Assimilation of Microwave Hydrometeor Retrievals and All-Sky Radiances in HWRF

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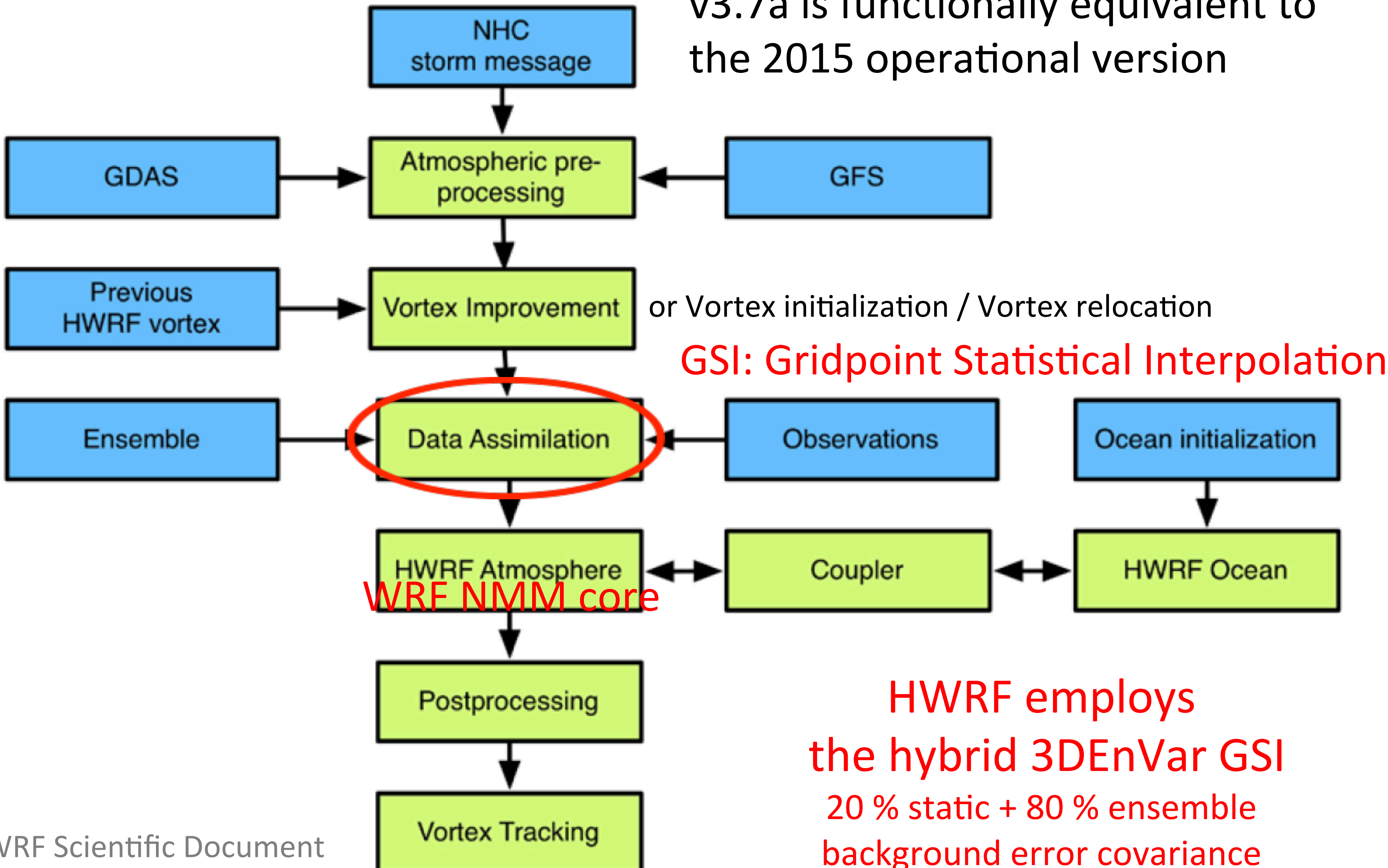
Hurricane WRF (HWRF) v3.7a System

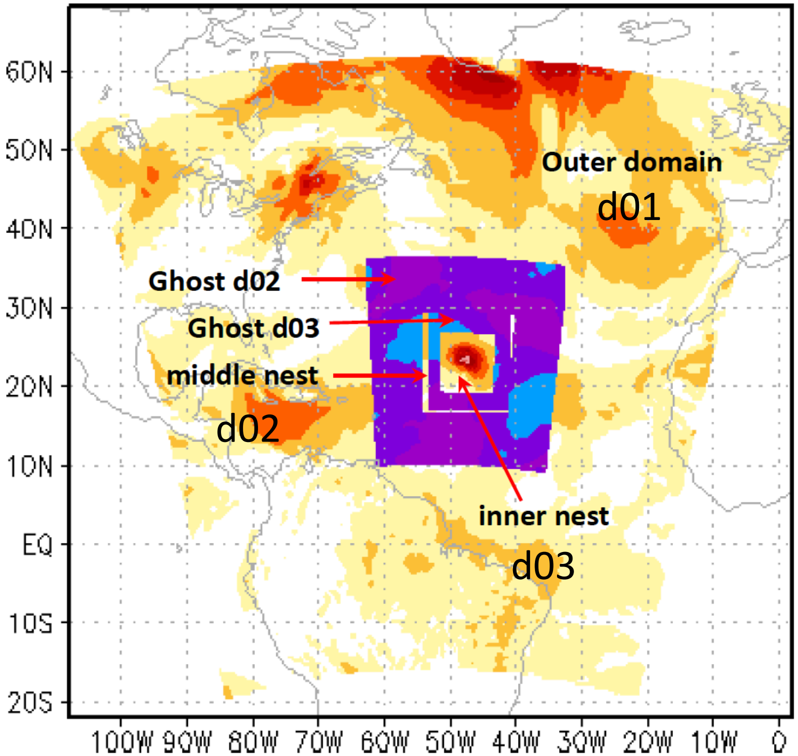
v3.7a is functionally equivalent to the 2015 operational version



HWRF employs
the hybrid 3DEnVar GSI
20 % static + 80 % ensemble
background error covariance

HWRF Scientific Document
Tallapragada et al. (2015)

HWRF Configuration (v3.7a)



HWRF Scientific Document
Tallapragada et al. (2015)

Domain (Δx)	Domain size	Data assimilation	Conv. observation assimilated	Satellite radiance assimilated
D01 (18 km)	216 x 432	Inherit from GDAS	-	-
ghost d02 (6km)	166 x 336	Hybrid 3DEnVar GSI	Yes	Clear sky only
ghost d03 (2km)	250 x 500	Hybrid 3DEnVar GSI	Yes	-

- 60 vertical levels
- Model top pressure = 2 mb
- FGAT: -3 h, 0 h, +3 h
- The Community Radiative Transfer Model

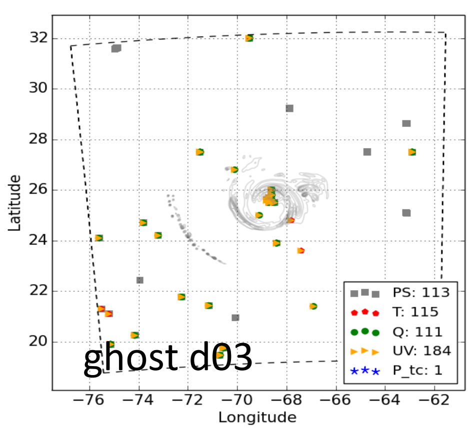
➢ To increase the utility of satellite observations in the core of hurricanes, we extends the HWRF-GSI capability to assimilate precipitation-affected data that includes microwave satellite retrievals and radiances.

Microwave Hydrometeor Retrievals
Hurricane GPROF

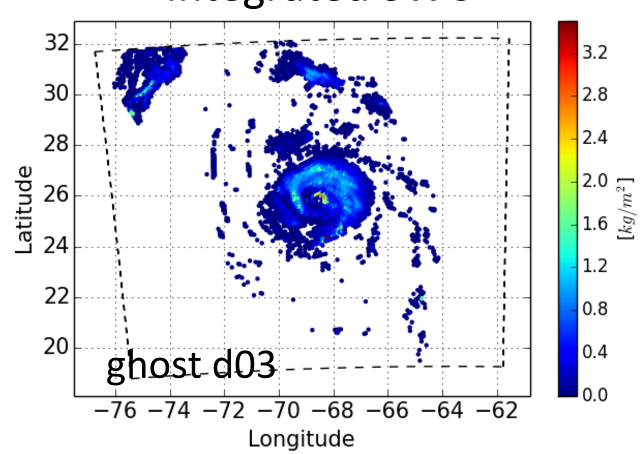
Hurricane GPROF

- A hurricane-specific microwave retrieval that utilizes data from GMI/TMI and HURDAT2 info (*Brown et al. 2016*)
- Provides retrieved instantaneous rain rates and hydrometeor profiles (cloud water, rain, mixed-phase, and ice)
- Transformed into two vertically integrated quantities to be assimilated into HWRF:
  - Integrated solid-water content (SWC) in kg m^{-2}
  - Integrated liquid-water content (LWC) in kg m^{-2}

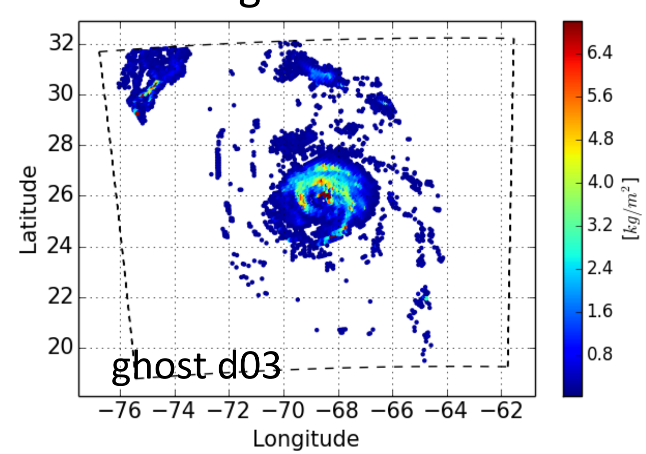
Conventional Obs



Integrated SWC



Integrated LWC



Choices for Observation Operator:

a) Use current set of control variables that includes *T, P,* and *q* and assume super-saturated water vapor will condense out:

$$h_s = \sum_{k=k_0}^{k_{\max}} \left[\left(\frac{q^k}{1-q^k}\right) - 0.622 \frac{e_s(T^k)}{P^k - e_s(T^k)} \right] \cdot \frac{\Delta P^k}{g}$$ Integrated SWC

$$h_l = \sum_{k=1}^{k_{mix}} \left[\left(\frac{q^k}{1-q^k}\right) - 0.622 \frac{e_s(T^k)}{P^k - e_s(T^k)} \right] \cdot \frac{\Delta P^k}{g}$$ Integrated LWC

Wu et al. (2016)

b) Add cloud condensate control/state variables:

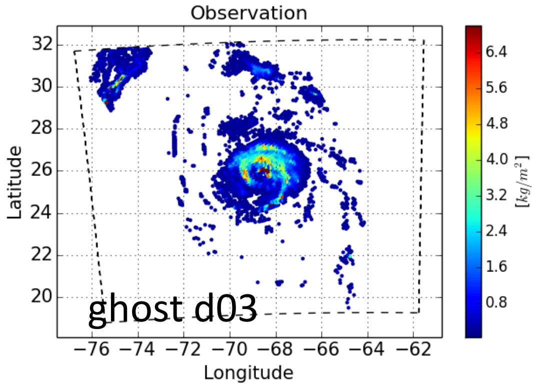
$$h_s = \sum_{k=k_0}^{k_{\max}} (q_i^k + q_s^k + q_g^k + q_h^k) \cdot \frac{\Delta P^k}{g}$$

$$h_l = \sum_{k=1}^{k_{mix}} (q_l^k + q_r^k) \cdot \frac{\Delta P^k}{g}$$

Wu and Zupanski (2017)

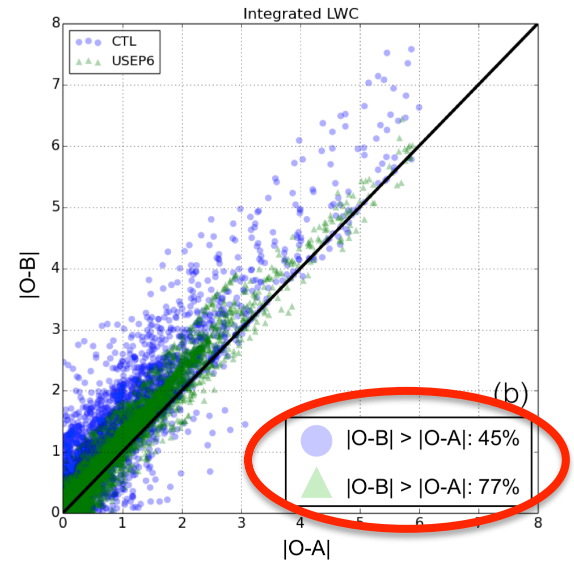
- HWRF uses Ferrier-Aligo microphysics scheme, prognostic microphysical variable is total cloud condensate mass (aka CWM) instead of individual hydrometeor species.
- Also need to address the decomposition of CWM into individual hydrometeor

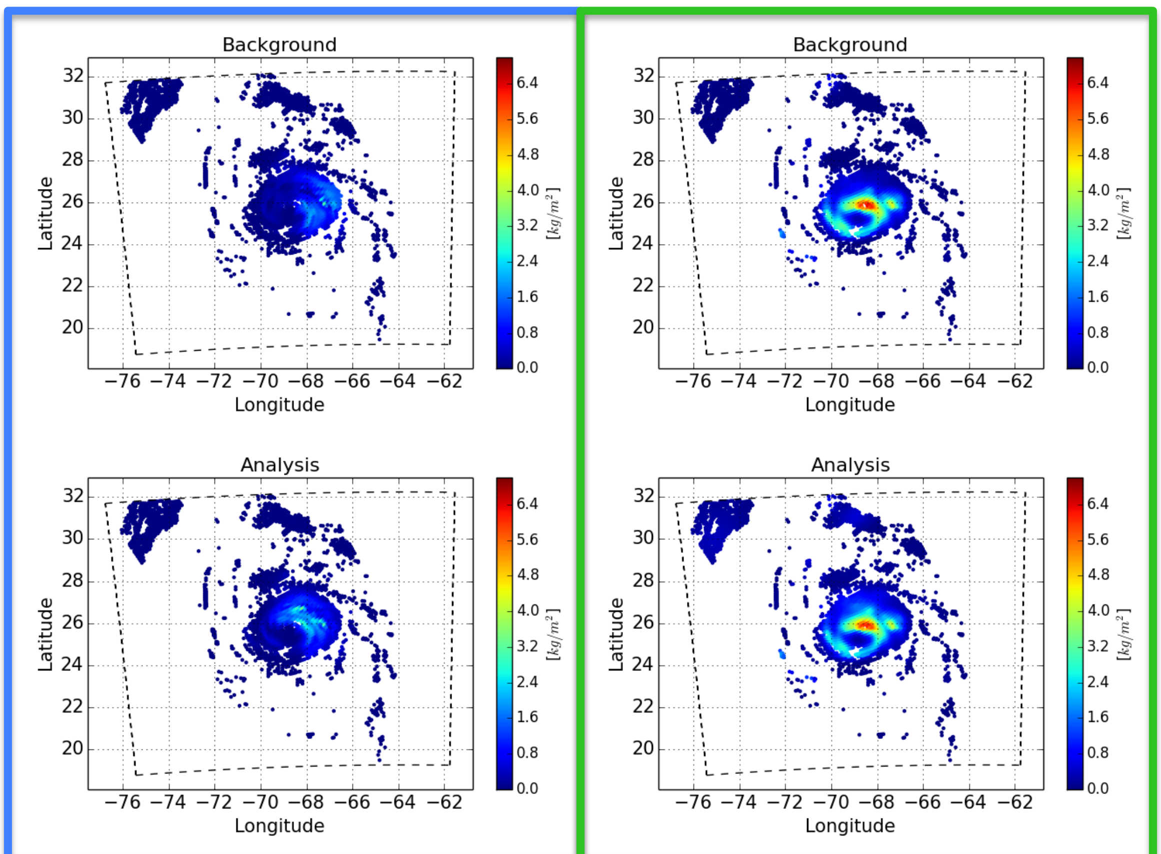
Integrated LWC



Hurricane Gonzalo (2014)

2014/10/16 1200 UTC

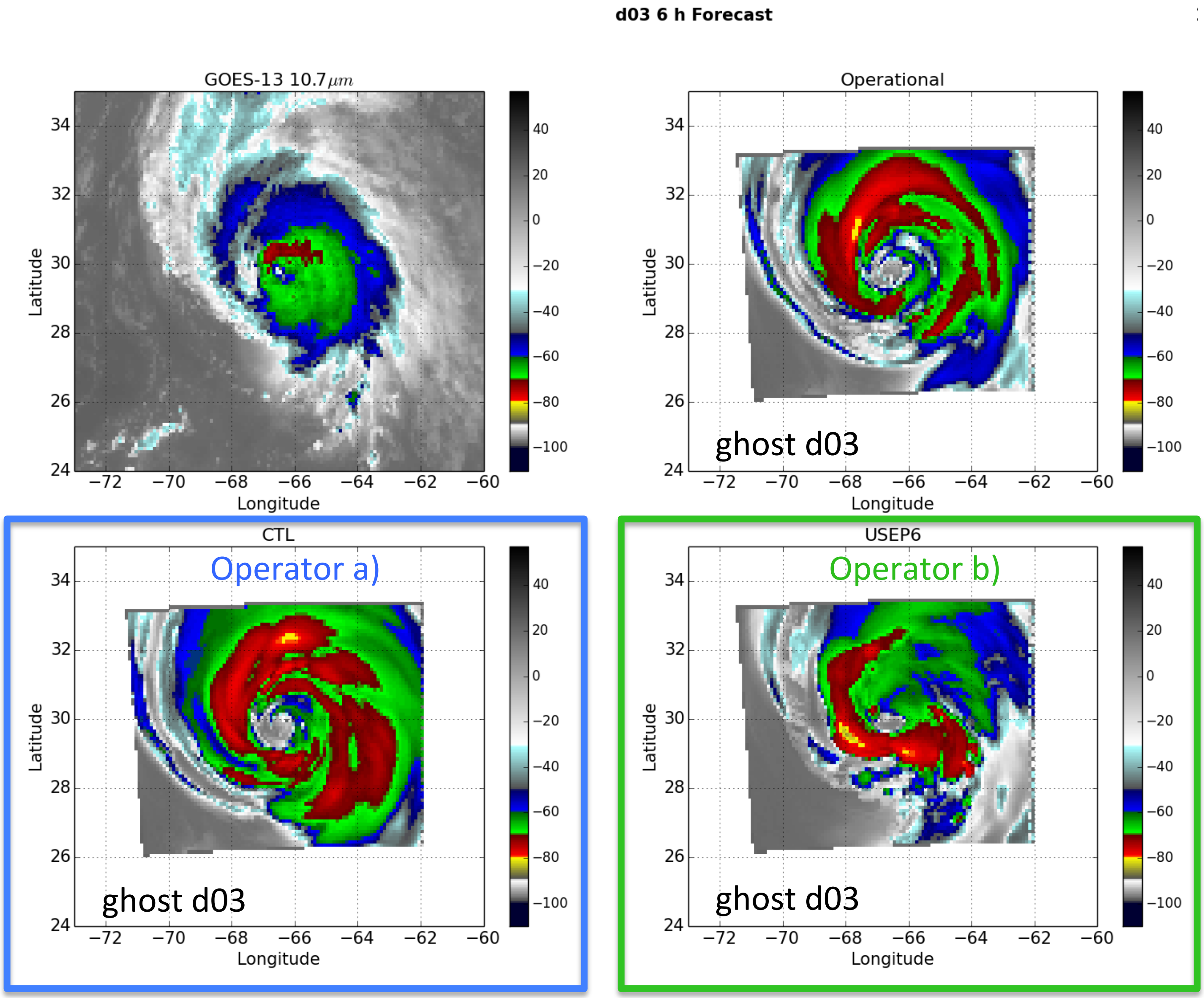




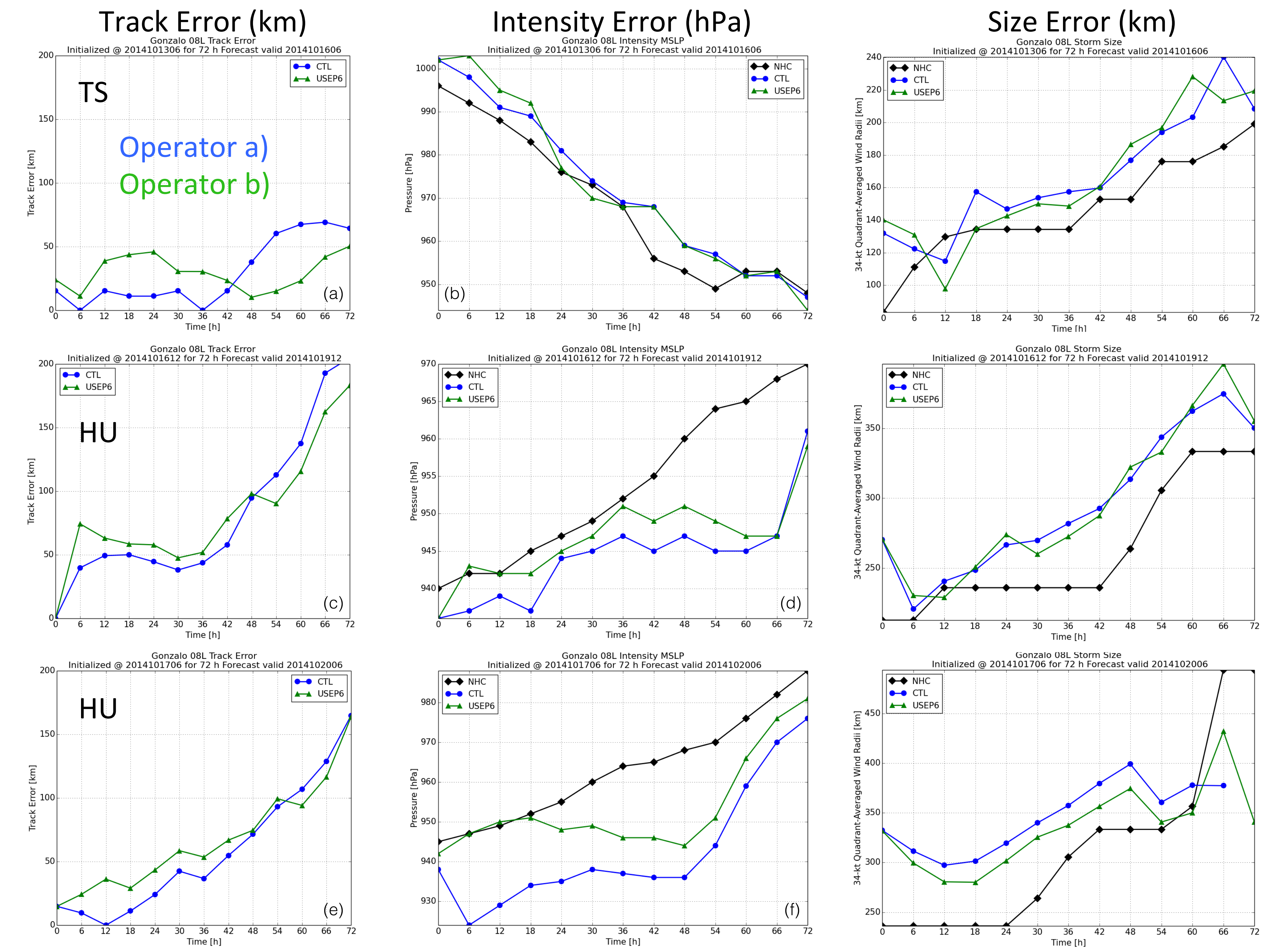
Operator a): values of liquid water contents are generally lower than observed

Operator b): background values of liquid water contents are comparable to observations

Compare w/ GOES-13 image at 10.7 µm



(Brightness Temperature in °C)


Track Error (km)
Intensity Error (hPa)
Size Error (km)
Gonzalo 08L Track Error
Initialized @ 2014101306 for 72 h Forecast valid 2014101606
TS
Operator a)
Operator b)
CTL
USEP6
Track Error [km]
Time [h]
(a)
Gonzalo 08L Intensity MSLP
Initialized @ 2014101306 for 72 h Forecast valid 2014101606
NHC
CTL
USEP6
Pressure [hPa]
Time [h]
(b)
Gonzalo 08L Storm Size
Initialized @ 2014101306 for 72 h Forecast valid 2014101606
NHC
CTL
USEP6
34-kt Quadrant-Averaged Wind Radii [km]
Time [h]
Gonzalo 08L Track Error
Initialized @ 2014101612 for 72 h Forecast valid 2014101912
HU
CTL
USEP6
Track Error [km]
Time [h]
(c)
Gonzalo 08L Intensity MSLP
Initialized @ 2014101612 for 72 h Forecast valid 2014101912
NHC
CTL
USEP6
Pressure [hPa]
Time [h]
(d)
Gonzalo 08L Storm Size
Initialized @ 2014101612 for 72 h Forecast valid 2014101912
NHC
CTL
USEP6
34-kt Quadrant-Averaged Wind Radii [km]
Time [h]
Gonzalo 08L Track Error
Initialized @ 2014101706 for 72 h Forecast valid 2014102006
HU
CTL
USEP6
Track Error [km]
Time [h]
(e)
Gonzalo 08L Intensity MSLP
Initialized @ 2014101706 for 72 h Forecast valid 2014102006
NHC
CTL
USEP6
Pressure [hPa]
Time [h]
(f)
Gonzalo 08L Storm Size
Initialized @ 2014101706 for 72 h Forecast valid 2014102006
NHC
CTL
USEP6
34-kt Quadrant-Averaged Wind Radii [km]
Time [h]

Summary

- Fit to observation was improved with operator b)
- While there was no obvious improvement in forecast track and size forecast, intensity forecast was found slightly improved when operator with cloud condensate update (operator b) is used
- Although initial cloud condensate field was comparable to observations (synthetic satellite image), there were too many cold clouds during HWRF forecast

	Pros	**Cons**
a)	• Relatively easy to implement • Code modifications are limited to GSI only	• Create bias from using already saturated-then-condensed water vapor from background guess • No cloud condensate update
b)	• In addition to dynamical variables, cloud condensate variables are also updated • Align with all-sky radiance assimilation efforts (see the next few slides)	• also need to modify procedures in HWRF related to cloud condensate (vortex relocation) • Depends on cloud microphysics scheme used by HWRF

All-Sky ATMS Radiances

Preparations for all-sky radiances assimilation in HWRF

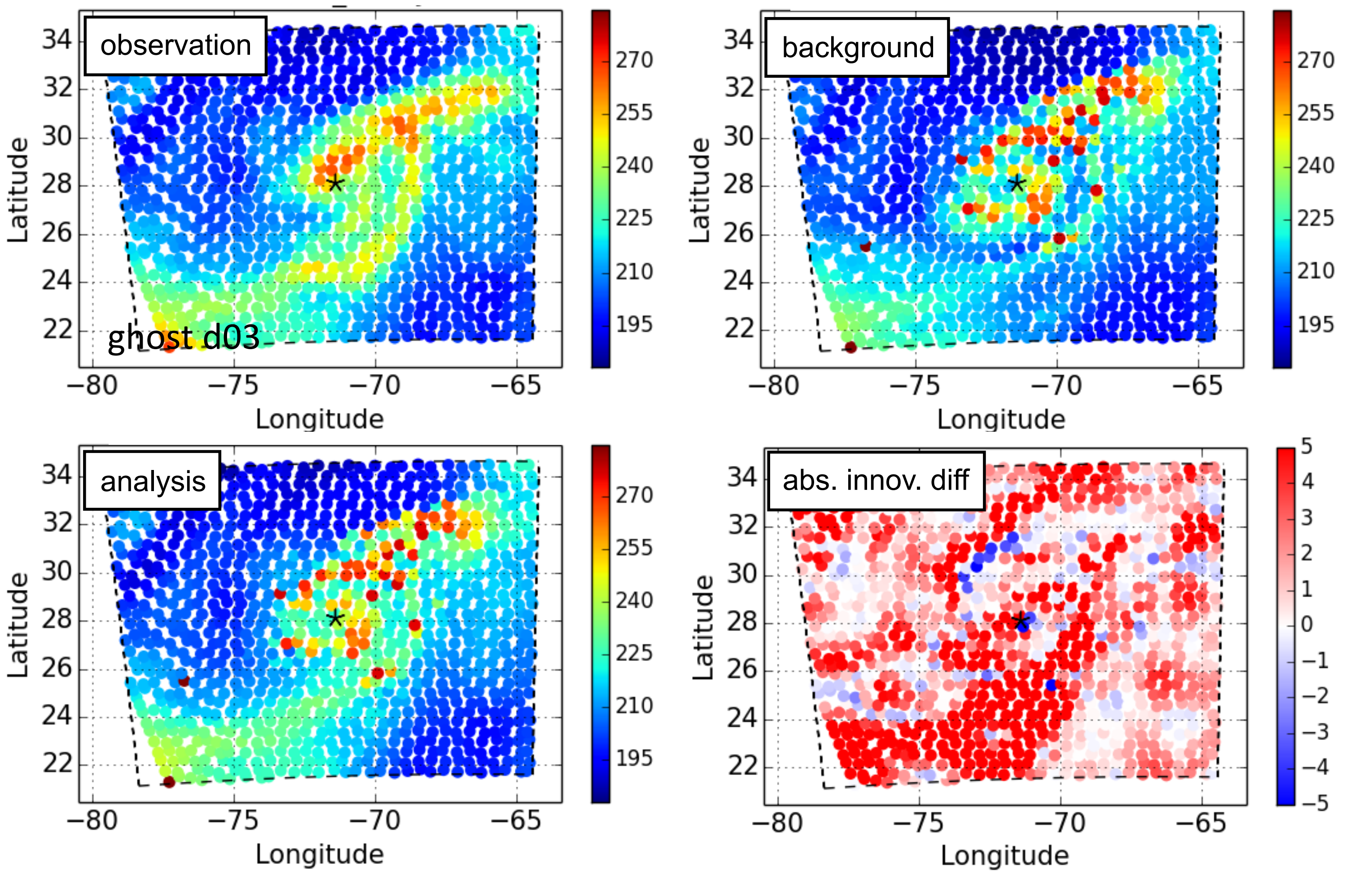
- Inherit the GSI all-sky assimilation capability developed for GFS (*Zhu et al. 2016)* by adding **CWM** as control variable and including **ql** and **qi** as state variables, and extend to **qr**, **qs**, **qg**, and **qh**
  - Static background error covariance
  - Ensemble background error covariance (GFS ensemble, non-native)

- An empirical formula based on Ferrier-Aligo microphysics scheme for partitioning **CWM** into **ql**, **qi**, **qr**, **qs**, **qg**, and **qh** with partition parameters (**F_ICE**, **F_RAIN**, and **F_RIMEF**) is available in GSI. The tangent linear and adjoint parts of the partition are included in cost function minimization (*Wu and Zupanski 2017*)

- Append **CWM** and its partition parameters from forecast of a previous cycle to background guess, as they are currently not considered during the vortex initialization procedure, a step prior to GSI data assimilation within HWRF.

ATMS Ch 1: 23.8 GHz (Tb in Kelvin)

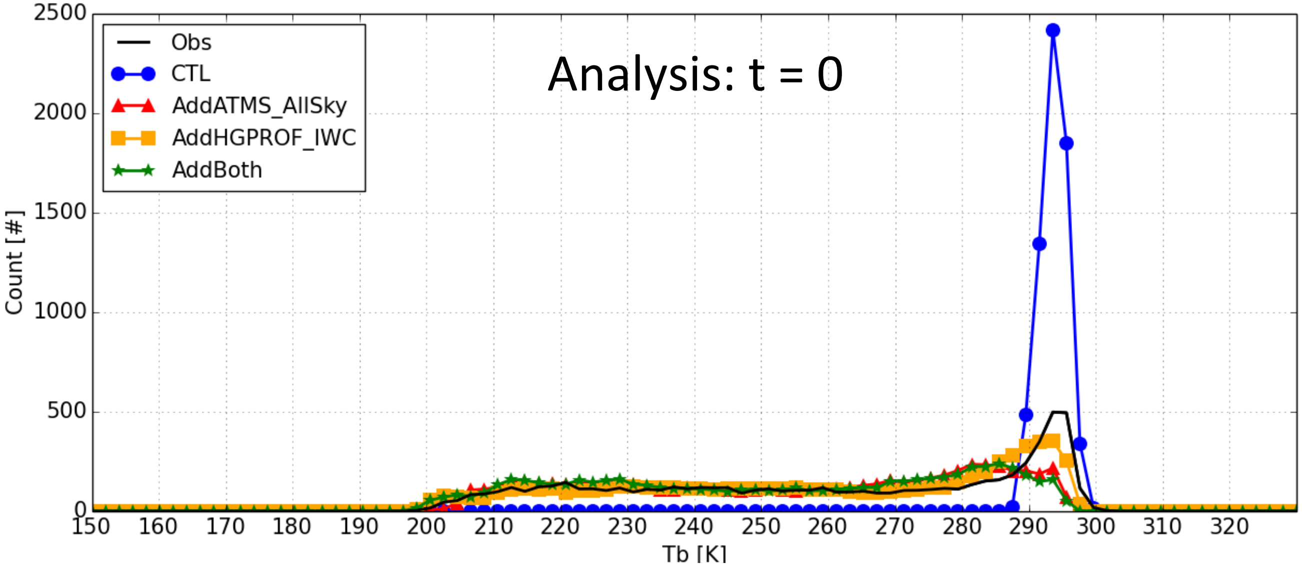
Hurricane Cristobal (2014) 1800 UTC, August 26



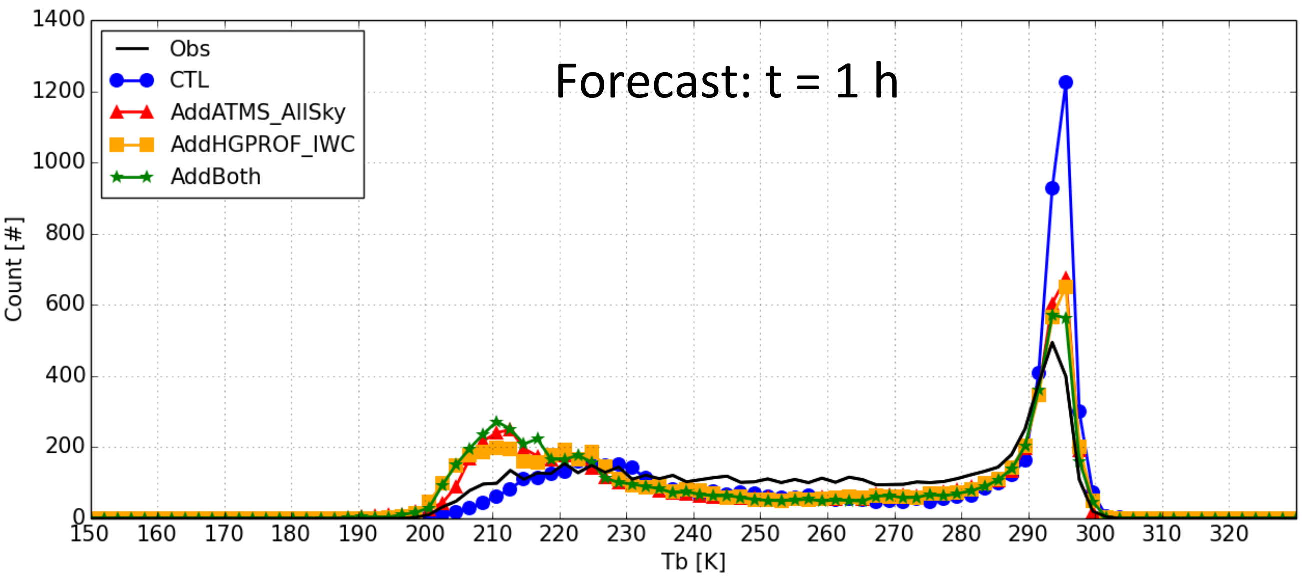
- ATMS channels 1-4, 7-9, 16-20 are used, but only channel 1 is shown here
- Ch 1 and 2 are sensitive to cloud liquid droplets and rain: ocean surface appears cold and condensate associated with hurricane (*) appears warm (>240K)
- Absolute innovation differences = |O-B|-|O-A|

Compare w/ GOES-13 data

Histogram of Tb of observed GOES-13 image (black) and synthetic images (colored)



- The distribution of brightness temperature at t = 0 is consistent with observation, except for CTL (blue) due to no cloud condensate.



- Within the first hour of the forecasts, a discrepancy developed, where the brightness temperatures are around 210 K
- Such discrepancy persists in the following (at least) 24 hours of forecast

Summary and Future Work

- Extended GSI capability to assimilate cloud and precipitation-affected satellite observations into HWRF.
- Both Hurricane GPROF hydrometeor retrievals and ATMS all-sky radiances were successfully assimilated into HWRF.
- Although forecast results from all-sky assimilation measured in metrics including track, intensity, and sizes were mixed (not shown), initial cloud fields (synthetic satellite images) from assimilation were comparable to observation.
- HWRF appears to produce too many clouds with cloud top temperature that is too cold compared to observations.

➢ Merge the extended capabilities to the HWRF and GSI repository (through DTC Visitor Program) to test and evaluate these new capabilities with more hurricane cases, as possible R2O consideration.

➢ GOES-16 GLM lightning assimilation in HWRF

Thank you!

CIRA Data Assimilation Group http://da.cira.colostate.edu

References:

- Brown P. J., Kummerow C. D., Randel D. L. 2016. Hurricane GPROF: an optimized ocean microwave rainfall retrieval for tropical cyclones. *Journal of Atmospheric and Oceanic Tech*nology 33: 1539–1556. https://doi.org/10.1175/JTECH-D-15-0234.1.

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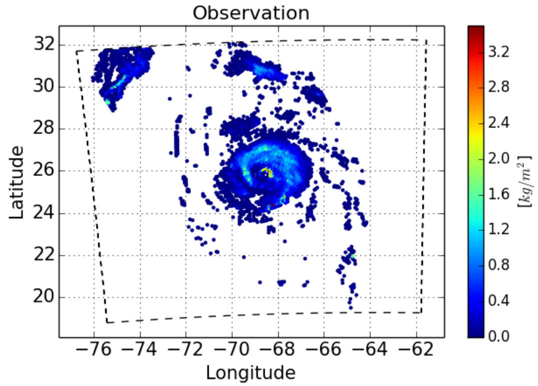
- Wu T.-C., Zupanski M., Grasso L. D., Brown P. J., Kummerow C. D., Knaff J. A. 2016. TheGSI capability to assimilate TRMM and GPM hydrometeor retrievals in HWRF. *Quarterly Journal of the Royal Meteorological Society* 142: 2768–2787. https://doi.org/10.1002/qj.2867.

- Wu T.-C., and Zupanski M. 2017. Assimilating GPM hydrometeor retrievals in HWRF: choice of observation operators. *Atmospheric Science Letters* 18: 238–245. https://doi.org/10.1002/asl.748.

- Zhu Y., Liu E., Mahajan R., Thomas C., Groff D., Van Delst P., Collard A., Kleist D., Treadon R., Derber J. C. 2016. All-sky microwave radiance assimilation in NCEP's GSI analysis system. MonthlyWeather Review 144: 4709–4735. https://doi.org/10.1175/MWR-D-15-0445.1.

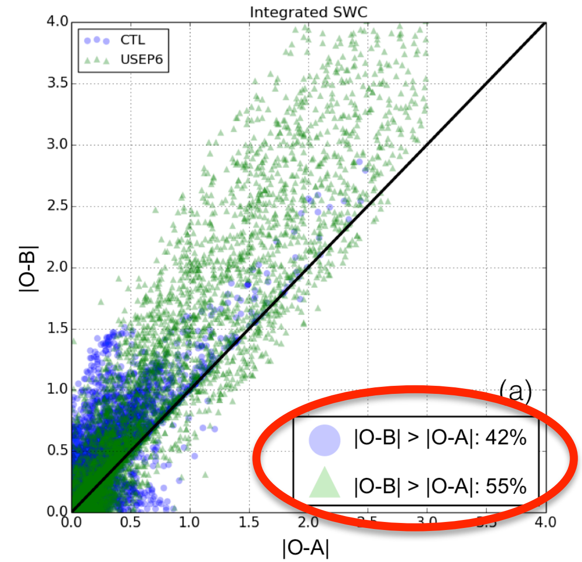
Backup slides

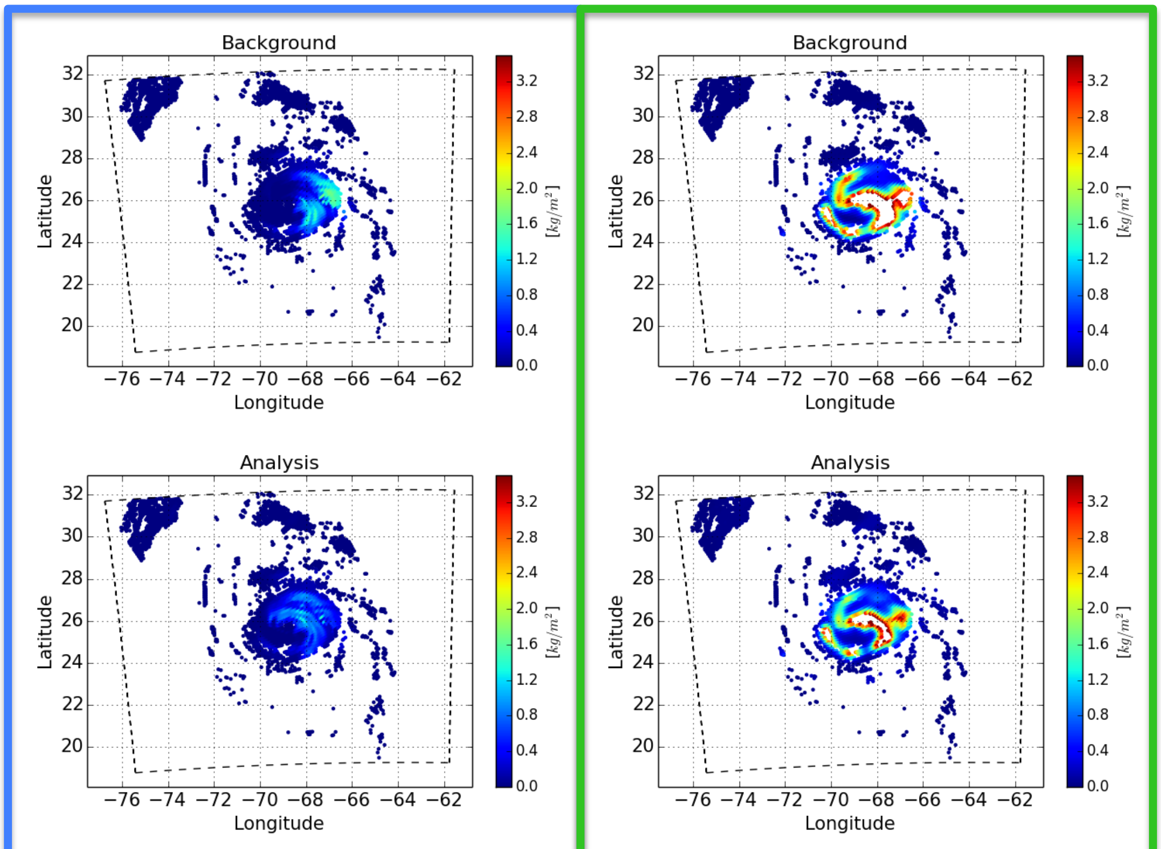
Integrated SWC



Hurricane Gonzalo (2014)

2014/10/16 1200 UTC

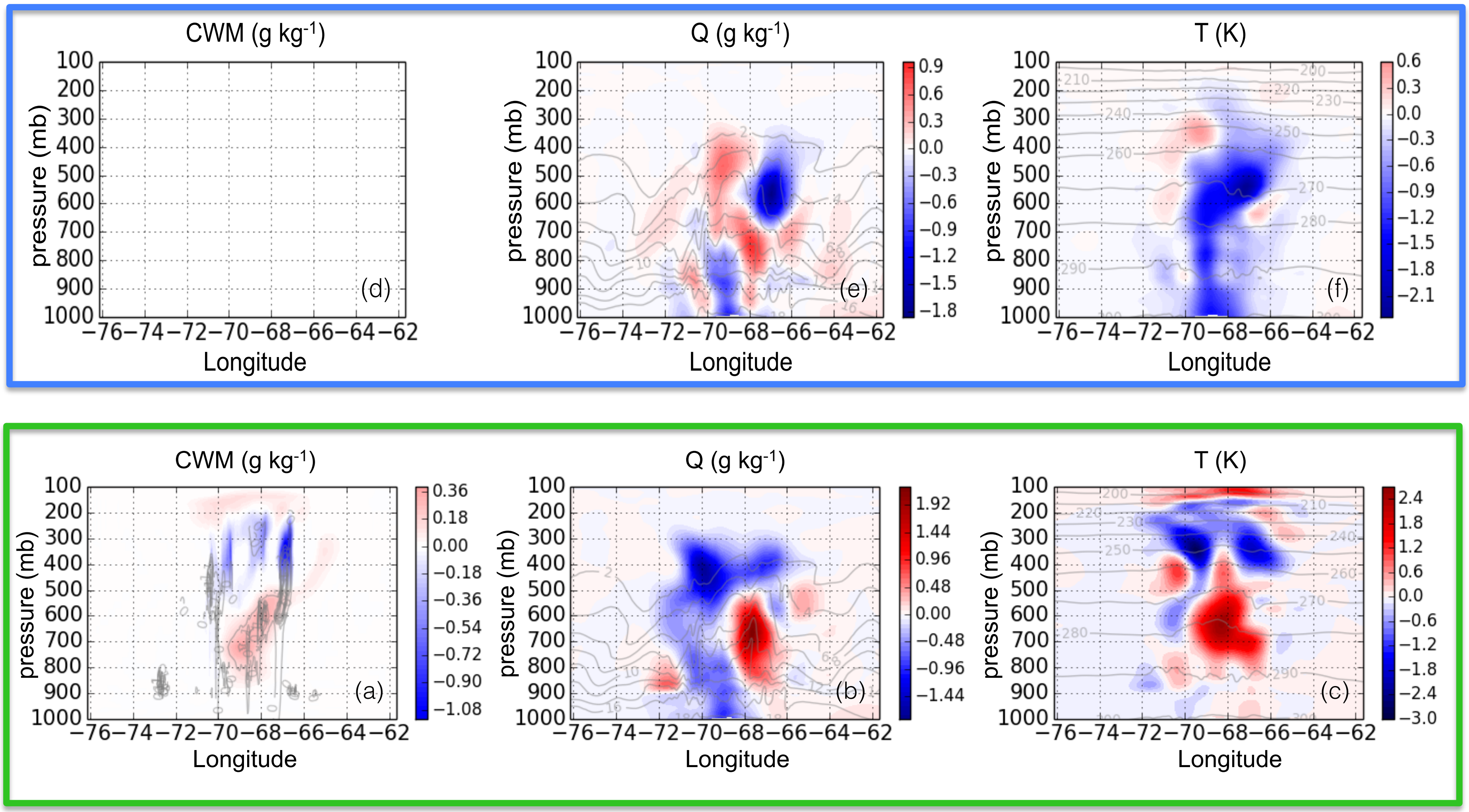




Operator a): although values of solid water contents comparable to observed ones, they are displaced to the east of Gonzalo

Operator b): In general, distribution of solid water contents is similar to observed ones, but their values are much larger

Analysis increment



Operator a) noHydro

Operator b) Hydro

ATMS Channel Selection

Channel	Center frequency (GHz)	Observation error (K)
1	23.8	5.0
2	31.4	5.0
3	50.3	5.0
4	51.76	3.0
7	54.40	0.3
8	54.90	0.3
9	55.50	0.3
16	87.9	5.0
17	166.31	2.5
18	183.31 ± 7.0	2.5
19	183.31 ± 4.5	2.5
20	183.31 ± 3.0	2.5

clear-sky error for now

- Ch 1-2: sensitive to cloud liquid droplets and rain
- Ch 7-9: provides information about the warm core of hurricane
- Ch 16: helps identify the location of the deepest convection through a scattering signal from precipitation-sized ice particles
- Ch 17-20: water vapor channels make moisture sounding possible in clear-sky regions