Benefits of Using a Variational Preprocessing Approach for the Assimilation of Satellite Radiances: An Application to Data Assimilation in Environmental Data Fusion

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Objective and Motivation

• The problem:
  • Satellite observations, especially those sensitive to moisture variables, tend not to be assimilated very well in data assimilation systems
    • Observations are often QC-ed out where the background differs too much from the observation, and/or in regions where observations tend not to be modeled well (e.g. cloudy or precipitating areas)
  • The result is an analysis that sticks to the background and contains displacements, especially in moisture fields
O-B (no bias corr): ATMS Ch 18

Standard Data Assimilation: GSI 4DEnsVar 20151223 12Z

O-B no/bc (K)

ChiSq: Water Vapor Channels

TPW: Analysis - ECMWF

GSI QC Flag

N Chan Assim: Water Vapor

Large dipoles / displacements in TPW where obs failed QC (mostly for gross check, emissivity, and precip)
Objective and Motivation

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    • Observations are often QC-ed out where the background differs too much from the observation, and/or in regions where observations tend not to be modeled well (e.g. cloudy or precipitating areas)
  • The result is an analysis that sticks to the background and contains displacements, especially in moisture fields

• The goal:
  • Lessen dependence on the background in the analysis:
    • Create an analysis that is more informed by satellite observations, especially for moisture variables
    • Address the problem of displacements in the analysis fields
  • This can be achieved by putting satellite data through a preprocessor prior to assimilation: MIIDAPS (The Multi-Instrument Inversion and Data Assimilation Preprocessing System)
MIIDAPS Background

- **MIIDAPS: The Multi Instrument Inversion and Data Assimilation Pre-Preprocessing System**
- 1DVar preprocessor based on the MiRS (Microwave Integrated Retrieval System) algorithm, which has been operational at NOAA since 2007:

\[
\begin{align*}
\text{Minimize the cost function:} & \quad J(\mathbf{X}) = \frac{1}{2} (\mathbf{X} - \mathbf{X}_0)^T \mathbf{B}^{-1} (\mathbf{X} - \mathbf{X}_0) + \frac{1}{2} (\mathbf{Y}^m - \mathbf{Y}(\mathbf{X}))^T \mathbf{E}^{-1} (\mathbf{Y}^m - \mathbf{Y}(\mathbf{X})) \\
\text{Solve for:} & \quad \frac{\partial J(\mathbf{X})}{\partial \mathbf{X}} = \nabla J(\mathbf{X}) = 0 \\
\text{Assume linearity:} & \quad \mathbf{y}(\mathbf{x}) = \mathbf{y}(\mathbf{x}_0) + \mathbf{K} [\mathbf{x} - \mathbf{x}_0] \\
\text{Iterative solution:} & \quad \mathbf{X}_{n+1} = (\mathbf{K} \mathbf{n} \mathbf{B}^T + \mathbf{E})^{-1} \left( \mathbf{Y}^m - \mathbf{Y}(\mathbf{X}_n) + \mathbf{K} \mathbf{n} \mathbf{X}_n \right)
\end{align*}
\]

This methodology can be applied to all parameters, including hydrometeors.
MIIDAPS Background

- **MIIDAPS**: The Multi Instrument Inversion and Data Assimilation Pre-Preprocessing System
  - Methodology doesn’t vary based on platform; approach could be extended to any sensor (microwave or infrared)
  - Approach is valid over all surfaces and in all-sky conditions
  - Can use climatology or an NWP field as a first guess/background to the 1DVar
  - Has several benefits, including:
    - Highly tunable retrievals
    - The potential to provide consistent quality control for a DA system
    - The ability to be run in a parallel in an HPC environment

ATMS in simulation, Verified against the Nature Run

<table>
<thead>
<tr>
<th>No Additional Tuning</th>
<th>Decrease Instrument Error</th>
<th>Decrease EOFs for Temperature</th>
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</table>

MIIDAPS retrievals can be tuned independently for each sensor to optimize performance.
Low chi square values indicate that MIIDAPS converged well. Cloud or precipitation is often present where chi square values are high; information that can be useful in informing QC.
## MIIDAPS Products and Performance

### MIIDAPS Satellite Products

<table>
<thead>
<tr>
<th>Instrument/Type</th>
<th>T(p)</th>
<th>Q(p)</th>
<th>SST/LST</th>
<th>TPW</th>
<th>Cloud &amp; Ice Amt</th>
<th>Precip</th>
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### Information Content / Confidence

- **Moderate Information Content / Confidence**
- **Good Information Content / Confidence**
- **Not Enough Information Content for Retrieval**
MIIDAPS Products and Performance

MIIDAPS removes horizontal and vertical displacements in model background temperature fields to fit them more closely to observations.

ATMS 54 GHz Residual $T_b$

500 mb Temp: MIIDAPS - ECMWF

Temp Profile: MIIDAPS - ECMWF

Hurricane Matthew
MIIDAPS Products and Performance

MIIDAPS moves background moisture fields closer to moisture fields retrieved from observed data.
MIIDAPS Applications

• MIIDAPS as a preprocessor for satellite data assimilation:
  • Retrieved products (e.g. temperature, moisture profiles) can be used to adjust the model background prior to assimilation
    • Tunable, depending on the sensor
  • Retrieved products can be used to inform/constrain unanalyzed variables (not part of the state vector, but impact radiance simulation) in the assimilation system
  • Convergence metrics and other products can be used for universal quality control in the assimilation system
    • More accurate quality control and more observations assimilated
MIIDAPS Applications

• Data Fusion:
  • Can use MIIDAPS as a preprocessor for data assimilation, with options to use background adjustment, MIIDAPS QC, and variable constraints
  • High resolution (25km) global hourly analysis informed by satellite data over the atmospheric column; useful for situational awareness

Water Vapor Statistics: DA/DF versus ECMWF

Data Assimilation Analysis

Data Fusion Background

Data Fusion Adjusted Background (MIIDAPS pre-processing)

No Background Adjustment

With Background Adjustment

ChiSq: Water Vapor Channels

Satellite Coverage

Adjusted Background - ECMWF

Unadjusted Background - ECMWF
Conclusions and Future Work

• MIIDAPS is a sensor-agnostic tool:
  • Capable of retrieving geophysical parameters from satellite data; retrievals are highly tunable
  • Can serve as a preprocessor in data assimilation
  • Valid for use with both microwave and IR sensors

• MIIDAPS results are valid over all surface types, and in all-sky conditions

• MIIDAPS has been shown to correct displacements in modeled fields
  • Able to adjust a data assimilation background to more closely fit the observations

• Work is ongoing to validate MIIDAPS as a preprocessor in the Data Fusion system

• Work is planned to test analyses produced using MIIDAPS as initial background for NWP