

Impacts of GPS-RO on Typhoon Forecasts*

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*Contributions from UCAR COSMIC Team
Taiwan's TTFRI, CWB, NSPO

Outline

- Advantages and challenges of using GPS RO for typhoon prediction
- Systematic evaluation of the impact of GPS RO on typhoon forecasts
- Impact of data QC in the lower tropical troposphere
- Challenges of medium range tropical cyclone prediction
- Concluding and outlook

GPS RO observations advantages for tropical cyclone prediction

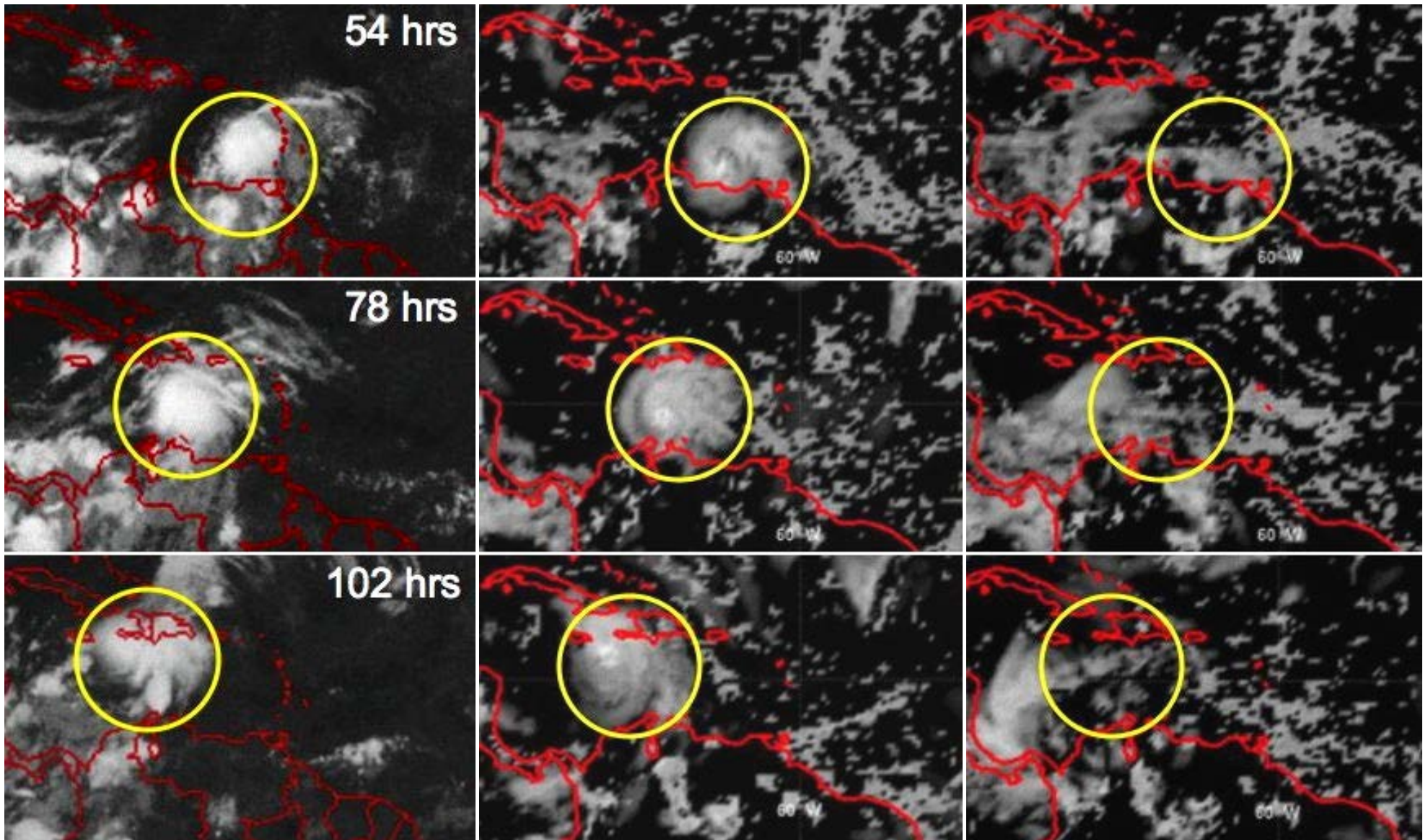
- There are considerable **uncertainties in global analyses over the tropics**.
- COSMIC provides **globally uniform distribution** of GPS RO data
- GPS RO observations are of **high vertical resolution** and **high accuracy**.
- GPS RO is an **active sensor**, minimally affected by clouds and precipitation
- GPS RO advantages for tropical cyclone prediction:
 - **Water vapor**: Important for convective development, genesis, intensity, track and precipitation forecast
 - **Temperature**: Important for large-scale circulations, and affect longer range track forecast

4-Day Ernesto (2006) Forecasts with WRF-ARW

The Actual

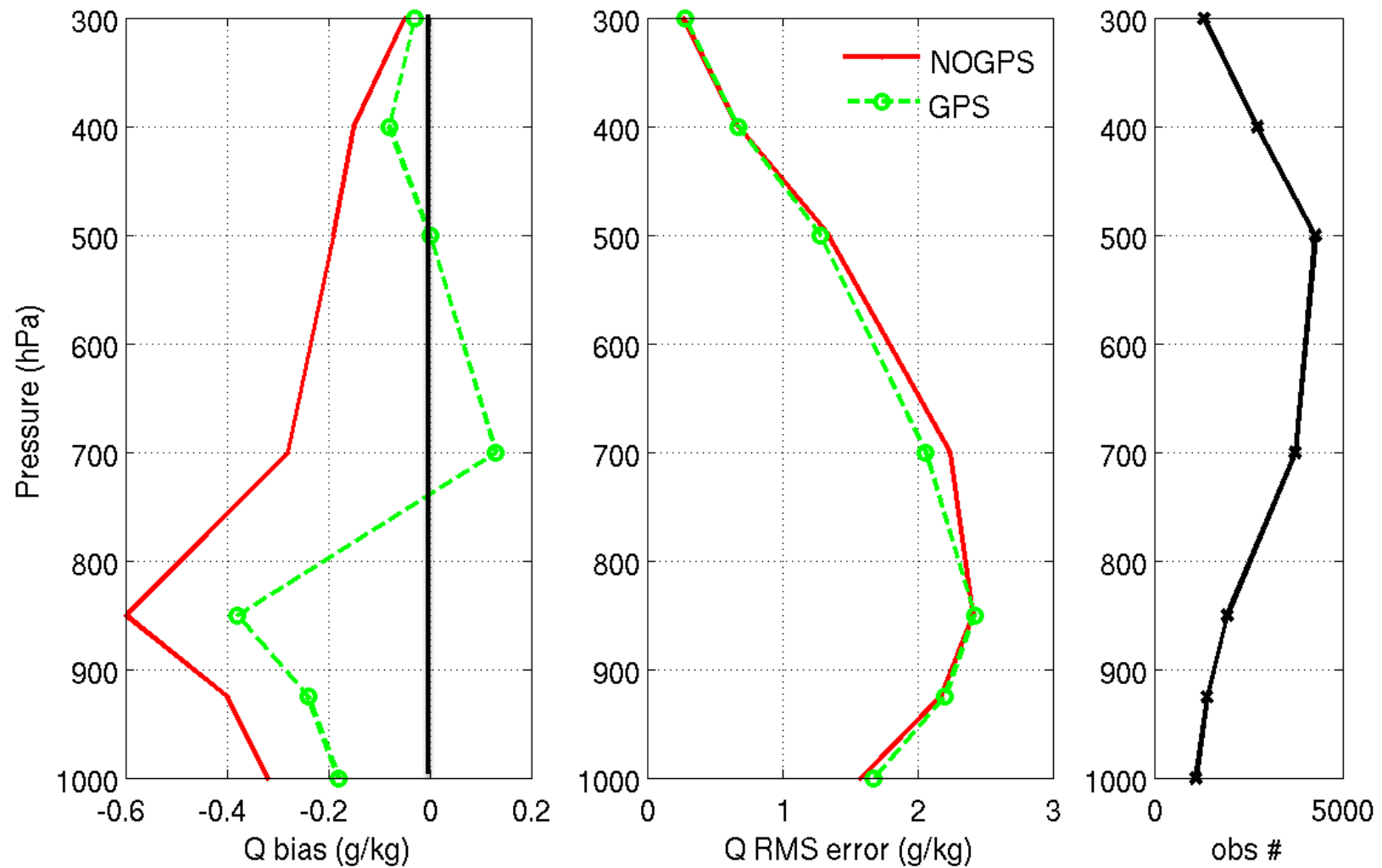
Forecast with

Forecast without



Liu et al. (2012, MWR)

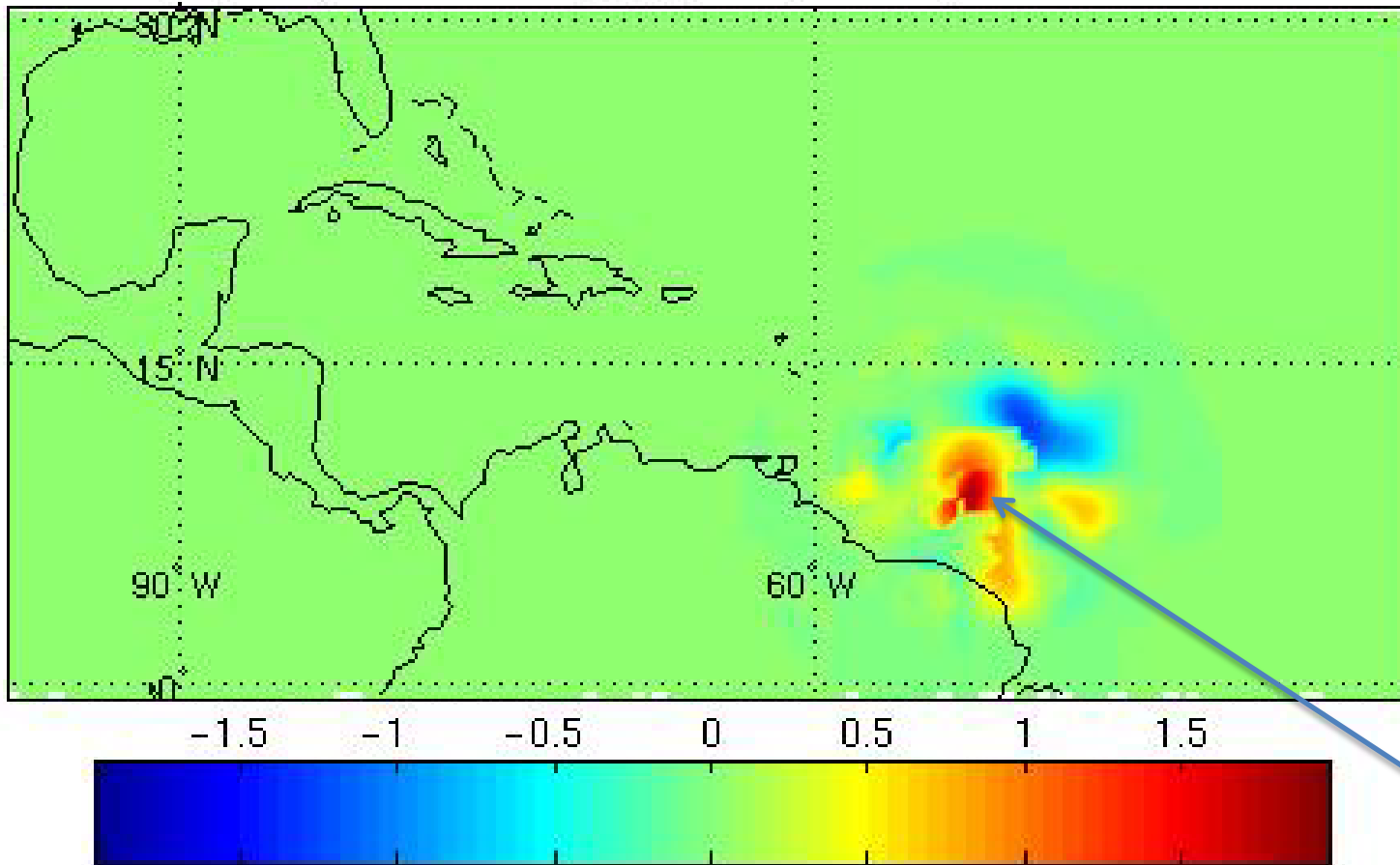
Assimilation of GPS RO substantially reduces model dry bias



Verification of WRF/DART analysis by about 100 dropsondes during the Ernesto genesis stage.

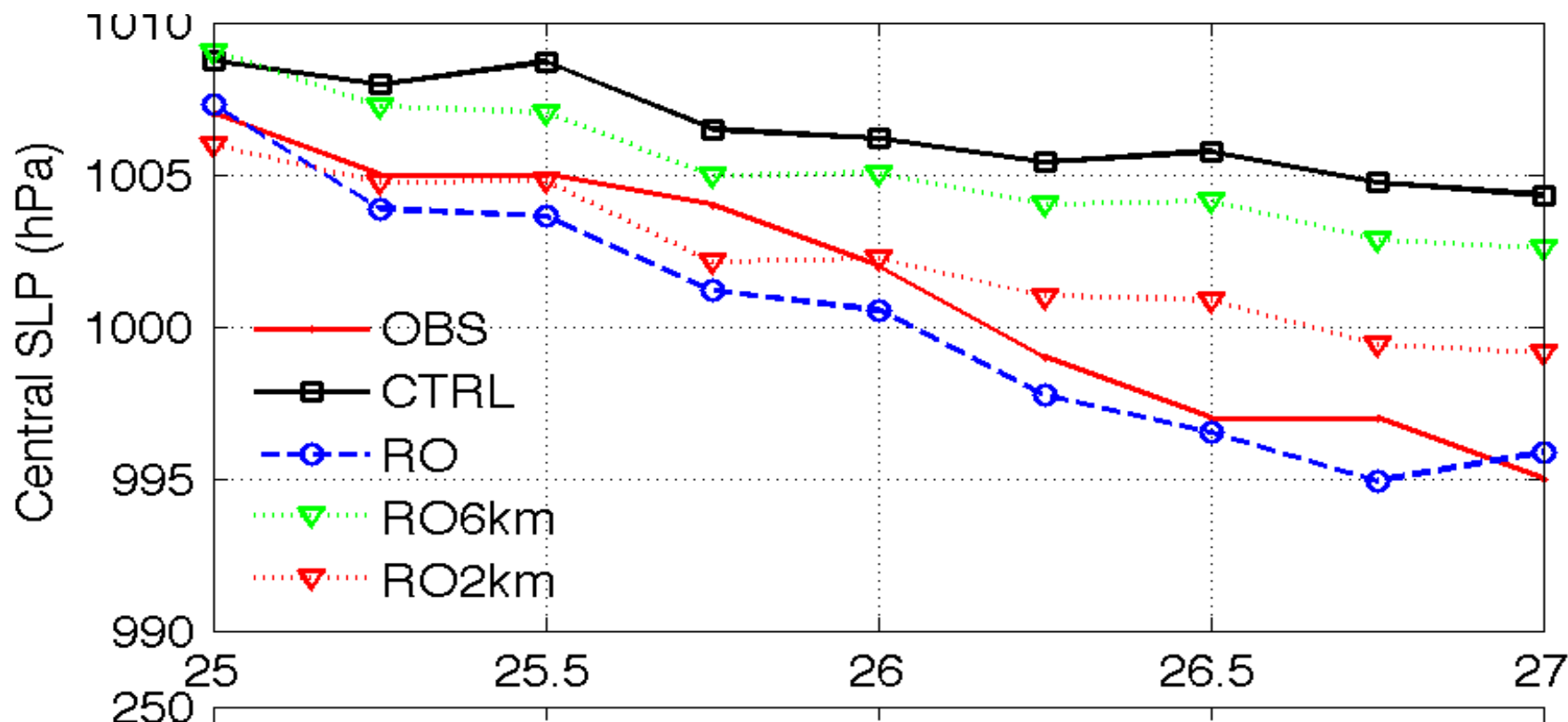
Low-level moisture change by assimilating GPS

GPS 1, Qvapor increment (g/kg), k=9 (~850mb), 2006-08-23-06Z



Assimilation of 1 GPS RO sounding in the vicinity of Hurricane Ernesto caused a 1.8g/kg increase in moisture at 1.5 km. This was enough to get the hurricane genesis going.

48h-forecast of SLP (starting at 00UTC 25 August)



August 2006

OBS: Observed storm

CTRL: No GPS RO assimilation

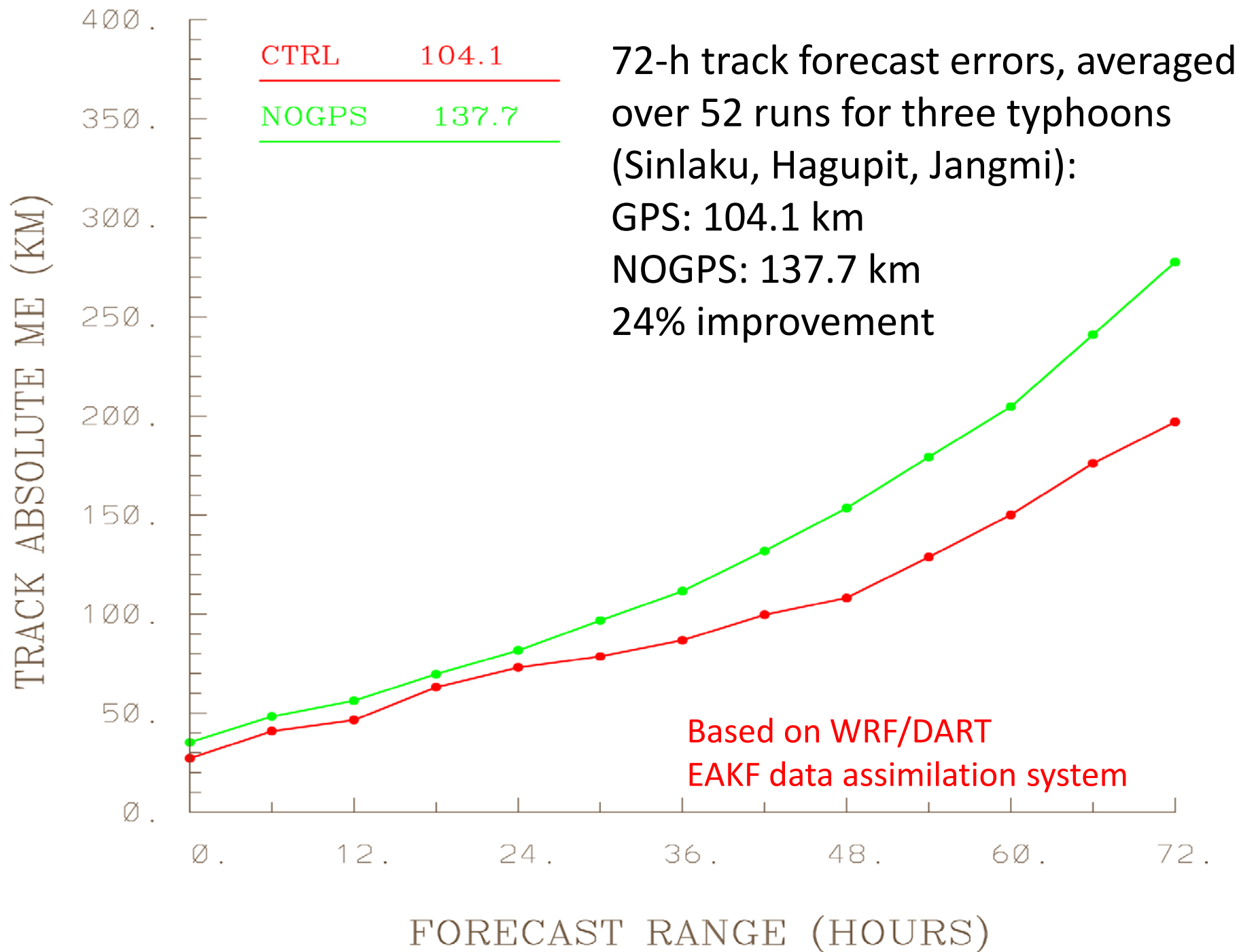
RO: Assimilation all RO data

RO6km: No RO data below 6km

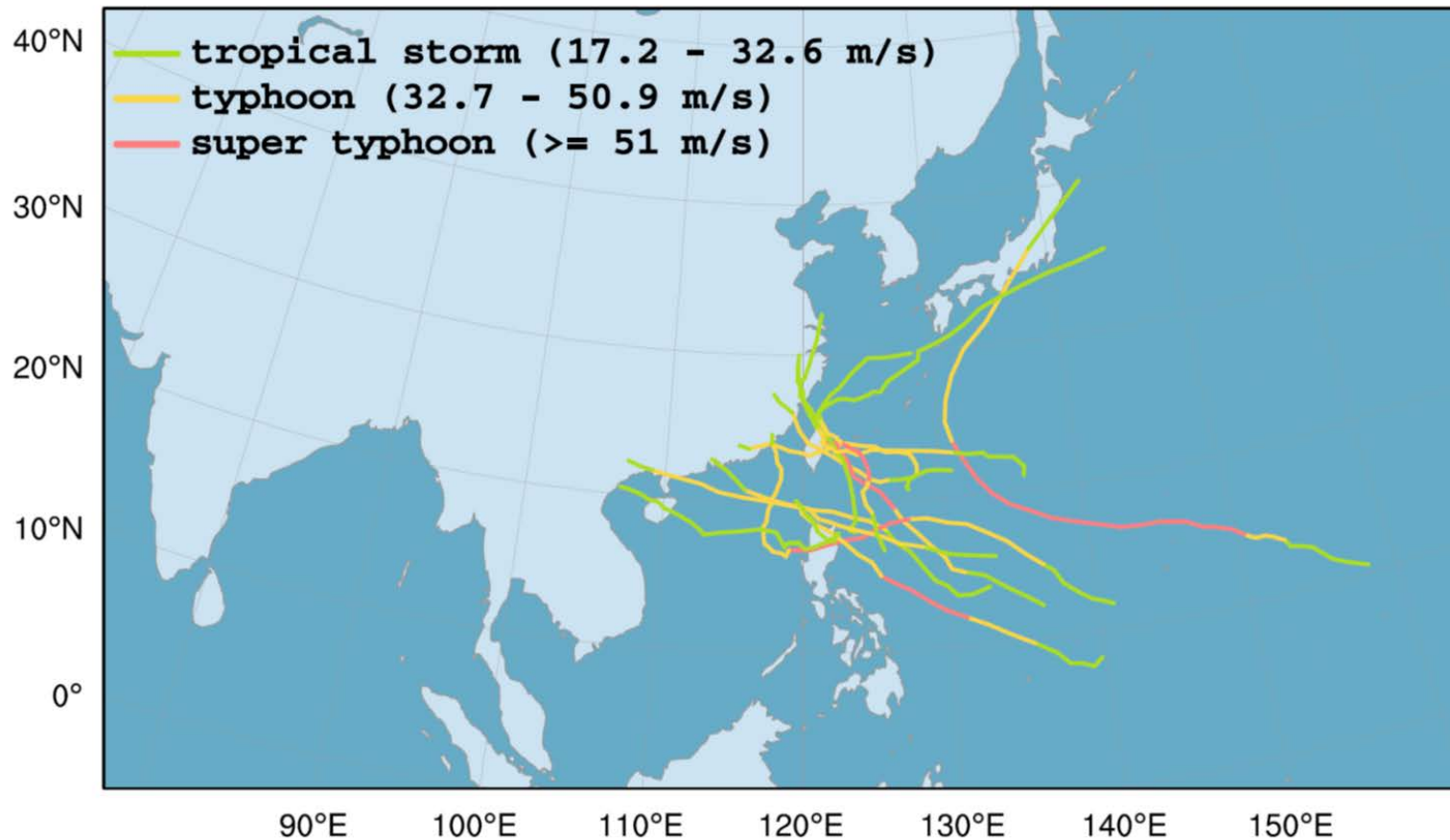
RO2km: No RO data below 2km

Lower troposphere observations
(below 6 km) most critical to
hurricane prediction

Impact of GPS RO on T-PAC Typhoon Prediction



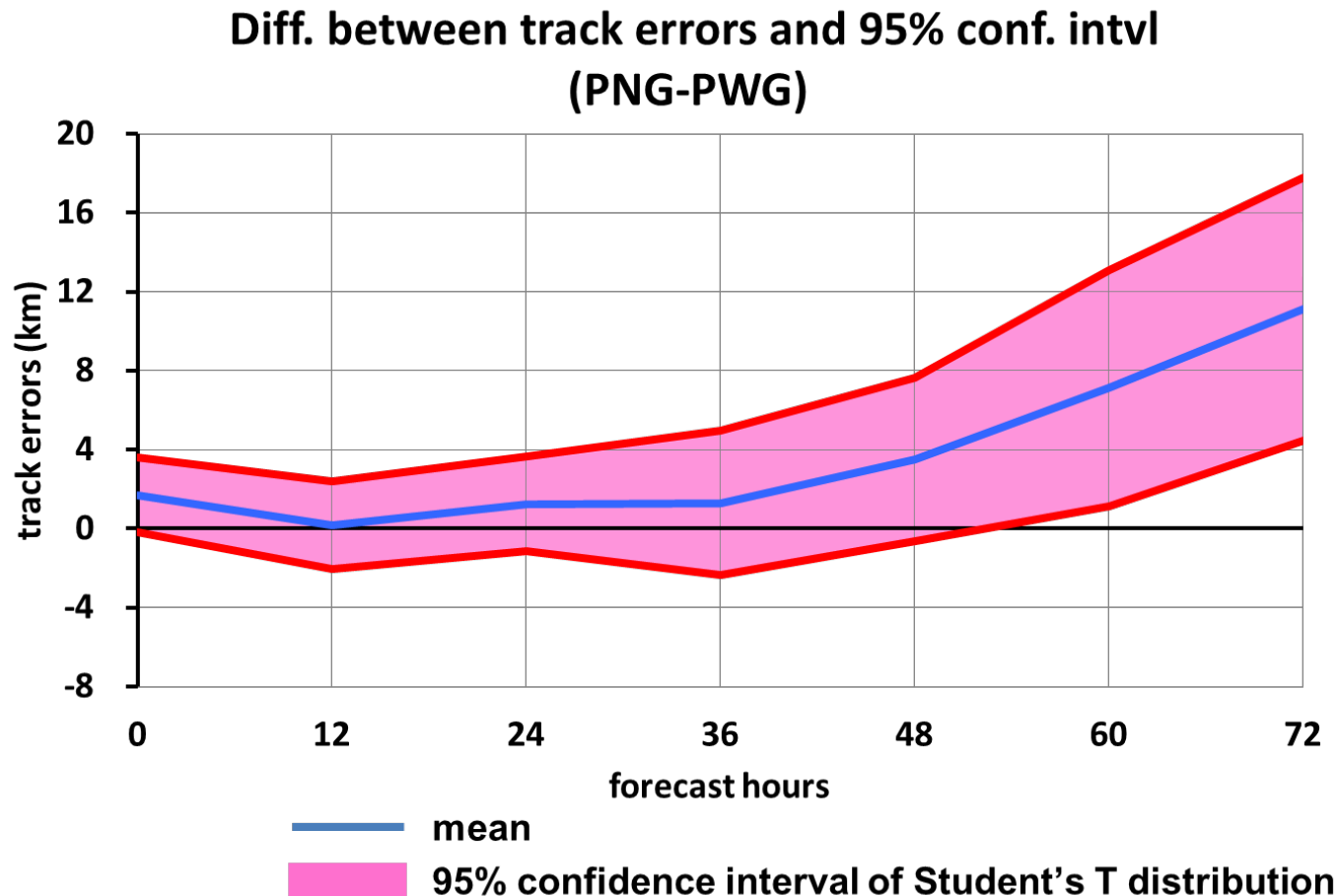
TTFRI performed systematic evaluation of GPS RO impact on track forecast of 11 Typhoons (2008-2010), for a total of 300 cases (analysis-forecast cycles), under sponsorship of NSPO.



Taiwan's CWB operational Typhoon WRF model, 45 km, 45 level. Partial cycling data assimilation over a 12-h period, starting at -12h using NCEP GFS analysis.

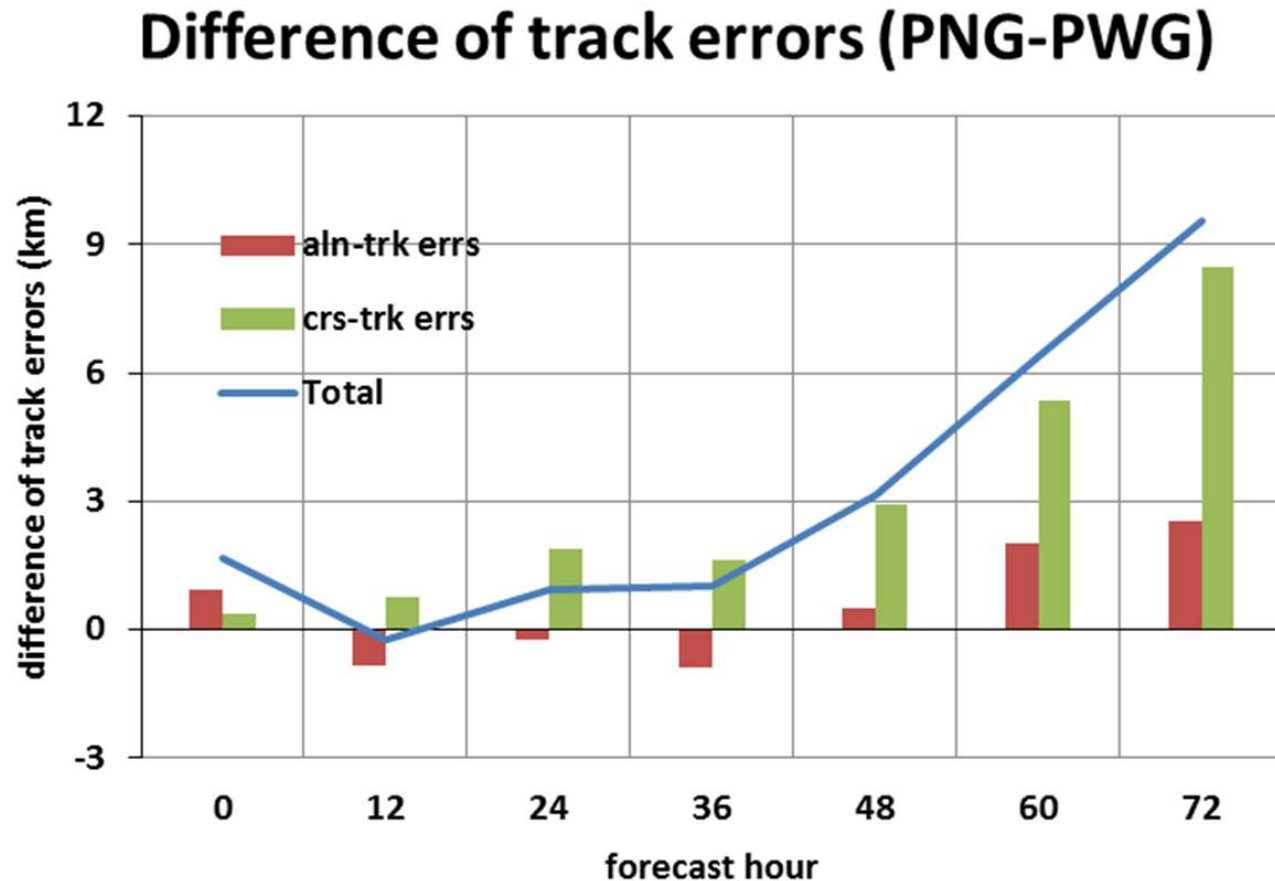
Impacts of GPS RO on typhoon track forecasts

- PNG: Assimilation of conventional observations, cloud track winds, SATEM thickness, NO radiance, NO GPS RO
- PWG: PNG + GPS RO



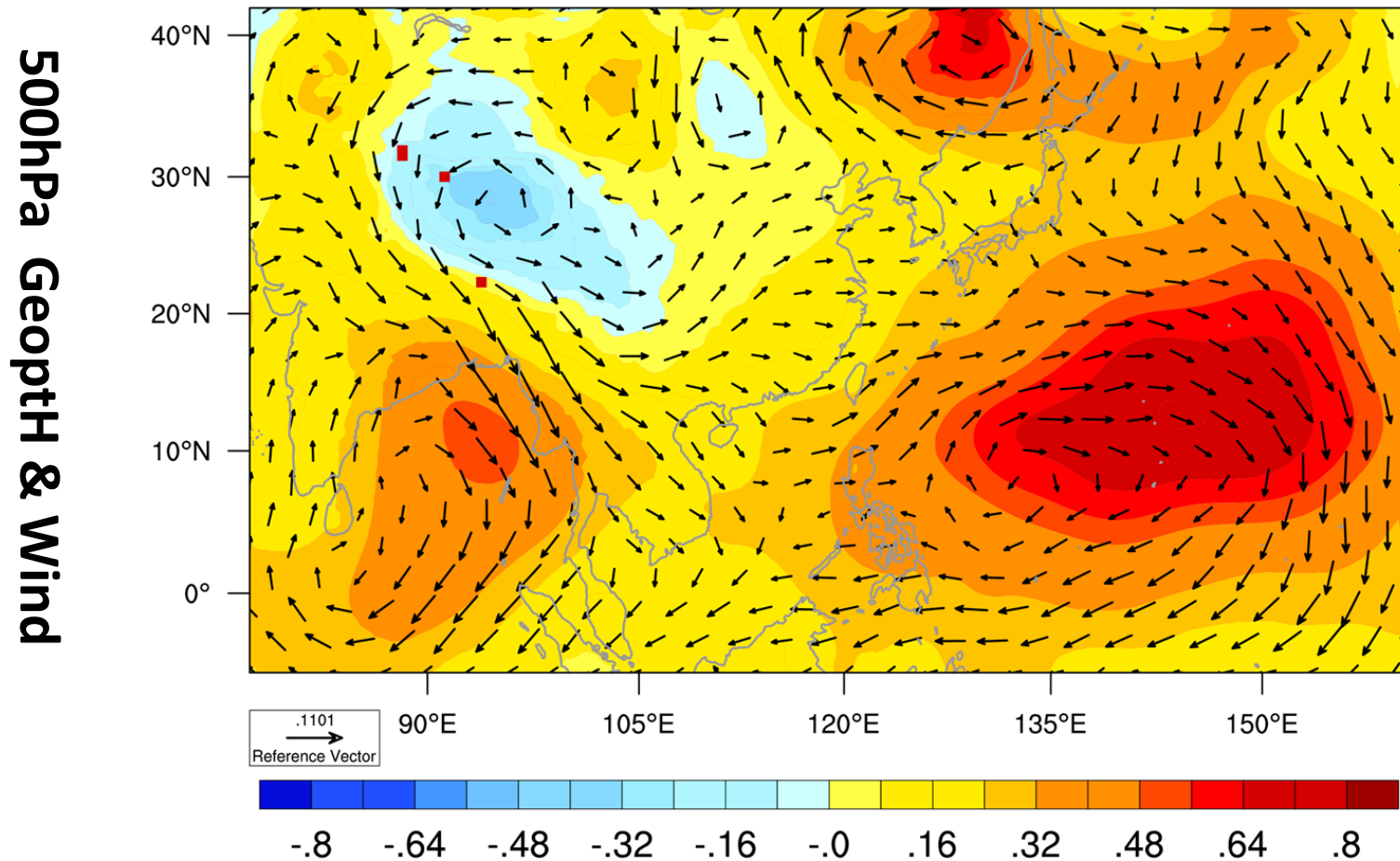
Impact on track forecast

Larger impact on cross-track prediction than along track prediction

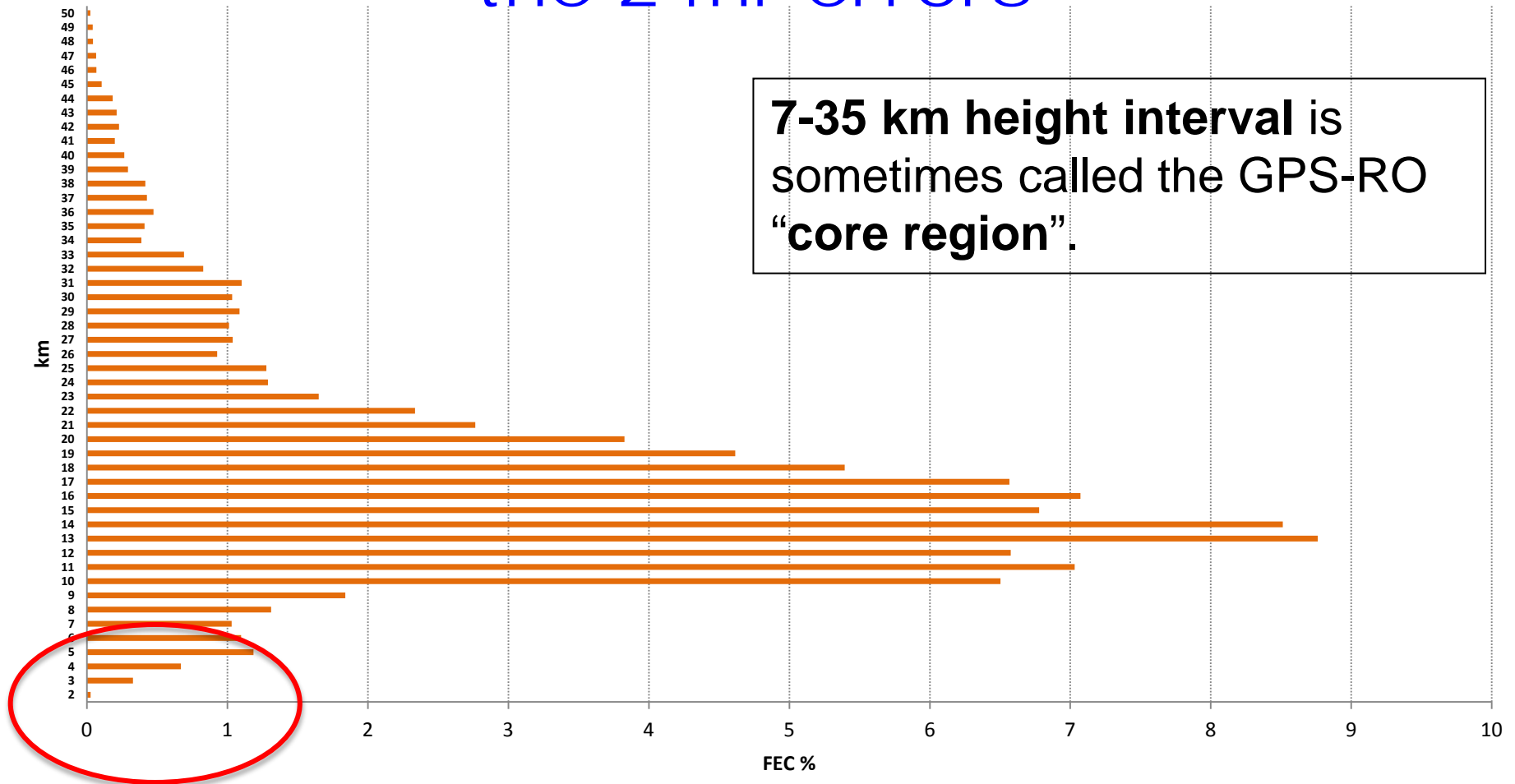


Systematic impact on 500 mb height and circulation

Assimilation of GPS RO produces a stronger subtropical high over the western Pacific, which can exert significant impact on typhoon track



Heights where GPS-RO is reducing the 24hr errors

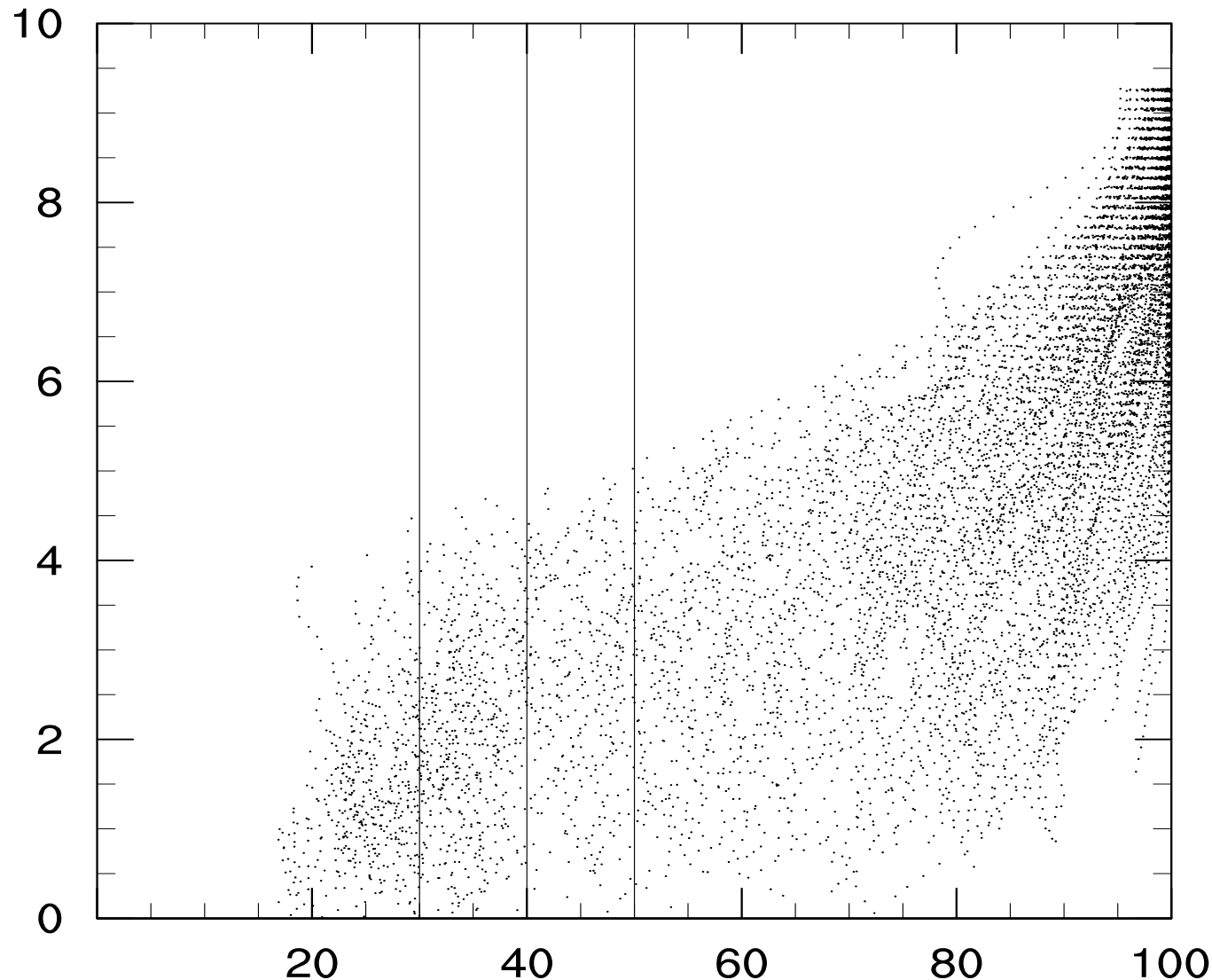


Lower troposphere is critical for hurricane prediction.
Yet, global NWP seeing little or no contributions.

Can we improve the impact of
GPS RO data through better QC?

Distribution RO data with confidence parameter

(Spaghetti distribution for all RO profiles in Western Pacific, Sept. 8-10, 2008)



$CP1 = (P1 - P2) / P1$
(%), where P1 and P2 are powers of the 1st and 2nd maximum local spectral component.
(See Sergey's talk)

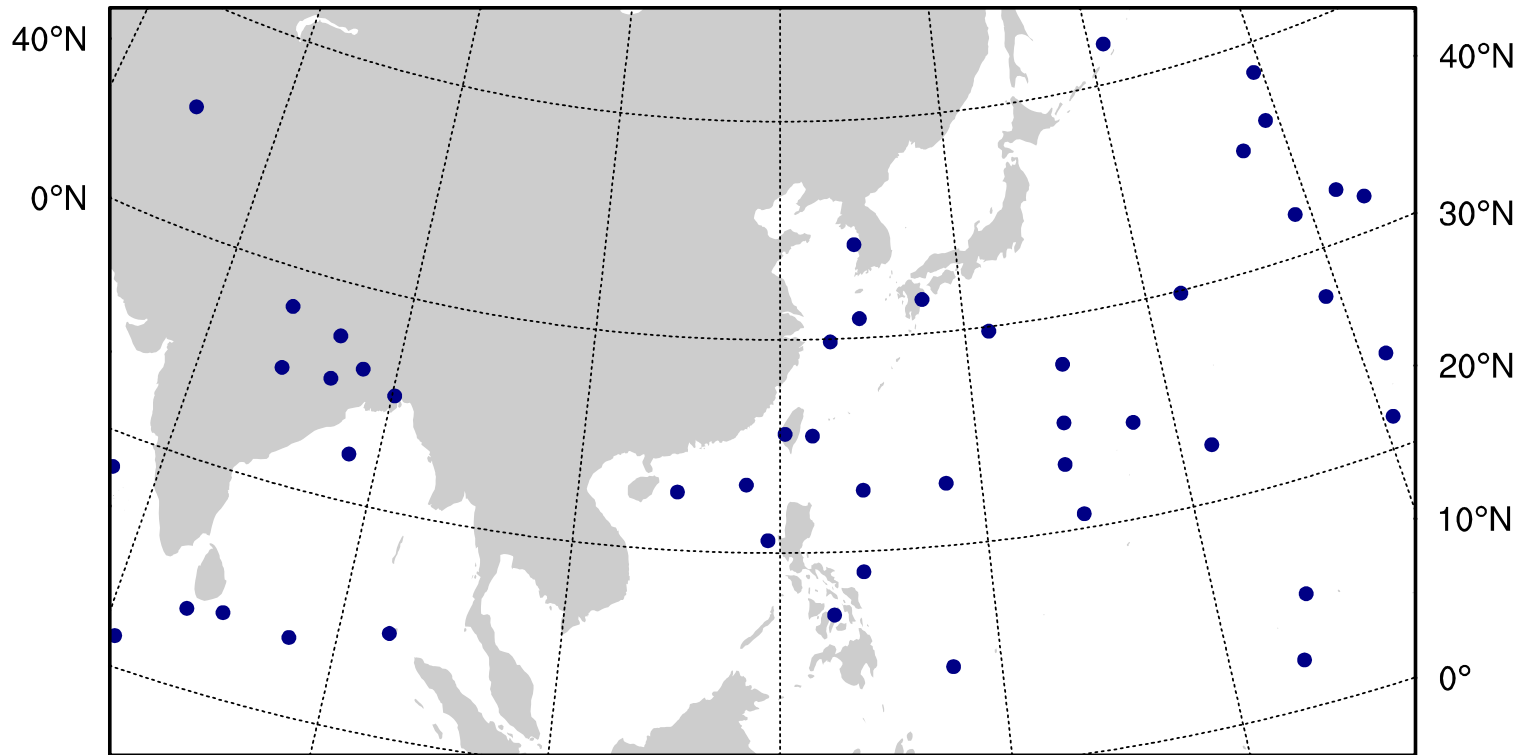
The RO data with $CP1 < 30\%$ are most located below 4km.

Distribution RO data with confidence parameter

(CP1 < 30% at 2km, Sept. 8-10, 2008)

September 8-10, 2008

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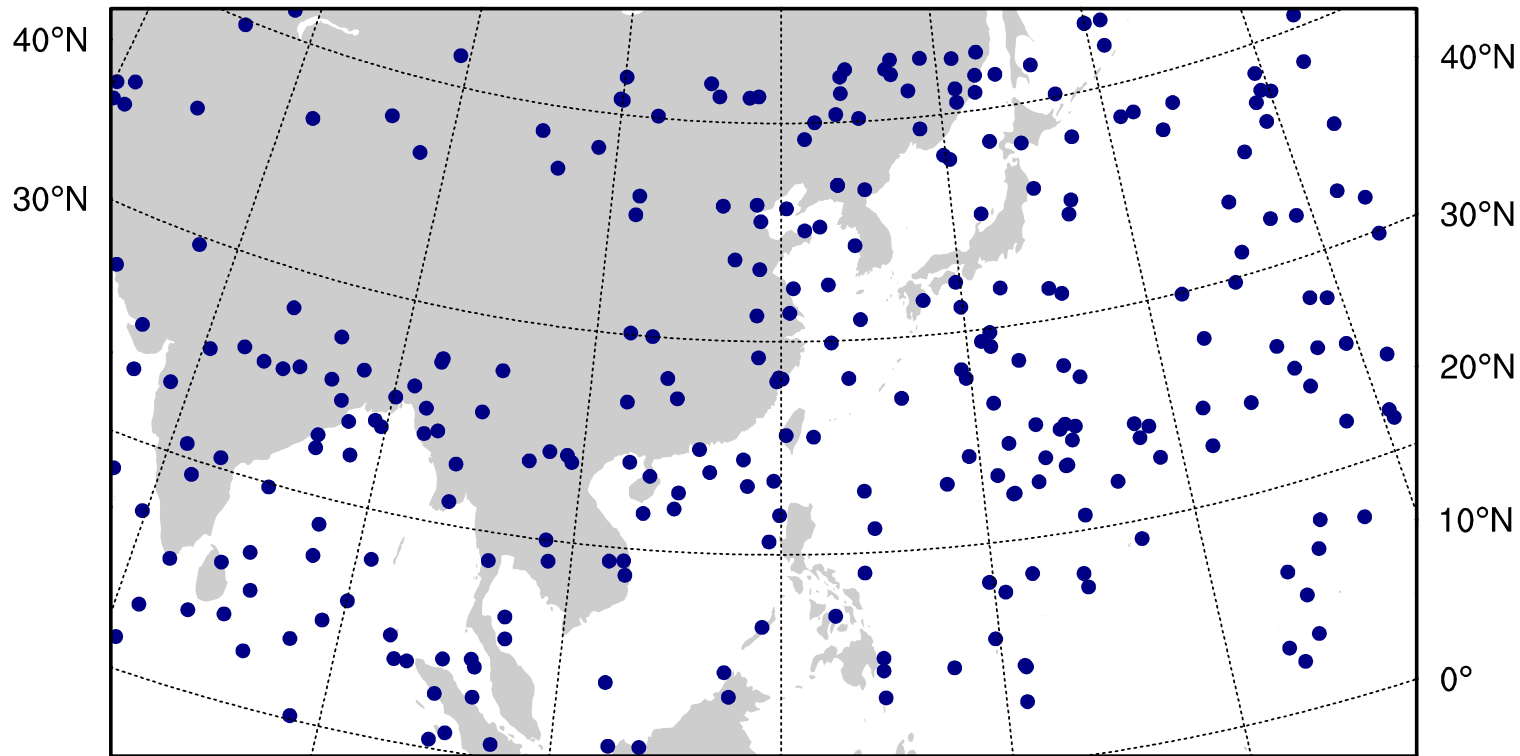


The RO data with CP1 < 30% are most located over ocean and affected by moist convection

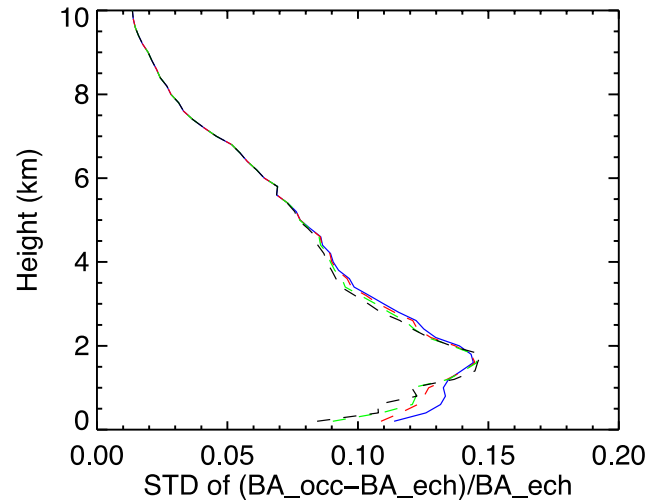
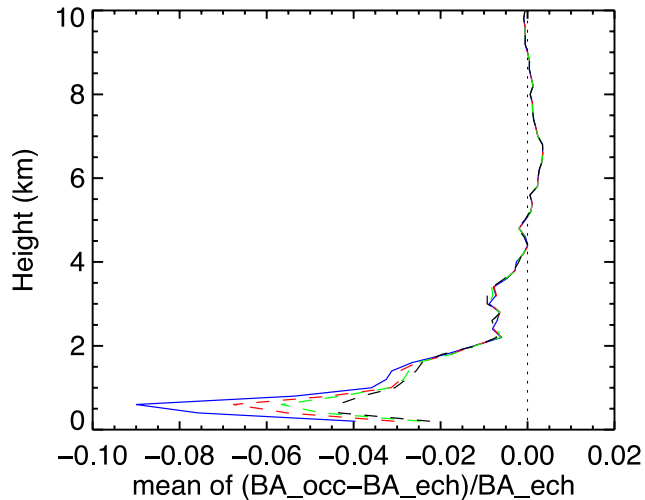
Distribution all available RO data (Sept. 8-10, 2008)

September 8-10, 2008

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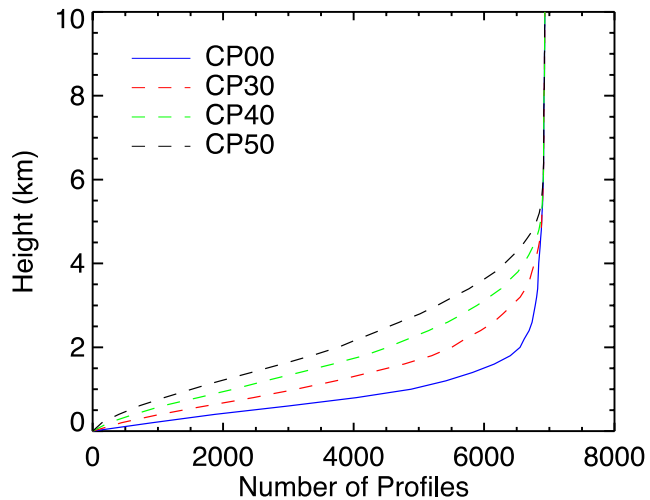


RO data comparison with ECMWF analyses (Sept. 2008)



Experimental RO data with Radio-holographic (RH) filtering are used.

Impact of the truncations by the CP is mainly evident below 2km. This suggests that RO data above 2km are good after application of the RH filtering.



Truncate GPS RO data based on confidence parameter (CP) changes BA biases relative to ECMWF global analysis.

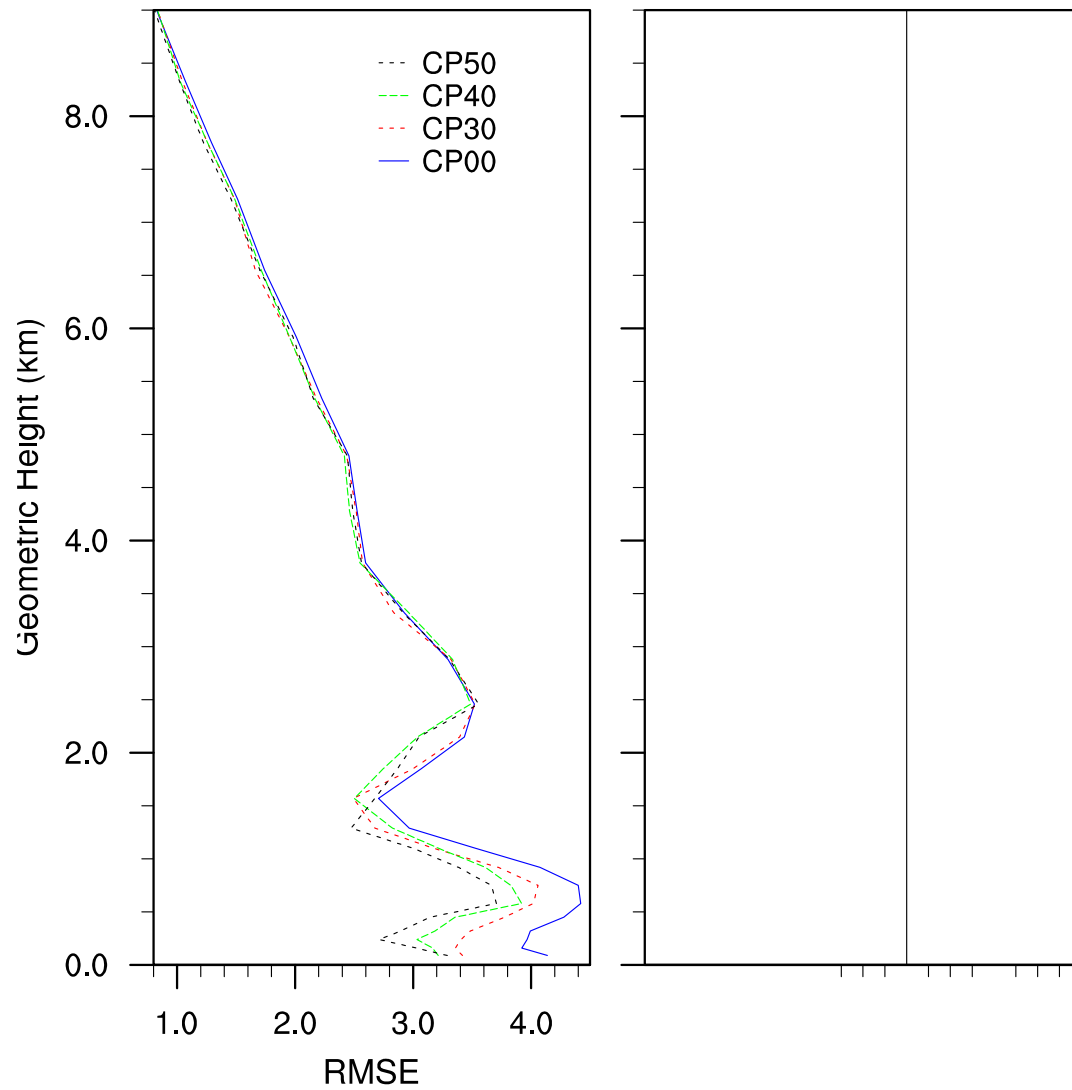
Assimilation experiments design

- ❑ WRF/DART cycling assimilation 6-hourly during September 4-28, 2008
- ❑ An experimental RO data set with Radio-holographic (RH) filtering and a relaxed truncation in lower troposphere
- ❑ **RO bending angle data between 0-10km is assimilated**
- ❑ RO bending angle data is customized filtered consistent with WRF vertical grid (Liu et al., 2014a)
- ❑ The CDAAC local bending angle forward operator is used
- ❑ 6h-forecasts are verified to RO and radiosonde observations over Western Pacific (120E – 165E, 0 -30N) over the assimilation period

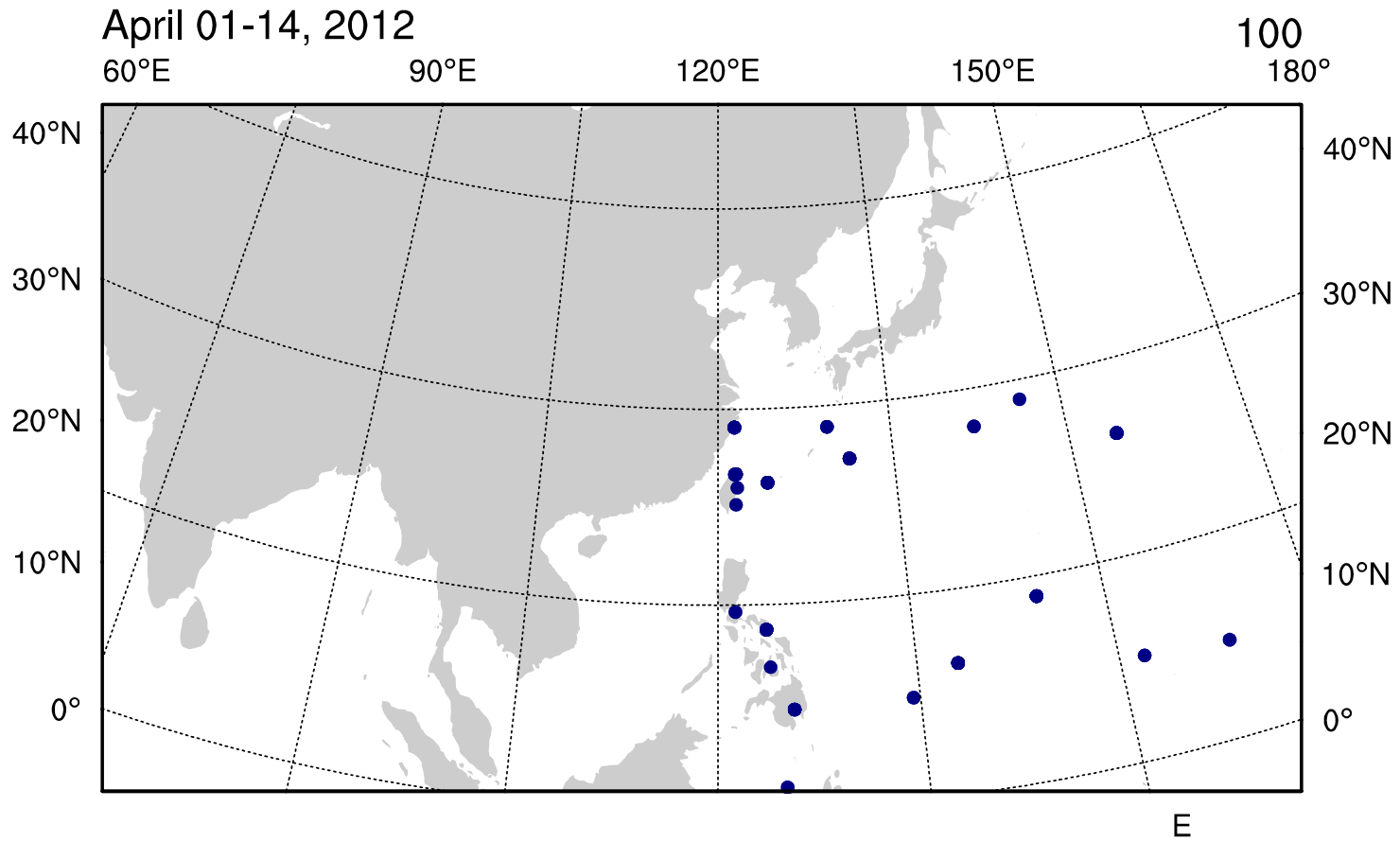
A set of assimilation experiments are performed:

- ❑ **CP00** run: Radiosondes, cloud winds, aircraft data, land and ship surface pressure data, SATEM, and RO bending angle data; No CP check
- ❑ **CP30** run: Same as CP00 run but reject RO data with CP < 30% below 2km
- ❑ **CP40** run: Same as CP00 run but reject RO data with CP < 40% below 2km
- ❑ **CP50** run: Same as CP00 run but reject RO data with CP < 50% below 2km

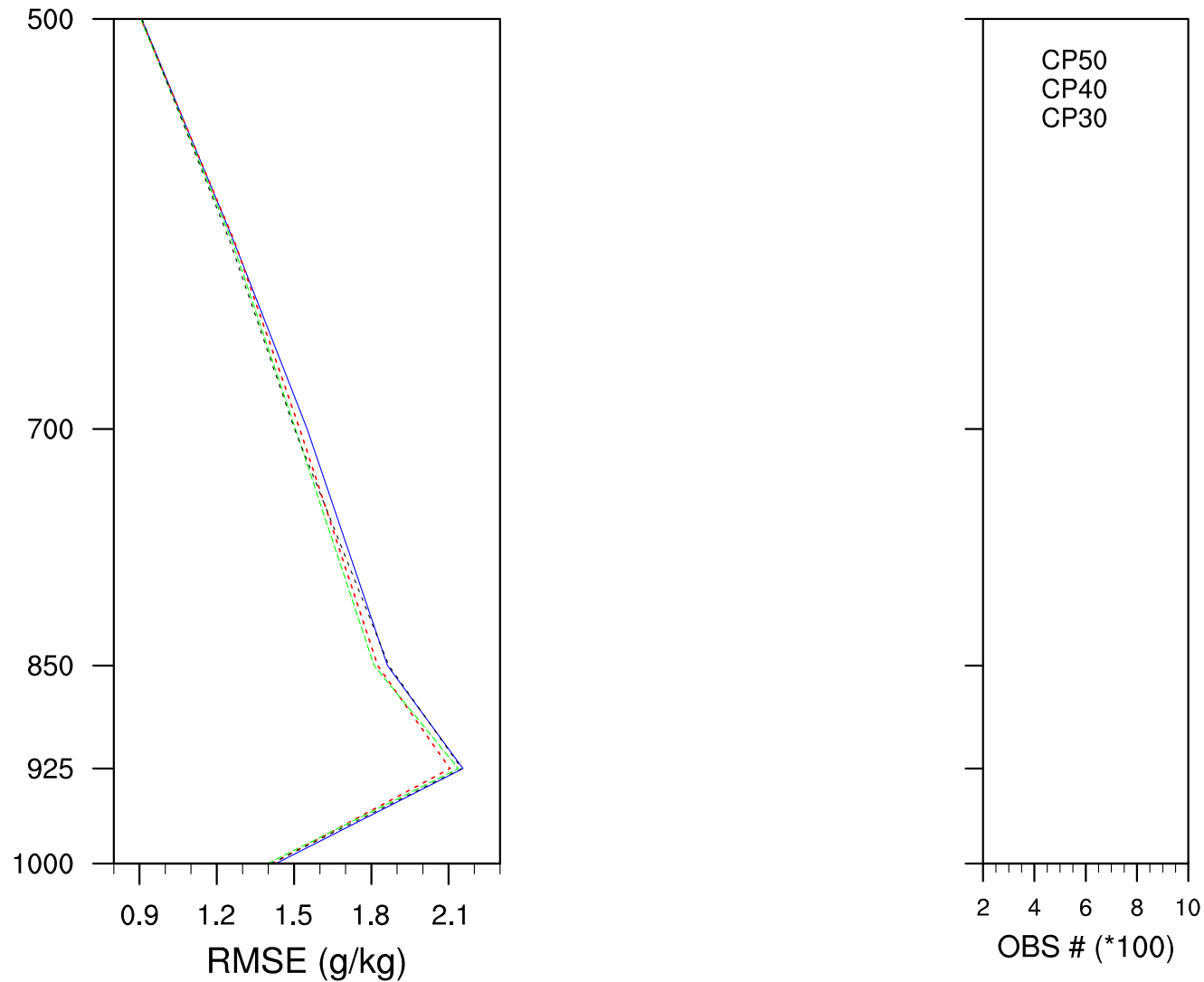
6h-Forecasts fits to RO refractivity data (CP checks below 2km)



Radiosonde used for verification of 6h forecasts

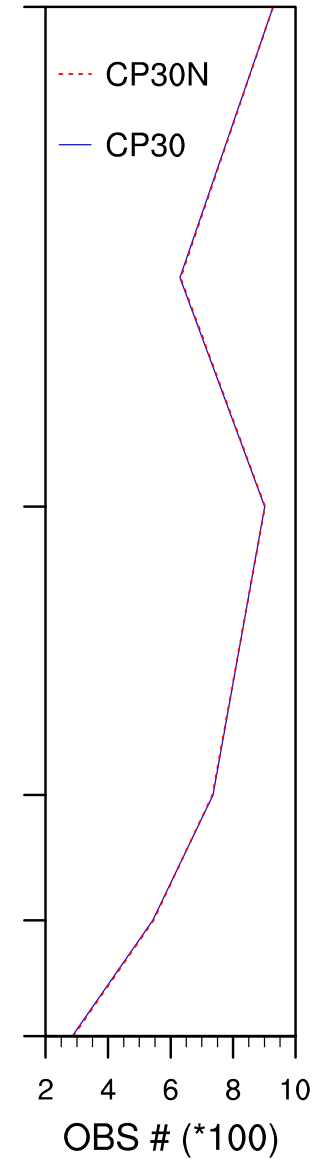
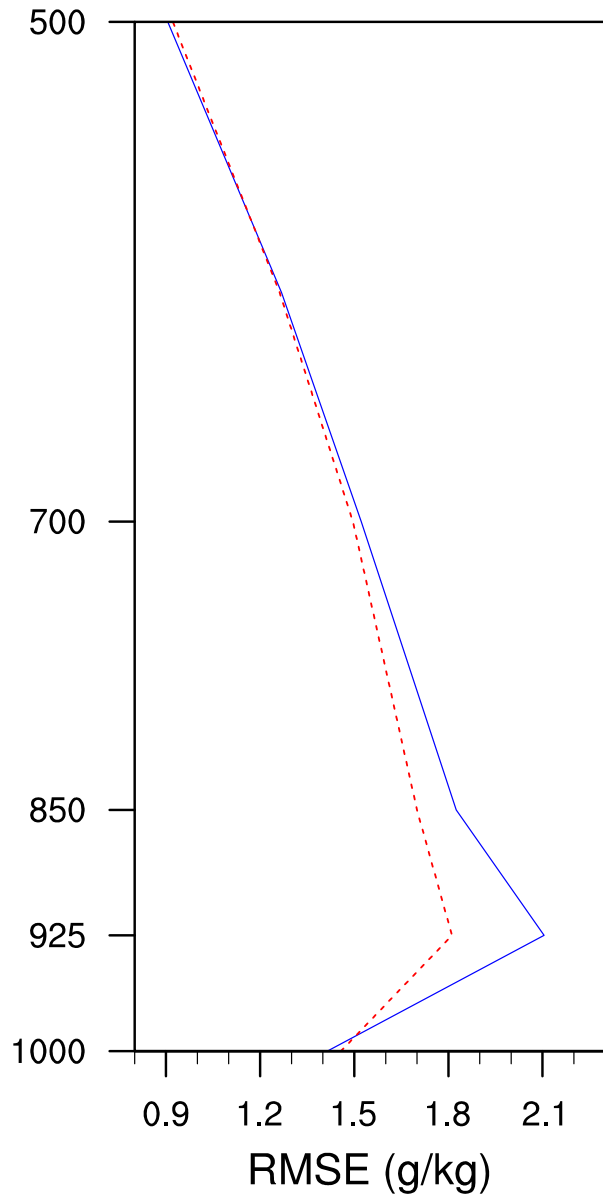


6h-Forecasts fits to radiosonde water vapor (CP checks below 2km)



- Biases of CP30, CP40, and CP50 are closer to CP00
- RMSEs of CP30, CP40, and CP50 are all smaller than CP00

6h-Forecasts fits to radiosonde water vapor

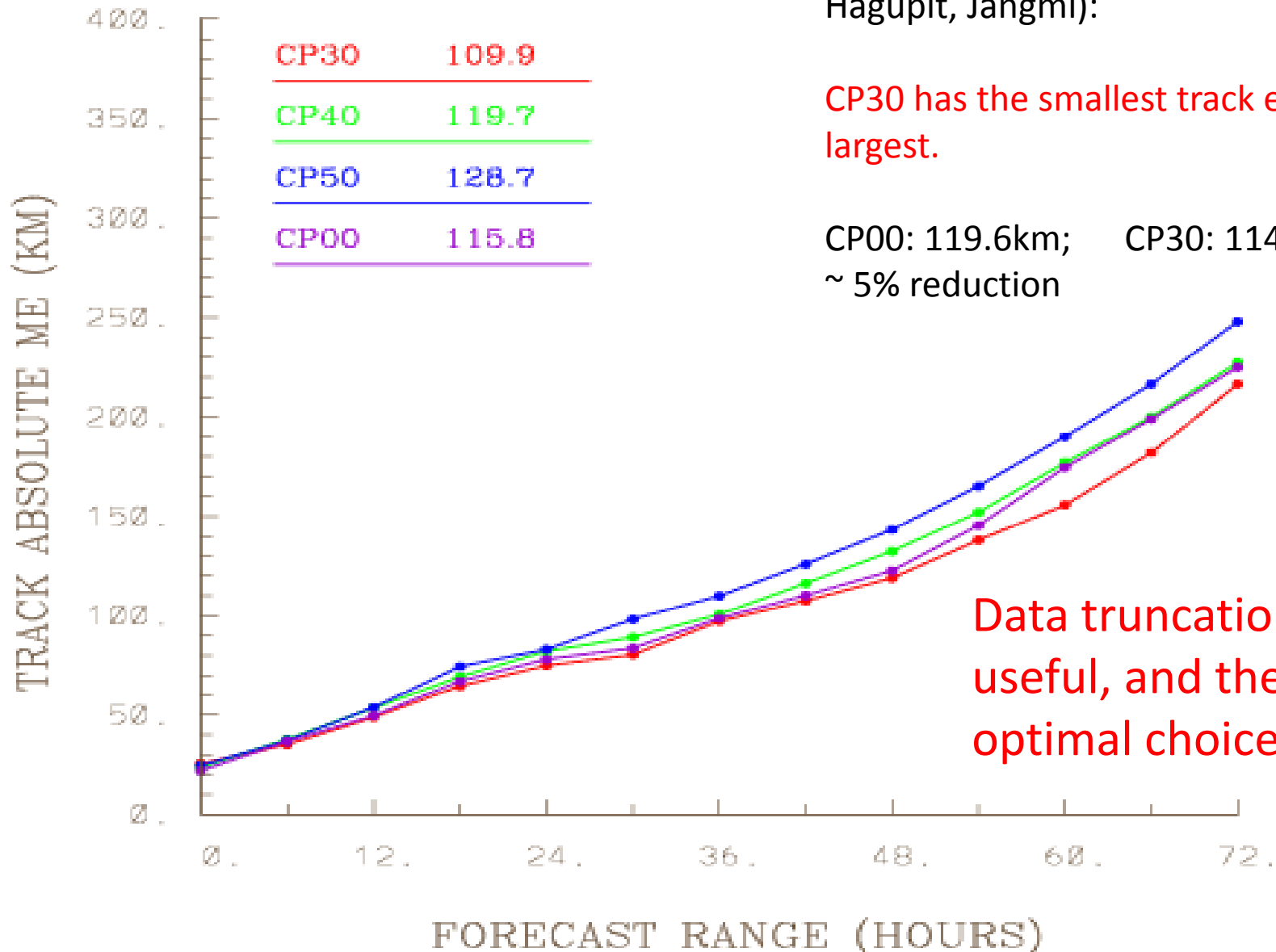


CP30N includes a new shallow convection scheme from YSU. Otherwise, everything is the same as CP30

- Biases of CP30 is largely removed by the new shallow convection scheme
- GPS RO 'negative N bias' may be partially attributable to model errors

Impact on track forecast of 2008 Typhoons

72-h track forecast errors, averaged over 52 forecasts for the three typhoons (Sinlaku, Hagupit, Jangmi):



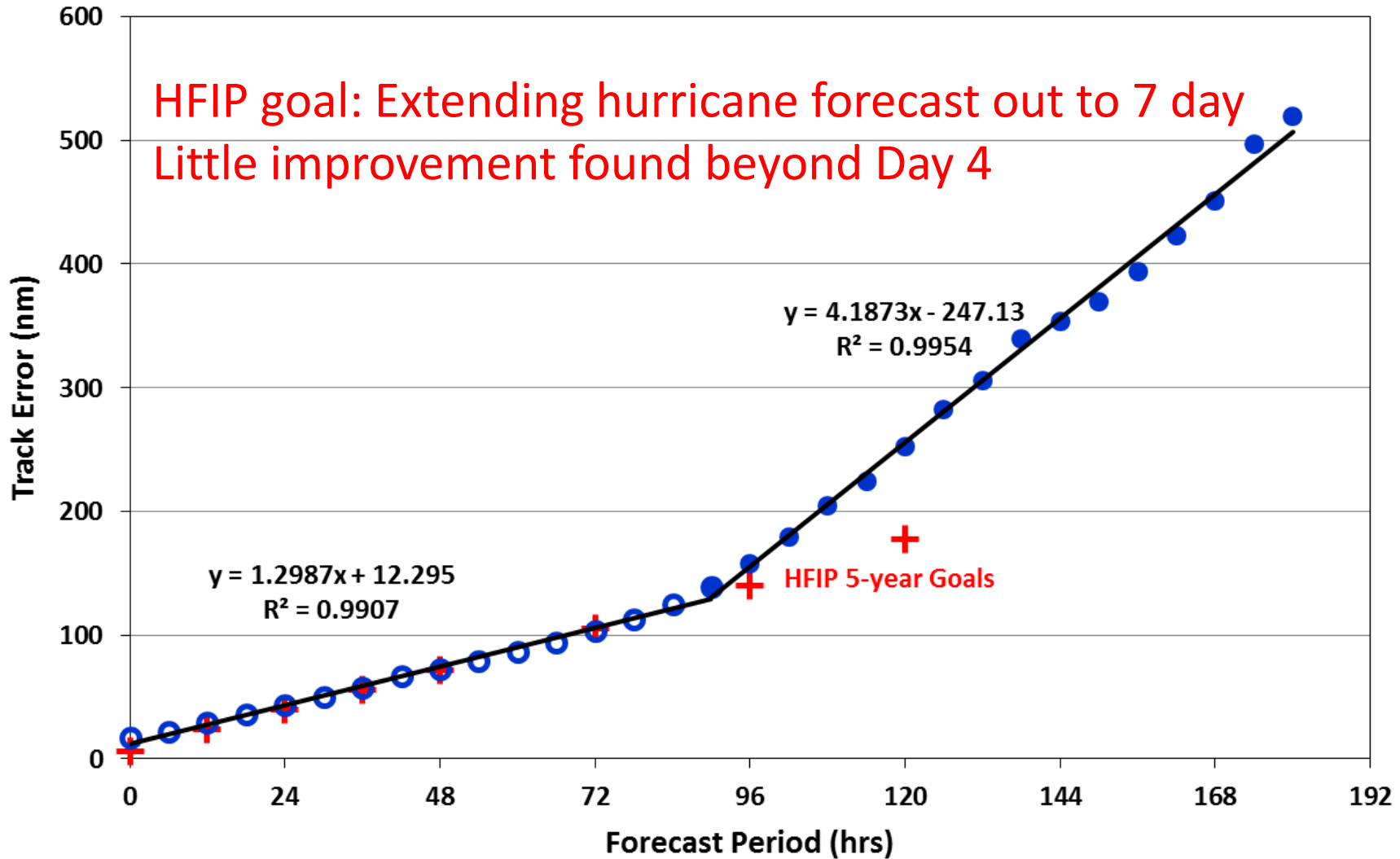
CP30 has the smallest track error, CP50 the largest.

CP00: 119.6km; CP30: 114 km
~ 5% reduction

Data truncation using CP is useful, and there is an optimal choice (CP1 = 30%)



Notable Change in Trend of NCEP GFS Track Errors 2012 Atlantic Basin

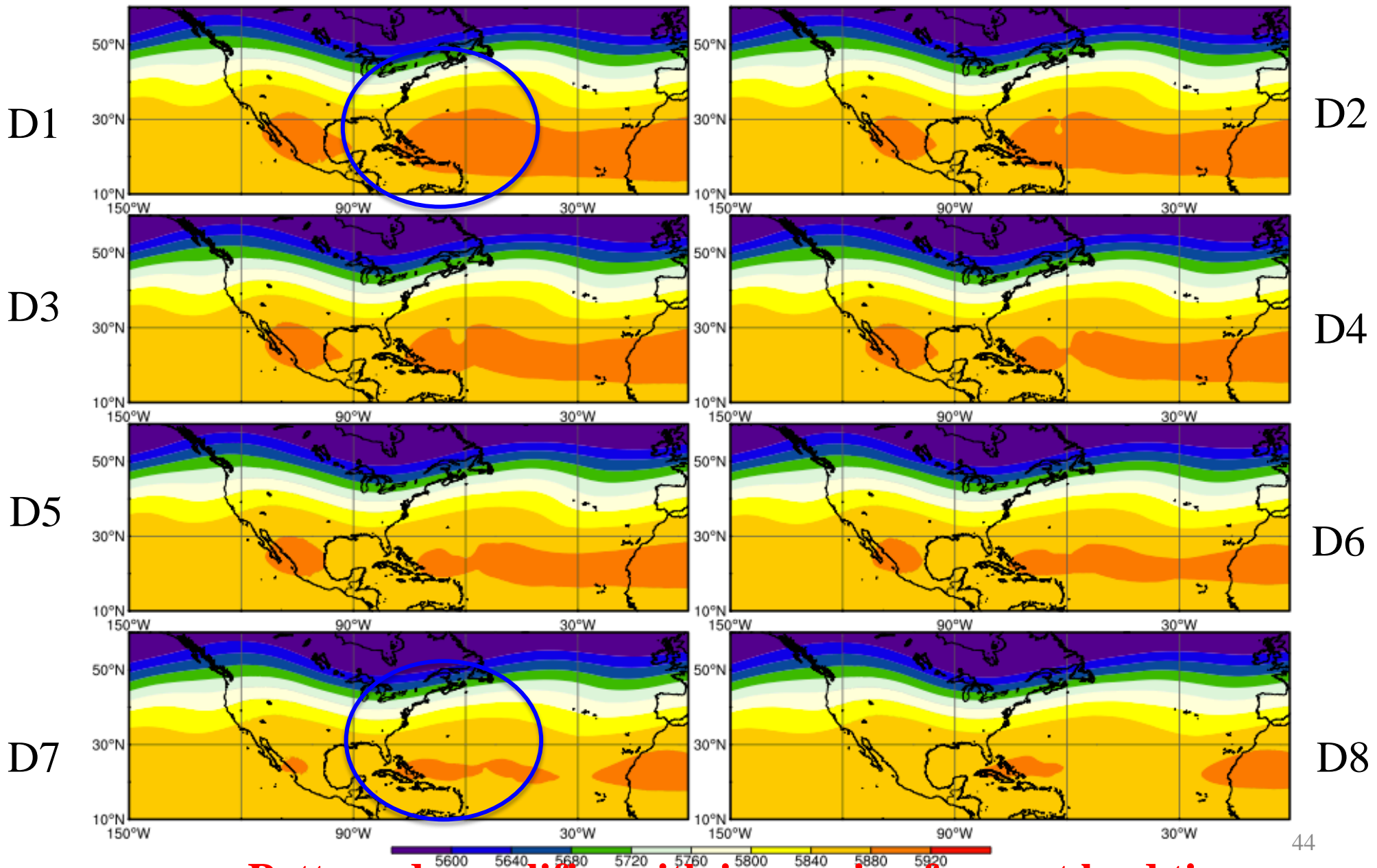


Diagnosis of GFS Forecast Error for Hurricanes Season of 2012

- GFS forecast error growth from Day 1 through Day 8:
 - **Seasonal mean:** Averaged over 92 days, 1 August – 31 October 2012
 - These errors represent model systematic errors. They depend only on forecast lead time, not the time of model initialization.

GFS forecast 500 hPa H (Day1 to Day8)

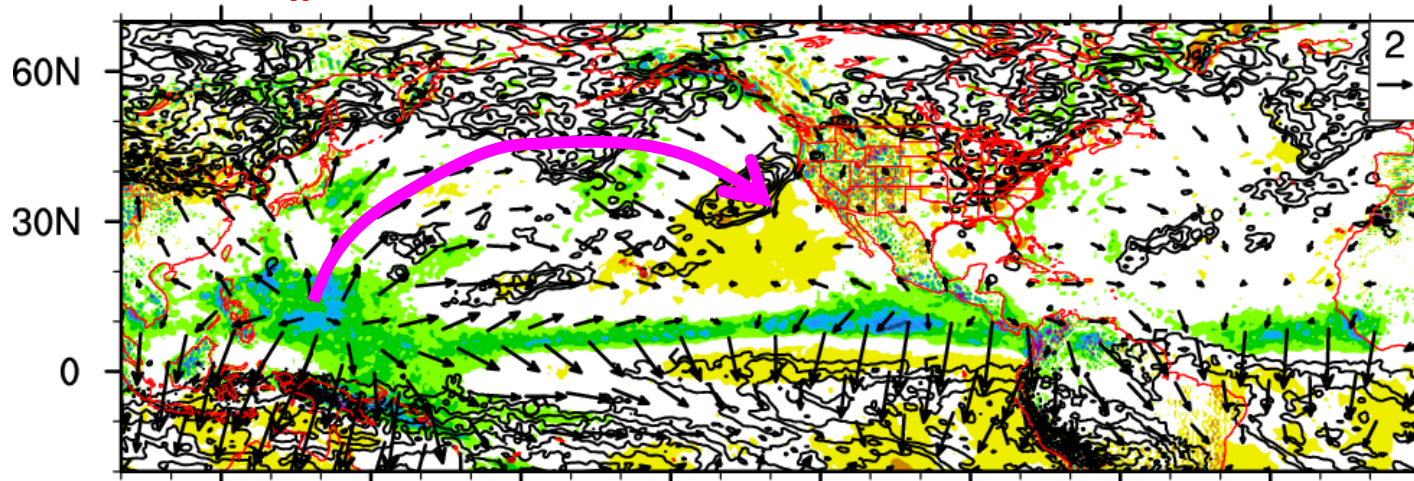
92-day mean: Aug.1-Oct.31, 2012



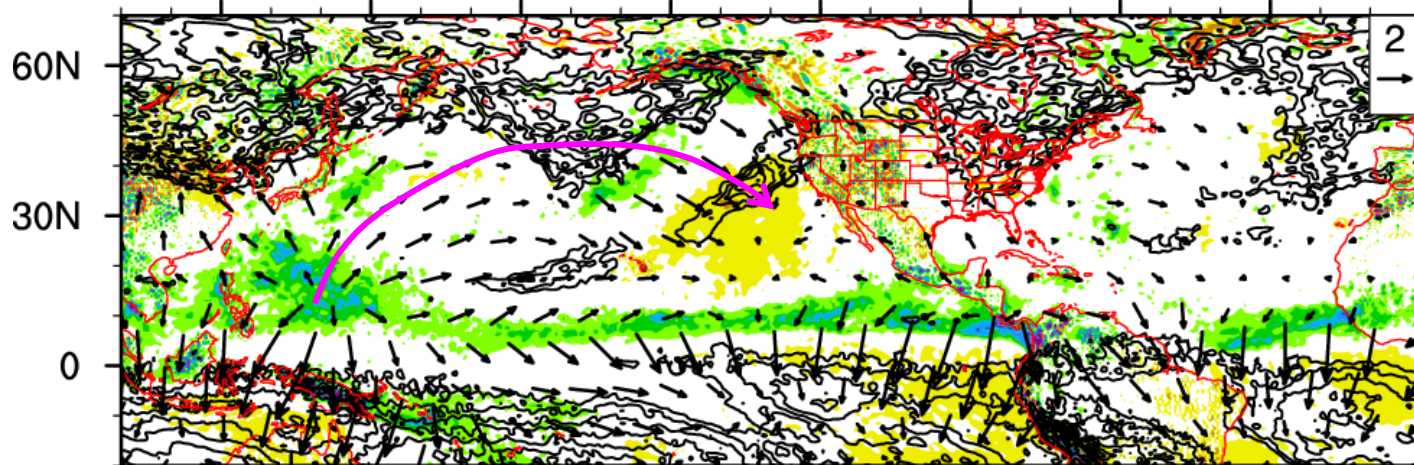
Pattern deamplifies with increasing forecast lead time

GFS 250 hPa ζ , V_{ir} , and 500 hPa ω : 92-day Mean 1 Aug–31 Oct 2012

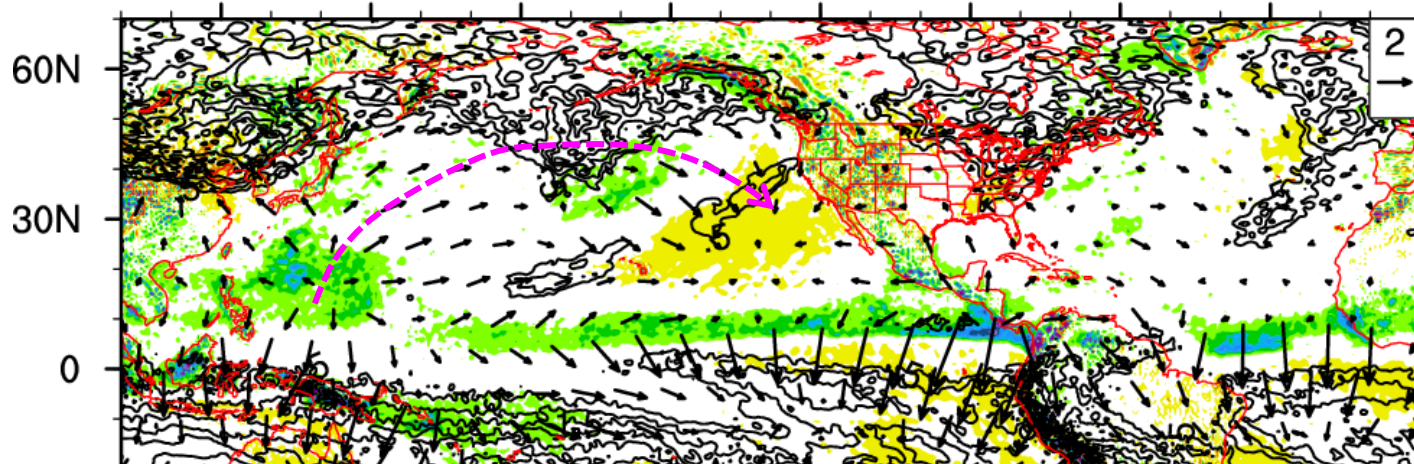
Analysis



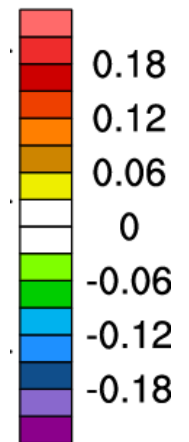
96-h



168-h



- Decrease in tropical convection overall with increasing lead; most notable over WPAC and EPAC
- Decrease in irrotational wind connecting tropics and midlatitudes
- Suggests connection between reduced tropical convection and decreased amplitude of midlatitude waveguide



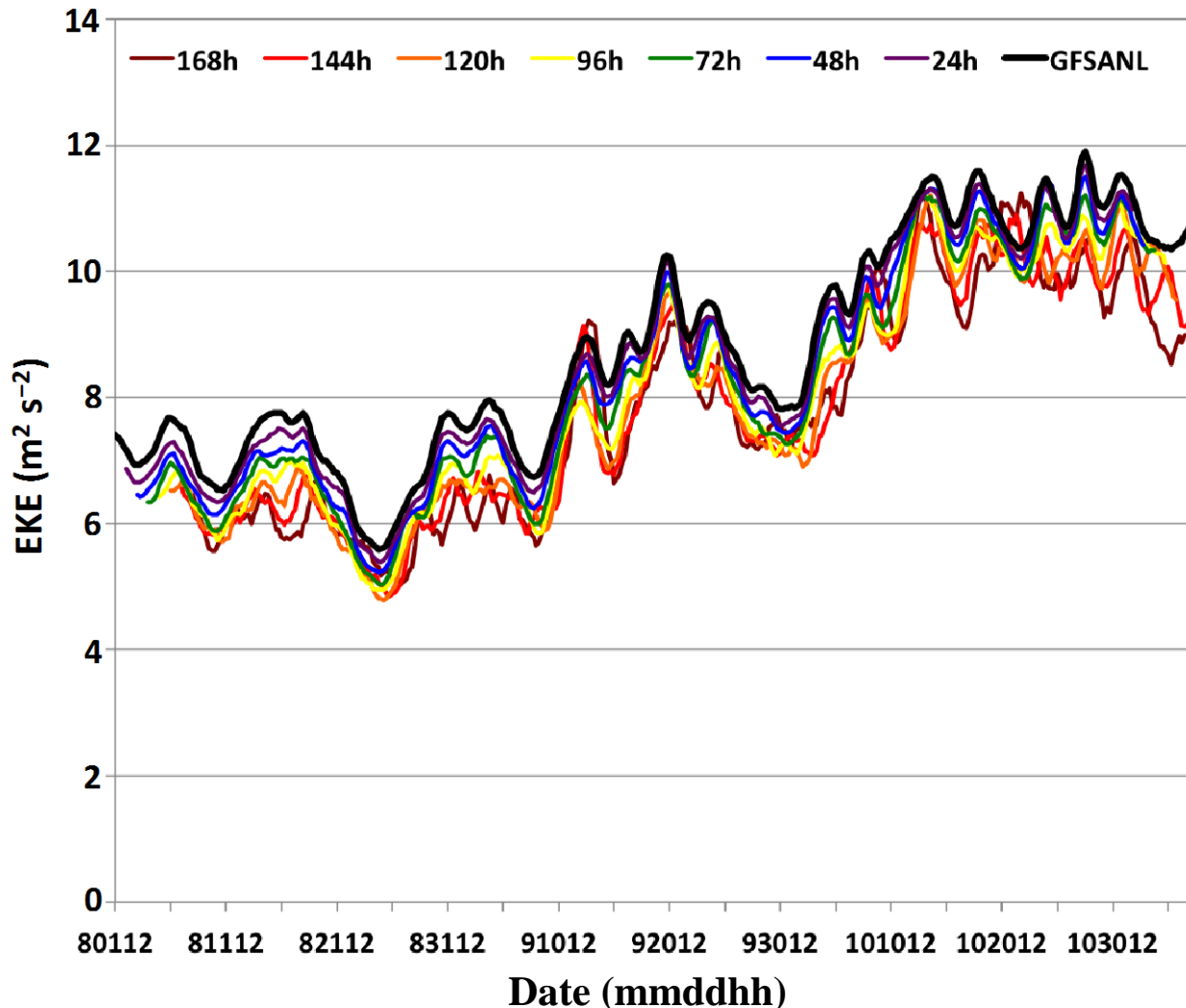
Pa s^{-1}

Energetics: Eddy Kinetic Energy

Lorenz (1955):
$$K_E = \frac{1}{gA} \int_{200}^{900} \int_A \frac{[u'^2 + v'^2]}{2} dAdp$$

Compute over latitude band 20°–85°N

GFS Forecast Northern Hemisphere Eddy Kinetic Energy



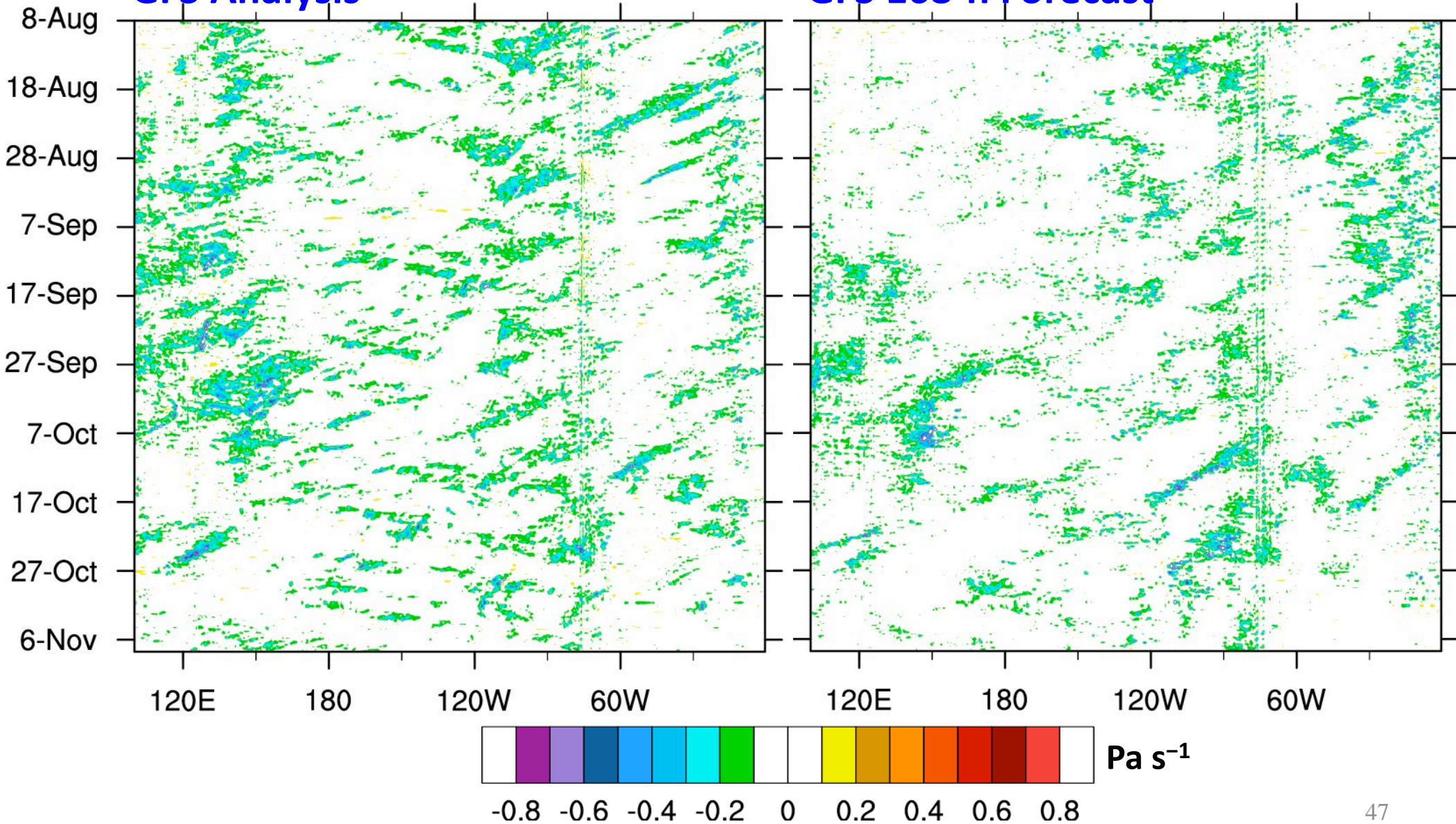
- Northern Hemisphere K_E increases during Aug-Oct
- Systematic reduction in K_E in GFS forecasts
- Reduction in K_E increases with forecast lead
- Suggests **synoptic-scale eddies too weak in GFS forecasts** → more difficult to maintain amplified (or even blocked) flow
- Consistent with time-mean DT jet/waveguide that is more zonal in GFS forecasts

Tropical Convection: Aug–Oct 2012

5–15°N latitude band

GFS Analysis

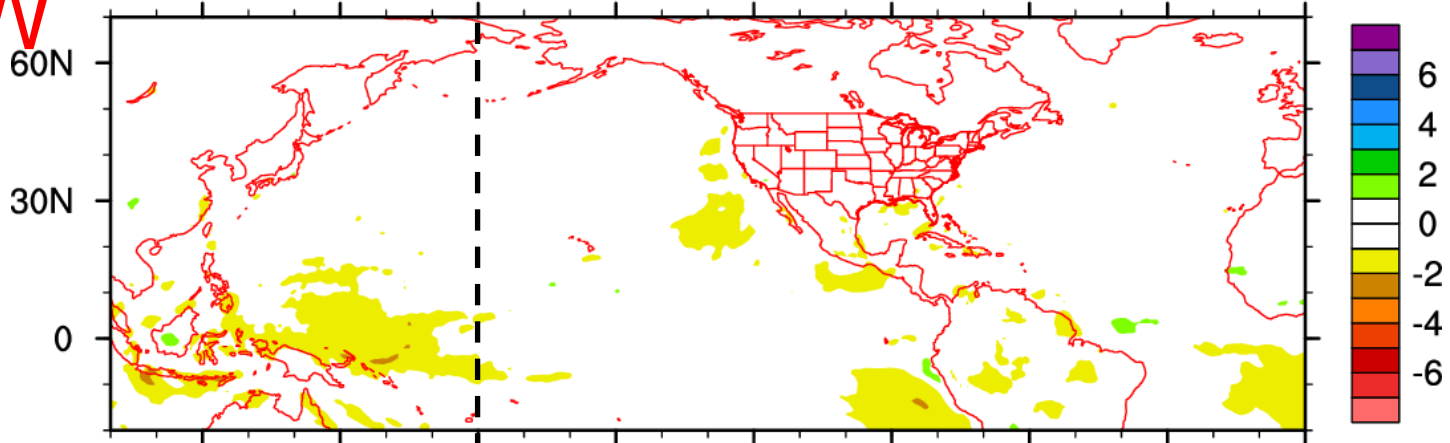
GFS 168-h Forecast



GFS PW

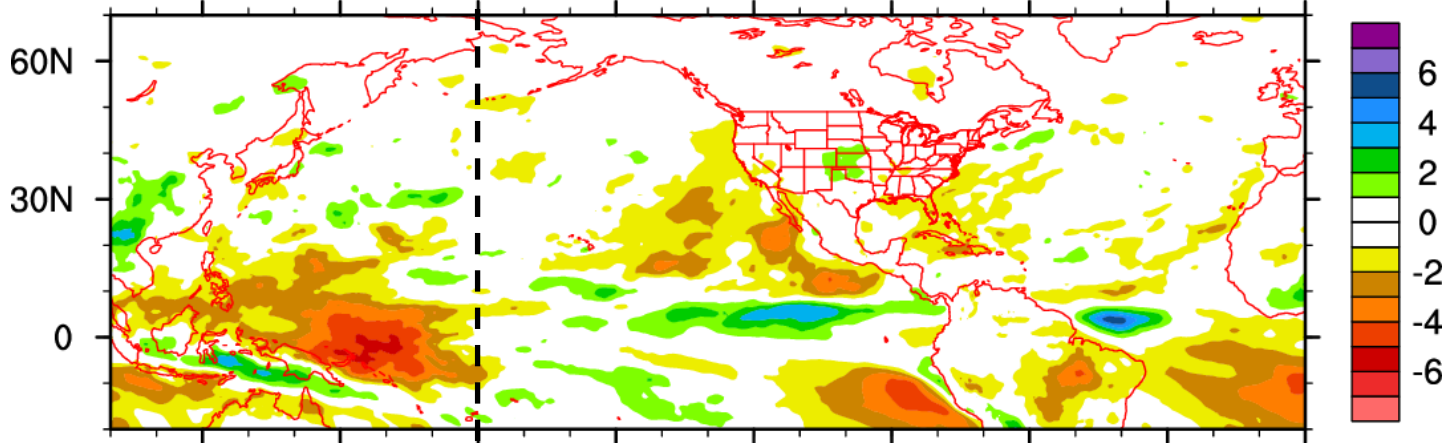
24-h GFS PW ERROR (92-day mean 1 Aug-31 Oct 2012)

24-h error



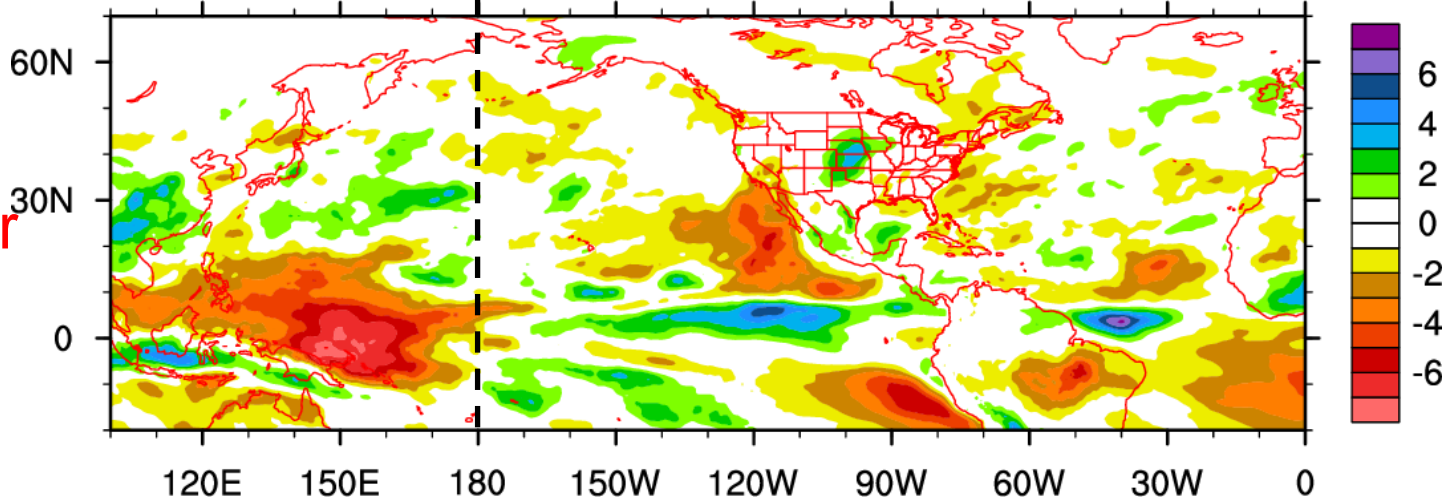
96-h GFS PW ERROR (92-day mean 1 Aug-31 Oct 2012)

96-h error



168-h GFS PW ERROR (92-day mean 1 Aug-31 Oct 2012)

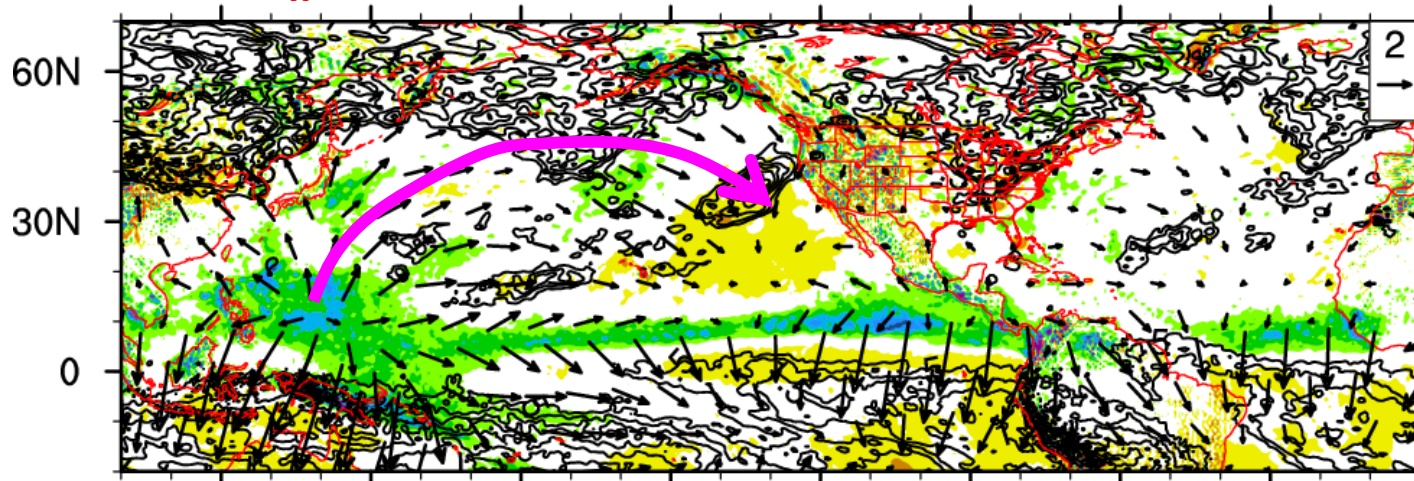
168-h error



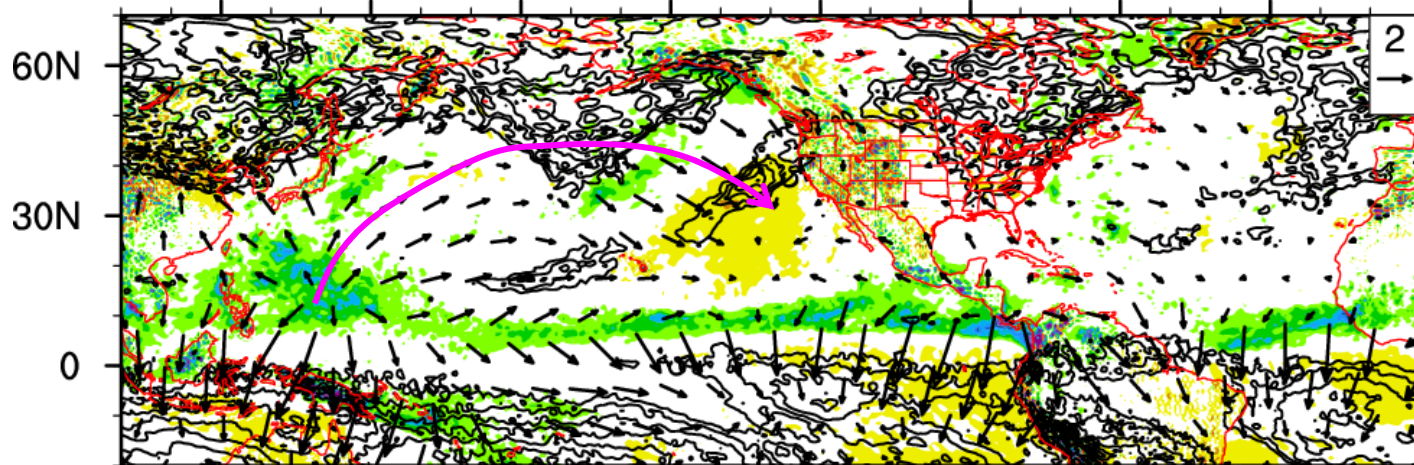
120E 150E 180 150W 120W 90W 60W 30W 0

GFS 250 hPa ζ , V_{ir} , and 500 hPa ω : 92-day Mean 1 Aug–31 Oct 2012

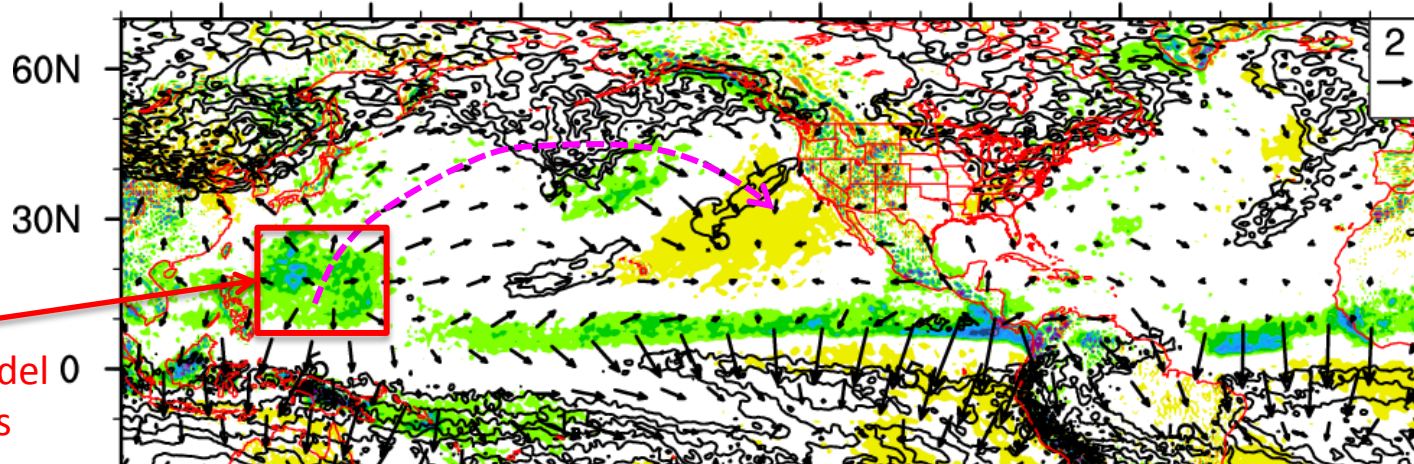
Analysis



96-h

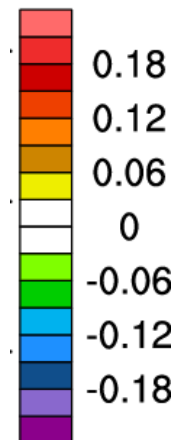


168-h



Region for Model Error Diagnosis

- Decrease in tropical convection overall with increasing lead; most notable over WPAC and EPAC
- Decrease in irrotational wind connecting tropics and midlatitudes
- Suggests connection between reduced tropical convection and decreased amplitude of midlatitude waveguide



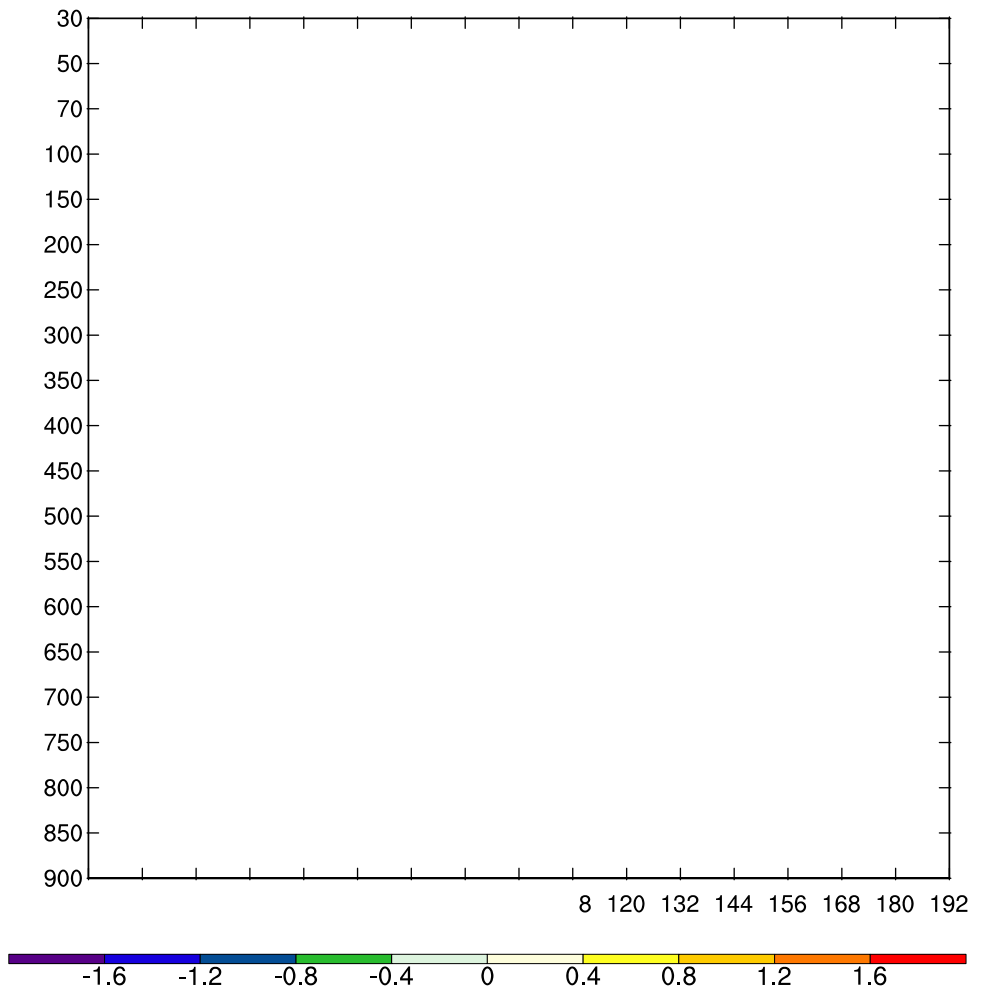
Pa s^{-1}

Mean Error for August



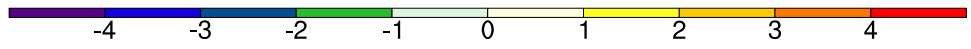
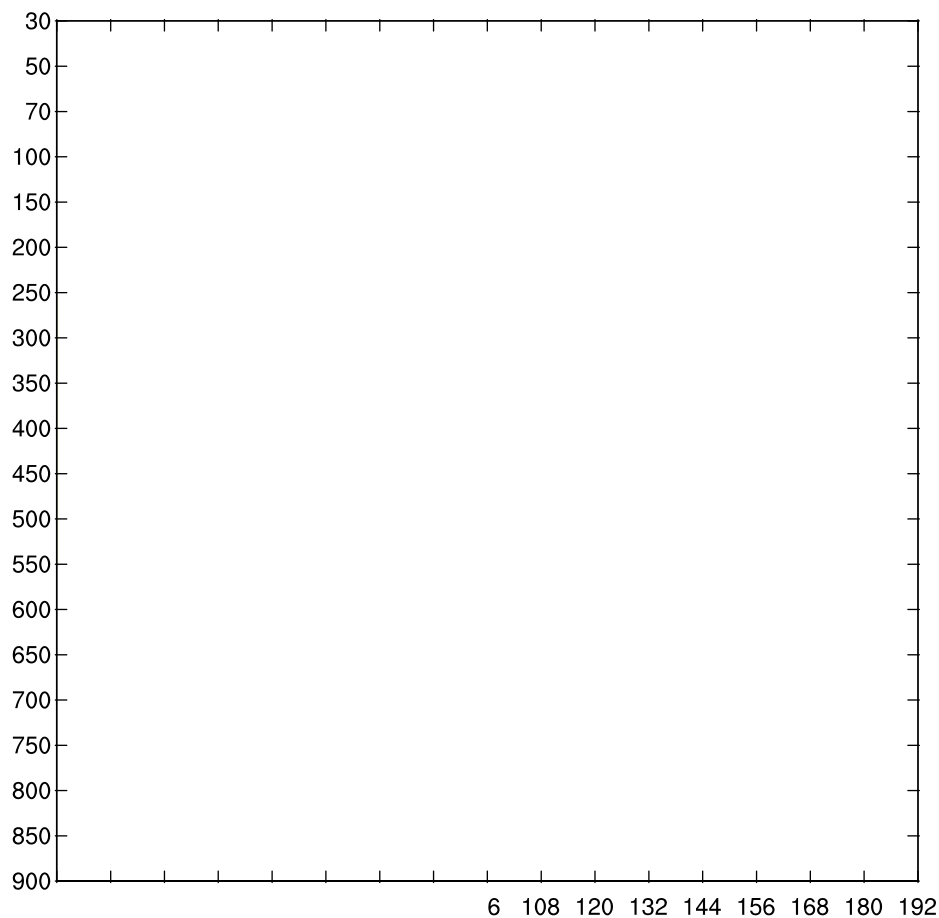
Temperature (k)

Mean Error for Aug



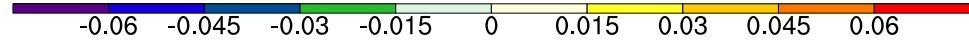
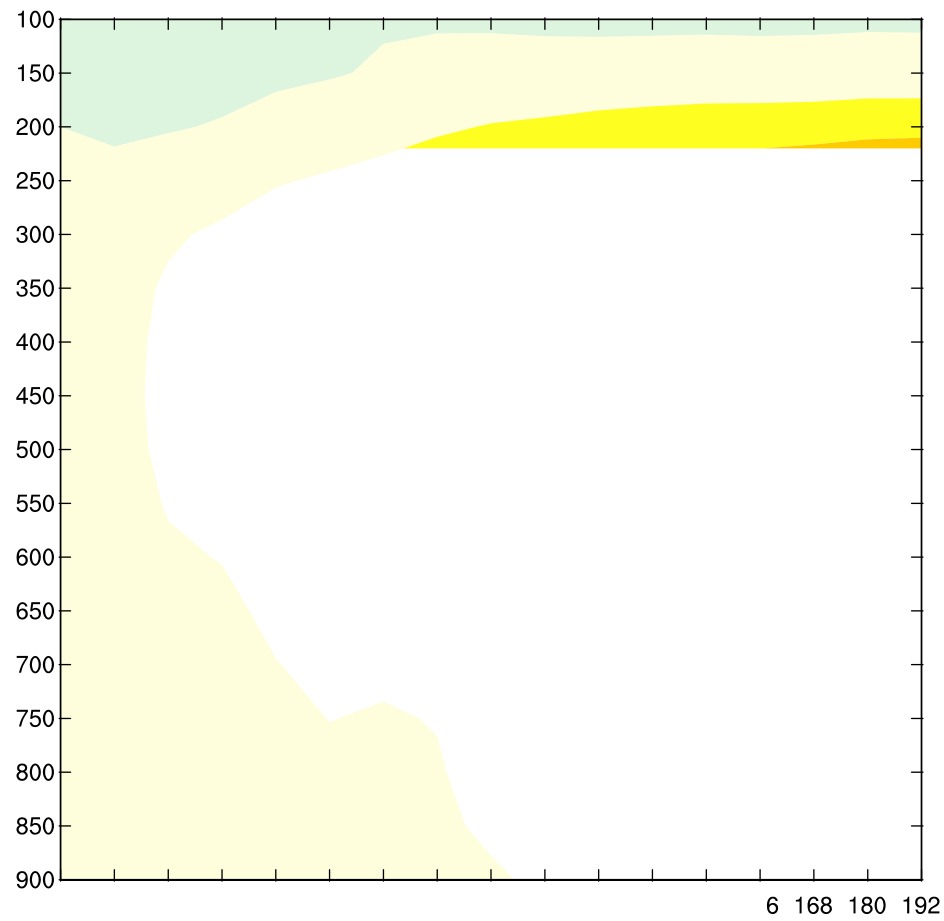
Water Vapor (g/kg)

Mean Error for August



Equivalent Potential Temperature (k)

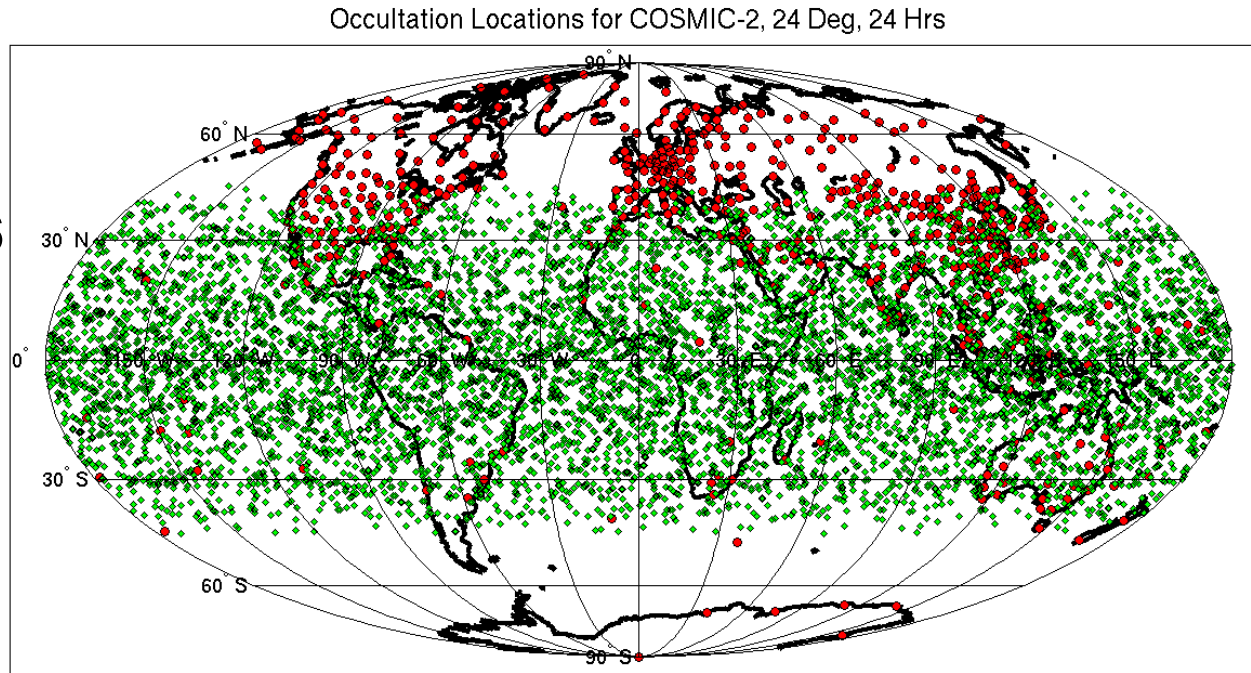
Mean Error for Aug



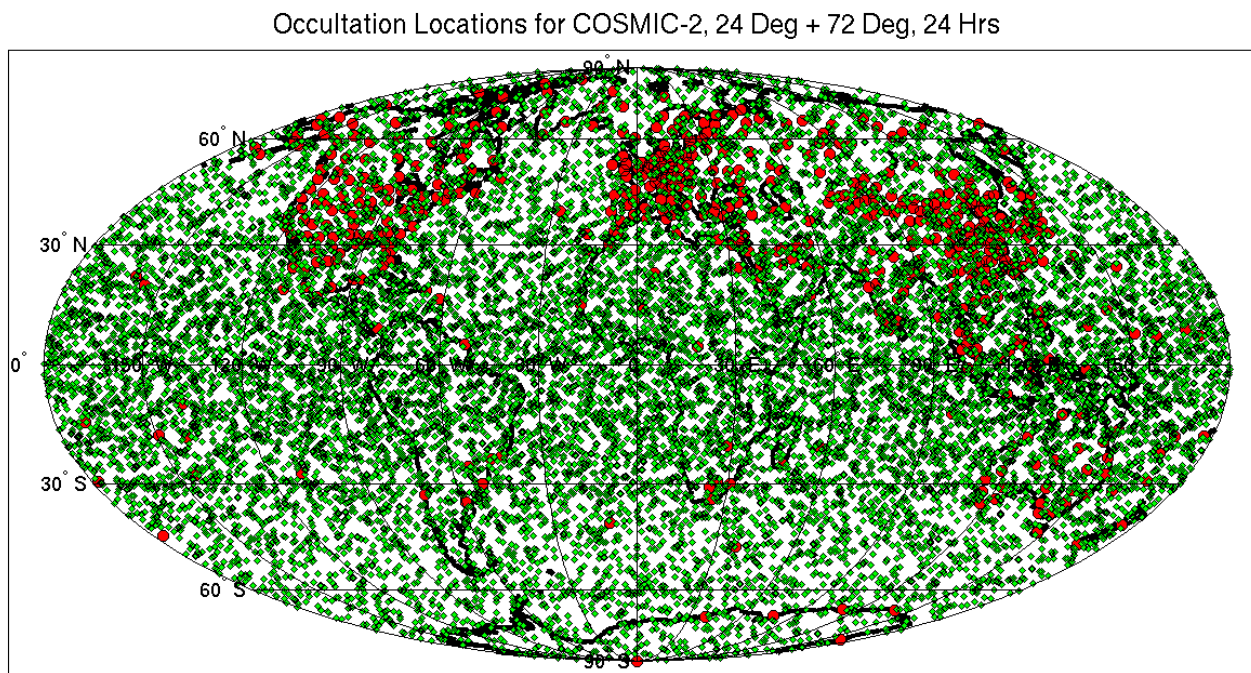
Vertical motion (Pa s⁻¹)

COSMIC-2: First and Second Launches

1st Launch 2016



With 2nd launch
2018 or 2019



Summary

- GPSRO observations:
 - Provide three-dimensional water vapor and temperature information over the tropics
 - Improves hurricane genesis, intensity, and track forecasts
 - Data below 6-km is most critical
- UCAR CDAAC will provide data QC parameters in new processing (i.e., CP, Obs error)
 - BA assimilation experiment shows that data truncation using CP parameter is useful
 - Next step: experiment with obs errors
- Improving WRF model's shallow convection substantially reduced biases in O-B
 - Some of the GPS RO negative N bias below 2-km may be attributable to model errors

Summary

- NCEP GFS global model has shown only small improvement in hurricane track forecast beyond Day 4, with notable systematic errors:
 - Decreased tropical convection → weakened eddy kinetic energy → weakened (deamplified) synoptic scale circulations → significant hurricane track errors
 - GPS RO may be used to diagnose and improve model physical parameterization
- COSMIC-2 GPS RO observations over the tropics will provide an opportunity to significantly improve tropical cyclone prediction:
 - Improved initial conditions through data assimilation
 - Better understanding and diagnosis of sources of model biases, necessary to improve medium range forecast of tropical cyclones

