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ASSIMILATION OF SURFACE, UPPER AIR, AND GRID-POINT DATA IN THE OBJECTIVE ANALYSIS PROCEDURE FOR A THREE-DIMENSIONAL TRAJECTORY MODEL

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Systems Development Office
Silver Spring, Md.
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UNITED STATES DEPARTMENT OF COMMERCE
Elliot L. Richardson, Secretary

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ABSTRACT. The objective analysis procedure for the Techniques Development Laboratory (TDL) three-dimensional trajectory model was modified to include surface land and ship reports and initialized grid-point values from the National Meteorological Center (NMC) six-layer primitive equation (PE) model. In the new analysis procedure, upper air and PE data are assigned relative weights by means of a unique function which measures the asymmetry of the radiosonde station distribution at the initial position for each trajectory. As a result, weights applied to the upper air data are diminished with increasing station asymmetry. Conversely, weights assigned to the PE data are increased. In effect, we use PE data which contains continuity from previous forecasts to supplement the radiosonde observations in regions where such data are sparse, missing, or irregularly spaced.

The lapse-rate and decision-tree methods are used to assimilate surface data into the analysis procedure. In the first method, radiosonde lapse-rates are interpolated to each surface station and applied to the surface report, yielding values of temperature and moisture aloft. The decision-tree method uses reliable statistical relationships between upper-level moisture and surface observed variables to estimate the dew-point spread at selected pressure levels aloft.

A total of 25 test forecasts were made to evaluate the effect of the new analysis procedure on subsequent model forecasts. The most significant improvements were obtained for the dew-point forecasts at 850 mb and 700 mb, resulting from the use of decision-tree information. The new analysis procedure has been run operationally since December 1974.

1. INTRODUCTION

Twenty-four hr forecasts of temperature, dew point, and 12-hr net vertical displacement from TDL's trajectory model (Reap 1972) are currently transmitted over National Weather Service facsimile and teletype circuits. The underlying feature of the forecast model involves the computation of three-dimensional air parcel trajectories from operational wind forecasts generated by NMC's six-layer primitive equation (PE) model (Shuman and Hovermale 1968). Detailed forecasts of temperature and moisture are subsequently derived by computing the six-hourly variations of potential temperature and mixing ratio for air parcels assumed to follow paths defined by the trajectories.

The analysis scheme in the model was designed to provide values of temperature and dew point at discrete points corresponding to the initial upwind positions, or origin points, for air parcels moving along the 24-hr prognostic trajectories. In earlier versions of the model, upper air observations constituted the sole data input to the objective analysis procedure. As a consequence, the quality of the initial analyses varied significantly in response to local variations in the station spacing and distribution. For example, the sparse upper air data over oceanic regions resulted in analyses which, to varying degrees, did not accurately depict the small-scale patterns and horizontal gradients often associated with low-level temperature and moisture distributions. The purpose of this report is to describe a consistent method for supplementing the upper air data with surface land and ship reports and initial grid-point values from NMC's full-mesh PE model. The method is also general enough to permit the addition of new data types (e.g., satellite observations), as they become available. The new analysis procedure has been run operationally since December 1974.

2. COMBINING UPPER AIR AND PE DATA

Procedures for combining upper air and PE data during the initialization process are now described. First, upper air observations and PE grid-point values are extracted from the current NMC data base stored on the IBM 360/195 computer. The upper air soundings are reproduced by consecutive ordering of the temperatures and dew points for mandatory and significant levels. Given the position of the trajectory origin point (OP), the five closest radiosonde stations are located. The temperature and dew point for each observation are subsequently obtained by linear interpolation between mandatory and/or significant-level data points which are vertically adjacent to the OP level. The temperature lapse rate between the selected data points is error-checked to eliminate any observations indicating superadiabatic lapse rates or unrealistically large inversions. Temperature and dew-point values from the PE initialized grid-point data are obtained by a three-dimensional interpolation into the 00-hr fields at the coordinates of the OP.

The problem subsequently arises of assigning relative weights to the upper air and PE data in the final fitting process, where the analyzed values are obtained by fitting a first-degree polynomial, or plane surface, to the data by the method of least squares. A decision was made to assign weights to both upper air and PE data on the basis of the radiosonde station distri-

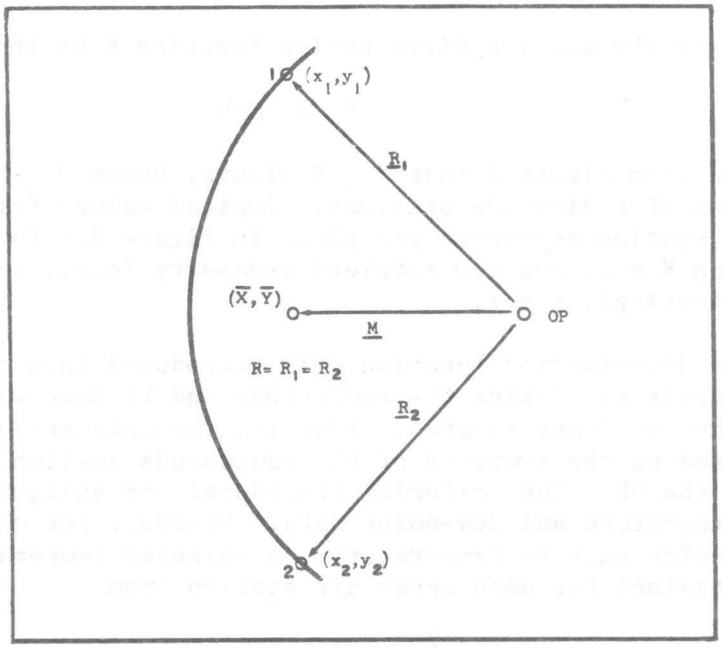

Fig. 1.--Diagram of position vectors $\underline{R_i}$ and $\underline{M}$ with radiosonde stations lying along a circle with center at the parcel origin point.

bution, which is highly variable near coastlines and in regions where reports are missing. To accomplish this, a simple function was derived to objectively measure the asymmetry of the station distribution in the vicinity of the OP.

First, the centroid coordinates $\bar{X},\bar{Y}$ for the five stations closest to the OP are computed by summing moments about each coordinate axis and dividing by the summed weights; that is

$$\bar{X} = \left(\sum_{i=1}^{n} X_i W_i\right) / \sum_{i=1}^{n} W_i, \qquad \bar{Y} = \left(\sum_{i=1}^{n} Y_i W_i\right) / \sum_{i=1}^{n} W_i \tag{1}$$

where X_i and Y_i are the station coordinates and W_i is the weighting function (see eq 7) used in the least squares fit. We now define a position vector $\underline{M}$ from the OP to $\bar{X},\bar{Y}$ (see fig. 1) whose magnitude is given by

$$M = [(\bar{X} - X_{OP})^2 + (\bar{Y} - Y_{OP})^2]^{1/2} \tag{2}$$

where X_{OP}, Y_{OP} are the horizontal coordinates of the OP. We also define a position vector $\underline{R_i}$ from the OP to each upper air station, whose magnitude is given by

$$R_i = [(X_i - X_{OP})^2 + (Y_i - Y_{OP})^2]^{1/2} \tag{3}$$

The average distance R is then

$$R = \frac{1}{n} \sum_{i=1}^{n} R_i \tag{4}$$

We now define the station distribution function K by the ratio

$$K = M/R \tag{5}$$

It is clear from figure 1 that $R \geq M$ always, hence $0 \leq K \leq 1$ for any given distribution of radiosonde stations. Typical values for K as a function of increasing station asymmetry are shown in figure 2. For a completely uniform distribution K = 0, and for complete asymmetry (e.g., only one radiosonde station reporting), K = 1.

The station distribution function K is introduced into the objective analysis procedure prior to fitting the radiosonde and PE data with a plane surface by the method of least squares. That is, the data are assigned relative weights based on the symmetry of the radiosonde station distribution with respect to the OP. The following procedures for assigning weights are applied to both temperature and dew-point data. However, for convenience, the discussion will refer only to temperature. A weighted temperature T_R at the OP level is obtained for each upper air station from

$$T_R = (1 - K)\, W_r\, T_r \tag{6}$$

where T_r is the observed temperature and

$$W_r = C^2 \left[(R_i + R^*)^2 + C \right]^{-1} \tag{7}$$

is a distance weighting factor introduced prior to the fitting process to avoid excessive smoothing (Endlich and Mancuso 1968). C^2 is a constant and R^* is a distance factor given by the magnitude of $\underline{k} \cdot \underline{R}_i x\ (\underline{V}/V)$ and computed as

$$R^* = (vx - uy)/\ (u^2 + v^2)^{1/2}\ ;\ R_i \geq R^* \geq 0 \tag{8}$$

where u and v are wind components interpolated to the observation and x and y are the scalar components of $\underline{R}$. The distance factor (R^*) is used to give upwind-downwind observations greater weight than crosswind observations. Isolines of the analyzed scalar are more closely aligned with the low-level flow as a result of this correction. The weighting function given by eq (7) is designed to reproduce detailed patterns and gradients with only light smoothing of the observations.

A weighted temperature T_P is computed for the PE data from

$$T_P = (K + B)\, T_{PE} \tag{9}$$

where T_{PE} is the initialized temperature at the OP from the PE model and B is a constant determined by experiment. The distance weighting factor W_r is not included in eq (9) because the PE data are interpolated directly to the OP. From eq (6) we see that the weights applied to the radiosonde data diminish with increasing station asymmetry. Conversely, the weights assigned to the PE data increase. In essence, the PE initialized data serve to supplement the radiosonde data only in those instances where the trajectory model

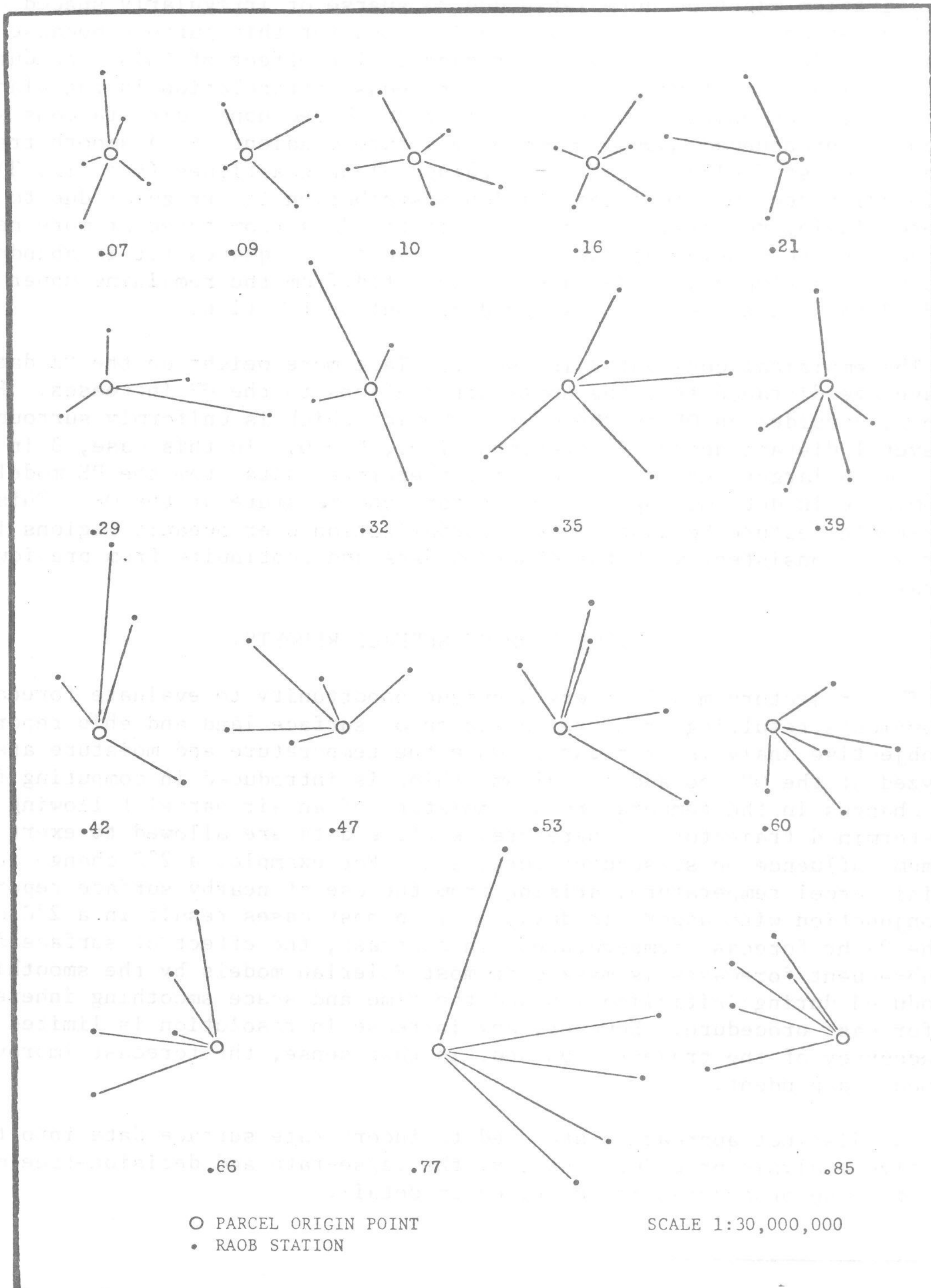

Figure 2.--Typical values of the distribution function K with increasing asymmetry in the radiosonde station distribution.

initialization might be unreliable due to sparse or irregularly spaced upper air observations. The PE data are well suited for this purpose because they contain continuity from previous forecasts. The effect of this procedure is to eliminate any tendency towards erroneous extrapolation in the plane surface fit when using data from poorly distributed upper air stations in regions of pronounced temperature or moisture gradients.* A smooth transition in the forecast fields is thereby obtained along coastlines (see fig. 3), and for interior regions where the station distribution is irregular due to one or more missing reports. In addition, if the data from three or more nearby radiosondes are missing at the OP level, the least squares fit is abandoned in favor of a simple weighted average computed from the remaining upper air and PE data, again with the station distribution function.

The empirical constant B is used to place more weight on the PE data as the average distance from the upper air stations to the OP increases. For example, consider an OP in the Gulf of Mexico which is uniformly surrounded by several distant upper air stations, i.e., $K \rightarrow 0$. In this case, B in eq (9) is much larger than W_r in eq (6); therefore, data from the PE model would predominate in determining the temperature and moisture at the OP. This is a desirable feature because the PE initialization over oceanic regions is internally consistent with the observed data and continuity from previous forecasts.

3. INCLUSION OF SURFACE REPORTS

The trajectory model offers a unique opportunity to evaluate forecast improvements resulting from the inclusion of surface land and ship reports in the objective analysis procedure. Once the temperature and moisture are analyzed at the OP, no additional smoothing is introduced in computing forecast changes in the temperature and moisture of an air parcel following a predetermined trajectory. Therefore, surface data are allowed to exert a maximum influence on subsequent forecasts. For example, a 2°C change in the initial parcel temperature, arising from the use of nearby surface reports in conjunction with upper air data, will in most cases result in a 2°C change in the 24-hr forecast temperature. In contrast, the effect of surface data on subsequent forecasts is masked in most Eulerian models by the smoothing introduced during initialization and the time and space smoothing inherent in the forecast procedure. However, any increase in resolution is limited by the accuracy of the trajectories and, in that sense, the forecast improvements are model dependent.

Two distinct approaches are used to incorporate surface data into the objective analysis procedure; namely, the lapse-rate and decision-tree methods. Each of these procedures is described in detail.

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*Experimental results indicate that when $K > 0.4$, as shown in figure 2, the radiosonde stations tend to lie to one side of the OP. Therefore, analyzed values at the OP would be obtained by an extrapolation process when only radiosonde data are used.

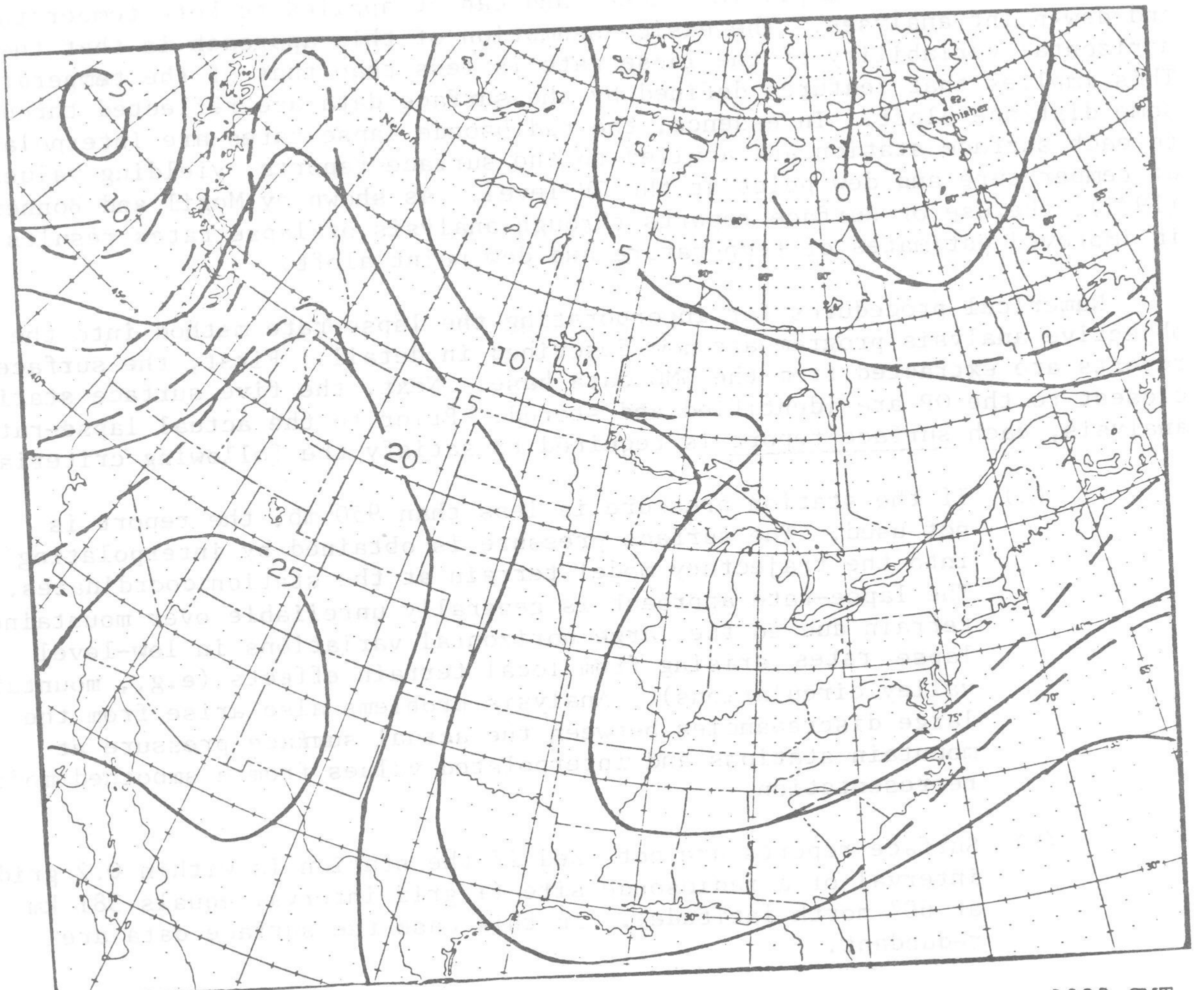

Figure 3.--24-hr temperature forecast for 850 mb verifying at 0000 GMT on July 7, 1972. Forecast made with radiosonde data only is shown by solid lines. Changes in the forecast arising from the use of PE grid-point data in the initialization procedure are shown by dashed lines.

A. Lapse-Rate Method

This method is simple in concept and can be applied to both temperature and dew-point analyses. The basic assumption of this approach is that the horizontal variability of the lapse rate is less than that of the temperature. This implies that features defined by the surface data are reflected through some distance aloft. In essence, the radiosonde lapse rates are interpolated to each surface station and applied to the surface reports, yielding values of temperature and dew point at the OP level. As shown by Mogil and Bonner (1971), the use of surface reports through analysis of lapse rates results in improved estimates of temperature and dew point aloft.

Numerical procedures for incorporating the lapse-rate method into the objective analysis program are now described in detail. First, the reports are extracted from the NMC data base. Next, the five surface stations closest to the OP are identified and stored. Prior to the actual lapse-rate analysis, each surface report is required to satisfy the following criteria:

(a) If the station pressure is less than 950 mb, the report is not used. The surface pressure is obtained by interpolating into the trajectory model terrain at the station coordinates. The lapse-rate approach is generally unreliable over mountainous terrain due to the large horizontal variations in low-level lapse rates arising from local terrain effects (e.g., mountain-valley circulations). Analysis problems also arise from the large discrepancies between the actual surface pressure at mountain stations and interpolated values from a smoothed model representation.

(b) Surface reports are not used if the station is within 0.2 grid interval of a radiosonde site (1 grid interval equals 381 km at 60° north latitude). In this case the surface data are redundant.

(c) Each surface report is error-checked by comparing the observed values to those obtained by interpolation into the PE initialized fields at the coordinates of the surface station. Temperatures and dew points which differ from the PE values by more than 7°C and 10°C, respectively, are eliminated. These error tolerances were determined by experiment.

Defining ΔP as the pressure increment (mb) from the surface to the OP at each radiosonde station, the following additional constraints on temperature lapse rates were developed by experiment and applied to each upper air report:

(a) For $\Delta P \leq 10$, it was found that lapse-rate computations for shallow surface layers less than 10 mb in depth did not yield reasonable spatial patterns due to the large variability in temperature and dew-point profiles near the surface. Therefore, surface temperatures and dew points are used directly if the OP is within 10 mb of the surface.

(b) For $10 < \Delta P \leq 25$, a gross error check is performed to insure that the lapse rate through the increment ΔP does not exceed $\pm$ 0.25°C/mb.

(c) For $25 < \Delta P \leq 50$, an upper air report is not used if the lapse rate through ΔP exceeds -0.125°C/mb; that is, slightly greater than superadiabatic.

(d) For $\Delta P > 50$, a report is not used if the lapse rate is superadiabatic or if it represents an unusually large inversion; that is, it exceeds $\pm$ 0.125°C/mb.

In effect, the preceeding constraints become more stringent as the depth of the layer increases. No attempt was made to develop similar constraints for dew-point lapse rates due to the wide variety of possible profiles. In addition, the lapse-rate analysis is not performed if two or more nearby radiosonde reports are missing data at the OP level, i.e., an adequate resolution of the lapse-rate field is not possible due to a lack of sufficient upper air data.

It was necessary to devise an alternate lapse-rate procedure to include surface land and ship reports for cases where $R > 600$ km. The mean distance from the radiosonde stations to the OP is too great in such cases to accurately specify the structure of the low-level lapse rates for surface stations or ships located near the OP. With this additional restriction, the region over the Continental United States where lapse-rate analyses are made is confined to the shaded area shown in figure 4. The western boundary of this area is given by the 950-mb constant pressure isopleth.

In essence, the alternate procedure consists of assigning fixed values to the lapse rates; that is, the dry adiabatic value is used over water (see Roll 1965, p. 290) and the standard atmosphere value is used over land. Dew-point lapse rates are determined by assuming a constant dew-point depression over land and a constant mixing ratio over water (see Roll 1965). Errors arising from the fixed lapse rates are acceptable considering the simple fact that when $R > 600$ km, the land stations or ships are much closer to the OP than the distant radiosonde stations. In addition, this procedure will primarily affect the initial analysis for parcels following trajectories near the surface; therefore, very little vertical extrapolation will be required using the fixed lapse rates. In any case, vertical extrapolation is not extended beyond the lowest 50 mb of the atmosphere.

In the actual lapse-rate analysis, the radiosonde lapse-rates are interpolated to each surface station and applied to the surface reports, yielding values of temperature and dew point at the OP level. At this point in the analysis procedure, unrepresentative radiosonde lapse-rate data and erroneous, missing, or redundant surface data have been eliminated. During initial tests, lapse rates at the surface stations were obtained by fitting a plane surface to the radiosonde lapse-rate data by the method of least squares. However, instabilities developed in the plane surface fit for cases with highly variable low-level lapse-rates and irregular station distributions. A practical solution to the

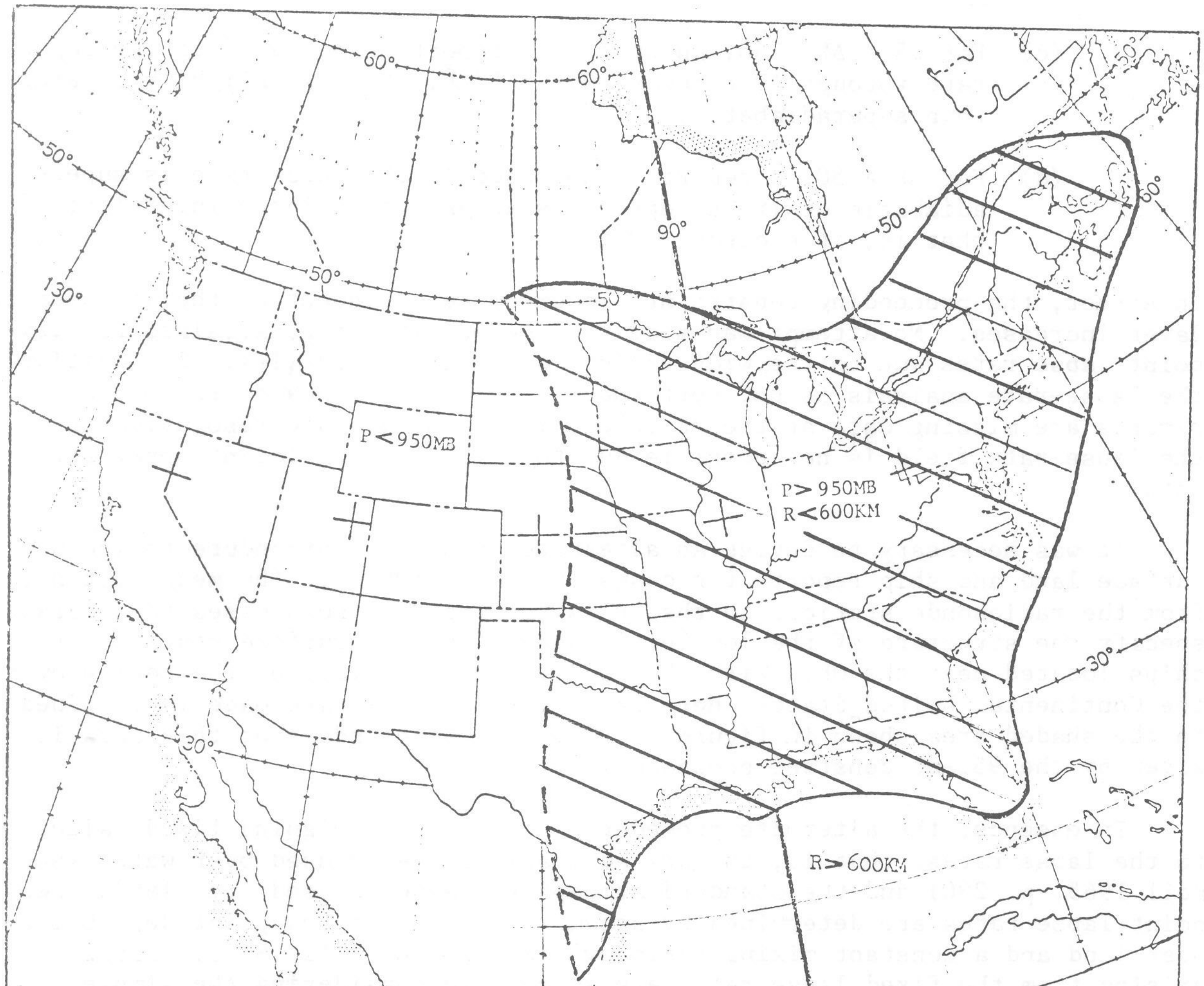

Figure 4.--Lapse-rate method is performed in shaded region bounded by the 950-mb constant pressure isopleth (dashed) from the model terrain and by the solid line bounding the region where R < 600 km.

stability problem was obtained by abandoning the plane surface fit and applying the weighting function given by eq (7) to the radiosonde lapse rates forming a simple five-station weighted average at each surface station. For this application, R* in eq (7) was set to zero. This interpolation procedure is quite stable and gives reasonable results, although it may at times fail to capture all exising detail in the low-level lapse-rate field. As noted by Bergthórssen and Döös (1955), any interpolation method, independent of whether it is linear, quadratic, or cubic, is subject to severe limitations in cases where the distance between the radiosonde stations is large compared with the size of the (lapse-rate) patterns to be analyzed.

Having estimated the temperature and dew point at the OP level for the five surface stations closest to the OP, the next step in the analysis procedure is to assign weights to these data prior to the final fitting process, where all available data are combined. As shown by Mogil and Bonner (1971), improvements in the analyses through use of surface data were restricted to the lowest 100 mb of the troposphere. This was expected because the correlation between a surface-observed variable and its value aloft decreases rapidly with height. In this study, weights on the inferred data were decreased linearly with height from a value of 1 at the surface to 0 at 100 mb above the surface by use of the simple factor $(1-\Delta P/100)$, where ΔP is the pressure difference (mb) between the surface and the OP level. In a sense, the factor $(1-\Delta P/100)$ acts as a reliability measure. That is, the surface data are weighted equally with the radiosonde observations when the parcel OP is near the surface, thus introducing desired detail into the analysis. When the parcel OP is some distance above the surface, the quality of the data inferred from surface observations decreases, therefore, weights on these data are correspondingly reduced.

As shown by Mogil and Bonner (1971), and Steyaert and Darkow (1973), the time of day is also significant. In general, it appears that improved analyses can be obtained with lapse-rate techniques only during that portion of the day when surface and lower tropospheric variables are highly correlated as a result of vertical mixing. Therefore, in the present study, the lapse-rate technique was applied only to the 0000 GMT data.

The station distribution function K was also introduced into the weighting function for surface data on the premise that a highly asymmetric distribution of radiosonde stations in the vicinity of the OP can lead to a faulty lapse-rate analysis resulting in poor estimates of temperature and dew point at the OP level. Therefore, weights on the data inferred from surface observations are reduced in accordance with the factor (1-K). This factor is identical to that used in weighting the radiosonde observations, as given by eq (6).

The weighted temperature T_S at the OP level is then obtained for each surface station from

$$T_S = (1 - K)\ (1 - \Delta P/100)\ W_r T_s \qquad (10)$$

where T_S is the inferred temperature obtained from the lapse-rate analysis and W_r is the distance weighting function given by eq (7). Weighted dew points are similarly obtained.

As given by eq (10), maximum weight is placed on T_S when the radiosonde station distribution is uniform ($K \rightarrow 0$), and when the parcel OP is at or near the surface ($\Delta P \rightarrow 0$). When K = 0 at the surface, eq (10) reduces to

$$T_S \simeq W_r T_S \tag{11}$$

B. Decision-Tree Method

The decision-tree method developed by Chisholm et al. (1968) consists of obtaining reliable statistical relationships between upper-level moisture and surface-observed variables. The inferred data are then combined with other available data to provide the best possible upper-level moisture analysis. In essence, the decision-tree method determines the combination of surface-observed variables that yields the greatest number of reliable estimates of moisture at specific pressure levels. For example, the sequence of variables producing the greatest number of reliable moisture estimates at 850 mb was given by the present weather type, low cloud type, low cloud amount and past weather type. At 700 mb, the decision-tree contained the present weather type, low cloud type, past weather type, and middle cloud amount.

After additional testing, it was decided to use only the highly reliable first branch of the 850-mb and 700-mb decision-trees; that is, the present weather type. For example, at 850 mb this branch assigns a dew-point spread of 2°C to 3°C if precipitation, in the form of drizzle, rain or snow, is falling continuously or in showers. Similar results are obtained at 700 mb. Note that only moist diagnoses are possible with this approach.

Problems arise in applying this method because the inferred data are available only at specific pressure levels; that is 850 mb and 700 mb. Obviously, these data cannot be extrapolated to determine the moisture content of a parcel located at some arbitrary pressure level and horizontal distance from the surface stations. Lacking a direct means for incorporating the decision-tree information into the OP moisture analysis, we decided to use the inferred data to improve the PE grid-point data. That is, the influence of the decision-tree data was allowed to operate through the weighted PE dew points. This procedure should provide a more reliable analysis, especially in regions of high moisture content. Following is the procedure for modifying the PE dew-point data.

First, temperatures and dew points at the 1000-, 850-, 700-, 500-, and 300-mb levels are obtained at the horizontal coordinates of the OP by means of bi-linear interpolation from the PE grid-point data. Temperatures and dew points are similarly obtained at the 850-mb and 700-mb levels for the seven surface stations closest to the OP. Next, the PE temperatures and dew points are converted to dew-point spreads. Corrections to the 850-mb and 700-mb PE dew-point spreads at the OP by the inferred dew-point spreads at the same levels for the nearby surface stations are computed from

$$CP = \sum_{r=1}^{7} W_r D_r \Big/ \sum_{r=1}^{7} W_r \qquad (12)$$

where CP is the correction to be applied, W_r is the distance weighting factor given by eq (7), and D_r is the deviation between the diagnosed dew-point spread and the PE dew-point spread at the location of the surface stations. The total correction is obtained from a single scan or pass through the data. A corrected dew-point spread (DS_{cor}) is then obtained from

$$DS_{cor} = DS - CP \qquad (13)$$

where DS is the original, or unmodified dew-point spread. Corrections are only applied at the 850-mb and 700-mb levels, where decision-tree data are available. Modified dew points are then extracted from the temperature and corrected dew-point spread at the 850-mb and 700-mb levels. Examples of modified dew-point profiles are shown in figure 5.

A weighted dew point D_P at the OP is then given by

$$D_P = (K + B + CP/DS)\ D_{PE} \qquad (14)$$

where D_{PE} is the dew point at the OP obtained by linear interpolation into the modified dew-point profile. Equation (14) is similar to eq (9), except for the additional factor CP/DS. This ratio was introduced to assign weights to the modified PE dew points on the basis of the percentage change, or decrease, between the corrected and original dew-point spread. For example, suppose we have a "dry" PE moisture analysis at the OP relative to a "moist" dew-point spread of 2°C to 3°C diagnosed from the surface reports. In this case, the surface data introduce new information into the analysis and should be weighted more heavily. From eq (12), we see that the correction CP responds to the distance weighting factor W_r and the deviation D_r. Therefore, for the factor CP/DS to exert maximum influence, the surface stations must be located fairly close to the OP and the difference between the PE and diagnosed moisture values must be large. If, on the other hand, both the PE and surface data indicate a relatively "moist" condition at the OP, the surface data are redundant and are weighted mainly by the station distribution function K in eq (14).

The final step in the analysis procedure is accomplished by fitting the radiosonde observations, PE grid-point data, and data inferred from surface observations with a first-degree polynomial, or plane surface, by the method of least squares. The least squares sums are formed from the weighted temperatures given by eq (6), (9), and (10); that is,

$$T_R = (1 - K)\ W_r T_r$$

$$T_P = (K + B)\ T_{PE}$$

$$T_S = (1 - K)\ (1 - \Delta P/100)\ W_r T_S$$

Least squares sums are similarly formed from the weighted dew points given by eq (14) and equations identical in form to those shown above.

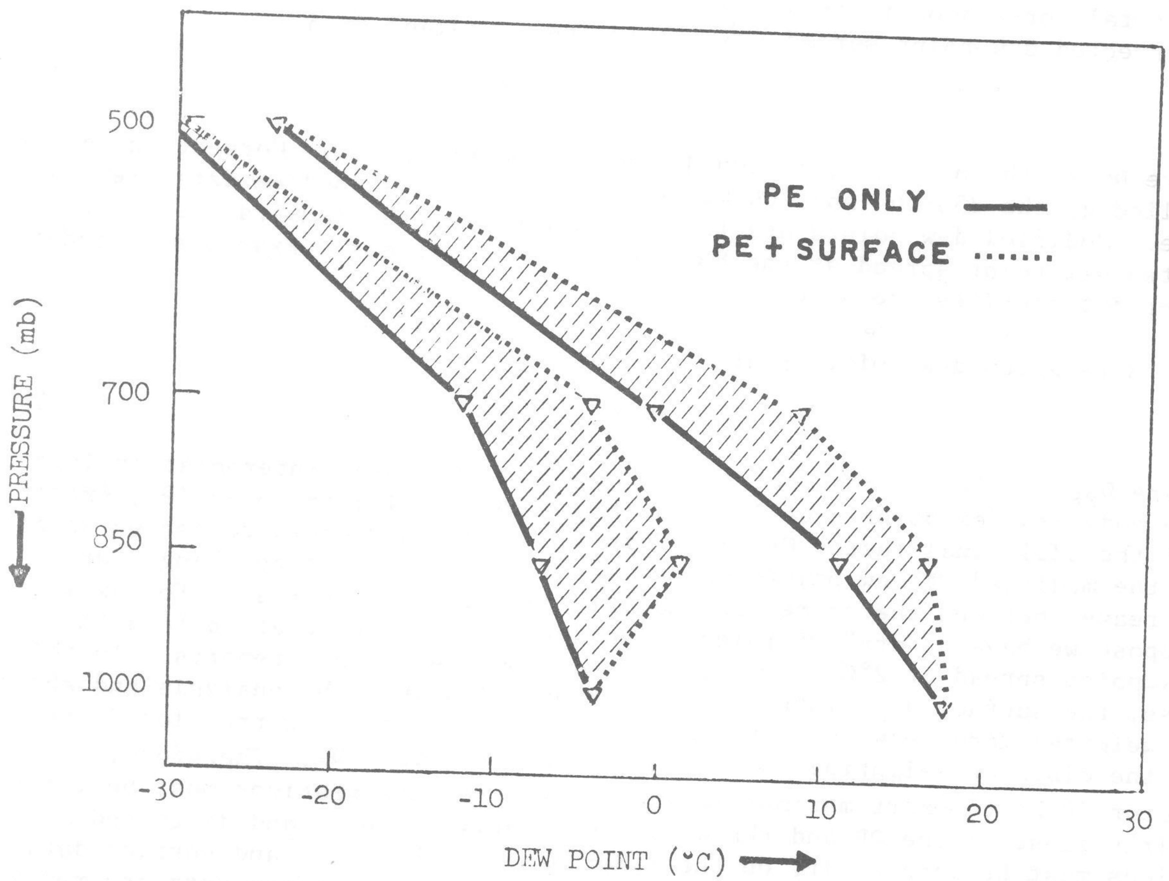

Figure 5.--Sample PE dew-point profiles (solid lines) obtained by interpolation into the PE grid-point data at the horizontal coordinates of the parcel OP. The modified profiles (dashed lines) were obtained by correcting the PE profiles at 850 mb and 700 mb with decision-tree data generated from surface observations.

In summary, we see that the available data are weighted according to their relative accuracy and their distribution with respect to the parcel origin point. For example, weights applied to the radiosonde data diminish with increasing station asymmetry while weights assigned to the PE data increase. Weights on the data inferred from surface observations, obtained through lapse-rate analysis, respond to the distribution of the upper air stations as well as the height of the parcel OP above ground. Weights on the moisture data inferred from the decision-tree approach respond to the distribution of the surface stations and the difference between the PE and inferred moisture values. The net effect of this procedure is to selectively smooth the analyses where the upper air data are sparse or poorly distributed and, where warranted, to introduce into the analyses additional detail based on surface observations.

4. Verification

A total of 25 test forecasts were made to evaluate the effect of the modified initialization procedure on subsequent model forecasts. The runs were made during the winter period from January 25, 1973 to April 12, 1973. Verification was accomplished by comparing the 24-hr temperature and dew-point forecasts at the surface, 850 mb, and 700 mb with radiosonde data for the shaded region shown in figure 4. Forecast soundings at individual radiosonde stations were constructed from the grid-point forecasts by means of bilinear interpolation. Error field statistics compiled by the verification program include the root-mean-square-error (RMSE) and mean algebraic error (MALG) between forecast and observed values.

Shown in table 1 are the verification statistics for the 24-hr temperature and dew-point forecasts verifying at 0000 GMT. The most significant reductions in the RMSE were obtained for dew-point forecasts at 850 mb and 700 mb, with decreases of 0.6°C and 0.3°C, respectively. Note also the corresponding reductions of 0.8°C and 0.9°C in the overall dry bias, as given by the MALG in table 1. These improvements resulted from the use of decision-tree information and PE grid-point data in the model initialization. The RMSE values in table 1 represent an average for all stations in the verification area shown in figure 4. However, in individual cases, most of the reduction in the RMSE was obtained from a fairly small number of grid points whose trajectories originated from areas of precipitation, where decision-tree information was generated and used to modify the initial PE dew-point profiles.

Results from the lapse-rate technique were disappointing in that no significant improvements were obtained in the surface temperature forecasts. The only noticeable difference at the surface was a reduction of 0.4°C in the dry bias for the dew-point forecasts. However, the corresponding RMSE was not significantly lowered. Although the modified objective analysis procedure yields better estimates of the initial temperature and dew-point distributions near the surface, it appears that these improvements were not carried forward over the course of the 24-hr test forecasts. This failure to significantly improve the surface temperature and dew-point forecasts most likely resulted from a lack of sufficient resolution in the prognostic trajectories near the surface, where complex flow patterns arise due to terrain variation, local circulations, movement of fronts or instability lines, etc. As noted in

Table 1.--Verification statistics for 25 test cases run during the period Jan. 25 - Apr. 12, 1973. All forecasts are valid at 0000 GMT. Asterisks denote significant improvements resulting from the use of surface reports and PE grid-point data in the model initialization.

Type of Fcst	Level	Root-Mean-Square Error (°C)		Mean Algebraic Error (°C)	
		Operational	Test	Operational	Test
24-Hr Temp	Surface	4.3	4.4	0.3	0.2
	850 MB	2.9	2.9	1.1	1.2
	700 MB	2.7	2.6	1.2	1.0
24-Hr Dew Pt.	Surface	4.8	4.7	-0.8	-0.4
	850 MB	7.1	6.5*	-1.2	-0.4*
	700 MB	7.5	7.2*	-1.4	-0.5*

the introduction, the surface trajectories are computed from smoothed wind forecasts generated by a large-scale prediction model. In essence, better forecasts of parcel trajectories may be required near the surface in order to take advantage of improved resolution in the model initialization.

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