# NOTES AND CORRESPONDENCE

# The Effect of Surface Observations on Low-Level Temperatures in the National Meteorological Center Regional Analysis Scheme

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## 1. Introduction

In a recent article, DiMego (1988) described the National Meteorological Center (NMC) regional optimum interpolation (ROI) scheme as it was run operationally from March 1985 through May 1986. Unlike NMC's global OI scheme, surface reports over land are included in the ROI. The use of corrections obtained from surface observations results in more detail in the low-level analyses. However, situations exist in which these surface corrections produce inaccurate analyses above the surface near 850 mb.

This report presents results of a diagnostic study focused on investigating the impact of the regional optimum interpolation (ROI) analyses on the short-term precipitation forecasts of the nested grid model (NGM, Hoke et al. 1989). It had been noted that the precipitation forecasts from the first 12-h forecast period of the NGM were persistently slow in developing organized regions of precipitation. One source of the precipitation forecast errors was traced to the use of inappropriate initialization procedures and has since been corrected (Carr et al. 1989). Another source of error has been traced to the Regional Analysis and Forecast System (RAFS) analyses, which at 0000 UTC can often treat observed low-level relative humidities inadequately. In this study, it was found that the relative humidity analyses can be adversely affected by the manner in which the temperature information from surface observations is distributed vertically in the RAFS height analyses. A modification to the procedure that uses the single level surface data is presented that improves the RAFS low-level analyses while making minimal changes to the operational ROI scheme.

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## 2. Background information

The adverse effects of misrepresenting the relative humidity analysis are clearly illustrated during a heavy precipitation event on 10–11 September 1986. At 0000 UTC on 11 September, the time period selected for this study, heavy precipitation was already occurring across central Michigan, which resulted in 24-hour amounts exceeding 25 cm. An examination of the analysis of relative humidity at 850 mb over Michigan, the area of low-level convergence, and across much of the Midwest, the area of south-southwesterly flow, revealed that the analyzed relative humidities were consistently drier than the observed radiosonde values (Fig. 1). Note that most values in excess of 90% in Minnesota, Wisconsin, Michigan, Illinois, Ohio, and Tennessee were analyzed as less than 85%.

To understand the source of this error, a brief review of the RAFS analysis procedures follows. The ROI scheme of the RAFS performs three-dimensional, multivariate analyses of the horizontal wind components and geopotential height on the 16 forecast model sigma layers and a univariate analysis of specific humidity on the 12 lowest sigma levels [see Hoke et al. (1989) for details on the vertical structure of the model]. Therefore, errors in the derived relative humidity fields can result from errors both in specific humidity analyses and in thicknesses (temperatures) derived from the level-to-level independent height analyses. Because the low-level specific humidity analyses were found to fit the observed data quite well, the underestimation of relative humidity was found to be primarily due to an overestimation of the derived temperature at levels above the surface.

DiMego (1988) provides a complete description of the RAFS ROI. Only details pertaining to surface observations will be reviewed here. In the multivariate

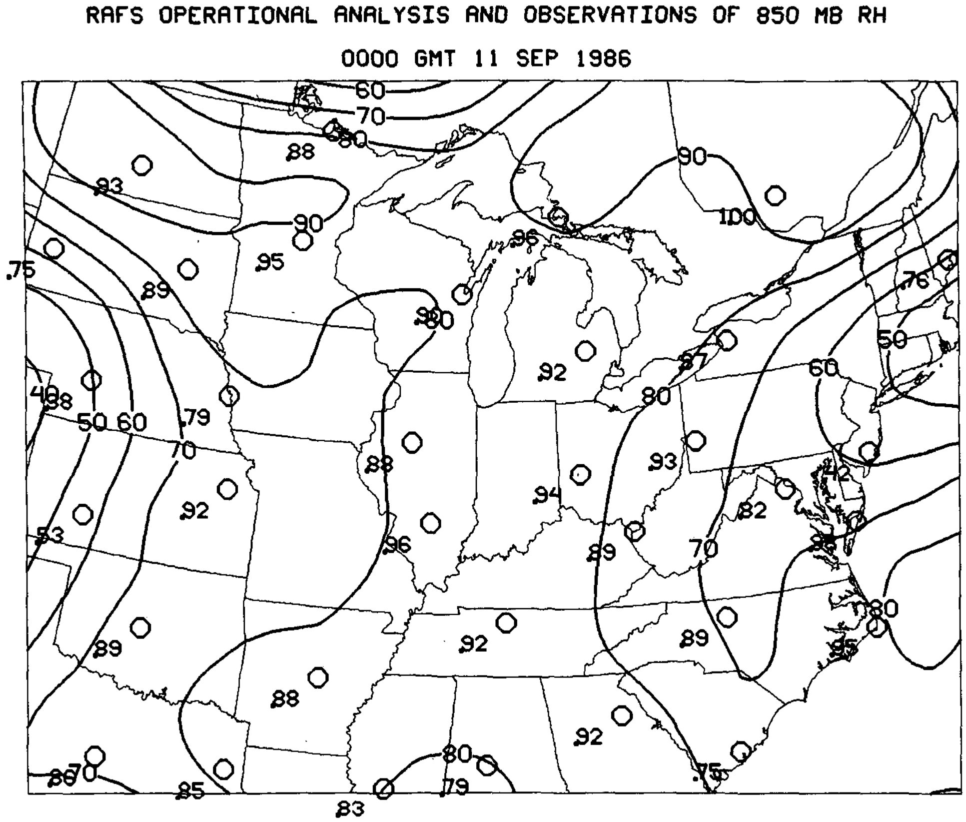


FIG. 1. Observed 850 mb radiosonde reports of relative humidity and ROI derived relative humidity field (%) for 0000 UTC 11 September 1986. Contours are shown at intervals of 10%.

analyses of height and horizontal wind, up to 30 observations can be used for each analysis point, with 20 allocated to be profile reports and the remaining allocated to be single-level reports. Surface reports selected for the first analysis level will be used for up to five subsequent analysis levels. At the time of this study, surface corrections of geopotential and temperature background fields were processed as follows. At the first sigma level, geopotential corrections were constructed from surface (station) pressure and station elevation and were used directly by the analysis. For the second level, the surface corrections were adjusted by interpreting the surface virtual temperature correction as a thickness correction valid over a 20 mb layer and computing a height correction at the top of the layer. At levels three and above, a depth of 40 mb was used. This procedure resulted in "mini-profiles," each consisting of a surface height correction and two extrapolated corrections separated by 20 mb.

The observation errors used in the analysis are considered to consist of two components. The first is the measurement error inherent in the instrument and the second is an error of representativeness, which is a function of the resolution of the analysis. At the time of this study, once the observation error was assigned to a surface correction, it remained constant at all analysis levels using the correction.

## 3. Experimental design and results

In this section, changes made to the ROI, the rationale behind them, and some results for 0000 UTC 11 September are presented. As mentioned previously, errors in the relative humidity field were primarily the result of an overestimation of the derived temperatures in the lowest levels. A comparison of the first-guess temperatures and the analyzed temperatures to the observations at 850 mb indicated that although the first guess was too warm over much of the Midwest, the analysis actually increased the temperatures.

The source of this temperature error must be traced through the analysis of heights at adjacent levels within the ROI scheme. Because temperature is not an analyzed variable, changes to the first-guess temperatures are inferred from differences in the changes of the height corrections between successive levels (i.e., thickness corrections). The analysis sequence can be viewed in more detail by examining the observed, first guess, and analysis soundings near Peoria, Illinois (Fig. 2). In regions of strong diurnal heating such as this,

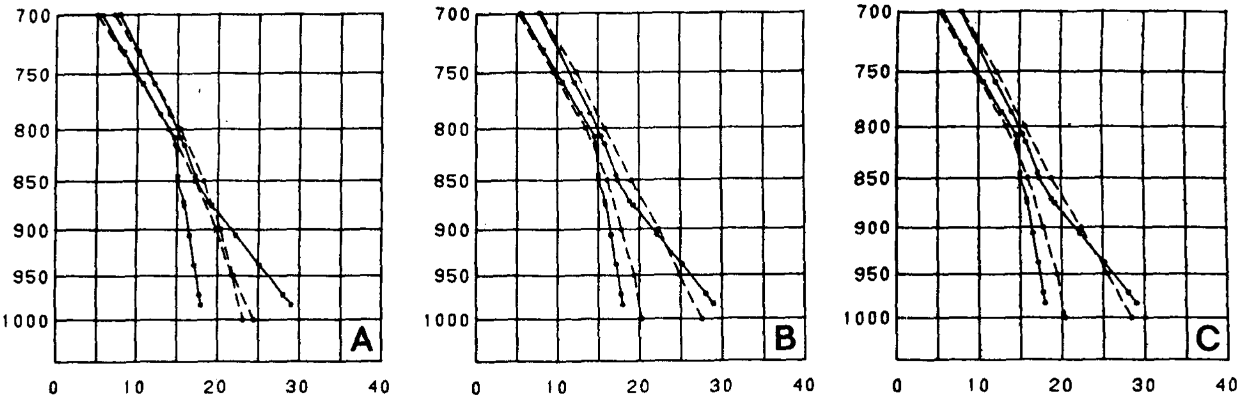


FIG. 2. Soundings of observed temperature and dewpoint temperature (C) for Peoria, Illinois at 0000 UTC 11 September 1986 (solid), with the same for (a) GDAS first guess (dashed), (b) operational ROI analysis (dashed), and (c) experimental analysis (dashed).

the first guess (which lacked a diurnal cycle at this time) is too cold at the surface (Fig. 2a) resulting in a large negative height correction. This is reflected in the analysis at the first level. The vertical correlation structure then dictates that the influence of the surface data decreases at each successive vertical analysis level. Therefore, if height corrections are largest at the surface, their magnitude becomes progressively less at higher levels through level 6. Analyzed height corrections and the relative contributions of the surface data from the operational analysis are shown in Table 1. The influence of the surface corrections results in an increase in thickness (and temperature) in the third and fourth sigma levels, as noted between 900 and 800 mb in Fig. 2b. In this case, the warming was detrimental because the large corrections, which were valid at the surface, were not appropriate aloft.

Several changes to the ROI were considered and reanalyses were completed using various combinations of these modifications. The forecast error correlation model was the first component of the analysis considered for modification since large height corrections at the surface were found to influence several of the lowest analysis levels. The vertical component of the function was sharpened when used with surface observations in an attempt to more rapidly reduce their influence with height. Although this achieved the desired effect of smaller corrections aloft, it adversely affected the matrix stability. The matrix remains more robust when changes are made only to the diagonal elements.

TABLE 1. Height corrections (m) for the operational ROI and the experimental reanalysis before smoothing and adiabatic adjustment for a point near Ft. Wayne, Indiana at 0000 UTC 11 September 1986. Percents in parentheses represent the contribution of the surface data to the corrections (see text).

| Analysis level | Pressure | Operational analysis | Experimental reanalysis |
|---|---|---|---|
| 7 | 676 mb | −24.8 | −25.7 |
| 6 | 741 mb | −26.8 (2%) | −27.1 (1%) |
| 5 | 801 mb | −27.4 (9%) | −25.0 (6%) |
| 4 | 856 mb | −23.4 (31%) | −20.5 (10%) |
| 3 | 905 mb | −29.8 (56%) | −22.9 (30%) |
| 2 | 947 mb | −33.4 (58%) | −31.5 (49%) |
| 1 | 983 mb | −36.4 (53%) | −36.9 (54%) |

Two modifications that did not affect the matrix stability became operational in December 1987 and are discussed here. Because surface height corrections generally were of a greater magnitude than those of low-level radiosondes, the depth over which the surface height corrections were extrapolated was reduced from 20 to 10 mb and the calculation was only performed once, resulting in profiles of two rather than three height corrections.

The second change was associated with the error of representativeness (a component of the observational error) of the surface height corrections. This change only affects the diagonal elements of the matrix. Recall that operationally the error remains fixed regardless of the analysis level (1–6). In the reanalysis, the surface observation error was quadratically increased with height so that the error ratio was increased and the weight given the report in the analysis was decreased. This is not to infer that the error of the observations increases with height, but rather that the observations are less representative away from the surface. These two changes resulted in a temperature analysis that had a better fit to the data than the operational analysis (Fig. 2c). In Table 1, the more rapid decrease in influence of the surface height corrections for successive analysis is apparent. The 850 mb relative humidity analyses are shown in Fig. 3, which illustrates increased humidities throughout the Midwest.

At the time of this initial case study, it was believed that an improved first guess (including a diurnal cycle) could alleviate some the low-level analysis problems. Tests of this hypothesis were started in August 1987, when the T80 GDAS (triangular truncation, 80-wave Global Data Assimilation System) was implemented.

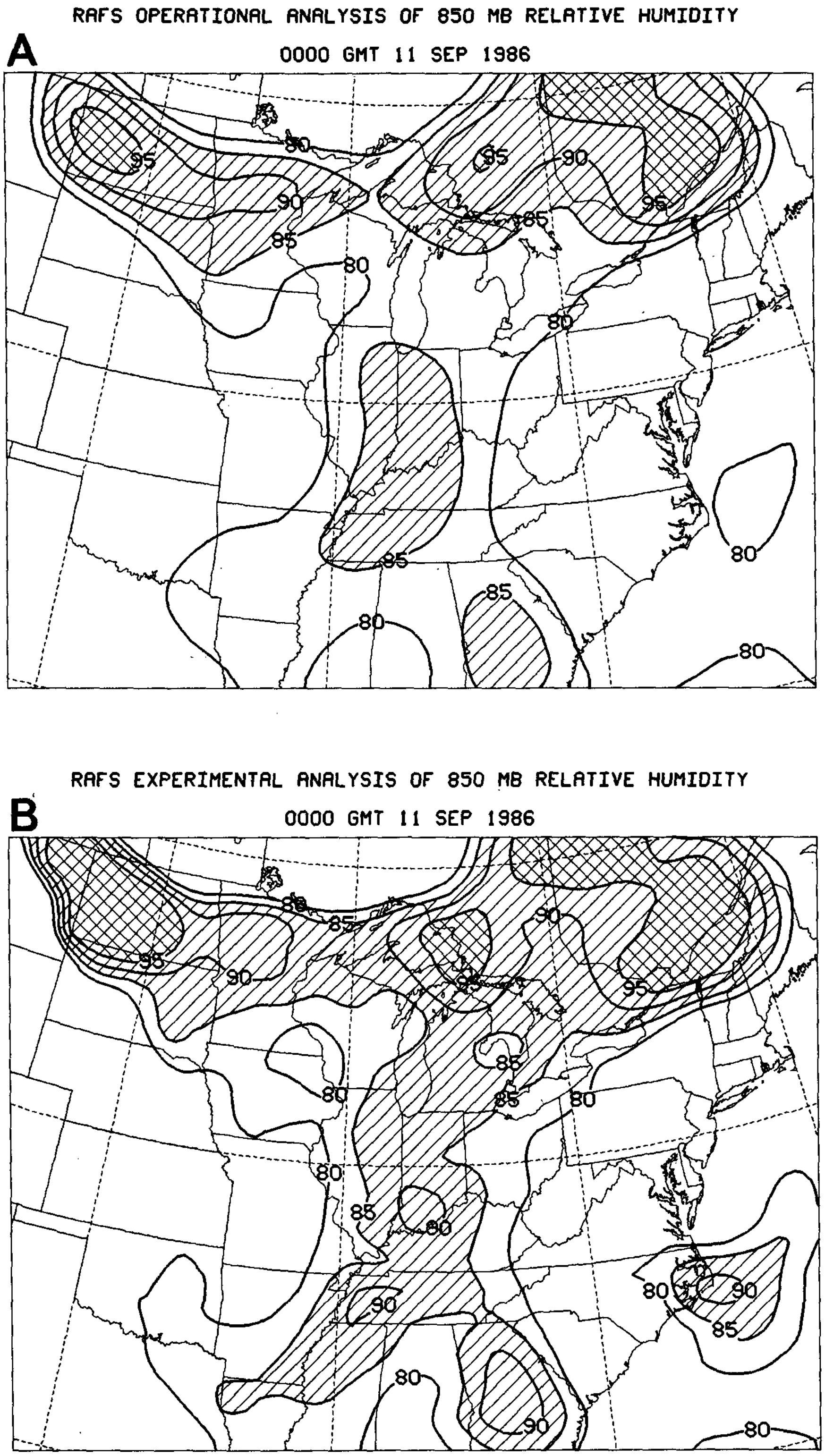


FIG. 3. ROI relative humidity fields for 0000 UTC 11 September 1986 derived from (a) the operational analysis, and (b) the experimental analysis. Contours are shown at intervals of 5% for values over 80%. Areas with relative humidities greater than 85% are shaded.

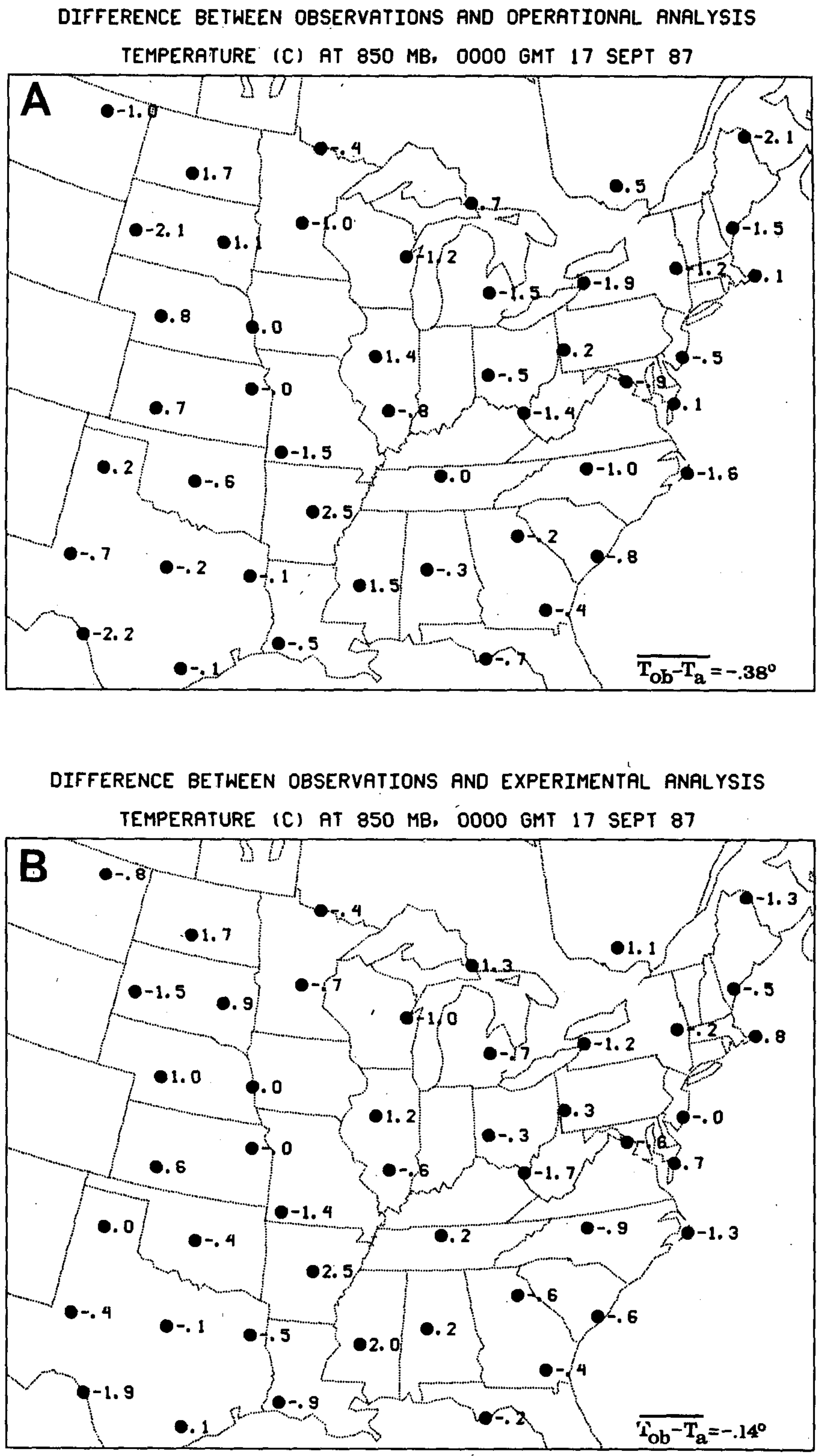


FIG. 4. Difference between radiosonde observations and ROI analysis for 850 mb temperature (°C) on 0000 UTC 17 September 1987 using (a) the operational analysis, and (b) the experimental analysis.

Although the first guess appears to have been improved, particularly near the surface, an examination of 30 days in September and October 1987 revealed that over the eastern two-thirds of the United States a systematic warming of nearly 0.5°C at 850 mb continued to be present in the 0000 UTC analyses. In September 1987, a parallel analysis with the changes noted for the experiment in Table 1 was run for two weeks and the warming at 850 mb was reduced by approximately 40%. Figure 4a shows the difference between the observations and the operational analysis at radiosonde stations in the eastern United States at 0000 UTC 17 September. At radiosonde locations the analysis is too warm by an average of 0.38°C, with large differences occurring from the Great Lakes to New England. These same differences from the parallel analysis are shown in Fig. 4b, where the analysis is too warm at radiosonde locations by 0.14°C. The two modifications discussed above were implemented in the operational ROI analysis in December 1987. An examination of monthly values of root-mean-square temperature errors computed at radiosonde locations over eastern North America from May 1985 through December 1988 shows a reduction since August 1987. It is not possible, however, to isolate the degree to which the change in the ROI scheme and the change in the first guess have each contributed to this decrease.

## 4. Concluding remarks

Experiments were conducted to evaluate the accuracy of NMC's operational ROI low-level analyses. In particular, temperatures in the 0000 UTC analyses were often too warm near 850 mb, resulting in relative humidities that were too dry.

The RAFS ROI that was operational at the time of this study could lead to erroneous warming above the surface in situations of large negative first-guess height corrections at the surface. Much of the problem was dependent on the manner in which information from surface data is distributed in the vertical, especially when the surface correction is large and not representative in layers away from the surface. Improvement over the operational analysis was obtained by changing the observational error and the vertical extrapolation process associated with the surface data. Operational implementation of these changes and the T80 GDAS has resulted in an improved fit of the analysis to the observations in the lowest levels.

In the future, it is anticipated that improvement could be obtained in a more appropriate manner through changes in the vertical component of the forecast error correlation function. This could be achieved using the assumption that the vertical correlation function is situation dependent and could be defined to be, for example, a function of the low-level stability. The resulting set of vertical correlations would be a more flexible and useful set for a broader range of low-level synoptic situations.

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