Physics-oriented Model Diagnostics

Zhuo Wang
Department of Atmospheric Sciences
University of Illinois at Urbana-Champaign

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Physics-oriented vs. Performance oriented Model Evaluation

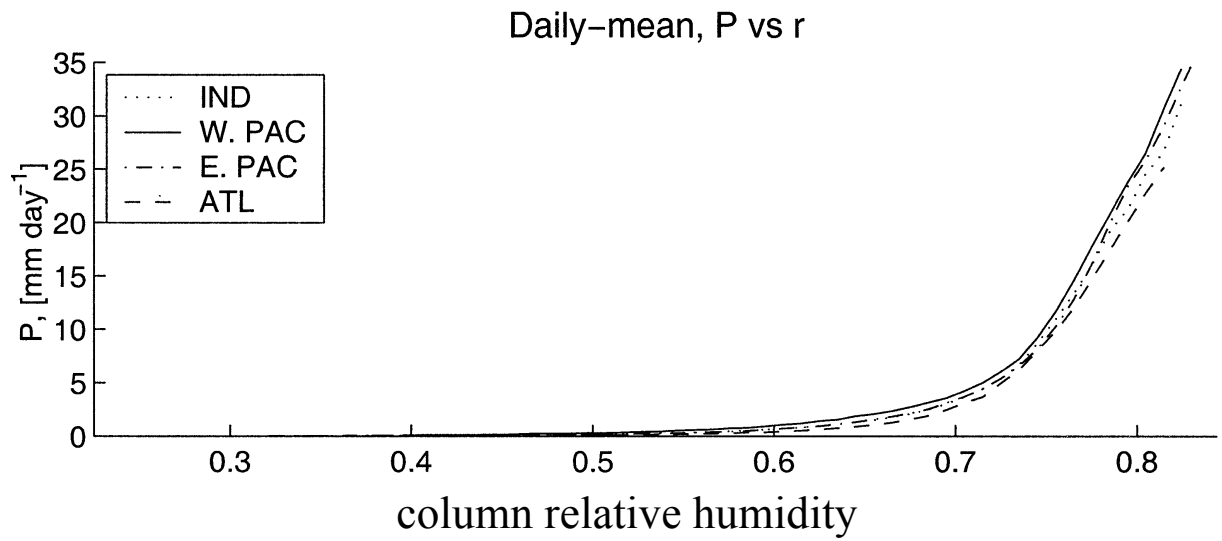
- Standard performance-oriented metrics, such as ACC and RMSE, are routinely used in operational centers for forecast verification. NCAR DTC also developed model evaluation tools (MET).
- Physics-oriented diagnostics focus on the critical processes or phenomena. The objective is to reveal model error sources and identify pathways to model improvements.

Three levels of diagnostics
– *A Proto-structure of a Unified Package*

- Physics-oriented model diagnostics are also known as process-oriented model diagnostics
  - Different users or researchers are interested in different physical processes. What physical processes should we target?
- Three levels of model diagnostics (to be transitioned to MET+)
  1. Model climatology and fundamental physical processes
     - Moist convection, cloud microphysics, cloud-radiation interaction
     - Precipitation distribution, Monsoon, ITCZ, Hadley circulation
  2. Sources of predictability on the relevant time scales
     - Subseasonal time scale: MJO, weather regimes, land conditions
     - Seasonal and longer time scales: ENSO, NAO, teleconnections, QBO, etc.
  3. High-impact weather phenomena
     - Tropical cyclones
     - Midlatitude blocking, etc.
- Challenges and Roadmap

Level 1: Precipitation-Humidity Relation

Precipitation increases exponentially with column relative humidity after a certain threshold (Raymond 2000; Bretherton et al. 2004; Neelin et al. 2008)



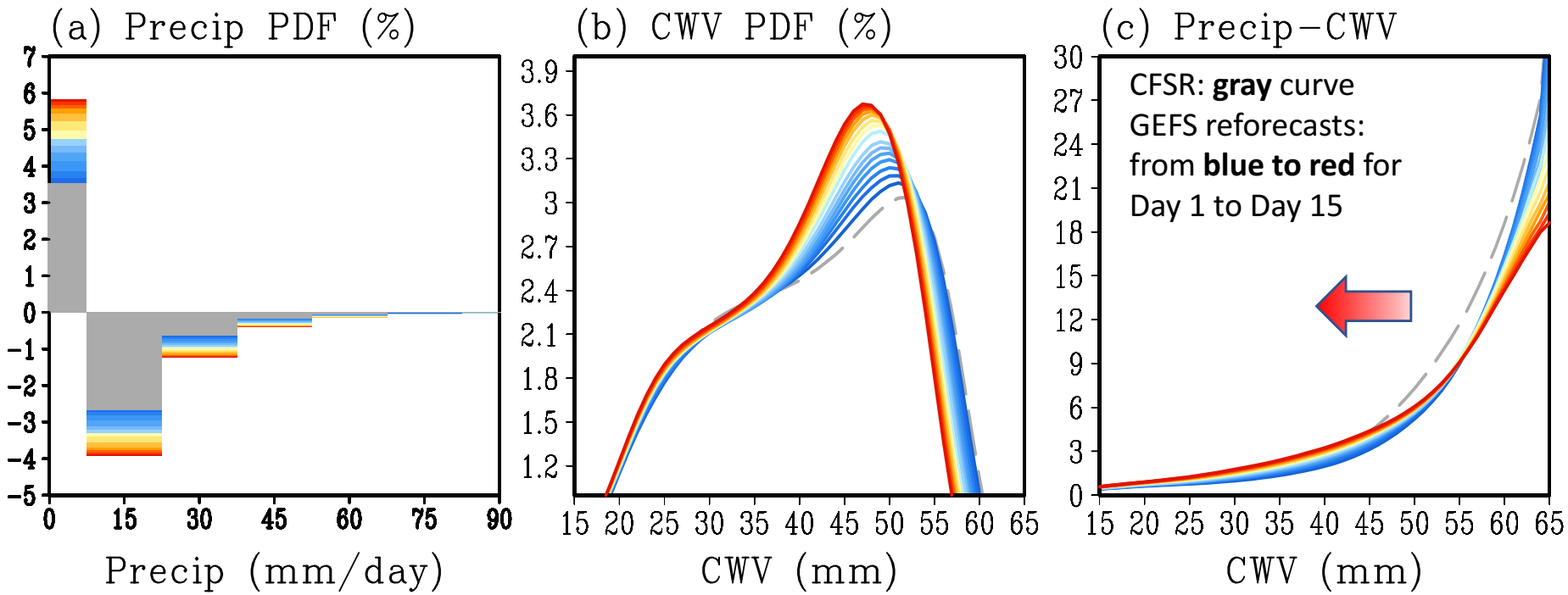
Convective adjustment time scale: the time scale over which the precipitation increase would remove the excess water vapor

$$\tau_c^m = \frac{\delta W}{\delta P} = \frac{W_*^{\mathrm{ref}}}{dP_m/dr(r_{\mathrm{ref}})}$$

W: column water vapor
P: precipitation

Bretherton et al. 2004

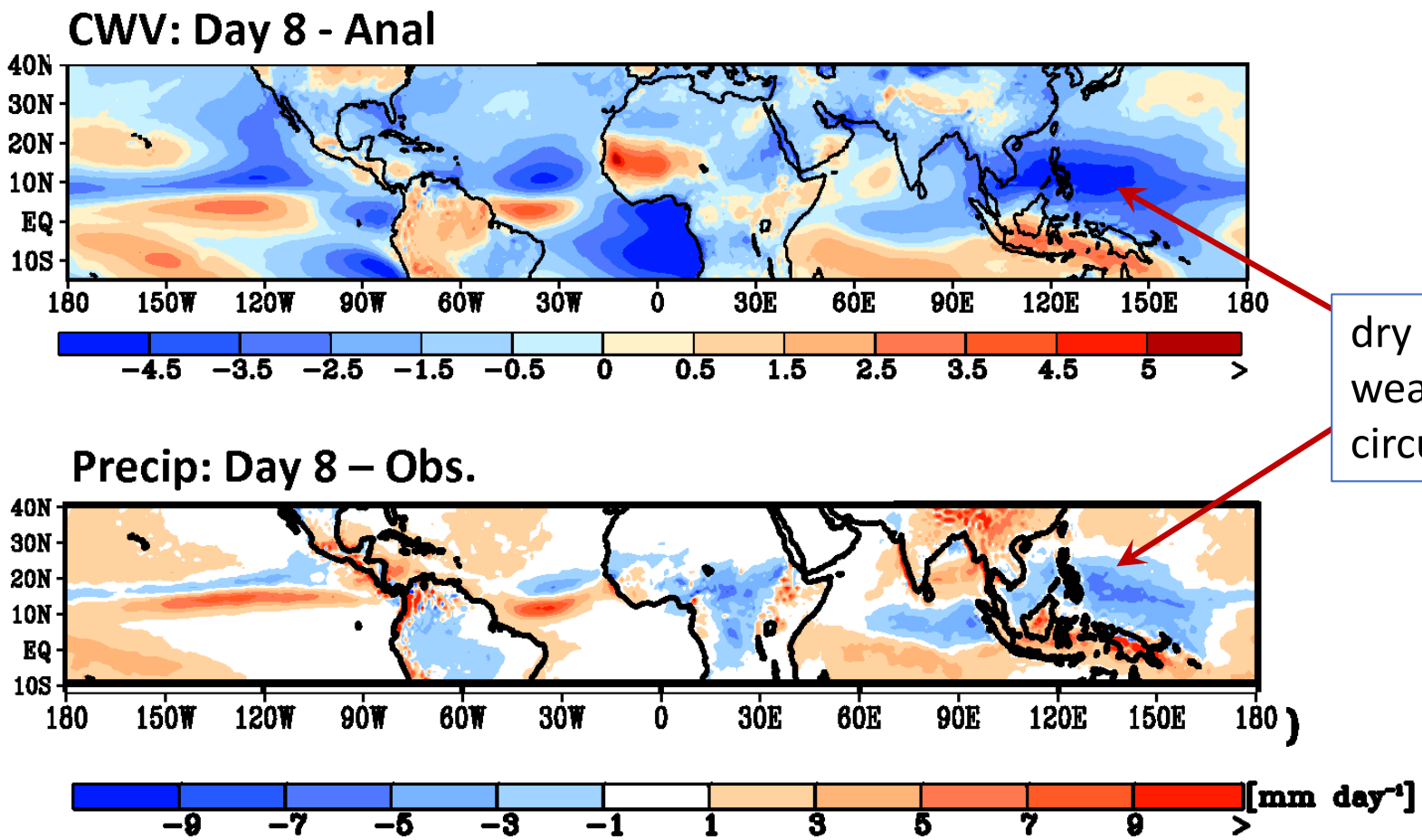
Level 1: Precipitation-Moisture Relation in the GEFS Reforecasts Version 2



The precip-humidity relation is closely related to precipitation distribution, including the occurrence of extreme precipitation

Wang et al. 2018

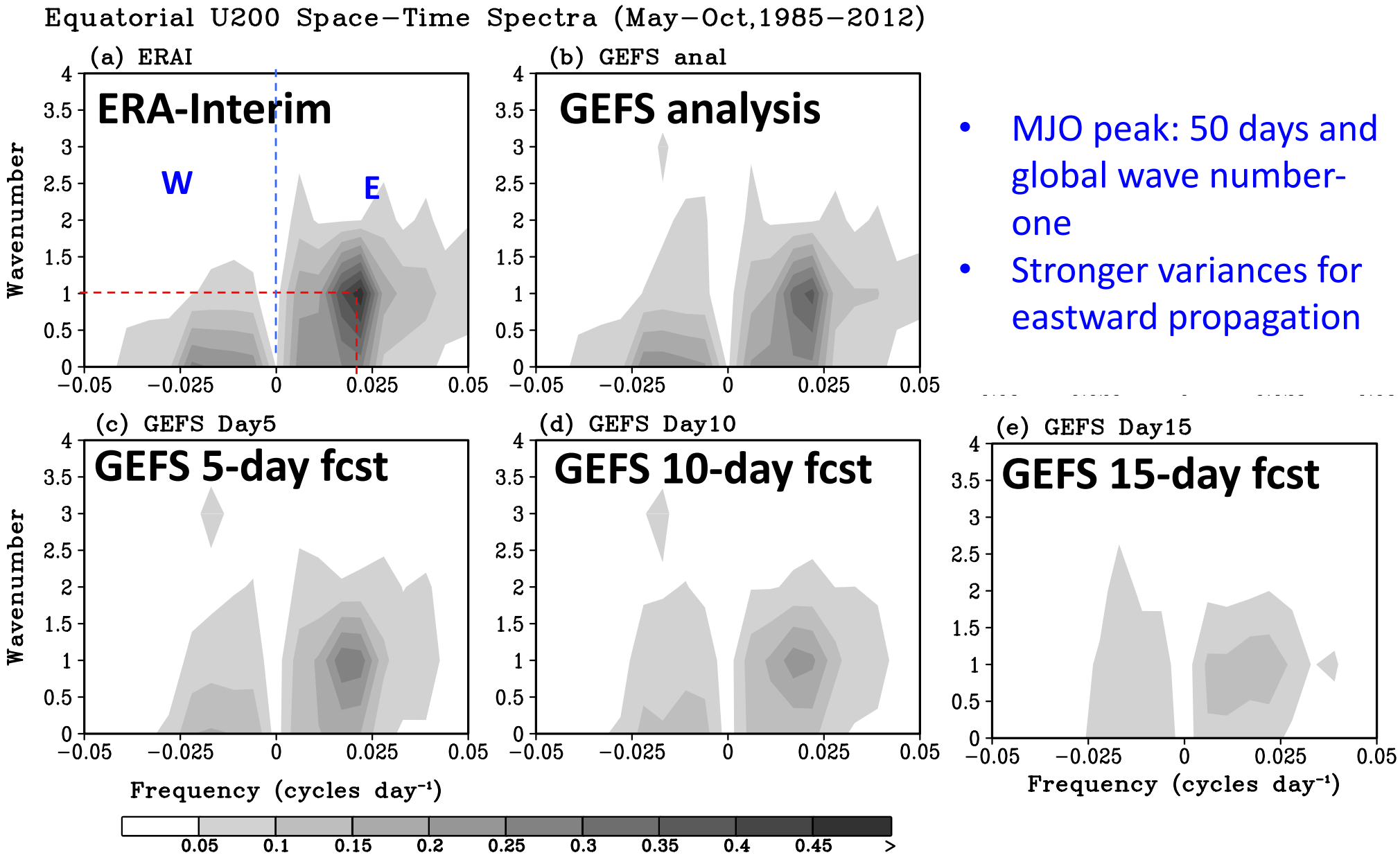
Climatological Mean CWV and Precipitation



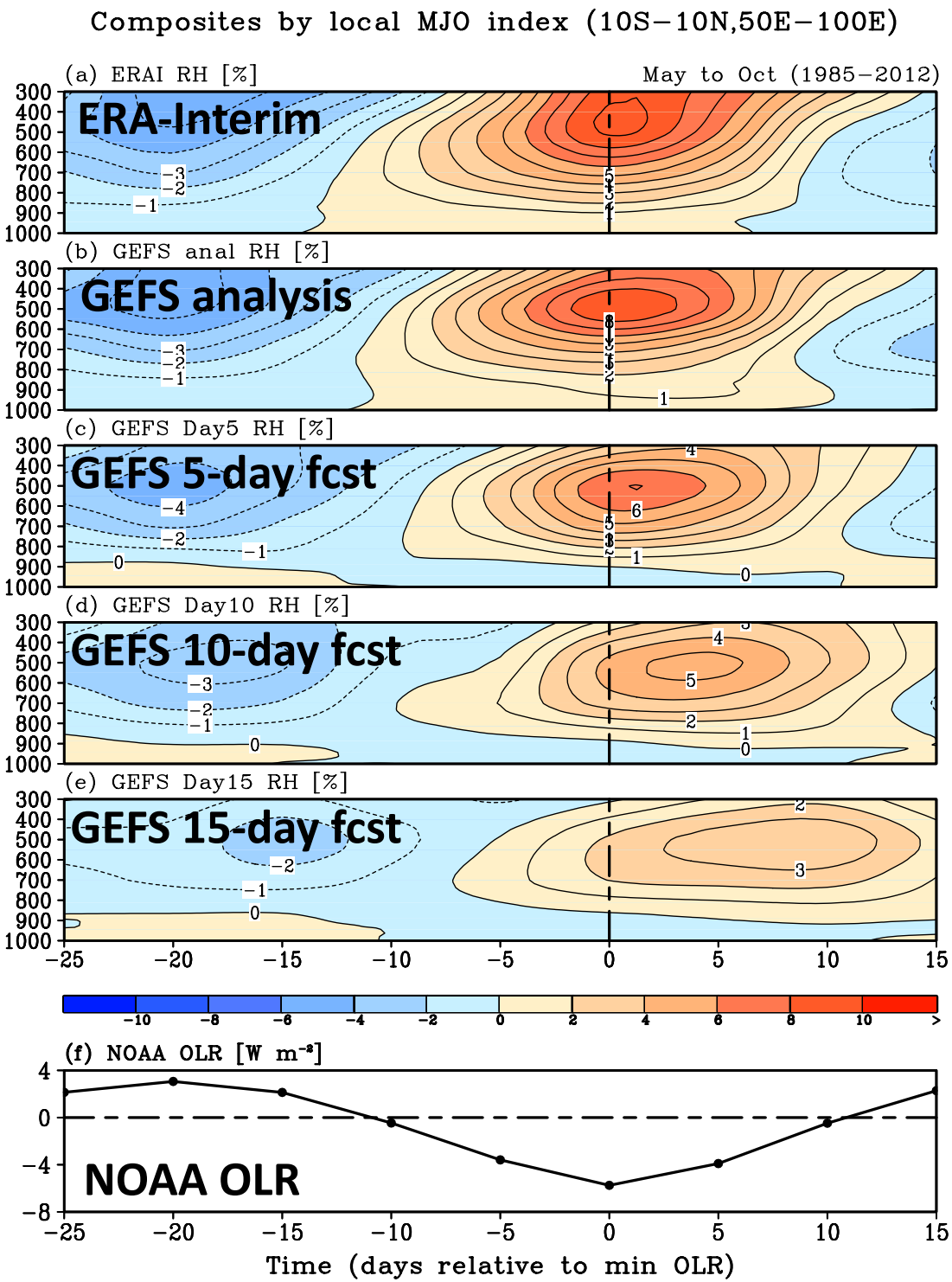
dry biases and weaker monsoon circulation

- The nonlinear curve is sensitive to i) the detrainment rate of condensates, rain evaporation rate in the cumulus parameterization and ii) raindrop and snow particle fall velocity in microphysics parameterization (Hagos et al. 2018).
- Evaluation against observations helps to constrain these uncertain parameters.

Level 2: MJO – Wavenumber vs. frequency Diagram

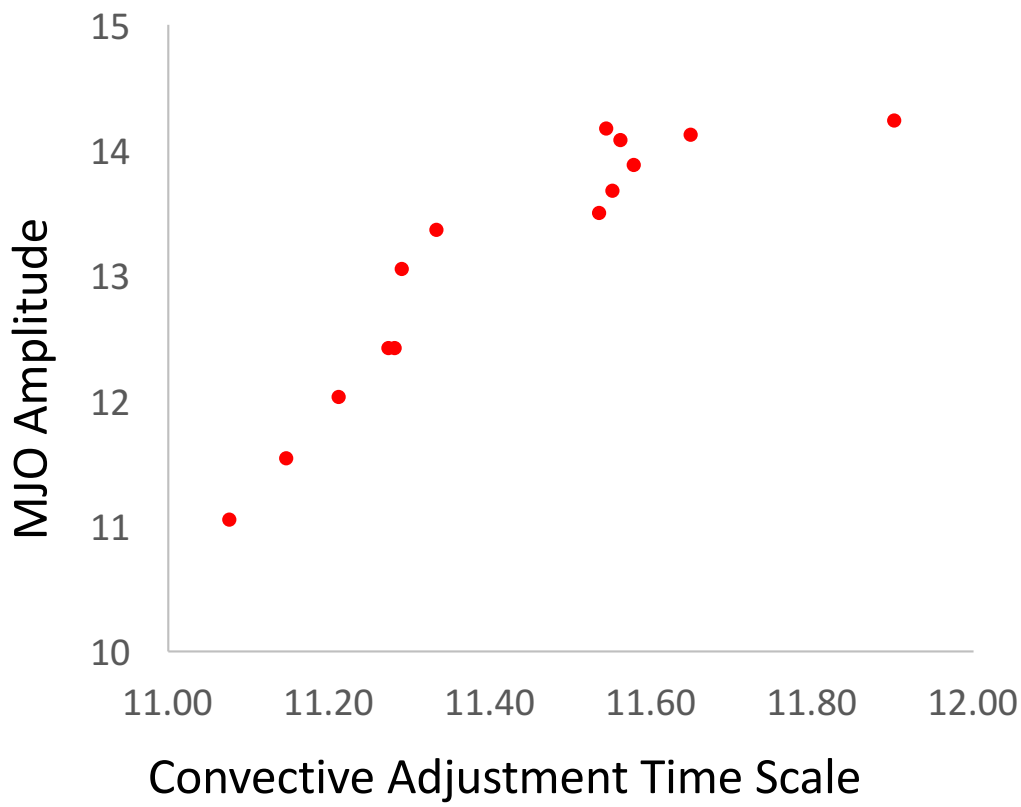


- MJO peak: 50 days and global wave number-one
- Stronger variances for eastward propagation



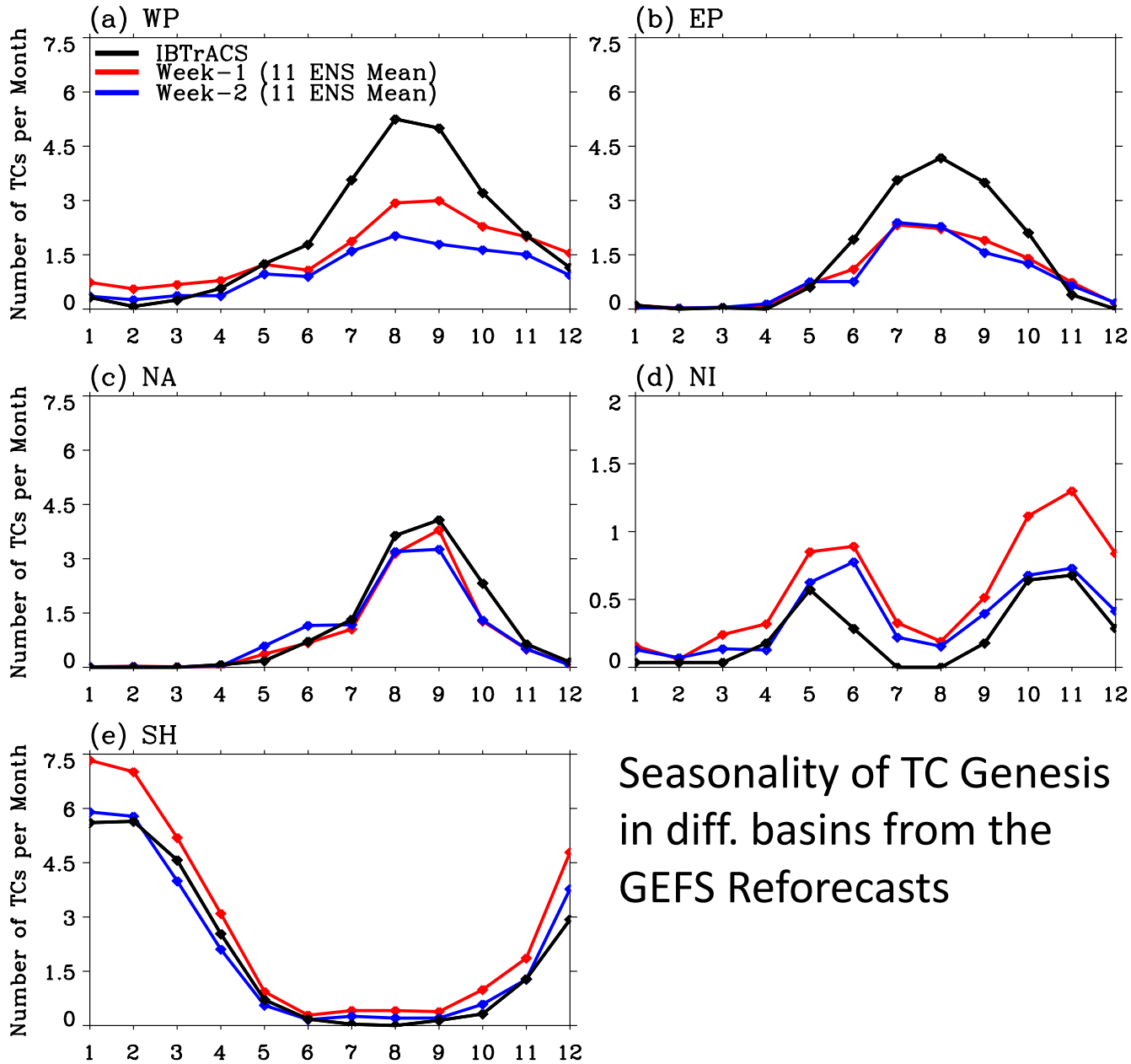
- A local MJO index was defined based on the band-pass filtered OLR.
- The magnitude of the RH anomalies weakens with the lead time.
- Cumulus congestus and startiform precip. are possibly under-predicted in GEFS-R.

MJO and Convective Adjustment Time Scale



Consistent with Jiang et al. (2016): Model MJO amplitude is closely related to the model convective moisture adjustment time scale.

Level 3: High-Impact Weather - Tropical Cyclones



Seasonality of TC Genesis in diff. basins from the GEFS Reforecasts

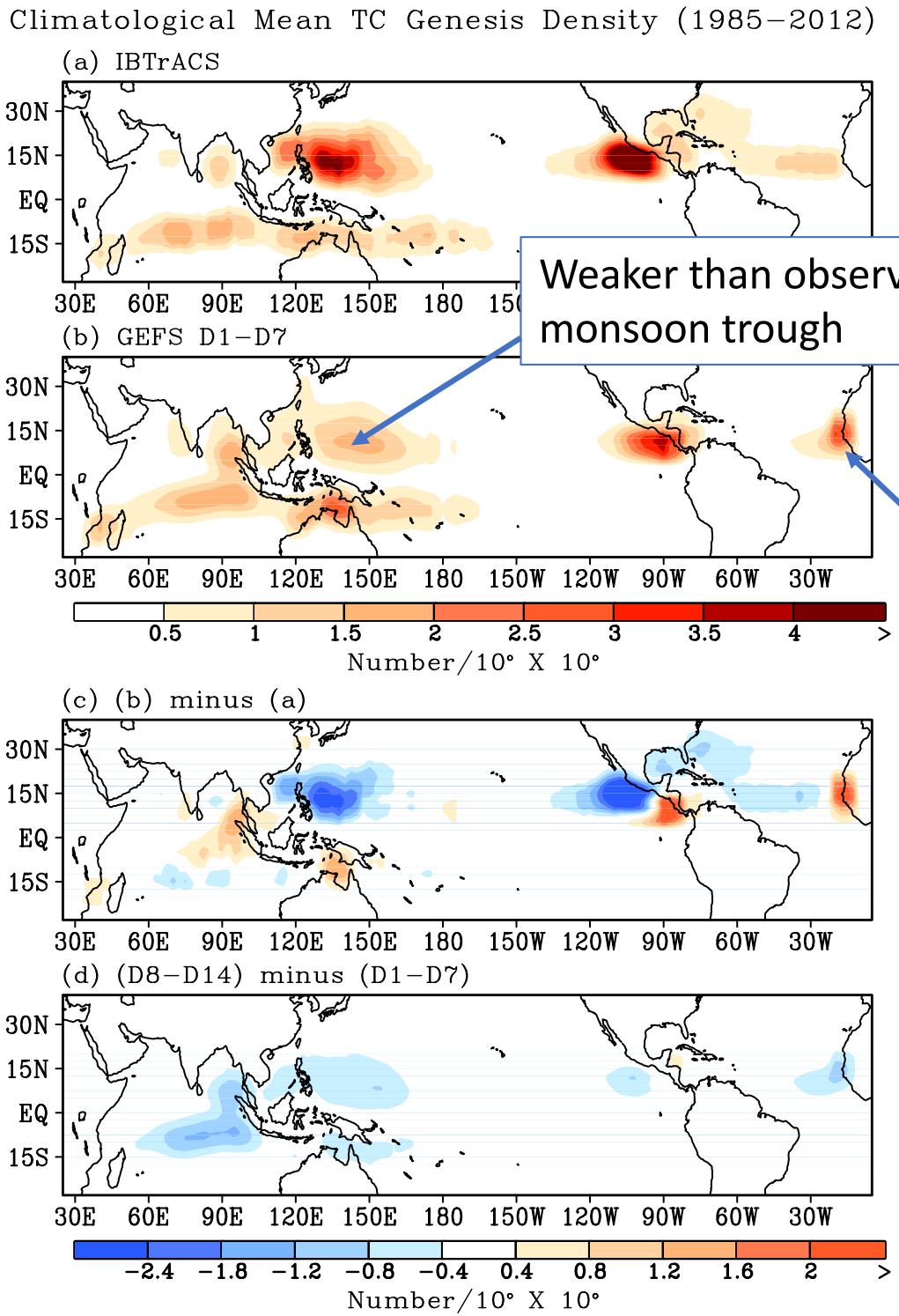
Genesis density function: 2D distribution of genesis frequency

IBTrACS

Week-1

"Week-1" - Obv

"Wk-2" –"Wk-1"



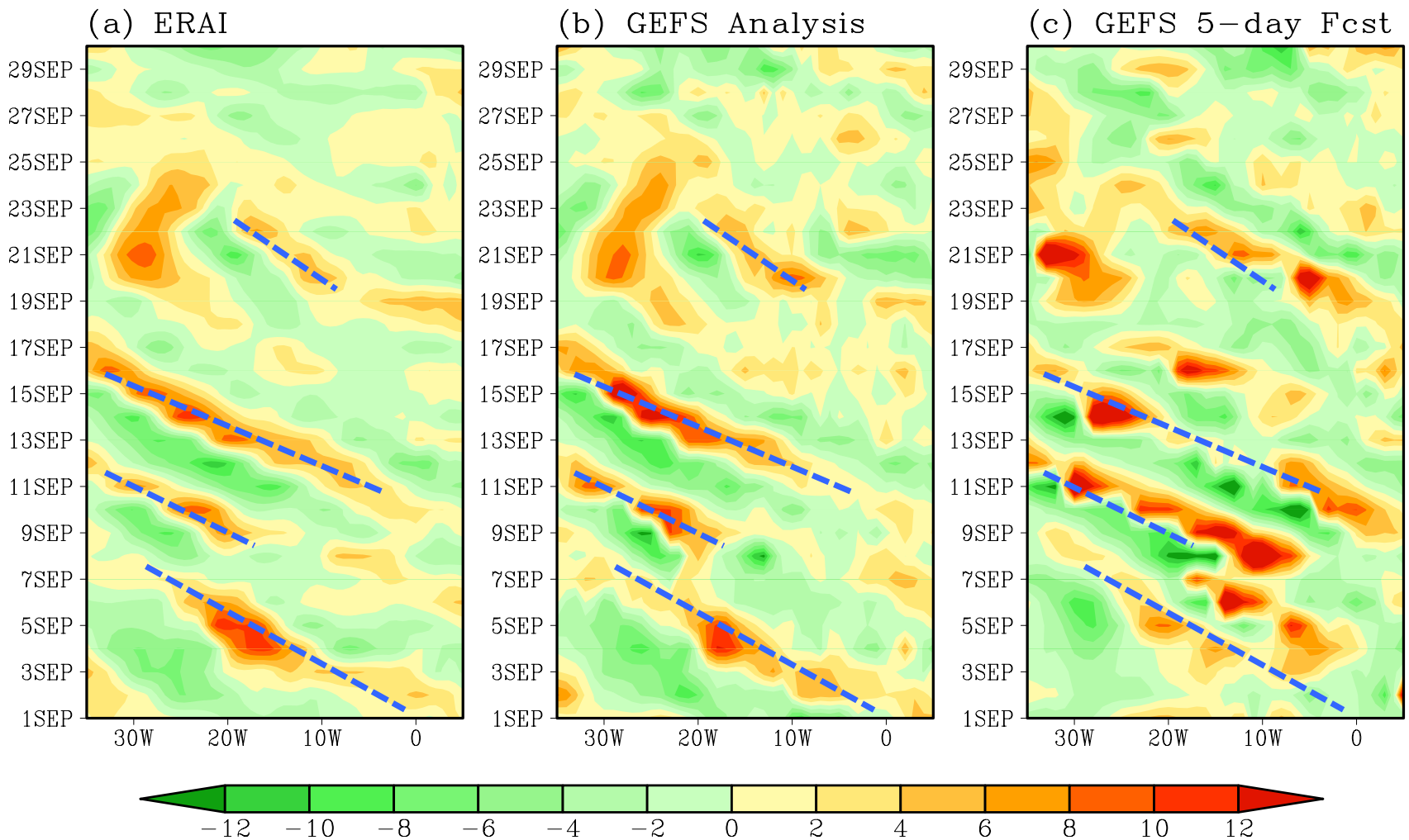
Weaker than observed monsoon trough

What about this region?

Unit:

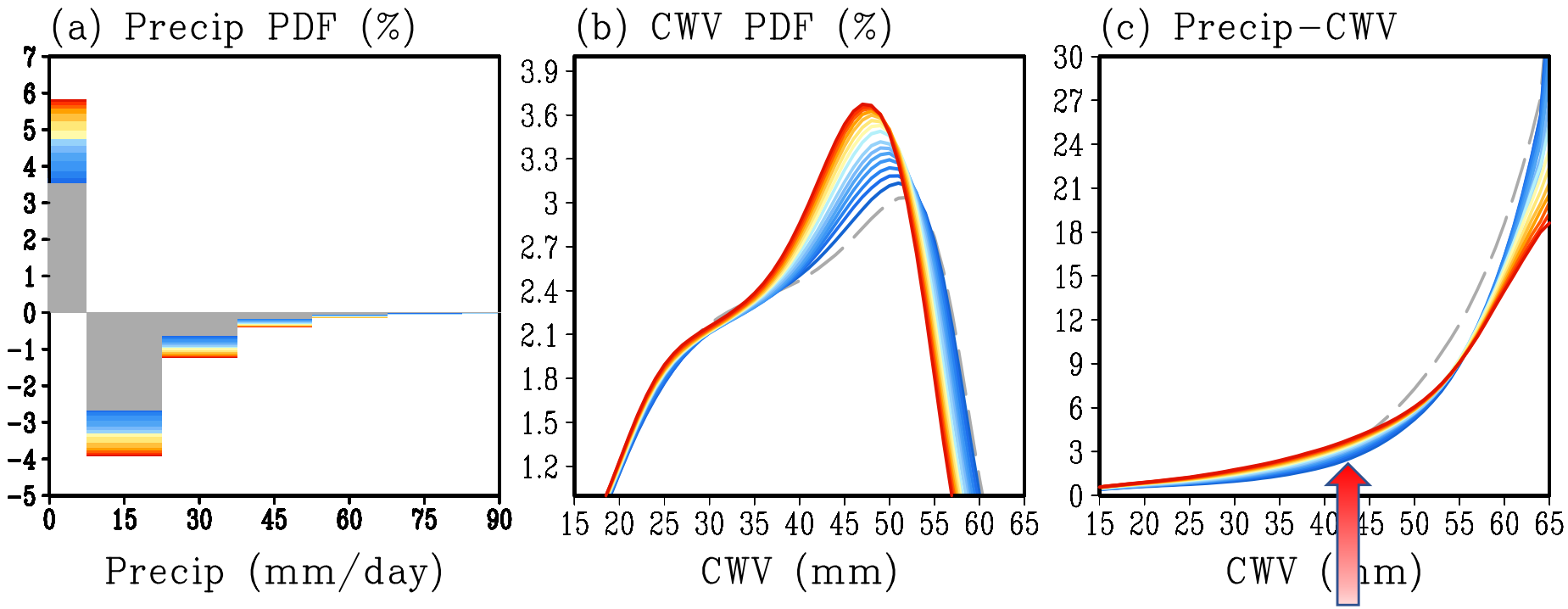
# of TCs forming within a 10-degree box per year

Hovmoller Diagram of V850 (15N, 2010)



Q1 diagnosis shows that hyperactive convection over land leads to stronger AEWs of deeper vertical structure, the early TC development (false alarms) off the coast, and the negative biases farther downstream.

Precipitation-Moisture Relation



Convection onset occurs too early in terms of column water vapor accumulation

Wang et al. 2018

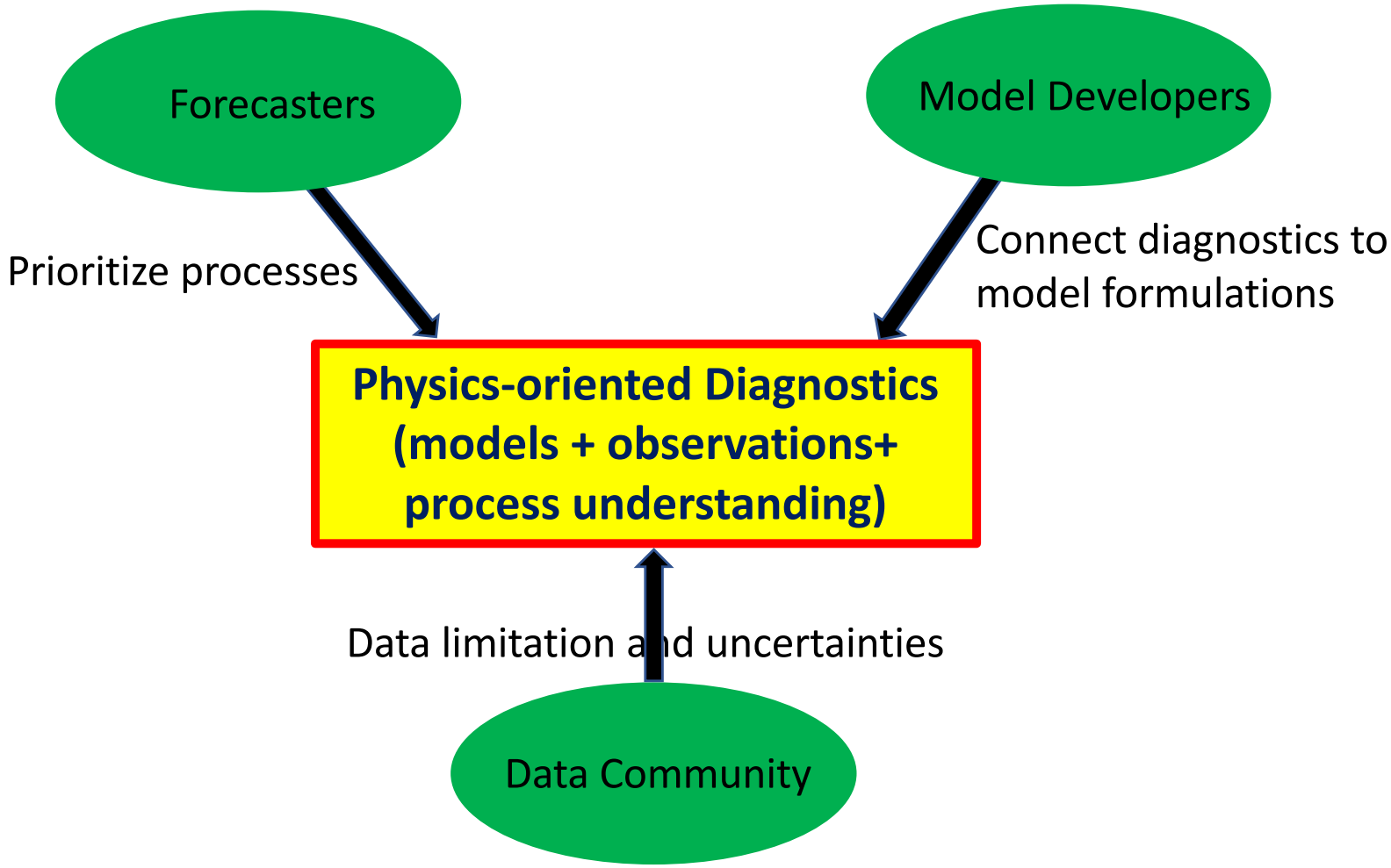
In brevity,

- Three levels of diagnostics
  - Model climatology and fundamental physical processes
  - Sources of predictability on the relevant time scales
  - High-impact weather phenomena
- Model diagnoses at the three levels are not independent of each other
  - Biases in Tropical Cyclogenesis ← Mean State Biases
  - Mean State Biases ← deficiencies in model physics
  - Physics-oriented model diagnostics help to constrain uncertain parameters and reduce model biases

Challenges and Road Map

- Prioritize the processes to evaluate and organize community resources:
  - A unified package: it means different things for different people. What are our priorities?
  - The proto-structure helps to get this started; will be transitioned to MET+
- Collaboration with forecasters, model developers, and the data community
- Emerging need to evaluate physics interaction and interaction between different climate components calls for collaboration between different specialties
- Long-term hindcasts
  - Different flavors of ENSO, different flavors of the MJO, flow-dependent predictability of tropical cyclones
- Data uncertainties and representativeness

Collaborative Efforts for Model Improvements



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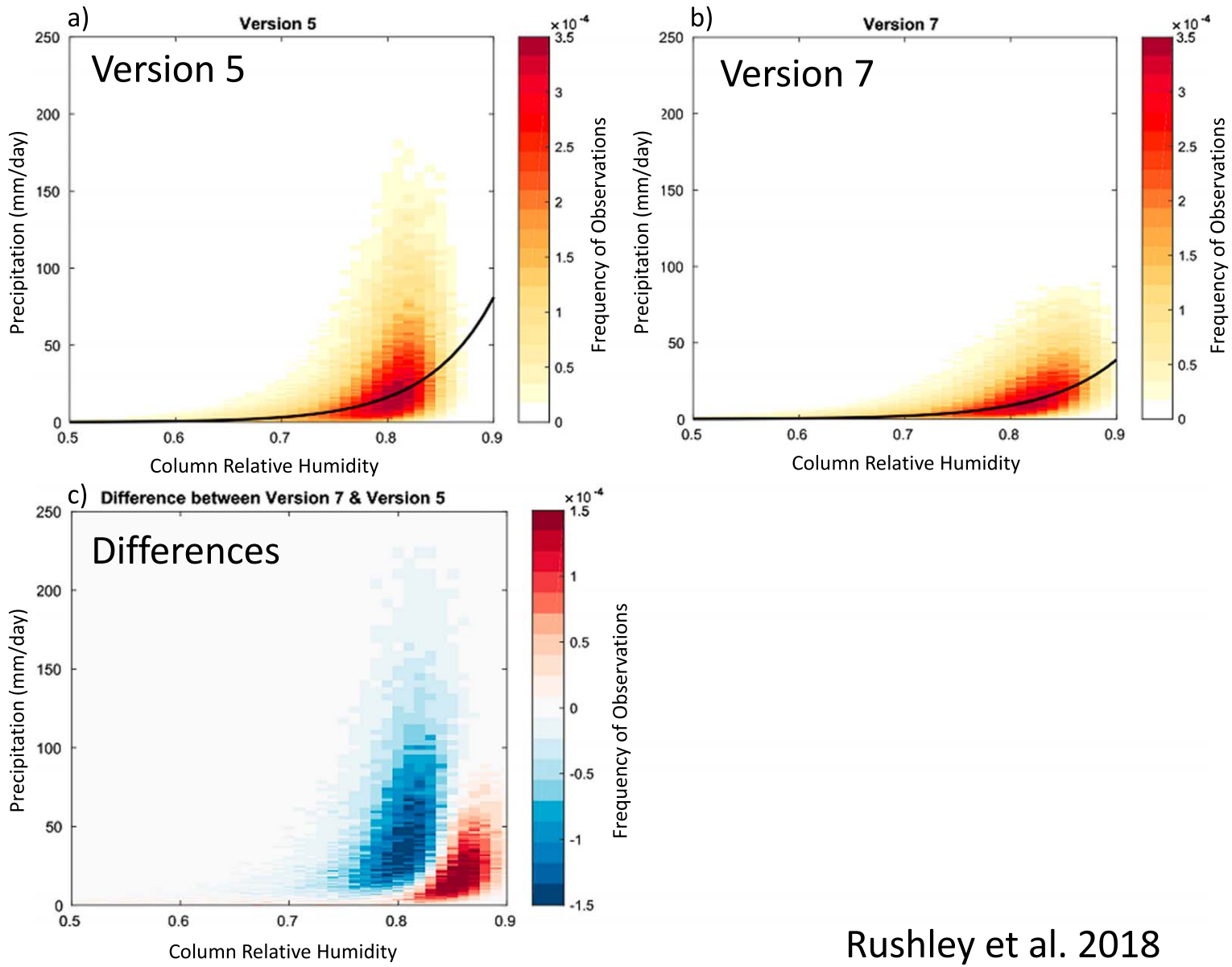
Data Uncertainties: Precipitation-Humidity Relationship: SSMI v5 vs. v7



Rushley et al. 2018