Utilizing All-sky Satellite Radiance Data to Improve GEOS-5 Clouds, Precipitation, and Water Vapor Analyses and Forecasts

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GEOS-5 Modeled Clouds
(Courtesy of Bill Putman, NASA GMAO)
Satellite data assimilation in GEOS-5 analysis system

Why all-sky satellite radiance data?

Challenges in developing all-sky data assimilation system

Impacts of all-sky GPM Microwave Imager (GMI) data on GEOS-5 Clouds, Precipitation, and Water Vapor analyses and forecasts

Future work
Atmospheric Data Assimilation

Background Fields

Observation Data

GEOS-5 Data Assimilation System (Hybrid 4D-EnVAR algorithm)

6hr window

GEOS-5 Model Forecasts

Analysis
Data Currently Assimilated In GEOS-5 System

- AMSU-A (in NOAA 15, 18, 19, Aqua, METOP-A & B AMSU-A)
- MHS (in NOAA 18, METOP-A & B)
- ATMS (in Suomi NPP)
- SSMIS (in DMSP F17, F18)

- AIRS (in Aqua)
- IASI (in METOP-A & B)
- HIRS (in METOP-A)
- CrIS (in Suomi NPP)

- SEVIRI (in METEOSAT-10)
- GOES13, GOES15
- GOES-13
- GOES-15

- Conventional Data: Sonde, Buoy, Ship data, Aircraft data
- GPS Radio Occultation: refractivity
- SatWind retrieved wind vectors
Motivation and Objectives

- Color map: GPM Microwave Imager 37 GHz brightness temperature observations
- Black symbols: Locations of lower/middle troposphere observing satellite data from AMSU-A, MHS, and AIRS that are currently assimilated in the GEOS-5 FP system
- Large number of radiance data containing cloud and precipitation signal are currently discarded.
- We want to improve NWP initial conditions especially in cloudy and precipitating regions by assimilating satellite data in these regions.

Hurricane Andres and Blanca (6/3/2015, 09Z-15Z)
Satellite Radiance Observations in Cloudy/Precipitating Sky Condition

IR sensors

Microwave sensors

Indirect estimation of precipitation using information from the cloud top.

- Poor temporal and horizontal resolution
- Long wavelengths allow microwave signals directly interact with precipitating particles.
Challenges: Assimilation of Satellite Radiance Data

\[ x_{\text{analysis}} = x_{\text{bkg}} + K \left( y_{\text{obs}} - H(x_{\text{bkg}}) \right) \]

\[ K = \frac{\sigma_{\text{bkg}}^2}{\sigma_{\text{bkg}}^2 + \sigma_{\text{obs}}^2} \]

“Observation operator”
(a radiative transfer model) converting \textit{model space} into \textit{observation space}

- **B**: background error variance
- **R**: Observation error variance
Challenges in simulating observations in precipitating regions using RT model

Monthly RMS of $(TB_{\text{Obs}} - TB_{\text{Model}})$

GPM Microwave Imager 166 GHz
Challenges: Background Errors

STD of Cloud Liquid at 850 hPa

STD of Rain Water at 850 hPa
Case Study: Hurricane Melor (Dec 2015)

GMI Observations

GEOS-5 forecast: 850hPa Rainwater

2015/12/12 09Z

2015-12-12: 09Z~15Z
Case Study: Hurricane Melor (Dec 2015)

Analysis - Background
Comparisons of Water Vapor Analyses

- All-sky GPM Microwave Imager (GMI) data increase lower tropospheric humidity in the GEOS analyses.
- The data generally have a significant impact on the lower tropospheric humidity and temperature analyses, especially in the tropics, which leads to improved forecasts of these quantities.
In addition, a noticeable positive impact of all-sky GPM Microwave Imager (GMI) assimilation on hurricane track forecasts was identified for Hurricane Melor, which occurred in the western Pacific during Dec. 2015.

More hurricane case studies to understand the impacts of all-sky radiance data are underway.
Comparisons of GEOS-5 Cloud Analyses

Monthly Mean Cloud Fraction Difference

\[ \text{CloudFrac}_{\text{AllskyGMI}} - \text{CloudFrac}_{\text{NoGMI}} \]

Low Cloud

High Cloud

December 2015

Noticeable impact of all-sky GPM Microwave Imager (GMI) assimilation on cloud fraction especially for middle and high cloud during Dec. 2015.
Work in Progress and Future Plans

- Apply all-sky framework to all other microwave observations such as AMSR-2, MHS, AMSU-A, ATMS, ...

- Extending to IR radiance data and active sensors’ data such as reflectivity data from CloudSat and GPM Dual Frequency Rada (DPR).

- Incorporate updates of CRTM into All-sky data framework which will allow to utilize **Cloud Fraction from GEOS-5 Microphysics** in simulating satellite radiances

- And more …
Back-up Slides
Difference of Analyses (Exp – Control) : 12 Dec 2015, 12UTC
Comparisons of Simulated GMI TBs

Observation: GMI 166 GHzV TB

Simulation: CRTM V2.2.3 CloudCoef (Mie)

Simulation: CRTM V2.2.3 CloudCoef (DDA)
\( \text{Reff} = 1000 \mu\text{m} \)

Simulation: 3-bullet (DDA)
\( \text{Reff} = \text{function of water content} \)
NASA GPM Microwave Imager (GMI): 13 Channels

- Blue line: Average atmospheric absorption of microwave at sea level (20°C, 1013.24mb, water vapor density 7.5g/m³)
- GMI channels are indicated with colored arrows.
Data: **GPM** Global Precipitation Measurement

- Launched February 27, 2014
- Orbit: non-sun synchronous, 65° inclination angle, 407km altitude,
- Instruments: **GPM Microwave Imager (GMI)** and Dual frequency precipitation radar (DPR)

Conical scanning
13 channels (10GHz~183GHz)

GPM Fuel predictions ~ will fly till 2037+