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DEPARTMENT OF THE ENVIRONMENT – CANADA

Technical Memoranda

AUTOMATED FORECAST CONVECTIVE DEVELOPMENT CHARTS

by

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ENVIRONMENT CANADA - ATMOSPHERIC ENVIRONMENT SERVICE
4905 Dufferin Street
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AUTOMATED FORECAST CONVECTIVE DEVELOPMENT CHARTS

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ABSTRACT

The performance of an automated technique for the provision of forecast guidance convective development charts over a period of 6 weeks in 1970 is reviewed. The technique is essentially a non-advective model based upon standard forecast tephigram and parcel theory. The chief desirable modification indicated is for the introduction of advection into the model.

TECHNIQUE AUTOMATISÉE DE CARTES DE CONVECTION À L'USAGE DES PRÉVISIONNISTES

par

A. F. Davies

RESUME

L'utilité d'une technique automatisée produisant des cartes de convection, utilisée par les prévisionnistes pendant 6 semaines en 1970, a fait l'objet d'une étude. Cette technique est essentiellement "non-advective", inspirée par le principe du téphigramme de prévision et de la méthode de la particule. La principale modification souhaitée concerne l'introduction dans le modèle d'un dispositif permettant de représenter l'advection.

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1. Introduction

As a further development in the provision of severe weather forecast aids in the Prairie Weather Central, automated forecast convective development charts were produced operationally during the summer of 1970. In the program which produced these charts, convective development characteristics such as height above ground of the cloud base, height of the cloud tops, maximum hail size, maximum surface wind gust, and minimum downdraft temperature were calculated at discrete points, by the construction of forecast tephigrams and the application of parcel theory. In this paper only the results of the forecasts of height of the cloud tops are presented.

2. Forecast Tephigrams

The current data input utilized in producing the automated forecast tephigrams consisted entirely of the early radiosonde reports at 1200 GMT (0700 local daylight time) from twenty-five radiosonde stations located in and near the Canadian Prairie Provinces. This data was read directly from teletype tape without manual modification.

A statistical-thermodynamic technique, which has been reported in detail elsewhere, Davies (1), was used to process the current data. It utilized an array of relationships derived from climatological upper air data to predict temperatures and mandatory heights above 500 mbs. A second series of relationships, derived from climatological data at the surface and 850 mbs, and also utilizing constant information such as height and slope of the terrain, were then applied to the current data to produce twelve hour forecasts of surface temperature and dewpoint. Although the model used in 1970 was non-advective, temperatures between 850 and 500 mbs were subject to modification due to diurnal heating. This was accomplished by permitting temperatures to respond to solar insolation up to a maximum diurnal temperature change height which was determined from climatological records for each station. Together with a dry adiabatic lapse rate from the surface, this height provided an upper limit on the forecast temperature sounding.

3. Cloud Top Calculations

It was assumed that such effects as liquid water loading and entrainment etc. tend to offset one another as far as their effect on tops are concerned, and that simple parcel theory could be used. The results to be subsequently discussed indicated that this was an acceptable operational assumption.

Procedures for the use of standard parcel theory techniques were included in the computer program. With reference to cloud top calculations the pertinent procedures were those which defined convective condensation levels, free convection levels, and cloud top limiting intersections, at each radiosonde station location.

Starting from the surface, the first convective condensation level was determined by the application of the Normand principle to the computer produced forecast maximum surface temperature and dewpoint. A search was then carried out for an intersection defining an associated free convection level. If no such intersection was found, convective development was forecast not to occur. If, however, the free convection level was defined, a search for a higher intersection defining a cloud top height was executed. The cloud top height thus determined was displayed, along with other parameters, on a convective development chart.

In those cases where this cloud top height was found to be lower than 700 mbs, the parcel temperature curve was examined for a higher second free convection level. Energy calculations were then carried out. If the positive energy below the calculated cloud top height was greater in absolute magnitude than the negative energy between the cloud top and the second free convection level, the convective development from the surface was considered to continue. The first cloud top height was then transferred to another display (for stratocumulus and cumulus). Meanwhile, a second cloud top limiting intersection was determined, and the cloud top height for the convective development chart was revised upward to this new value. In the event that the energy calculations showed that the convective development from the surface could not penetrate the negative energy level above the first cloud top height, the 700 mb temperature and dewpoint were used to calculate a second condensation level, free convection level and cloud top limiting intersection. If these calculations forecast convective development from the 700 mb level, the original cloud top height was transferred to the stratocumulus and cumulus chart, and the cloud top height for the convective development chart was again revised upward to the new value.

4. Interpretation

The calculated cloud top heights at radiosonde locations were plotted (along with various other parameters) by a subroutine of the program which had determined them. The base chart used was identical with the 1:10,000,000 scale surface charts used operationally. These printed forecast convective development charts were available approximately one hour after the receipt of the early radiosonde data upon which they were based. The convective development tops were contoured manually at 10,000 ft. intervals, as illustrated in Figures 1 to 7. These isopleths enclosed geographical areas within which the individual calculations were considered representative of the convective development to be forecast from 1800 GMT to 2400 GMT.

5. Assessment

With some exceptions, actual cloud tops could not be measured directly. Hourly weather reports were, however, readily available. Consequently, an assessment procedure based upon observations from surface weather observing sites was adopted.

In order to correlate forecast cloud tops with observed cloud and precipitation types, the "Manual of Standard Procedures for Surface Weather Observing and Reporting" (3) was first consulted. This indicated that the observer would differentiate between cumulus and cumulonimbus clouds by the appearance of the cloud top. Cumulus tops are described as being reported when there are "sharp outlines, developing vertically in the form of rising sounds, domes or towers, of which the bulging upper part often resembles a cauliflower". Cumulonimbus tops on the contrary are described as "At least part of its upper portion is usually smooth, or fibrous or striated, and nearly always flattened; this part often spreads out in the shape of an anvil or vast plume."

Essentially, then, the observer will differentiate between cumulus and cumulonimbus on the basis of the presence or absence of cloud forms which devleop as the cloud tops move upward from the tropospheric region of relatively steep lapse rates into the stratospheric region of near isothermal lapse rates.

During the six week period from May 1 to June 16, 1970, climatological records showed that extreme tropopause heights ranged from 23,000 to 43,000 ft. over the charted area with means at individual stations ranging from 31,000 to 37,000 ft.

The 20,000 to 30,000 ft. forecast interval consequently generally corresponds to the tropospheric region of steep lapse rates where the observer should observe sharp bulging outlines and report towering cumulus or altocumulus castellanus.

The 30,000 to 40,000 ft. forecast interval generally corresponded to the region of transition (in the vicinity of the tropopause) from tropospheric to stratospheric lapse rates, where the observer should observe smooth, flattened cloud forms, anvils or plumes, and consequently report cumulonimbus.

The 40,000 to 50,000 ft. forecast interval should similarly correspond to reports of cumulonimbus.

In the following discussion the term "event" is used to denote a single first occurrence, at a specific location, of one of four categories of phenomena, namely: towering cumulus or altocumulus; showers; cumulonimbus; and thundershowers. Hourly weather reports, at all stations in the charted area from 1800 GMT to 2400 GMT were examined. The first occurrence at each station of each of these categories was recorded, as illustrated in Figures 1 to 7. This procedure was adopted in order to verify the correspondence between the forecasts and observations on the basis of location only.

6. Results

In Table No. 1 a summary of the observations for forty days is presented, categorized with respect to forecast cloud top intervals of ten thousand feet.

Forecast Interval 0 to 10,000 Feet

A total of 160 events were recorded in the average daily area of 903,000 square miles for which the forecast interval was 0 to 10,000 feet. This average daily area was 61% of the charted area.

Of the 160 events recorded, 120 occurred downstream from forecast areas of higher tops, and close enough to be explained by advection. The remaining 40 events, an average of one event per day, were not forecast correctly, nor could they be explained by advection.

Forecast Interval 10,000 to 20,000 Feet

In the 10,000 to 20,000 ft. interval, which had an average daily area of 327,000 square miles, or 15% of the charted area, 221 events were observed. Of these, 173 or 78% were reports of towering cumulus, altocumulus or showers. Of the remaining 48 cumulonimbus or thundershower reports, only 12 could not be explained by the advection of an upstream area of greater forecast development.

Forecast Interval 20,000 to 30,000 Feet

In the 20,000 to 30,000 ft. forecast interval, which averaged 280,000 sq. miles or 13% of the charted area, 278 events occurred. Of these, 216, or 78%, consisted of reports of cumulus, altocumulus or showers. Only 22% of the total subsequently developed into cumulonimbus or thundershowers.

Forecast Interval 30,000 to 40,000 Feet

In the 30,000 to 40,000 ft. forecast interval, which averaged 165,000 square miles, or 8% of the charted area, 186 events were reported. Of these 123 or 66% were cumulus, altocumulus or shower reports. Fifty-three or 34% of the total subsequently developed into observed cumulonimbus or thundershowers.

Forecast Interval Greater Than 40,000 Feet

In the final interval greater than 40,000 ft., which averaged only 3% of the charted area, 57 events occurred. Thirty-seven or them or 65% were initially reported as cumulonimbus or thundershowers.

Areal Frequency of Observed Events Versus Forecasts

In order to portray the areal density of events in the various forecast categories, the figures from Table 1 were reduced to a common area of 100,000 square miles and shown in Table 2.

The greatest frequency of events for the 40 days was 80.5 cumulonimbus or thundershower reports per 100,000 square miles observed in the forecast interval greater than 40,000 feet. This is an average of just over 2 events of this type per day.

The second highest frequency of events was 77.1 cumulus, altocumulus or showers per 100,000 square miles observed in the forecast interval 20,000 to 30,000 feet.

The total frequency of events increased sharply from 16.6 per 100,000 square miles in the 0 to 10,000 ft. forecast interval to 67.3 in the 10,000 to 20,000 ft. interval, then steadily to 99.2, 112.7, and finally 124.0 events per 100,000 square miles in the three remaining categories.

Average Daily Frequency of Observed Events Versus Forecasts

On a daily basis, 0.41 events per 100,000 square miles occurred in the 61% of the charted area within the 0 to 10,000 ft. forecast interval. Similar figures for remaining intervals were: 1.68 per 100,000 square miles in the 15% of the charted area within the 10,000 to 20,000 ft. interval; 2.48 in the 13% within the 20,000 to 30,000 ft. interval; 2.82 in the 8% within the 30,000 to 40,000 ft. interval; and 3.08 in the 3% of the charted area within the forecast interval greater then 40,000 feet.

Relation of Observed Convective Development Tops and Tropopause Heights to Forecast Cloud Top Heights

When the cloud top heights were predicted to be lower than tropopause heights, the predominant observed convective development types were heavy cumulus, altocumulus and showers, as indicated in Figure 8.

On the other hand, when the cloud top heights were predicted to be higher than tropopause heights, the predominant observed convective development types were cumulonimbus and thundershowers, as indicated in Figure 9.

7. Verification of Forecast Cloud Top Heights by Radar Measurement

On seven days during the period May 28 to June 16, radar reports were available for cumulonimbus development in the vicinity of Winnipeg.

On five of these days the program forecast cumulonimbus development from the 1200 GMT Shiloh early radiosonde report. On the two days that the processed Shiloh radiosonde did not indicate cumulonimbus, the International Falls radiosonde did. On all seven days, interpolated values could be read from isoplethed charts.

Date	Observed Radar Tops Near Winnipeg	Isoplethed Tops at Winnipeg	Tops Forecast From LO Radiosonde	Tops Forecast From INL Radiosonde
May 28	270-300*	250*	300*	-
June 1	300-350	270	300	-
June 8	350-400	400	-	410*
June 9	350-400	330	-	420
June 10	300-350	400	440	-
June 12	350-370	380	420	-
June 16	340-370	400	400	410

*Heights in hundreds of feet.

8. Conclusions

Parcel theory calculations from 1200 GMT early radiosonde data, which were performed by a non-advective automated forecast convective development program, regularly provided guidance for the forecasting of convective phenomena over Western Canada six to twelve hours later.

This guidance material demonstrated several desirable types of selectivity. Firstly, for forecast tops lower than the tropopause, cumulus and altocumulus cloud actually predominated. On the other hand, for forecast tops higher than the tropopause, cumulonimbus was actually the predominant cloud type.

Secondly, the observed frequency per unit area of cumulus and altocumulus development reached a maximum in the 20,000 to 30,000 ft. forecast interval, decreasing to approximately one half of the maximum frequency in the 40,000 to 50,000 ft. forecast interval. In contrast, the observed frequency of cumulonimbus development per unit area increased quadratically (above 20,000 ft.) up to the highest forecast interval.

Thirdly, the forecasts exhibited the capability of defining a relatively sharp threshold between the large area (61% of the total) where convective development was infrequent, and the smaller area (39% of the total) where 83% of the observed development occurred.

Fourthly, the total areas in successive forecast intervals (above 20,000 feet) decreased quadratically, while at the same time the observed frequency per unit area of all events increased linearly.

As a result the isoplethed materials tended to be realistically specific in forecasting the areal extent of the greatest convective development.

Although the sample of radar verification was too small to generalize for the whole forecast area, in the Winnipeg area the isoplethed 6 to 12 hour forecast heights were within 2500 feet of the observed range of radar tops, on the average.

The chief disadvantage of the technique was its non-advective character. It was demonstrated that this could be corrected by judicious displacement of the forecast isopleths downstream. A more permanent correction could be made by including advection in the program.

The technique can be applied to any location at which current or forecast 850, 700 and 500 mb information is available, together with terrain height and slope and climatological upper air data. For wider applicability and finer detail the program could be readily adapted to utilize grid point data derived from a numerical objective analysis or prediction model.

9. Acknowledgements

The assistance of Mr. F. Hunter in abstracting the verification data is recognized with thanks. Appreciation is also expressed to Mr. D. McGeary who supervised the daily executions of the computer programs, and to Dr. A. Chisholm for his helpful comments concerning the applicability of parcel theory.

APPROVED,

J.R.H. Noble,
Assistant Deputy Minister,
Atmospheric Environment Service.

TABLE 1.

Observed First Reports of Convective Development Clouds and Precipitation vs. Forecast Convective Development Cloud Top Heights

FORECAST INTERVAL

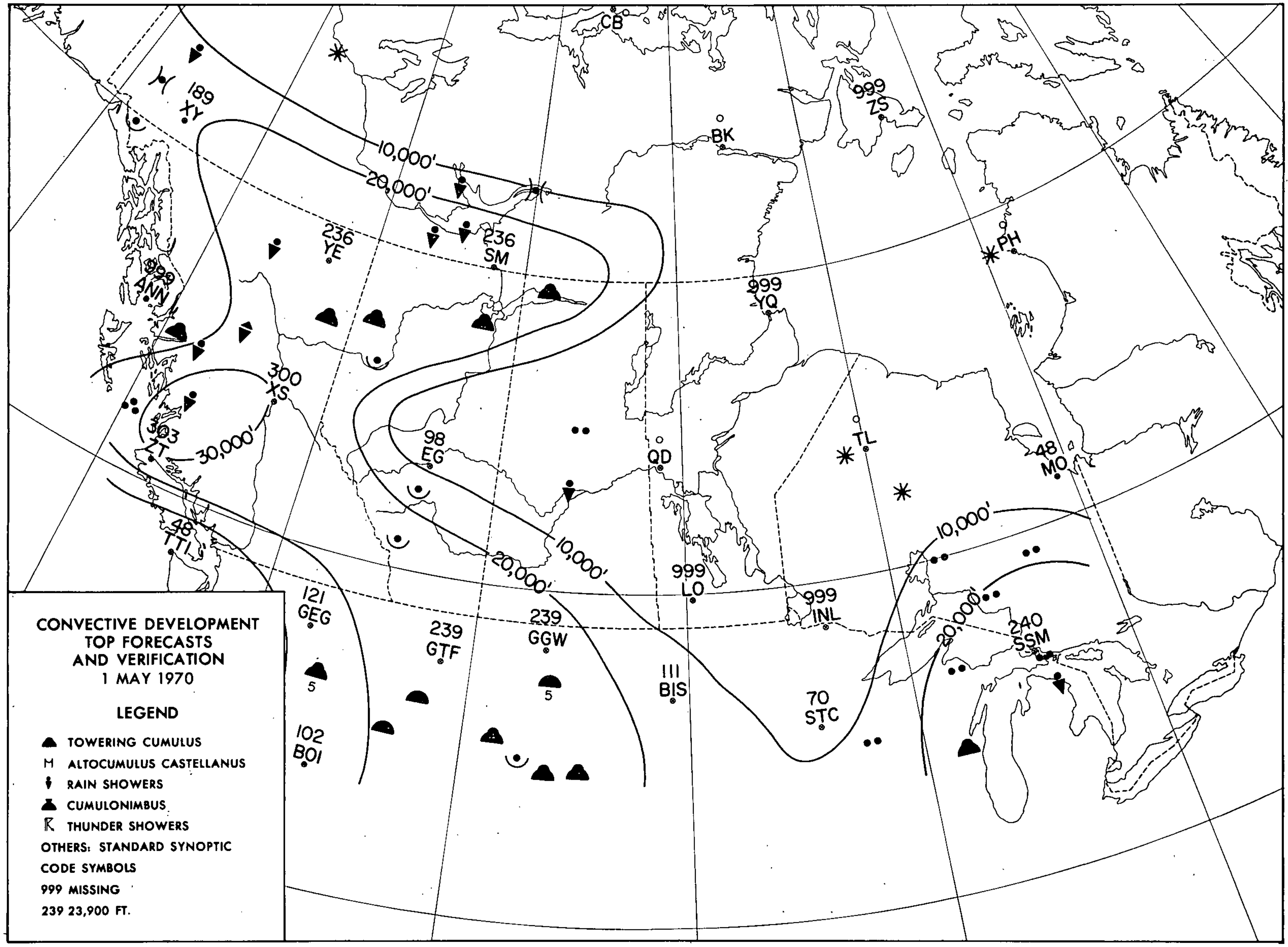
	0 to 10,000			10,000 to 20,000	20,000 to 30,000	30,000 to 40,000	40,000 to 50,000
Average Daily Area Mi.^{2}	903,000			327,000	280,000	165,000	46,000
Percentage of Total Area	61%			15%	13%	8%	3%
Observations (Forty Day Totals)	Location of observed event with respect to 10,000 to 20,000 interval						
	Up-stream	Down-stream	Distant				
Number of first reports of towering cumulus or altocumulus, or showers, during the period 1800 to 2400 GMT	18	82	9	173	216	123	20
Number of first reports of cumulonimbus or thundershowers, during the period 1800 to 2400 GMT	10	28	3	48	62	63	37
Total number of reports of convective development.	28	120	12	221	278	186	57

TABLE 2.

Forty Day Totals of First Reports of Convective Development Per 100,000 Square Miles

FORECAST INTERVAL

Observations	0 to 10,000			10,000 to 20,000	20,000 to 30,000	30,000 to 40,000	40,000 to 50,000
	Location of observed event with respect to 10,000 to 20,000 ft. interval						
	Up-stream	Down-stream	Distant				
Forty Day Totals of First Reports Per 100,000 Square Miles							
Towering cumulus, altocumulus castellanus or rain showers	2.0	9.1	1.0	51.9	77.1	74.5	43.5
Cumulonimbus or Thundershowers	1.1	3.1	0.3	15.4	22.1	38.2	80.5
All First Reports	3.1	12.2	1.3	67.3	99.2	112.7	124.0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TOP FORECASTS
AND VERIFICATION
1 MAY 1970
LEGEND
TOWERING CUMULUS
ALTOCUMULUS CASTELLANUS
RAIN SHOWERS
CUMULONIMBUS
THUNDER SHOWERS
OTHERS: STANDARD SYNOPTIC CODE SYMBOLS
999 MISSING
239 23,900 FT.
CB
BK
999 ZS
189 XY
236 YE
236 SM
PH
999 ANN
999 YQ
300 XS
303 ZT
98 EG
QD
TL
48 MO
48 TTI
10,000'
20,000'
30,000'
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999 INL
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239 GGW
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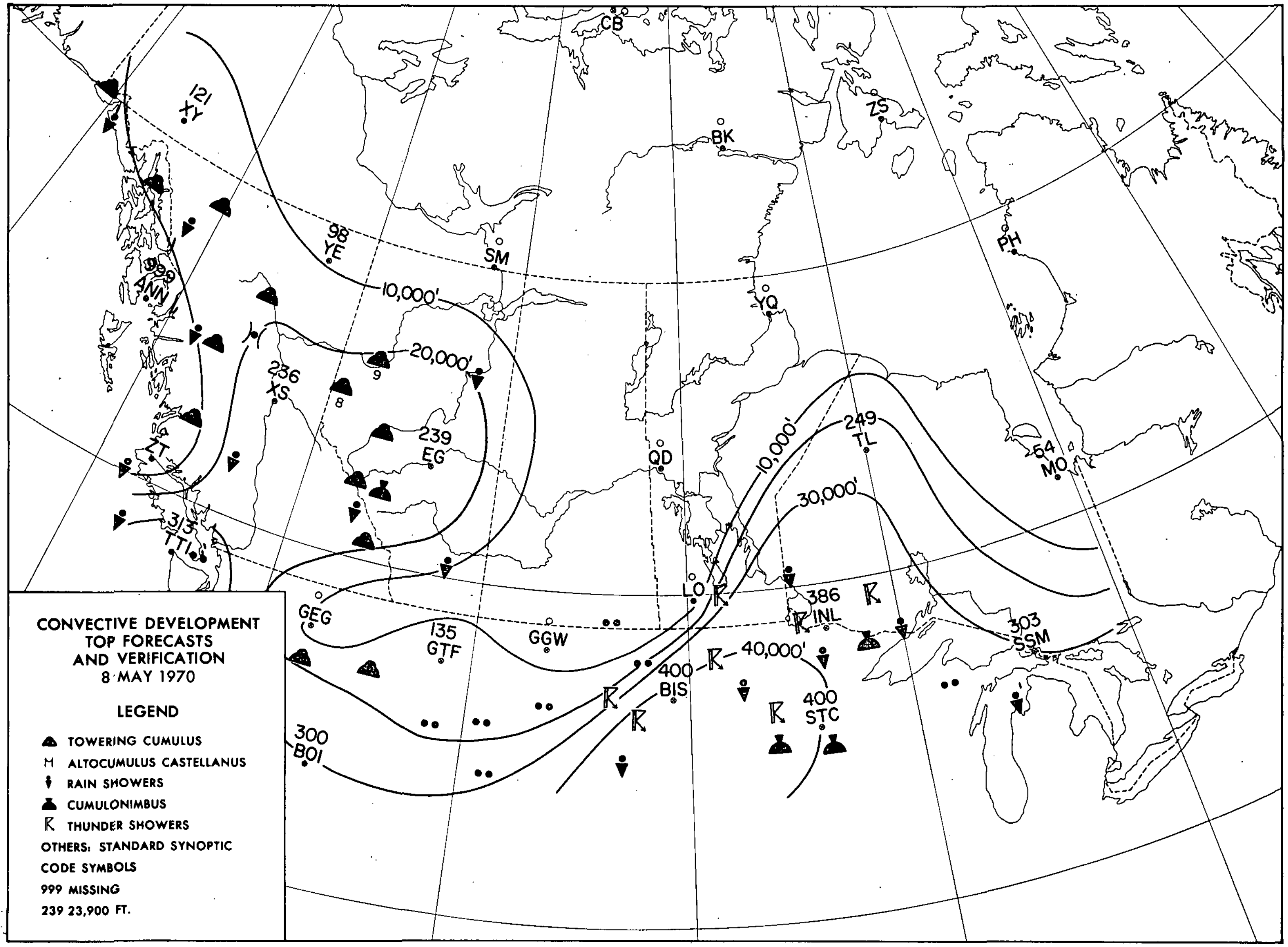
70 STC
102 BOI
5
5

Figure 1.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AND VERIFICATION
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ALTOCUMULUS CASTELLANUS
RAIN SHOWERS
CUMULONIMBUS
THUNDER SHOWERS
OTHERS: STANDARD SYNOPTIC
CODE SYMBOLS
999 MISSING
239 23,900 FT.
CB
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121
XY
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SM
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10,000'
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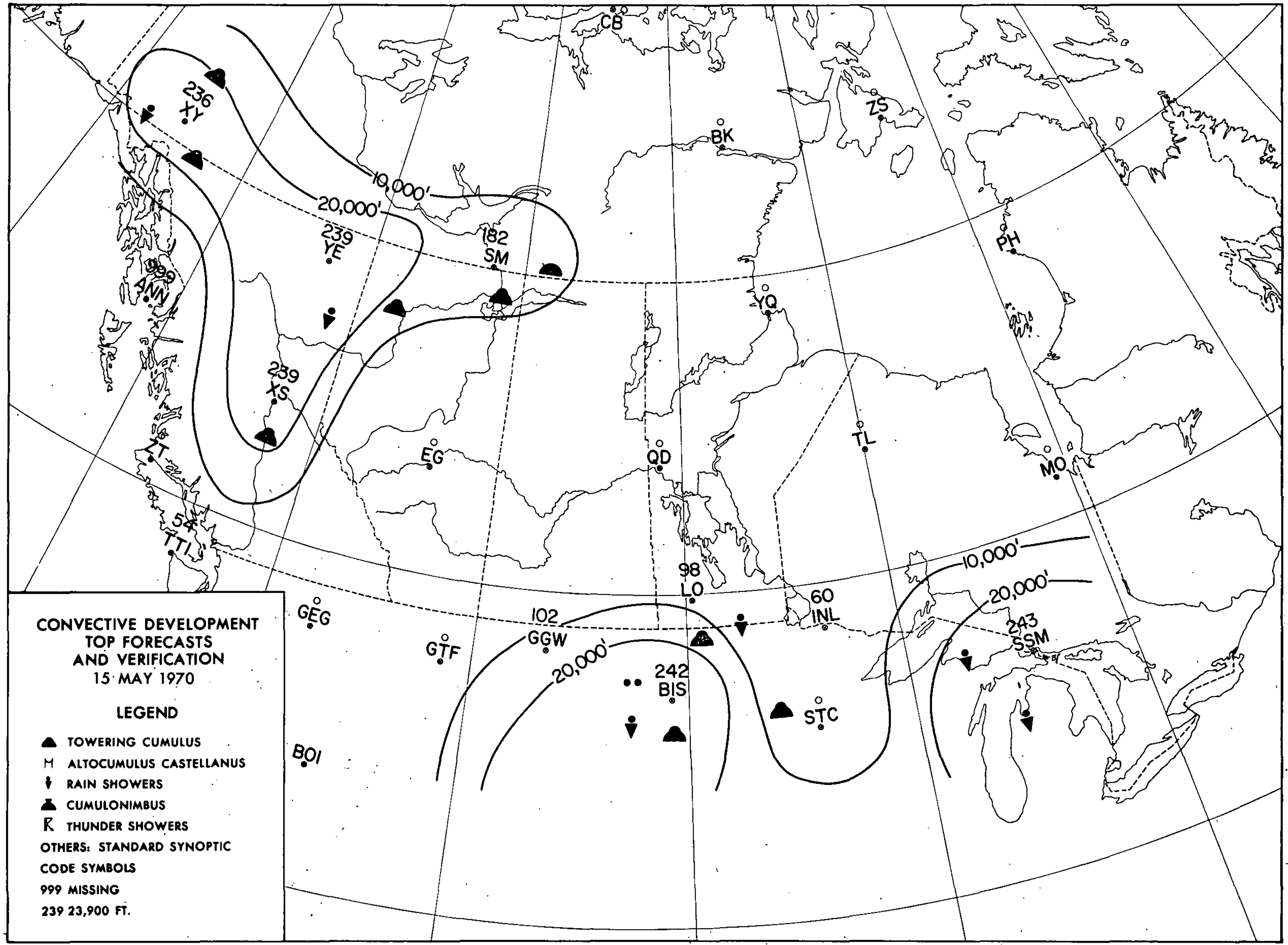
Figure 2.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RAIN SHOWERS
CUMULONIMBUS
THUNDER SHOWERS
OTHERS: STANDARD SYNOPTIC
CODE SYMBOLS
999 MISSING
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Figure 3.

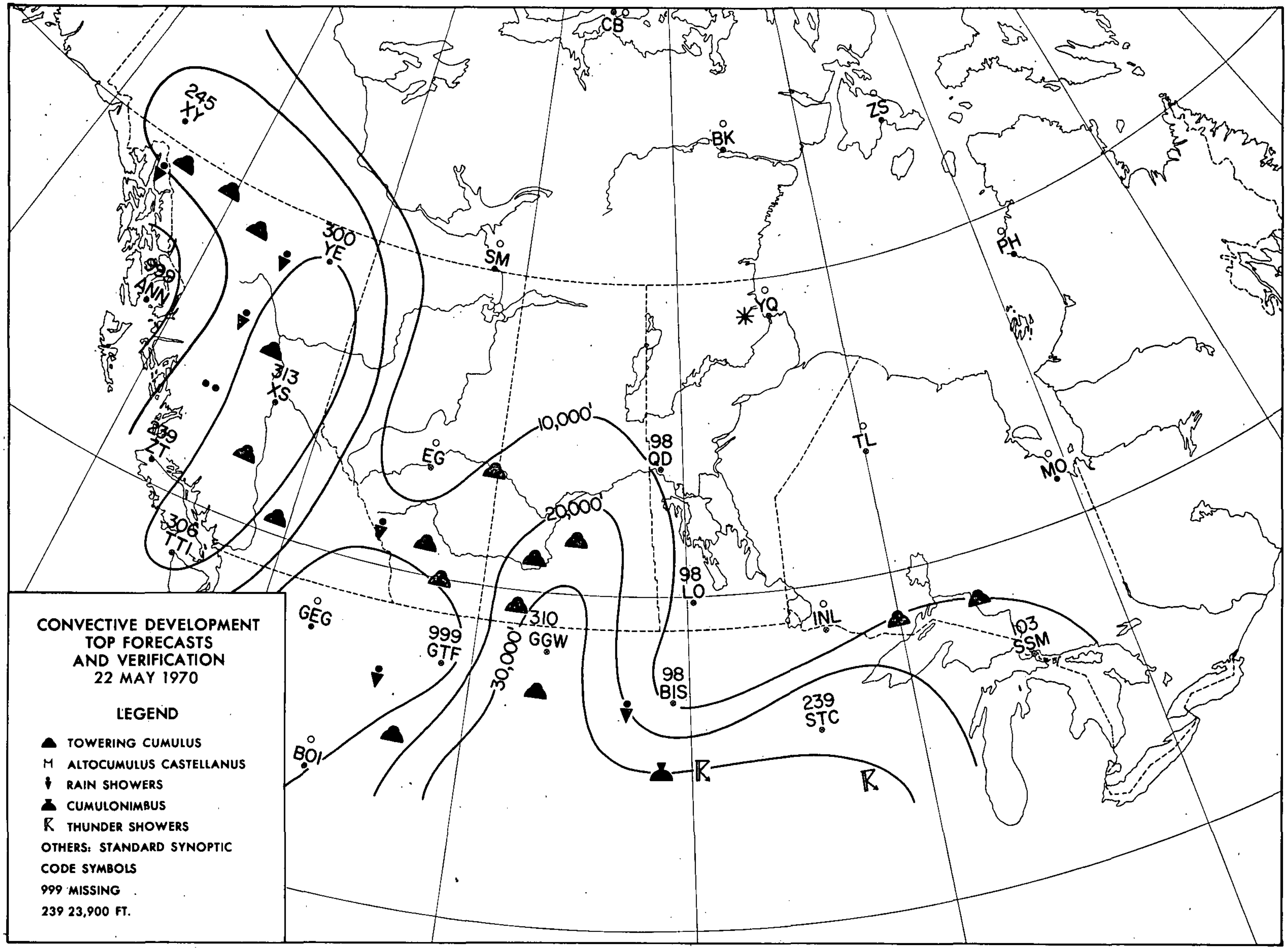
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Figure 4.

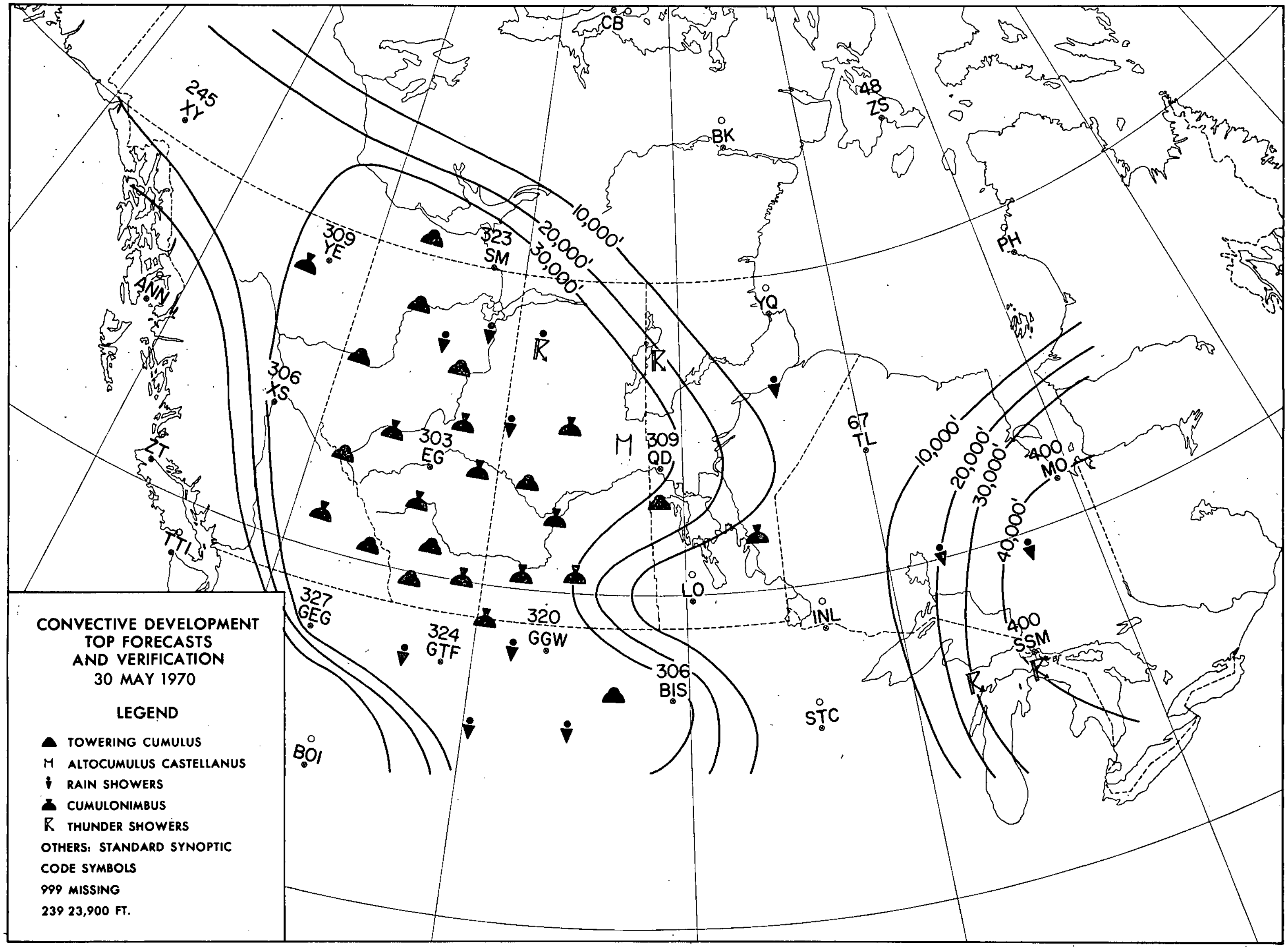
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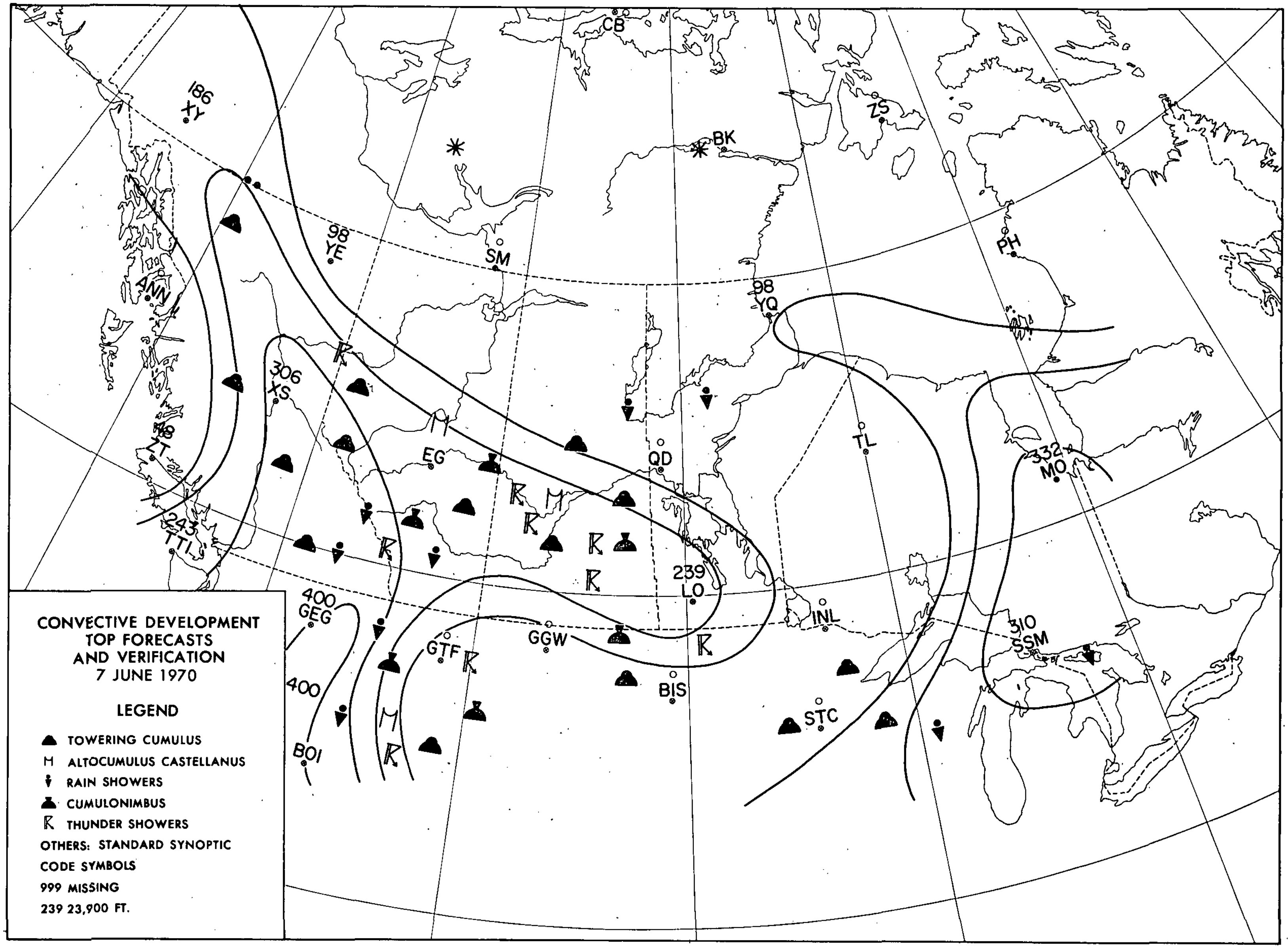
Figure 5.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AND VERIFICATION
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▼ RAIN SHOWERS
▲ CUMULONIMBUS
K THUNDER SHOWERS
OTHERS: STANDARD SYNOPTIC
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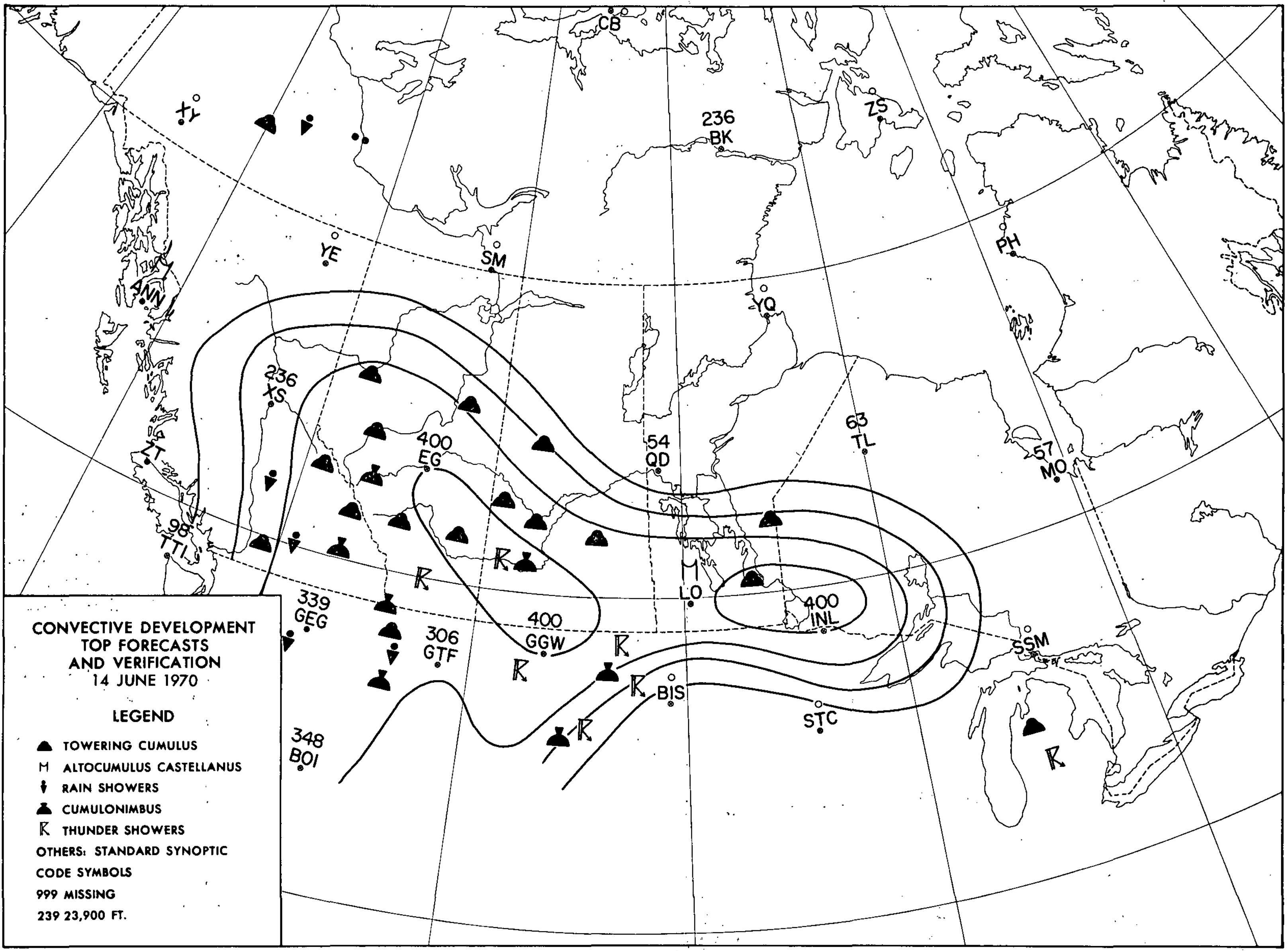
Figure 6.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AND VERIFICATION
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Figure 7.

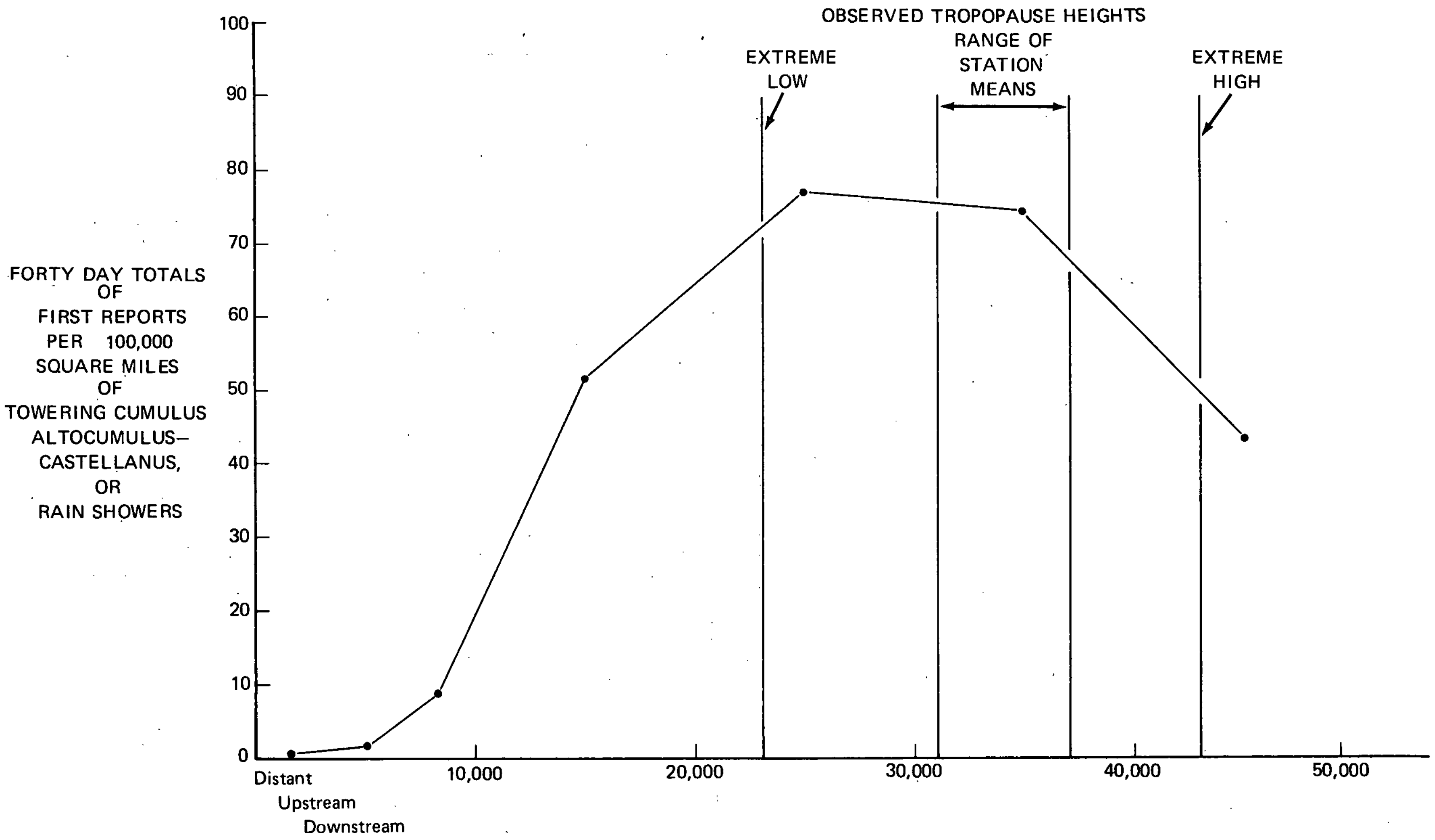

Figure 8.

Observed Forty Day Totals per 100,000 Square Miles of First Reports of Towering Cumulus, Altocumulus Castellanus or Showers vs. Forecast Height of Convective Development Tops and Observed Tropopause Heights

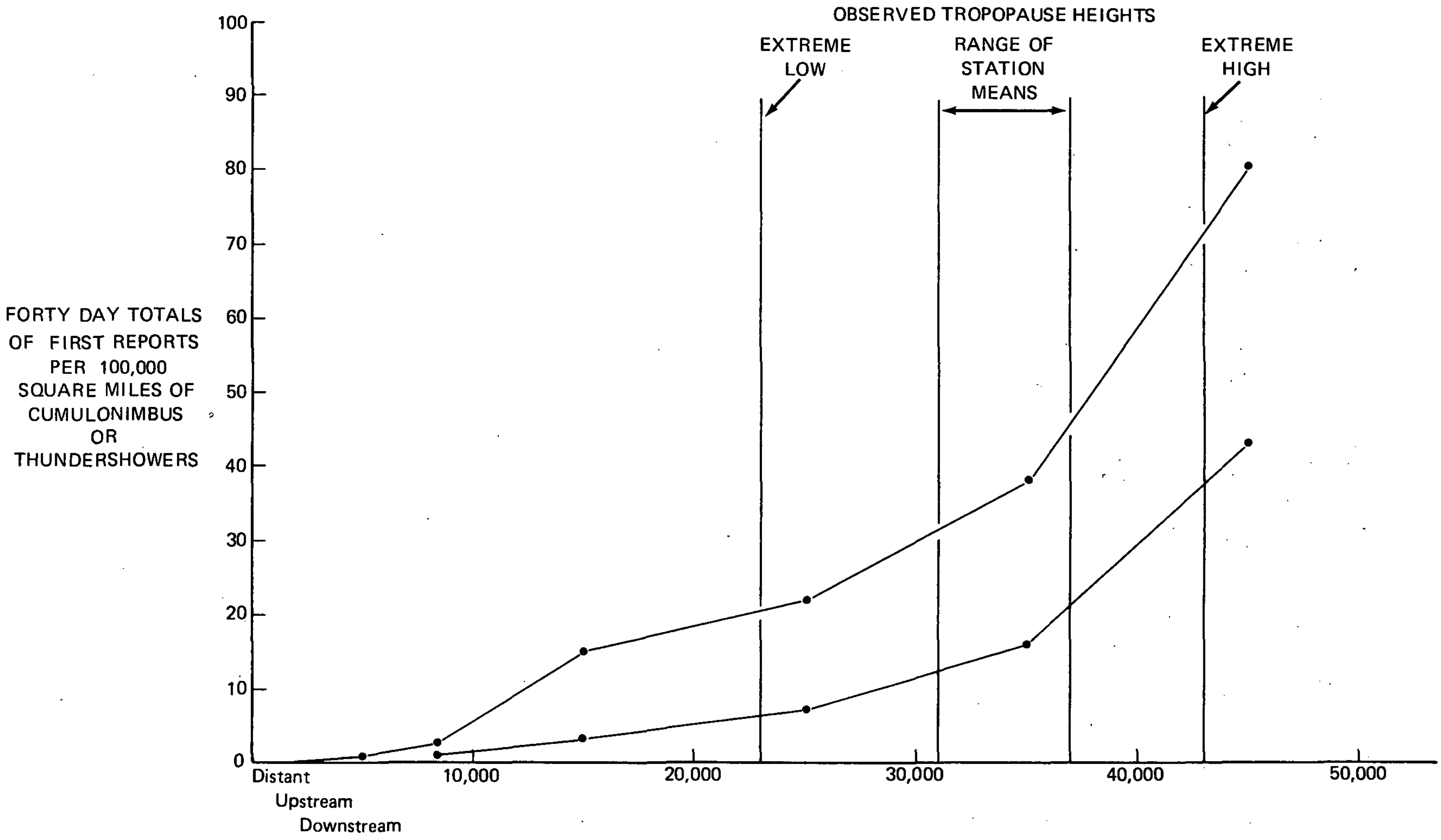

Figure 9.

Observed Forty Day Totals per 100,000 Square Miles of First Reports
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Automated Forecast Convective Development Charts
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8 pps. 9 figs. 2 tables 3 refs.

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2. Convection

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