POTENTIAL IMPACT OF VISIBLE AND INFRARED SATELLITE MEASUREMENTS IN CLOUD DATA ASSIMILATION

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1. INTRODUCTION

Numerical weather prediction today is faced with the challenge to improve forecast skill on ever increasing range of spatial and temporal scales and of weather parameters traditionally difficult to model and initialize such as precipitation, soil moisture, surface fluxes and clouds. The initialization errors contribute significantly to the forecast skill. These errors may be reduced by means of direct assimilation of satellite observations strongly sensitive to the poorly initialized quantities. In this study we test potential impact of Visible and IR satellite radiance measurements on 3D cloudy state analysis using a mesoscale model with explicit cloud microphysics and a set of optical property and radiative transfer (RT) models.

Cloudy states consist of the 3D clouds and their environment simulated with the Regional Atmospheric Modeling System (RAMS, Pielke et al., 1992) . The clouds in RAMS are represented with mixing ratio and number concentration for 7 hydrometeor types (cloud droplets, pristine ice, aggregates, snow, graupel, hail and rain; Walko et al, 1995). The set of optical property and RT models suitable for use with an explicit cloud microphysics background is described in detail in Greenwald et al. (2002). It is referred to here as observational operator, for short denoted VISIROO.

2. ANALYSIS OF POTENTIAL INFORMATION CONTENT OF RADIANCE OBSERVATIONS THROUGH AN ADJOINT OF THE VISIROO

The VISIROO features two different RT models, both of which account for multiple scattering. One computes radiances at solar wavelengths, called the Sperical Harmonics Descrete Ordinate Method (SHDOM: Evans, 1998), and the other computes IR radiances using delta-Eddington two-stream approach (Deeter and Evans, 1998). The operator also makes use of anomalous diffraction theory (ADT; van de Hulst, 1981) to estimate cloud single-scattering properties used as input to the RT models. The ADT is used to obtain physical parameterizations for the optical properties rather than employing look up tables. The accuracy tests with these parameterizations showed that errors associated with the approximations are far less than the total errors expected in the assimilation of radiance observations resulting from combined background and observation errors. The benefits of using physical parameterizations in the optical properties part of VISIROO are: a) easy incorporation of different particle types b) straightforward development of the adjoint model and c) general application to satellite measurements with different spectral characteristics.

The complex problem of assessing quantitative information content of visible and IR measurements on explicit cloudy states was divided into two phases. First, we performed a sequence of sensitivity analyses of the separate components (cloud optical property models and RT models) using the associated adjoints of VISIROO. These tests were done for a set of idealized perturbations across a wide range of hydrometeor sizes and number concentrations to test the accuracy and feasibility of the adjoint analysis. Then the adjoint analysis was applied to three cases of cloudy weather evolution simulated by the mesoscale weather prediction model: a) continental stratiform low level liquid cloud deck, b) deep convective summer storm and c) winter storm.

The first set of sensitivity experiments showed that the adjoint analysis is valid for wide range of perturbations. The quantitative deviation from the nonlinear 'true' solution is largest (~30%) for large hydrometeors. Qualitatively, the adjoint sensitivity has the same sign of response in all ranges as the nonlinear response and represents an upper limit to the nonlinear perturbation amplitude.

The conclusion from the second set of experiments with the three simulated cases of mesoscale cloud systems, and pertaining to the impact of cloudy radiance in data assimilation, is that the Solar and IR observations in the cloudy regions are sensitive to the cloud properties in the entire column provided by the 3D mesoscale model simulations. Although the sensitivity is largest for the top cloud layers, as expected, these results imply potential to decompose the observed signal into 3D information in the data assimilation with the mesoscale models. This in turn could lead to better understanding of how to assimilate raw radiance observations in cloudy regions for the forecast systems which do not use cloud resolving models.

3. 4DVAR PRELIMINARY DATA ASSIMILATION RESULTS

A 4DVAR data assimilation algorithm was developed in CIRA with the purpose to study impact of satellite and other observations on the mesoscale weather analysis where the emphasis is on high temporal variability and hydrologic cycle. The algorithm is designated Regional Atmospheric Modeling and Data Assimilation System (RAMDAS). It currently incorporates RAMS, the associated RAMS-adjoint (Vukicevic et al., 2002) and a modified version of the Eta model 4DVAR algorithm (Zupanski et al, 2002ab).

The VISIROO has just been incorporated in RAMDAS to study assimilation of GOES imager observations. The alpha testing is, however, not complete at the time of this writing. We discuss instead preliminary results from the assimilation of synthetic cloud observations which were produced by the mesoscale model.

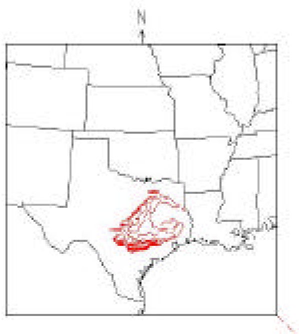

Figure 1: Forecast response (optimal – guess) in the Visible reflectance at the top of the atmosphere due to assimilation of synthetic 3D cloud mixing ration '"bservations". Assimilation period 3h.

The model simulated low level liquid cloud over Texas, described in Greenwald et al. (2002) was used in the experiment. The observations were represented with perturbed 3D cloud water mixing ratio at 1, 2 and 3 hours of the assimilation period. The perturbation had larger cloud mass in the SW corner of the cloudy region than the original forecast. Thus, the data assimilation experiment consisted of minimizing the mixing ration cost function within the assigned accuracy of the synthetic observations. Given the univariate observations (only the cloud mixing ratio was used) and the complexity and nonlinearity of the mesoscale model with explicit microphysics this experiment was non trivial. The 4DVAR results showed successful recovery of the "observed" cloud. The associated improvement (optimal – guess forecast) in the visible reflectance is presented in Figure 1. The largest change in the reflectance is at the cloud edge as expected from the adjoint sensitivity experiments for this case. This change in the model cloud was associated with appropriate change in the synoptic environment: slight cooling and positive pressure perturbation below the added cloud mass.

These preliminary results indicate that observations sensitive to the 3D cloud properties can be assimilated into mesoscale model and would impact not only the cloud state but also its environment at large. The results of assimilating actual GOES observations will be presented at the conference.

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ACKNOWLEDGMENTS

This work was supported by the DoD Center for Geosciences/Atmospheric Research at Colorado State University under the Cooperative Agreements DAAL01-98-2-0078 with the Army Research Laboratory and partially by the National Science Foundation grant NSF -DEB-9977066