Developing Continuous SCM/CRM Forcing Using NWP Products Constrained by ARM Observations

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Introduction

This study examines the feasibility of using numerical weather prediction (NWP) model products to replace radiosondes to develop long-term continuous forcing, instead of just intensive operational periods (IOPs), for single-column models (SCMs) and cloud-resolving models (CRMs). This is motivated by the need for long-term continuous forcing for statistical studies of SCMs/CRMs results. Studies show that SCMs/CRMs results are sensitive to their detailed initial conditions. One way to reduce this sensitivity is through statistical studies of SCMs/CRMs results so that one can filter out those uninteresting random errors and focus on those physically important systematic errors. The long-term forcing can be obtained directly from NWP model analyses, but the forcing is largely affected by model physical parameterizations that are used in the data analysis procedure. To reduce the problem, we propose a combined NWP data analysis and the Atmospheric Radiation Measurement (ARM) Program objective variational analysis approach to derive the long-term continuous forcing. In the combined system, NWP data provide vertical distribution of atmospheric state variables and the variational analysis is used to derive the required large-scale forcing data constrained by the ARM surface and top of the atmosphere (TOA) measurements. We conducted a preliminary study using data from the National Oceanic and Atmospheric Administration (NOAA) mesoscale model Rapid Update Cycle (RUC) analysis during the ARM SCM Summer 97 and Spring 2000 IOPs for this study. Results are compared with those from the ARM operational objective variational analysis (Zhang and Lin 1997; Zhang et al. 2001a,b) and those from the European Center for Medium-range Weather Forecasts (ECMWF) analysis. Impacts of the derived forcing on Community Climate Model Version 3 (CCM3) SCM are also analyzed.

Problems with the Large-Scale Forcing Directly from NWP Analysis

Figures 1a,b respectively, compare the vertical velocity produced from the ECMWF analysis for the ARM Southern Great Plains (SGP) site with that derived from the ARM variational analysis during the Summer 97 IOP. For comparison, the observed and model produced surface precipitation rates during the same periods are shown in Figure 1c. The surface precipitation rates are closely coupled with the large-scale vertical motions. Corresponding to these precipitation events, large-scale upward motions are seen in the vertical velocity field. However, the ECMWF model largely underestimates most of the observed precipitation events and it also shows problems in capturing the timing of these convective events. As the result, the model upward motions are much weaker than those derived from the ARM variational analysis. For some periods, such as on day 177, they are even out of phase. During this day, weak downward motion is seen in the model analysis while very strong upward motion

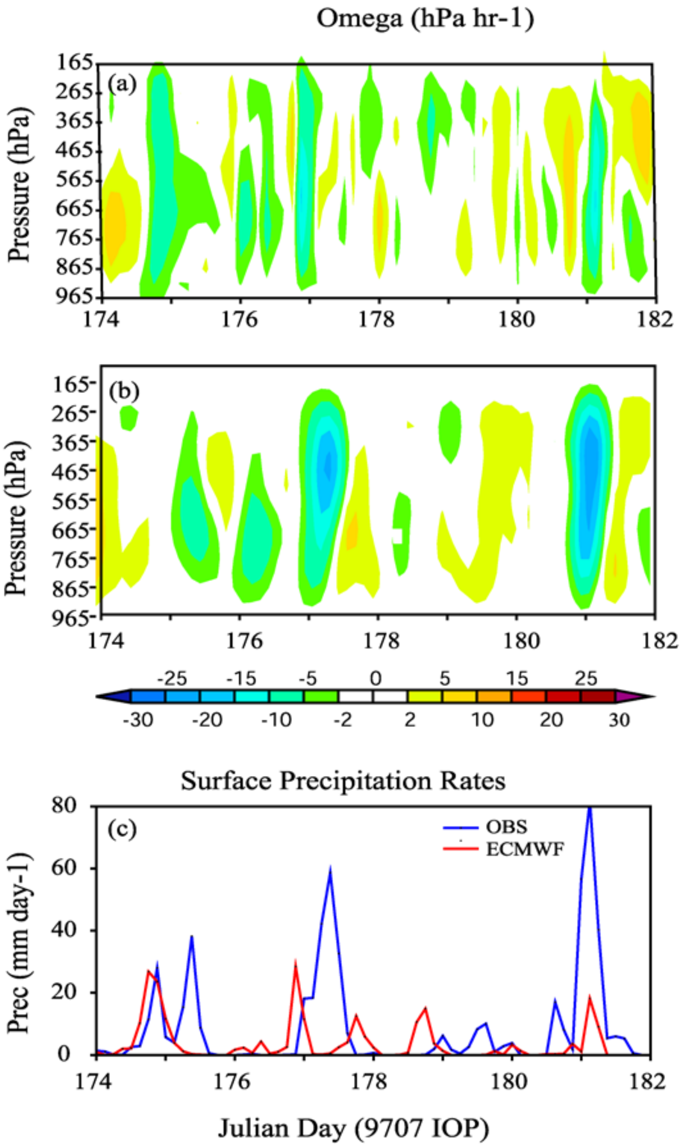

Figure 1. Vertical velocity (hpa hr^{-1}) from (a) the ECMWF analysis and (b) the ARM variational analysis, and the model produced (red) and observed (blue) surface precipitation rates (mm day^{-1}) (c) for the Summer 97 IOP.

is seen in the variational analysis corresponding to the observed strong convective event. As shown later, using the large-scale forcing directly from the ECMWF analysis will cause serious problems in driving SCMs.

New Approach and Experiments

This paper proposes a new approach to derive long-term continuous forcing for SCMs/CRMs. As shown in Figure 2, the new approach uses NWP products to provide vertical profiles of atmospheric state variables (e.g., winds [u, v], temperature [T], and moisture [q]) during the period when radiosondes are not available and uses the ARM objective variational analysis to derive the required large-scale forcing data constrained by the ARM surface and TOA measurements.

In this study, we use NOAA mesoscale model RUC analysis to provide the required upper-air input data. The surface and TOA constraints are from (1) the Surface Meteorological Observation Stations (SMOS) that measure surface precipitation, surface pressure, surface winds, temperature, and relative humidity; (2) The Oklahoma and Kansas mesonet stations (OKM and KAM) that measure surface precipitation, pressure, winds, and temperature; (3) The Energy Budget Bowen Ratio (EBBR) stations that measure surface latent and sensible heat fluxes and surface broadband net radiative flux; (4) The microwave

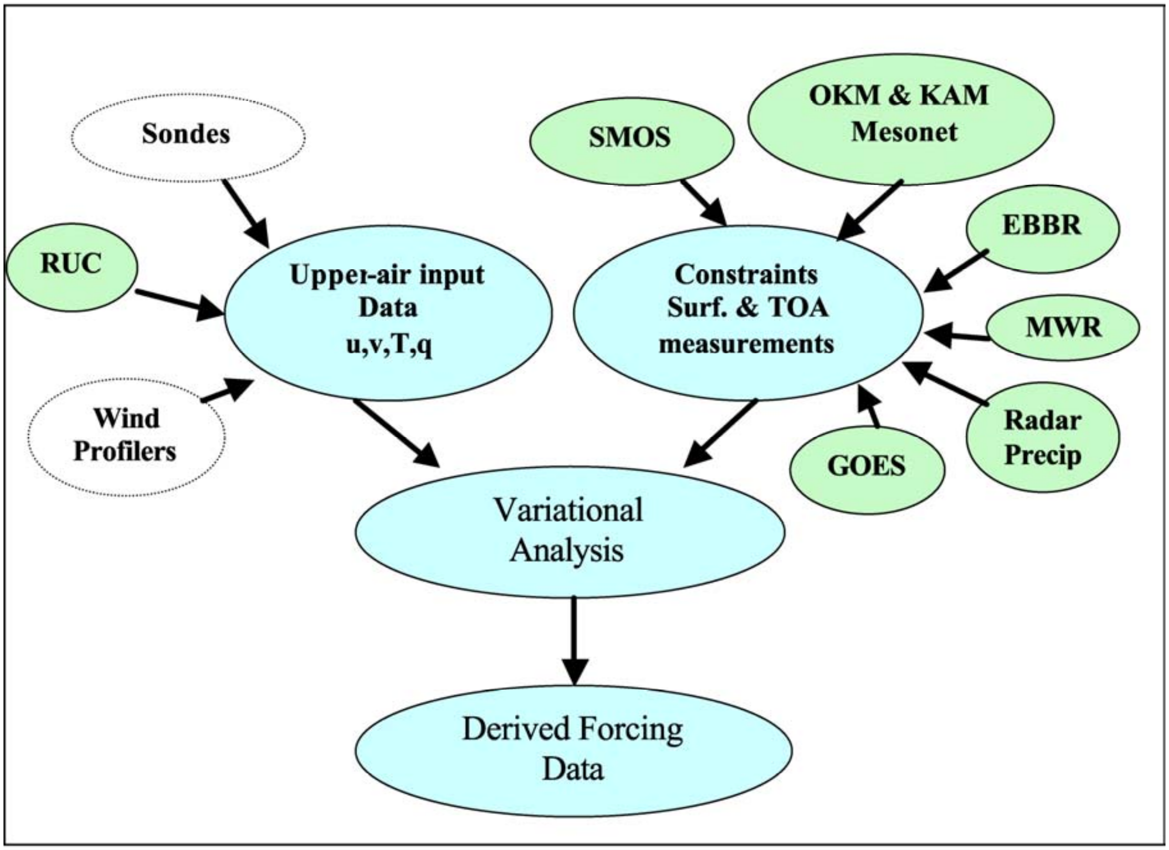

Figure 2. A new approach to derive the long-term continuous forcing using NWP products constrained by the ARM observations.

radiometer (MWR) stations that measure the column precipitable water and total cloud liquid water; (5) Radar rainfall; and (6) the Geostationary Operational Environmental Satellite (GOES) that measures clouds and broadband radiative fluxes (Minnis et al. 1995).

Table 1 summarizes the experiments we performed in this study. The control run is the standard approach currently used in the ARM operational objective variational analysis. In the study, we test sensitivity of the derived forcing to the use of upper-air input data from RUC analysis, wind profilers (PROF) (for wind fields only, T and q are from RUC analysis), and changes in the length scale used in the Barnes interpolation scheme (Barnes 1964) in the objective analysis. The large-scale forcing derived from ECMWF analysis is used for comparison.

Table 1. Summary of experiments.

Experiments	Descriptions
CONTL	Control run. (T, q) are from sondes; (u, v) are from sondes merged with wind profiler data; First guess is from RUC analysis
RUC	(u, v, T, and q) are all from RUC analysis
PROF	(u, v) are from wind profilers and (T, q) from RUC analysis
SCALE	Same as CONTL except the length scale used in the objective analysis is changed from (Lx=Ly=50 km, Lt=3hr) to (Lx=Ly=100km, Lt=6hr)
ECMWF	Forcing derived from the ECMWF analysis for the ARM SGP site
Note: All above experiments except for ECMWF use the same surface and TOA constraints.	

Results Analysis

Upper-Air Input Data

The root-mean-square (rms) errors for the upper-air input data (u, v, T, and q) for experiments RUC, PROF, and ECMWF are shown in Figure 3 for the Summer 97 IOP. The rms errors are calculated using the 'truth' from the control run (CONTL) against those from RUC, PROF, and ECMWF. For comparison, the standard deviations (black lines) of these upper-air input data in CONTL are also shown in the figure. It is seen that the RUC analysis generally shows rms errors of around 1 m s^{-2} in the wind fields, 0.5 K in temperature field (200 – 900 hPa), and less than 1.5 g/kg in moisture field. These are comparable to the uncertainties in the observations and are much smaller than the observed temporal variability. It is interesting to see that, in the upper troposphere, RUC shows smaller rms errors in the wind fields in comparison with PROF. Note that the rms errors for temperature and moisture for PROF are not shown in the figure because these two fields are from RUC analysis. The rms errors are larger for ECMWF analysis than RUC and PROF. One of the reasons is that RUC analysis data are used as the first guess in CONTL.

Derived Large-Scale Forcing

The rms errors for the derived large-scale forcing fields from these experiments (see Table 1) for the Summer 97 IOP and Spring 2000 IOP are shown in Figures 4a,b and Figures 4c,d, respectively. Here

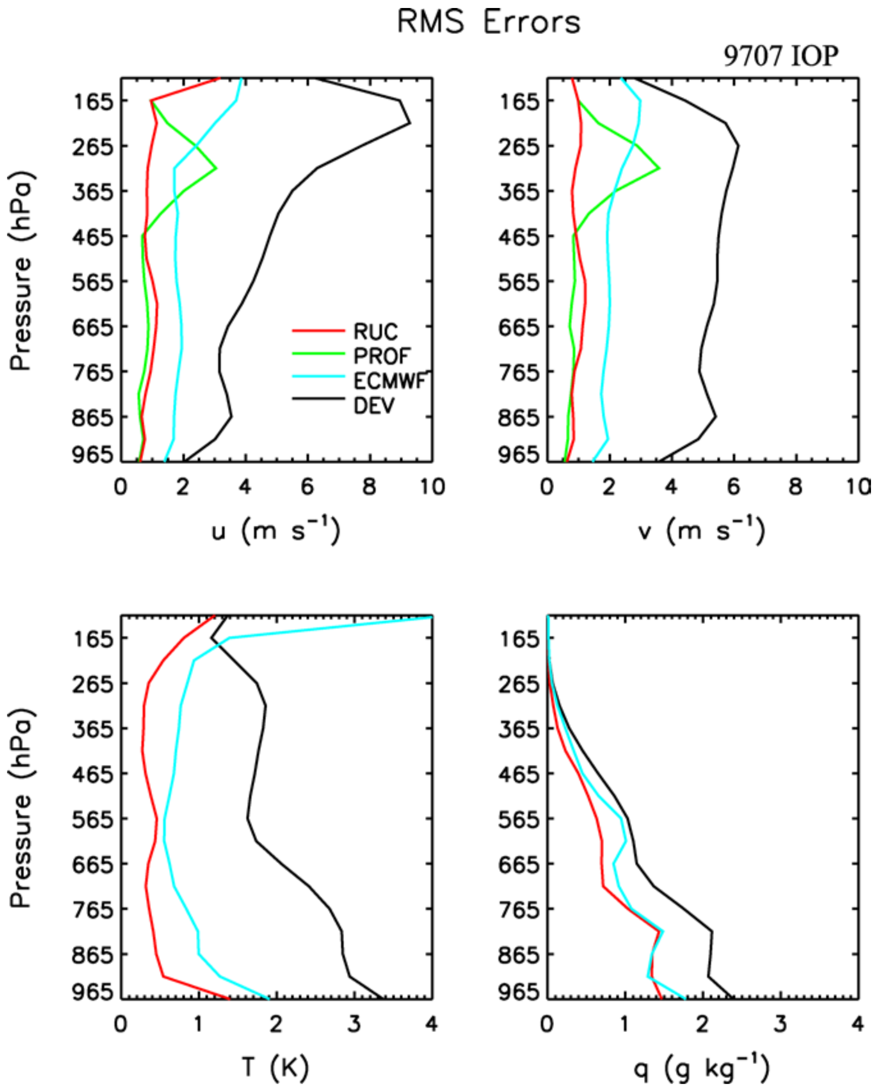

Figure 3. Root-mean-square errors for the upper-air input data (u, v, T, q) for experiments RUC, PROF, and ECWMF, compared to CONTL for the Summer 97 IOP. Black lines are the standard deviations of these variables in CONTL.

we only show the large-scale advective tendency of temperature and the vertical velocity. One important feature is that, with the constraints, the variational analysis desensitizes the final products to the differences in the input data. For example, although considerable differences exist in RUC and PROF in the wind fields in the upper troposphere, both show very similar rms errors for the derived forcing fields.

These rms errors are also comparable to SCALE, which represents one of the uncertainties in the large-scale forcing derived from the current variational analysis (CONTL). It is seen that the rms errors are smaller than the observed variability, especially for the Spring 2000 IOP. It is noted that the large-scale

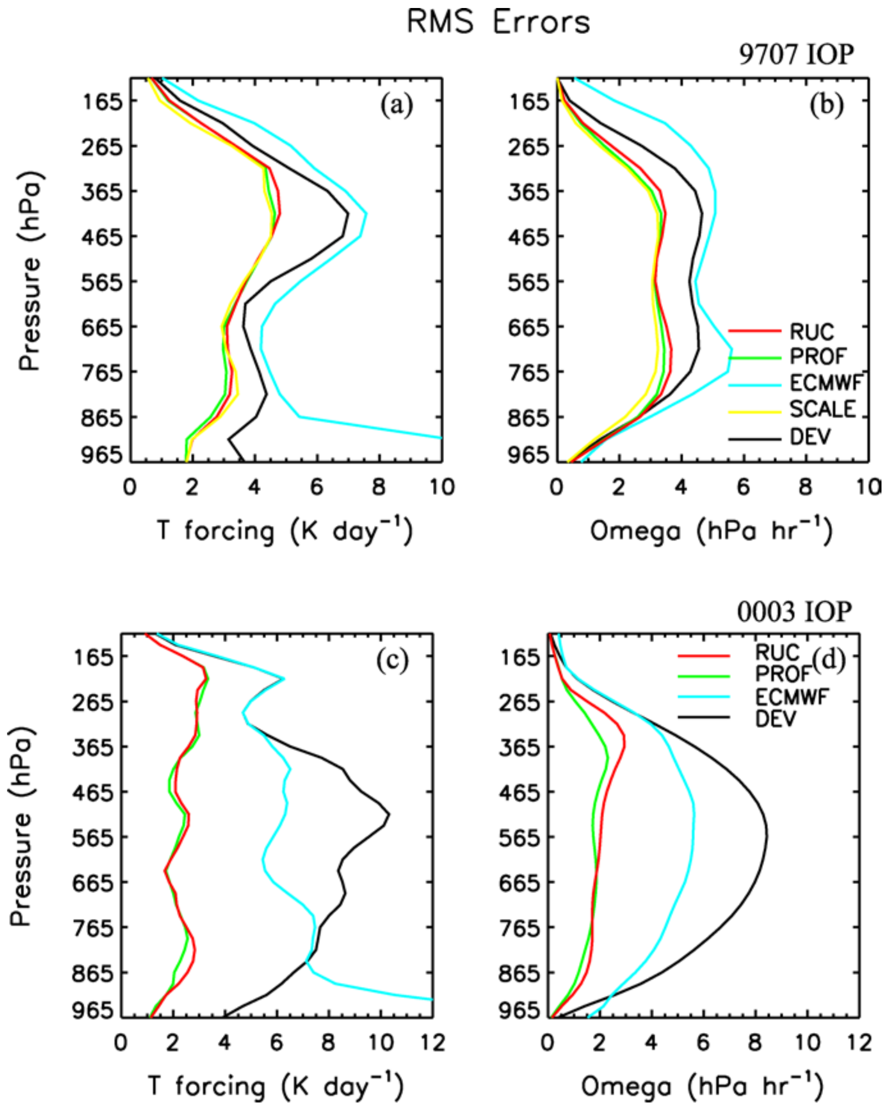

Figure 4. Root-mean-square errors for the derived large-scale advective tendency of temperature (K day^{-1}) and vertical velocity (hPa hr^{-1}) from experiments RUC, PROF, SCALE (only for the Summer 97 IOP) and ECWMF, compared to CONTL. The upper panels (a, b) are for the Summer 97 IOP and the lower panels (c, d) are for the Spring 2000 IOP.

forcings from the ECMWF analysis have rather large rms errors, especially near the surface for the temperature forcing. The large rms errors in the ECMWF analysis mainly reflect impacts of the model imperfect physical parameterizations on the derived forcing fields.

SCM Simulations

The National Center for Atmospheric Research (NCAR) CCM3 SCM is used to investigate impacts of the derived large-scale forcing on SCM simulations. The large-scale total advective tendencies of temperature and moisture are specified from the derived forcing fields and the surface forcing is calculated by the model surface parameterizations. Figures 5a,b respectively, show model simulation errors in temperature and moisture fields. It is seen that the SCM does show sensitivity to the large-scale forcing in temperature. Compared to CONTL, RUC reduces the errors in the upper troposphere, but increases the errors in the middle and lower troposphere. For moisture, they produce similar results as CONTL.

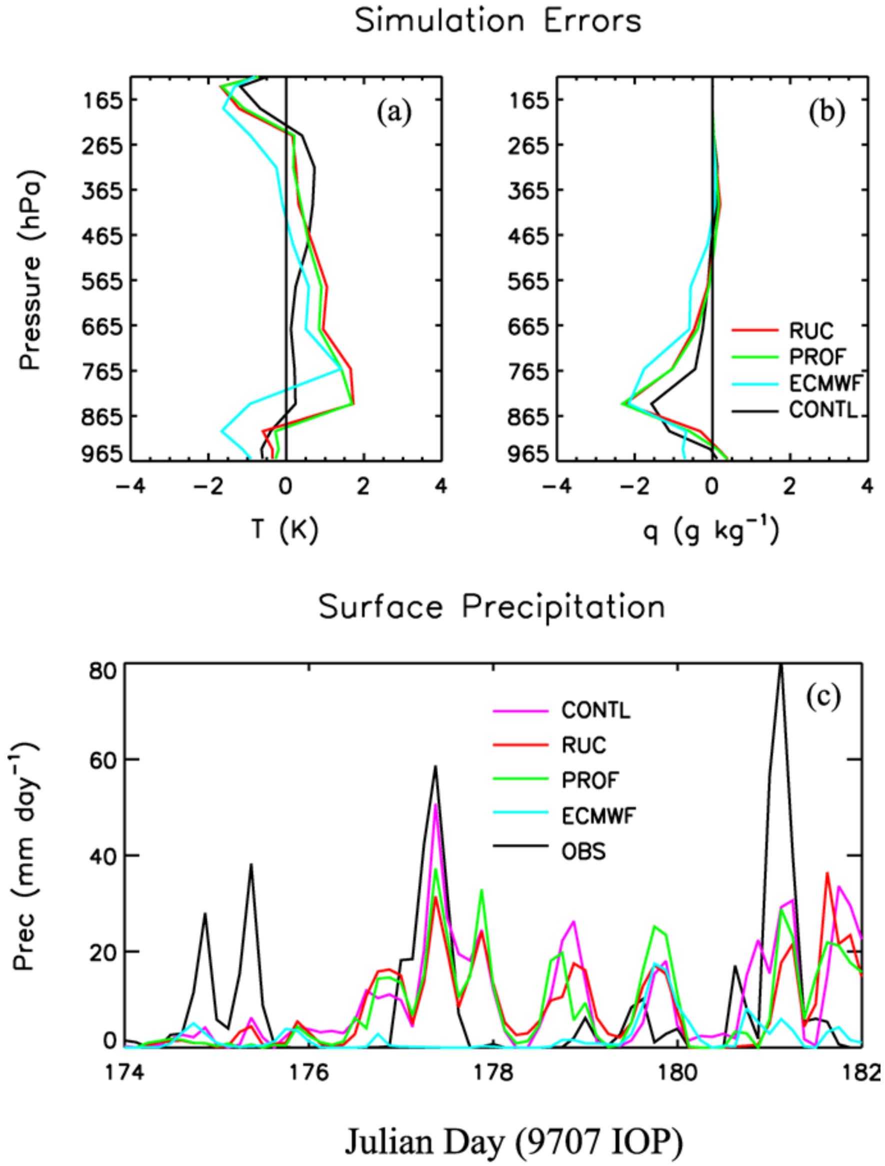

Figure 5. (a) Temperature biases, (b) moisture biases, and (c) surface precipitation rates produced from CCM3 SCM driven by the forcing derived from experiments CONTL, RUC, PROF, and ECWMF during the Summer 97 IOP.

For the simulated precipitation (Figure 5c), RUC and CONTL show very similar results. Results from PROF are very similar to RUC. However, the SCM with the ECMWF analysis forcing fails to reproduce almost all the observed precipitation events.

Summary

Compared to the large-scale forcing directly from NWP ECMWF analysis, the forcing derived from the new approach is physically consistent with the ARM surface and TOA measurements. Impacts of model physical parameterizations on the derived forcing are considerably reduced. The rms errors in the forcing derived from using RUC analysis are comparable to that with wind profiler data added and changes in some parameters (e.g., length scale) used in the interpolation scheme in CONTL. They are smaller than the range of observed temporal variability.

When driving the CCM3 SCM with the derived forcing from RUC, similar simulation results are obtained in moisture and surface precipitation rates but relatively larger differences are seen in temperature field in comparison with CONTL.

Due to impacts of model imperfect physical parameterizations and inability to capture mesoscale features, the forcing from the ECMWF analysis shows rather large differences compared with those derived from the ARM variational analysis. The CCM3 SCM with the ECMWF forcing fails to capture almost all the observed convective events. This suggests that forcing directly from NWP analysis needs to be used cautiously.

Future Plans

1. Use retrievals to improve vertical structures of temperature and moisture in the boundary layer.

2. Incorporate four times/day radiosondes at the central facility during times of no IOPs into the variational analysis system to further improve the results.

3. Derive advective tendencies of cloud liquid and ice water using the combined approach.

Acknowledgments

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