Examination of Objective Analysis Precision Using Wind Profiler and Radiosonde Network Data

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Introduction

One of the principal research strategies that has emerged from the science team of the Atmospheric Radiation Measurement (ARM) Program is the use of a single column model (SCM). The basic assumption behind the SCM approach is that a cloud and radiation parameterization embedded in a general circulation model can be effectively tested and improved by extracting that column parameterization from the general circulation model and then driving this single column at the lateral boundaries of the column with diagnosed large-scale atmospheric forcing. A second and related assumption is that the large-scale atmospheric state, and hence the associated forcing, can be characterized directly from observations. One of the primary reasons that the Southern Great Plains (SGP) site is located in Lamont, Oklahoma, is because Lamont is at the approximate center of the NOM Wind Profiler Demonstration Array (WPDA). The assumption was that hourly average wind profiles provided by the 7 wind profilers (one at Lamont and six surrounding it in a hexagon) coupled with radiosonde launches every three hours at 5 sites (Lamont plus four of the six profiler locations forming the hexagon) would be sufficient to characterize accurately the large-scale forcing at the site and thereby provide the required forcing for the SCM. The goal of this study was to examine these three assumptions.

Evaluation of Objective Analysis Techniques

The wind profilers and radiosondes provide vertical profiles of wind speed and direction and thermodynamic variables. A diagnostic determination of the large-scale forcing requires specification of the horizontal gradients of these wind, temperature, and moisture fields. An accepted technique for deriving the horizontal gradients is a least-squares fitting of polynomial surfaces to the spatially distributed profile observations. In this study, five objective analysis techniques were used to derive the horizontal gradients: 1) exact fitting of a plane surface to 3 observations (L3), 2) least-squares fitting of a plane surface to 4 observations (L4), 3) least-squares fitting of a plane surface to 5 observations (L5), 4) least-squares fitting of a plane surface to 6 observations (L6), and 5) least-squares fitting of a quadratic surface to 7 observations (Q7). Once the surface-fitting is completed, gradients are determined analytically from the fitted functions. Error in the diagnosed gradients can arise from two principal sources. The first is uncertainty in the input observations arising from instrument noise and small scale variability. The second is misspecification of the fitted surface, i.e., the chosen functional form of the fitted surface does not match that of the actual atmospheric field.

Influence of Observational Uncertainty

Observational errors propagate into the diagnostic results through the fitting process. The resulting uncertainty in the objective analysis results can be estimated if the errors are assumed to be spatially uncorrelated and of known magnitude. We have carried out this estimation using a prescribed rms uncertainty of 1.3 m/sec in wind speed and 0.5 K in temperature and all reasonable combinations of existing profile observation locations at the SGP site. The average magnitudes of the uncertainty in horizontal divergence (HDiv), horizontal advective acceleration (HAcc), and temperature advection (TAdv) for all 5 objective analysis techniques are given in the Table 1. The table values show that the objective analysis uncertainty due to observational error is nearly the same magnitude as the expected synoptic-scale signal.

Table 1. Magnitudes of objective analysis errors.

	L3	L4	L5	L6	Q7
HDiv (10-5/sec)	0.832	0.819	0.741	0.663	2.03
HAcc (10-4/sec)	0.845	0.845	0.767	0.663	1.95
TAdv (10-4/sec)	0.325	0.325	0.295		

Influence of Functional Misspecification

This error arises primarily from using too simple a surface to represent a particular meteorological quantity. Thus, it depends on the characteristics of the field of the particular quantity and becomes important when that field contains variability at higher order than is in the objective analysis model. The logical approach would seem to be to fit the field with the highest order surface possible. However, increasing the complexity of the approximating polynomial guarantees increasing errors due to observational uncertainty (see the Q7 values in Table 1).

We have carried out a case study of this error using the 6 profilers in a hexagon around Lamont. The profilers are divided into two separate, overlapping triangles. Thus, there are no common profilers between the two triangles and both triangles are centered on Lamont, at which location we would expect the analysis results from the two triangles to be nearly identical. The case study period was November 26-27, 1991, using data acquired during the FIRE II field program. The results from the two triangles are compared in Figure 1 to a third curve computed from a quadratic fit to all 6 profilers. The range of magnitudes of the difference between the two triangle curves is as large as the range of variability expected over a full synoptic wave.

Conclusions

Our research leads us to conclude that objectively analyzed data from the profiler array and ARM sonde network are generally not suitable for initialization of SCMs. Significant errors are introduced by a combination of uncertainty in the observations and higher order variability in the actual fields not accounted for in the least squares fits. We see three possible steps that can be taken to improve the situation. The first is to carefully screen meteorological situations in order to identify the cases that are suitable for SCM forcing. This will limit the breadth of the data base and the data available for parameterization improvement. The second is to use more sophisticated objective analysis techniques. While this may lead to a reduction in errors, the techniques will be time-consuming and the error uncertainty difficult to quantify.

The third step is to use operational assimilation models such as the Mesoscale Analysis and Prediction System (MAPS) to provide initialization data. These models have the virtue of providing standardized, mathematically balanced forcing fields. If the SCM experiments are going to follow this path, we question the utility of the ARM radiosonde program. We recommend that the most efficient use of the resources expended on the boundary facility radiosondes is to make sure that the observations are immediately available for assimilation into whatever model (such as the MAPS) is used.

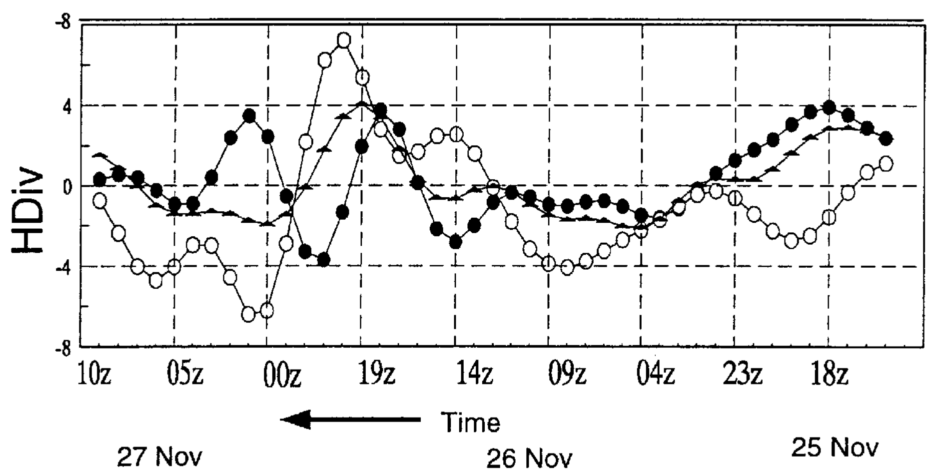

Figure 1. Time series of horizontal divergence at 9-km altitude for case study period. Circles denote results from profiler triangles. Hatched line is computed from a quadratic fit to 6 profilers.