Model Diagnostics Task Force

A Walkthrough of the Technical Vision and the Diagnostics Packages

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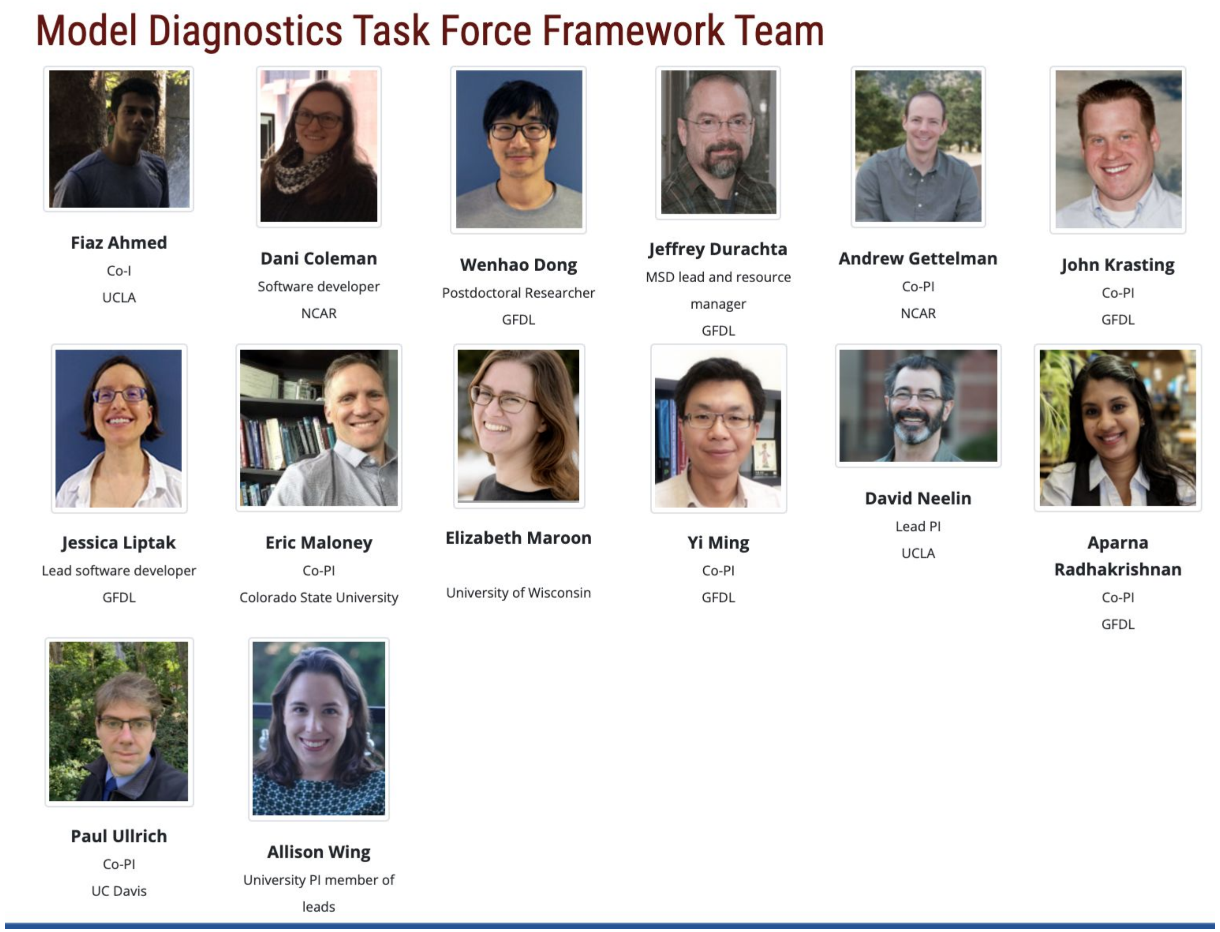
And MDTF Leads group

1. Princeton University CIMES, 2. UCAR, 3. NOAA GFDL, 4. MDTF

CIMES UCAR

UFS Webinar Series, Dec 9th, 2021

Acknowledgments



MDTF Task Force.

Other contributors: Jack Chen, Thomas Jackson, Yi-Hung Kuo, Elizabeth Maroon, Ana Ordonez, Joyce Meyerson, Rayette Tolles-Abdullah, Unni Kirandumkara, Thomas Robinson, Tristan Dietz , Krishna Kumar,V.Balaji, Rusty Benson.

Funding acknowledgment: NOAA MAPP program, OAR CTI and OAR RDHPCS cloud awards

Other resources: Open-source GitHub actions templates and docs by the community.

Outline

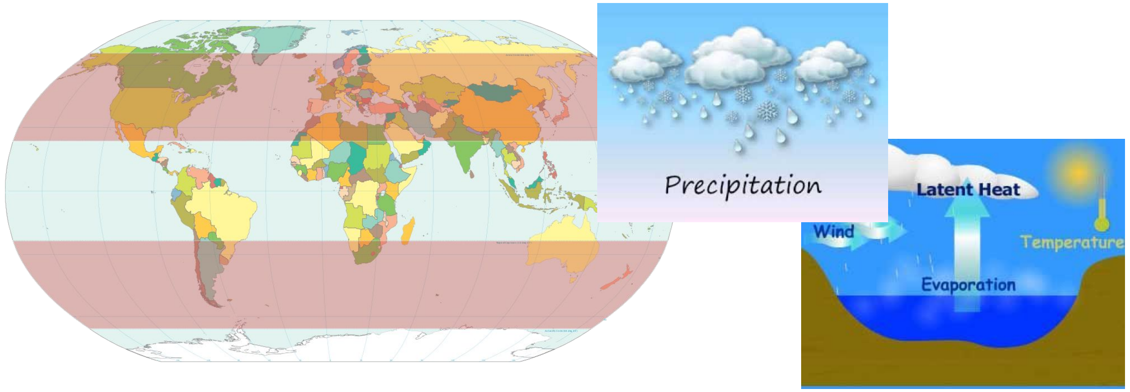
1. Background and Motivation
2. Intro: Process Oriented Diagnostics and MDTF
3. Highlights: MDTF Framework Phase-3
4. Phase-3 and beyond: What are the 3Cs?
5. PODs Deep-dive: MJO PODs and Mesoscale Convective System over North America
6. Conclusion

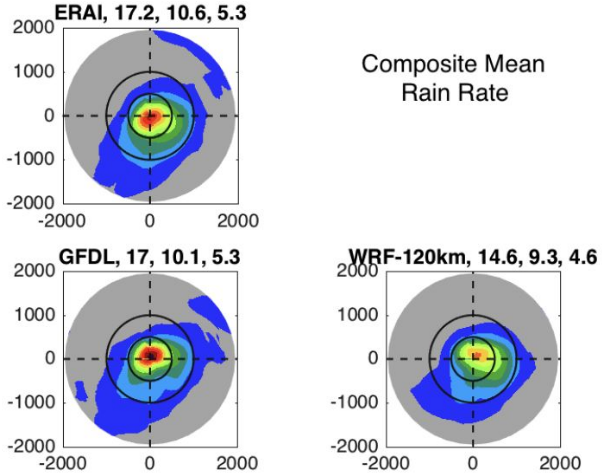
Challenges: Need for details

The simulation of clouds in climate models remains challenging.
[IPCC AR5, Chapter 9]

The majority of models underestimate the sensitivity of extreme precipitation to temperature variability or trends, especially in the tropics, which implies that models may underestimate the projected increase in extreme precipitation in the future.
[IPCC AR5, Chapter 9]

Storm track biases in the North Atlantic have improved slightly, but models still produce a storm track that is too zonal and underestimate cyclone intensity.
[IPCC AR5, Chapter 9]





Extratropical cyclones (ETCs) are responsible for the majority of wintertime precipitation in the midlatitudes. e.g. , Hawcroft et al. 2012

Cyclone-centered composite mean precipitation J.Booth, 2017

Representation of several processes and their feedback are important to study extratropical cyclones and for mid-latitude precipitation simulation

Process Oriented Diagnostics

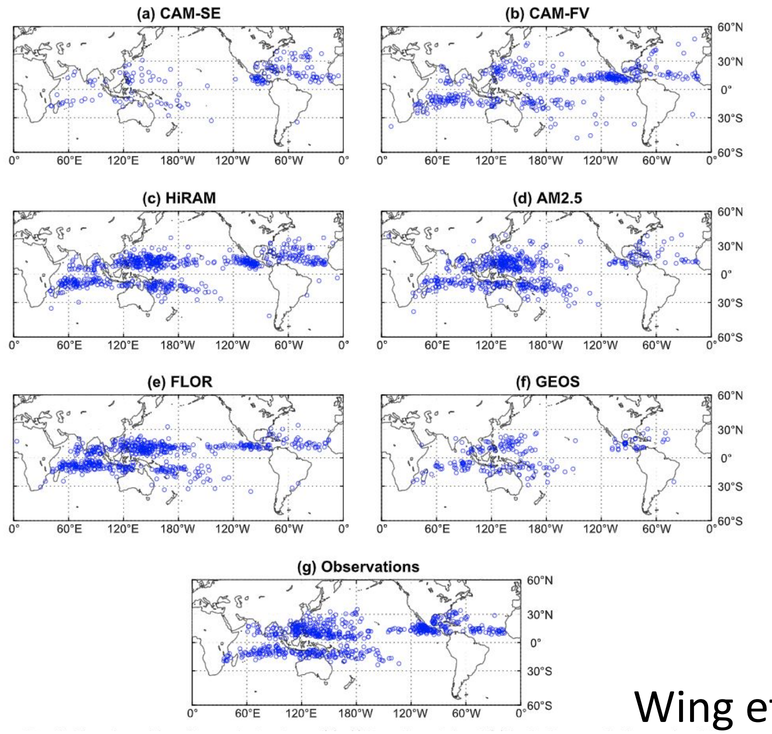
Processes tell us about the model state, or how the model state changes in space and time.
It's not just the state, it's the derivative of the state with respect to other things or with respect to time

Gettelman et al. AGU 2020

Develop process-oriented diagnostics to identify model characteristics that are responsible for proper simulation of TCs and that will explain the inter-model spread in TC frequency and intensity distributions. These diagnostics go beyond simply quantifying the simulated TC activity and focus on how simulated TCs respond to their environments..

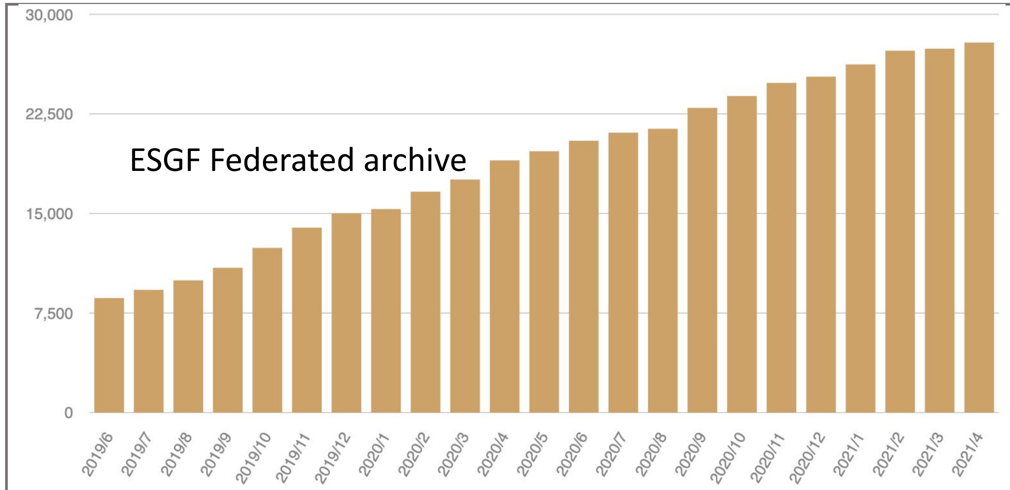
Increasingly, models are being analyzed in more detail against observations of **specific processes**, and the MDTF is approaching PODs in this spirit. The closer to a model process the observations and evaluation are, the better the ability to constrain the process and hence provide a guide to parameterization improvement.

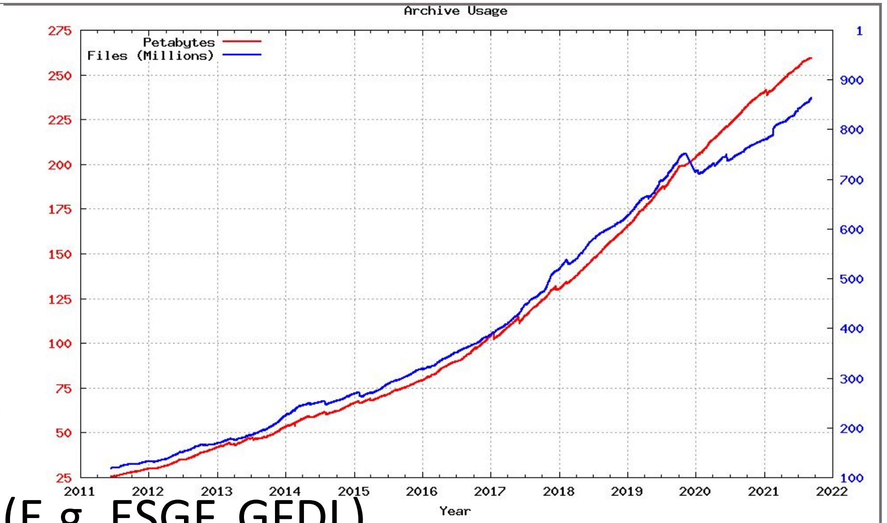
Maloney et al, 2019



Wing et al, 2019

Need for collaboration

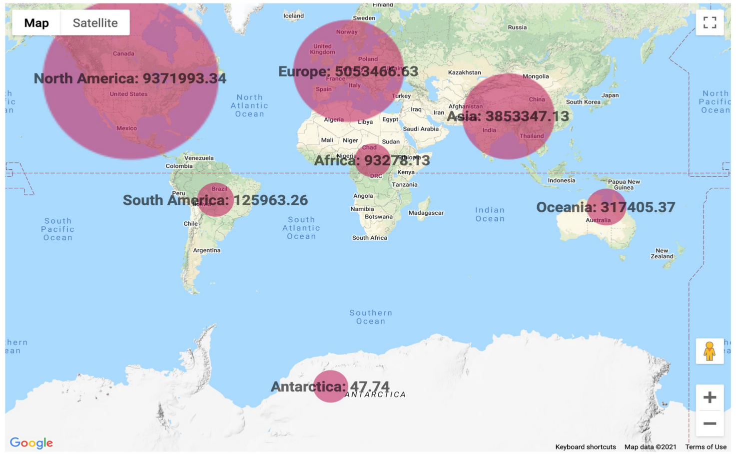




Data, Data everywhere (E.g. ESGF, GFDL)

VARYING: experimental design, model output formats, variable names, units, resolution,….

Experts everywhere. (extends worldwide)



Diverse users (ESGF example only, from CMCC portal)

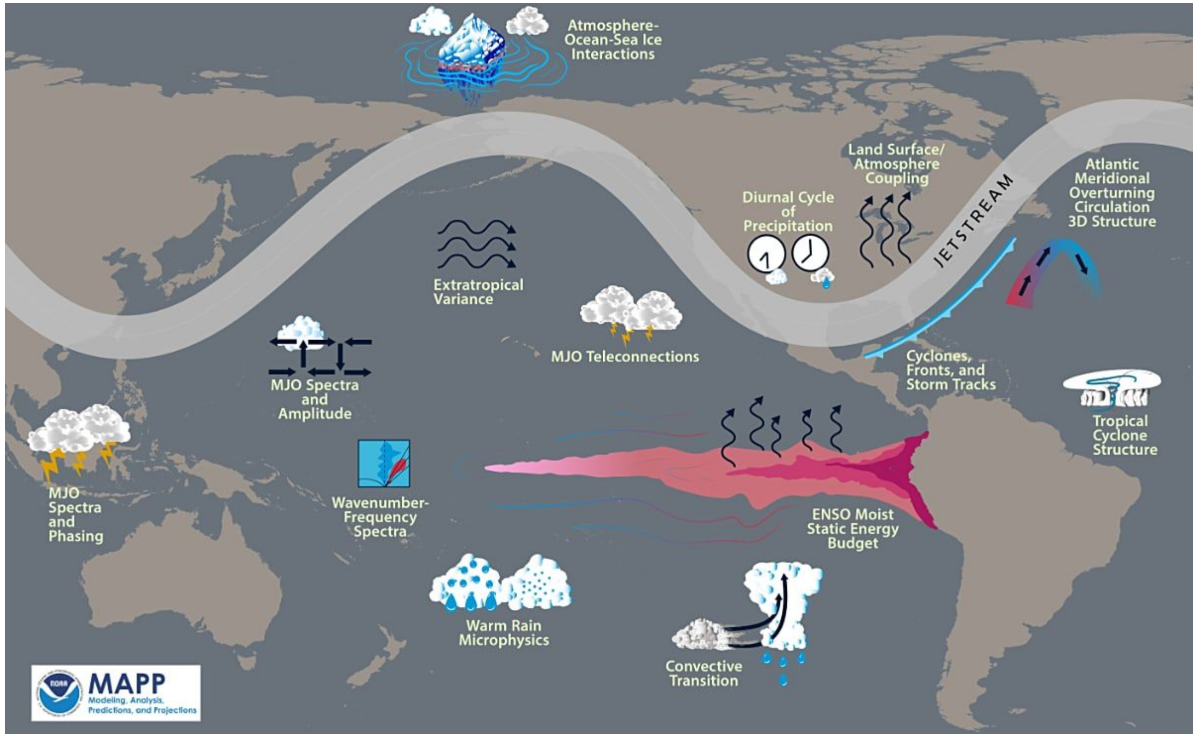
Need results now

Model Diagnostics Task Force: History and background

Engage research community developing process-oriented diagnostics (PODs) to improve the performance of Earth system models at ***NOAA* , *NCAR, DOE.***

Multi-institutional effort funded through the Model Analysis, Prediction, and Projection (MAPP) program at NOAA's Climate Program Office

- History dates back to 2012 CLIVAR MJO Task Force
- Phase 1 framework development led by NCAR (2015-2018)
  - Public release of "version 2"
  - Initial set of 8 process-oriented diagnostics (PODs)
- **Phase 2 and 3 development led by GFDL (2018-2022, 2021-2024)**
  - More contributed diagnostics
  - Move toward open source software model
  - Lead PI - David Neelin (UCLA)
  - Collaboration, collaboration.



Expanding suite of diagnostics

Atmosphere

Convective transition diagnostics

MSE variance of tropical cyclones

Precip. buoyancy diagnostics

Precip. Distribution diagnostics

Rossby wave sources

Surface flux diagnostics

Top-heaviness metrics

TUTT index

Vertical processes

Ocean

Arctic Ocean ML diagnostics

Arctic surface SW feedbacks

Land Climate Process Team

Convective triggering

Heated condensation

ILAMB

LCL deficit

Mixing diagrams

RH tendency

Marine Ecosystems CPT

CA Current biogeo. processes

Northeast Pacific SSTs

Time evolution of biogeo. variables

Time evolution of marine heat waves

Climate Sensitivity Task Force

Boundary layer clouds

Cloud controlling factors

Emergent constraints

Humidity cloud circulation

Kernel-based climate feedbacks

Low clouds

***Green denotes** diagnostics that were part of the 2018-22 MAPP funding opportunity.

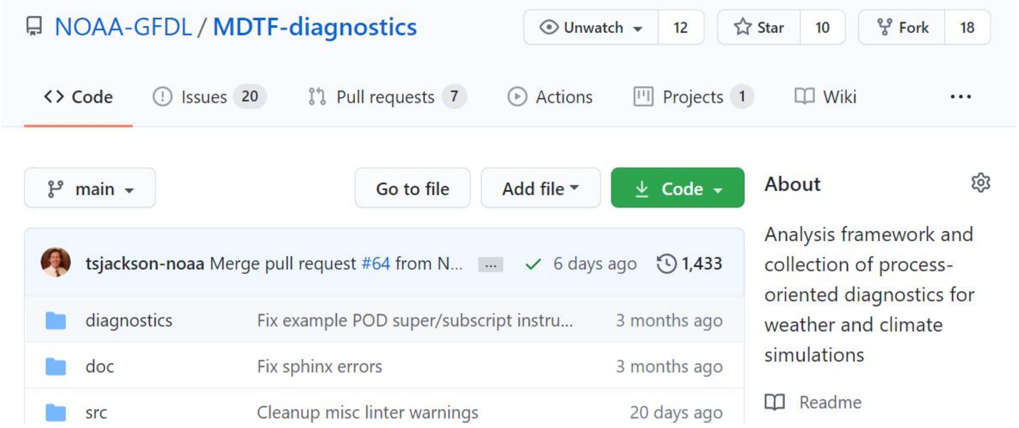
Expanded set of new PODs are coming in for the new phase.

Slide credit: Krasting et al, AGU 2020

Framework Software Enhancements (Phase-2)

T. Jackson, D. Coleman, Y. H. Kuo

- Migrated to open source development on GitHub
- Anaconda-based installation routines
- Migrated to Python 3.x
- Adoption of CMOR/CF variable naming conventions
- Detection of internal GFDL formats vs. CMIP output
- Improved unit and workflow testing
- Introduced settings.jsonc file
- Collaborated with DOE's Coordinated Metrics and Evaluation Capabilities (CMEC) on a joint CMEC-MDTF standard for setting and naming conventions



MDTF Diagnostic code now hosted at https://github.com/NOAA-GFDL/MDTF-diagnostics

MDTF-diagnostics framework: software for running process-oriented diagnostics (PODs) on climate and weather data. Write-once and Run anywhere!

Developments centered on increasing community ***participation***, improving the software ***portability***, and ***providing clear documentation*** to developers and end-users.

MDTF Phase-3 and beyond

MDTF Framework development

Closer integration with the model development process and modeling center workflows

Multi-run capability

Analysis Provenance mechanisms

Containerization of MDTF

Cloud-based **Continuous integration**

Open discussions, code reviews

contributorship recommendations

Usability

Maintainability

Interoperability

POD development

Development of diagnostics from different modeling components

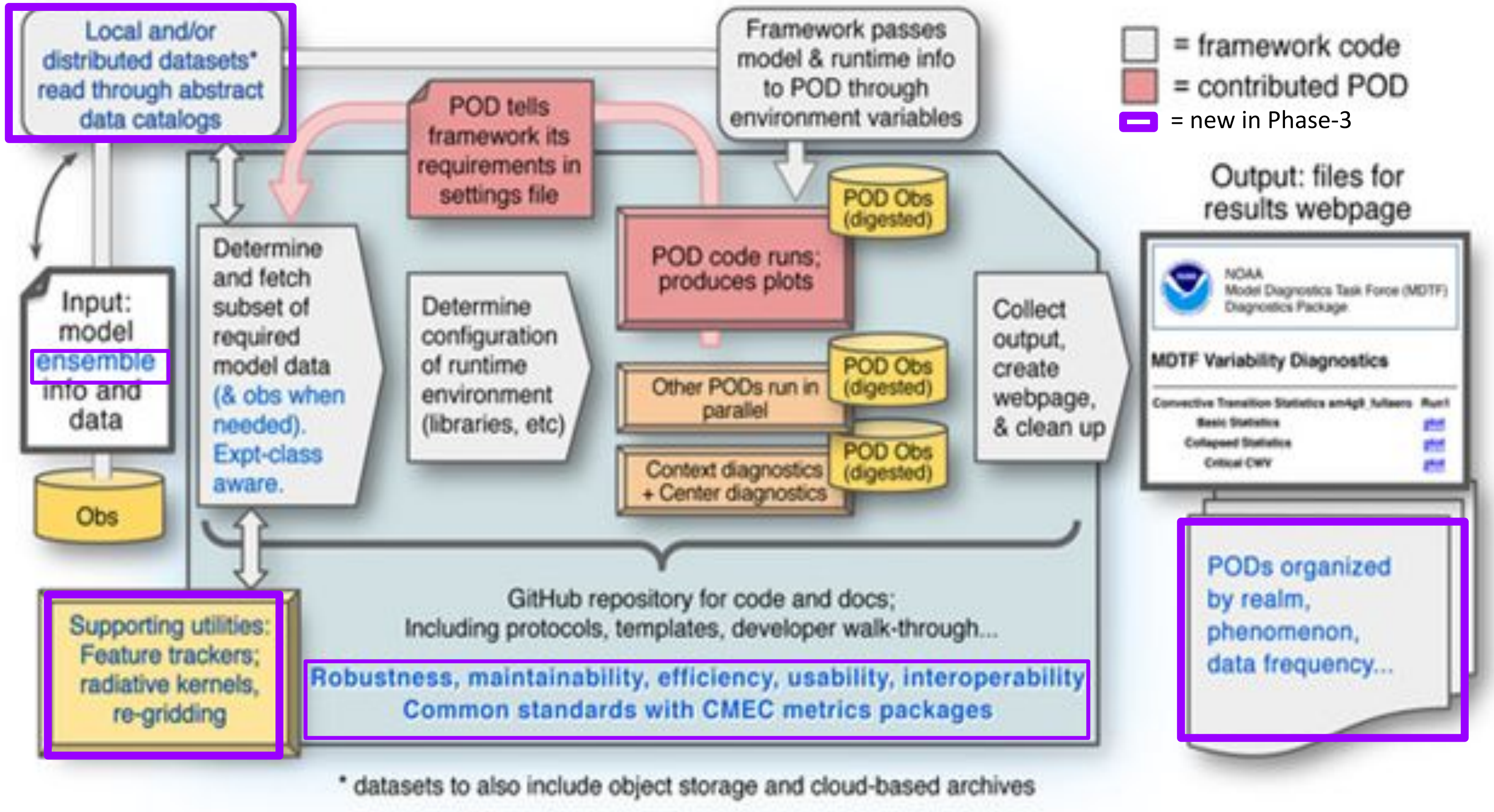
Spanning a wider range of weather to climate time scales and characterizing variability

Model Development

Build *stronger connections* between the Task Force and model developers at GFDL and NCAR

Focus on adding more diagnostics

Framework overview (Phase-3)



Scientist-developers contribute PODs to the MDTF-diagnostics repository

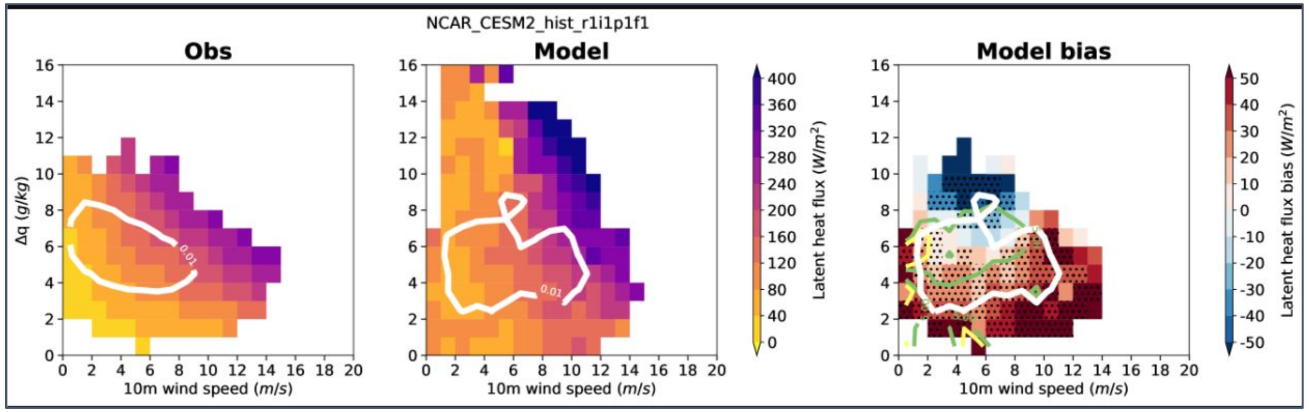
MDTF-diagnostics framework

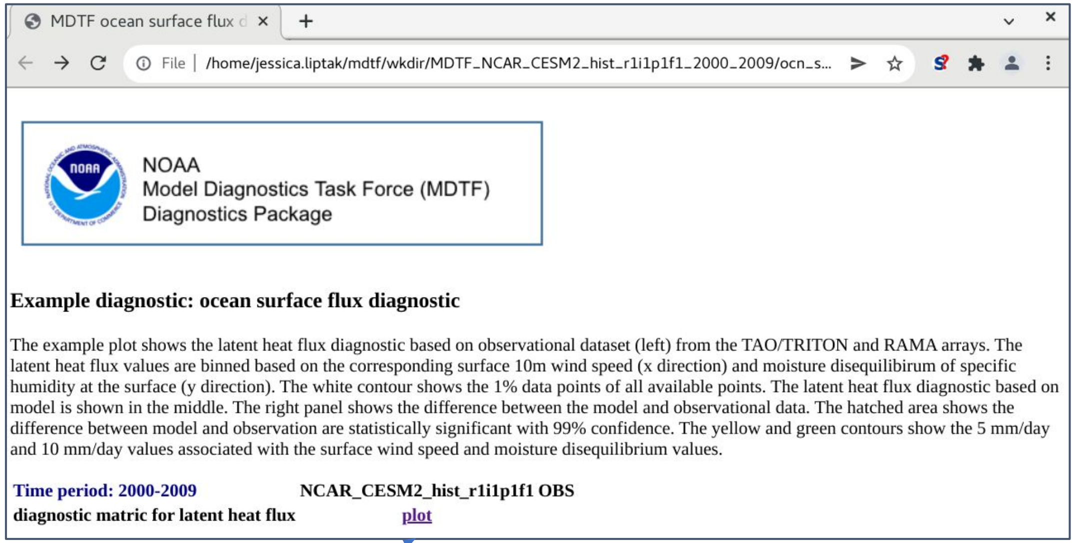
- configures the environments to run desired PODs
- processes the input data to match the specified standard (CMIP, GFDL, CESM/NCAR)
- runs the PODs
- organizes the output files into a webpage

Python-based driver handles ***data ingest*** and manipulation, calls the ***diagnostic routines***, and ***generates an html page*** with the results.

MDTF POD output webpage example

POD: Ocean Flux Matrix





POD developers provide documentation for their POD

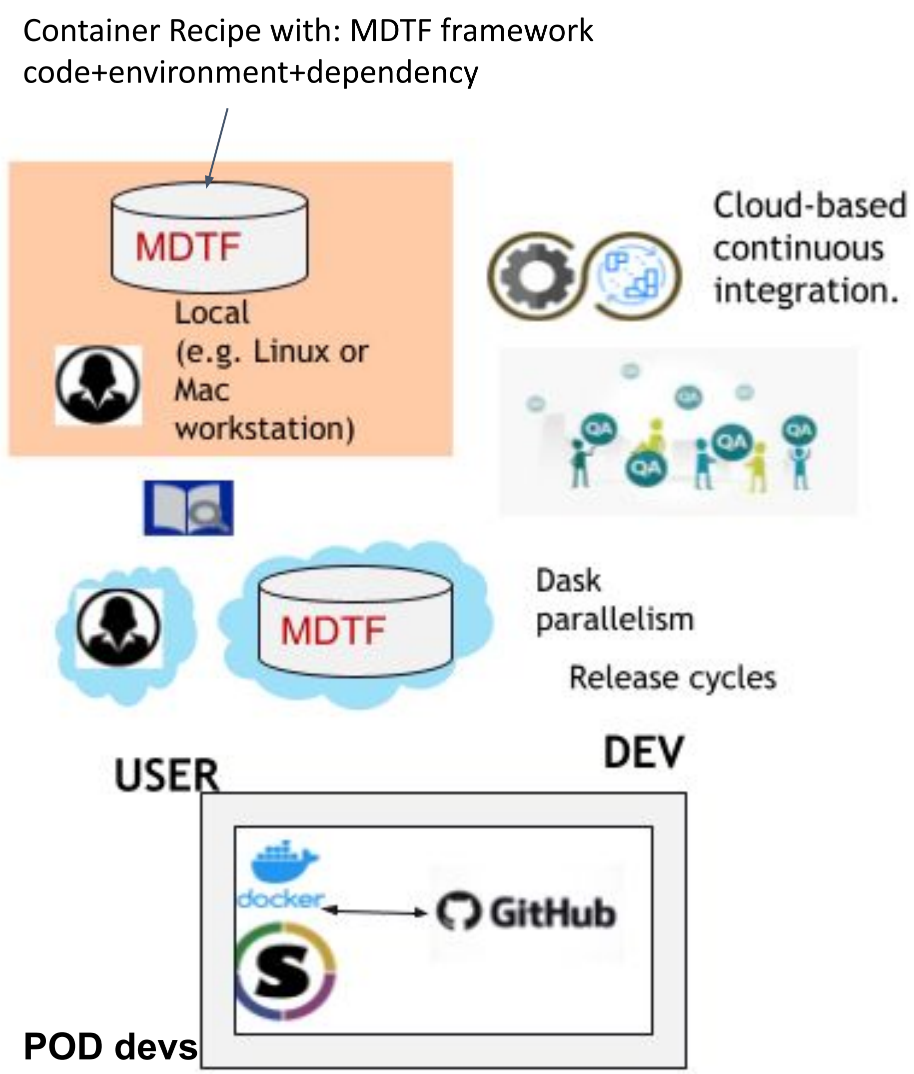
POD developer: Chia-Weh Hsu
https://github.com/chiaweh2

3Cs: Containers, CI and cloud

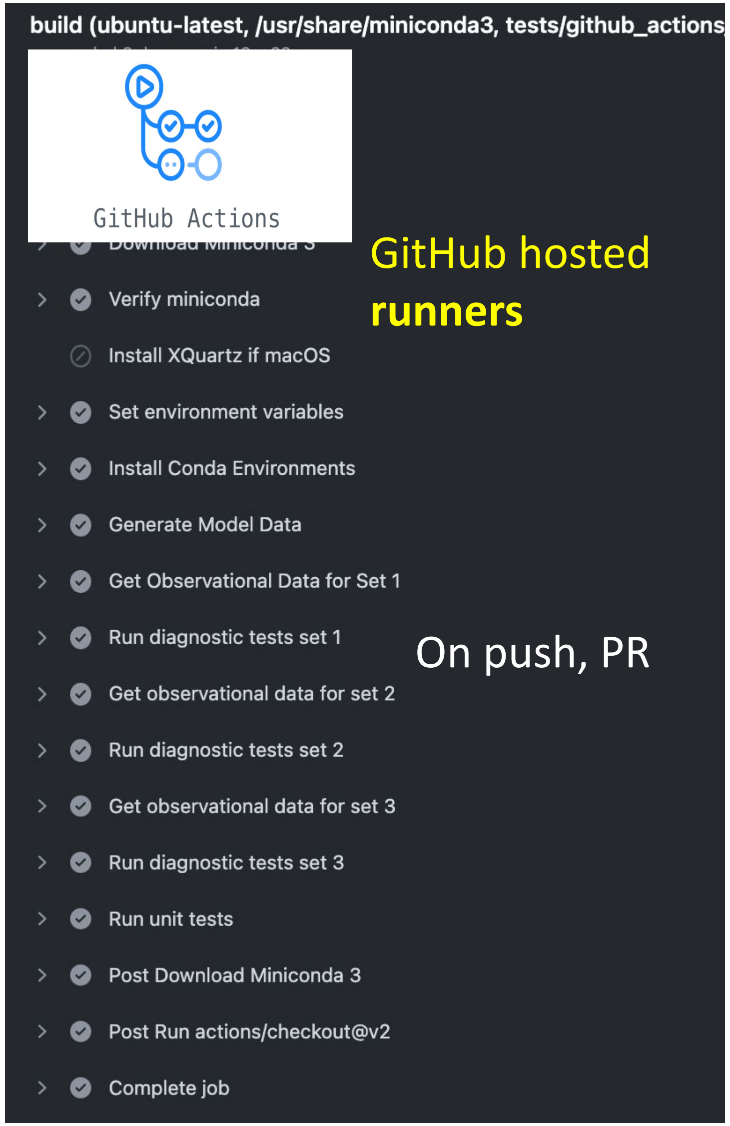
Containers for simplified, portable, repeatable software.

Continuous Integration Review, Test, Merge often, Automate builds and testing with scalable resources (**CLOUD**)

- Incorporate lessons learned from the above exercise and Task Force feedback to build our **production container** image.
- Leverage community-developed data cataloguing APIs and **cloud-optimized analysis workflows** (e.g.xarray, dask)
  - MDTF PODs in the cloud using existing publicly hosted cloud-data (e.g. CMIP6/netCDF/Zarr under ASDI initiative)



Now: CI pipeline

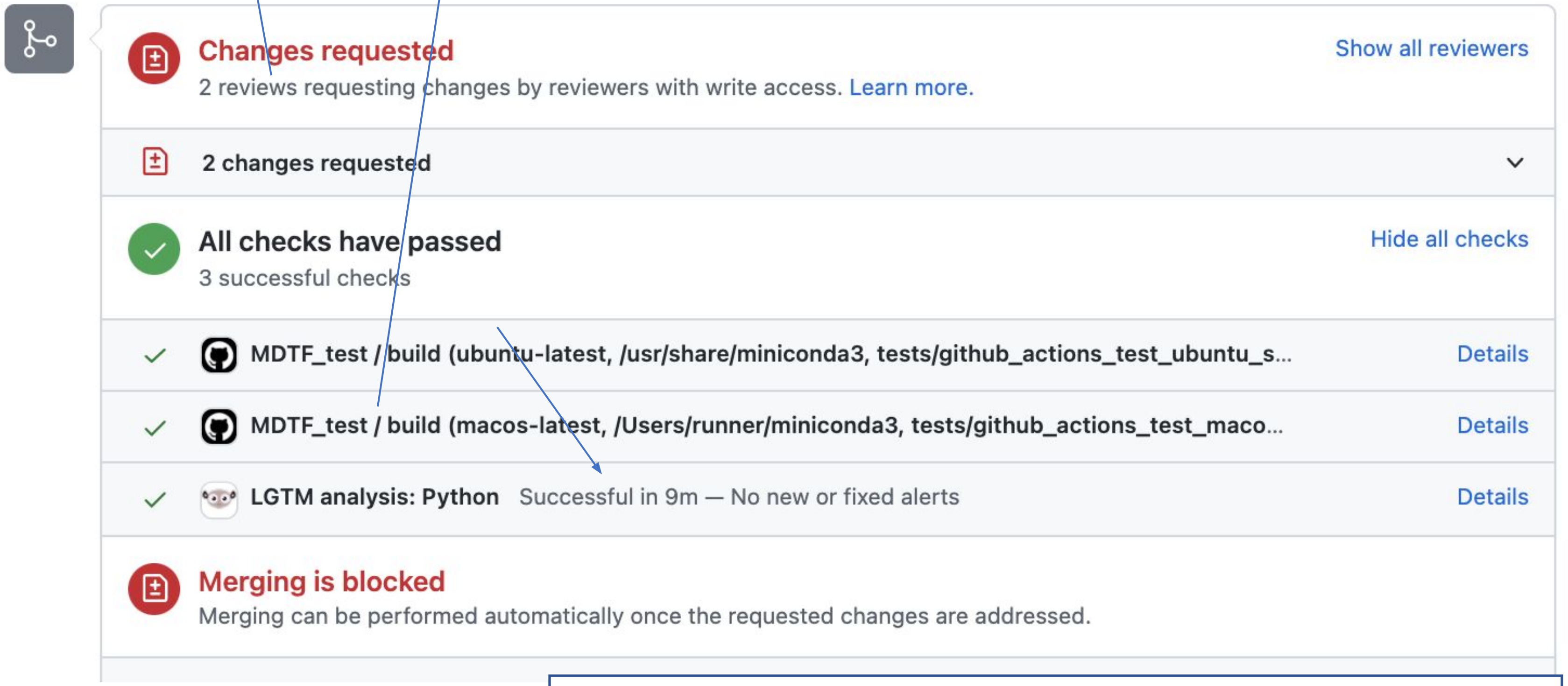


GitHub hosted **runners**

On push, PR

Code review

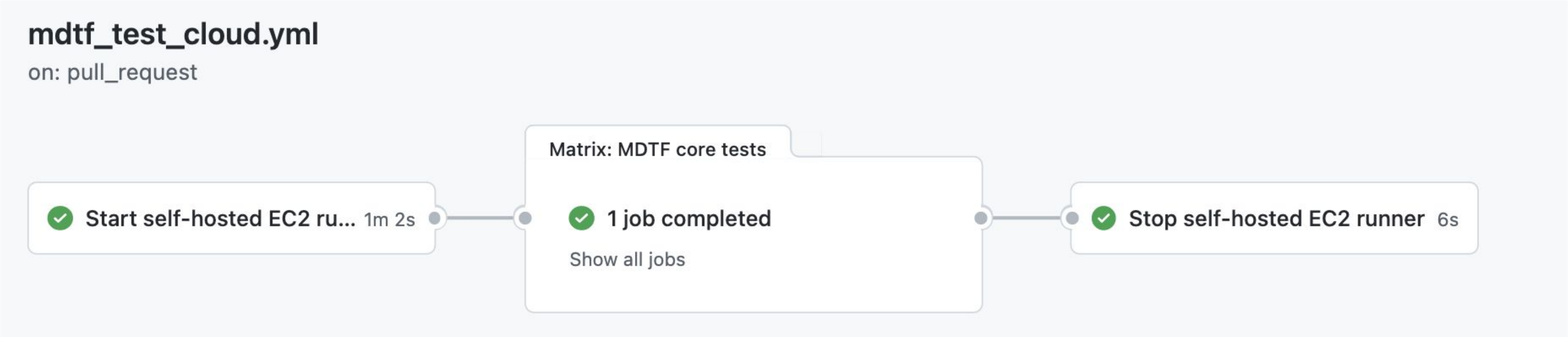
Unit testing
PODs run with synthetic model data generated by the mdtf-test-data package



LGTM software runs linter and security analysis on Python code

Use of GitHub actions and GitHub hosted runners for Continuous integration

In progress: Test#1 CI pipeline using Amazon self-hosted elastic compute cloud runners (EC2)

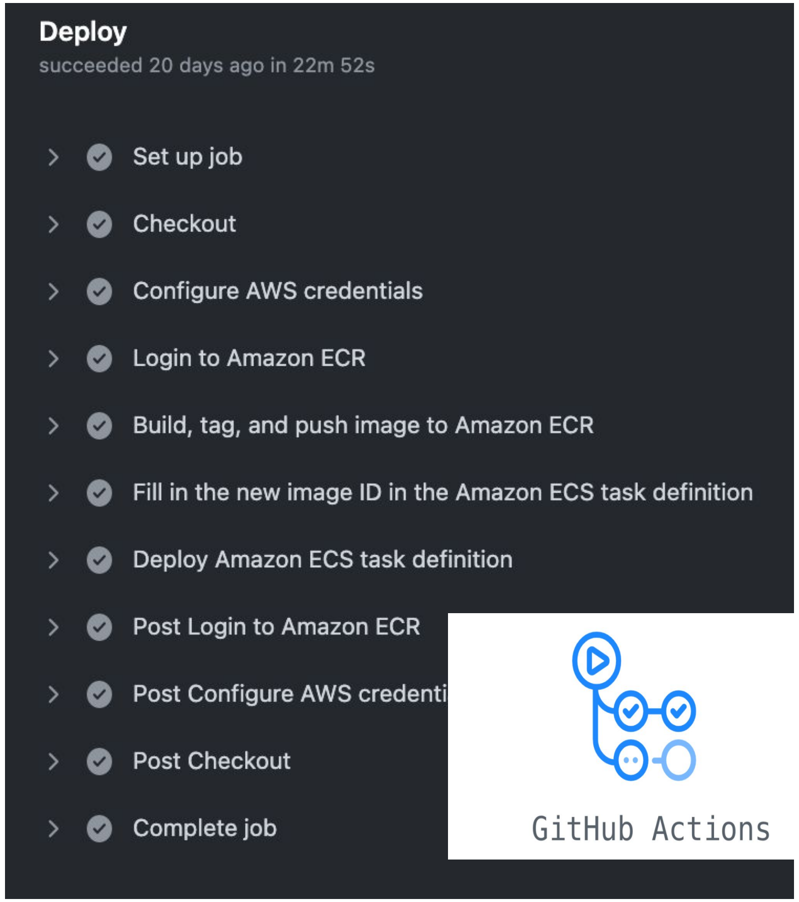


Use of elastic compute instances in AWS as self-hosted runners to explore scalable and cost-optimized solutions. Basic testing routines remain the same.

GitHub Actions

Amazon EC2

In progress: Test#2 CI pipeline using AWS ECS and CodeBuild



AWS CodeBuild

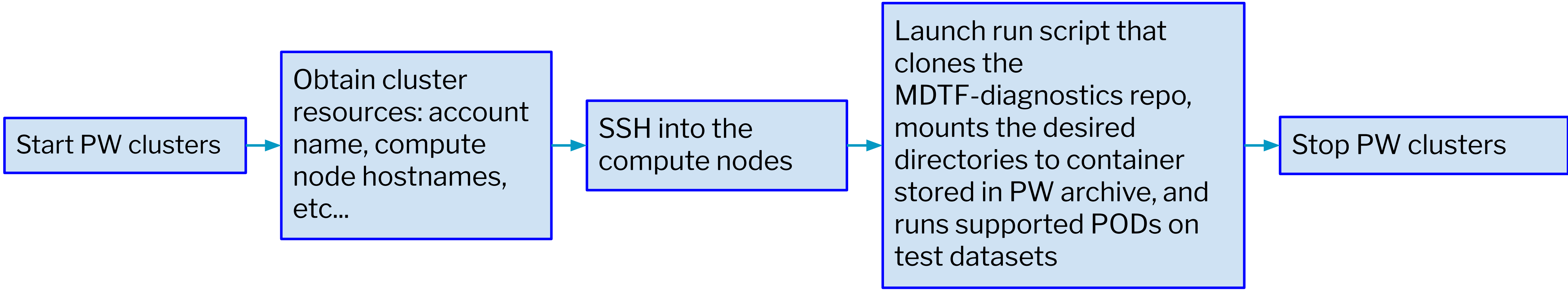
For application tests and status-reporting

Automation
Scalability
Convenience
Cost-optimized
Usability

Use of AWS Elastic Container Registry (ECR) to build/push MDTF docker image. Use of Elastic Container Service (ECS) to deploy MDTF application. Basic testing routines to be run using CodeBuild.

In progress: Test#3 CI pipeline using Google Cloud

Use of GitHub actions, Singularity containers and Google Cloud cluster in NOAA Parallelworks infrastructure to explore CI pipelines



GitHub Actions

Google Cloud

Slide credit: Jess Liptak

Part-1: Take home message

MDTF:

- Provides and Promotes unified,open frameworks for process oriented diagnostics
- Leverages use of CMOR/CF conventions
- Collaborates on metrics and diagnostic standards with CMEC
- Enables researchers focus more on actual scientific research
  - Write once, run everywhere
- Strives to simplify user experience (3Cs + D-ocumentation)
- Fosters engagement with modeling centres (NCAR, GFDL)
- Facilitates model evaluation and model development

1. MDTF framework
   Take MJO PODs for example
   Apply them to three GFDL models (AM4.0, CM4.0, ESM4.0)

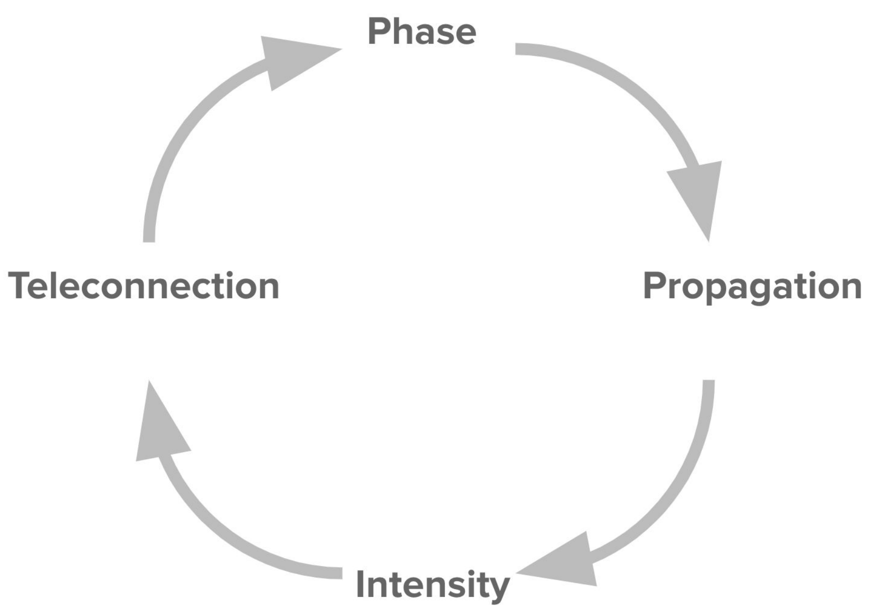
1. In-house development
   Mesoscale Convective System over North America

Acknowledgement: Y. Ming, J. Krasting, T. Jackson

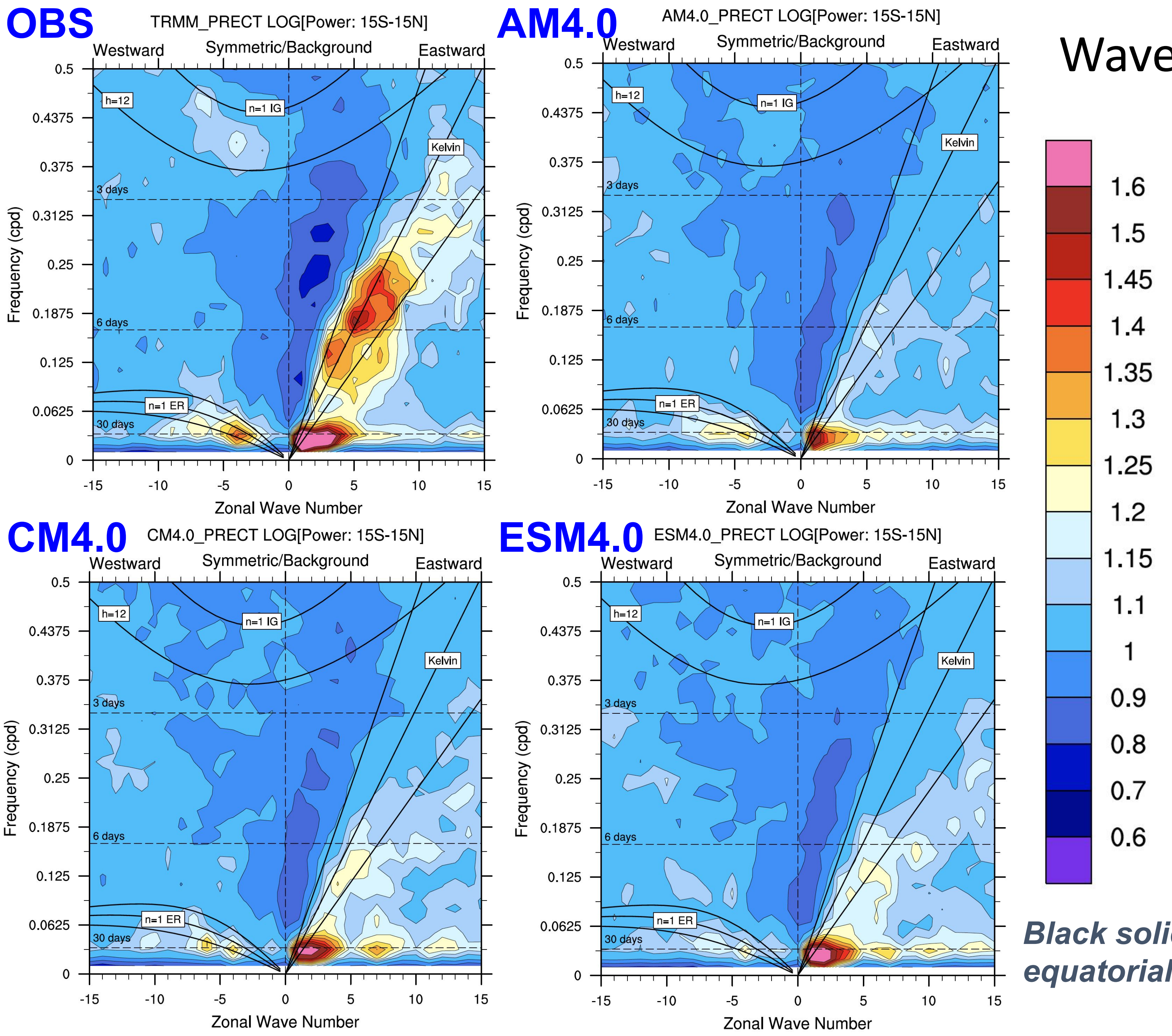
Process-oriented diagnostics (PODs)

- Convective transition
- Diurnal cycle of precipitation
- Extratropical variance
- Wavenumber-frequency spectra
- MJO prop and amp
- MJO spectra and phasing
- MJO teleconnection
- … …

MJO simulations



Wavenumber-Frequency Spectra



- **Large difference in Kelvin waves**
- **Robust MJO signal**

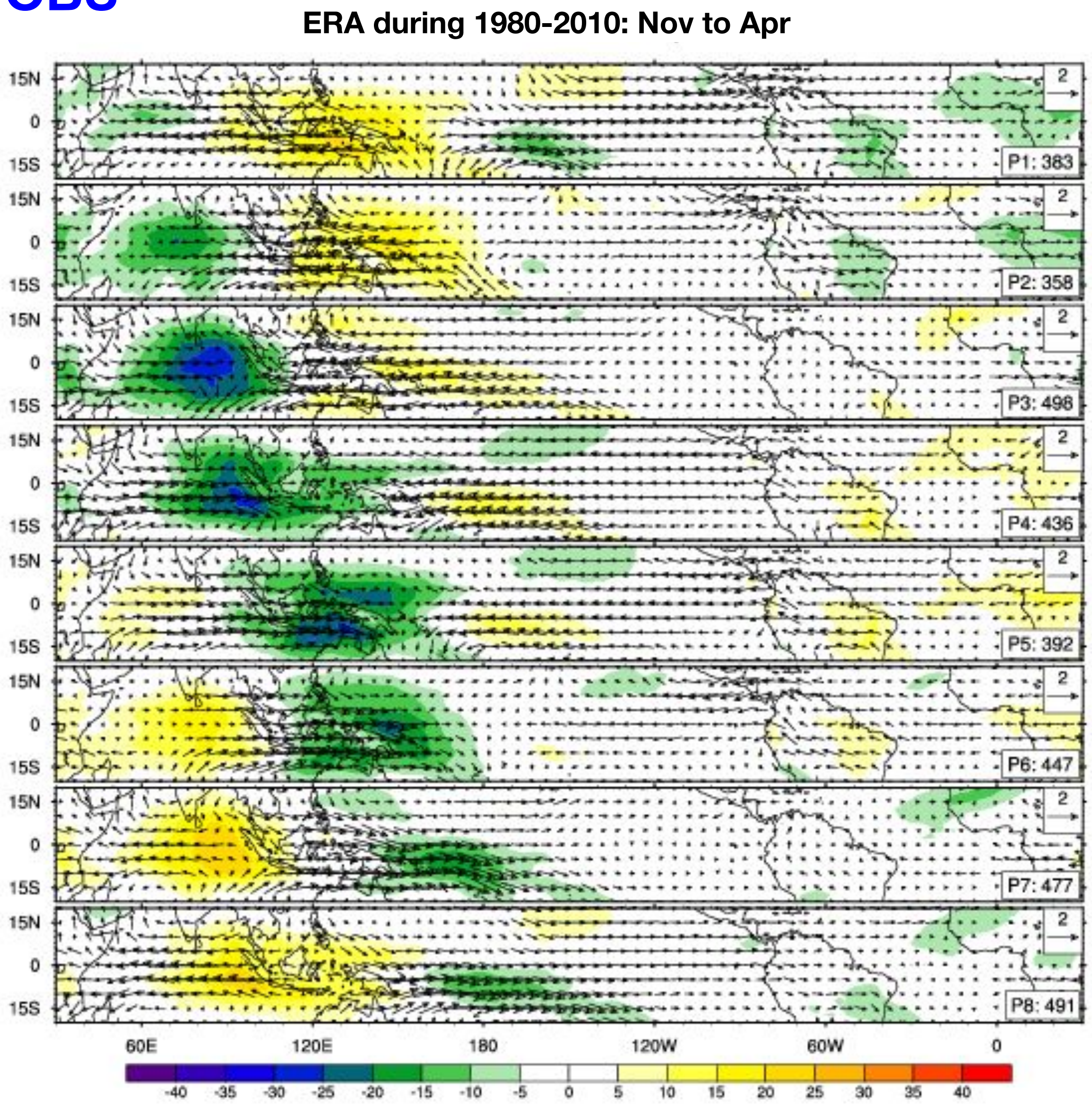
Variable(s): daily precip

Black solid lines in each plot denote theoretical equatorially trapped wave dispersion curves

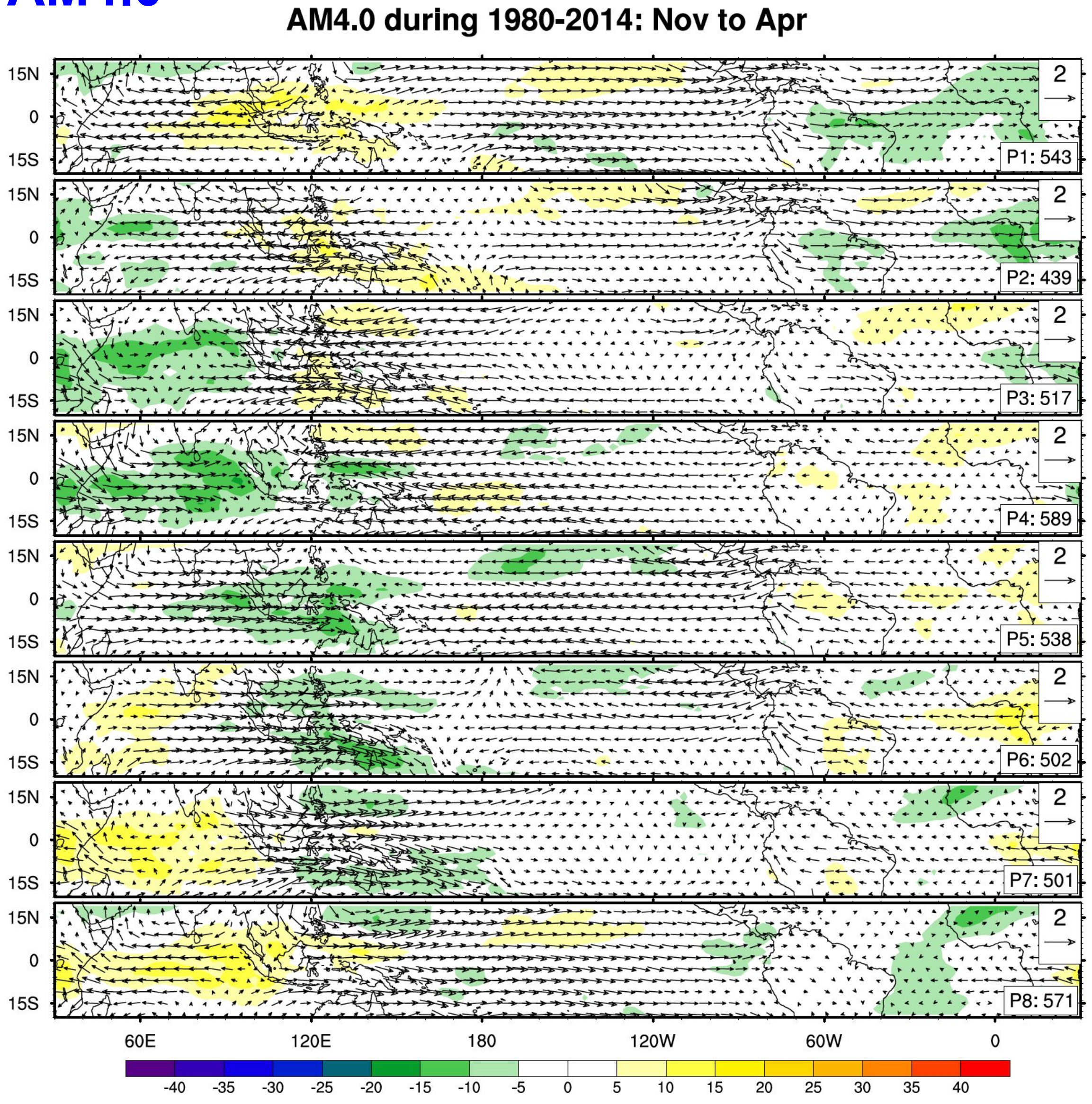
MJO Spectral and Phasing

Composite life cycle of the boreal winter MJO events

OBS

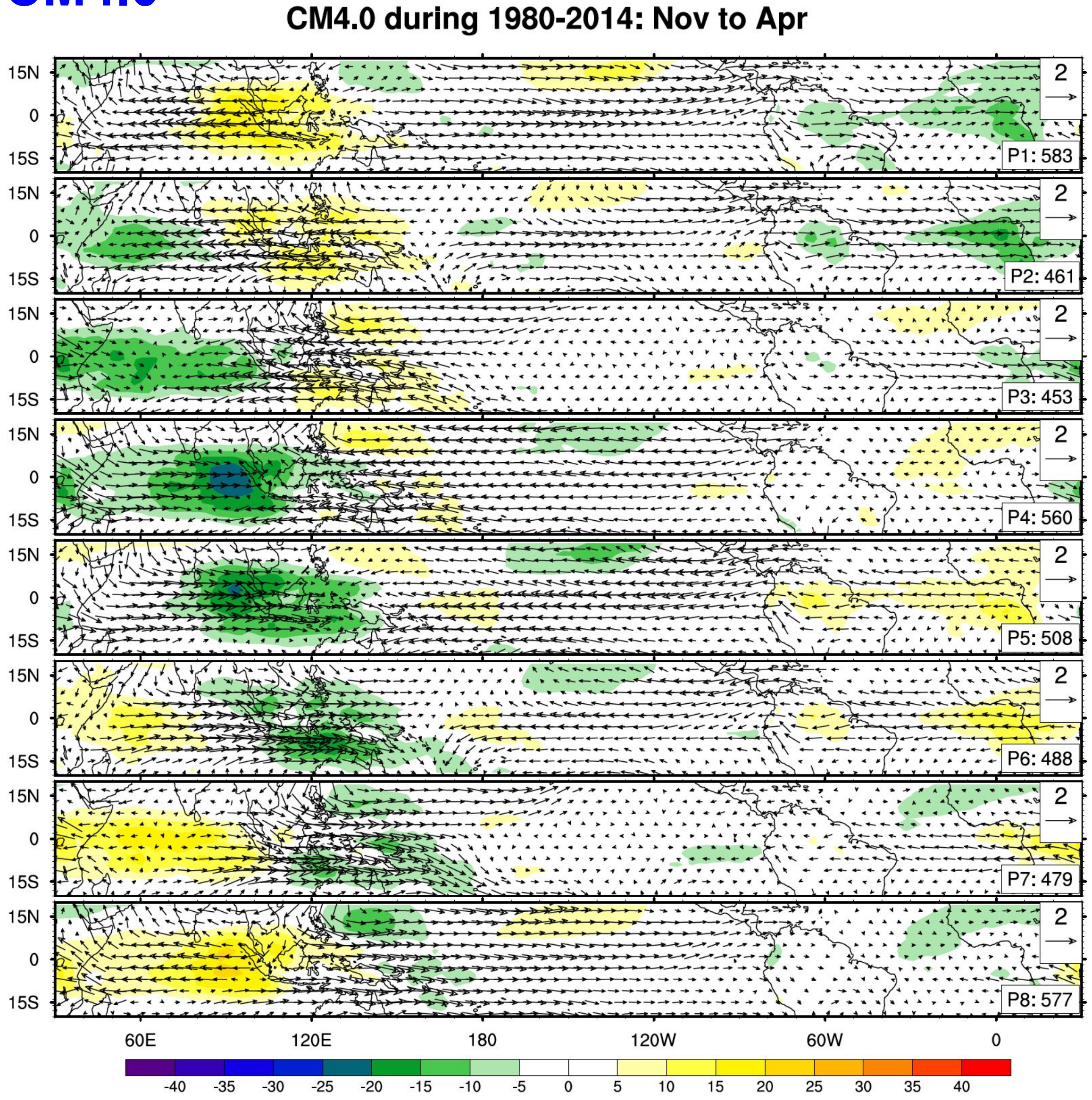


AM4.0

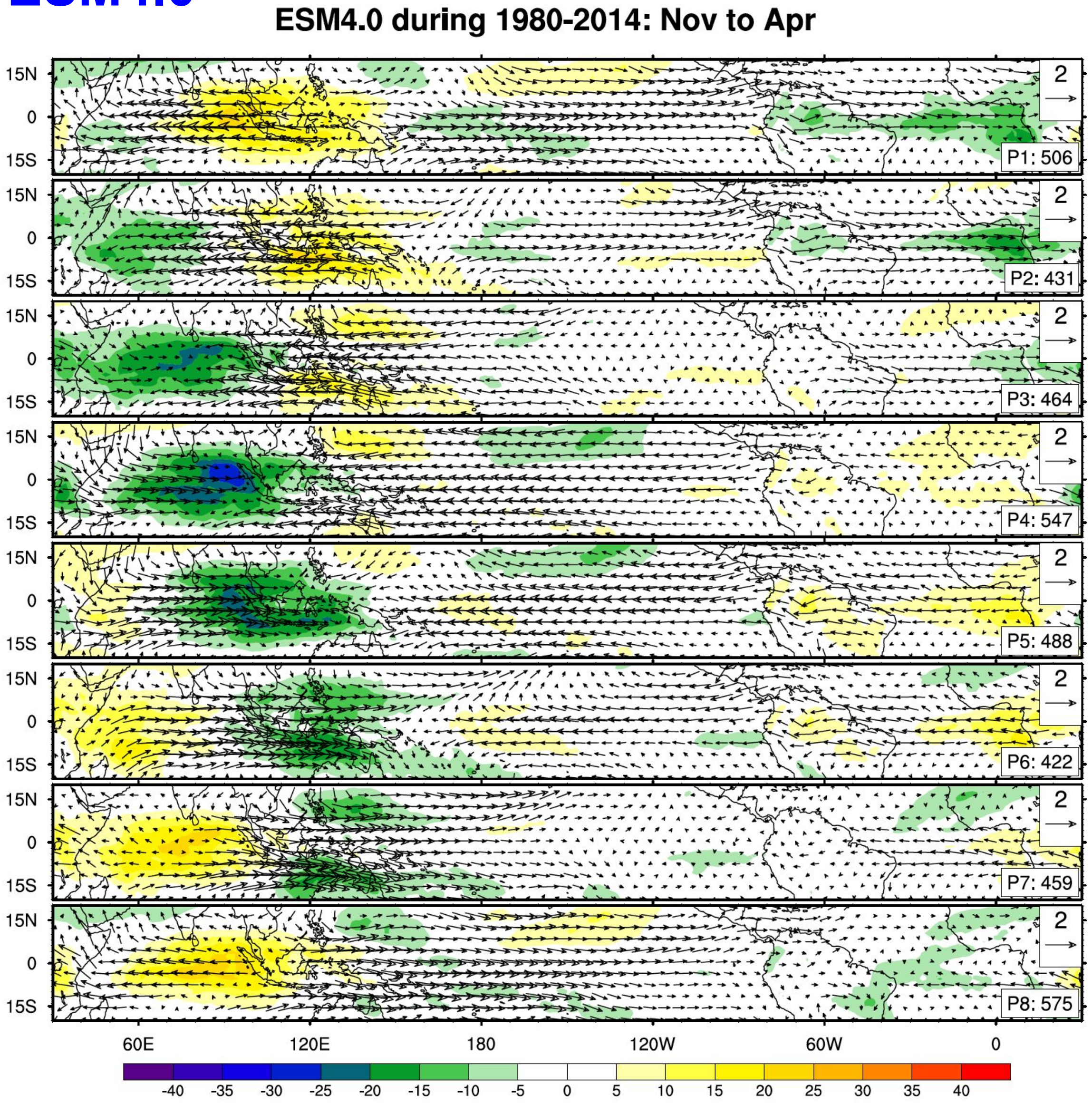


Variable(s): daily olr & uv(850 hPa)

CM4.0



ESM4.0



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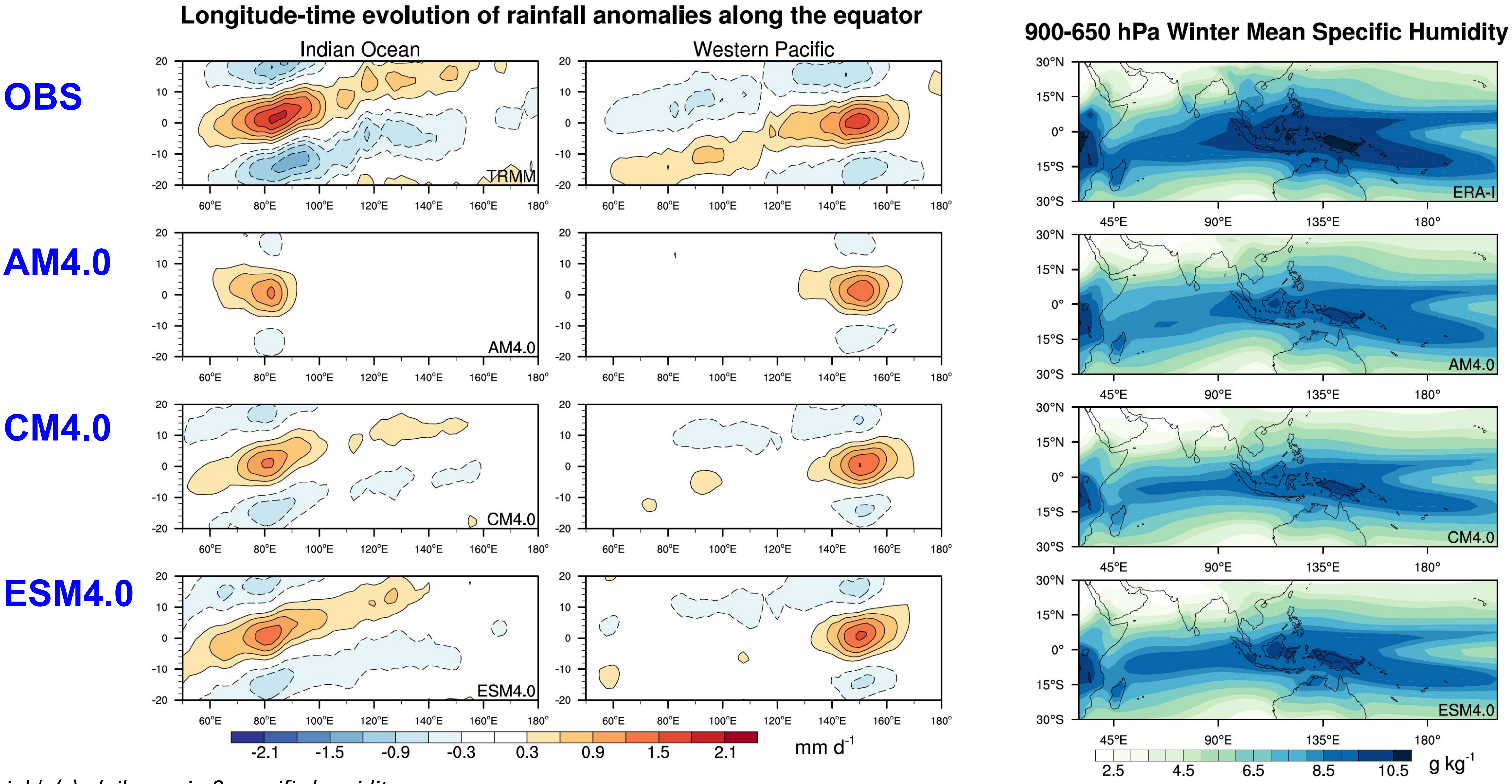
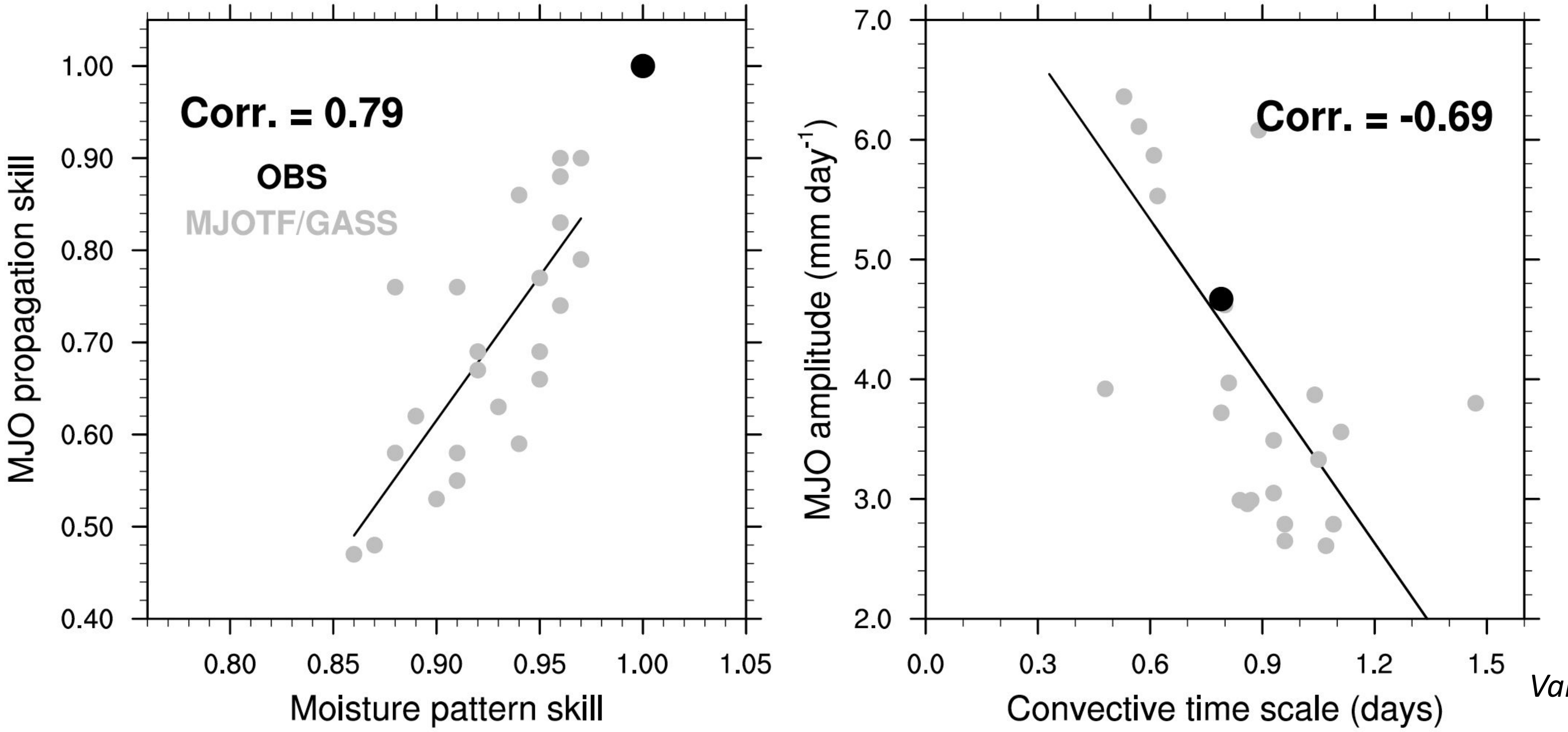
MJO Propagation and Amplitude



Variable(s): daily precip & specific humidity

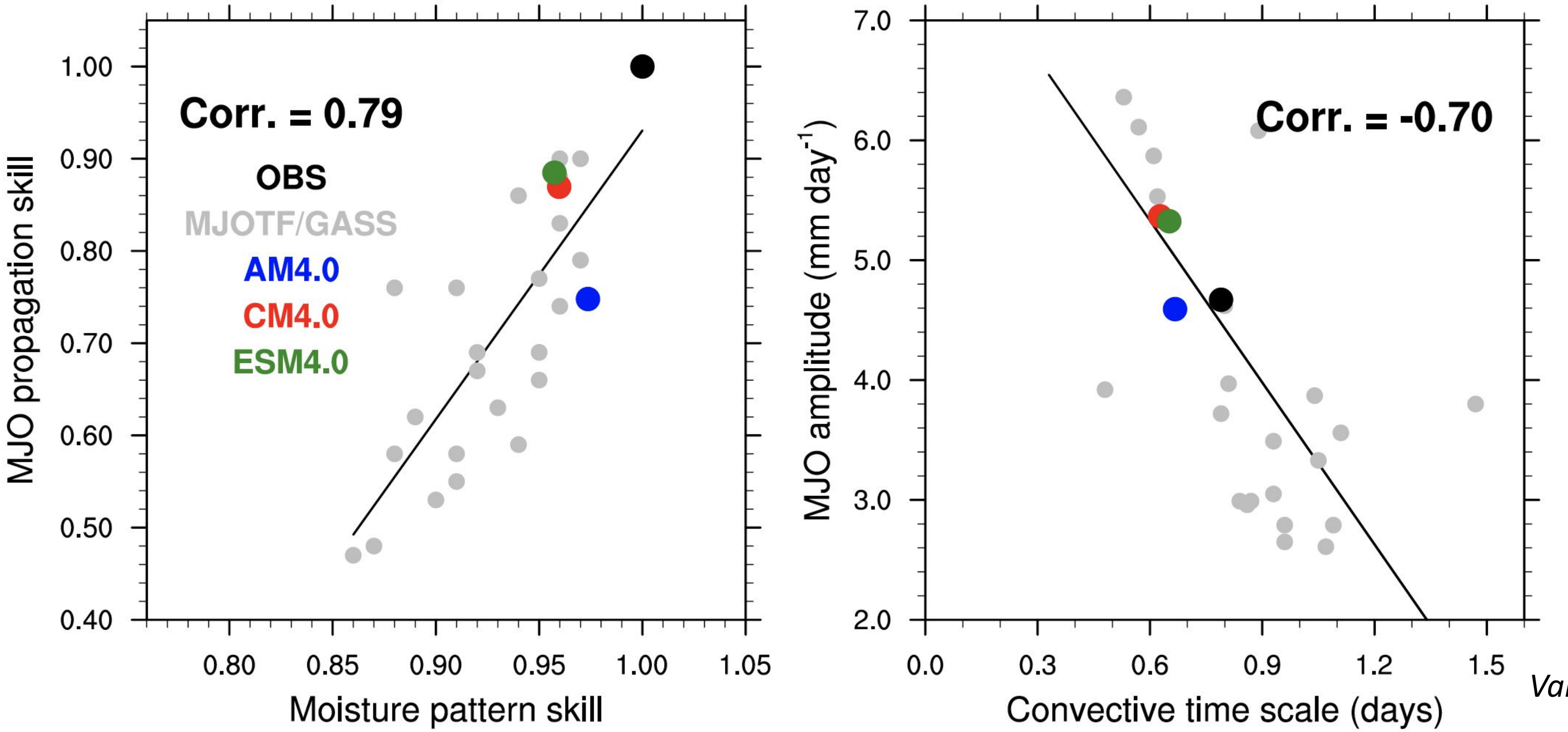


- **Better moisture +Circulation pattern >>Eastward propagation**
- **Stronger MJO amplitude >>Shorter convective time scales**

Variable(s): daily precip & specific humidity

MJO propagation skill: *pattern correlation of anomalous rainfall Hovmöller diagram*
Moisture pattern skill: *pattern correlation of wintertime moisture over Maritime Continent (20°S–20°N, 90°E–135°E)*

MJO amplitude: *the standard deviations of winter intraseasonal rainfall*
Convective time scale: *the ratio of mean precipitable water anomaly to mean precipitation anomaly over Indian Ocean (5°S–5°N, 75°E–85°E) using a regression approach*



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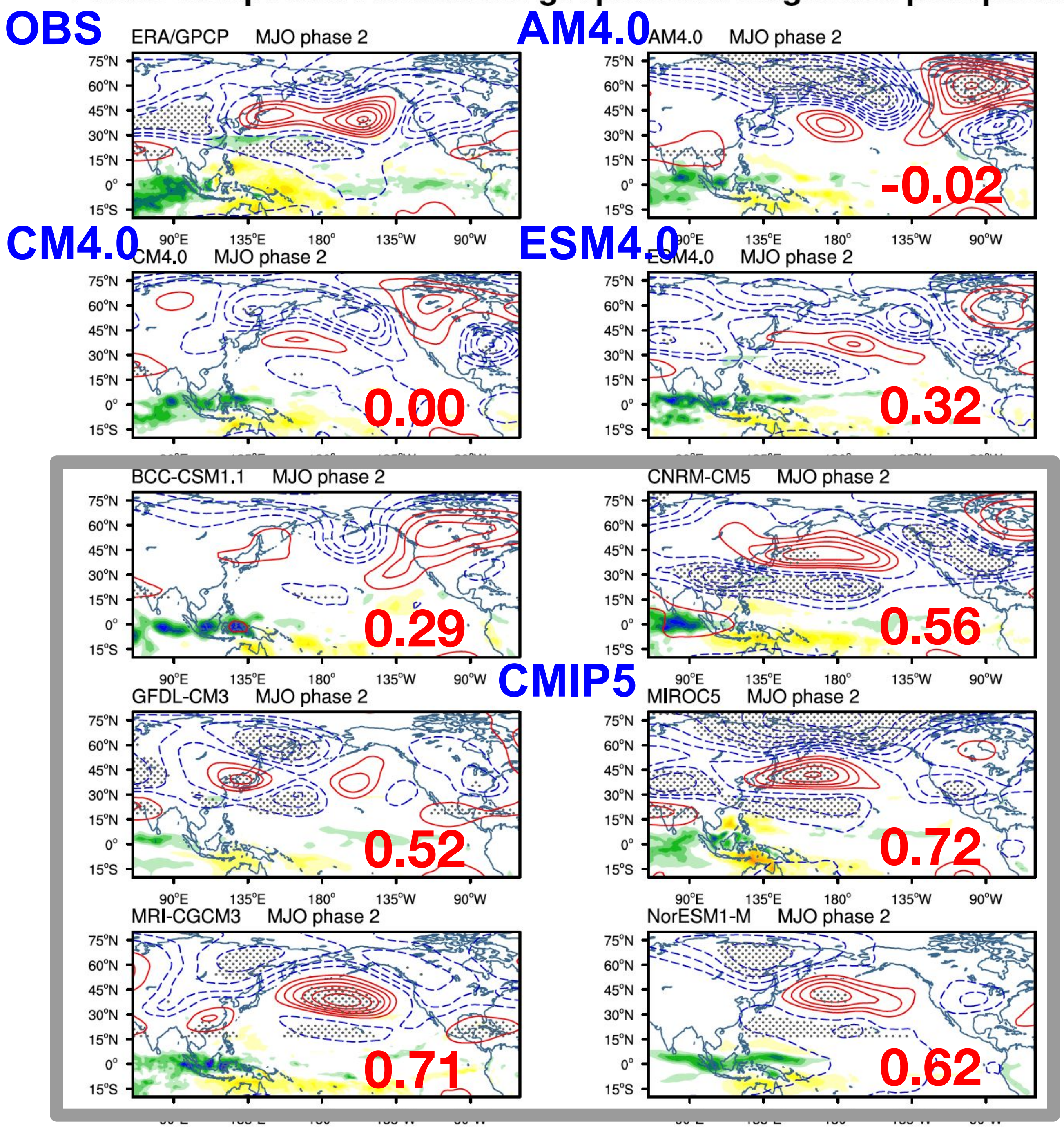
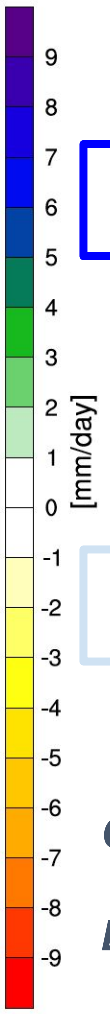
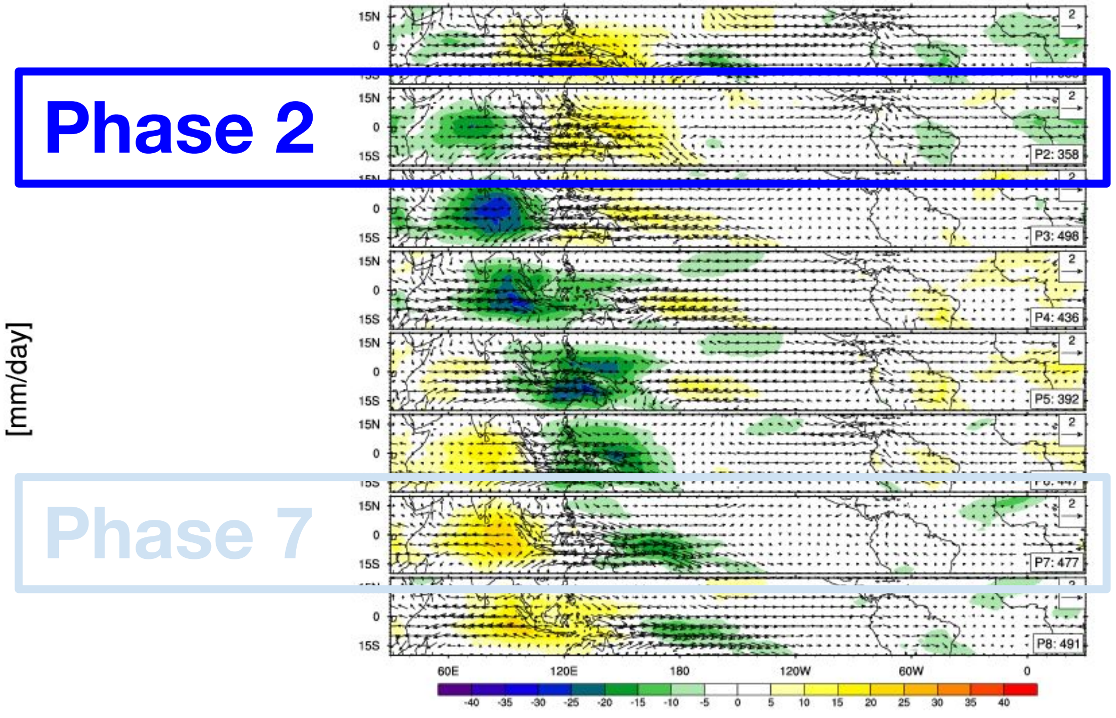
MJO Teleconnection

Variable(s): daily precip & geopotential height (250 hPa)

Phase Composite: Anomalous geopotential height and precipitation







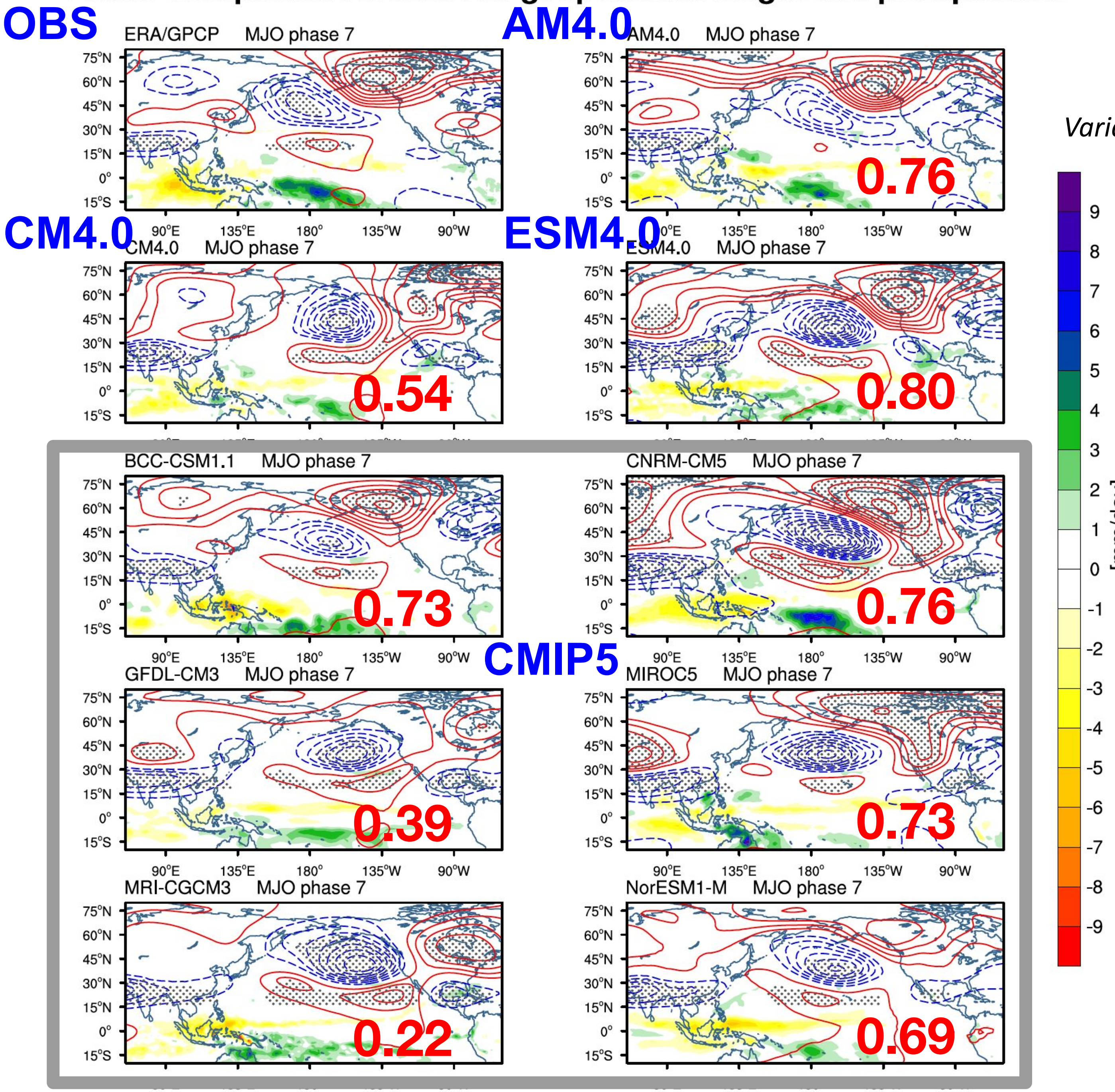
Contours: *250 hPa geopotential height anomalies (+ red solid and – blue dash)*

Dots: *anomalies that are different from zero at 95% confidence interval*

Shading: *tropical precipitation anomalies*

Number: *pattern correlation of geopotential height anomalies*

Phase Composite: Anomalous geopotential height and precipitation



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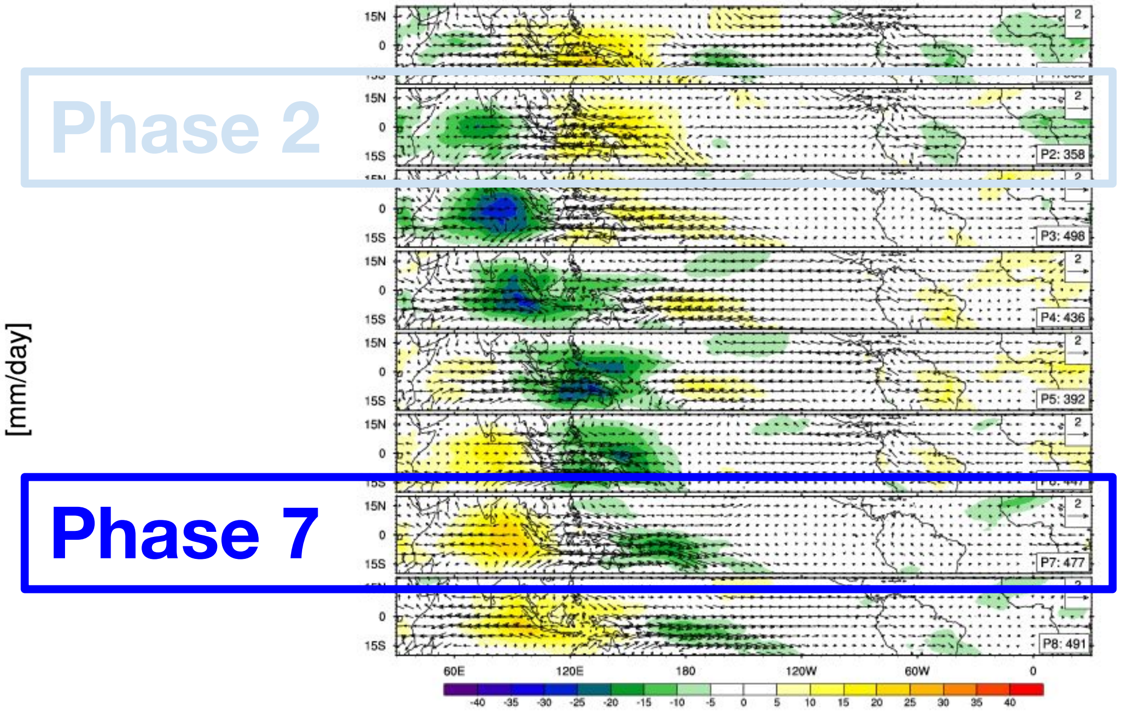

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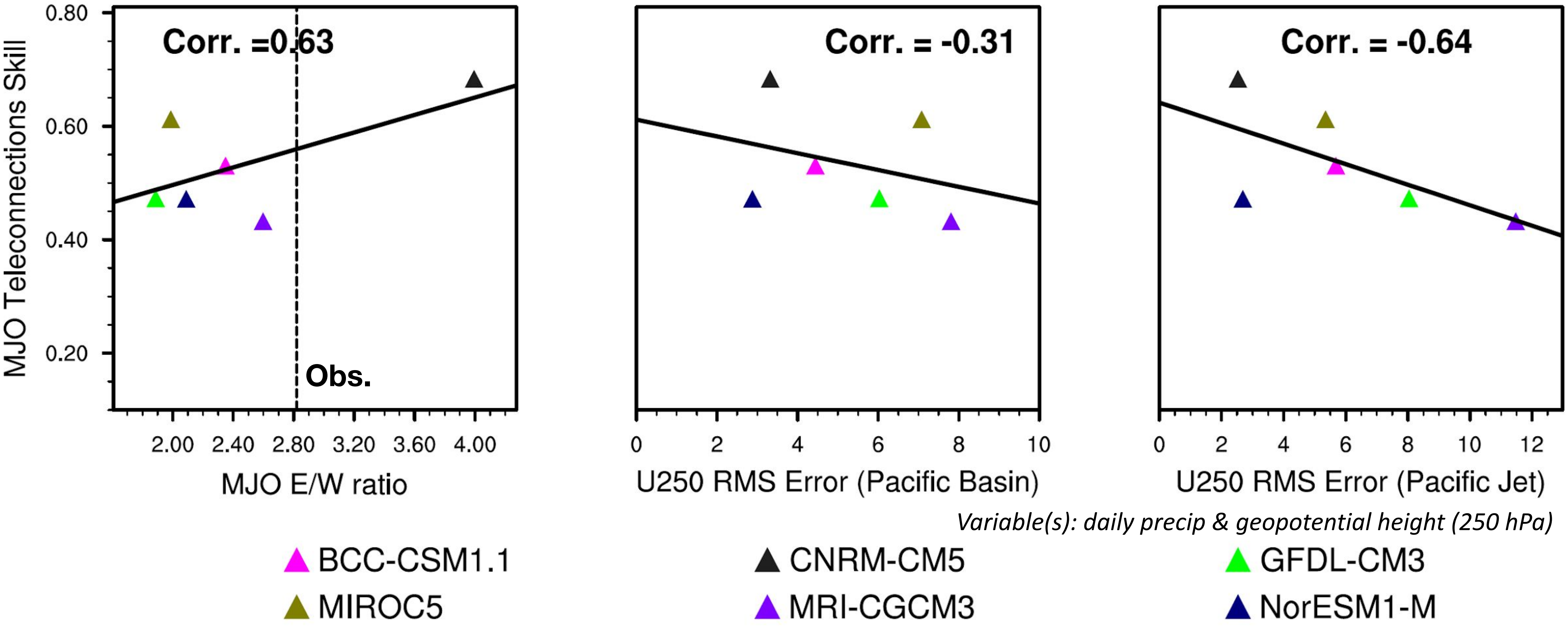
Teleconnection skill V.S. MJO skills and Mean State

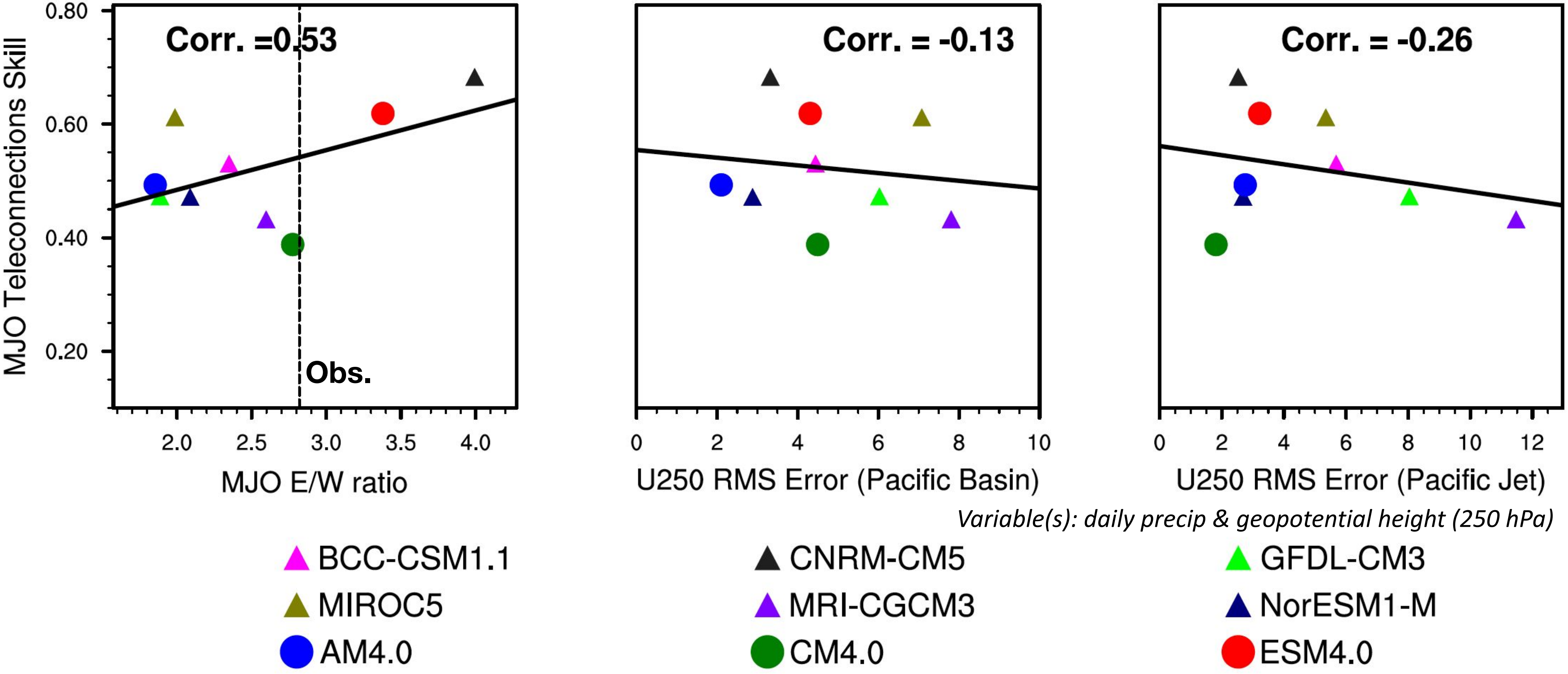


MJO Teleconnection Skill: *Pattern correlation of Z250 anomalies over 15ºN–80ºN, 130ºE–60ºW*

MJO E/W ratio: *MJO E/W wavenumber-frequency propagation power (Zonal wave number 1-3 & period 30-60 days)*

U250 RMS Error: *RMS error in longitude span of full Pacific Basin (middle) over 15ºN–60ºN, or the Pacific Jet region (right) for the good MJO models*

Teleconnection skill V.S. MJO skills and Mean State



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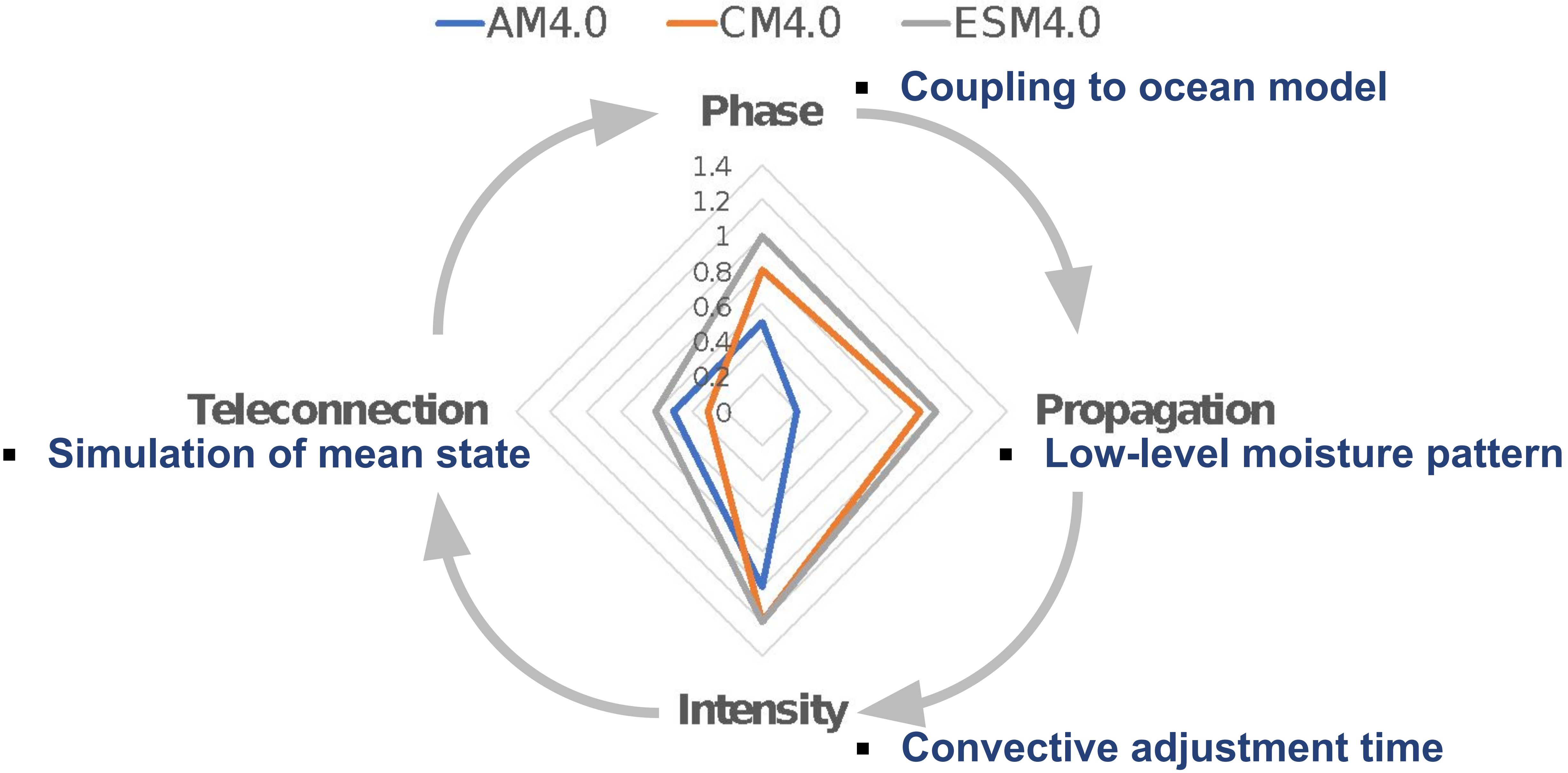
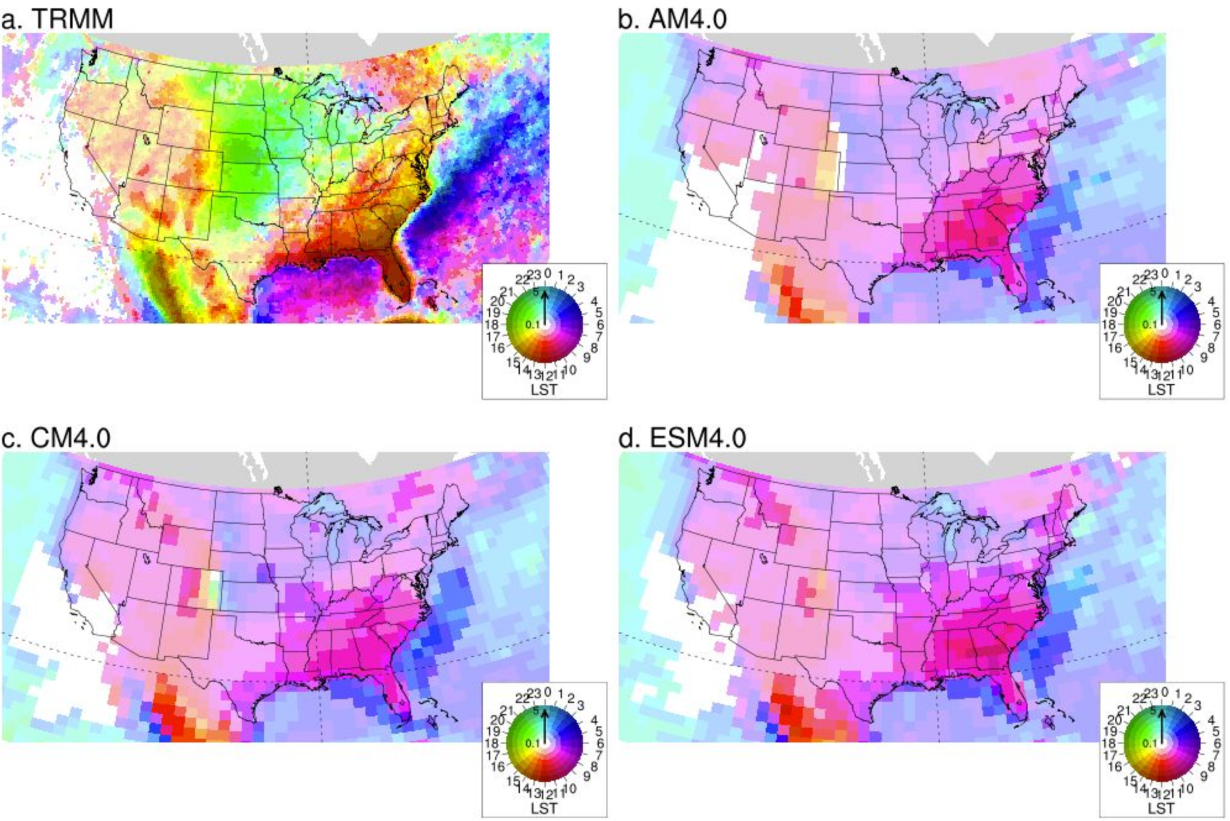
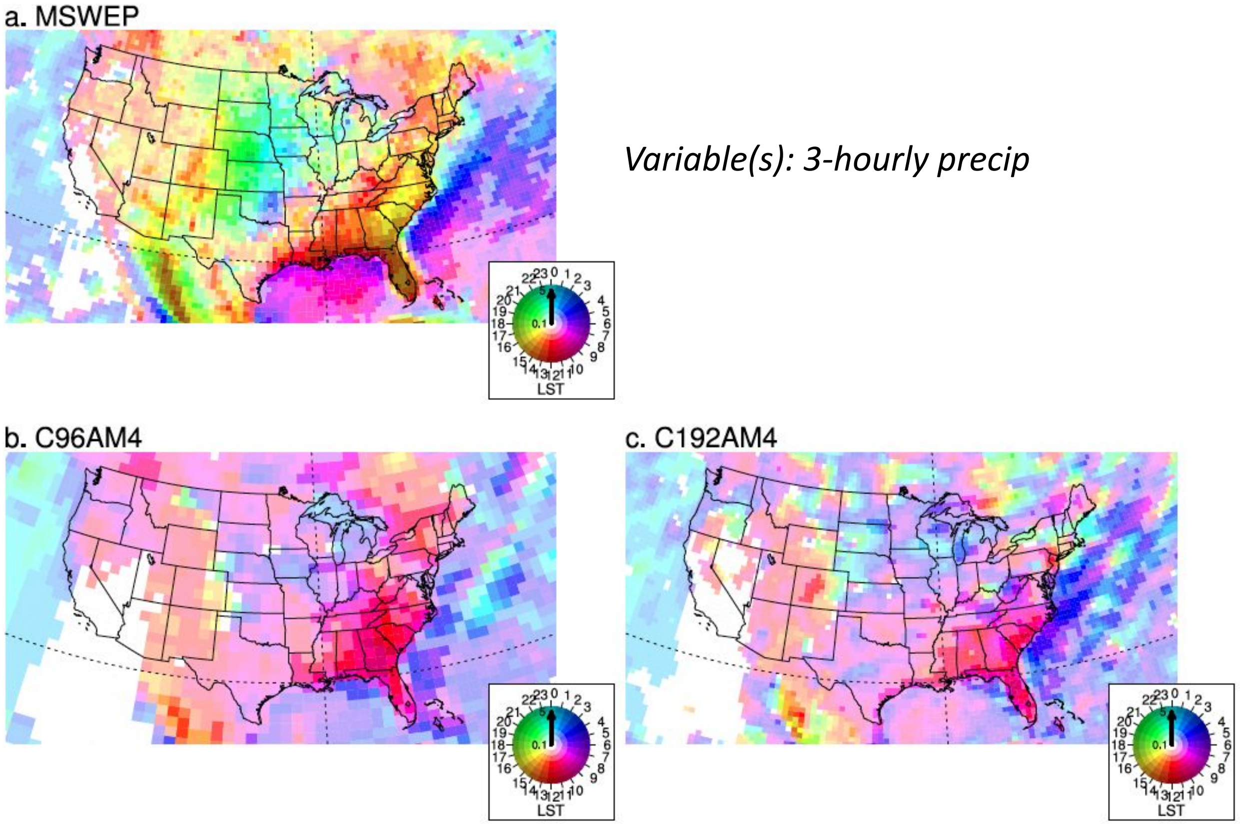
Scores of MJO simulations



Diurnal cycle of precipitation





Variable(s): 3-hourly precip

Hue: *phase of the diurnal cycle in local time*
Saturation: *amplitude of the diurnal cycle*

Data and Method

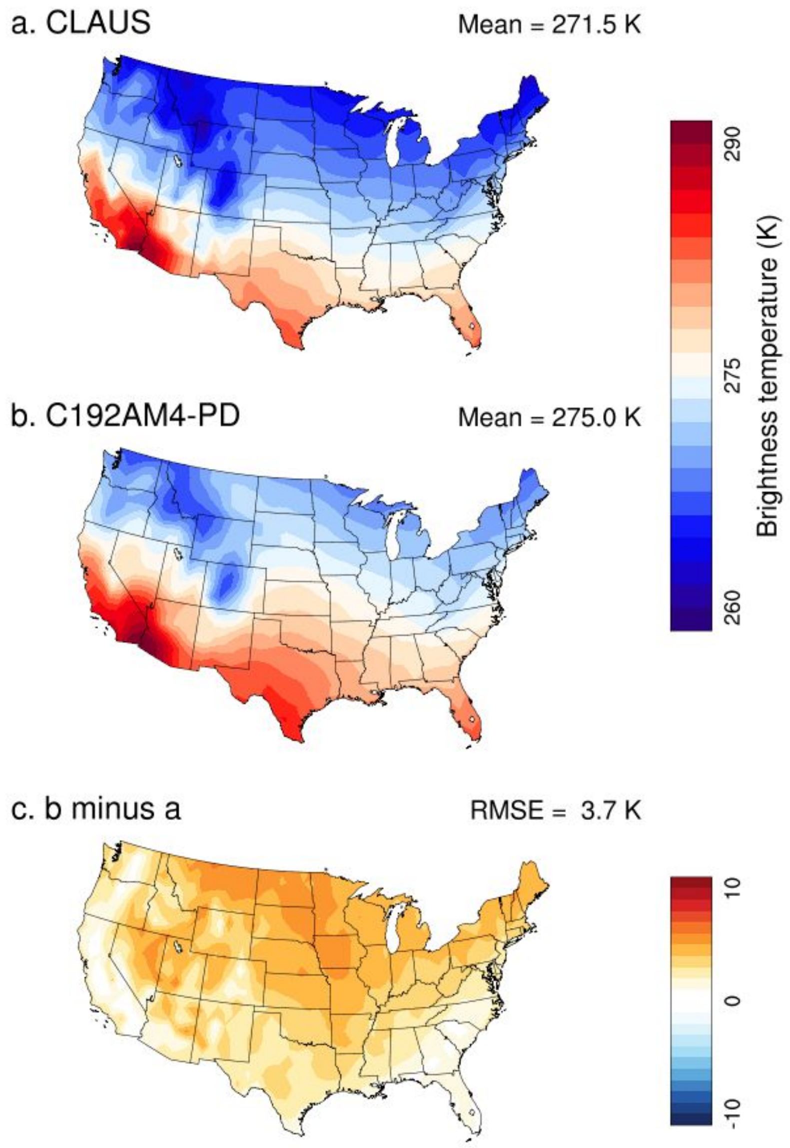
- CLAUS (1985-2008)
  3-hour ⅓ º Brightness temperature (T_b)
- C192AM4-PD (1985-2008)
  3-hour ~50 km OLR
- Conversion from *OLR* to T_b

  $T_F = T_b(a+bT_b)$ …… (1)

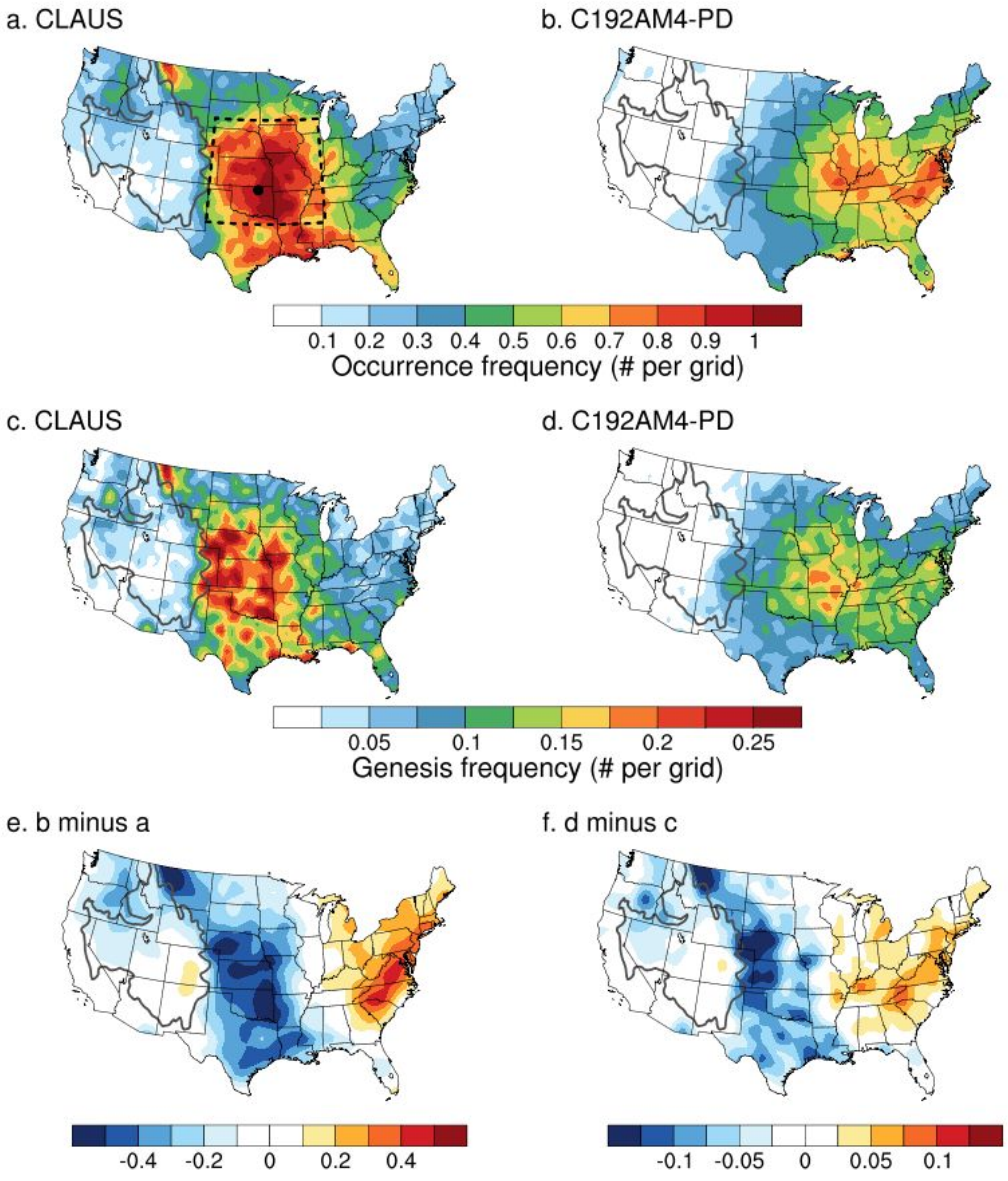
  $OLR = \sigma T_F^{\ 4}$ …… (2)

  where T_F is the flux equivalent brightness temperature, σ is the Stefan-Boltzmann constant, and *a* and *b* are empirical coefficients. a=1.228 and b= -1.106x10^{-3} K^{-1}.
- A two-step algorithm is designed to identify MCSs based on a T_b threshold and a minimum area coverage threshold, which are set at 221 K and 30,000 km^2, respectively.

Variable(s): 3-hourly olr



Dong et al., in preparation

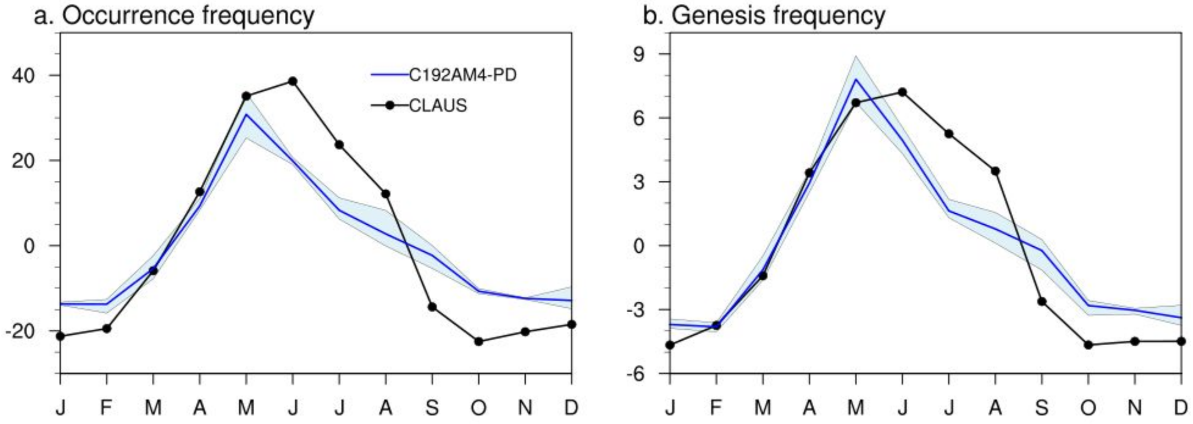


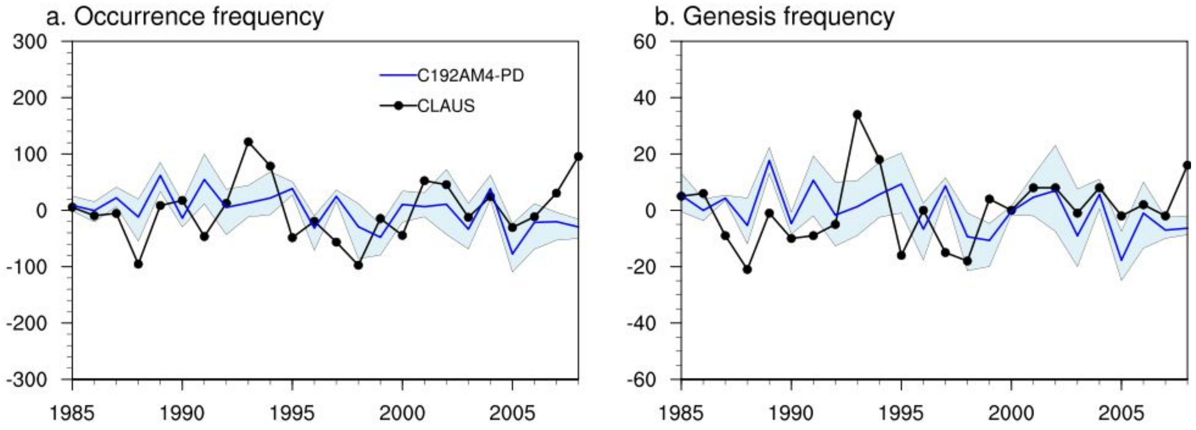
Occurrence and genesis

- Generated near the Rocky Mountain in observation
- Occurrence frequency generally follows genesis frequency
- Large bias over central US in the model

Dong et al., in preparation

Seasonality and interannual variability



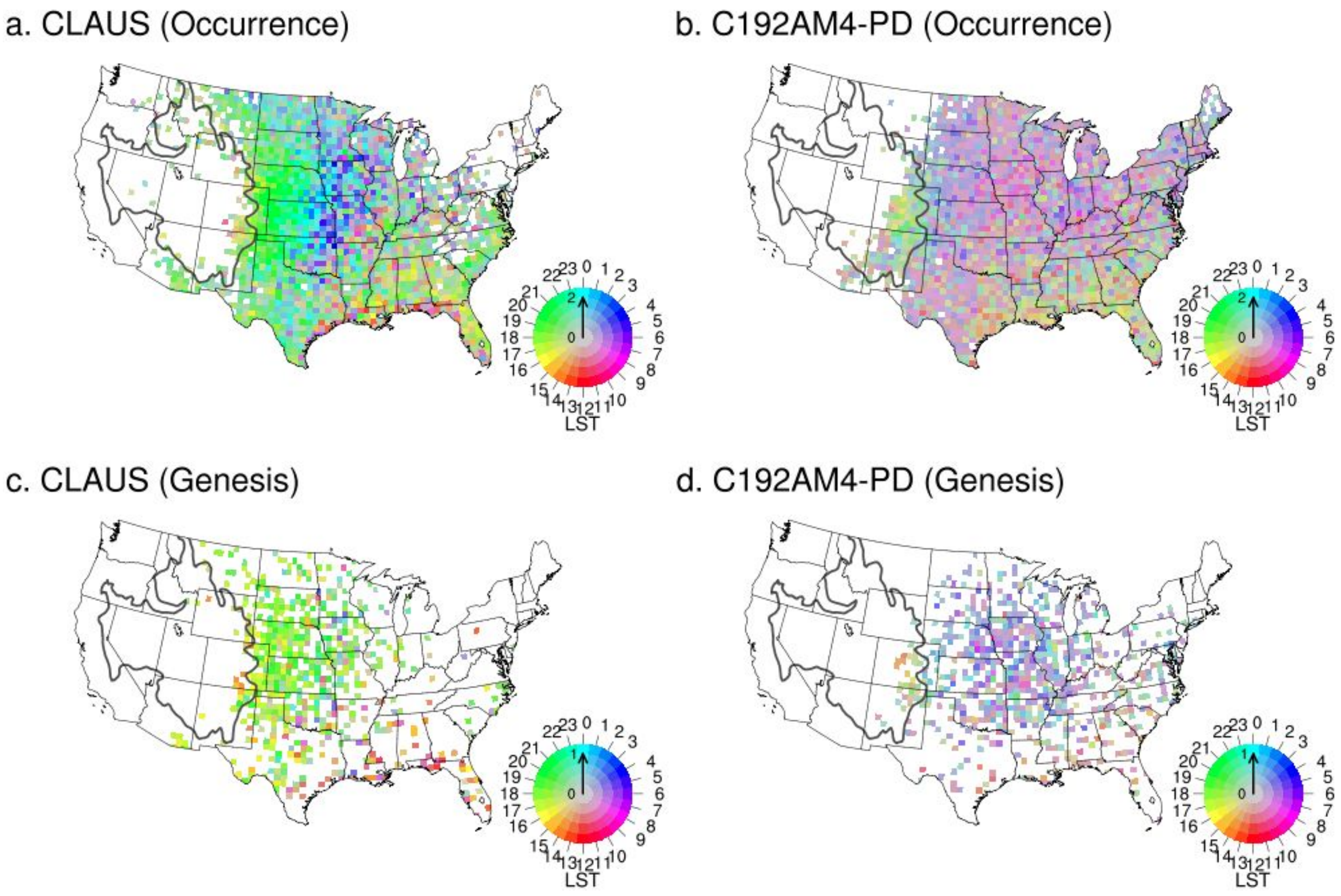


- Larger values in warm-season (Apr. - Aug.)
- Reasonable simulation of seasonal cycle

- No significant trend during 1985-2008
- The model could not capture the interannual variability

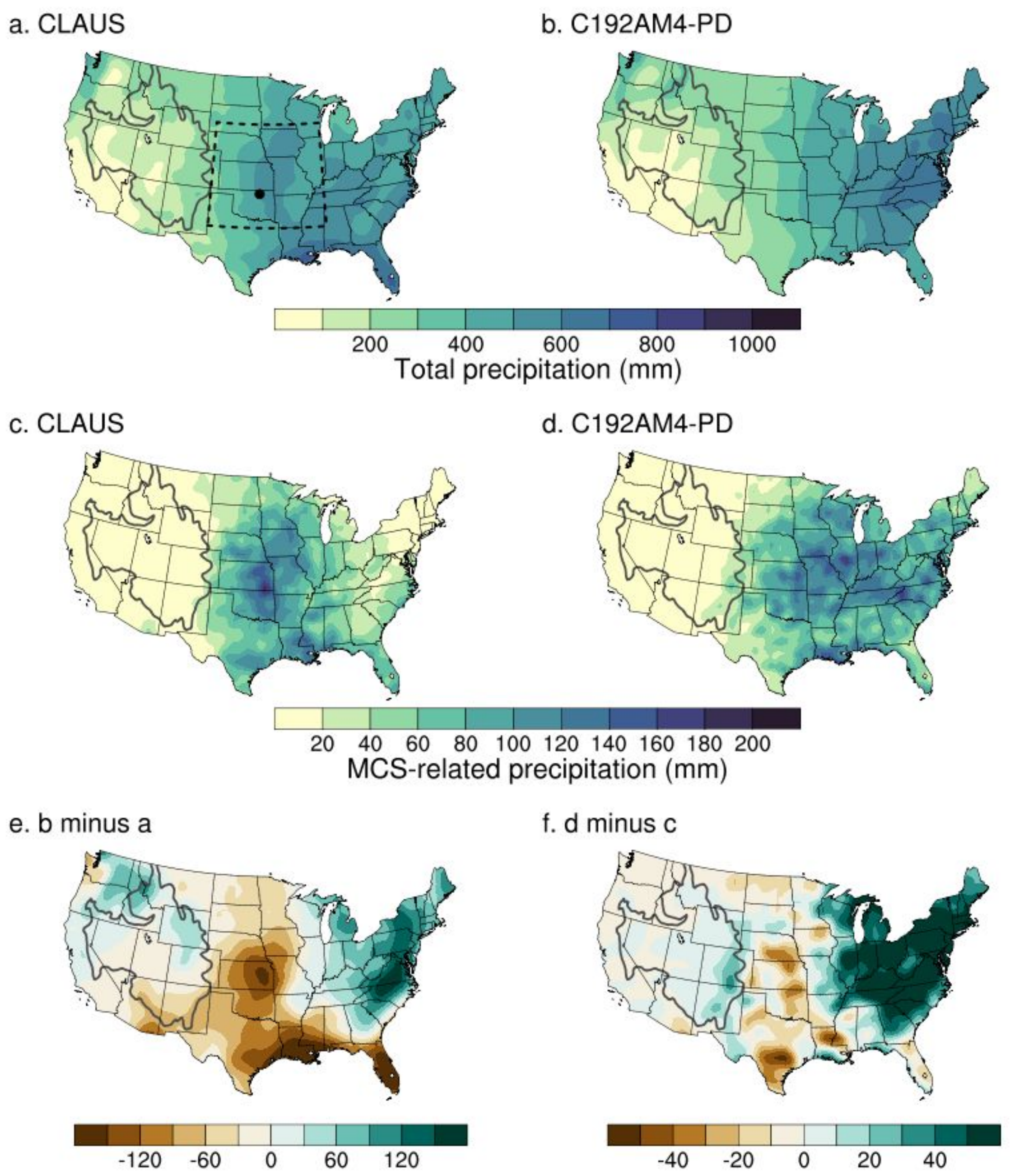
Dong et al., in preparation

Diurnal cycle



- Nocturnal peak in observation for both occurrence and genesis
- Diurnal cycle is weak in the model and the simulated peak is too early

Dong et al., in preparation



Associated precipitation

- MCS-related precipitation contributes to ~40% of the total precipitation (lower limit)
- The mean dry bias could partly attributed to the MCS-related precipitation

Take home message

- MDTF-diagnostics package is a powerful tool/resource for model evaluation and model development
  - Provides and Promotes unified,open frameworks for process oriented diagnostics
  - Leverages use of CMOR/CF conventions
  - Collaborates on metrics and diagnostic standards with **CMEC**
  - Enables researchers focus more on actual scientific research
    - Write once, run everywhere
  - Strives to simplify user experience (3Cs + D-ocumentation)
  - Fosters engagement with modeling centres (NCAR, GFDL)
  - Facilitates model evaluation and model development

- Application in GFDL Seasonal prediction model (SEPAR), CM4_MG2 model, High-resolution model development, etc.
- GFDL Atmosphere Model Task Force: to advance “seamless” atmospheric modeling at GFDL building from the two major atmospheric modeling efforts in the laboratory, namely SHiELD (weather scale) and AM4 (climate focused).
  - Adopt the AM4 framework and introduce SHiELD functionality to create a seamless system
  - Test and examine short -term forecast skill

References

MDTF-DIAGNOSTICS GITHUB REPOSITORY: https://github.com/NOAA-GFDL/MDTF-diagnostics

mdtf-test-data package: https://pypi.org/project/mdtf-test-data

Process-Oriented Evaluation of Climate and Weather Forecasting Models

From "Inspiration-driven" Research to "Industrial-strength" Research: Applying User-developed Climate Analytics at Large scale

Deploying user-developed scientific analyses on federated data archives