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All-Sky Radiance Assimilation for COAMPS-TC Tropical Cyclone Track and Intensity Prediction[(1)]

Dr. Nancy Baker*, Dr. Allen Zhao, Dr. Yi Jin and Dr. Jim Doyle

Marine Meteorology Division

Naval Research Laboratory, Monterey CA

[(1)] In Collaboration with Penn State University Scientists: Dr. Fuqing Zhang, Robert Nystrom, Xingchao Chen, Jerry Zhang

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Introduction

New data assimilation capabilities have been developed within the NRL EnKF for COAMPS-TC[1] in collaboration with scientists from Penn State University.

- Advances include assimilation of all-sky geostationary IR radiances, airborne Tail Doppler Radar (TDR) data, dropsondes from hurricane reconnaissance aircraft, and other special *in-situ* observations.
- New capabilities were implemented to make COAMPS-TC model work more effectively with the new EnKF-based DA system.
- The NRL COAMPS-TC/EnKF system was tested with two challenging TC cases (Patricia and Harvey). Our experiments show substantial impacts of all-sky radiance assimilation on both TC intensity and track forecasts with the impacts lasting more than 3 days into the forecasts.

[1]COAMPS-TC is the Coupled Ocean/Atmosphere Mesoscale Prediction System for Tropical Cyclones (COAMPS-TC)

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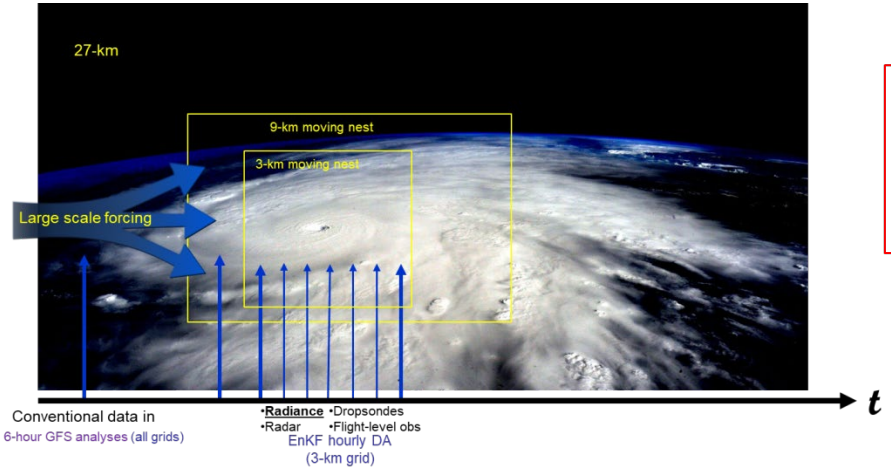
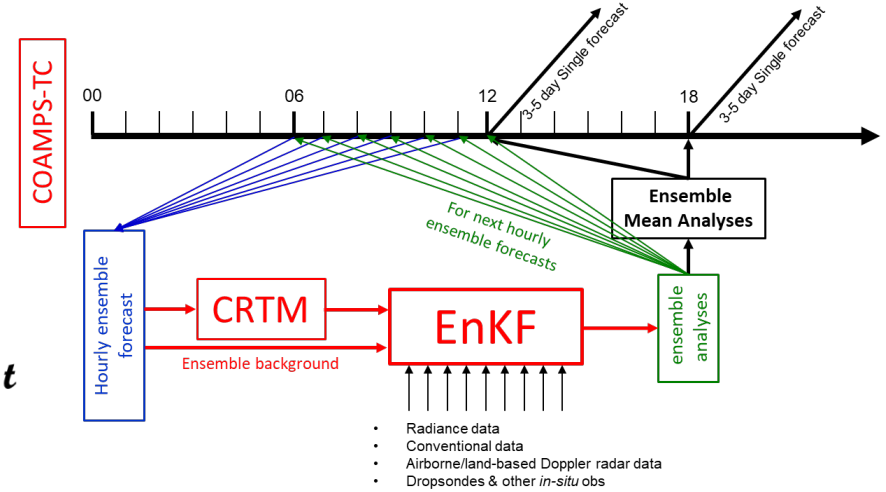
All-sky Radiance DA Setup



NRL Hourly-Cycled EnKF All-sky Radiance Assimilation System

- Ensemble DA for deterministic forecast
- NRL TC relocation capability



NRL COAMPS-TC/EnKF Key Features

- All-sky geostationary IR radiance assimilation (water vapor channel)
- Hourly cycling DA, with initialization at both the synoptic and off synoptic times
- GFS used for initial (cold start) conditions and perturbed boundary conditions
- TC relocation for the 60 (40) ensemble

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COAMPS-TC/EnKF New Methodology

- COAMPS-TC has been modified to relocate the entire TC structures (within the moving nests) for the ensemble forecasts for used for the EnKF data assimilation.
- Hourly interpolated TC center locations used for the relocation
- This allows the model dynamical balance for each ensemble member to be maintained.

- NRL EnKF includes:
  - 3-km inner (moving) nest
  - All-Sky radiance using CRTM v2.1.3 (with minor modifications by PSU)
  - Airborne Doppler radar wind assimilation (not used for these tests)
  - Hourly GOES-13(16) imager water vapor radiances ~ 6.55 um were assimilated
  - GOES-13(16) water vapor radiances ~10.7 um were used for additional verification
  - Covariance localization (radius=300 km) and adaptive error inflation following Minamide (2017)

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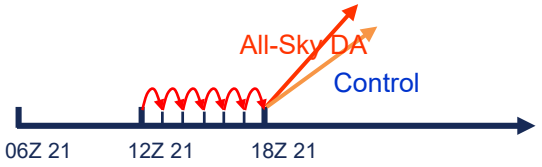
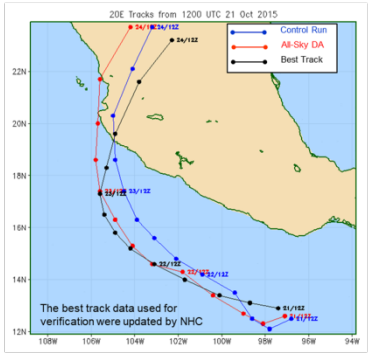
Patricia (2015)

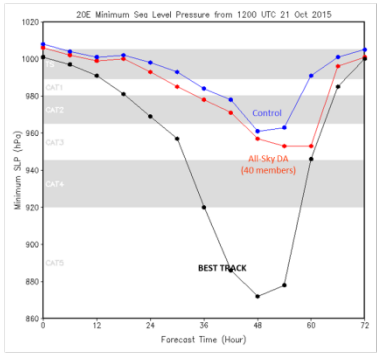


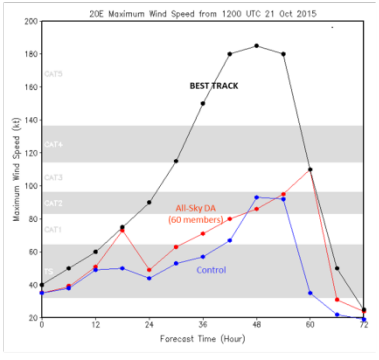
- Control: GFS cold started with TC bogus
- EXP: Initialized with EnKF mean perturbations from hourly-cycled all-sky radiance DA (**60 or 40 members**)
- GOES-13 Imager Channel 3 (6.55 um) for Patricia
- GOES-16 ABI Channel 8 (6.15 um) for Harvey

- Reduced Intensity errors by up to 58% with much improved TC development

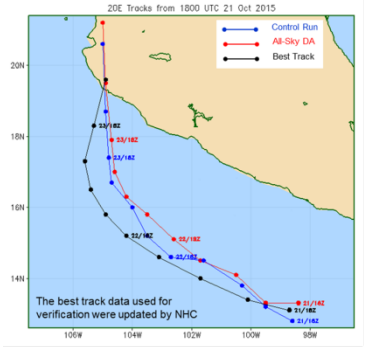
12:00 UTC 21 Oct. 2015 (40 ensemble members)

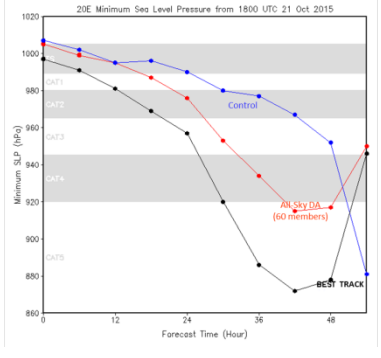


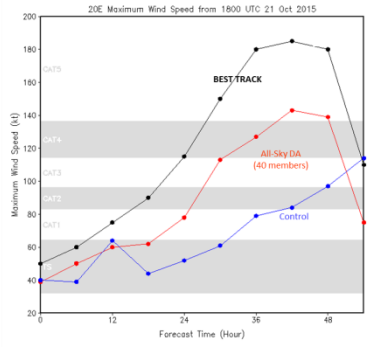




18:00 UTC 21 Oct. 2015 (60 ensemble members)







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Harvey (2017)

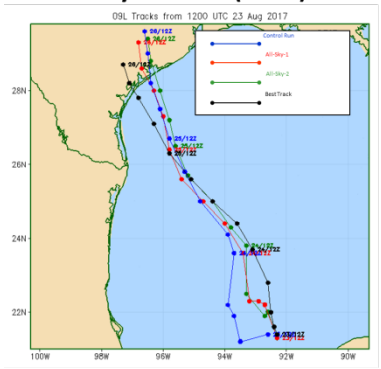
(12:00 UTC 23 Aug. 2017)

All-Sky DA Test (3 km)

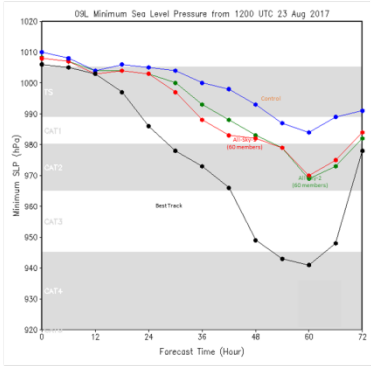
GOES-16 ABI
Channel 8 (6.15 um)

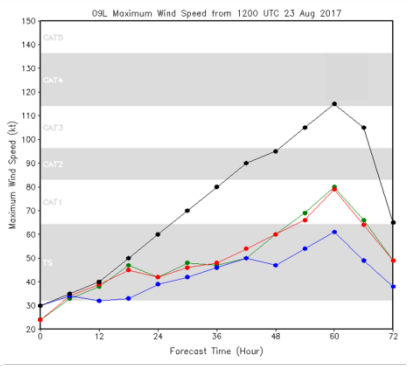
2017
Real-Time Run (4 km)

All-Sky DA Test (3 km)

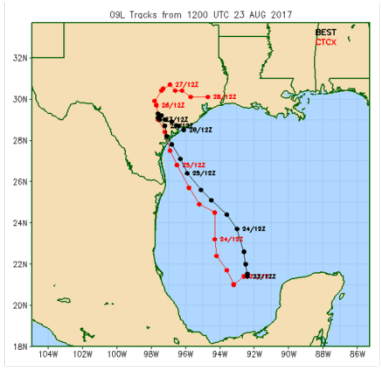


12:00 UTC 23 Aug. 2017 (60 ensemble members)

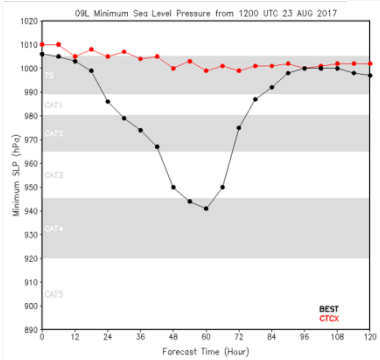


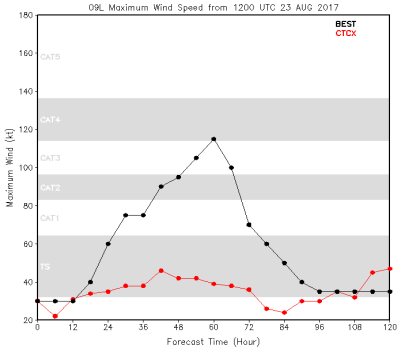


Real-Time Run (4 km)



12:00 UTC 23 Aug. 2017 (60 ensemble members)





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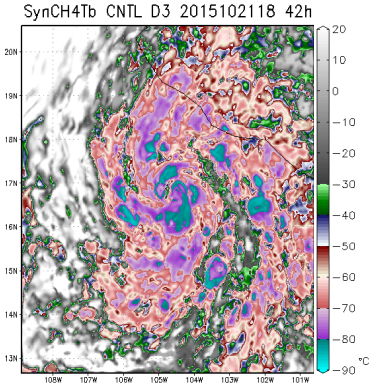
Patricia (2015)

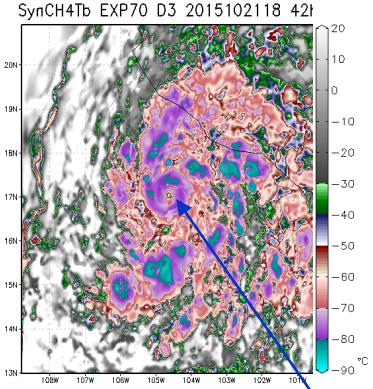
42H Forecast Control Run

42H Forecast All-Sky DA

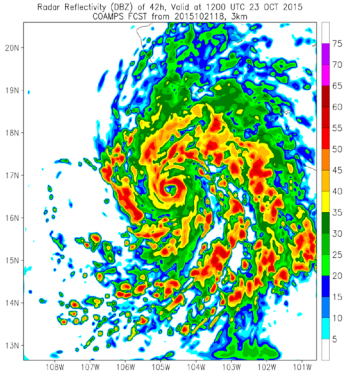
Observed TB at (6.2 μm, ^oC)

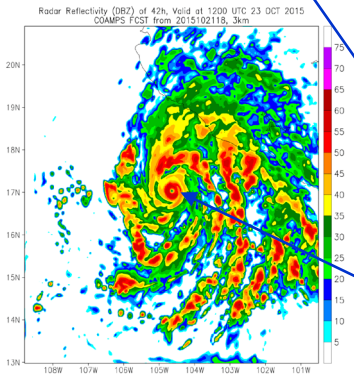
Simulated 10.7 μm Brightness Temperature (^oC) from COAMPS-TC **Free Forecasts**

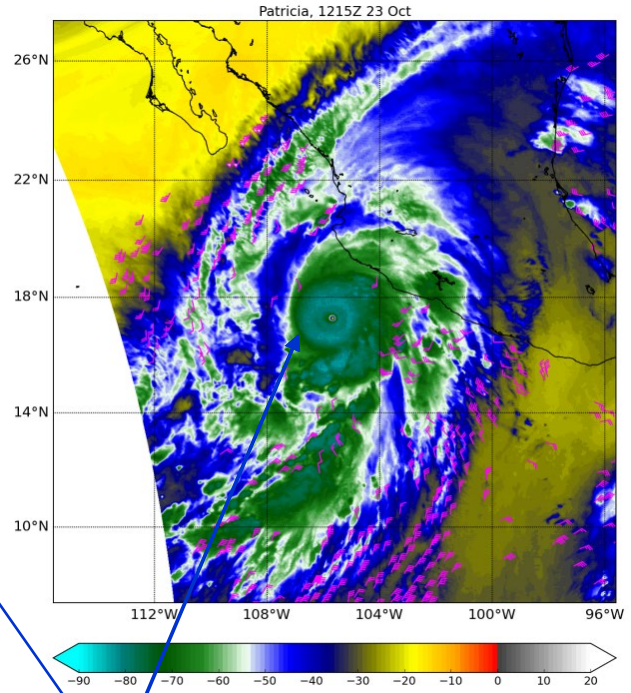




Simulated Radar Reflectivity (DBZ) from COAMPS-TC **Free Forecasts**







(provided by Dave Ryglicki)

Tighter inner core and smaller hurricane eye

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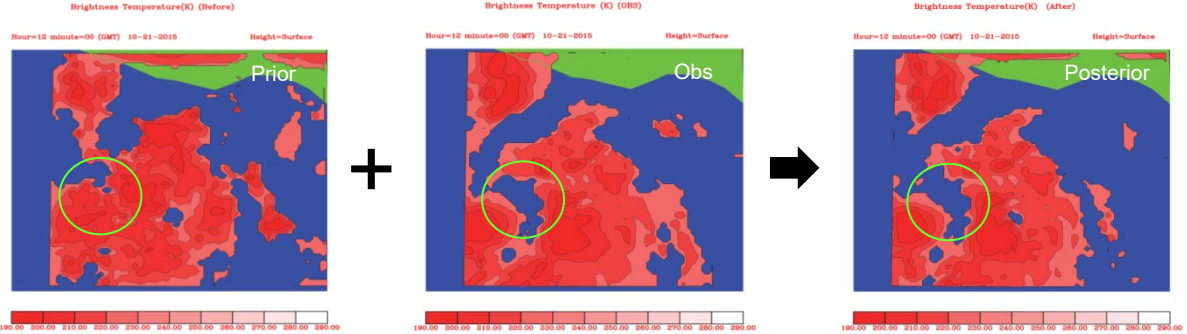
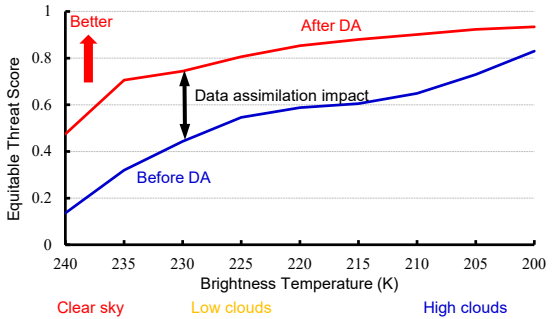
Brightness Temperature (K) from IR (water vapor channel, 6.2 μm)

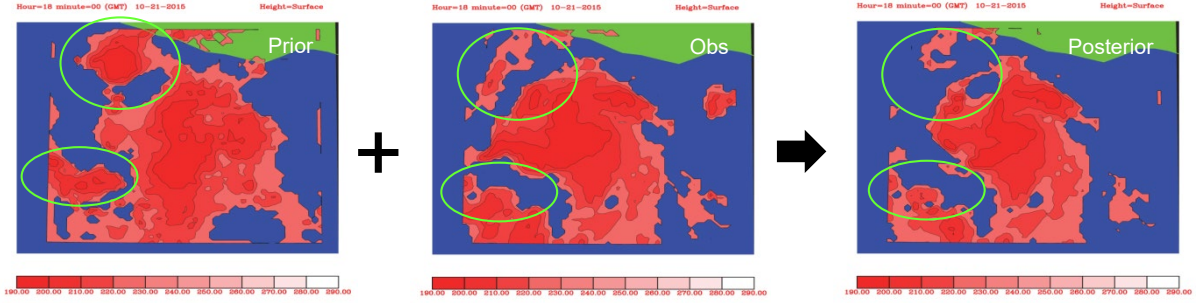
Before DA (1h-forecast) | **Observations** | **After DA (analysis)**

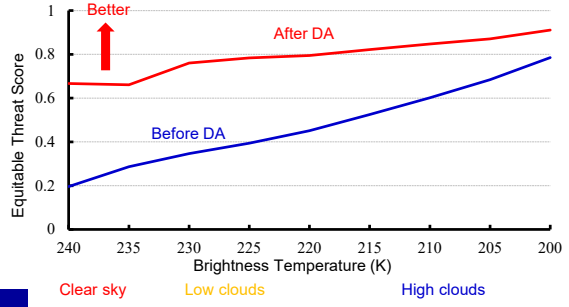
1200 UTC 21 Oct. 2019





1800 UTC 21 Oct. 2019

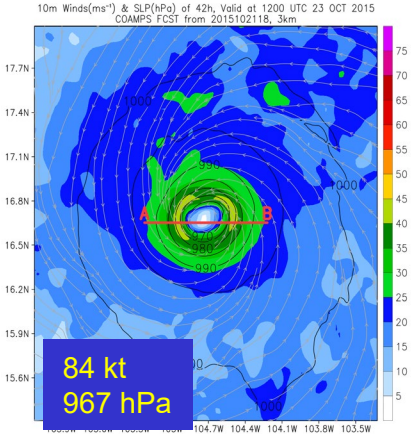


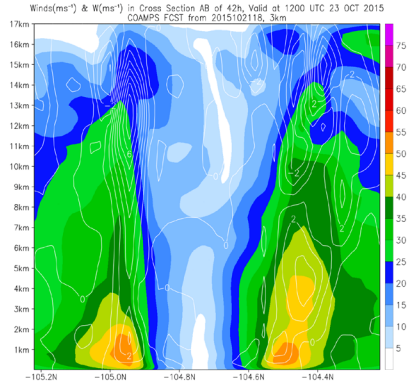


- All-Sky radiance assimilation is effective
- Improves TB for both clear sky and cloudy areas

Patricia (2015) at Strongest Stage (42hr)

Control





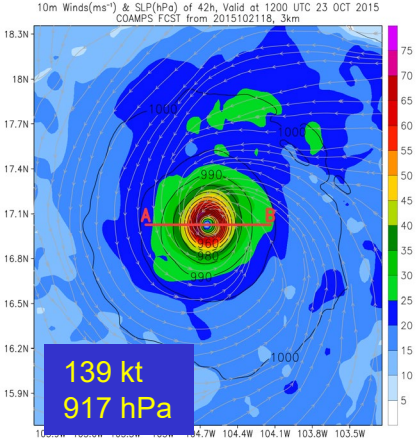
SLP
(contours, hPa)
10m Wind Speed
(color, m/s)

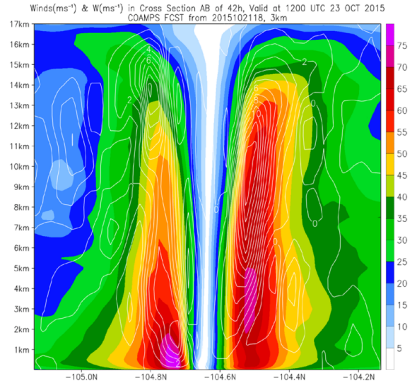
OBS
185 kt
872 hPa

Vertical Wind Speed
(contours, m/s)
Horizontal Wind Speed
(color, m/s)

(provided by Hao Jin)

All-Sky DA

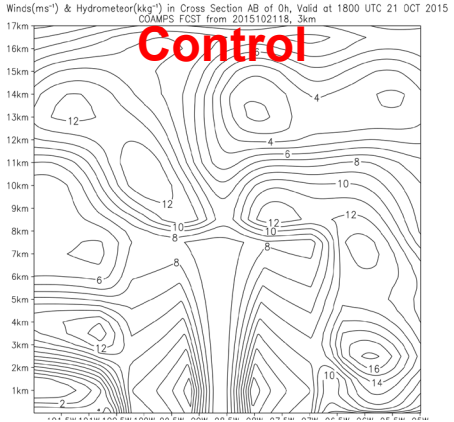




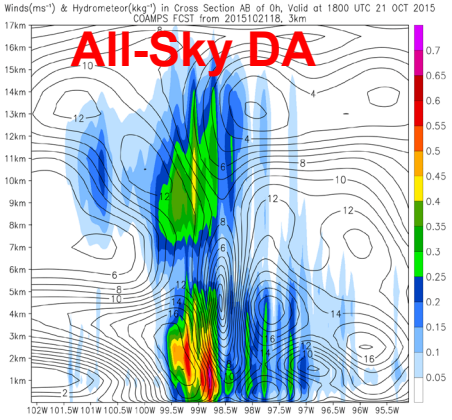
EnKF leads to stronger winds, lower sea-level pressure, and a tighter inner core structure.

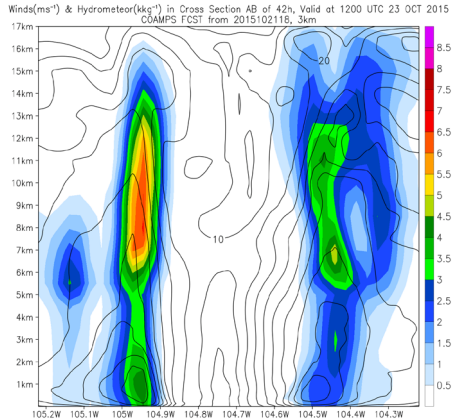
Winds and Hydrometeor Mixing Ratio

Cross-Section AB

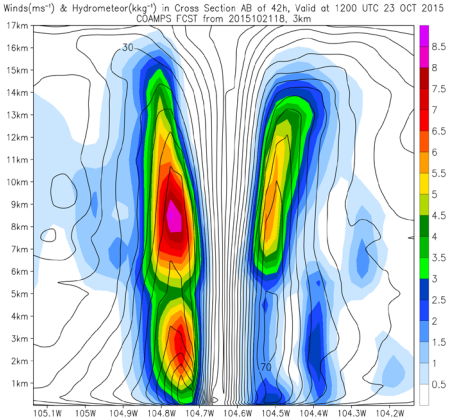


Initial Time
(00h)





Strongest Stage
(42h)



EnKF cross-variances also enhance the microphysics structure.

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Summary and Next Steps

For the two challenging TC storms (Patricia and Harvey), the new EnKF DA capabilities work well with COAMPS-TC. In particular, the geostationary IR radiance assimilation and the CRTM-based forward operator perform very well in both **clear and cloudy sky regions**.

The system (based on the testing so far) demonstrates the potential for improved TC **intensity, structure, and track forecasts** that last for days with improved initial storm conditions, indicating the potential benefits of a well-designed DA system to COAMPS-TC.

We plan to further develop the system by:

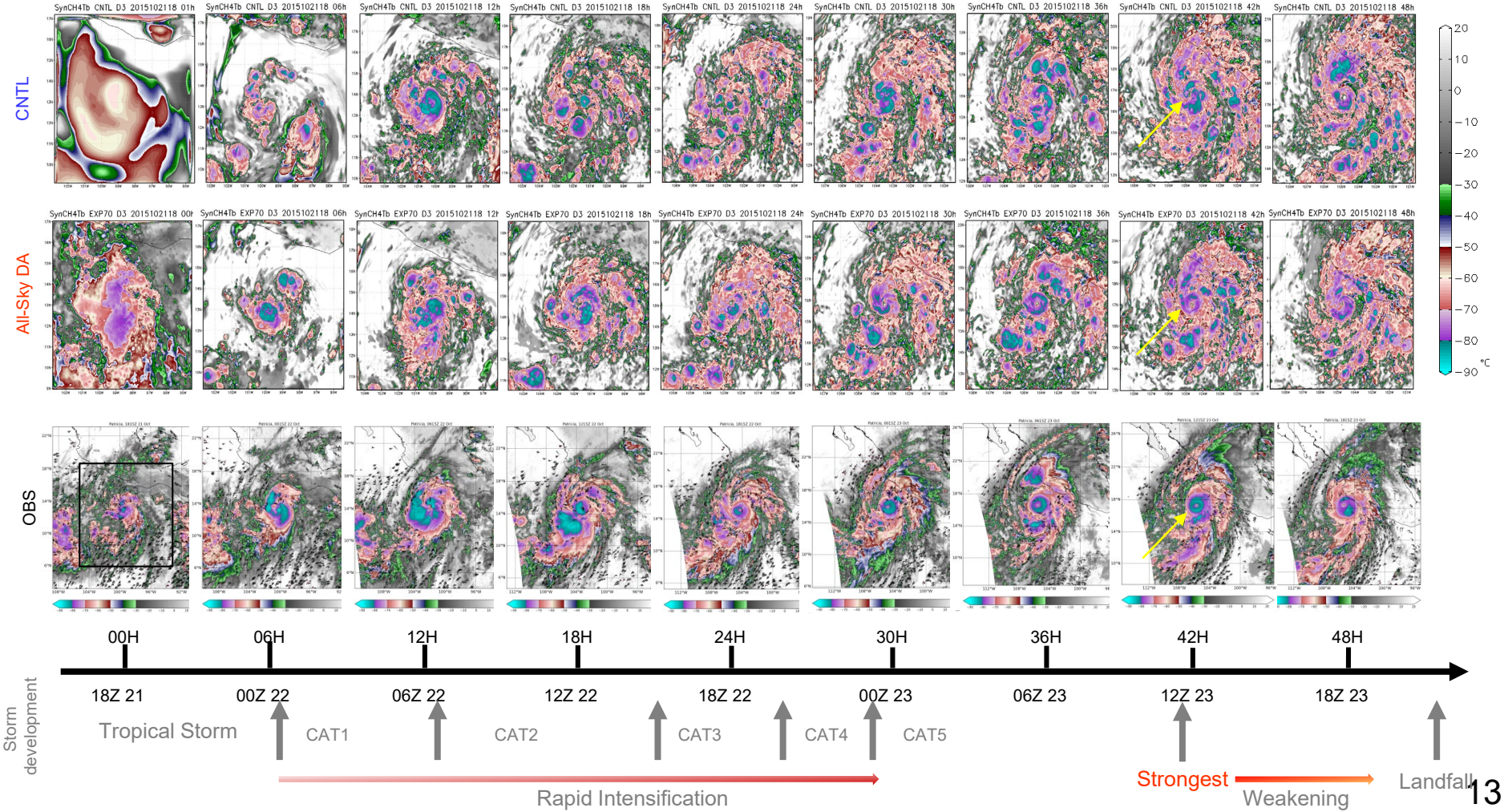
- Connecting the NRL observation stream to the EnKF system.
- Adapt/develop algorithms for generating perturbed initial and boundary conditions from real-time GFS (or GEFS) for COAMPS-TC
- Optimizing the system for improved effectiveness and computational efficiency
- Completing more extensive testing with storms from 2020 hurricane season (offline) to further evaluate the system performance
- Exploring the potential to develop all-sky microwave radiance assimilation with collaborations within DA community

References

Minamide, M., and F. Zhang, 2017: Adaptive Observation Error Inflation for Assimilating All-Sky Satellite Radiance. *MWR*, **145**, 1063-1081.

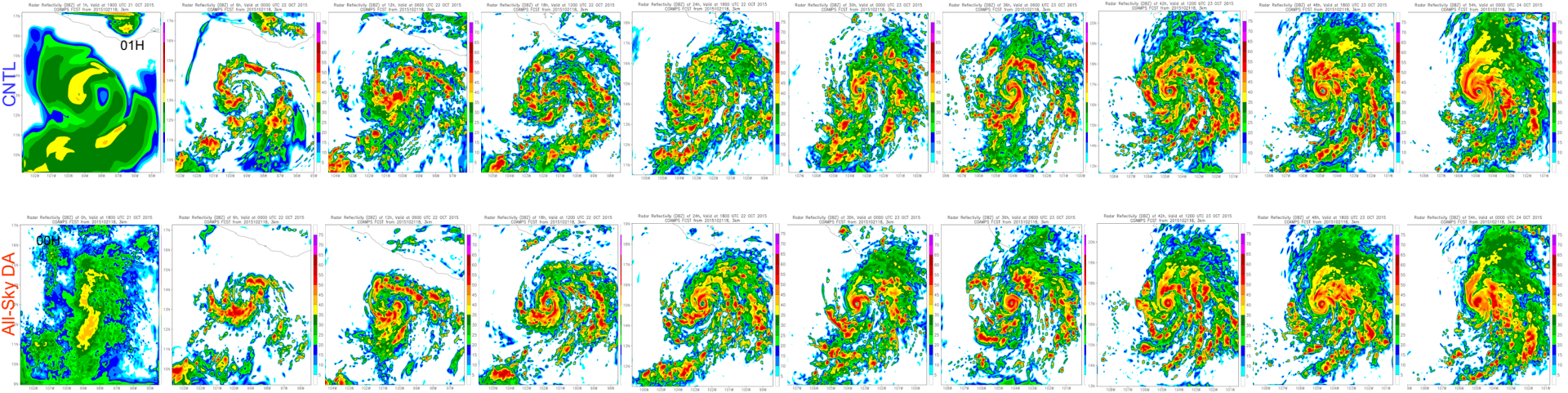
Zhang, F., M. Minamide, and E. E. Clothiaux, 2016: Potential impacts of assimilating all-sky infrared satellite radiances from GOES-R on convective-permitting analysis and prediction of tropical cyclones. *Geophys. Res. Lett*., **43**, 2954-2963.

Brightness Temperature (K) from COAMPS-TC **Free Forecasts** and Satellite IR (10.3 μm) Observations (Patricia 2015)



Radar Images from COAMPS-TC Free Forecasts (Patricia , 2015)

	00H	06H	12H	18H	24H	30H	36H	42H	48H	54H	
CNTL	40	39	64	44	52	61	79	84	97	114	
	1007	1002	995	996	990	980	977	967	952	881	
AllSky	39	50	60	62	78	113	127	143	139	75	
	1005	999	995	987	976	953	934	915	917	950	
OBS	50 (kt)	60	75	90	115	150	180	185	180	130	Max wspd
	997 (hPa)	991	981	996	957	920	886	872	978	932	Min pres



00H 06H 12H 18H 24H 30H 36H 42H 48H 54H

18Z 21 00Z 22 06Z 22 12Z 22 18Z 22 00Z 23 06Z 23 12Z 23 18Z 23 00Z 24

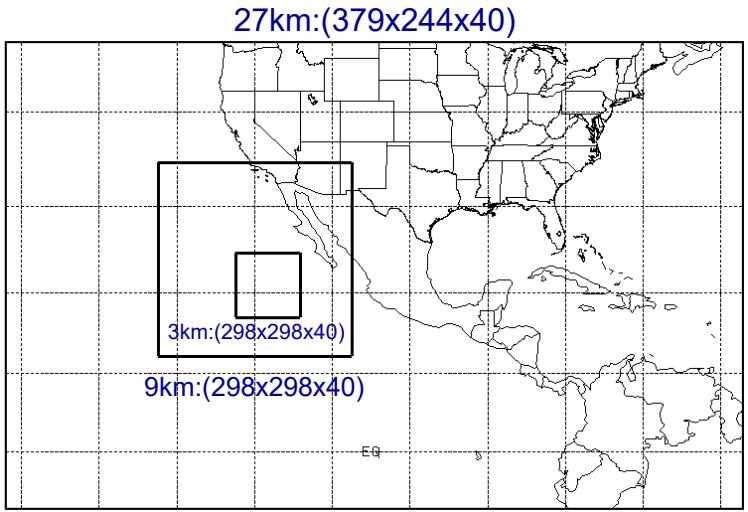
Observed Storm development

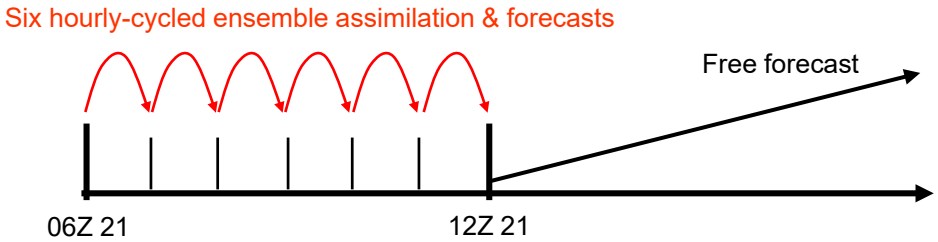
Tropical Storm CAT1 CAT2 CAT3 CAT4 CAT5

Rapid Intensification

Strongest Weakening Landfall

Computational Cost

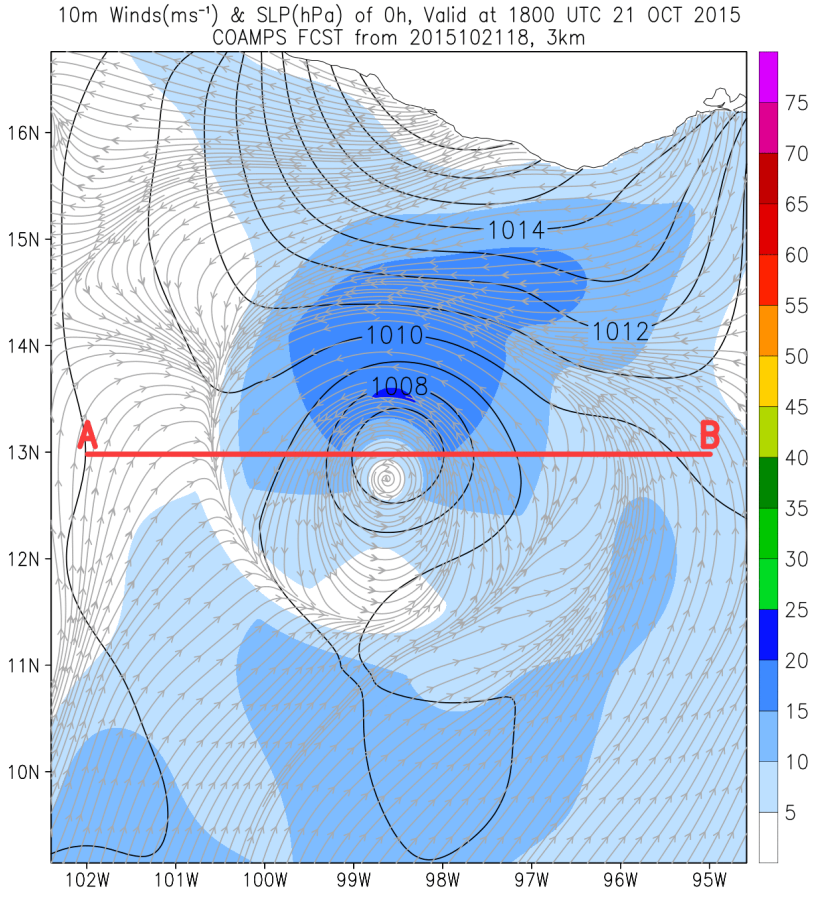




1H EnKF DA:	40~50 min (in slow debug mode. PSU Demo: 30~35 min),
	61 CPUs for 60 members
1H ensemble forecast:	4~5 min (256 CPUs/member, 60 members run in parallel),
	Total CPUs=15,360
Single free forecast:	50~65 min (256 CPUs) for 3 days

10m Winds and SLP for Patricia (2015) at Initial Time (0h)

Control



All-Sky DA