

# Development of an MJO testbed to support UFS global applications

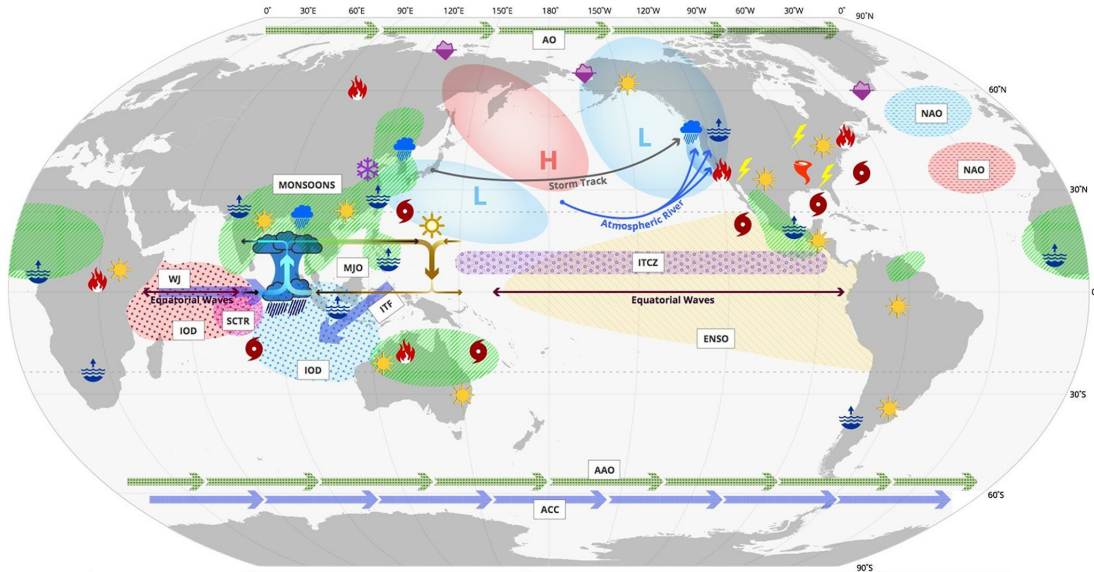
**Juliana Dias<sup>1</sup>, Maria Gehne<sup>2</sup>, Lisa Bengtsson<sup>1</sup> and Cristiana Stan<sup>3</sup>**

*1: Physical Sciences Laboratory, 2: CIRES University of Colorado, 3: George Mason University*



# What is the MJO and why is it important?

MADDEN-JULIAN OSCILLATION (MJO): GLOBAL IMPACTS

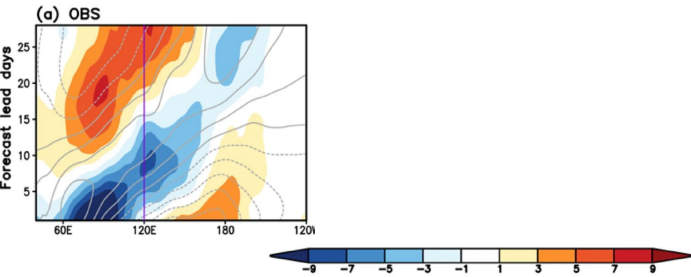


- The MJO is a prominent element of intraseasonal (30- to 90-day) variability in the tropical atmosphere that interacts with faster (weather) and slow (climate) atmospheric processes.
- The MJO is a precursor of weather events around the world, and a main source of subseasonal predictability (Weeks 2-4)

<p>eastward movement</p> <p>stormy and wet</p> <p>sunny and dry</p>	<ul style="list-style-type: none"> <li>→ Atmospheric River</li> <li>☀ Heat Waves</li> <li>⚡ Lightning</li> <li>↔ Equatorial Waves</li> <li>☁ Extreme Rainfall</li> <li>→ Storm Track</li> <li>🔥 Fires</li> <li>🌊 Flood</li> </ul>	<ul style="list-style-type: none"> <li>🌪 Monsoons</li> <li>🌊 Cold Surges</li> <li>🌊 Sea Ice</li> <li>🌊 Tropical Cyclones</li> <li>🌊 Atmospheric Circulation (AO, AAO)</li> <li>🌊 El Niño-Southern Oscillation (ENSO)</li> <li>🌊 Indian Ocean Dipole (IOD)</li> <li>🌊 InterTropical Convergence Zone (ITCZ)</li> <li>🌊 North Atlantic Oscillation (NAO)</li> <li>🌊 Oceanic Circulation (ITF, WJ, ACC)</li> <li>🌊 Seychelle-Chagos Thermocline Ridge (SCTR)</li> </ul>
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Not represented on map: Aerosol, Carbon Dioxide, Earth's Annular Momentum, Electromagnetic Field (Schumann Resonance), Length of the day, Ocean Chlorophyll, Ozone

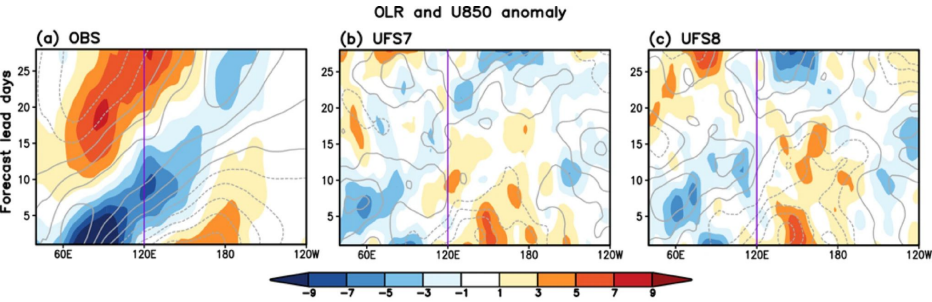
# MJO and MJO-teleconnections in UFS global applications



Phase 2 & 3 OLR and U850 composites

*Figure from Wang et al. (2025)*

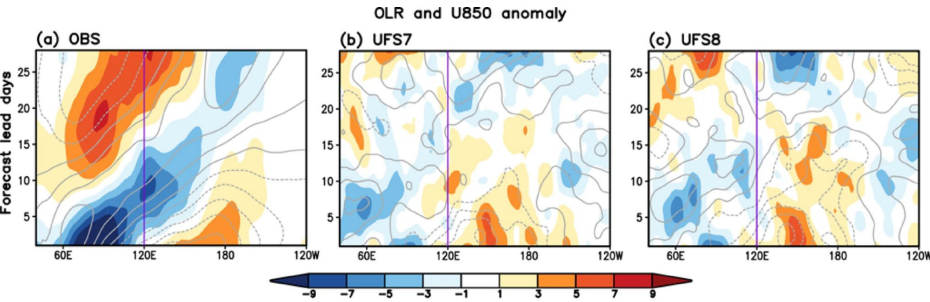
# MJO and MJO-teleconnections in UFS global applications



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The MJO, and tropical variability in general have improved in the UFS;

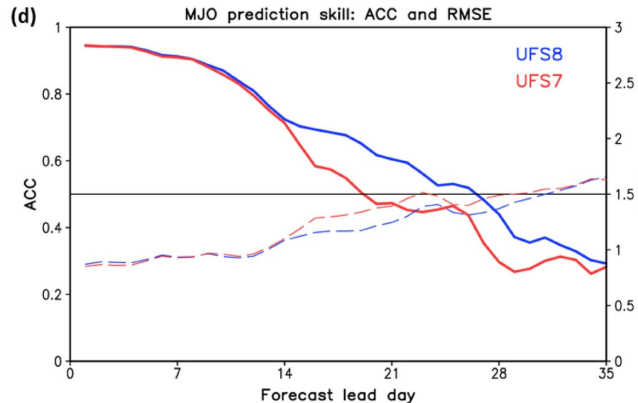


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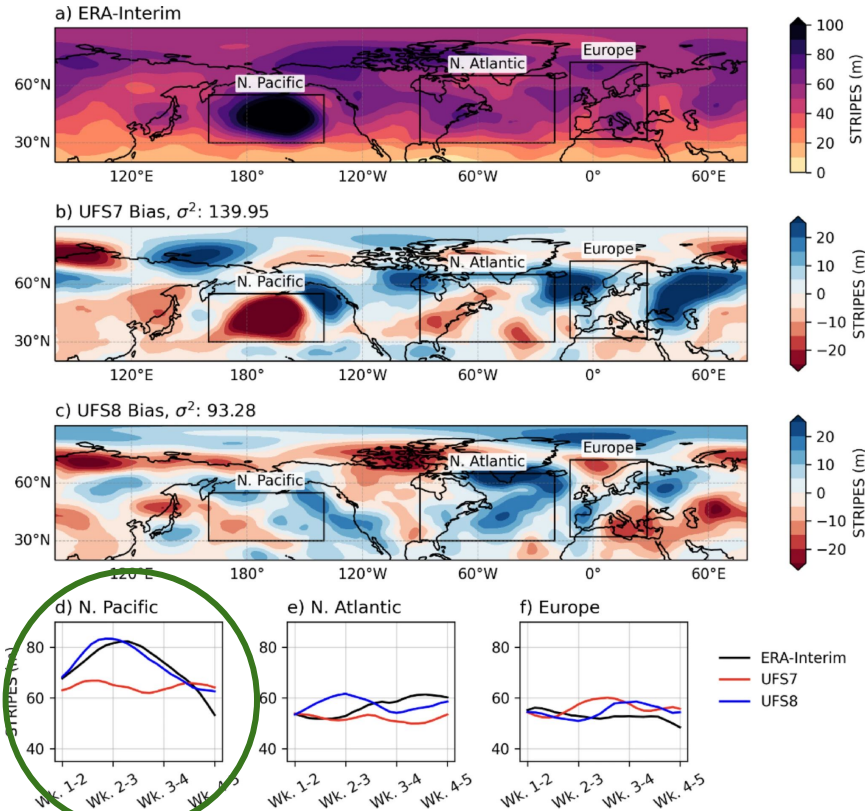
Ye et al. (2023): [Evaluation and Process-Oriented Diagnosis of the GEFsv12 Reforecasts.](#)

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# MJO and MJO-teleconnections in UFS global applications



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# MJO and MJO-teleconnections in UFS global applications

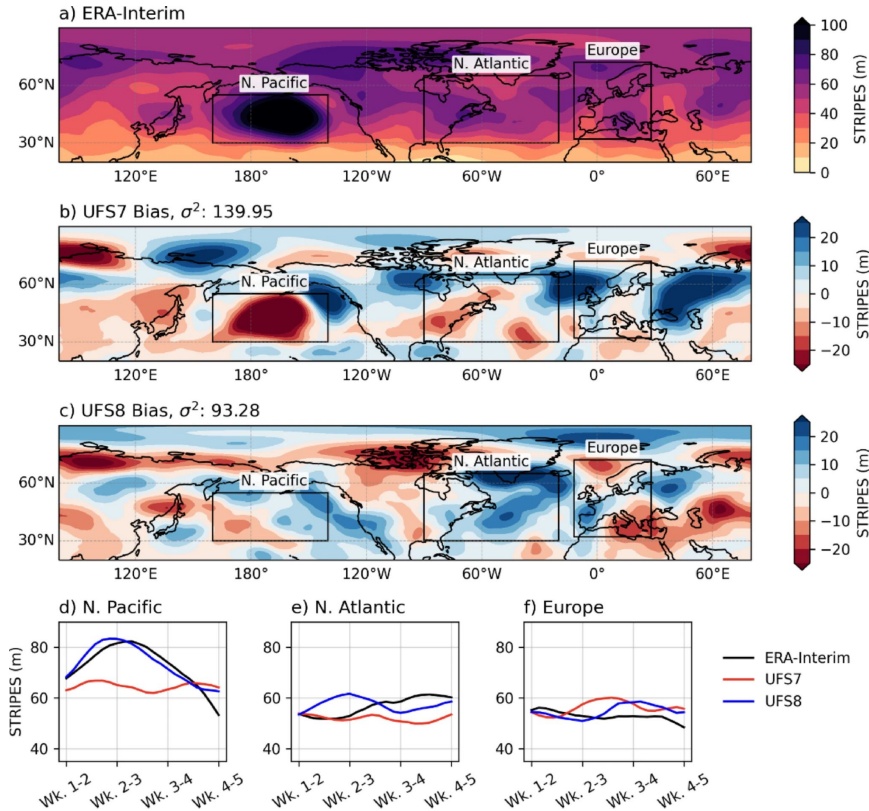


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The MJO, and tropical variability in general have improved in the UFS;

MJO teleconnections have also improved;

**MJO is still too fast and both MJO amplitude at its teleconnections are too weak**

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# How can we accelerate MJO evaluations and integrate it with model development?

Traditional diagnostics rely on long records of MJO events;

Reforecasts take a while to become available;

MJO process level diagnostics are time consuming and they rely on both domain and model expertise to be leveraged into improved predictions.

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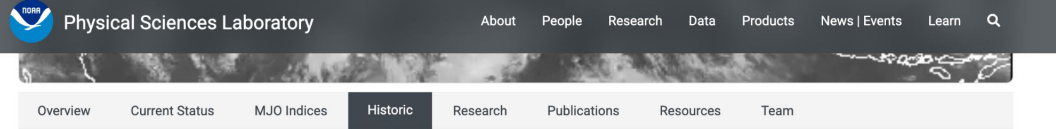
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Our goal is to establish a common set of MJO events to use a testbed for accelerating MJO improvements in UFS global applications during development stages (GEFS, SFS?)



## What we have done so far...



### MJO Historical Events

#### MJO DJF Events Tabled

The ERA5 OLR MJO Index (ERA5 OMI) is used to identify historical MJO events from 1940 to 2023. An MJO event is defined as times when OMI amplitude local maxima within a centered 30 day period that also exceeds one standard deviation (as illustrated in the schematic below). **Note:** Dias et al. 2025 discusses the use of ERA5 to characterize the MJO during the pre-satellite period. Tables with OMI events by phase can be found below.

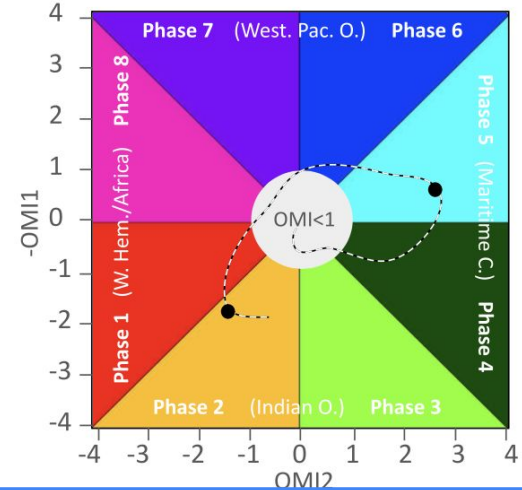
Table Guide

Use the dropdown below to select a phase and display the corresponding table:

Phase 2

LocMaxDate	OMI1	OMI2	OMI amp	OMI phase	# days to demise	phase of demise	Nino3p4	QBO
17-Jan-1942	1.2704	-0.66739	1.4350351	2,6,2	0.61	NaN		
12-Feb-1945	1.72306	-1.07276	2.0297167	2,8,1	-0.47	NaN		
11-Jan-1946	2.28387	-0.34699	2.3100789	2,8,1	-0.44	NaN		
24-Dec-1948	3.22737	-1.30028	3.4794605	2,14,5	0.38	-9.11		
18-Dec-1955	0.90314	-0.84626	1.2376664	2,4,1	-1.52	0.99		
24-Jan-1957	2.04253	-0.49531	2.1017282	2,14,4	-0.56	-10.81		
03-Feb-1958	2.73717	-0.09871	2.7389493	2,14,6	1.4	2.98		
20-Dec-1960	1.80589	-1.47958	2.3346083	2,14,5	0.02	-10.83		

MJO events are defined by local peaks in OMI amplitude

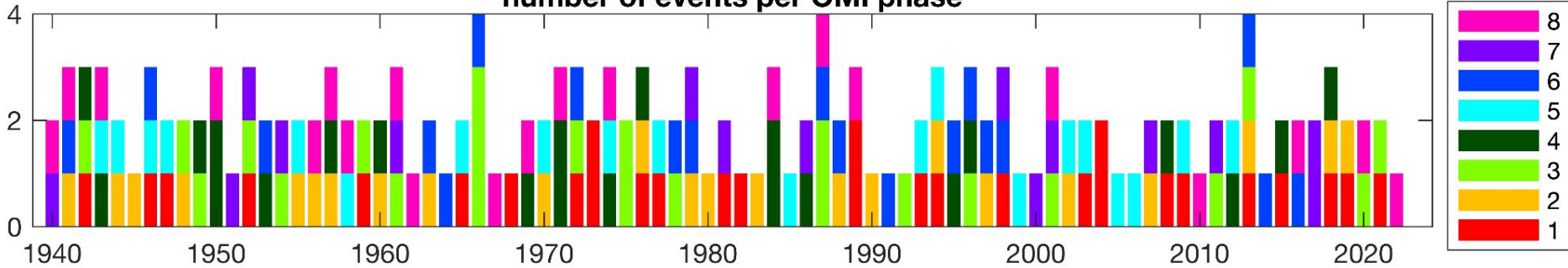


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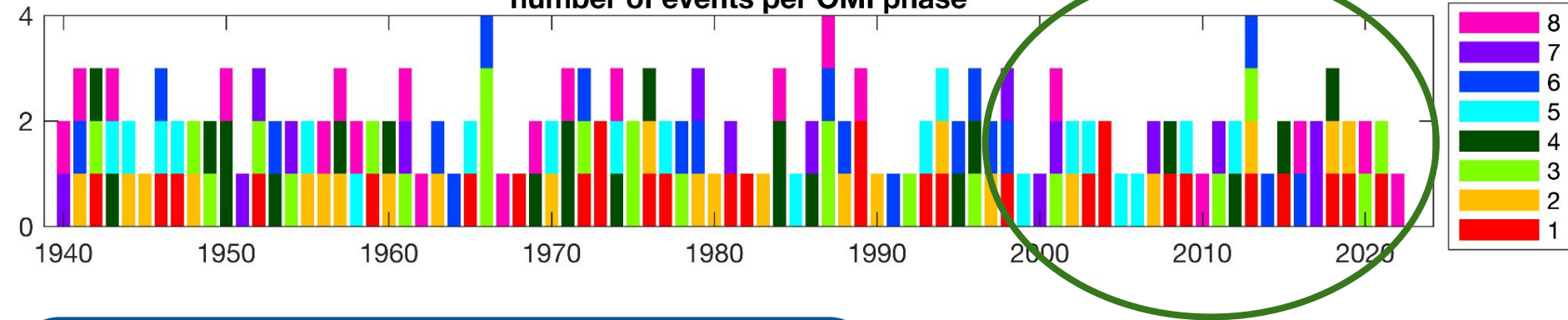
number of events per OMI phase



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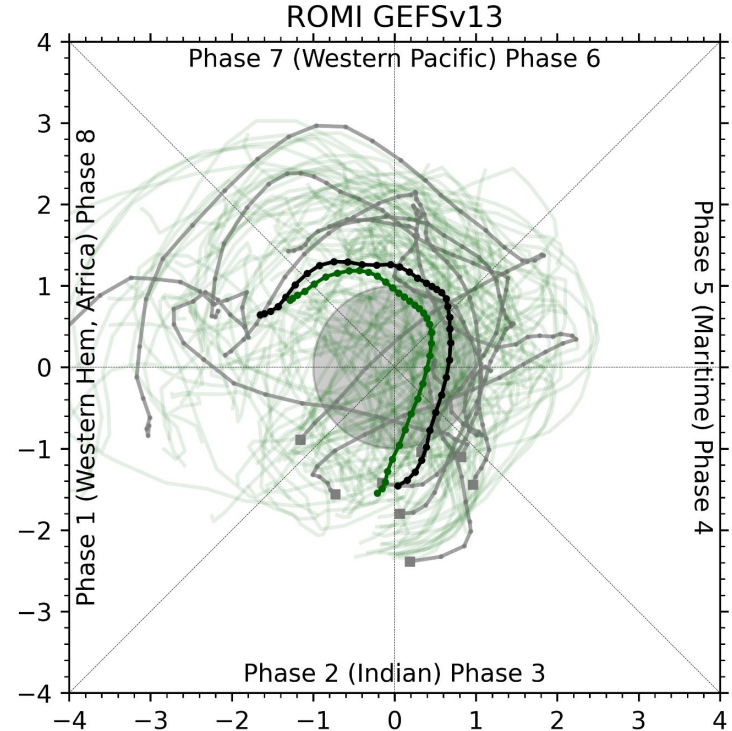
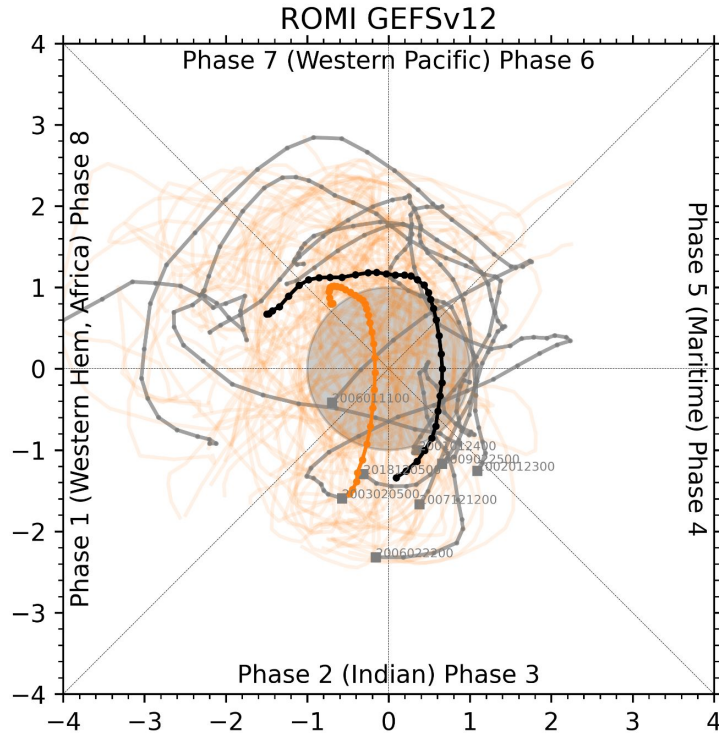


Sample sizes are small, for example, there are 12 MJO events that peak during phases 2 & 3 that also overlap with the available GEFSv13 reforecasts, if we want to compare those to GEFSv12, then there are 8 events.

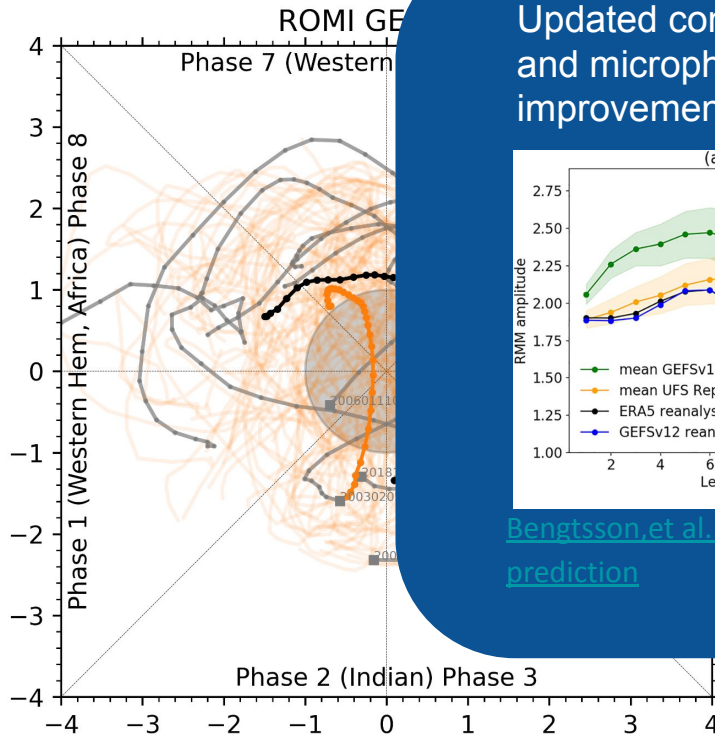
<https://psl.noaa.gov/mjo/>

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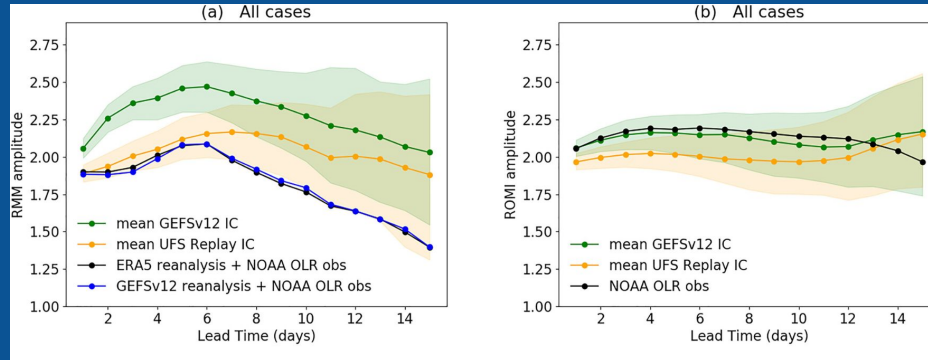
# MJO performance in the GEFSv13 vs GEFSv12



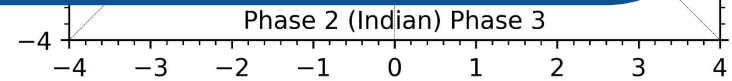
# MJO performance in the GEFSv13 vs GEFSv12



Updated convection scheme, PBL scheme and microphysics scheme are likely contribute to MJO improvements, but IC are also important!

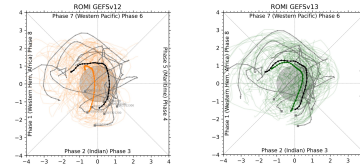


[Bengtsson, et al. \(2025\). The crucial role of the initial state in MJO prediction](#)

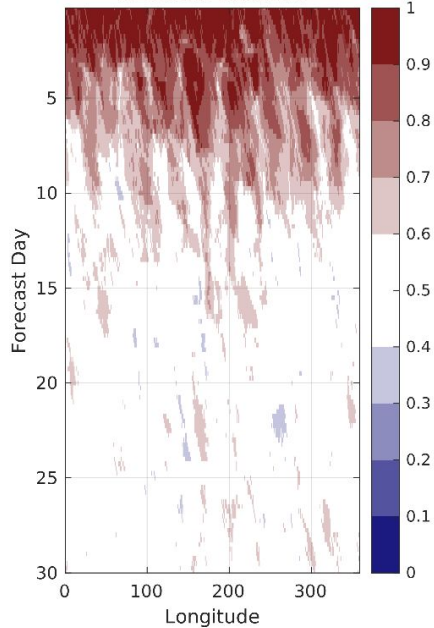


# MJO teleconnections might also have improved

(average V200 hit rates between 35°N-55°N)



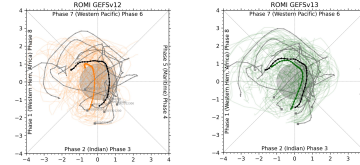
GEFSv13 Hit Rate



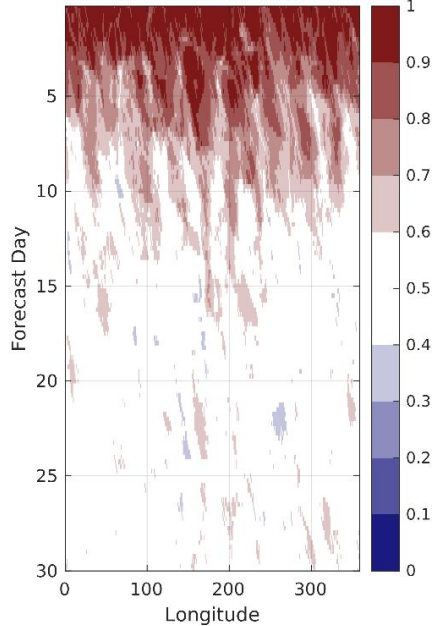
**Hit:** V200 anomalies in ERA5 and forecast match sign

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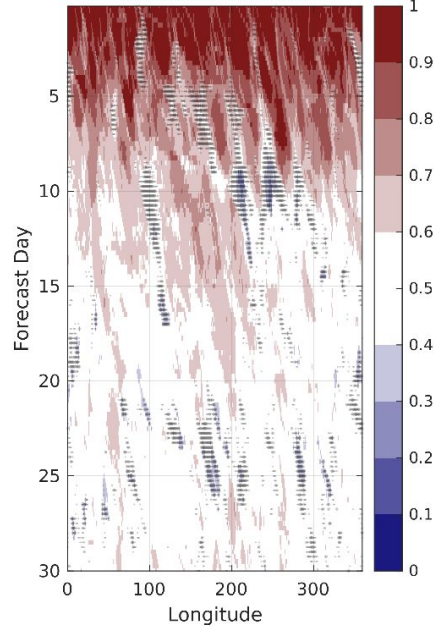
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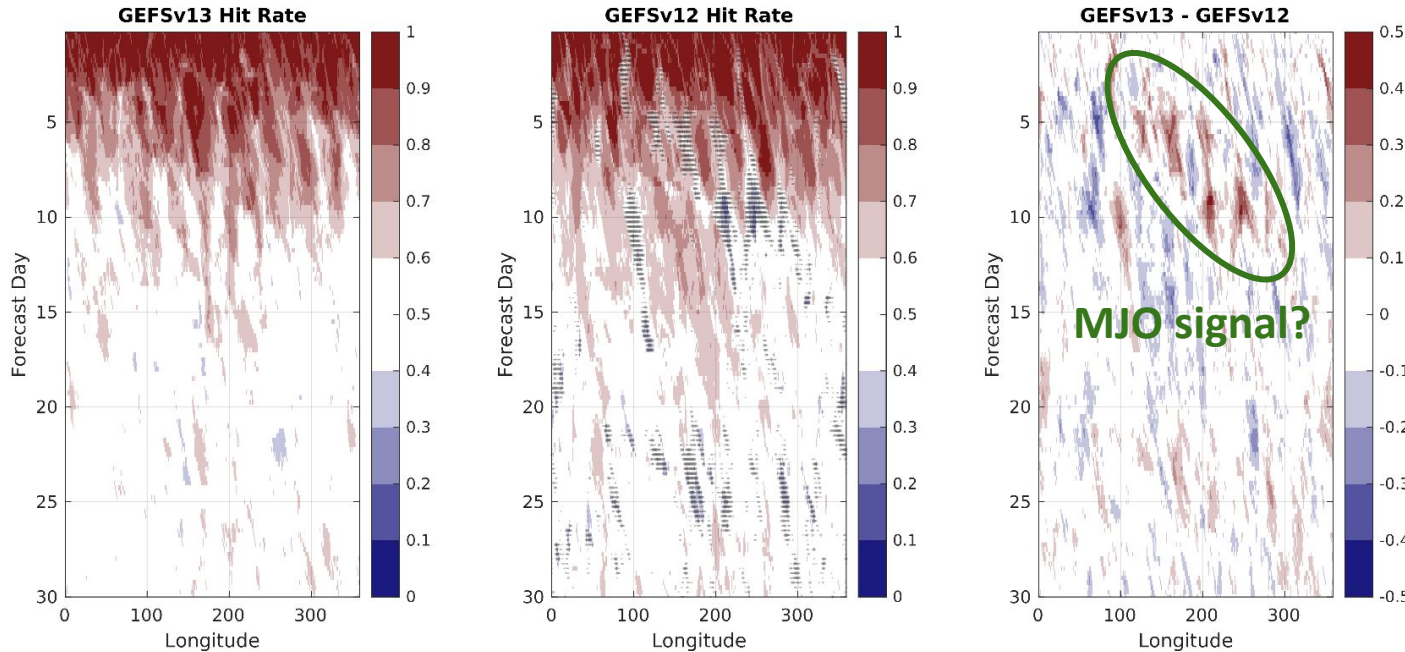
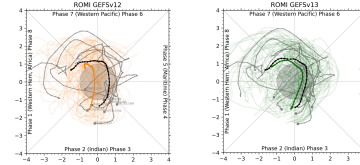
**GEFSv12 Hit Rate**



**Hit:** V200 anomalies in ERA5 and forecast match sign

# MJO teleconnections might also have improved

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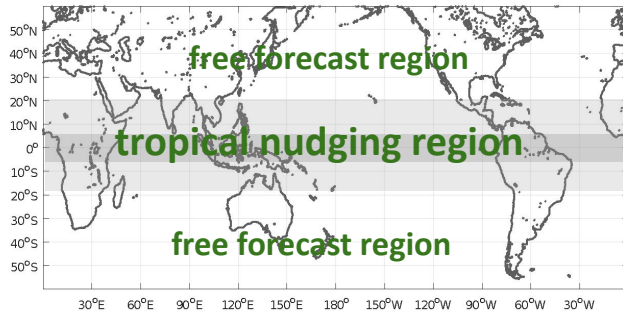


**Hit rates in midlatitude upper level meridional wind anomalies (v200 35N-45N) are improved from GEFSv12 to v13, potentially following the expected MJO teleconnection pathway.**

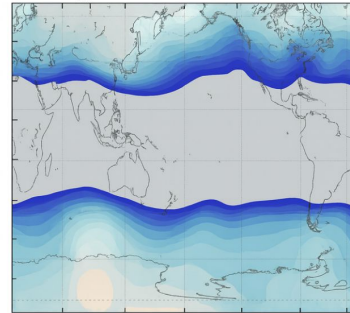
**Hit:** V200 anomalies in ERA5 and forecast match sign

# Looking ahead, how much should we expect from improved MJO predictions?

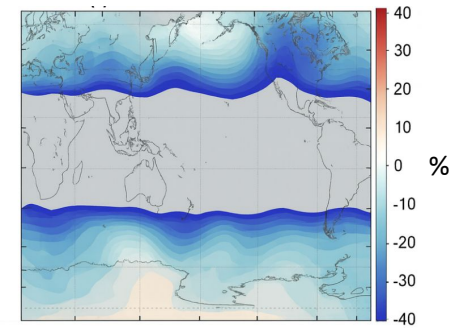
Our approach is to nudge the tropics towards reanalysis allowing forecasts to freely evolve at higher latitudes (“perfect MJO scenario”, and this is applied to the MJO phase 2 & 3 IC



Week 3 Z500  $\Delta$ MAE



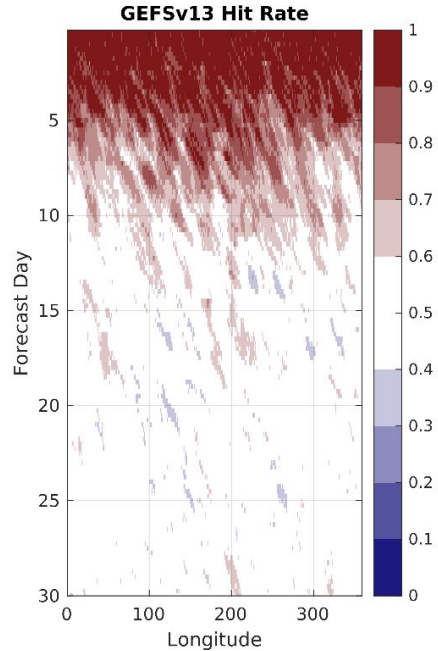
Week 4 Z500  $\Delta$ MAE



**Blue shading denotes regions where Z500 MAE is reduced comparing tropical nudged and free forecasts**

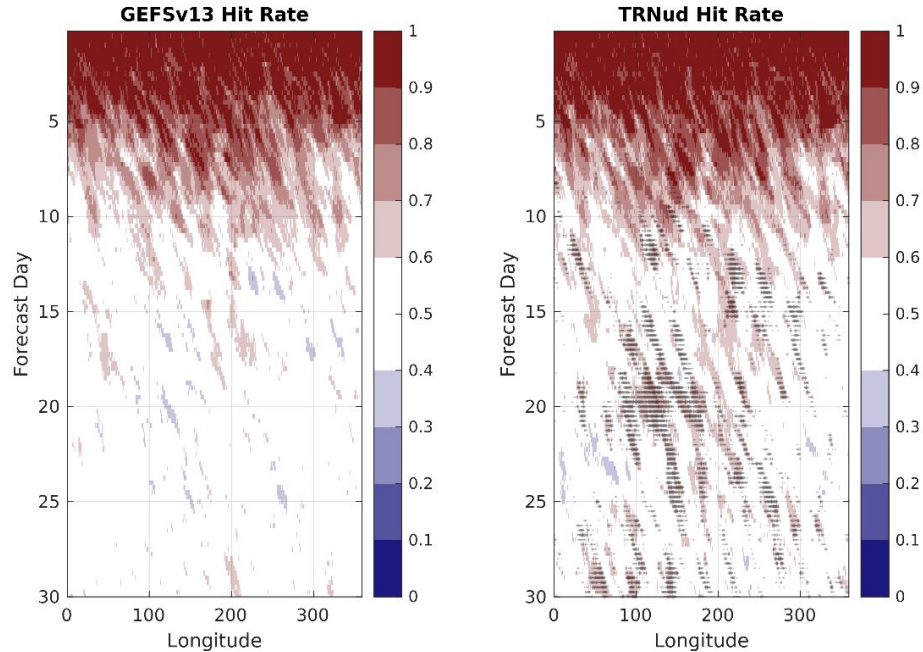
# Midlatitude hit rates improve when the tropics is nudged

(average V200 hit rates between 35°N-55°N)



# Midlatitude hit rates improve when the tropics is nudged

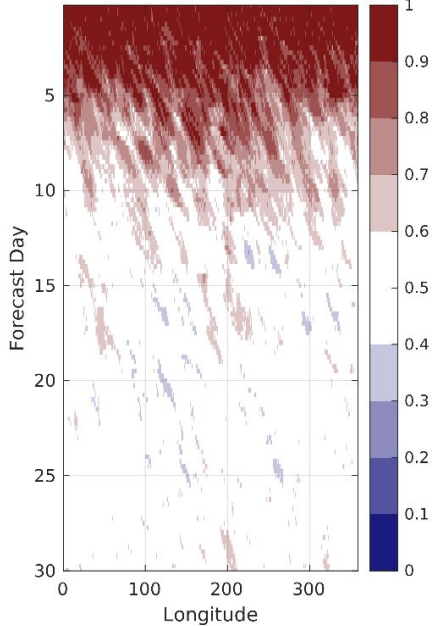
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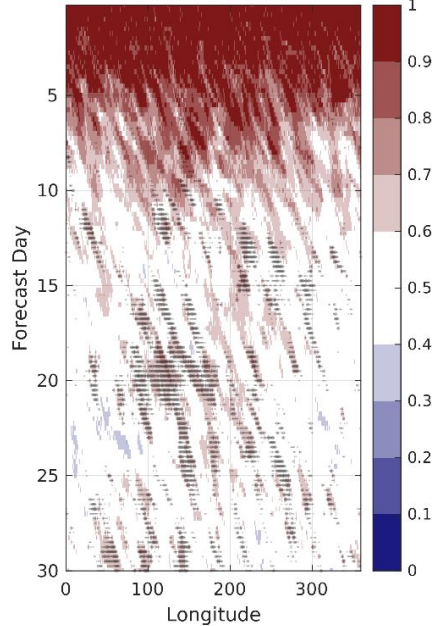
# Midlatitude hit rates improve when the tropics is nudged

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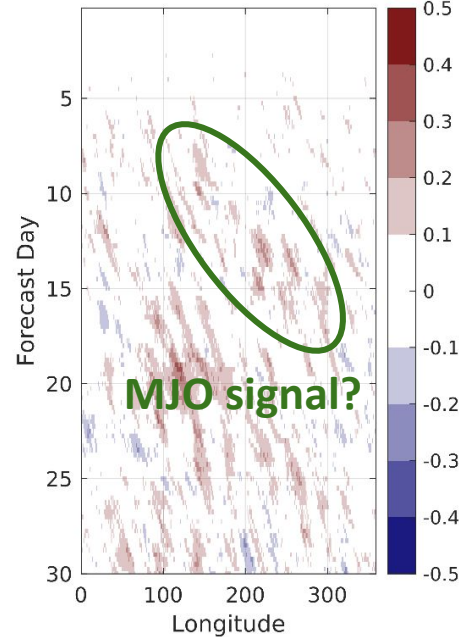
GEFSv13 Hit Rate



TRNud Hit Rate



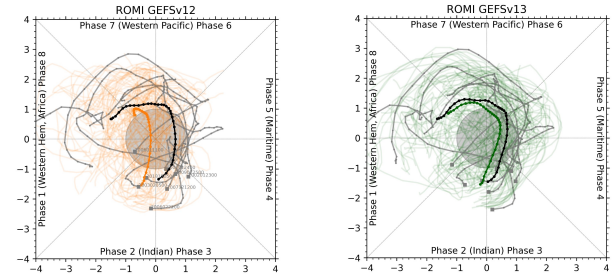
GEFSv13 - TRNud Hit Rate



Hit rates in midlatitude upper level meridional wind anomalies (v200 35N-45N) are **improved** when GEFSv13 is nudged in the tropics, potentially following the expected **MJO teleconnection pathway**.

# Summary:

- A list of “MJO events” can be found here: <https://psl.noaa.gov/mjo/>
- Eight MJO events in phases 2 & 3 that overlap with GEFSv12 and GEFSv13 initializations were sufficient to evaluate MJO improvements;
- Tropical nudging suggests that we have not reached an upper bound on how much the MJO can contribute to Weeks 2-4 NH prediction skill.



Hit Rate averaged over all cases and 35-55 and over all longitudes

