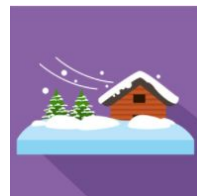
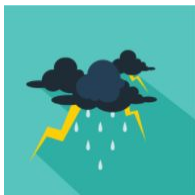




# Constructing Equatorial Wave Indices for Historical Analysis with Application to Real-Time Ensemble Model Systems using Objectively Filtered 200-hPa Velocity Potential Anomalies over the Global Tropics

Nick Novella, Jon Gottschalck  
Climate Prediction Center

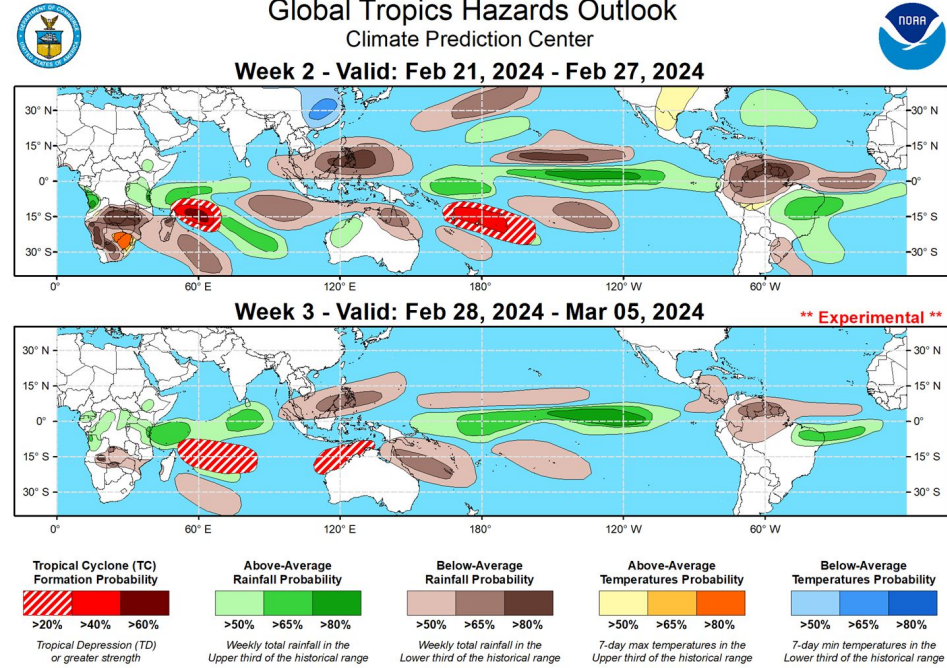
CDPW / CPAS March 29, 2024





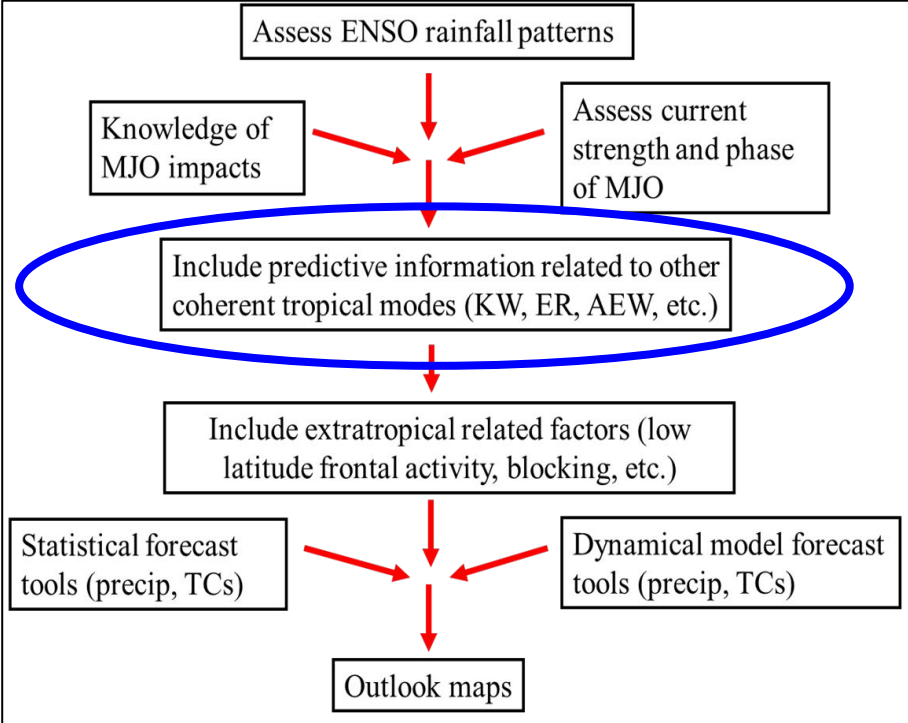
# GTH Forecast Basis: A "Top-Down" Paradigm

## Weeks 2&3 Tropical Cyclogenesis, Precipitation, and Temperature Outlook



Issued: 02/13/2024  
Forecaster: Novella

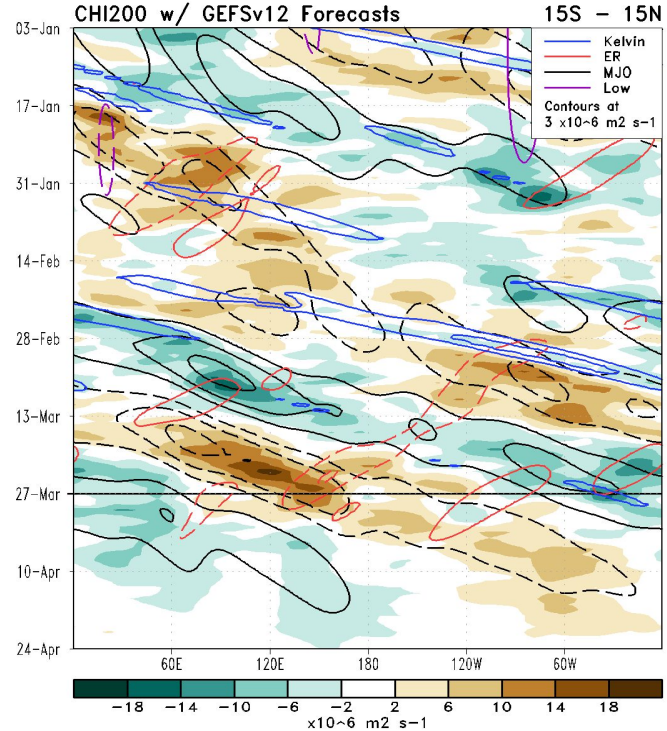
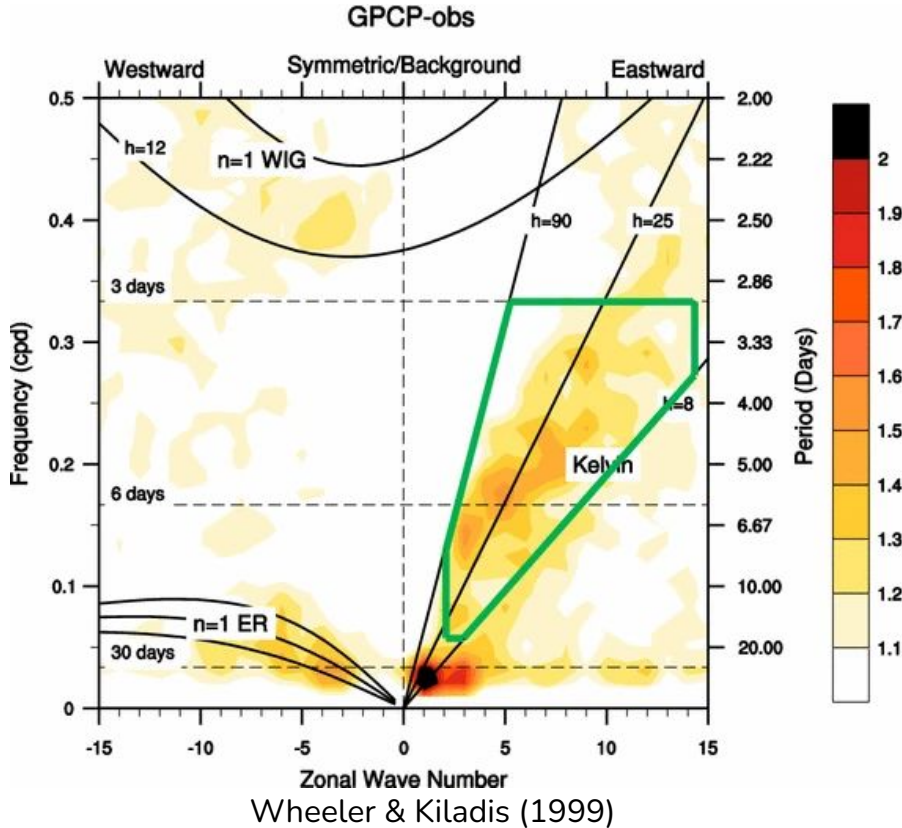
This product is updated once per week and targets broad scale conditions integrated over a 7-day period for US interests only. Consult your local responsible forecast agency.



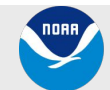


# Background / Motivation

## Tropical Modes of Variability / Wave Filtering



CPC MJO Wave Tool implemented in coordination with Carl Schreck at NCICS/NC





# Data / Methods

## Main Goal and Filtering performed in literature

### For this project:

- An EOF / Principal Component (PC) Analysis was performed on daily MJO, equatorial Kelvin Wave (KW), and equatorial Rossby Wave (ERW) filtered 200-hPa velocity potential anomalies (CHI200) using CDAS (w/ 91-20 base period) from 1979-2022 in order to construct a long-term time series capturing various attributes of wave activity (strength, phasing, repetancy).
- Per WH2004 who used a combined multivariate EOF approach, an advantage of projecting daily data onto a single variable field is a substantial increase in variance contributed from frequencies outside the 30-80day range.

### Variations of Filtered Data for EOF Analysis:

- CPC, 2002: Bandpass time filter on CHI200 (univariate EEOF).
- Kessler, 2001: Bandpass (Lanczos) time filter on OLR (univariate EOF/REOF).
- Wheeler and Hendon (WH2004): Annual cycle and low frequency (120-day mean) filter on OLR, u200, u850, (multivariate EOF)
  - *Paper cautions that bandpass filters are restricted from RT tasks because of their requirement for information beyond the end point of a time series.*
- Ventrice, 2013: Annual cycle and low frequency (120-day mean) filter on CHI200, u200, u850 (multivariate EOF).
- Wheeler and Weickmann, 2001: Fourier Filtering for specific zonal wavenumber-frequency waves applied to various MJO related variables.



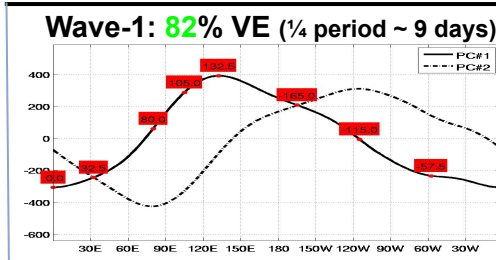




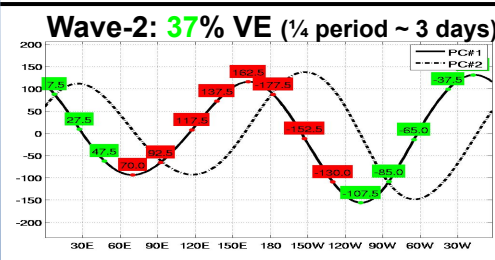
# EOF Results

## Stats and Retention

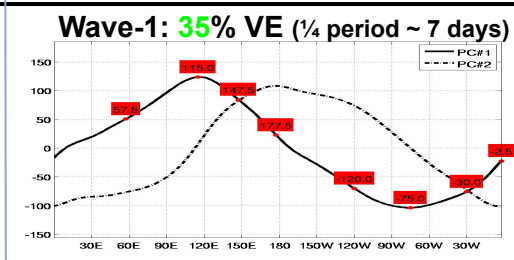
### MJO



### KW



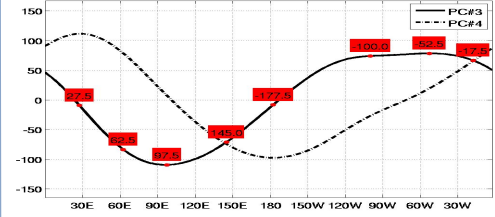
### ERW



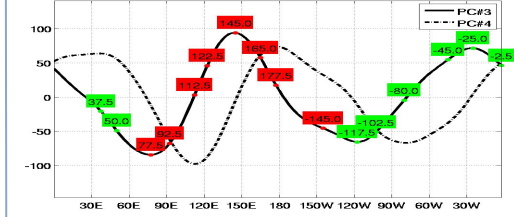
PCs 1 & 2

- All leading PC pairs appear to satisfy wave mode phasing and periodicity criteria (Roundy, 2015) and validated via EEOF analysis.
- The first 3 pairs for KW and ERW were retained based on high percentages of Variance Explained (VE), separability (North et al, 1982), with combined percentages comparable to the leading PC pair for MJO (76% & 65%). Beyond this, VE and lambdas level off substantially.

### Wave-1: 21% VE (¼ period ~ 4 days)

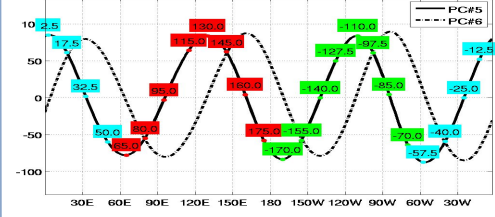


### Wave-2: 19% VE (¼ period ~ 6 days)

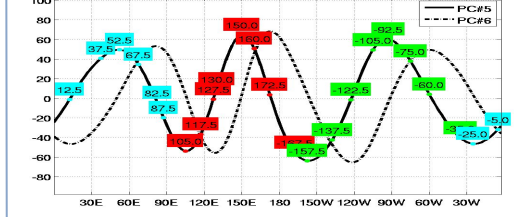


PCs 3 & 4

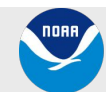
### Wave-3: 17% VE (¼ period ~ 2 days)



### Wave-3: 11% VE (¼ period ~ 3 days)



PCs 5 & 6

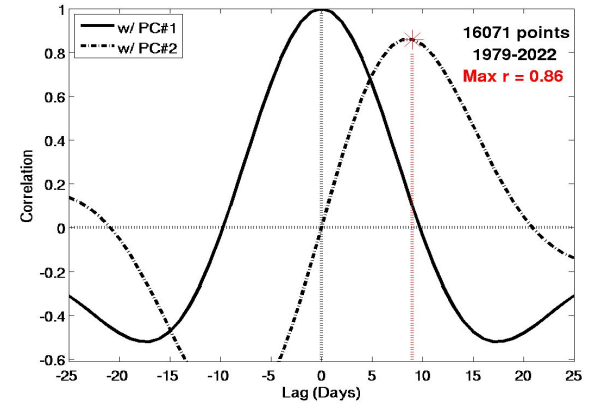
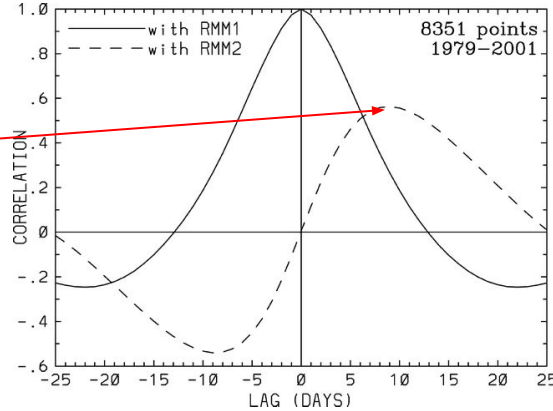




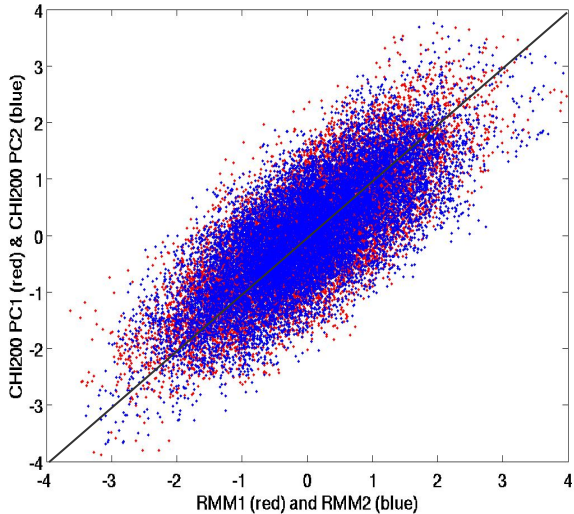
# Results: MJO

## PC & Amplitude Comparison with CPC RMM index

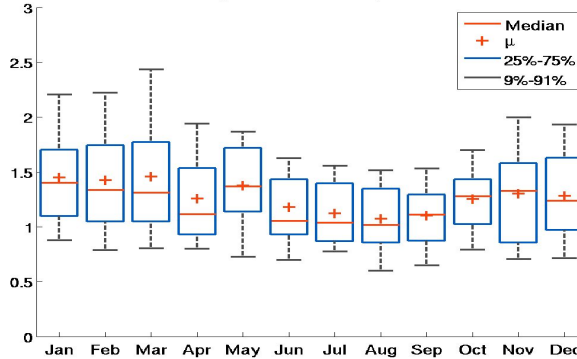
WH2004 (Fig 6): “The maximum correlation between RMM1 and RMM2 is **0.56** at a lag of **9 days**.”



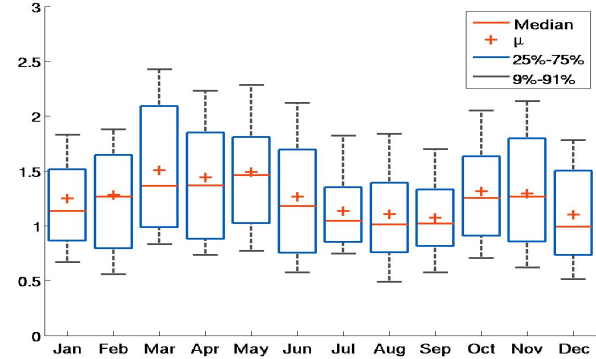
CHI200 Filtered PCs1+2 vs RMM1+2  
Correlation: 0.773(red) / 0.752(blue)



Mean Annual Cycle RMM MJO Amplitude : 1980-2021



Mean Annual Cycle CHI200 Filtered MJO Amplitude : 1980-2021



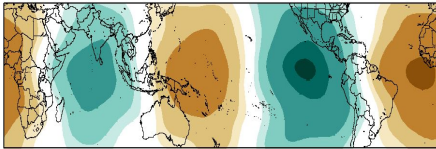


# Results: Kelvin Wave (KW)

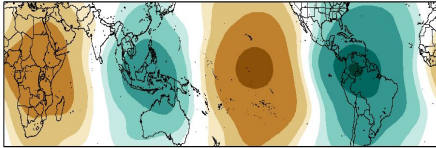
## Phase Composites of Filtered 200-hPa Velocity Potential

Composites consist of broadening # of phases (8->4) and removing all days where MJO and ERW amp > 1.5, while retaining KW amp  $\geq 1.5$

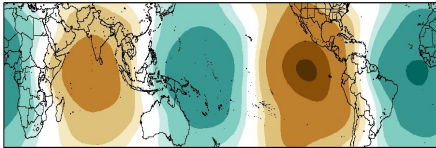
KW wave-2 Composite: Filt CHI200 ( $\times 10^{-6}$  m<sup>2</sup>/s)



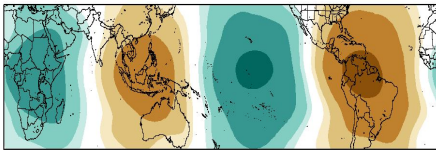
Phase 1



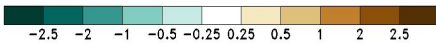
Phase 2



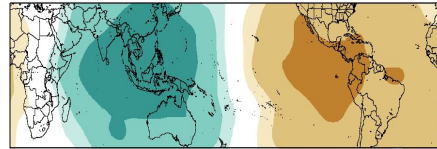
Phase 3



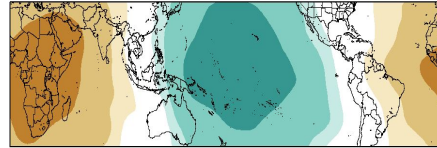
Phase 4



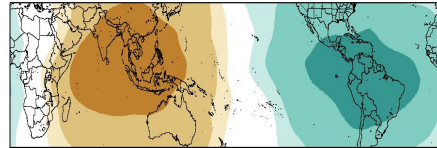
KW wave-1 Composite: Filt CHI200 ( $\times 10^{-6}$  m<sup>2</sup>/s)



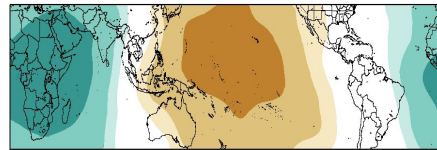
Phase 1



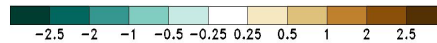
Phase 2



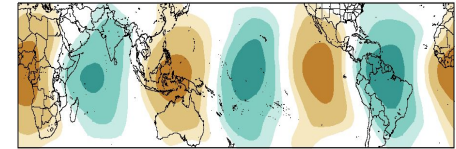
Phase 3



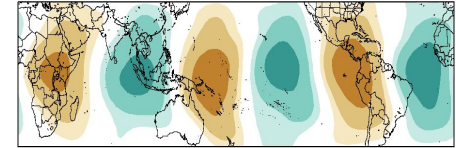
Phase 4



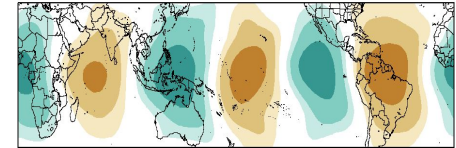
KW wave-3 Composite: Filt CHI200 ( $\times 10^{-6}$  m<sup>2</sup>/s)



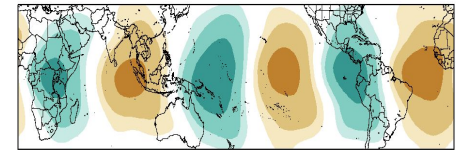
Phase 1



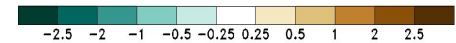
Phase 2



Phase 3



Phase 4







# Results: Kelvin Wave (KW)

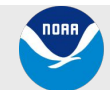
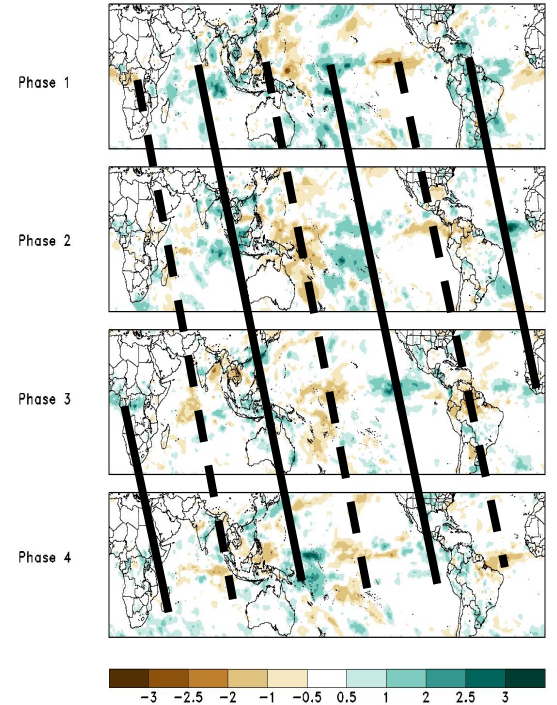
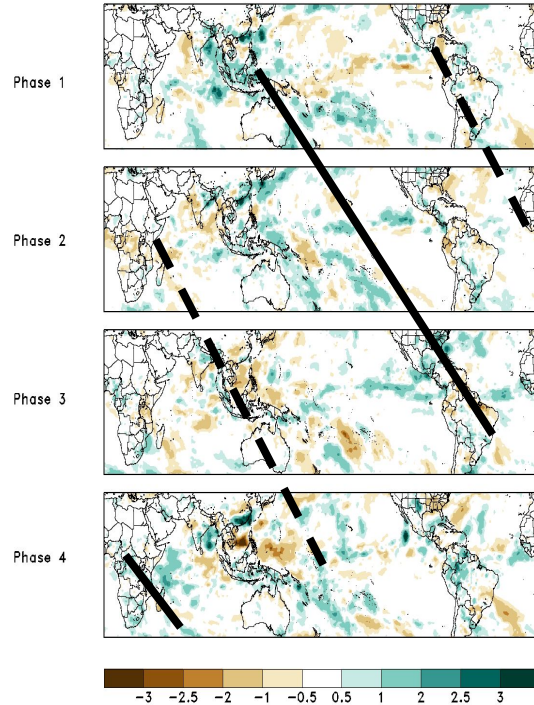
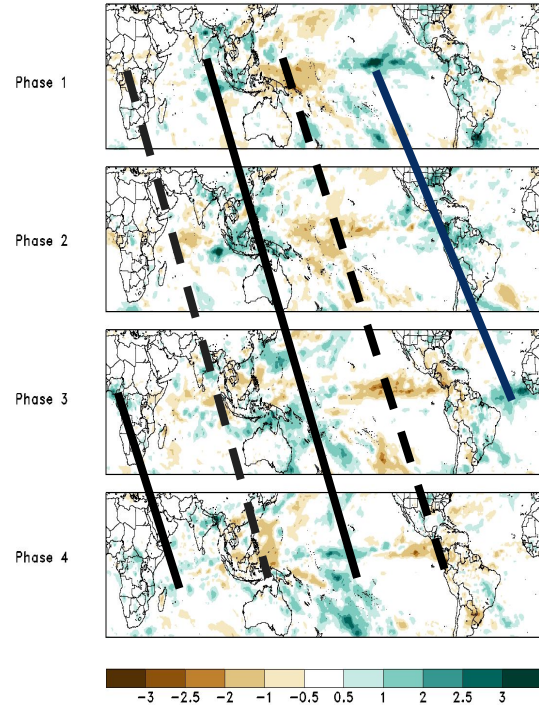
## Phase Composites of Precipitation Anomalies

Composites consist of broadening # of phases (8->4) and removing all days where MJO and ERW amp > 1.5, while retaining KW amp  $\geq 1.5$

KW wave-2 Composite: GPCP1DD (mm/day)

KW wave-1 Composite: GPCP1DD (mm/day)

KW wave-3 Composite: GPCP1DD (mm/day)



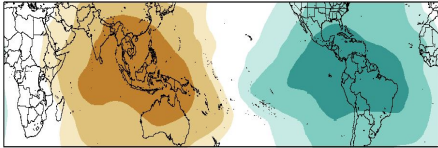


# Results: Rossby Wave (ERW)

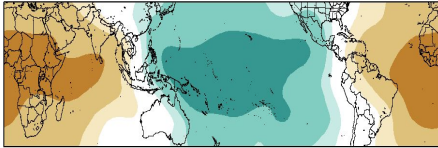
## Phase Composites of Filtered 200-hPa Velocity Potential

Composites consist of broadening # of phases (8->4) and removing all days where MJO and KW amp > 1.5, while retaining ERW amp >= 1.5

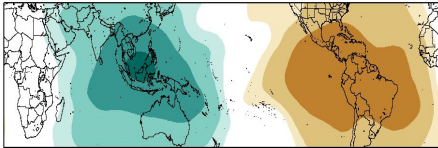
RW wave-1 Composite: Filt CHI200 ( $\times 10^{-6}$  m<sup>2</sup>/s)



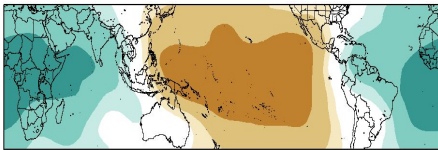
Phase 1



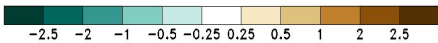
Phase 2



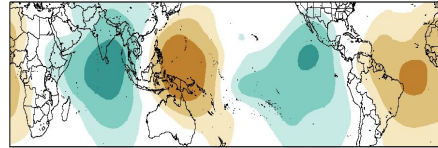
Phase 3



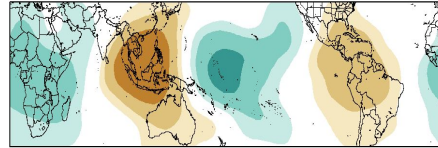
Phase 4



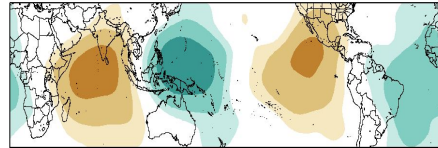
RW wave-2 Composite: Filt CHI200 ( $\times 10^{-6}$  m<sup>2</sup>/s)



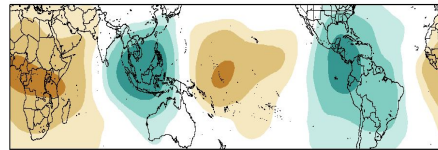
Phase 1



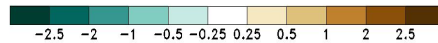
Phase 2



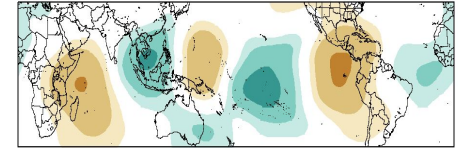
Phase 3



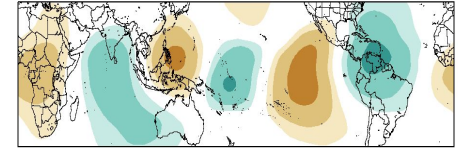
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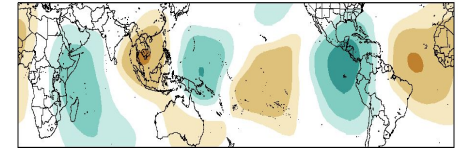
RW wave-3 Composite: Filt CHI200 ( $\times 10^{-6}$  m<sup>2</sup>/s)



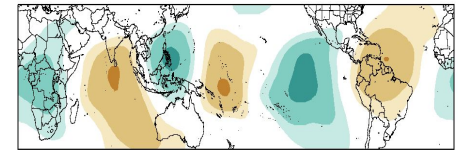
Phase 1



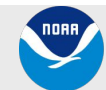
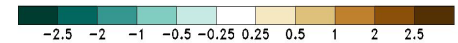
Phase 2



Phase 3



Phase 4





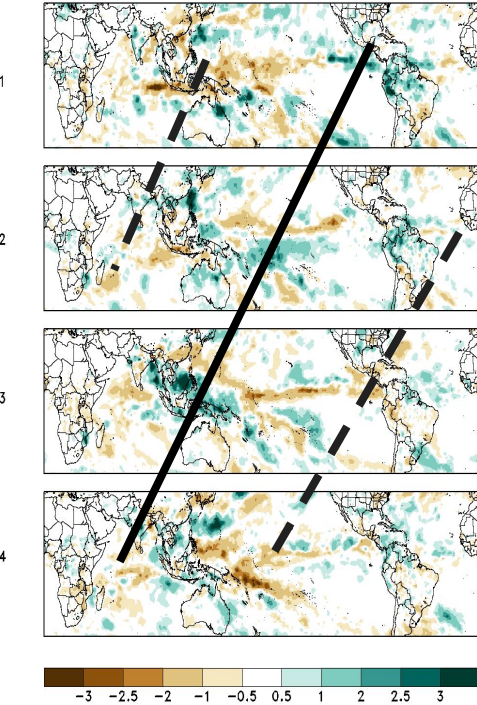


# Results: Rossby Wave (ERW)

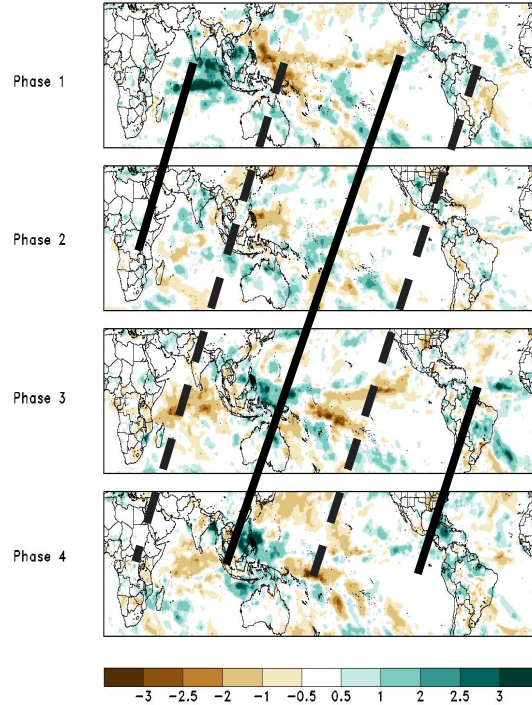
## Phase Composites of Precipitation Anomalies

Composites consist of broadening # of phases (8->4) and removing all days where MJO and KW amp > 1.5, while retaining ERW amp  $\geq 1.5$

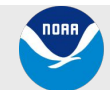
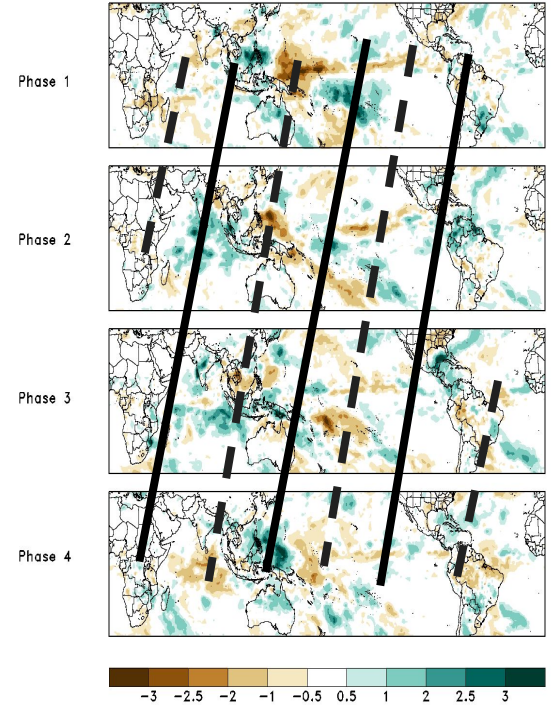
RW wave-1 Composite: GPCP1DD (mm/day)



RW wave-2 Composite: GPCP1DD (mm/day)



RW wave-3 Composite: GPCP1DD (mm/day)

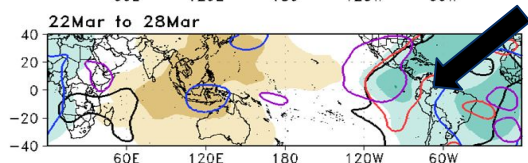
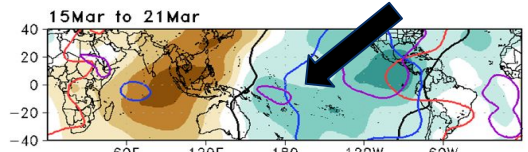
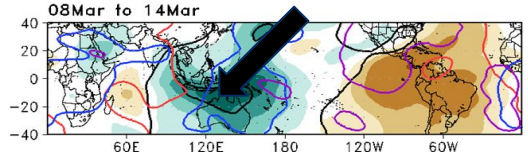
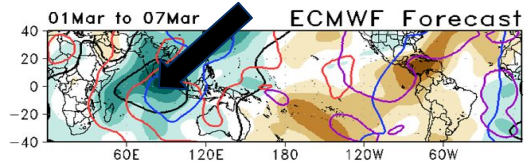




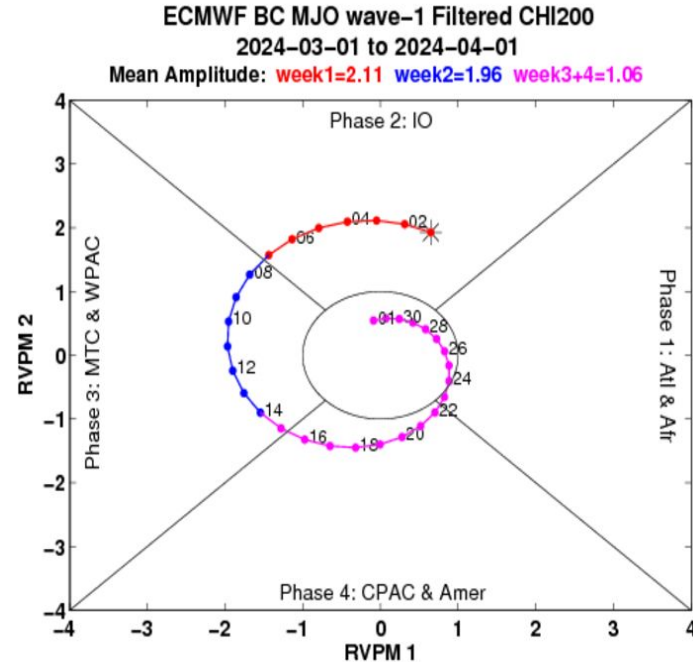
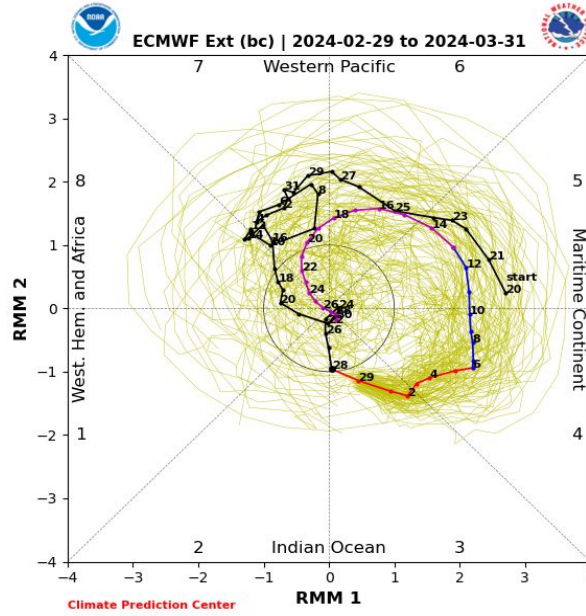
# Real-time Velocity Potential Indices (RVPI)

## Projecting EOFs to create Phase Diagrams

- With eigenvectors/eigenvalues based on 44 years of observed tropical wave modes now available, we can apply these to the same objectively wave filtered 200-hPa velocity potential anomaly forecasts from the GFSv12, CFSv2 and ECMWF ensemble model systems.



— MJO      — Kelvin\*2  
 — Low      — ER  
 Contours at  $-2, -6 \times 10^{-6} \text{ m}^2 \text{ s}^{-1}$

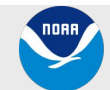
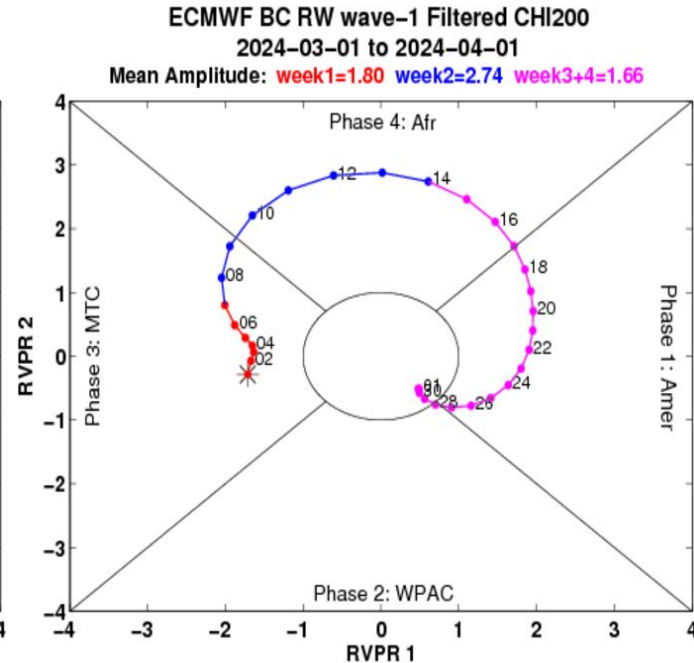
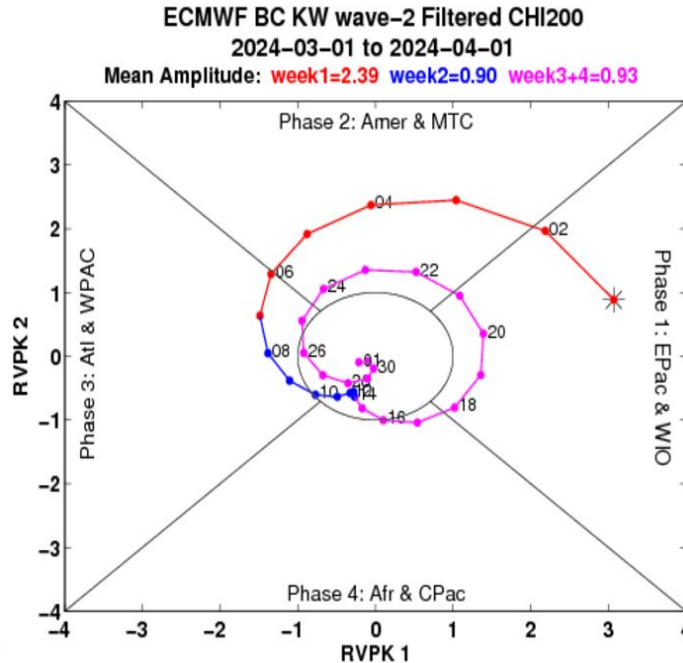
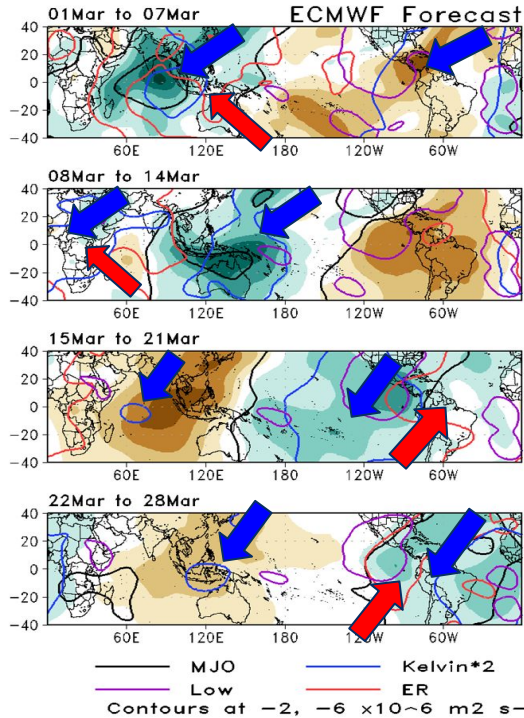




# Real-time Velocity Potential Indices (RVPI)

## Projecting EOFs to create KW and ERW Phase Diagrams

- With eigenvectors/eigenvalues based on 44 years of observed tropical wave modes now available, we can apply these to the same objectively wave filtered 200-hPa velocity potential anomaly forecasts from the GFSv12, CFSv2 and ECMWF ensemble model systems.



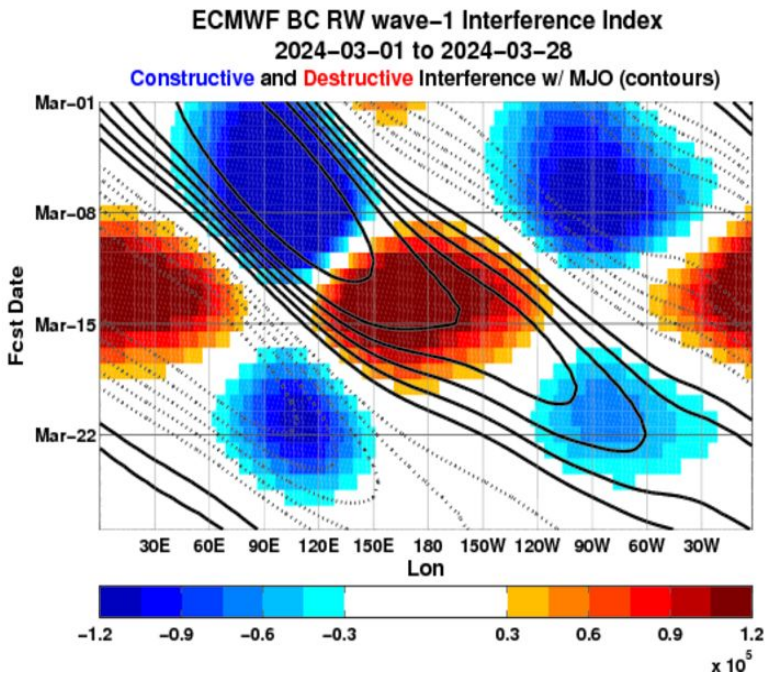




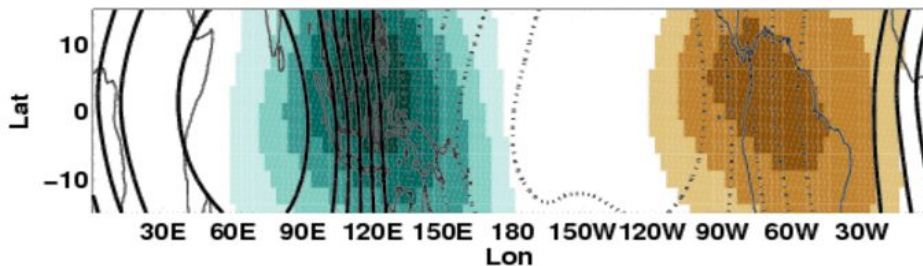
# Real-time Velocity Potential Indices (RVPI)

## Interference Indices (II)

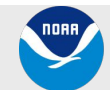
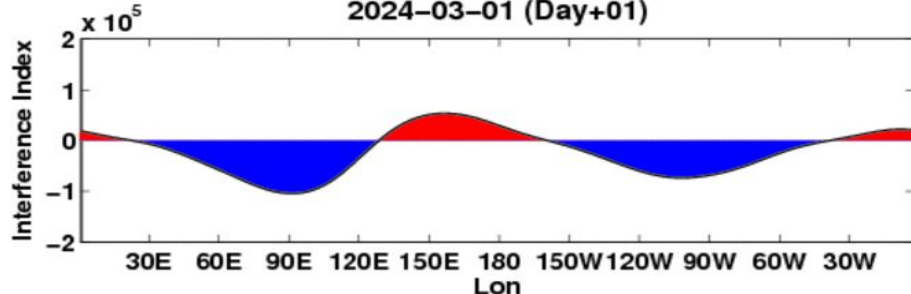
- To quantify interactions between all waves, the predicted wave fields of KW and ERWs are multiplied by that of the MJO and averaged from 15S-15N to form an Interference Index (II). This illustrates where and when MJO phases maybe further enhanced or suppressed by higher frequency modes in the forecast period.



ECMWF BC RW wave-1 (shaded) w/ MJO (contours)  
2024-03-01 (Day+01)



Constructive and Destructive Interference w/ MJO (contours)  
2024-03-01 (Day+01)





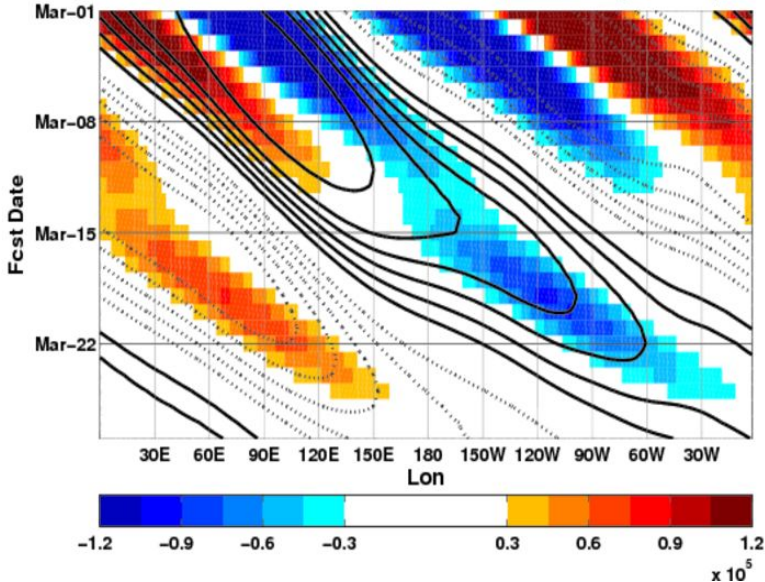
# Real-time Velocity Potential Indices (RVPI)

## Interference Indices (II)

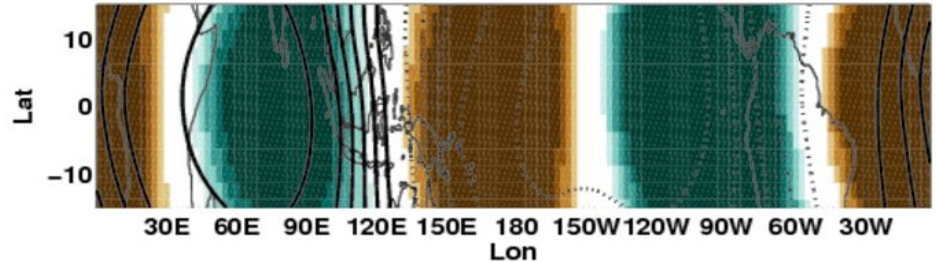
- To quantify interactions between all waves, the predicted wave fields of KW and ERWs are multiplied by that of the MJO and averaged from 15S-15N to form an Interference Index (II). This illustrates where and when MJO phases maybe further enhanced or suppressed by higher frequency modes in the forecast period.

ECMWF BC KW wave-2 Interference Index  
2024-03-01 to 2024-03-28

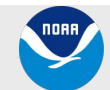
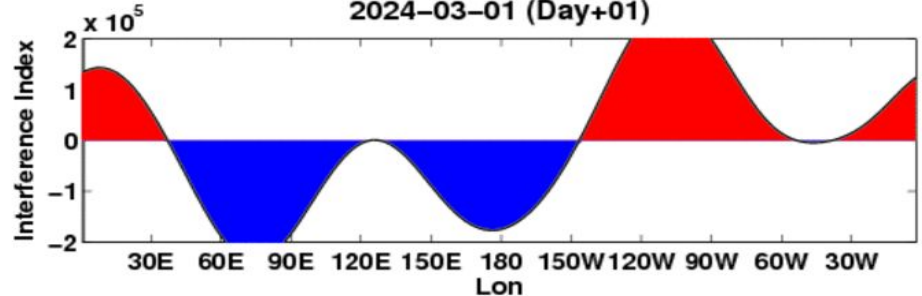
Constructive and Destructive Interference w/ MJO (contours)



ECMWF BC KW wave-2 (shaded) w/ MJO (contours)  
2024-03-01 (Day+01)



Constructive and Destructive Interference w/ MJO (contours)  
2024-03-01 (Day+01)







# Summary

- An EOF / PC Analysis was performed on daily MJO, KW and ERW filtered 200-hPa Velocity Potential Anomalies from 1979-2022 to diagnose propagating wave patterns predominantly featured in the tropics.
  - Low frequency modes (ENSO, IOD) were ignored in this study, largely because of the filtering's ability to well separate waves from standing or quasi-stationary modes (w/ no 120-day mean removal either), but this may need to be revisited.
- The resultant PC time series permit the creation of historical composites based on each wave's repentance, amplitude and phase location, where good consistency exists between the VP filtered MJO and Wh2004 RMM index w.r.t. PCs, amplitude, and the mean annual cycle of MJO activity.
- The leading eigenvector pairs can be used to project onto the same objectively wave filtered 200-hPa Velocity Potential Anomaly forecast fields from the GEFSv12, CFSv2, and ECMWF extended range ensemble systems, to formulate Real-time Velocity Potential Indices (RVPI).
  - RVPI and the associated eigendata are then used to develop an Interference Index (II), which illustrates where and when MJO activity may be further enhanced or suppressed by KW and ERW activity.
- The provision of new equatorial wave indices can serve as both a diagnostic and forecast attribution aid at weekly and subseasonal timescales, and is expected to better inform forecasters at the Climate Prediction Center (CPC) in the issuance of the official CPC Week 2-3 Global Tropics Hazards Outlook.





Thank You !

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