Understanding Tropical Climate to Advance Sub-seasonal to Seasonal Prediction

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NOAA/NWS Climate Prediction Center (CPC)
RITT Forum, April 2013

I. The El Niño- Southern Oscillation (ENSO): Is it Solved?

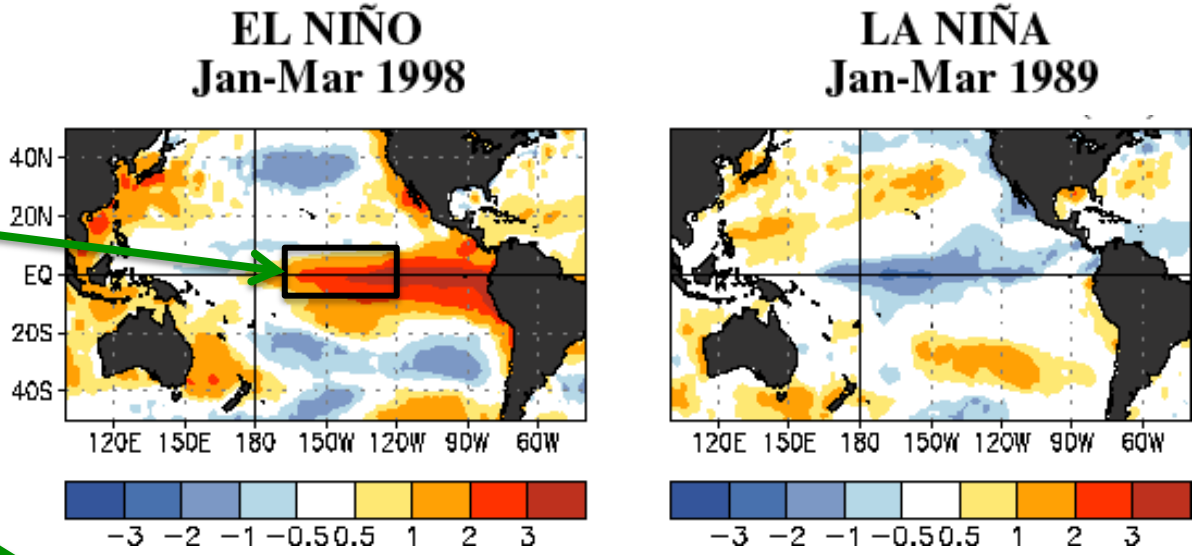
Later on…

II. Madden-Julian Oscillation (MJO) Attribution and Prediction

What is ENSO?

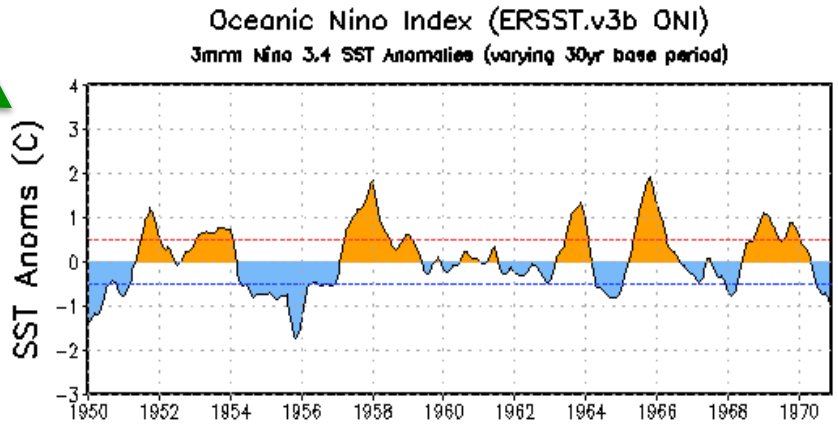
- Irregular cycle (every 2-7 years) of warm (El Niño) or cold (La Niña) conditions in the tropical Pacific Ocean.
- Ocean changes occur alongside changes in the tropical atmosphere circulation & rainfall
- On average, events last 9-12 months (La Niñas can persist longer) and peak in strength during N. Hemisphere winter

Niño 3.4 sea surface temperatures (SST): Primary ENSO index or time series



Red colors: above average sea surface temps

Blue colors: below average sea surface temps

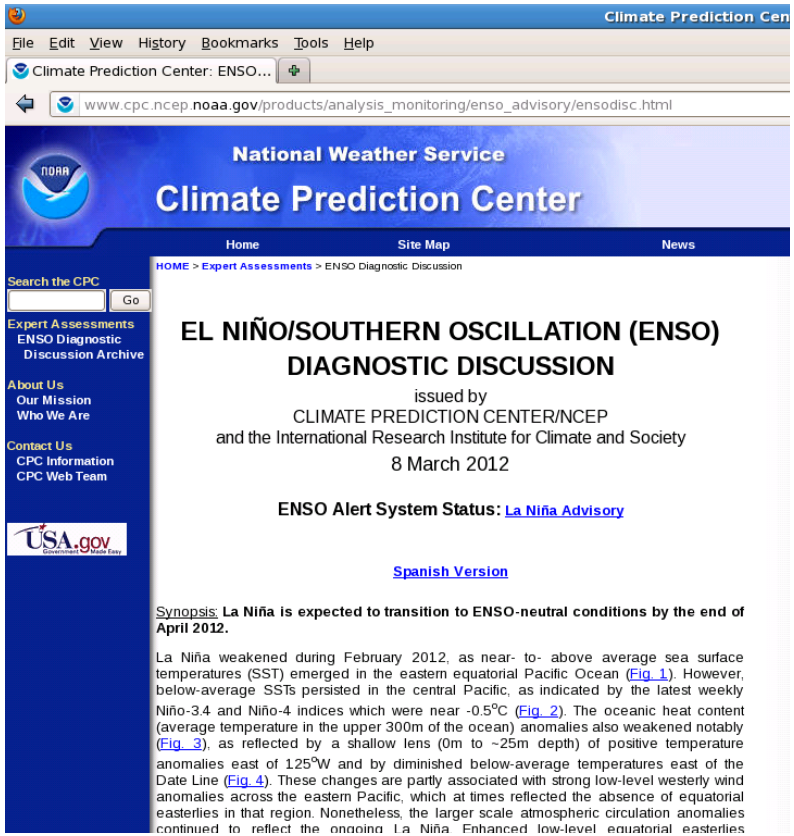


Creation of the NOAA ENSO Outlook

- CPC provides weekly (every Monday) + monthly monitoring and prediction products for ENSO, which are available on our website:

http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml
Indices: http://www.cpc.ncep.noaa.gov/data/indices/

- The ENSO Diagnostics Discussion is released on the Thursday between the 4-10th of each month. Concurrent with that release, the "ENSO Alert System" and the official outlook is updated.



El Niño or La Niña Watch:
Favorable for development of ENSO within the next six (6) months.

El Niño or La Niña Advisory:
conditions are observed and expected to continue.

Final El Niño or La Niña Advisory:
conditions have ended.

NA: Not Active

To receive monthly notification:
ncep.list.enso-update@noaa.gov

Creation of the NOAA ENSO Outlook

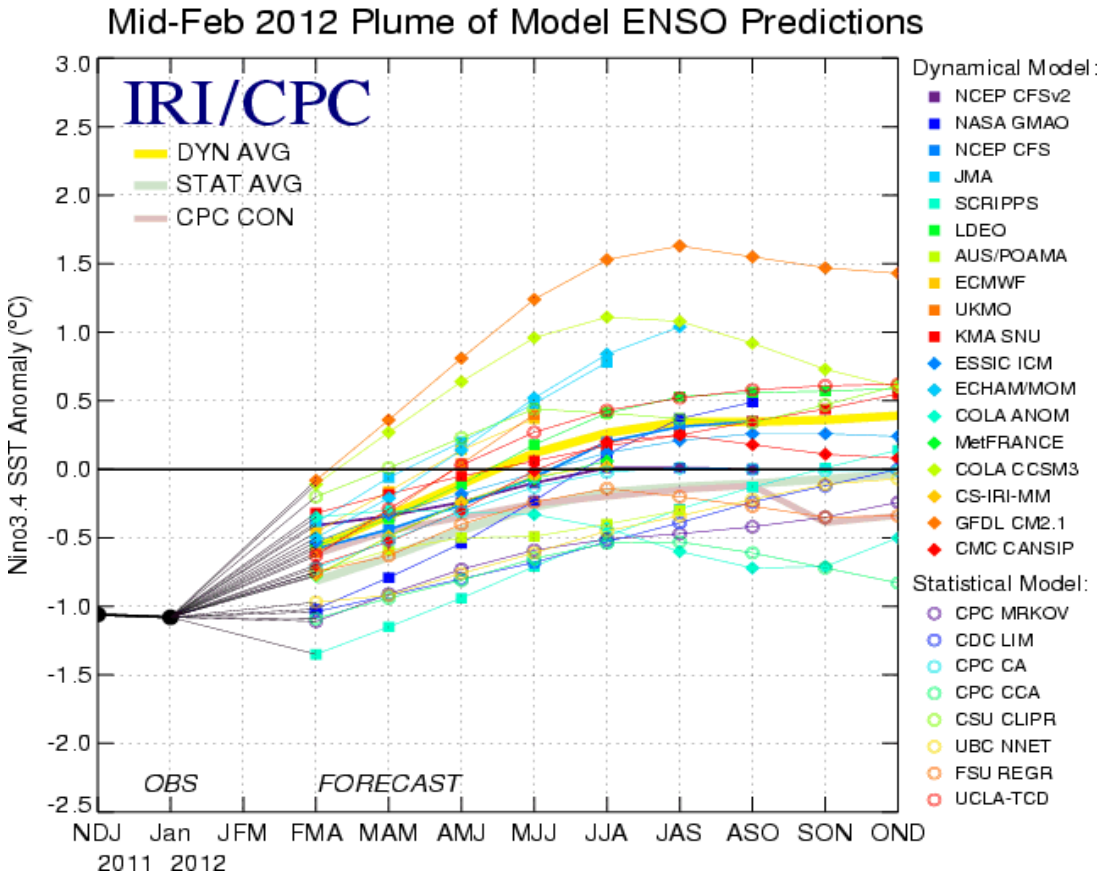
The ENSO team (7 CPC forecasters + Tony Barnston at the IRI) determines the probabilities for each ENSO category, which provides the ENSO prediction for the upcoming ~8 seasons.

Forecasters consider:

(1) The observed state of the tropical Pacific

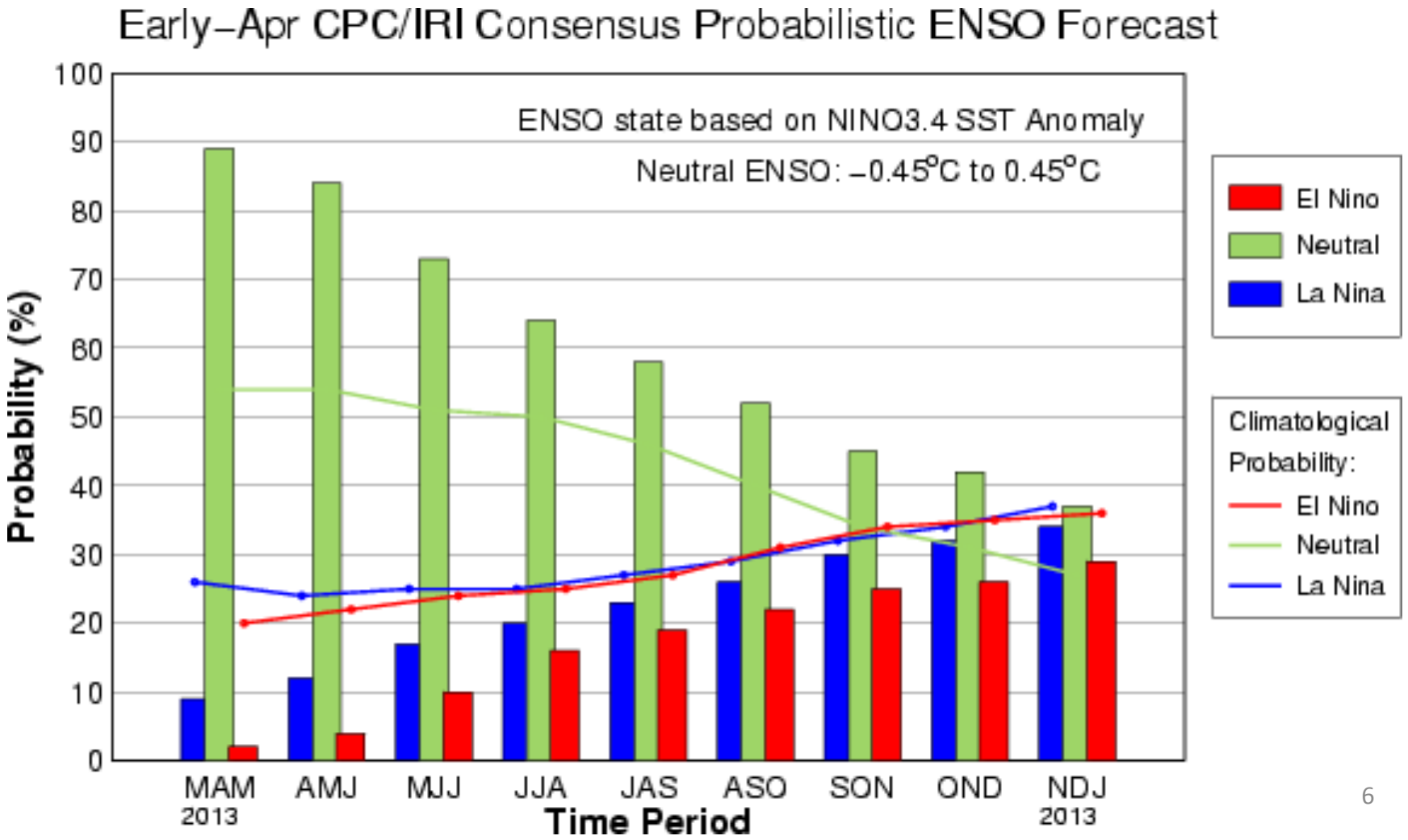
(2) Dynamical and statistical model output and multi-model ("MME") combinations

(3) Knowledge and experience of previous ENSO episodes



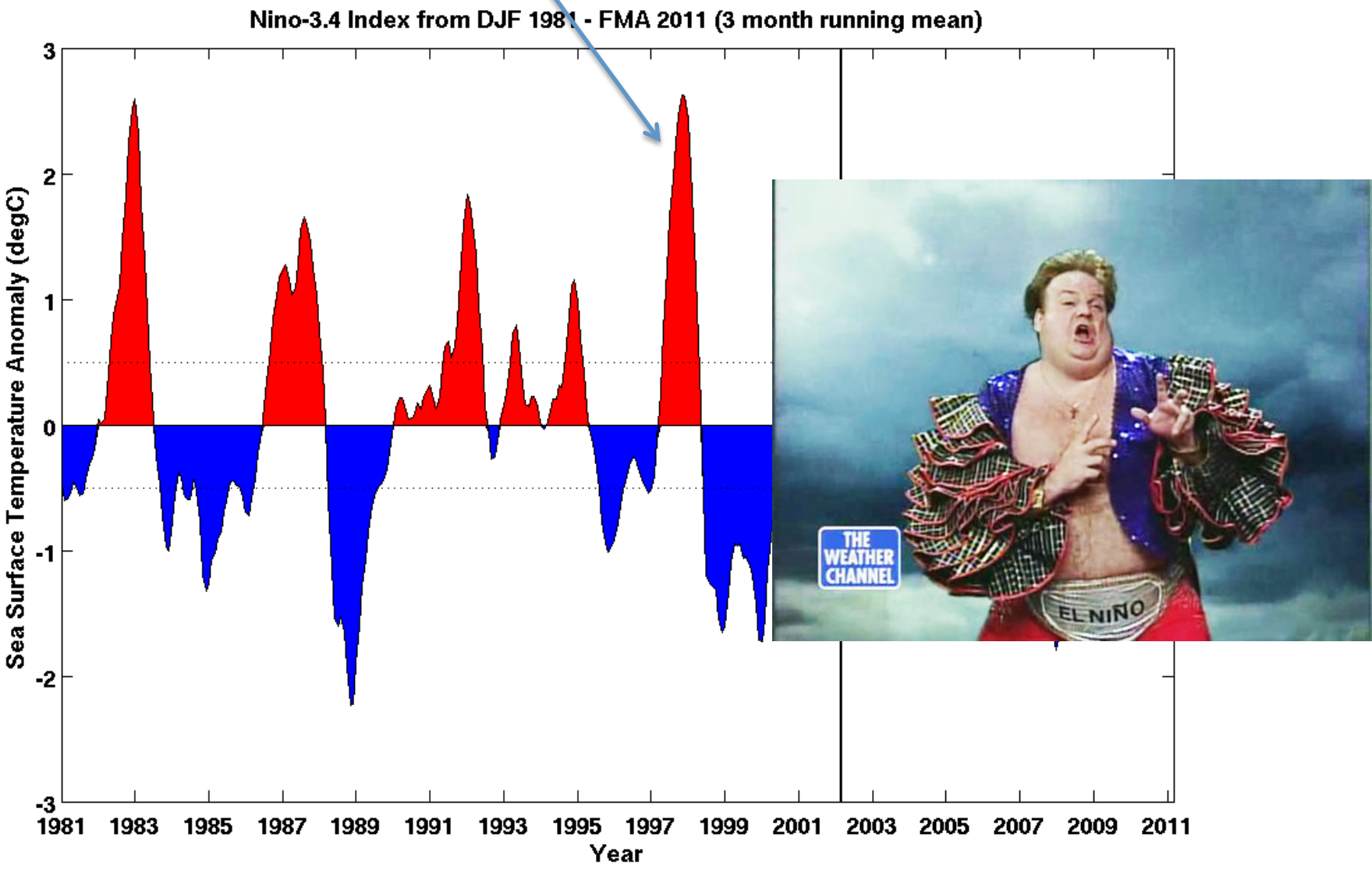
How Is the probability of ENSO determined?

Each forecaster individually provides probabilities of three categories (El Niño – Neutral – La Niña). Individual forecasts are averaged to create the "Consensus" probabilities and form the basis for the diagnostics discussion.



So, how well do these ENSO predictions work?

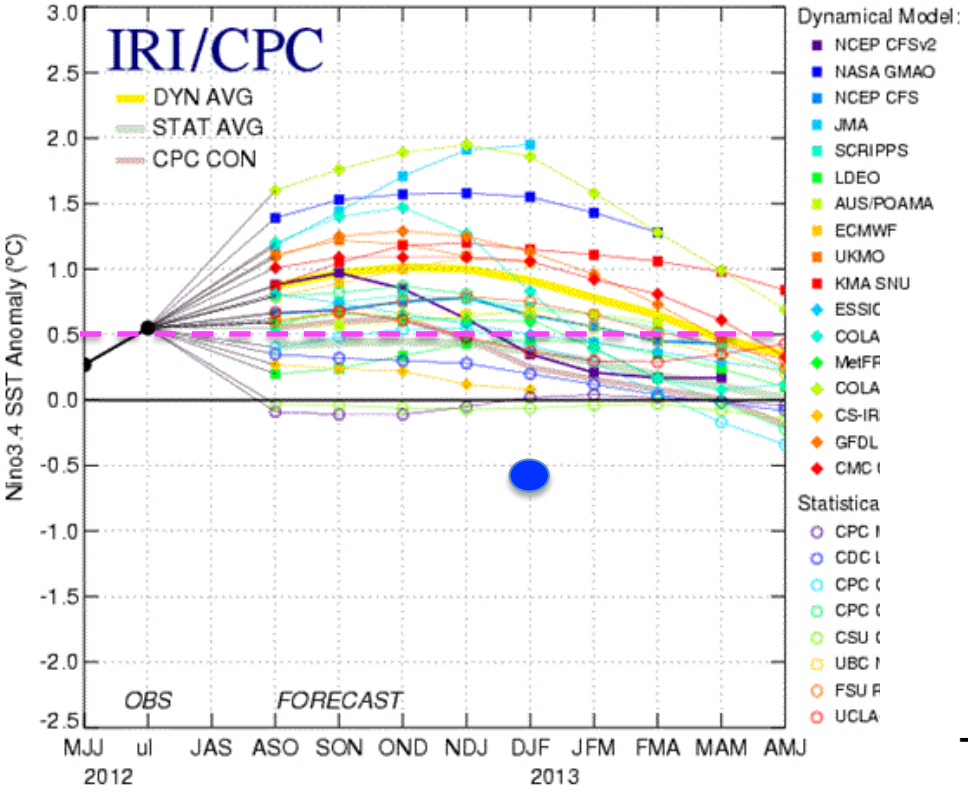
Pretty well when you see the strong 1997-98 El Niño, six months in advance:



So, how well do these ENSO predictions work?

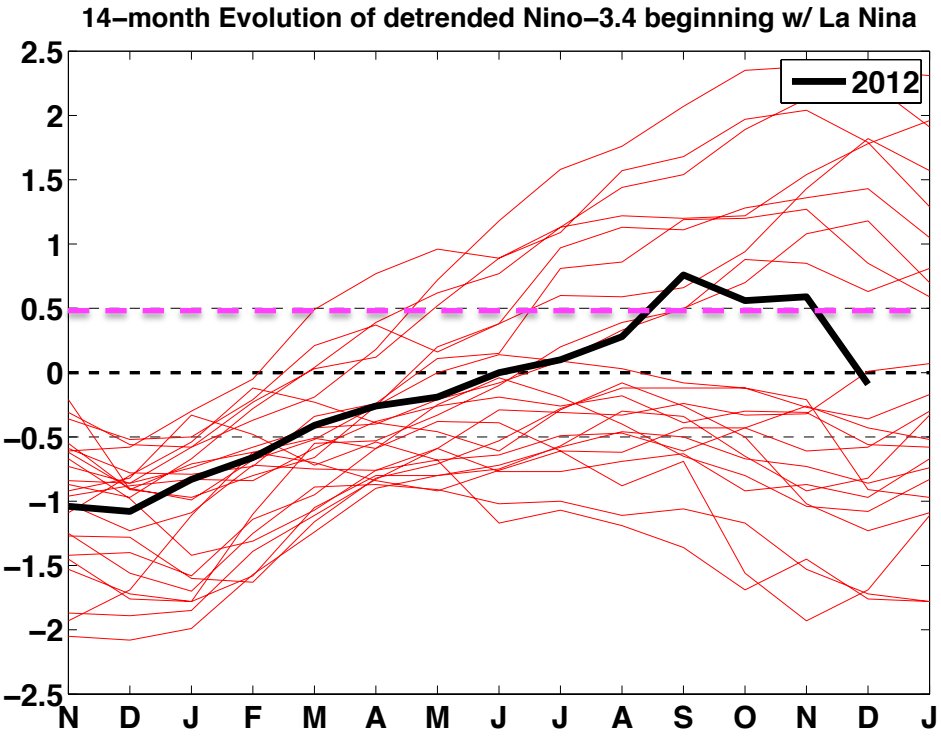
Not so well when this happens….

Early September 2012 Model Predictions



Most models predicted El Niño (> +0.5°C) for the 2012-13 winter

Black Line: Observed Niño-3.4 Index through December 2012



DJF Niño-3.4 index value was -0.6°C

Primary features of ENSO model performance

- Recently, dynamical models have *slightly* edged statistical models in forecast skill (see Barnston et al. BAMS, 2012)

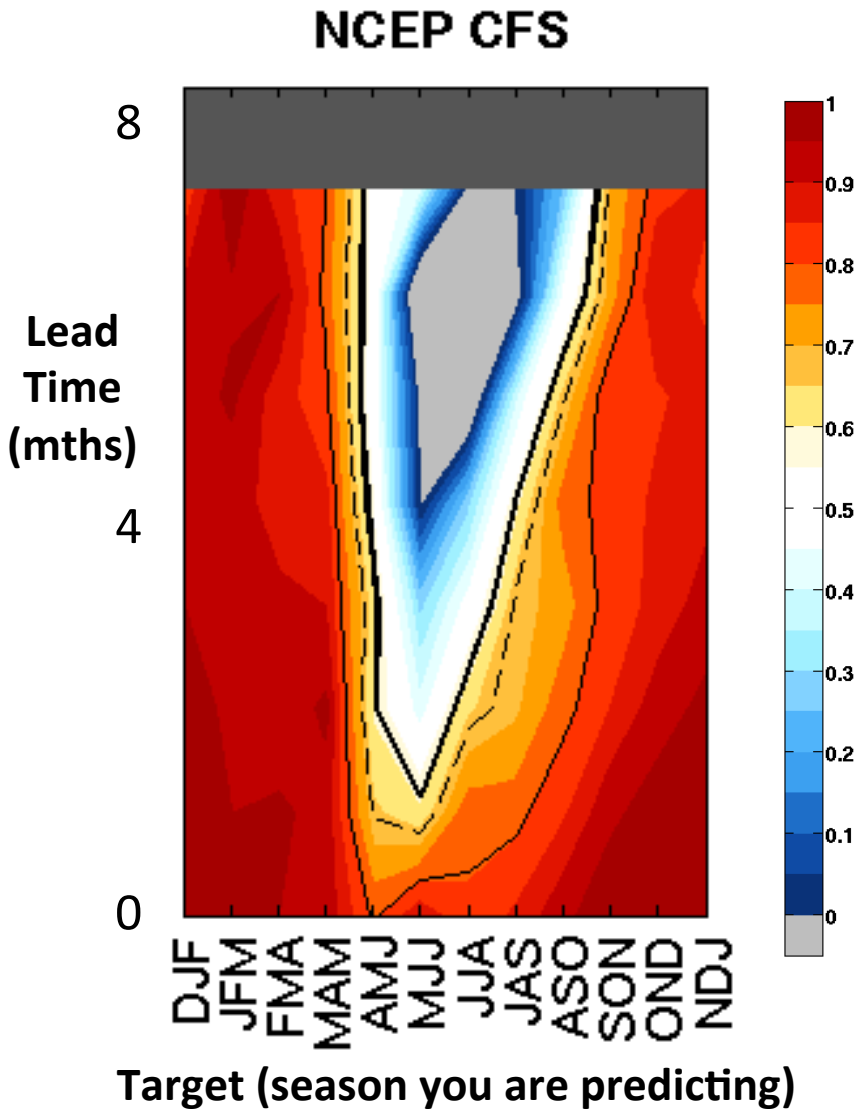
- Models have trouble with transition timing and predicting amplitude of ENSO events.

- The transition to stronger ENSO events tends to be better predicted than transitions to weaker ones.

- "Spring prediction barrier:" historically, forecasts before the Northern Hemisphere Spring have low skill.

Prediction of Niño-3.4 Index by NCEP CFS from 2002-2011

(Note: statistical corrections were applied after 2009)



Orange/Red Shading: Higher correlations (more skill)

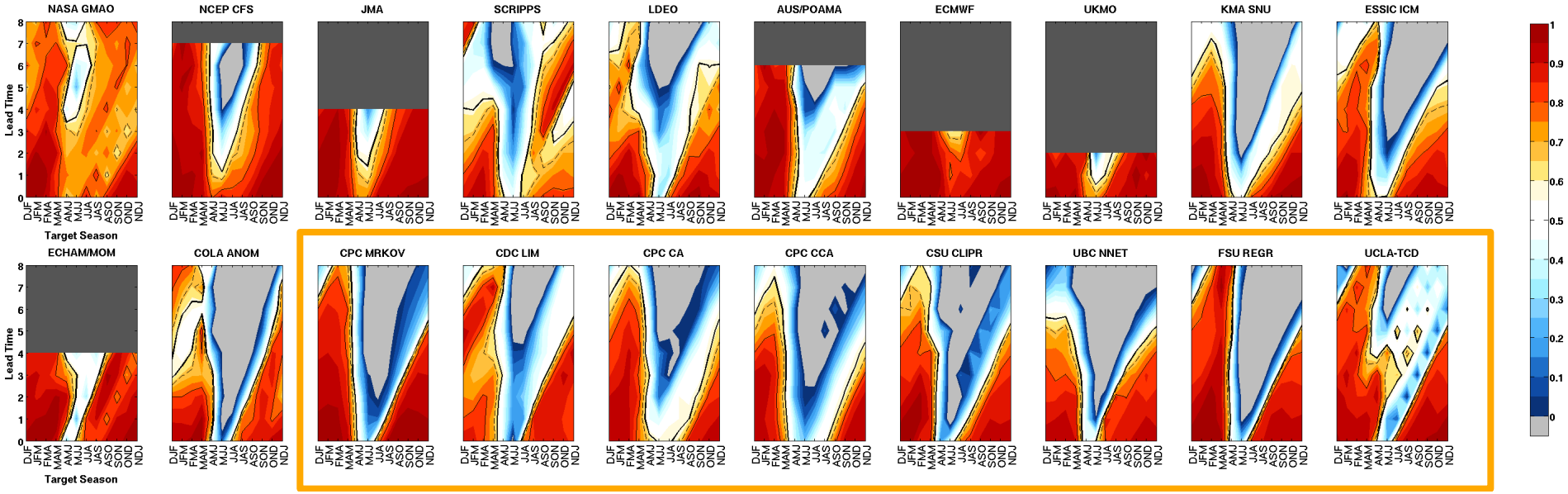
White/Blue: Lower correlations (0 < r < 0.5)

Light Grey: Negative correlations (very poor skill!)

- Model skill is reduced during the N. Hemisphere spring when ENSO often emerges or decays
- CFS prediction improves to ~0.8 to 0.9 correlation for prediction of the N. Hemisphere winter (after ~June)
- RMSE (amount of error in amplitude) is ~0.5°C to 1.0°C in Niño-3.4

From Barnston et al. (BAMS, 2012)

Anomaly Correlations of ENSO models from 2002-2011
(from the IRI/CPC ENSO Prediction Plume)



The orange box designates the statistical models (the rest are dynamical)

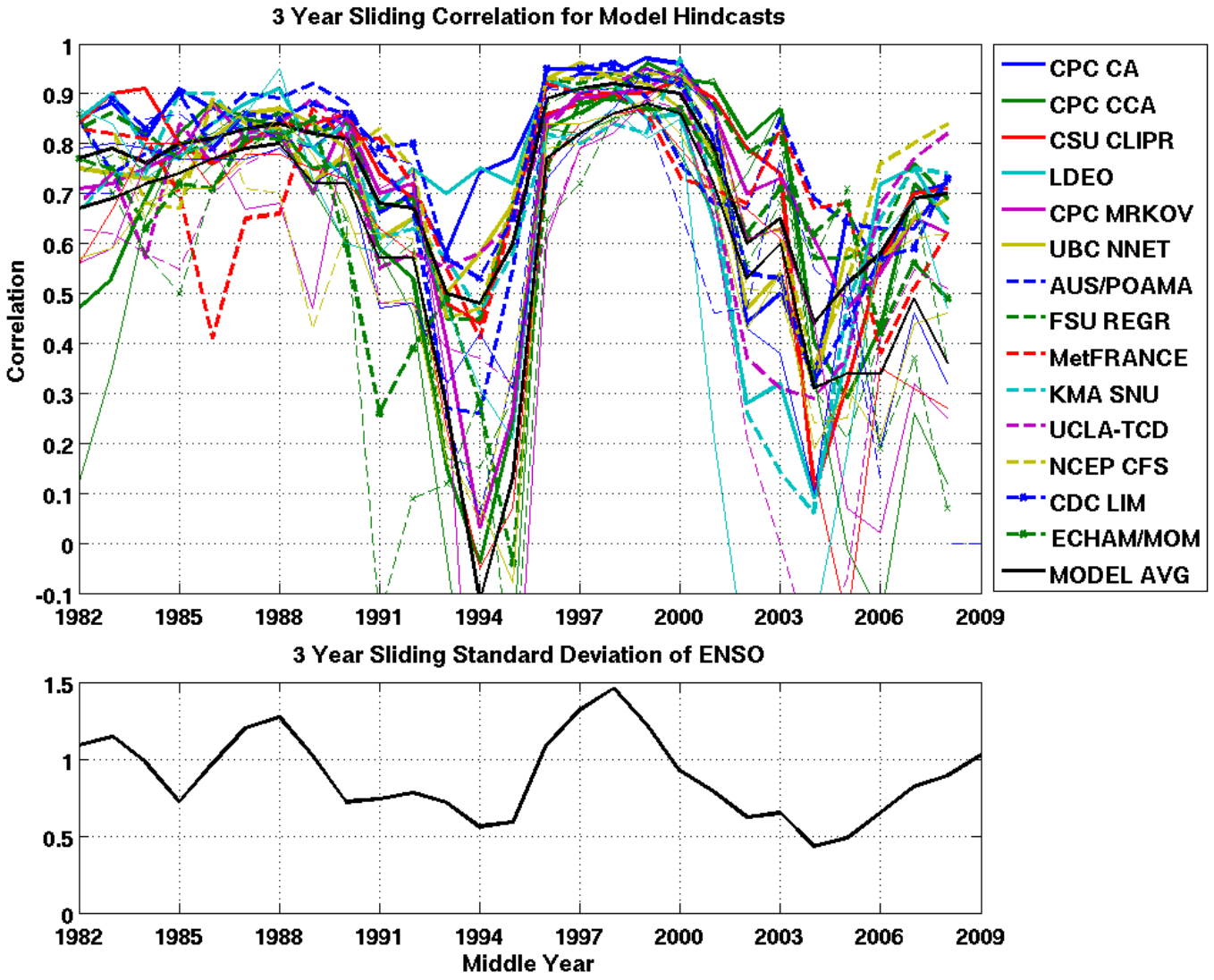
- Skill for mid-year targets: Dynamical Models > Statistical models

-- Dynamical models have better initial conditions and ability to detect changes on shorter timescales than statistical models (often trained on monthly or seasonal data)

- For NH winter target, statistical and dynamical models are more comparable.

From Barnston et al. (BAMS, 2012)

Top Panel: 3-year sliding Correlation based on Hindcasts (1981-2010)
Bottom Panel: 3-year sliding variability of Niño-3.4



Periods of smaller Niño-3.4 variability → Lower Model Skill (and vice versa)

ENSO model skill decreased during 2002-10 in part due to the observed ENSO variability.

Model predictions can fluctuate due to natural, multi-year/decade variability of ENSO (and overwhelm attempts to detect forecast model improvements)

From Barnston et al. (BAMS, 2012)

Currently Popular Areas of ENSO Investigation

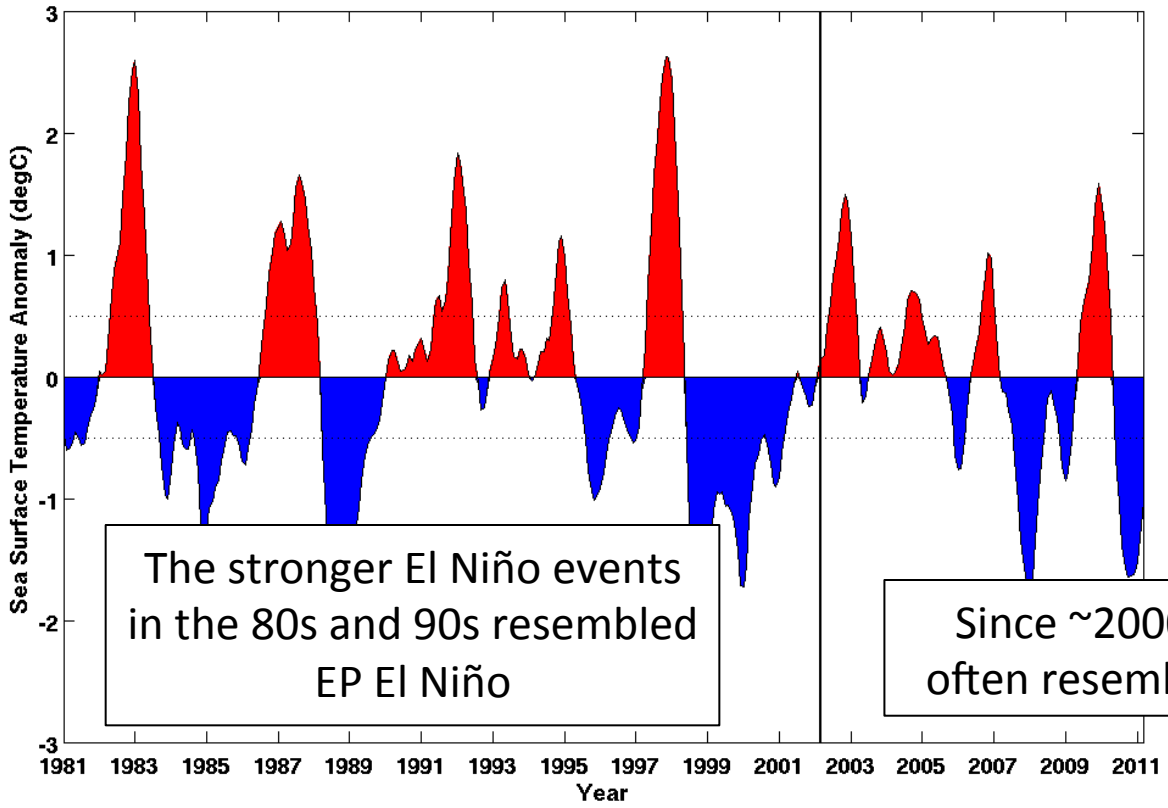
(1) Understanding different types, or "flavors," of ENSO

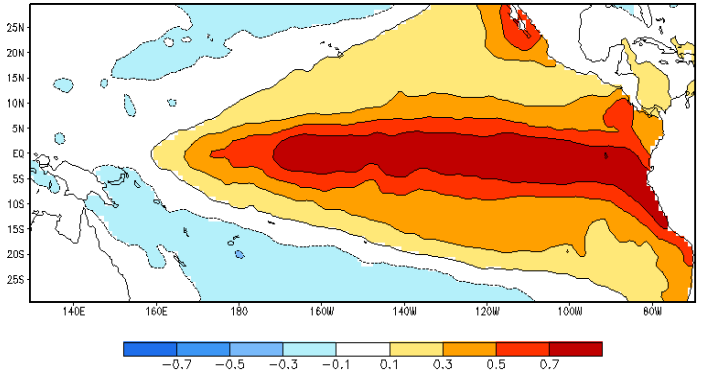
***Potential Operational linkage*: better understanding of ENSO intensity and impacts over the United States**

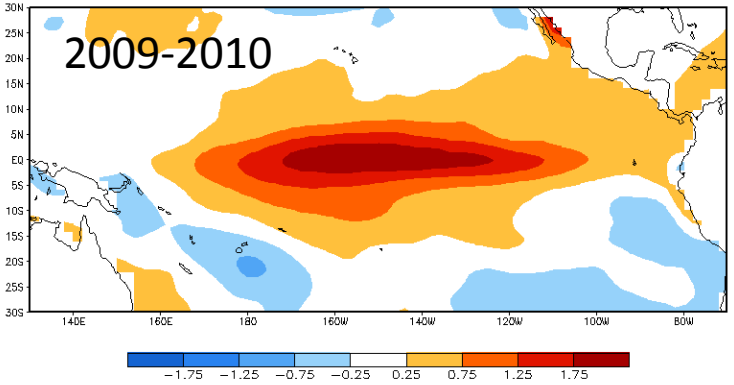
(2) Exploring the role of mid-latitude variability on ENSO

***Potential Operational linkage*: extending ENSO forecast skill out to a year?**

Considerable Variety in the Structure and Amplitude of El Niños







Eastern Pacific (EP) El Niño = Cold Tongue El Niño = Conventional or Canonical El Niño

Central Pacific (CP) El Niño = Warm Pool El Niño = El Niño Modoki = Date Line El Niño

Eastern Pacific vs. Central Pacific Impacts

PRO: Data from CMIP3 model runs, which increase the number of cases and significance (# of cases too small in the observational record). CON: is susceptible to model errors.

From Mo (2010)

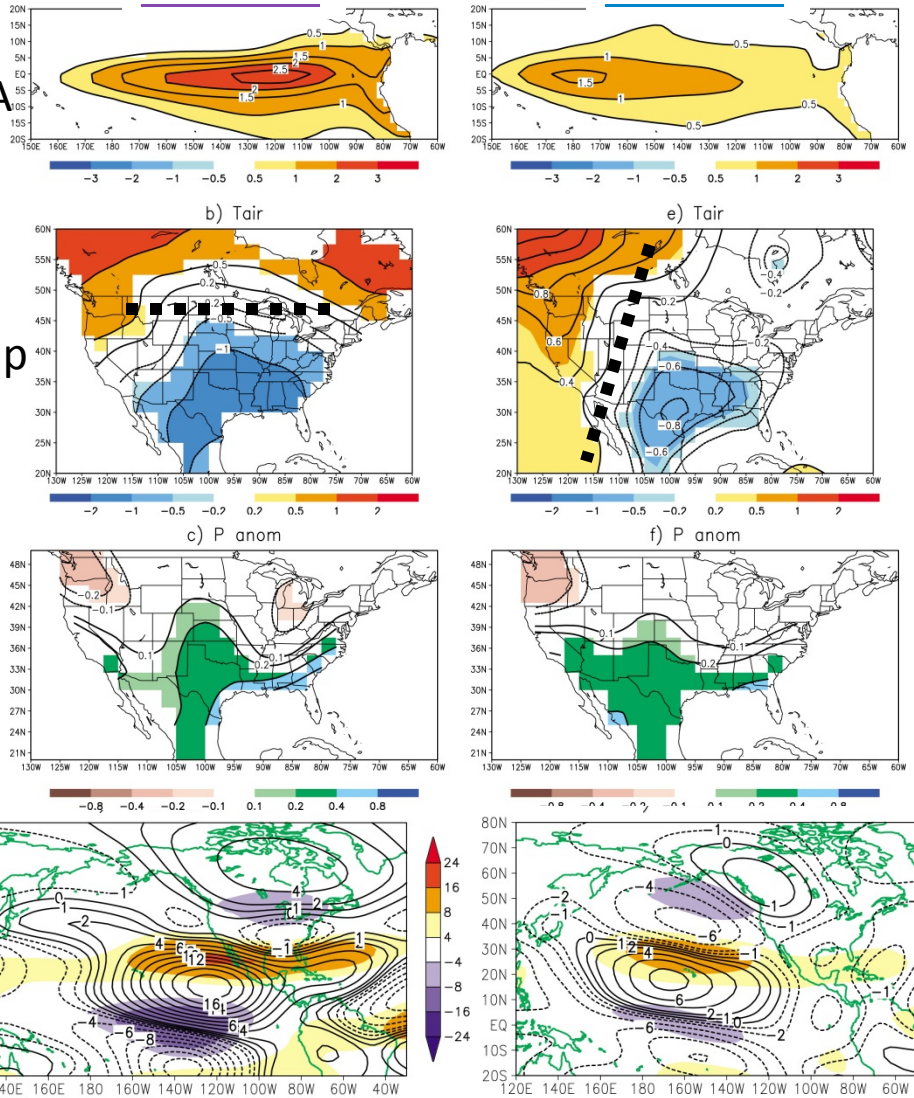
EASTERN CENTRAL

SSTA

Temp

Precip

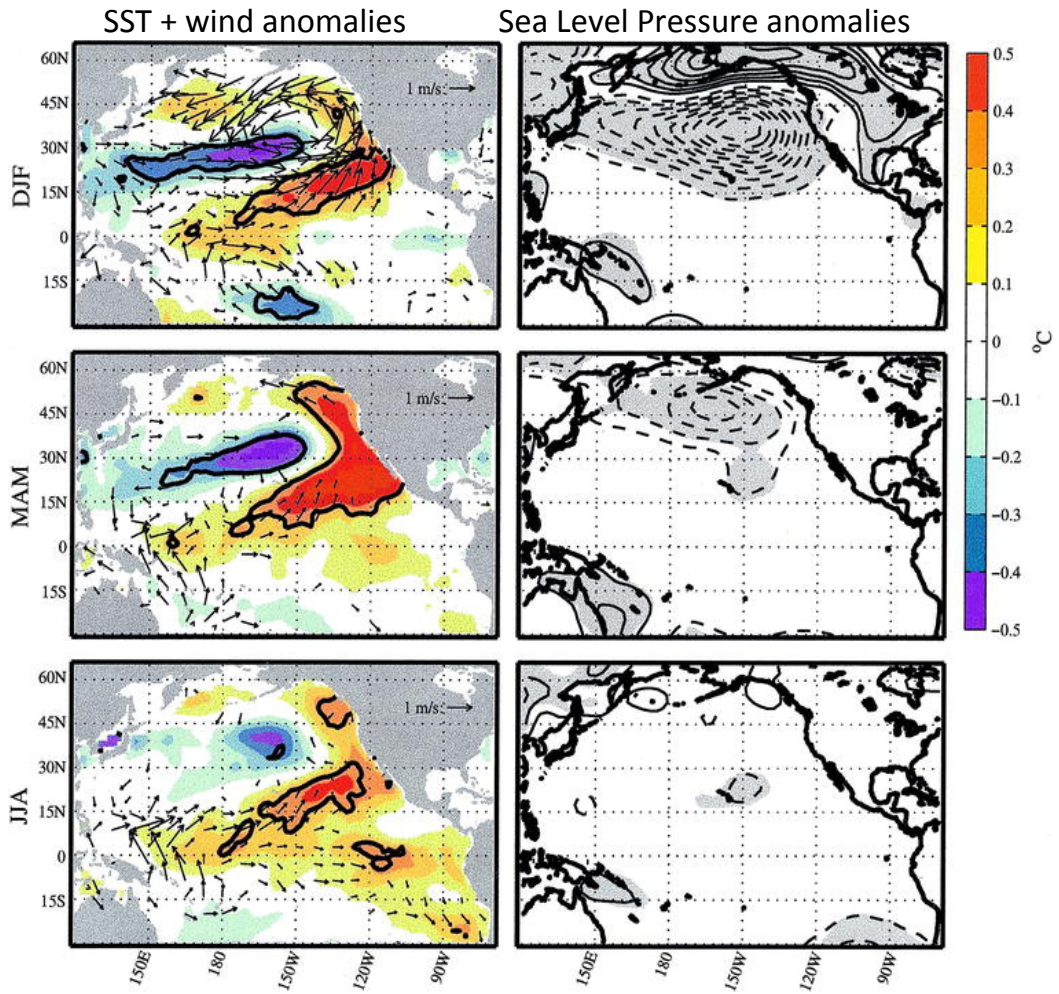
200mb winds & streamfunction



Eastern Pacific (EP) El Niño has a stronger zonal configuration

Central Pacific (CP) El Niño:
Pacific jet does not extend as far eastward and flow is less zonal over the U.S.

Role of Mid-latitude variability on ENSO



Chiang and Vimont (2004)

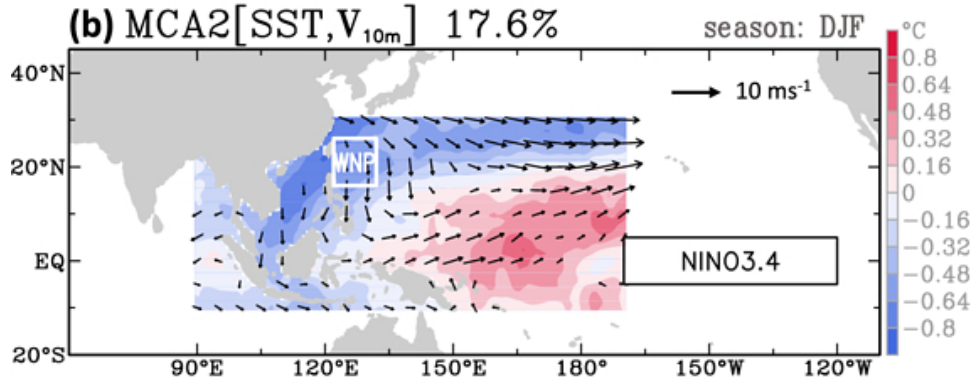
"Seasonal Footprinting Mechanism (SFM)"

(1) "North Pacific Oscillation"- NPO (upper right panel) during winter → subtropical SST "footprint" that persists for several seasons

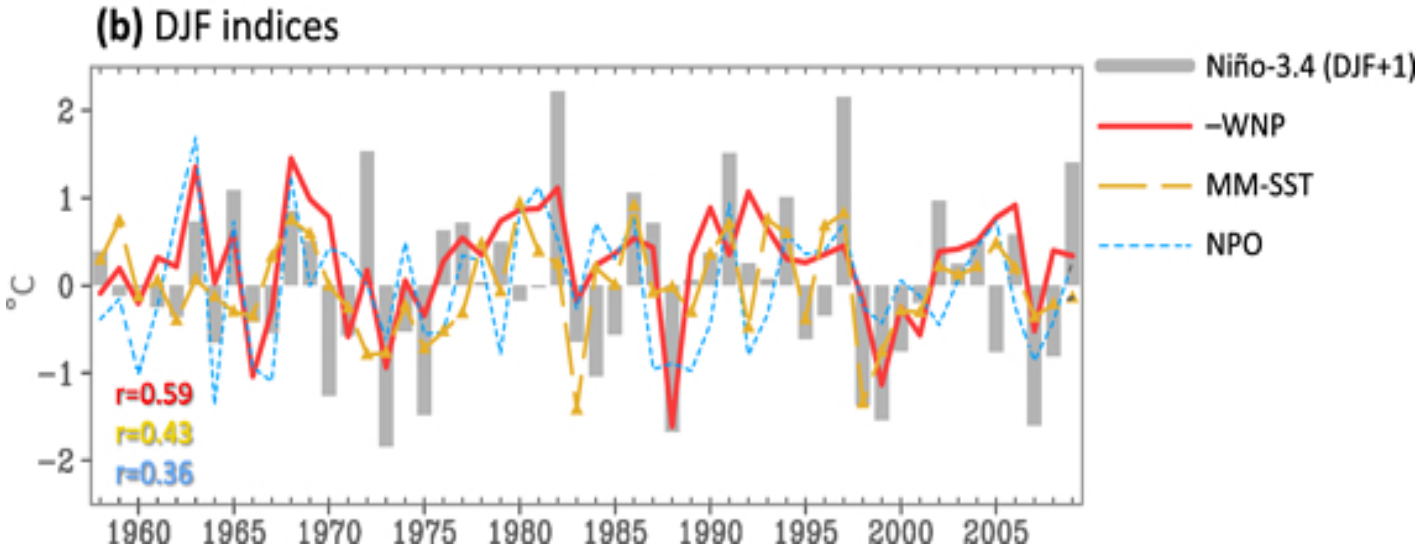
(2) Subtropical SSTs → winds that extend to the equator and eventually can influence equatorial SSTs

Role of Mid-latitude variability on ENSO

SST + low-level wind anomalies in the western N. Pacific (WNP)



WNP index (red line) against Niño-3.4 one year later (grey bars)



- S.-Y. Wang et al. (2012, GRL) identify "Western North Pacific (WNP)" index that correlates well with Niño-3.4 index one year in advance (~36% of variance using dependent data).

- The WNP is likely a part of the broader SFM idea, but may more directly influence generation of ocean waves (Kelvin waves) on the equator.

Q: Has ENSO been solved? A: No.

How do we move forward?

(1) Better understand mechanisms and evaluate models to distinguish and predict ENSO flavors and their impacts
-- EP El Niño are generally stronger El Niños (forecasted better) and CP El Niños are weaker (and not forecasted as well)

(2) In tandem with observations, evaluate how well models simulate different aspects of the Seasonal Footprinting Mechanism (SFM) → ENSO linkage

(3) Improve model physics (especially clouds/convection): "Cold tongue" and double ITCZ biases affect ENSO frequency and flavor.

(4) Produce ensembles + long reforecasts + develop statistical procedures to correct for systematic model biases and generate probabilities.

(5) Improved ocean observations for the best initial conditions possible- includes the subsurface ocean! [note: over the last year, reduction in data from the TAO/TRITON buoys in the eastern half of the Pacific]

(6) Developing and improving historical SST datasets will be helpful to put ENSO events (and flavors) in better context and strengthen confidence in associated impacts.

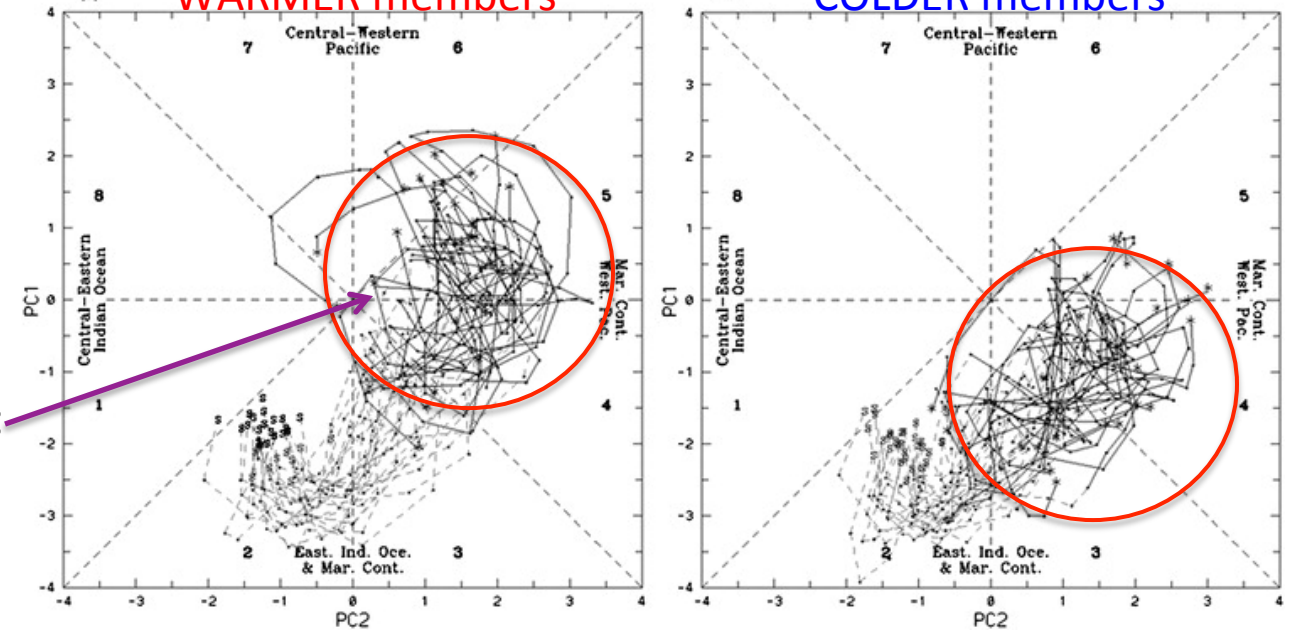
1997-98 El Niño amplitude/strength was not well predicted by deterministic models (Barnston, BAMS 1999).

Ensemble members with a more progressive MJO shift did better with the strong 97-98 event than those without (Shi et al. 2009).

90 member POAMA model initialized in Dec 1996 out to 9 mths

MJO index for WARMER members

MJO index for COLDER members



WARMER members: MJO propagating further east than in COLDER case

Ensemble prediction enables a percent chance (%) of a high intensity event that a deterministic/ensemble mean does not provide (Federov et al., BAMS 2003).

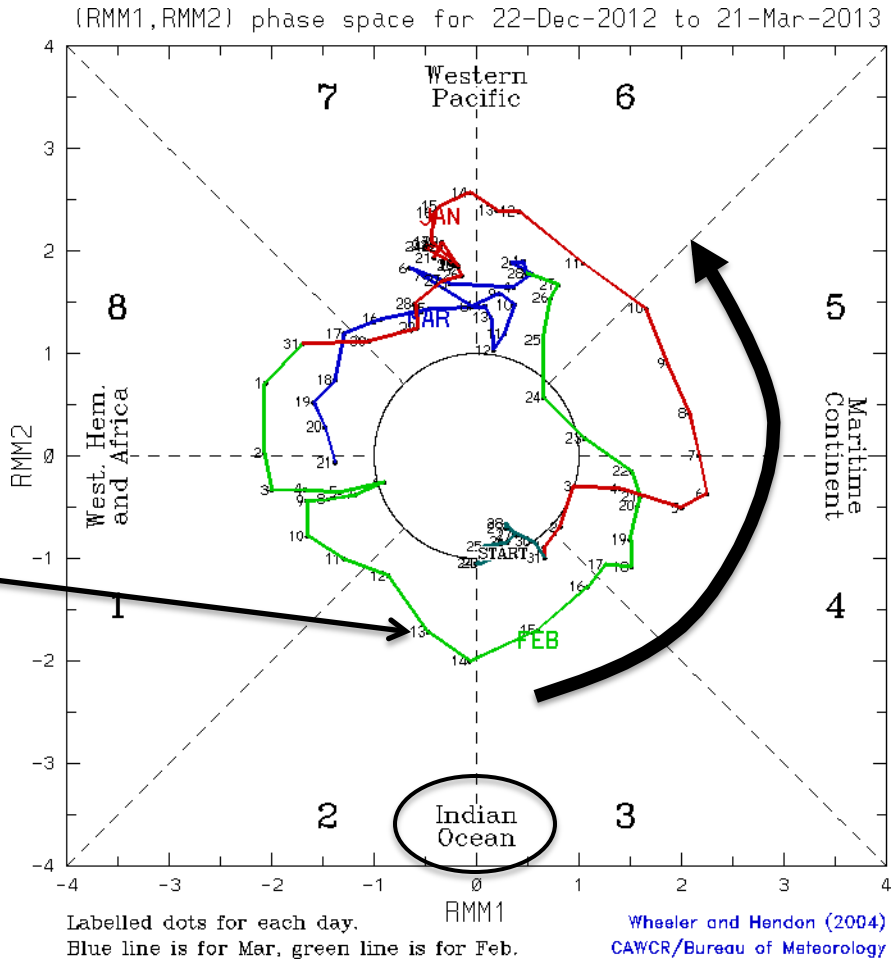
II. Madden-Julian Oscillation (MJO) Attribution and Prediction

What is the MJO?

- Sub-seasonal (varies within a month/season) climate pattern that moves eastward around the global tropics in ~30-60 days.
- Has its strongest tropical impacts (winds, rainfall) over the Indian and Pacific Oceans when it moves slower (5 m/s). But still affects the Western Hemisphere even though moving faster.
- Exists ~40-50% of the time, but can go many seasons without an MJO.

CPC monitors the MJO with the Wheeler and Hendon MJO index

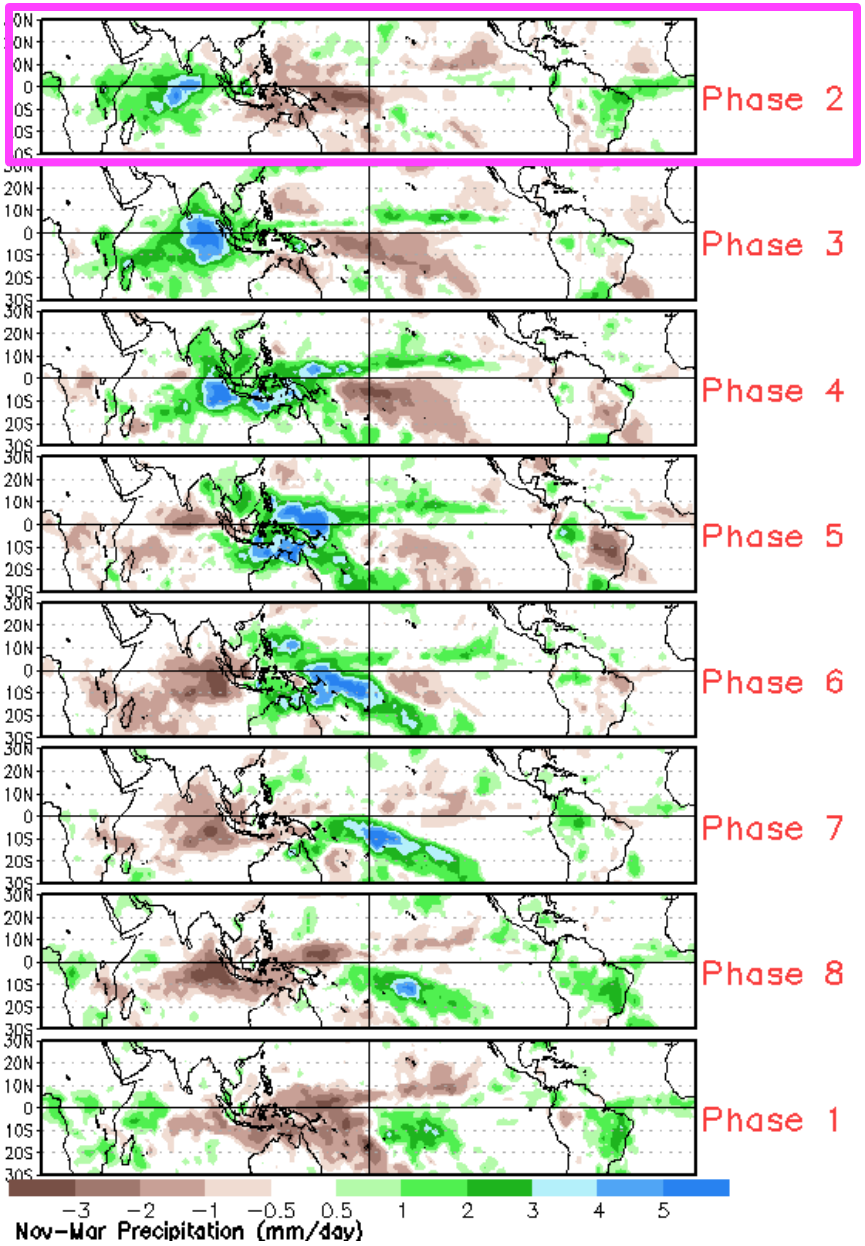
Each dot/number represents a single day and location of the MJO enhanced rainfall.

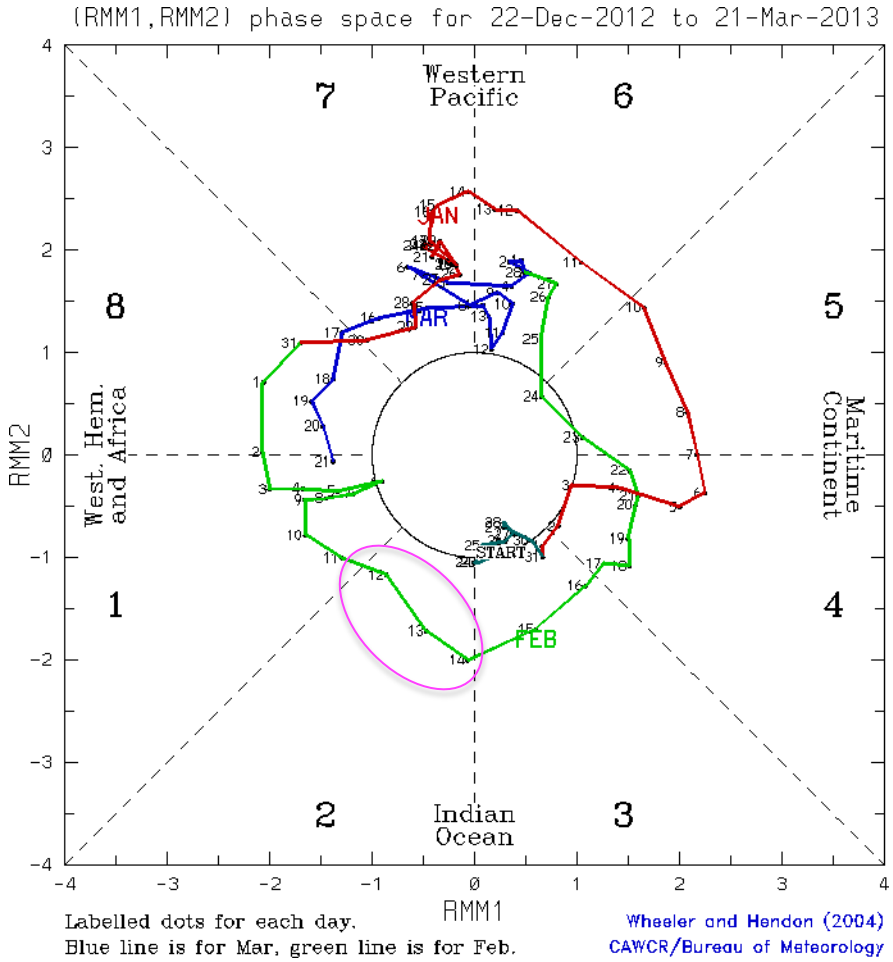


MJO exists when there is counterclockwise movement on diagram

Madden Julian Oscillation

Tropical Rainfall Patterns linked to MJO phases

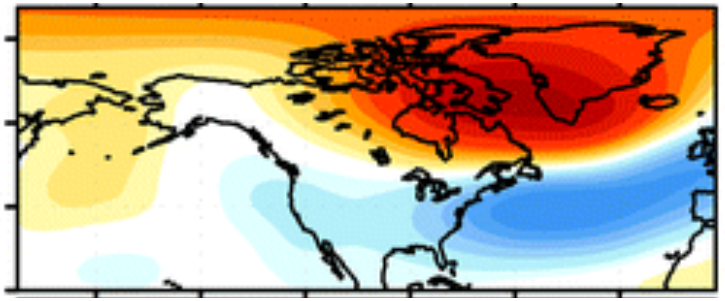




Wheeler and Hendon MJO index shows the position of the MJO in real time.

For example on February 12-14th, 2013, MJO in Phase 2 so expected tropical rainfall pattern is shown on the upper left.

Certain Wintertime 500-hPa Geopotential Height Patterns occur more frequently with MJO



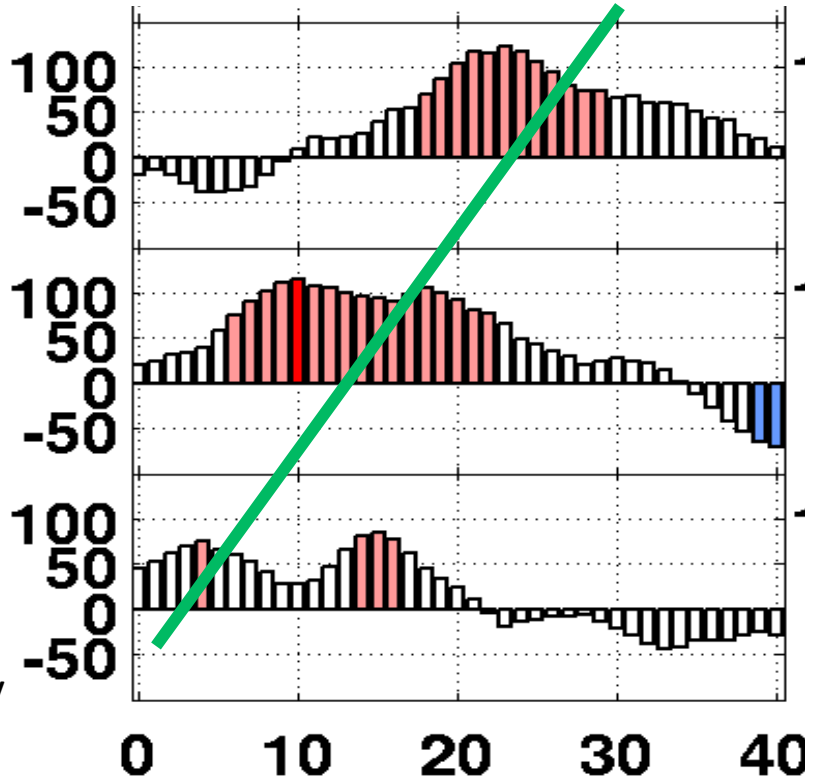
Negative AO/ NAO-ish pattern

Bars = Frequency of occurrence over climatology
(100 means twice as frequent as the full record).

POSTIVE/RED BARS: pattern more frequent

NEGATIVE/BLUE BARS: pattern less frequent

Colored bars are statistically significant at 95% level



MJO PHASE 6: Central Pacific Ocean

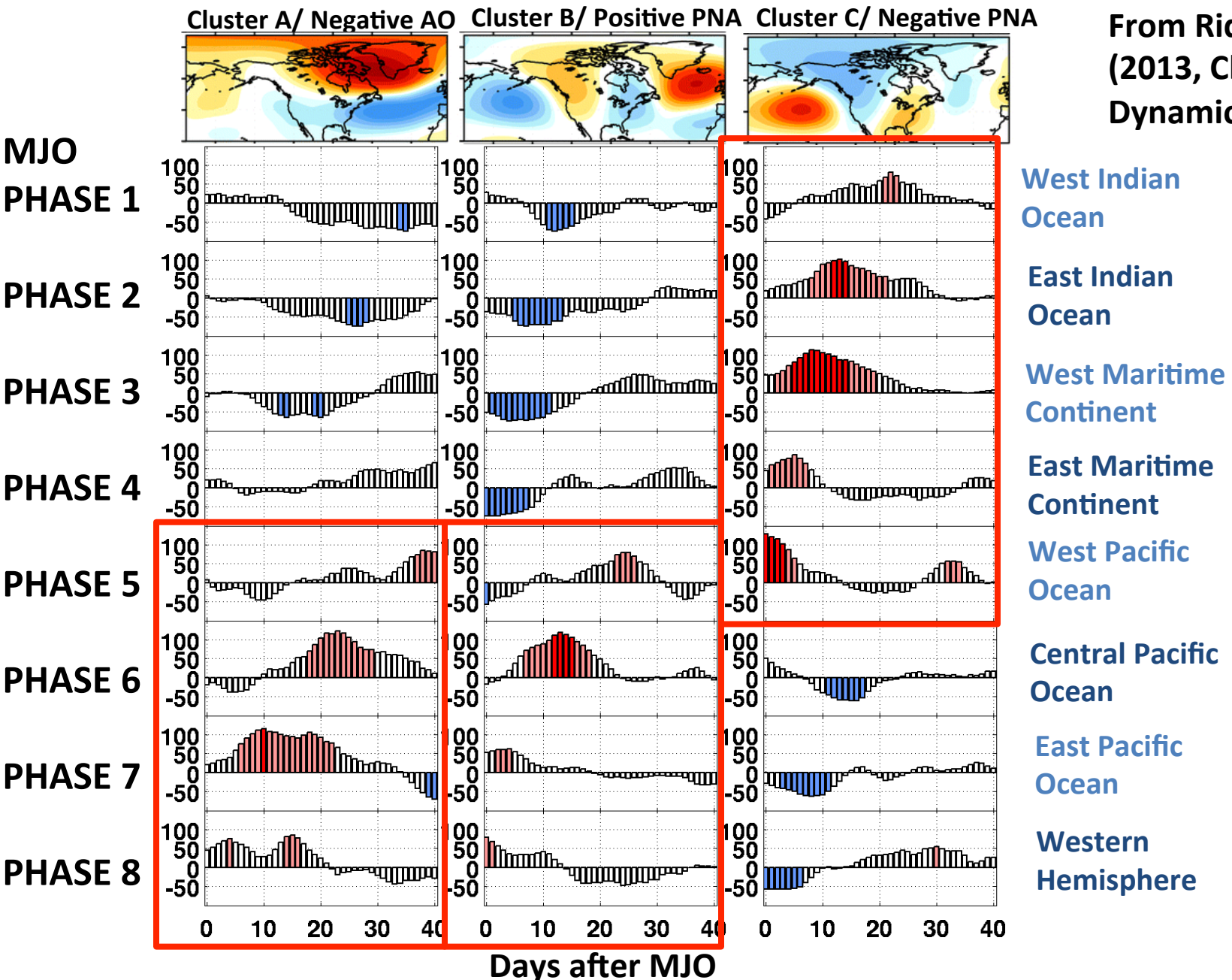
MJO PHASE 7: East Pacific Ocean

MJO PHASE 8: Western Hemisphere

SLANT IS EVIDENCE OF EASTWARD MOVING MJO SIGNAL

From Riddle et al. (2013, Climate Dynamics)

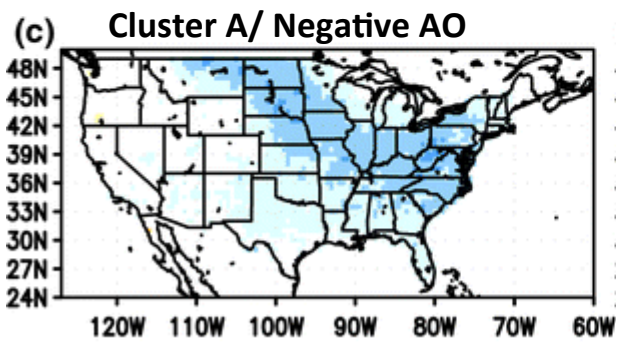
Influence of the MJO on the Extratropical Circulation

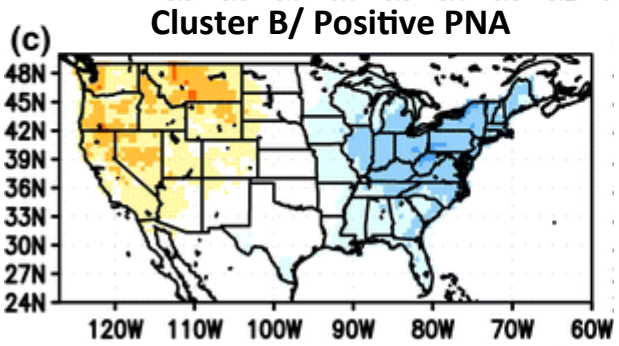


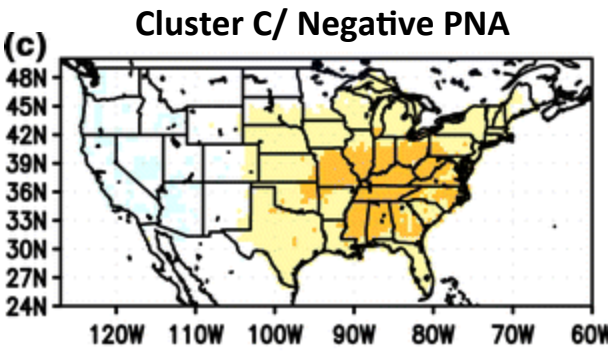
From Riddle et al. (2013, Climate Dynamics)

Connection with Wintertime U.S. Surface Temperature

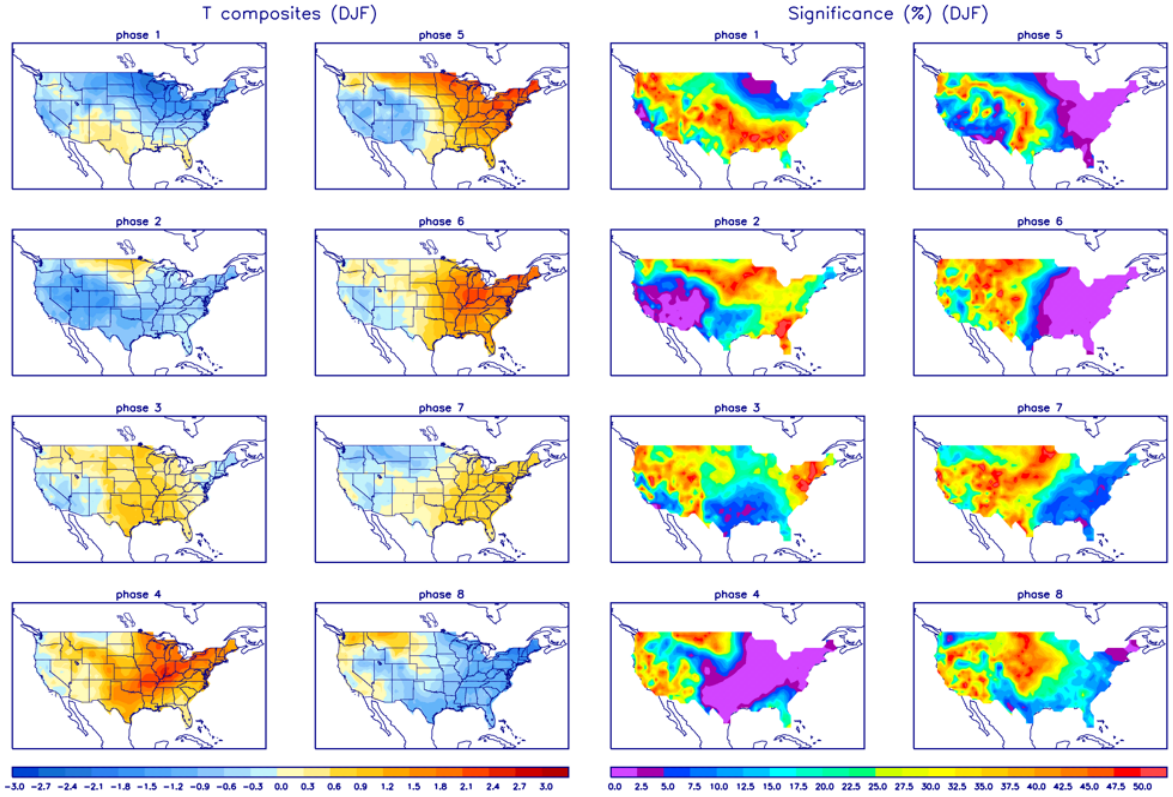
Surface Temperature associated with MJO circulation patterns:







Composites of Surface Temperature based on MJO Phase:

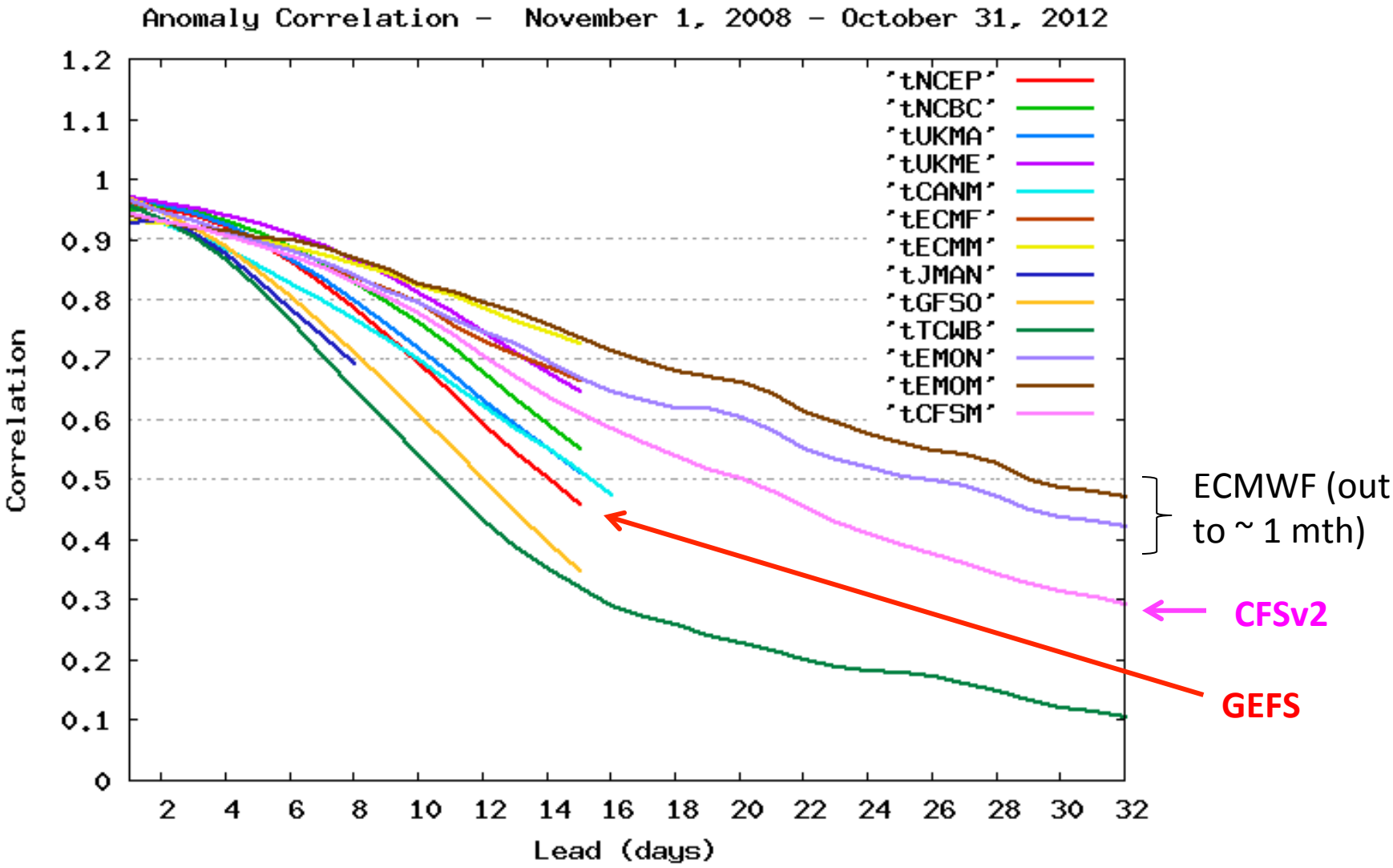


From Riddle et al. (2013, Climate Dynamics)

From Zhou et al. (2012, Climate Dynamics)

How good is the prediction skill of the MJO?

- Not terrible ☺. For prediction of *the MJO index* (Wheeler&Hendon), reasonable skill is found out to 2 weeks for nearly all models.



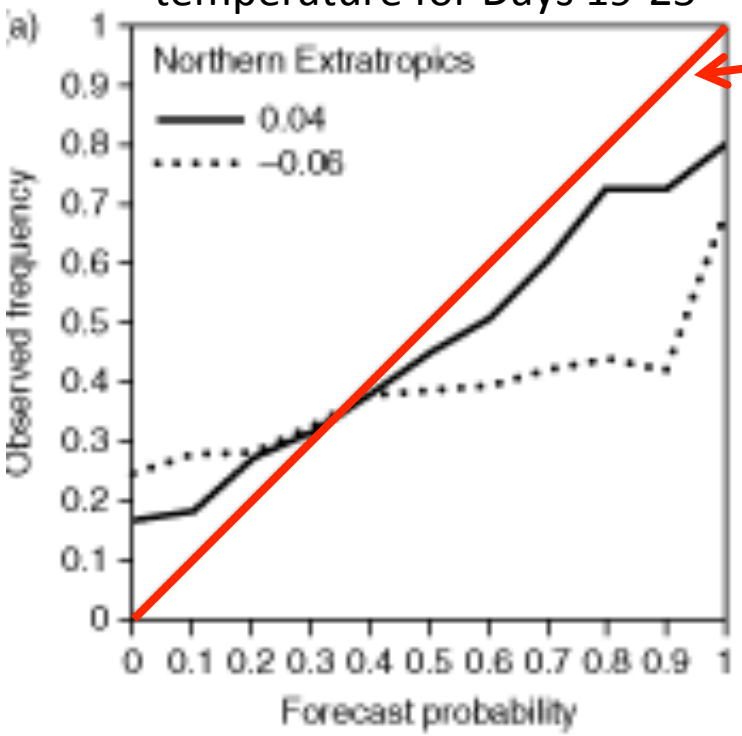
Analysis by Jon Gottschalck and Augustin Vintzileos

How good is the prediction skill of the MJO?

- Do models capture the influence of *MJO on the temperature in N.H. (north of 30°N)*?

-- ECMWF show considerable improvement with MJO occurring (thick black line) VS. *no* MJO occurring (dotted black line)

For upper tercile of 850-hPa temperature for Days 19-25



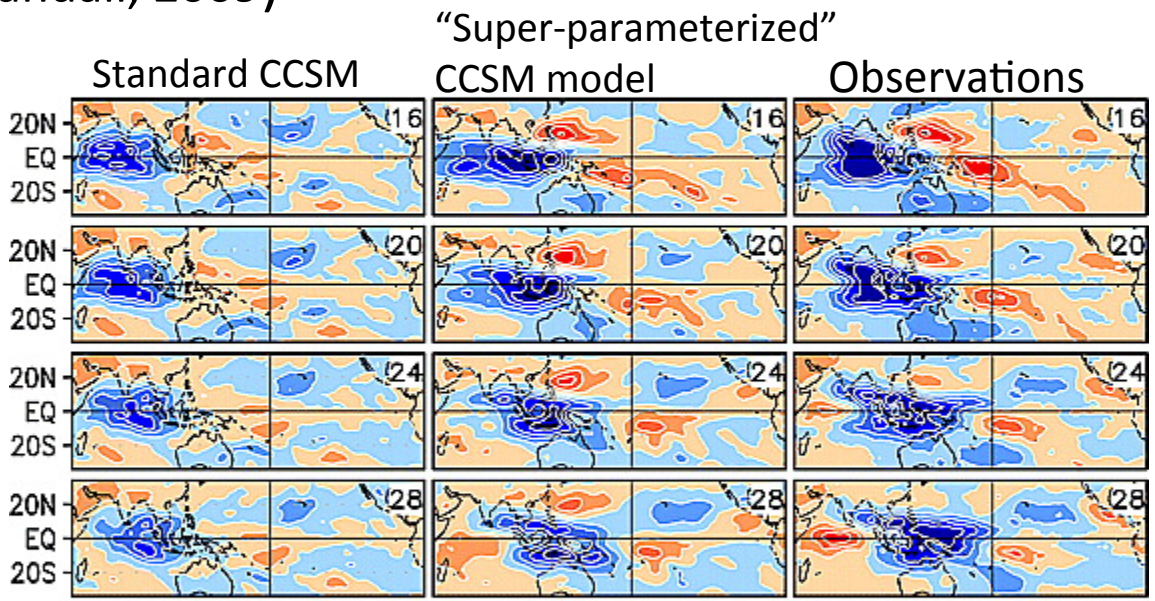
A reliable probabilistic prediction would lie perfectly on this diagonal line

(an unreliable one would be a nearly horizontal or flat line)

Using 20 year reforecasts in ECMWF system
(from Vitart and Molteni, 2010)

Where do we have room to improve?

- Better initializations and model physics to resolve the MJO (i.e. better clouds/moisture/convective processes– Stan et al. 2010; Thayer-Calder & Randall, 2009)



From Stan et al. (2010)

OLR anomalies during an MJO (blue: more rainfall orange: less rainfall)

- Continued studies on how the MJO influences the United States.

-- extracting "signal" (MJO) from the "noise" (synoptic detail) is more difficult on sub-monthly timescales.

---requires rigorous statistical testing on *both* observational and model (reforecast) data.

What does improved representation of the MJO give us?

- More skillful prediction over the globe:

-- Temperature (cold air outbreaks)

-- ENSO onset and decay

-- Severe weather (hurricanes–Maloney and Hartmann, 2000/2001, potentially tornadoes– Thompson and Roundy, 2012)

-- Etc.

- A better MJO would lead to better **probabilistic** outlooks (##) for **Weeks 1 through 4**.
- Better understanding of the MJO and its impacts leads to increased **attribution** capability (i.e. what is driving this cold air outbreak?)

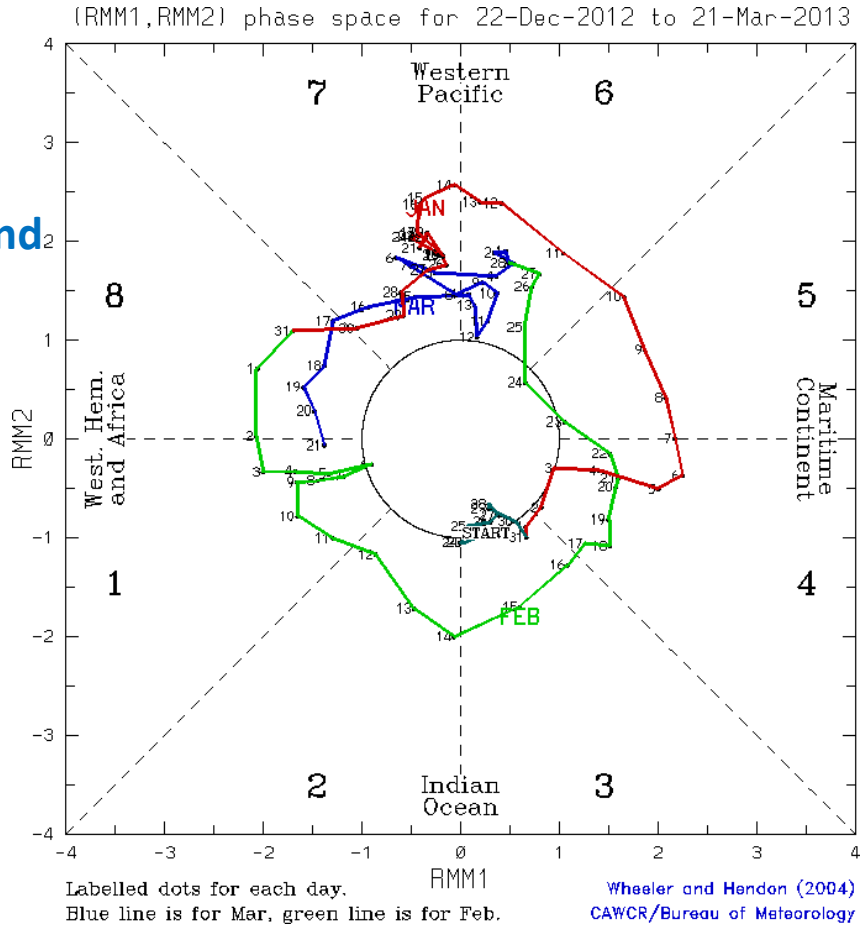
This requires ensemble prediction (many members) and statistical calibration methods (requires reforecasts belonging to the current forecast model).

A Recent Case Study: January-March 2013

CLIMATE INGREDIENTS:

- **ENSO-neutral (neither El Niño or La Niña)**
- **Sudden Stratospheric Warming (SSW)**
- **Active Madden Julian Oscillation (MJO)**

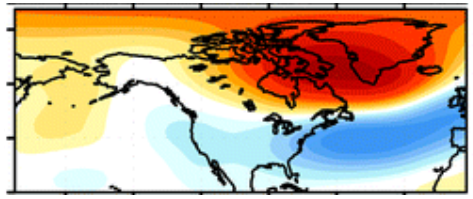
MJO in phases 7/8/1 during last half of January and March

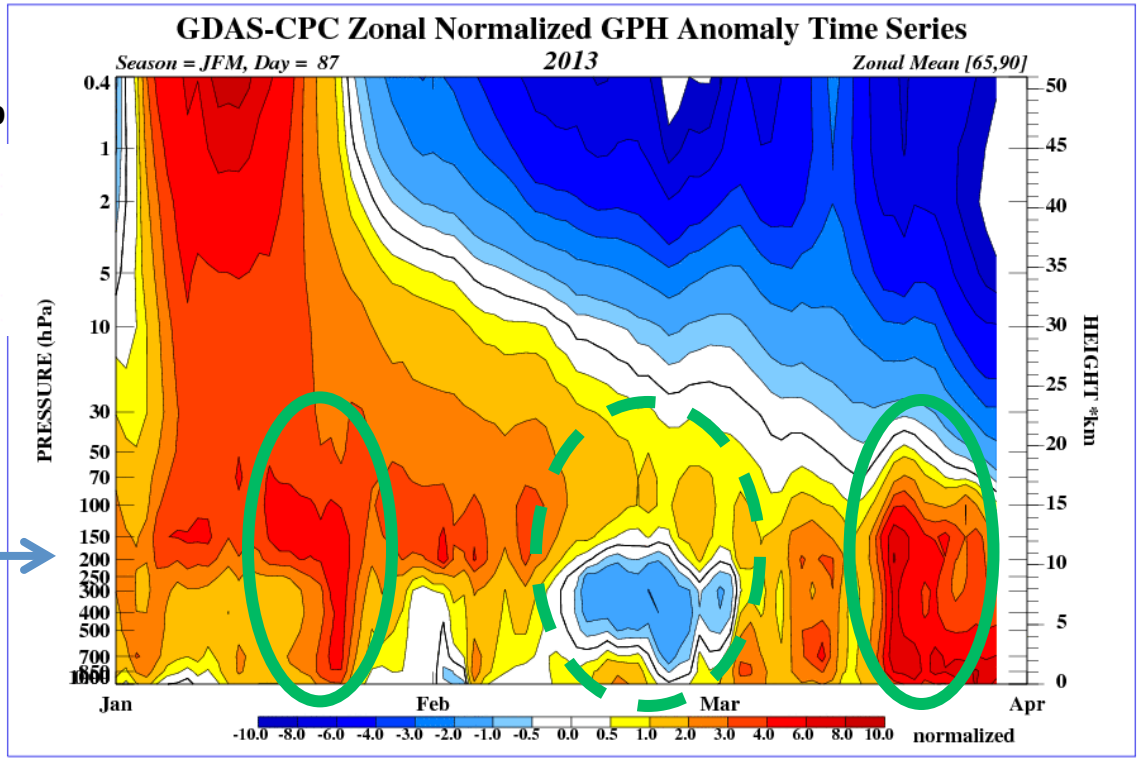


MJO in phases 3-6 during last half of February

Vertical cross section of zonally averaged Geopotential Height (GPH) over the N. Hemisphere Polar Cap

Cluster A/ Negative AO = positive heights over polar cap





Tropopause

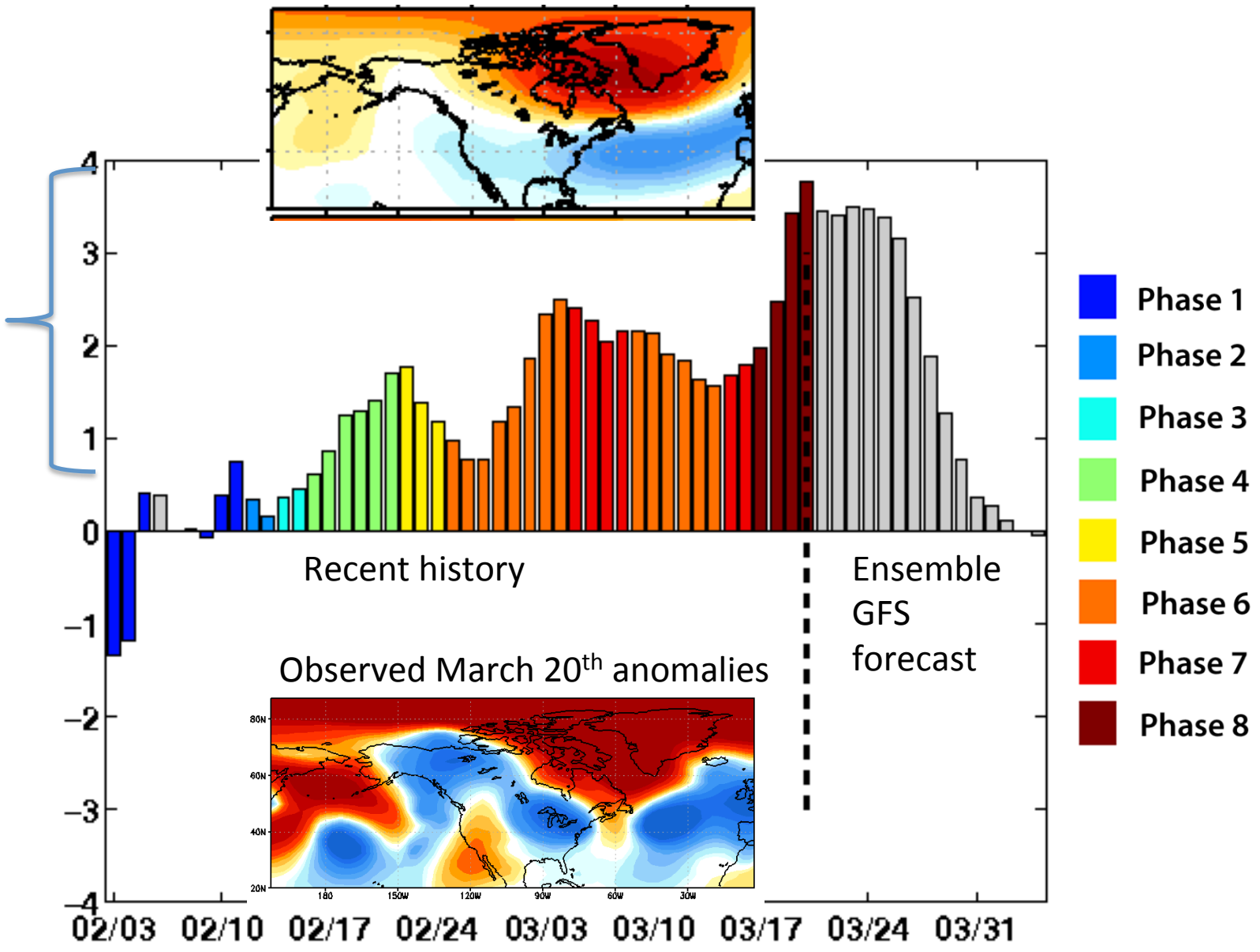
Real-time monitoring by CPC's stratosphere team

January through March 2013

- **Solid green: Surface GPH was most positive when MJO-related convection followed phases 7/8 (coincided with cold air outbreaks/ below avg. surface temps in the northern and eastern United States)**

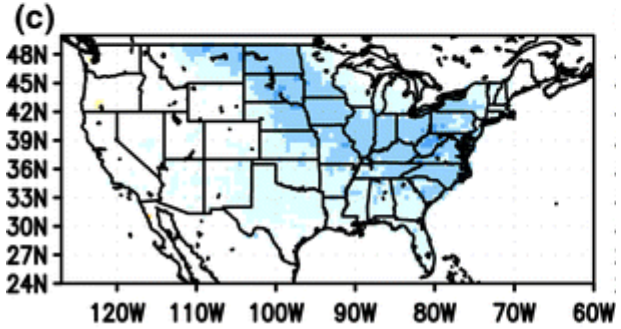
- **Dashed green: Polar cap GPH was weakest when MJO-related convection followed phases 3/4**

A snapshot from March 20th, 2013: The MJO was in Phase 8. The observed 500-hPa height pattern strongly matched the expected negative AO/NAO-ish pattern shown below.



Courtesy of Emily Riddle

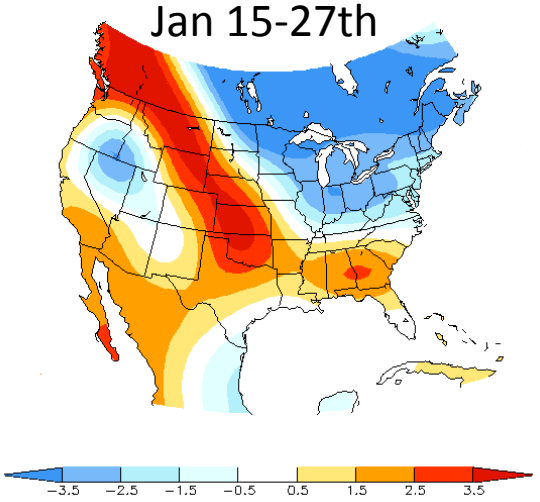
Averaging daily data
January-March 2013



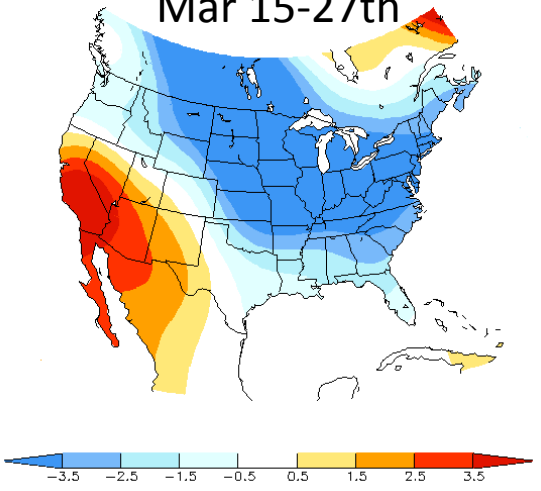
Expected MJO forced Surface Temperature pattern after Phase 7/8

925hPa Temperature from GDAS

Jan 15-27th

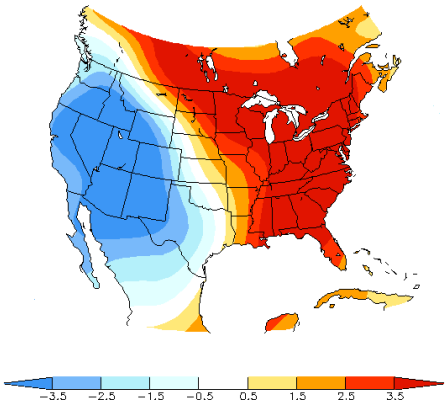


Mar 15-27th

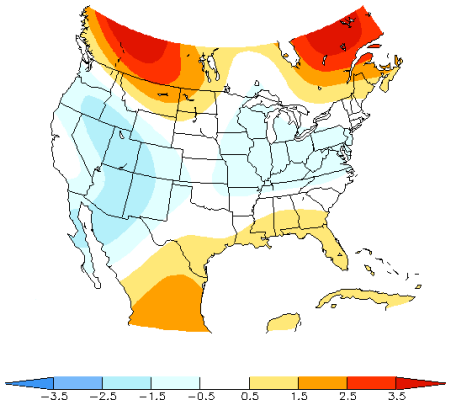


~ 2 week period following MJO into Phase 7.

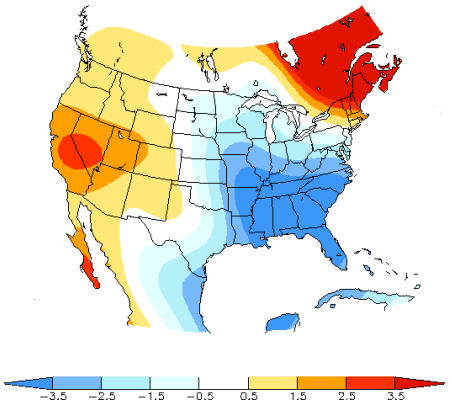
Jan 1-14th



Feb 1-28th



Mar 1-14th



Averages for the remainder of the JFM period

Where can I get information on the MJO?

CPC MJO webpage (links to **MJO Composites/Impacts**):
http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/mjo.shtml

Real-time MJO forecasts from various dynamical models (sponsored by CLIVAR):
http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/CLIVAR/clivar_wh.shtml

Weekly Update on the **current status & prediction of the MJO** (every Monday):
http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/mjo.shtml#discussion

Week-1 and Week-2 outlook for **rainfall and tropical cyclones over the global tropics** (every Tuesday):
http://www.cpc.ncep.noaa.gov/products/precip/CWlink/ghazards/index.php

Email Jon.Gottschalck@noaa.gov and Matthew.Rosencrans@noaa.gov
(CPC MJO Forecast Team)

Thanks for listening.
Any Questions?

You can also contact me at:
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