GSI Capability to Assimilate Precipitation-Affected Satellite Observations in Application to HWRF: Assimilation of TRMM Cloud Water Retrievals

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1. Introduction

NOAA operations are currently not assimilating the majority of satellite information in the hurricane core and near-core environment. Assimilation of moisture and precipitation observations in cloudy regions of hurricane inner core environments has potential to improve the analysis and forecast of hurricane intensity, structure and precipitation.

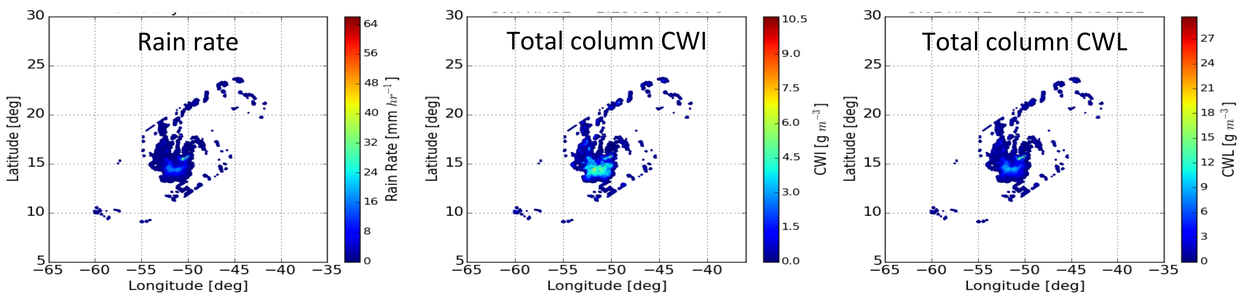
Objectives: 1) Introduce Hurricane GPROF product to GSI. 2) Investigate the potential impact of TRMM Hurricane GPROF product on the analysis and forecast of hurricane. 3) Evaluate the performance of GSI assimilating GPM (GMI) version of Hurricane GPROF product for the recent hurricane season.

2. TRMM Cloud Water Retrievals

*the Goddard PROFiling algorithm

Hurricane GPROF* *(Brown and Kummerow 2015)*

- Improved hurricane rain rate retrievals and hydrometeor profiles
  - Use TMI footprint, raining, and ocean pixels only
  - CWI: ice water + ½ (upper) mixed-phase water
  - CWL : cloud water + rain water + ½ (lower) mixed-phase water



3a. New Observation Operators in GSI

Assume that all water vapor in excess of the saturation mixing ratio with respect to ice and liquid water is immediately condensed out.

$$\delta q_{i(l)} = q_v - q_{si(sl)} \quad where \quad q_{si(sl)} = 0.622\frac{e_{si(sl)}}{p - e_{si(sl)}}$$

$$e_{si} \approx \exp[23.33086 - \frac{6111.72784}{T} + 0.15215\ln(T)]$$ where T, p, and q

$$e_{sl} \approx 6.112\exp[\frac{17.67(T-273.15)}{(T-273.15)+243.5}]$$ ($q_v = q/1-q$) are GSI state variables

The corresponding tangent linear and the adjoint operators with respect to ice and liquid are also implemented in GSI respectively.

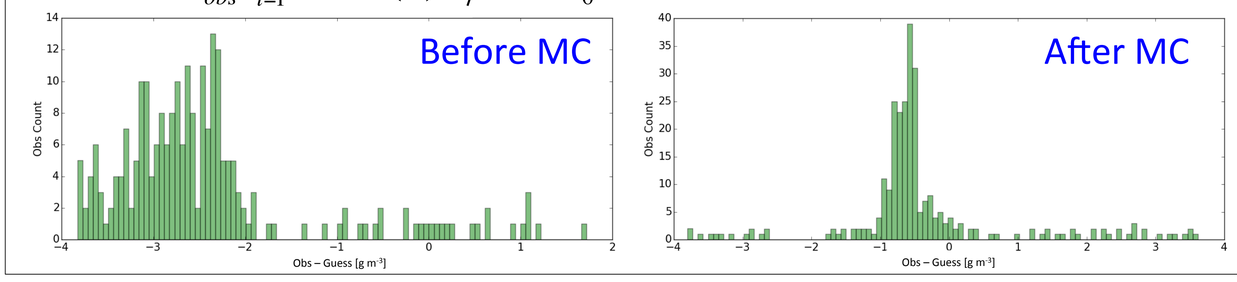
3b. Correction to the Observation Operators

An adjustable multiplicative correction (MC) parameter ε is included in the observation operator, h, so that $h(x) \rightarrow \varepsilon h(x)$ (*Apodaca et al. 2014*). ε is calculated for h_{ice} and h_{liquid} respectively.

$$J(\varepsilon) = \frac{1}{2}\left\{[\log(\frac{\varepsilon}{\varepsilon_0})]^T \mathbf{W}^{-1}[\log(\frac{\varepsilon}{\varepsilon_0})] + [\log(\frac{y}{\varepsilon h(x^f)})]^T \mathbf{R}_L^{-1}[\log(\frac{y}{\varepsilon h(x^f)})]\right\}$$

Minimize $J(\varepsilon)$ and a typical guess of $\varepsilon_0 = 1$

$$\varepsilon = \exp[\frac{1}{N_{obs}}\sum_{i=1}^{N_{obs}}\log(\frac{y}{h(x)})_i \Big/ 1 + \frac{r_0}{w_0}] \text{ where } r_0 = diag(\mathbf{R}_L); \quad w_0 = diag(\mathbf{W})$$



4. Experimental Design

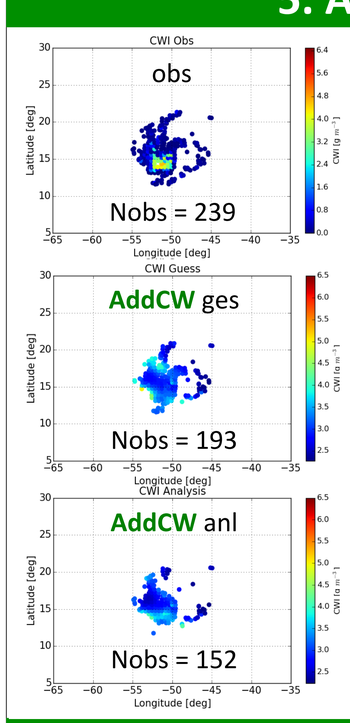
NOAA Operational HWRF (2014; HWRF v3.6a)

- d01/d02/d03 Δx = 27/9/3 km; d02 and d03 are storm-following
- GSI data assimilation on d02 and d03; No satellite data assimilated in d03
- Hybrid GSI: 80 GFS ensemble forecasts (0.2 on B_{var} 0.8 on B_{ens})
- FGAT (First-Guess at Appropriate Time): - 3, 0, +3 hours

Expt.	Domain 2 Obs		Domain 3 Obs	
	Conv.	Sat.	Conv.	Sat.
CTL (as operational)	yes	yes	yes	no
AddCW	yes	yes + TRMM CW	yes	TRMM CW
AddCW_MC	yes	yes + TRMM CW with MC	yes	TRMM CW with MC

- TRMM CW is thinned to 45 km and assimilated in both d02 and d03
- Currently testing on Hurricane Leslie (2012) at 1800 UTC 31 Aug 2012

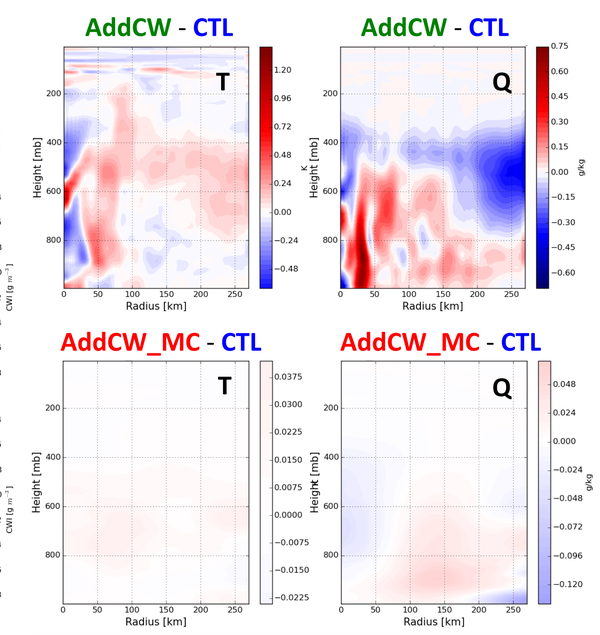
5. Analysis near the Core (domain 3)



5a. Observational Space

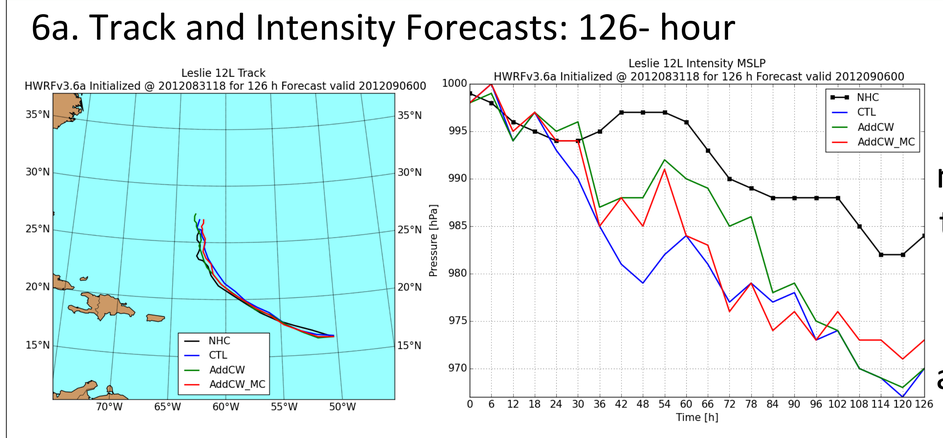
- guess is closer to obs after MC

5b. Azimuthal-mean Difference



6. Influence on HWRF Forecasts

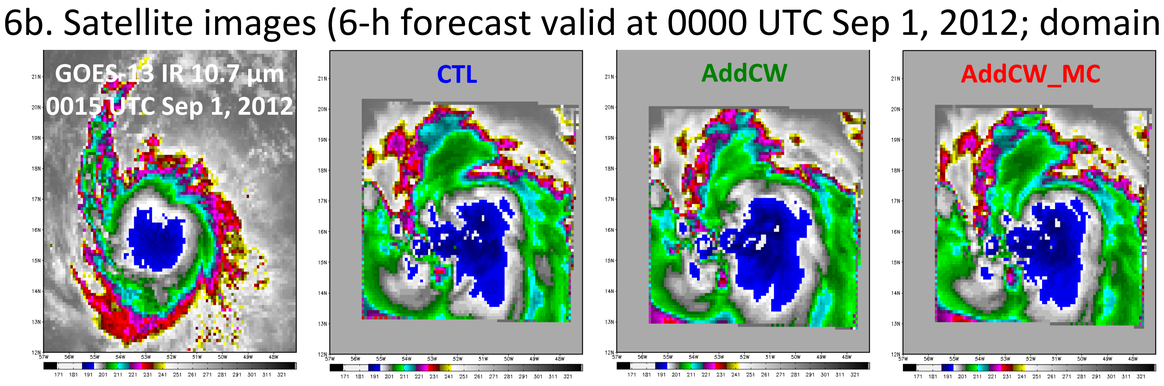
6a. Track and Intensity Forecasts: 126- hour



← CTL, AddCW, and AddCW_MC forecasts are all much stronger than the NHC best track.

↓ Clouds in synthetic images are colder and have broader extent.

6b. Satellite images (6-h forecast valid at 0000 UTC Sep 1, 2012; domain 3)



7. Summary and Future Work

- GSI is adapted to assimilate precipitation-affected TRMM cloud water retrievals in HWRF. Further investigations on optimizing the GSI assimilation strategies (i.e. bias correction, observation weighting, etc) regarding these new observations are required and are currently underway.
- Use GPM (GMI) version of Hurricane GPROF hydrometeor products and evaluate the assimilation performance for the recent hurricane season.
- Combine precipitation- and cloud-affected observations including ATMS MW and GOES IR all-sky radiances in the context of hurricane data assimilation.

Reference: Brown J. P. and C.D. Kummerow, 2015: Hurricane GPROF: An improved hurricane rain rate retrieval for TRMM and GMI. *The 95th AMS Annual Meeting*, Phoenix, Arizona. Jan 4-8, 2015.
Apodaca K., M. Zupanski, M. DeMaria, J. A. Knaff, and L. D. Grasso, 2014: Development of a hybrid variational-ensemble data assimilation technique for observed lightning tested in a mesoscale model. *Nonlin. Processes Geophys.*, 21, 2017-1041

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