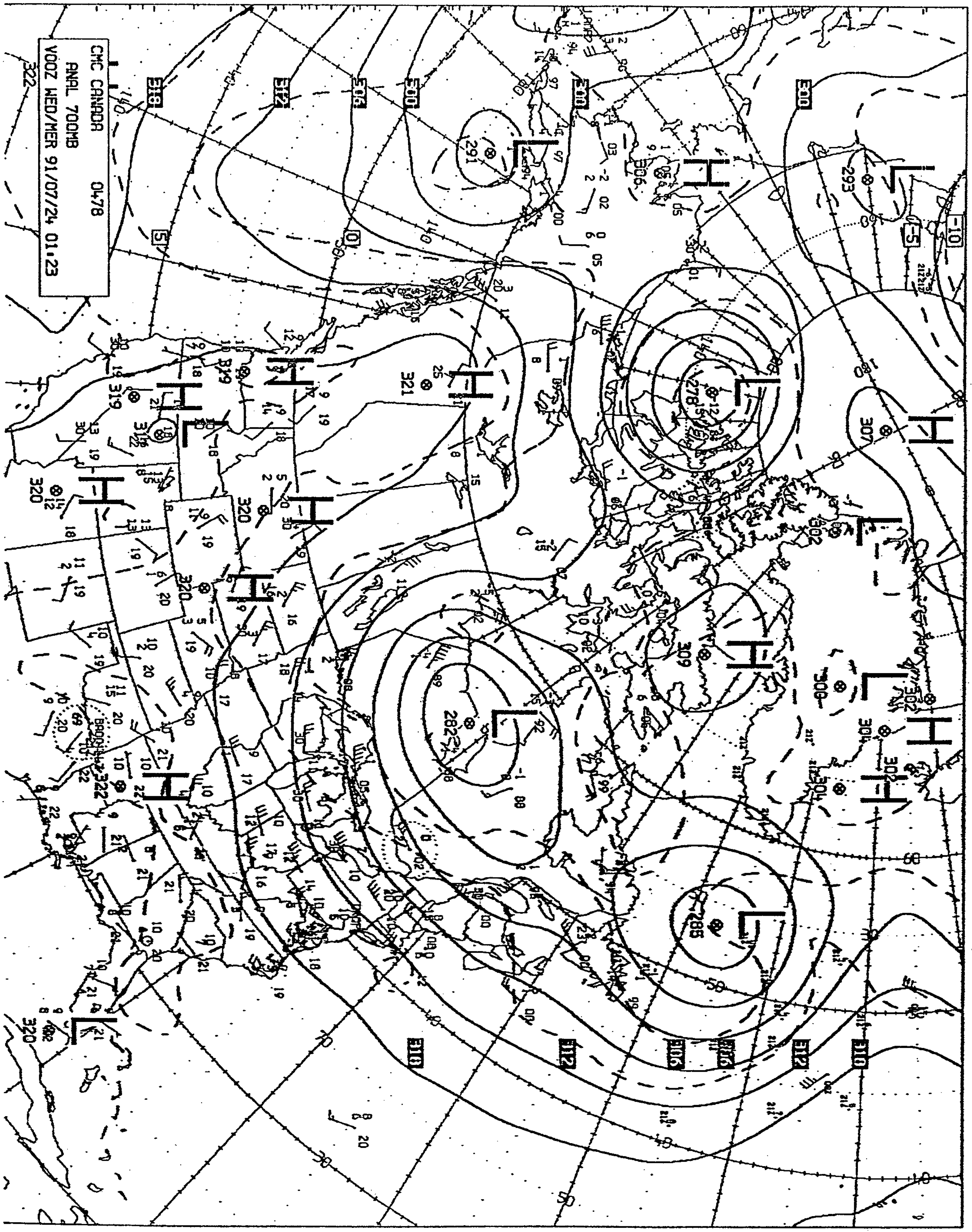
<u>CASE #2 - Thermally-induced Wind</u>

DATE: 23 JULY 91
TIME: 5PM (JULY 24, 00Z)
SYNOPTIC CONDITIONS: Subsidence inversion
STABILITY: Stable

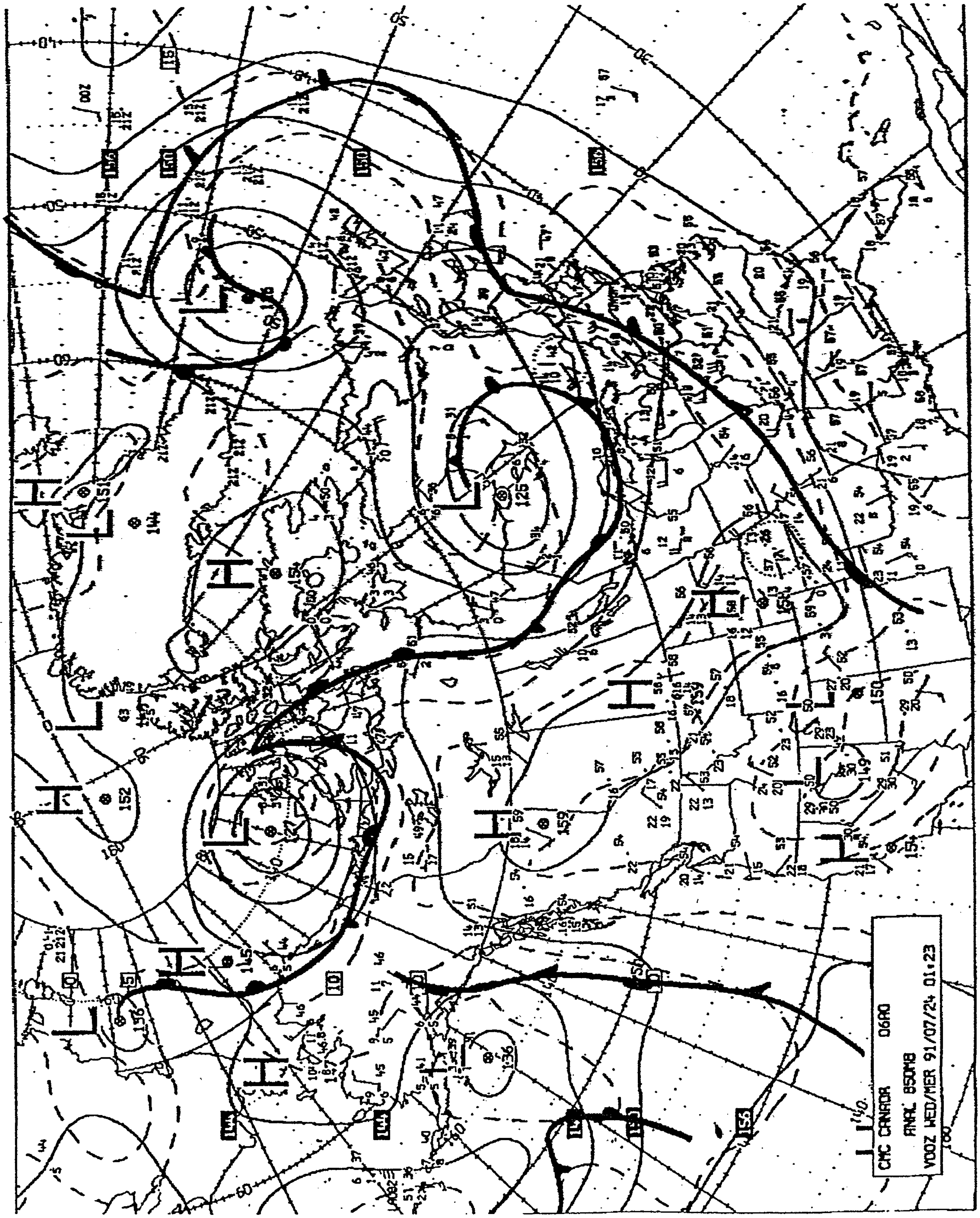


52

MAPS A0712C CMC478 700MB ANALYSIS (00Z)
Printed Wed Jul 24 01:42:19 UTC 1991



APS W0946C CMC06AO 850MB ANAL (FRONTAL ANAL) 0000Z
rinted Wed Jul 24 02:17:43 UTC 1991



GRAMME

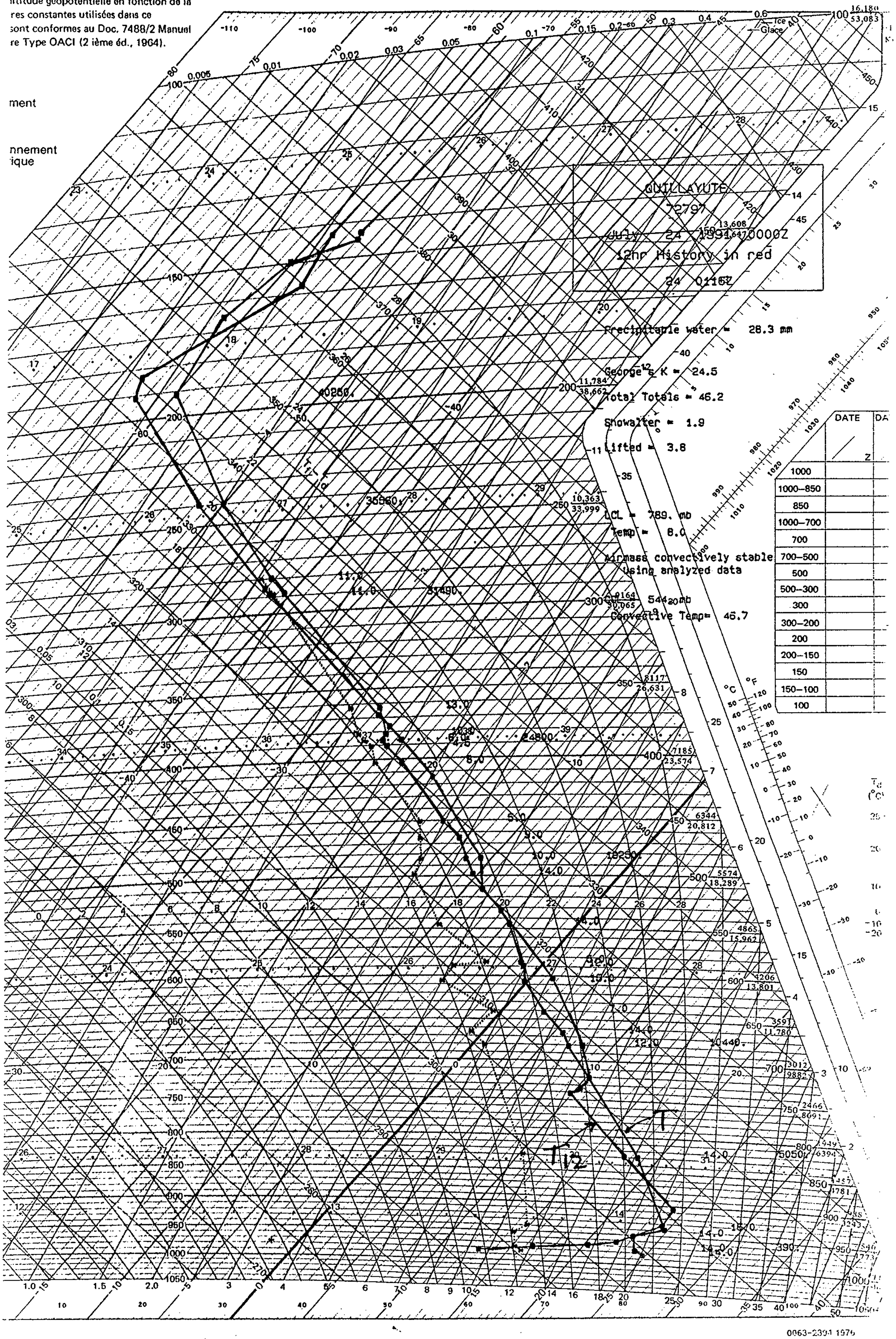
STATION ____ DATE ____ 55

STATION ____ DATE ____

ıltitude géopotentielle en fonction de la
res constantes utilisées dans ce
sont conformes au Doc. 7488/2 Manuel
re Type OACI (2 ième éd., 1964).

ment

nnement
ique



DATE	DATE
1000	
1000–850	
850	
1000–700	
700	
700–500	
500	
500–300	
300	
300–200	
200	
200–150	
150	
150–100	
100	

0063-2394 1976

GRAMME

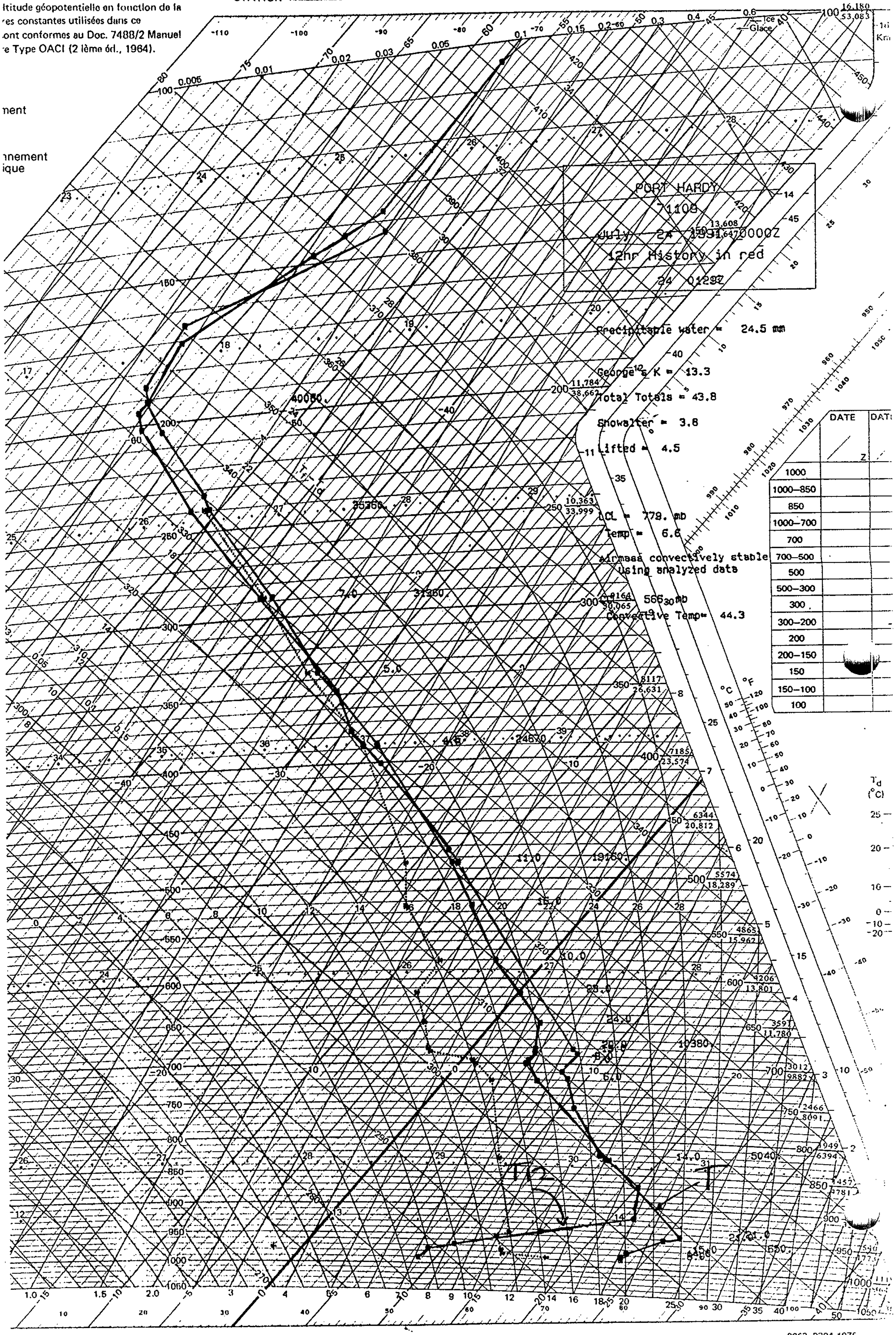
STATION .... DATE ....

STATION .... DATE ....

ltitude géopotentielle en fonction de la
es constantes utilisées dans ce
ont conformes au Doc. 7488/2 Manuel
e Type OACI (2 ième éd., 1964).

nent

nnement
ique



0063-2394 1976

Geostrophic Wind - Wind soundings in knots from YVR, YZT and UIL for 24JUL91 00Z are given below in Table C1.

HEIGHT (ft)	YVR	YZT	UIL
Surface	07/300	05/010	07/180
1000	04/290	05/170	05/210
2000	01/165	08/160	07/190
3000	02/115	08/160	12/170
4000	04/135	08/150	18/150

Table C1: Upper Air Wind Soundings - CASE #2 - 23JUL91

The above data provides a good example of decoupling of the winds in the boundary layer, below the inversion, from the dynamically induced winds above the ABL. At YVR, a sea-breeze circulation can be envisioned with NW winds in the lower layer backing sharply and slowing to southeasterly at 2000 feet. A similar profile exists at YZT but not at UIL where there appears to be little vertical shear in the boundary layer. Above the inversion layer there is much greater agreement in the soundings among the three stations. Choosing YVR for its proximity to the region of interest, and selecting the wind nearest the top of the boundary layer, the 1000 foot level of the YVR sounding is chosen to represent the surface geostrophic wind.

$$Vg = 2.0 \text{ m/s @ } 290; \quad u = 1.88 \text{ m/s}, \quad v = -0.68 \text{ m/s}; \quad Zg = 300 \text{ m}.$$

Observations - YXX SA 0000Z 300 -SCT 30 120/36/14/2904/988/CI1

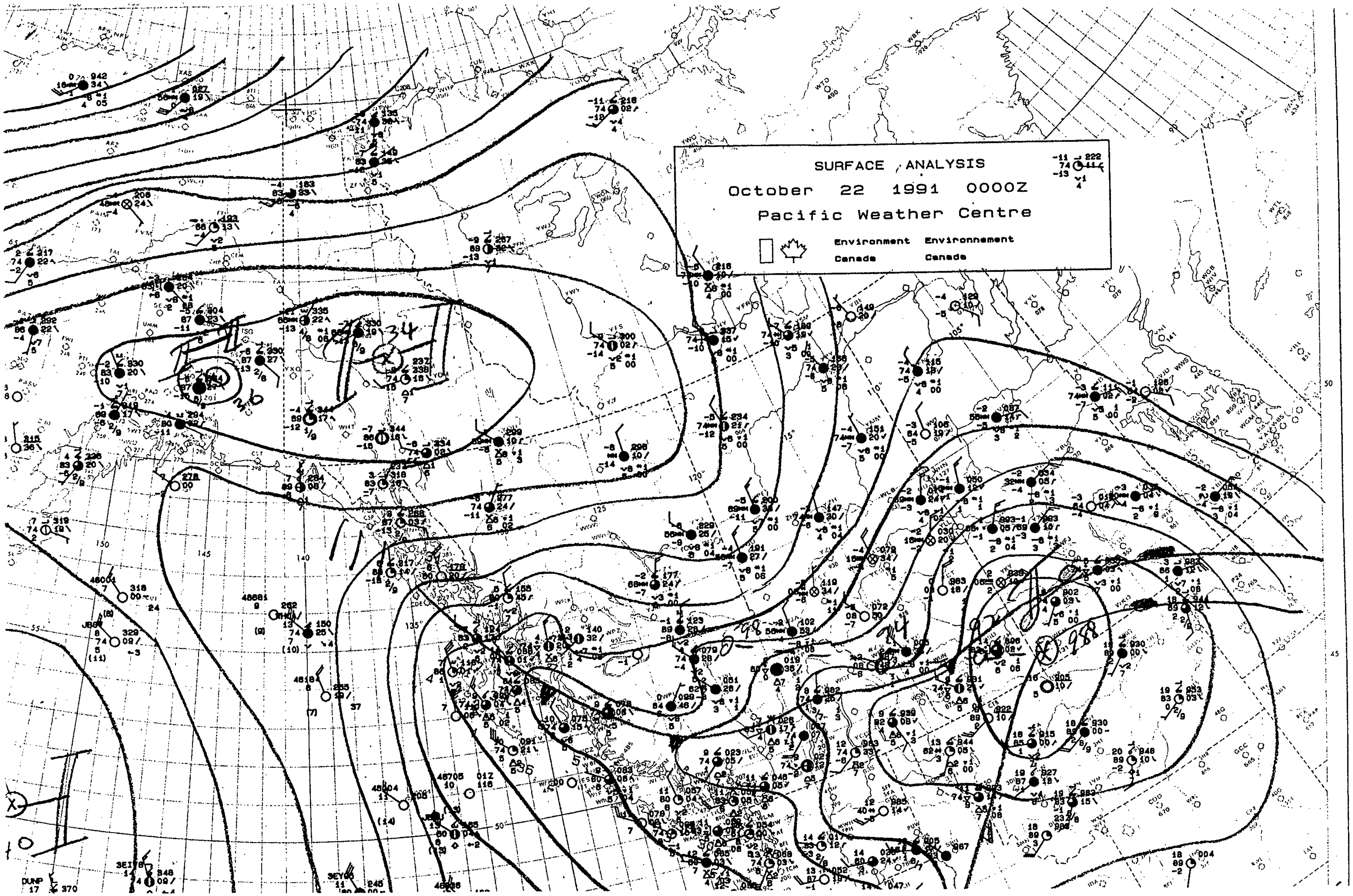
YVR SA 0000Z 270 -SCT 30 128/27/16/2907/990/CI2

APPENDIX D

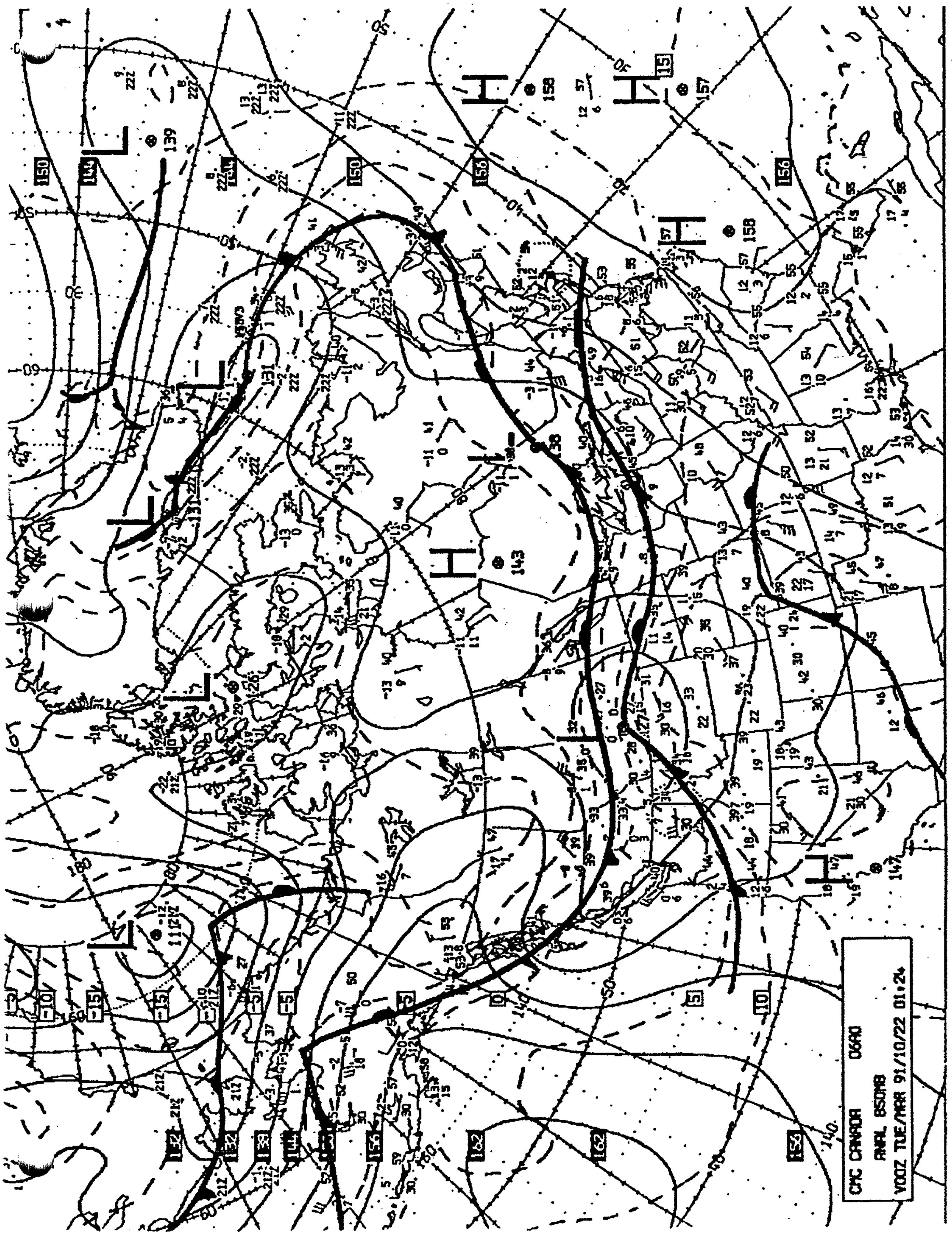
SYNOPTIC CHARTS AND WIND DATA

<u>CASE #2 - Dynamically-induced Wind</u>

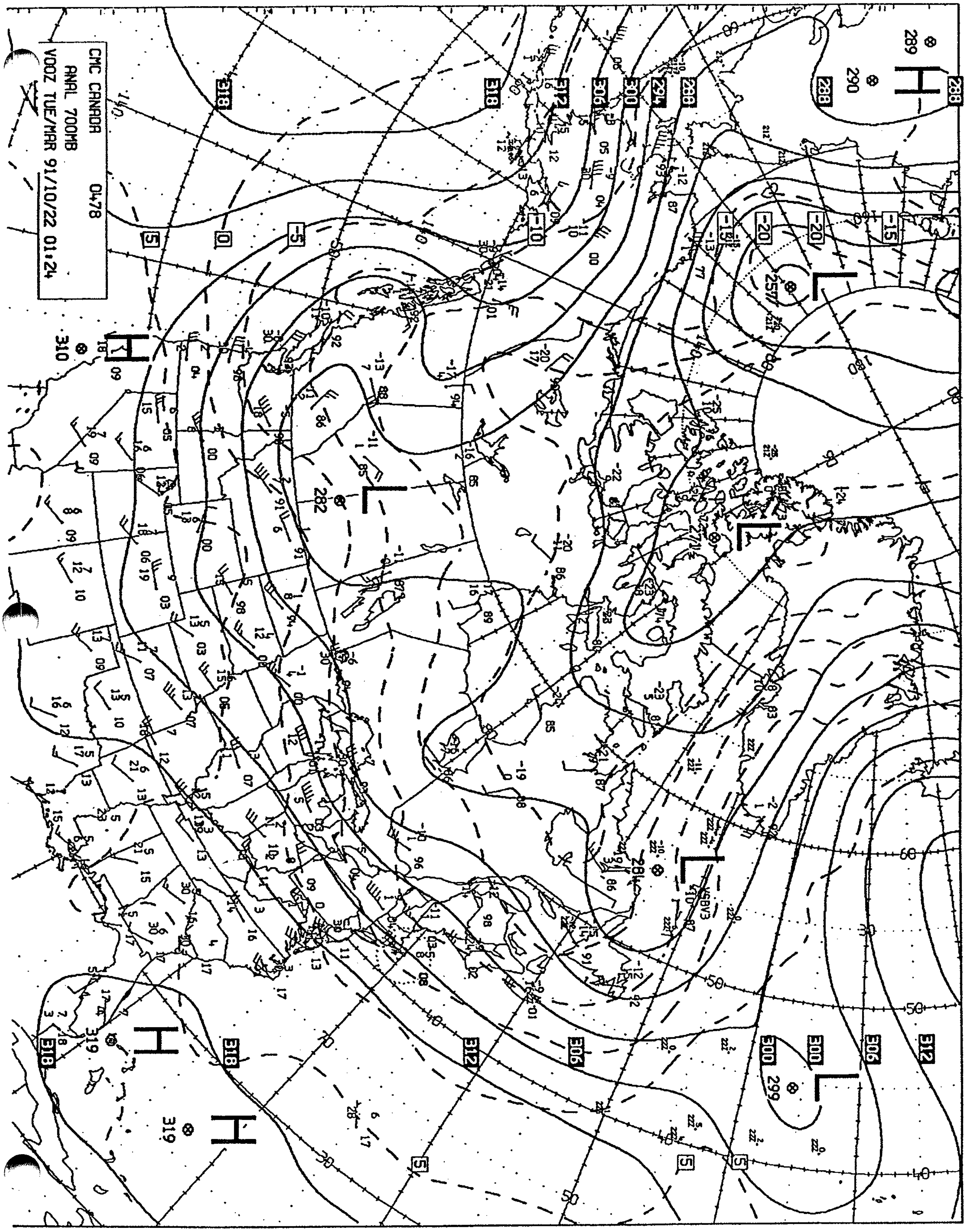
DATE: 21 OCTOBER 91
TIME: 5PM (OCT 22, 00Z)
SYNOPTIC CONDITIONS: Cold airmass, strong NW flow
STABILITY: Unstable


SURFACE ANALYSIS
October 22 1991 0000Z
Pacific Weather Centre
Environment Canada
Environnement Canada

PS W0946C CMC06AO 850MB ANAL (FRONTAL ANAL) 0000Z
inted Tue Oct 22 02:17:13 UTC 1991



MAPS A0712C CMC478 700MB ANALYSIS (00Z)
Printed Tue Oct 22 01:43:41 UTC 1991



IIGRAMME

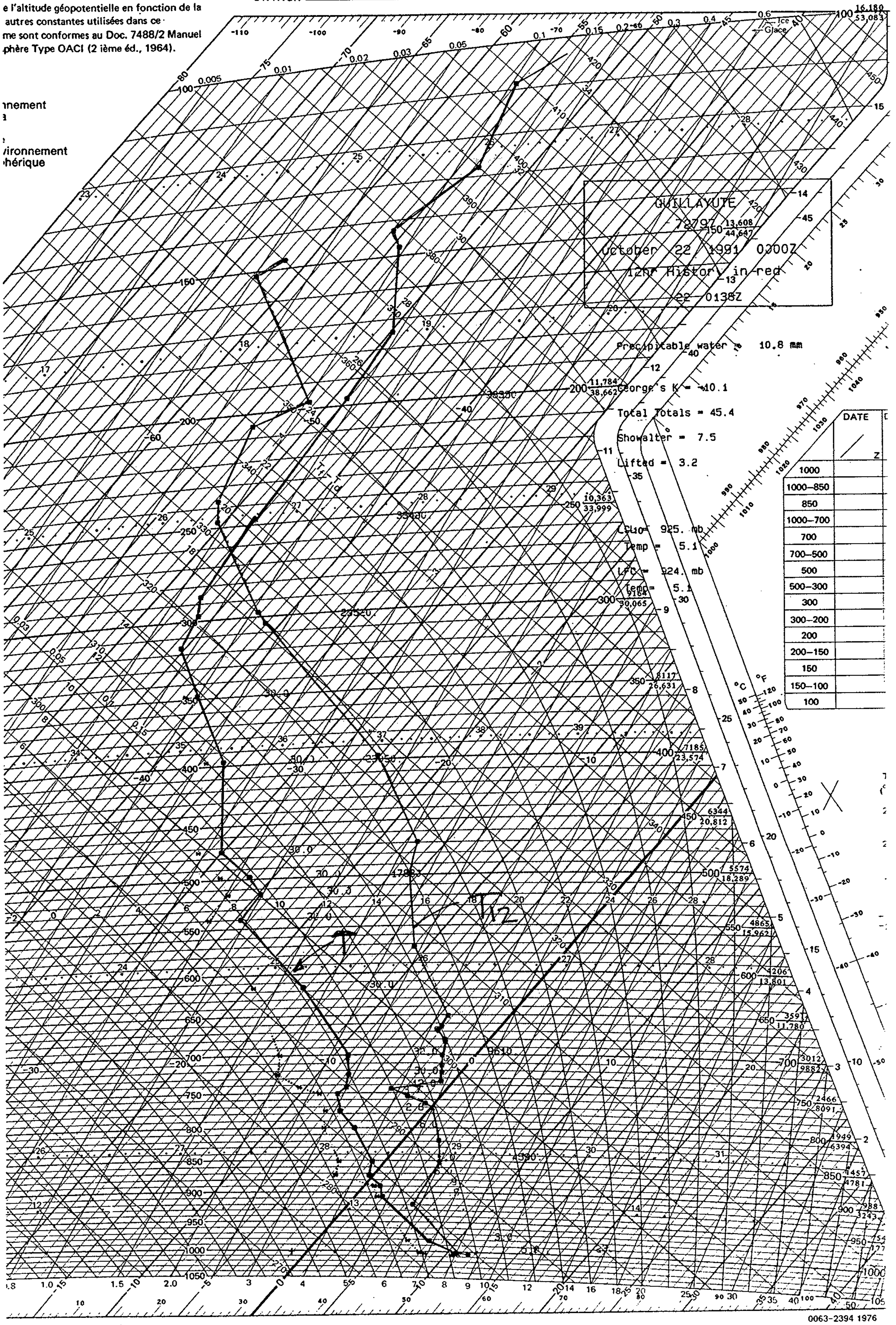
STATION ______________________ DATE ______ 63

STATION ______________________ DATE ______

e l'altitude géopotentielle en fonction de la
autres constantes utilisées dans ce
me sont conformes au Doc. 7488/2 Manuel
phère Type OACI (2 ième éd., 1964).

nnement
a

ironnement
hérique



0063-2394 1976

PHIGRAMME

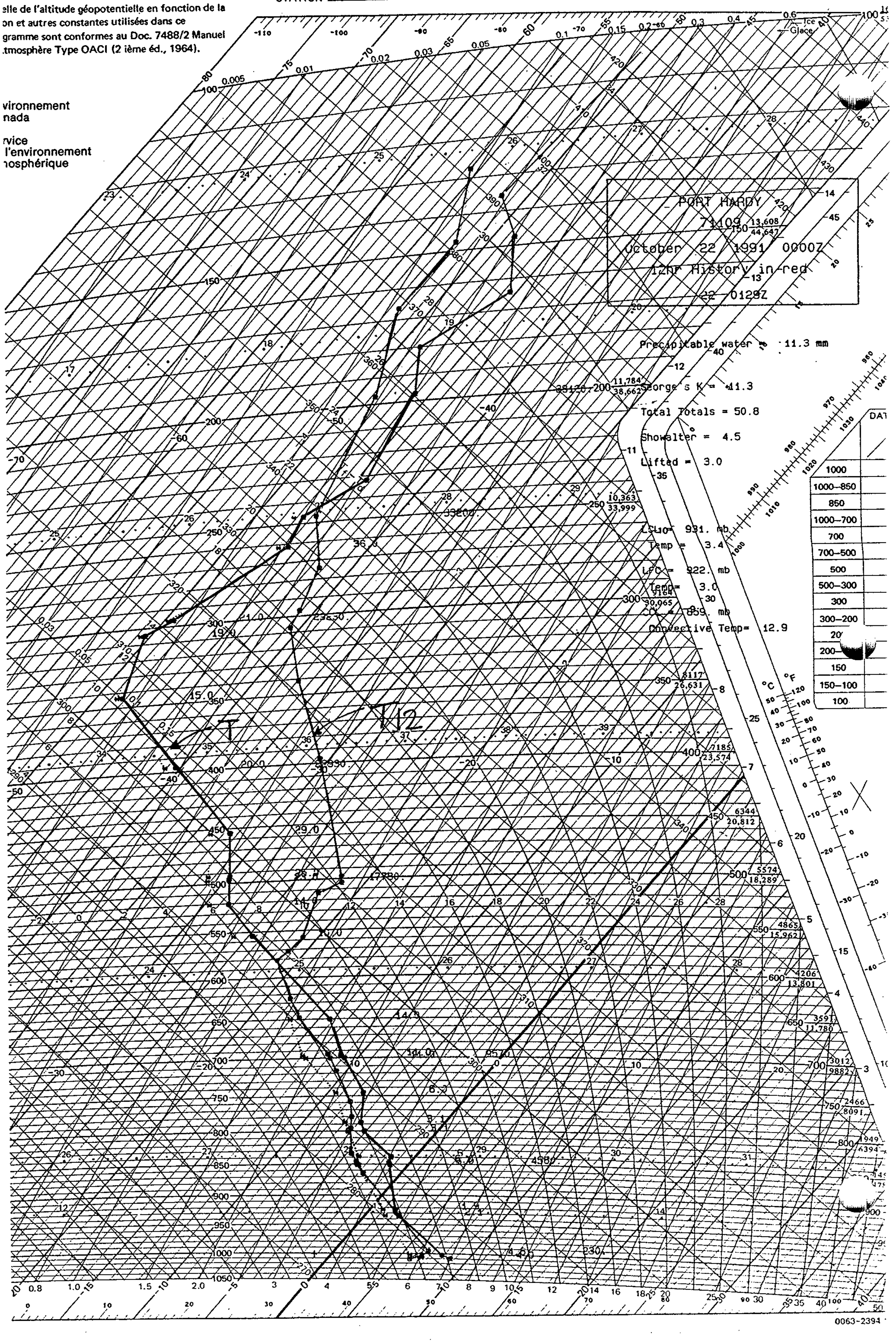
STATION
STATION
STATION

DATE
DATE 64
DATE

elle de l'altitude géopotentielle en fonction de la on et autres constantes utilisées dans ce gramme sont conformes au Doc. 7488/2 Manuel tmosphère Type OACI (2 ième éd., 1964).

vironnement
nada

rvice
l'environnement
nosphérique



Geostrophic Wind - Wind soundings in knots from YVR, YZT and UIL for 22OCT91 00Z are given below in Table D1.

HEIGHT (ft)	YVR	YZT	UIL
Surface	16/270	Missing	08/310
1000	29/285	20/315	21/300
2000	43/295	23/315	23/310
3000	43/295	27/315	25/310
4000	23/285	25/310	20/310

Table D1: Upper Air Wind Soundings - CASE #3 - 21OCT91

The wind speeds at YVR stand in contrast to the high degree of agreement between UIL and YZT, particularly at the 2000 and 3000 foot levels. The dynamics responsible for the differences in these wind profiles are not clear since the temperature gradient cannot account for the wind shear between the surface and 1000 feet at YVR. With some reluctance, the 1000 foot level of the YVR sounding is chosen to represent the surface geostrophic wind.

$$Vg = 14.5 \text{ m/s @ } 285; \quad u = 14.00 \text{ m/s}, \quad v = -3.75 \text{ m/s}; \quad Zg = 300 \text{ m}.$$

Observations - YXX SA 0000Z 35 SCT 15 055/12/4/2210/969/CU4 TCU MTNS N&E

YVR SA 0000Z 45 SCT 90 SCT 30 050/11/6/2718G23/967/CU2AC1
TCU E