Assessing the influence of background state on weather extremes using initialized ensembles

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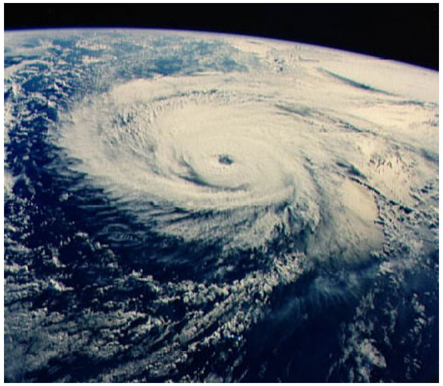
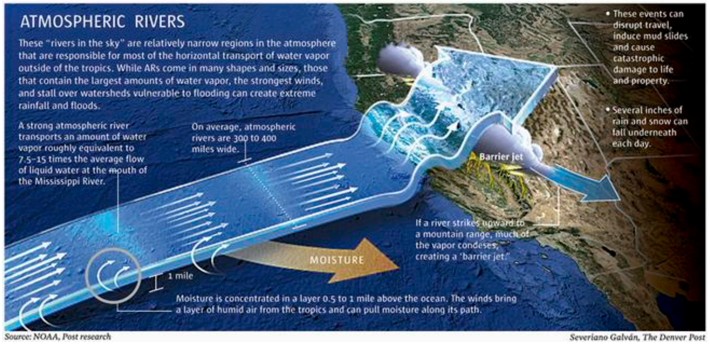
Weather Extremes

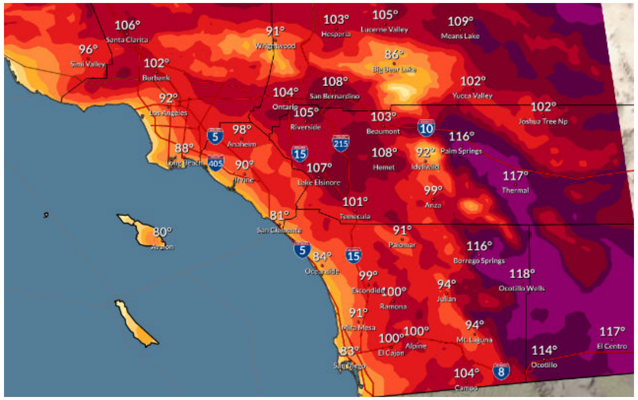
Tropical Cyclones (TCs)



Atmospheric Rivers (ARs)



Heat Waves (HWs)



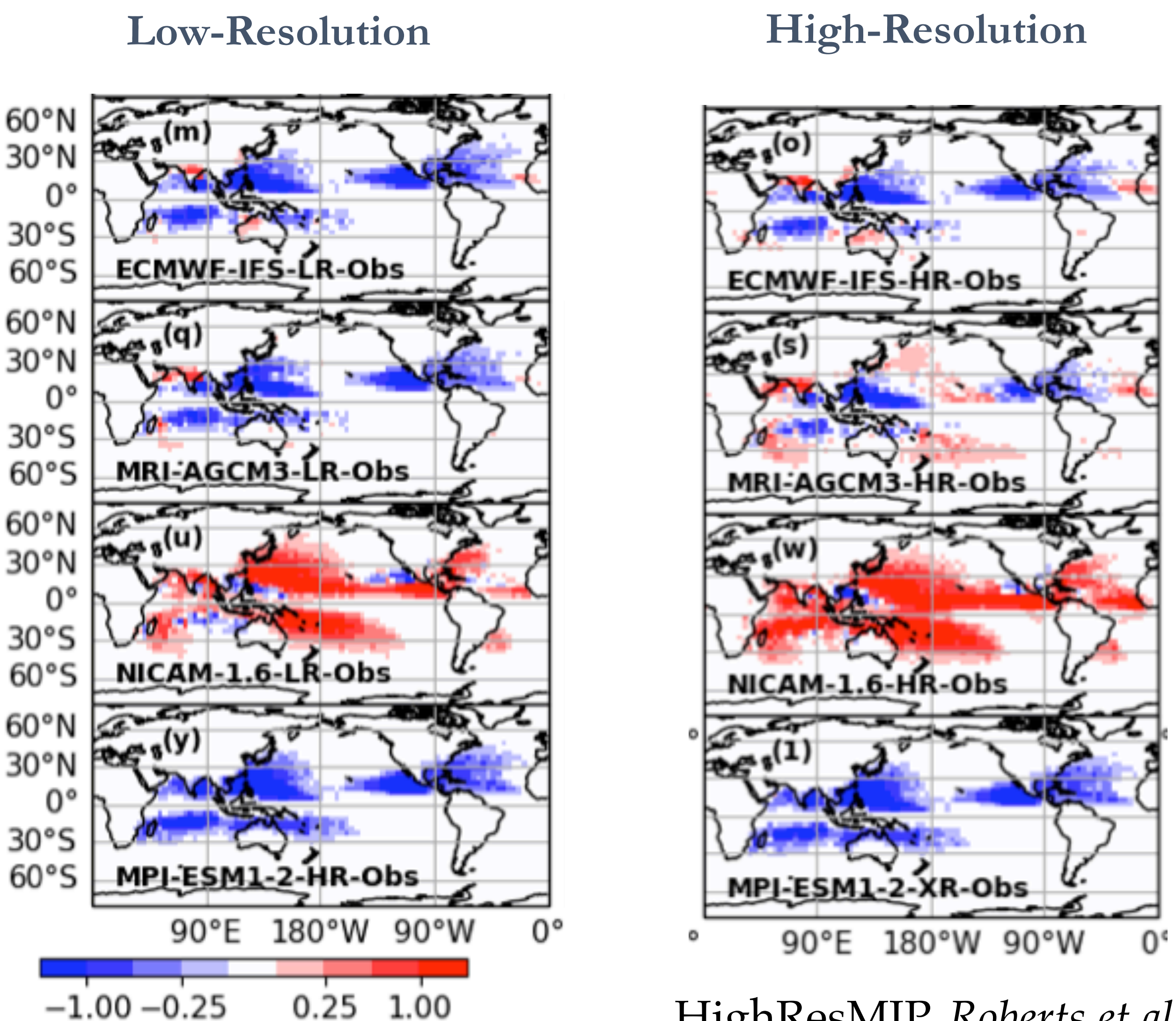
Cold spells

Motivation

- Simulations of extreme weather events affected by
  - *Background flow*
  - *Model resolution*
  - *Model parameterizations*

- Long climate simulations have
  - *Biases in background flow due to model errors*

Simulated Tropical Cyclone Track Density Bias



HighResMIP, *Roberts et al., 2020*

Approach

- Analyze a large-ensemble of short (2-4 week) forecasts
  - *Initialize from observations*
  - *Analyze simulations as a function of forecast lead time*
  - *Method similar to DOE/CAPT, but for longer forecast timescales, focusing on extremes (TCs, ARs, …)*

- Model resolution and parameterization errors
  - *kick-in immediately*

- Model bias
  - *grows slowly*
  - *asymptotically approaches its "final" value over a few weeks*

Experiment Design

- E3SM Atmospheric Model, EAMv1
- *Initial conditions*: 6 hourly ERA5
- *Surface b.c.*: 1-degree HADISST

- *Initialization*: ILIAD (InitiaLized-ensemble Identify, Analyze, Develop) framework
    - *Reference*: O'Brien *et al*., 2016: Resolution dependence of precipitation statistical fidelity in hindcast simulations

- **LR-CTRL**: AMIP-type, 10 years, 2000-2009

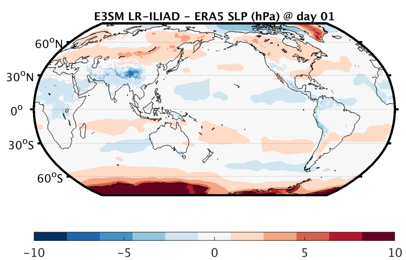
- **LR-FCST**: NH TC season (JJASON), 2000-2009
    - 4-week forecasts, initialized every 3 days (610 total)

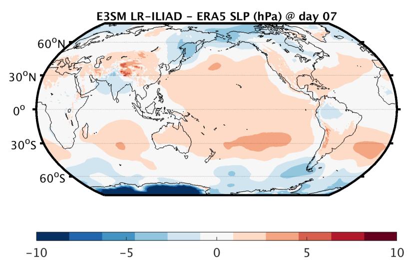
Bias growth: LR-CTRL vs. LR-FCST

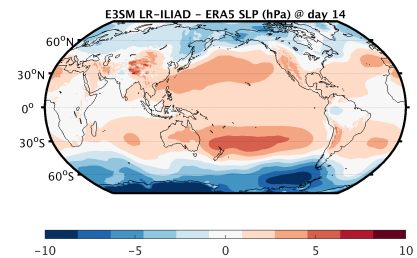
LR-FCST

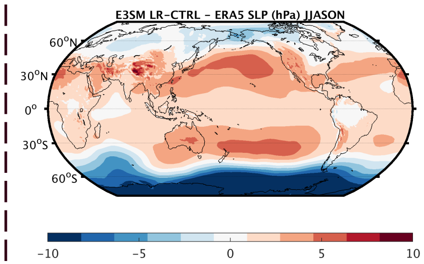
LR-CTRL

Sea Level Pressure









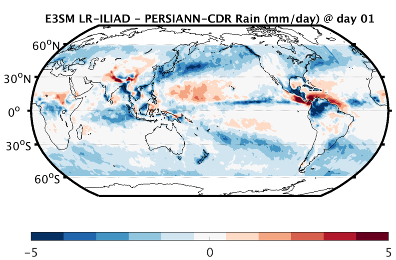
day 1

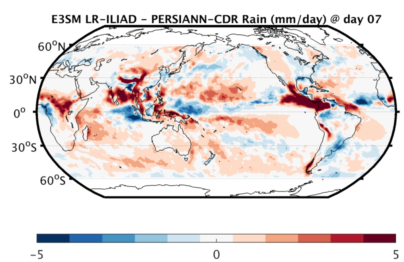
day 7

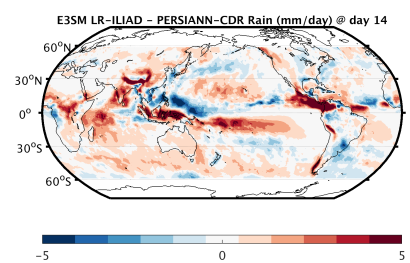
day 14

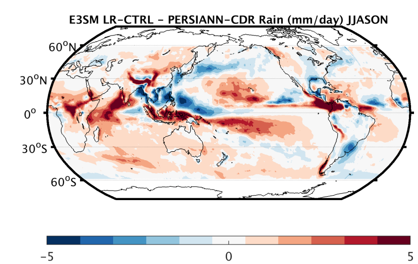
day ∞

Rain



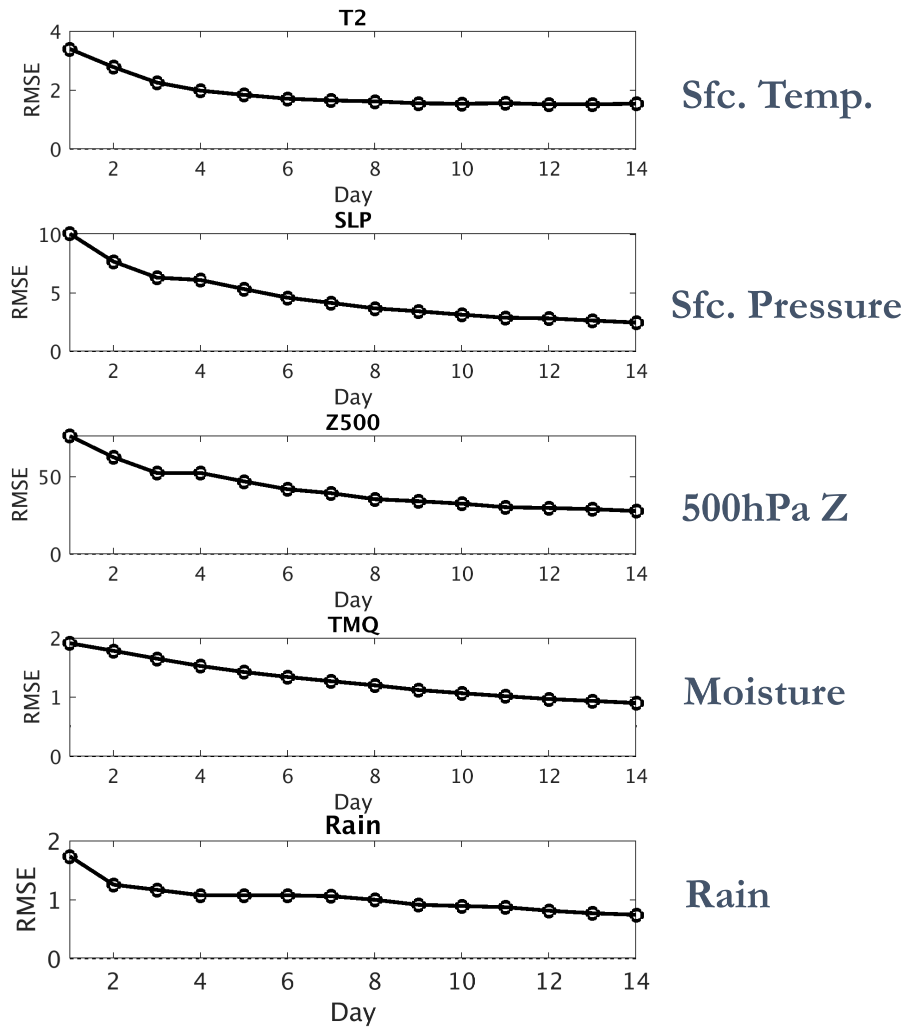






RMS Difference between

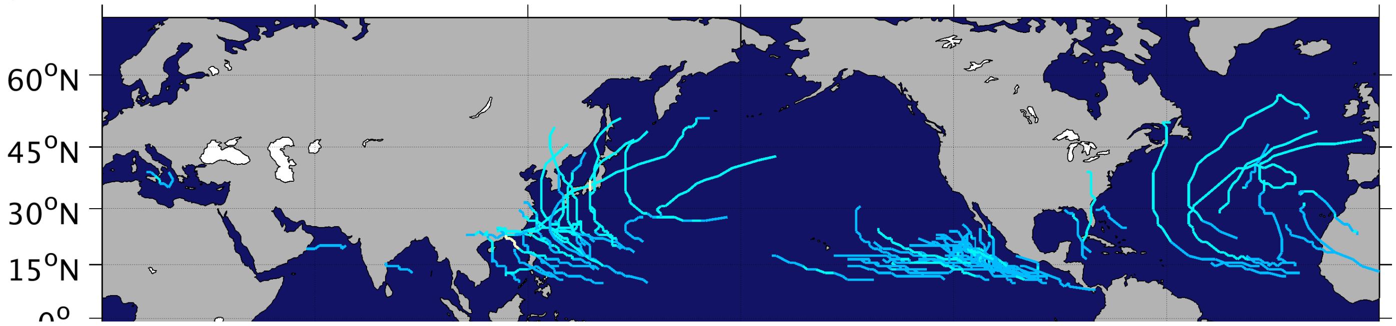
LR-FCST and LR-CTRL anomalies



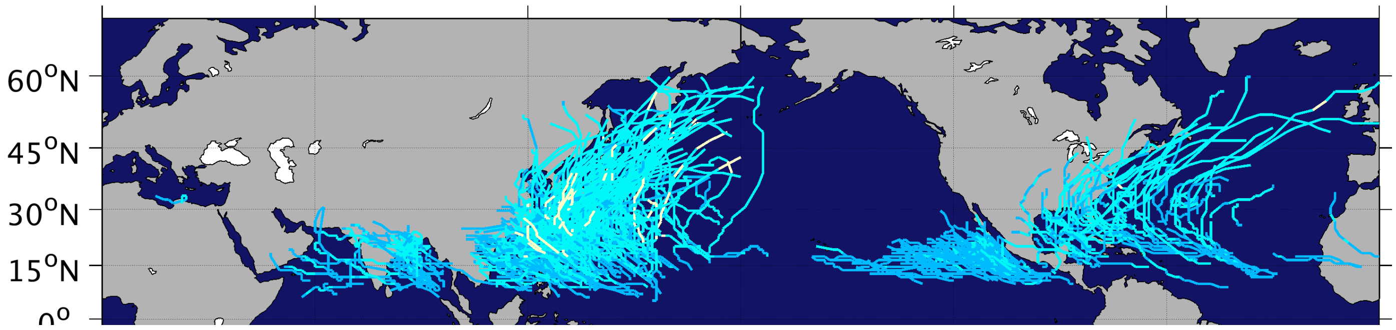
Tropical Cyclone tracks

LR-CTRL

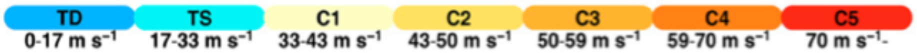
95 TCs in 183x10 days (0.045 per day)



LR-FCST



561 TCs in 14x610 days (0.065 per day)

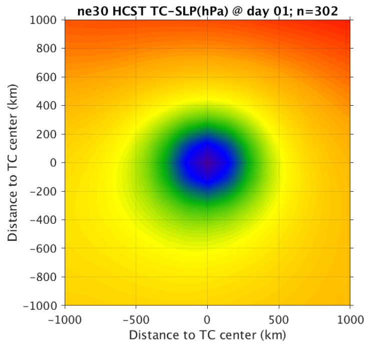


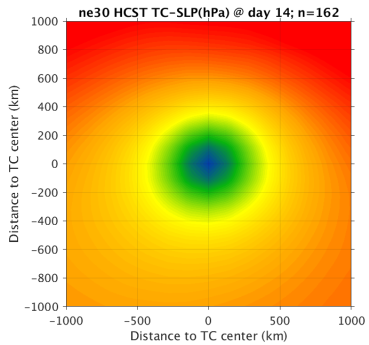
Tropical Cyclone Composites

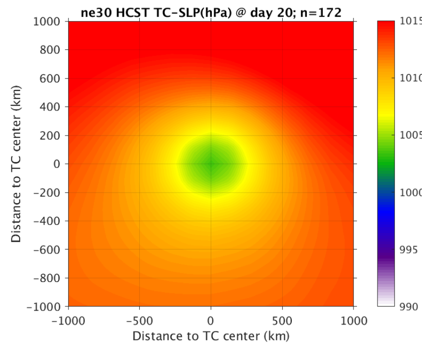
LR-FCST

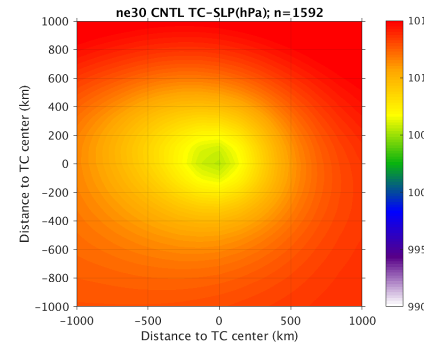
LR-CTRL

Sea Level Pressure







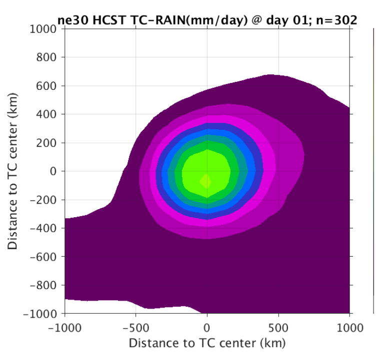


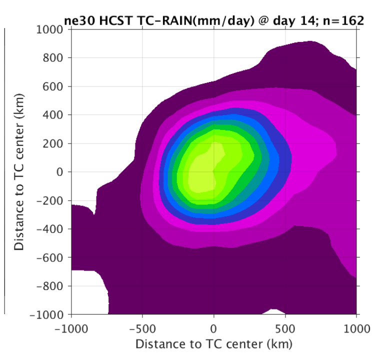
day 1

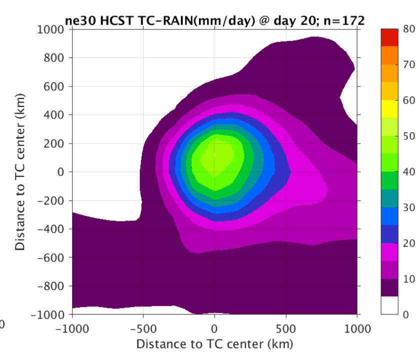
day 14

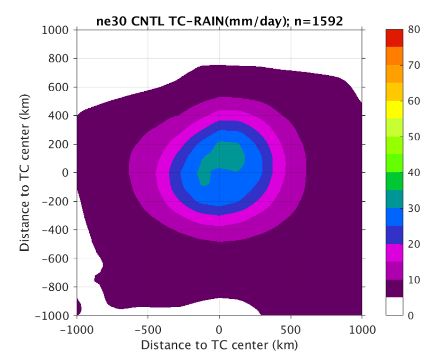
day 20

Rain









Genesis Potential Index (GPI) for Tropical Cyclogenesis

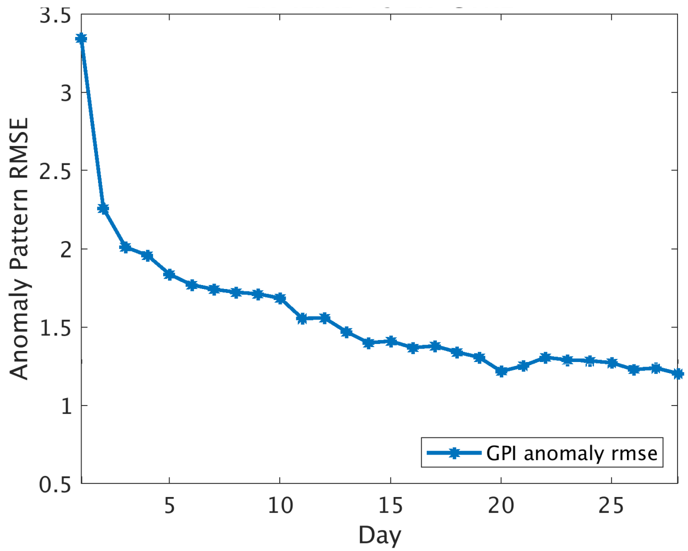
$$GPI = \left|10^5 \eta\right|^{3/2} \left(\frac{H}{50}\right)^3 \left(\frac{V_{pot}}{70}\right)^3 \left(1 + 0.1 V_{shear}\right)^{-2}$$

η	= **absolute vorticity** at 850 hPa
H	= **relative humidity** at 600 hPa
V_{shear}	= vertical wind shear between 850 hPa and 200 hPa
V_{pot}	= potential intensity (function of SST and vertical profiles of atmospheric temperature and moisture)

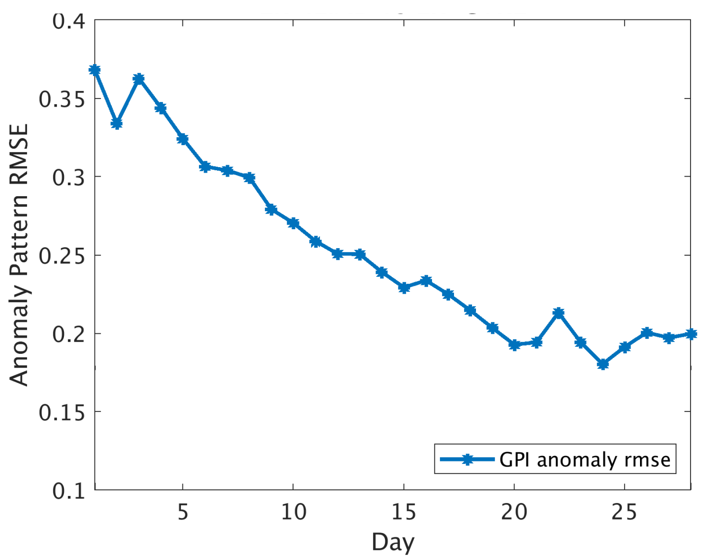
(*Emanuel and Nolan, 2004*)

RMS Difference between

LR-FCST and LR-CTRL anomalies



Absolute vorticity in Genesis Potential Index



Relative humidity in Genesis Potential Index

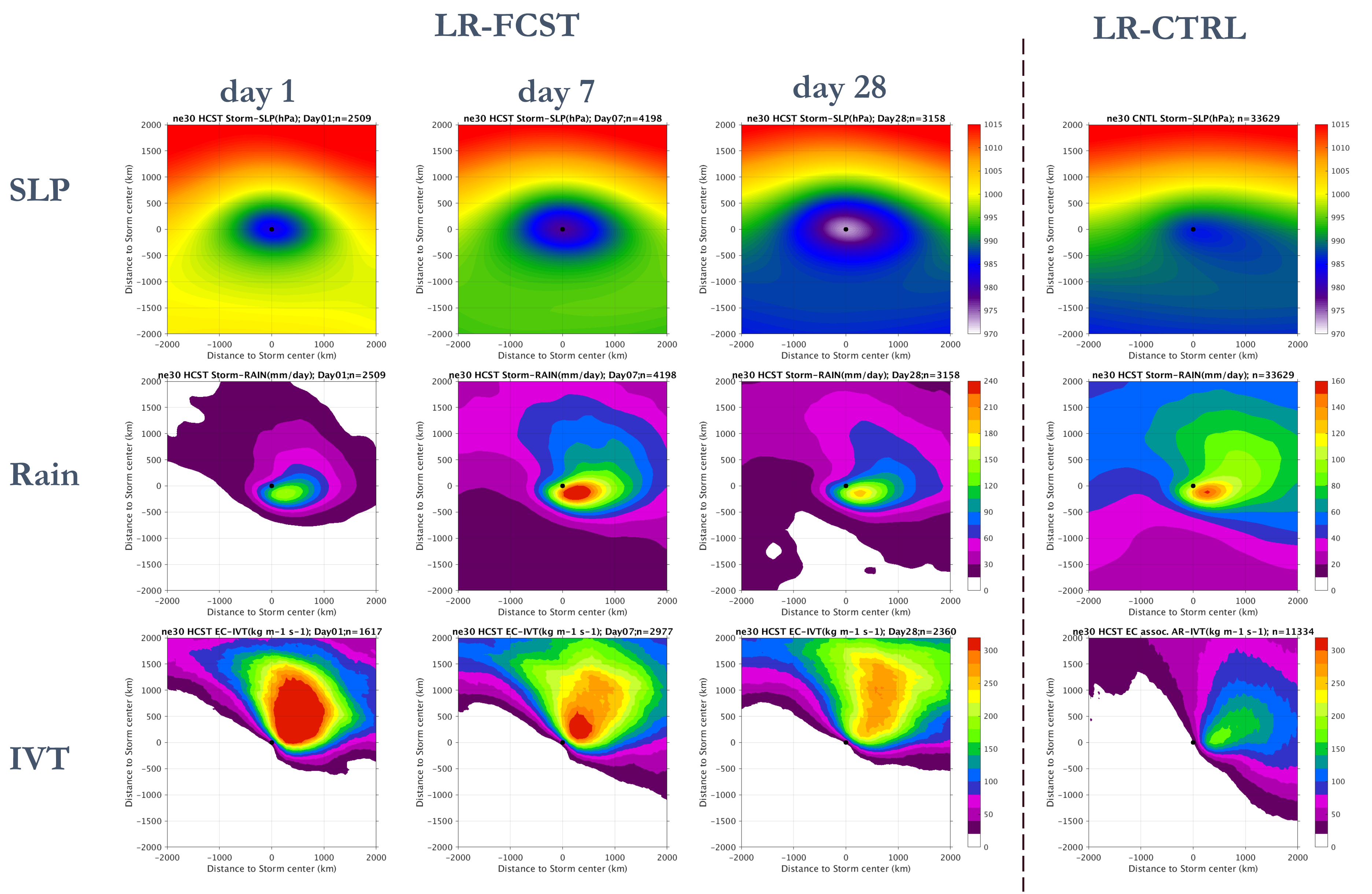
Preliminary Results and Future Work

- Model bias develops within the first 2-4 weeks
  - *Biases in different aspects of the circulation take different time to develop*
  - *Flow bias seems to develop quicker than humidity bias*

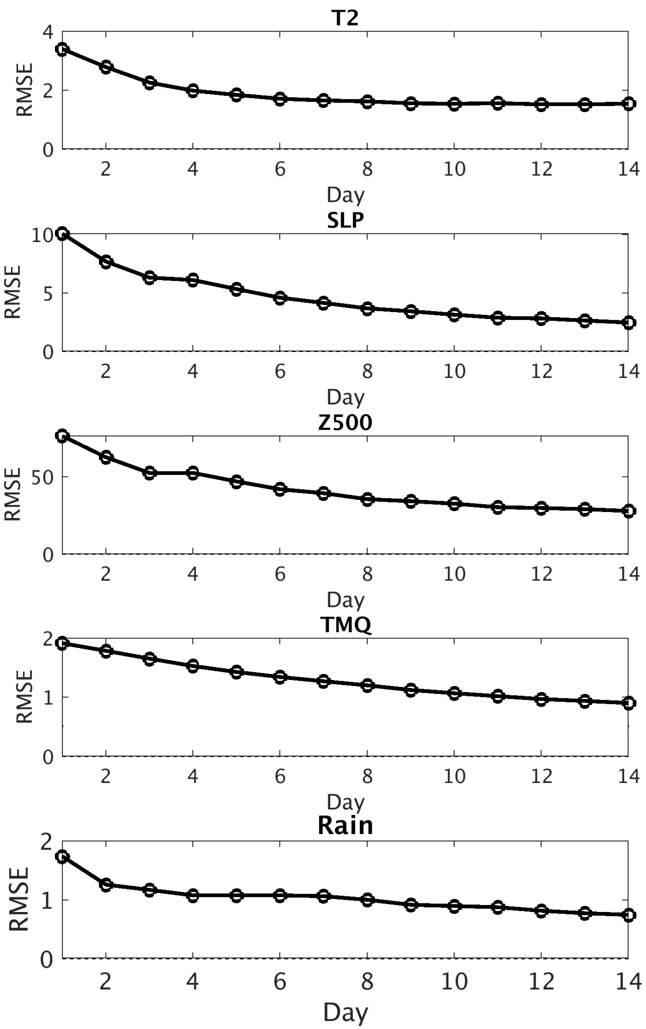
- Tropical cyclone bias shows non-monotonic behavior
  - *Model is able to maintain strong TCs initially*
  - *Atmospheric Rivers/Extratropical Cyclones also exhibit non-monotonic behavior (not shown)*

- Future work
  - *Understand non-monotonic behavior*
  - *Ensemble using high-resolution (0.25 deg.) EAM*
  - *Repeat using Regionally-Refined Mesh*

Extratropical Cyclone Composites (S. Hemisphere)



RMS Difference between LR-FCST and LR-CTRL anomalies



Sfc. Temp.

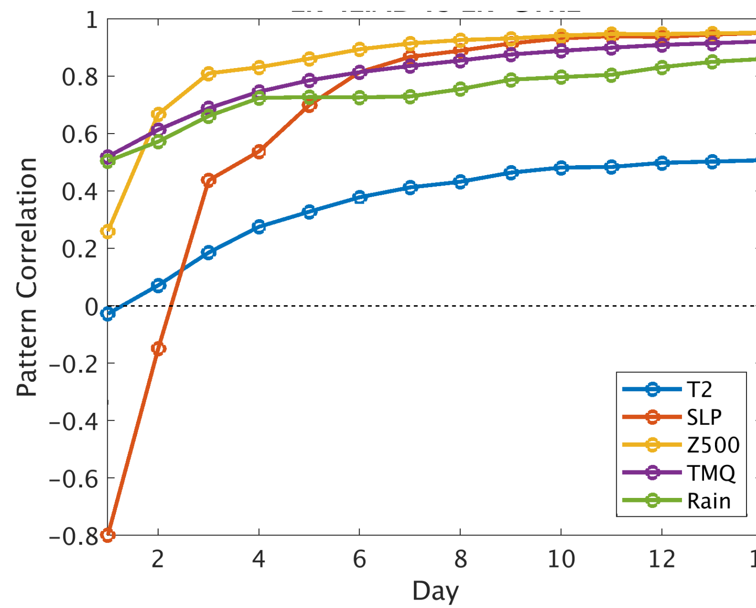
Sfc. Pressure

500hPa Z

Moisture

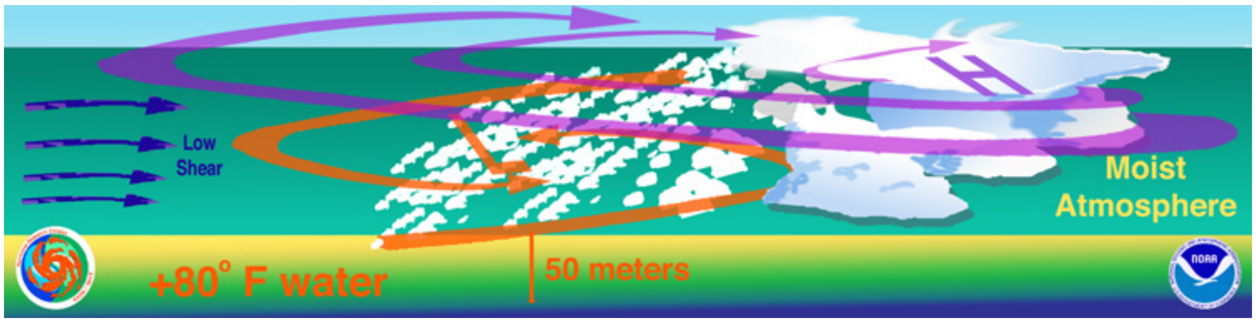
Rain

Pattern Correlation between LR-FCST and LR-CTRL anomalies



Environmental precursors for tropical cyclogenesis

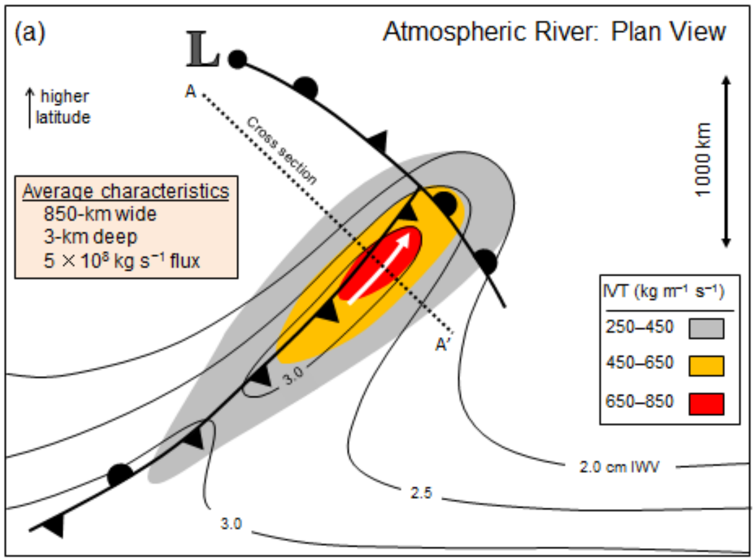
Gray (1968, 1979)



- Warm sea surface temperatures (> 26° C)
- *Moist mid-troposphere*
- Low values (< 10 m/s) of vertical shear between 850 hPa and 200 hPa
- Sufficiently removed from equator for Coriolis effect
- Pre-existing disturbance with *cyclonic vorticity*

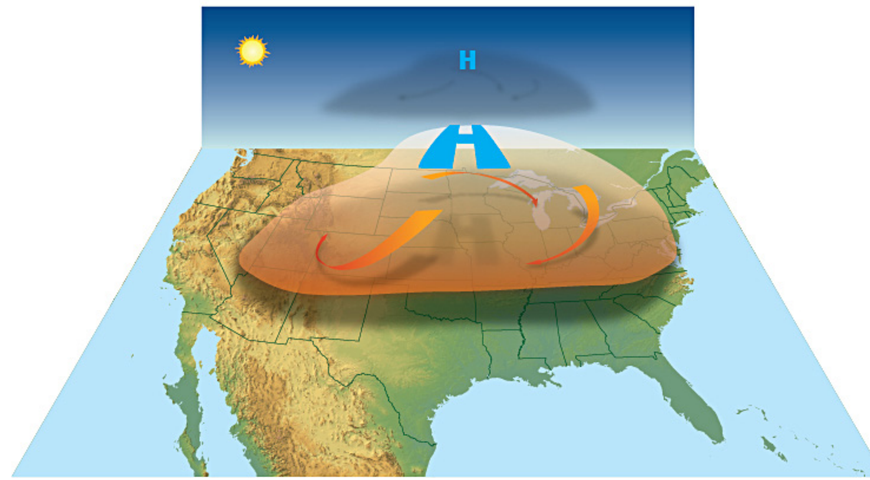
Environmental conditions affecting weather extremes

ARs



- The stronger winds, the more moisture that can be transported
- Increased atmospheric moisture enhance the ARs intensity

Heat Waves



High-pressure systems can create a 'cap' that traps air in one place as it warms. This can lead to a heat wave.

Limits in GCM Simulation Skills of ARs

Wea. Forecasting. 2013;28(6):1337-1352. doi:10.1175/WAF-D-13-00025.1

An Observed AR

Model Predicted AR