Assimilation of cloudy ATMS radiances at NCEP

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In the past decade, with the advances of forecast models and the improvement of radiative transfer models, Numerical Weather Prediction centers have made steady progress towards utilizing cloudy radiances in addition to clear sky radiance observations (Geer et al. 2018). In the Gridpoint Statistical Interpolation (GSI) analysis system at the National Centers for Environmental Prediction (NCEP), the assimilation of cloudy radiances from the Advanced Microwave Sounding Unit-A (AMSU-A) microwave radiometer for ocean fields of view (FOV) became operational in the 4D hybrid Ensemble-Variational (EnVar) Global Forecast System (GFS) in 2016 (Zhu et al. 2016). Since then, an effort has been made in the expansion of the all-sky approach to use radiances from the Advanced Technology Microwave Sounder (ATMS). This work is currently being included in a real-time parallel for an upcoming operational implementation in 2019, and more detailed information can be found in Zhu et al. 2019.

ATMS has 22 channels and combines most of the channels from AMSU-A and the Microwave Humidity Sounder (MHS). With the MHS-like channels, this work also introduces water vapor channels into the all-sky approach. Normalized cloud water is used as the cloud control variable. Total cloud water is decomposed into liquid and ice cloud state variables based on a temperature-dependent empirical function. Only the radiances affected by non-precipitating clouds and clear-sky radiances are used, due to the lack of a snow and precipitation first guess from the original operational forecast model. The background error covariance is composed of the static term and another part generated from the ensemble forecasts, with 87.5% weight given to the ensemble part.

Since ATMS has varied beam widths, the ATOVS and AVHRR Pre-processing Package (AAPP, NWP SAF/EUMETSAT) with remapping and spatial averaging is applied to all 22 channels, instead of just channels 1–16 in the operational GFS system, to convert the beam widths to 3.3^{o} in the all-sky approach. It has also been noticed in this study that ATMS radiances have large departures from the first guess (OmF) around coastlines and cryosphere boundaries. The capability of modeling surface properties (including land/sea fraction) based on the FOV size and shape is exercised for the all-sky ATMS radiances, and the ATMS radiances over mixed surface type locations are excluded.

With the introduction of MHS-like channels into the all-sky framework, the scattering effect increases due to the higher frequencies. In the CRTM, however, non-precipitating clouds (cloud liquid water and cloud ice) are assumed to be small particles in comparison to microwave wavelengths; thus the scattering is not considered by design when there is no information about snow, graupel and precipitation. Considering the consistency between the observations and simulated radiances from the CRTM, a new observation scattering index (SI) is constructed to exclude those radiances that are affected by strong scattering. SI is defined as the difference in cloud effects between channels 16 and 17, where the cloud effect is calculated as the difference between the observed brightness temperature and the brightness temperature without hydrometeor information being considered. Observations from channels 1–7 and 16–22 with $|SI| > 10.0K$ are excluded in this study. In the final gross error check, bias-corrected ATMS radiances with OmF magnitude larger than 10.0K or three times the observation error, whichever is smaller, are excluded from the data assimilation system.

The ATMS radiances that pass the quality control procedures are bias corrected in the GSI's variational bias correction framework (Derber and Wu 1998; Zhu et al. 2014), but by using a selected data sample in the bias coefficient derivation to avoid the impact of large model errors. The observation error of the ATMS radiance is assigned as a function of the symmetric cloud amount (Geer and Bauer 2011) followed by the situation-dependent observation error inflation procedure (Zhu et al. 2016), where the two most important physicallybased factors are cloud placement difference and cloud liquid water difference between the first guess and observation.

Overall, the assimilation of ATMS radiances in the all-sky approach improves the consistency of microwave radiance OmFs among different sensors. An example is given in Fig. 1 with ATMS channel 16 and its closest matches: MHS channel 1 and AMSU-A channel 15. The bias correction is seen to have a big impact on the OmF patterns. After bias correction, while the OmF patterns for ATMS channel 16 and MHS channel 1 are similar in the clear-sky approach, they are significantly different in several regions from the OmF patterns of ATMS channel 16 and AMSU-A channel 15 in the all-sky approach. One such region is to the west of the South American continent. Issues are identified in the clear-sky approach of operational MHS and ATMS radiance assimilation, with the possible leaking of radiances affected by clouds into the GSI or an incomplete removal of cloud effects. As a small improvement in the fits to rawinsonde specific humidity data is observed to persist in the 48h forecast, the assimilation of all-sky ATMS radiances is found to have an overall neutral impact on the model forecast skill, with a small improvement in the Southern Hemisphere mainly at day 3. The all-sky ATMS radiance assimilation will become operational in the upcoming GFS implementation in 2019.

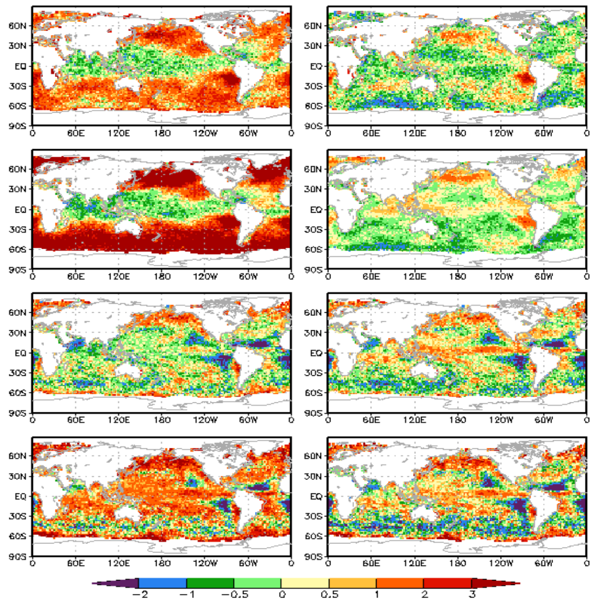

Figure 1 One-month averaged OmF over water of June 2015: before (left column) and after (right column) bias correction for MHS channel 1 (row 1) and ATMS channel 16 (row 2) in the clear-sky approach, and ATMS channel 16 (row 3) and AMSU-A channel 15 (row 4) in the all-sky approach. The unit is K.

Although initial efforts made to account for the non-Gaussian distribution of innovations using an adaptation of variational quality control based on a super-logistic distribution (Purser 2018) have not so far been successful, future work will continue on this topic. Since the all-sky AMSU-A and ATMS radiance assimilation are currently implemented only over ocean FOVs, a research study on the all-sky radiance assimilation over land is also underway. As the forecast models are transitioning to the Finite-Volume Cubed-Sphere Dynamical Core (FV3) model with more advanced physics at NCEP, the choice of cloud control variables will be examined. Meanwhile, the tests on the inclusion of subgrid-scale clouds and precipitation in the all-sky radiance assimilation are ongoing.

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