Advanced Techniques for Satellite Microwave Data Assimilation and Application to Global and Regional NWP

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1. Introduction

Here, we present recent efforts supported by the JCSDA to advance and increase satellite observations assimilated within the GSI analysis system used to initialize both the Global Forecast System (GFS) model and regional Hurricane WRF (HWRF) model at NOAA NCEP.

Specifically, the use of a 1d-variational (1DVAR) preprocessor within the GSI will be discussed. The 1dvar preprocessor is applicable to current and future microwave satellite sounders and imagers including those from POES and MetOp AMSU-A and MHS, NPP/JPSS ATMS, DMSP F16-F20 SSMI/S, GCOM-W AMSR2, and GPM GMI. The capability of the 1DVAR preprocessor includes increased quality control of the microwave radiances to be assimilated, and also to provide surface emissivity or hydrometeor (cloud, rain) information to the assimilation system which may increase the number and types of observations that can be assimilated. The information provided by the 1DVAR preprocessor could be considered complimentary to ongoing GSI development efforts associated with the assimilation of surface sensitive channels over non-ocean surfaces as well as cloudy radiance assimilation. Advancement in the assimilation of these types of observations should have significant positive impact on both global NWP forecast and regional NWP and tropical cyclone track and intensity forecasts. Current status of the implementation of the 1dvar preprocessor in the GSI will be shown, along with examples and benefits from the quality control information it may provide, followed by discussion of its overall utility in data assimilation.

2. Description of the 1DVAR Preprocessor

The 1DVAR algorithm applied here is also known as the Microwave Integrated Retrieval System (MiRS). It is based on a physical approach using the CRTM for its forward and jacobian operators. As such, the retrieval is valid in all cases the CRTM is valid in, including all weather conditions and over all surface types. The state vector supports the retrieval of temperature, water vapor, and hydrometeor profiles, along with surface emissivity and skin temperature depending on the information content of the sensor data being applied. A post-processor then derives products from the core-retrieval, such as TPW or Rainfall Rate.

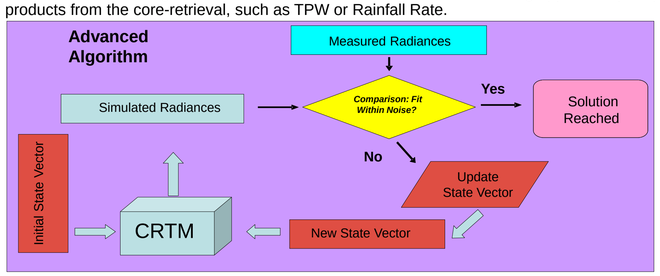

Figure 1. Schematic of the MiRS retrieval algorithm iterative process. The initial state vector is a regression algorithm applied on the observed brightness temperatures, but could also come from a climatological background or NWP model.

To reach the iterative solution, the algorithm seeks to minimize the cost function

$$J(X)=\left[\frac{1}{2}(X-X_0)^T\times B^{-1}\times(X-X_0)\right]+\left[\frac{1}{2}(Y^m-Y(X))^T\times E^{-1}\times(Y^m-Y(X))\right]$$

where X in the 1st term on the right is the retrieved state vector, and the term itself represents the penalty for departing from the background X_0, weighted by the error covariance matrix B. The 2nd term represents the penalty for the simulated radiances Y departing from the observed radiances Y^m, weighted by instrument and modeling errors E. This leads to the iterative solution

$$\Delta X_{n+1}=\left\{BK_n^T\left(K_nBK_n^T+E\right)^{-1}\right\}\left[\left(Y^m-Y(X_n)\right)+K_n\Delta X_n\right] \quad ,$$

where ΔX is the updated state vector at iteration n+1, and K is the matrix of Jacobians which contain the sensitivity of X (parameters to retrieve) to the radiances.

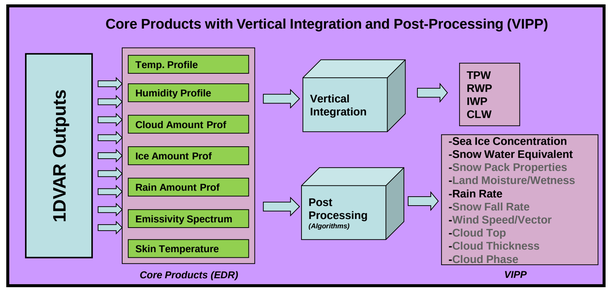

Figure 2. 1DVAR core and post-processing products. Core products are retrieved simultaneously as part of the state vector. VIPP products are derived through vertical integration (hydrometeors), catalogs (SIC, SWE), or fast regressions (Rain Rate).

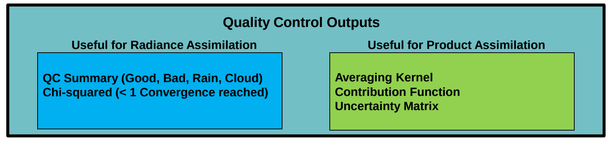

Figure 3. The 1DVAR outputs several metrics useful for data assimilation, including quality control flags, convergence metrics, and averaging kernel.

3. NOAA (JCSDA) Testbed Activities

The tasks for implementing the 1DVAR in the GSI, fine tuning its application, and testing impact on radiance assimilation and forecasts will involve 3 phases. Optimization of the code and operational readiness define the 4th phase pending demonstrated improvement or use as in offline utility in the GSI. Phase 1 is completed.

Phase 1	Phase 2
✓ Conversion of MIRS 1DVAR algorithm to a subroutine ✓ Integration of the 1DVAR subroutine into the GSI library (with linking to MIRS library) ✓ Interface 1DVAR subroutine with GSI (read* and/or setuprad routines) ✓ Test interface	➔ Apply and optimize quality control output from MIRS (chi-squared, QC flags, cloud detection) in GSI ➔ Assess impact on radiance assimilation (O-B, O-A, bias, number of obs, etc) ➔ Assess impact on regional/global forecasts
Phase 3	**Phase 4**
➔ Explore application of 1DVAR retrieved surface emissivity in radiance assimilation ➔ Assess impact on surface-sensitive channels assimilation ➔ Explore use of retrieved cloud/rain for assimilation of cloudy/precipitating radiances or rain rates ➔ Assess impact on regional/global forecasts	➔ Extend 1DVAR to parallel computing capability ➔ Optimize codes and interfaces ➔ Code reviews, official implementation in GSI/operations* *Contingent on demonstrated positive impacts in Phase 2/3

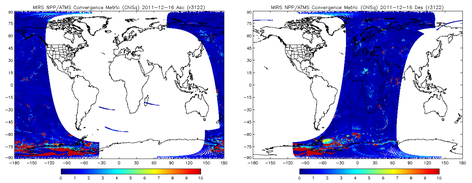

Figure 4. Chi-squared convergence metric output from the 1DVAR preprocessor in the GSI for 1 GDAS cycle. The 1DVAR was applied to NPP ATMS and is separated into ascending (left) and descending (right) nodes for display. Values greater than 1 denote observations which may be difficult to assimilate due to precipitation or mixed surface signals in the radiances that cannot be properly modeled.

4. Potential Impacts

The primary objective of the 1DVAR preprocessor is to increase to number and quality of satellite observations (radiances, products) in data assimilation systems to improve medium-range NWP at both regional and global scales, with a focus on surface sensitive channels and cloudy/rainy radiances. The improvement of forecasts for extreme weather events is also paramount.

The 1DVAR preprocessor can provide a retrieved surface emissivity for all channels and surfaces and increase the number of assimilated surface-sensitive channels.

Over non-ocean surfaces, clear-sky passive microwave radiances are difficult to assimilate due to the lack of knowledge about surface properties which are generally characterized by surface emissivity. Current assimilation systems combine emissivity catalogs with land emissivity models to provide a surface emissivity value for each grid point. In most cases, large differences between simulated and observed radiances (dTB) at these points, are due to error in the assumed surface emissivity. Typically quality control procedures set a dTB threshold of 10-15 K to exclude these observations from assimilation. This is illustrated in the bottom row of Figure 5.

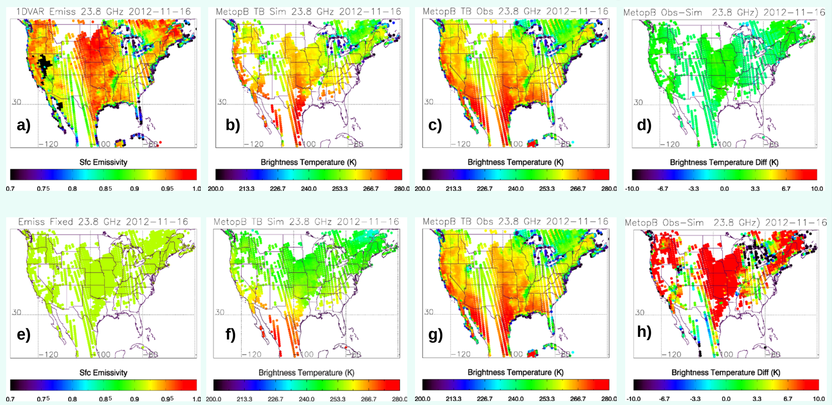

Figure 5. Top row: a) 1DVAR retrieved (dynamic) surface emissivity from MetopB, b) corresponding brightness temperature simulation, c) observed brightness temperature, and d) observed minus simulated brightness temperature difference (dTB). Bottom row: Same as the top row but with fixed surface emissivity shown in e). Small dTB shown in d) could lead to an increase in assimilated observations compared to h) where dTB would likely exceed most QC thresholds.

A 1DVAR preprocessor can provide information on cloud liquid water content (CLW) to flag cloudy/rainy radiances for QC.

For clear-sky radiance assimilation, it is necessary and critical to remove all observations containing clouds and precipitation since the radiative transfer model (RTM) biases are not well characterized in these conditions (nor are they equivalent to clear-sky radiance bias).

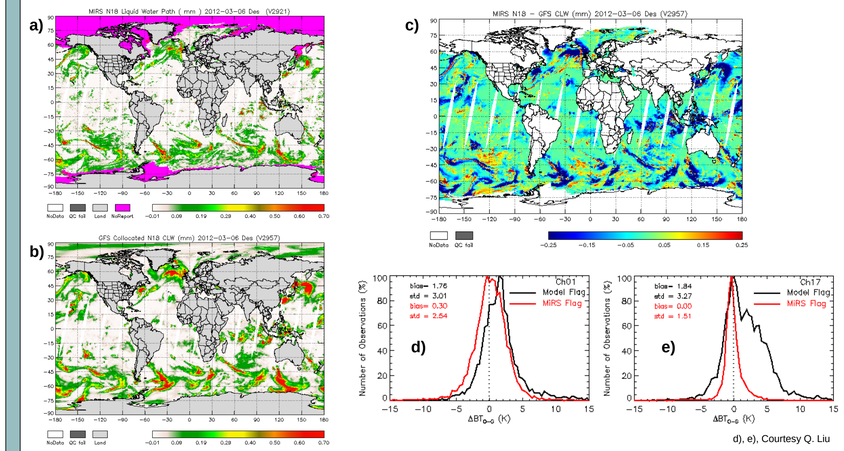

Figure 6. a) 1DVAR retrieved CLW from NOAA-18, b) collocated GFS 6-hr forecast CLW, c) difference between 1DVAR and GFS cloud. Histograms of the dTB for AMSU-A channel 1 (d) and MHS channel 2 (e) using the GFS for cloud filters (black) and 1DVAR for cloud filters (red). Using enhanced cloud filtering of the 1DVAR shows generally narrower histograms with less bias, particularly at 157 Ghz. Operationally, the GSI uses an alternate TB-based cloud detection algorithm.

A 1DVAR preprocessor can provide information on cloud, rain and ice to flag cloudy/rainy radiances for cloudy/rainy radiance or rainfall rate assimilation.

Passive microwave radiances are sensitive to non-precipitating cloud over ocean, and most precipitation events over ocean and land. 1DVAR retrieved hydrometeor amounts can be used to derive instantaneous rainfall rates to be used as observations in data assimilation. Assimilated rainfall rates can then be used to reverse parameterize model state variables and reduce forecast spin-up times as well as improve accuracy.

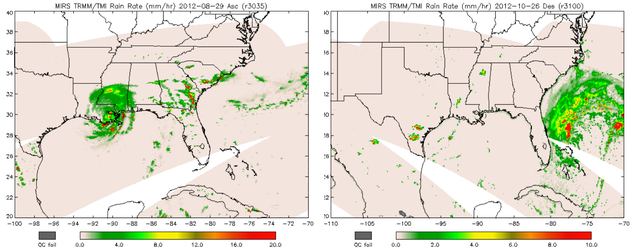

Figure 7. 1DVAR retrieved rainfall rate from TRMM TMI over Hurricane Isaac (left) and Hurricane Sandy (right).

5 . Collaborations and Future Work

Collaborations

- Collaboration with NCEP EMC
  - GSI radiance assimilation team
  - HWRF team

Future Work

- Optimize use of 1DVAR quality control metrics for radiance observation selection and assimilation
- Use surface emissivity to increase number of surface-sensitive channels assimilated
- Explore assimilation of 1DVAR hydrometeor-based rainfall rate in regional and global models to improve hurricane track and intensity forecasts.