Practical Details of Assimilating GPM Hydrometeor Retrievals in HWRF

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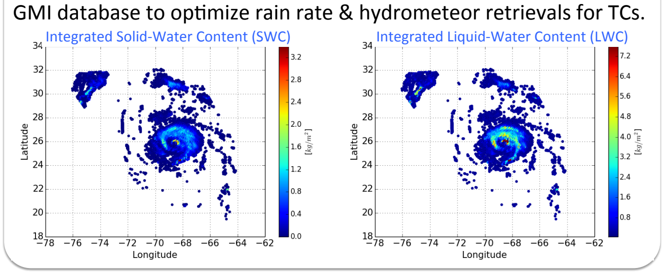
1. Introduction

Hurricane intensity and structure are fundamentally related to clouds and moisture. All-sky satellite radiances and satellite-retrieved hydrometeors are especially important because they contain valuable information about clouds and precipitation that often occur in sensitive regions in terms of forecast impact and their assimilation may be essential to improve hurricane forecasting skills. However, many NWP centers currently do not include those observations in their assimilation practice. One example is the NOAA HWRF system. This study examines the GSI capability to assimilate hydrometeor retrievals in the operational HWRF system.

2. Hydrometeor Retrievals

Hurricane GPROF *(Brown et al. 2016):* Incorporates HURDAT2 into TMI/GMI database to optimize rain rate & hydrometeor retrievals for TCs.



3. Two Possible Approaches to Assimilate Them in HWRF

A. Add hydrometeor as control variable (straightforward, but requires extensive modification to the operational configuration)

B. Extend the impact of assimilation to the HWRF-GSI standard control variables (T, Ps, and q) (based on assumption that super-saturated water vapor is immediately condensed out, and only requires minimal changes to operational configuration).

Observation operators following approach B are then:

$$h_{s\_noHydro} = \sum_{k=k_0}^{k_{\max}} \left[\left(\frac{q^k}{1-q^k}\right) - 0.622 \frac{e_s(T^k)}{P^k - e_s(T^k)} \right] \cdot \frac{\Delta P^k}{g} \quad \text{and} \quad h_{l\_noHydro} = \sum_{k=1}^{k_{mix}} \left[\left(\frac{q^k}{1-q^k}\right) - 0.622 \frac{e_s(T^k)}{P^k - e_s(T^k)} \right] \cdot \frac{\Delta P^k}{g}$$

Approach B was implemented and examined in *Wu et al. (2016)* because the operational HWRF is configured as follow:

1) No hydrometeor initialization; background is in clear sky condition
2) Hydrometeor is not considered as control variable; no hydrometeor update during data assimilation

➢ This study will implement A and compare to results from B.

4. Partitions and Observation Operators

HWRF employs Ferrier-Aligo microphysics scheme, which predicts changes in water vapor and hydrometeor species but only considers advection of water vapor and the combined sum of hydrometeor species, i.e., the total cloud condensate (CWM). In GSI, CWM can be partitioned into hydrometeor species by P6 (Partition6) formula :

$$q_l = (1 - F\_RAIN) \cdot (1 - F\_ICE) \cdot CWM \quad \text{Liquid water}$$

$$q_r = F\_RAIN \cdot (1 - F\_ICE) \cdot CWM \quad \text{Rain water}$$

F_RAIN: fraction of rain, F_ICE: fraction of ice, and F_RIMEF: riming rate

$$q_i = w \cdot F\_ICE \cdot CWM \quad where \quad w = \begin{cases} 0.05 \cdot \frac{T - 233.15}{10} + 0.1 \cdot \frac{T - 243.15}{(-10)} & if \quad T \le 243.15K \\ 0.05 & if \quad T > 243.15K \end{cases} \quad \text{Ice}$$

$$precip\_ice = (1 - w) \cdot F\_ICE \cdot CWM = \begin{cases} q_s & if \quad 1 \le F\_RIMEF \le 5 & \text{Snow} \\ q_g & if \quad 5 < F\_RIMEF \le 5 & \text{Graupel} \\ q_h & if \quad F\_RIMEF > 20 & \text{Hail} \end{cases}$$

Observation operators following approach A are then:

$$h_s = \sum_{k=k_0}^{k_{\max}} (q_i^k + q_s^k + q_g^k + q_h^k) \cdot \frac{\Delta P^k}{g} \quad and \quad h_l = \sum_{k=1}^{k_{mix}} (q_l^k + q_r^k) \cdot \frac{\Delta P^k}{g}$$

k is model vertical level index, k_0 is vertical level where T=273.15K, k_{max} is model top level, k_{mix} is vertical level where T=253.15K, and ΔP is pressure difference between two vertical levels $P(k) - P(k+1)$.

4. Experimental Design

NOAA Operational HWRF (2015; HWRF v3.7a, *Tallapragada et al. 2015*)

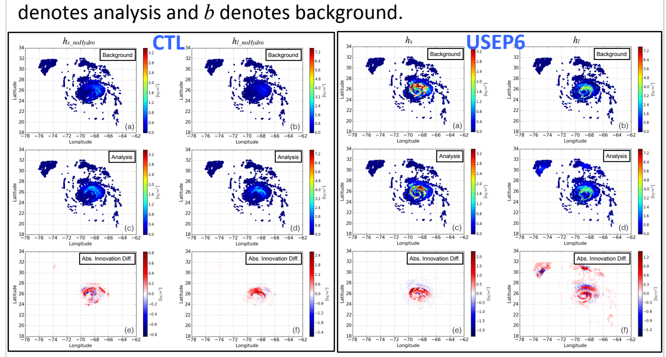
- d01/d02/d03 Δx = 18/6/2 km; d02 and d03 are storm-following
- data assimilation: Hybrid GSI (20% static + 80% ensemble from GFS EnKF)
- DA on d02: conv. obs + clearsky satellite radiance; DA on d03: conv. obs only
- FGAT (First-Guess at Appropriate Time): - 3, 0, +3 hours

Experiment	Observation Operators for integrated SWC and LWC
CTL	$h_{s\_noHydro}$ and $h_{l\_noHydro}$
USEP6	h_s and h_l
SMP6	h_s and h_l with smoothing

- Hurricane Gonzalo (2014) at 1200 UTC 16 October 2014
- **SMP6** includes additional smoothing on background hydrometeor fields
- Results will be presented on the innermost domain (d03)

5. Results and Summary

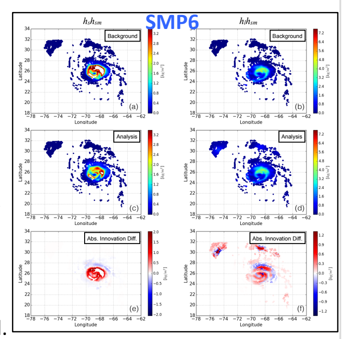
A metric to measure improvement is defined as $|y - h(x_a)| - |y - h(x_b)|$ and is referred to as absolution innovation difference, where y is observation, h is observation operator, and x is state variable. The subscript a denotes analysis and b denotes background.



➢ The background guessed values in CTL are generally under-estimated (known issue in *Wu et al. (2016)*). In contrast, the background guessed values in USEP6 are generally over-estimated. Nevertheless, both experiments suggest an overall improvement after the assimilation.

➢ A smooth procedure using a formulation of recursive filter (*Hayden and Purser 1995*) is proposed to suppress the over-estimated background fields of hydrometeor species (q_l, q_i, q_r, q_s, q_g, and q_h). This is equivalent to applying an additional operator h_{sm} on the background fields of hydrometeor species.

➢ Applying smoothing allows fewer observation rejection, thus more observation are assimilated.



By allowing the CWM initialization and update, this study prepares the work to implement HWRF-GSI capability to perform all-sky satellite radiance assimilation. Future work will extend upon current efforts to directly assimilate all-sky satellite radiance in HWRF.

Reference

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