Single-Column Data Assimilation for the Atmospheric Radiation Measurement Program

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The goal of our work is to develop a data assimilation system that will use as much of the Atmospheric Radiation Measurement (ARM) data as possible and will provide a continuous description of the atmosphere over the Cloud and Radiation Testbed (CART) site. This would be useful for initializing and validating single-column models.

We use a variational data assimilation method. The analysis is defined as the state of the atmosphere which, over a given analysis period, is closest to the observations, weakly constrained by the equations of a model. We use a single-column model, the AER Local Forecast and Assimilation (ALFA) model. A weak constraint means that the analyzed state obeys modified model equations, to which terms accounting for the model errors have been added. These added terms are the control variables in minimizing the difference between the model simulation and the observations.

Given a model

$$\frac{\partial X}{\partial t} = f(X)$$

where *c* is the state vector, the analysis is a solution of

$$\frac{\partial X}{\partial t} = f(X) + v$$

in which the vector *n* (which we call nudging terms) is adjusted to minimize

$$J = \sum_i w_i \left(X_i - \hat{X}_i\right)^2 + \sum_j w_j \left(\partial^2 v / \partial z^2\right)_j^2$$

The objective function *J* is a weighted sum of the squared differences between the solution of the approximate model and the observations $\hat{X}_i$ available during the assimilation period. The second term on the right hand is a smoothness constraint on *n*, where the sum is over the model levels. Without this term, the analysis could become noisy in the vertical because of uneven distribution of data levels. We use an assimilation period of 24 hours.

The adjoint model is integrated to compute the gradient of the objective function with respect to the nudging terms. This computation becomes the input to a minimum search algorithm which computes a new set of nudging terms. This process is repeated iteratively until the minimum of *J* is found. In practice, we find that the convergence becomes very slow after 20 or 30 iterations, and we generally truncate the procedure at that point. The state of the model at the end of the 24-hour assimilation period becomes the starting point for the forecast for the next day, which is also the first guess for the next analysis.

We performed a number of data assimilation tests, for different seasons. So far, we have used mainly the data from the National Weather Service. We are now starting to use ARM data. The data used in the tests shown here (Figures 1 and 2) are the hourly surface observations at Oklahoma City and the twice daily soundings at Norman, Oklahoma. The raw data are transformed into the model prognostic variables: potential temperature, water vapor mixing ratio, and two wind components. The weights assigned to each variable in the equation for J are based on the following values of what we consider "acceptable" root mean square analysis errors:

- potential temperature—1 K
- wind components—1 m/s
- water vapor mixing ratio—0.5 g/kg at the surface, decreasing exponentially with a scale height of 5 km.

These values are rather arbitrary at this stage. They should be refined using actual statistics of the differences between the analyses and the observations. This procedure should

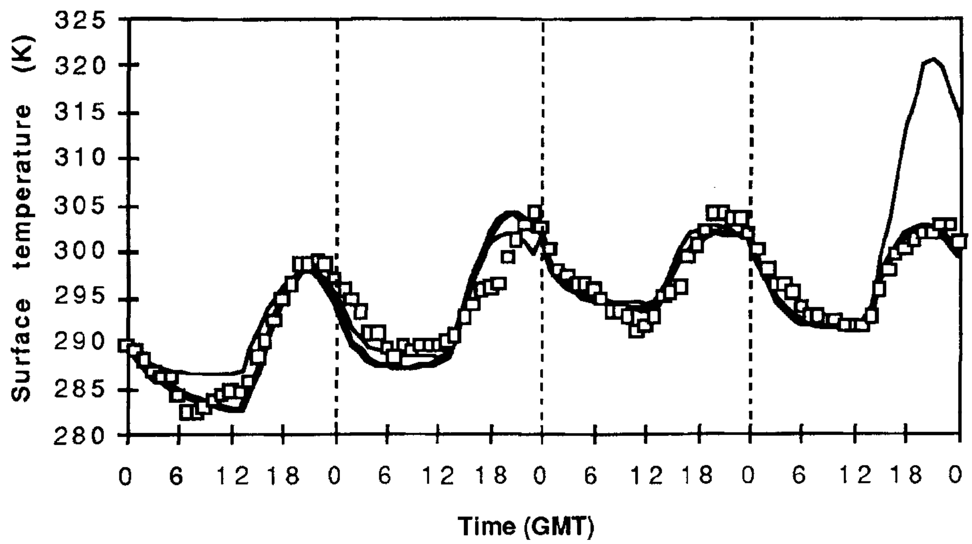

Figure 1. Four cycles of data assimilation for April 7 through 10, 1992. Surface temperature is shown. Squares are observations; thin line, first guess; thick line, analysis. Each cycle starts at 0GMT.

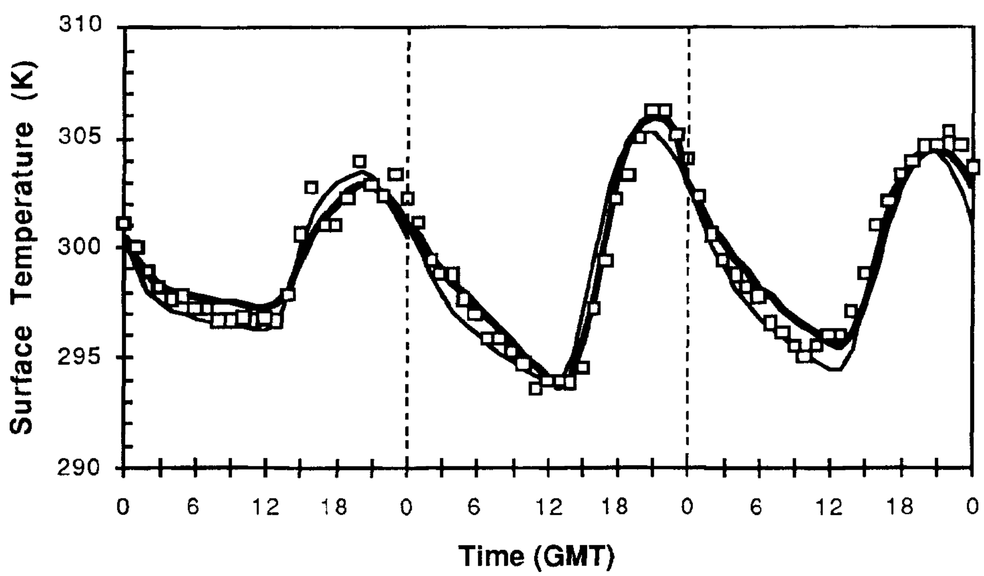

Figure 2. Same as Figure 1, but for September 2 through 4, 1992.

Figure 1. In general, the nudging terms are much smaller than the other tendencies. For the winds (not shown), the relative magnitude of the nudging terms is even smaller than for specific humidity. Only for temperature do they account for a sizable fraction of the tendencies. This difference between the variables may be due to the relative weights used to compute the analysis error, which is minimized by the data assimilation procedure.

The work planned for the coming years will include

- Assimilating indirect observations (surface fluxes, remote sensing) in addition to *in situ* measurements.
- Optimizing weights in the definition of the objective function *J*.
- Comparing single-column assimilation results with 4D data assimilation during intensive observing periods.