1DVAR Data Assimilation of Cloudy and Precipitation-affected Satellite Observations

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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 the Global Forecast System (GFS) model at NOAA/NCEP. Specifically, the use of the Multi-Instrument Inversion and Data Assimilation Preprocessing System (MIIDAPS) within the GSI will be discussed.

This 1DVAR preprocessor is applicable to current and future microwave satellite sounders and imagers including POES and MetOp AMSU-A and -B, NOAA/JPSS-1/2/3/4/5/6/7/8/9/10/11/12/13/14 AMSR2 and GPM. The capability of the 1DVAR preprocessor includes increased quality control of the microwave radiance 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-icean surfaces as well as cloudy radiation attenuation. Advancement in the assimilation of these types of observations should have significant positive impact on global NWP forecasts.

Description of MIIDAPS

• The 1DVAR preprocessor is based on Microwave Integrated Retrieval System (MIRS) technology.
• A physical approach using the Community Radiative Transfer Model (CRTM) for forward and jacobian calculations.
• Valid in all-weather conditions and over all surfaces.
• State vector elements include profiles of temperature, water vapor, cloud, rain, and ice, as well as the skin temperature and surface emissivity.

To reach the iterative solution, the 1DVAR algorithm seeks to minimize the cost function:

\[ J(X) = \frac{1}{2} (Y - X)T(Y - X) + \frac{1}{2} \Delta X^T \Delta X \]

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 \( Y_0 \), weighted by instrument and modeling errors \( E \). This leads to the iterative solution

\[ \Delta X_{n+1} = -K_n(Y_n - X_n) \]

where \( \Delta X \) 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.

Integration with GSI

The 1DVAR is called from the astropal module to preprocess all observations ingested by GSI.
• Called at first iteration of each outer loop.
• Use GSI background fields as first-guess/background to 1DVAR.
• Highly tunable (channel selection, max number of iterations, Delphi/NSIDC variances).
• Use QC outputs in GSI to determine which observations are assimilated.
• Use cloud/rain/ice 1DVAR analysis fields for cloud screening, bias correction, etc.
• Use surface emissivity as input to background field simulation rather than model or atlas.
• Namelist parameter to control if 1DVAR is called or not (turned off for EnKF).
• Use GSI background fields as first-guess/background to 1DVAR.

Extension of MIIDAPS to IR and Active Sensors

• MIIDAPS was extended to hyperspectral IR sensors including AIRS, IASI, and CrIS.
• The capability was added to use combined IR/MMR inversions with CTS/ATMS.
• MIIDAPS was also extended to MetOp IR and MW sensors like space-borne. The extension is valid for all parameters in the MW state vector.
• Extension in the future will include active microwave sensors like space-borne.

Future Work

• Finalize state vector extension to the effective radiances.
• Finalize extension to IR and active MW sensors (CrIS).
• Explore extension to MW sensors (CrIS).
• Use satellite observation error estimates (equipped in 1DVAR) to carefully weight microwave observations similar to microphysical/optical properties.
• Utilize MIIDAPS for a background adjustment for global NWP.
• Explore the adjustment of background fields in advance of precipitation-sounding satellite observations prior to assimilation.
• Also for using other 1DVAR output for boundary conditions of background simulation, like surface emissivity.

Sensitivity to Hydrometeor Assumptions

• The 1st attempt inversion of hydrometeors includes profiles of non-precipitating cloud only (pure absorption/emission).
• The 2nd attempt inversion of hydrometeors includes profiles of rain and graupel-ice (absorption and scattering).
• All other elements are in the state vector for each attempt (e.g. Q, Tskin, Surface Emissivity).
• Forward and TL operator, CRTM 2.1.3, allows for specification of hydrometeor effective radius \( r_e \), but has a fixed particle size distribution (PSD) and density.
• Hydrometeor effective radius fixed for each layer, and does not vary during the inversion.

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Figures.

- MIIDAPS inversion of CrIS/ATMS brightness temperatures over Hurricane Iselle and Hurricane Julio on August 7, 2014.
- Top: Effective radius fixed to 500 µm for rain and graupel during inversion.
- Bottom: Effective radius fixed to 1000 µm for rain and graupel during inversion.

More figures...