The Impact of Mean State Moisture Biases on MJO Skill in the Navy ESPC

Stephanie S. Rushley[1], Matthew A. Janiga[2], James A. Ridout[2], Carolyn A. Reynolds[2]

[1]National Research Council, Naval Research Laboratory, Monterey, CA [2]Naval Research Laboratory Marine Meteorology Division, Monterey, CA

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Motivation

The Madden-Julian Oscillation (MJO) is a convectively coupled, planetary scale disturbance in the tropics that propagates eastward at 4-8 m/s. The MJO has far reaching teleconnections from local tropical phenomena such as monsoons and tropical cyclones, to extratropical phenomena such as Northern Hemisphere storm tracks and temperatures. The MJO dominates intraseasonal variability (30-90 days) in the tropics and as such is a key source of predictability for subseasonal to seasonal (S2S) timescales (15-60 days).

Currently, many forecast and climate models struggle to accurately simulate the MJO. This study examines the MJO in the Navy Earth System Prediction Capability (Navy ESPC) forecasts performed for the Subseasonal eXperiment (SubX) and identifies biases in the MJO's amplitude and propagation and uses the moisture mode framework to explain these biases.

Data and Methods

Data:

- Navy ESPC 45-day forecasts initialized four times a week from 2009-2015.
- NOAA Climate Data Record Outgoing Longwave Radiation (OLR).
- ERA-interim Reanalysis mean state variables (wind, moisture, temperature).
- Special Sensor Microwave Imager (SSM/I).

MJO Filter: The forecast is padded with observational data and zeros (FilPad method) then a wavenumber-frequency filter is performed to isolate eastward wavenumbers 1-6 and periods 30-90 days.

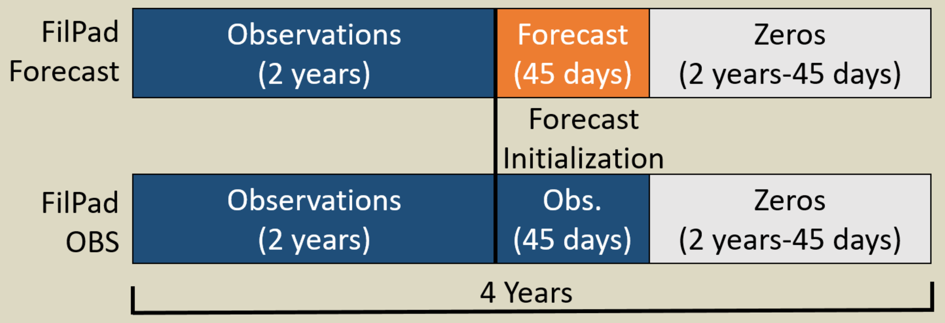


Figure 1: Schematic of the FilPad method for the forecast (top) and observations (bottom)

Model Skill

Windowed Average Anomaly Correlation:

The windowed average anomaly correlation is calculated over progressively longer timescales at later lead times. Anomaly correlations at the S2S timescales are greatest in the IO and NWP where the MJO is strongest.

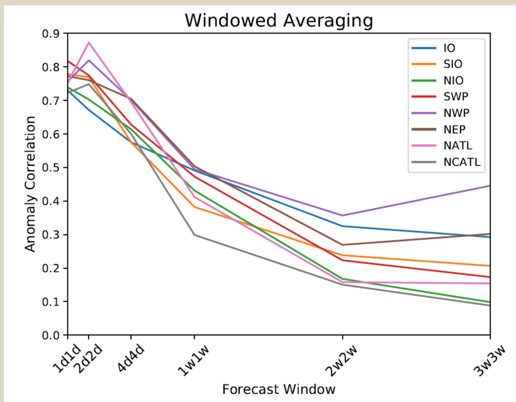


Figure 2: Window averaged OLR anomaly correlation at various lead times over 10° ocean boxes.

Moisture-precipitation relationship:

The Navy ESPC has too much (little) precipitation at low (high) column relative humidity (CRH). Resulting in a lower convective moisture adjustment timescale (τ_c).

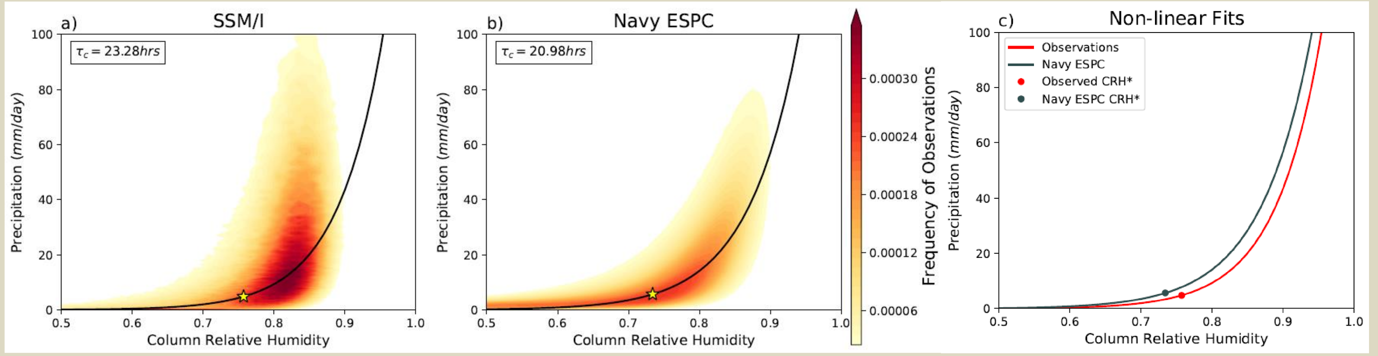


Figure 3: The joint probability distribution function for observations (a) and the Navy ESPC (b). Black lines indicate the nonlinear fit of the moisture-precipitation relationship. Stars indicate the reference CRH and the corresponding τ_c is shown in the upper left of (a) and (b). (c) The non-linear fits of observations (red) and the Navy ESPC (gray) and their reference CRH are shown in the colored dots.

MJO Biases

MJO Amplitude:

The MJO is too strong in the Navy ESPC. In DJF the MJO is too strong in the Navy ESPC throughout the southern tropics with the exception of a weak bias over the Maritime Continent.

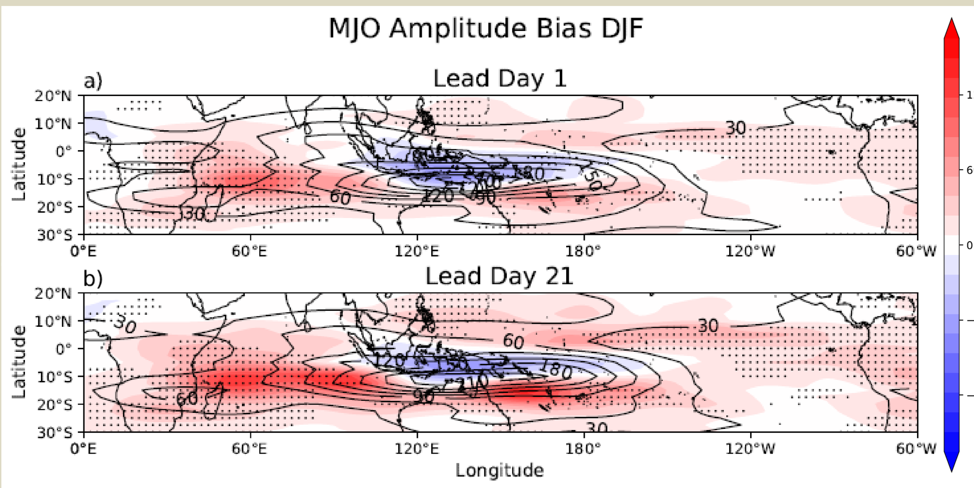


Figure 4: DJF MJO filtered OLR variance bias (Navy ESPC – observations, shading) and observed MJO filtered OLR variance (contours) at lead day 1 (a) and 21 (b).

In JJA the MJO is stronger than observed in the Navy ESPC throughout the northern tropics.

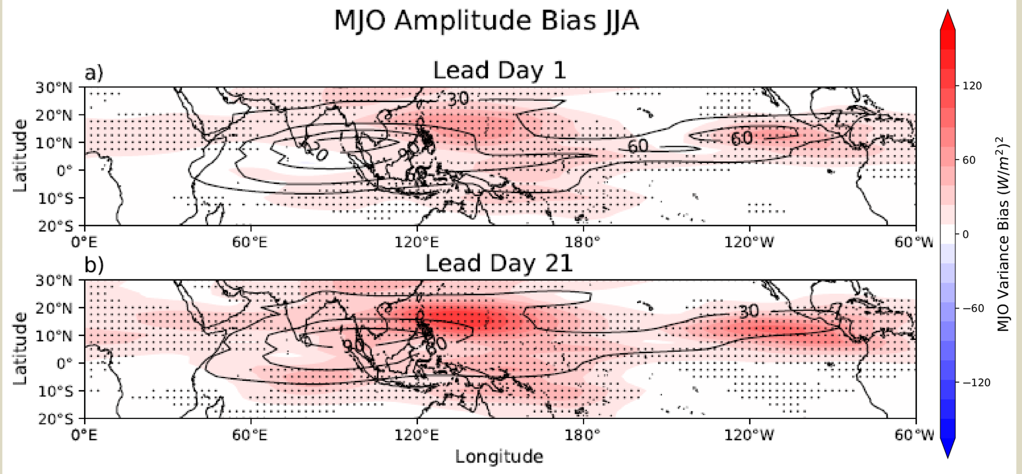


Figure 5: JJA MJO filtered OLR variance bias (Navy ESPC – observations, shading) and observed MJO filtered OLR variance (contours) at lead day 1 (a) and 21 (b).

MJO Phase Speed:

The Navy ESPC's MJO is faster than the observed MJO. This acceleration is largely due to the moisture tendency, which drives a rapid acceleration in the MJO OLR anomalies to the east of the Maritime Continent at 120°E.

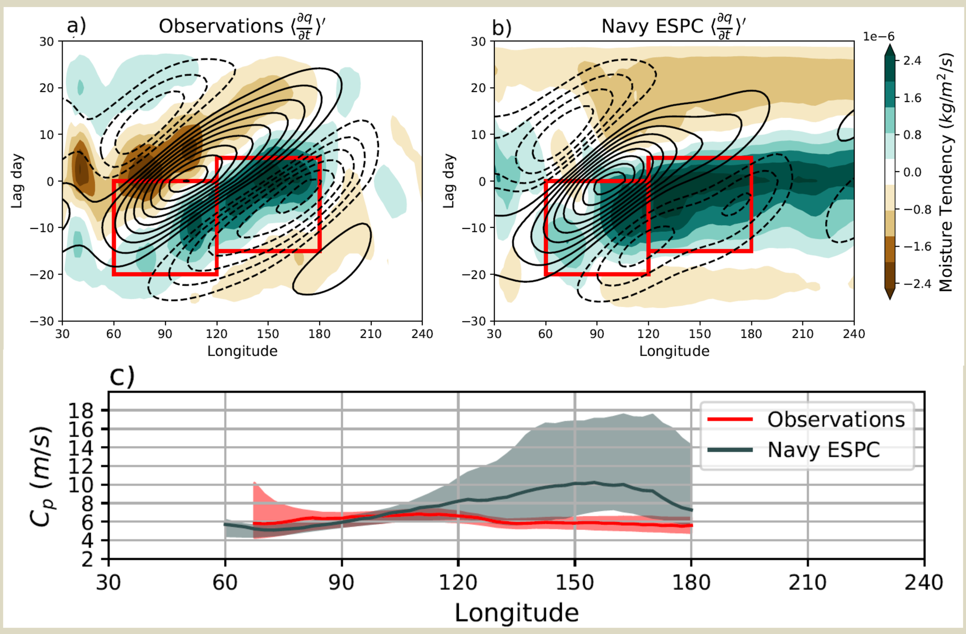


Figure 6: DJF lag-regression of intraseasonal moisture tendency onto a time series of MJO filtered OLR anomalies centered in the Indian Ocean (shading) for observations (a) and the Navy ESPC (b). Auto-lag-regressions of MJO filtered OLR anomalies are overlaid in black contours. (c) The phase speed (c_p) estimated by the slope of the linear best fit of local regression maximums of MJO filtered OLR anomalies for observations (red line) and the Navy ESPC (gray line).

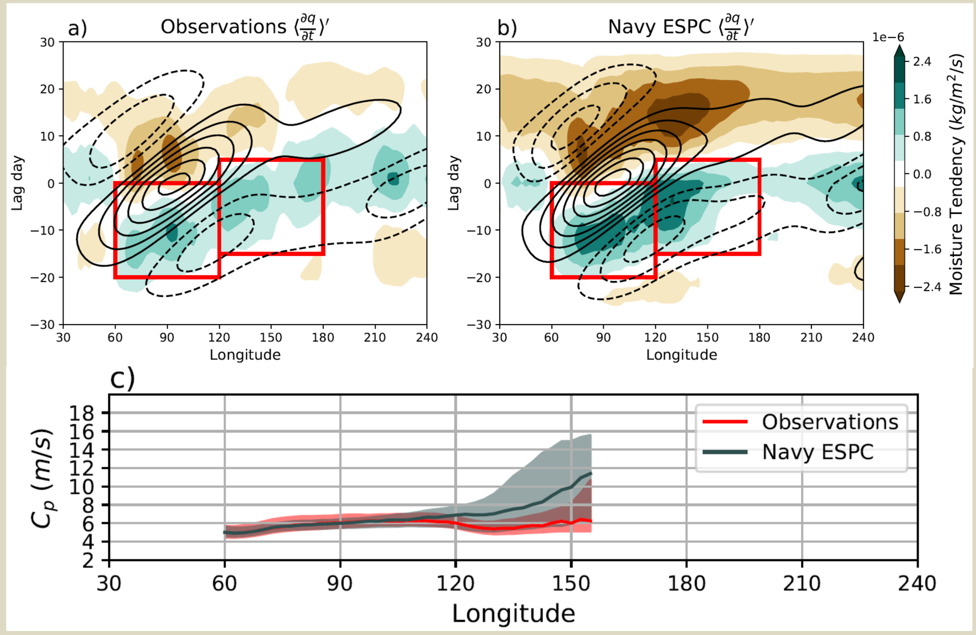


Figure 7: JJA lag-regression of intraseasonal moisture tendency onto a timeseries of MJO filtered OLR anomalies centered in the Indian Ocean (shading) for observations (a) and the Navy ESPC (b). Auto-lag-regressions of MJO filtered OLR anomalies are overlaid in black contours. (c) The phase speed (c_p) estimated by the slope of the linear best fit of local regression maximums of MJO filtered OLR anomalies for observations (red line) and the Navy ESPC (gray line).

Moisture Budget Analysis

Intraseasonal Moisture Budget:

′: Intraseasonal (20-100 day) filtered data
⟨ ⟩: mass weighted vertical integration from 1000-100 hPa

$$\underbrace{\frac{\partial\langle q\rangle'}{\partial t}}_{\text{Moisture Tendency}} = -\underbrace{\langle\vec{V}\cdot\nabla q\rangle'}_{\text{Horizontal Advection}} - \underbrace{\left\langle\omega\frac{\partial q}{\partial p}\right\rangle'}_{\text{Vertical Advection}} - \underbrace{P'}_{\text{Precipitation}} + \underbrace{E'}_{\text{Evaporation}}$$

Contributions to Moisture Maintenance:

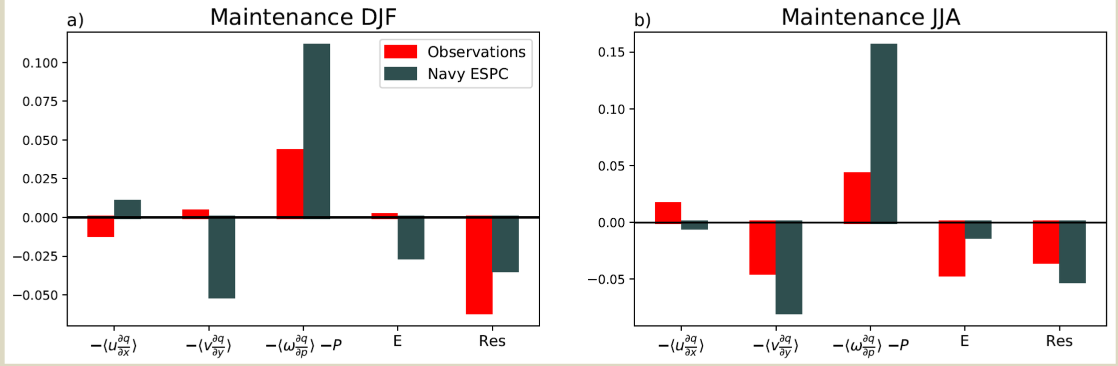


Figure 8: Covariance of the intraseasonal moisture budget onto intraseasonal column moisture for observations (red) and the Navy ESPC (gray) over (a) 60°-240°E, 20°S-10°N for DJF and (b) 60°-240°E, 10°S-20°N for JJA.

The vertical moisture advection in the Navy ESPC has a larger contribution to moisture maintenance than is observed.

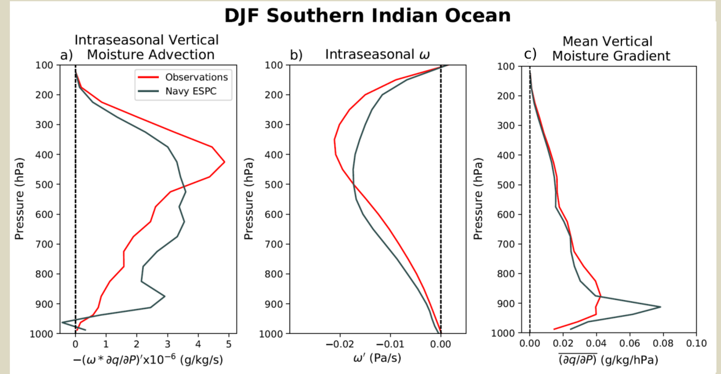


Figure 9: DJF (a) Intraseasonal moisture advection, (b) intraseasonal ω, and c) mean vertical moisture gradient for observations (red lines) and the Navy ESPC (gray lines).

The vertical moisture advection in the Navy ESPC is stronger over a deeper layer, due to a stronger and deeper ω profile and a steeper vertical moisture gradient in the lower troposphere. JJA results show the same mechanism.

Contributions to Moisture Tendency:

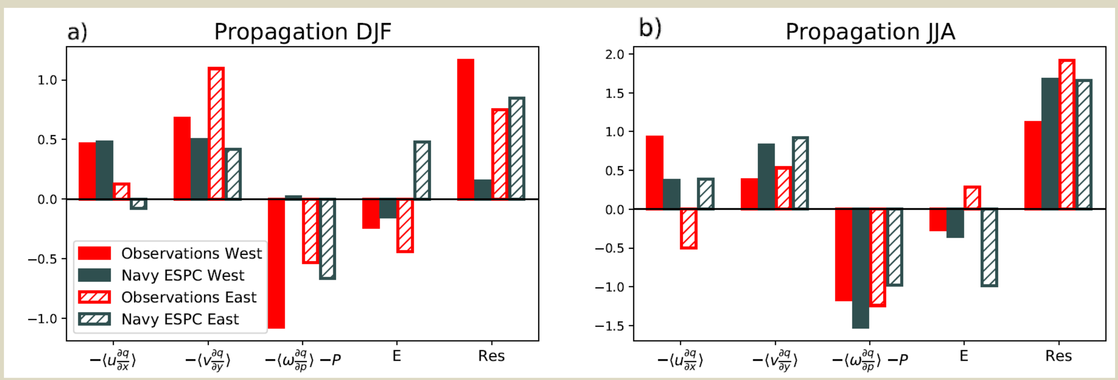


Figure 10: Covariance of the intraseasonal moisture budget onto column moisture tendency for observations (red) and the Navy ESPC (gray) for (a) DJF and (b) JJA. Solid bars correspond to the western box in figures 6 and 7, hatched bars correspond to the eastern box in figures 6 and 7.

The largest contributor to the acceleration of the MJO east of 120°E in DJF is evaporation, while in JJA it is the horizontal advection.

DJF: Stronger mean easterlies positively contribute to the MJO scale easterlies in the western Pacific. Increasing the total wind and evaporation.

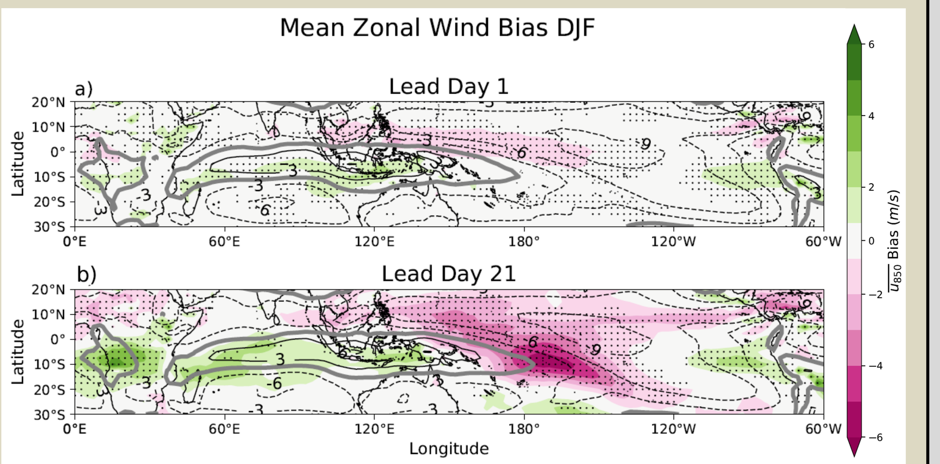
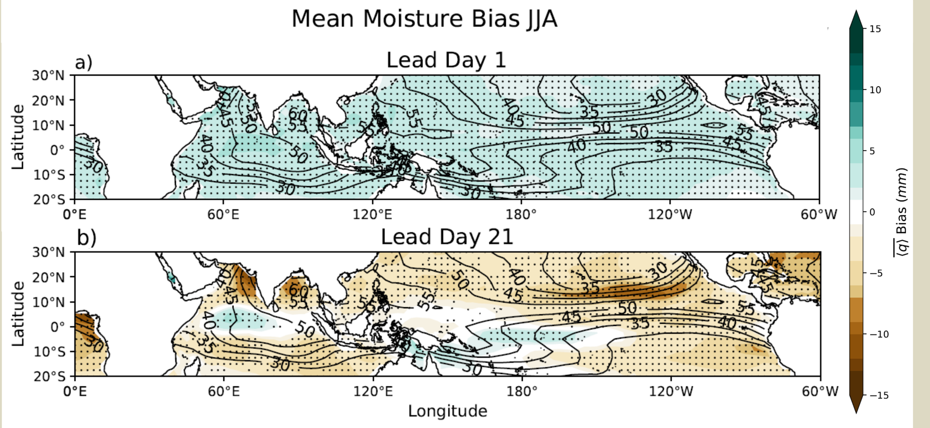


Figure 11: DJF mean zonal winds at 850hPa bias (shading) and observed mean moisture at lead day 1 (a) and 21 (b).



JJA: The pattern of the moisture bias in the Navy ESPC steepens the horizontal moisture gradient.

Figure 12: JJA mean moisture bias (shading) and observed mean moisture at lead day 1 (a) and 21 (b).

Conclusions

The MJO is too strong in the Navy ESPC due to:

1) A faster convective moisture adjustment timescale, increasing the amount of precipitation for a given moisture anomaly
2) Stronger vertical moisture advection driven by a more bottom heavy vertical motion profile and steeper lower level vertical moisture gradient

The MJO in the Navy ESPC accelerates east of the Maritime Continent driven by the acceleration of the moisture tendency which is due to:

JJA: Stronger horizontal moisture advection in the Western Pacific due to steeper mean meridional and zonal moisture gradients
DJF: Stronger evaporation in the Western Pacific driven by stronger mean easterlies combined with intraseasonal easterlies associated with the MJO