Subgrid-Scale Variability and Data Assimilation Over Cloud and Radiation Testbed Observational Facilities

M. Živković and J.-F. Louis
Atmospheric and Environmental Research, Inc.
Cambridge, Massachusetts

A successful variational data assimilation procedure should produce an analysis that fits the data to within the observation errors. The observation errors include non-representativity, that is, the effect of small scale atmospheric features, which are present in the observations but unwanted in the analysis. In the context of the Atmospheric Radiation Measurement (ARM) Program and climate modeling, any feature that is smaller than the Cloud and Radiation Testbed (CART) area can be considered as sub-grid scale. The work presented here investigates the sub-grid scale variability within the CART site in relation to data assimilation.

We used the data obtained at several observational facilities within the CART site during three single column model (SCM) intensive observation periods (IOP) of 1994. We used sounding data from four boundary facilities and the central site. Also, we used energy balance Bowen ratio (EBBR) data sets at ten facilities, surface meteorological observation system (SMOS) observations at five facilities, and broad-band radiometer observations (Baseline Surface Radiation Network [BSRN]) at the central facility. We performed data assimilation experiments for five observational sites: E8, E9, E13, E15, and E20.

Data Processing

We applied simple data quality control by eliminating missing data and obviously non-physical outliers (for example, negative humidity data, wind speeds larger than 75m/sec, speed direction larger than 360 degrees, etc.). From the Bowen ratio measurements, we used the net radiative, latent heat, and sensible heat fluxes. The latter two are not direct measurements, but are inferred from temperature and moisture gradients, with some assumption on the energy balance of the surface. This computation seems to be unreliable when the computed Bowen ratio is close to -1. Therefore, we eliminate data when the Bowen ratio is between -0.5 and -2.

In the current experiments, we use a model with 25 vertical layers. Since the radiosonde data have a much finer resolution than the model, we average the data over the model layers. We use the downward radiative fluxes from the broad-band radiometers, separately for short and long waves.

Sub-grid Scale Variability

The data assimilation procedure minimizes a measure of the difference between model simulation and observations (Louis and Živković 1997). In principle, the weights assigned to the various observations used in the data assimilation should be inversely proportional to the square of the expected observation error.

To evaluate the expected observation error for EBBR and SMOS, we calculated first and second statistical moments for these data from complete IOP time series. We also calculated the mean time series for all relevant stations after applying data quality control and retaining only concurrent observations. The departures of the local measurements from this mean time series are described by the RMS differences shown in Table 1.

Part of this variability is due to measurement errors and part is due to the non-representativity of the observations. It is not possible to distinguish between the two effects, but both need to be included in evaluating the weights to be used in calculating the objective function when assimilating data from these stations on a general-circulation-model (GCM) scale.

To some extent, these scores also reflect differences in surface characteristics and elevation that exist between various sites. For example, among the SMOS facilities, E8 is located at the highest altitude of 664 m, and its temperature records should be systematically lower (particularly during clear nights) than the other stations, in a commonly defined boundary layer. This is reflected in its larger RMS difference from the mean time series: 3.1 degrees. The E20 station is located at an altitude comparable to the altitude of the central facility (E13) and other sites, but its temperature still departs an average of 3.1 degrees from the mean. Examination of the time series for this station indicates that its RMS score reflects a systematically higher night temperature on clear days. The

Table 1. RMS differences between observations and mean time series for ten sites during October 1994 IOP (Bowen ratio measurements and surface observations).

Variable	E4	E7	E8	E9	E12	E13	E15	E20	E22	E26
Sensible Heat [watts/m^2]	59.8	80.6	37.1	44.1	70.9	36.7	45.1	58.2	48.8	44.4
Latent Heat [watts/m^2]	117.1	53.4	59.6	81.5	78.6	72.4	87.1	56.4	78.3	74.5
Net Radiation [watts/m^2]	129.9	128.1	114.7	124.2	112.3	124.2	133.1	108.0	131.6	119.1
Temperature [deg C]	-	-	3.1	1.0	-	1.0	1.0	3.1	-	-
Rel. Humidity [%]	-	-	10.5	6.3	-	4.8	5.9	7.8	-	-
Wind Speed [m/sec]	-	-	1.9	1.2	-	1.2	1.0	1.8	-	-

RMS differences for the surface fluxes (EBBR data) show an even larger span of uncertainties among the stations. The current values of the weights will be refined when longer time series are processed and station climatology removed.

Results

Variational data assimilation involves the calculation of the objective function which measures overall closeness of observations and analysis. Its value decreases as the analysis becomes closer to the observations. We made a series of data assimilations on 8 independent days during the October 1994 IOP. The initial value of the objective function (so-called “first guess”), which is used to start the data assimilation, is listed in a single row for each of the five stations. The final value of the objective function obtained after the analysis is listed in the next row (so-called “analysis”).

An examination of these values shows that the data assimilation improves the fit to the observations on average by more than 50%. Also, for a single day, all stations show a consistent decrease in the objective function. This decrease is most significant in the cases of larger initial values of the objective function (for example, dates 11/9 and 11/13). This indicates that the data assimilation procedure accomplishes its goal, since bad initial conditions result in large values of the objective function, and the new analysis should rectify this effect. Similarly, when initial conditions are not that bad, for example, date 11/10, the objective function starts with a small value and analysis reduces it by only 29% on average.

Although no firm conclusions can be drawn from this small sample, some features of the analysis can be identified from Table 2. For example, the analyses improve the most for station E9 (on average 57%), and the least for station E8 (on average 36%). The fixed values of the soil parameters used in this set of model runs may be more appropriate for E9 than for the other stations. An encouraging result is that the most significant improvement occurs on days of a strong synoptic activity (for example, a warm front passing over the site on 11/13 or a cold front passing on 11/9).

To examine the closeness of the fit to the individual type of observations that were assimilated, we also calculated the RMS scores of individual variables (analyzed minus observed) at each facility over a 24-hr assimilation window. Among the variables that we looked at are the surface temperature, net radiation, latent and sensible heat fluxes, and short wave and long wave radiative fluxes. Figure 1 illustrates these results for the central observational facility for the 8 days during the October IOP.

We found that the analyses are improved for surface temperature and net radiation, but most significantly for the short-wave and long-wave fluxes for all five stations. Mixed results were obtained for sensible and latent heat fluxes. This deficiency of the surface fluxes analysis can be explained in part by the very small weights that have been given to the Bowen ratio measurements. As the values in Table 1 pointed out, the surface fluxes values vary considerably across the CART site, which results in a standard deviation much larger than the observational error that is usually used in data assimilation procedures.

Table 2. Initial and final values of the objective function during 24-hr data assimilation experiments for 5 observational facilities.

Date	Value	E8	E9	E13	E15	E20
10/24/94	First guess Analysis	1.04 0.55	1.26 0.63	0.90 0.39	0.98 0.48	1.30 0.59
10/25/94	First guess Analysis	0.86 0.61	1.00 0.47	0.71 0.36	0.75 0.42	0.75 0.41
10/26/94	First guess Analysis	0.63 0.47	0.81 0.25	0.49 0.30	0.52 0.40	0.45 0.24
11/09/94	First guess Analysis	1.12 0.46	1.73 0.48	1.79 0.31	1.61 0.42	0.45 0.24
11/10/94	First guess Analysis	0.40 0.31	0.53 0.42	0.52 0.28	0.60 0.49	0.72 0.46
11/11/94	First guess Analysis	- -	0.71 0.28	0.67 0.45	- -	1.02 0.51
11/12/94	First guess Analysis	0.81 0.41	0.75 0.24	0.82 0.20	0.86 0.32	0.78 0.28
11/13/94	First guess Analysis	2.10 1.66	2.54 0.89	 1.13	2.63 0.81	2.75 0.35

Reference

Louis J.-F. and M. Živković. 1997. Single column variational assimilation experiments with Atmospheric Radiation Measurement data. *Proc. Fifth Atmospheric Radiation Measurement (ARM) Science Team Meeting*. U.S. Department of Energy, Washington, D.C.

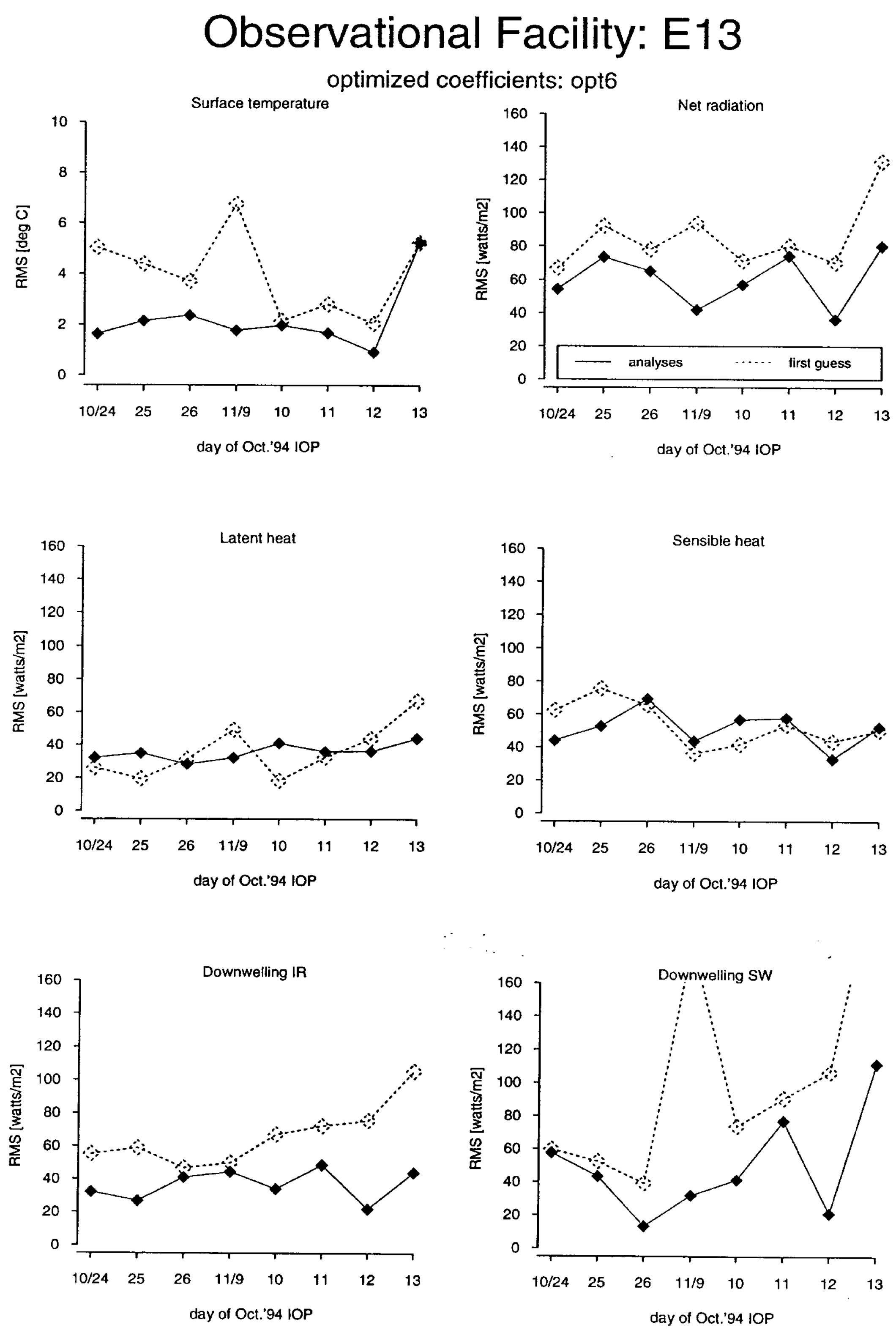

Figure 1. The RMS scores of 8 independent 24-hr analyses for the central observational facility.