Intraseasonal Variability and TC Forecasting

2017 WMO Class

Eric Blake
Hurricane Specialist
National Hurricane Center

3/1/2017

Outline

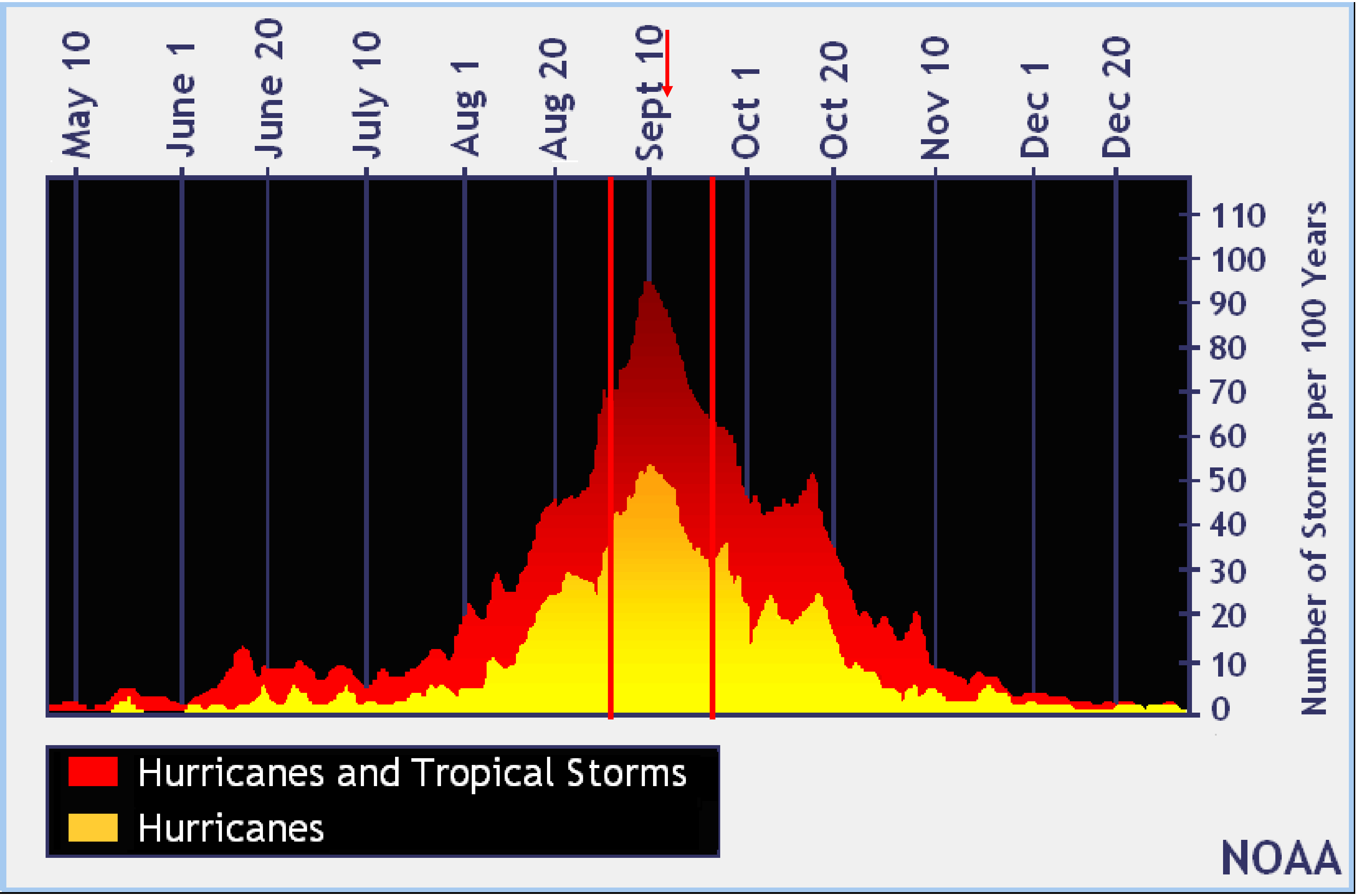
- Madden-Julian Oscillation (MJO)
- MJO analysis tools
- Kelvin Waves
- Brief exercises

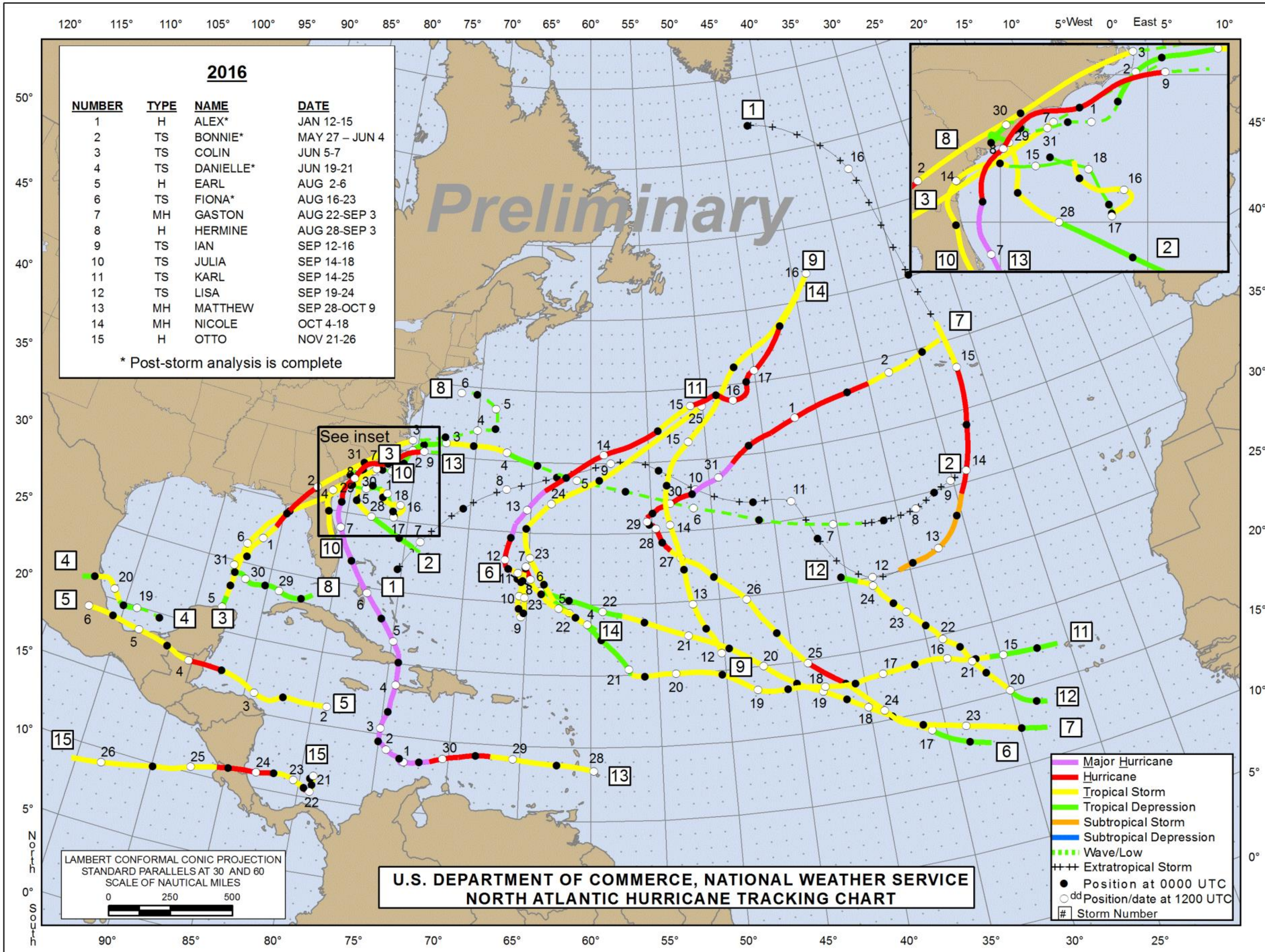
Question 1

What's the 3rd busiest month on average in terms of Atlantic ACE?

A. July
B. August
C. September
D. October

No Storm
Formations in 2008




2016
NUMBER TYPE NAME DATE
1 H ALEX* JAN 12-15
2 TS BONNIE* MAY 27 – JUN 4
3 TS COLIN JUN 5-7
4 TS DANIELLE* JUN 19-21
5 H EARL AUG 2-6
6 TS FIONA* AUG 16-23
7 MH GASTON AUG 22-SEP 3
8 H HERMINE AUG 28-SEP 3
9 TS IAN SEP 12-16
10 TS JULIA SEP 14-18
11 TS KARL SEP 14-25
12 TS LISA SEP 19-24
13 MH MATTHEW SEP 28-OCT 9
14 MH NICOLE OCT 4-18
15 H OTTO NOV 21-26
* Post-storm analysis is complete
Preliminary
See inset
Major Hurricane
Hurricane
Tropical Storm
Tropical Depression
Subtropical Storm
Subtropical Depression
Wave/Low
Extratropical Storm
Position at 0000 UTC
dd Position/date at 1200 UTC
Storm Number
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30 AND 60
SCALE OF NAUTICAL MILES
0 250 500
U.S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
North
South
West
East

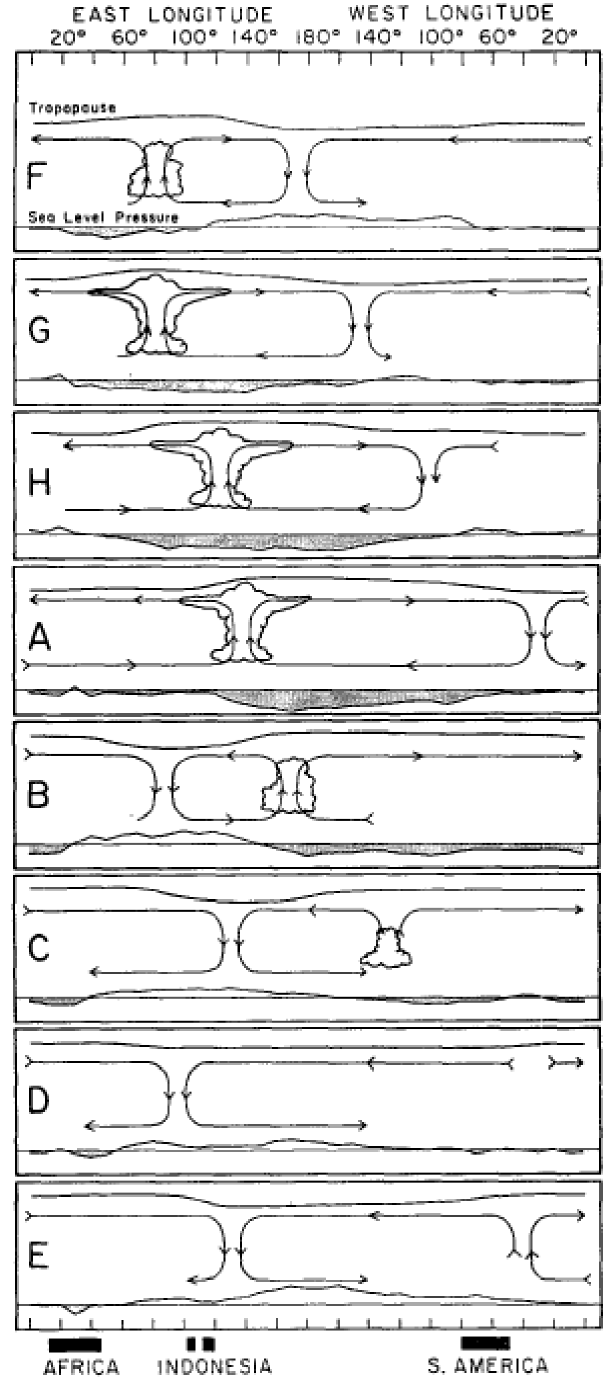
Madden-Julian Oscillation

- Discovered in the early 1970s by Roland Madden and Paul Julian.
- An eastward propagating wave that circles the globe in about 40-50 days involving tropical convection.
- Detected in the Outgoing Longwave Radiation (OLR) and wind fields across the tropics.
- Later papers showed that it is an important modulator of TC activity, especially in the Pacific Ocean.

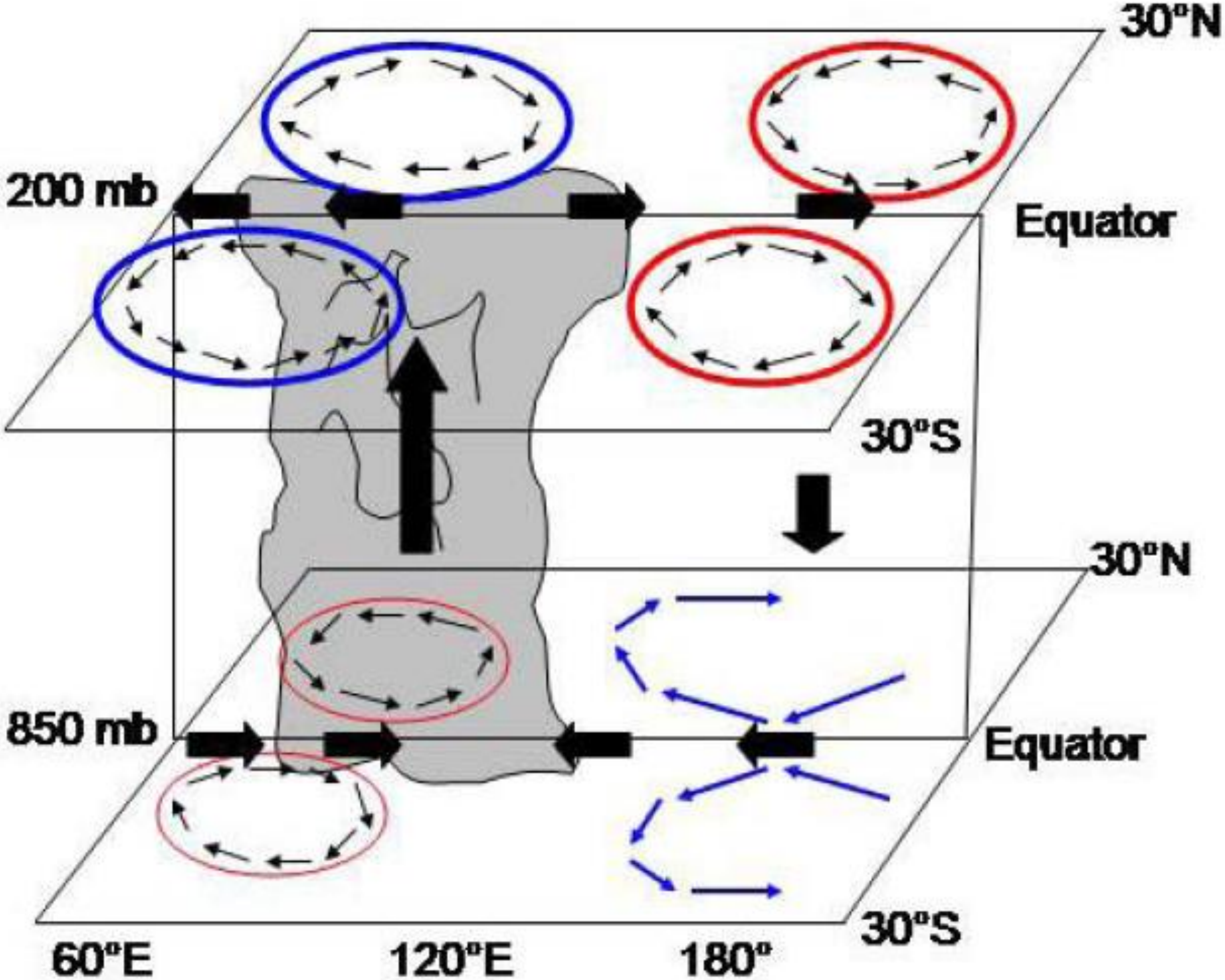
-Idealized Diagram of the 40-50 day Tropical Intraseasonal Oscillation

-Became known as the Madden-Julian Oscillation in the late 1980s

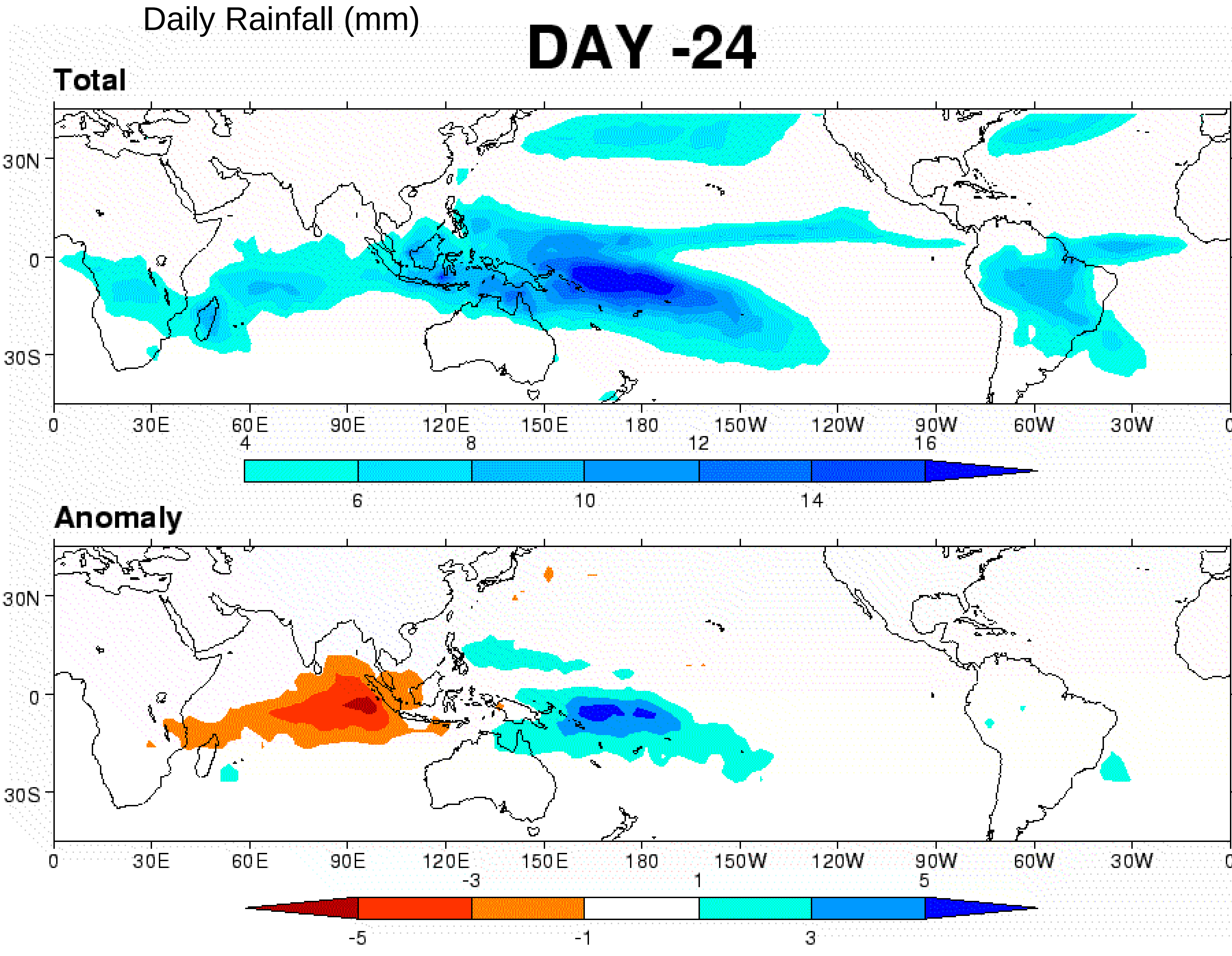
-Generally forms over the Indian Ocean, strengthens over the Pacific Ocean and weakens due to interaction with South America and cooler eastern Pacific SSTs



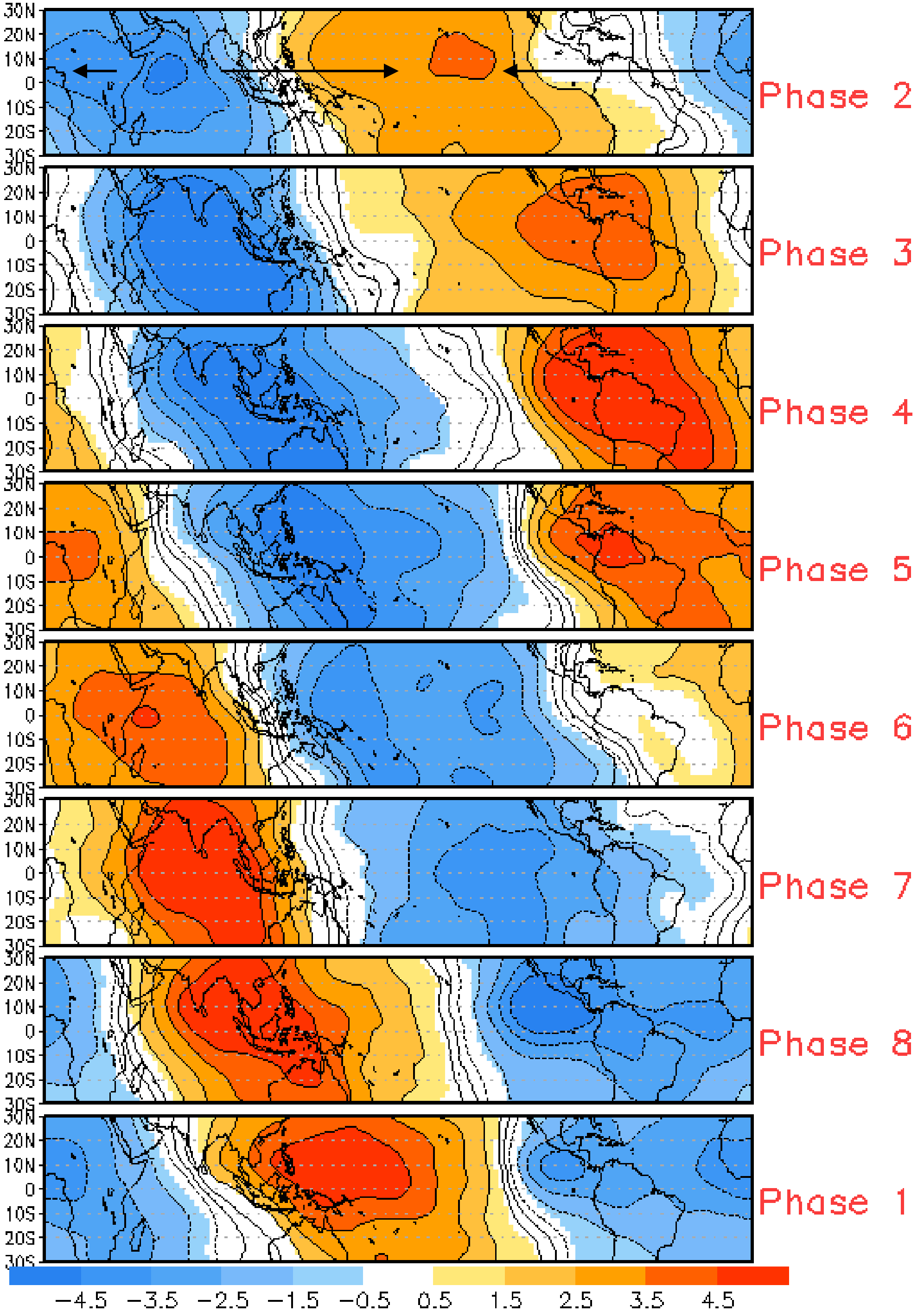
(Madden and Julian 1972)



Rui and Wang (1990)



Daily Rainfall (mm)
DAY -24
Total
30N
0
30S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0
4 8 12 16
6 10 14
Anomaly
30N
0
30S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0
-3 1 5
-5 -1 3

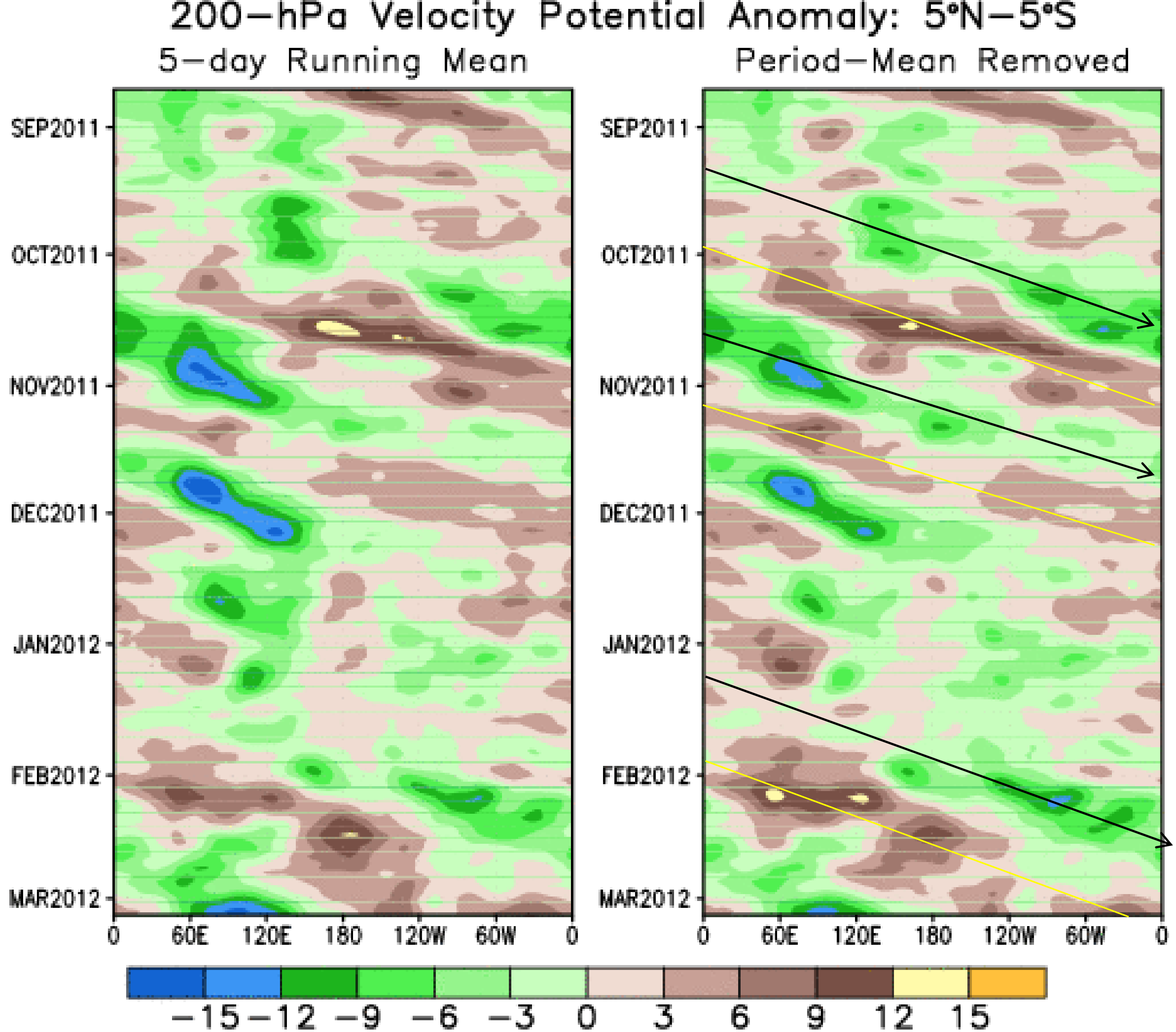


200 mb Velocity Potential fields– one way to track the MJO

Blue= ~divergence

Red= ~convergence

Center of the blue area tracks the most upper divergence, which is usually well-linked to thunderstorms



Time–longitude sections of anomalous 200–hPa velocity potential (x 10^6 m^2 s^{-1}) averaged between 5°N–5°S for the last 180 days ending 05 MAR 2012: (Left) 5–day running means and (Right) 5–day running means with period mean removed. Anomalies are departures from the 1981–2010 period daily means. CLIMATE PREDICTION CENTER/NCEP

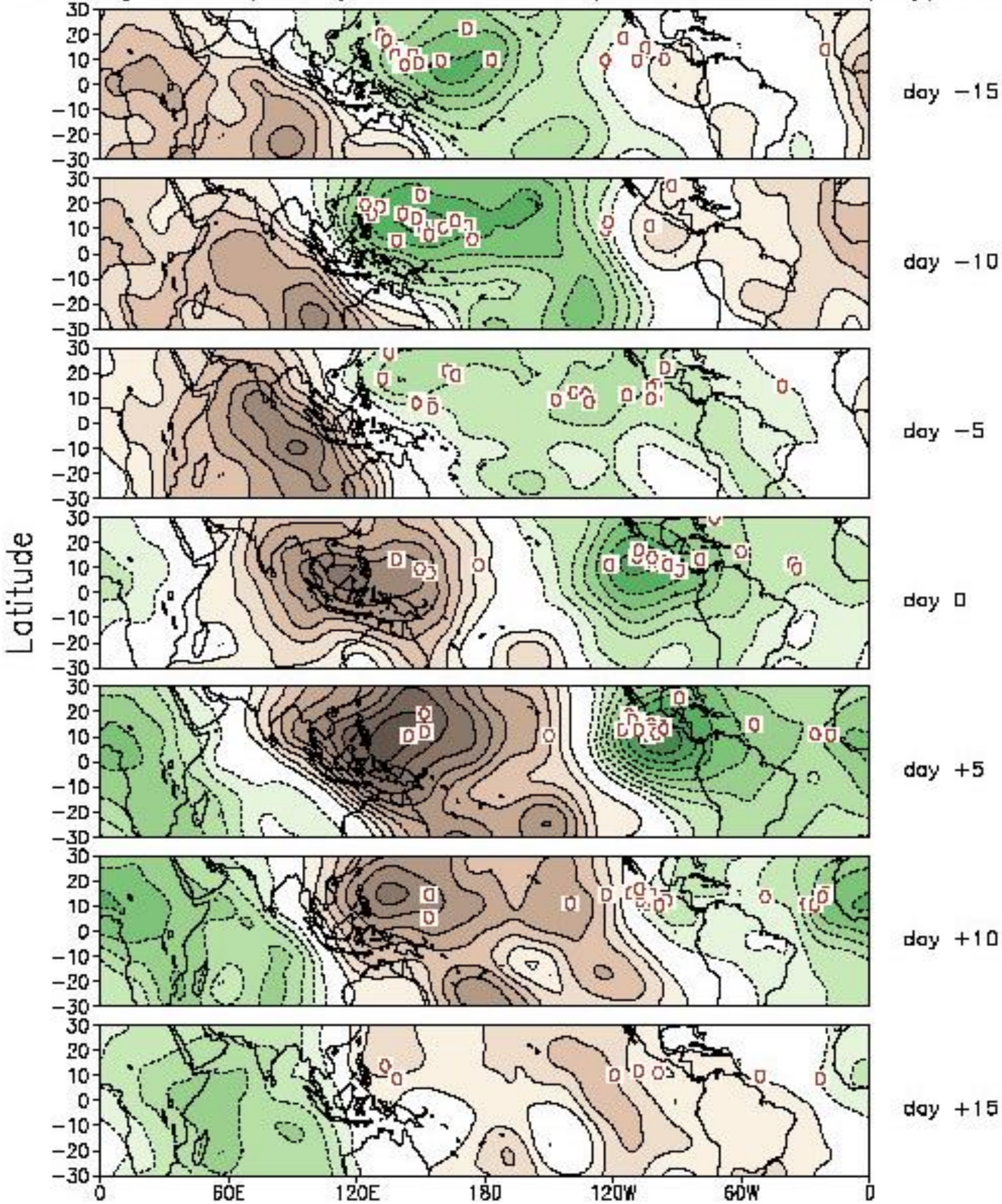
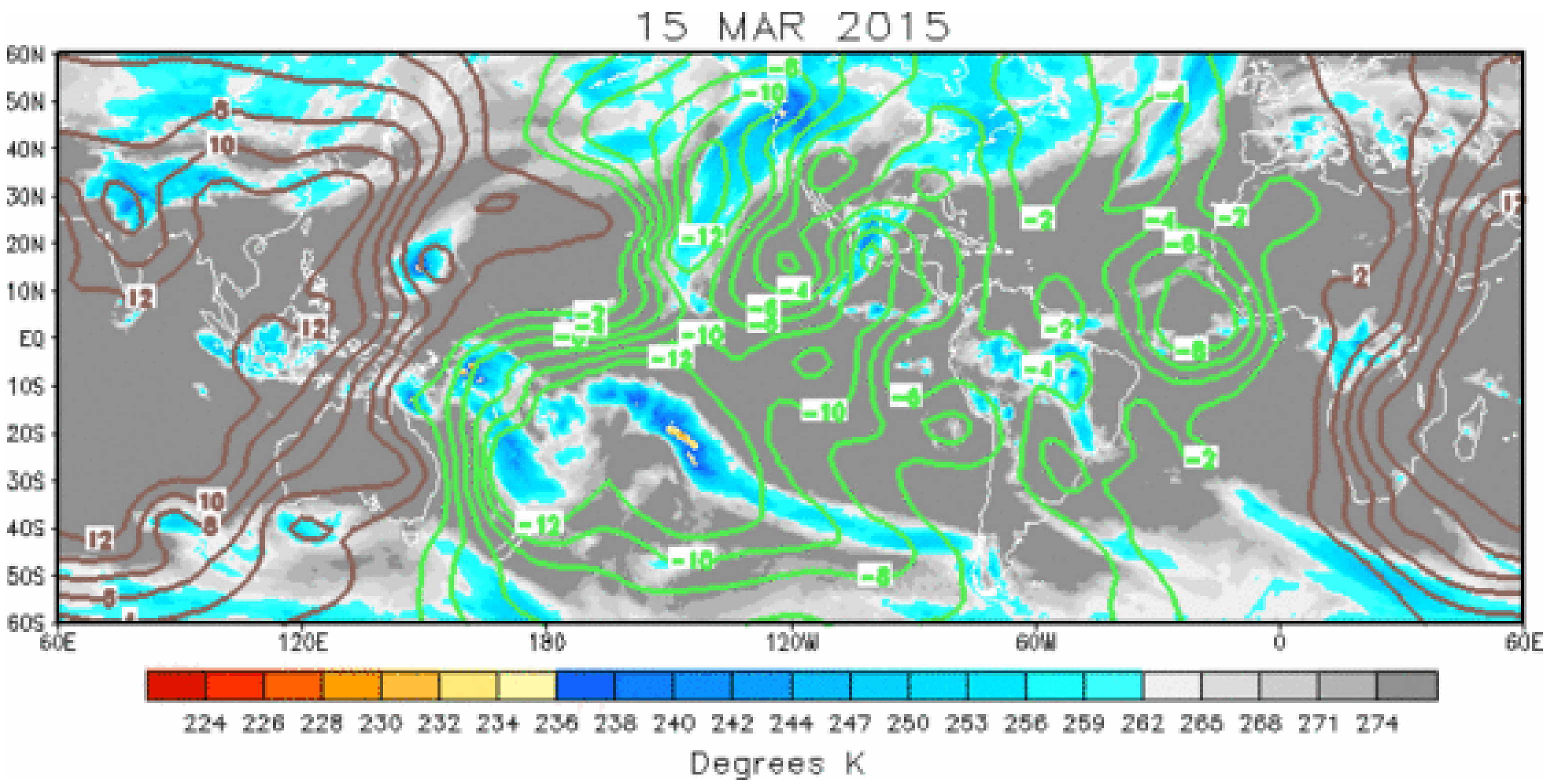


Figure 10: Velocity potential composites for different phases of the MJO cycle with hurricane/typhoon origin locations. Green shading indicates upper level divergence and brow shading indicates upper level convergence. Open circles indicate hurricane/typhoon origin centers.

- Most genesis points are near or behind the upper-level divergence center.

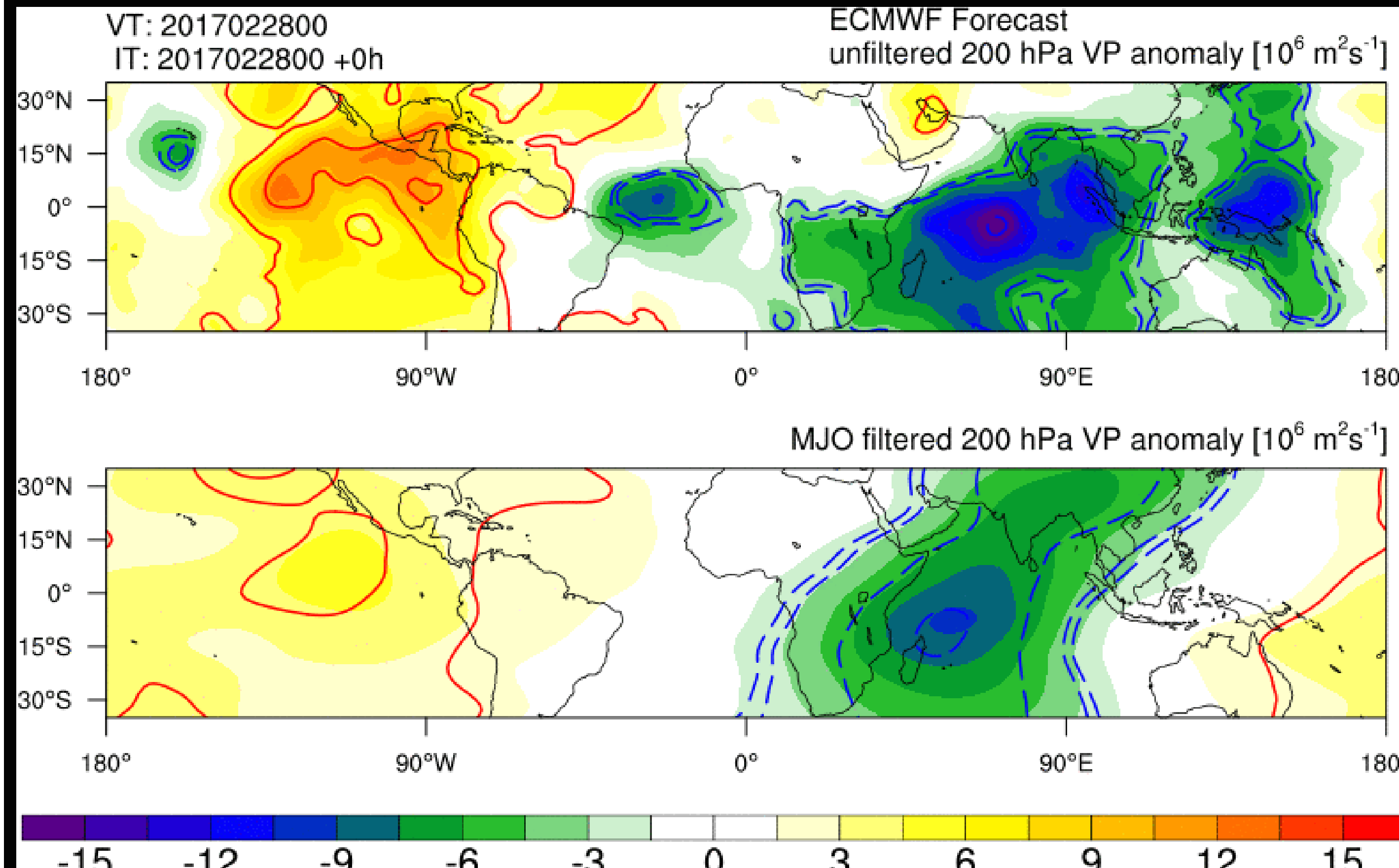
Another way to track the MJO



Animation of daily IR and 200-hPa velocity potential anomalies (base period 1971-2000). Velocity potential anomalies are proportional to divergence with green (brown) contours corresponding to regions in which convection tends to be enhanced (suppressed).

http://www.cpc.ncep.noaa.gov/products/precip/CWlink/ir_anim_monthly.shtml

10-day ECMWF MJO Forecast

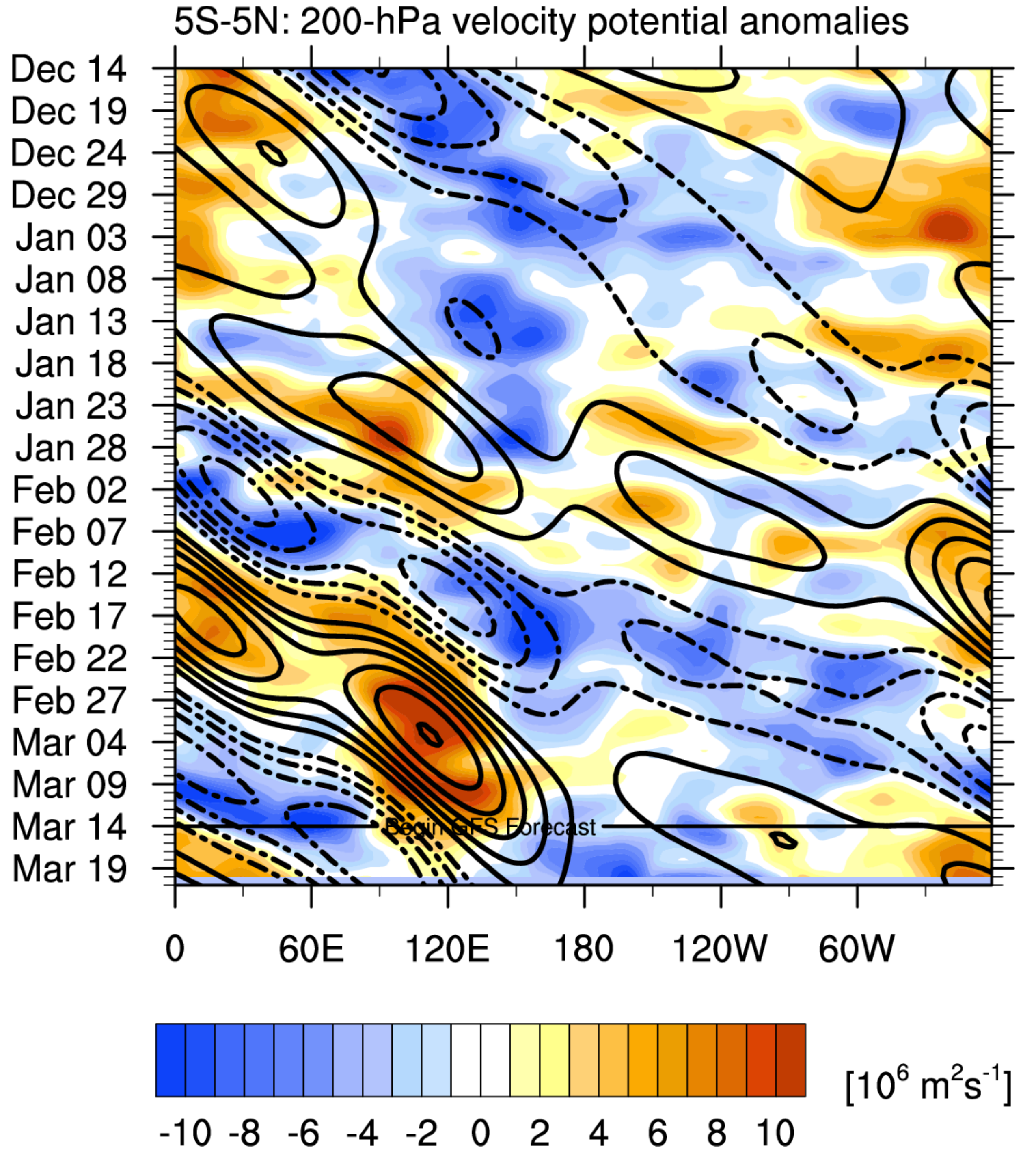


MJO characteristics

Note signal is much stronger in eastern Hemisphere than western

Eastward phase speed is a lot slower in eastern than western Hemi (convective coupling)

In western hemisphere, upper-level signal usually much easier to track than lower-level



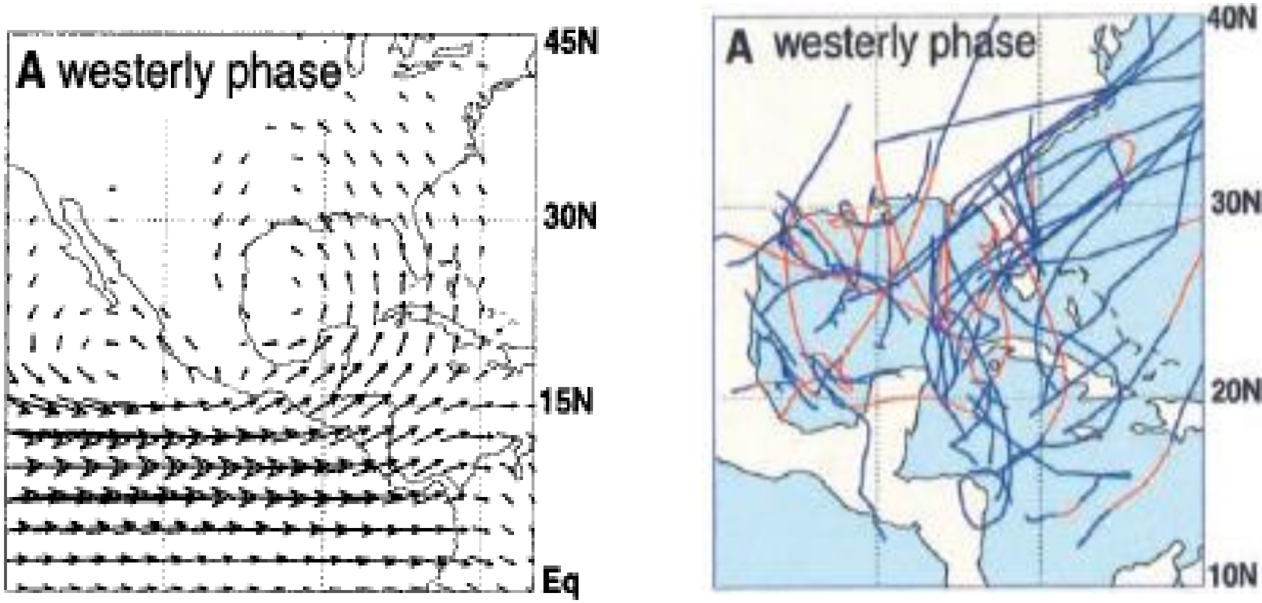
MJO Effects in the Atlantic Basin

- The MJO can lose much of its strength before entering the Atlantic basin.
- In addition, the MJO is weakest during the late summer, near the peak of Atlantic activity.
- Western part of the basin most strongly affected (Maloney and Hartmann 2000).

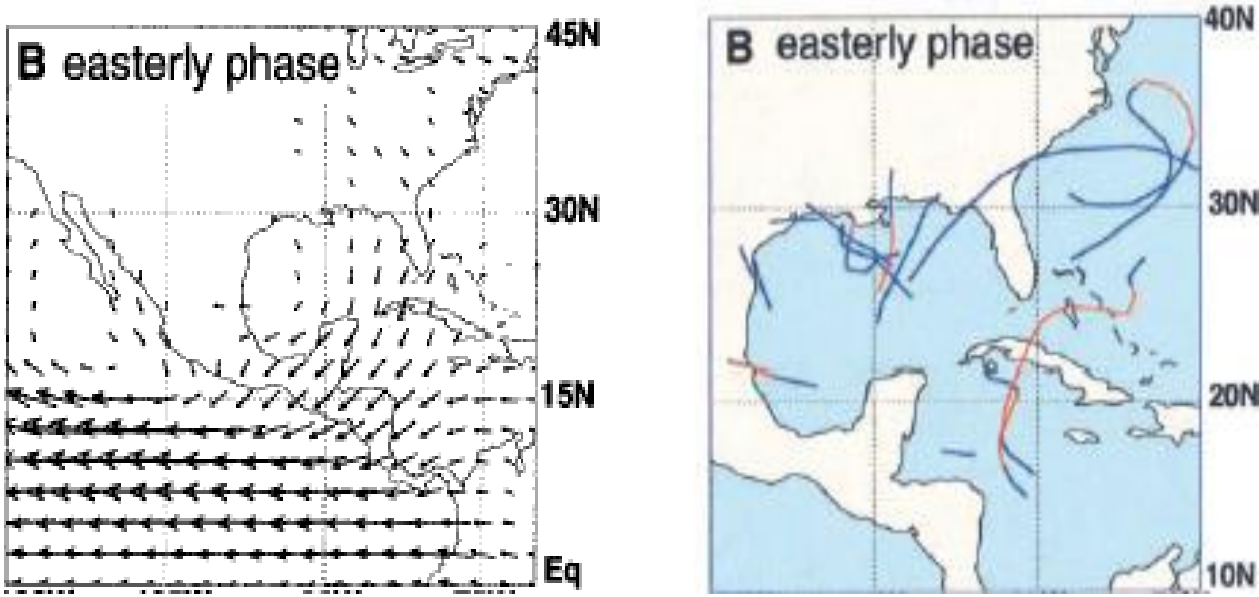
Active MJO in the western Caribbean Sea and Gulf of Mexico produces more storms due to:

- Increase in low-level convergence (ITCZ moves farther north)
- Low-level vorticity is also increased due to westerly low-level flow meeting easterly trades
- Upper divergence is stronger than average during the westerly phase, with a drop in shear as well

Active MJO EOF and corresponding TS and H tracks

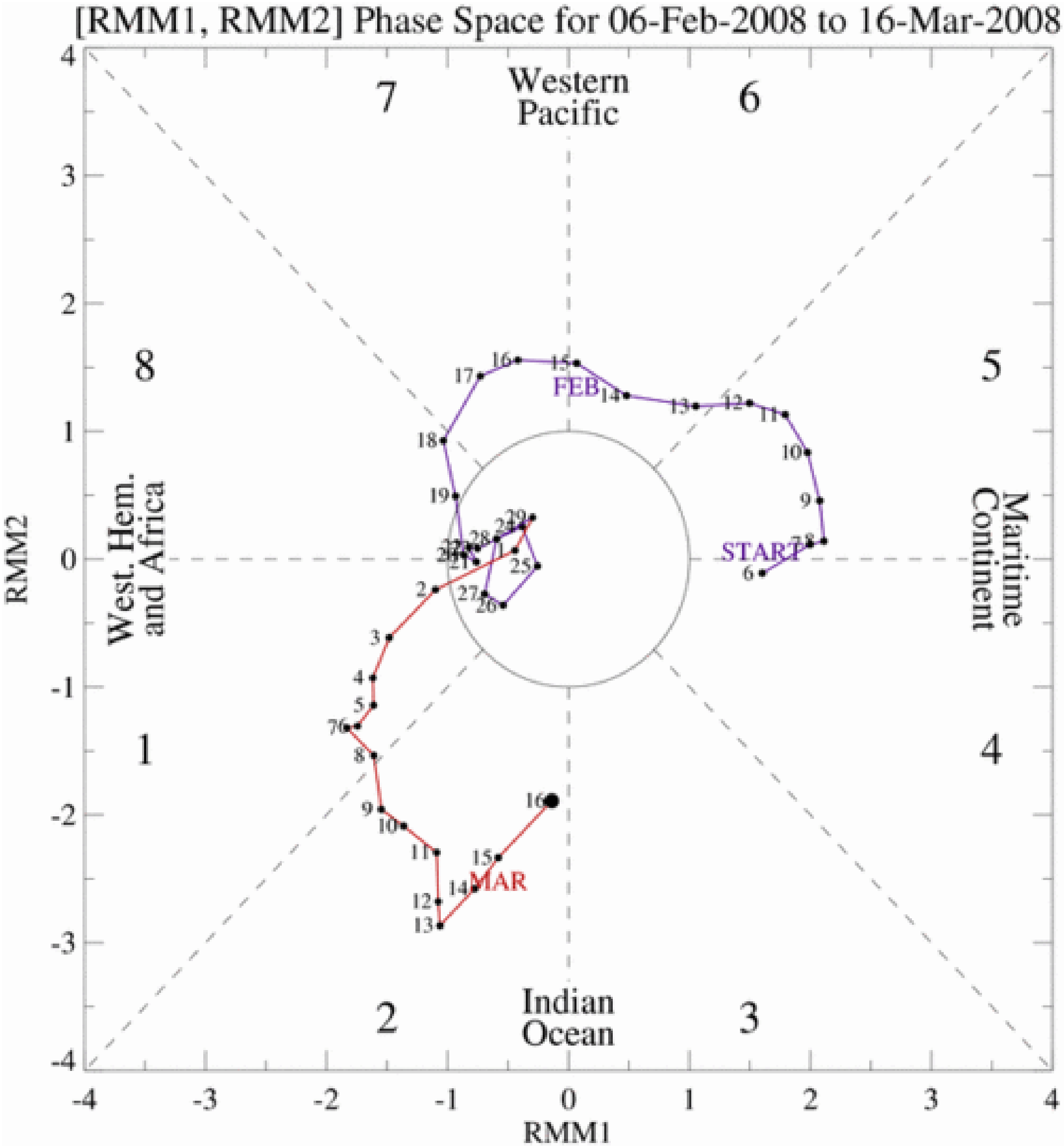


Inactive MJO EOF and corresponding TS and H tracks



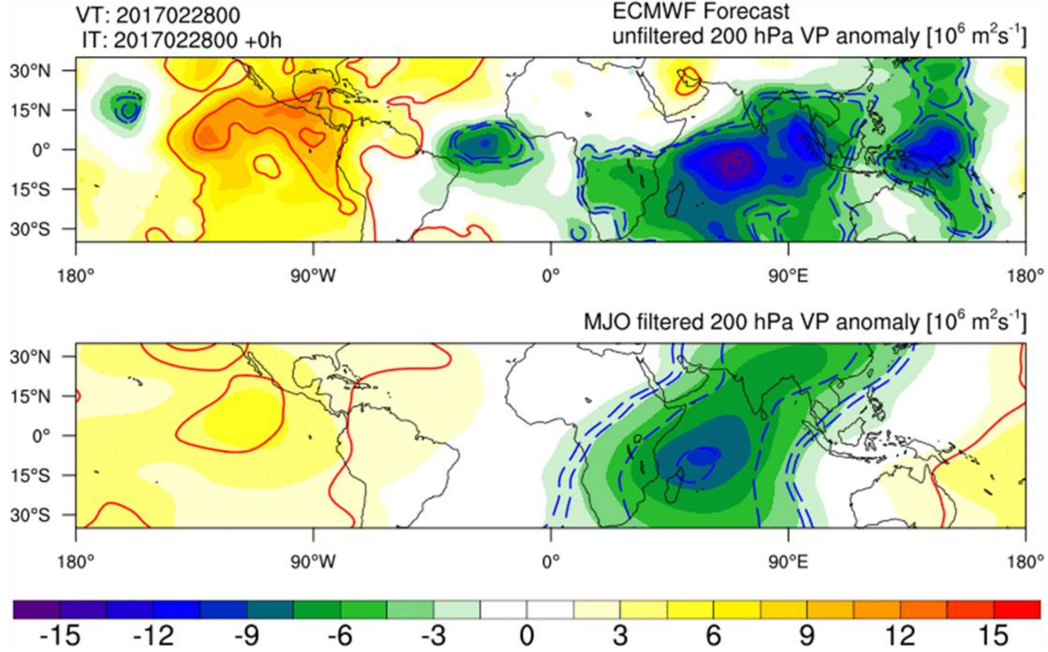
Adapted from Maloney and Hartmann (2000)

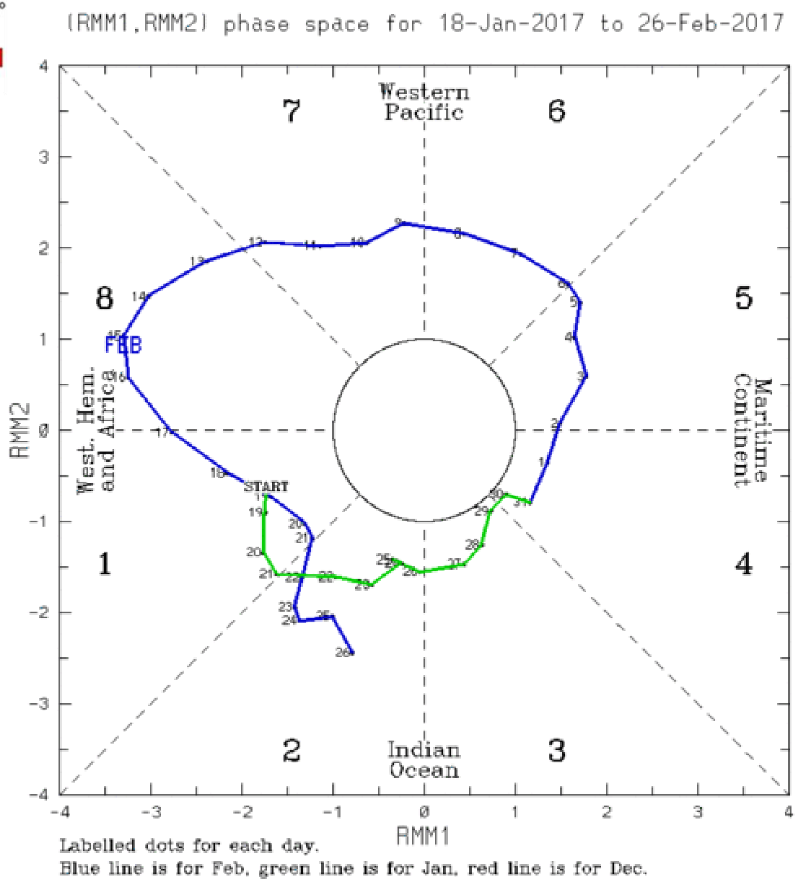
A different way to visualize the MJO

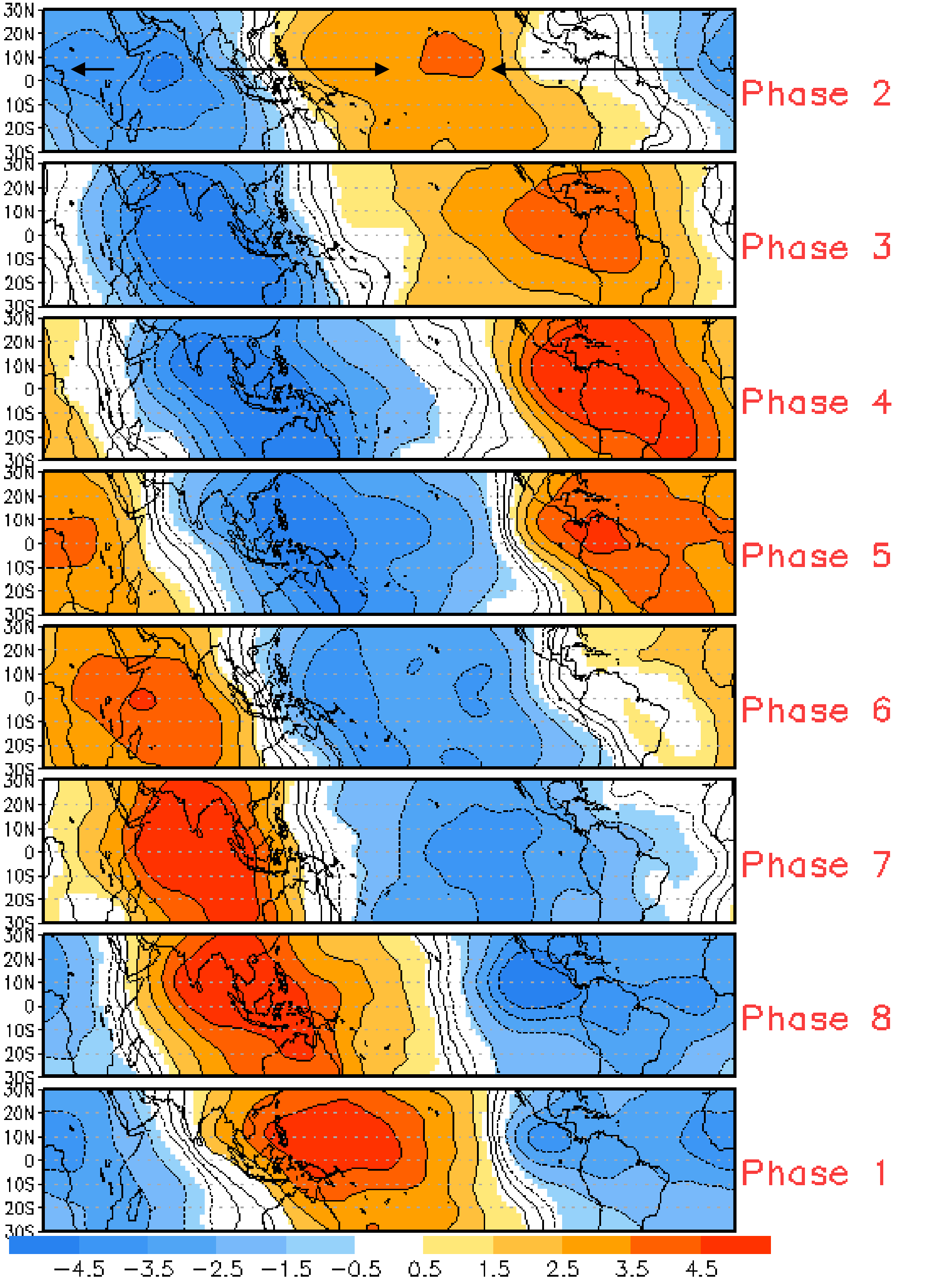


- The axes (RMM1 and RMM2) represent daily values of the principal components from the two leading modes, following the active convection.
- The triangular areas indicate the location of the enhanced phase of the MJO
- Counter-clockwise motion is indicative of eastward propagation
- Distance from the origin is proportional to MJO strength
- Line colors distinguish different months

Current MJO:
Plan view versus
RMM diagram







200 mb Velocity Potential fields– one way to track the MJO

Blue= ~divergence

Red= ~convergence

Center of the blue area tracks the most upper divergence, which is usually well-linked to thunderstorms

Question 2

What phases of the MJO are most favorable for Atlantic TC activity?

A. Phases 3/4

B. Phases 5/6

C. Phases 7/8

D. Phases 1/2

Normalized Activity by MJO Phase (1974-2007)

MJO Phase	NS	NSD	H	HD	MH	MHD	ACE
Phase 1	**2.7**	**22.9**	**2.3**	**13.5**	**1.4**	**4.9**	**57.5**
Phase 2	**3.0**	**24.7**	**2.5**	**13.2**	**1.8**	**4.2**	**53.0**
Phase 3	2.6	19.8	1.7	12.1	0.9	2.1	41.4
Phase 4	1.7	12.1	1.1	8.1	0.7	2.7	32.0
Phase 5	2.7	14.8	1.6	6.3	0.7	1.3	35.7
Phase 6	*2.6*	*13.1*	*1.2*	*3.9*	*0.6*	*0.9*	*20.3*
Phase 7	*1.6*	*9.4*	*0.6*	*3.7*	*0.5*	*1.1*	*17.5*
Phase 8	1.9	12.2	1.1	6.5	0.6	1.9	25.3
Ratio of Phases 1+2 to Phases 6+7	**1.4**	**2.1**	**2.7**	**3.5**	**2.9**	**4.6**	**2.9**

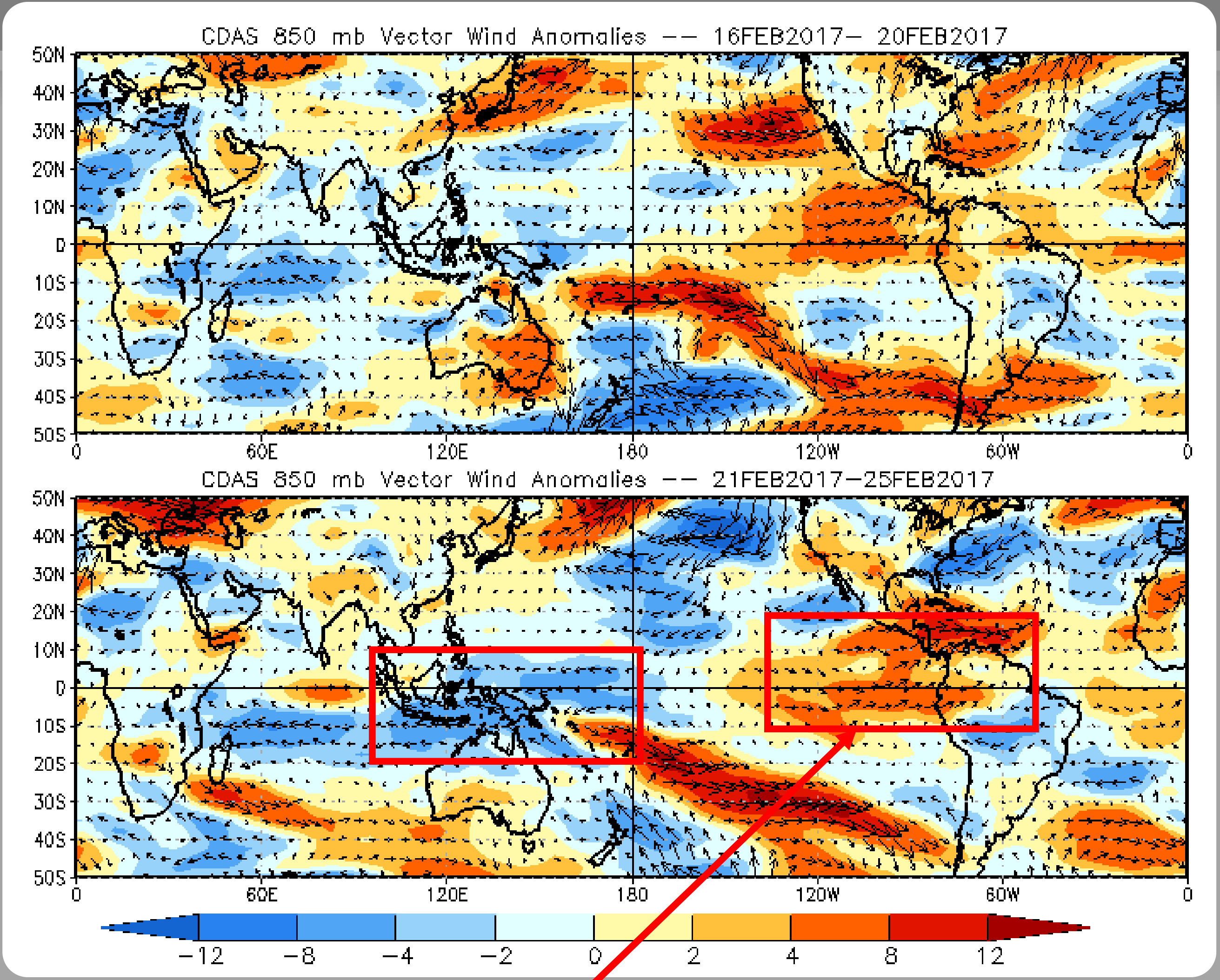
From Klotzbach (2010)

850-hPa Vector Wind Anomalies (m s-1)

Note that shading denotes the zonal wind anomaly

<u>Blue shades</u>: Easterly anomalies

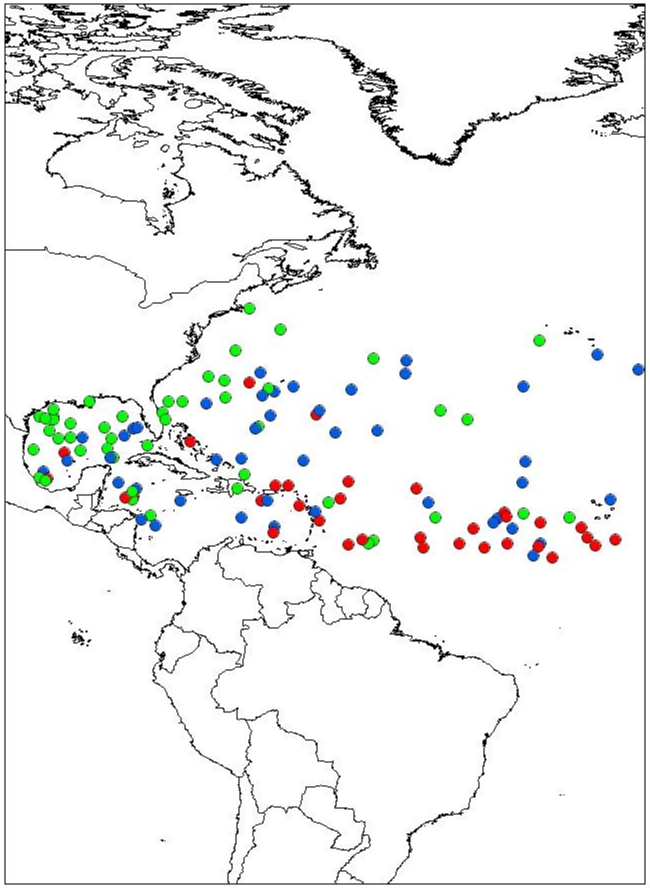
<u>Red shades</u>: Westerly anomalies



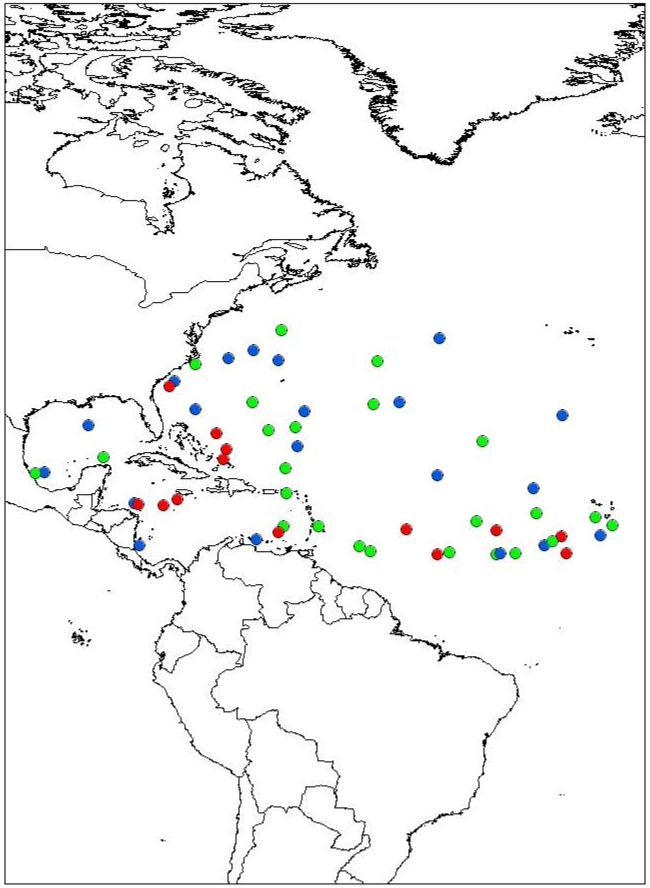
Typical Active Atlantic pattern (if in summer-time)!

All Genesis Points

MJO Phases 1+2

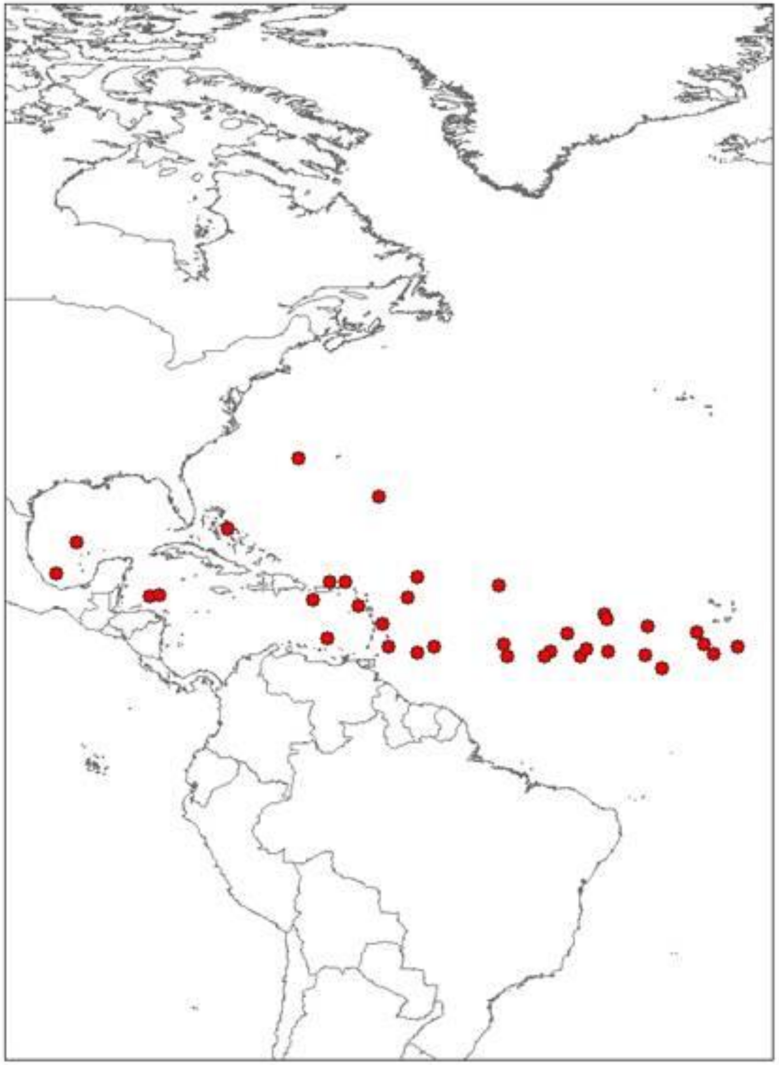


MJO Phases 6+7



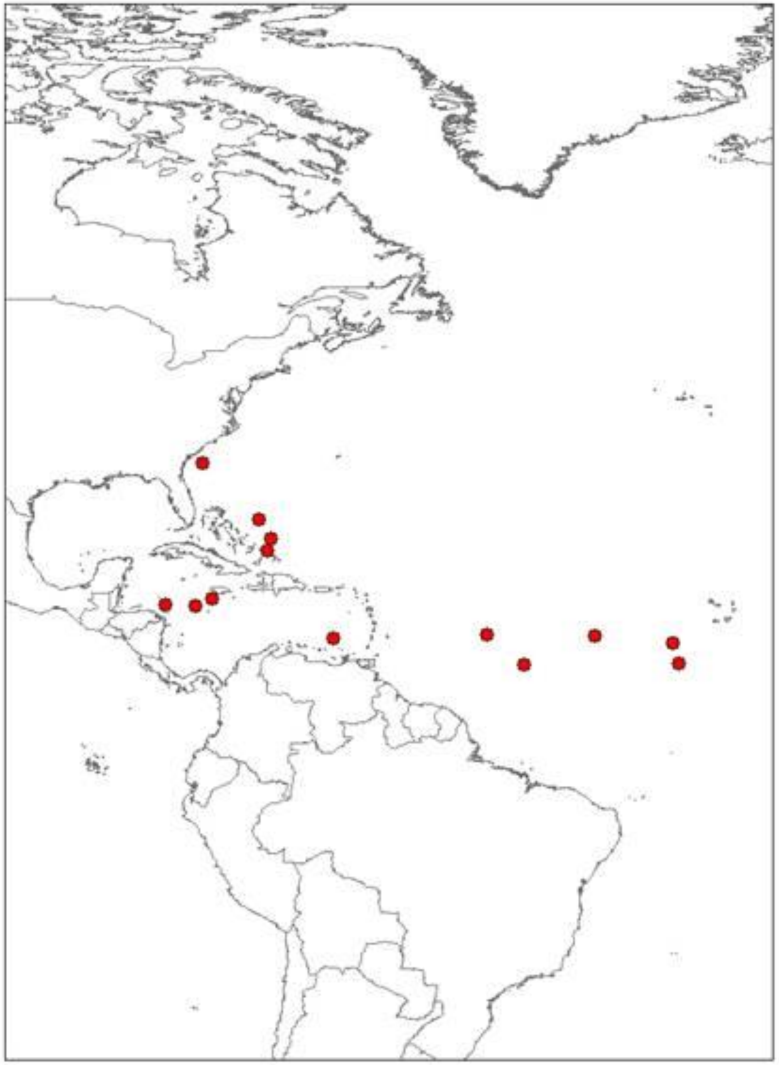
36 Major Hurricanes

MJO Phases 1-2 - Atlantic Major Hurricane Formations



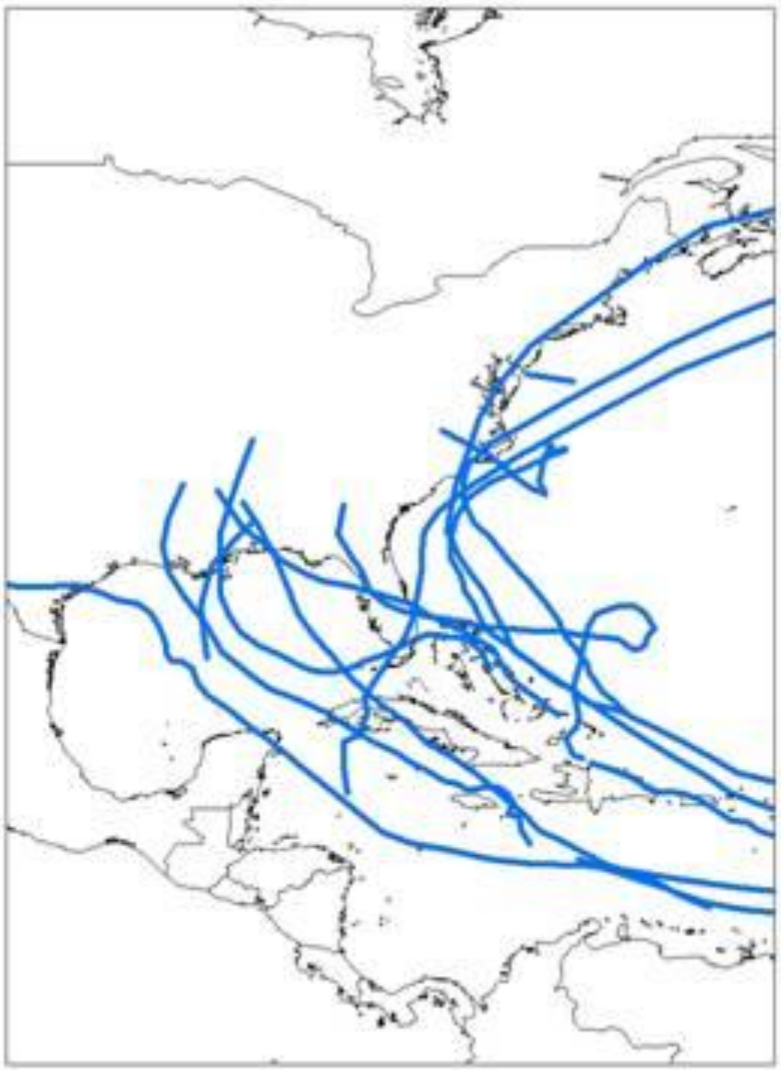
13 Major Hurricanes

MJO Phases 6-7 - Atlantic Major Hurricane Formations



10 Hurricane Landfalls

MJO Phase 2

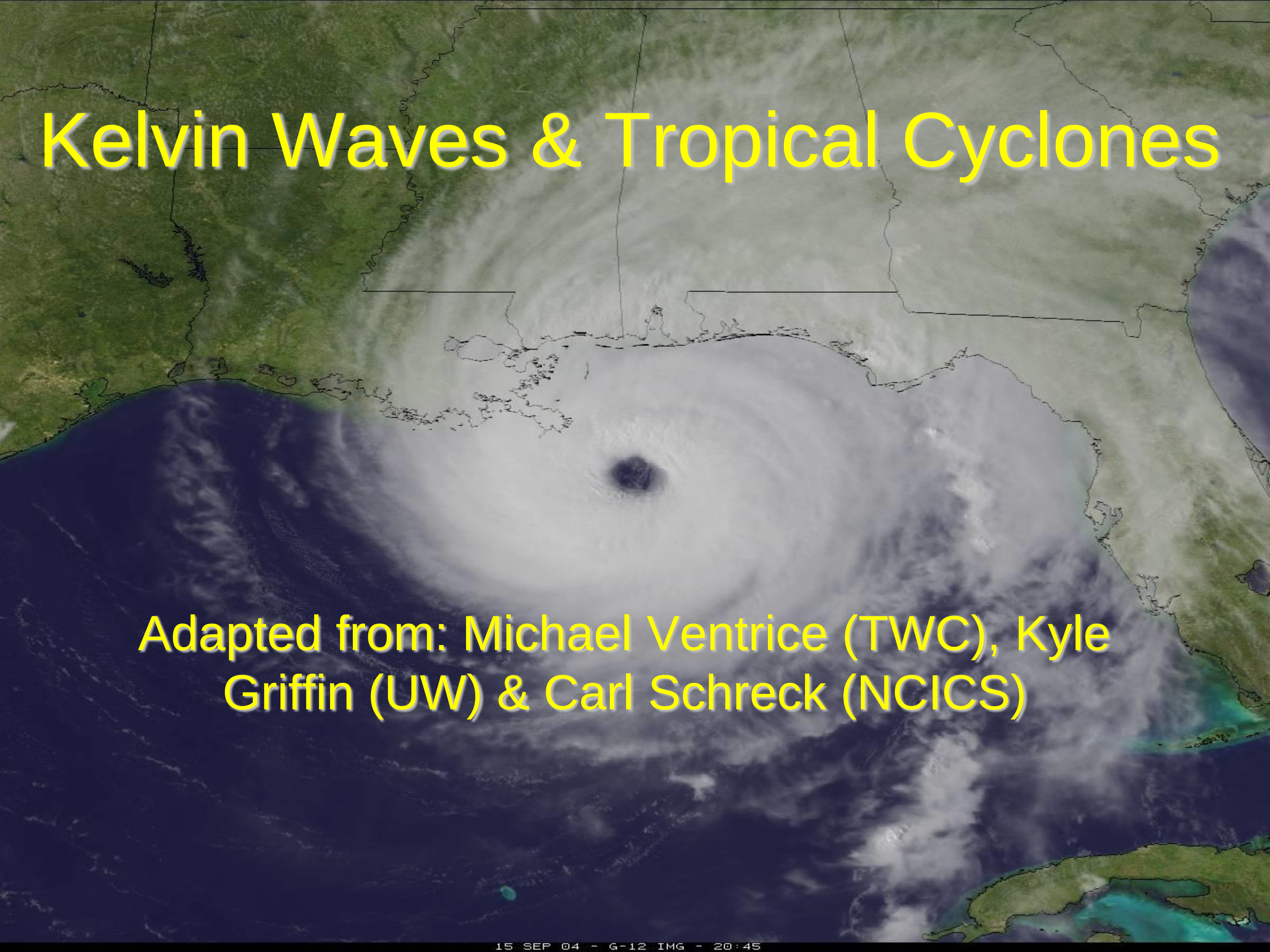


1 Hurricane Landfall

MJO Phase 7

Kelvin Waves & Tropical Cyclones

Adapted from: Michael Ventrice (TWC), Kyle Griffin (UW) & Carl Schreck (NCICS)



Background

The idea of equatorial waves interacting with TCs is relatively new…

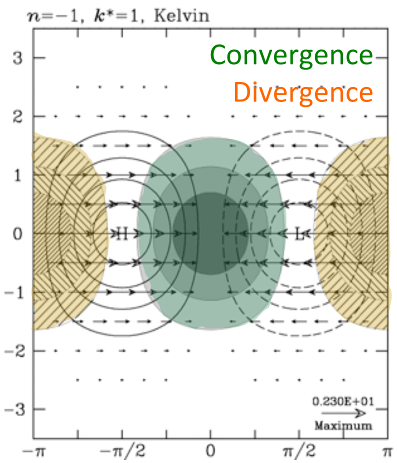
- An objective method of tracking equatorial waves in real-time wasn't published until 1999

- First AMS papers mentioning (atmospheric) equatorial waves and TCs appeared around 2002

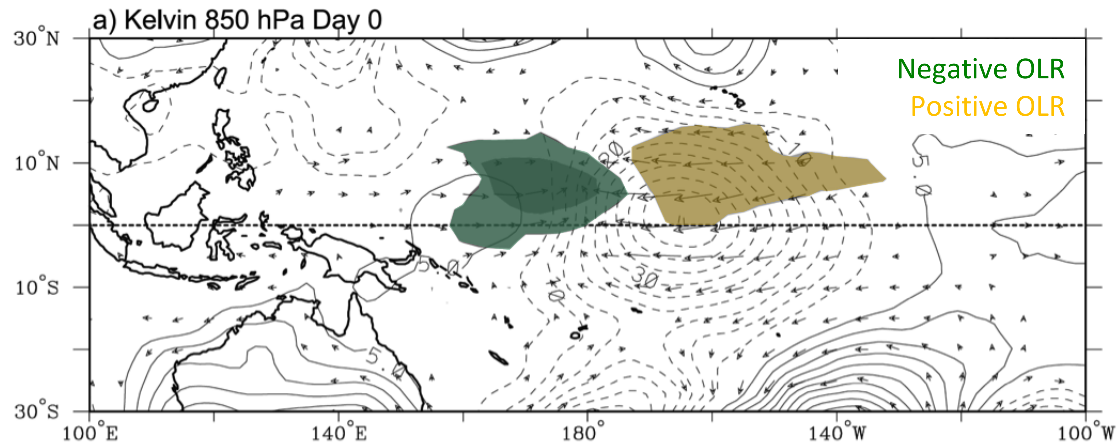
- Number of papers that involve this or similar topics in AMS journals only number in the ~2 dozen range

Equatorial waves aid in *enhanced* predictability of TC genesis several (3-7) days into the future.

Kelvin Waves



Matsuno (1966)



Kiladis et al. (2009)

- Alternating westerlies and easterlies on the equator
- Enhanced convection where low-level winds converge
- Active phase associated with **latent heating** & the generation of **low-level relative vorticity** due to presence of meridional flow

Propagation:	Eastward
Phase speed:	10–20 m s^{-1}
Period:	3–10 days
Wavelength:	2000–4000 km

Adapted from Carl Schreck 2017

MJO vs. KW

The **Madden-Julian Oscillation** (MJO) consists of an active and suppressed phase, dominated by low-level westerly and easterly anomalies, respectively. Convection is preferred in the active phase.

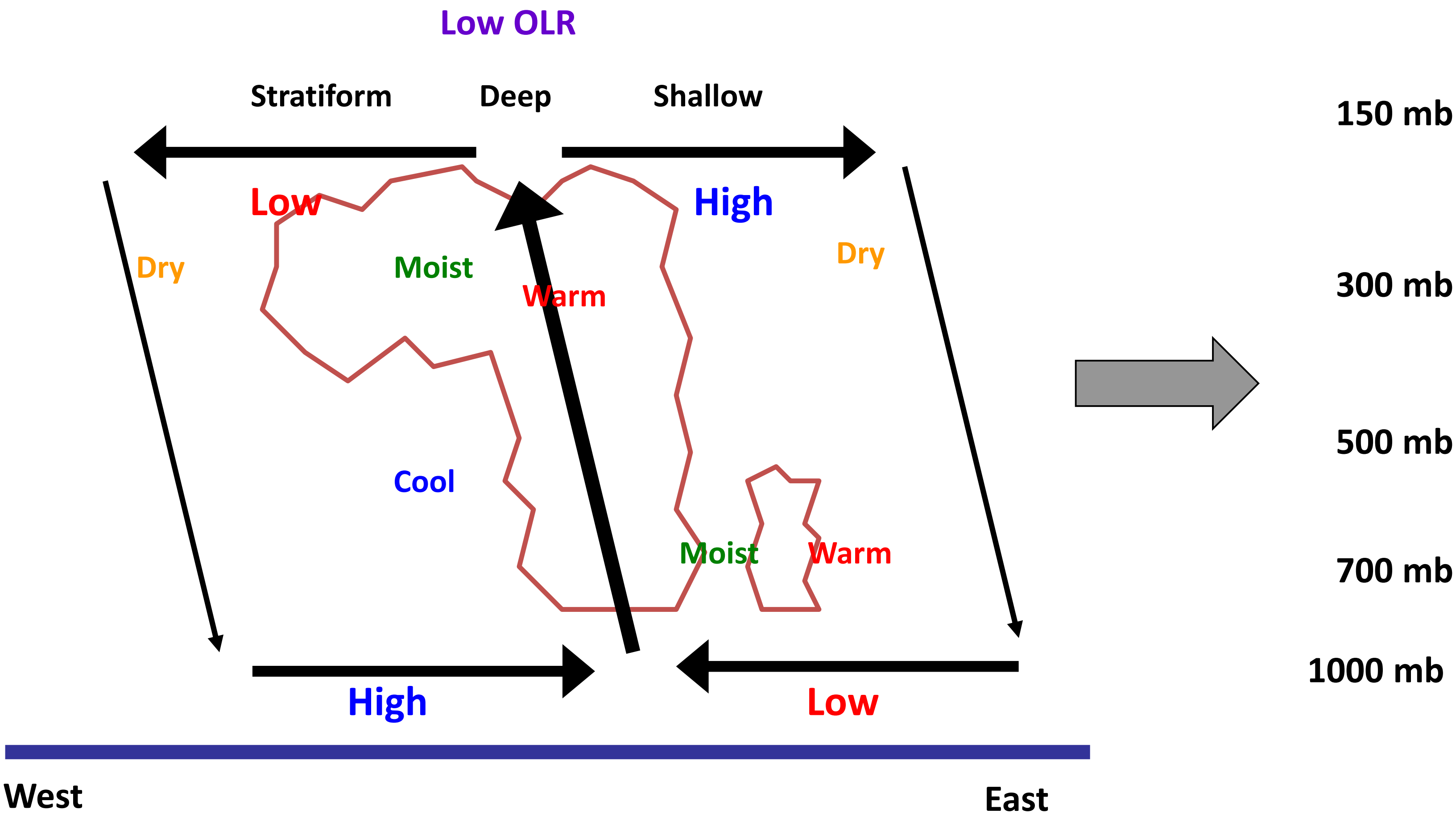
- A typical MJO moves eastward at 4 to 8 m s^{-1} with a zonal extent that spans planetary to synoptic scales.

A **Kelvin wave** is spatially very similar to the MJO, but is typically observed at higher zonal wavenumbers and moves eastward at 10 – 20 m s^{-1}.

- Effects are more constrained within the Tropics and associated wind anomalies are spatially smaller than the MJO.

Adapted from Griffin (2014)

Conceptual Model of Vertical Structure



Straub and Kiladis (2003)

WSI

CCKW composites

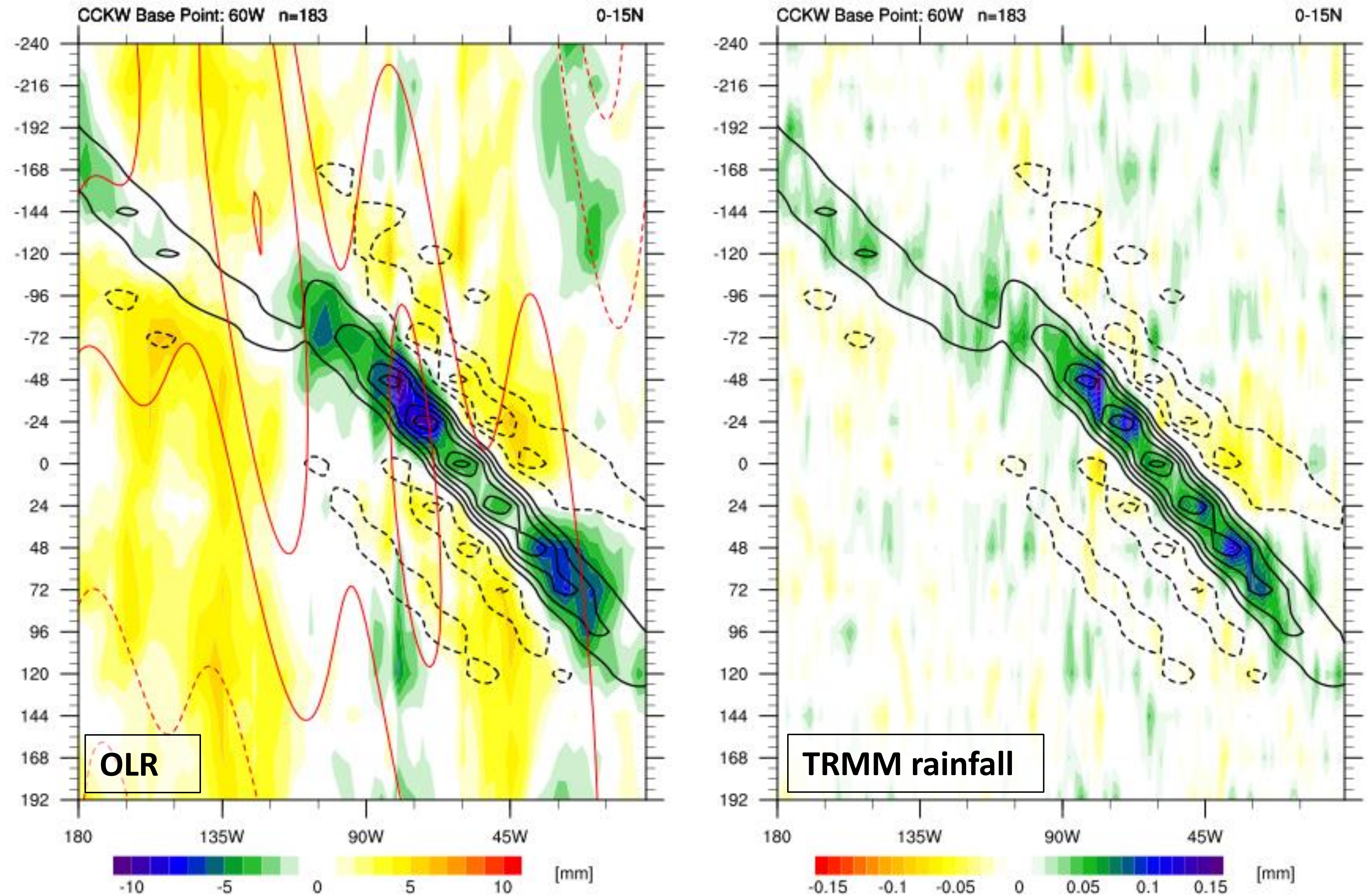
Performed using a base point of 60˚W

Averaged dates when CCKW-filtered TRMM rainfall reached minimum and was above +1 sigma.

Relationships generally hold true for various base points across the Atlantic and Eastern Pacific, as well as the Eastern Hemisphere

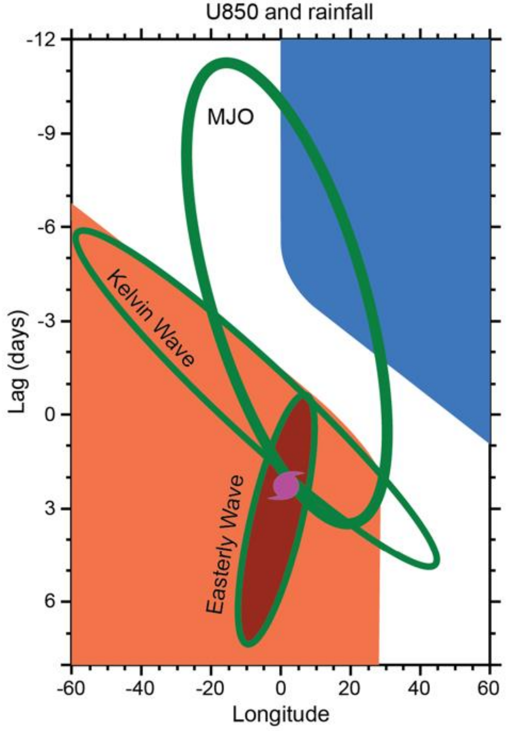
For Atlantic, most results smear after +/- 4-5 days
- Due to higher variability in phase speed of CCKW over Western Hemisphere

CCKW composites



Kelvin Waves and Tropical Cyclogenesis

- Storms typically form 0–3 days after the Kelvin wave's convective peak
- Often interacting with MJO and Easterly Waves during genesis
- Easterly wave initiates or amplifies in the Kelvin wave convective envelope

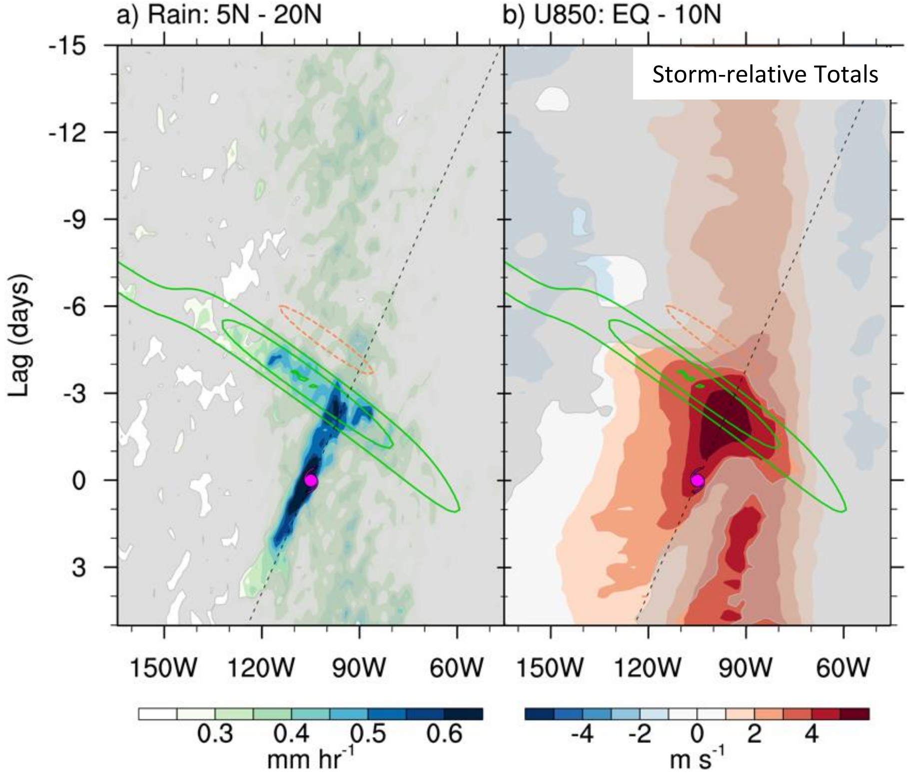


Schreck (2015, MWR)

Background

Tropical wave + CCKW composite

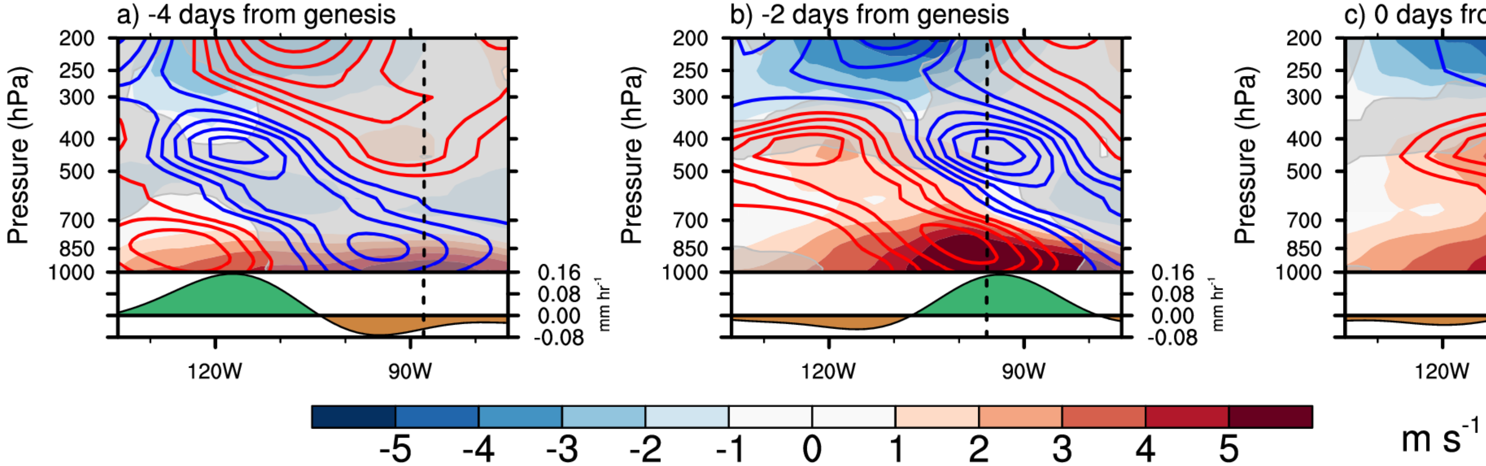
East Pacific: 40 storms



- Composite Hovmöllers of storms forming at the most favorable lags (2-3d) from Kelvin wave crest
- The wave is invigorated with convection/rainfall, leading to genesis.
- CCKW most effective when some westerly flow already present

Vertical Structure

East Pacific Zonal Wind Eq–10°N



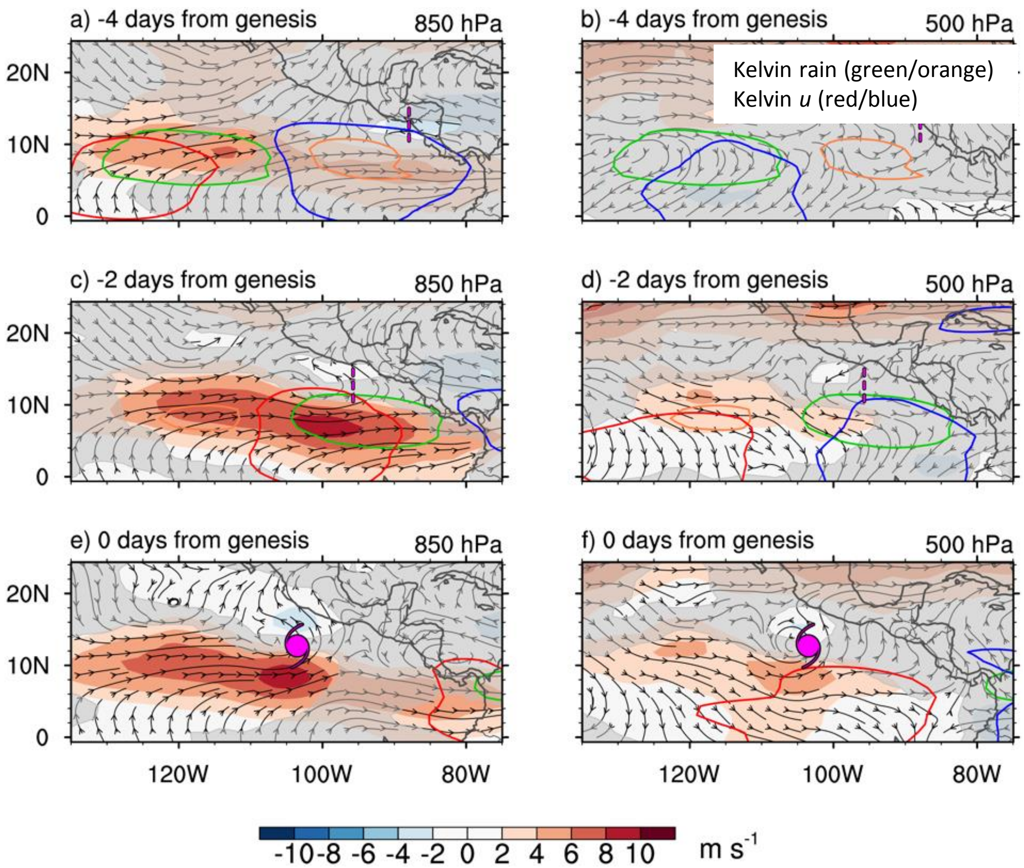
- Convection and storm-relative westerlies intersect easterly wave 2 days before genesis
- Easterly wave circulation builds upward as the Kelvin wave propagates

- Kelvin tilt might explain lag in genesis from convection
  - 400-hPa is 30° longitude behind 850-hPa
  - Kelvin speed of 15 m s^{-1} gives a 2.5-day lag between 850 hPa and 400 hPa

Storm-Relative Zonal Winds

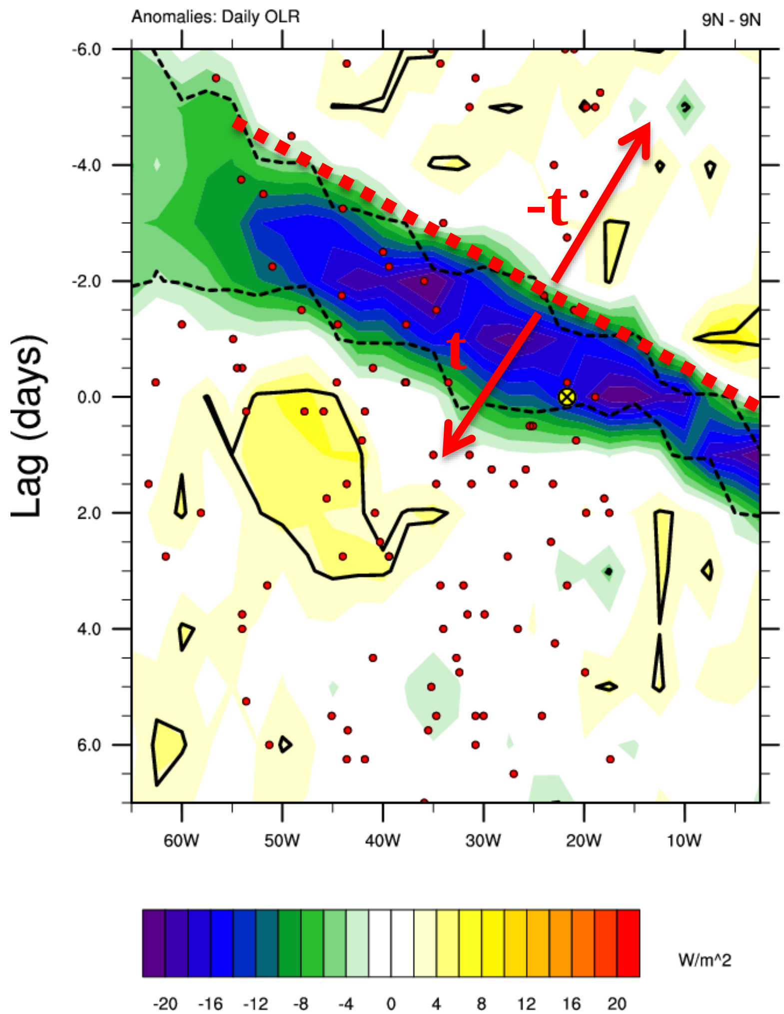
- Broad, persistent 850-hPa Westerlies
- 400-hPa westerlies develop with Kelvin wave

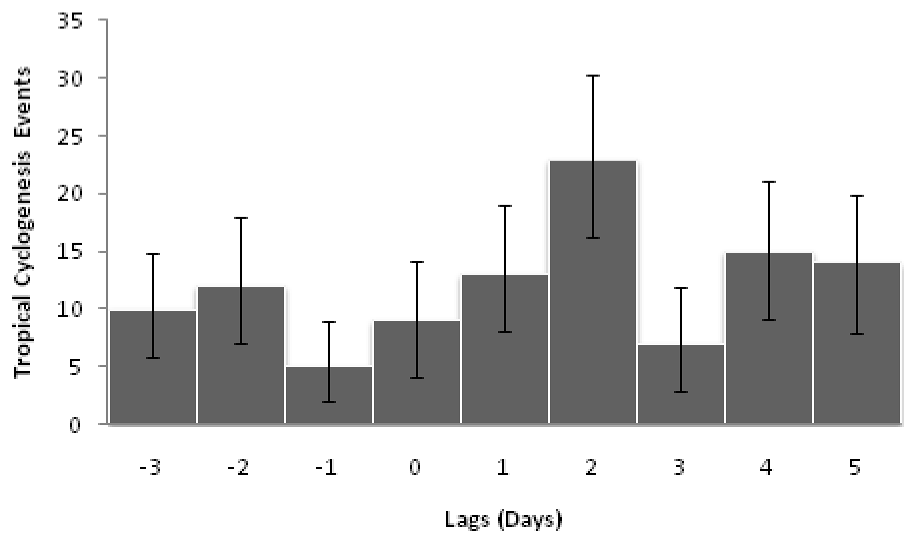
- 2 Days before Genesis
  - Kelvin wave enhances 850-hPa westerlies and rain
  - Kelvin easterlies at 400-hPa counter Easterly wave
- At Genesis:
  - Kelvin wave no longer effects 850-hPa winds or rainfall
  - At 400-hPa, Kelvin wave helps close circulation



Horizontal

Atlantic CCKW genesis composites

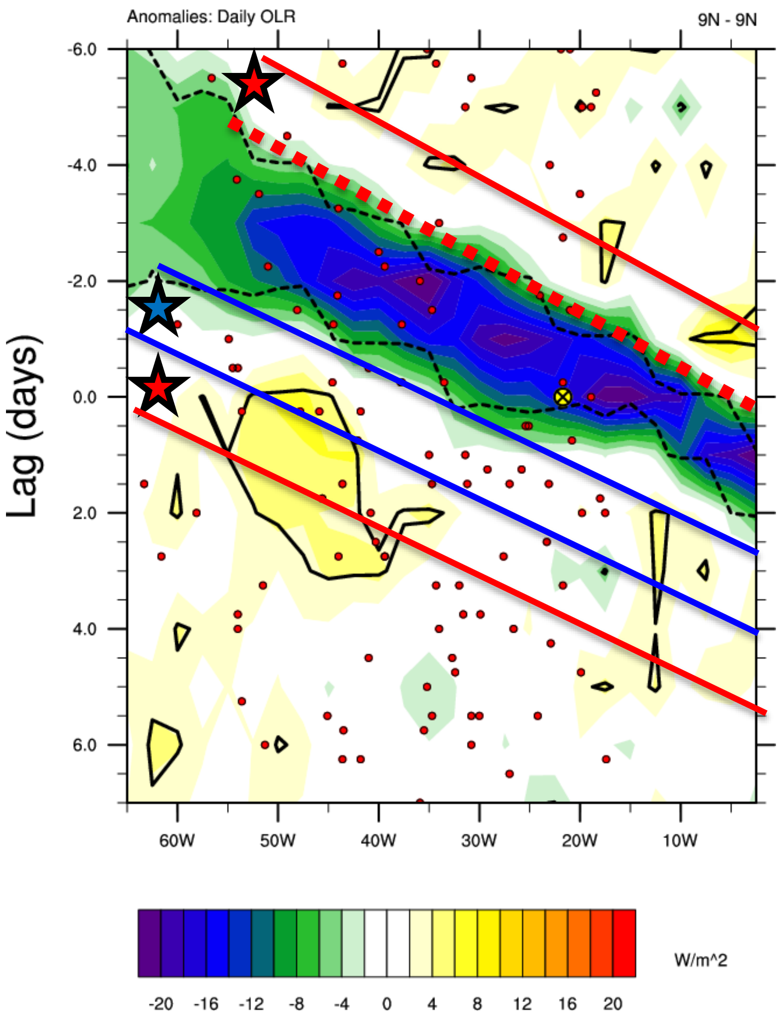


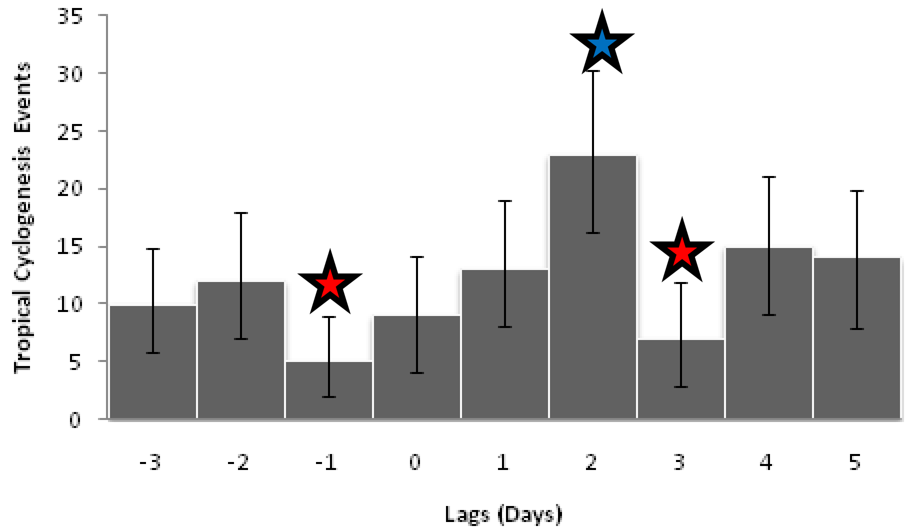


Tropical cyclogenesis events over the MDR (5-25°N, 15-65°W) relative to the CCKW during June-September 1979-2009

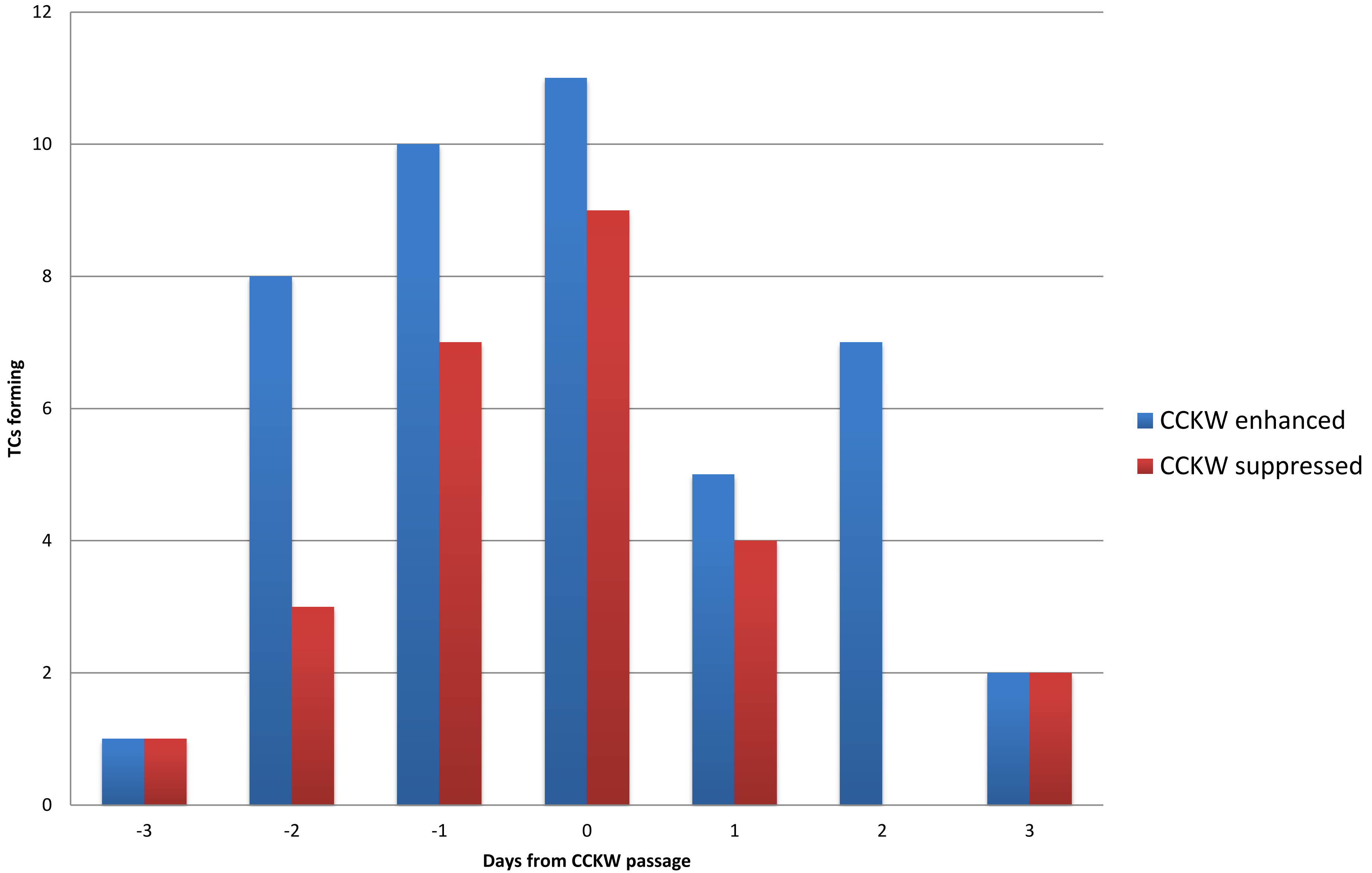
- Day 0 highlights the transition to statistically significant negative unfiltered OLR anomalies, or the eastern-most side of the convectively active phase of the CCKW.
- Error bars indicate the 95% confidence interval.

Tropical cyclogenesis relative to the Kelvin wave





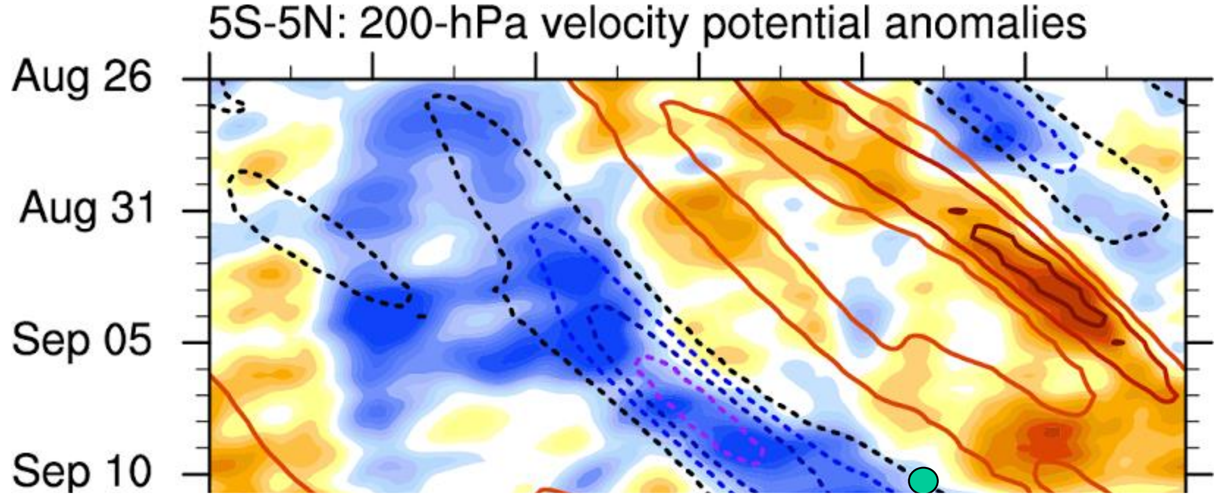
Epac TC formations within active MJO east of 120W

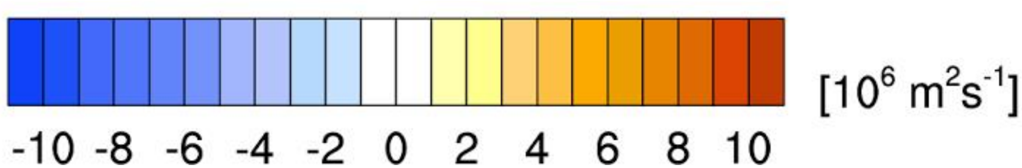


Kelvin Waves help focus the day of genesis within an active MJO

Extremely strong (4 SD) CCKW approaching an active tropical cyclone

What happens?

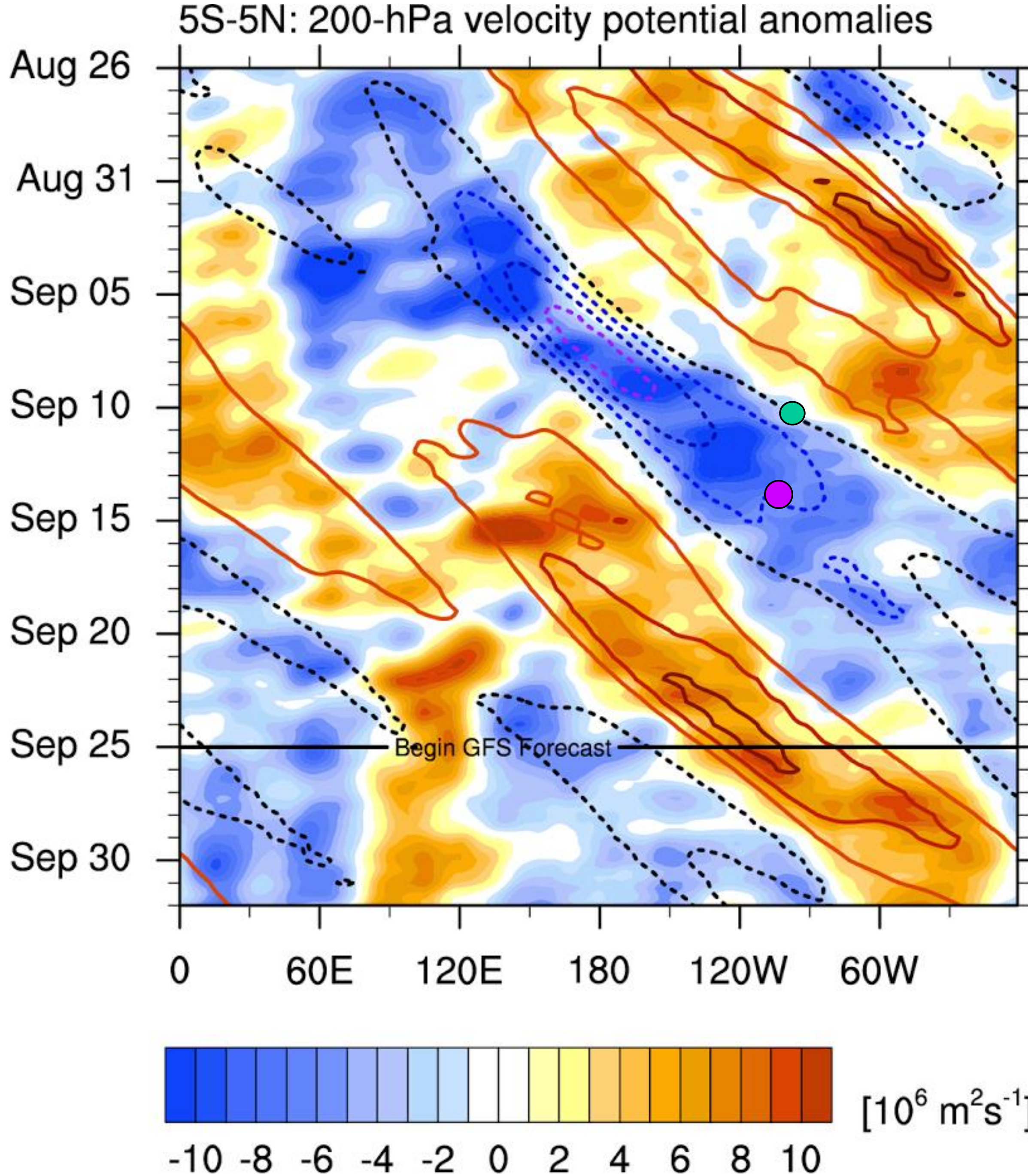




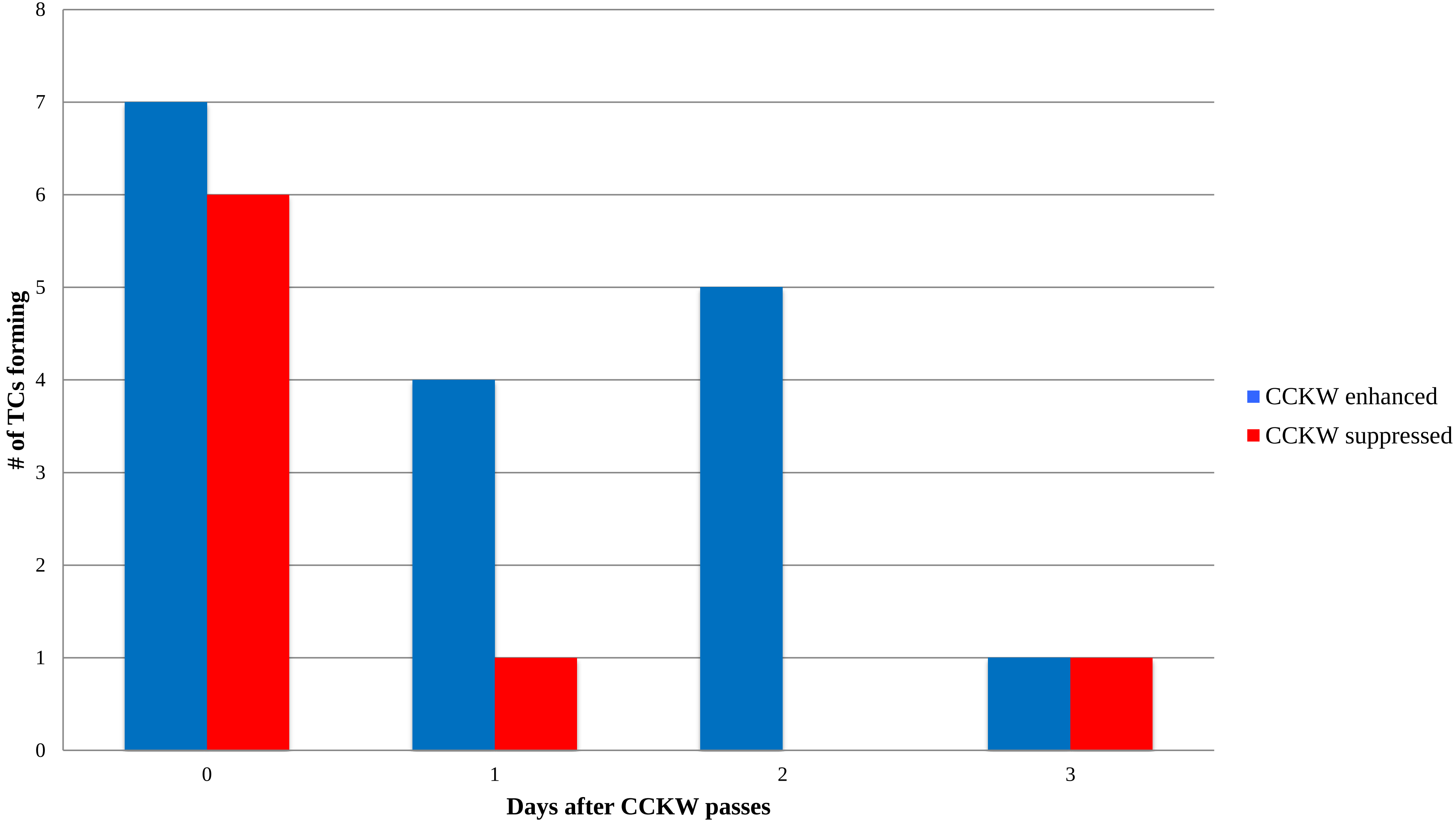
Extremely strong (4 SD) CCKW approaching an active tropical cyclone

What happens?

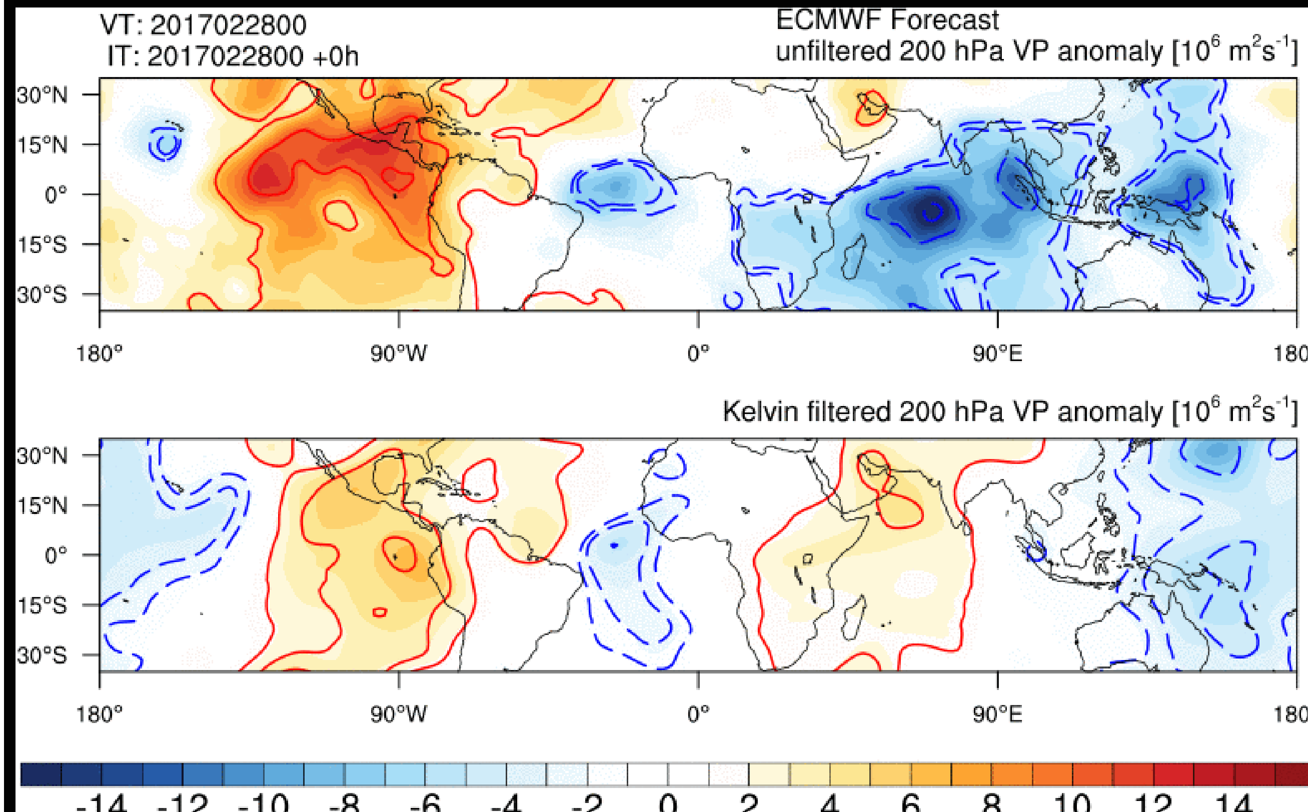
Odile rapidly intensifies into a Category 4 hurricane



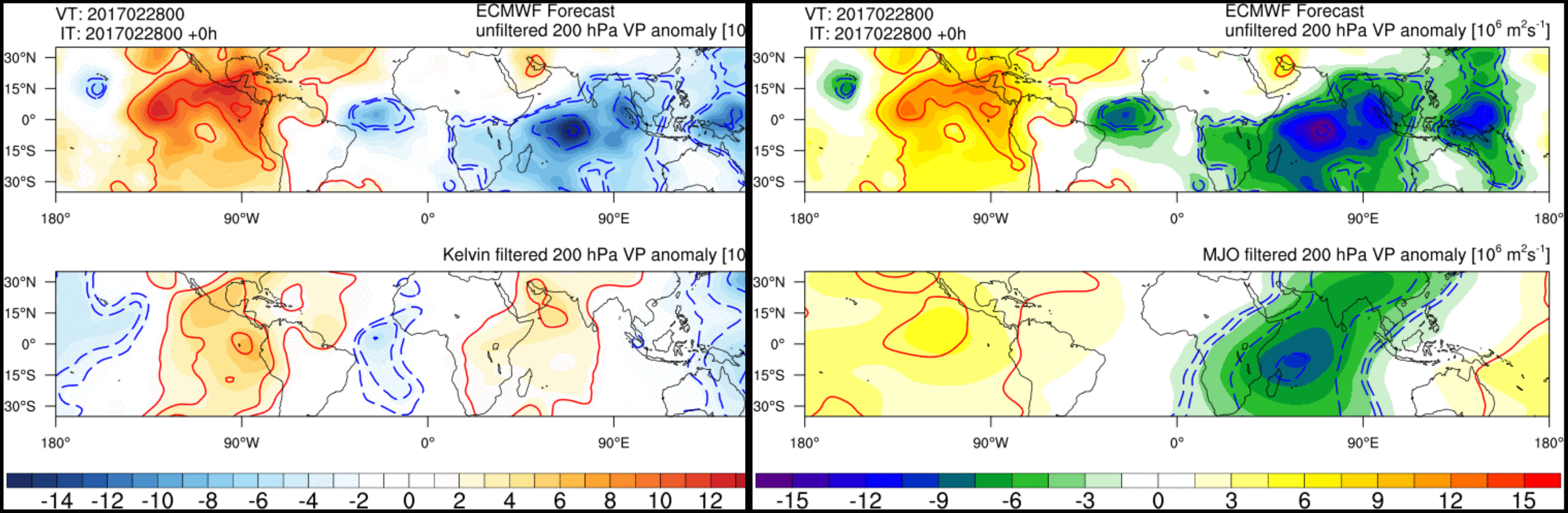
Hurricane formations within active MJO East of 120W



10-[redacted]Ws



10-day ECMWF forecast of eastward-moving waves

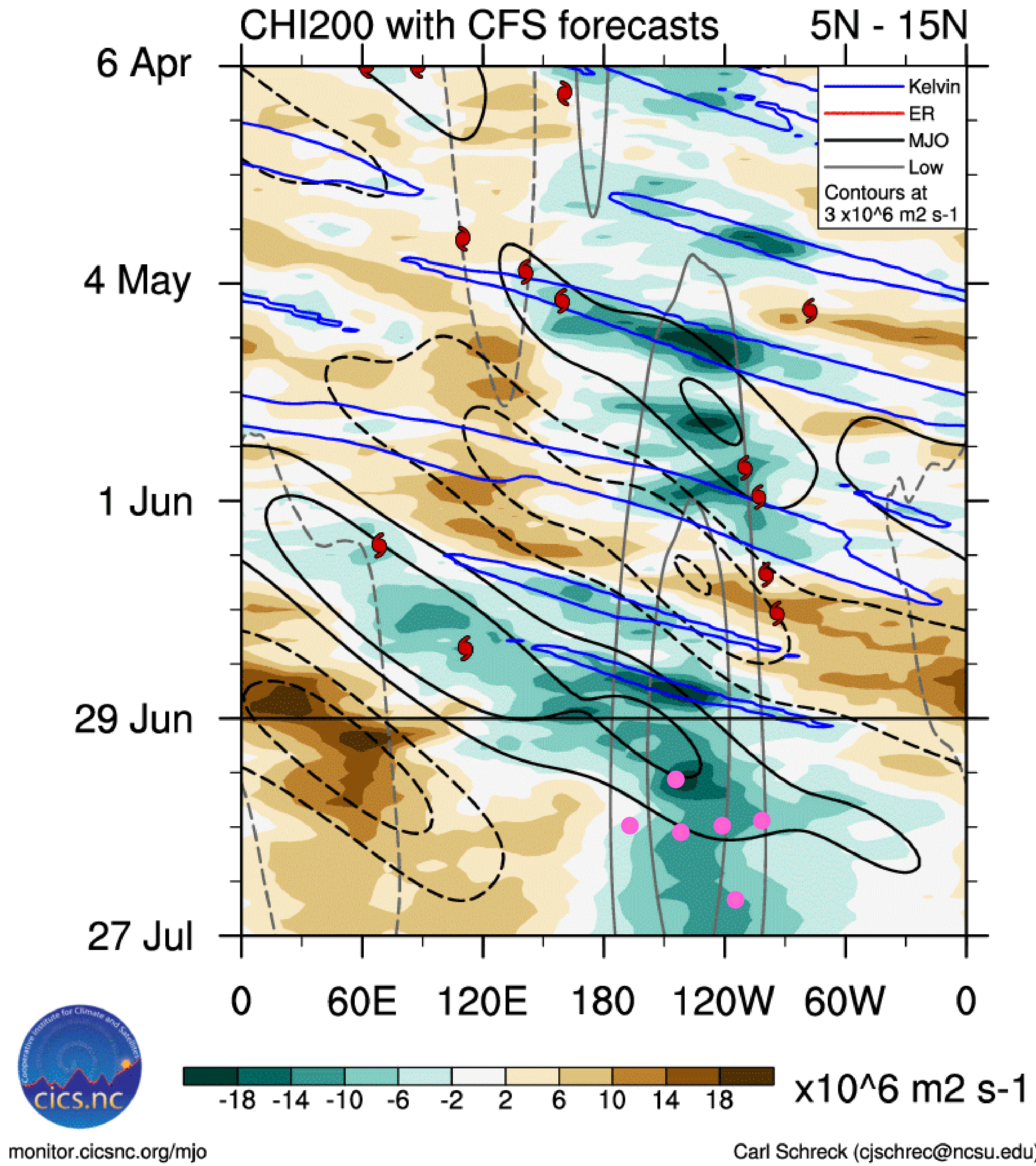


Exercises

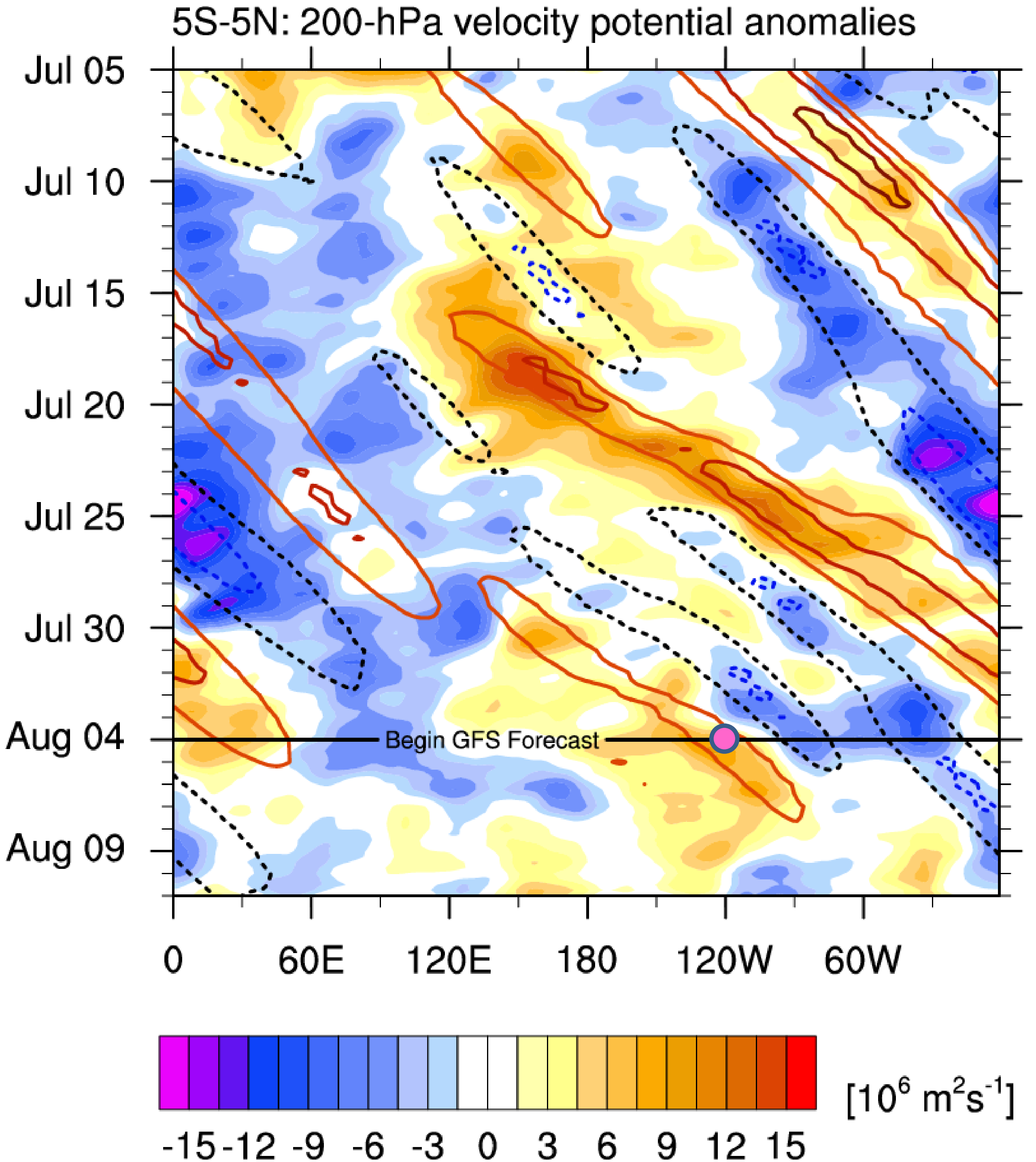
June 29 CFS Forecast:

Strong MJO headed into the western Hemisphere with an El Nino base state.

Expectations for July TCs?

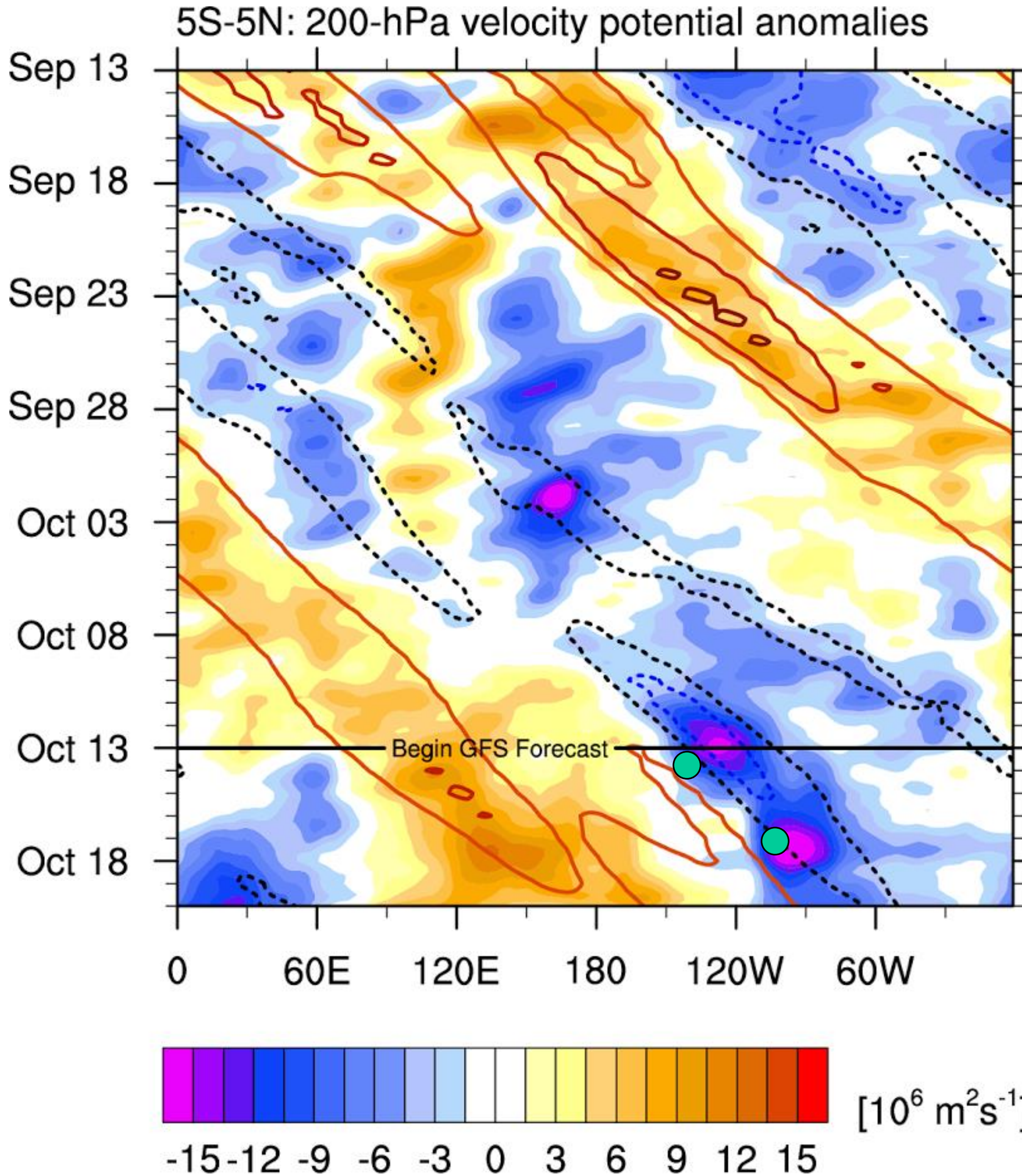


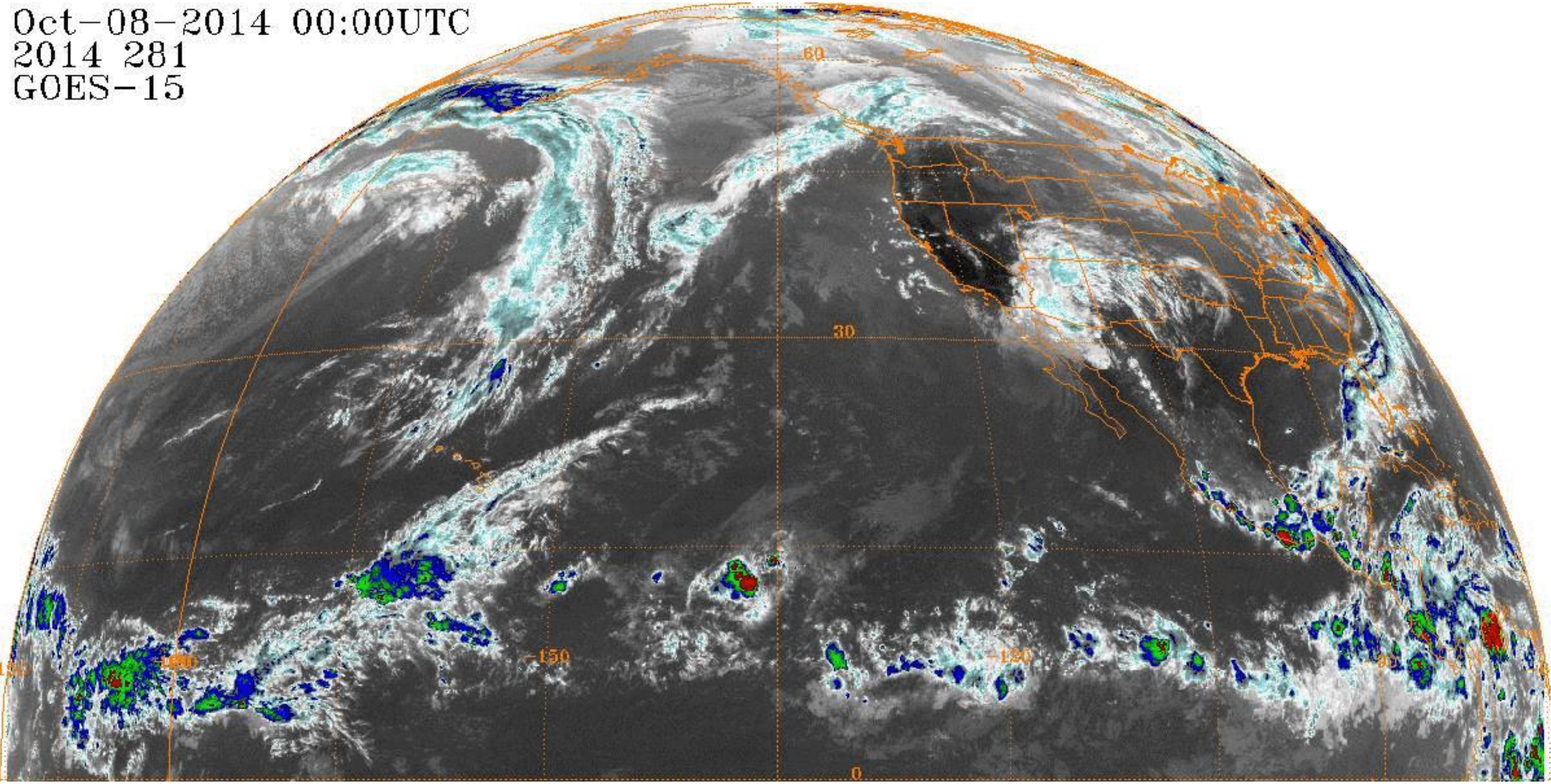
All things being equal, describe the genesis potential over the next 3 days of a disturbance centered at the magenta dot.



"Yet another strong CCKW is moving across the eastern Pacific…This system should move through the eastern Pacific within the next few days, with genesis possible in the far eastern Pacific Days 3-5."

Ana & Trudy form





Ana Trudy

Question 3

Global models forecast which type of wave the best?

A. Tropical Wave

B. MJO

C. Kelvin Wave

D. Gravity

Operational challenges

- Real-world CCKWs have day-to-day weather patterns overlaid on them, making them harder to recognize.
- When making genesis forecasts for a particular system, any CCKW information must be taken in context with the entire weather situation.
- Knowledge about the base state (~120 d mean or ENSO), MJO phase, climatology and numerical weather models must all be considered in concert with CCKW interactions.
- For example, if the base state is extremely unfavorable, can it overcome other enhancing factors? (e.g. most of the 2014 Atlantic hurricane season, 2015 EPac is the counter example)

Current NHC practices

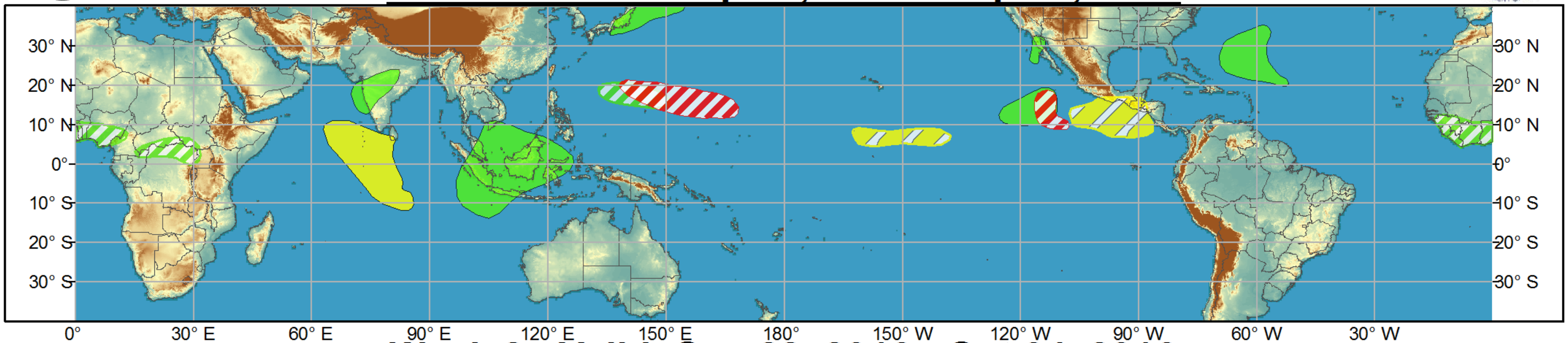
- No operational standard on use of CCKW in genesis forecasts (about half of forecasters use it), not used at all for intensity forecasts.
- It is believed that global models handle the MJO much more accurately than individual CCKWs (too much dampening), and thus the forecaster can add value to the deterministic models.
- Any adjustments to 5-day genesis probabilities are small and subjectively determined.
- Also used as a way to increase forecaster confidence in a given situation if conceptual model of CCKWs and genesis matches model solutions.

Operational long-range TC forecasts

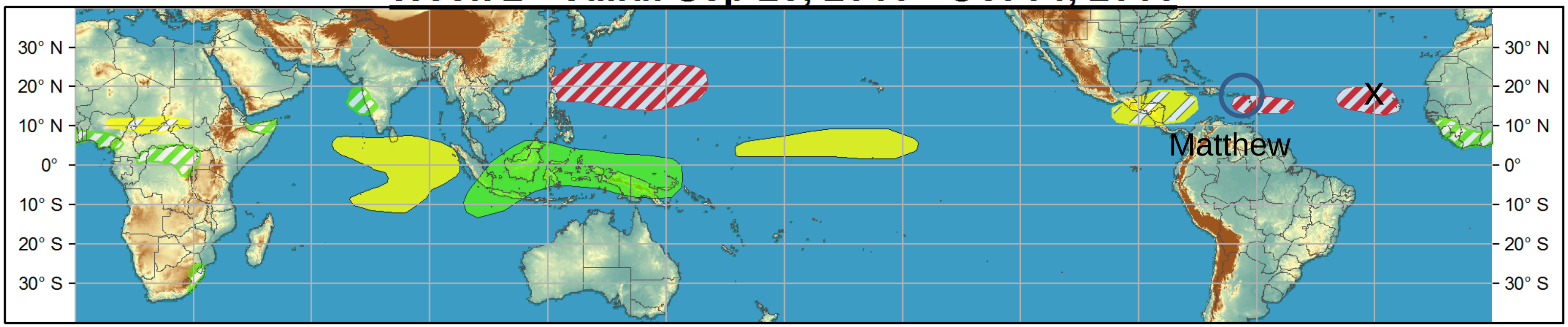
- CPC, in combination with other NOAA/federal/university partners, issues a week 1 and week 2 possible TC risk areas (in addition to other global hazards)
- These global forecasts are released Tuesday afternoons
- The TC-only forecasts are updated on Friday afternoons, if necessary, for the Atlantic/E Pacific only during week 1/2

Global Tropics Hazards and Benefits Outlook - Climate Prediction Center

Week 1 - Valid: Sep 21, 2016 - Sep 27, 2016



Week 2 - Valid: Sep 28, 2016 - Oct 04, 2016



Produced: 09/20/2016

Forecaster: Rosencrans

	Confidence High	Confidence Moderate	
Tropical Cyclone Formation			Development of a tropical cyclone (tropical depression - TD, or greater strength).
Above-average rainfall			Weekly total rainfall in the upper third of the historical range.
Below-average rainfall			Weekly total rainfall in the lower third of the historical range.
Above-normal temperatures			7-day mean temperatures in the upper third of the historical range.
Below-normal temperatures			7-day mean temperatures in the lower third of the historical range.

Product is updated once per week, except from 6/1 - 11/30 for the region from 120E to 0, 0 to 40N. The product targets broad scale conditions integrated over a 7-day period for US interests only. Consult your local responsible forecast agency.

中央氣象局 Central Weather Bureau
UNIVERSITY AT ALBANY State University of New York
EARTH SYSTEM SCIENCE INTERDISCIPLINARY CENTER ESSIC UNIVERSITY OF MARYLAND
Australian Government Bureau of Meteorology
cics.nc
NPS PRAESTANTIA PER SCIENTIAM

Future Questions/Work

- How does the strength of the CCKW significantly affect the chance of TC genesis?
- Need a more objective way to attribute CCKWs to tropical cyclogenesis. A one-size-fits-all approach is not applicable with these waves due to various triggering mechanisms.
- Can a better TC-CCKW relationship be teased out of the data if one could more effectively remove the base state?
- How do you properly attribute TC intensity change to a CCKW?