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Technical Memoranda

A DIAGNOSTIC MODEL FOR COMPUTING POTENTIAL AIRFRAME ICING

by

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ENVIRONMENT CANADA - ATMOSPHERIC ENVIRONMENT SERVICE
4905 Dufferin Street
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A DIAGNOSTIC MODEL FOR COMPUTING POTENTIAL AIRFRAME ICING

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ABSTRACT

A technique for determining the type and intensity of icing has been modified and programmed for operational use. The model and the results obtained for 1200Z April 25, 1971 are discussed.

MODÈLE D'ANALYSE POUR ÉVALUER LA FORMATION POTENTIELLE DE GIVRAGE SUR LES CELLULES D'AÉRONEF

par

R.G. Lawford

RÉSUMÉ

On a modifié et préparé pour répondre à un besoin pratique une méthode d'évaluation du genre et de l'intensité du givrage. Le modèle et les résultats obtenus à 1200Z le 25 avril sont expliqués.

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1. Introduction

The icing encountered by an aircraft as it travels through the earth's atmosphere results from a complex interaction of aerodynamic and meteorological factors. Although the aircraft's speed, skin temperature and efficiency of catch are variables meteorologists can provide an estimate of the atmosphere's potential to produce icing based on an analysis or a prognosis of temperatures, dew points and instability. This report describes a computerized diagnostic technique currently in operational use at the Central Analysis Office designed to estimate this potential.

Aircraft are frequently affected by two general types of icing. These types include:

a) rime ice - a white crystalline deposit with both low density and low cohesive properties. Ice of this nature not only changes the weight of the aircraft but it breaks away from airframe entering jet and turbo-jet engines to cause permanent damage.

b) clear ice - a cohesive sheet of transparent ice which forms when supercooled droplets greater than 20 microns in diameter flow over the aircraft's surface. The effects of clear icing in increasing the aircraft's weight and modifying the shape of the airfoil make this phenomenon hazardous to all small aircraft.

2. Meteorological Basis for the Model

The fundamental logic for this model has come from the work of Jensen; (1). After the mid-troposphere is split into four layers mean temperatures (T), temperature dew point spreads (Δ) and lapse rates (γ) are computed. The layers considered include the

1. 850 - 770 mb. layer
2. 770 - 700 " "
3. 700 - 590 " "
4. 590 - 500 " "

From these three parameters Jensen devised a scheme to determine the intensity and type of icing most likely to occur in any particular layer. Although Jensen derived these critical values empirically by an examination of many aircraft icing reports his results have physical significance.

The temperature determines the proportion of water and ice which will co-exist at sub-freezing temperatures. From simple vapour pressure considerations it can be seen that most super-cooled water droplets will exist in the temperature range from 0 to -10°C. It is also assumed that all excess moisture will exist in the ice phase when the temperature sinks below -25°C.

The temperature-dew point spread gives a measure of the amount of moisture in the air. If the air is dry no icing will occur. When the spread decreases below a threshold value the air is assumed to be saturated, consequently, icing is possible. The model currently uses a threshold value of 4°C.

Vertical motions are frequently responsible for raising super-cooled water droplets to higher levels. The excessive icing encountered in a cumulonimbus exemplified this process. In this model the lapse rate is assumed to provide an indicator of instability and vertical ascent. This criterion is used in separating between the clear (unstable) and rime (stable) icing situations.

Further modifications have been incorporated into the scheme. Experimentation with the model demonstrated that in certain situations no significant clear icing could be associated with freezing rain and thunderstorm situations. This weakness, which arose from computational smoothing in determining means for the layers was rectified by a consideration of the surface weather observed. On several occasions the stable lapse rates associated with freezing rain situations resulted in reports of moderate rime icing although the liquid water content of the clouds appeared to make moderate or severe clear icing inevitable. In order to circumvent this problem it was assumed that clouds producing freezing precipitation reached to the 700 mb level and contained the super-cooled water droplets essential for the formation of moderate or heavy clear icing. The model was modified to associate moderate or severe icing with the lower layers in all freezing rain, freezing drizzle and thunderstorm situations.

The model provided little resolution at cold temperatures and as a result Godson's (2) -8D curve was used to predict icing at temperatures below -25°C. This curve was used to determine if the air was saturated with respect to ice. In cases where saturation occurred light rime icing was forecast.

The reader wishing a more comprehensive discussion of many of the basic premises for this model is referred to the U.S.A.F. Airframe Icing Manual (3).

A flow diagram outlining the decision making procedure is presented in Figure 1. On this figure T refers to the mean temperature of the layer, the mean temperature-dew point spread for the layer, -the lapse rate for the layer and ISW refers to the surface weather.

The term γ is defined by the formula

$$\gamma = \frac{(T_{Top} - T_{Bottom}) \times 1000}{3.048 \times 52}$$

where γ is the lapse rate in deca degrees per geopotential kilofoot

δz is the thickness of the layer in geopotential meters

T_{Top} is the temperature at the top of the layer in degrees Calcius

T_{Bottom} is the temperature at the bottom of the layer in degrees Calcius.

3. The Model in the Operational Setting

The model currently exists as a computer program compatible with the OA phases of operational data processing. The model which we shall subsequently refer to as FROST obtains temperatures, dew-points and pressure levels from the merged data file (4). Icing situations are classified and two letter acronyms are printed out either on the appropriate tephigram or on a 1:20 M map. The first letter of the acronym refers to the intensity of the icing while the second refers to the type. The possible combinations are listed below.

SR - severe rime	CB - cumulonimbus
MR - moderate rime	SC - severe clear
MM - moderate mixed	MC - moderate clear
LR - light rime	LM - light mixed
NO - no icing	NR - no report
	LC - light clear

Currently this analysis is being made available to the meteorologist three and one half hours after observations are taken.

4. A Case Study Using the Model

April 25, 1971 was used as an example to illustrate the use of the model. Figure 2 shows the 500 millibar flow at 1200Z. A High was bringing clear skies to the western Prairies while a complex binary

low made the situation in the eastern part of the country rather complex. The barotropic low situated over central Quebec served as an anchor for the low to the southeast. The southern low had lost much of its baroclinicity as the Arctic cold front had advanced well out into the Atlantic. Vertical motions in the older cold low resulted in saturation to 500 mb level. The trough associated with the complex low center was maintaining vertical motion over most of northern Ontario and central Manitoba. Another low moving northeastward onto the Alaska Panhandle was eroding the ridge on the west coast. A thickness ridge, a frontal surface, saturated air at both 850 and 700 millibars (see Figure 4), ascending motions and positive vorticity advection were all evident over the Gulf of Alaska.

Figures 5 and 6 are the analysis of icing obtained using the diagnostic model. In areas where only sparse data was available the temperature and moisture patterns inferred from the upper air charts were used to supplement the analysis of icing at radiosonde stations. Figure 5 which provides an analysis of the region from 850 to 700 mb indicates that the areas most likely to produce icing are those where vertical motions exist. The higher freezing level over the Atlantic results in the poor fit between low level icing and the surface front. The fit over southeastern Alaska and the Arctic Front just off the map is one of many examples where the icing area lies just to the north of the warm front. Most of the Icing in the upper level (see Figure 6) is associated with the cold low over Quebec. It is interesting to note that the icing type changes from light clear southeast of the low to moderate rime north of the low.

These results lend support to the validity of the model as do Boucaud's (5) experiences with a simplified graphical version.

5. Conclusions and Recommendations for Further Research

The ability of a computerized diagnostic model to rapidly delineate potential areas of icing has been demonstrated. Although the model has limitations due to the availability of data and its inherent averaging processes the results obtained for the 25th of April, 1971 have been shown to be in good agreement with those which would have been derived subjectively from the surface and upper air analyses.

Further investigations designed to make this model compatible with forecast moisture and temperature fields or to produce a Lagrangian scheme whereby these icing areas could be advected would be a valuable asset in completing significant weather charts. An empirical study relating icing reports solicited from pilots to the results obtained from this model would be of value in evaluating the technique. Use of this model in conjunction with the temperature and moisture fields around cold lows and baroclinic lows could increase our knowledge relative to the icing hazards associated with these synoptic features.

6. Acknowledgements

I am grateful to my colleagues at the Central Analysis Office for their comments and assistance. In particular the discussions with A. Boucaud which gave initial impetus to the project have proven most beneficial.

APPROVED

J.R.H. Noble,
Assistant Deputy Minister,
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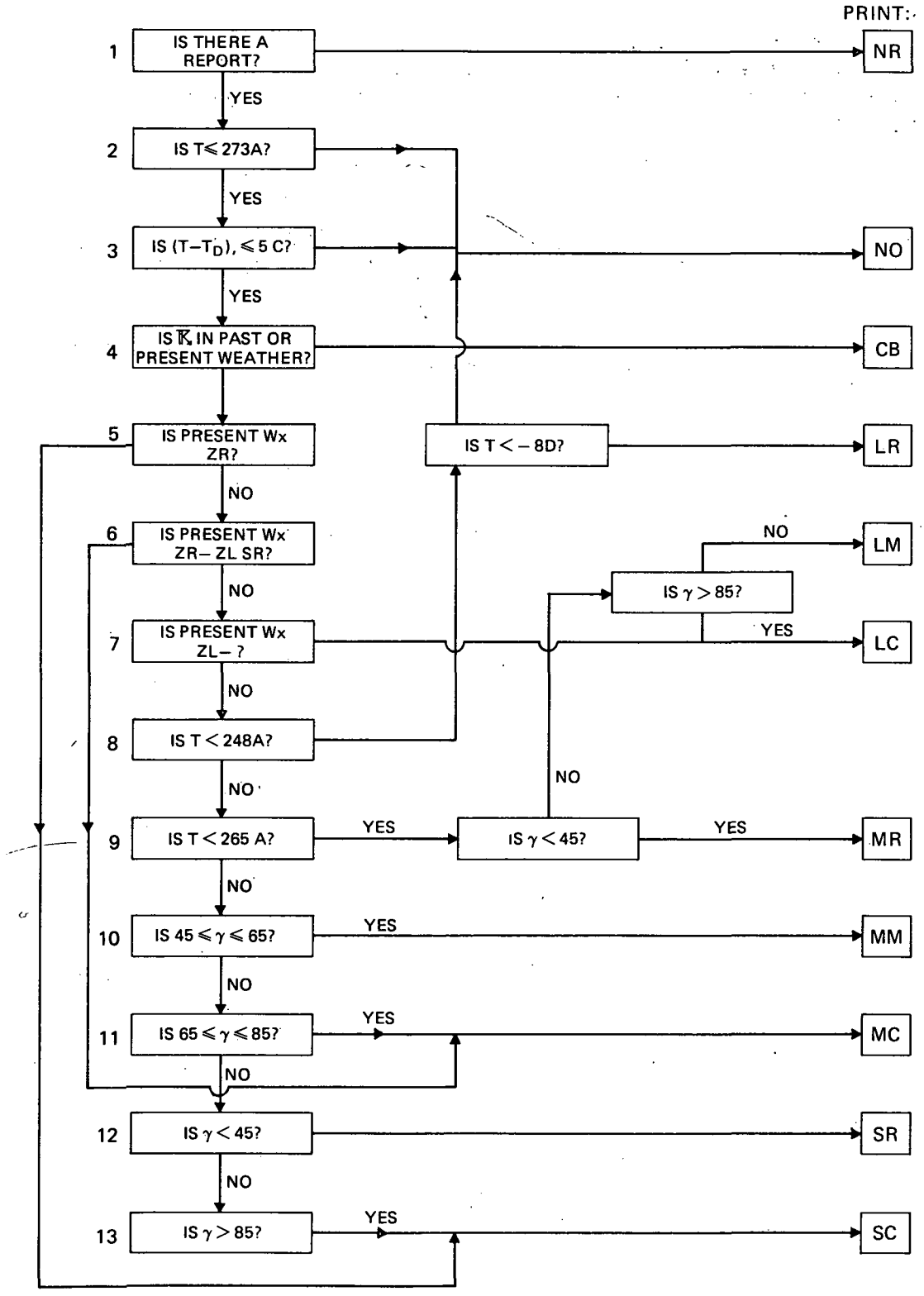

Figure 1.
LOGIC DIAGRAM
The Sequence of Decisions Made in the Diagnostic Model of Potential Airframe Icing for the Levels Between 850 and 700 mb

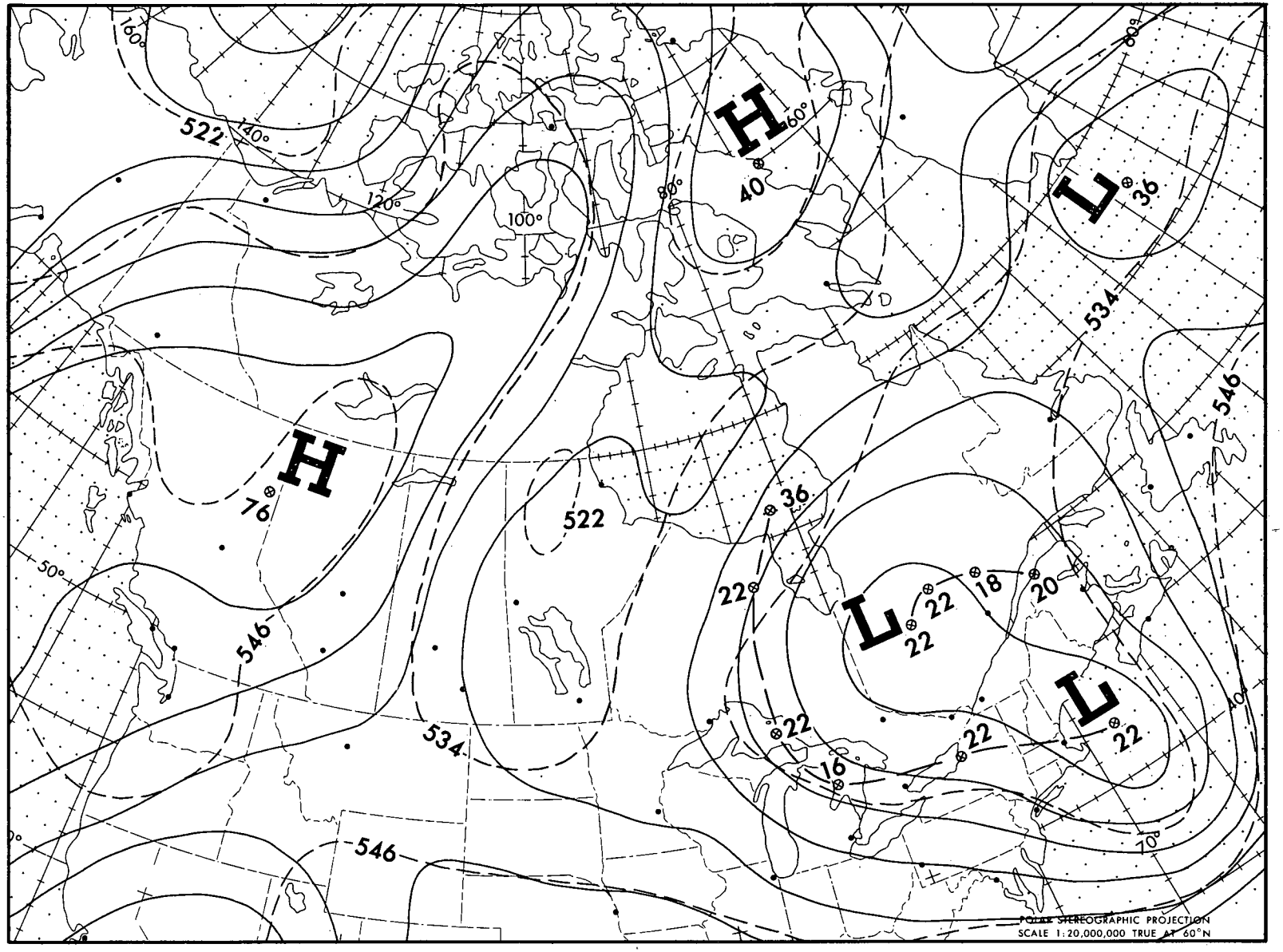

Figure 2.
Analysis of the 500 mb Chart for April 25, 1971 at 1200Z
The solid lines are contours while the dashed lines are thickness

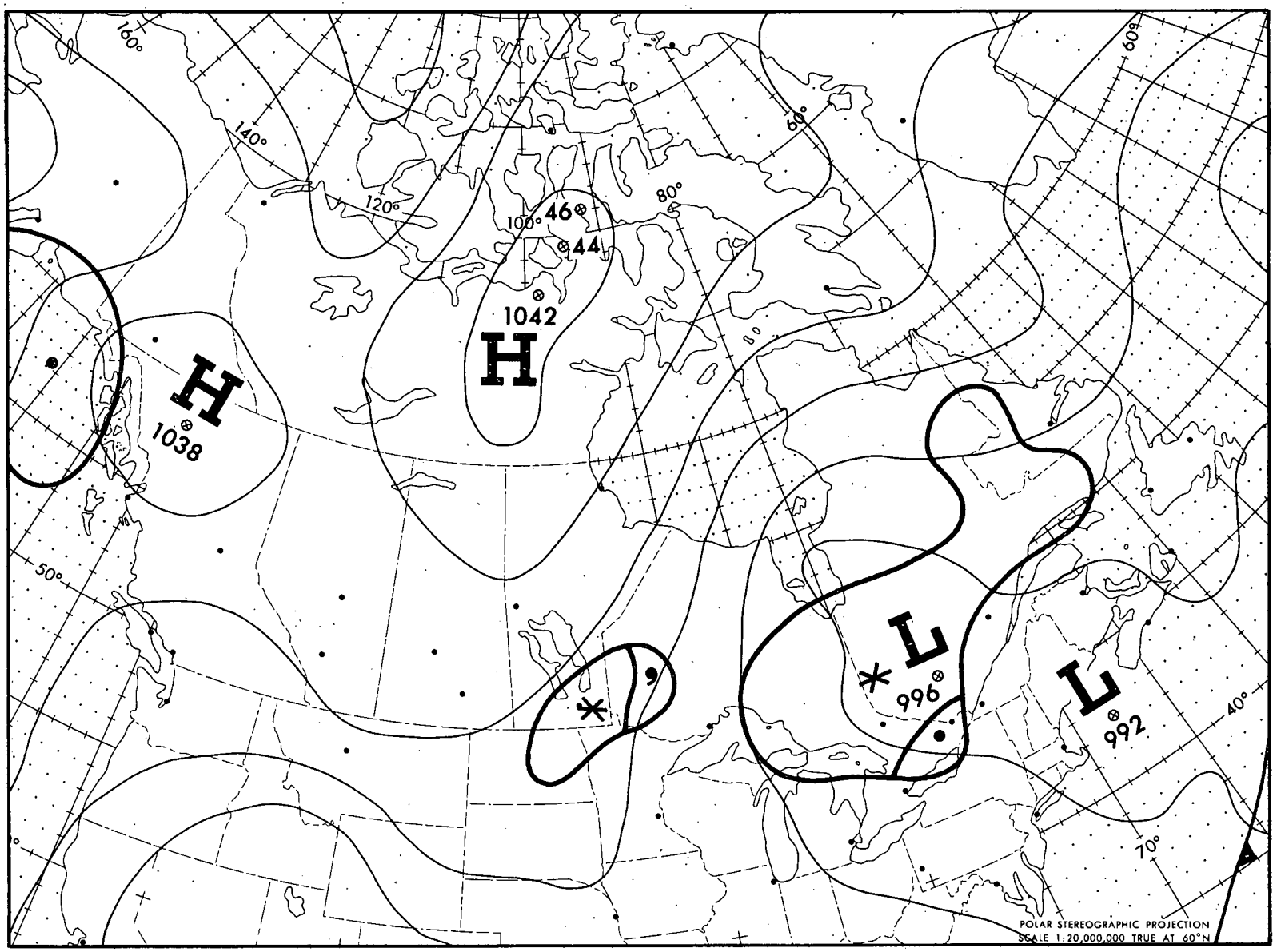

Figure 3.
Surface Analysis for April 25, 1971 at 1200Z
Isobars at 8 mb Intervals
Boundaries on Areas of Precipitation

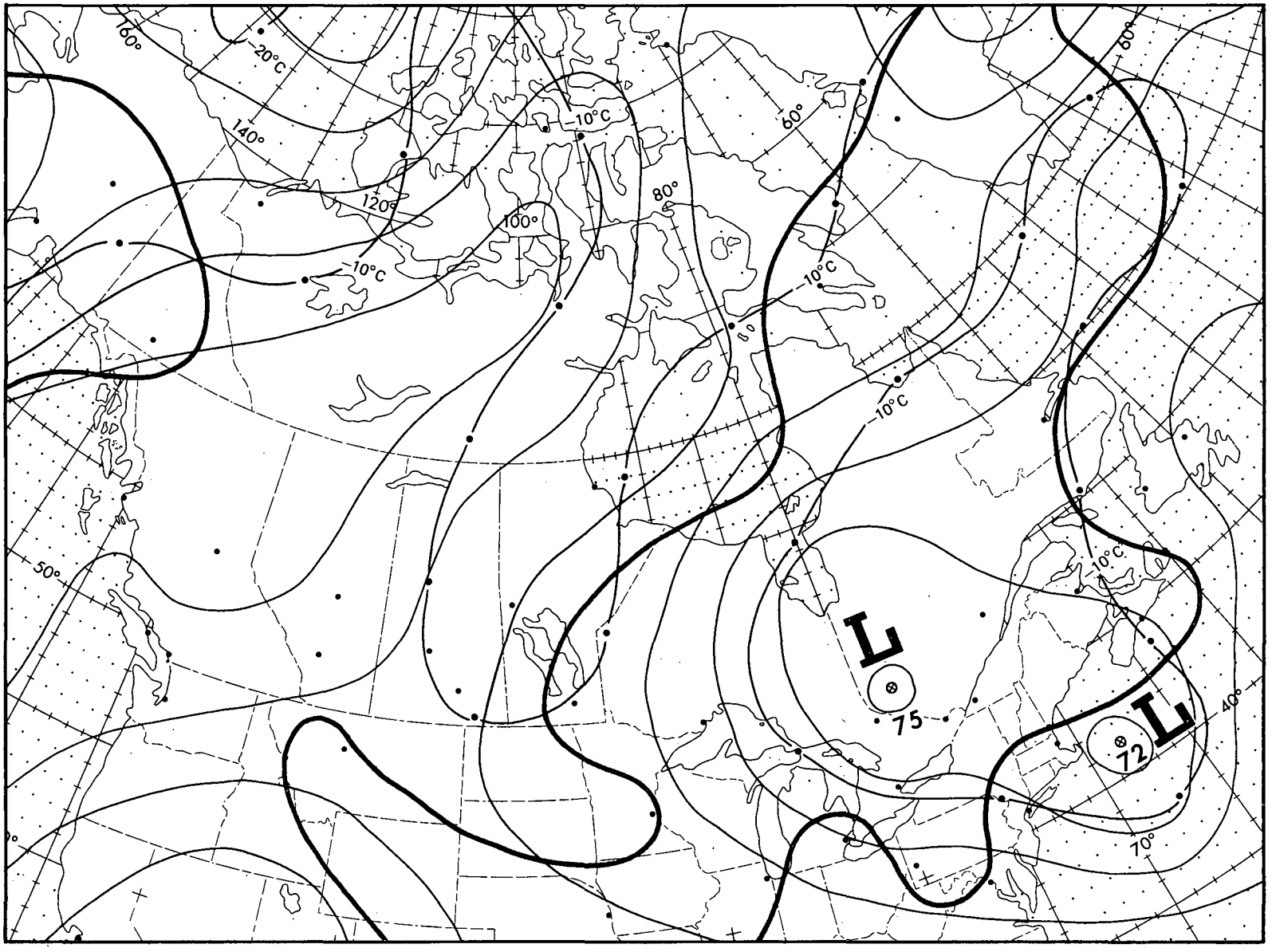

Figure 4.
Analysis of the 700 mb Chart for 12Z April 25, 1971
Contours
Isotherms at 10° C Intervals
The Boundaries of the Area Where $(T-T_D)$ 5° C

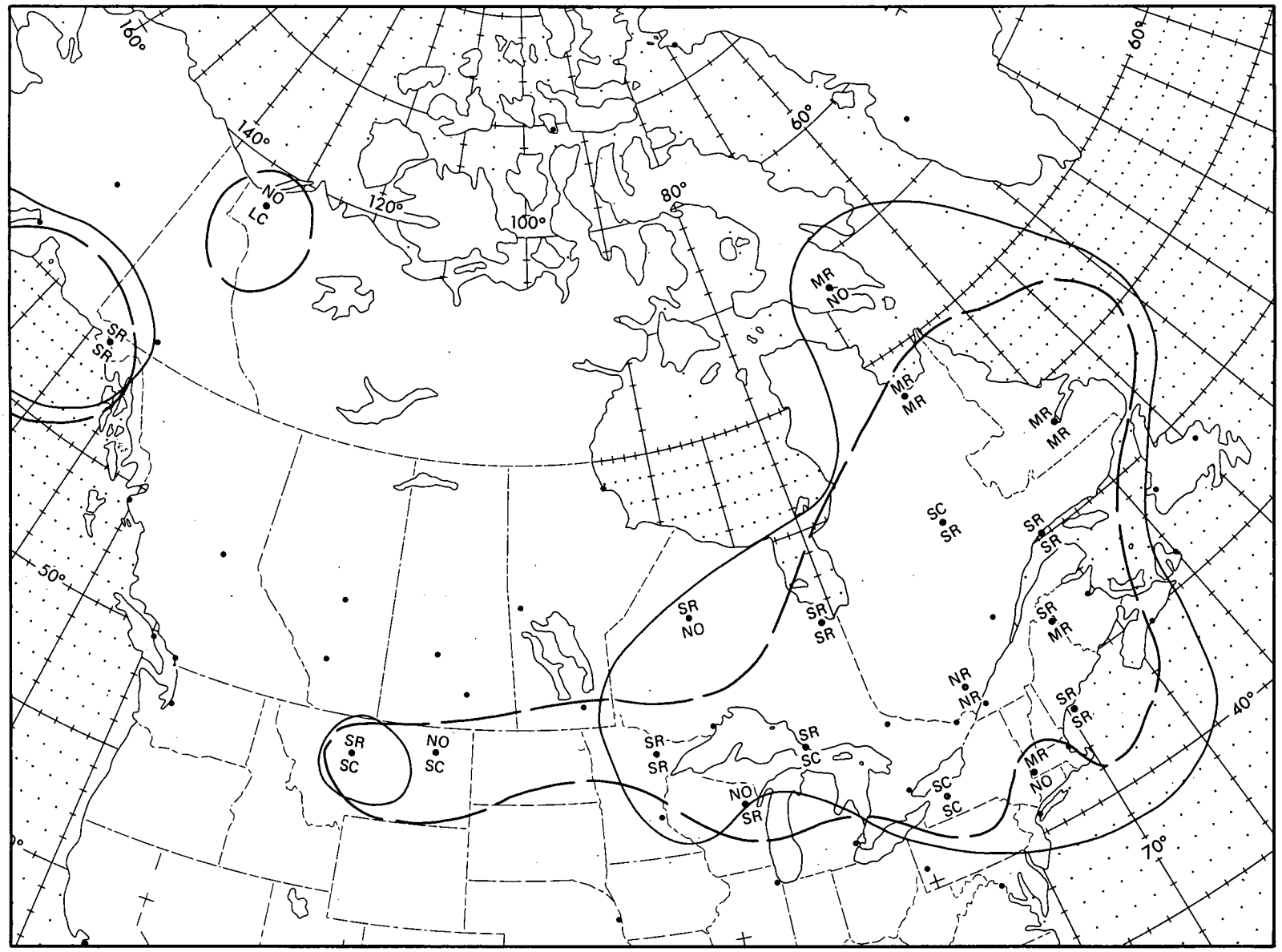

Figure 5.
Analysis of Icing for April 25, 1971 Between 850 and 700 mb
The acronyms below individual stations refer to the layer from 850-770 mb
while the acronyms above refer to the 770-700 mb layer
The solid line delineates icing between 700 and 700 mb
The dashed line delineates icing between 850 and 770 mb

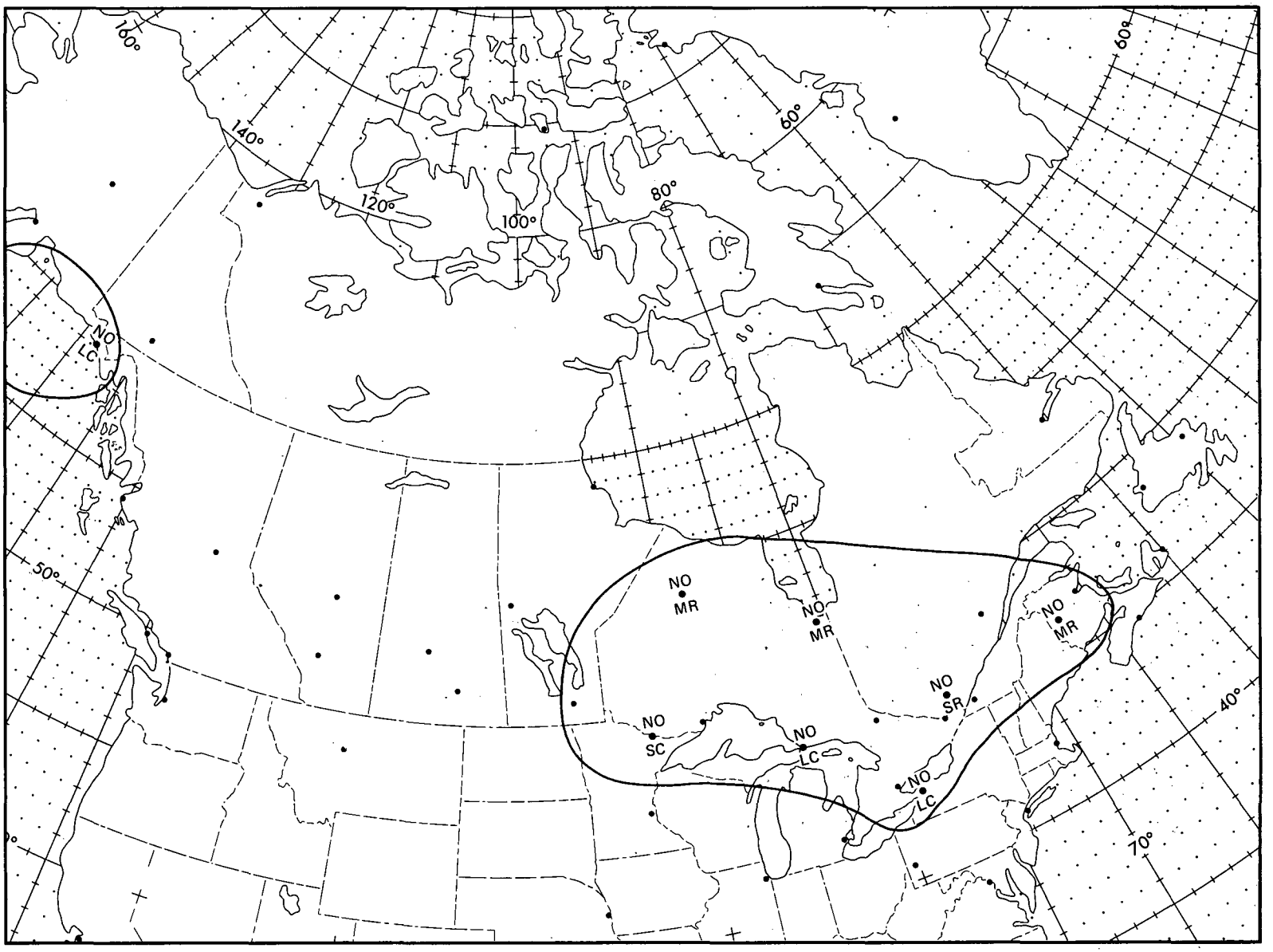

Figure 6.
Analysis of Icing for April 25, 1971 Between 700 and 590 mb
The acronyms below individual stations refer to the layer from 700 to 590 mb
Solid line delineates area where icing occurs

7. References

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