Integrating ARM Measurements to Force and Evaluate GCM Parameterizations

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Introduction

Data from a sounding array can be used to calculate vertical velocity and advective tendencies for an atmospheric column defined by the array. These diagnostics are often used to 1) describe the structure of the large-scale systems and budgets (e.g., Thompson et al. 1979); 2) drive semi-prognostic general circulation model (GCM) physical parameterizations (e.g., Lord 1982, Wang and Randall 1996) or single-column models (Randall et al. 1996); and 3) diagnose effects of sub-grid circulations on the resolvable scale fields (Yanai and Johnson 1993).

This study describes a method to integrate Atmospheric Radiation Measurement (ARM) data sets from different platforms to provide an accurate, internally consistent, data set that is appropriate to force and evaluate GCM parameterizations. Figure 1a shows the available upper-air atmospheric data in ARM. During a typical intensive observation period (IOP), balloon soundings are launched every 3 hours at five stations. Atmospheric hourly winds are also measured at a dozen National Oceanic and Atmospheric Administration (NOAA) profiler stations. This set of upper-air measurement stations, in conjunction with the NOAA mesoscale model analysis [e.g., the Rapid Update Cycle (RUC) model], is ideal to define a domain (Figure 1b) that is comparable in size with a GCM grid. Figure 2 shows the concurrent surface and top-of-the-atmosphere (TOA) measurement platforms that are available in ARM to close the mass, energy, water, and momentum budgets for an atmospheric column.

The Method

Regardless of the physical parameterizations used, any model, as well as the real atmospheric data, should obey the following first principles of conservations for an atmospheric column as outlined in Figures 1 and 2:

$$<\nabla\cdot\vec{V}> = -\frac{1}{g}\frac{dp_s}{dt} \tag{1}$$

$$\frac{\partial <q>}{\partial t} + <\nabla\cdot\vec{V}q> = E_s - Prec - \frac{\partial <q_1>}{\partial t} \tag{2}$$

$$\frac{\partial <s>}{\partial t} + <\nabla\cdot\vec{V}s> = R_{TOA} - R_{SRF} + L\,Prec + SH + \frac{\partial <q_1>}{\partial t} \tag{3}$$

$$\frac{\partial <\vec{V}>}{\partial t} + <\nabla\cdot\vec{V}\vec{V}> - f\vec{k}\times<\vec{V}> - \nabla<\phi> = \vec{\tau}_s \tag{4}$$

where

$$<X> \equiv \frac{1}{g}\int_{p_T}^{p_s}(X)dp$$

These are column-integrated conservations of mass, water vapor, dry static energy and momentum. R is the net downward radiative flux at the TOA and at the surface (SRF). $\vec{\tau}_S$ is the surface wind stress. Prec is precipitation. SH is the sensible heat flux, and E_s is the surface evaporation. Horizontal advection of hygrometers and all horizontal eddy covariance terms have been neglected due to insufficient knowledge. These omissions are not expected to seriously affect our results.

Terms on the right-hand side of Eqs. (1) through (4) are available from surface and satellite measurements as outlined in Figure 2. They are the area-averaged fluxes within the observational network. Terms on the right side of Eqs. (1) through (4) can be calculated from upper-air sounding and profiler measurements as outlined in Figure 1. Because of the large uncertainty in deriving the secondary variables of atmospheric vertical velocity and advective tendencies, the current strategy of data integration method is

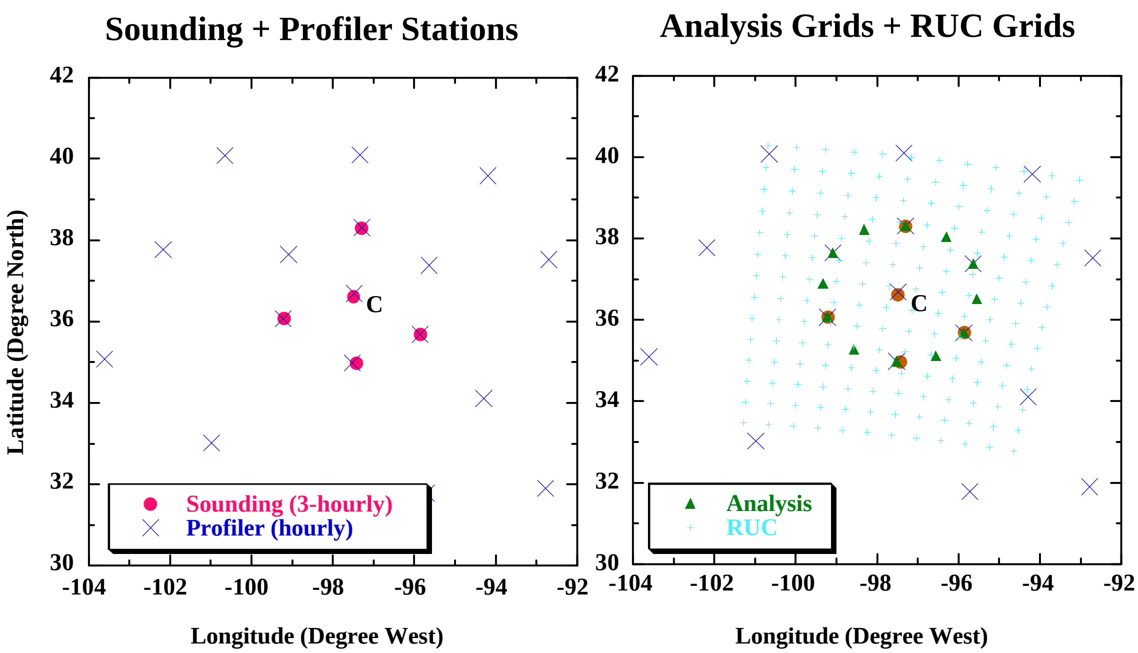

Figure 1. (a) Distribution of sounding stations and profiler stations at the ARM Southern Great Plains (SGP) site. (b) Objective analysis grids and model grids in the NOAA RUC model. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/zhang-98.pdf*.)

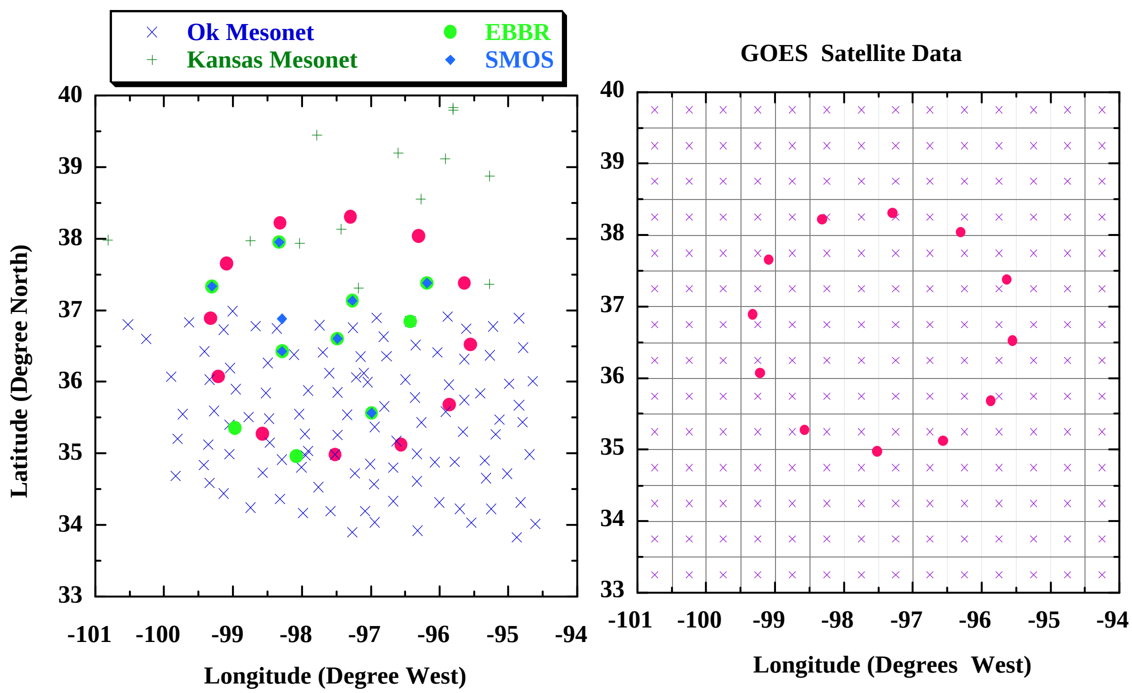

Figure 2. (a) Surface measurements stations used in the variational analysis. (b) Satellite 0.5 degree by 0.5 degree grids from the Geostationary Operational Environmental Satellite (GOES). (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/zhang-98.pdf*.)

to constrain the atmospheric variables ($\vec{v}$, s, q) to satisfy Eqs. (1) through (4) with minimum possible adjustments to the upper-air measurements. The adjustment is justifiable after consideration of instrument and measurement uncertainties, errors from handling of missing sounding data, and aliasing of small-scale features to large-scale fields in the instantaneous soundings.

The analyzed product, denoted as $\vec{v}*$, s*, q*, is derived by minimizing the following cost function:

$$I(t) = \iiint_{p,x,y} \Big[\ \alpha_u (u*-u_o)^2 + \alpha_v (v*-v_o)^2 + \alpha_s (s*-s_o)^2 + \alpha_q (q*-q_o)^2\ \Big] dxdydp \qquad (5)$$

with Eqs. (1) through (4) as strong constraints, where subscript "o" denotes direct upper-air measurements, α is the weighting function (discussed later). The integration will be replaced by summation over the stations and on vertical layers. A detailed description of this variational approach is described in Zhang and Lin (1997).

Performance

As in cases of all objective analysis of data, the analyzed data are typically neither measurements nor true values of the variables. An important aspect of the analysis procedure is, therefore, to justify the magnitude of adjustments made to the direct measurements.

Figure 3 shows the frequency distribution of the difference of the final analyzed data with the direct sounding measurements at the sounding stations. As can be seen, the adjustment magnitude of the atmospheric variables is comparable with measurement and instrument uncertainties. Yet, these adjustments make a huge difference to the secondary variables of divergence, vertical velocity and advective tendencies (Zhang and Lin 1997).

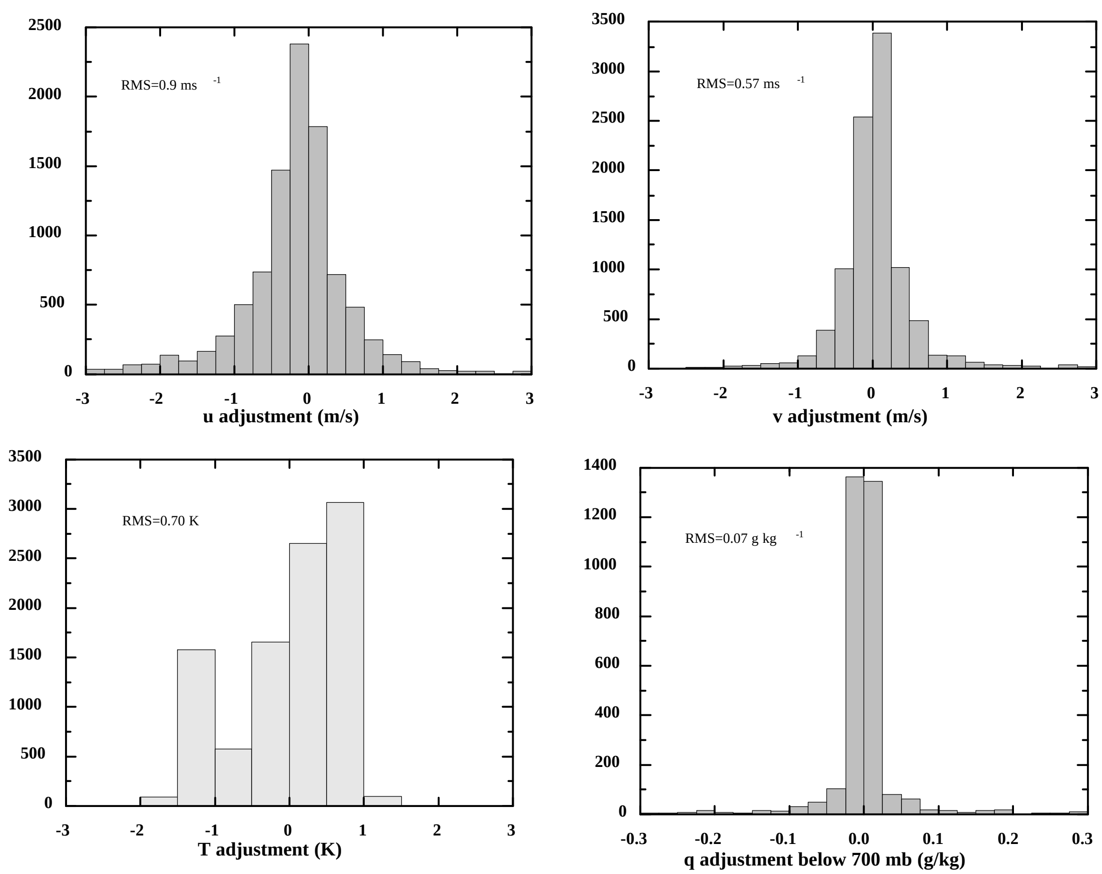

Figure 3. Frequency distribution of the variational adjustments of atmospheric variables.

Figures 4 and 5 show the energy and water budget components of the Southern Great Plain (SGP) atmospheric column for the July 1995 IOP. Without making the variational adjustments to the atmospheric data, the spurious residual terms of the atmospheric energy budget could reach over 100 Watts per meter square, and the spurious residual term in the atmospheric moisture budget could reach 3 mm per hour.

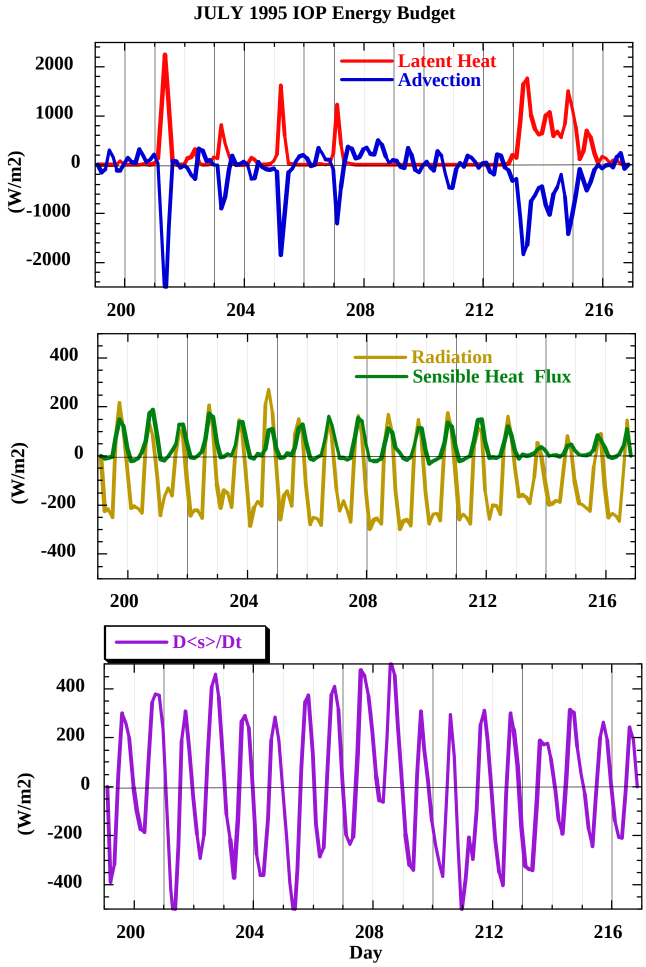

Figure 4. Components of column integrated energy budgets of the atmosphere at the SGP site during the July 1995 IOP. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/zhang-98.pdf*.)

This constrained data set, since it is internally consistent, and it has used a variety of measurements, has been used to force and evaluate GCM parameterizations. Improved model simulations have been obtained. The results are reported elsewhere (Xie and Zhang 1998).

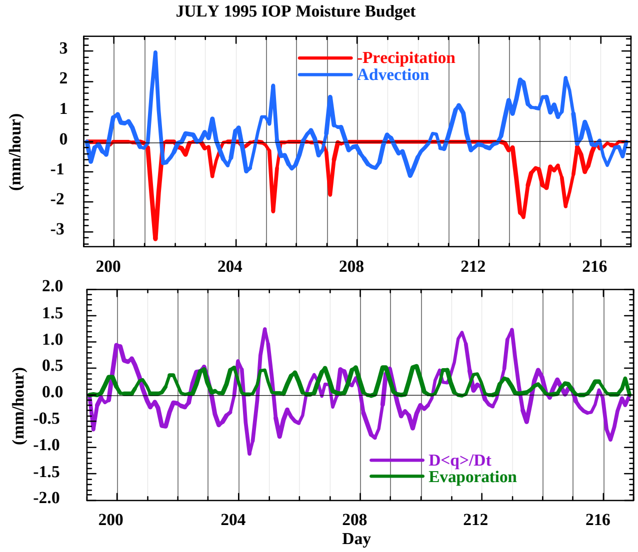

Figure 5. Components of column integrated moisture budgets of the atmosphere at the SGP site during the July 1995 IOP. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/zhang-98.pdf*.)

Conclusion

A variational analysis scheme has been developed to integrate ARM measurements from a variety of platforms. The data set represents a significant improvement to those processed using a traditional approach.

The variational approach can be improved and extended to incorporate more remote sensing measurements in the future.

Acknowledgment

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