Impact of Refractivity Profiles from a Proposed GNSS-RO Constellation on Tropical Cyclone Forecasts in a Global Modeling System

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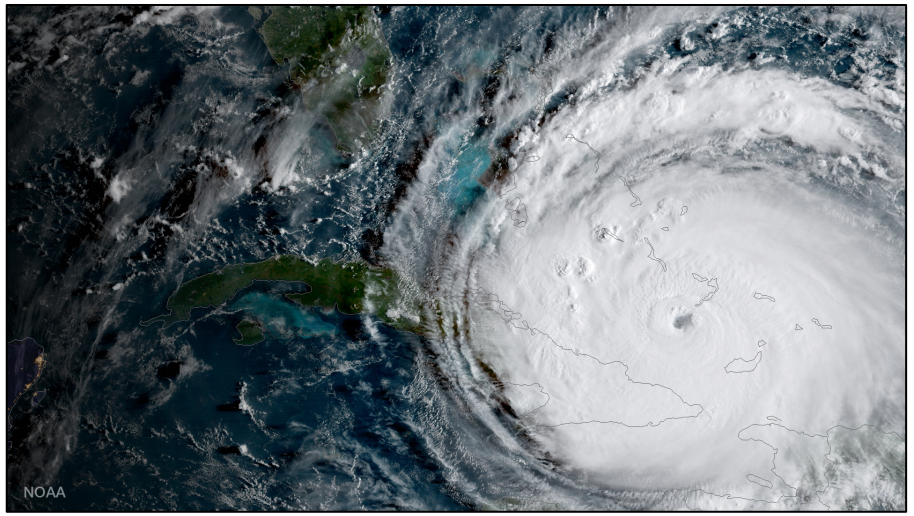
Background: Tropical Cyclones

- Tropical cyclones (TCs) pose serious threat to life, disruption to society
- Track and intensity forecasts are heavily scrutinized and used to make very expensive decisions
- TC forecasts challenging due in part to lack of observations
  - Ships and aircraft generally avoid core of the storm
  - Satellite radiances do not sample below dense overcast
  - Very few surface or vertical observations collected in storm environment
- Need better observation coverage over oceanic data void, especially below dense overcast near TC core

Hurricane Irma (NOAA)



Evacuation on I-75

Background: Radio Occultation

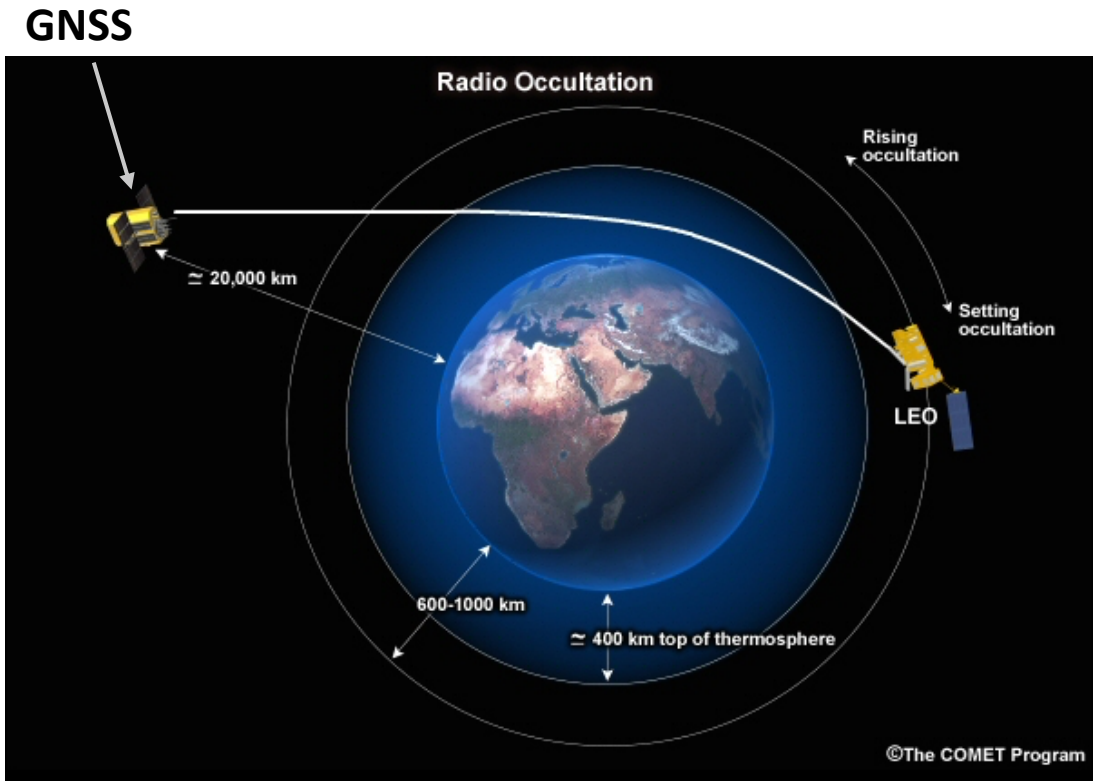
- RO improves global-scale forecast skill

How does RO work?

- Radio signals from Global Navigation System Satellites (GNSS) traverse atmosphere en route to Low Earth Orbit (LEO) satellite

- Air density refracts radio signal

- Extent of refraction at different levels of atmosphere yields refractivity profiles



- Profiles contain information about temperature, moisture, and pressure

Why might RO improve TC forecasts?

- Signals minimally attenuated by clouds or precipitation, allowing profiles through TC core

- **Offers coverage over oceanic data voids and under dense clouds**

Background: Goals and Objectives

How does global RO data assimilation impact model track and intensity forecasts for tropical cyclones?

We want to use:

1. Many TCs and TC forecasts

2. Global analysis and forecast system, cycled over an extended period

3. Proposed LEO satellite constellation based on original configuration of COSMIC-2
   - 12 satellites: 6 equatorial orbiting, 6 polar orbiting
   - ~12,000 profiles per day worldwide

Since observations don't currently exist, must use Observation System Simulation Experiment (OSSE) framework:

- Simulated "real atmosphere" called Nature Run

- Simulated observations (existing observations plus RO profiles)

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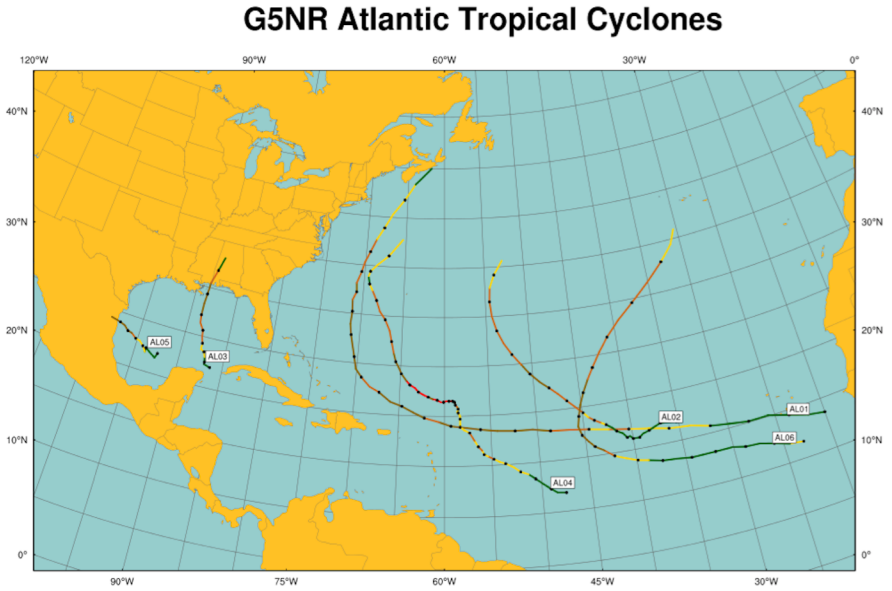
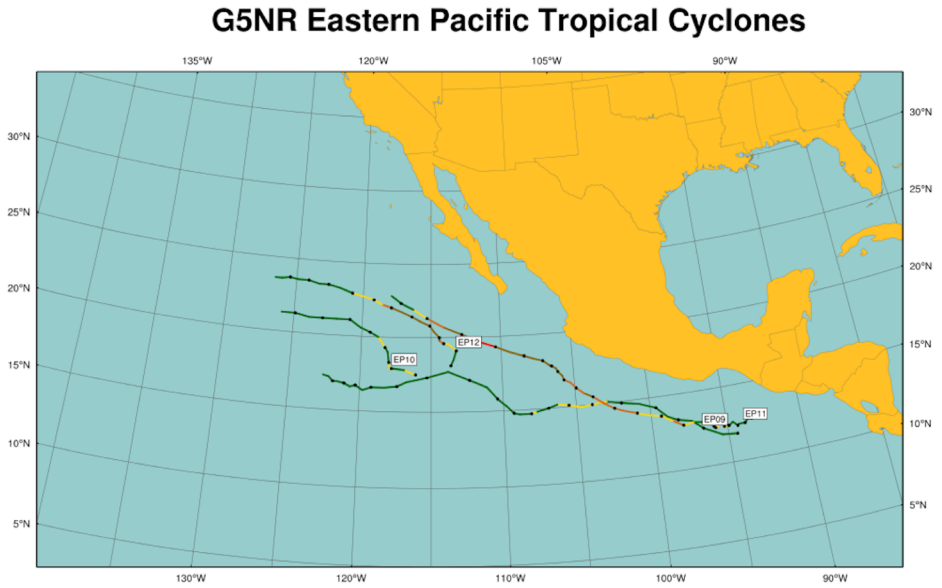
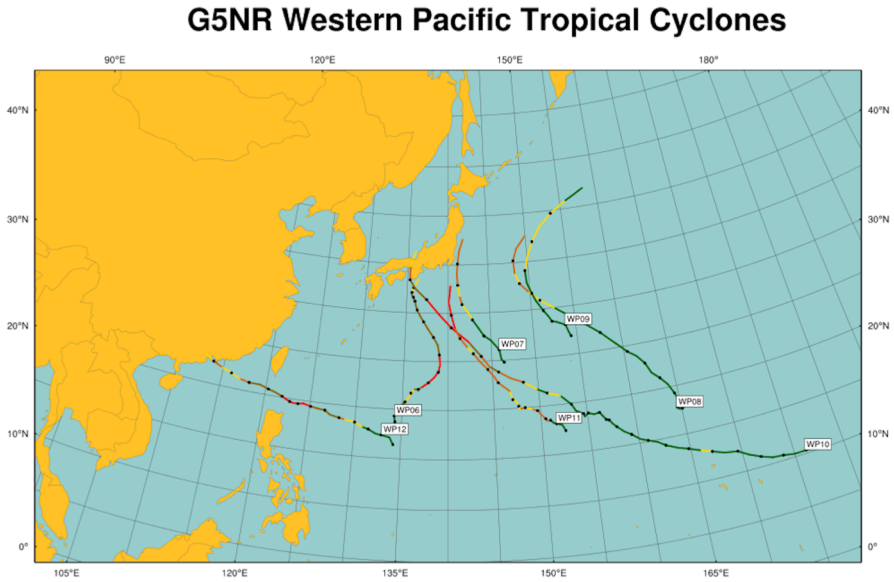
Methods: OSSE Configuration: Nature Run







- NASA/GMAO GEOS-5 global mesoscale nature run (G5NR; Putman et al 2016)
- Stand-in for real atmosphere
- Verified against climatology of real atmosphere (e.g. Gelaro et al 2015; Reale et al 2017)
  - Realistic TCs
  - ~7-km x 7-km horizontal grid
  - 72 vertical levels

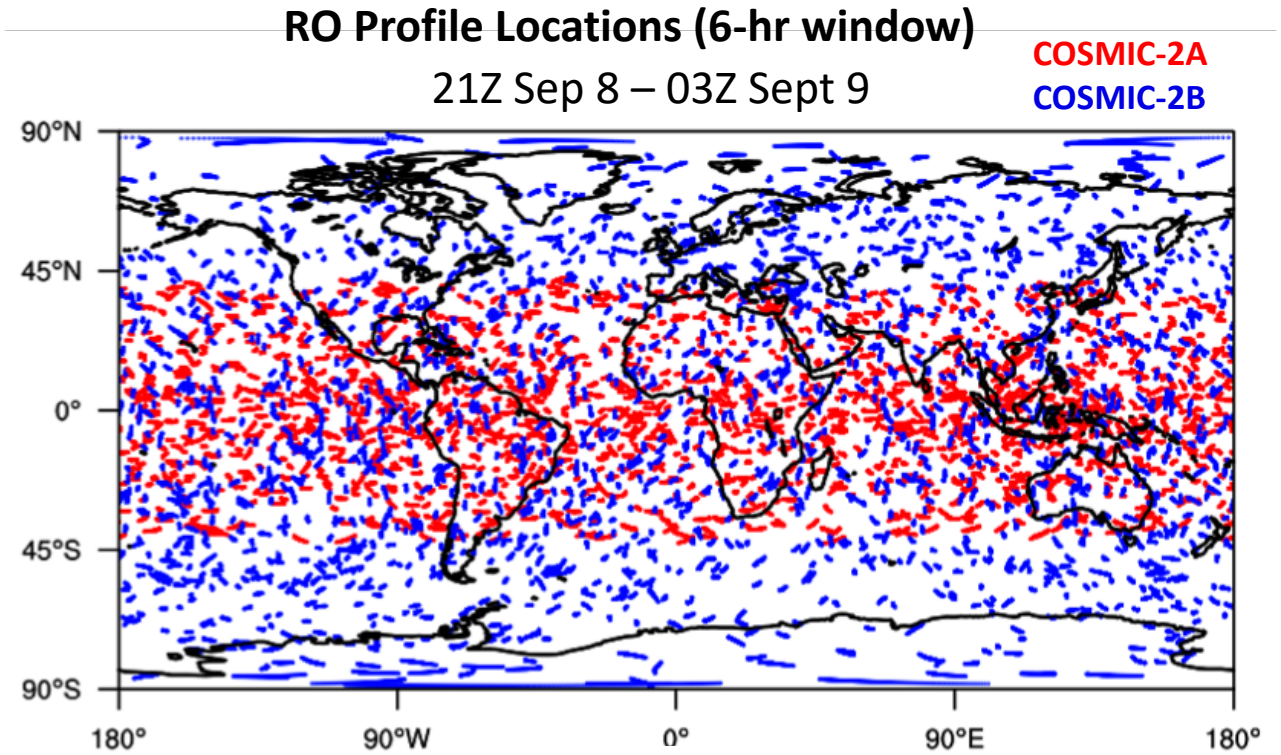
Methods: OSSE Configuration: Simulated Observations

Simulated Observations

- Surface pressure, temperature, u-, and v-wind, specific humidity, satellite radiances, and RO refractivity profiles

Distribution

- Conventional and radiance observations: real-world stats (Aug – Sept 2014)
- RO profiles: Realistic orbits of original proposed COSMIC-2 constellation



Methods: OSSE Configuration: Analysis and Forecast Cycling System

NCEP's GDAS/GFS (Q1FY15)

- GDAS cycles 00Z, 06Z, 12Z, 18Z (3DEnVar GSI)
- 6-hr assimilation window
- Global cycling for 2 months: 1 August – 30 September (Nature Run Year)
- Spin up 1 – 14 August
  - Real-world GFS initial conditions converge to Nature Run "reality"
- Experimental period 15 August – 30 September
  - 168-hr GFS forecasts at 00Z
- GFS run at T670L64, GSI at T254L64

Methods: Experiments

CTL

ps t u v q satellite radiances

RO_err

ps t u v q satellite radiances RO with errors added

RO_err_1cyc

Same as RO_err, but started from CTL background

All conventional and satellite radiance data had errors added

Methods: OSSE Configuration: Verification

Datasets

- **Truth: G5NR Global Nature Run (~7-km x 7-km grid)**
- G5NR TC track and intensity based on Reale et al 2017 TC climatology
- GFS forecasts: 0.25° x 0.25° data; GFDL Vortex Tracker

The Cases

- 17 TCs occurred from 15 August – 30 September
- Many global forecasts contained multiple TCs: **132 TC forecasts**

Error Statistics Calculations

- Averaged track and maximum wind speed errors for 132 forecasts
- Statistical significance with respect to CTL assessed using paired t-test

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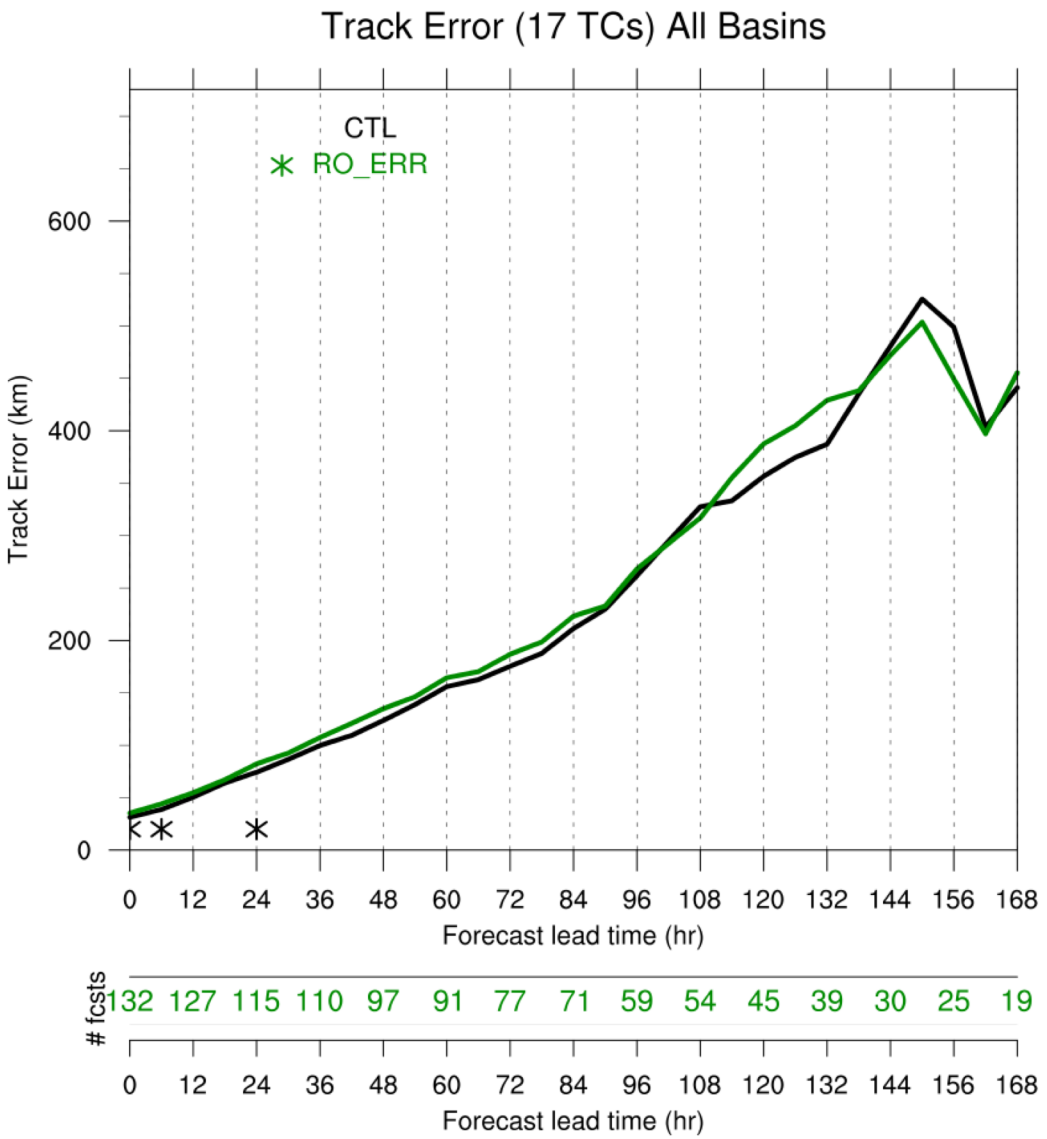
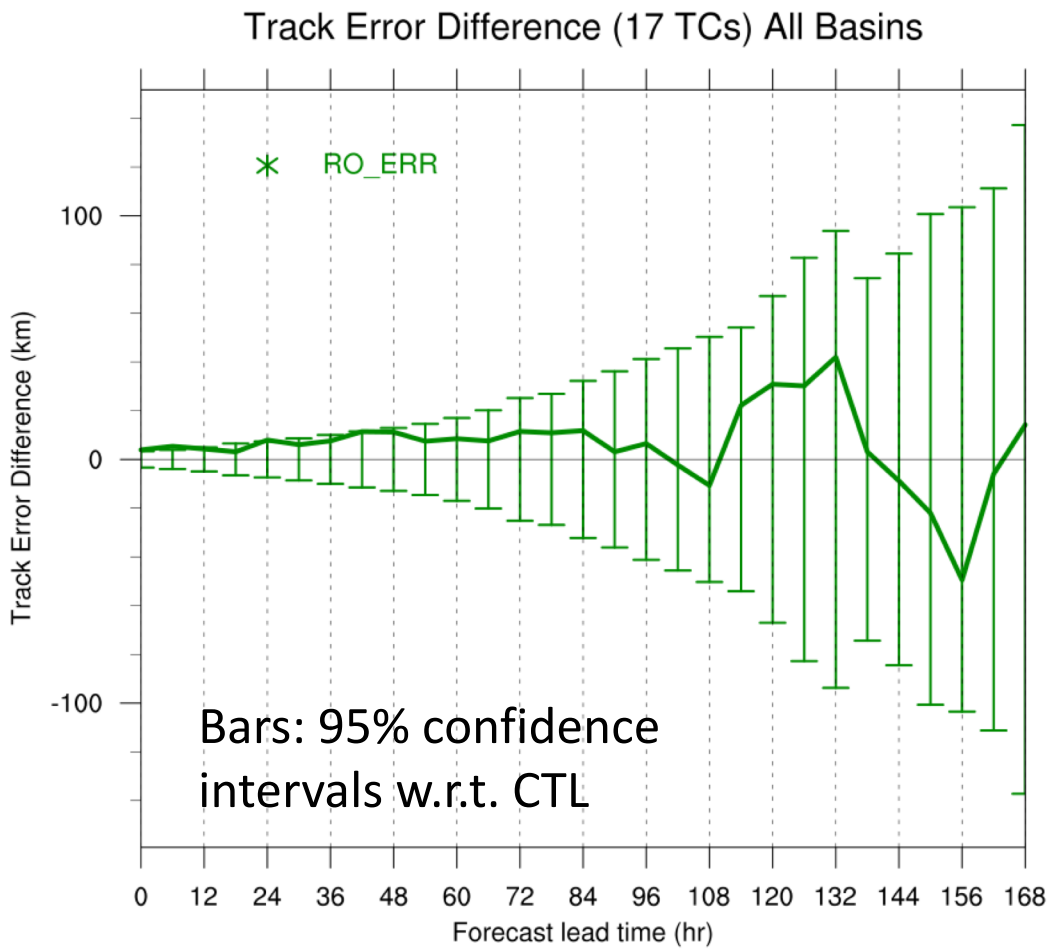
Results: Global Track Forecast Statistics (132 forecasts)





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- Significant degradation at 0,6, and 24 h

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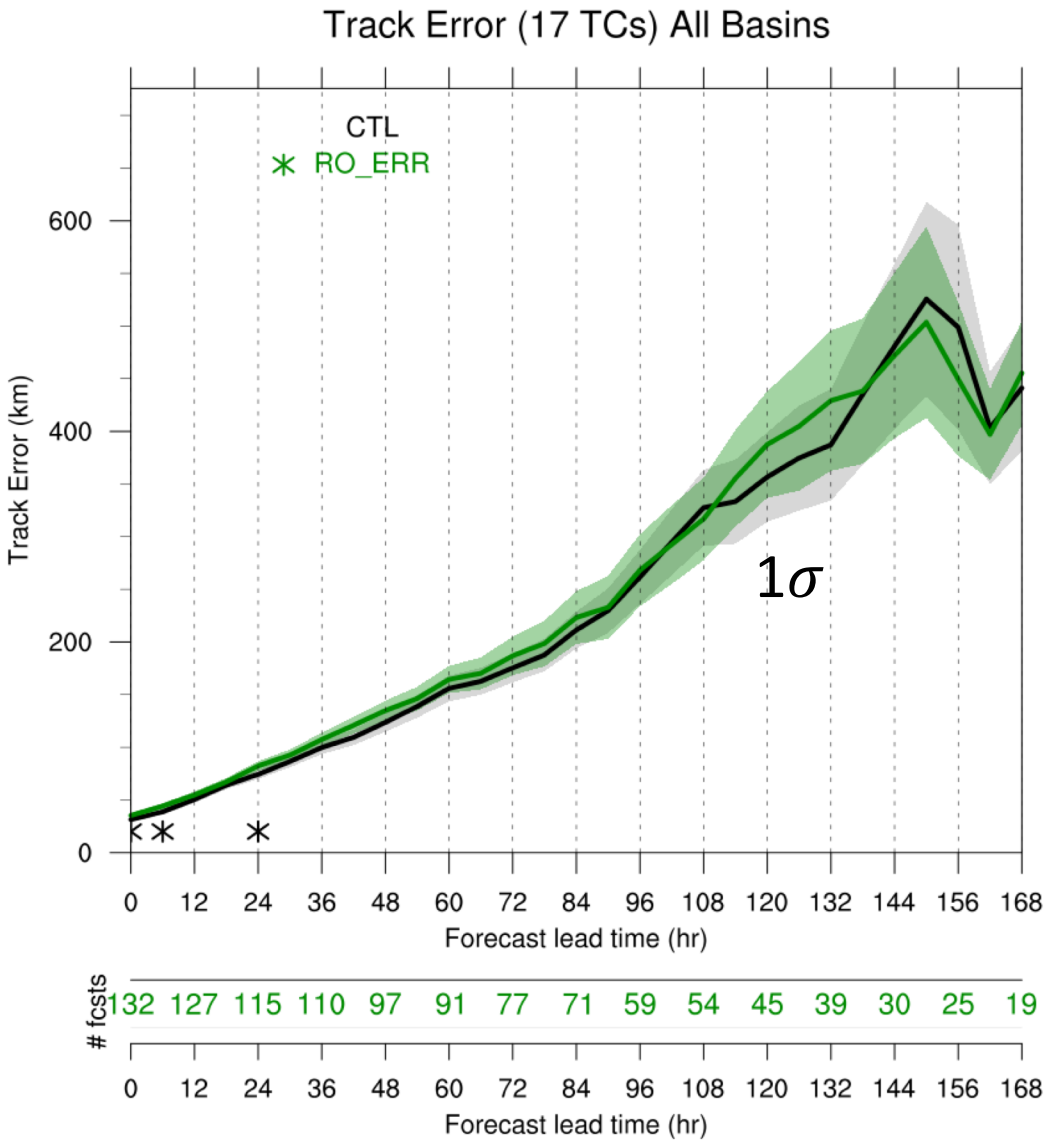

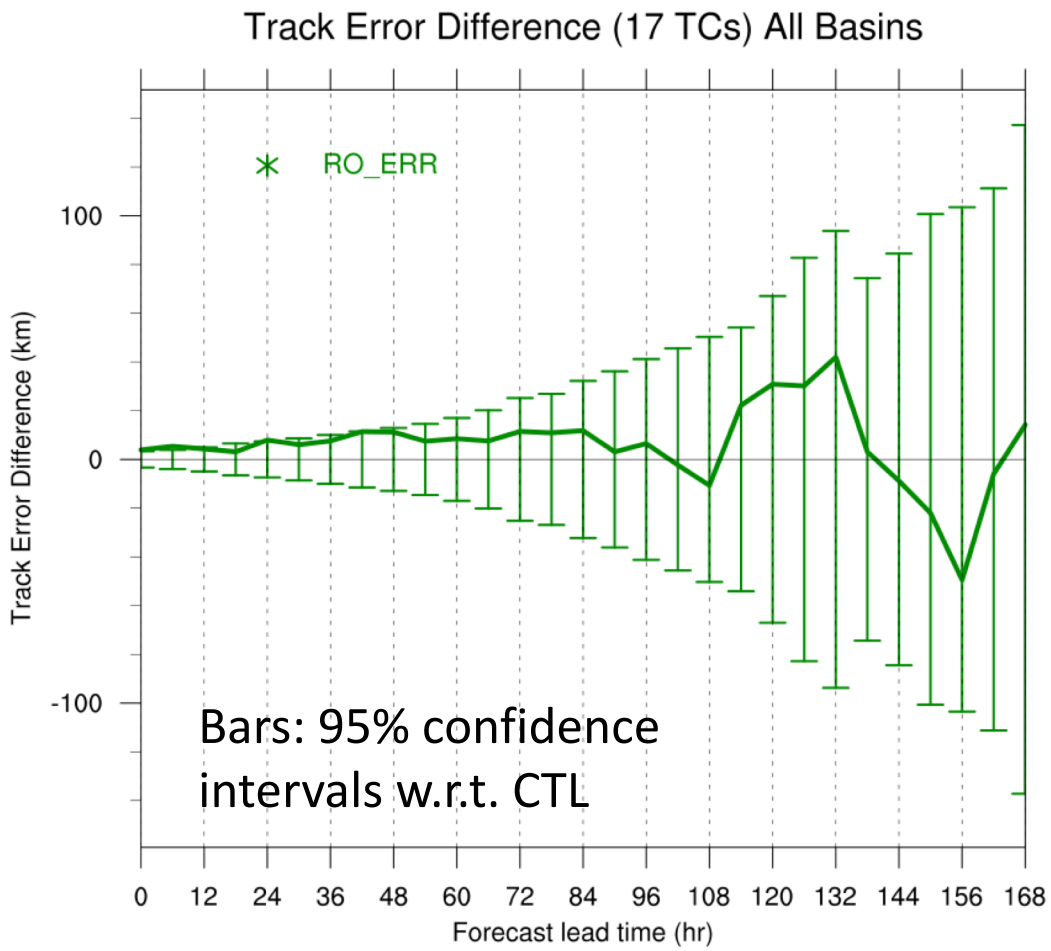

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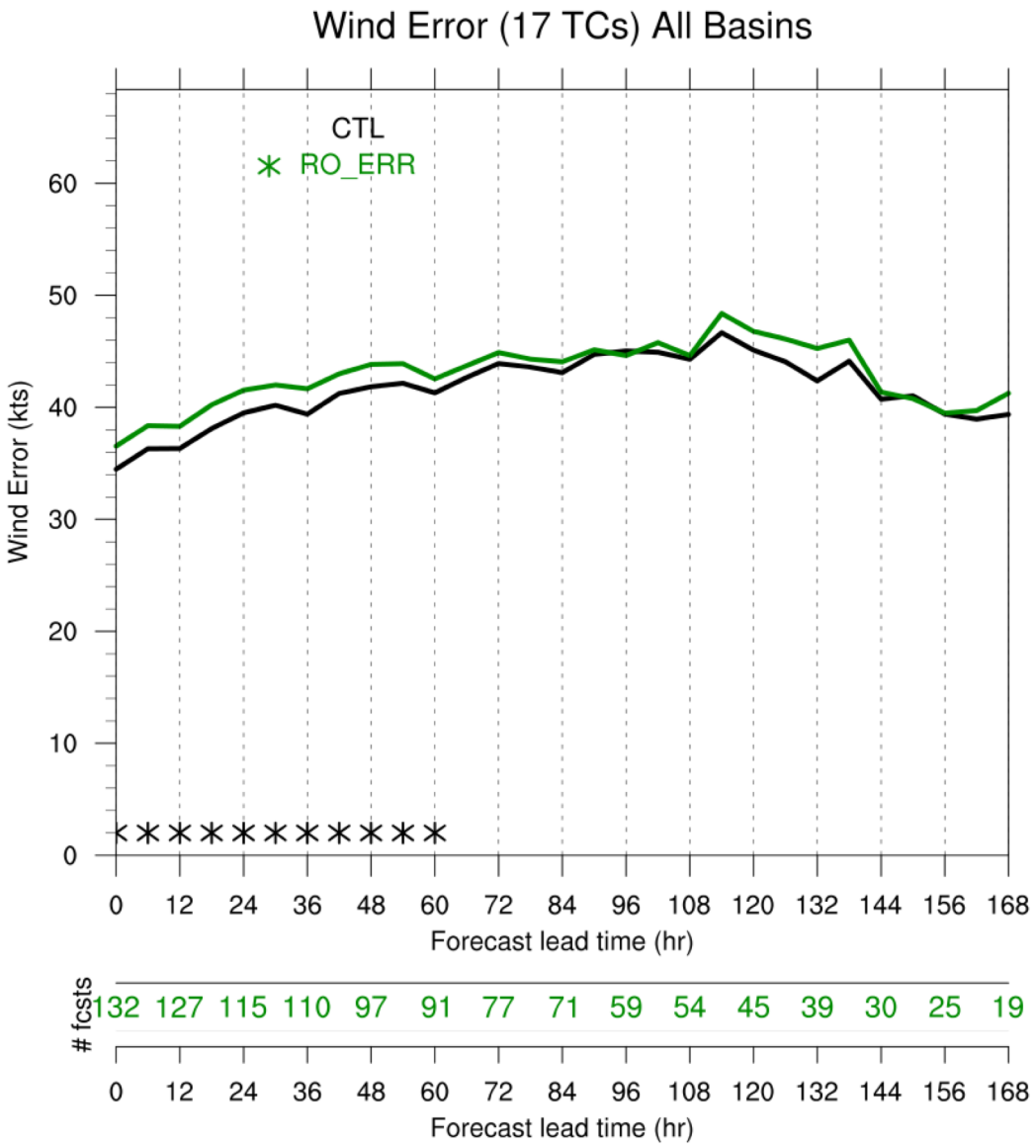
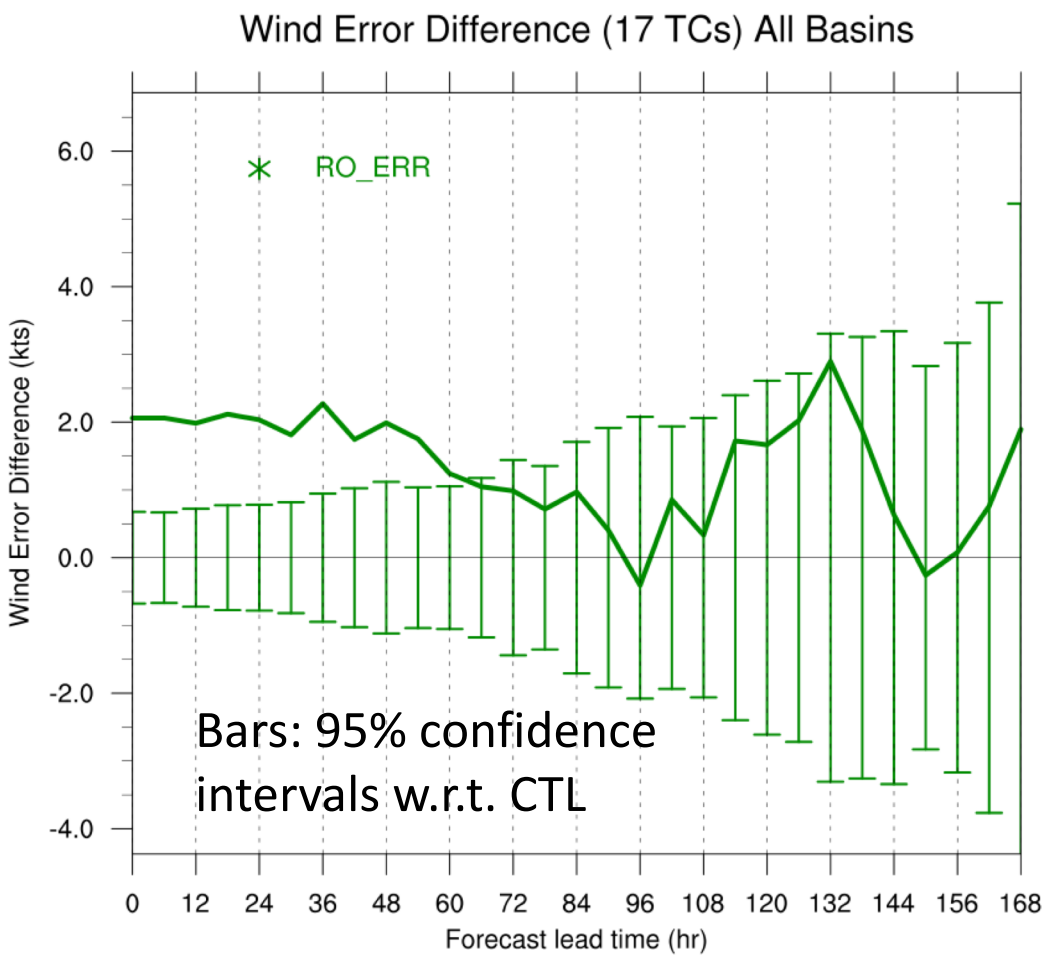
Results: Global Wind Forecast Statistics (132 forecasts)





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- Neutral impact after 60 h

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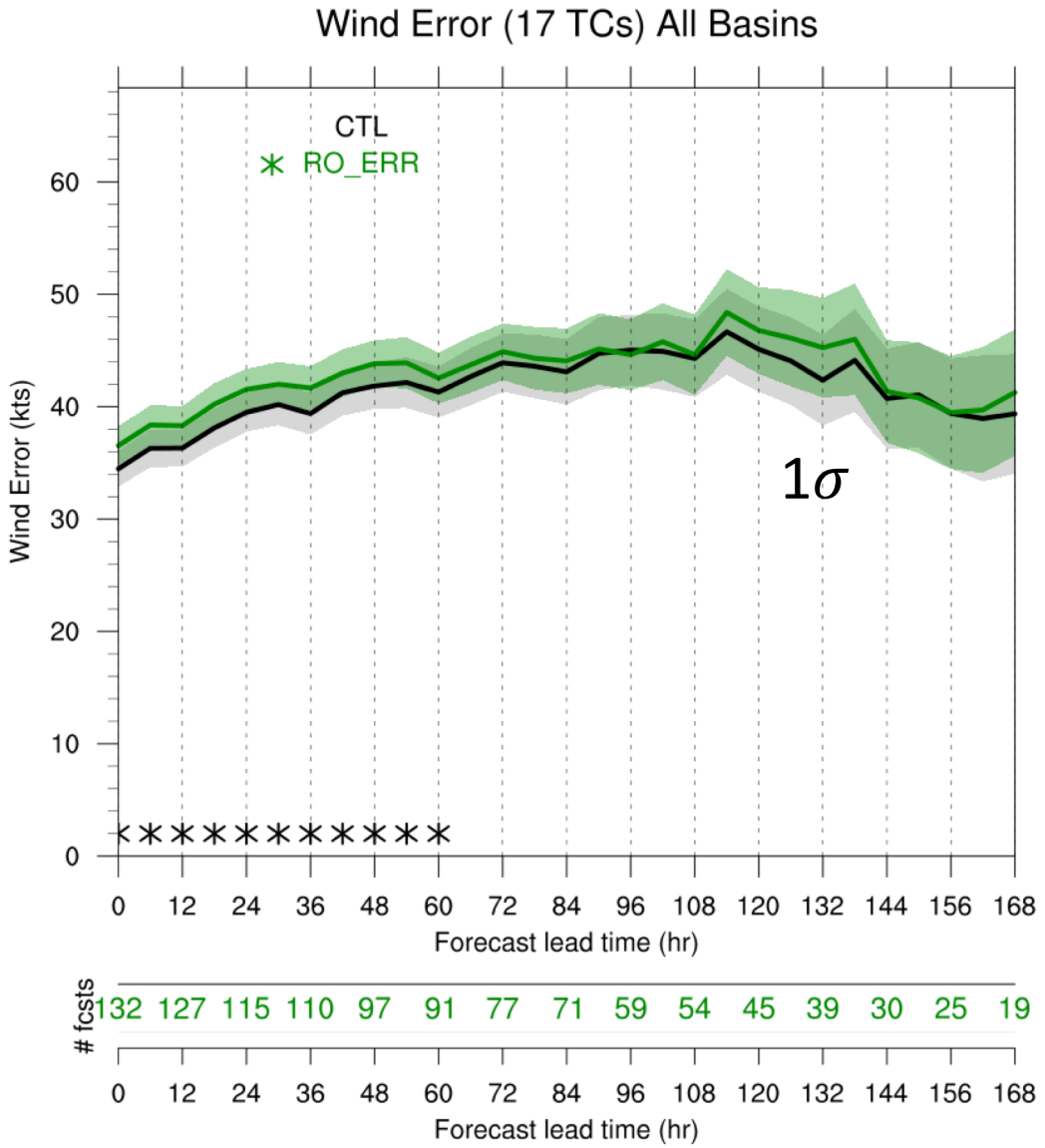

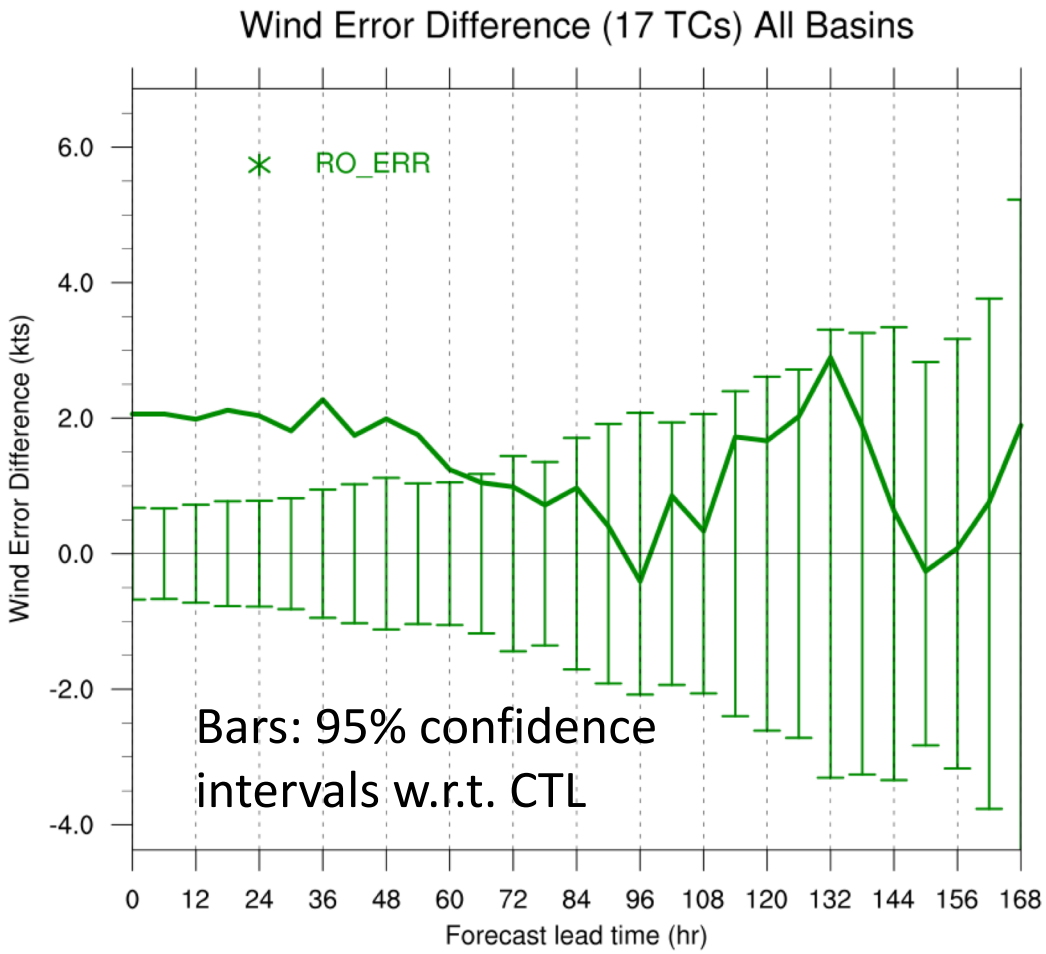

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What Influences RO Impact?

Why are some forecasts improved, others degraded?
Were there storm attributes that influenced RO impact?

Categorize storms by attribute:

1. **Tropical cyclone basin?**
2. **Latitude of "real" G5NR storm at initialization?**
3. **Maximum wind speed of "real" G5NR storm at initialization?**
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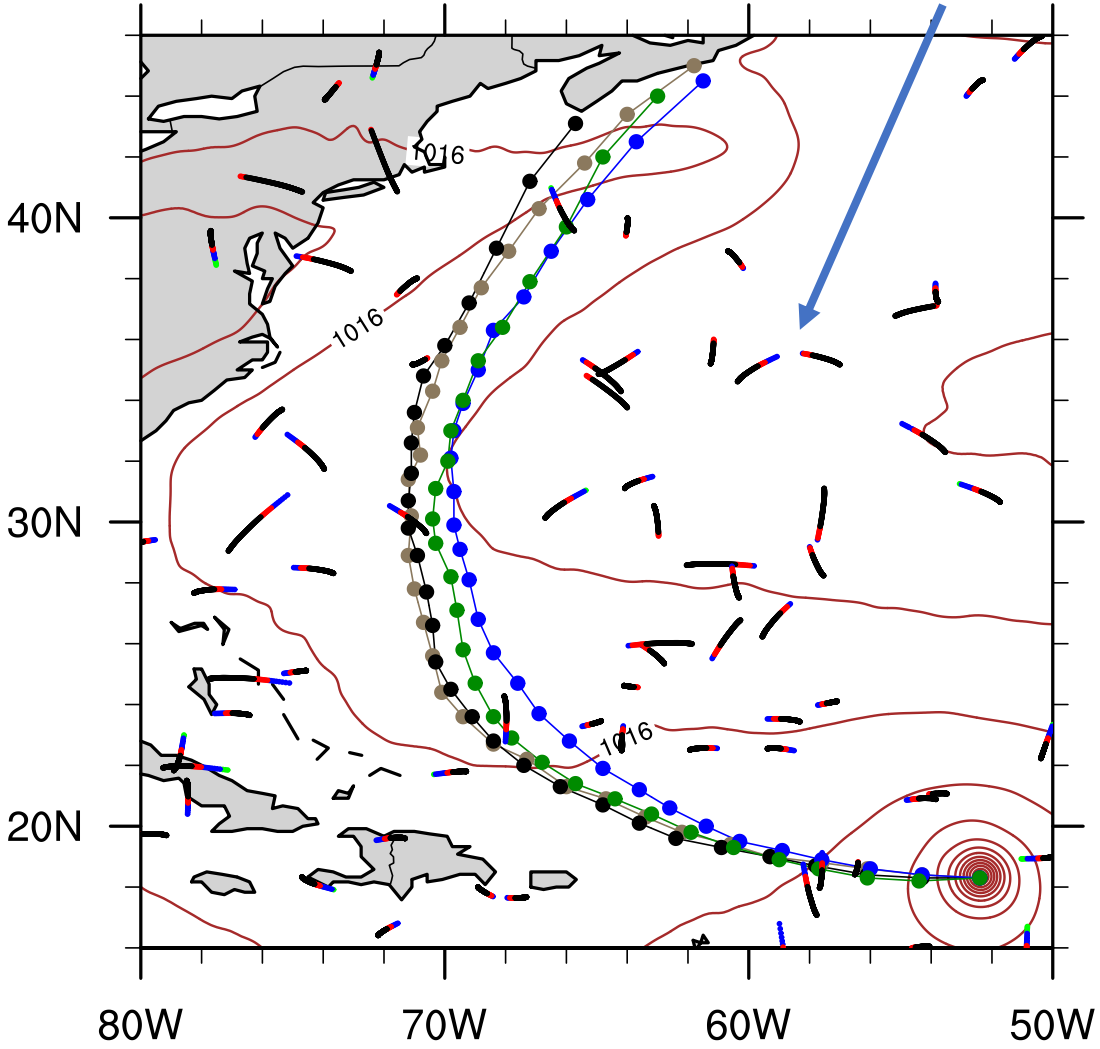
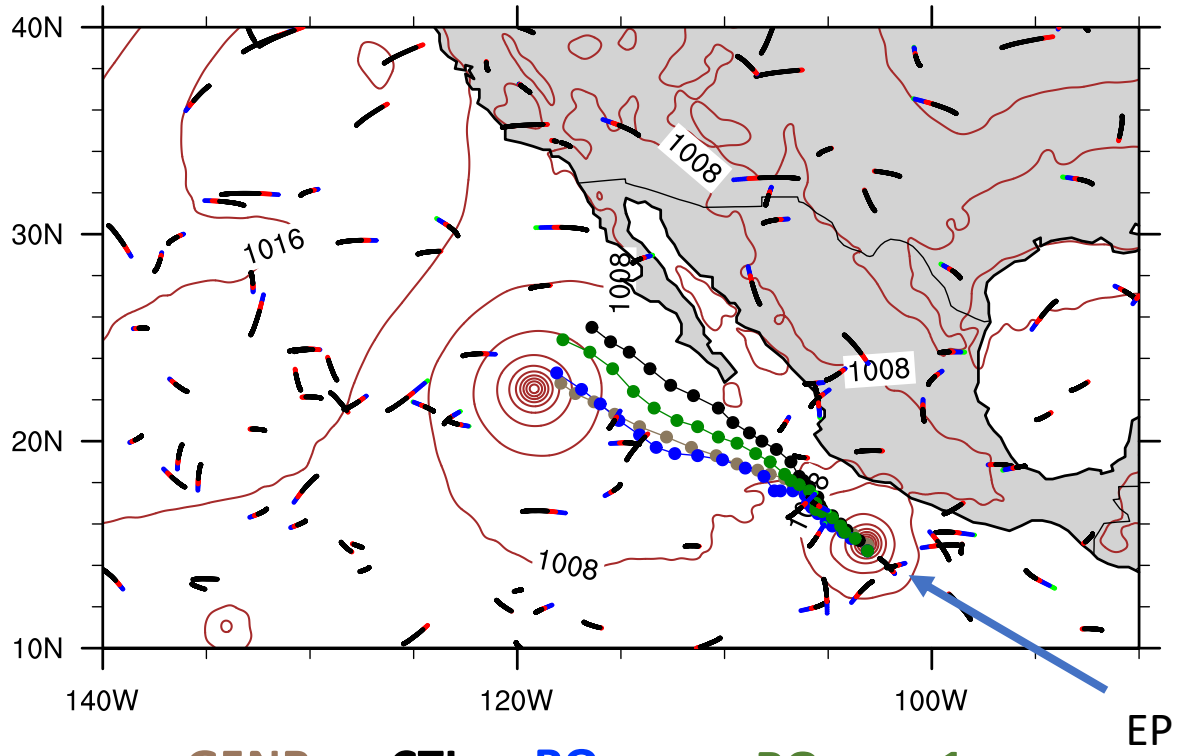
Go back and look at individual case studies…
What is really going on meteorologically case by case?

What Influences RO Impact?

AL01: 23 August RO profile



EP11: 8 September



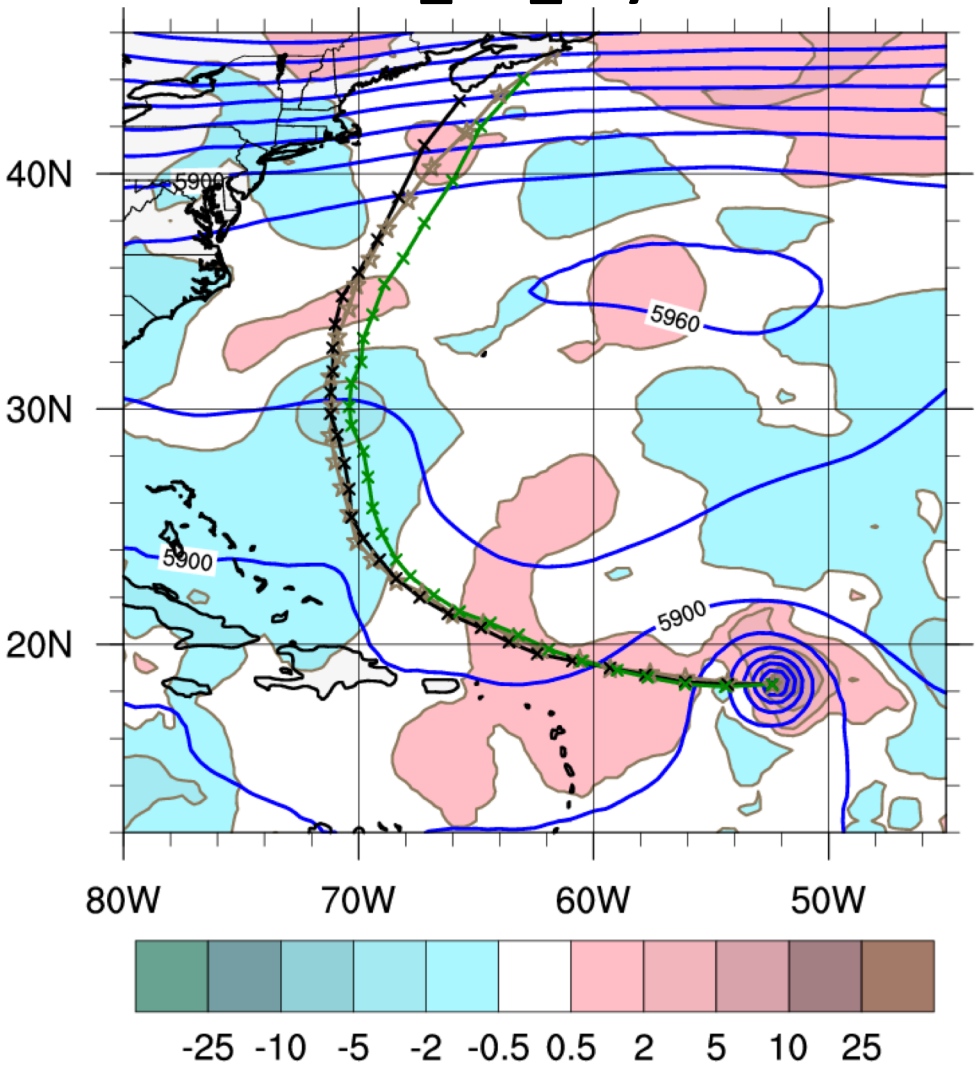
G5NR **CTL** **RO_err** **RO_err_1cyc**

- Contours of MSLP
- Assimilated RO observations
  - **BLACK: 5km-30km**
  - **RED: 3km-5km**
  - **BLUE: 1km – 3km**
  - **GREEN: below 1km**

AL01: 23 August (500hPa Heights)

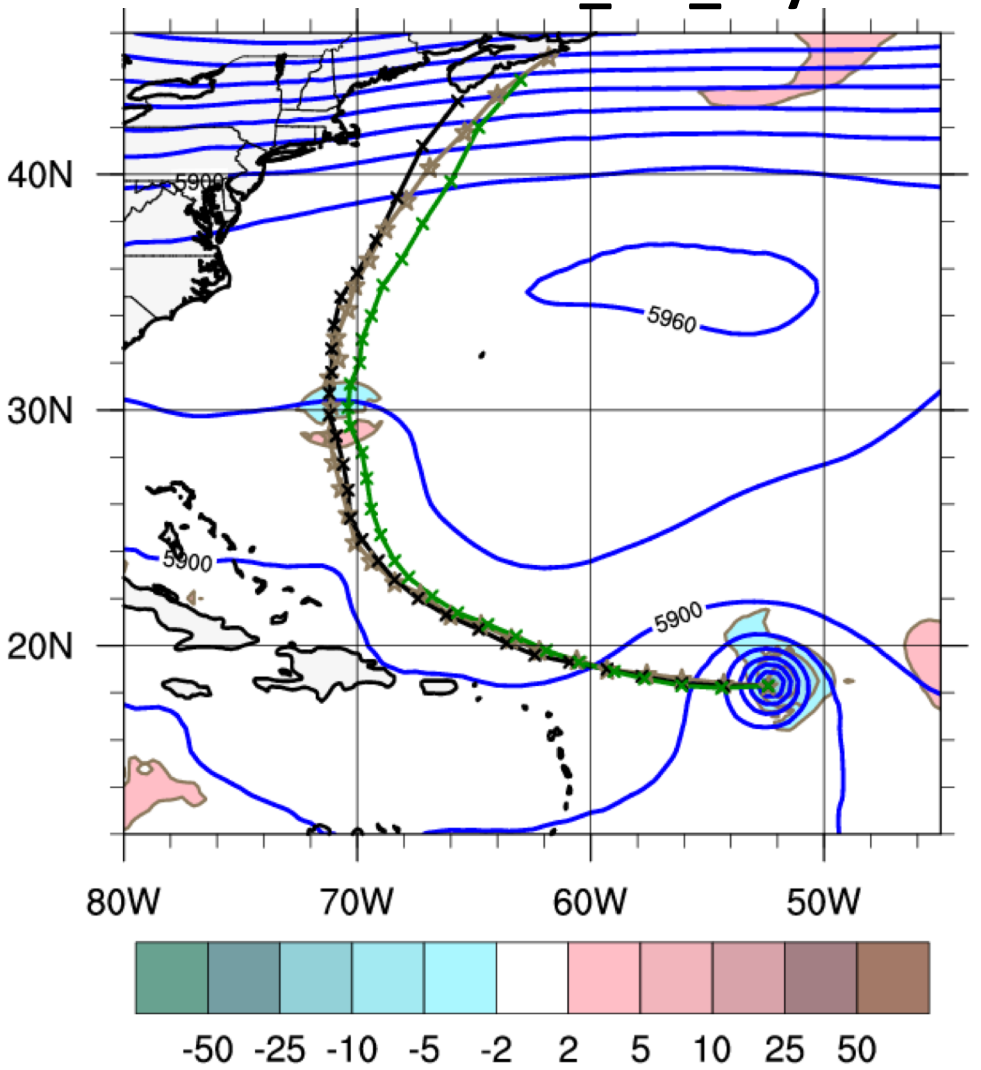
Storm Tracks: G5NR CTL RO_err_1cyc

Fill: RO_err_1cyc - CTL



500 hPa HGT (m)

Fill: CTL error – RO_err_1cyc error



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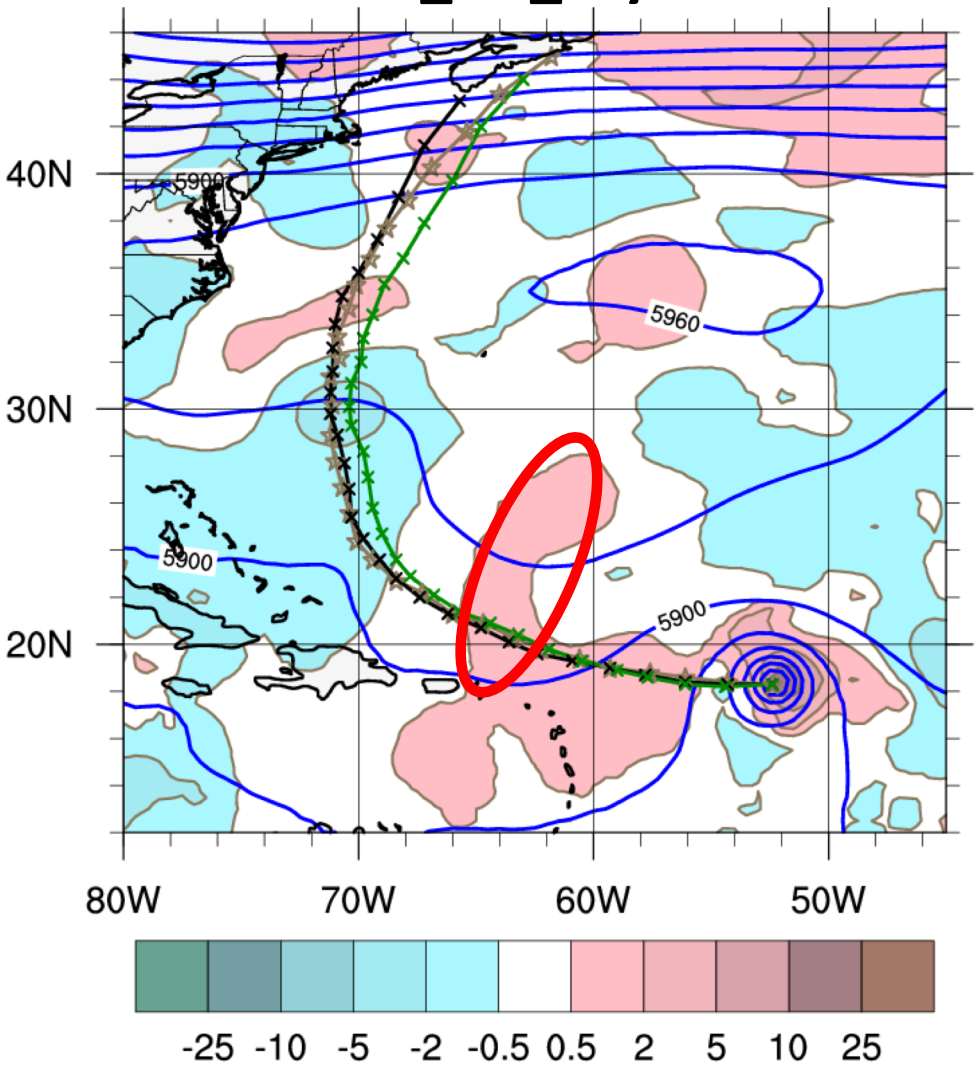

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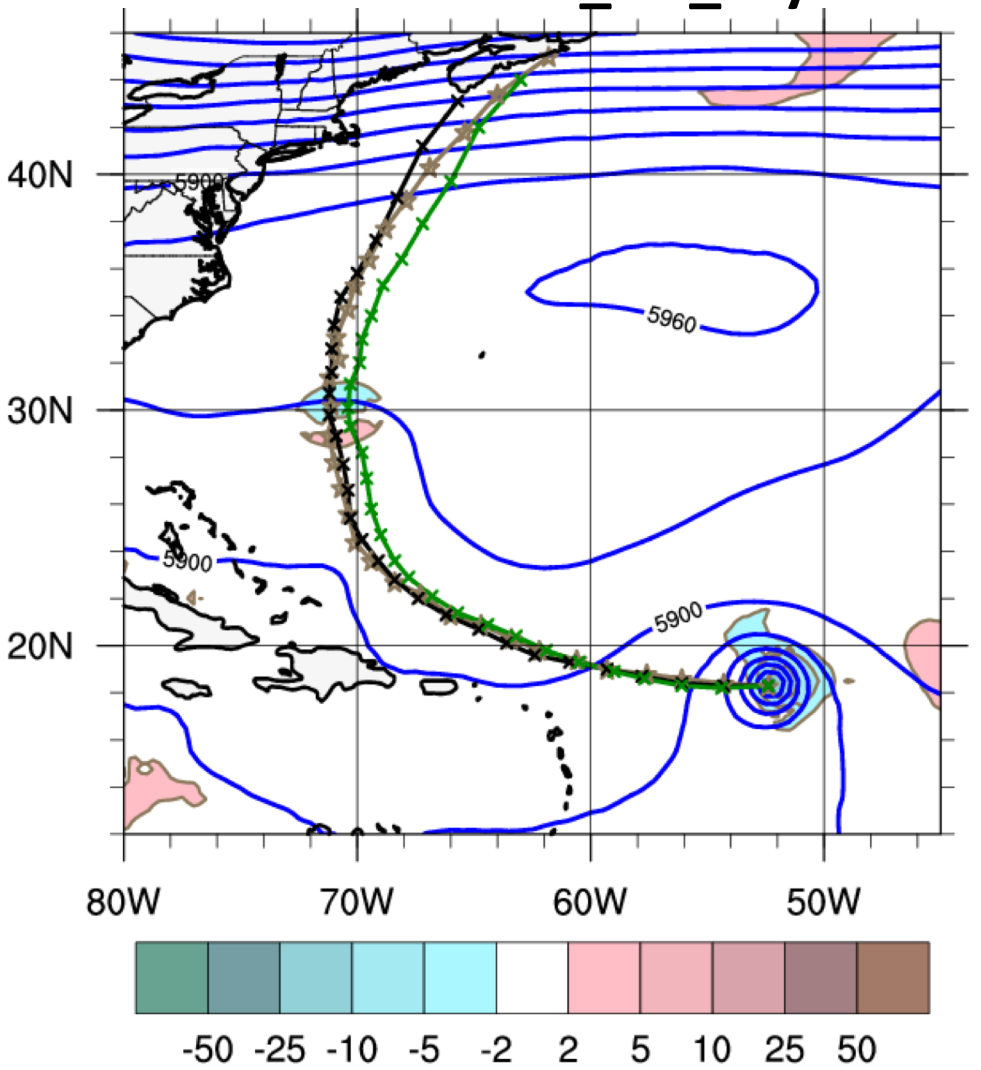

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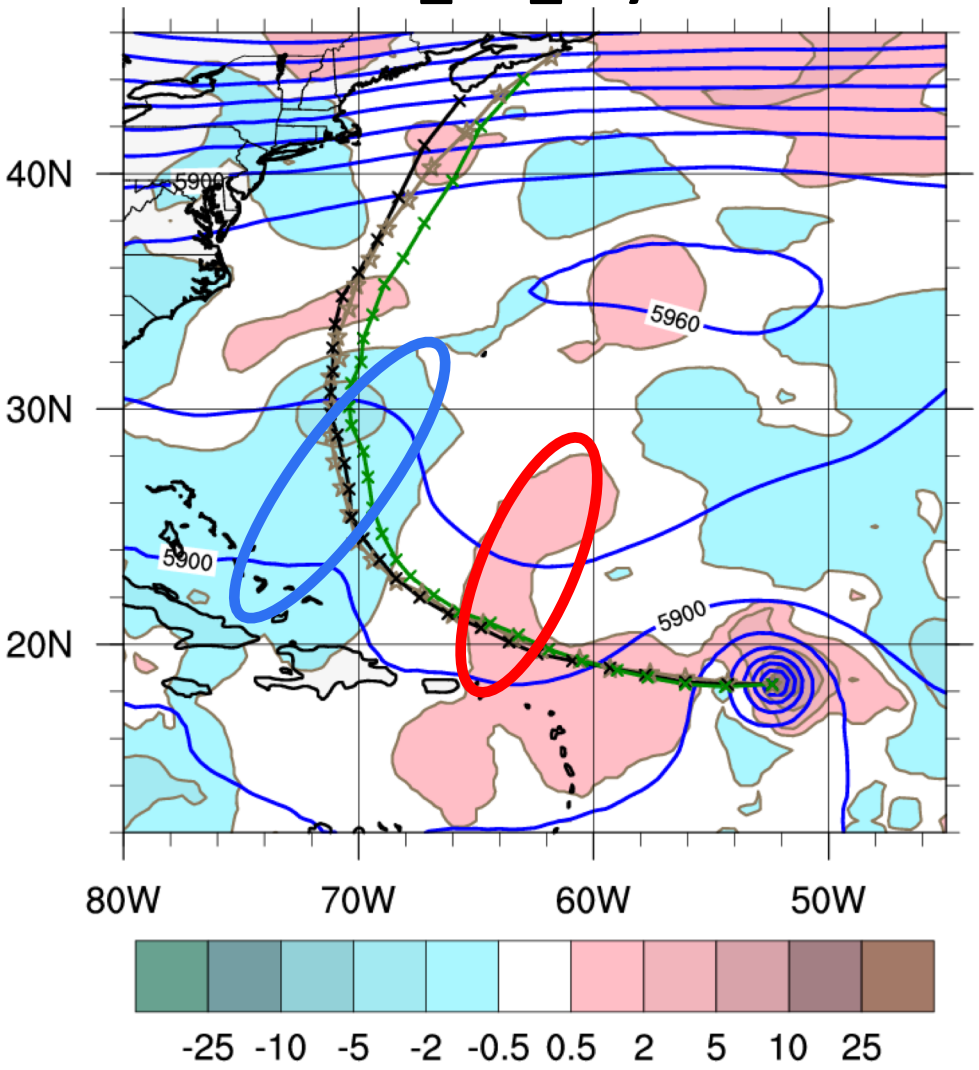

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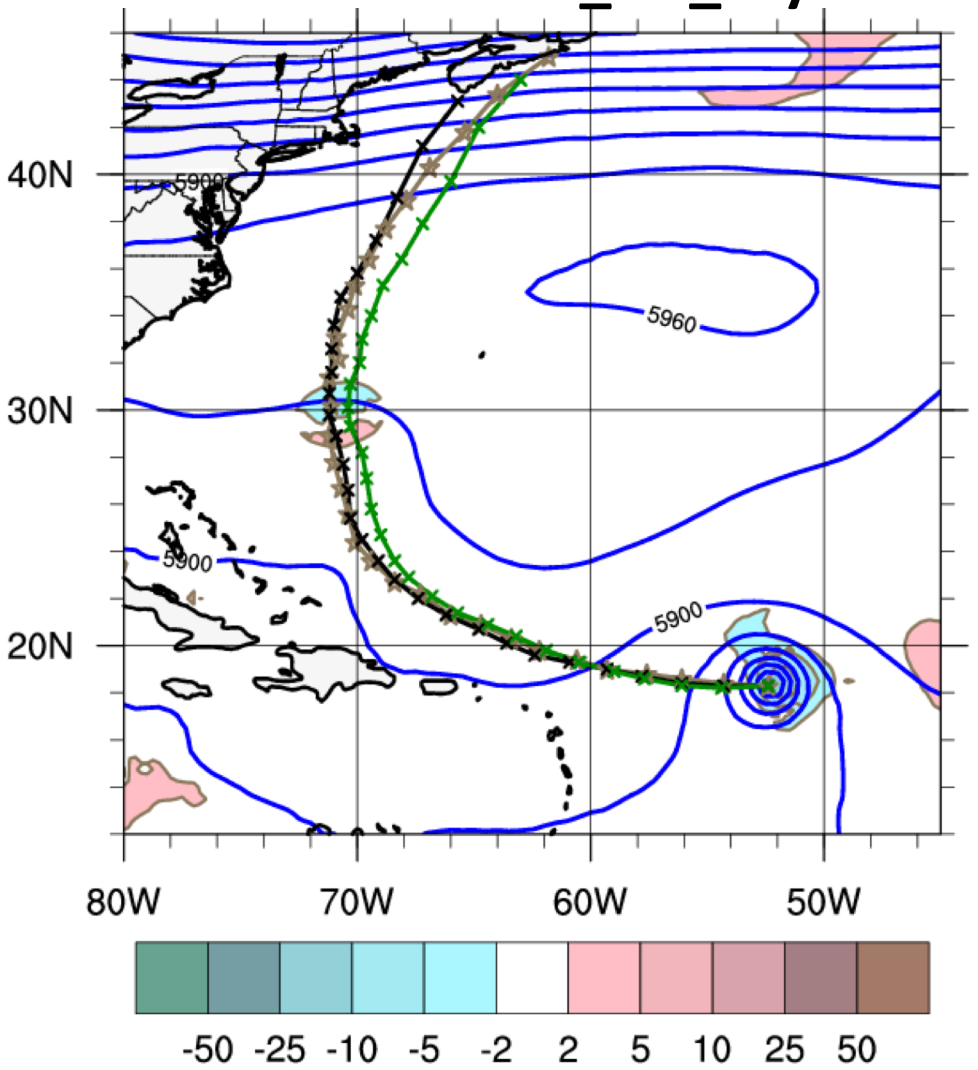

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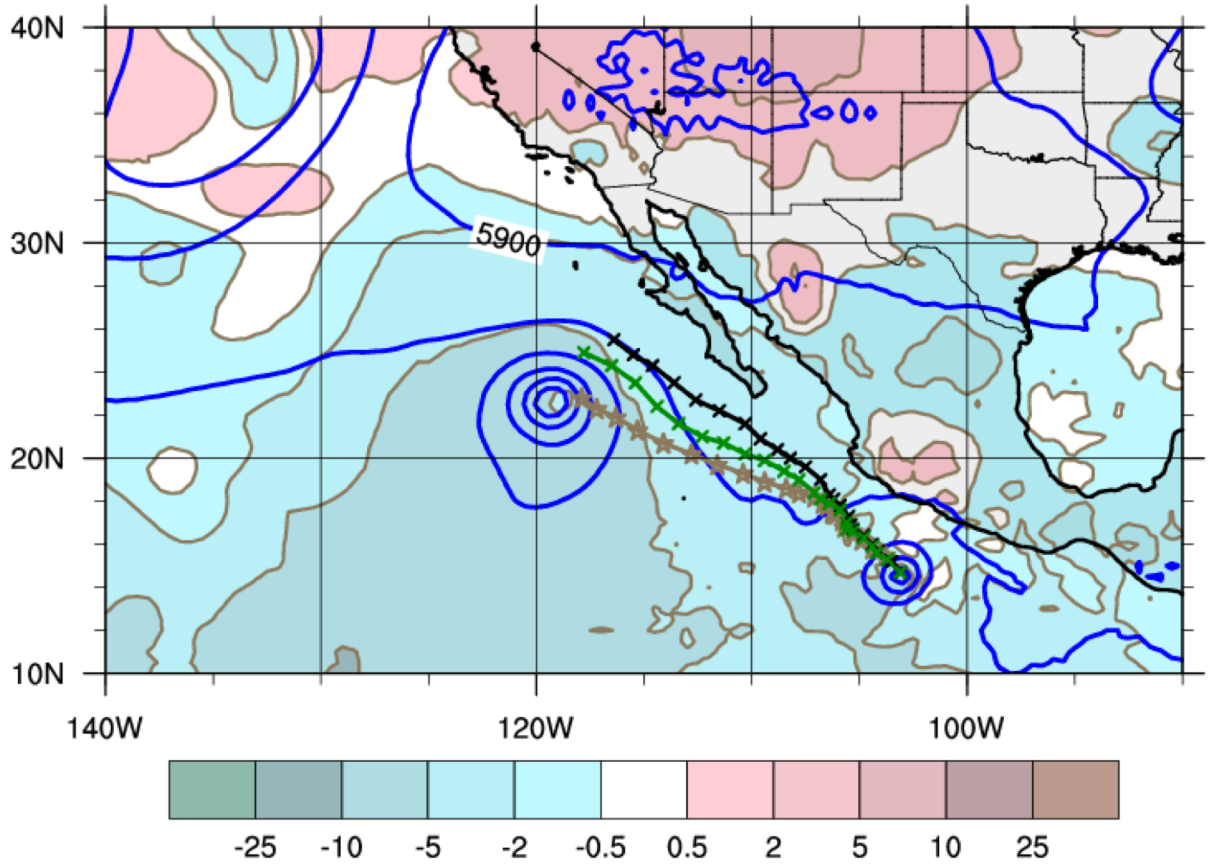

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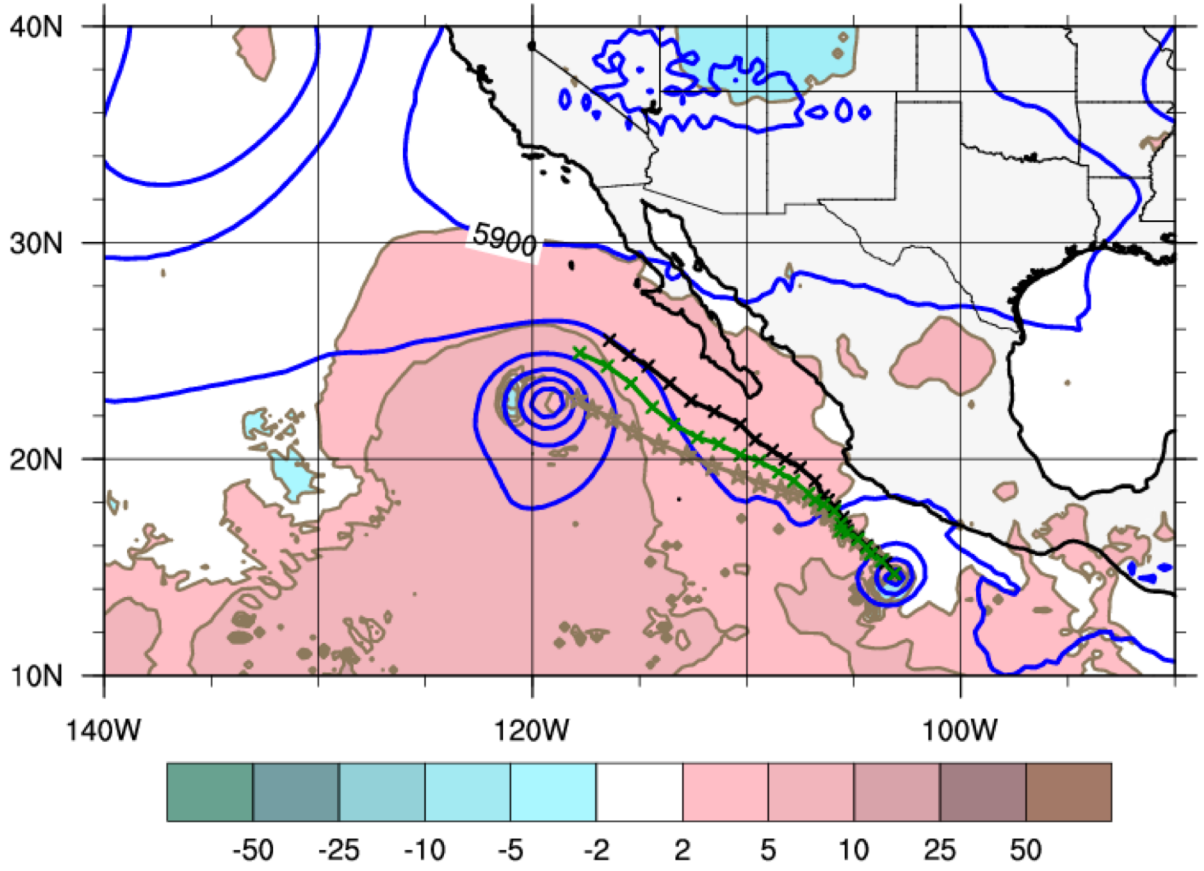

Conclusions and Next Steps

How does global RO data assimilation impact model track and intensity forecasts for tropical cyclones?

What We Know

- Neutral impact on track
- Statistically significant wind degradations 0-60hrs
- Results differ from forecast to forecast, especially for track forecasts
- Maybe a matter of impact in sensitive regions

Next Steps

- Investigate degradation in near-term wind forecasts
- Strengthen investigation of track impact variability

Acknowledgments

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Thank You!

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