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Forecasting Snow Amounts from Net Vertical Displacements

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This bulletin describes the 12-24, 24-36, and 36-48 hour net vertical displacement fields that have been transmitted twice-daily on the AFOS communications system since February 7, 1990. The fields are produced by the NGM-based three-dimensional trajectory model, which now generates forecasts for projections of 36 and 48 hours following initial data time, in addition to the usual 24-hour forecasts provided in the past. The displacement fields are designed for use with 850-mb temperature forecasts as input to a technique that predicts both the occurrence of snow and snowfall amounts, especially for heavy snow events. The technique, dubbed the "Magic Chart", was originally developed at WSFO Milwaukee.

This bulletin describes a specific use of the net vertical displacement fields. There are other uses for the fields unrelated to snow events, such as assessment of upward motion for synoptic scale uplift and for convective development.

This bulletin was prepared by Mr. Ronald M. Reap of the Techniques Development Laboratory.

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FORECASTING SNOW AMOUNTS FROM NET VERTICAL DISPLACEMENTS

by Ronald M. Reap

1. INTRODUCTION

This bulletin describes the 12-24, 24-36, and 36-48 hour (h) net vertical displacement fields for air parcels terminating at the 700 millibar (mb) level that appear in graphical form on the AFOS communications system. The fields are generated by the Nested Grid Model (NGM)-based three-dimensional trajectory model that is run twice daily at the National Meteorological Center (NMC). Development of the new 36- and 48-h forecast projections and the attendant net vertical displacement forecasts from the NGM-based trajectory model was initiated in response to a request from the 1989 Line Forecasters Technical Advisory Committee (LFTAC) to provide additional guidance for heavy snow forecasts at extended forecast ranges. Net vertical displacement forecasts from the new model were implemented on the AFOS system on February 7, 1990.

Previous Model Output Statistics (MOS) development efforts (Reap and Foster, 1979; National Weather Service, 1986) have incorporated net vertical displacement forecasts in probability equations that were designed to predict the occurrence of thunderstorms and severe local storms. Net vertical displacement forecasts have also been used in assessing upward motion for synoptic-scale uplift, unrelated to snow events. However, the focus in this bulletin is on the use of net vertical displacement forecasts with 850-mb temperature forecasts from the NGM as input to a technique that predicts both the occurrence and amount of snow, especially for heavy snow events. The technique, dubbed the "Magic Chart" (Sangster and Jagler, 1985), was originally developed at WSFO Milwaukee and has since been successfully applied to snow prediction at a number of NWS forecast offices.

2. OPERATIONAL TRAJECTORY MODEL

Previous versions of the trajectory model, driven by wind forecasts from the Limited-area Fine-mesh Model (LFM), have been in operation since the early 70s (NWS, 1978; Reap, 1972). Since its inception, the LFM-based trajectory model has produced forecasts that were limited to a 24-h projection. Several improvements to the trajectory model have been made over the years, including the simulation of air-sea energy exchanges for overwater trajectories (Reap, 1971) and the assimilation of surface land and ship reports, upper-air data, and initialized grid point values in an improved objective analysis procedure for the model (Reap, 1976). These improvements resulted in more accurate model forecasts of low-level (surface, 850-mb) temperature and moisture. The "Magic Chart" for predicting snowfall amount, as originally designed, used the trajectory model 850-mb temperatures in combination with the net vertical displacement forecasts.

The underlying feature of the current version of the trajectory model involves the computation of three-dimensional air parcel trajectories from the u, v, and w wind component forecasts generated by NMC's NGM. Trajectories for each forecast level are computed backwards in 2-h time steps from their terminal points, which initially form a rectangular array of grid points, to their origin points in three-dimensional space. Parcel trajectories for the 24-, 36-, and 48-h projections are prepared separately. Net vertical displacement is simply the total vertical movement of an air parcel following a trajectory that terminates at a specific level. In effect, net vertical displacement represents the integrated NGM vertical velocities experienced by the parcel over a specific period of time during its movement along a trajectory. The 36-48 h net vertical displacements for the 700-mb level, for example, represent the total vertical movement of air parcels arriving at the 700-mb level during the last 12 hours of the 48-h forecast, i.e., from 36 to 48 hours. Net vertical displacement is expressed on the graphical output in terms of millibars, with upward motion being positive. A value of 80 on the AFOS display, for example, represents a total upward vertical movement of 80 mb in 12 hours for a parcel arriving at the 700-mb level. Thus, the parcel was located at 780-mb at the start of the 12-h period. Examples of net vertical displacement forecasts are shown in Appendix A (Chaston, 1989) as they appear in graphical form on the AFOS system.

3. METHODOLOGY

For a snow forecasting technique such as the "Magic Chart" to be successful, it must be based on sound physical principles. Since the trajectories represent integrated three-dimensional motions of the atmosphere, they relate closely to observed large-scale cloudiness and precipitation. Therefore, in a sufficiently moist environment, large positive values of net vertical displacement imply substantial precipitation due to large-scale uplift. This is the general physical basis for the observed success of net vertical displacements in forecasting snowfall amounts, i.e., the greater the large-scale uplift, the greater the corresponding snow production and accumulation in regions where sufficient moisture exists and the low-level temperature is at or below freezing.

In a study of eight major synoptic-scale storms for the 1987-88 snow season, Chaston (1989) (see Appendix A) listed the following assumptions or restrictions for using the "Magic Chart" to predict snow and snowfall amounts:

- The approach does not apply to mesoscale snowstorms related to topographical or frictional convergence or to lake-effect snowstorms;
- Adequate deep moisture must first be available or forecast to be available; and
- The NGM and, hence, the NGM-based trajectory model are accepted as being reasonably reliable for the forecast projections of interest.

To use the "Magic Chart" procedure, it is necessary to overlay the particular net vertical displacement field of interest with the NGM 850-mb temperature forecast valid at the start of the 12-h forecast period. The heaviest snowfall is likely to occur where the greatest net vertical displacement overlays the region between the -3 and -5 degree (deg) C isotherms on the 850-mb temperature forecast chart. Temperatures less than -5 deg C decrease the amount of moisture the air can hold; therefore, the same net vertical displacement will yield a lower snowfall amount. In general, the procedure works best with a mature or developing synoptic-scale low-pressure system.

A detailed discussion of the procedure, including two sample forecasts, is given in Appendix A. The appendix contains, in its entirety, an article by Peter Chaston, of the National Weather Service Training Center, describing an evaluation of the performance of the "Magic Chart" for eight major snowstorms during the 1987-88 snow season. Several forecasts were made during the life-cycle of each of the storms and it was found that the technique did more than accurately locate the heavy snow areas; it actually succeeded in predicting the heavy snow amounts with very good accuracy.

The evaluation by Chaston (Appendix A) was based on net vertical displacement forecasts for the 12-24 h projection from the LFM-based trajectory model, which was the only projection available at that time. We anticipate that the current 12-24 h displacements from the NGM-based trajectory model will exhibit similar skill. Some decrease in forecast accuracy is expected, however, as the forecasts are made for increasingly longer projections. To evaluate the new 24-36 and 36-48 h net vertical displacement fields, a subjective appraisal of forecast performance was made during the daily map discussions held at the Techniques Development Laboratory (TDL) during the 1989-90 snow season. A consensus was reached by the participants that the longer-range snow forecasts appeared to have considerable skill. In several cases, a successful 36-48 h snow forecast turned out to be equal in skill to the 12-24 h forecast issued 24 hours later for the same valid period. If these results hold up in general operational usage, the new guidance should be of significant value to forecasters in increasing the lead time for alerting users to the possibility of snow. Another positive result of the subjective evaluation was the increased confidence gained in preparing snow forecasts when the three forecast projections indicated good development and continuity from one forecast cycle to the next.

Perhaps the most important feature of the "Magic Chart" is its success in forecasting actual snow amounts. The relationship between 12-h net vertical displacement and observed 12-h snowfall is shown in Appendix A. In general, about 1 inch of snow was observed for each 10 mb of upward parcel displacement within the -3 to -5 deg C temperature band at 850-mb. For example, we would expect about 10 inches of snow with a 12-h net vertical displacement of 100 mb where adequate moisture is available. As noted in Appendix A, adequate moisture implies temperature-dew point spreads of no more than a few degrees at 850- and 700-mb, or a 1000-500 mb mean relative humidity of about 90% or greater. The relationship between net vertical displacement and snowfall amount is essentially empirical in nature, therefore, its use should be restricted to preparation of the "Magic Chart" as described in this bulletin.

The relationship between net vertical displacement and snow amount in Appendix A was based on forecasts from the LFM-based trajectory model. As experience is gained in operational use, the snow amounts will probably need to be adjusted slightly downward since the operational net vertical displacement fields from the current NGM-based trajectory model exhibit somewhat more amplitude for a given snow amount than those previously produced by the LFM-based version. The increased amplitudes are a result of the improved physics and greater horizontal resolution of the NGM, relative to the LFM. Based on experience gained at the TDL daily map discussions, the reduction of the snow amount forecast should be relatively small, i.e., 1-2 inches or less.

4. PRODUCT CONSIDERATIONS

The AFOS product identifiers for the 12-24, 24-36, and 36-48 h net vertical displacement fields are:

NMCGPH7WG	(12-24 h)
NMCGPH7XG	(24-36 h)
NMCGPH7YG	(36-48 h)

The same product identifiers are used on the Family of Services AFOS Graphics Service.

The charts are available for both the 0000 UTC and 1200 UTC model runs. Product identifers for the corresponding NGM 850-mb temperature forecasts at the start of each of the above 12-h periods are as follows:

NMCGPH82T	12-h
NMCGPH84T	24-h
NMCGPH86T	36-h

The displacement fields are contoured every 20 mb with upward motion being positive. As previously noted, forecasts from the NGM-based trajectory model are dependent on the accuracy of the wind forecasts from the NGM used as input to compute the parcel trajectories. The net vertical displacements and corresponding snow forecasts, therefore, may have to be used with caution if the forecaster detects possible errors in the NGM predictions. In effect, the success of the "Magic Chart" technique is directly related to the accuracy of the NGM forecasts in a given situation. The forecaster should carefully diagnose the meteorological situation and evaluate all numerical model guidance before utilizing this technique to prepare the final snow forecasts.

5. REFERENCES

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APPENDIX A *

FORECASTING

THE MAGIC CHART FOR FORECASTING SNOW AMOUNTS

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ABSTRACT

One of the major challenges for meteorologists is accurately predicting the amount of snowfall, especially for a major storm. A form of the magic chart was initially experimented with at the NWS Forecast Office at Milwaukee to attempt to pinpoint where the heaviest snowfalls would occur during synoptic-scale storms. During the 1987–88 snow season, a modified form of this chart was used at the NWS Training Center to forecast not only where the heaviest snowfall would occur, but also the amounts during 12-hr periods. The appropriate moisture supply must be expected before the chart is useable. The magic chart is a combination of a 12-hr period 700-mb net vertical displacement (NVD) prog by NMC's Trajectory Model, and a 12-hr prog of the 850-mb temperature field by the NGM. The initial results from one snow season were surprisingly accurate. The physical reasoning behind this approach is also given.

1. INTRODUCTION

During the past several decades, weather forecasters have been struggling with the problem of predicting as accurately as possible the amounts of snowfall from major synoptic systems. More recently, as NMC forecast models improved, some of their output have been applied to this challenge, employing unique approaches. Essentially, the best techniques locate approximately where the heaviest snowfalls would likely occur. Development of a method that predicted actual amounts of heavy snow remained elusive.

It is obvious that a reliable technique for forecasting actual snowfall amounts with a high degree of accuracy, would benefit society. This paper presents the results of a technique known as **THE MAGIC CHART** for forecasting snow amounts, so-named because it is easy to use and works "like magic." Initially, the chart was a modification of the approach tried at the NWS forecast office at Milwaukee (2) for identifying the areas of heaviest snow. Partially by accident, it was discovered that the modified approach did more than locate heavy snow areas; this forecasting scheme actually succeeded in predicting the actual amounts of heavy snow with surprising accuracy.

2. METHODOLOGY

Any weather forecasting scheme must be based on sound physical reasoning. Therefore, a forecasting scheme for snow amounts must be logically developed, based on physical principles.

The magic chart is based on the following assumptions:

1. This approach does not apply to mesoscale snowstorms such as topographical/frictional convergence types and lake-effect snowstorms;
2. Adequate moisture must first be available or forecast to be available,
3. The LFM and its subset, the Trajectory Model, are accepted as being reasonably reliable for the first 24-hr projection, and the NGM for the first 12 hr.

The Steps of the MAGIC CHART Procedure

1. Call up AFOS chart 7WG, which is the 12-hr net vertical displacement, in millibars, for air that will arrive at the 700 mb level 24 hr after initial time. (This displacement is for the 12 to 24 hr time-period after initial time.)
2. Overlay AFOS chart 82T, which is the 12-hr 850-mb temperature prog from the NGM.
3. Where the greatest net vertical displacement (NVD) overlays the temperature region between −3°C and −5°C is where the heaviest snowfall is likely to occur using the following guidance for the time-period 12 to 24 hr after initial time:

NET 12-HOUR VERTICAL DISPLACEMENT	12-HOUR SNOWFALL
20 mb to 40 mb	2″ to 4″
40 mb	4″
60 mb	6″
80 mb	8″
100 mb	10″
120 mb	12″
140 mb	14″
>140 mb	>14″

4. The above procedure works with a mature or developing synoptic low-pressure system but only after determining that adequate moisture will be available for 12 to 24 hr after initial time for that region where the NVD overlays the −3°C to −5° C area. Adequate moisture means temperature-dew point spreads of no more than a few degrees at 850 mb and 700 mb, or a 1000-500 RH of about 90% or greater.

3. EXPLANATION OF FIGURES 1 AND 2:

The presentations overlay AFOS charts 7WG and 82T. Where the −3°C to −5°C temperature band overlays the highest NVD band, is where the heaviest snowfall is predicted for that 12-hr period.

In Figure 1, the −3° to −5°C temperature zone that lies within the +040 isoline of NVD is the area where about 4 in. of snowfall can be expected in the 12-hr period from 0000 to 1200 GMT Wednesday, February 10, 1988. Warmer temperatures lead to a snow/rain transition zone and then to rain; therefore, −3°C is the warmest allowable temperature in this forecasting scheme. Colder temperatures than −5°C lower the amount of moisture (saturation mixing ratio) the air can hold; therefore, the same NVD would yield a lower snowfall

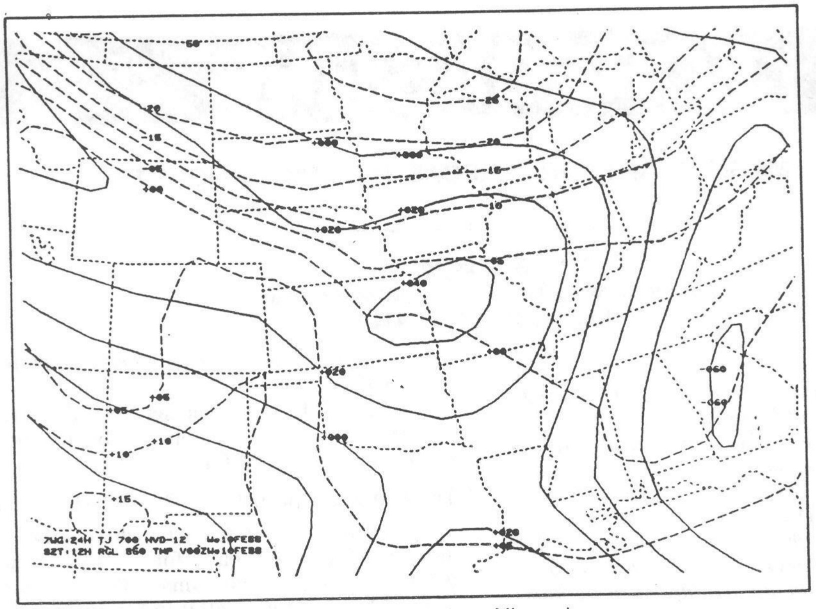

Fig. 1. Two to four in. snowfall forecast for northern Missouri.

amount. In this case, 4 in. was the representative snowfall over northern Missouri during this time period.

In Figure 2, the $-3°$ to $-5°C$ temperature band overlays an essentially $+120$ to $+140$ mb 12-hr net vertical displacement for air that will be at 700 mb 24 hr after the initial time. In this case, 12 in. to 14 in. of snowfall can be predicted for central Illinois during the 12-hr period of 0000 to 1200 GMT Tuesday, December 15, 1987. The actual snowfall during this period for the region was about 13 in. This particular storm was followed from the Plains to the Northeast, employing the magic chart technique. For example, in the prior 12-hr period, the $-3°$ to $-5°C$ area coincided with a $+120$ area over northern Missouri. Thus, 12 in. of snowfall was predicted. The observed snow amounts that fell were from 11 in. to 13 in.

Eight major synoptic storms were followed, using the magic chart to forecast snow amounts. There were several forecasts during the life-cycle of each of these storms. The magic chart was successful in 100% of these cases. This author believes that some of this was due to nothing more than luck. When the magic chart fails, which it undoubtedly will in some cases, the reasons why must be determined. In all of the storms in 1987–88 for which the magic chart approach was used, the LFM and NGM were reliable for the 12- and 24-hr forecasts.

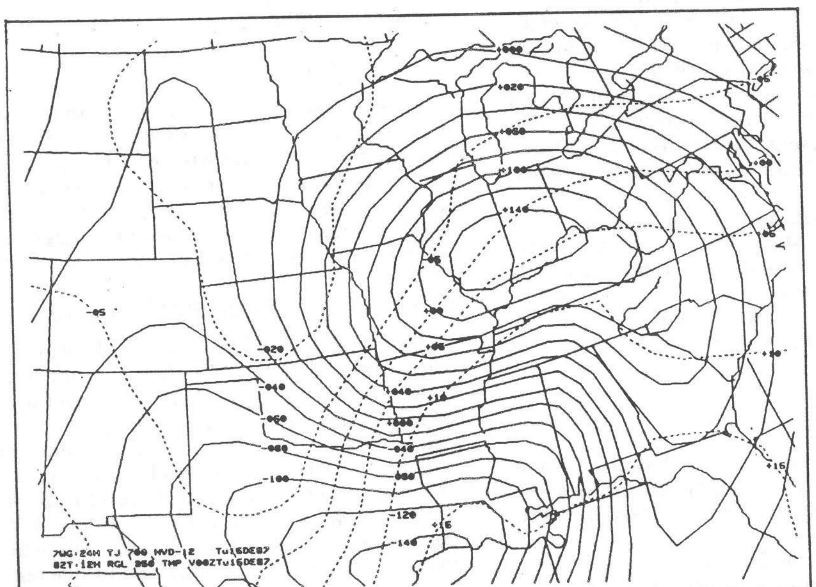

Fig. 2. Twelve to fourteen in. snowfall forecast for central Illinois.

If a model does not have an acceptable diagnosis and prognosis of the weather, then obviously the magic chart cannot be used. The forecaster needs to determine the level of competence of the models' forecasts—sometimes not an easy task.

The meteorological rationale for the magic chart approach needs to be explained, because the technique appears to work exceptionally well, even though it has been applied in this way for only one snow season.

4. METEOROLOGICAL REASONING

This can best be described by a question and answer format:

Question: This method is questionable. Isn't it just another rule-of-thumb scheme?

Response: Try it for a couple of winters to assess it yourself. It works for the area between the Rockies and the East Coast. For the Western Region, a 700-mb temperature threshold seems appropriate and more research and case studies are needed to determine appropriate values. As with all rules-of-thumb, understand the physical reasoning behind it so that you know when to use it and when to suspect it. Also, this approach was presented in a recent talk in Fairbanks, Alaska, suggesting that the technique is not limited to the lower 48 states.

Question: What is the physical rationale for this procedure?

Response: For the heaviest snowfall in a developing or mature synoptic low-pressure system, we are looking for the highest available moisture amounts occurring simultaneously with the greatest synoptic-scale lifting, in a region where the temperature regime is sufficiently cold for snow.

The higher the temperature, the higher the saturation mixing ratio, at the same pressure. Therefore, we are analyzing for the highest moisture content occurring with the highest possible temperatures that are still cold enough for snow. Thus, the 850-mb temperature ribbon of −3°C to −5°C is the choice temperature zone because, if saturated through a deep layer, it would contain the highest volume of moisture (compared with lower temperatures in saturated air). The −3° to −5°C zone also is normally cold enough for snow.

We also want that area to coincide with the strongest synoptic-scale lifting; lifting implies low-level convergence. A strong lift implies strong low-level moisture convergence. If the air being lifted is moist, then the stronger the lift the greater the likelihood of higher amounts of precipitation.

Keep in mind that the temperature-dew point spread must be no more than a few degrees at both 850 and 700 mb before this procedure is useable.

Question: How did you equate the 700-mb NVD values with the snowfall amounts?

Response: This project began as an experiment with meteorological interns doing daily forecasting exercises in the Forecaster Development Course at the weather service's in-house training academy. We noticed that within the −3°C to −5°C band, the heaviest snowfall amounts occurred with the strongest NVDs. During the 1987–88 snow-season, we followed eight major synoptic storms that fit the conditions described earlier for using this method. In each of these storms, two to four 12-hr periods were followed and forecasts made. To our amazement, the technique worked in every forecast episode, for forecasting where the heaviest snow would fall in that 12-hr period as well as accurate amounts. It is a rather nice coincidence that the snowfall amounts correspond to the NVD amounts (e.g., 60 mb relates to 6 in. of snowfall, 80 mb relates to 8 in. etc). For NVDs above 120 mb, it is preferable to forecast "in excess of 12 in." rather than try to pinpoint the value precisely.

Question: The magic chart as herein proposed uses output from the trajectory model but the temperature prognostication from the NGM. Is it not inconsistent to use the NGM rather than the LFM, because the trajectory model is essentially a 3-layer subset of the LFM?

Response: At first impression, it would seem logical to overlay the trajectory model's NVD with the LFM temperature prog. However, in doing this, we found that the forecast snow amounts were slightly displaced, whereas the NGM's temperature forecast had greater accuracy. In dealing with a 12-hr 850-mb temperature forecast, it is true that most of the time the LFM and NGM forecasts should be essentially identical. However, with a large-scale low-pressure system typically undergoing major development, the 12-hr NGM apparently does a better job at delineating the thermal field in the area of that system, compared with the LFM's performance.

Question: What caveats should be kept in mind when using the magic chart?

Response: The magic chart works only when the moisture in the area of concern is forecast to be deep; thus, temperature-dew point depressions through 700 mb should ideally be no more than about 3°C. Moreover, the magic chart is used only for large-scale low-pressure systems and does not include local effects such as orographic, frictional convergence, and lake effect.

Keep in mind, also, that the NGM is still being modified and tweeked, whereas the LFM is not being changed because the MOS equations are based on the LFM. However, it is inconceivable that any good modification of the NGM would harm the 12-hour 850-mb temperature prog.

Finally, the magic chart works only when the 12–24 hr 700-mb NVD prog from the trajectory model is accurate and when the 12-hour NGM 850-mb temperature prog is accurate. If you suspect a forecast problem with either model, do not use the magic chart.

5. RECOMMENDATIONS

Try the magic chart for forecasting the area of greatest snowfall potential, and experiment with forecasting the amounts. It would be prudent not to base official snowfall projections on this procedure unless the magic chart works for your area and the staff knows when to use it.

More seasons of verification are necessary to uphold or dispute the conclusions of the original findings. Moreover, Western mountainous areas would need a scheme developed based on 700-mb temperature forecasts, rather than on 850 mb. Therefore, we need many more case studies to fully substantiate this approach.

NOTES AND REFERENCES

1. Peter R. Chaston is in charge of the Meteorology Program at the NWS Training Center in Kansas City. Previously he was the Meteorologist-in-Charge at the NWS Office at Rochester, NY, and has been stationed at various other NWS offices in the Eastern Region. Chaston received his M.S. in Meteorology from the University of Wisconsin while on a NOAA Fellowship. He is current President of the Kansas City Chapter of the AMS.

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