Intraseasonal TC Variability and Seasonal Hurricane Forecasting

2022 WMO Class

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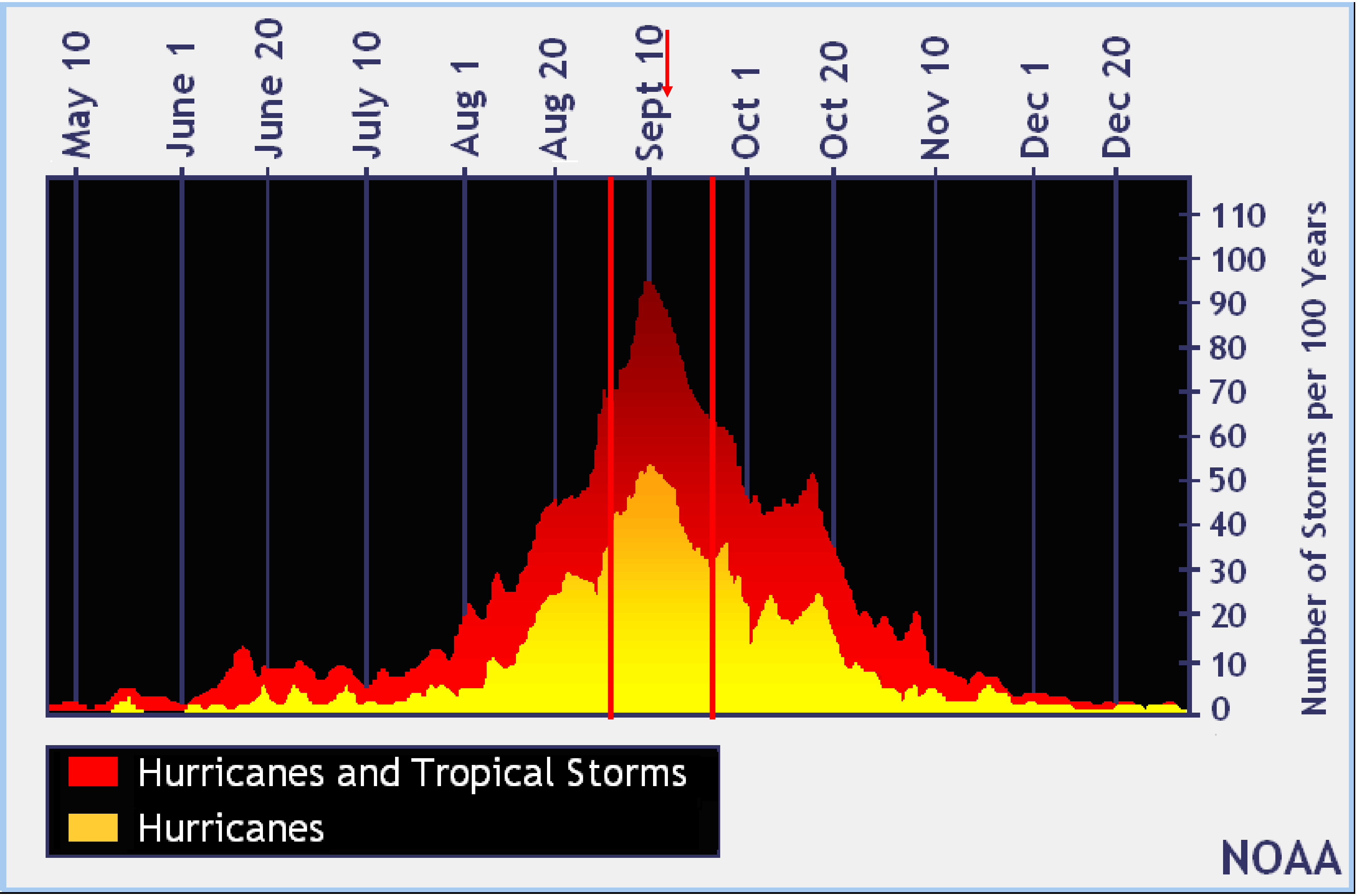
3/2/2022

Outline

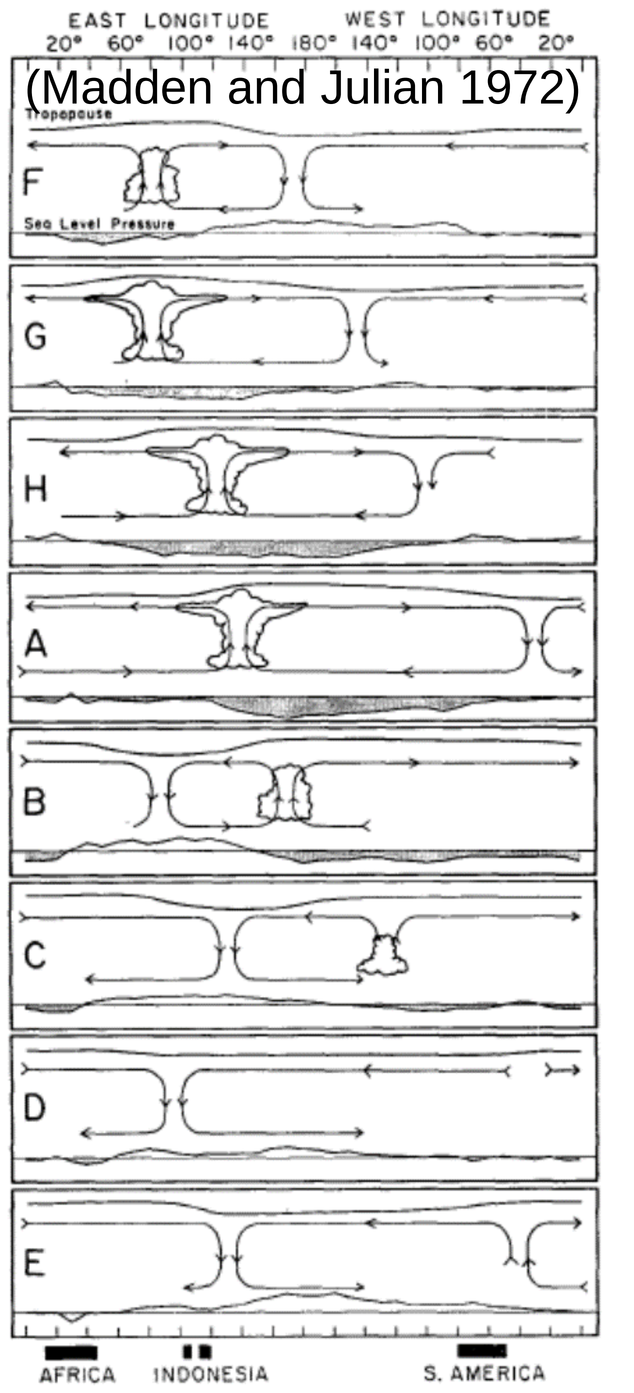
- Madden-Julian Oscillation (MJO)
- MJO analysis tools
- Kelvin Waves
- Seasonal forecasting
- Brief look at 2022

No Storm
Formations in 2008



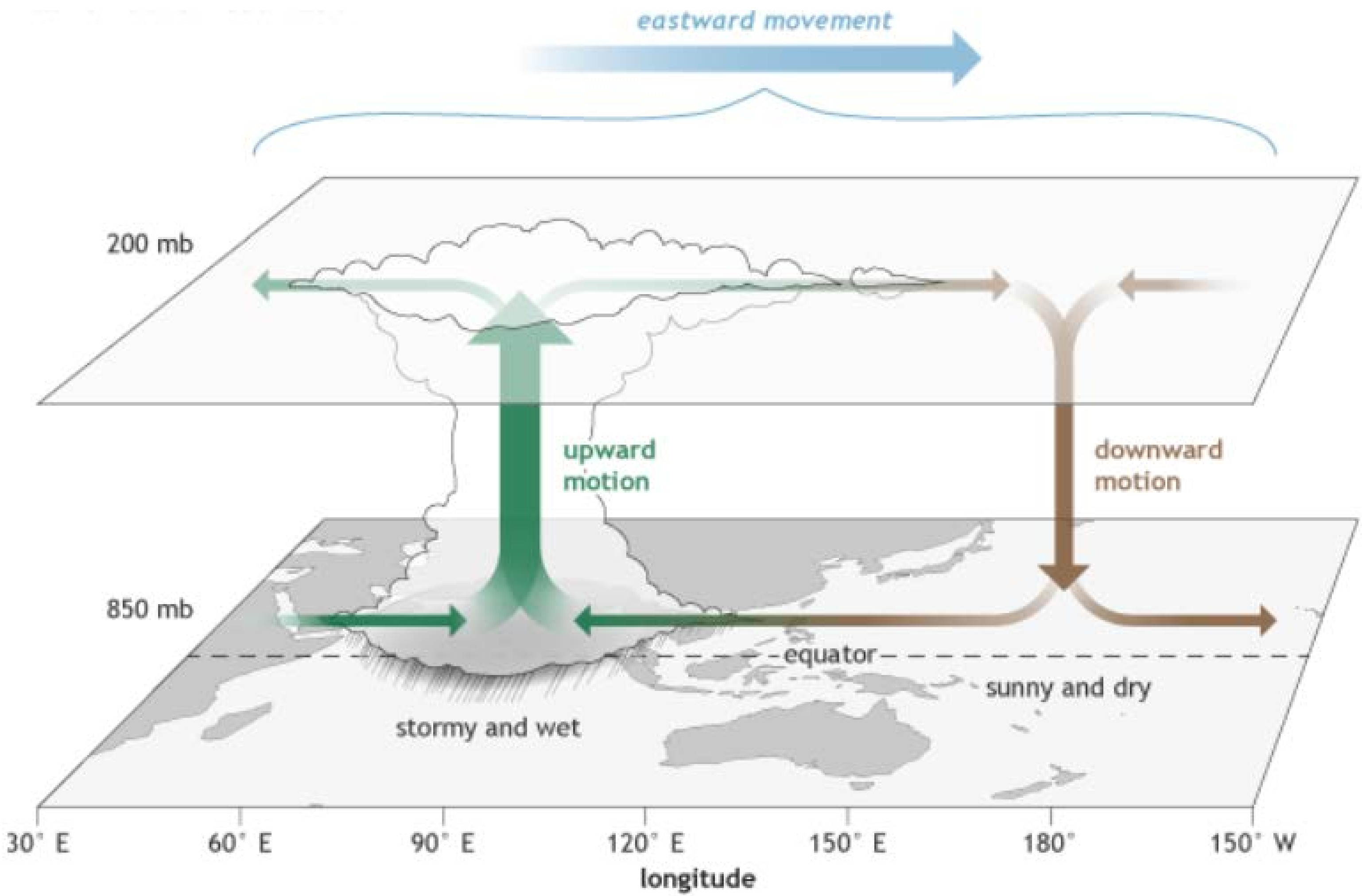
Madden-Julian Oscillation

- An eastward propagating wave that circles the globe in about 30-60 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.

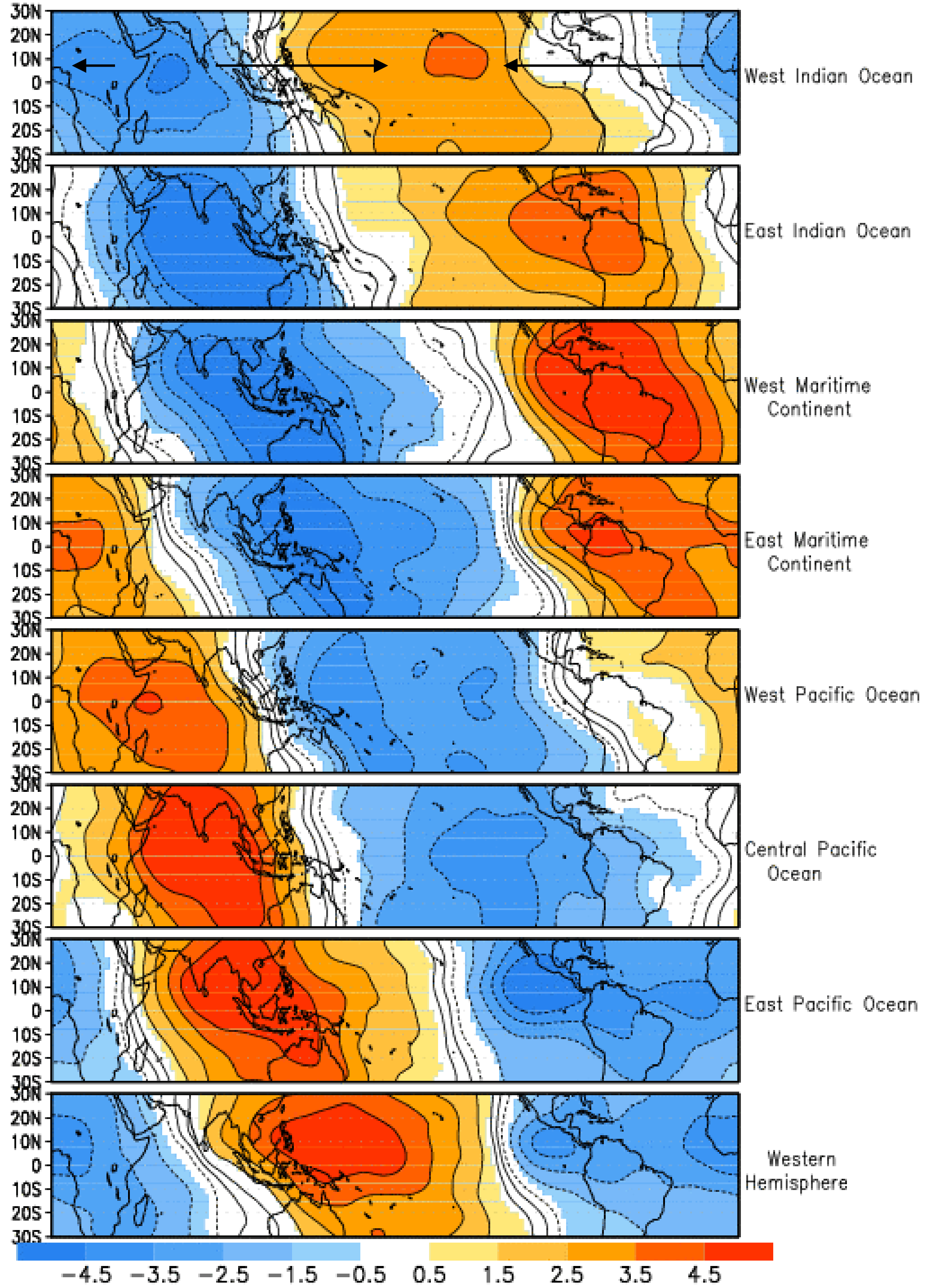


(Madden and Julian 1972)

Idealized MJO cross-section



Courtesy Fiona Martin, climate.gov blog

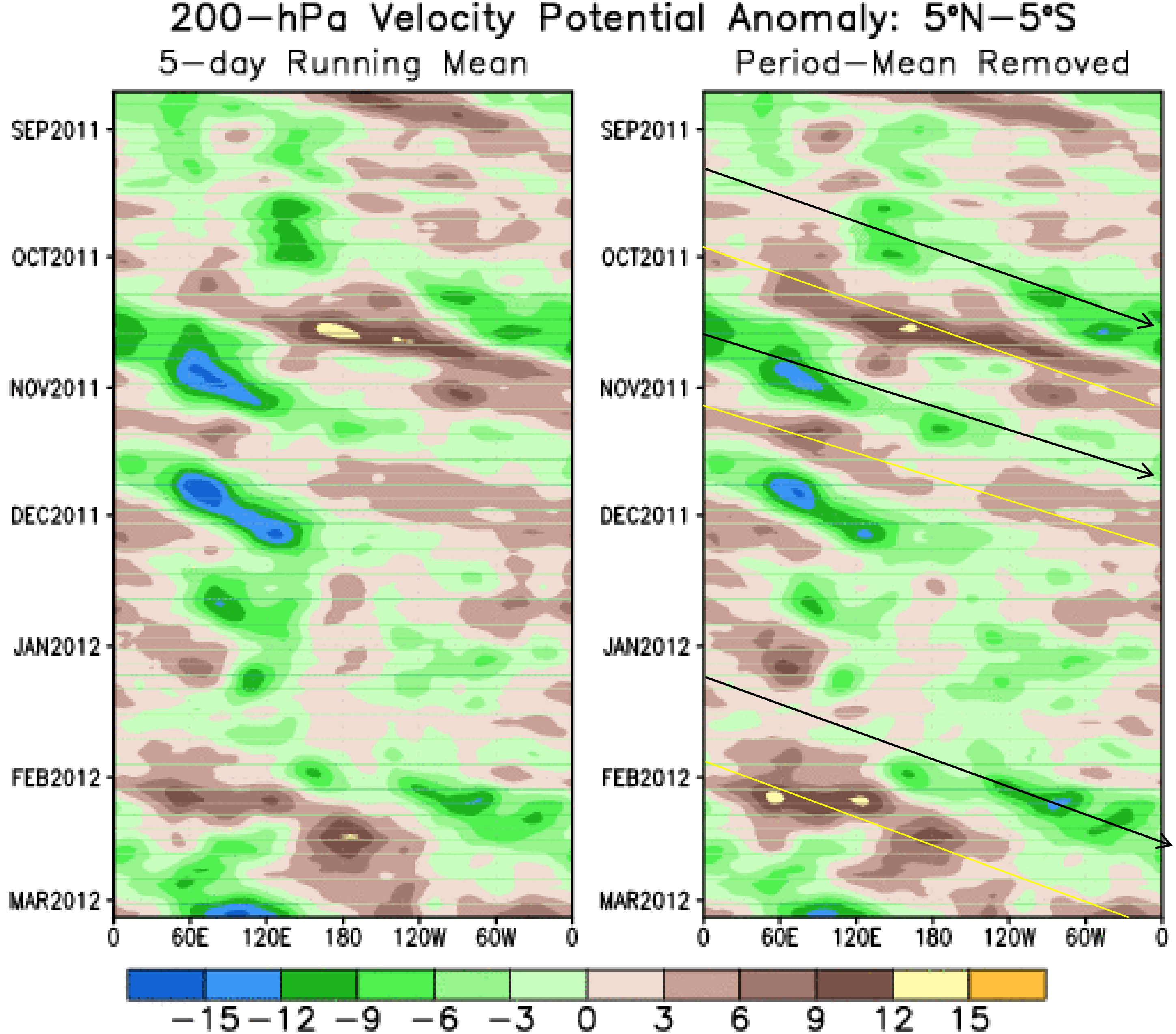


200 mb Velocity Potential fields–one way to track the MJO

Blue= ~divergence

Red= ~convergence

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



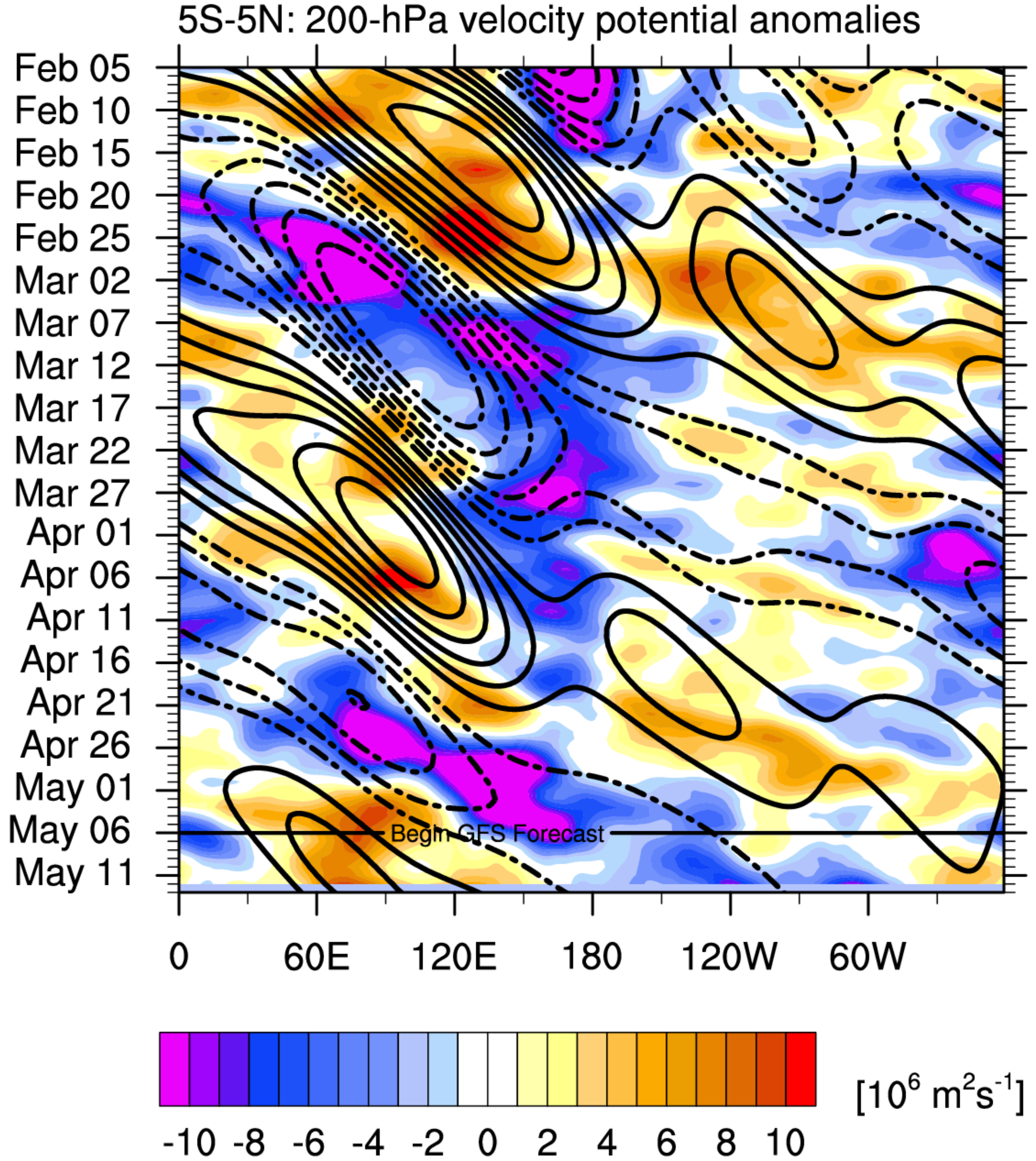
Time–longitude sections of anomalous 200–hPa velocity potential (x 10⁶ m² s⁻¹) averaged between 5°N–5°S for the last 180 days ending 05 MAR 2012: (Left) 5–day running means and (Right) 5–day running means with period mean removed. Anomalies are departures from the 1981–2010 period daily means. CLIMATE PREDICTION CENTER/NCEP

<u>MJO characteristics</u>

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



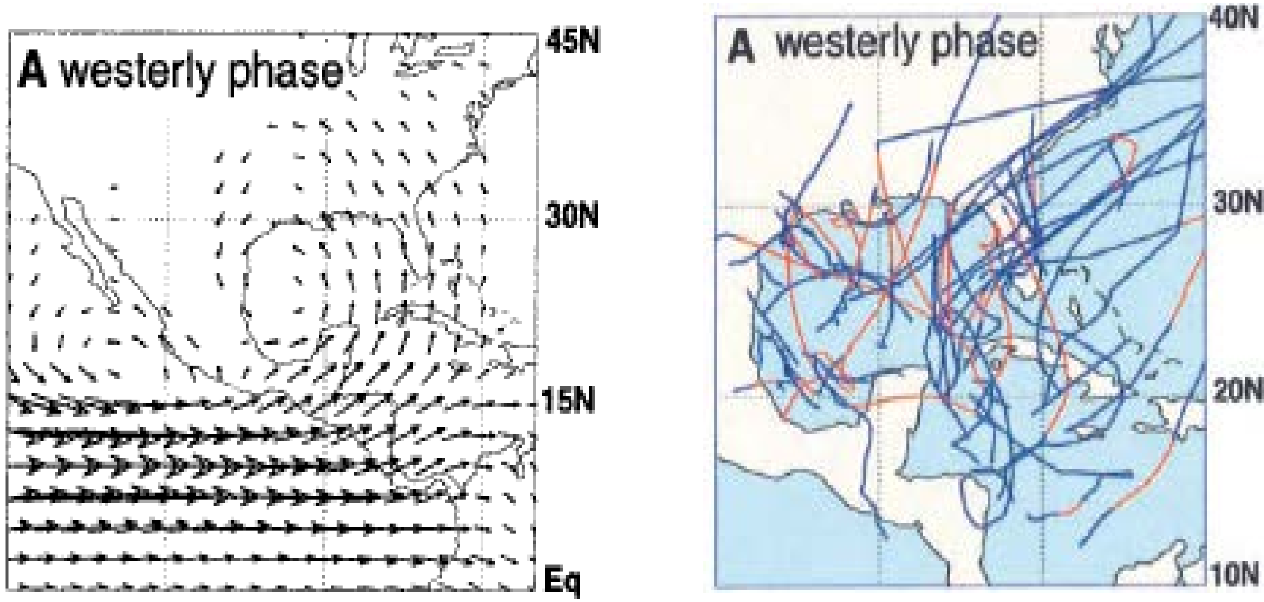
MJO Effects in the Atlantic Basin

- 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).

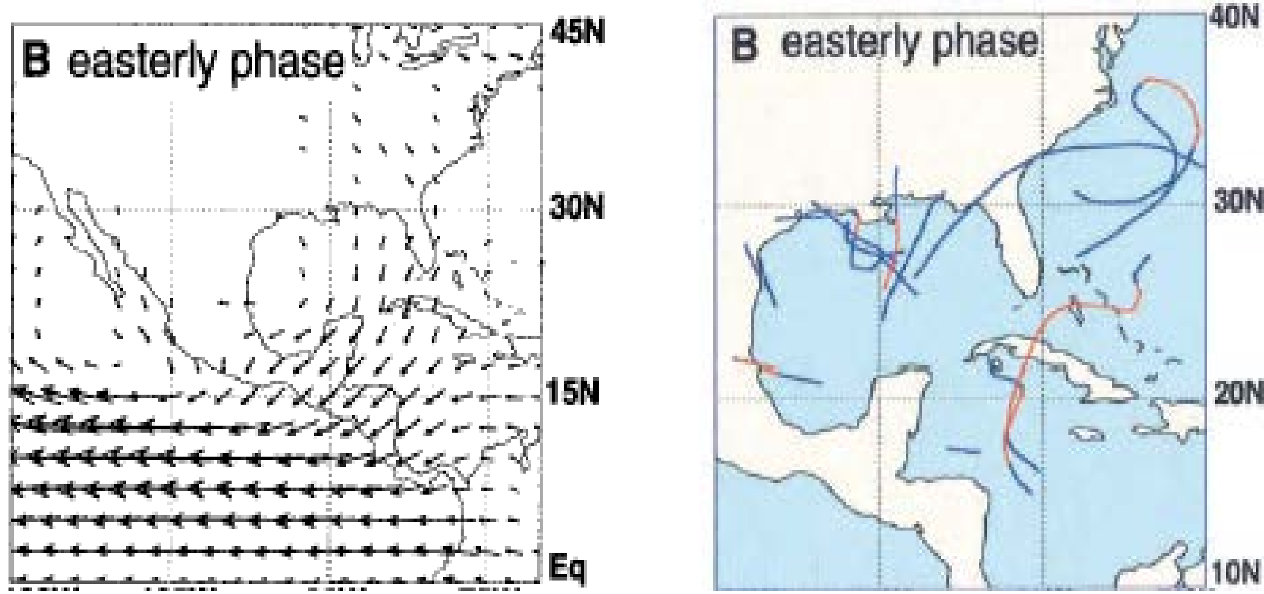
Active MJO in the western Caribbean Sea and Gulf of Mexico produces more storms due to:

- 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

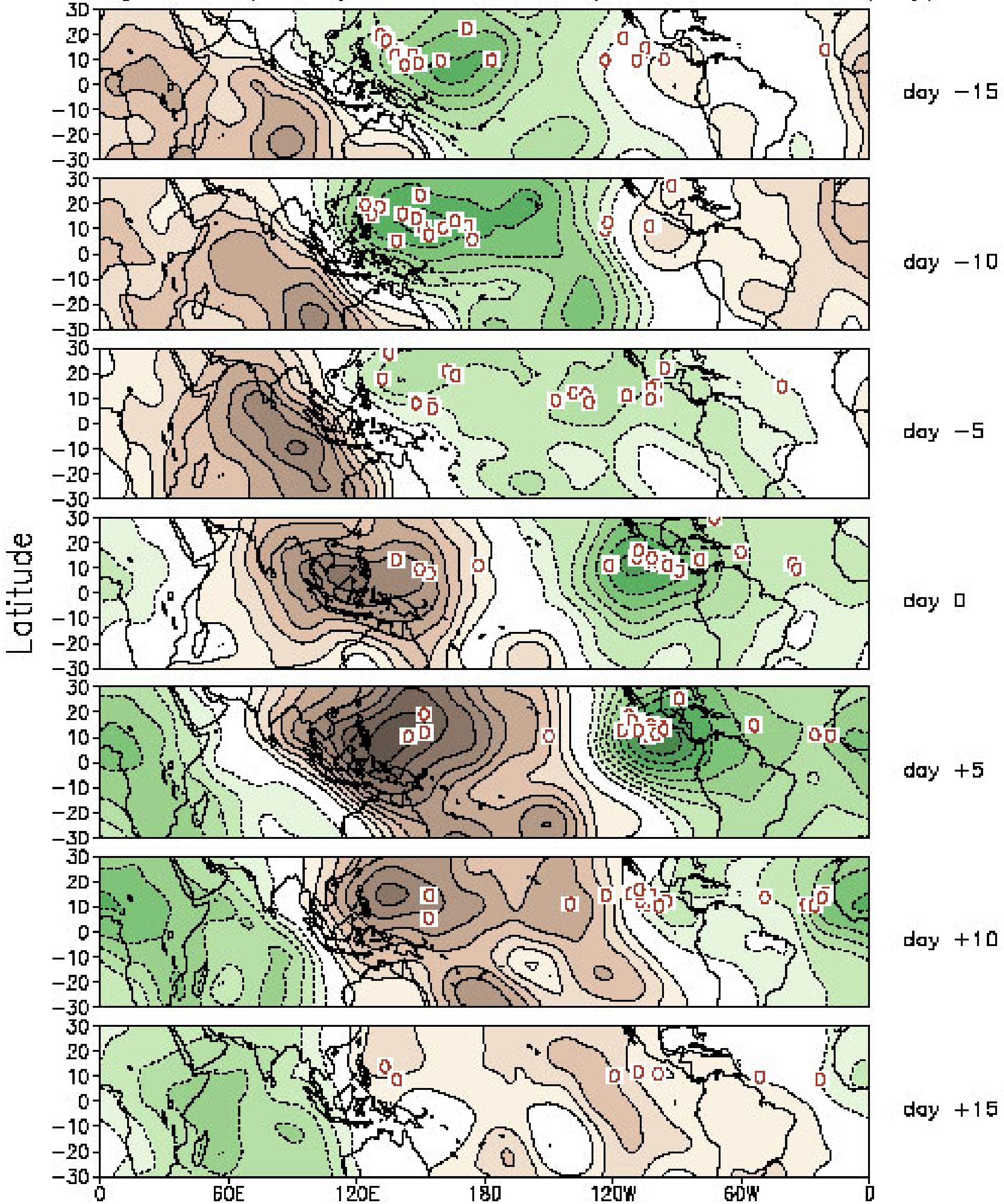
Active MJO EOF and corresponding TS and H tracks



Inactive MJO EOF and corresponding TS and H tracks



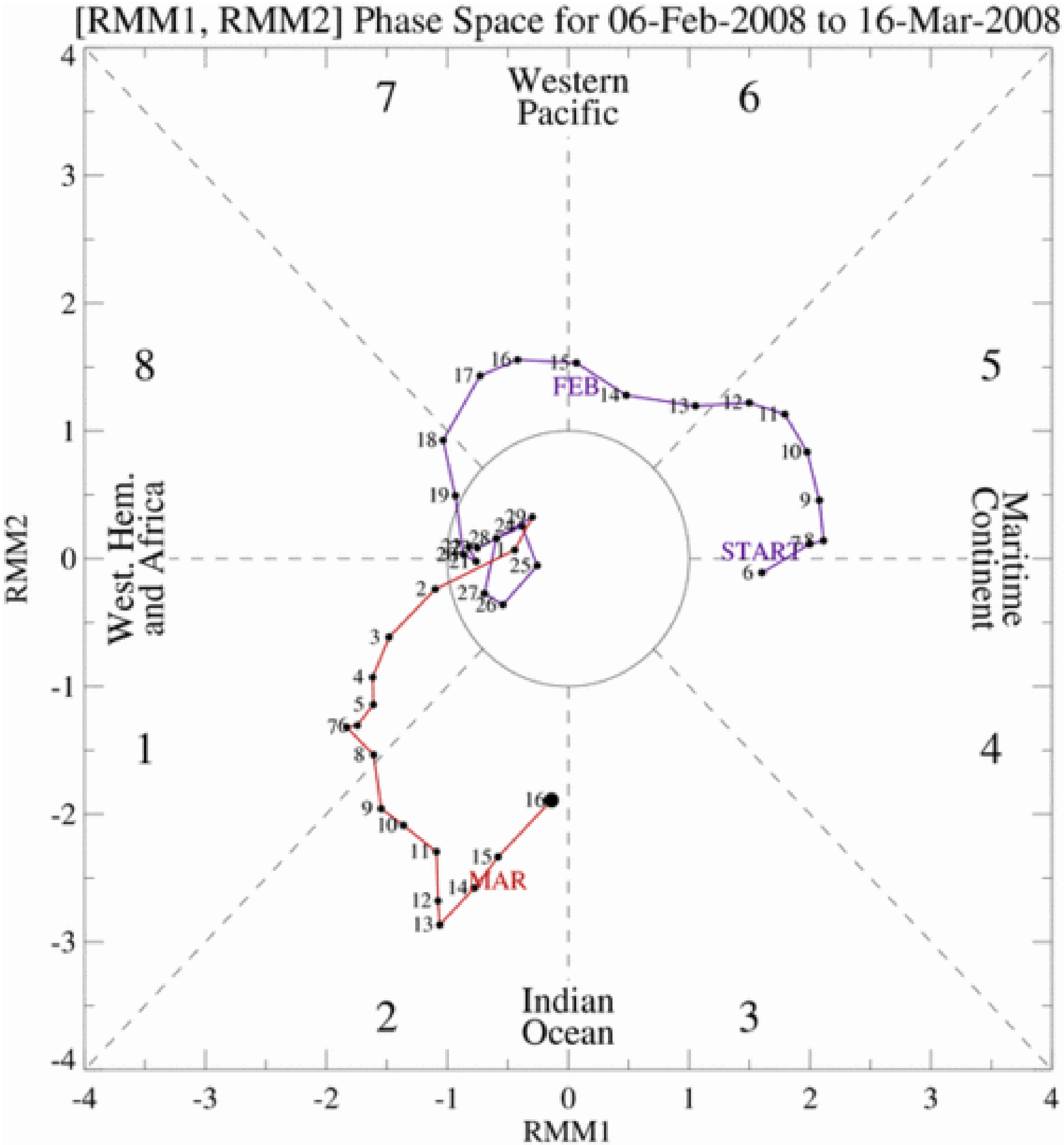
Adapted from Maloney and Hartmann (2000)



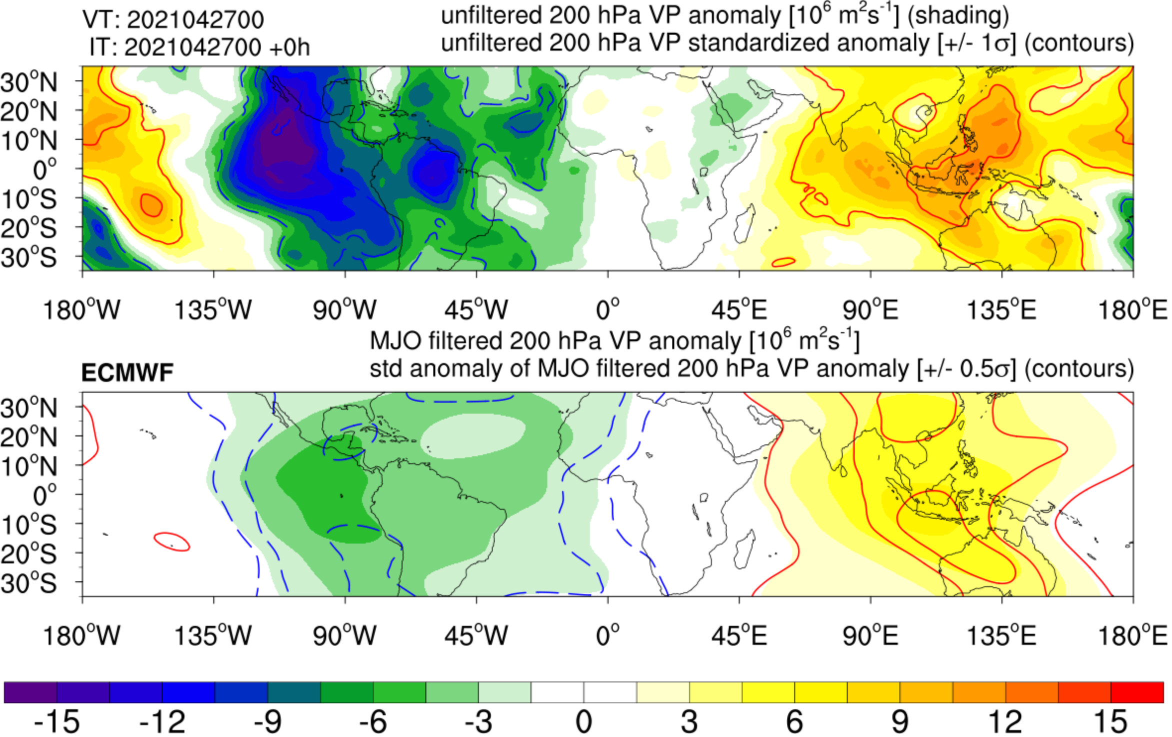
• Most genesis points are near or behind the upper-level divergence center.

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.

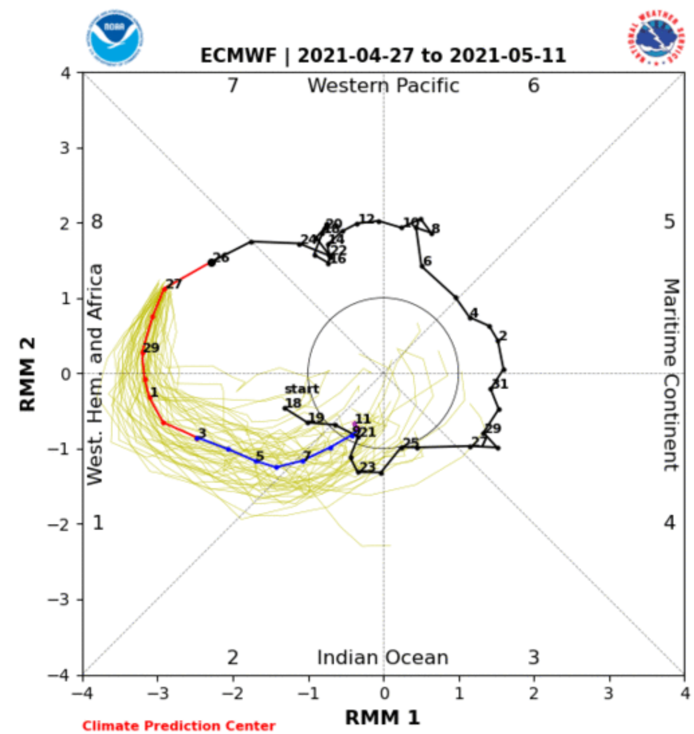
A different way to visualize the MJO

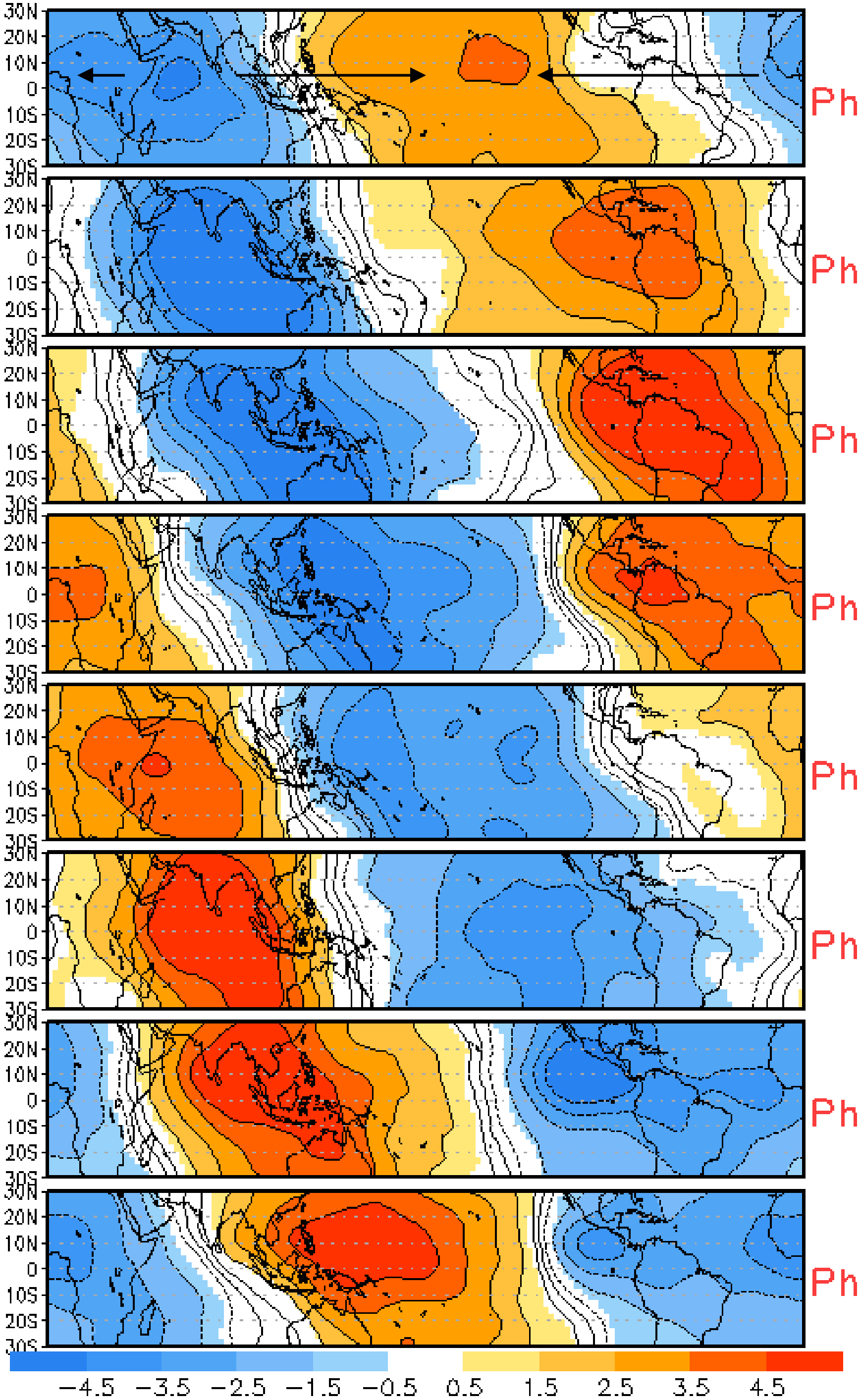


- The axes (RMM1 and RMM2) represent daily values of the principal components from the two leading modes, following the active convection.
- The triangular areas indicate the location of the enhanced phase of the MJO
- Counter-clockwise motion is indicative of eastward propagation
- Distance from the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



MJO:
Plan view versus RMM diagram





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

Blue= ~divergence

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

Question 1

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

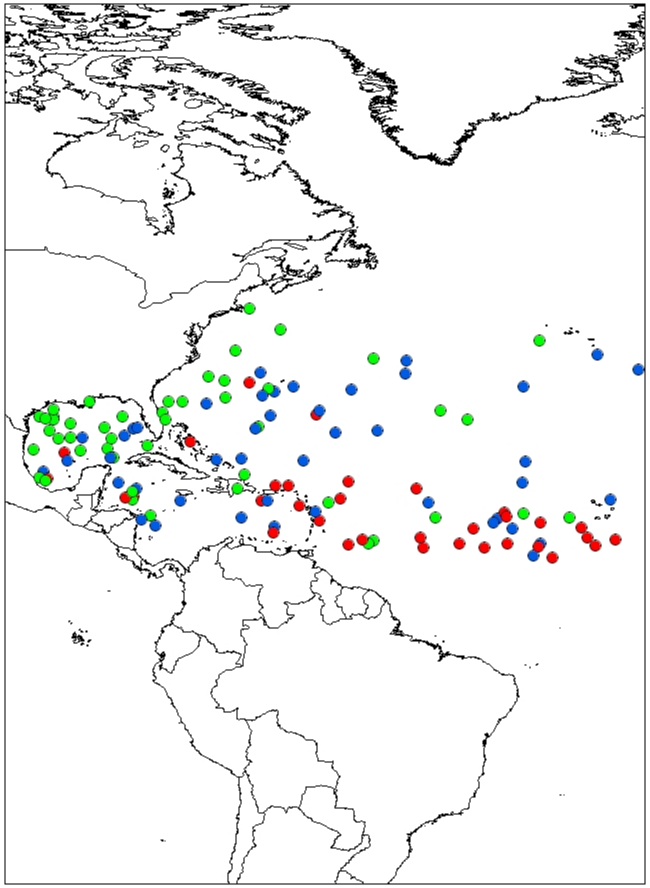
Normalized Activity by MJO Phase (1974-2007)

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**

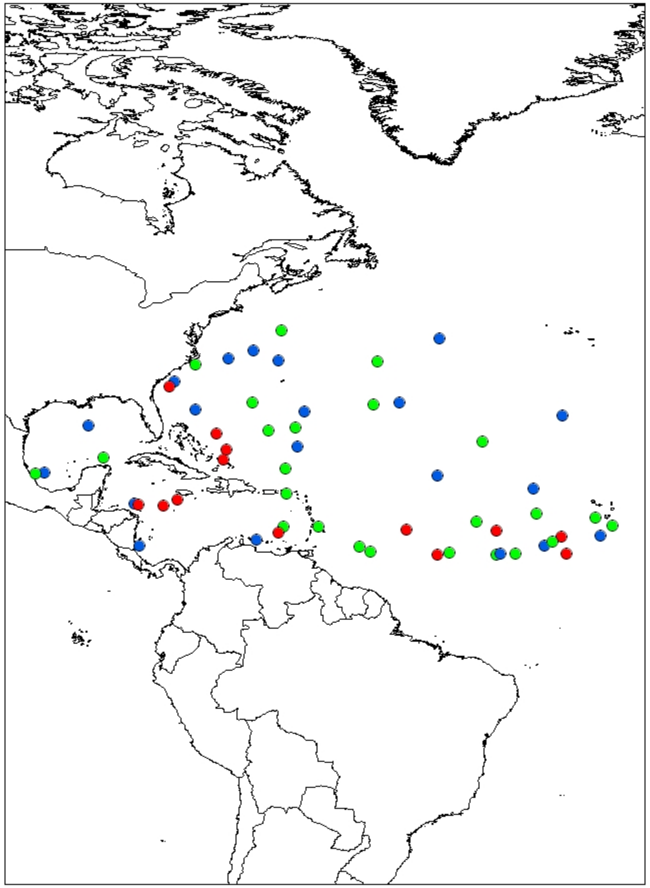
From Klotzbach (2010)

All Genesis Points

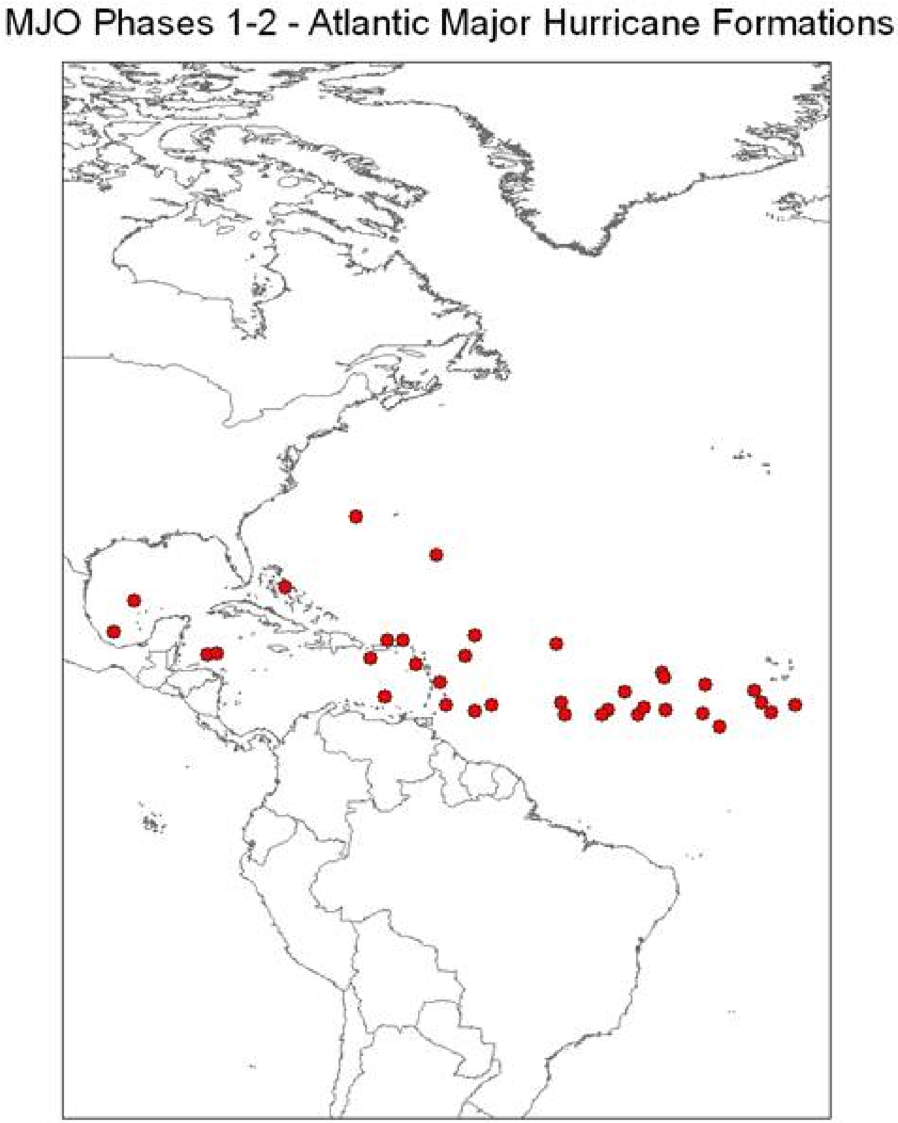
MJO Phases 1+2



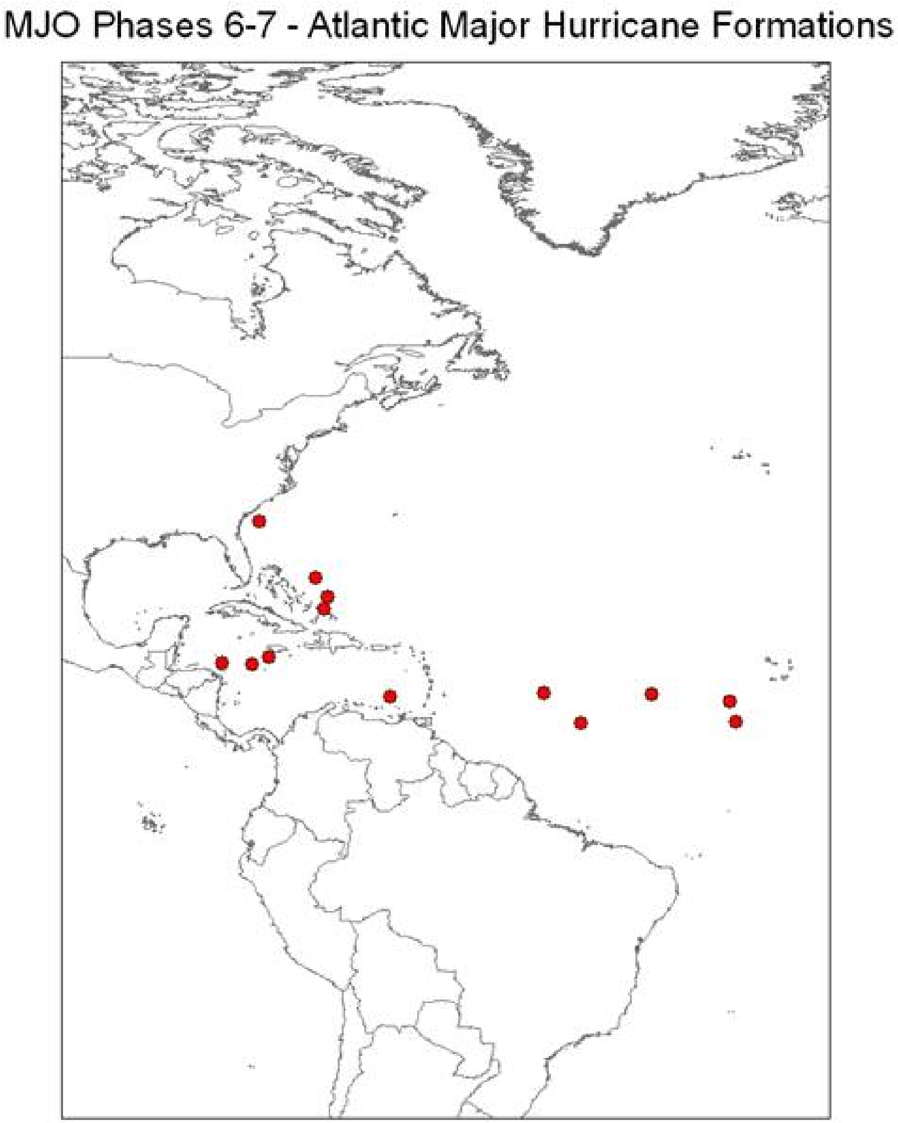
MJO Phases 6+7



36 Major Hurricanes

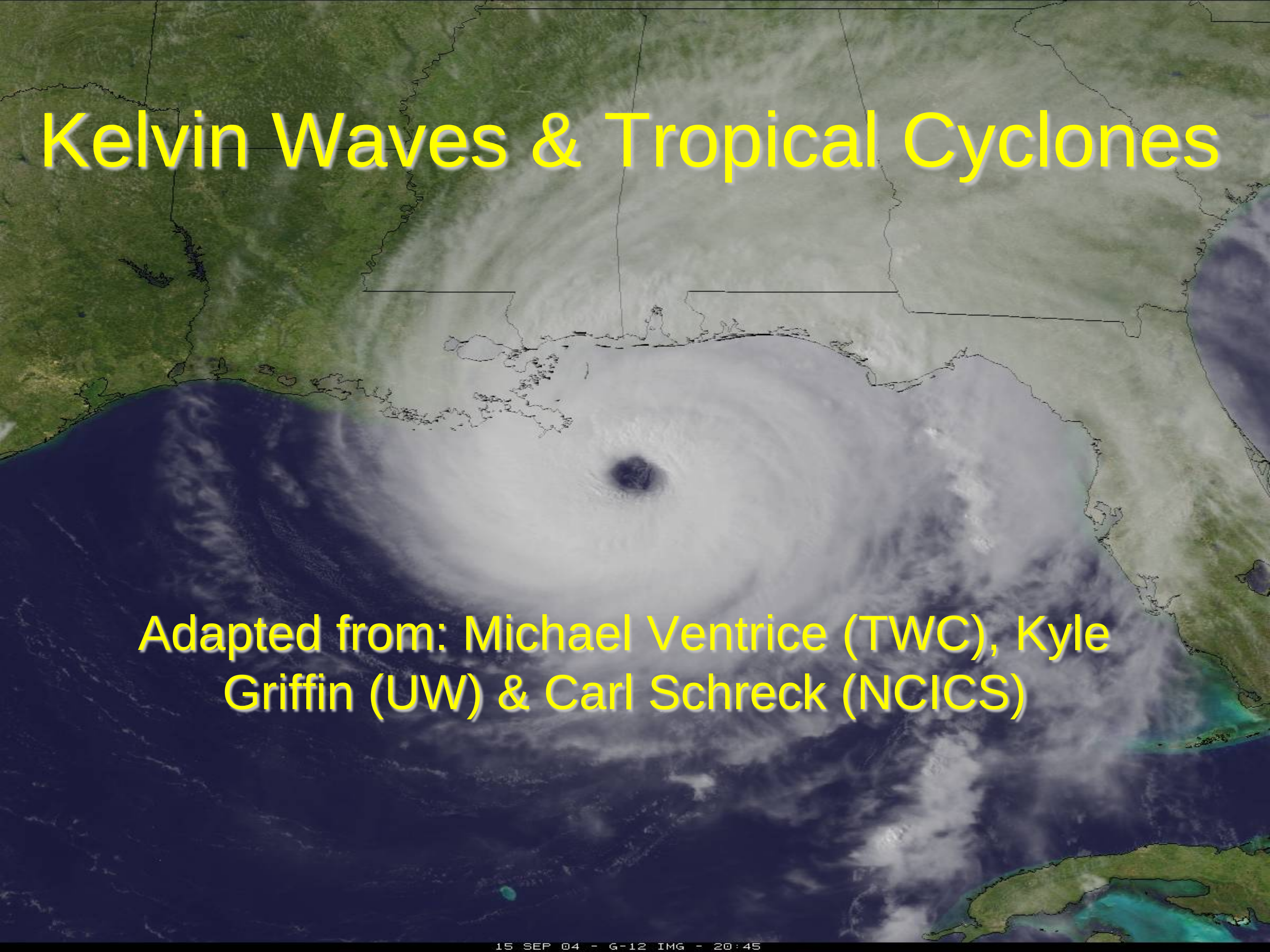


13 Major Hurricanes

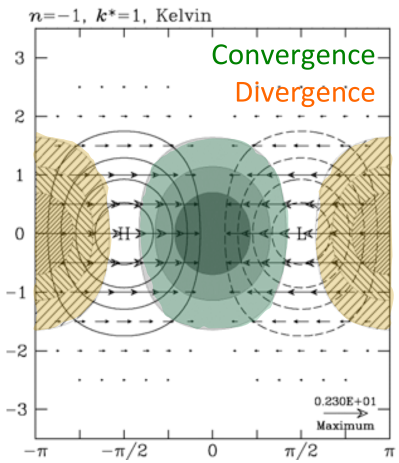


Kelvin Waves & Tropical Cyclones

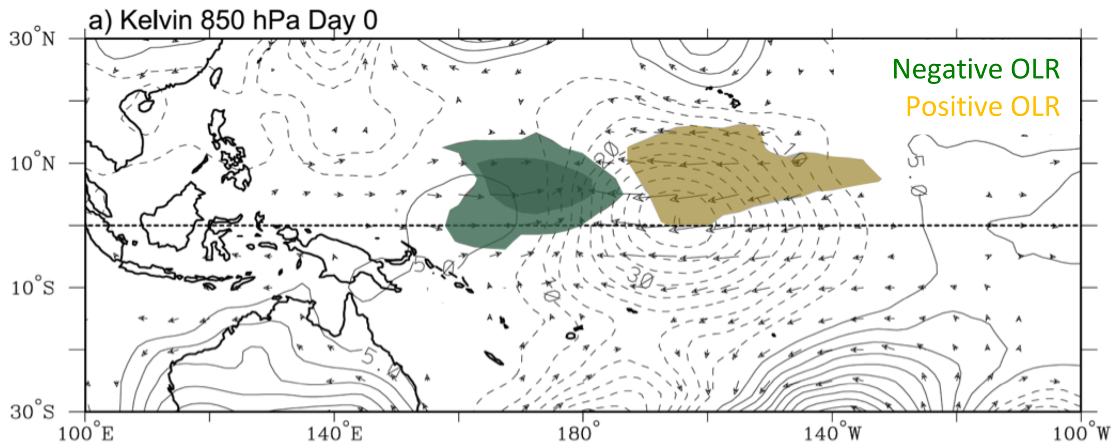
Adapted from: Michael Ventrice (TWC), Kyle Griffin (UW) & Carl Schreck (NCICS)



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
- Modifies ITCZ convection, which causes significant changes to a system's local environment

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.

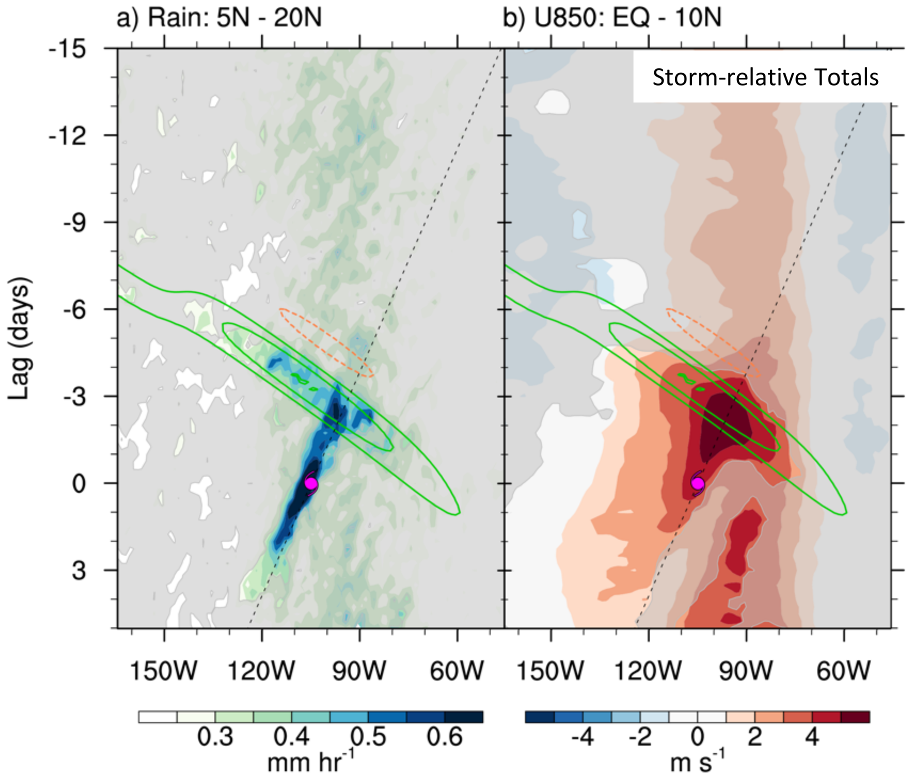
A **Kelvin wave** is spatially very similar to the MJO, but is typically observed at higher zonal wavenumbers and moves eastward at 10 – 20 m s^{-1}.

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

Adapted from Griffin (2014)

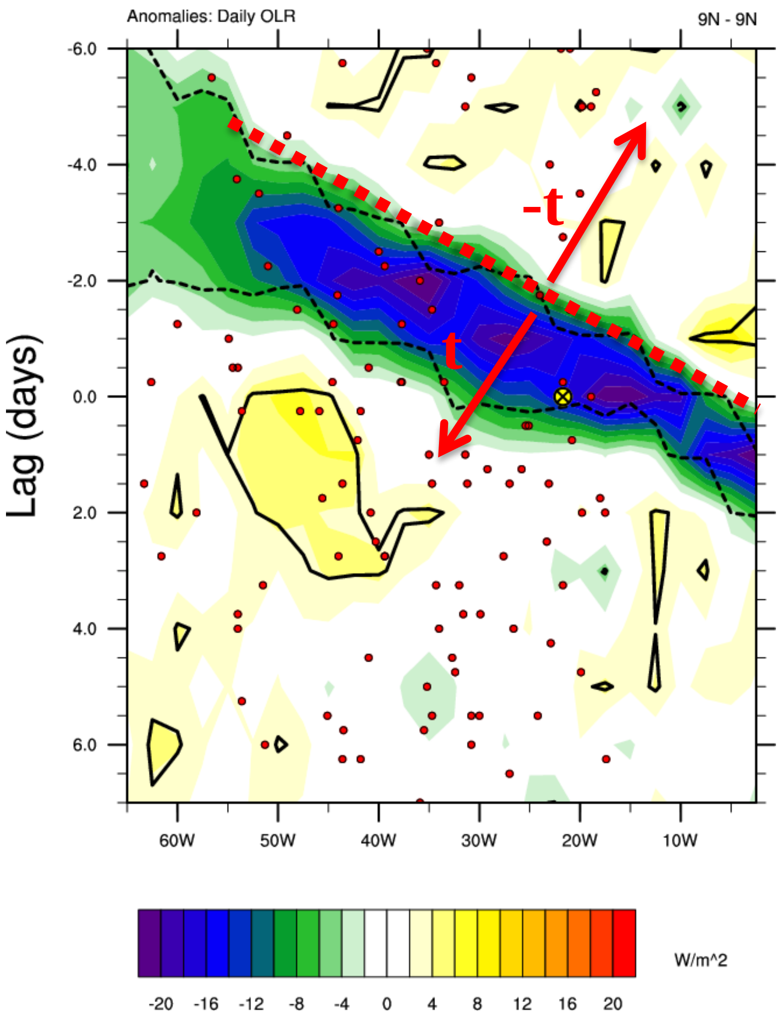
Tropical wave + CCKW composite

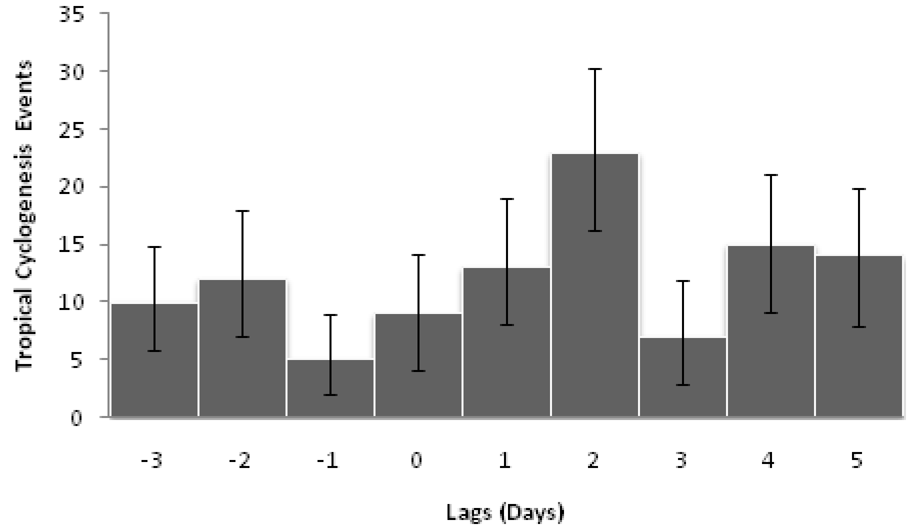
East Pacific: 40 storms



- 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

Atlantic CCKWs and genesis

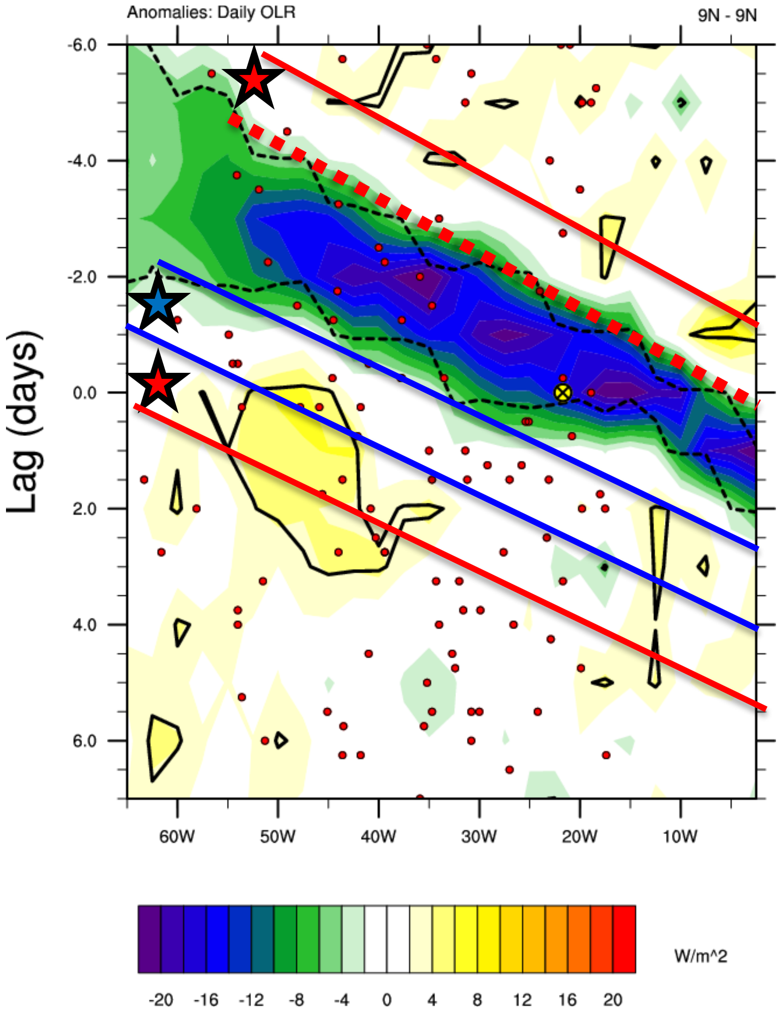


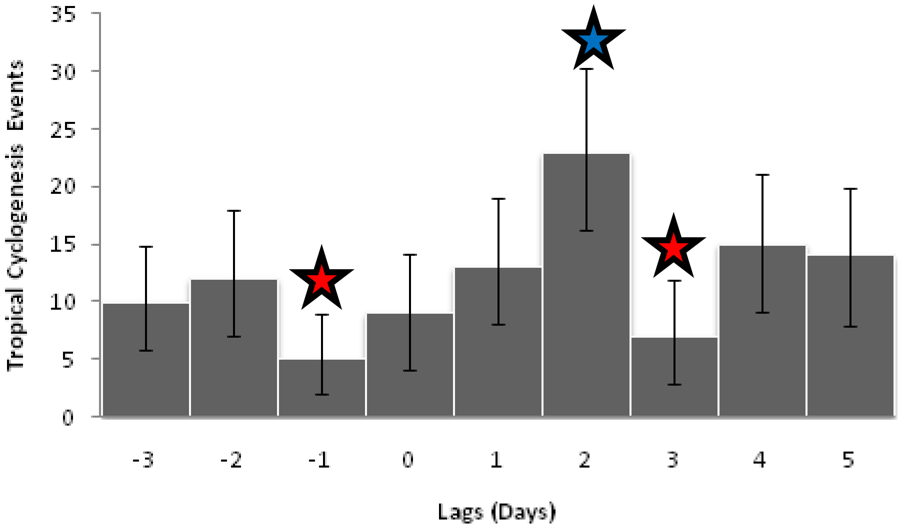


Tropical cyclogenesis events over the MDR (5-25°N, 15-65°W) relative to the CCKW during June-September 1979-2009

- 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.

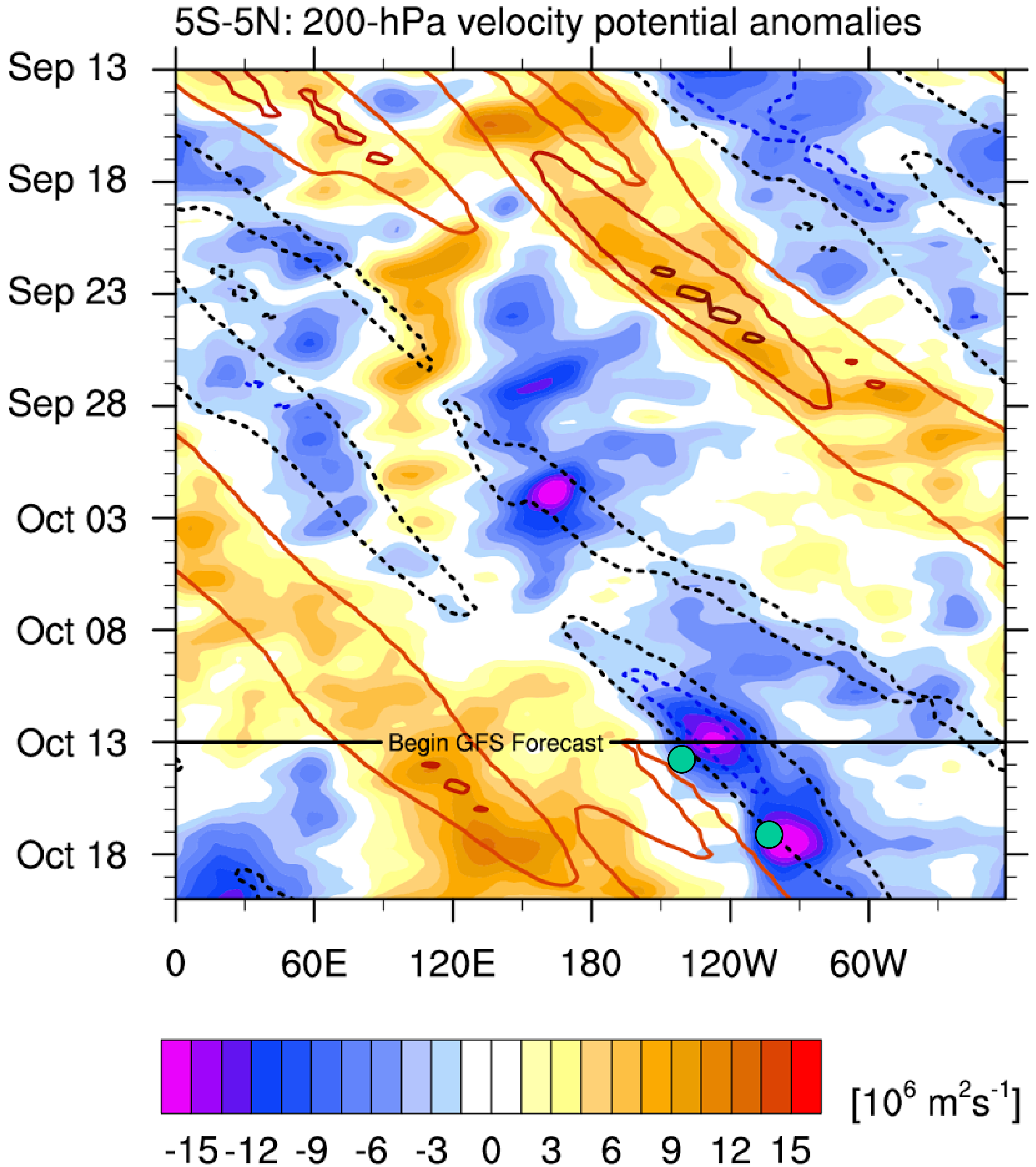
Atlantic CCKWs and genesis

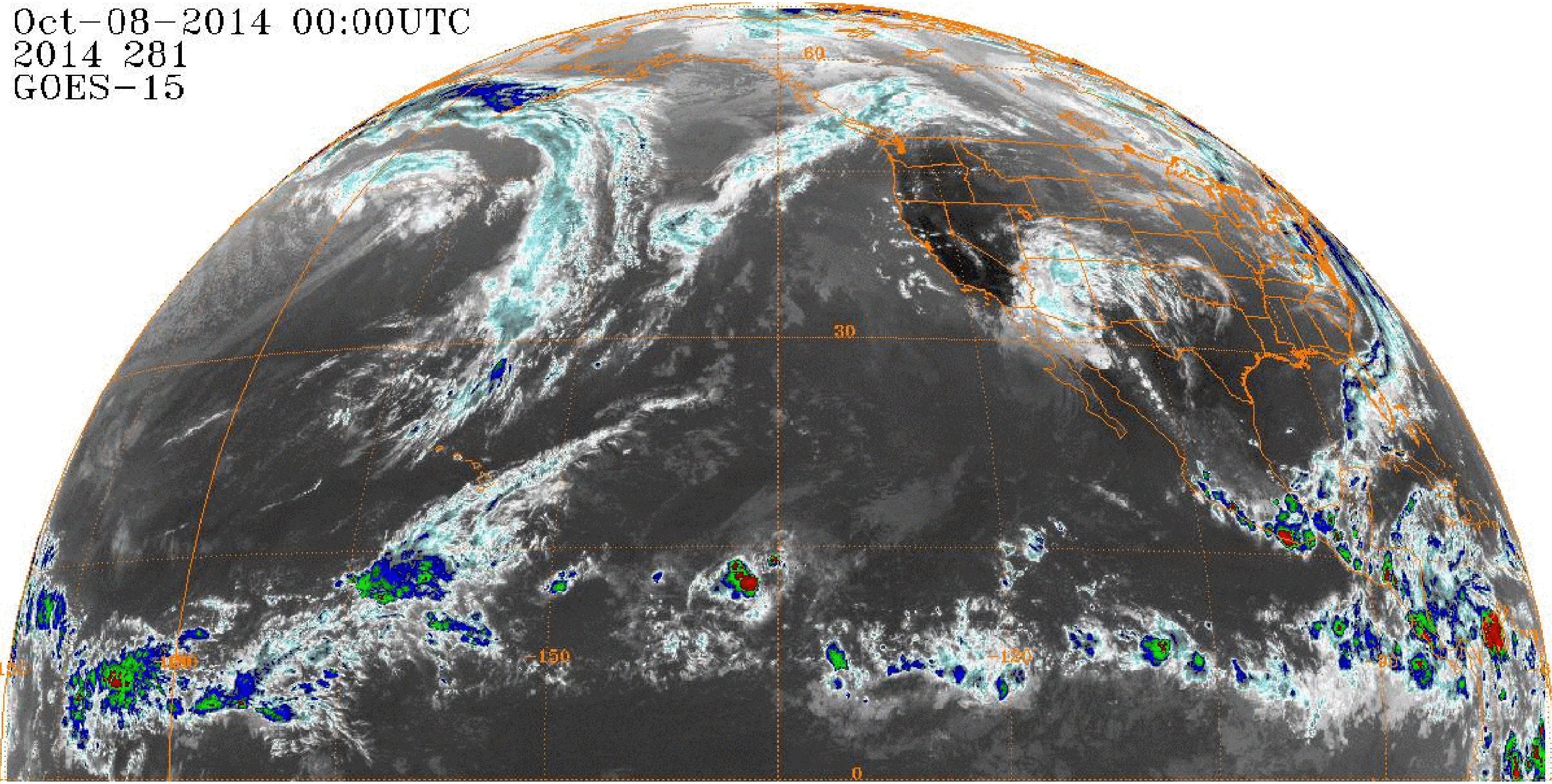




“Yet another strong CCKW is moving across the eastern Pacific…This system should move through the eastern Pacific within the next few days, with genesis possible in the far eastern Pacific Days 3-5.”

Ana & Trudy form





Ana Trudy

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, time of year and NWP output 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) – 2020 everything formed regardless

Current NHC practices

- No operational standard on use of CCKW in genesis forecasts (more than half of forecasters use it).
- 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.

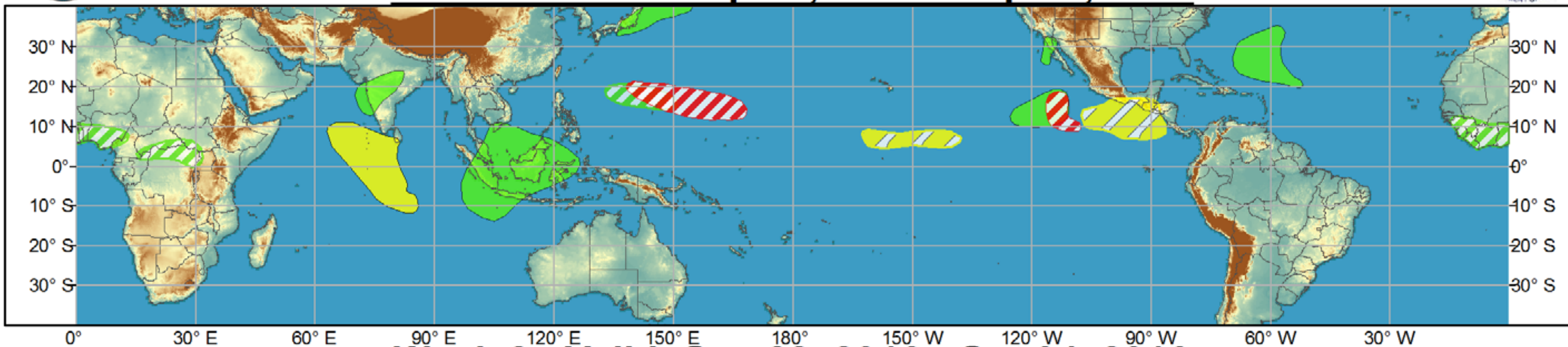
Courtesy
climate.gov
blog

Operational long-range TC forecasts

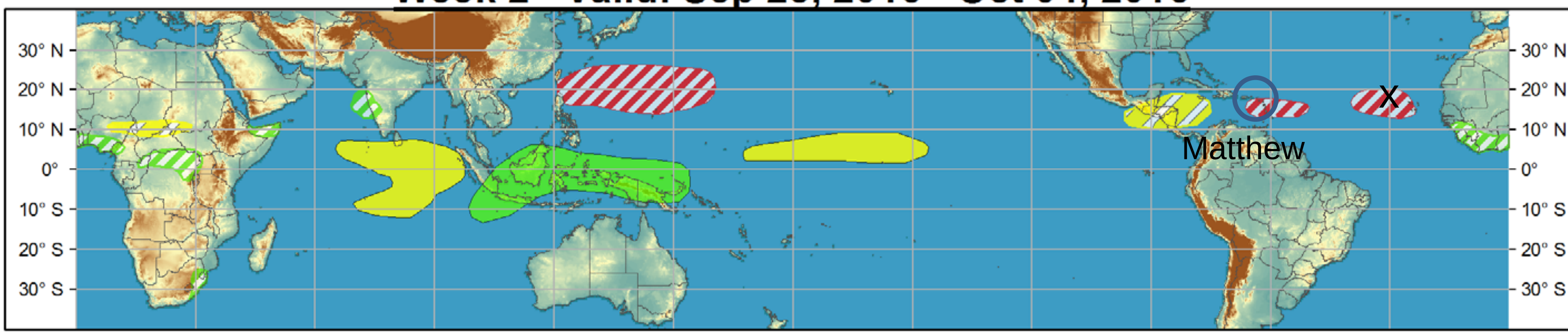
- CPC, in combination with other NOAA/federal/university partners, issues a week 1 and week 2 possible TC risk areas (in addition to other global hazards)
- These global forecasts are released Tuesday afternoons
- The TC-only forecasts are updated on Friday afternoons, if necessary, for the Atlantic/E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

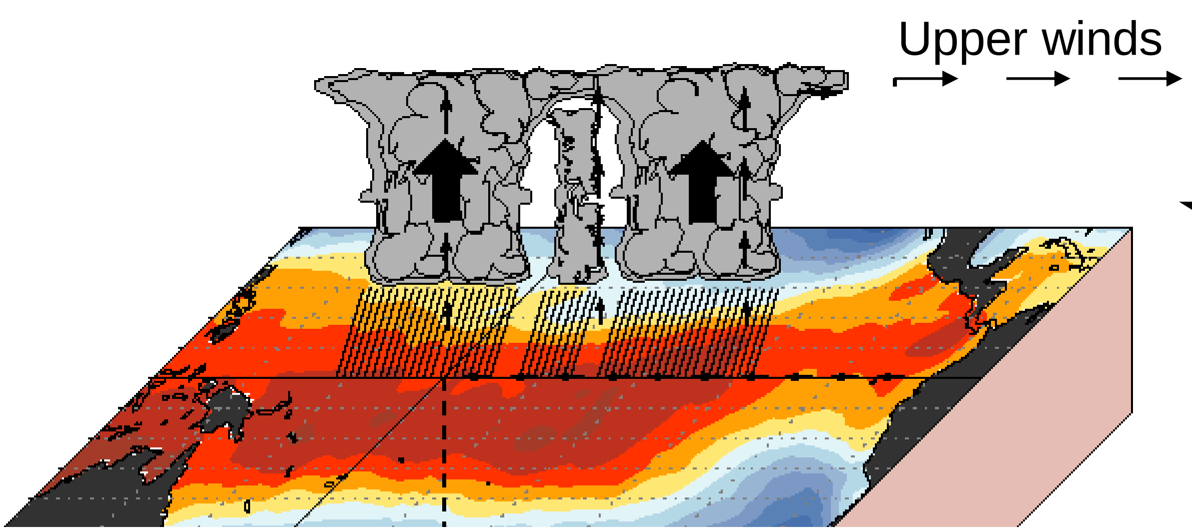
中央氣象局 Central Weather Bureau
UNIVERSITY AT ALBANY State University of New York
EARTH SYSTEM SCIENCE INTERDISCIPLINARY CENTER ESSIC UNIVERSITY OF MARYLAND
Australian Government Bureau of Meteorology
cics.nc
NPS

Seasonal Forecasting

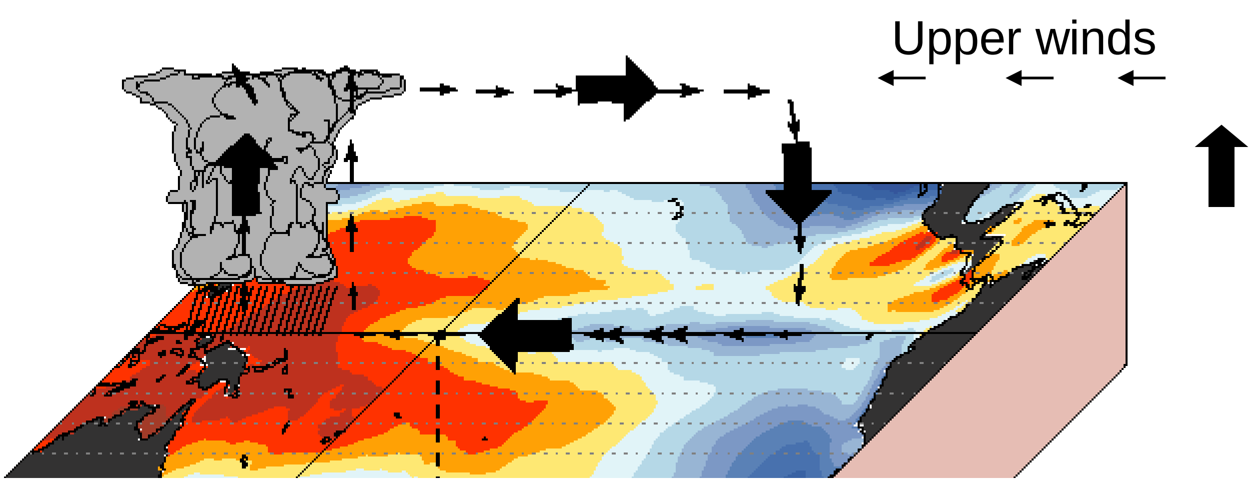
Short history of NOAA seasonal hurricane forecasting

- The Climate Prediction Center (CPC) began issuing Atlantic seasonal hurricane forecasts after the Gray 1997 forecast bust.
- Outlooks issued in late May and early August.
- Collaborative effort between the CPC, National Hurricane Center and Hurricane Research Division.
- Outlooks are a qualitative combination of statistical and dynamical tools, but have become more quantitative over time.

El Niño versus La Niña



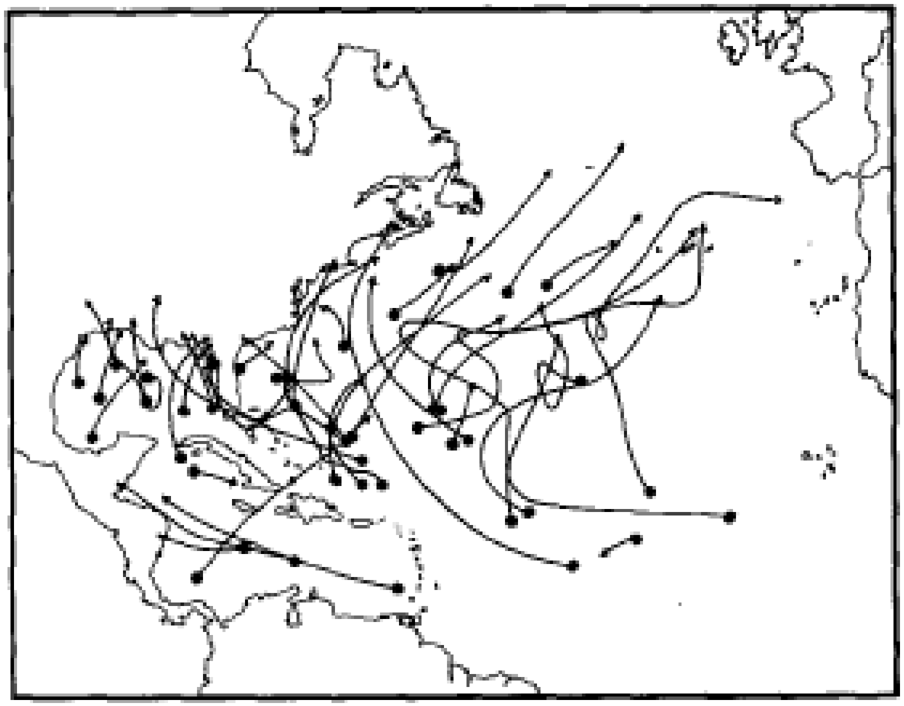
Convection shifted eastward during El Niño causes more shear and sinking air over the Atlantic.



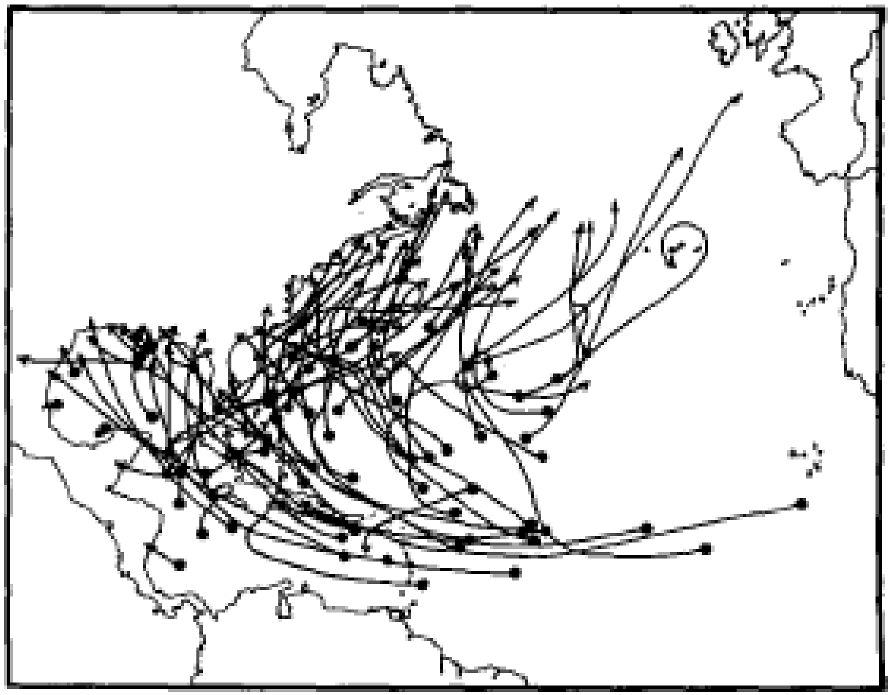
Convection shifted westward during La Niña causes less sinking air and shear over the Atlantic.

Composite of tropical cyclone tracks during 14 moderate to strong El Niño years versus the next year

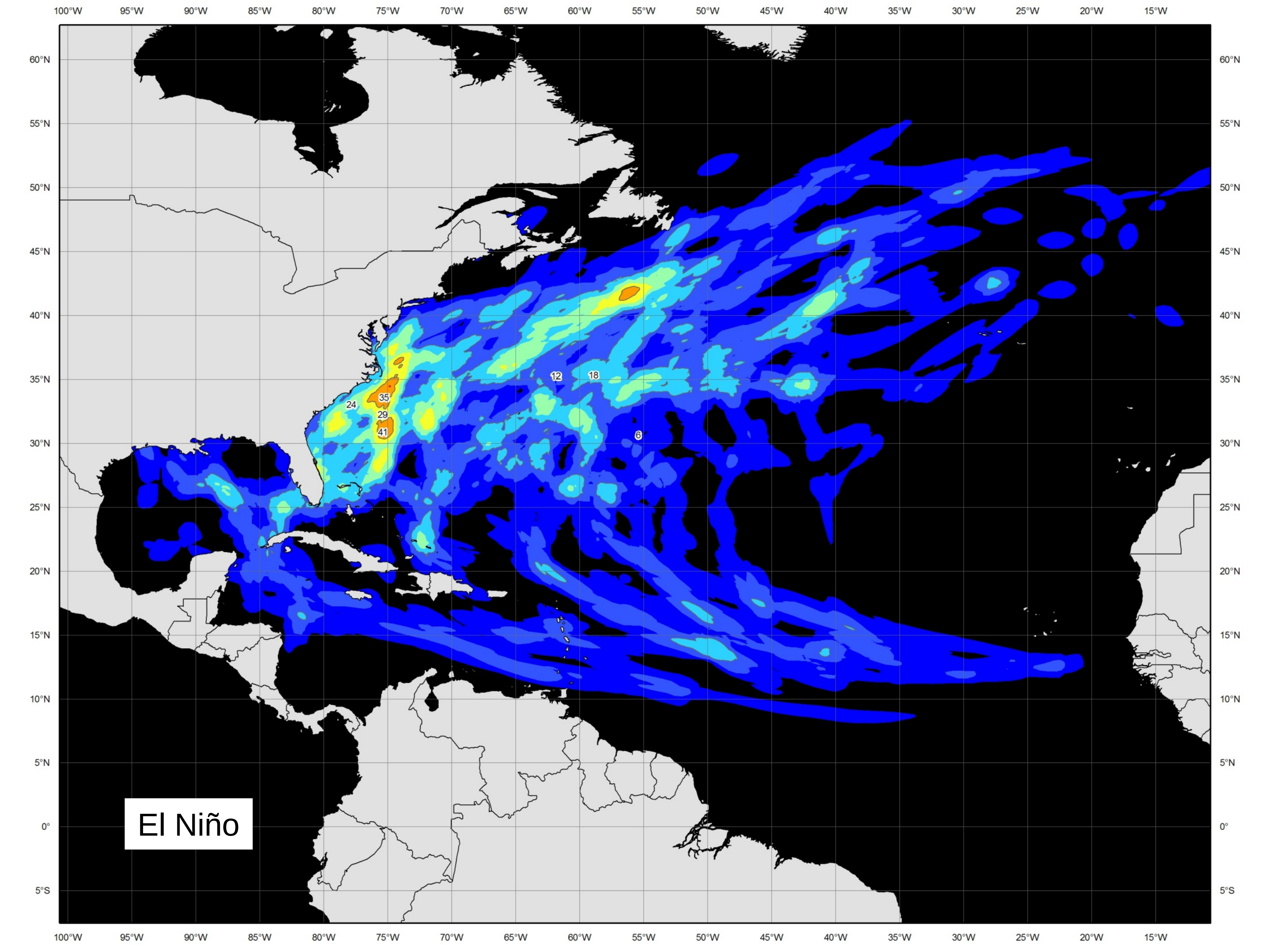
El Niño Years

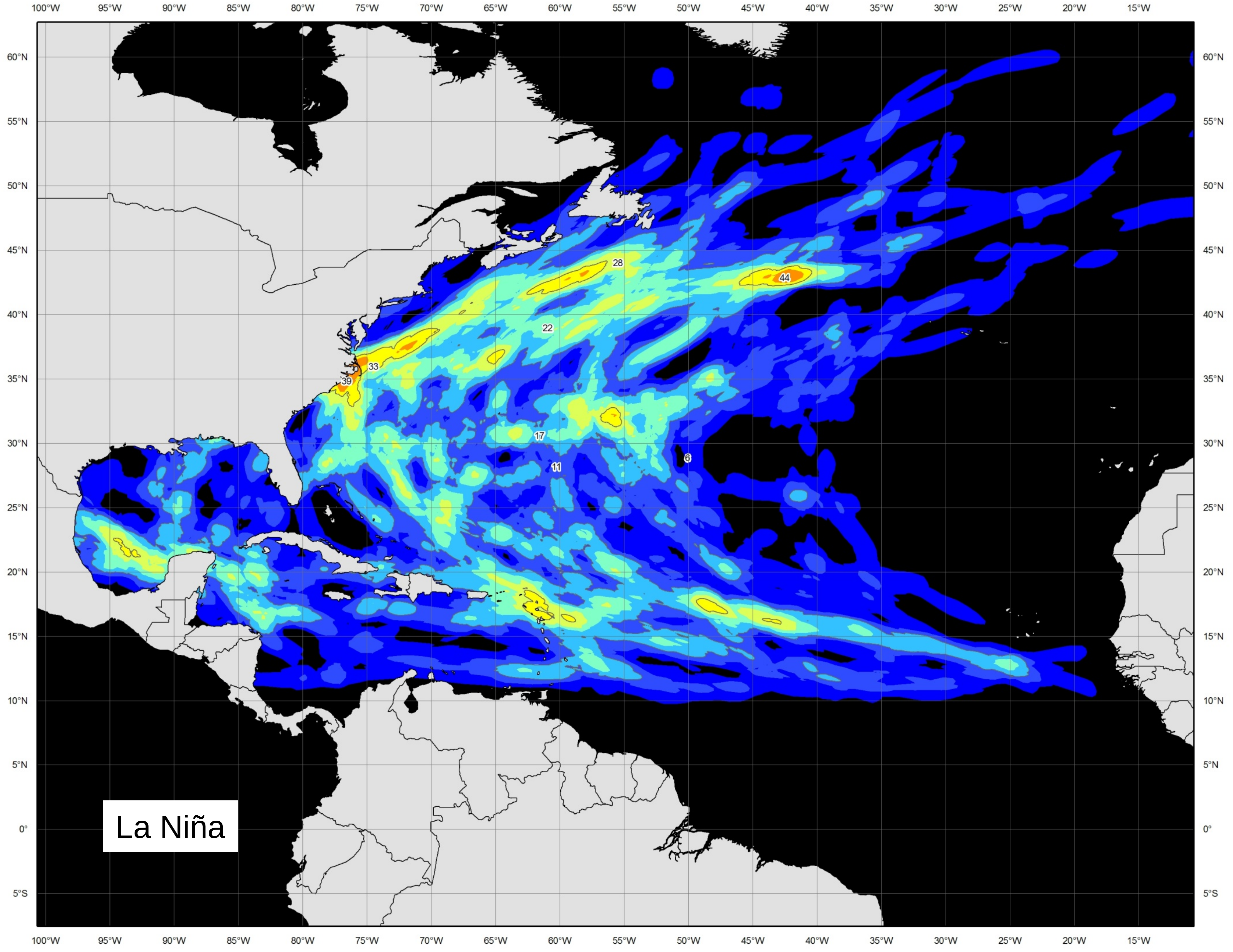


Year after El Niño



From Gray 1984


100°W
95°W
90°W
85°W
80°W
75°W
70°W
65°W
60°W
55°W
50°W
45°W
40°W
35°W
30°W
25°W
20°W
15°W
60°N
55°N
50°N
45°N
40°N
35°N
30°N
25°N
20°N
15°N
10°N
5°N
0°
5°S
12
18
24
35
29
41
6
El Niño



La Niña
28
44
22
33
39
17
11
6
100°W
95°W
90°W
85°W
80°W
75°W
70°W
65°W
60°W
55°W
50°W
45°W
40°W
35°W
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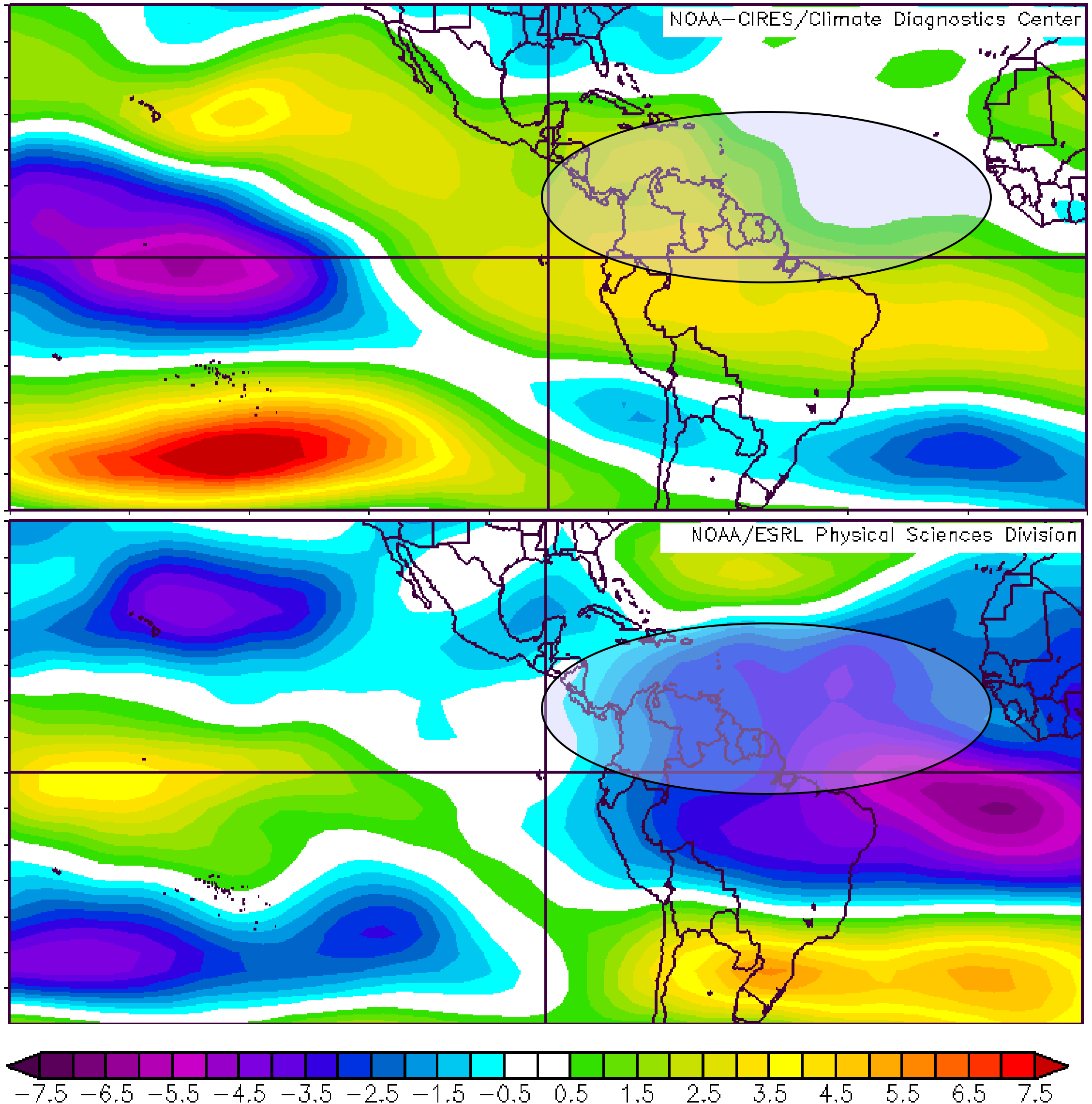
25°W
20°W
15°W
60°N
55°N
50°N
45°N
40°N
35°N
30°N
25°N
20°N
15°N
10°N
5°N
0°
5°S

Vertical Wind Shear

- Tropical cyclones generally require low vertical wind shear to develop, less than about 20 mph.
- Early-season vertical shear (June-July) relates well to August-October shear (peak season).
- Since 90% of the season is usually after 1 August, useful to update then.

200mb zonal wind anomalies (m/s) during June-July of 10 ENSO events.



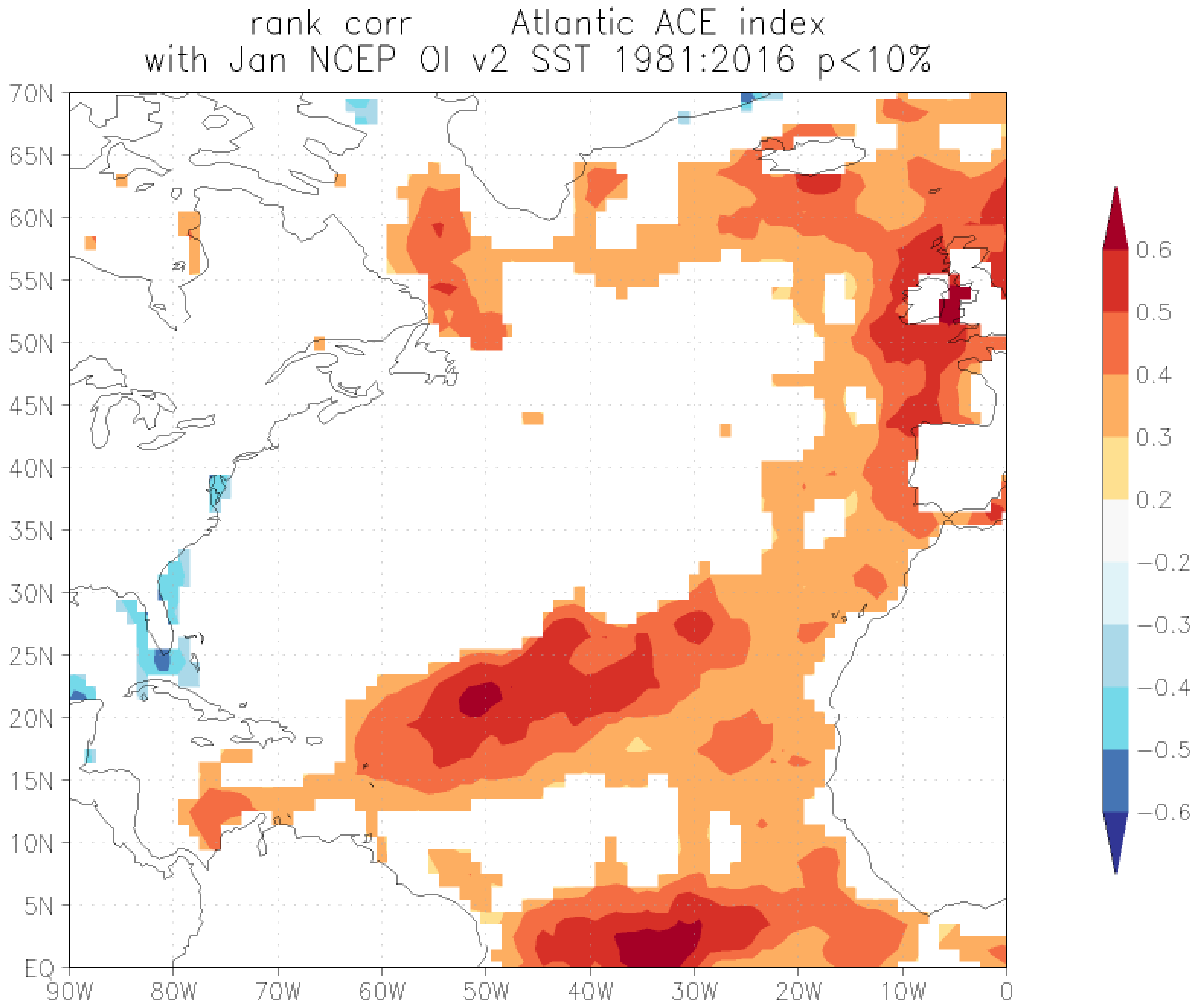
El Niño

La Niña

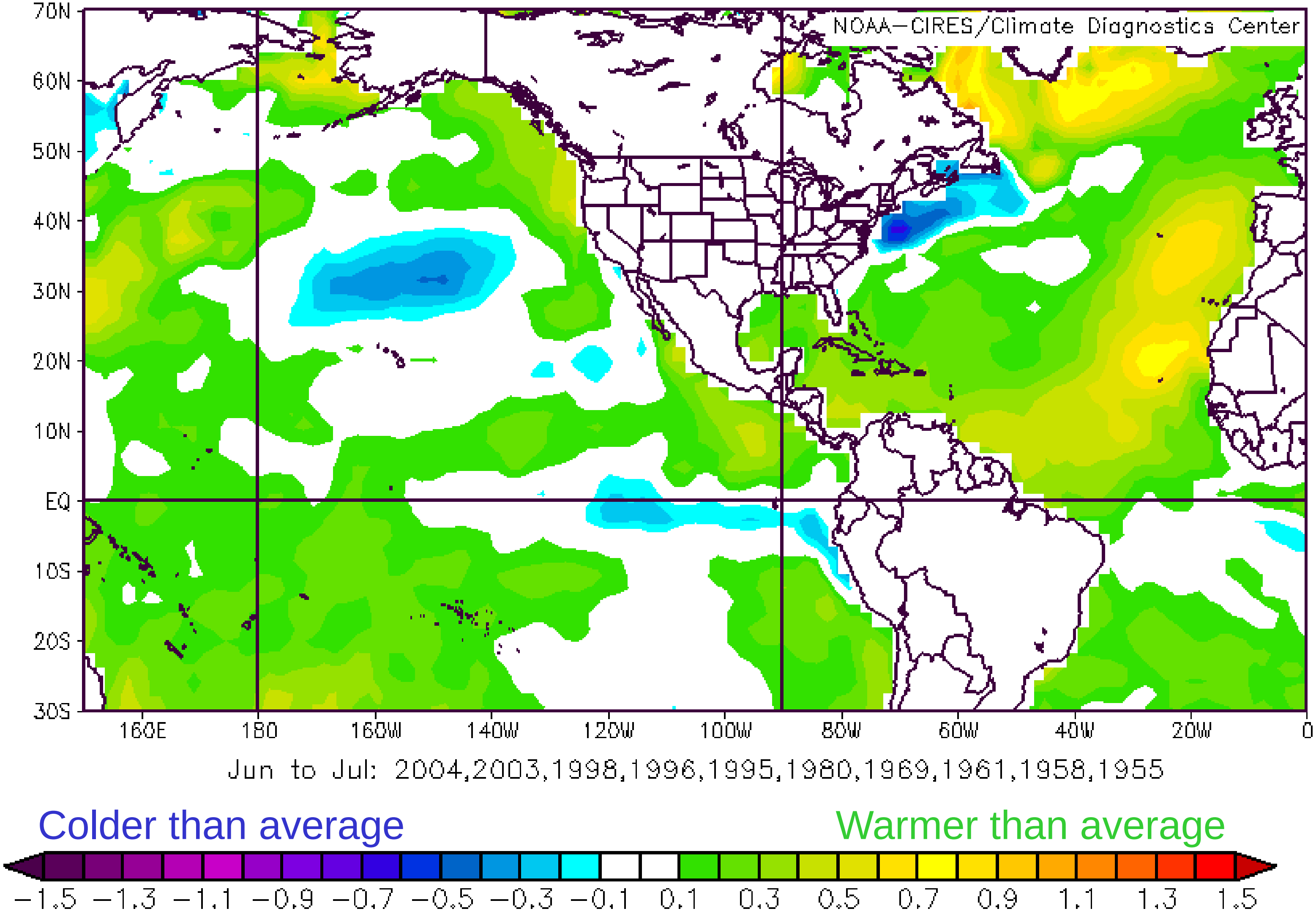
Sea-Surface Temperatures (SSTs)

- Warmer Atlantic waters generally mean a more active hurricane season
- Relative warmth of Atlantic to global tropics also important
- Atlantic warmth linked to Atlantic surface ridge strength

Correlation between Atlantic SST and Atlantic Hurricane Activity

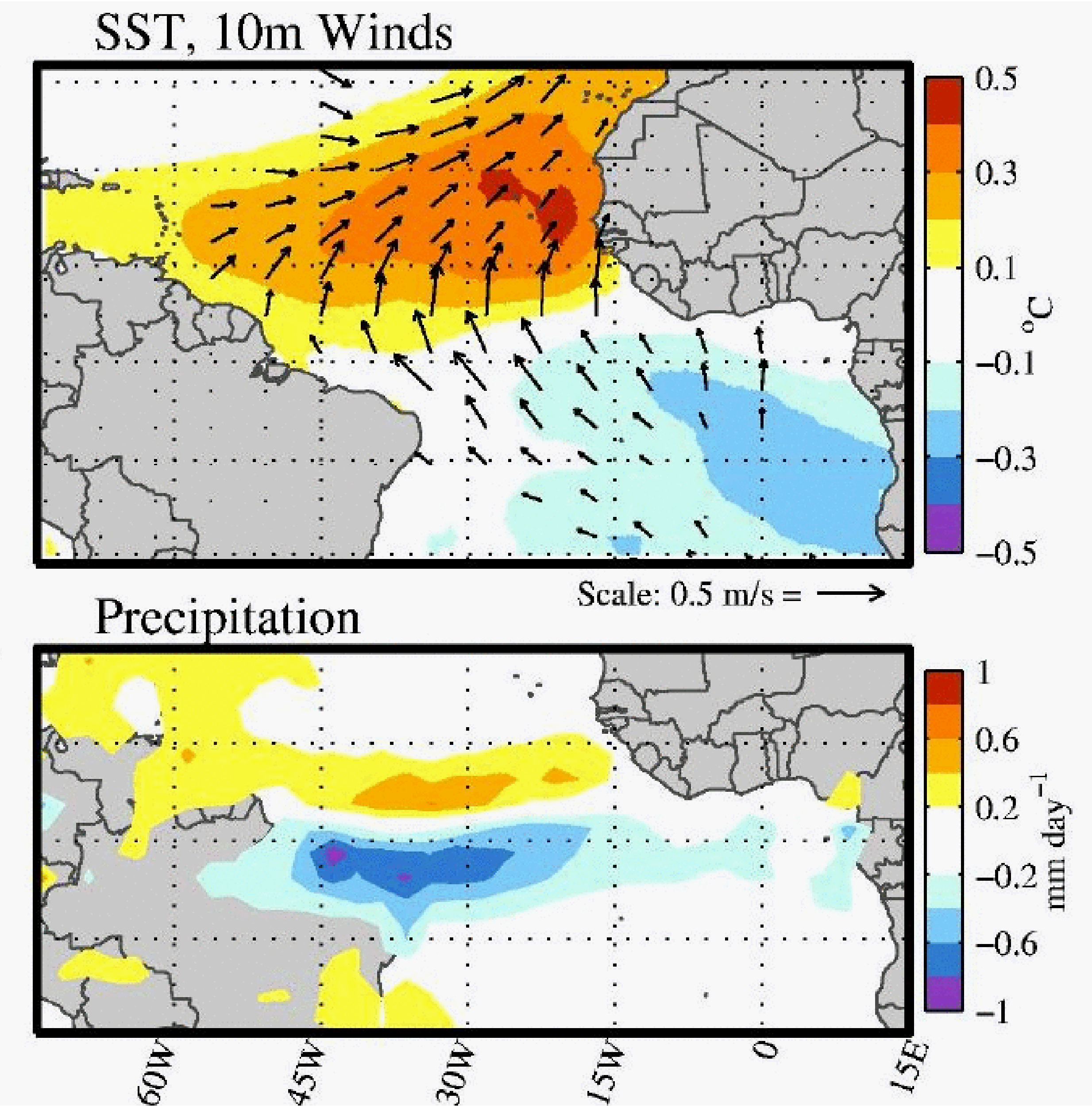


Composite map of June-July SST anomalies during 10 active hurricane seasons

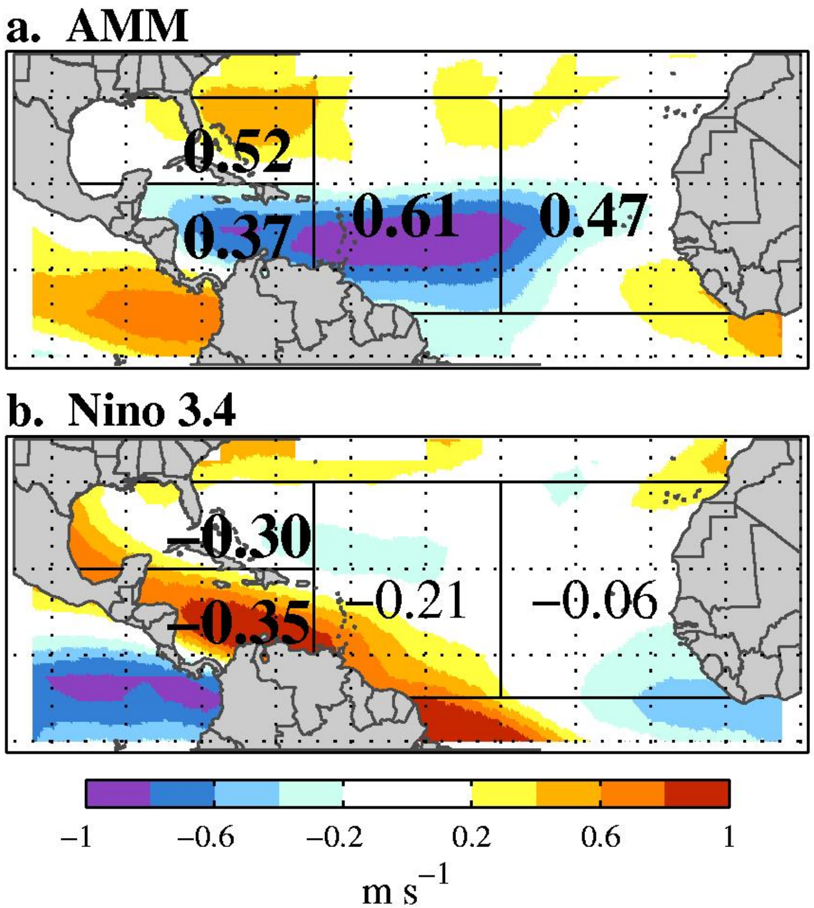


The Atlantic Meridional Mode: SST, wind, and precip anoms

- Leading mode of basin-wide ocean-atmosphere interaction between SST and low-level winds
- Amplifies via the **wind-evaporation-SST (WES)** feedback mechanism
- Strongest signal during the spring, but persists into hurricane season



Comparative effects of the AMM (local) and ENSO (remote) on vertical wind shear in the Atlantic



units: m/s per standard deviation

Shear regressed onto AMM and N34 indices, and correlations between the indices and storm activity.

NOAA Forecast Methodology

1) Assess states of the ocean and atmosphere.
2) Use model forecasts for El Niño/Atlantic SSTs and incorporate any analog techniques and dynamical model forecasts of TCs.
3) Predict range of overall activity and probabilities of above-, near-, and below-average seasons.
4) Qualitative/Quantitative process.
5) **No forecast of hurricane landfalls, just the total seasonal activity for the entire basin.**

CFS-based TS, Hurricanes and ACE Index Forecast Atlantic Basin– May forecast

	Tropical Storms	Hurricanes	ACE Index % of Median
402	14	4	132
403	15	5	131
404	11	2	94
405	11	2	132
406	10	3	72
407	9	3	106
408	15	5	131
409	14	2	84
410	11	4	88
411	13	6	184
412	11	0	77
413	14	7	166
414	16	8	185
415			
416			
417			
418			

2012
Slightly Above Normal Year

	Tropical Storms	Hurricanes	ACE Index % of Median
Ensemble	**12.6**	**3.9**	**121.6**
Standard Deviation	**2.2**	**2.3**	**39.0**
Range	**10-15**	**2-6**	**83-161**
Model Clim	**10.6**	**3.8**	**85.4**

Seasonal Forecast Caveats:

1) Even with perfect knowledge of all predictors – only 50-60% of the variance in TC activity is explained. This could increase as dynamical model skill grows.

2) This make a 1-category forecast error possible in 1 out of 3 or 4 years, and a 2-category error in 1 in ~7 years.

3) In seasonal forecasting, you will be flat wrong some years despite your best efforts. 2013 is a prime example.

Model Forecast Summary: 2013 Atlantic Outlook

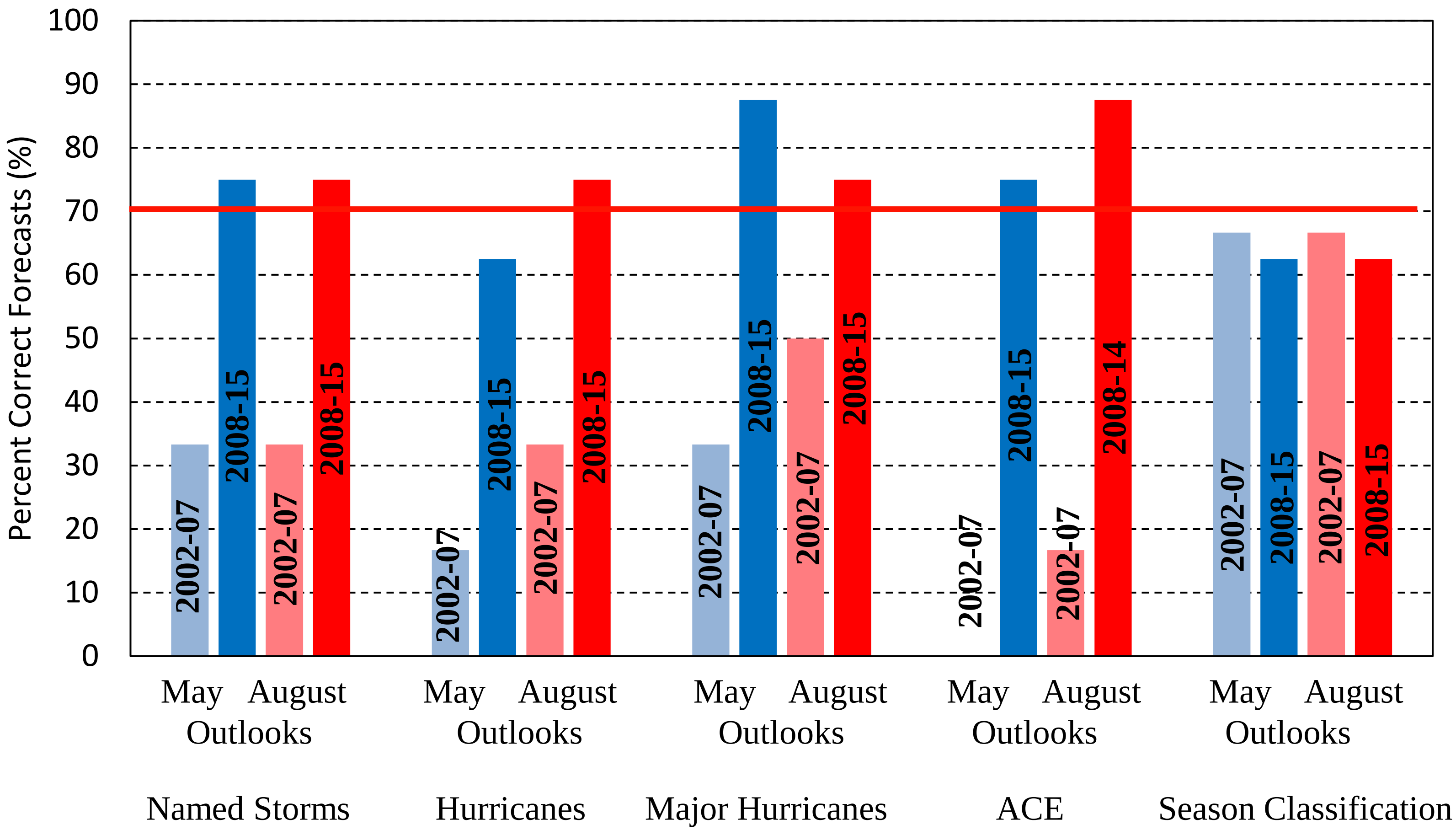
Model predicted ranges (± 1 σ) and mean activity (in parenthesis). The model averages (yellow) and NOAA's outlook (Red) are shown at bottom.

	Model	Named Storms	Hurricanes	Major Hurricanes	ACE (% Median)
Statistical	**CPC Regression:**	14-18 (16)	7-9 (8)	3-4.5 (3.75)	140-170 (155)
	CPC Binning : Nino 3.4+SSTA	7.9-21.5 (14.7)	4.2-11.5 (7.85)	2.1-5.9 (4)	69-217 (143)
	CPC Binning ENSO+SSTA	10.1-21 (15.55)	5.2-11.7 (8.45)	2.8-5.9 (4.35)	106-229 (167)
CFS	**CFS: Hi-Res T-382**	13.4-19.4 (16.4)	5.2-11.2 (8.2)		111-199 (155)
	CFS-V2 T126: 1	12-16 (14)	6-9 (7.5)	3-4 (3.5)	112-168 (140)
	CFS-V2 T126: 2	13-17 (15)	7-10 (8.5)	3-4 (3.5)	121-182 (152)
	CFS-V2 T126: 3	13-17 (15)	6-10 (8)	3-4 (3.5)	119-184 (152)
European	**ECMWF:**	8.9-16.3 (12.6)	5.5-10.5 (8)		90-167 (128)
	EUROSIP:	7.6-14.4 (11)			
	Guidance Mean	**11.1-17.8 (14.5)**	**5.8-10.4 (8.1)**	**2.8-4.7 (3.8)**	**108-190 (149)**
	NOAA Outlook	**13-20 (16.5)**	**6-11 (8.5)**	**3-6 (4.5)**	**120-205 (163)**
	Actual:	14	2	0	39

Why issue a seasonal hurricane outlook then?

- One of the top questions NOAA gets in the offseason is “What’s the season going to be like?”
- Large amount of media coverage makes it ideal to get the preparedness/awareness message out, even if most people can’t use the forecast.
- Gets people thinking about the upcoming hurricane season/activity.
- Specialized users (reinsurance companies, offshore interests etc.)

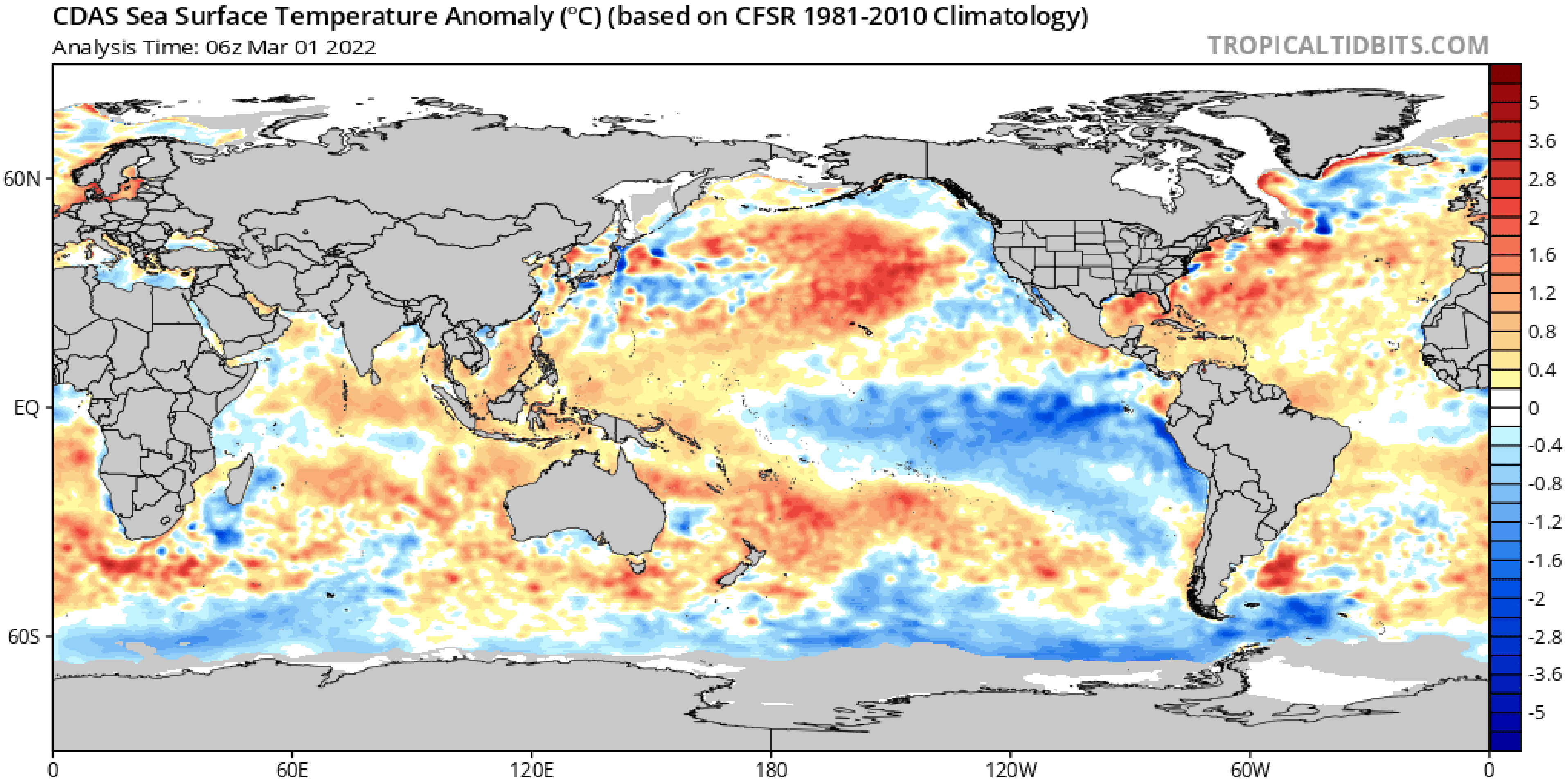
Percent of Correctly Forecasted Parameters



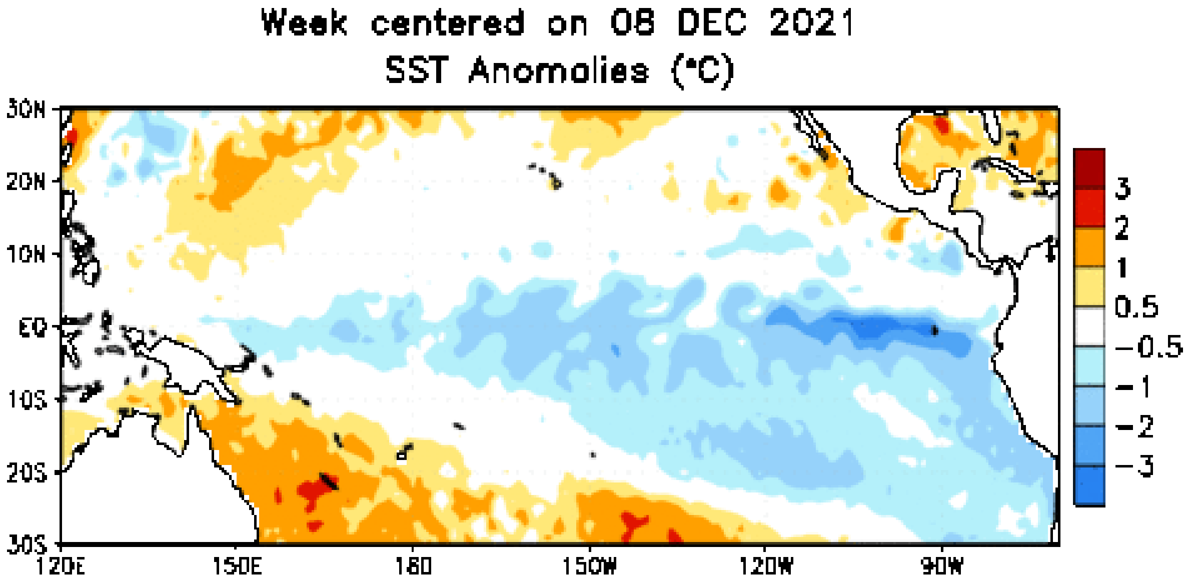
For both the May (Blue) and August (Red) outlooks, large skill improvements are seen since 2008 for all predicted parameters except Season Classification,.


What about 2022?
15 SEP 04 - G-12 IMG - 20:45

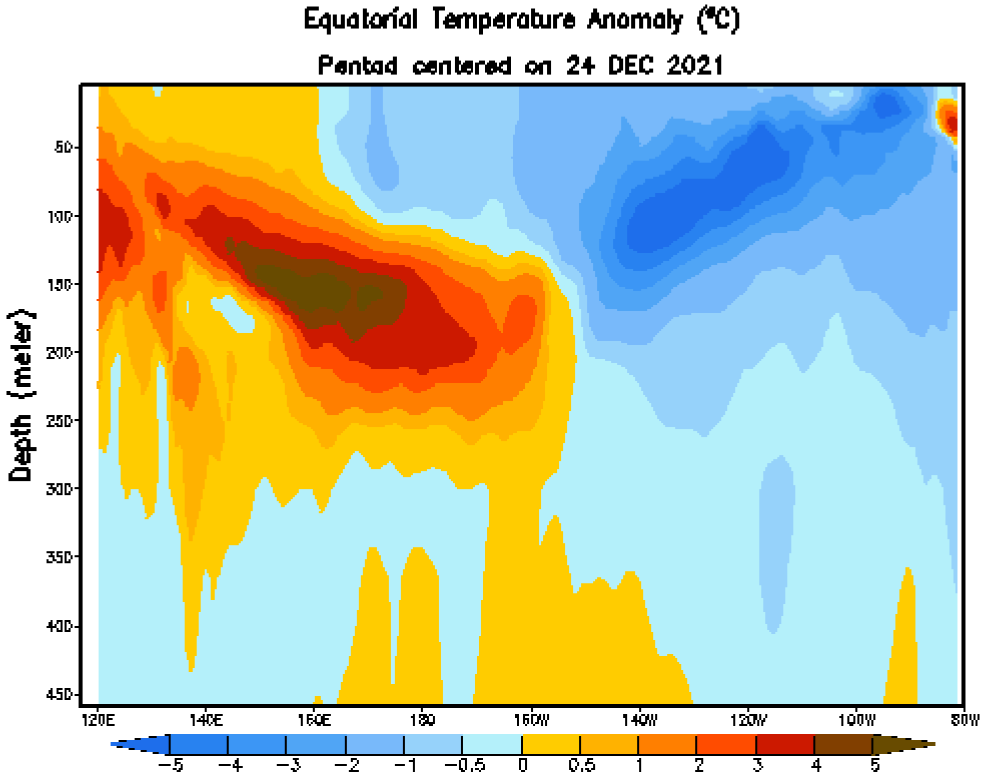
Current Global SST anomalies



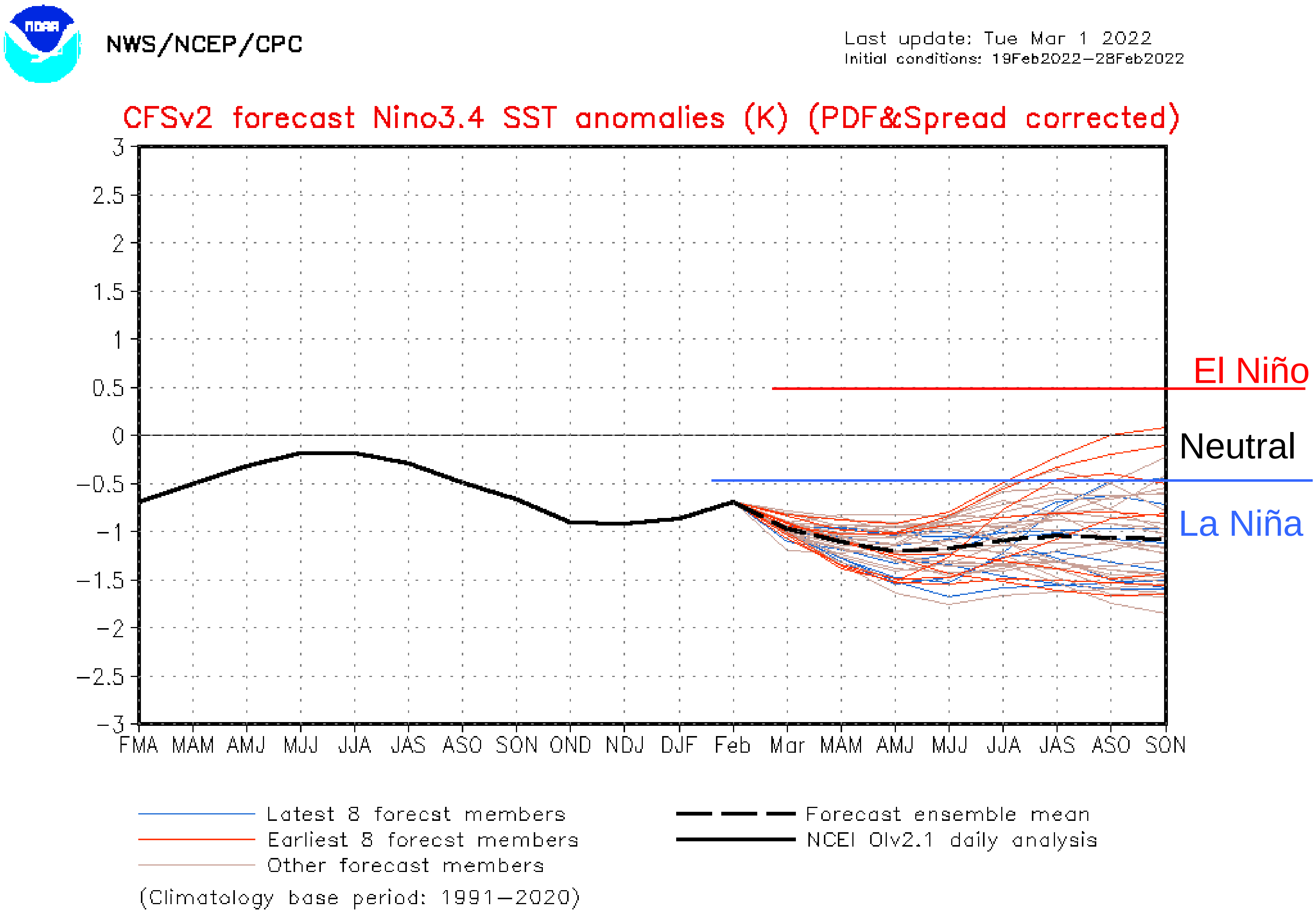
La Niña conditions in the Pacific



Thermocline- more neutral

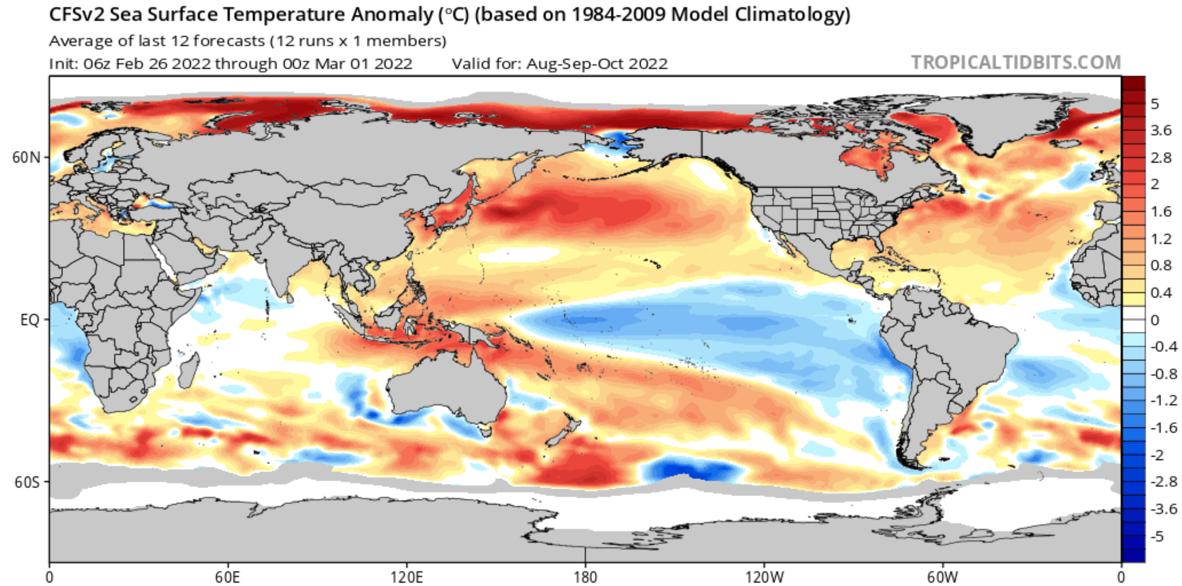


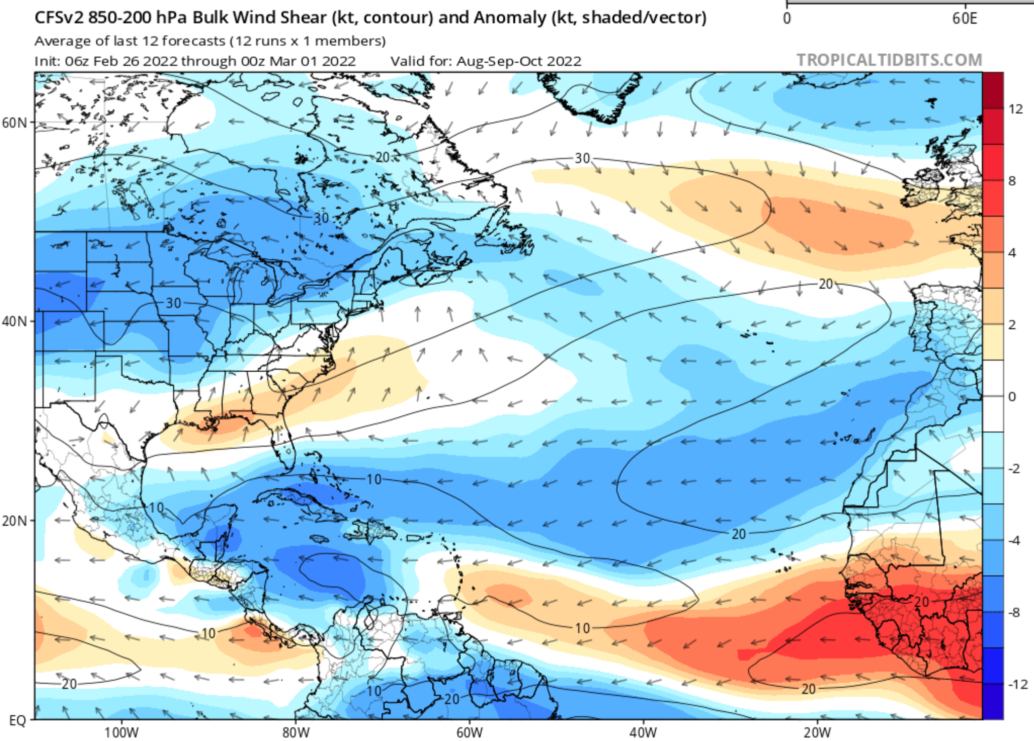
CFS forecasts La Niña conditions continuing



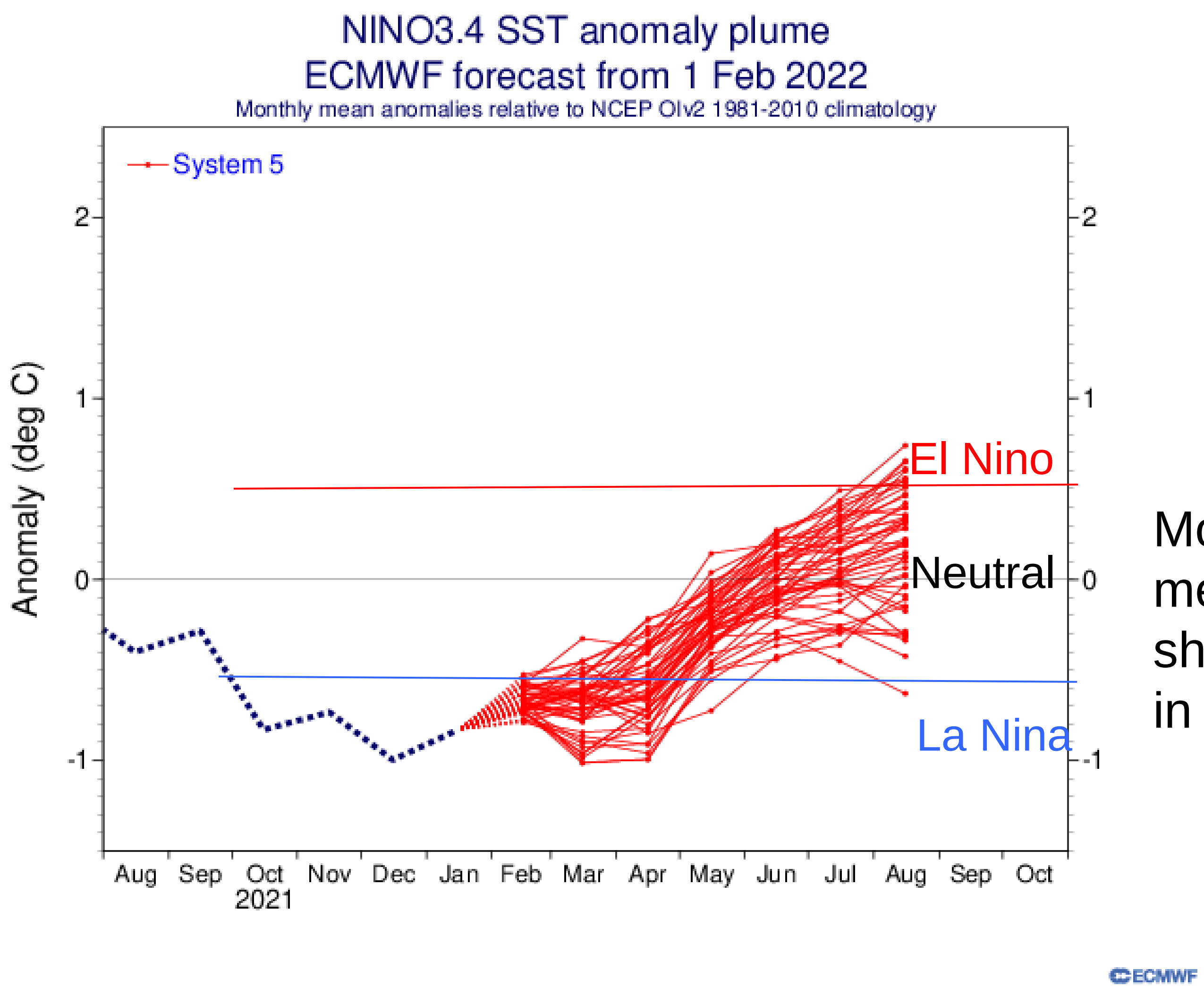
CFS ASO Seasonal Forecasts from Mar 1

SST (very warm Atlantic, cool ENSO)



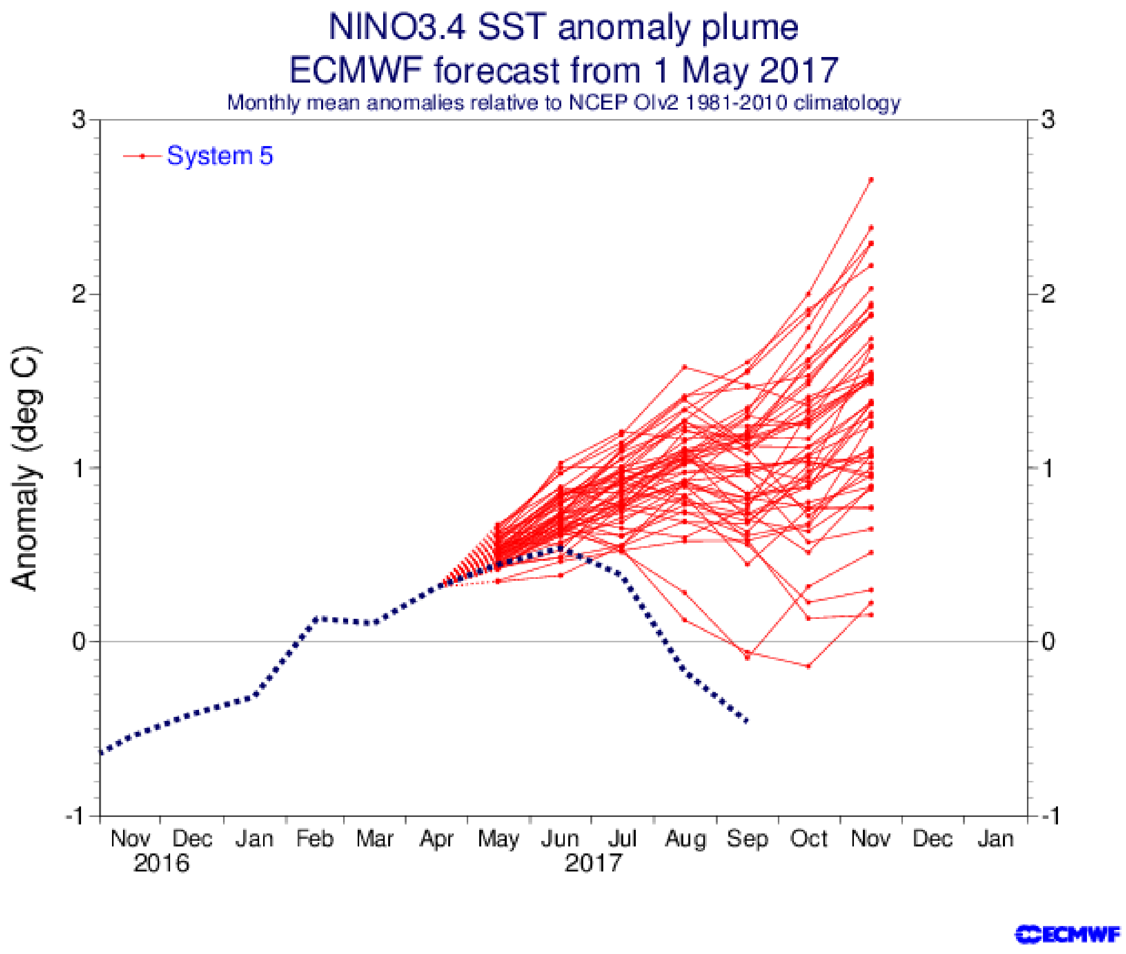


Vertical Shear (lower than normal)



Most ECMWF members show neutral in summer

Niño models aren't very good though!



Conclusions

- The MJO and Kelvin waves modulate TC activity around the globe (Epac more than Atlantic)
- El Niño/La Niña conditions are probably the most important factor in a seasonal forecast.
- Tropical Atlantic Ocean water temperatures and multi-decadal cycles are also very important.
- There are also year-to-year differences in vertical wind shear, sea-level pressures, and global circulation changes during the early part of the season that may give clues to how the rest of the season may turn out.
- 2022 a hard forecast given Nino uncertainties