Prediction & Predictability of Hurricane Joaquin (2015) Revealed through Convection-permitting Real-time Deterministic and Ensemble forecasts

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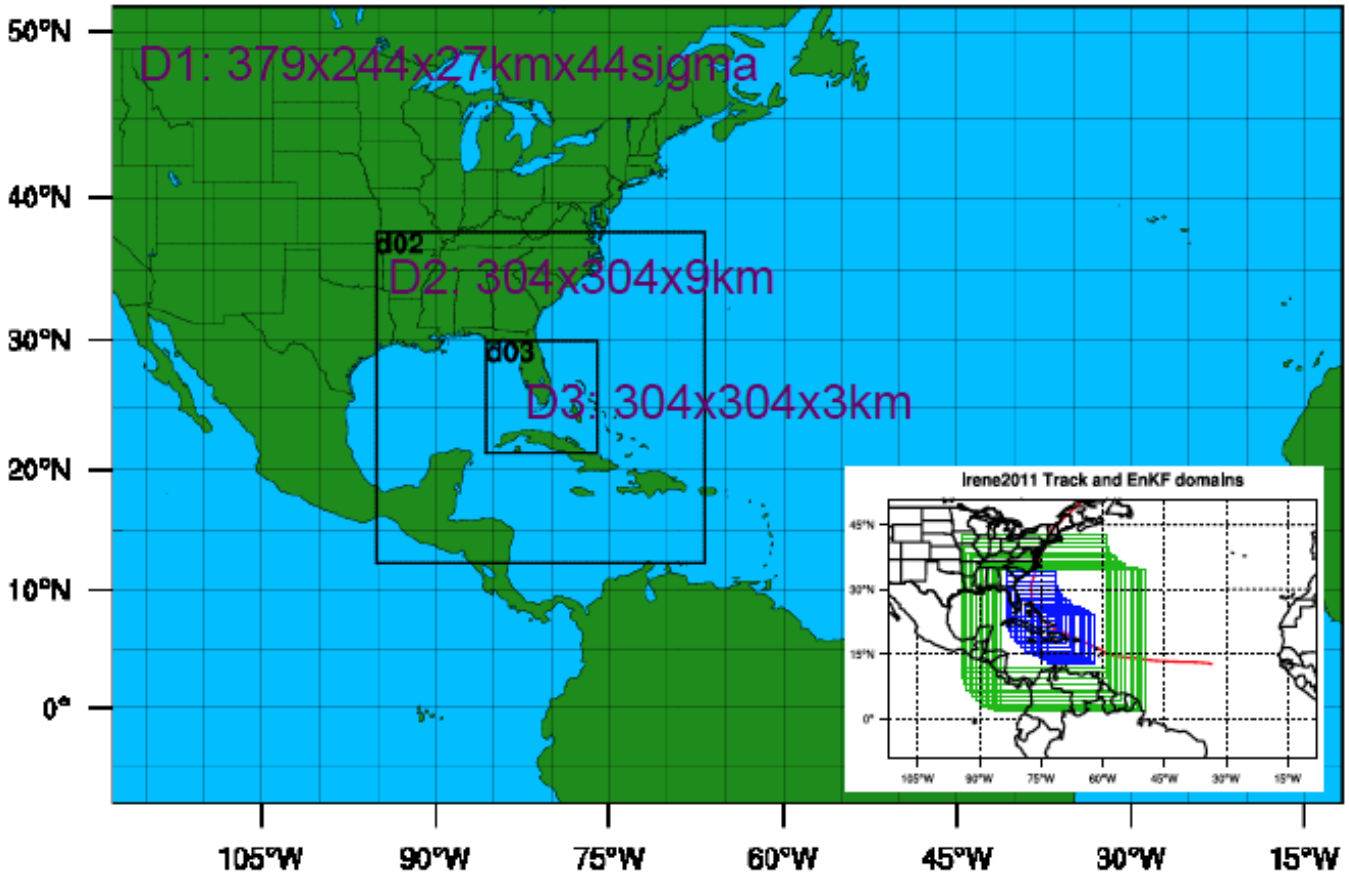
Penn State University

Contributor: Christopher Melhauser

Sponsored by NOAA/HFIP and ONR

APSU real-time configurations



ARW	V3.4.1
Cumulus	Grell-Devenyi ensemble (27 km domain only)
Microphysics	WSM 6-class graupel
PBL	YSU
Surface Layer	Monin-Obukov
Land Surface	thermal diffusion
Radiation	Rrtm / Dudhia
Air-sea flux	Green and Zhang
Ocean	1-D

- 60-member ensemble
- Gaspairi & Cohn 99' covariance localization with varying RoI
- IC & BC: GFS using 3DVAR background uncertainty
- Hourly assimilation with TDR over all 3 domains

ATCF IDs:

APSU: stream 1.5, ARW 3-km deterministic forecast;

PS01-10: stream 2.0, ARW 3-km ensemble forecasts.

ARW-EnKF Performance Assimilating Airborne Vr

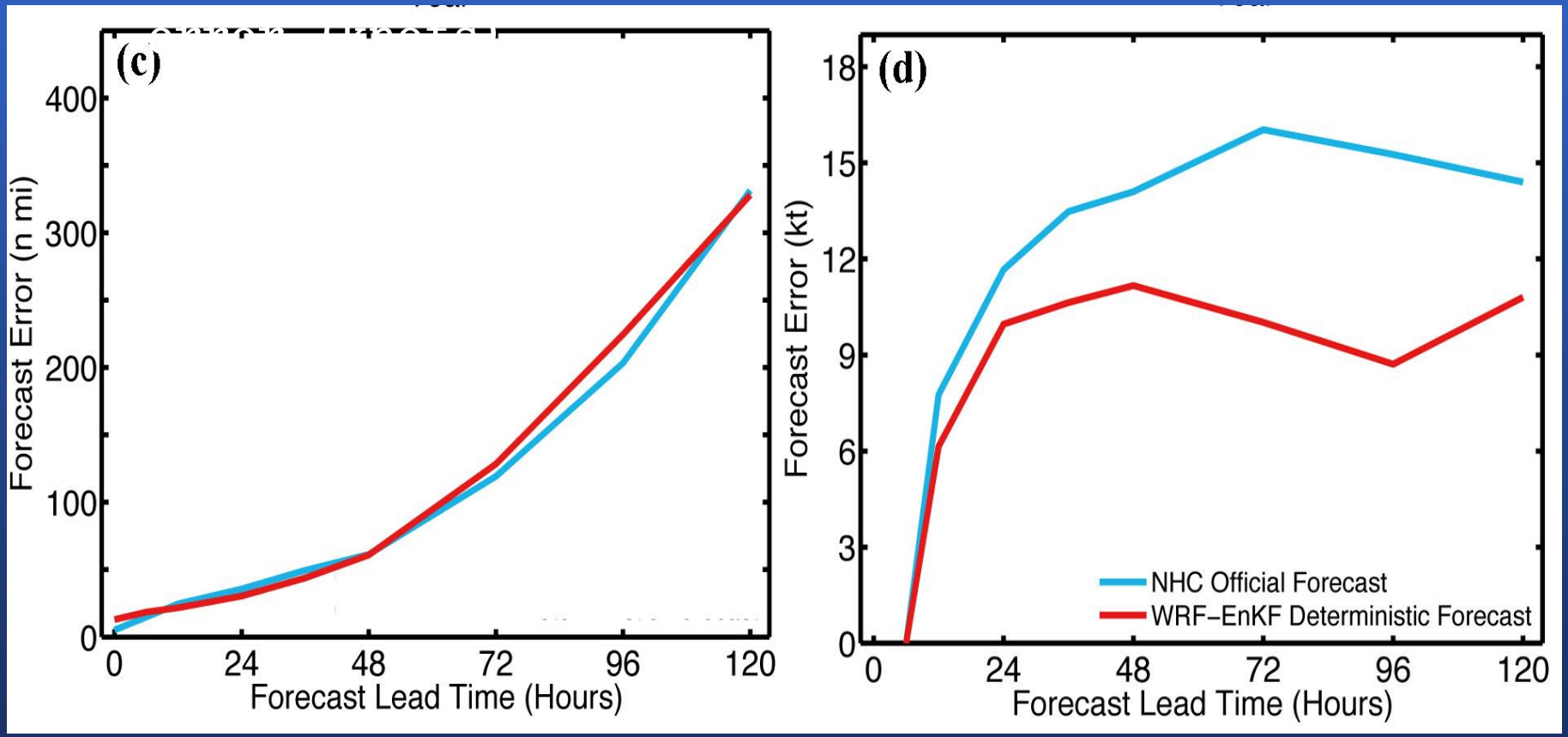
all 100+ P3 TDR missions during 2008-2012

Quasi-operational evaluation by NOAA/NHC since 2011 as stream 1.5 run

WRF-EnKF: 3 domains (27, 9 , 3km), 60-member ensemble, PSU TC flux scheme

Position error (km)

Intensity



(Zhang and Weng, 2015 BAMS)

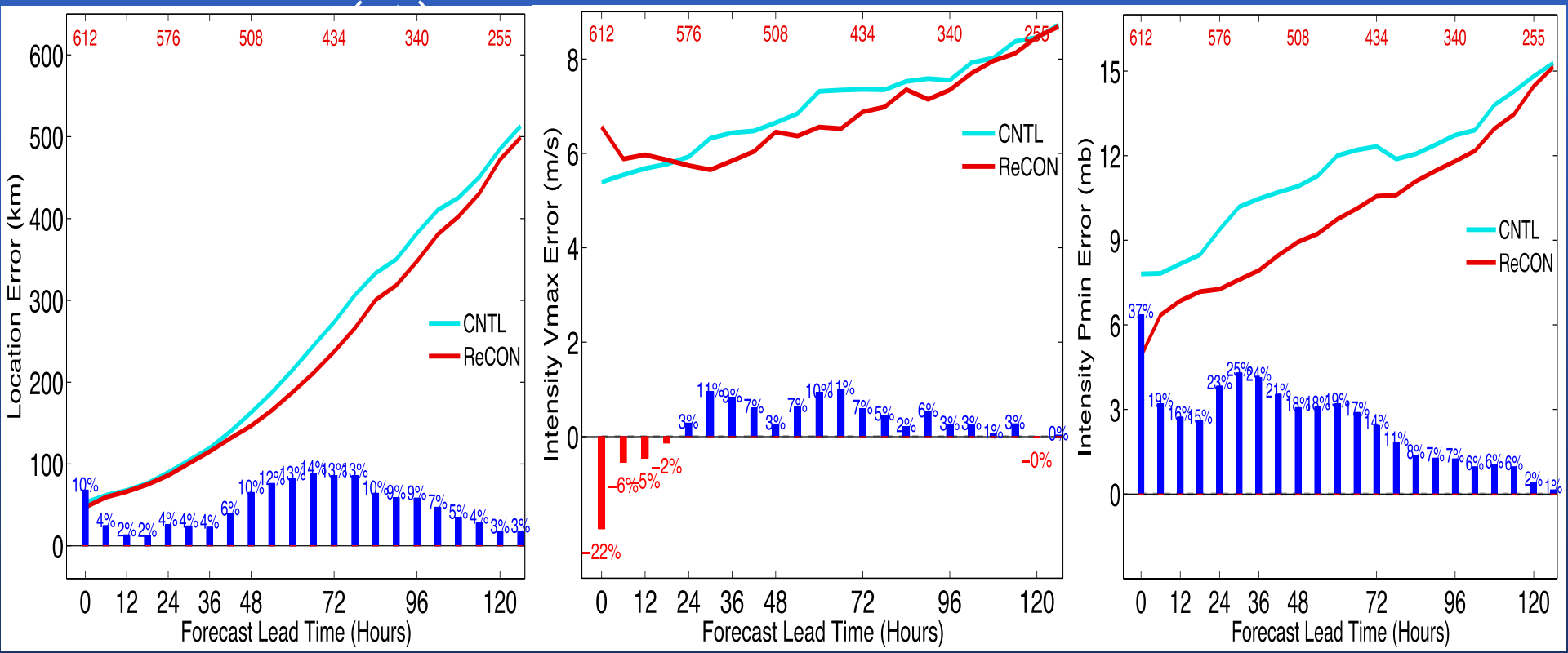
WRF-EnKF Performance w/ versus w/o Aircraft OBS

for HFIP/NHC selected RDITT cases w/o TDR during 2008-2012

WRF-EnKF: 3 domains (27, 9 , 3km), 60-member ensemble, PSU TC flux scheme

Position error (km)

Vmax error (knots)



(Weng and Zhang, 2016 JMSJ)

HPSU System (PSU HWRF-EnKF)

- Based on HWRF (or NMM)
  - No convert or interpolation from/to other map projection, coordinates and variables;
  - Can be started from any HWRF/NMM runs
    - w/ or w/o GSI; w/ or w/o ocean
- EnKF is fully functioned as PSU WRF-EnKF
  - Fully parallel, member+domain parallel;
  - Currently can digest GTS, Tcvitals, sat winds;
- Cycling system
  - The system will be initialized at the very begging of the storm, after spin-up, the system will run data assimilation every 3 hours till the end of the storm;
- Initialized with GDAS-EnKF 80 perturbations

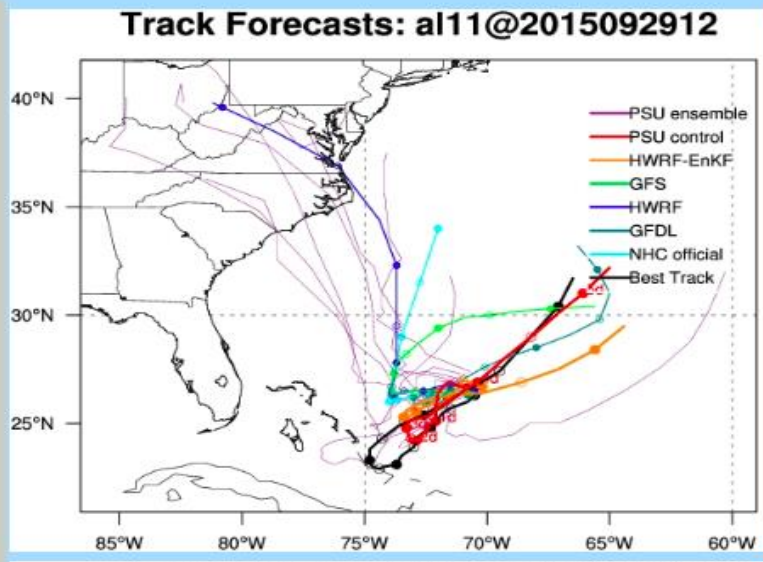
PSU WRF/EnKF Real-time Atlantic Hurricane Forecast

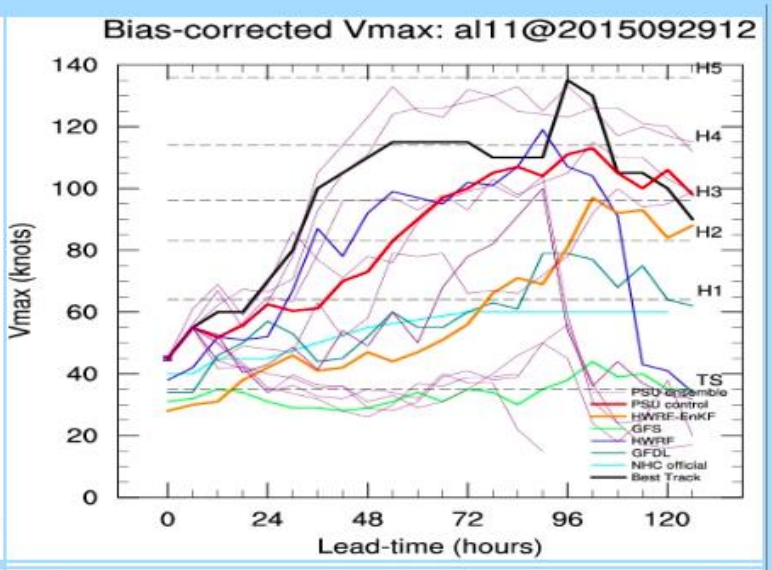
Select an active storm

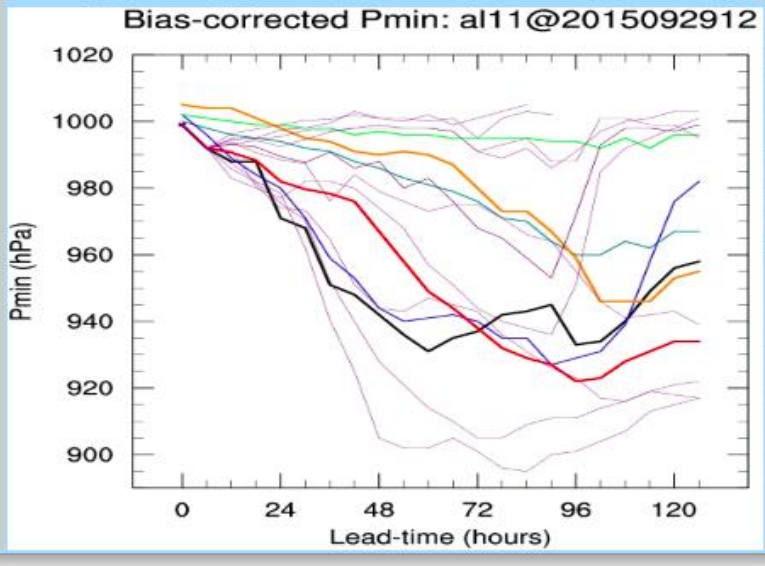
SELECT ACTIVE STORM
JOAQUIN

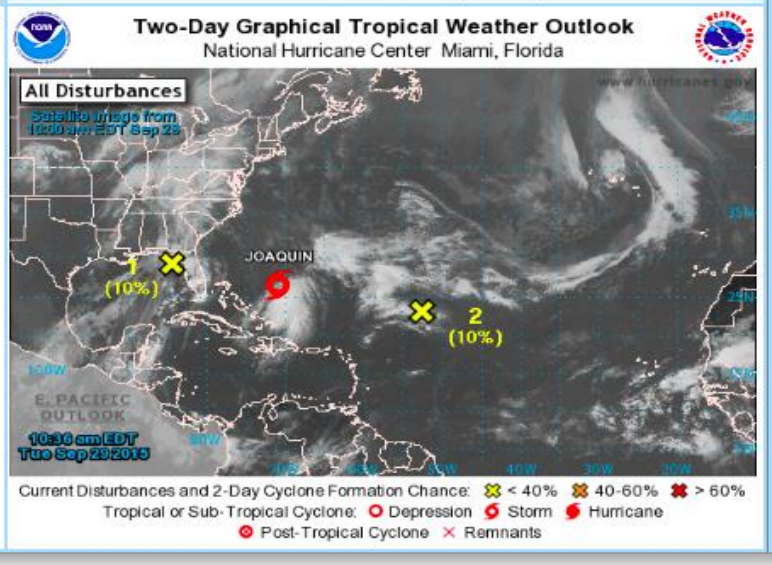
Forecast initial time
2015092912
<< previous (-6hr)
next (+6hr) >>

Select initial time
2015 Sep
29 12Z



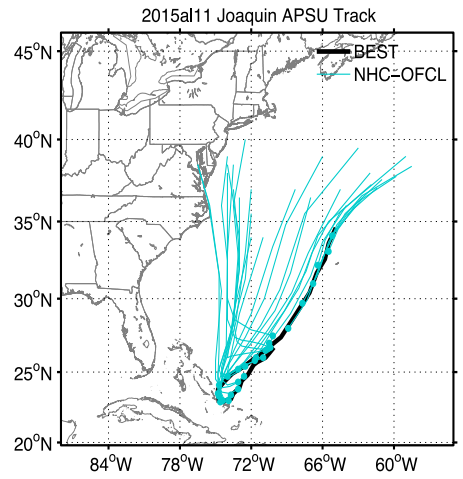




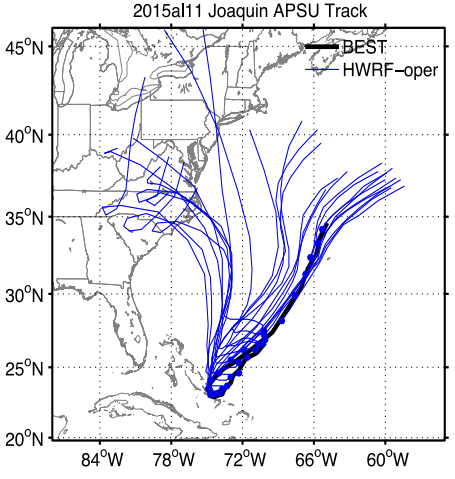


PSU HWRF-EnKF and ARW-HWRF real-time systems for Joaquin (2015)

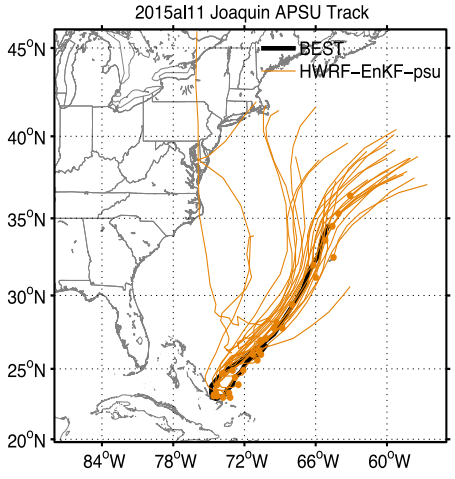
NHC OFCL



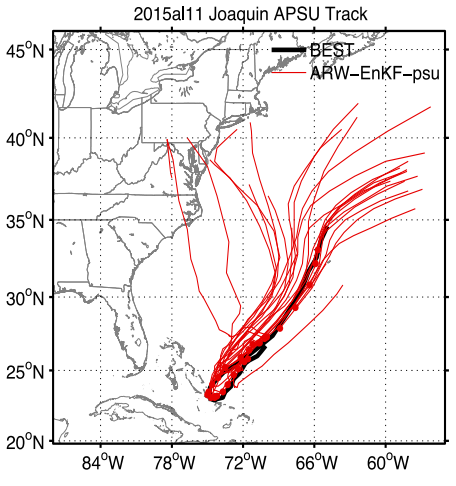
EMC HWRF



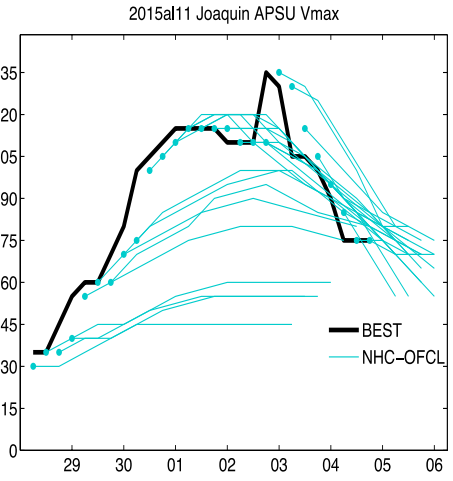
PSU HWRF-EnKF



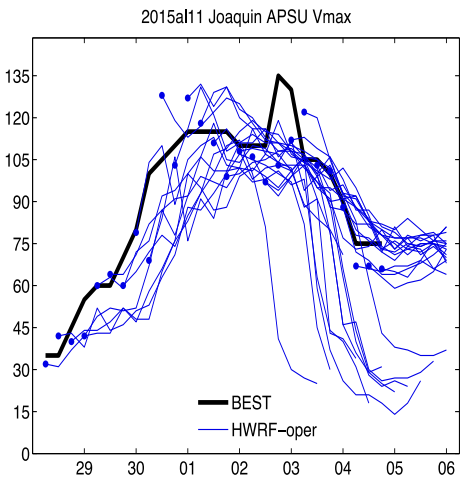
PSU ARW-EnKF



NHC OFCL



EMC HWRF



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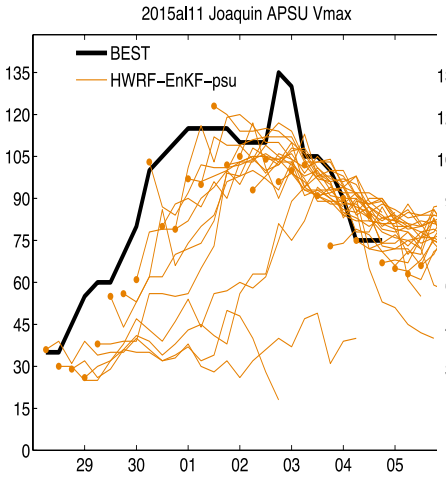
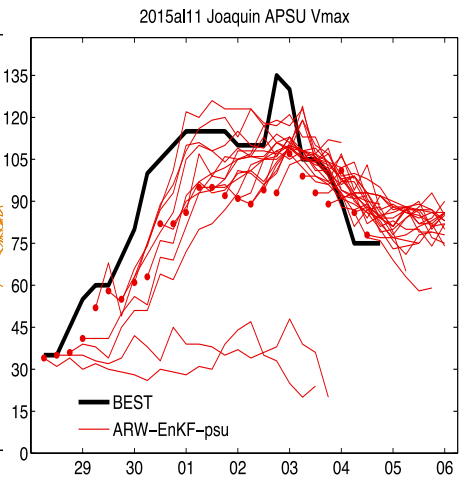
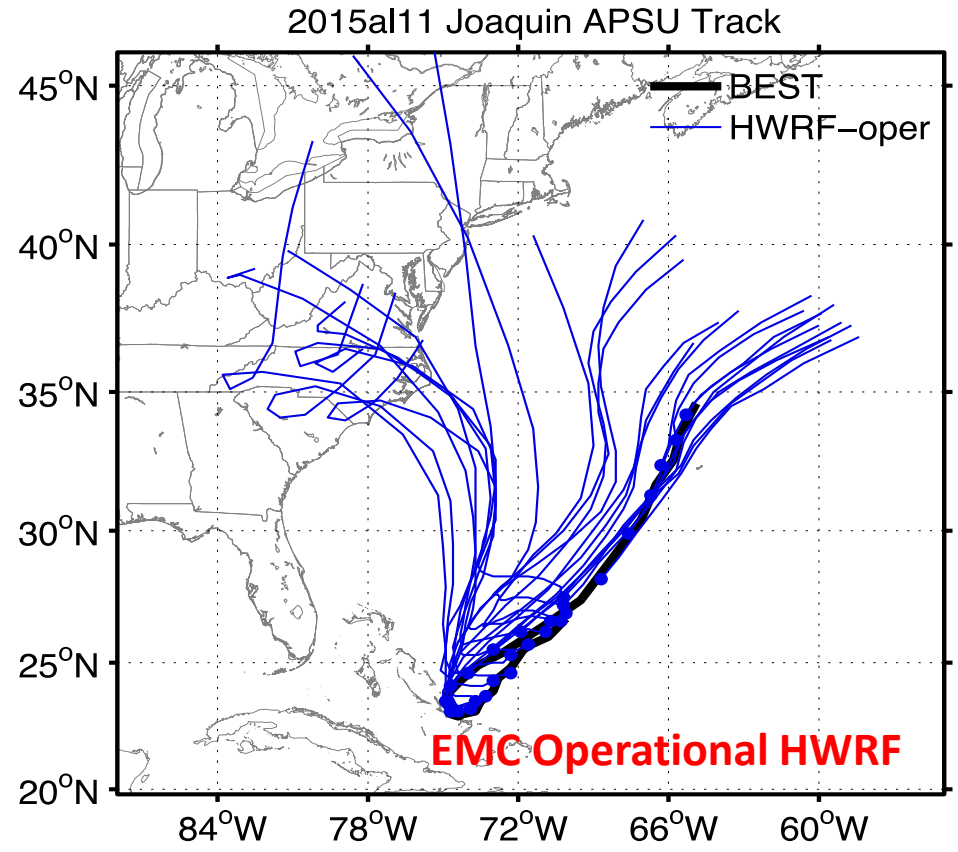


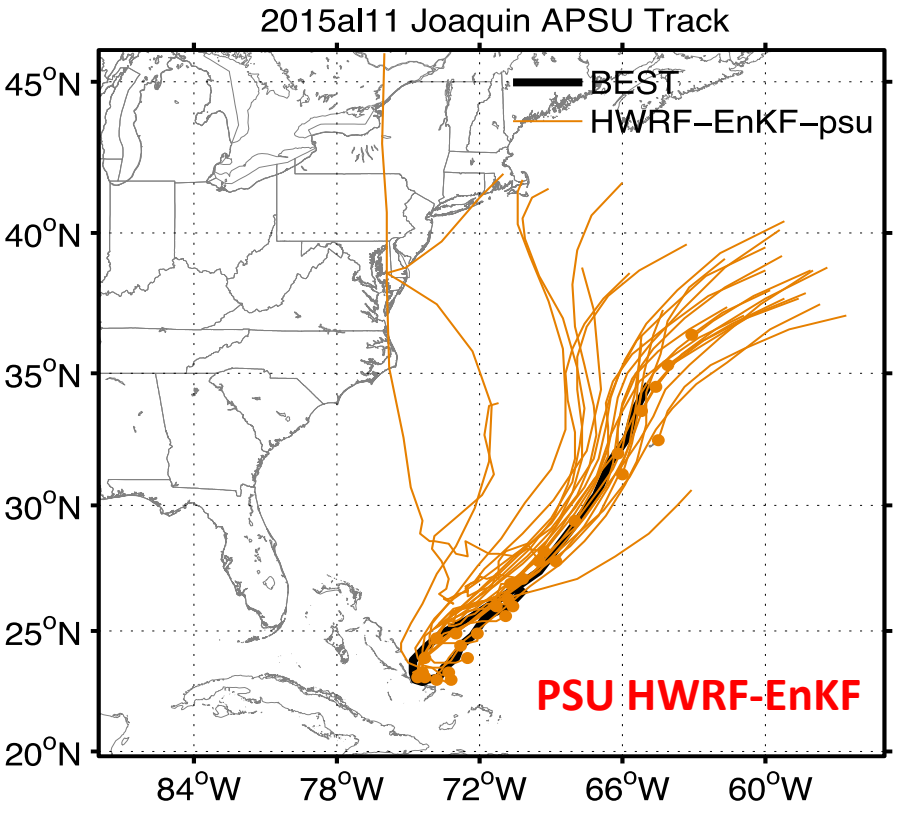
PSU ARW-EnKF



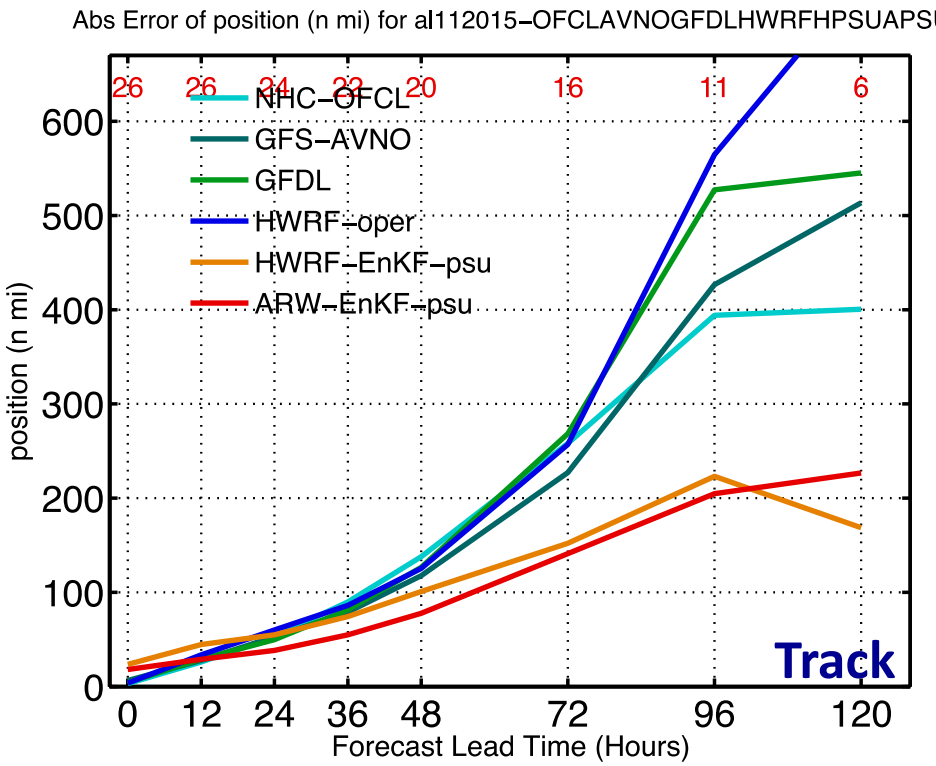
- **Cycling EnKF assimilating all conventional observations including aircraft Recon, satellite derived winds were assimilated. 26 forecasts every 6h starting 12Z/28th**

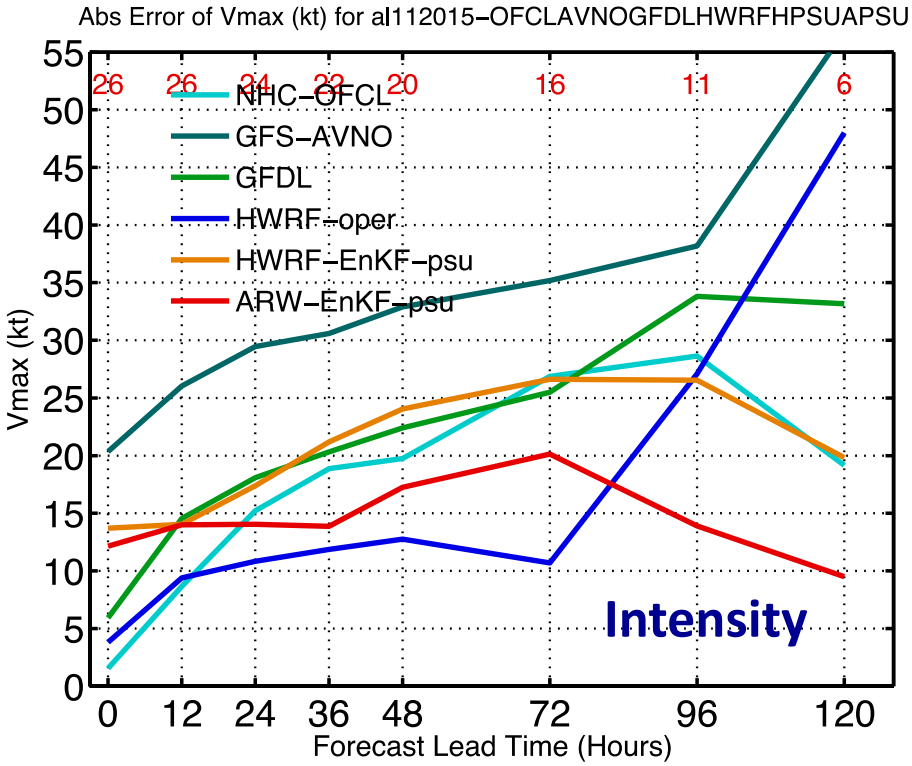
PSU HWRF-EnKF real-time systems for Joaquin (2015)





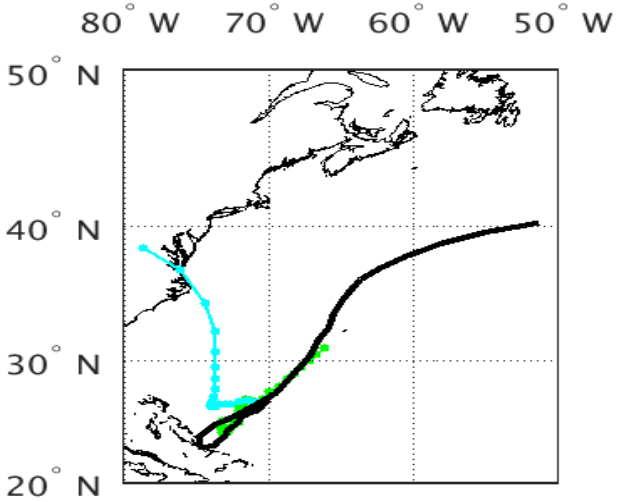
PSU HWRF-EnKF and ARW-EnKF real-time systems for Joaquin (2015): homogeneous comparison of mean absolute errors with operational products



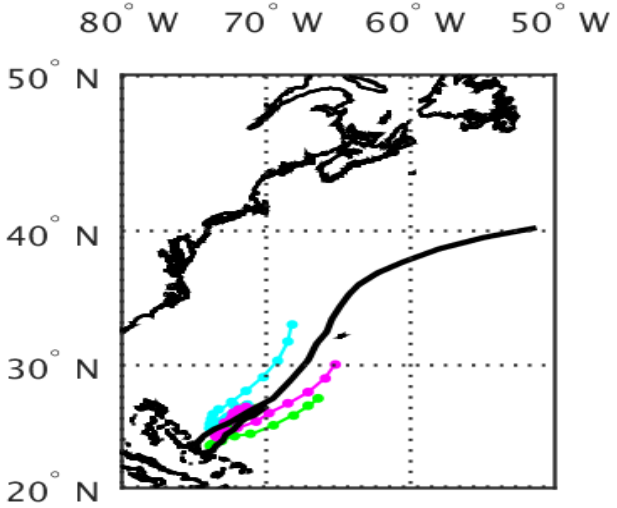


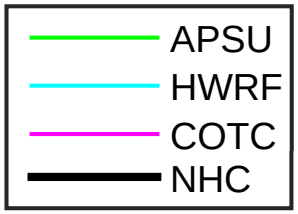
- **Cycling EnKF assimilating all conventional observations including aircraft Recon, satellite derived winds were assimilated. 26 forecasts every 6h starting 12Z/28th**

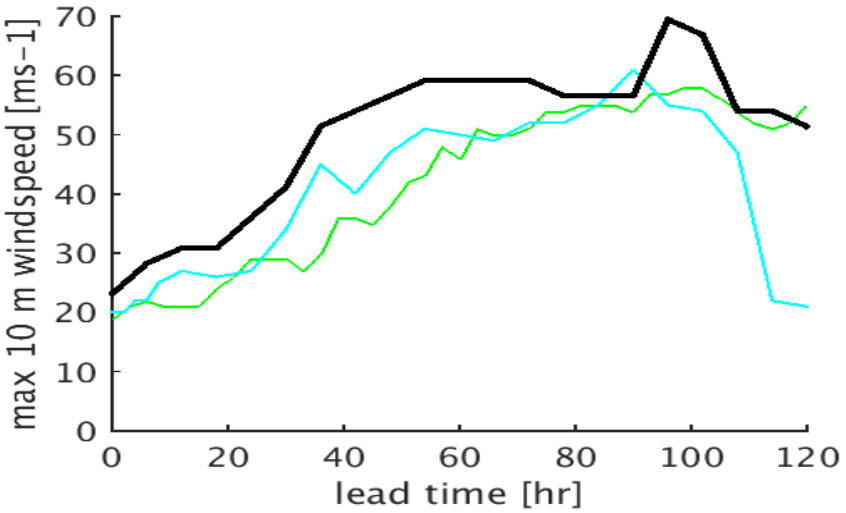
Operational HWRF and real-time PSU WRF-EnKF deterministic runs

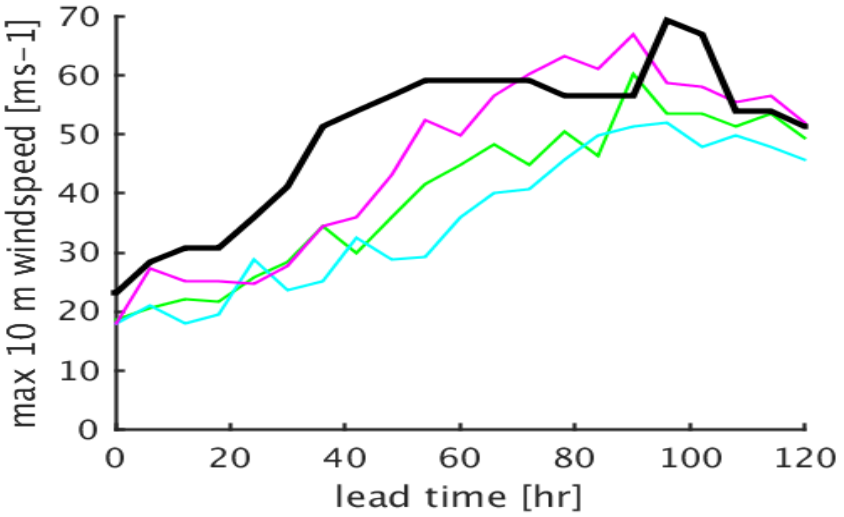


Hindcasts by 3-km regional models using the APSU ICs interpolated to a common grid





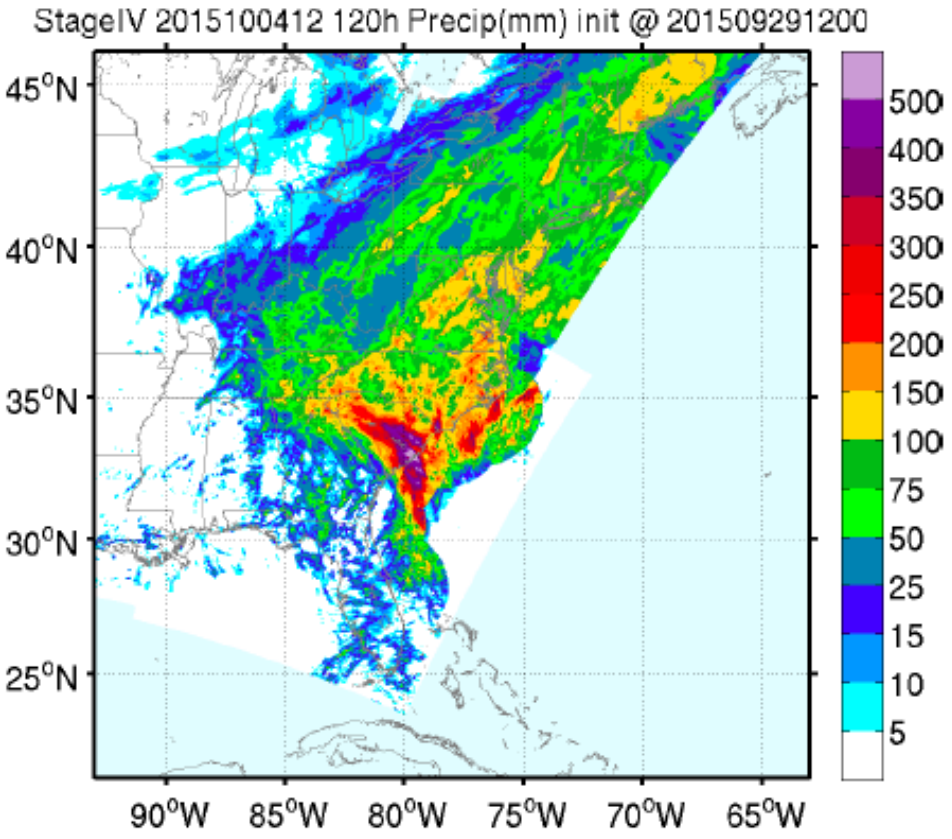


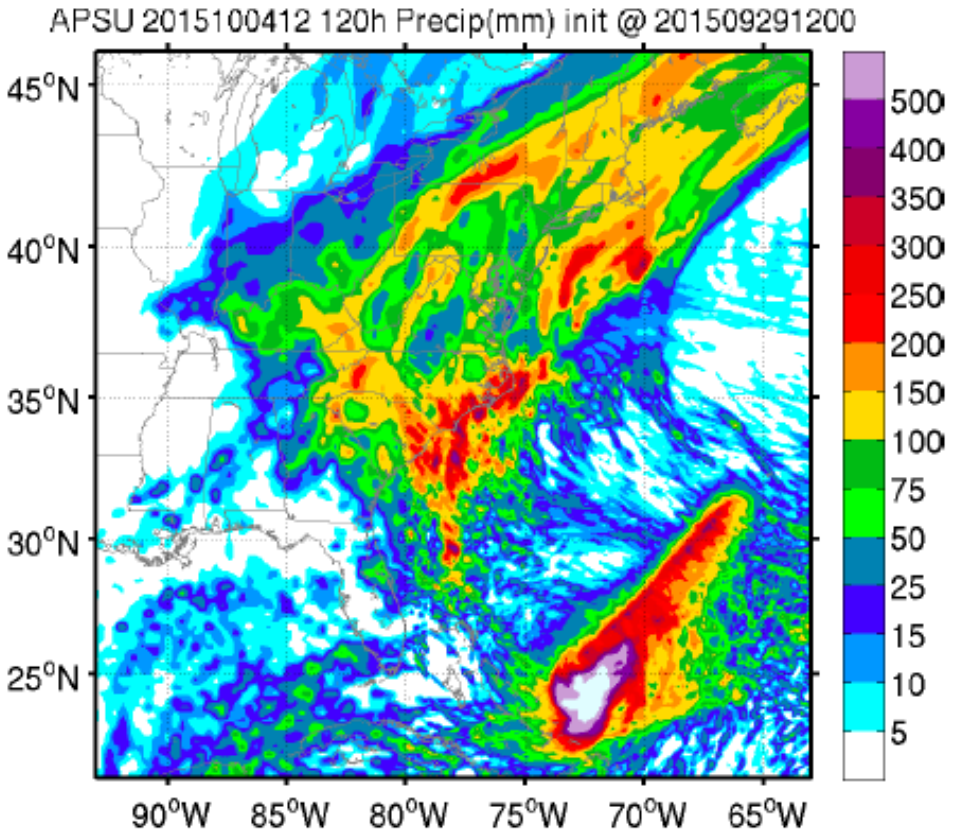


Hindcasts by Christopher Melhauser

5-d Rainfall Forecasts w/ realtime PSU WRF-EnKF

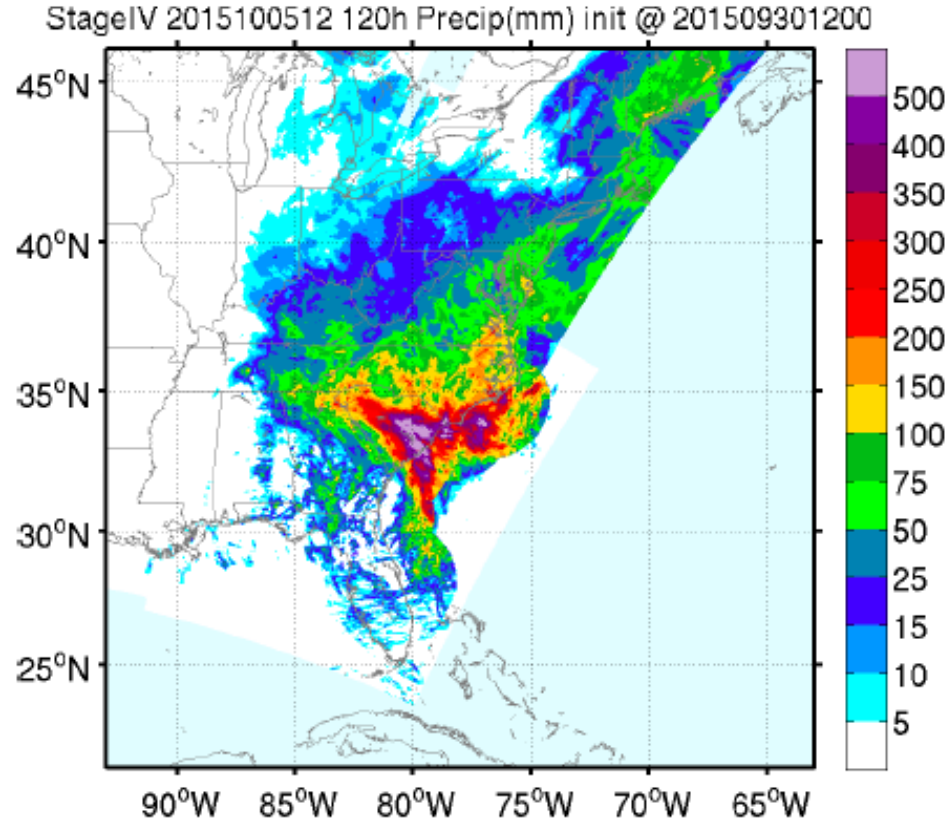
Initialized at 12Z 29 Sept

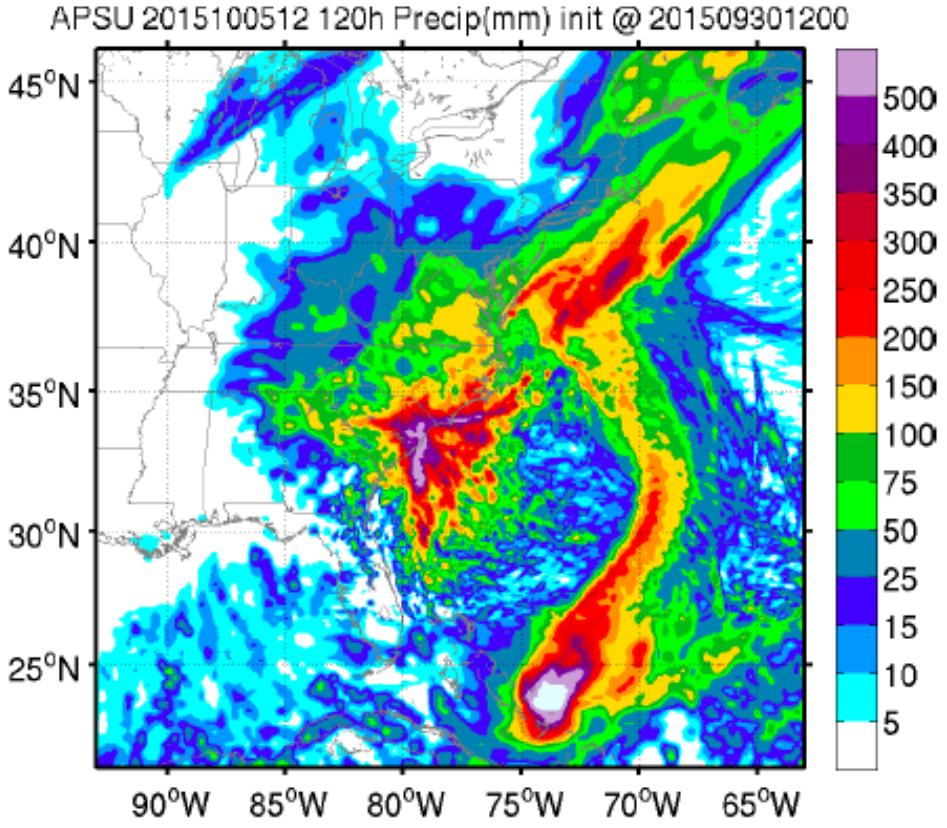




5-d Rainfall Forecasts w/ realtime PSU WRF-EnKF

Initialized at 12Z 30 Sept





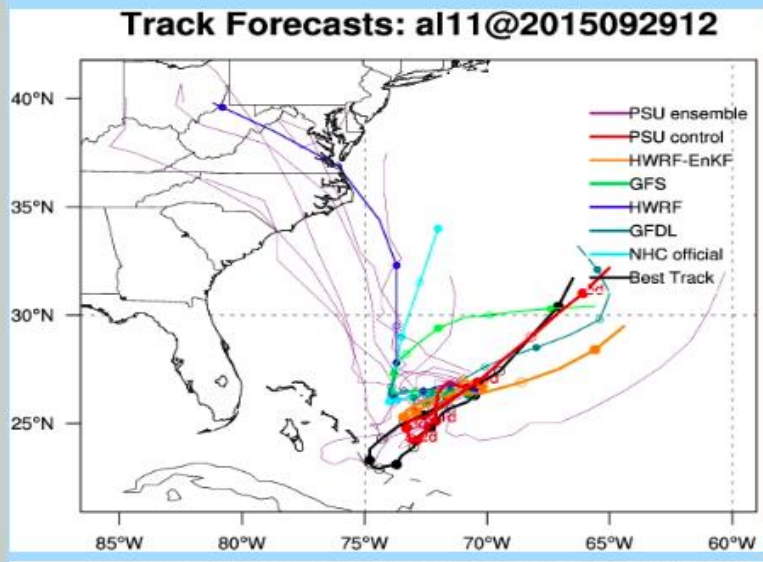
PSU WRF/EnKF Real-time Atlantic Hurricane Forecast

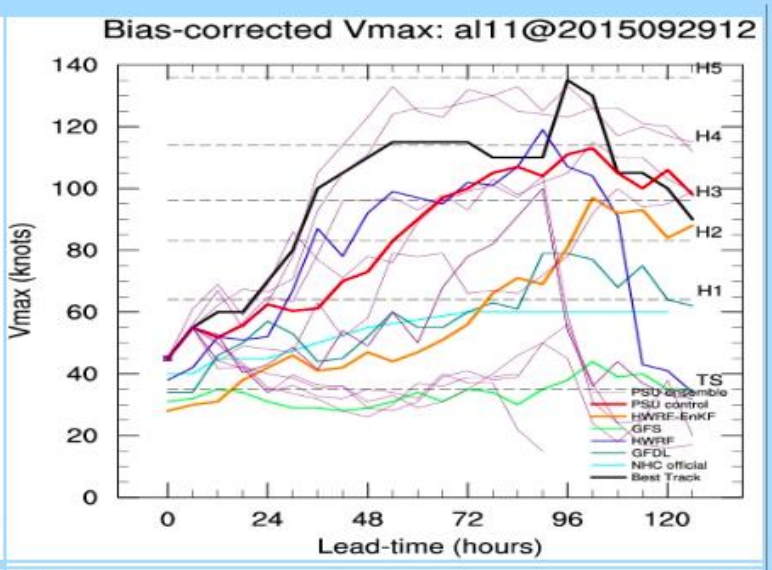
Select an active storm

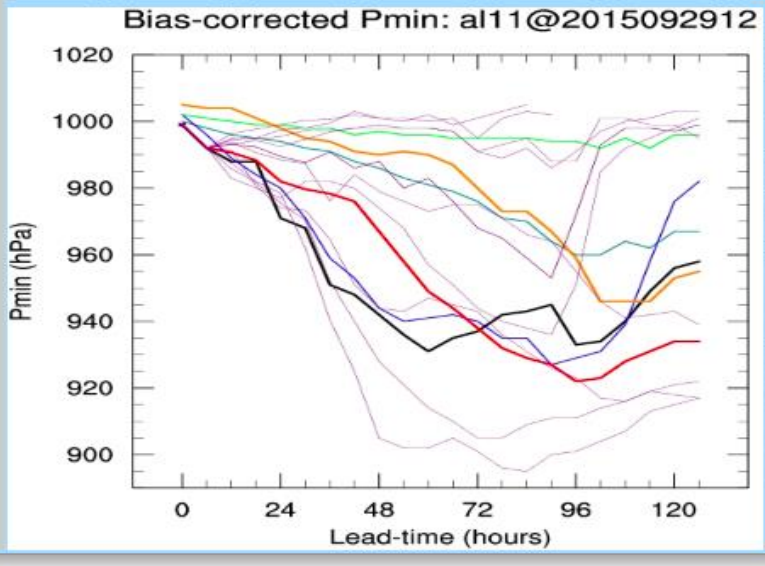
SELECT ACTIVE STORM
JOAQUIN

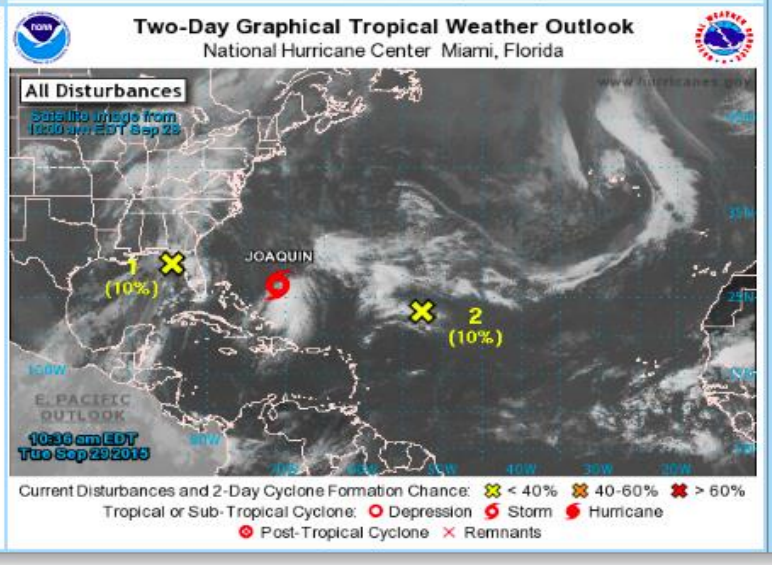
Forecast initial time
2015092912
<< previous (-6hr)
next (+6hr) >>

Select initial time
2015 Sep
29 12Z









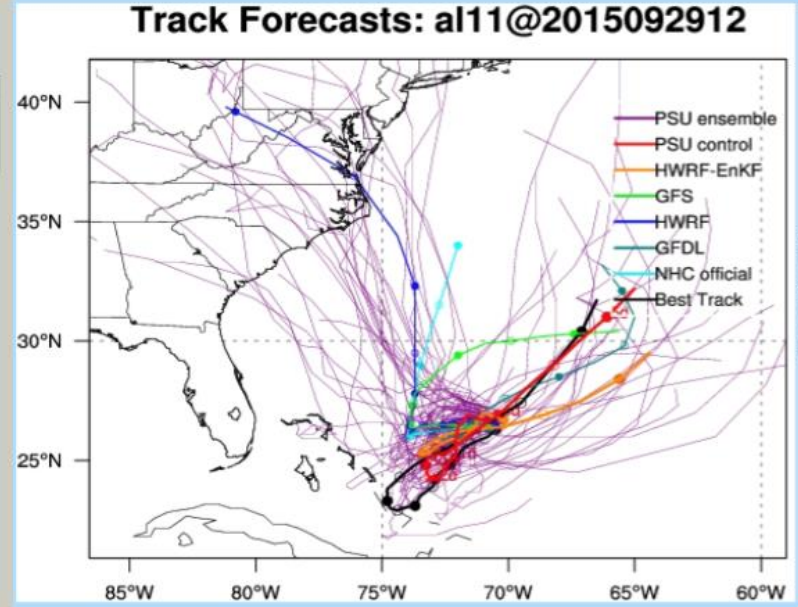
PSU WRF/EnKF Real-time Atlantic Hurricane Forecast

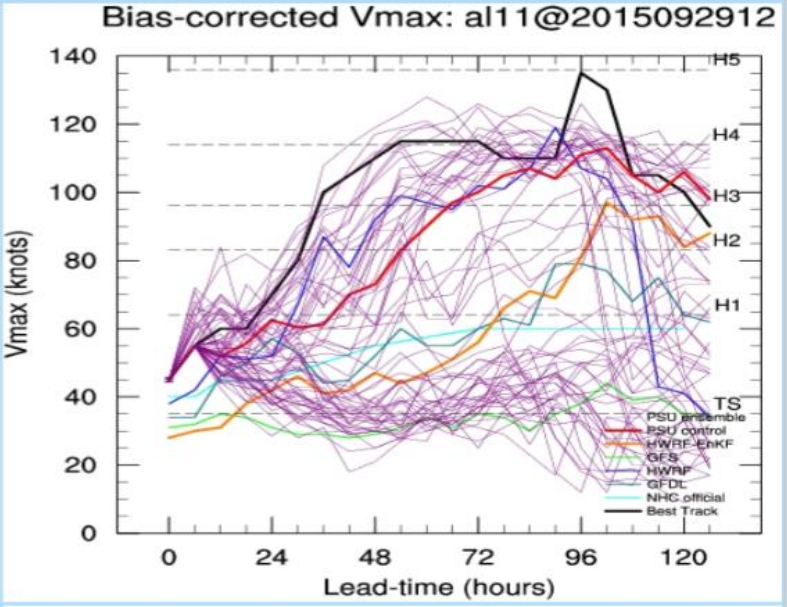
Select an active storm

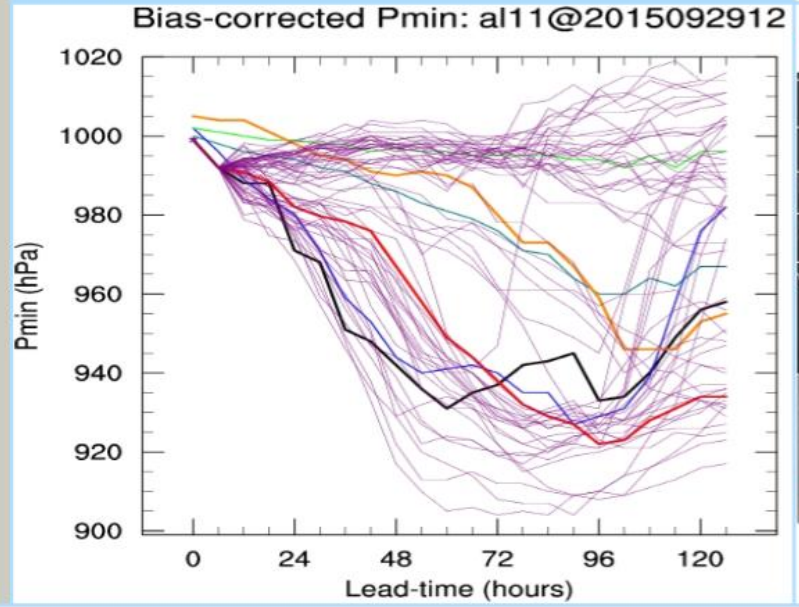
SELECT ACTIVE STORM
JOAQUIN

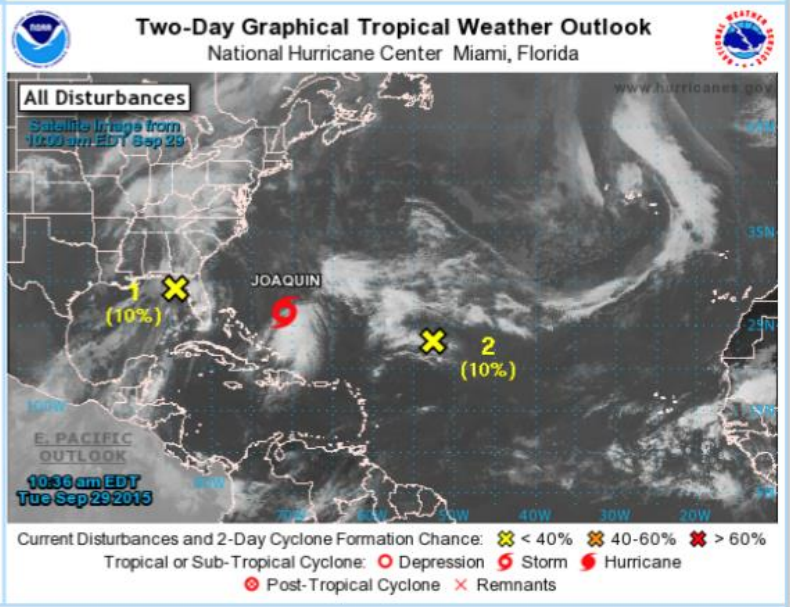
Forecast initial time
2015092912
<< previous (-6hr)
next (+6hr) >>

Select initial time
2015 Aug
DAY UTC

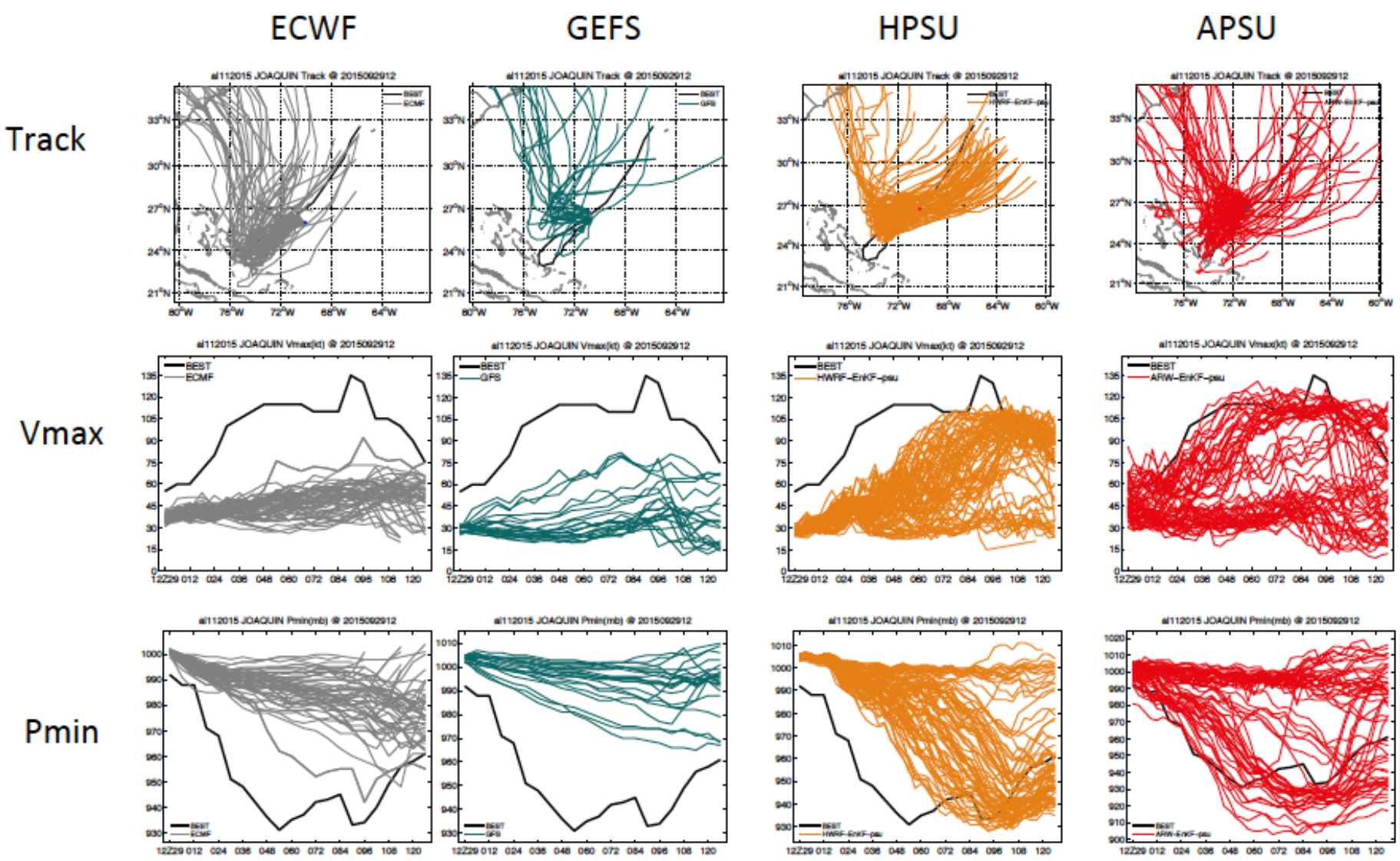








Ensembles at 12Z 29 Sept.



Ensembles at 00Z 30 Sept.

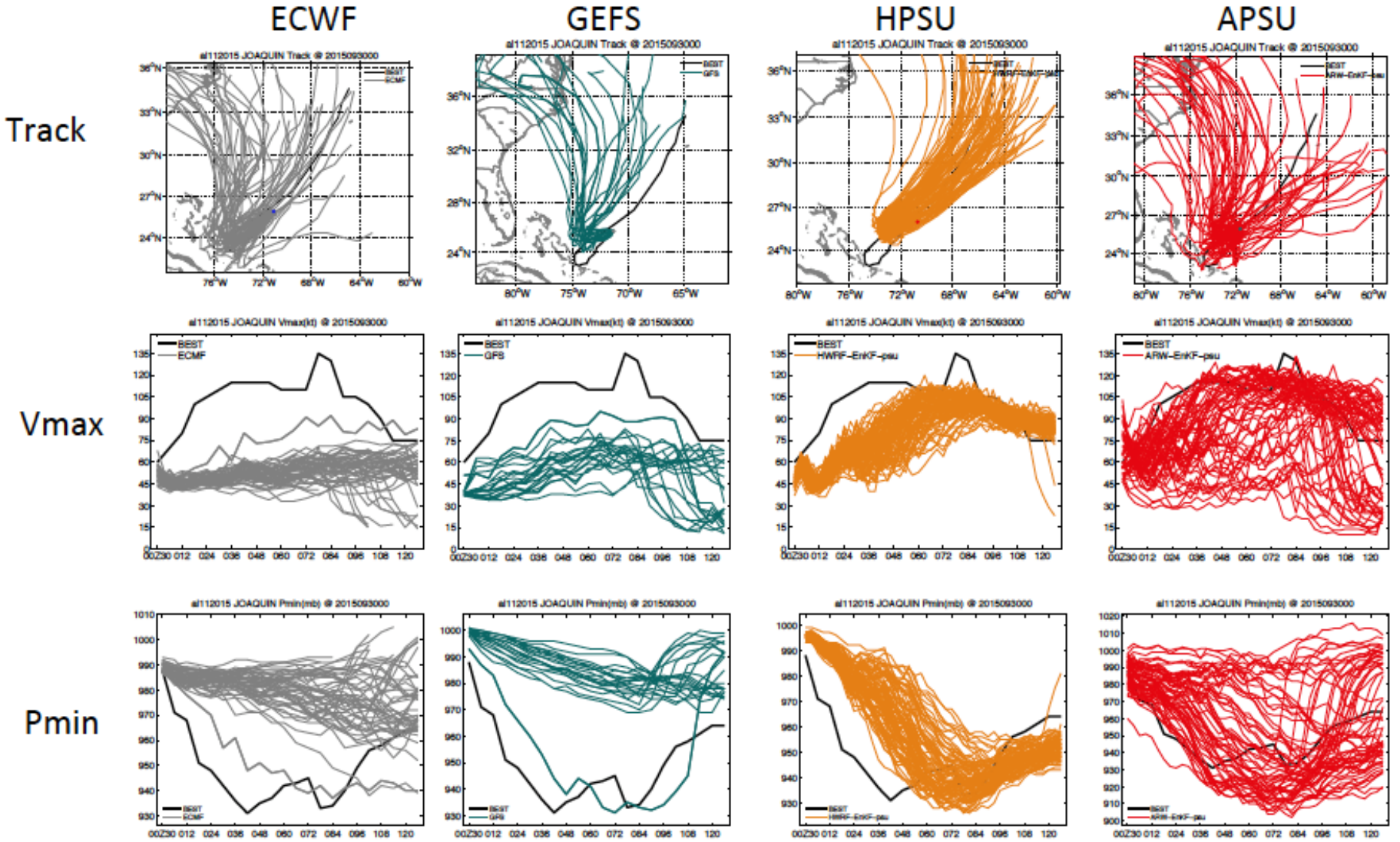
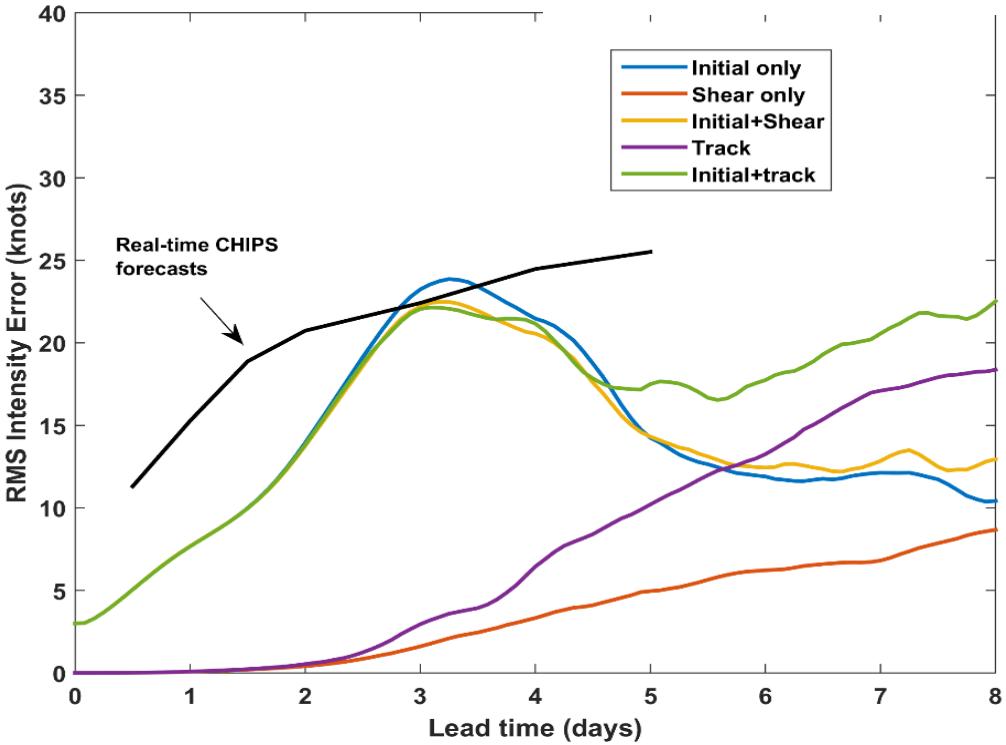


Table 2: Description of Perturbation Experiments

Perturbation Experiment	Description	Number of Overlapping Cases
Initial intensity only	3 knots added to initial intensity.	2711
Shear only	Shear decorrelates from control over 25 days. Track and initial intensity identical to control.	2916
Shear + initial intensity	3 knots added to initial intensity and shear decorrelates from control over 25 days. Track identical to control.	2656
Track	Winds (affecting shear and steering) decorrelate from control over 25 days. Tracks respond to changing steering flow.	2204
Track + initial intensity	Same as track but 3 knots added to initial intensity.	2051



Predictability and Error Sources of Tropical Cyclone Intensity Forecasts: CHIPS 2009-2015

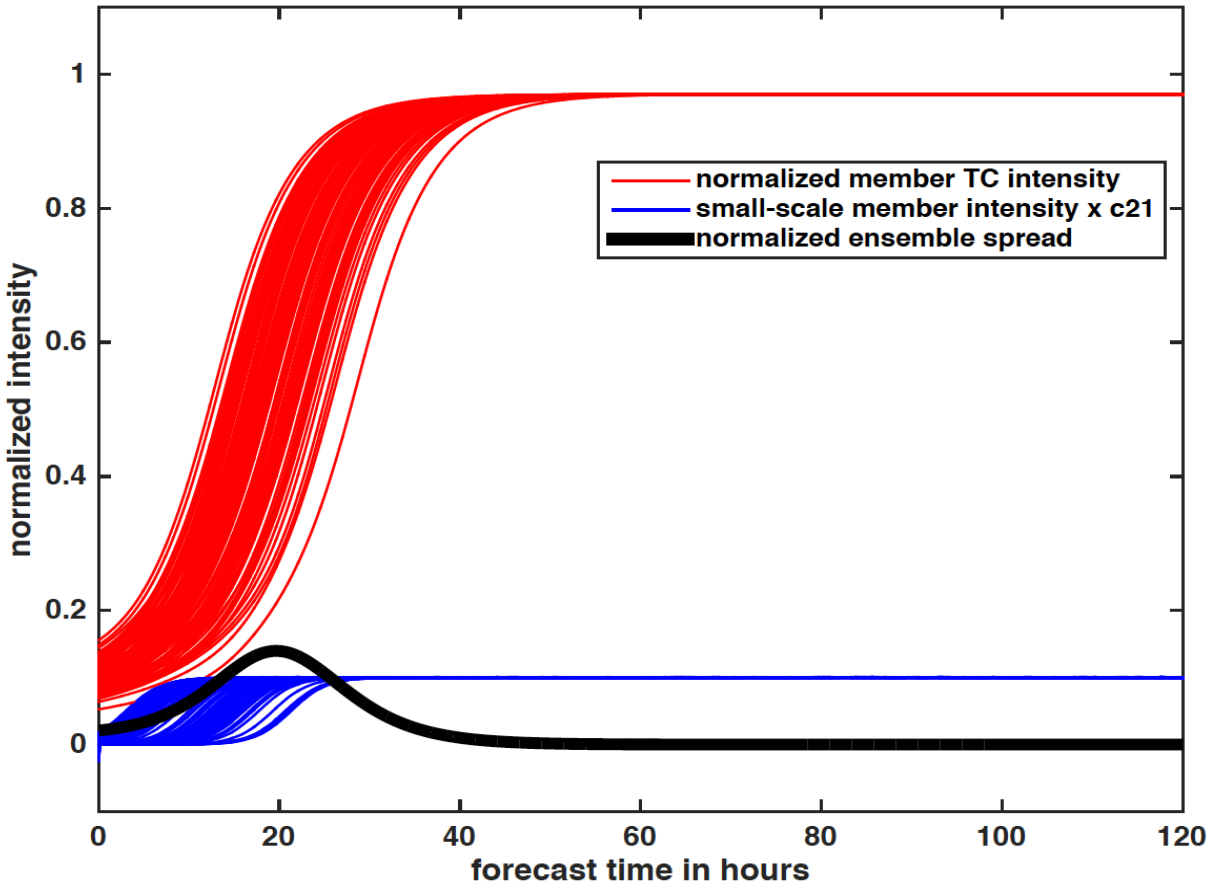
Emanuel and Zhang

(2016, JAS, in review)

A conceptual two-scale-coupled error growth model

$$\frac{d(El)}{dt} = \sigma l * El * (1 - El) + Es2El * \frac{d(Es)}{dt}$$

$$\frac{d(Es)}{dt} = (1 - Es2El) * \sigma s * Es * (1 - Es) + noise$$



Ongoing research with Kerry Emanuel

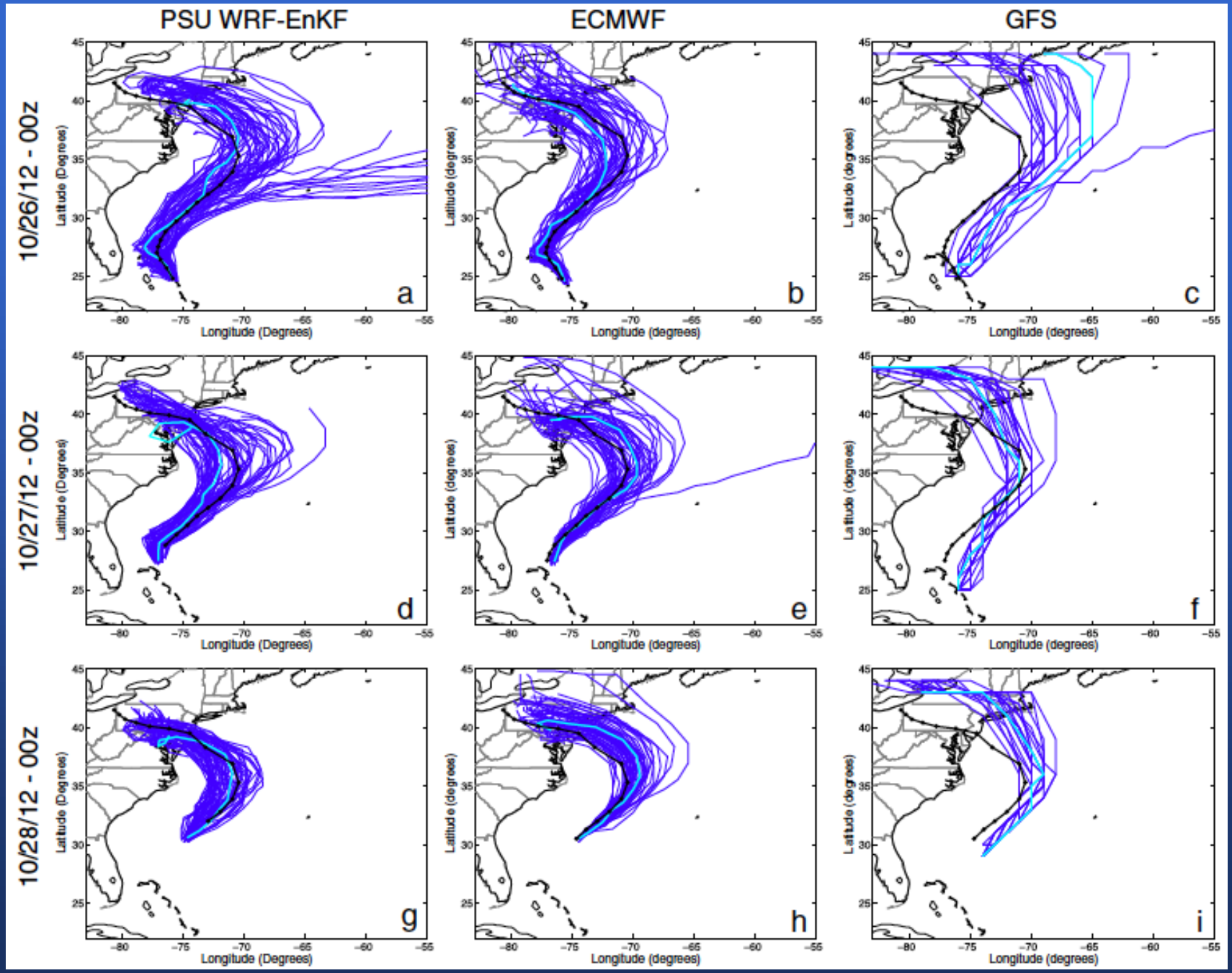
Concluding Remarks

Two fully-cycled convection-permitting ensemble Kalman filter analysis and forecast systems both performed reasonably well throughout Hurricane Joaquin's lifecycle.

The PSU WRF-EnKF deterministic runs provides exceptional 5-day rainfall guidance for the record breaking flooding associated with Joaquin.

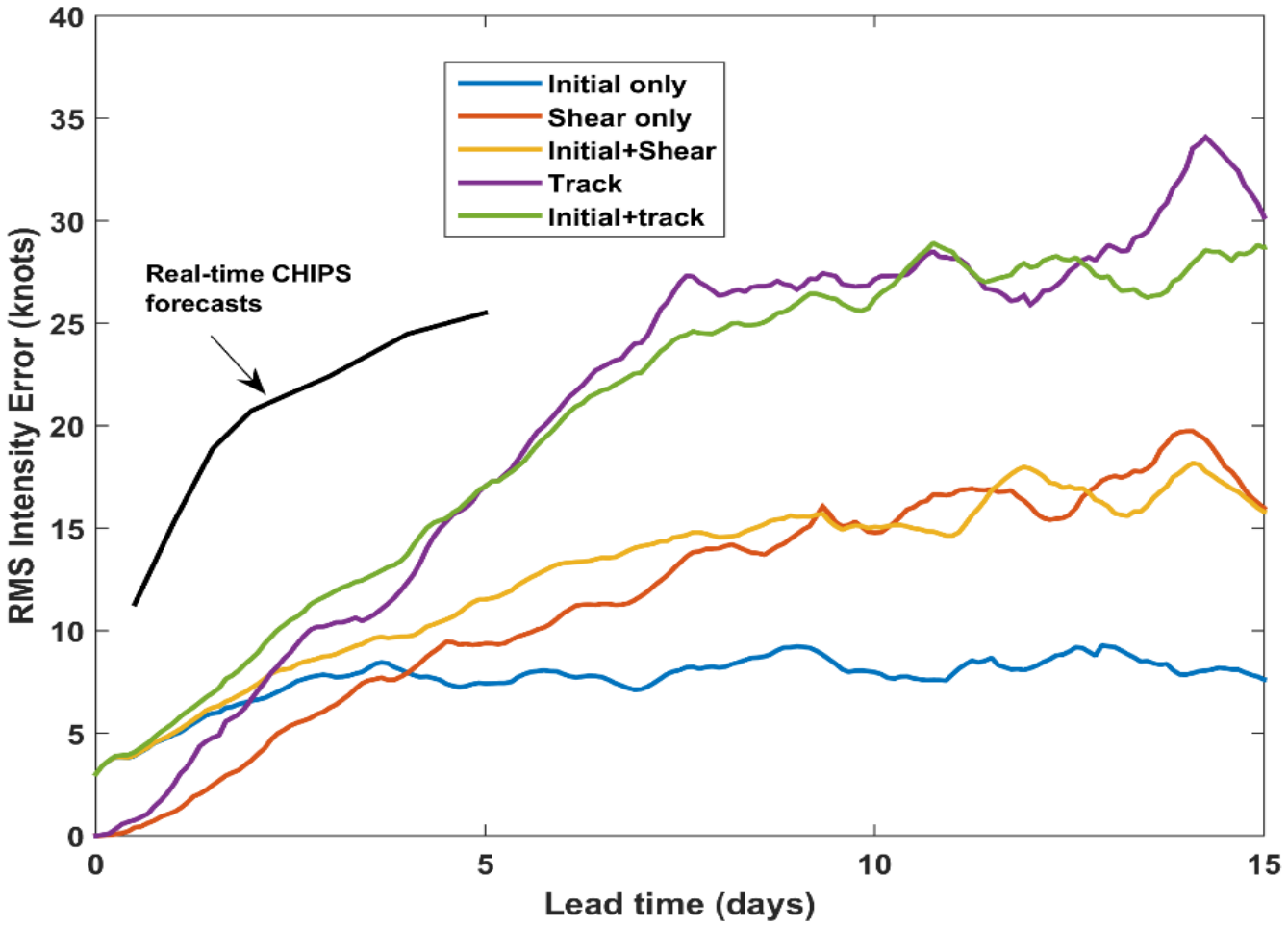
Limited sensitivity experiments suggest initial conditions are crucial for Joaquin's forecasts but there is a large forecast uncertainty in early stage of Joaquin.

A large convection permitting ensemble with proper vortex-scale initial condition uncertainty is needed for probabilistic prediction of such extreme events like Joaquin, especially when the track error is apparently non-Gaussian.



(Munsell & Zhang 2014 JAMES)

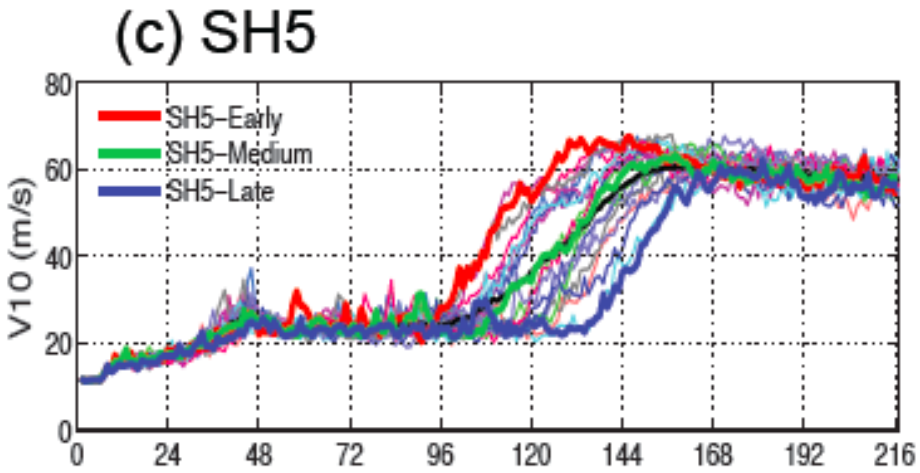
On the Predictability and Error Sources of Tropical Cyclone Intensity Forecasts

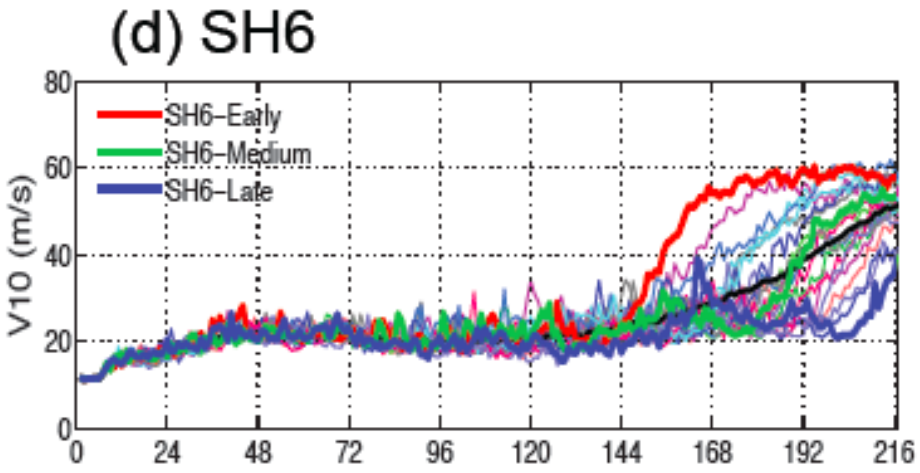


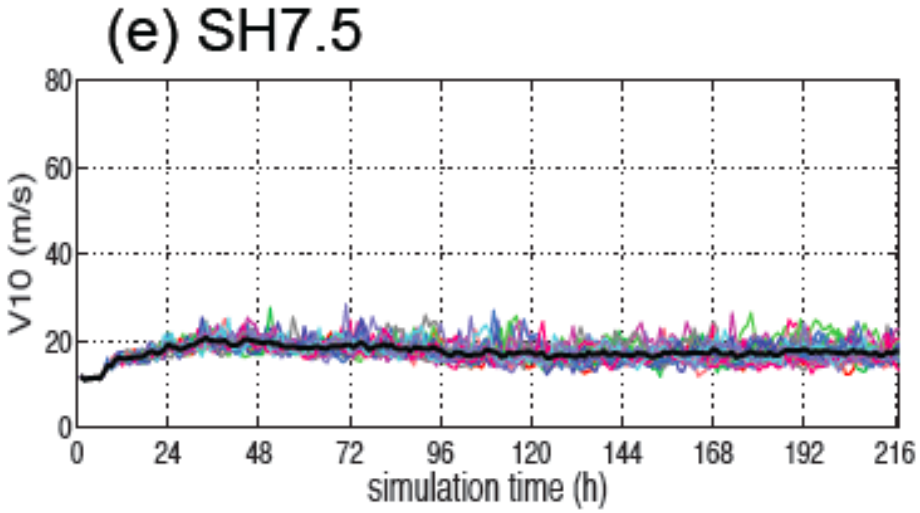
Emanuel and Zhang (2016, JAS, in review)

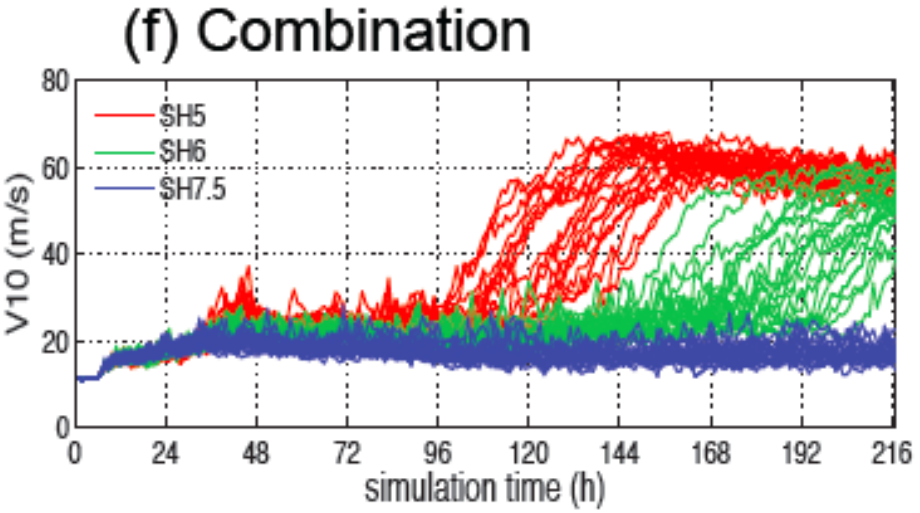
TC Predictability under different shear (5, 6, 7.5m/s)

(Zhang and Tao 2013 JAS; Tao and Zhang 2014 2015 JAMES)









Small random initial perturbations in BL moisture, 20 otherwise identical ensemble members