P 3.8 **QUANTIFICATION OF ERRORS IN SATELLITE DATA ASSIMILATION**

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1. INTRODUCTION

The goal of this study is to characterize and quantify errors pertaining to atmospheric profiles, measurements and forward model that convert temperature and humidity profile into radiance for pre-selected spectral bands of an instrument. The satellite data assimilation method finds analysis solution by minimizing errors. It requires an accurate specification of error covariances of all related components both in profiles and radiances. We use atmospheric profiles from ARM/CART Southern Great Plain (SGP) site at Lamont, Oklahoma as 'ground truth' to simulate GOES-8 sounder channel radiances. The forward model used in this study is the Community Radiative Transfer Model (CRTM) developed and used by NCEP for satellite data assimilation into operational NWP model. The transmittance model of CRTM is OPTRAN (McMillin, et al., 1995). Also collected are 18 channel GOES-8 sounder and 4 channel imager radiances within +/- 0.2 deg of the site along with model forecast (1,2,3,6,9,12-h) profiles from 20km Rapid Update Cycle (Benjamin et al, 2004).

2. DATA

The samples are collected for June 2002 and screened for clear cases by imposing standard deviation of GOES-8 imager channel 4 (window) be less than 0.8 deg K. We interchange radiance with brightness temperature.

2.1 Atmospheric Profiles

Atmospheric profiles at ARM/CART site have vertical resolution less than 1.0hPa reaching up to 20*hPa*. Balloon is launched 30min before the hour in every 3-h, and travels for about 100 *min* with sampling rate 2 *sec*. For information of Balloon Borne Sounding System (BBSS), see www.arm.gov/docs/instruments/static/bbss.html. It is not unusual to see the balloon is drifted out of the collocation condition of +/- 0.2deg from the launch site as seen in Fig.1. There has been concern about dry bias of the instrument, but it has been corrected since 2001 (Miller et al. 1999)

2.2 GOES-8 Radiance Data

The hourly GOES-8 sounder's scheduled scan is 1 *min* ahead of each hour at the site and about 20 field-of-views (*fov*) are collected. The GOES-8 imager data are also collected within the same sampling domain with sample size of 220 for channel 4 and 110 for channel 3 (moisture channel). The measurement time in the collected data is about 20 minutes after the hour. Both radiance data are locally received by GVAR station and processed in Forecast Systems Laboratory. Figure 1 shows an example of collocated data and their respective spatial resolutions and sample sizes. The mean value in each channel is being used to verify simulated radiances.

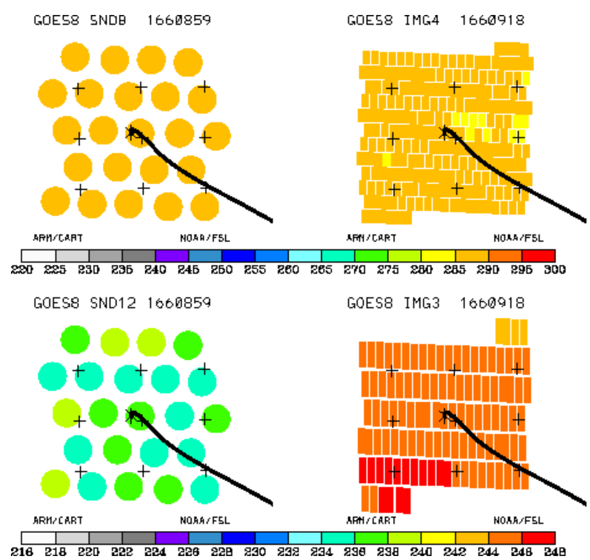

***Fig.1**. An example of collocated sample of GOES-8 sounder and imager field-of-view. Nine "+" marks are the locations of RUC20km grid locations and thick solid line is the balloon track. The valid time for the collocated data is 09 UTC of the day.*

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2.3 RUC20 forecast profiles

The prediction model of 20km Rapid Update Cycle (RUC) adopts hybrid vertical grid system merging terrain-following sigma coordinate and isentropic coordinate. Therefore, pressure is a predictive variable. We have collected all predicted (1, 2, 3, 6, 9, 12-h) variables of dynamic, thermodynamic and hydrometeor variables every hour at the grid-point nearest to the ARM/CART site during June, 2002.

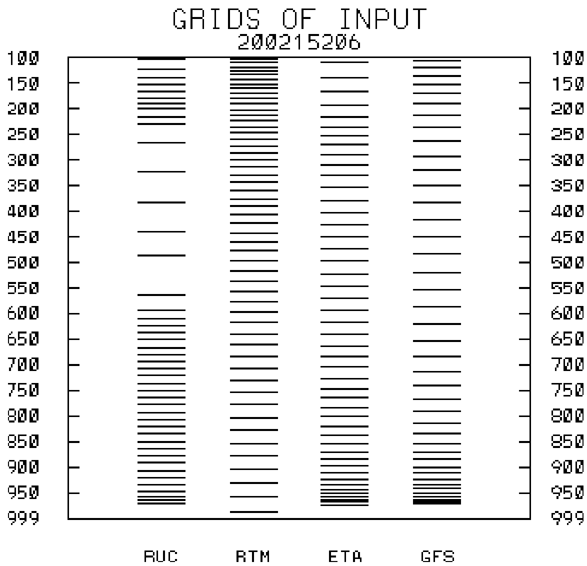

***Fig.2**. Four vertical grid systems used in the test of GOES sounder radiance simulations shown up to 100 hPa. Each grid system is converted into pressure grid for comparison of vertical resolutions.*

3. RADIANCE SIMULATION

We have designed a sensitivity experiment of vertical coordinates used in operational NWP models to CRTM such that any discrepancies among three simulated radiances will be as a result of different vertical coordinate. Three NWP models are; (1) RUC, 50 levels with top at about 50 hPa, (2) ETA, 60 layers with top at 25hPa, (3) GFS, 64 layers with top around 0.3hPa. For the consistency of the experiment, we made followings common to three radiance computations; 1) atmospheric profiles from ARM/CART site, 2) replacement of climate profiles above 30hPa level, 3) surface variables: pressure, temperature, and water vapor mixing ratio. Thus, by taking mean of high resolution ARM/CART profiles for the specified layer, the difference in input profile to CRTM will be difference in vertical resolution in the coordinate system. For example, for the layer of 500/550 hPa, RUC will represent deeper layer mean than layer of ETA.

The simulated GOES-8 sounder radiances were compared with observed radiances in clear cases. Figure 3 is an example of RMS differences of simulated radiances with RUC grid system and measured radiances. Two others are almost identical with fig. 3 except that of Channel 10. We conclude that errors due to vertical resolution are negligible and biases (circles in Fig. 3) are pertained to measurement and atmospheric profiles.

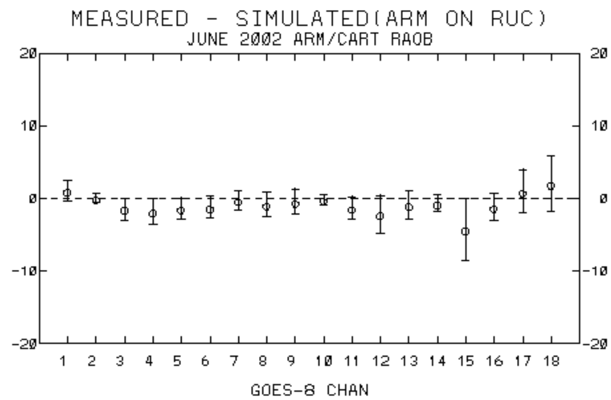

***Fig.3**. Statistics of differences (measured minus simulated) with RUC grids. Circles are mean and vertical bars extend twice standard deviations. Two other grids showed very similar statistics (not shown)*

4. OBSERVATION ERRORS

We have computed residuals of measured sounder radiances from the local mean within the sample domain (see Fig. 1). The number of residuals is number of *fovs* (20) times number of clear cases (57) during June 2002.

Figure 4 characterizes measurement errors. Top figure is mean of standard deviations. Large value indicates large variability within the sample domain. The middle box plot shows distribution of local residuals (residuals from local mean) of sounder data. Box plot shows the symmetry of the residual distribution and outliers. Channel 15 is affected by large negative outliers, hence the use of this channel in the assimilation is not desirable. The bottom figure is the inter-channel correlation from the local residual dataset. Apparently, there are strong inter-channel correlations. Channels of 5, 6, 7, 8 are highly correlated (greater than 0.4), so is a set of channels 10, 11 and a set of 16, 17, 18. The practice of data assimilation sets inter-channel of observation error covariances to zero.

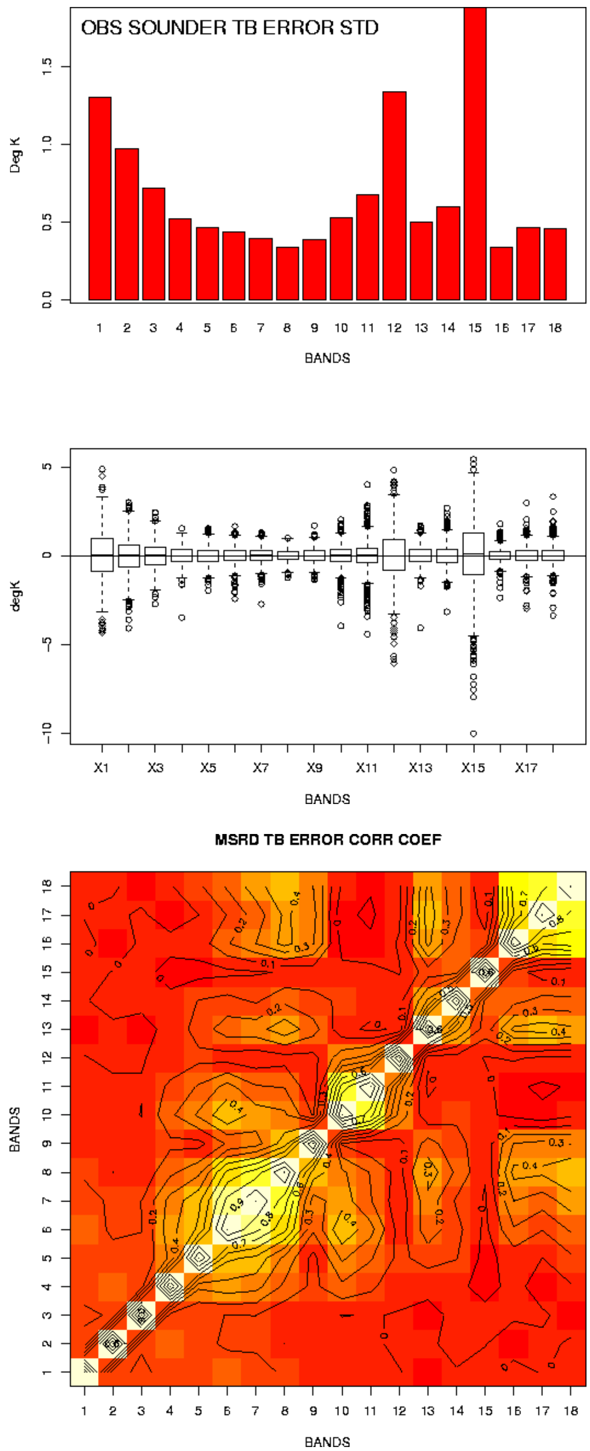

***Fig.4**. Statistics from the local residuals of measured radiances. (Top) Mean of local standard deviation, (Middle) Box plot of local residuals, (Bottom) Inter-channel radiances residual error correlation coefficients. Apparently certain channels are highly correlated and they have to be used in the data assimilation.*

Assumption of zero error correlations is tolerable in infra-red channels (5, 6, 7, 8) because errors are already small (less than 0.5 degK), but moisture channels 10 and 11 (greater than 0.5 deg K) will adversely affect the analysis.

5. BACKGOUND ERRORS

The RUC 1h forecast profiles at the grid point nearest to ARM/CART site were compared with BBSS profiles. All the clear cases consistent with analysis of radiances were used for calculating forecast error statistics of variables of temperature (deg K), water vapor mixing ratio (g/Kg), and relative humidity (%).

Figure 5 shows mean difference (left vertical line) and the rms differences (right vertical line) of RAOB temperature profiles of BBSS minus 1h RUC forecast at the native RUC vertical grids. As expected, temperature at the top model level is not represented well. The unusually large forecast error near surface is caused by forecast problem during summer night over land.

The RUC 1h forecast profiles were simulated for GOES-8 sounder radiances, and compared with measured radiances the same way as described in section 3. Any bias error of forecasts (Fig. 5) will have to be shown in radiance error. Figure 6 shows statistics of radiance differences of measured minus simulated using RUC forecast profiles.

Comparison between Figs 5 and 6 reveals a consistency between temperature bias and radiance bias. Throughout the atmosphere except

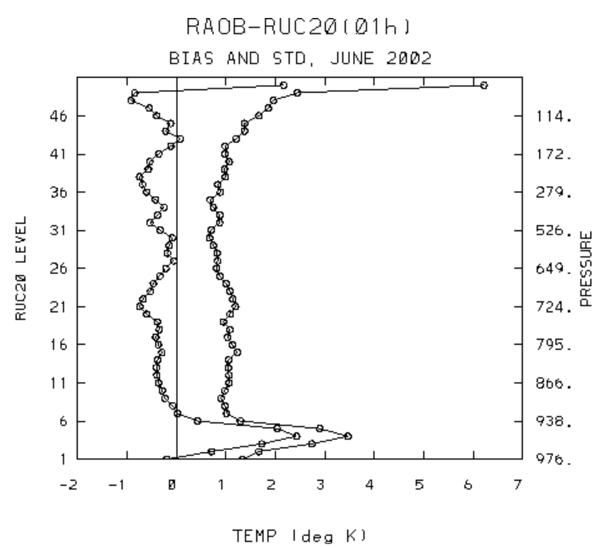

***Fig.5**. RUC 1h forecast error verified against RAOB of BBSS at ARM/CART site. Left line is bias, right line is std. Large boundary layer errors are caused by outliers which account about 20% of occurrences.*

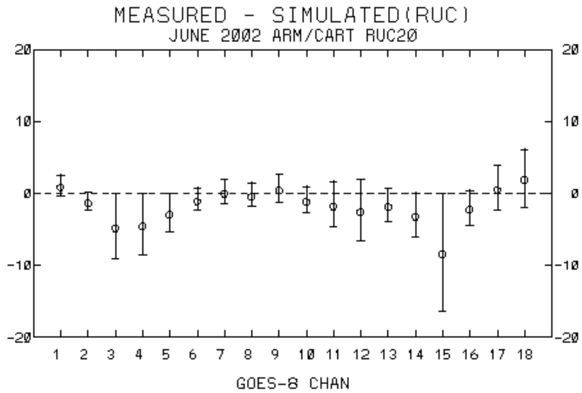

***Fig.6**. Statistics of differences (measured minus simulated) with RUC 1h forecast.*

boundary layer temperature forecast has warm bias against RAOB in Fig. 5, and simulated RUC radiances also show warm bias against measured radiances in infra-red channels.

6. SUMMARY

Satellite data have been an important contributor for improvement of initial analysis used for forecast thanks to advancement of variational assimilation method. Further improvement is possible with accurate specification of errors, errors in the measured satellite data, errors in the background profiles, errors in forward/adjoint model. The characterization of each component requires large resources. We have shown characterization of some components is possible without resorting to large resources.

The performance of CRTM (forward part) is shown to be stable with carefully designed experiment. The bias error in the profiles is consistent with bias error in the radiances. Yet, the inter-channel radiance error correlations are quite large among some channels. The dataset used in this study limited uncertainties by carefully collocating all necessary dataset. We plan to analyze polar orbiting satellite data is similar way.

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