Intraseasonal TC Variability and Seasonal Hurricane Forecasting

2024 WMO Class

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Outline

- Madden-Julian Oscillation (MJO)
- MJO analysis tools
- Kelvin Waves
- Seasonal forecasting
- Exercise
- Brief look at 2024

Courtesy climate.gov blog

Poll Question

What characteristic of both the active phases of the MJO and Kelvin Waves help aid in TC Genesis?

A. Increased SSTs

B. Increased Outgoing Long Wave Radiation

C. Increased Cyclonic Vorticity

D. Lower vertical wind shear

E. Increased Vertical Motion

What characteristic of both the active phases of the MJO and Kelvin Waves help aid in TC Genesis? Check all that apply.

0

Increased SSTs — 0%

Increased Outgoing Longwave Radiation — 0%

Increased Cyclonic Vorticity — 0%

Lower Vertical Wind Shear — 0%

Increased Vertical Motion — 0%

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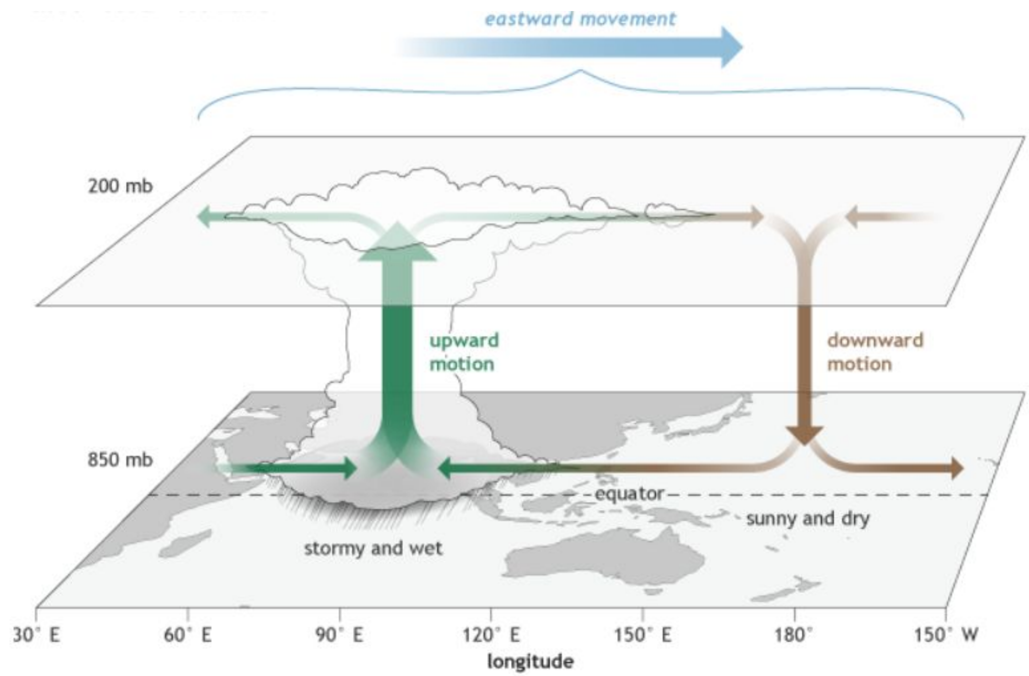
Idealized MJO cross-section

- 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.

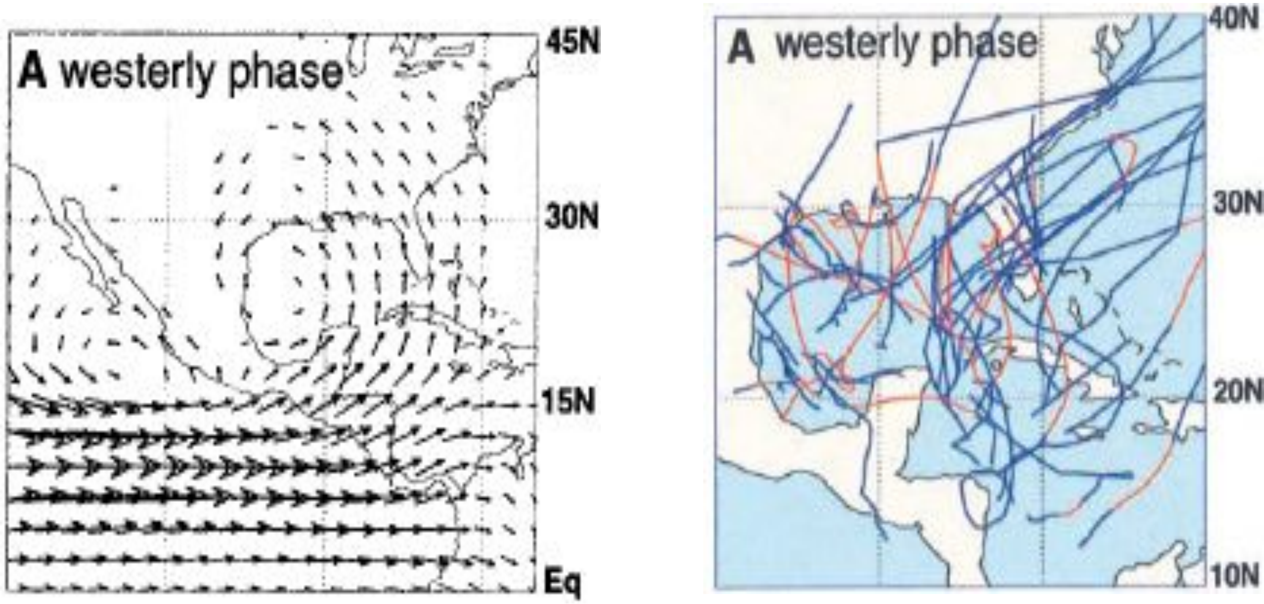


Courtesy Fiona Martin, climate.gov blog

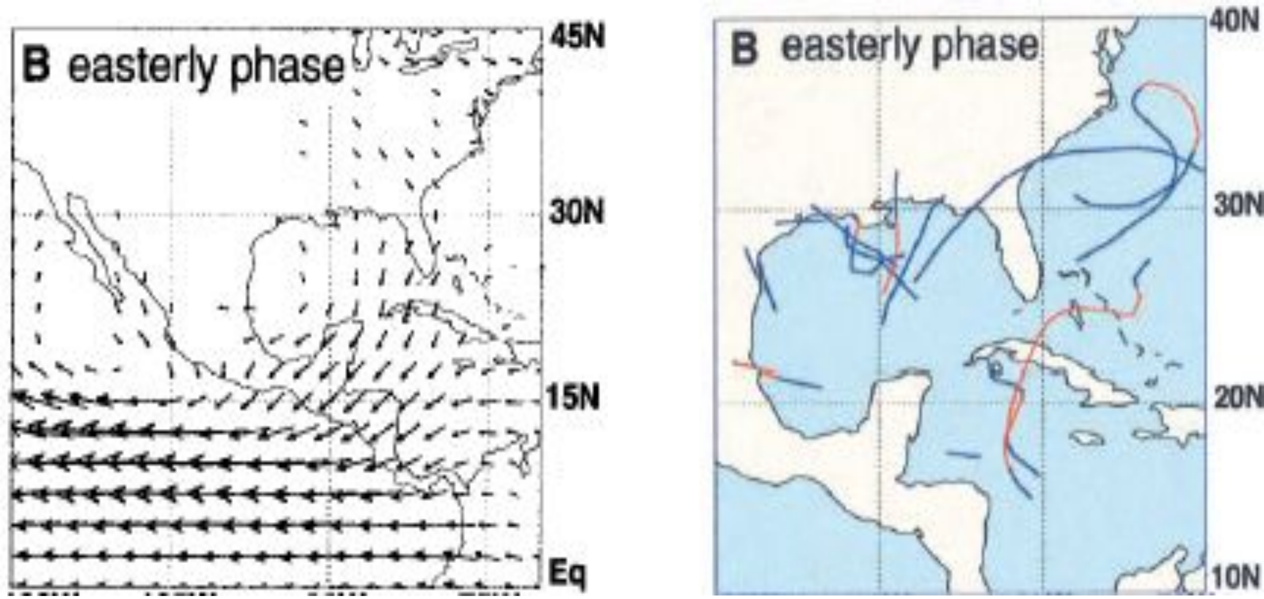
Active MJO in the western Caribbean Sea and Gulf of Mexico produces more storms due to:

- 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



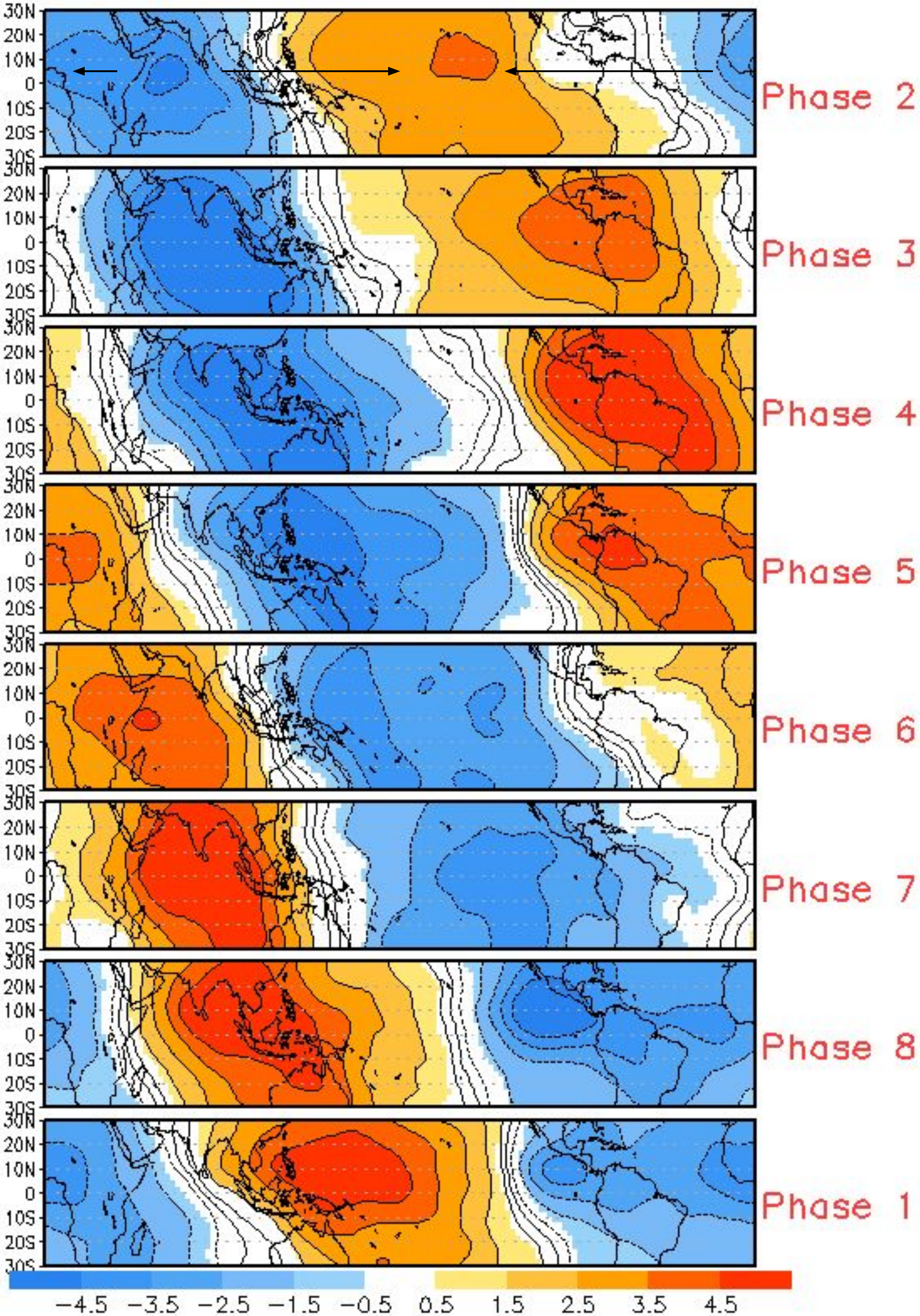
Inactive MJO EOF and corresponding TS and H tracks



Adapted from Maloney and Hartmann (2000)

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).



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

Blue= ~divergence

Red= ~convergence

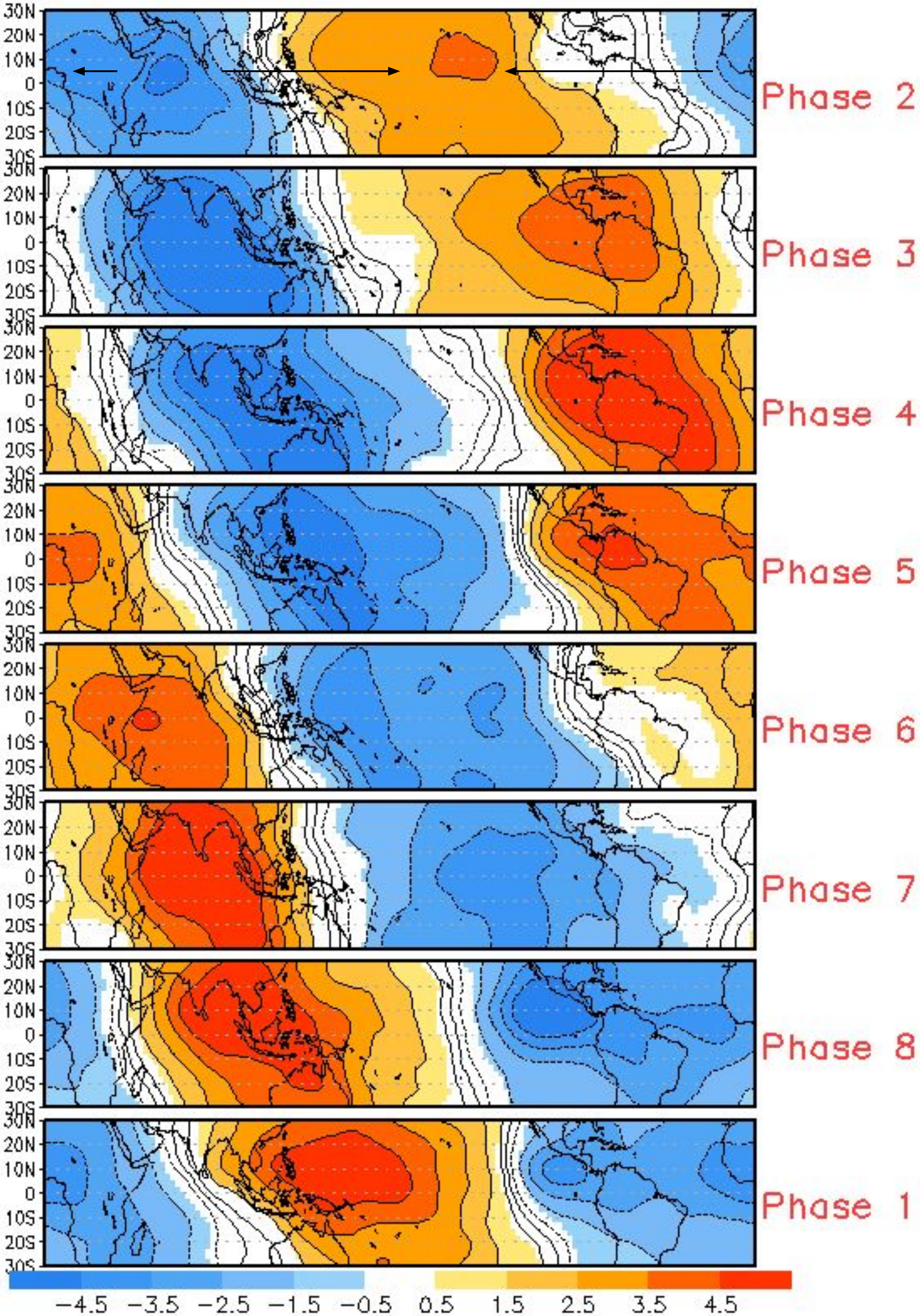
What phases of the MJO are most favorable for Atlantic TC activity?

A. Phases 3/4

B. Phases 5/6

C. Phases 7/8

D. Phases 1/2

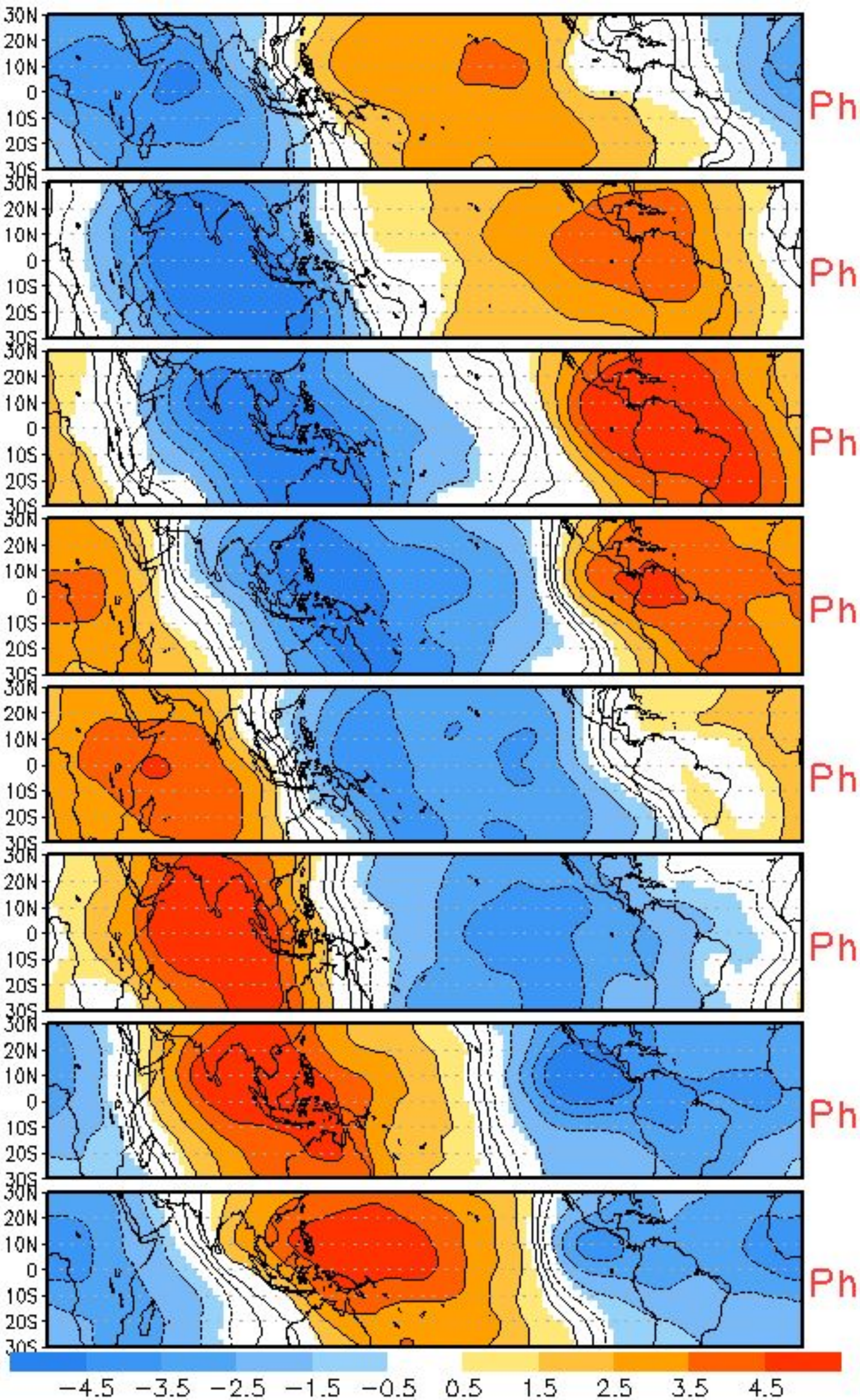


200 mb Velocity Potential fields– one way to track the MJO

Blue= ~divergence

Red= ~convergence

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



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

Phases 1/2 0%

Phases 3/4 0%

Phases 5/6 0%

Phases 7/8 0%

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200 mb Velocity Potential fields

Blue= ~divergence Red= ~convergence

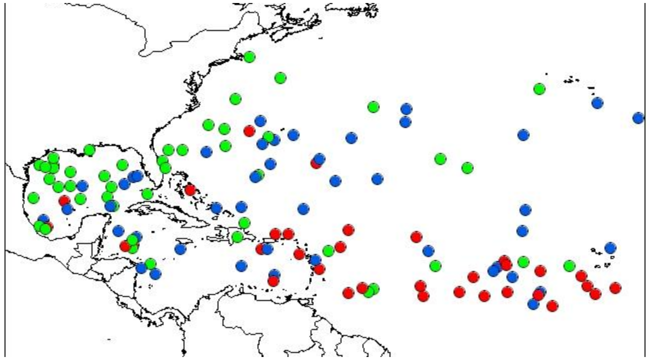
Normalized Activity by MJO Phase (1974-2007)

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**

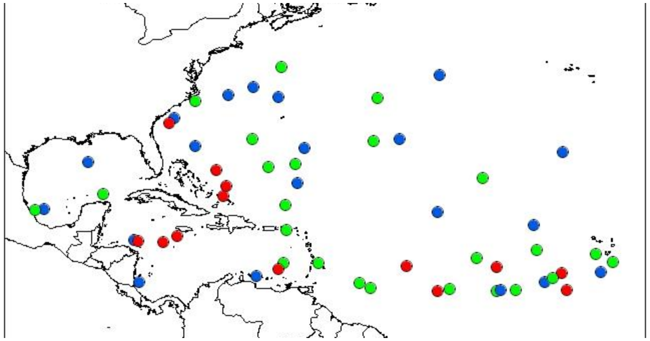
From Klotzbach (2010)

All Genesis Points

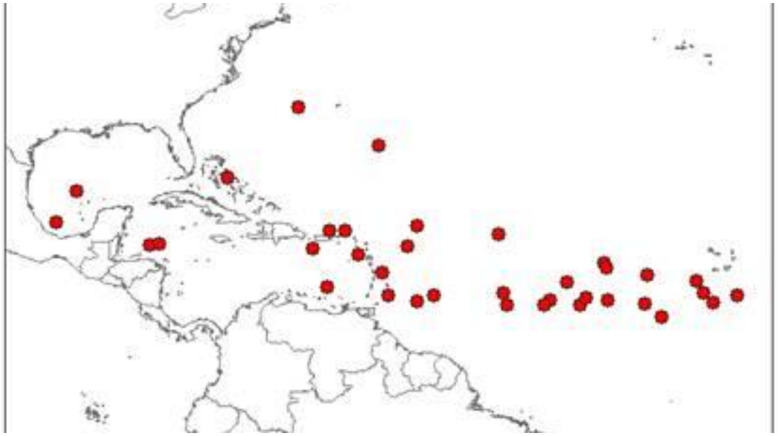
MJO Phases 1+2



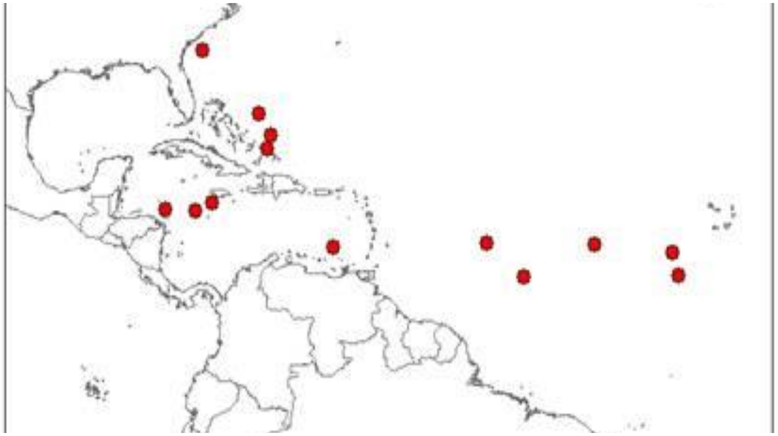
MJO Phases 6+7



36 Major Hurricanes



13 Major Hurricanes



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.

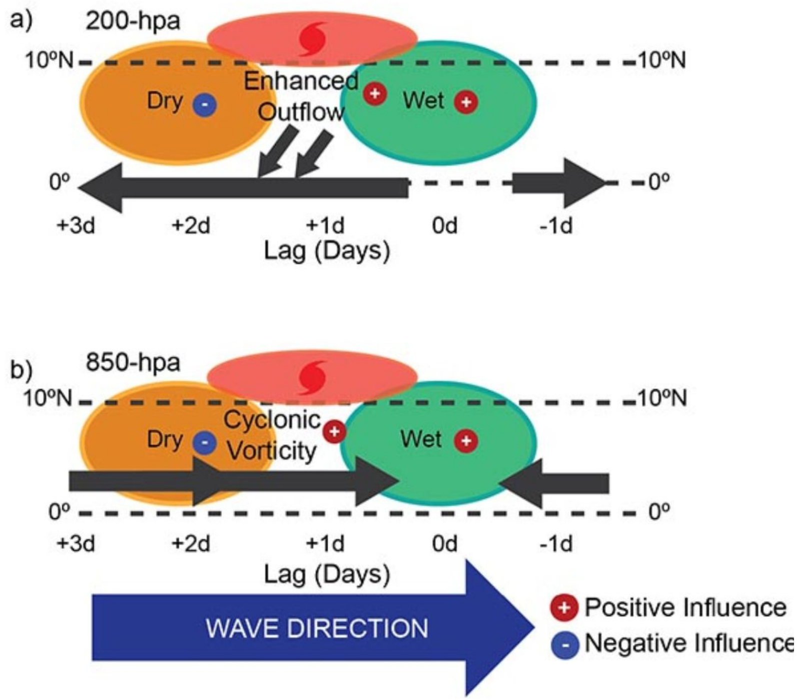
- A typical MJO moves eastward at **4 to 8 m s^{-1}** with a zonal extent that spans planetary to synoptic scales.

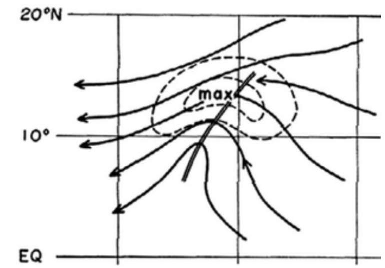
A **Kelvin wave** is spatially very similar to the MJO, but is typically observed at higher zonal wavenumbers and moves eastward at **10 – 20 m s^{-1}**.

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

Adapted from Griffin (2014)

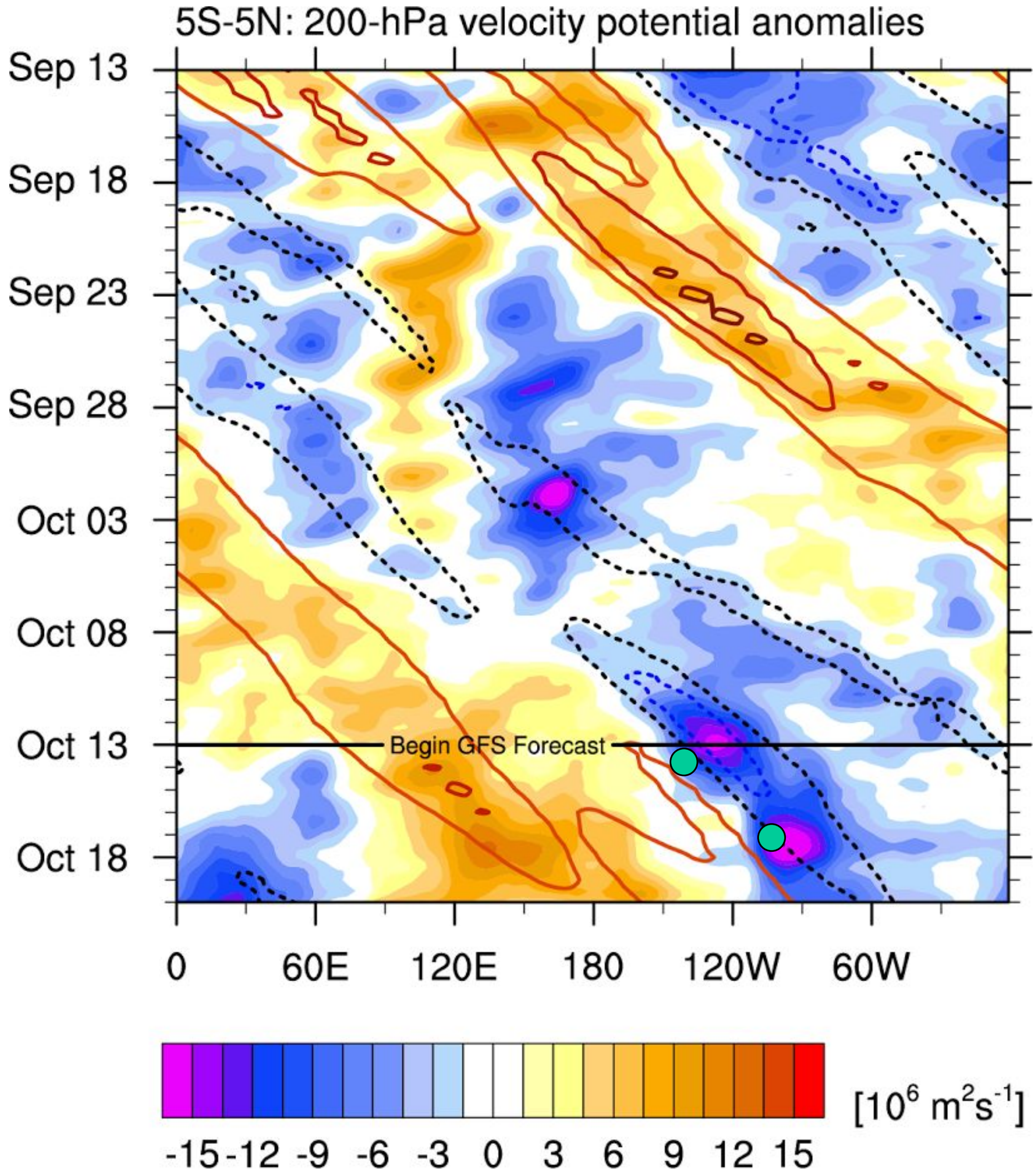
Kelvin Waves





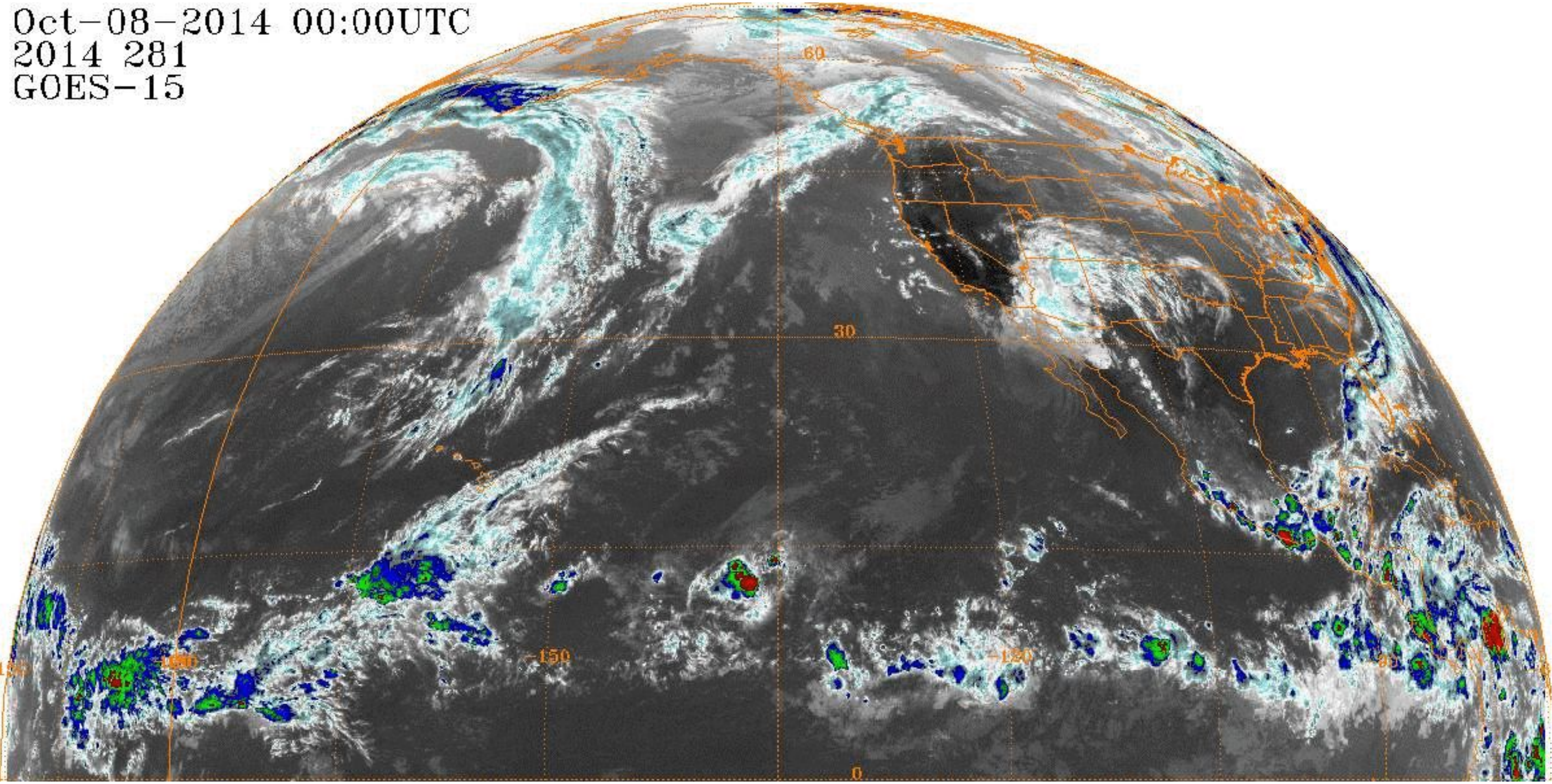
- Rainfall associated with Kelvin waves has been found to enhance easterly wave signals as they intersect (Schreck 2017)
- Enhanced upper easterlies + lower westerlies + convection = favorable for TC genesis
- KWs can also enhance upper level divergence (outflow), favorable for TC genesis
- Often a two day lag between low-level passage of KW and TC genesis - likely due to the fact that upper-level wave lags the lower level, and as the circulation builds upward as the Kelvin wave propagates

"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."



Negative velocity potential aligns with UL Divergence from KW

● Ana & Trudy form



Ana Trudy

Operational challenges

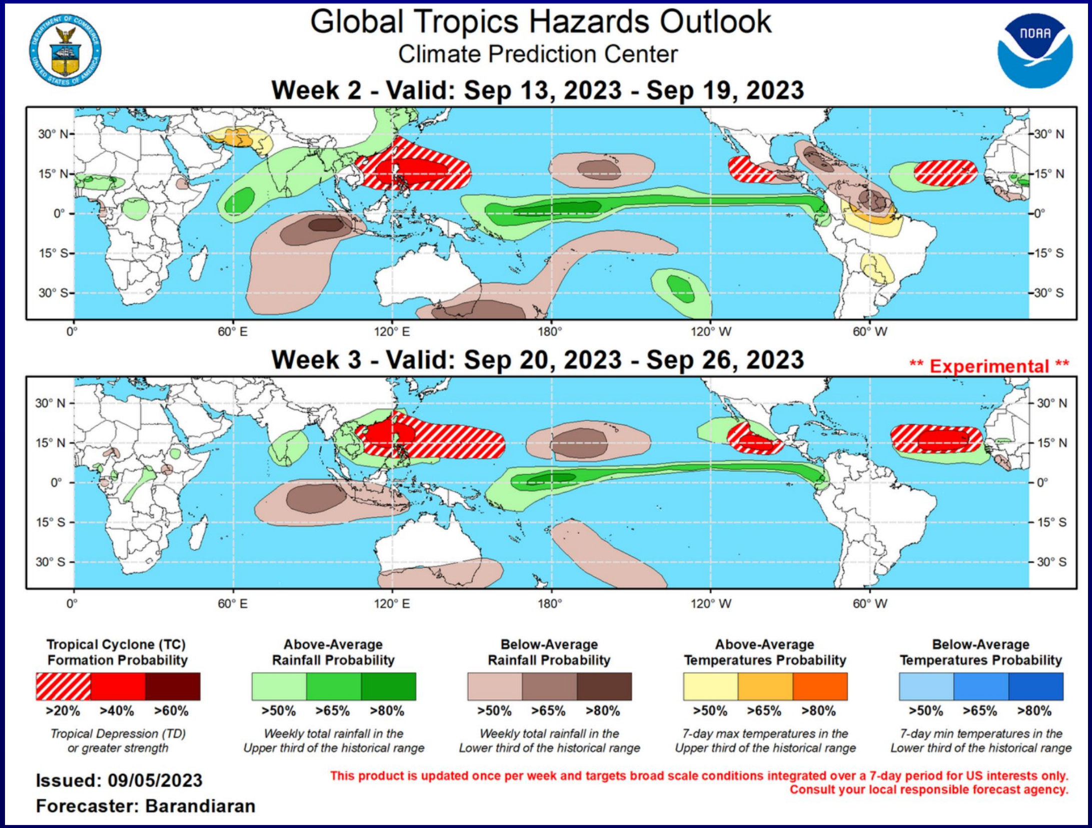
- Real-world CCKWs have day-to-day weather patterns overlaid on them, making them harder to recognize.
- When making genesis forecasts for a particular system, any CCKW information must be taken in context with the entire weather situation.
- Knowledge about the base state (~120 d mean or ENSO), MJO 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 7-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 2 possible TC risk areas (in addition to other global hazards)
- These global forecasts are released Tuesday afternoons
- Take into account MJO and KW
- Week 3 experimental for 2024



Seasonal Forecasting

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.**

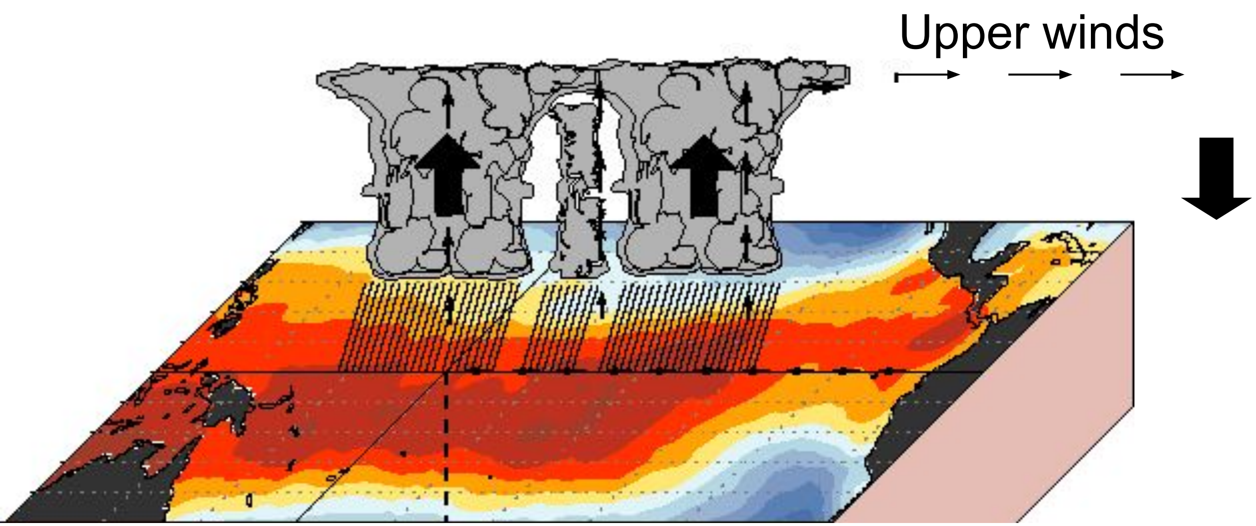
El Niño

- Changes global atmospheric circulation by altering low-latitude deep convection.
- Moderate/strong events generally cause a reduced Atlantic season
- Weaker events have little relationship to Atlantic hurricane activity

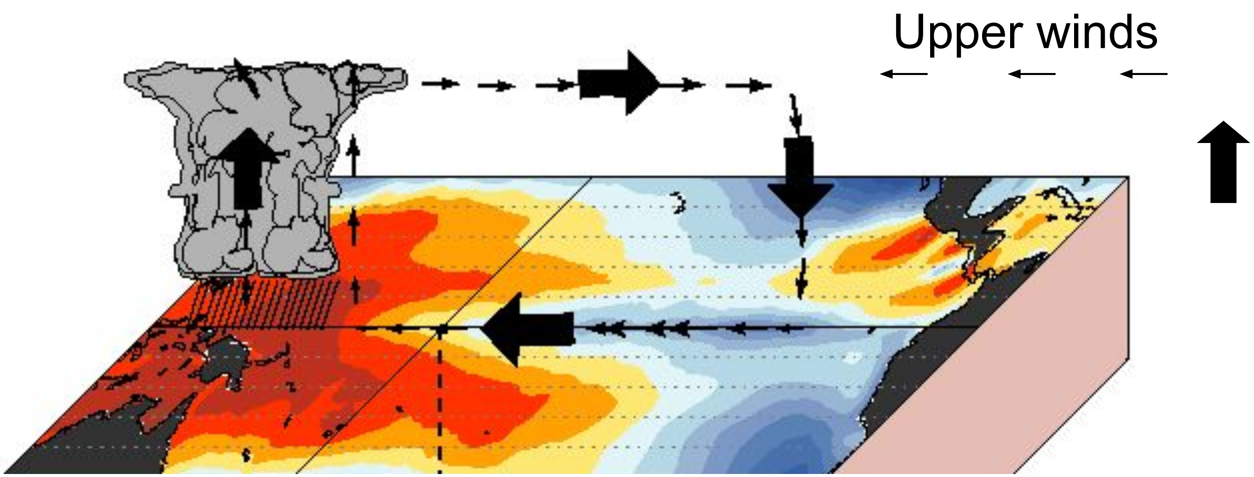
Forecast Parameters

1) Sea Surface Temperatures in the Atlantic (SSTs)
   - Temperatures in the Main Development Region (MDR) and Caribbean/GoM
2) El Nino/La Nina
   - Subsidence in Atlantic/Rising Motion in Atlantic
   - High Shear/Low Shear

El Niño versus La Niña



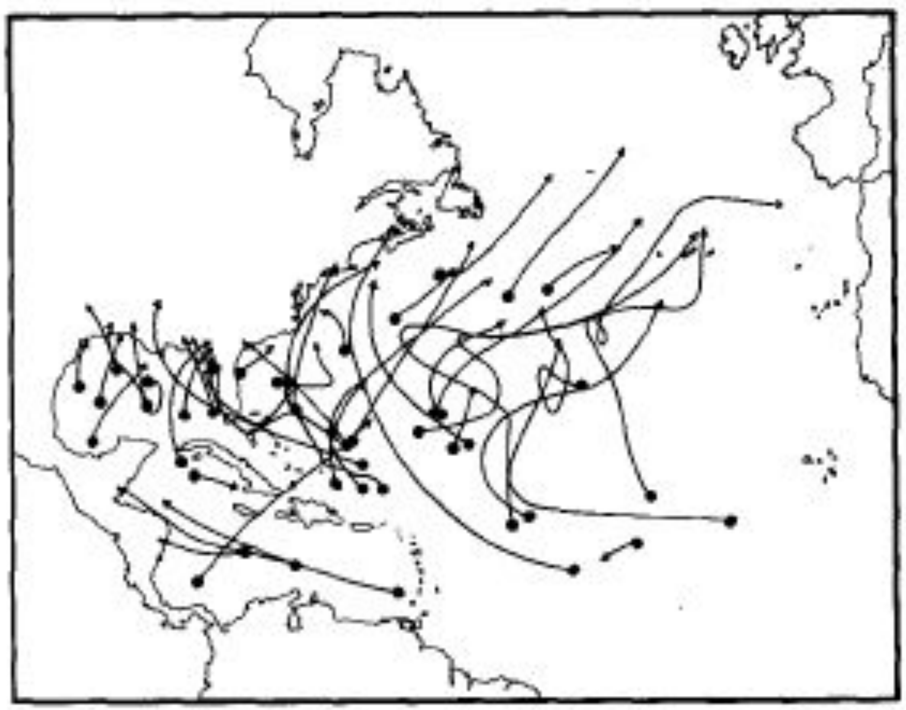
Convection shifted eastward during El Niño causes more shear and sinking air over the Atlantic.



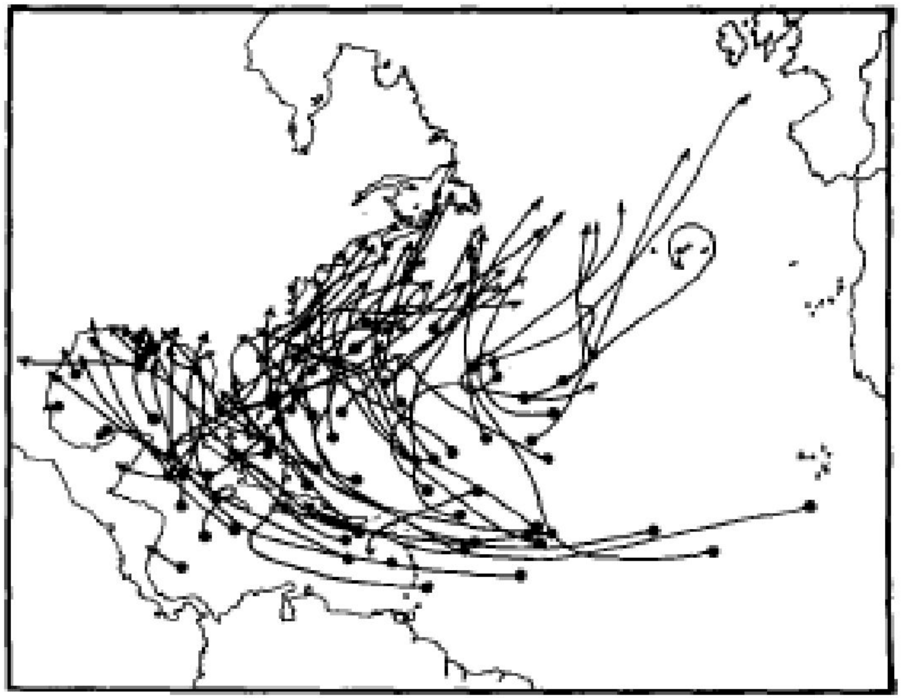
Convection shifted westward during La Niña causes less sinking air and shear over the Atlantic.

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

El Niño Years

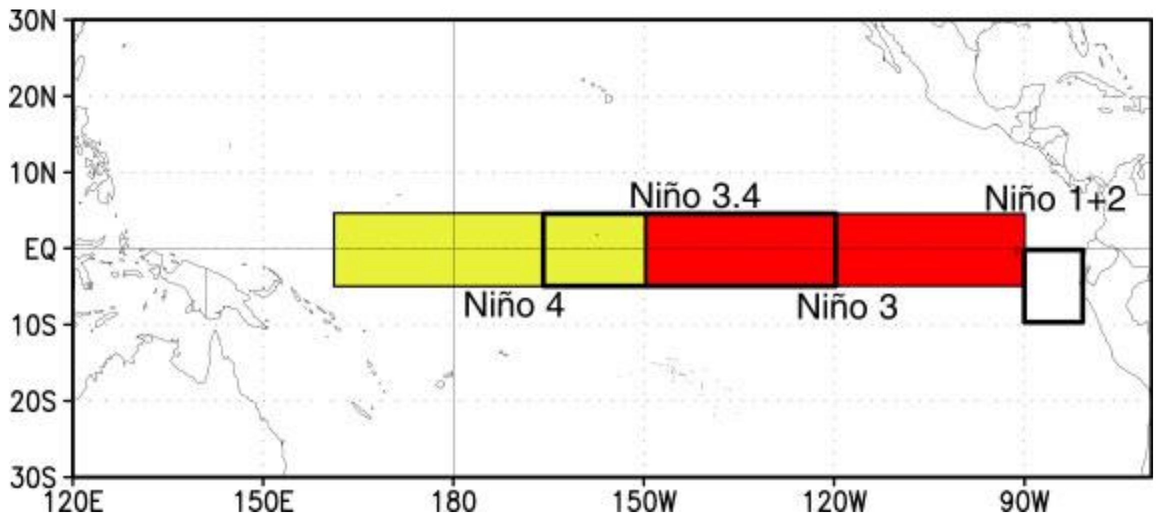


Year after El Niño



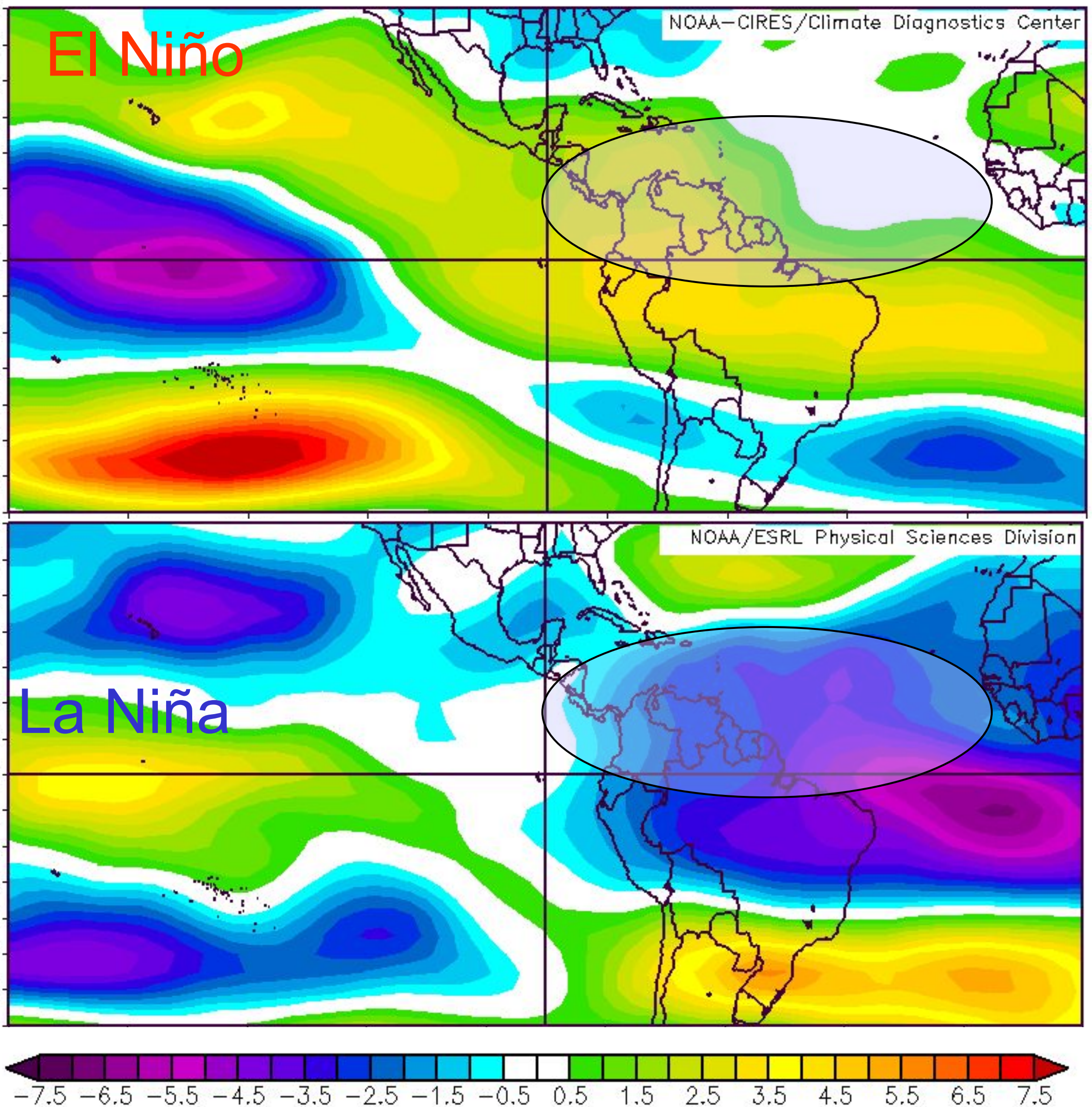
From Gray 1984

Niño regions



Nino 3.4 region generally has the strongest relationship with Atlantic hurricane activity.

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

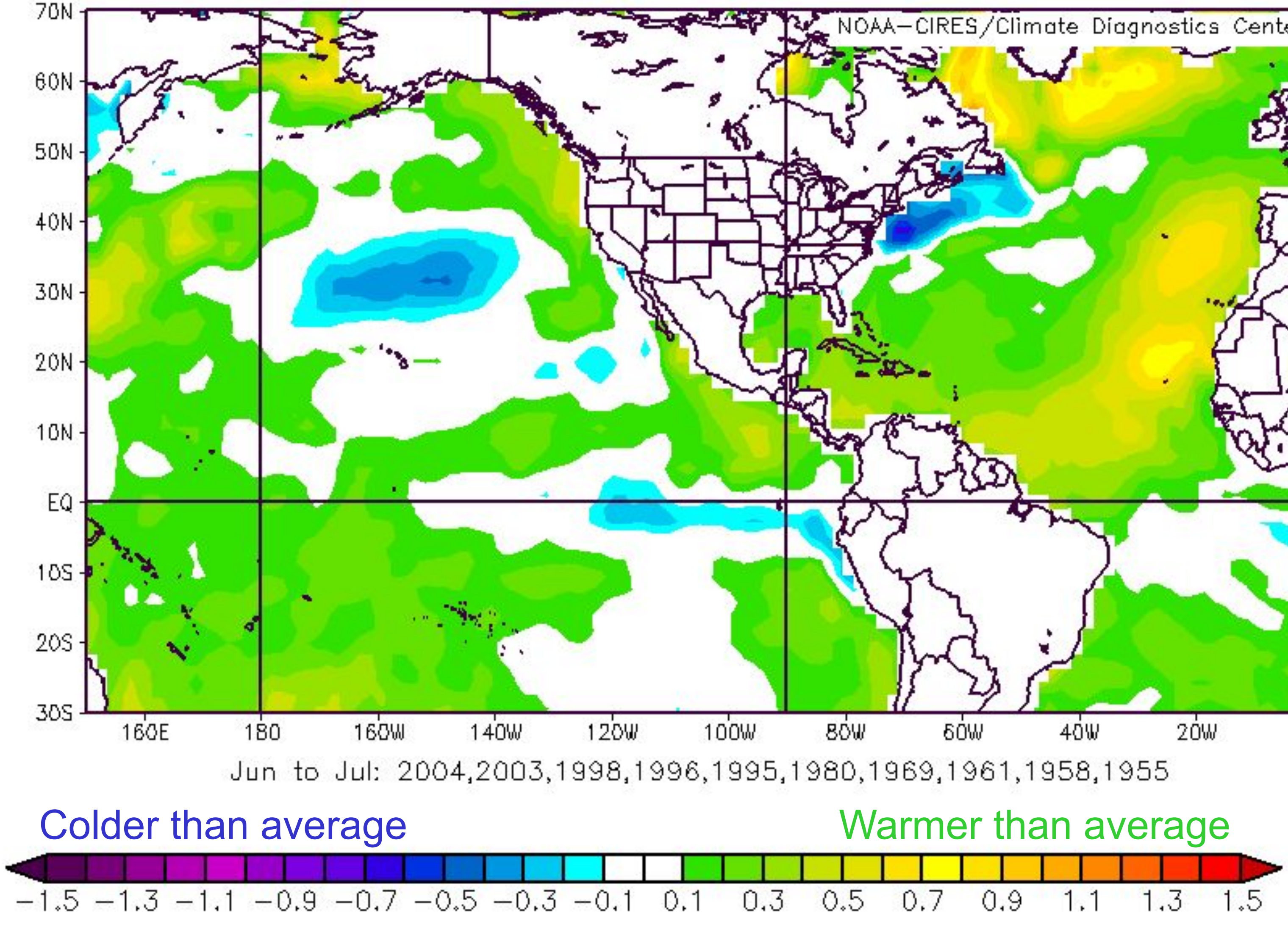


- Tropical cyclones generally require low vertical wind shear to develop, less than about 20 mph.
- Early-season vertical shear (June-July) relates well to August-October shear (peak season).
- Since 90% of the season is usually after 1 August, useful to update then.

Sea-Surface Temperatures (SSTs)

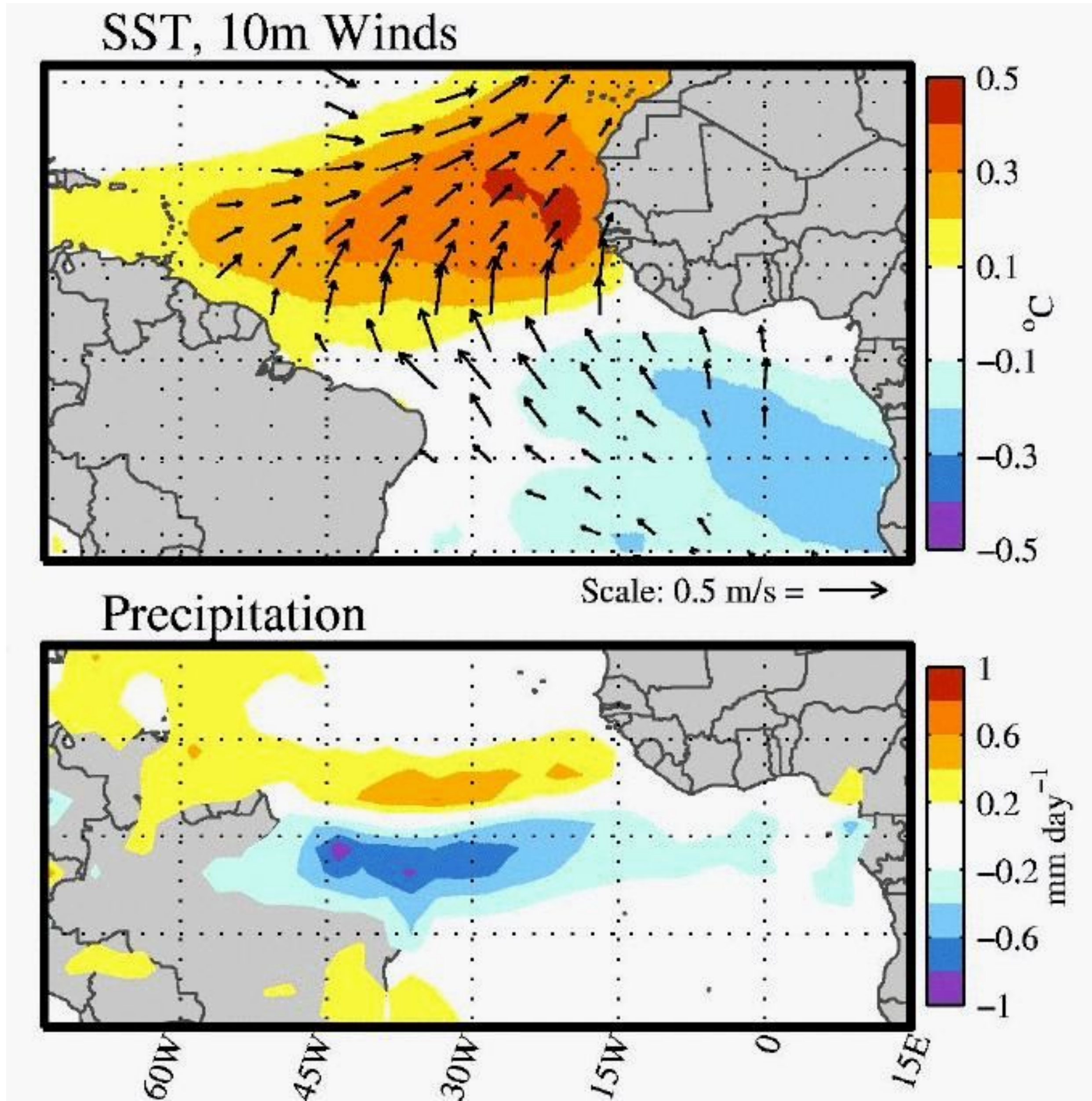
- Warmer Atlantic waters generally mean a more active hurricane season
- Relative warmth of Atlantic to global tropics also important
- Atlantic warmth linked to Atlantic surface ridge strength (AMM?)

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



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

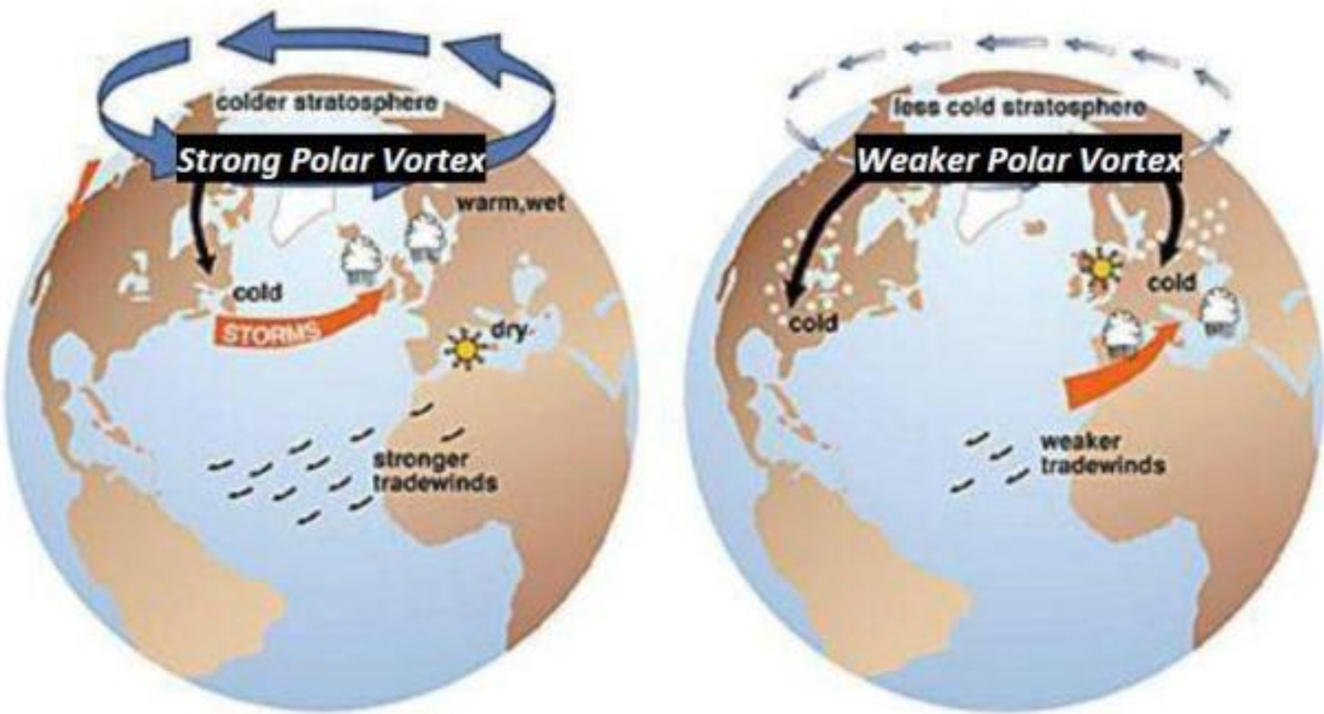
- Positive AMM is characterized by positive SST anomalies, weaker trade winds, and more precipitation in the eastern Atlantic



- Strongest signal during the spring, but persists into hurricane season

This is favorable for TC development

Mid-latitudes in winter/spring can have an impact on the next hurricane season



Positive phase of AO

Negative Phase of AO

1) Negative NAO/AO in winter/spring (could be preceded by a stratospheric warming event), leads to weak Atlantic trade winds.
2) Weak trades excite a positive AMM for the summer, leading to warmer-than-average waters and favorable low-level winds for genesis.

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.)

Atlantic - May and August Outlooks

2002-2022

May				
NS	H	MH	ACE	All
62%	52%	62%	33%	49%
August				
NS	H	MH	ACE	All
57%	57%	62%	48%	54%

2009-2022

May - Since 2008				
NS	H	MH	ACE	ACE Me
64%	64%	71%	43%	43%
August - Since 2008				
NS	H	MH	ACE	Ace %
64%	64%	64%	57%	50%

NS - Named Storms
H - Hurricanes

MH - Major Hurricanes (Cat 3,4,5)
ACE - Accumulated Cyclone Energy

- Percent that a forecast parameter verifies within the given ranges
- Standardized in 2009 for a goal of 70%, plus added dynamical guidance in that year

Exercise

- Make a seasonal forecast with the data available.
- Please forecast ranges of activity for tropical storms, hurricanes, major hurricanes and ACE.
- Remember long term averages are 14 TS, 7 H, 3 MH and ACE of 100
- What are the expected climate conditions for hurricane season? How will these conditions affect your forecast?

Data: https://tinyurl.com/kah4jd42

What is your forecast for season total ACE?

0

<70 — 0%

70-100 — 0%

100-130 — 0%

>130 — 0%

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

What is your forecast for the number of named storms in the season?

0

<10

0%

10-13

0%

14-17

0%

>18

0%

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

What is your forecast for the number of Atlantic hurricanes this season?

0

<5	0%
5-7	0%
8-10	0%
>10	0%

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

What is your forecast for the number of Major Atlantic Hurricanes this season?

0

<2 — 0%

2-3 — 0%

4-5 — 0%

>5 — 0%

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

What climatological conditions influenced your forecast? Check all that apply.

0

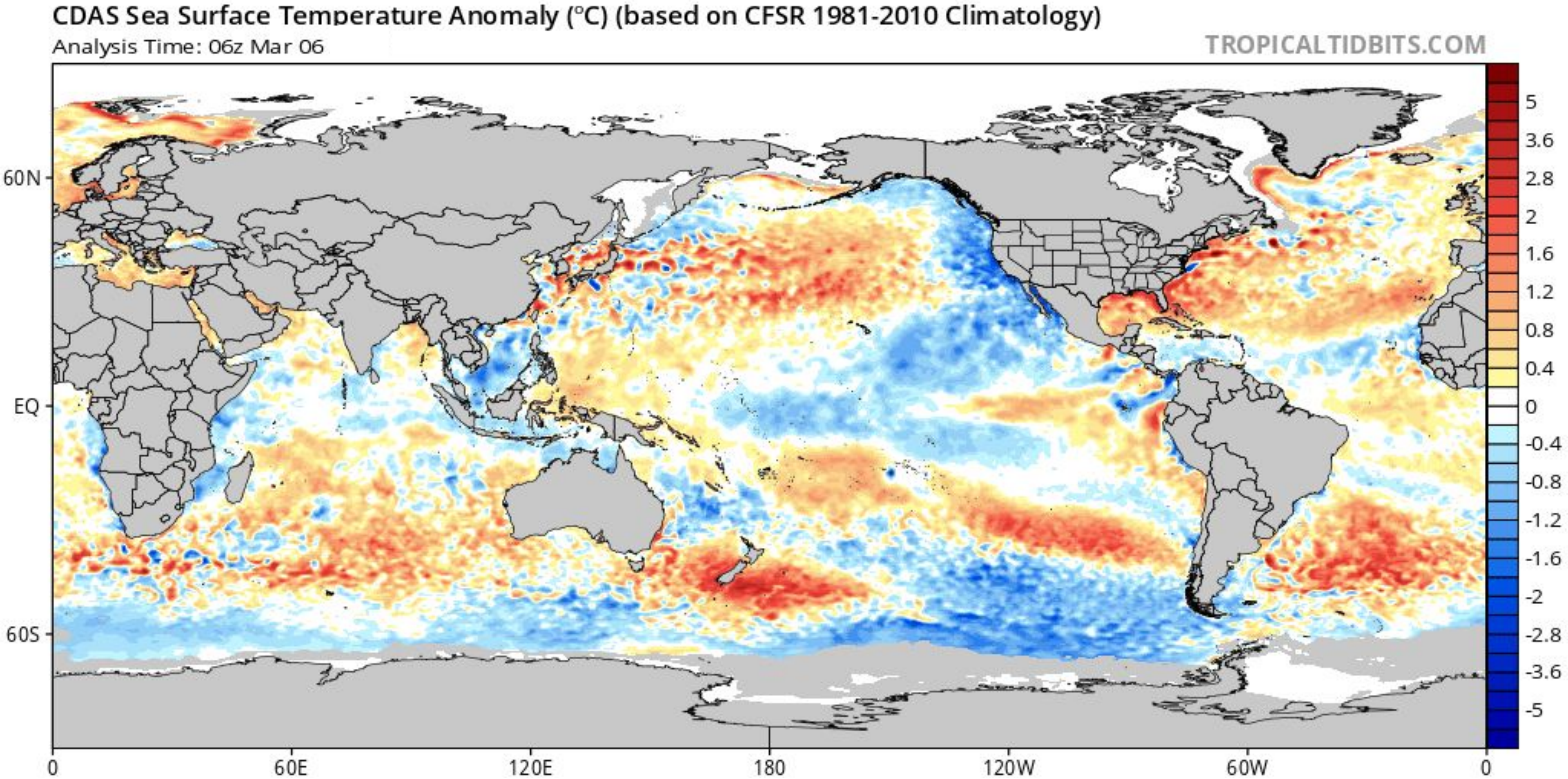
El Nino	0%
La Nina	0%
Warm SST anomalies	0%
Cold SST Anomalies	0%
High Shear	0%
Low Shear	0%

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

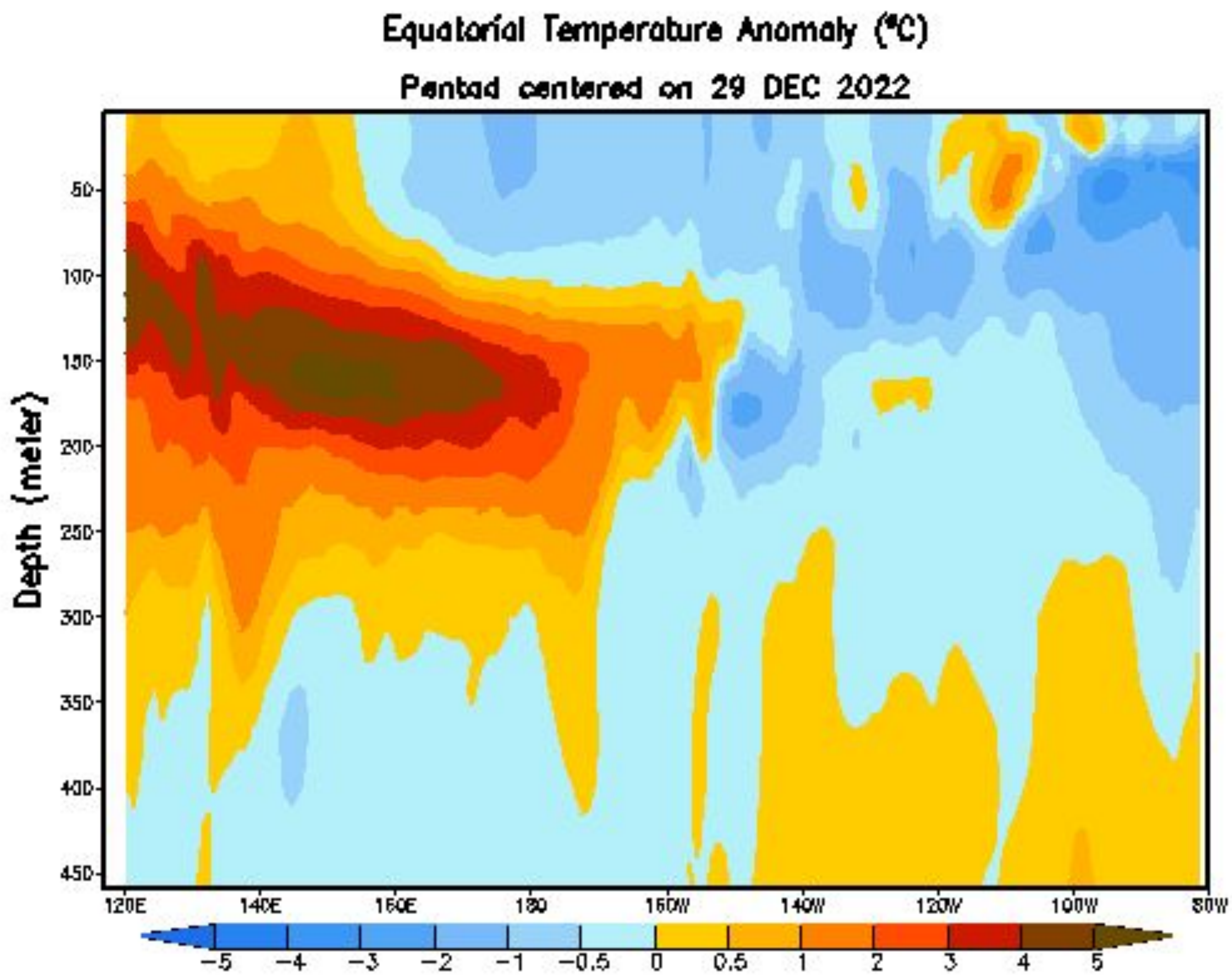
Results: 2023

Named Storms: 20 (high)
Hurricanes: 7 (average)
Major Hurricanes: 3 (average)
Total ACE: 145 (high)

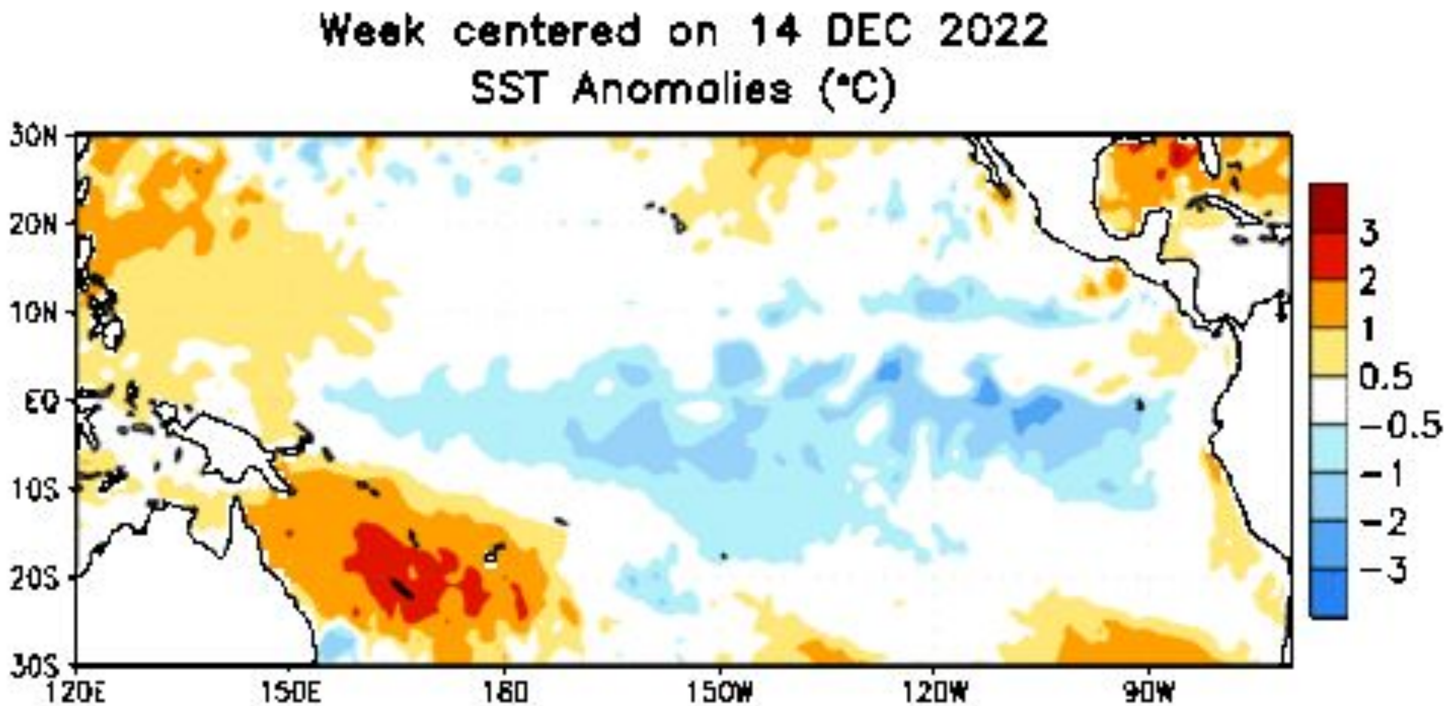
Current Global SST anomalies



Thermocline- loaded



Neutral conditions in the Pacific

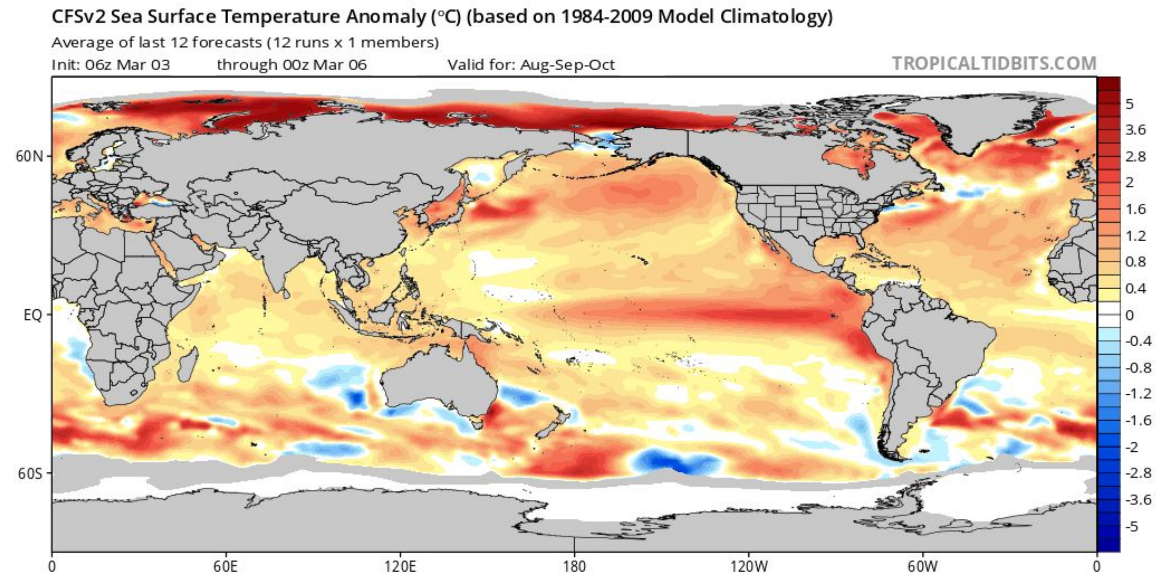


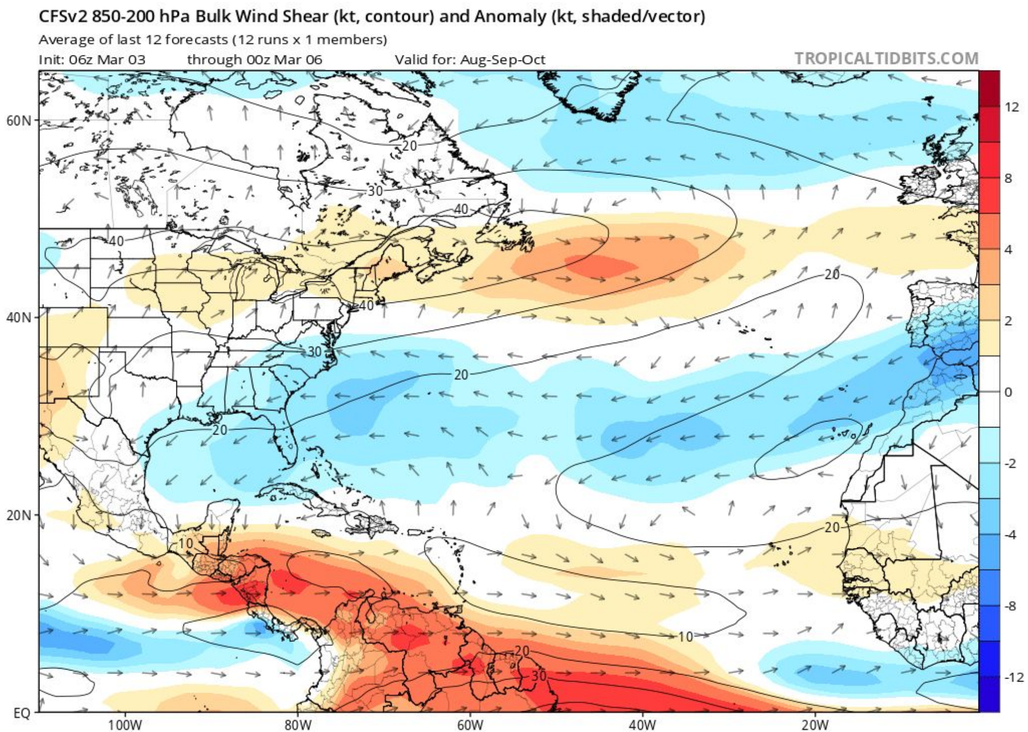
Atlantic Hurricane Season Model Forecast Summary

	Model	Named Storms	Hurricanes	Major Hurricanes	ACE (% Median)
Statistical	CPC Regression: Nino 3.4 (0.5 to 1.5C) MDR SSTA (0.1 to 0.6C) MDR-Tropics (-0.05 to 0.35C)	12.6-14.7 (13.65)	4.9-6.8 (5.85)	2.1-3 (2.55)	96-142 (119)
Statistical	CPC Binning high-activity era: 7 cases: Nino 3.4 (0.5 to 1.5C) MDR SSTA (0.1 to 0.6C) MDR-Tropics (-0.05 to 0.35C)	9.7-17.43 (13.55)	3.8-10.23 (7)	2-4.89 (3.45)	71-197 (134)
Statistical	AOML regression	12-16 (14)	6.5-9 (7.5)	2-4 (3)	92-160 (126)
Statistical / Dynamical Hybrid	CFSv2 T128	10-14 (12)	4-7 (5.5)	2-3 (2.5)	71-125 (98)
Statistical / Dynamical Hybrid	NMME (CFSv2, GEM-NEMO, CanCM4i, CCSM4)	12-16 (14)	5-8 (6.5)	2-4 (3)	106-157 (132)
Dynamical	GFDL (SPEAR-MED, HiFLOR-S)	13-18 (15.5)	6-9 (7.5)		117-195 (156)
Dynamical	CFS: Hi-Res (Bias adjusted)	15-20 (17.5)	4-10 (7)		85-160 (123)
Dynamical	ECMWF	14.1-21.7 (17.9)	6.5-12.1 (9.3)		114-242 (178)
Dynamical	UKMET	7-19 (13)	4-10 (7)	1-5 (3)	57-239 (148)
	Guidance Mean	**11.7-17.4 (14.6)**	**4.9-9.1 (7)**	**1.9-4 (2.9)**	**90-180 (135)**

CFS ASO Seasonal Forecasts from Mar 6

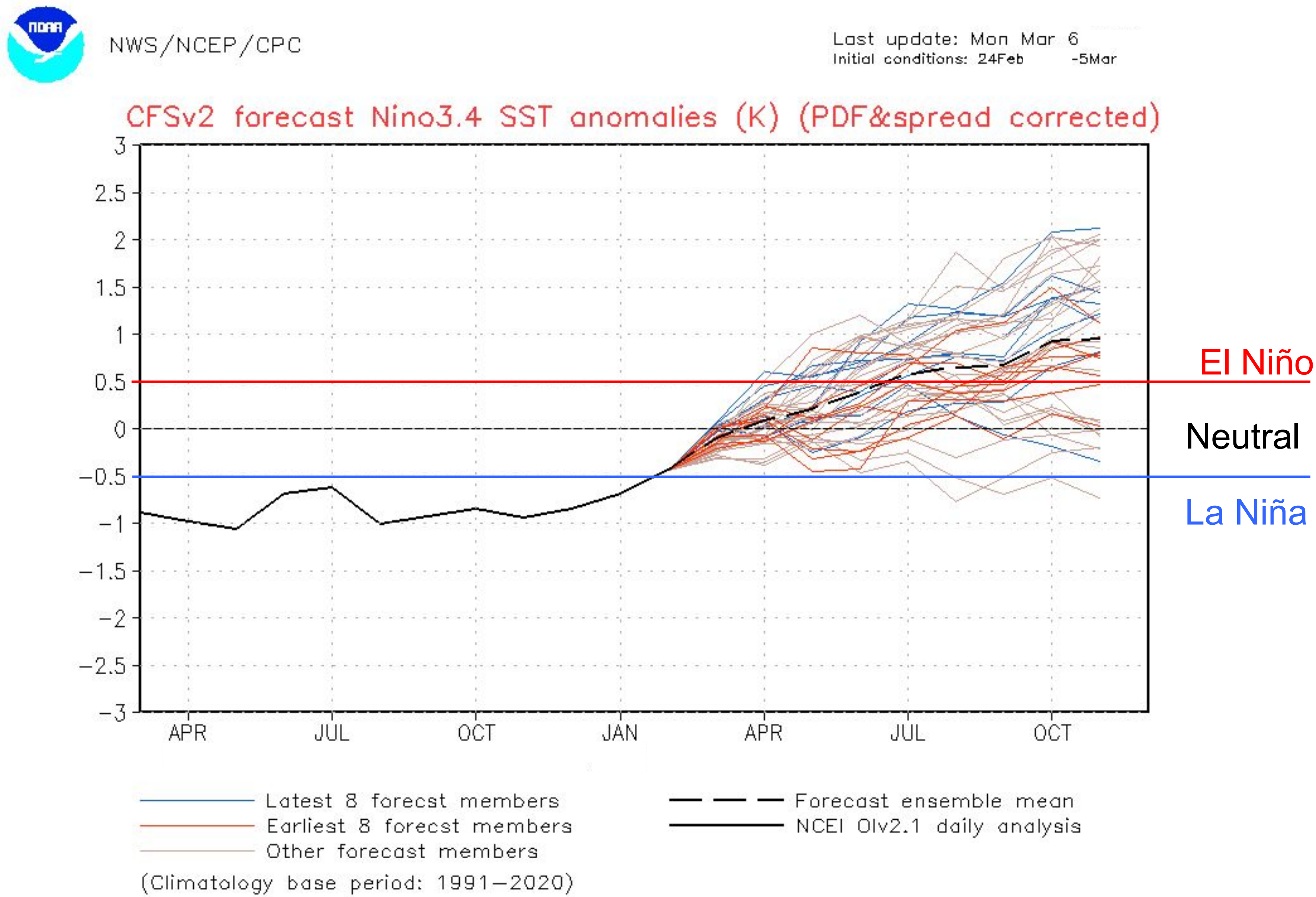
SST (very warm Atlantic & ENSO)



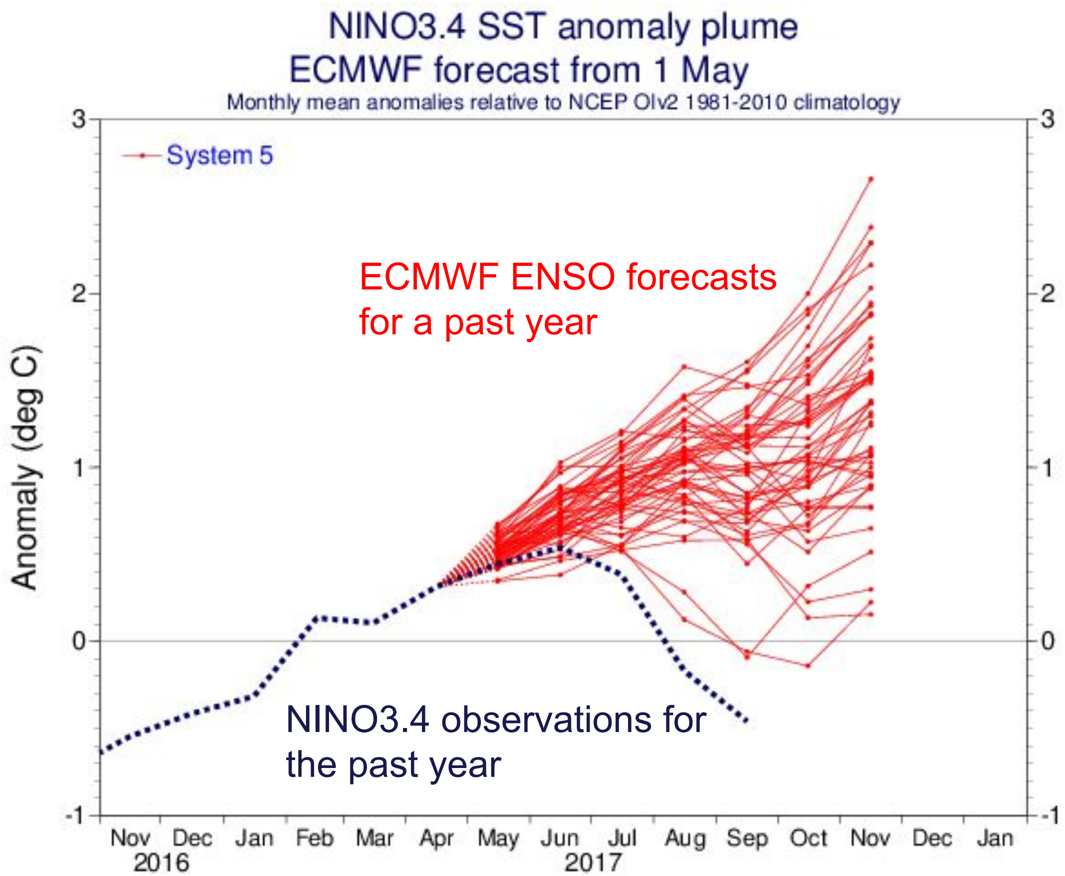


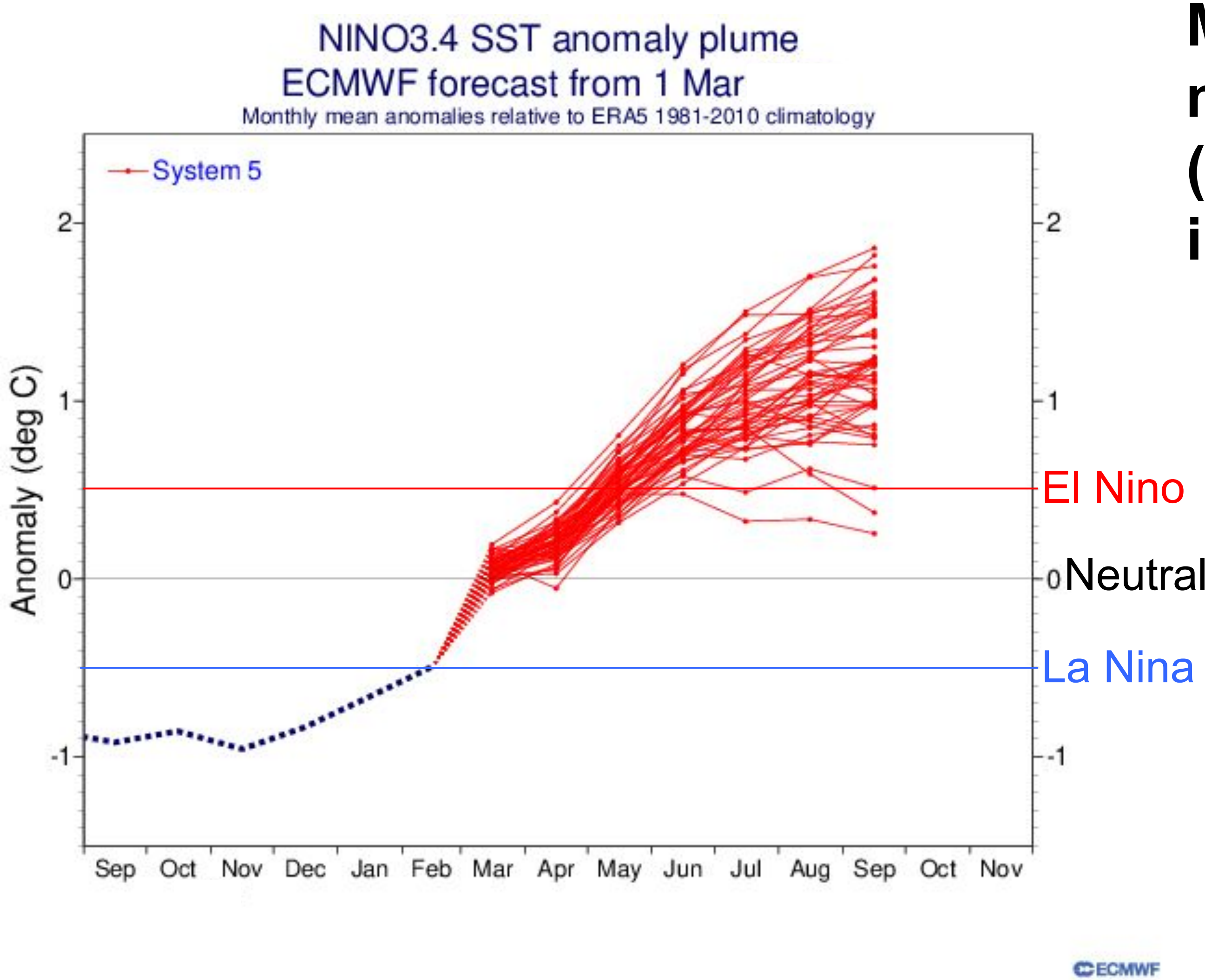
Vertical Shear (higher than normal)

CFS highest probability of El Niño conditions in summer



Niño models aren't very good though!

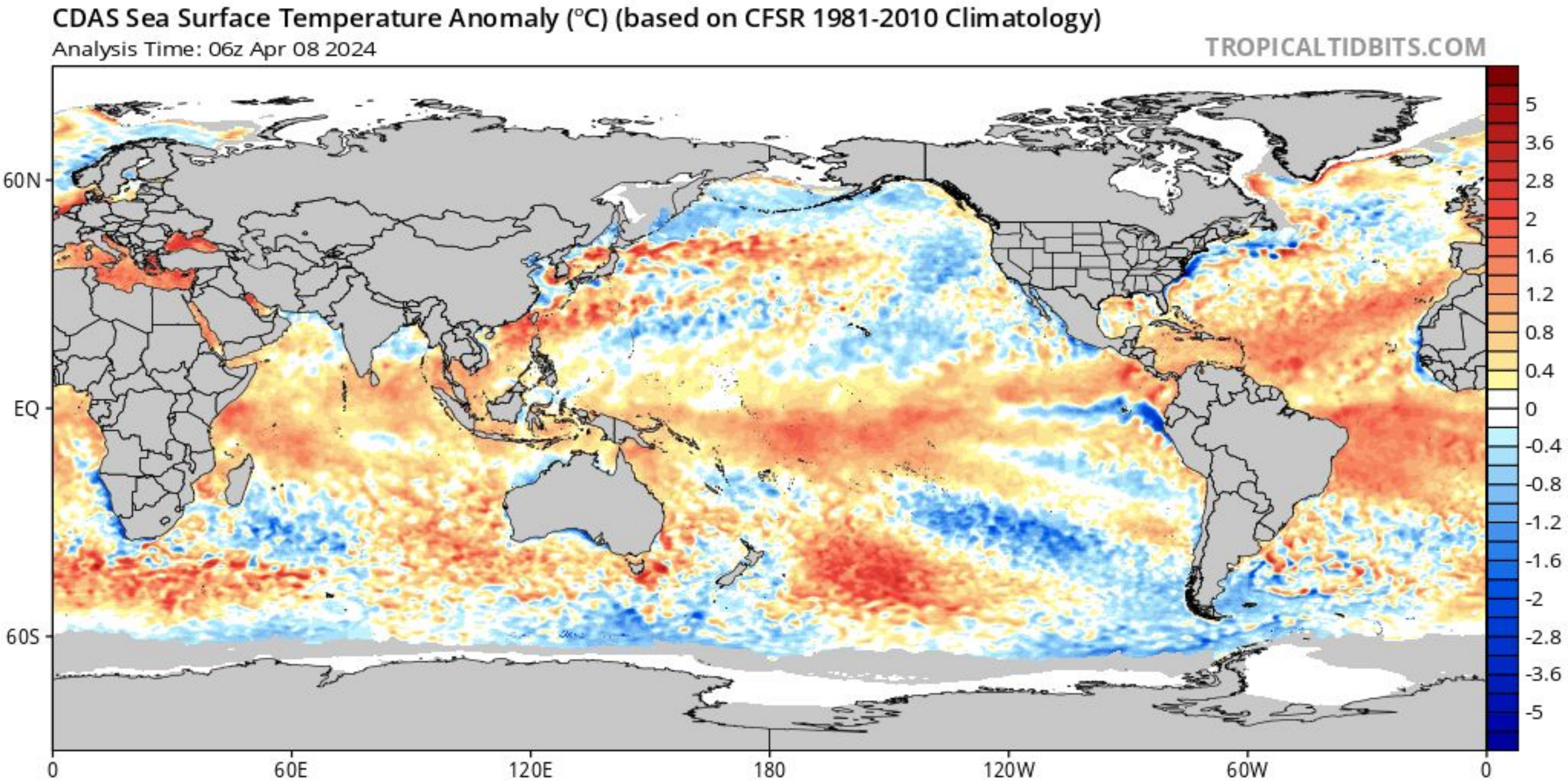




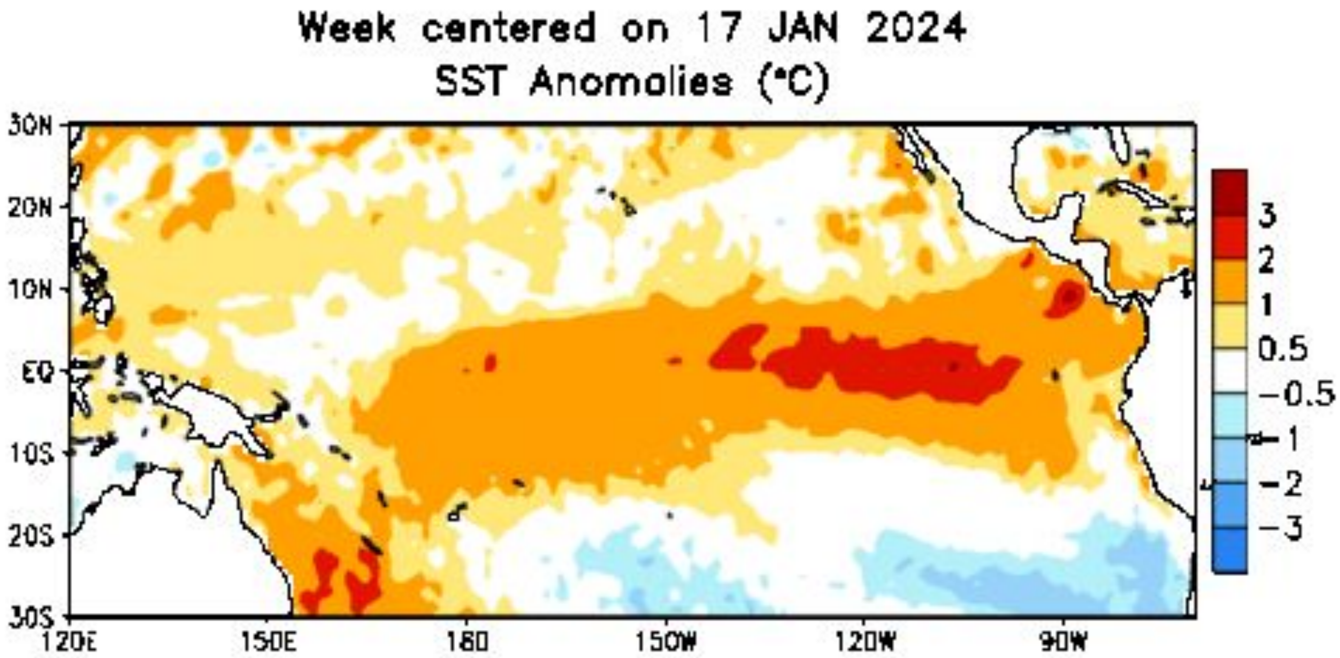
Most ECMWF members (very) warm in summer

What about 2024?

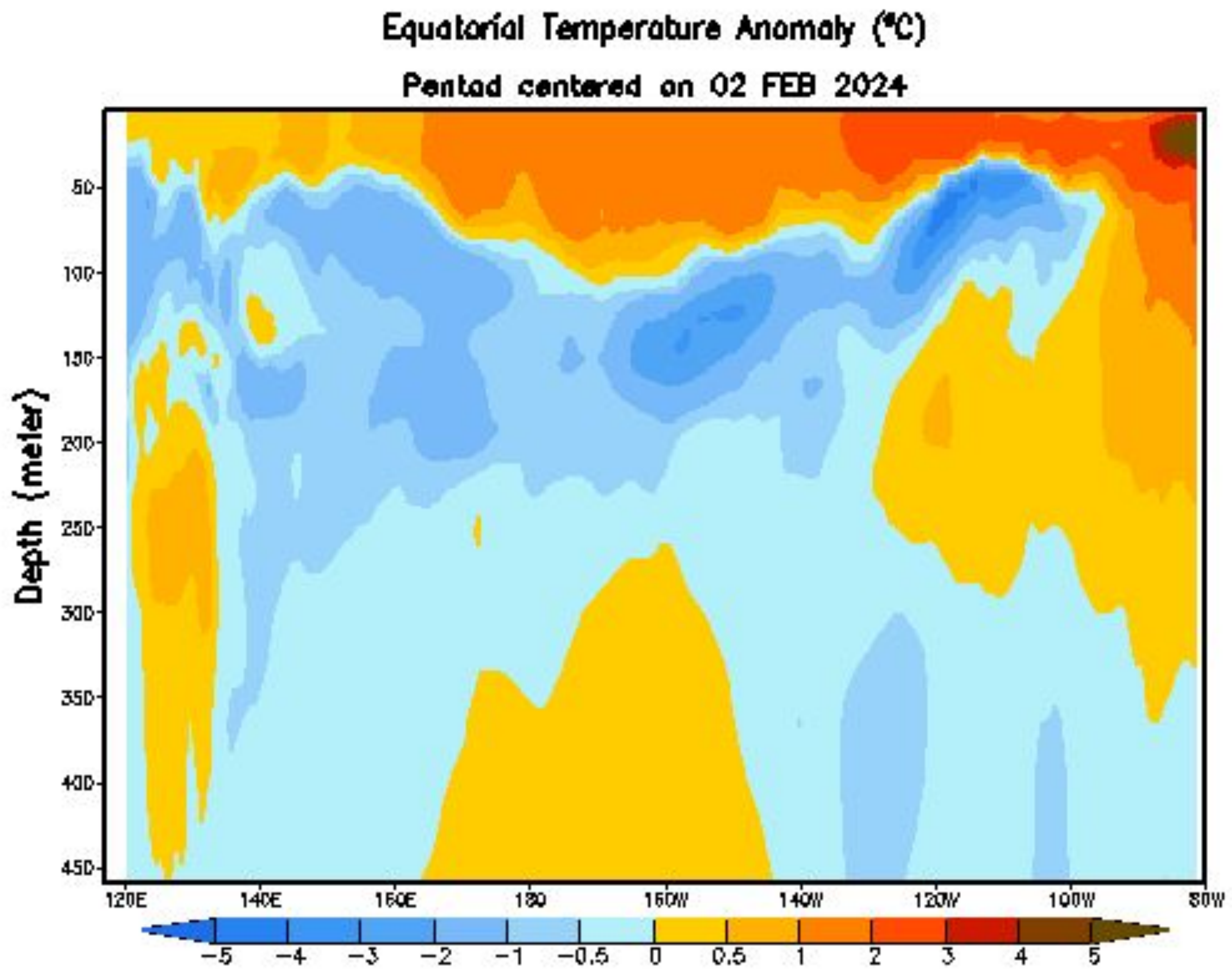
Current Global SST anomalies



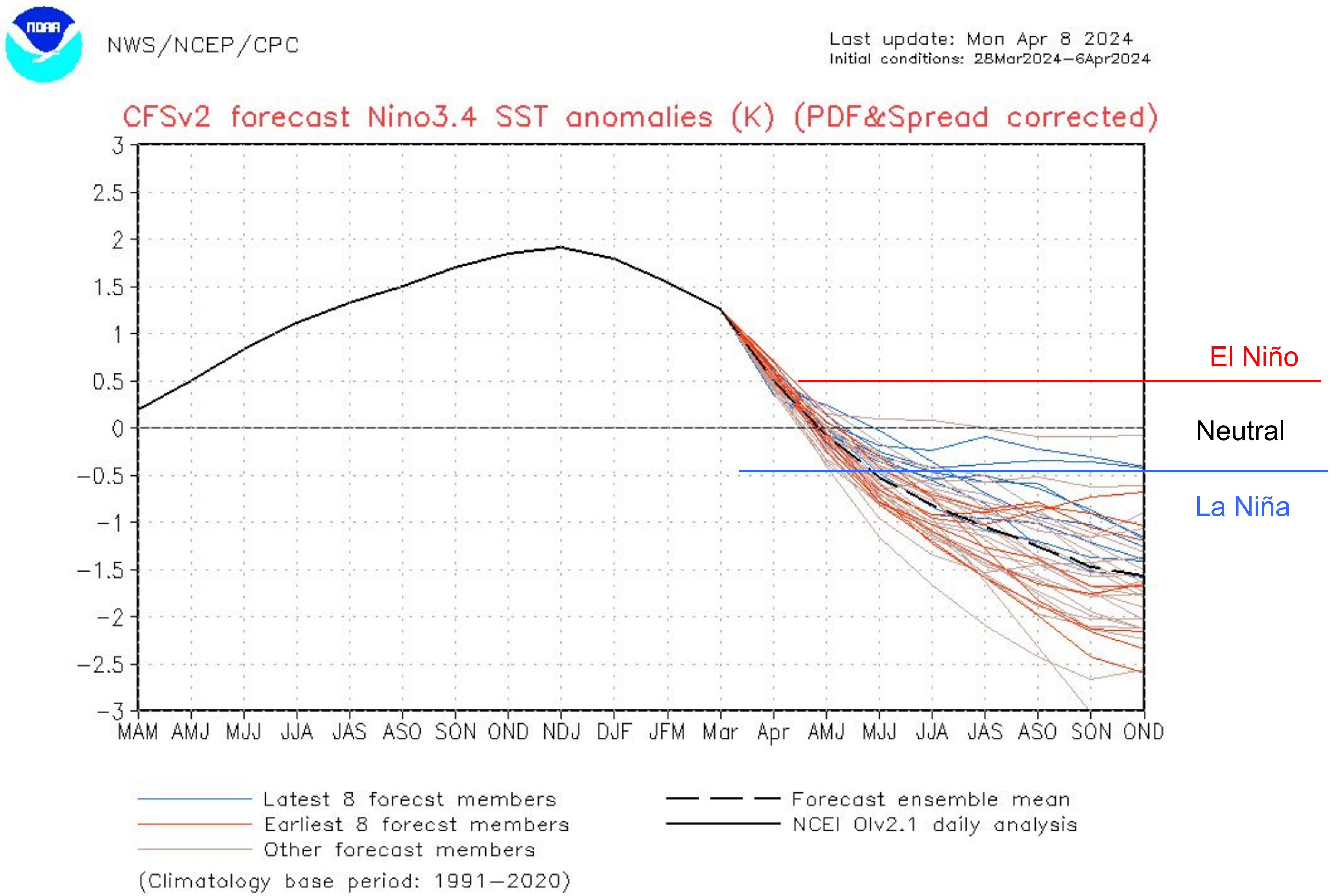
El Niño fading in the Pacific



Thermocline- supports transition soon

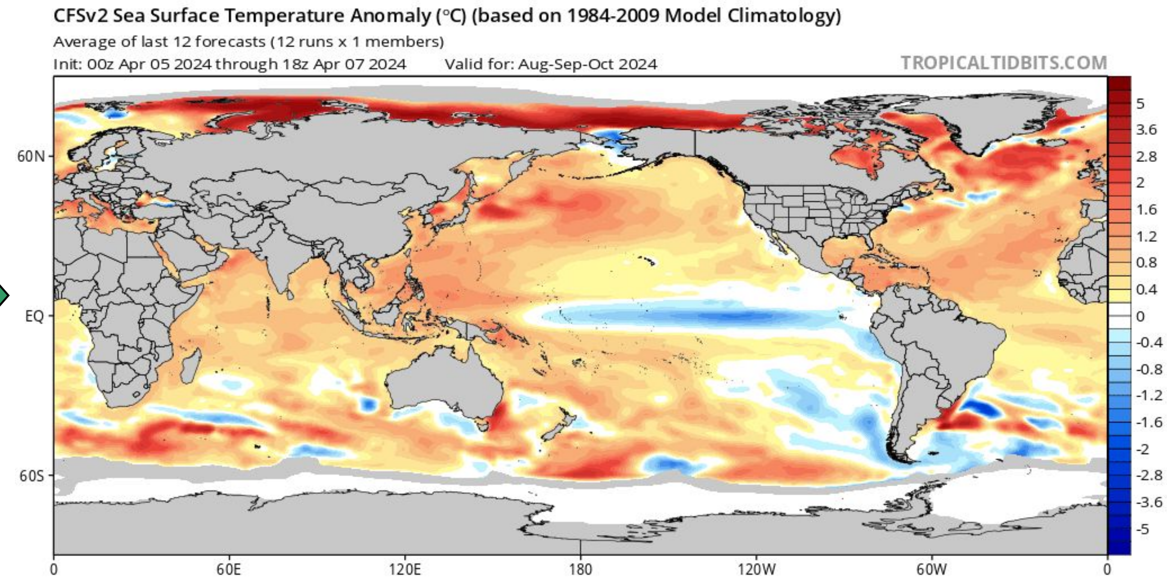


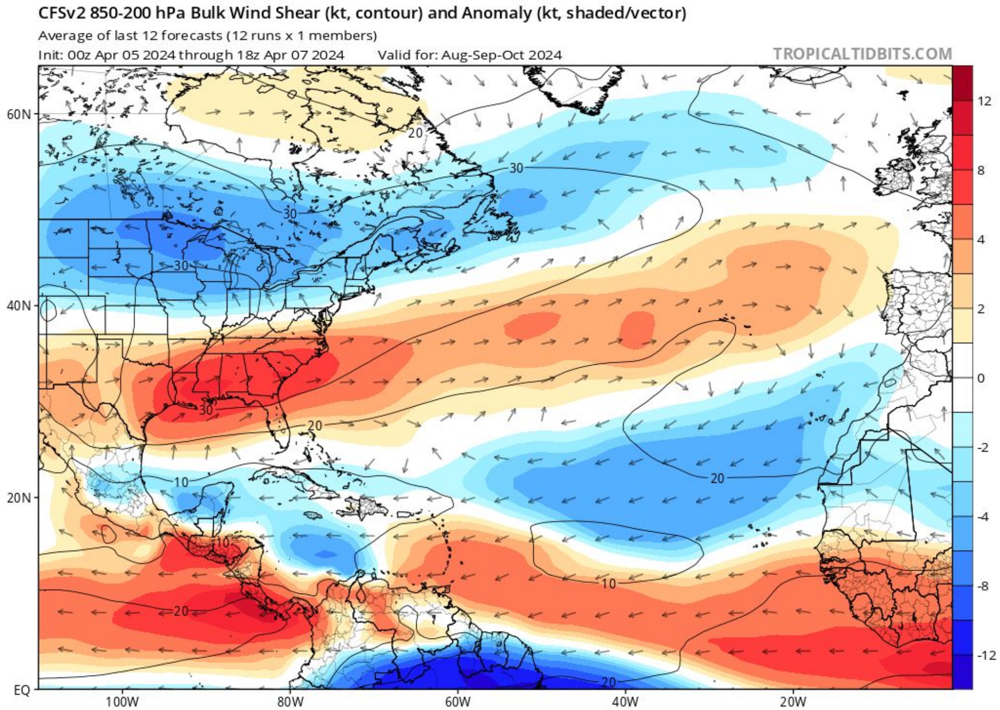
CFS strongly suggests La Niña for summer/fall



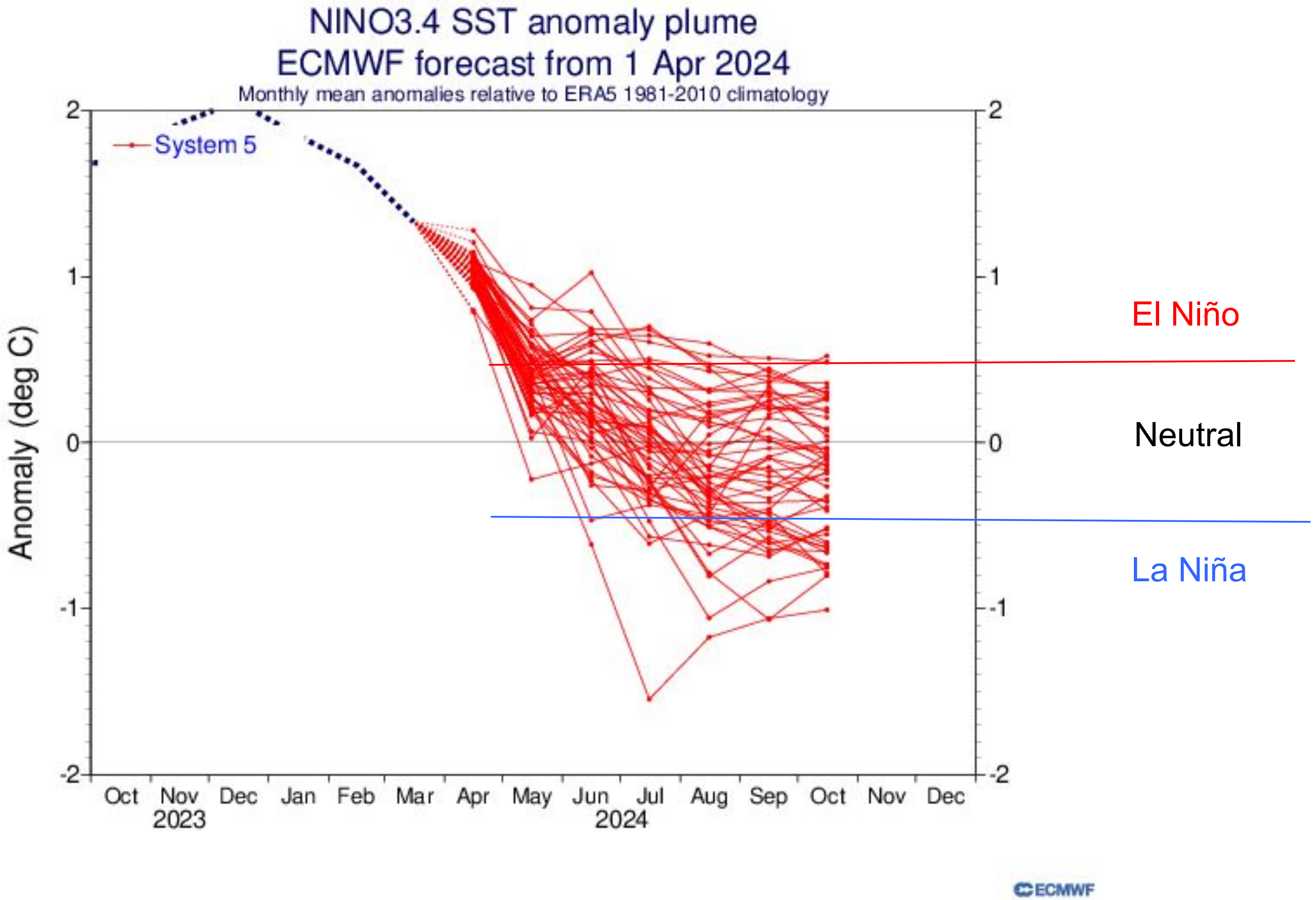
Recent CFS ASO Seasonal Forecasts

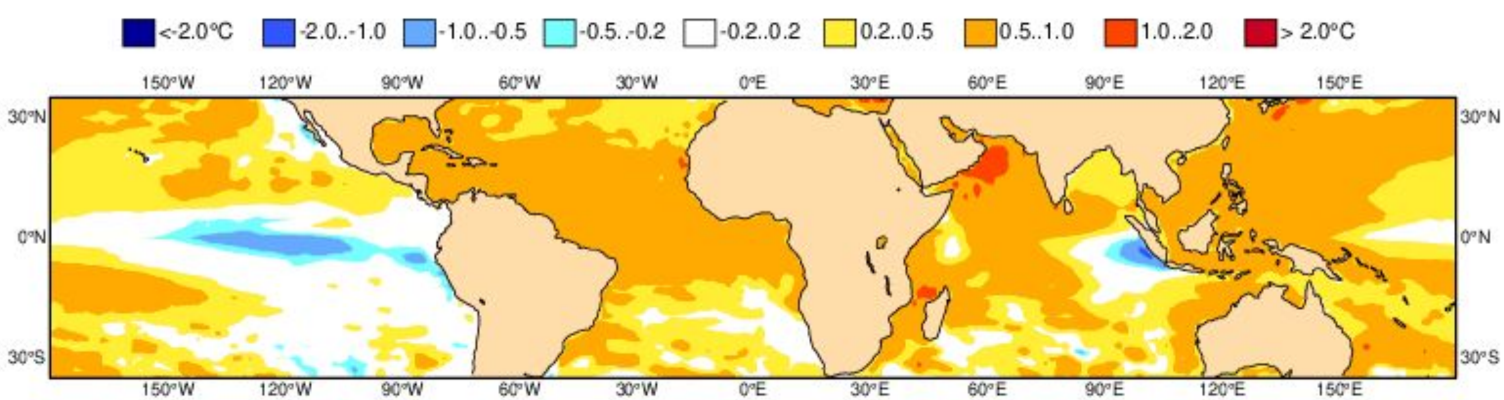
SST (very warm Atlantic & Niña)





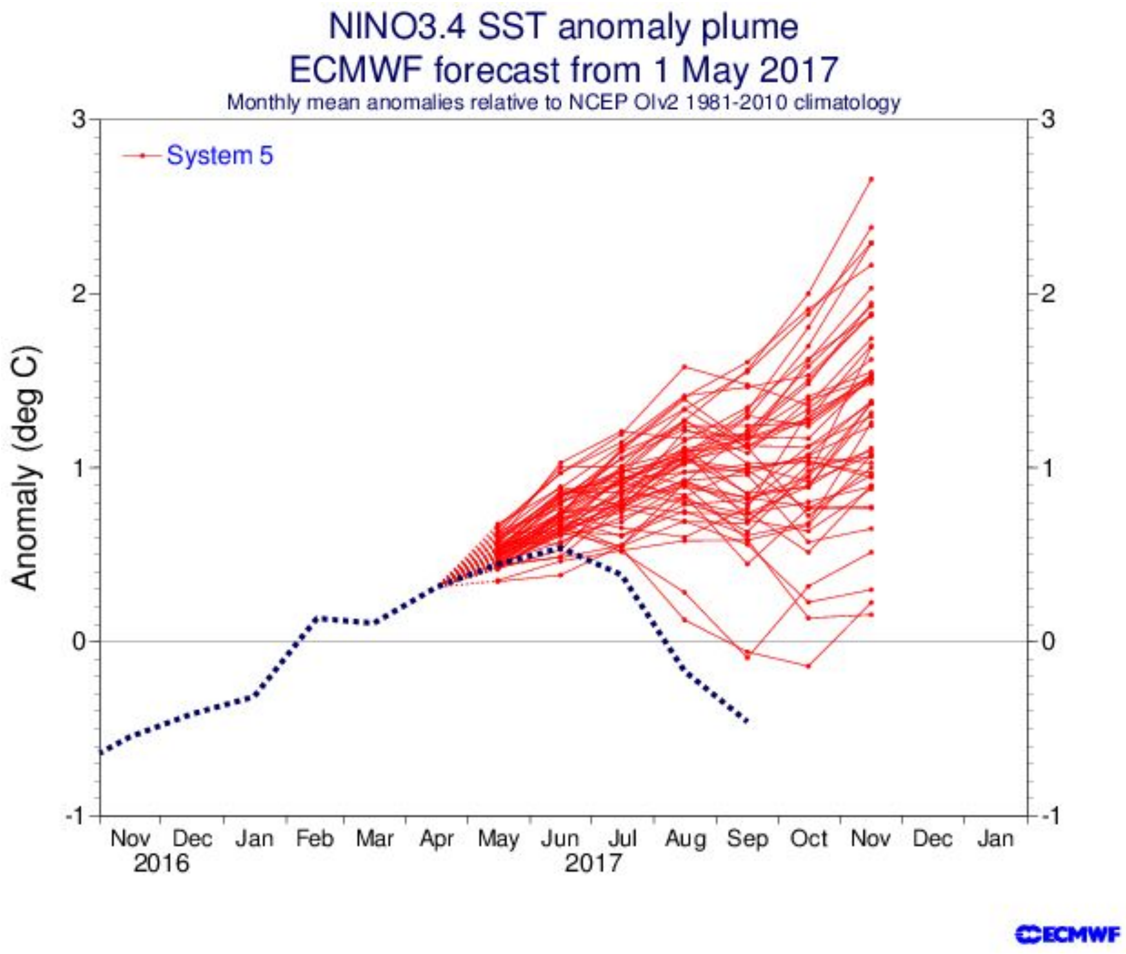
Vertical Shear (lower than normal)





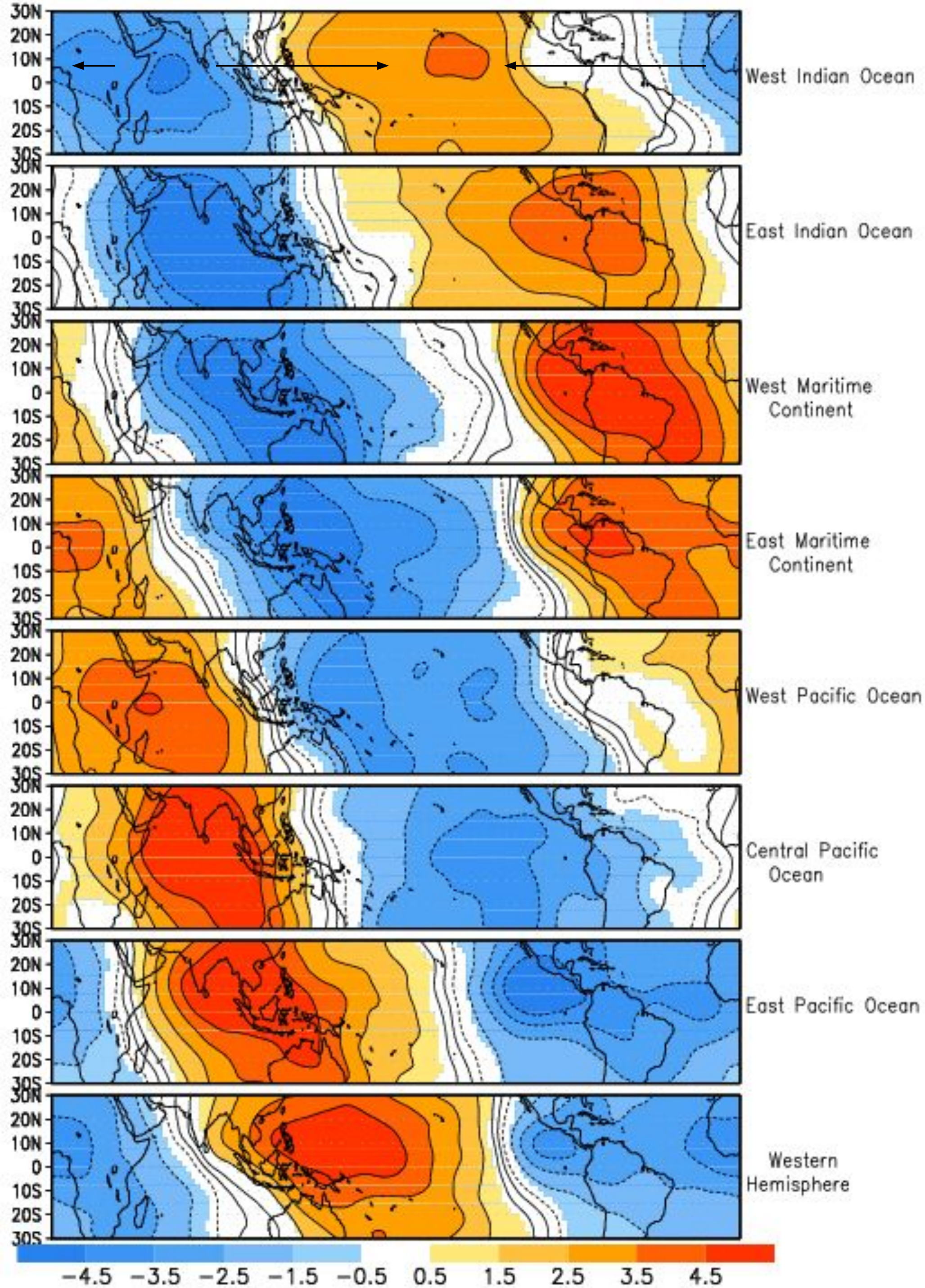
ECMWF more neutral in summer but very warm Atlantic SSTs

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.
- 2024 could be very busy

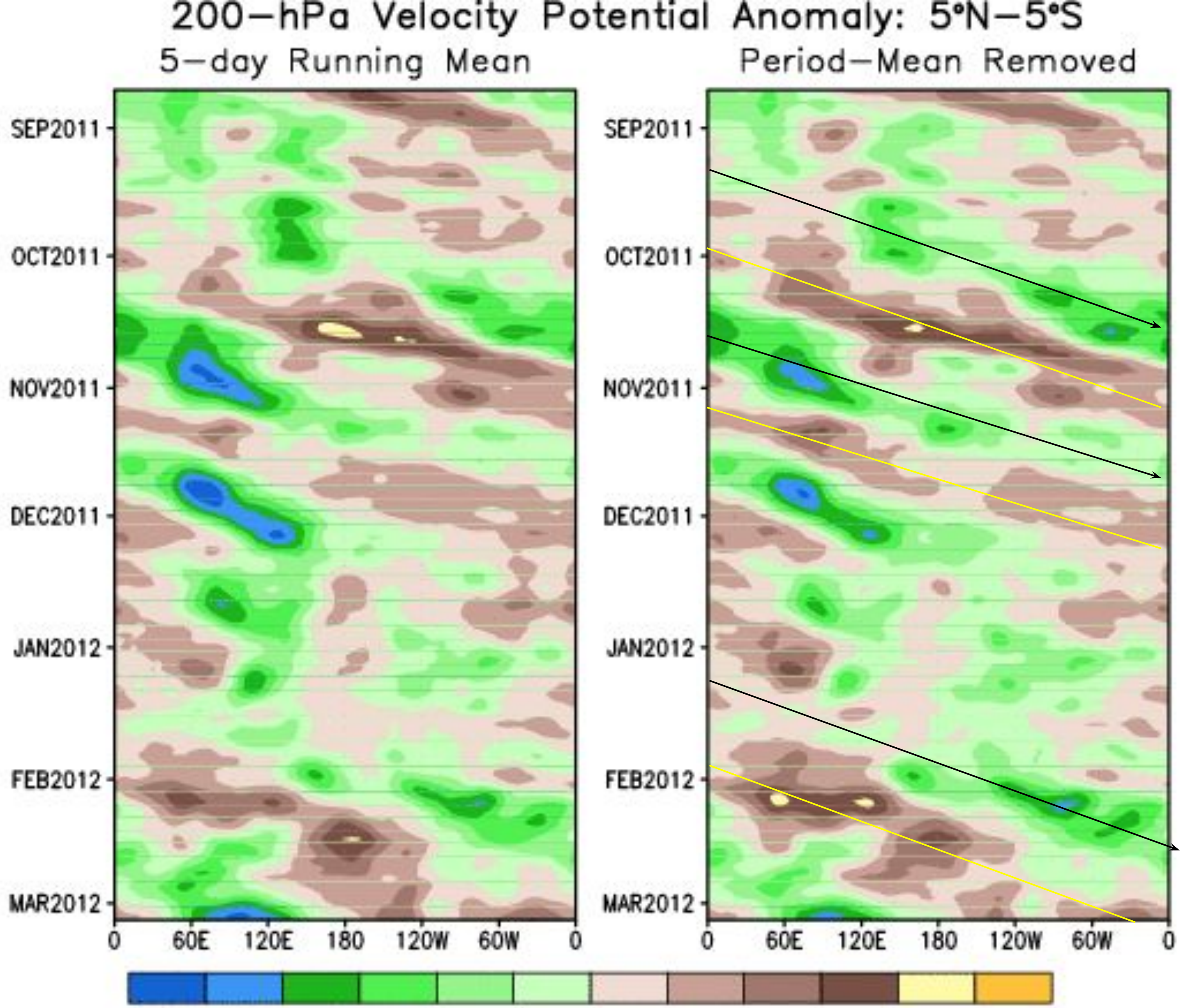


200 mb Velocity Potential fields– one way to track the MJO

Blue= ~divergence

Red= ~convergence

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



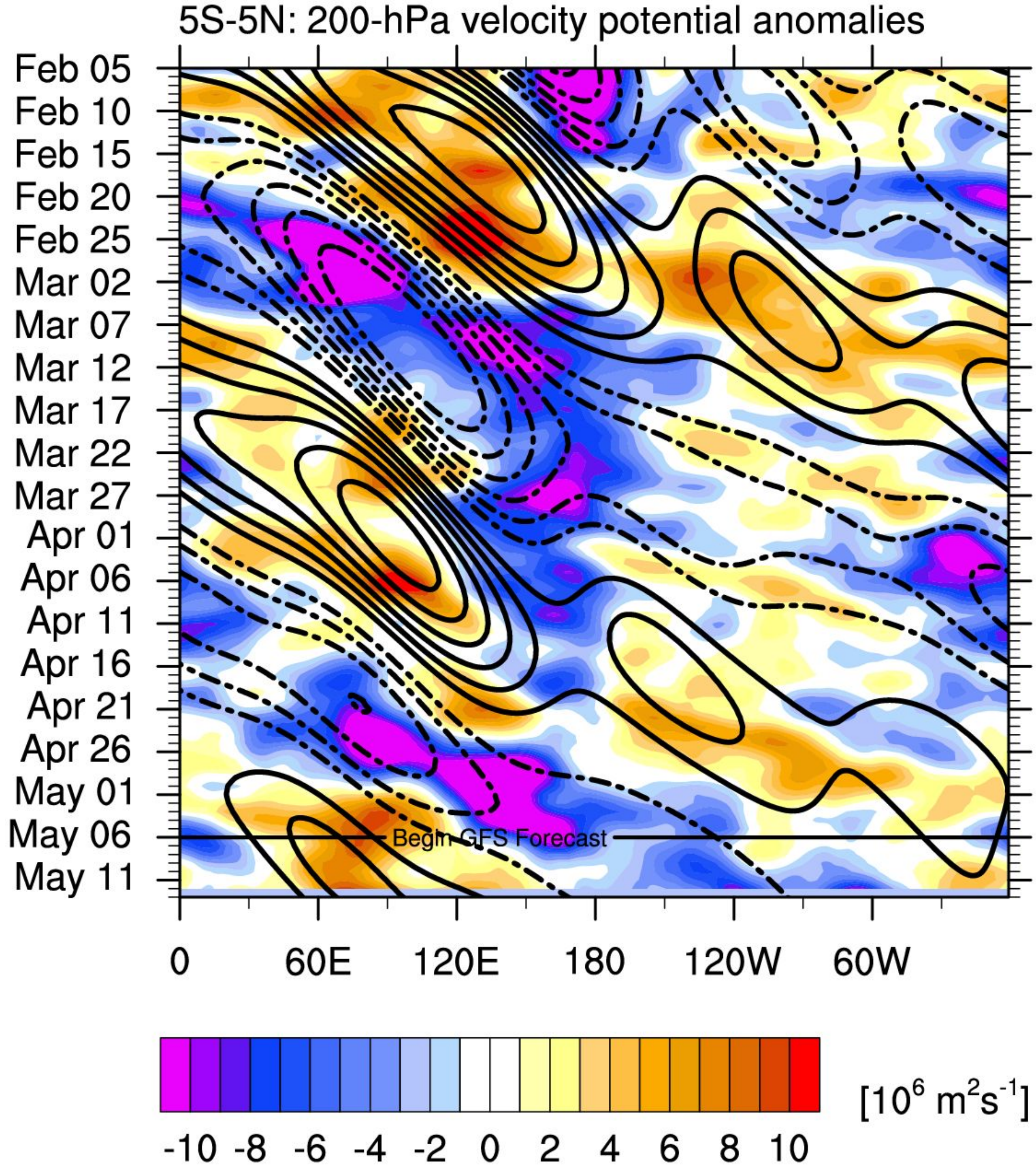
Time–longitude sections of anomalous 200–hPa velocity potential (x 10^6 m^2 s^{-1}) averaged between 5°N–5°S for the last 180 days ending 05 MAR 2012: (Left) 5–day running means and (Right) 5–day running means with period mean removed. Anomalies are departures from the 1981–2010 period daily means. CLIMATE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

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



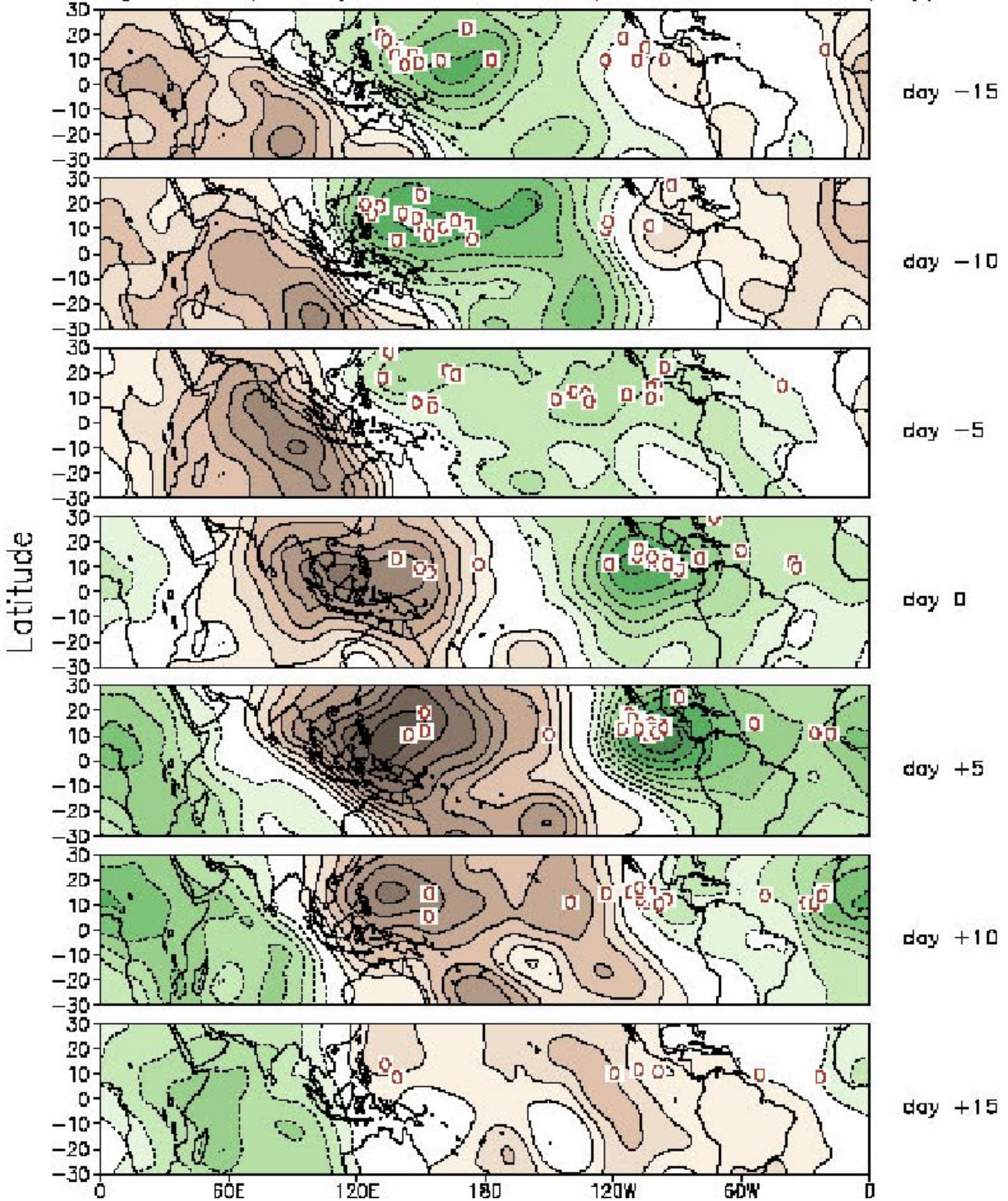
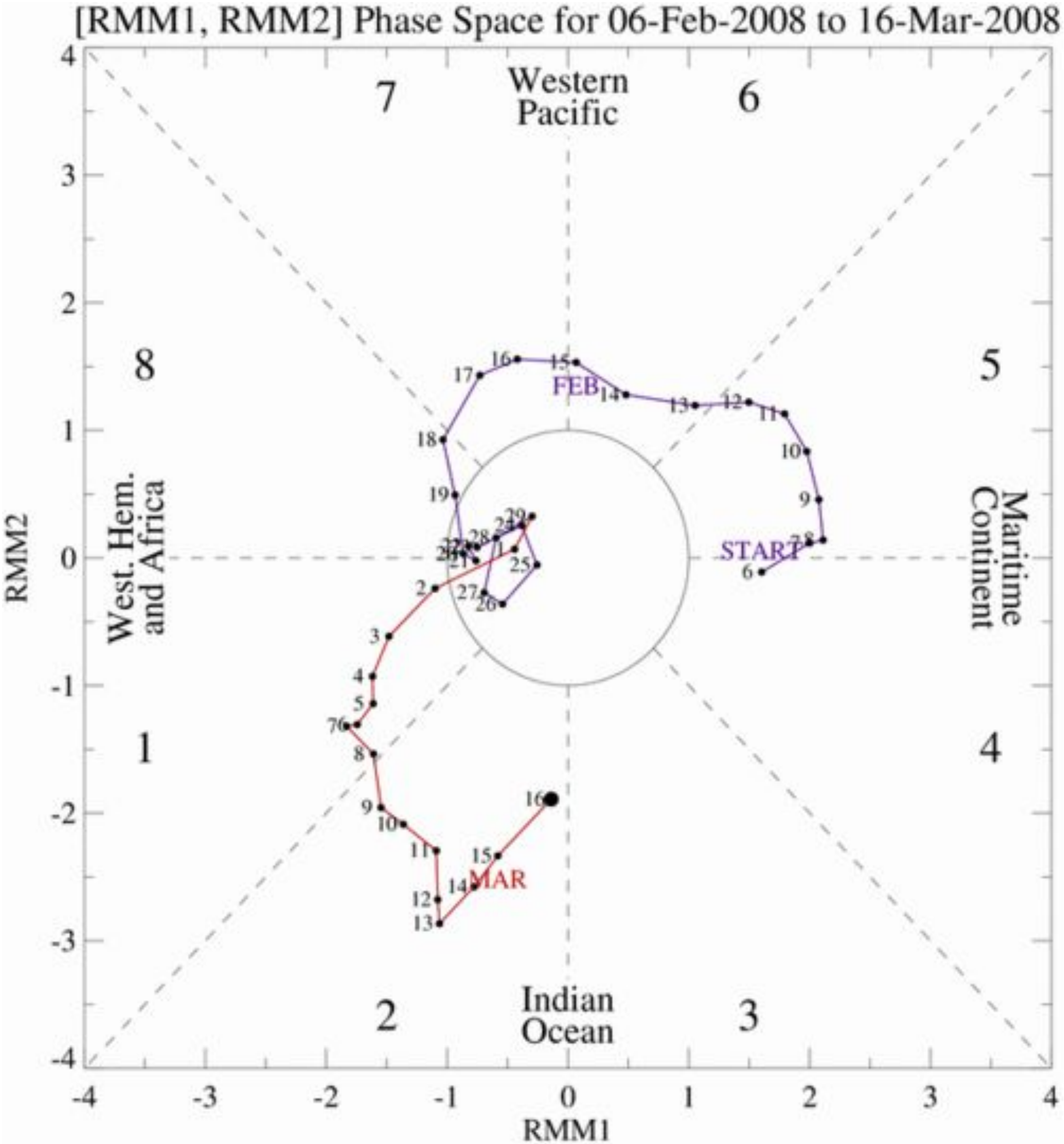


Figure 10: Velocity potential composites for different phases of the MJO cycle with hurricane/typhoon origin locations. Green shading indicates upper level divergence and brow shading indicates upper level convergence. Open circles indicate hurricane/typhoon origin centers.

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

A different way to visualize the MJO



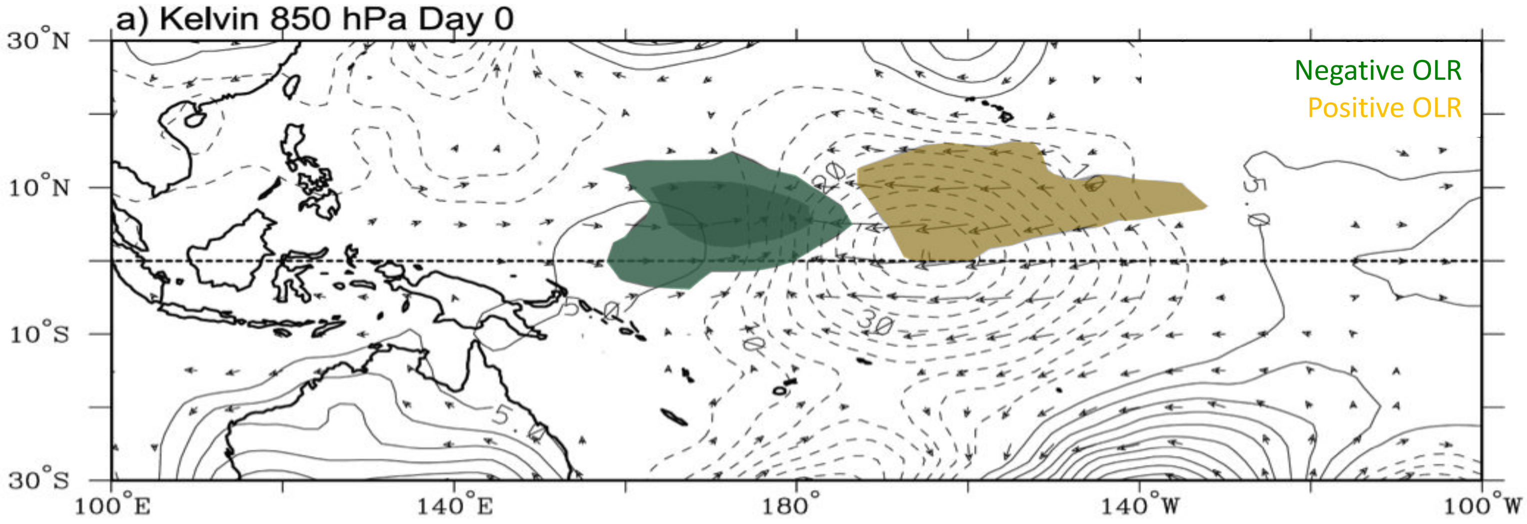
- The axes (RMM1 and RMM2) represent daily values of the principal components from the two leading modes, following the active convection.
- The triangular areas indicate the location of the enhanced phase of the MJO
- Counter-clockwise motion is indicative of eastward propagation
- Distance from the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

Question

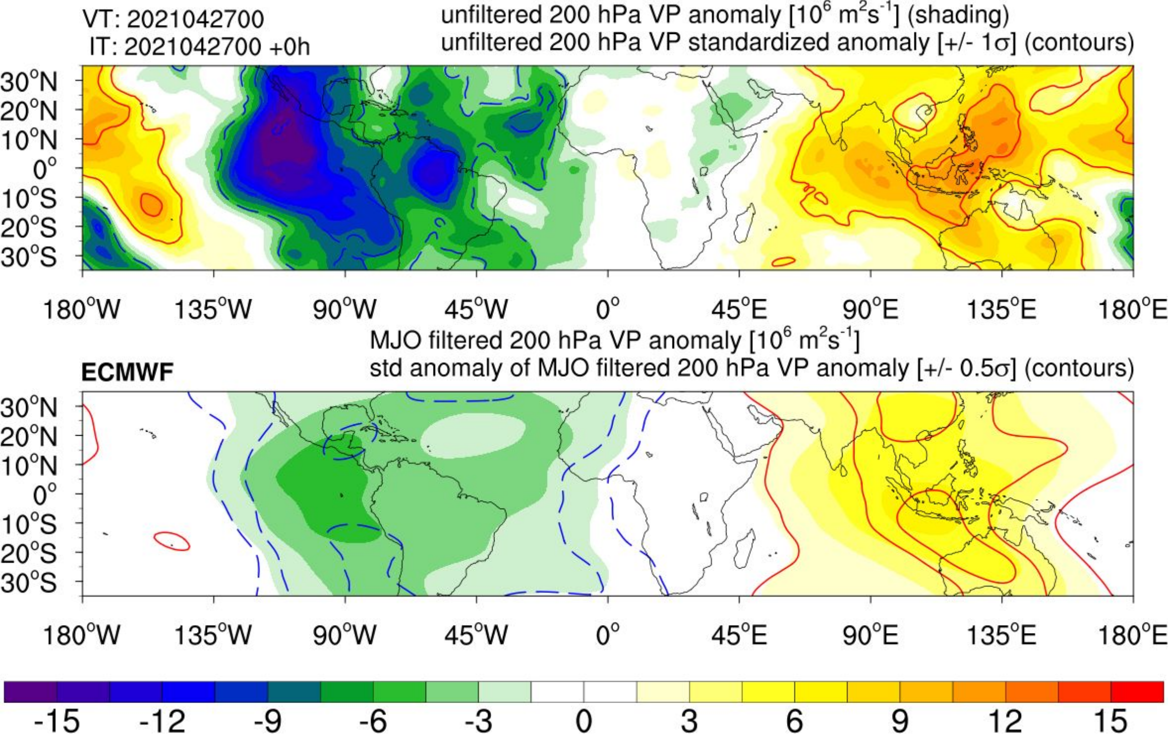
What ACE did you predict for the exercise?

A. Under 70
B. 70-100
C. 101-130
D. Over 130

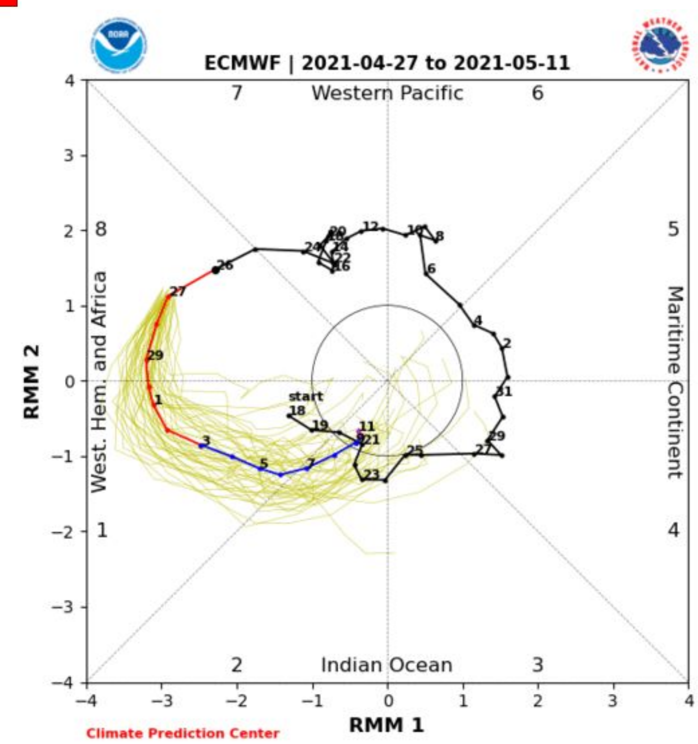
Kelvin Waves



- Kelvin waves characterized by alternating westerlies and easterlies on the equator
- The KWs propagate eastward and the active (westerly) phase enhanced convection (due to low-level convergence)
- Along with **latent heating, low-level relative vorticity** **is generated due to equatorial westerlies)**
- This improved environment can lead to TC genesis



MJO:
Plan view versus
RMM diagram



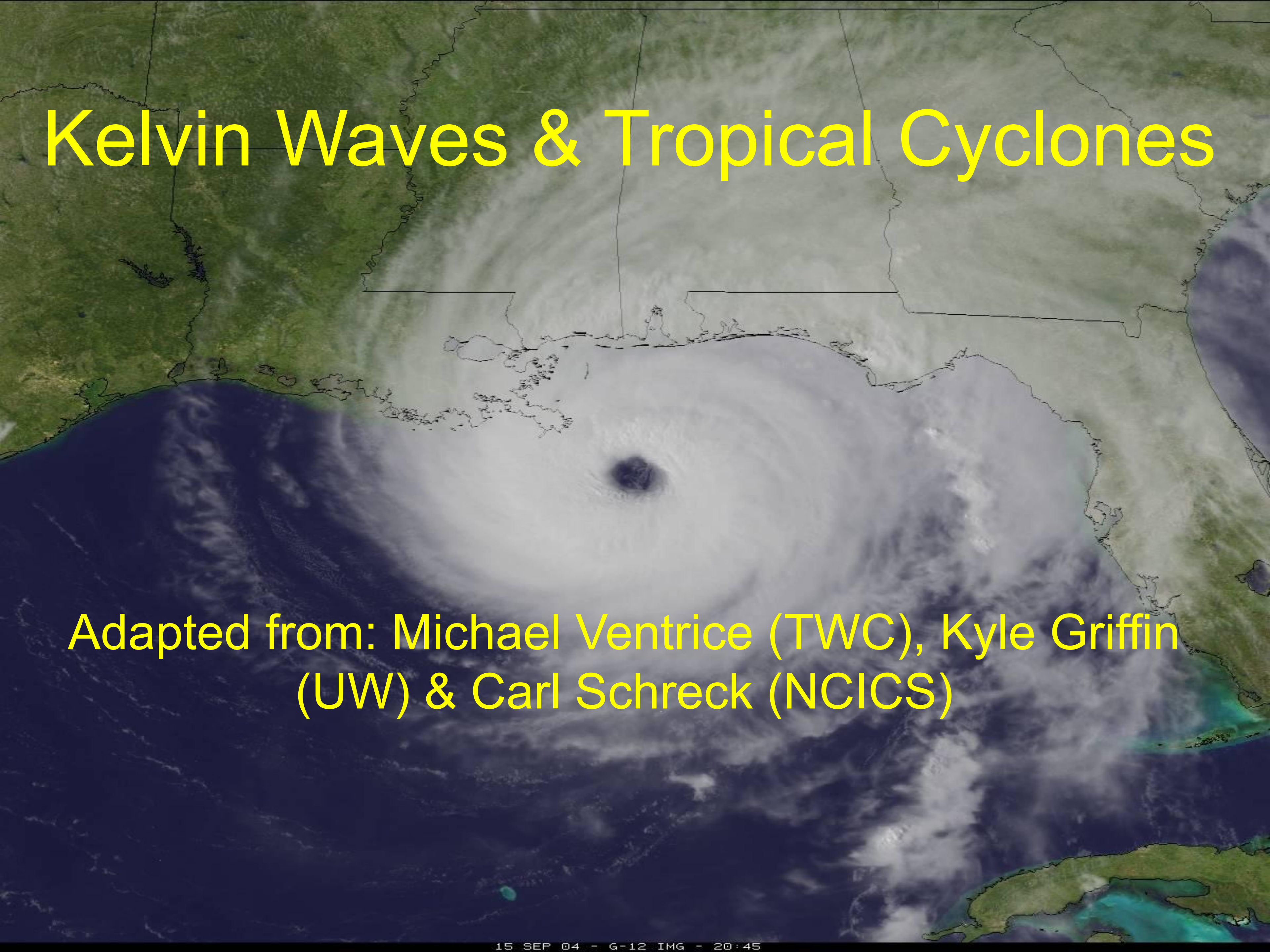
Question 1

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

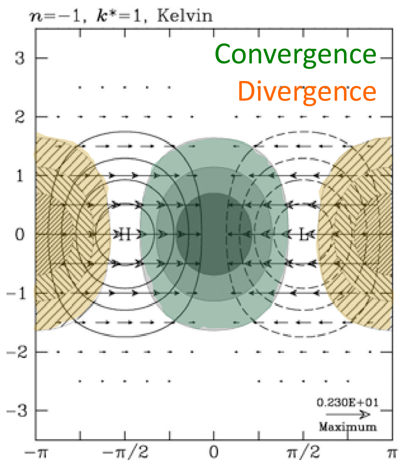
A. Phases 3/4
B. Phases 5/6
C. Phases 7/8
D. Phases 1/2

Kelvin Waves & Tropical Cyclones

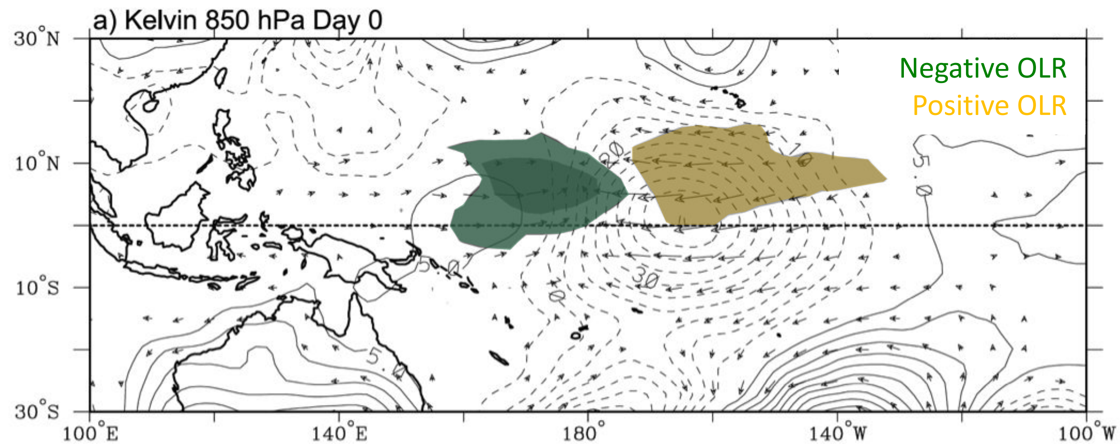
Adapted from: Michael Ventrice (TWC), Kyle Griffin (UW) & Carl Schreck (NCICS)



Kelvin Waves



Matsuno (1966)



Kiladis et al. (2009)

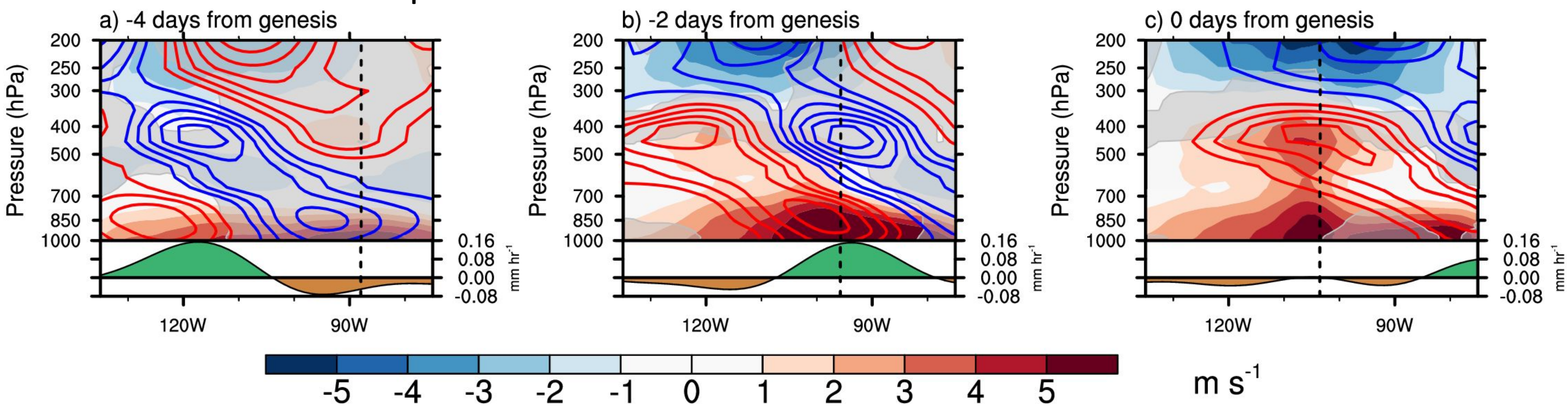
- Alternating westerlies and easterlies on the equator
- Enhanced convection where low-level winds converge
- Active phase associated with **latent heating** & the generation of **low-level relative vorticity** due to presence of meridional flow
- Modifies ITCZ convection, which causes significant changes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

Vertical Structure

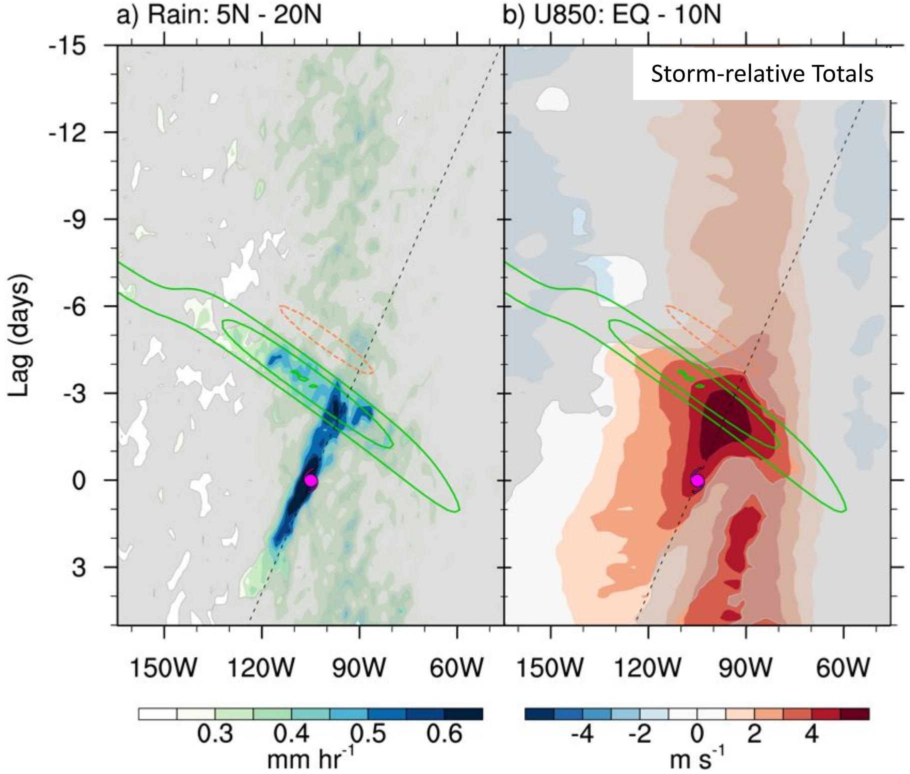
East Pacific Zonal Wind Eq–10°N



- 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

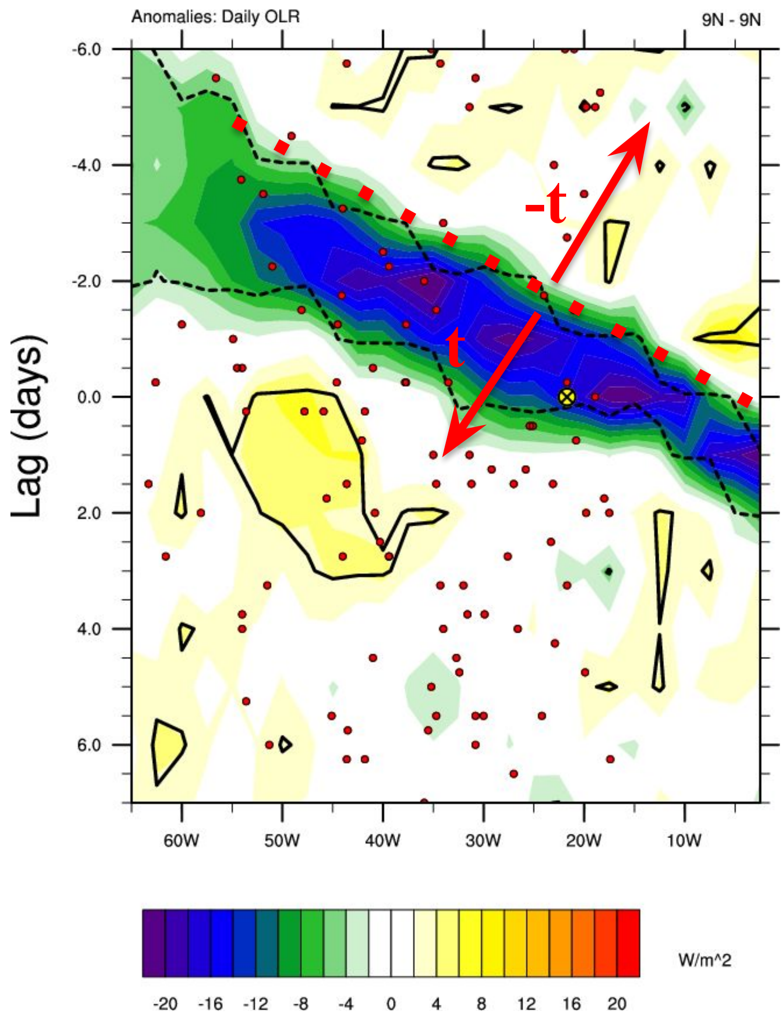
Tropical wave + CCKW composite

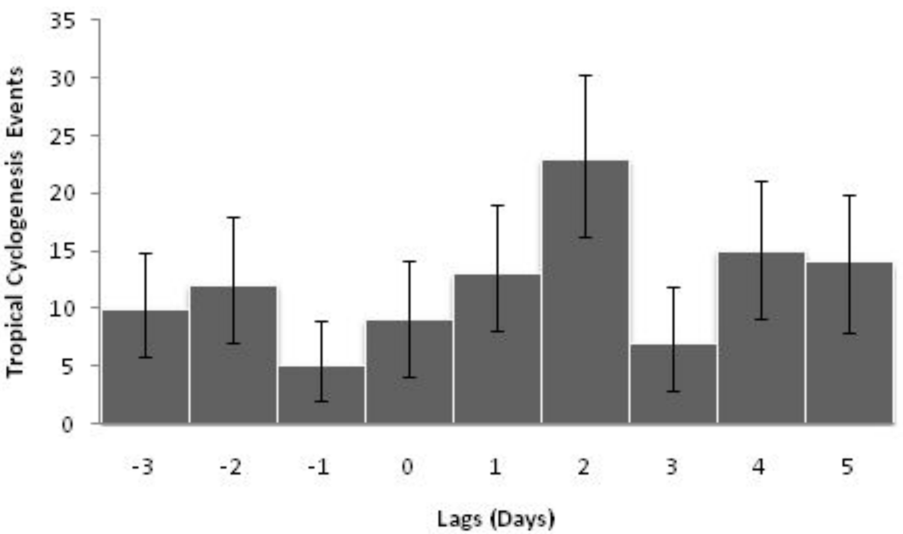
East Pacific: 40 storms



- 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



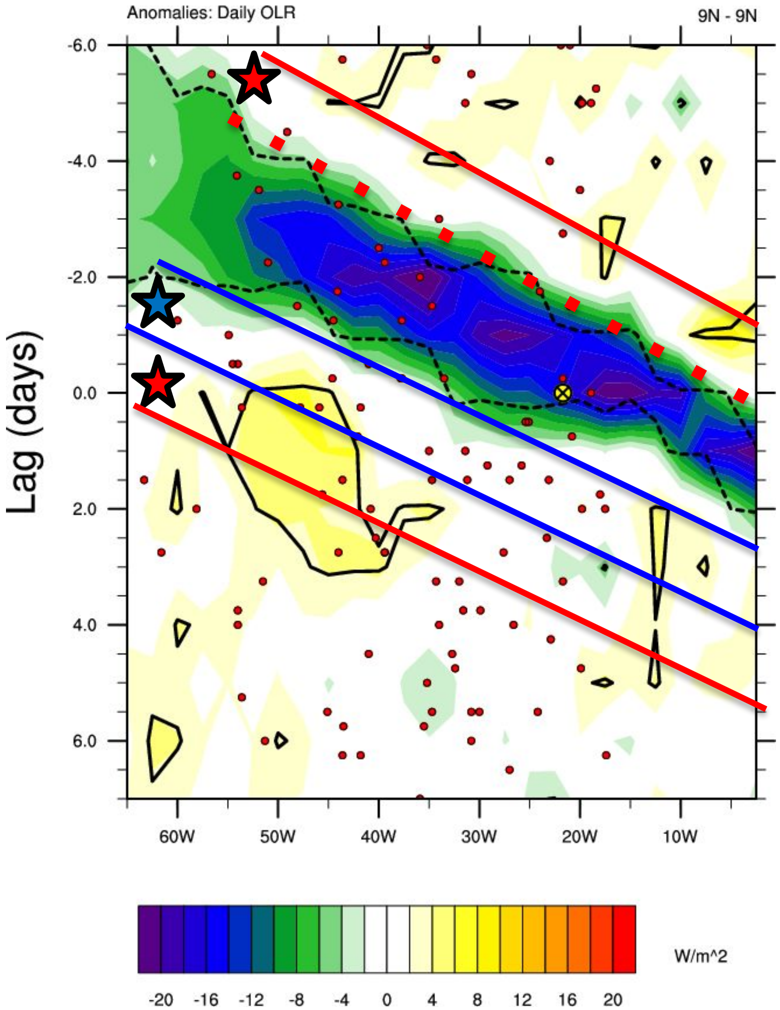


Tropical cyclogenesis events over the MDR (5-25°N, 15-65°W) relative to the CCKW during June-September 1979-2009

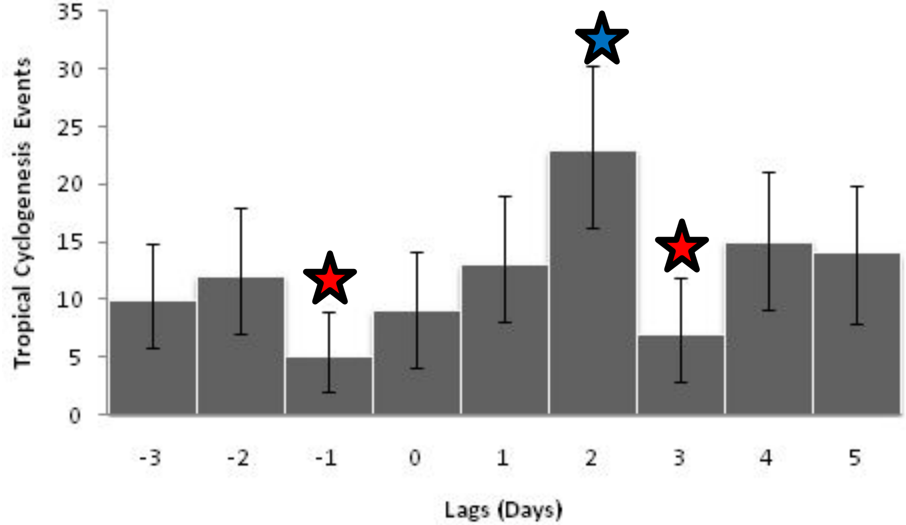
- Day 0 highlights the transition to statistically significant negative unfiltered OLR anomalies, or the eastern-most side of the convectively active phase of the CCKW.

- Error bars indicate the 95% confidence interval.

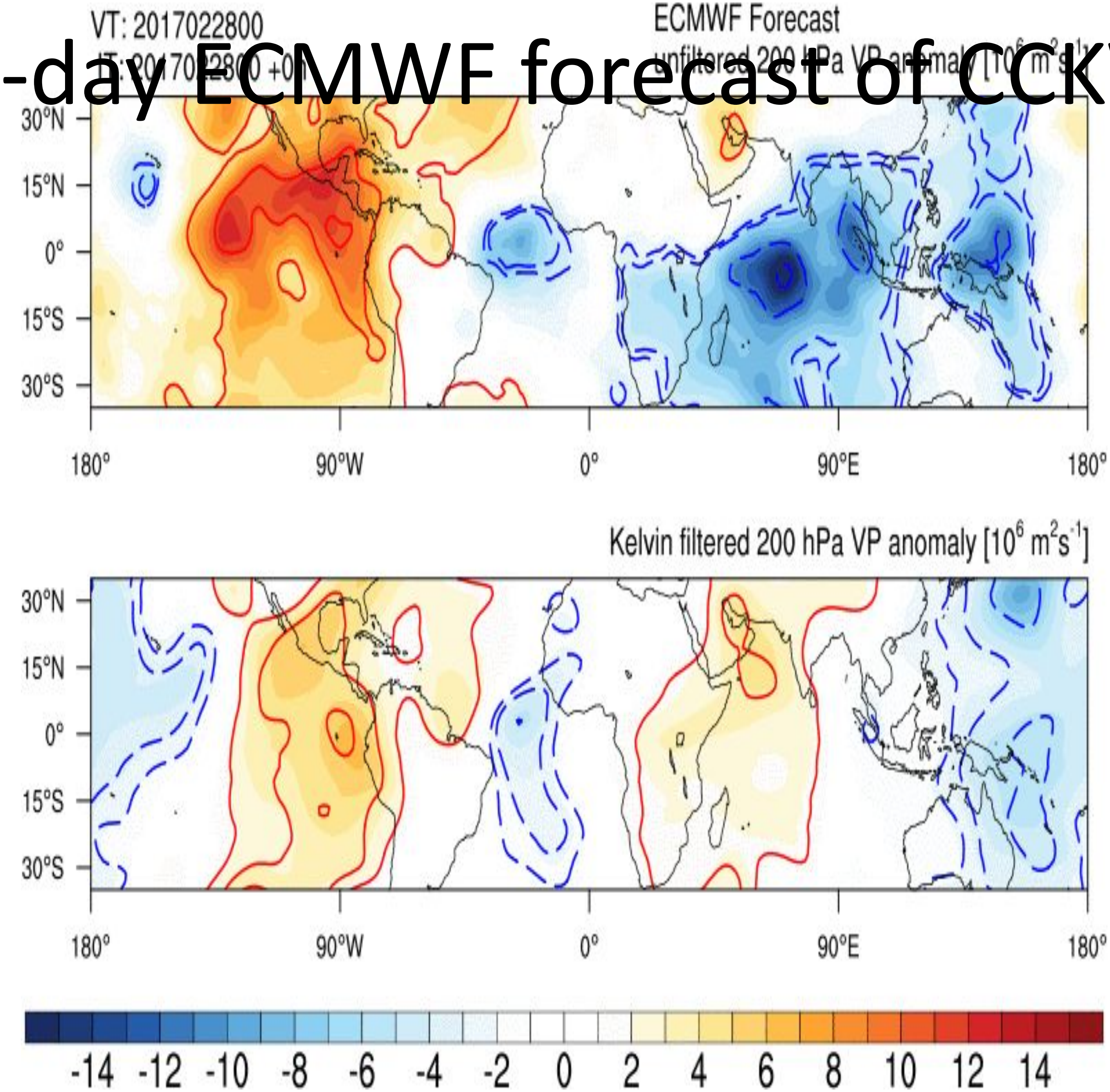
Atlantic CCKWs and genesis



Tropical cyclogenesis relative to the Kelvin wave

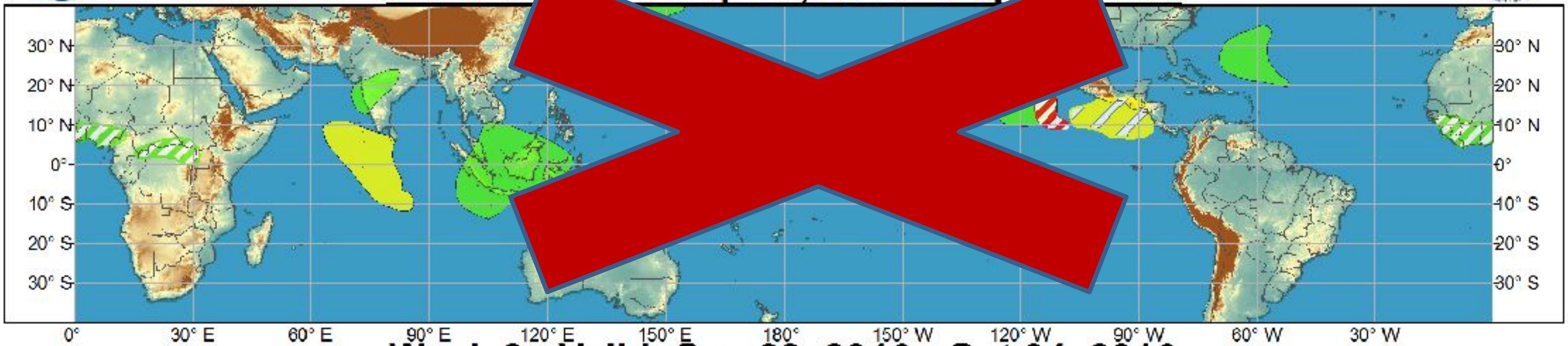


10-day ECMWF forecast of CCKWs

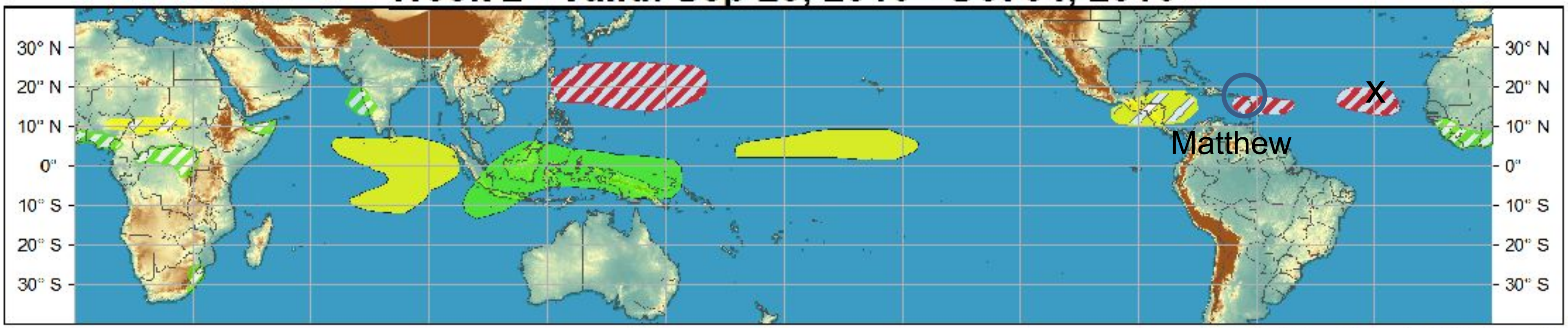


Global Tropics Hazards and Benefits Outlook - Climate Prediction Center

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

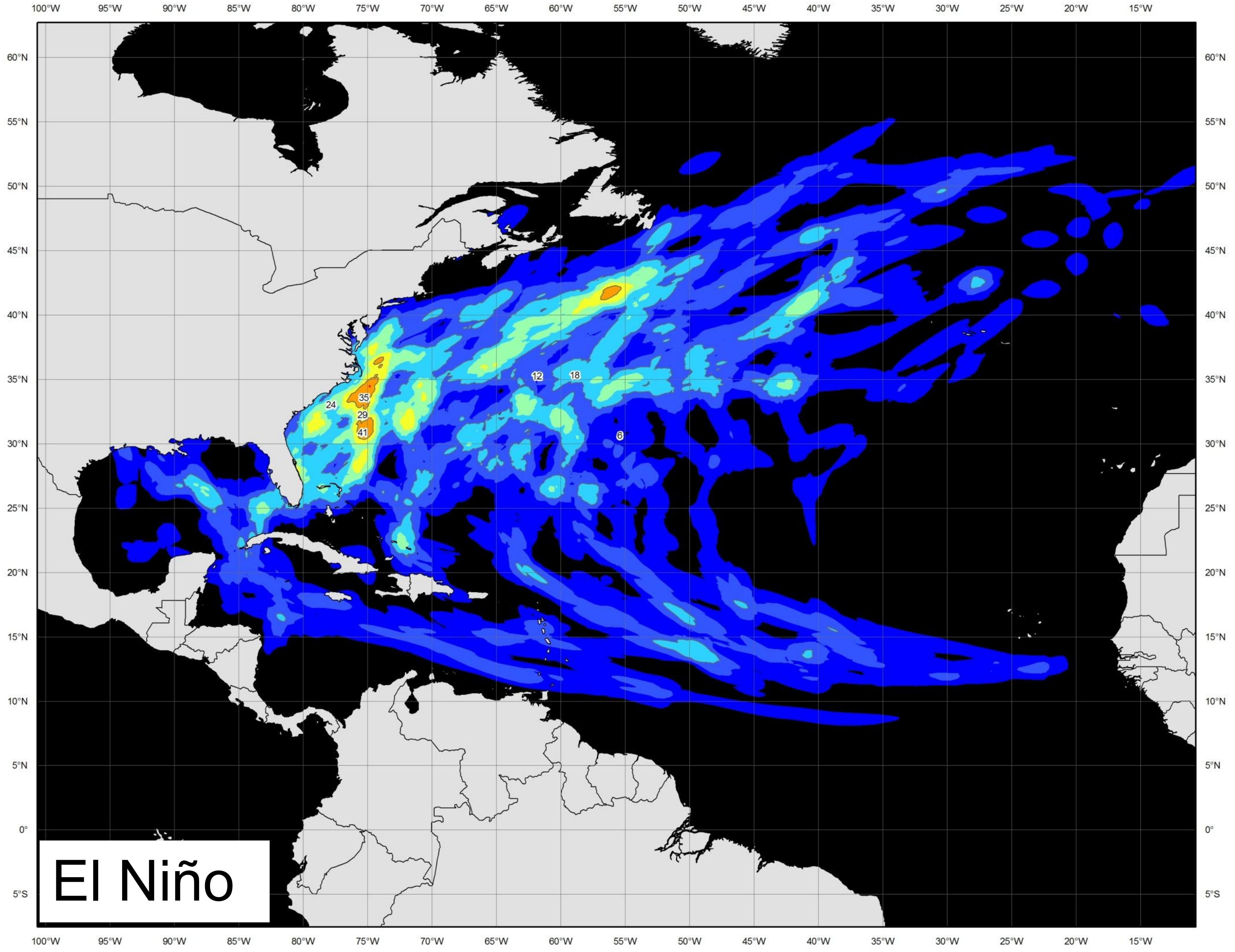
Australian Government Bureau of Meteorology

CICS-NC

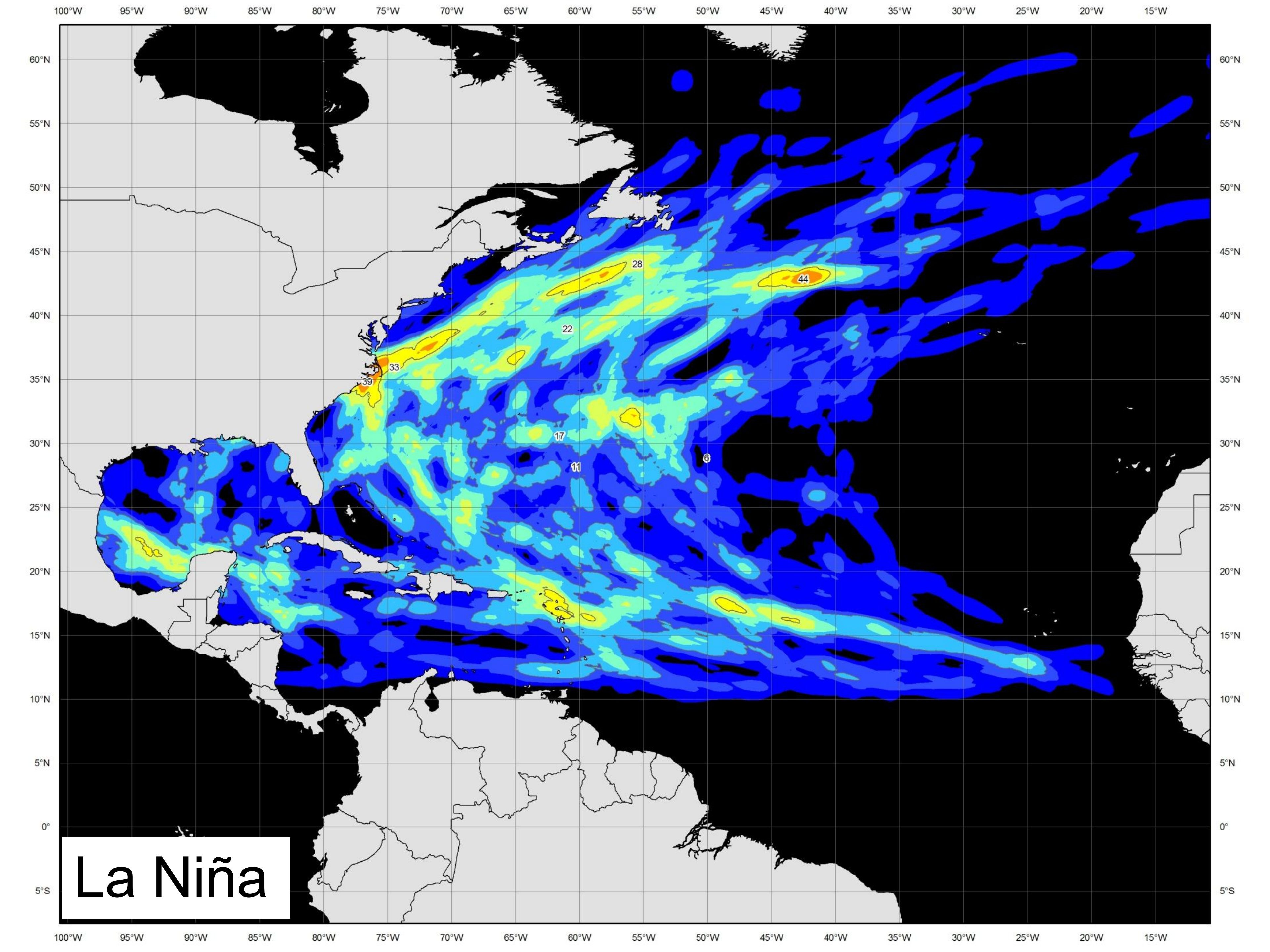
NPS

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.



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
35
24
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
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40°W
35°W
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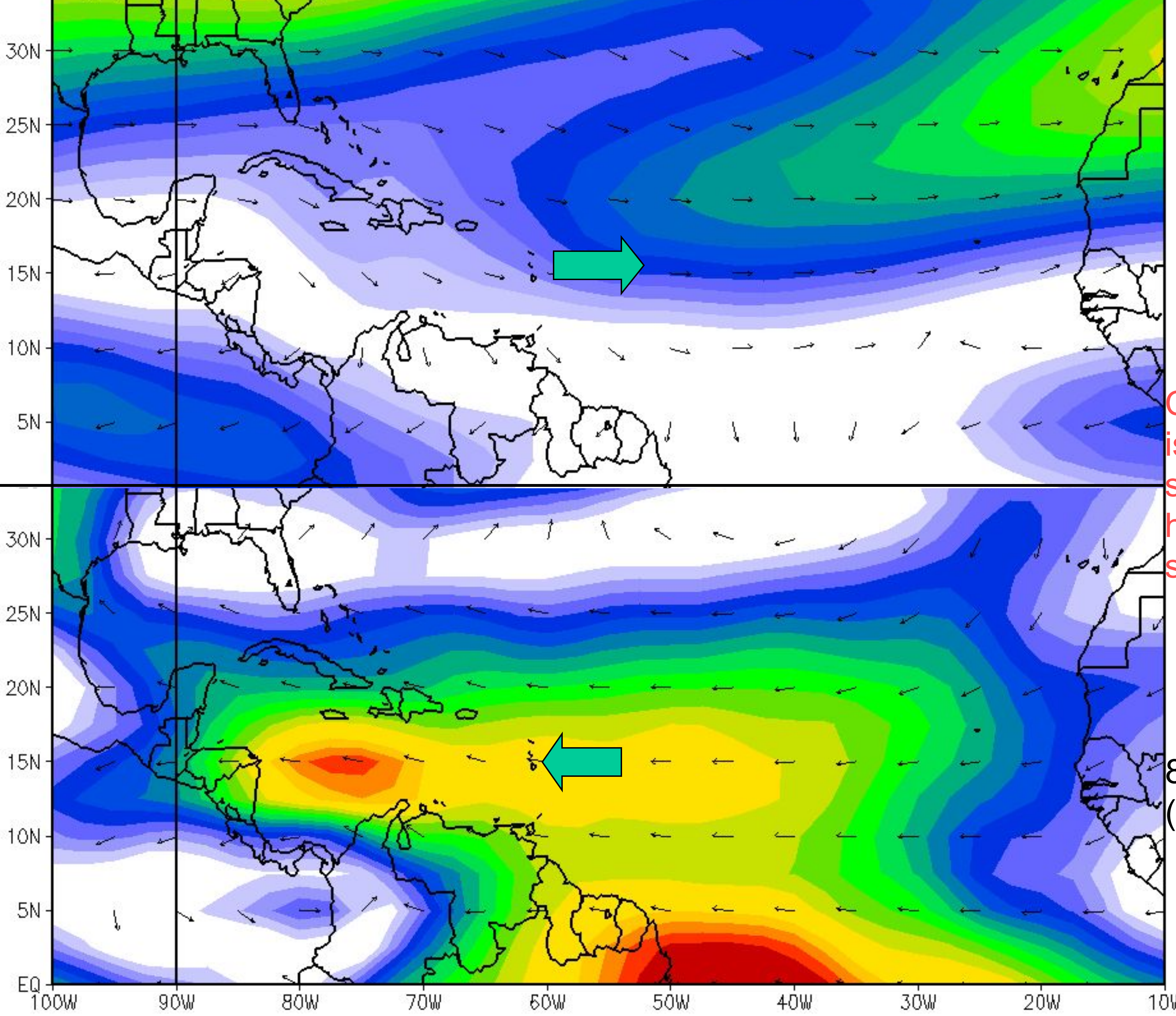
20°W
15°W
60°N
55°N
50°N
45°N
40°N
35°N
30°N
25°N
20°N
15°N
10°N
5°N
0°
5°S

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.

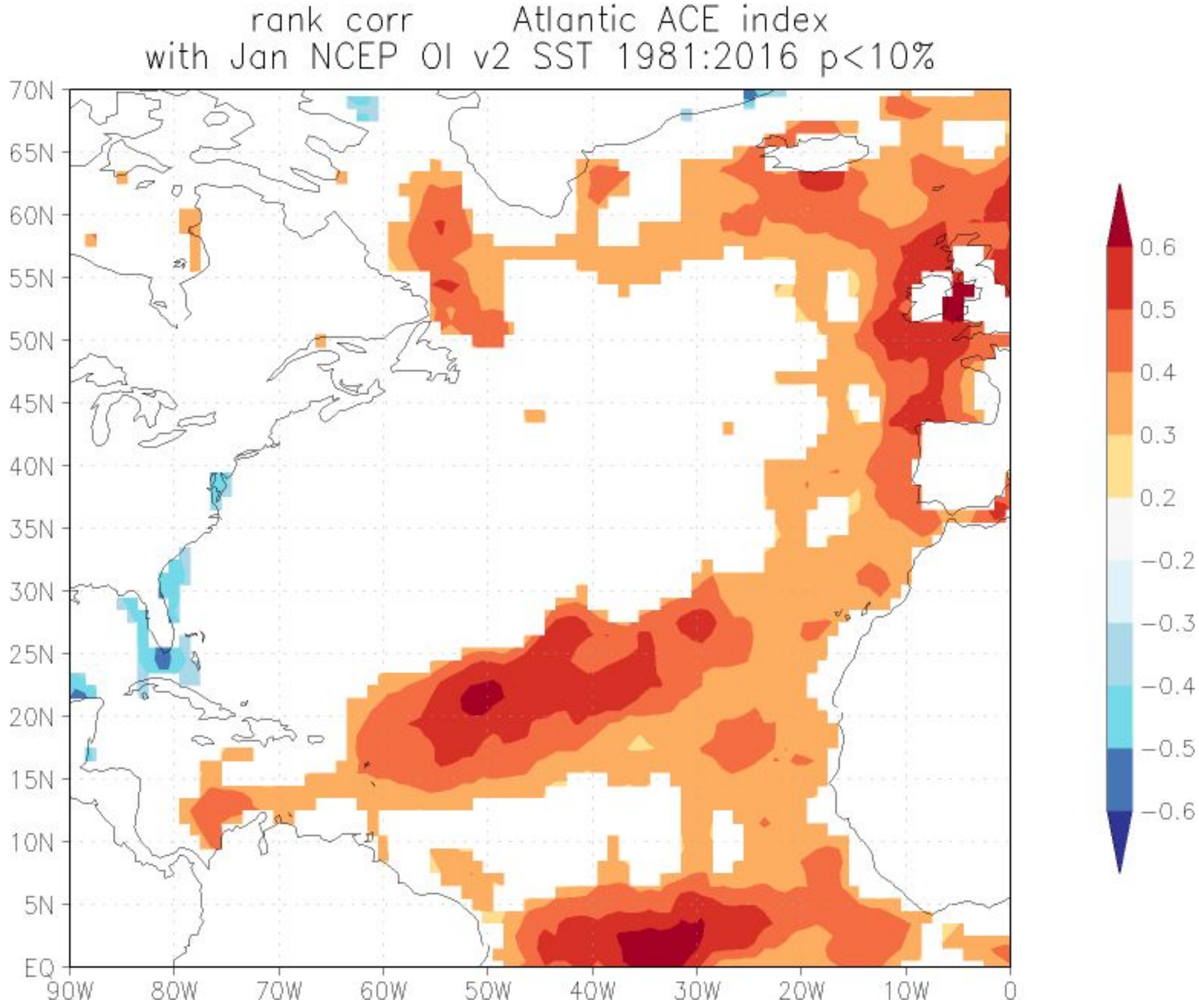


200 mb
(~40,000 ft)

Climatology is for lots of shear during hurricane season

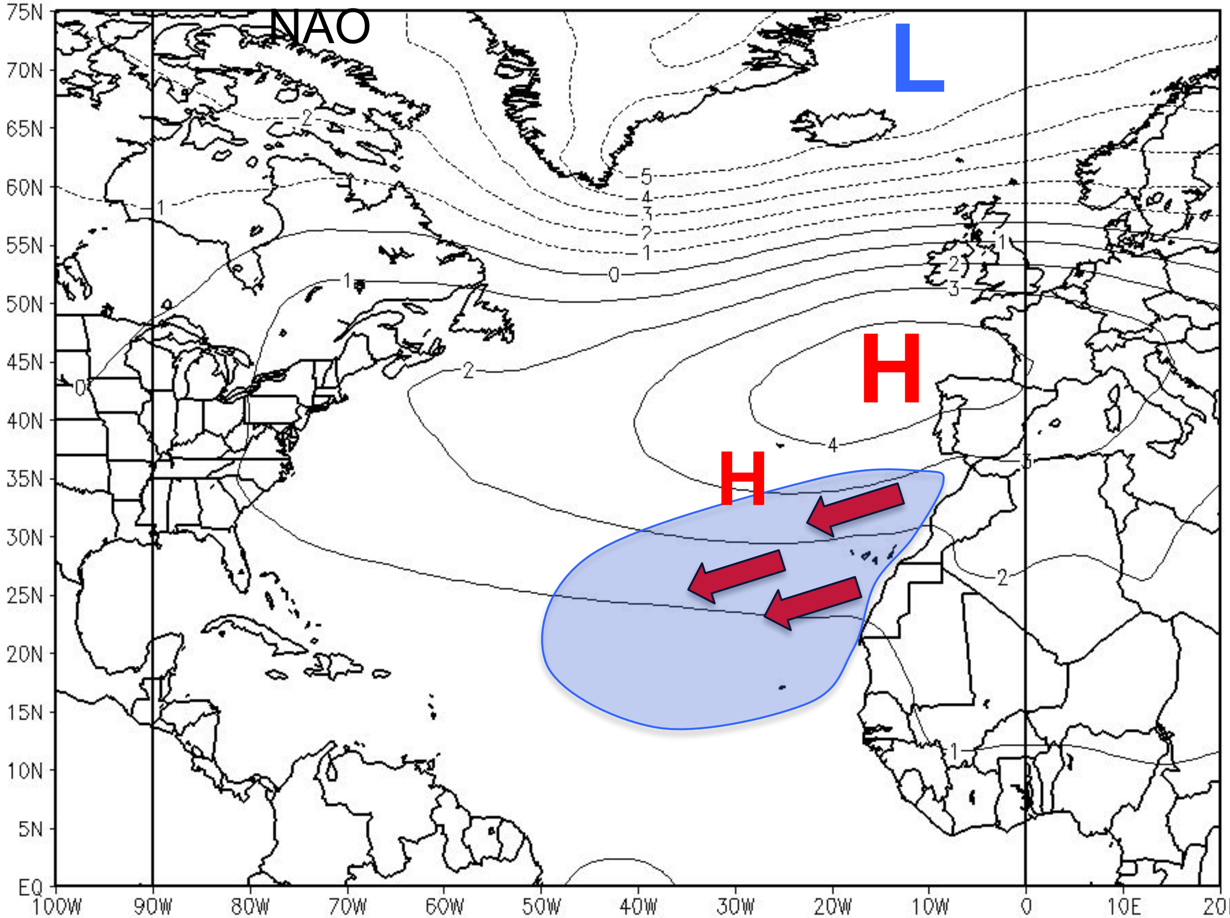
850 mb
(~5,000 ft)

Correlation between Atlantic SST and Atlantic Hurricane Activity



Forcing the AMM

SLP anomaly associated with (+) NAO



1. Subtropical SLP anomalies associated with NAO

2. Cool SST through enhanced evaporation (stronger easterlies)

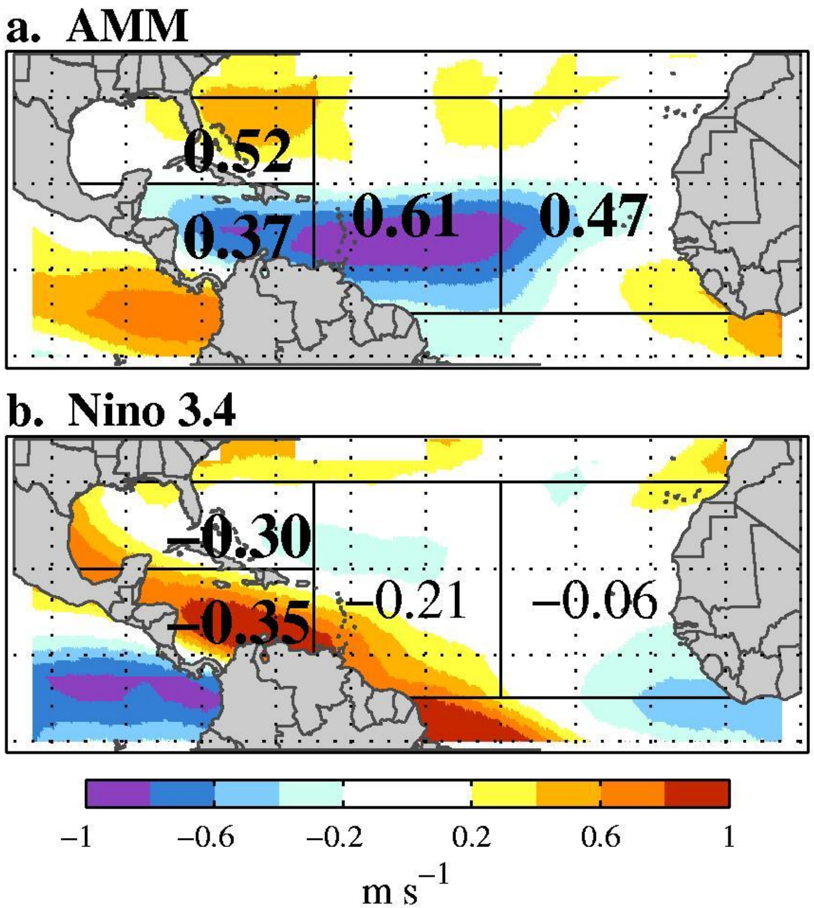
3. Atmosphere responds through anticyclonic circulation, reinforcing wind anomalies □ (-) AMM

4. Resulting feedback can last for several months, even after NAO forcing subsides

[FLIP sign for (-) NAO]

Courtesy Dima Smirnov ESRL

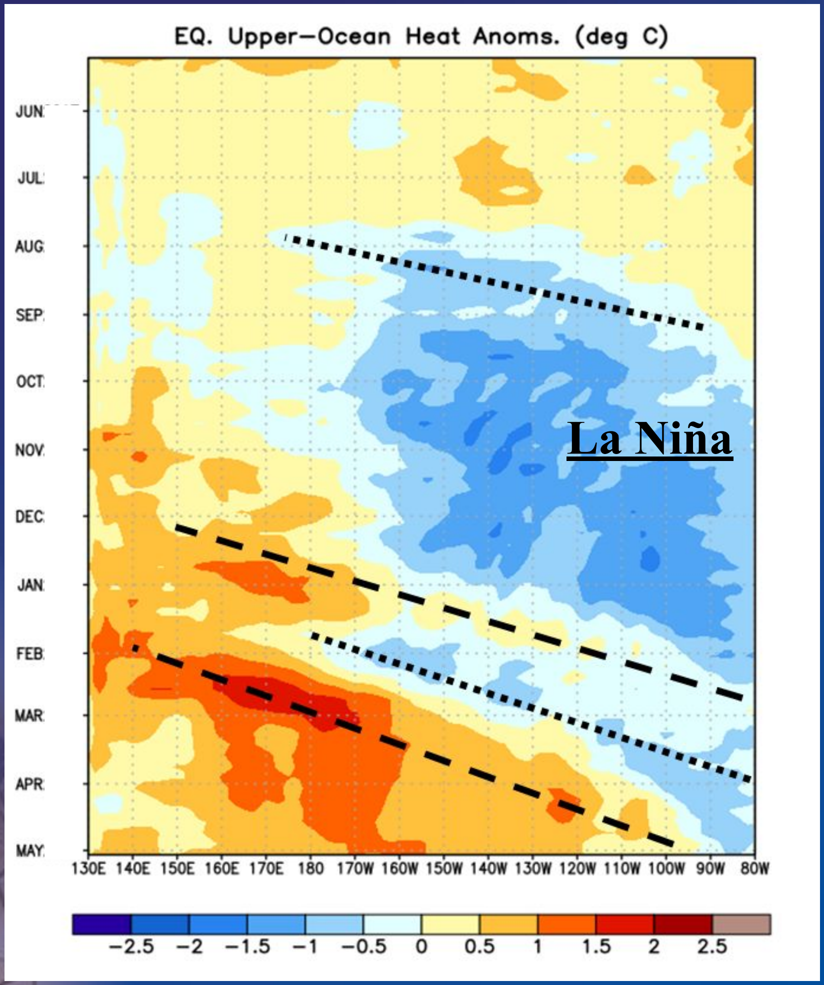
Comparative effects of the AMM (local) and ENSO (remote) on vertical wind shear in the Atlantic



units: m/s per standard deviation

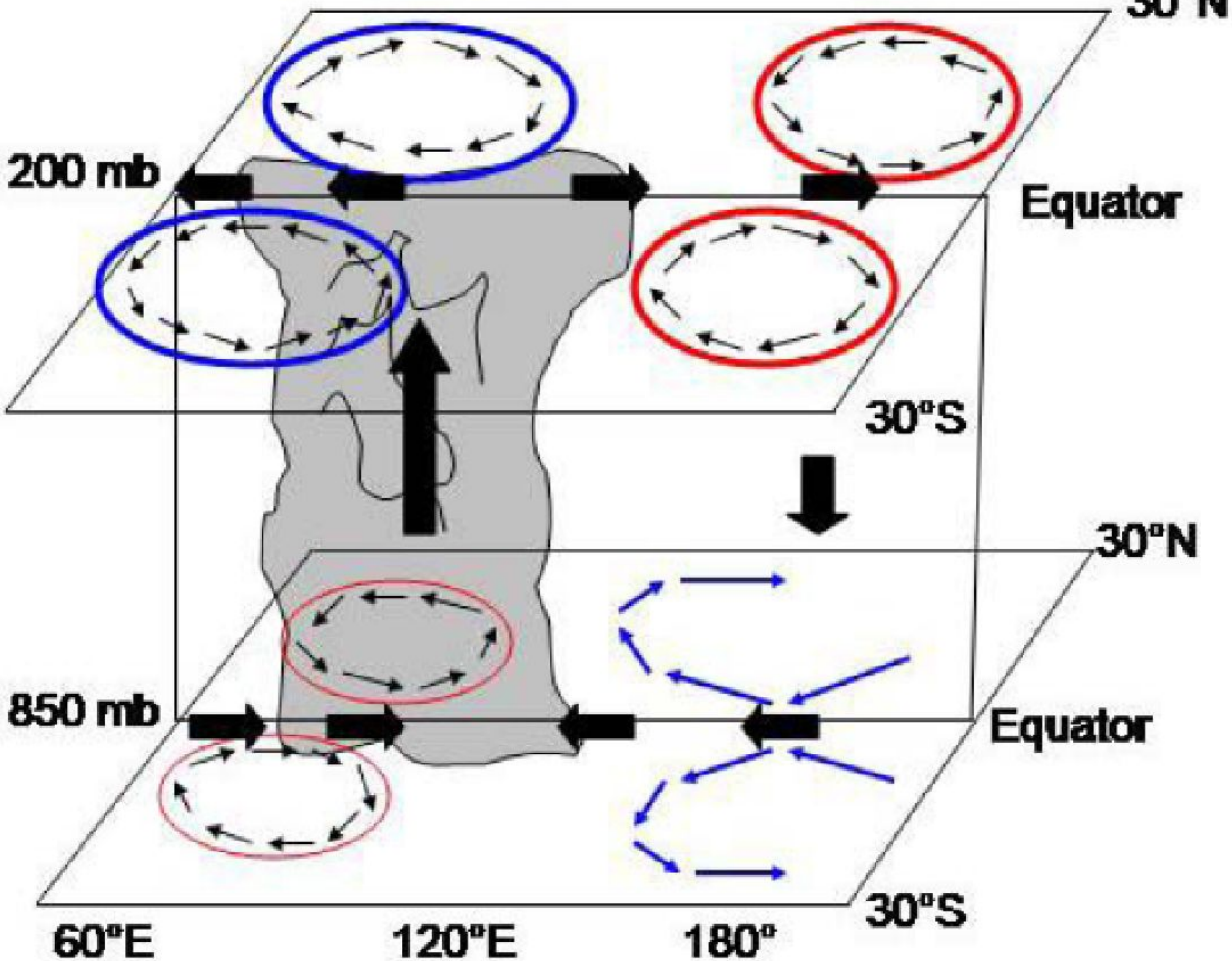
Shear regressed onto AMM and N34 indices, and correlations between the indices and storm activity.

Heat Content Anomalies (ºC) in the Equatorial Pacific



Equatorial oceanic Kelvin waves are indicated by dashed black lines.

ENSO Forecasts



Rui and Wang (1990).

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

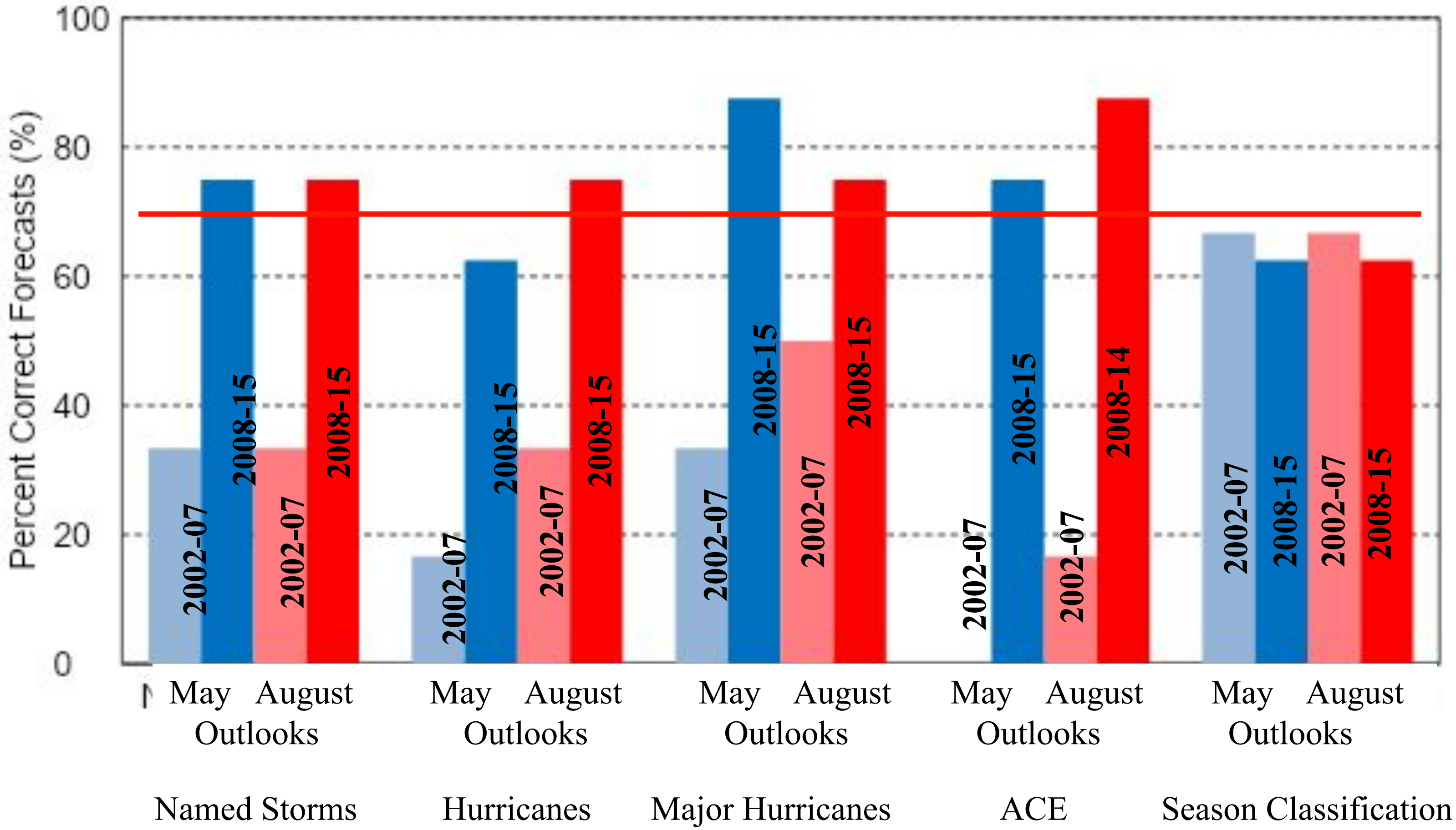
- Number of papers that involve this or similar topics in AMS journals only number in the ~2 dozen range

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

CFS version 2

1. An atmosphere at high horizontal resolution (spectral T574, ~27 km) and high vertical resolution (64 sigma-pressure hybrid levels) for the real time analysis
2. An atmosphere of T126L64 for the real time forecasts
3. An interactive ocean with 40 levels in the vertical, to a depth of 4737 m, and horizontal resolution of 0.25 degree at the tropics, tapering to a global resolution of 0.5 degree northwards and southwards of 10N and 10S respectively
4. An interactive 3 layer sea-ice model
5. An interactive land model with 4 soil levels

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,.

Seasonal Forecasting is more than this!