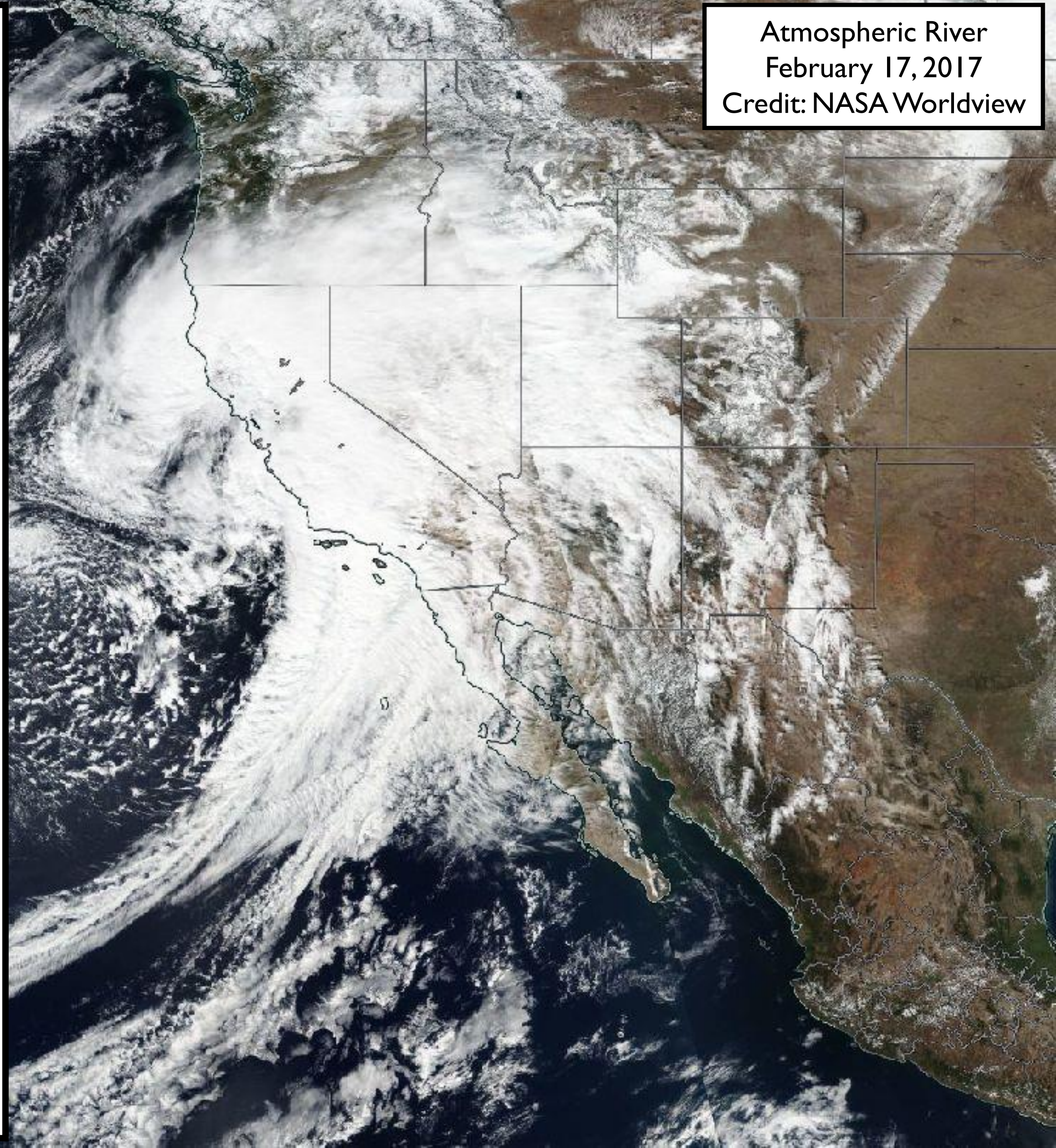
Atmospheric River and S2S Prediction Research

Colorado State University

Cory Baggett
(cbaggett@rams.colostate.edu)

Western States Water Council Workshop

May 15, 2018



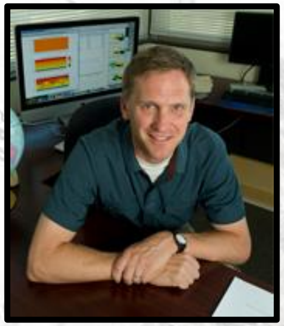
Atmospheric River
February 17, 2017
Credit: NASA Worldview

The Researchers

Cory F. Baggett
Research Scientist at CSU

Elizabeth A. Barnes
Professor at CSU

Bryan D. Mundhenk
USAF Lt Co at Asheville, NC



Eric D. Maloney
Professor at CSU

Kai-Chih Tseng
Graduate Student at CSU

Kyle M. Nardi
Graduate Student at CSU

Atmospheric Rivers (ARs)

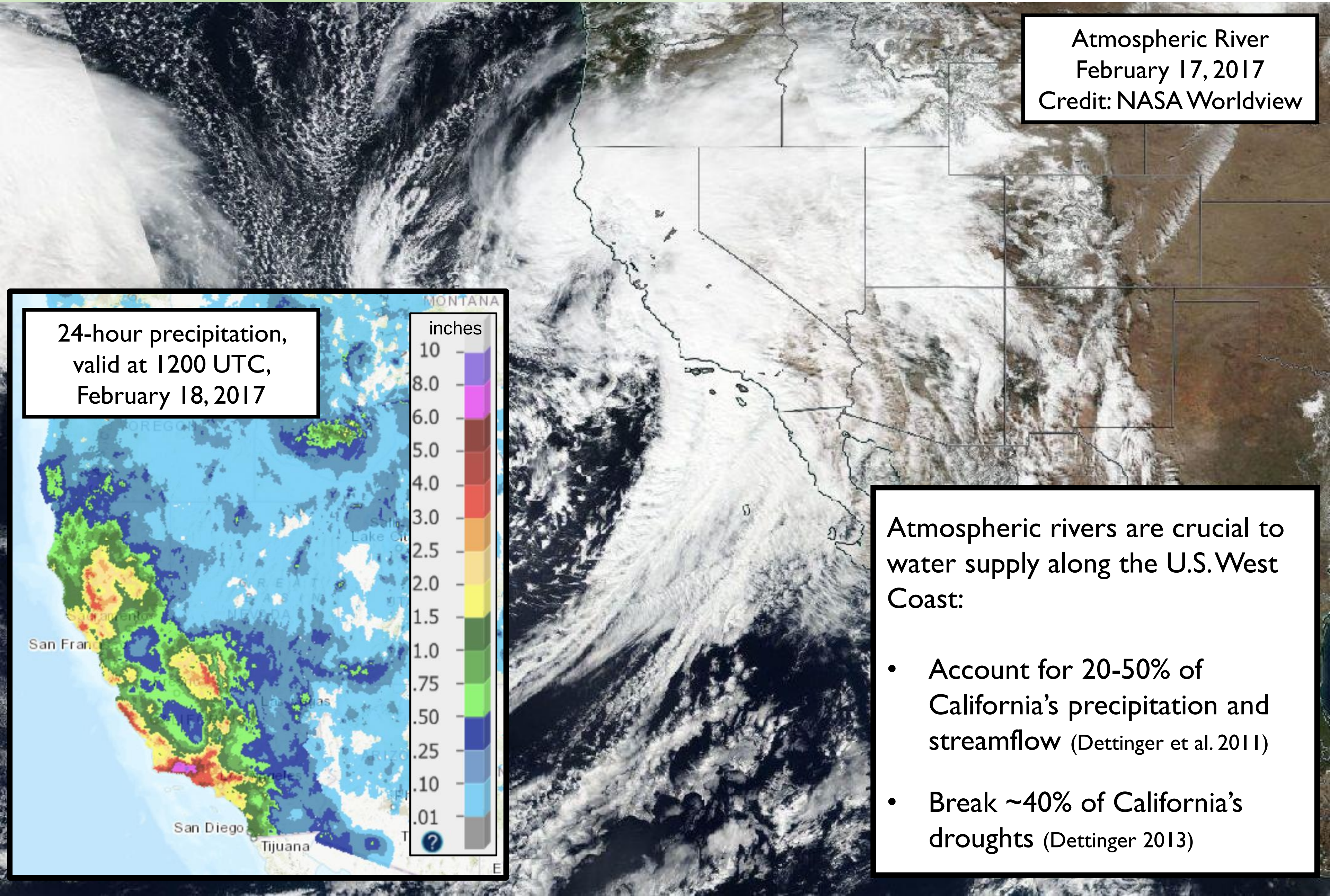
Atmospheric River
February 17, 2017
Credit: NASA Worldview

Atmospheric rivers are ”long, narrow, and transient corridors of strong horizontal water vapor transport that frequently lead to heavy precipitation. They are the largest ‘rivers’ of fresh water on Earth, transporting on average more than double the flow of the Amazon River.”

- AMS Glossary

Atmospheric Rivers (ARs)

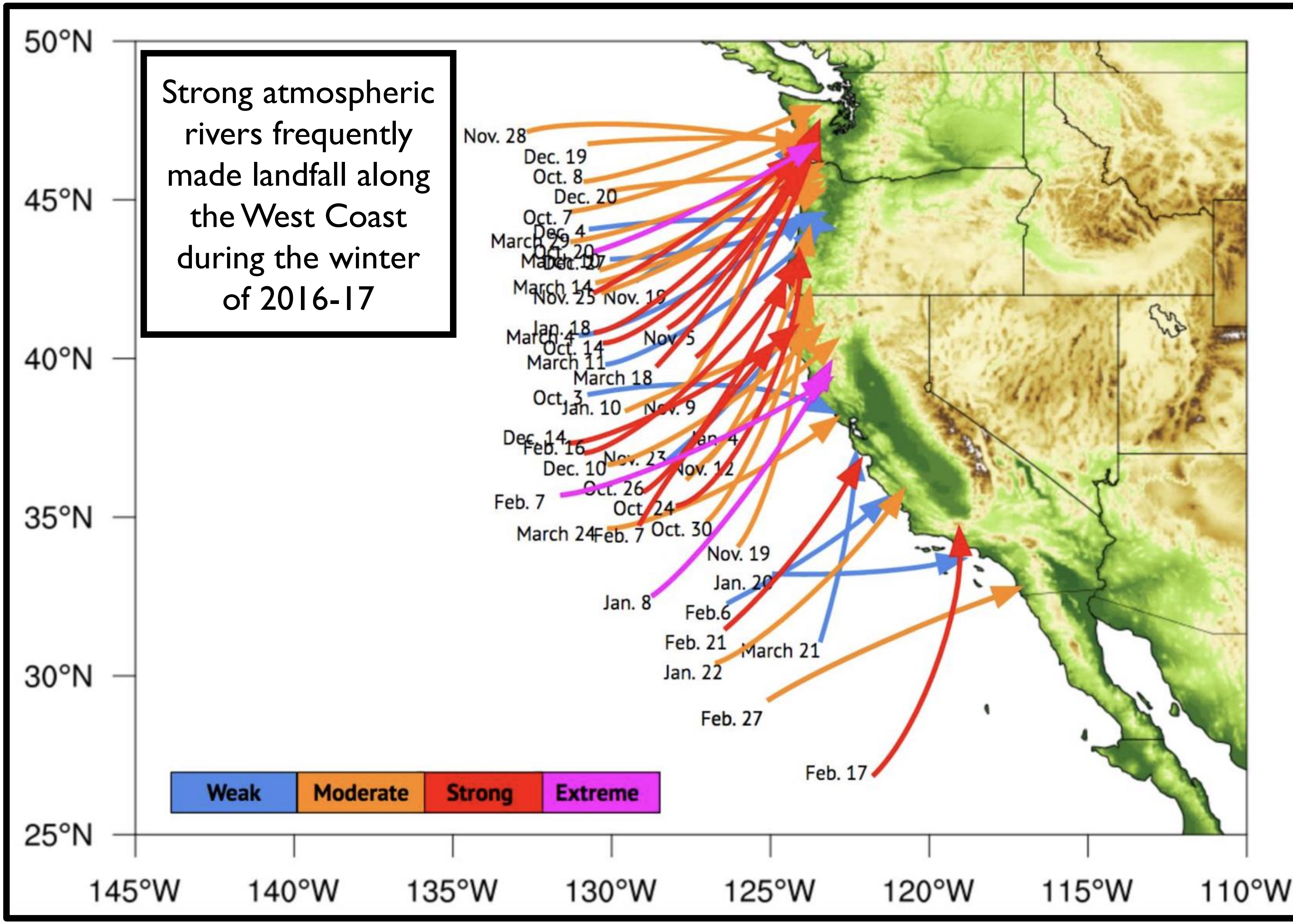
Colorado State University



Atmospheric rivers are crucial to water supply along the U.S. West Coast:

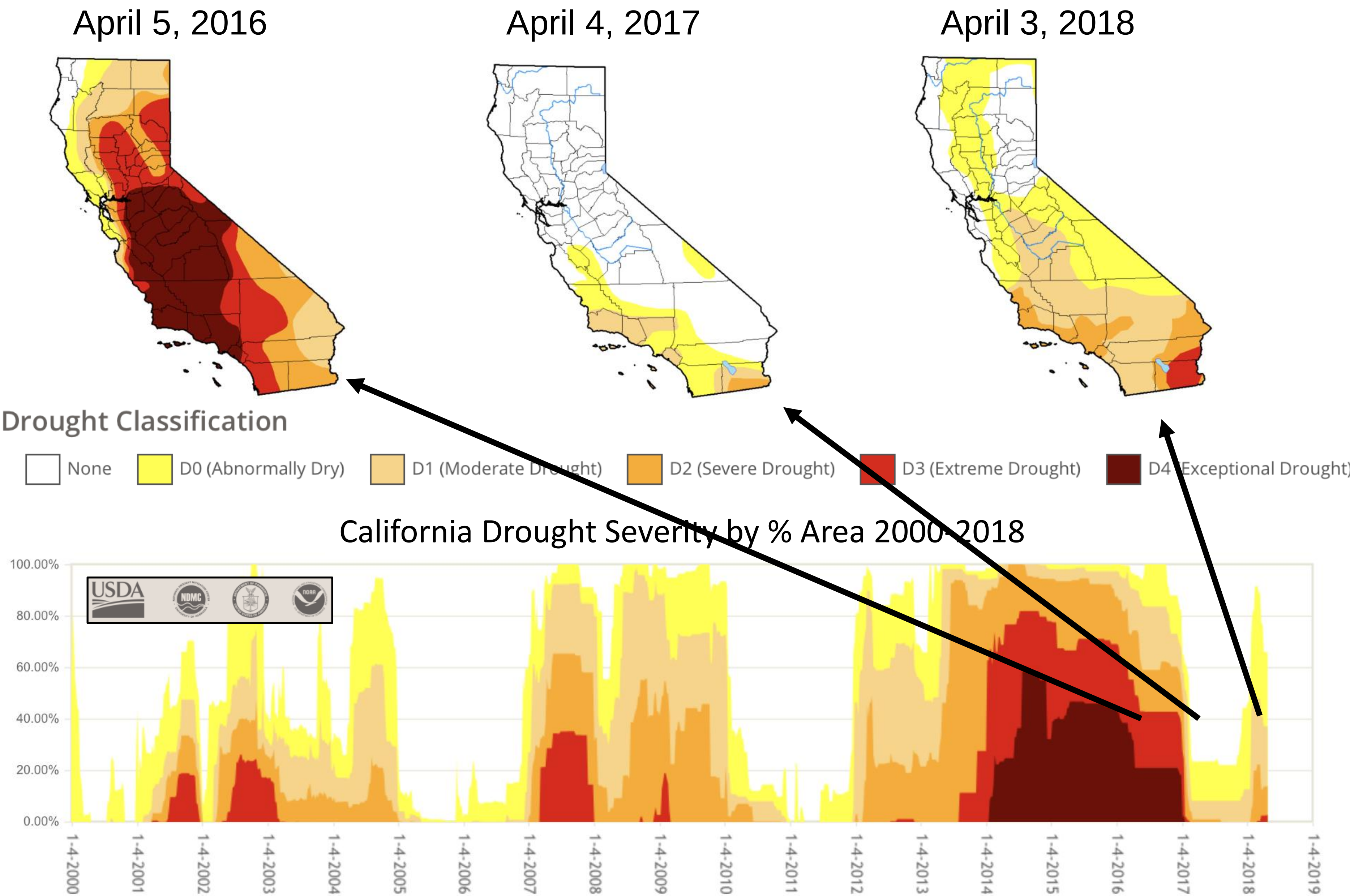
- Account for 20-50% of California's precipitation and streamflow (Dettinger et al. 2011)
- Break ~40% of California's droughts (Dettinger 2013)

Atmospheric River Landfalls 2016-17

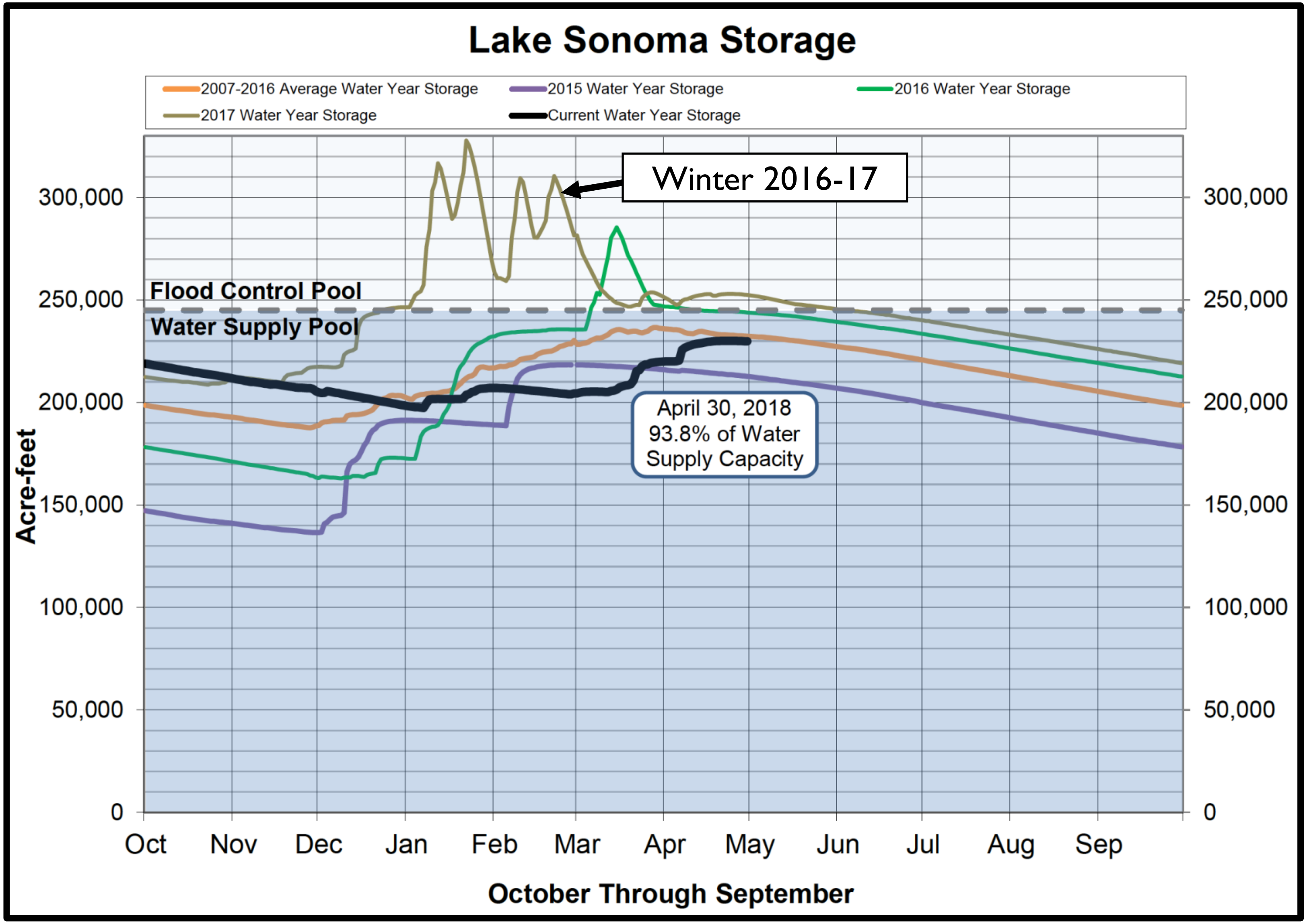


Credit: F.M. Ralph, B. Kawzeunk, C. Hecht, J. Kalansky

Ebb and Flow of California Droughts



Lake Sonoma Reservoir Conditions



Credit: Sonoma County Water Agency

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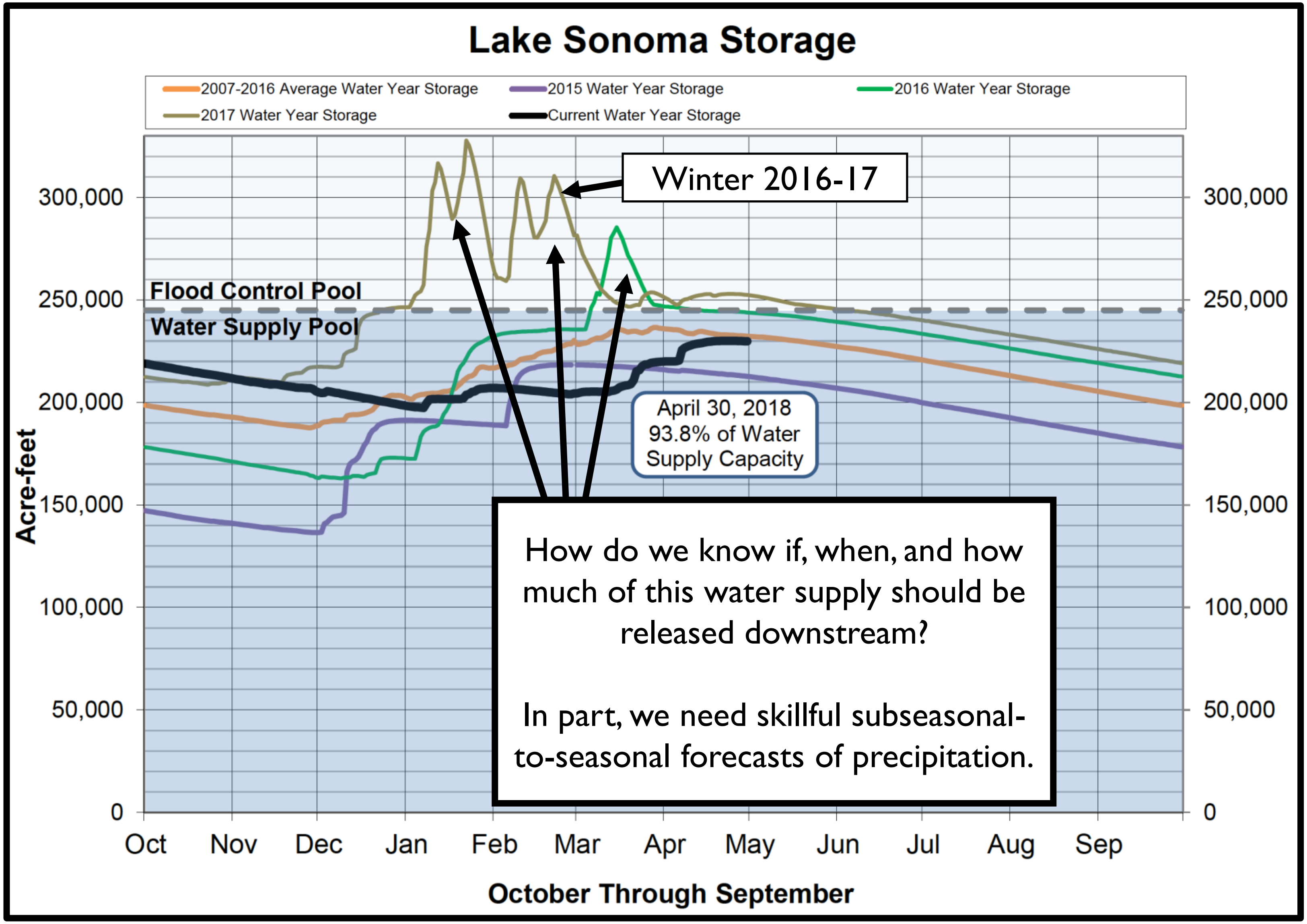
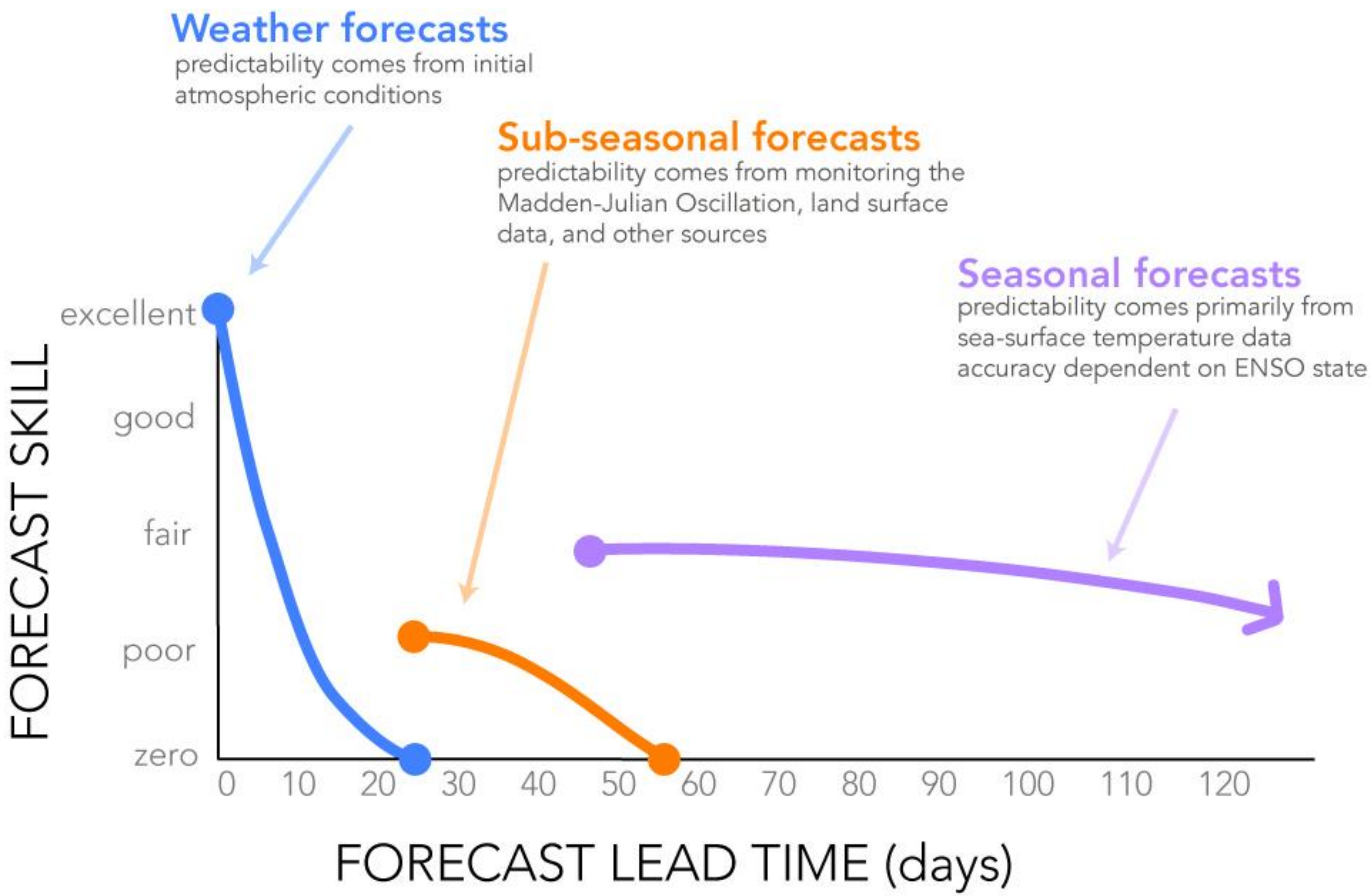


Credit: Sonoma County Water Agency

The Subseasonal-to-Seasonal (S2S) Forecast Gap



Adapted from: https://iri.columbia.edu/news/qa-subseasonal-prediction-proj

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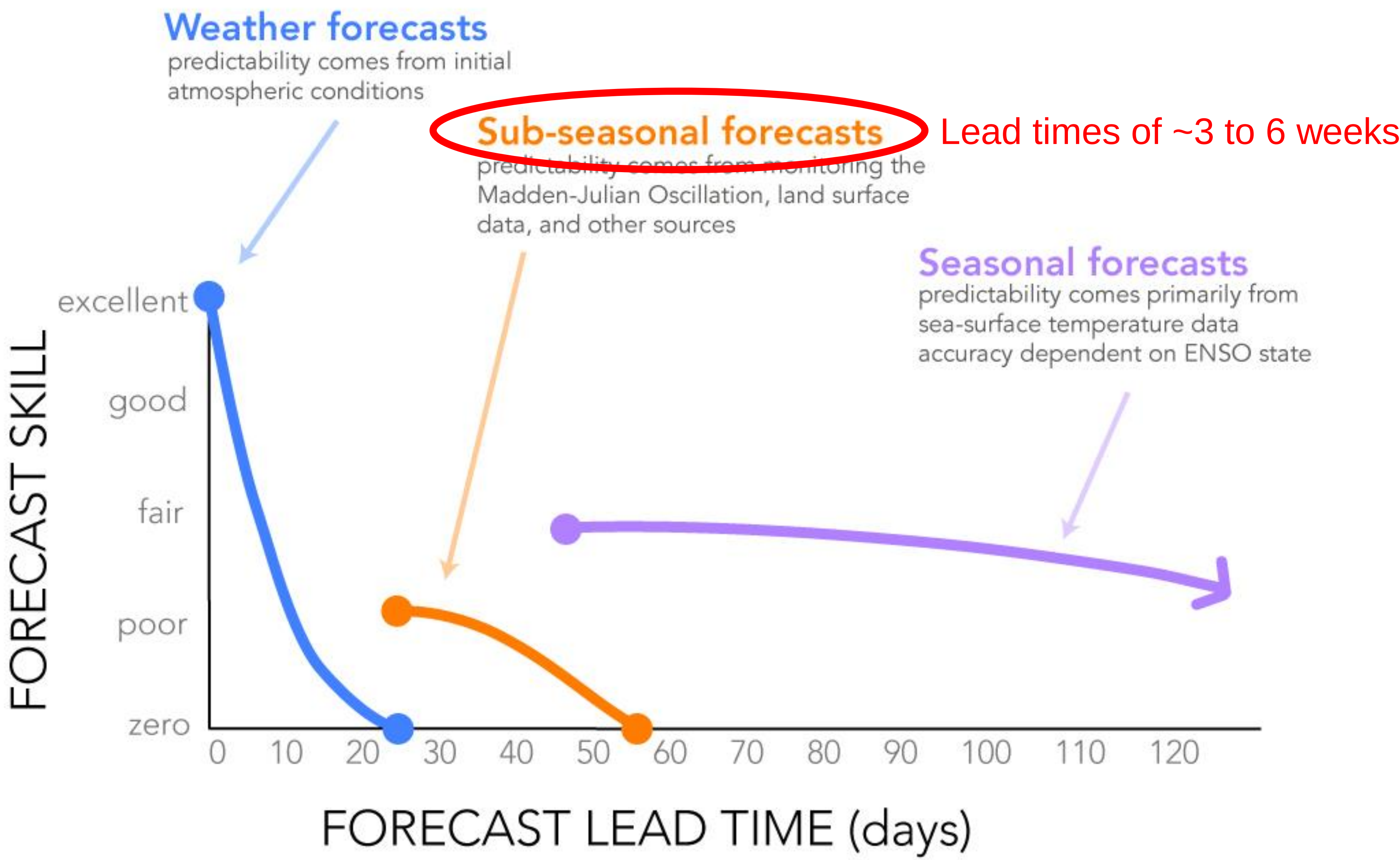

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Question

Can state-of-the-art numerical weather models help us in forecasting atmospheric river activity at subseasonal-to-seasonal lead times (~3 to 6 weeks in advance)?

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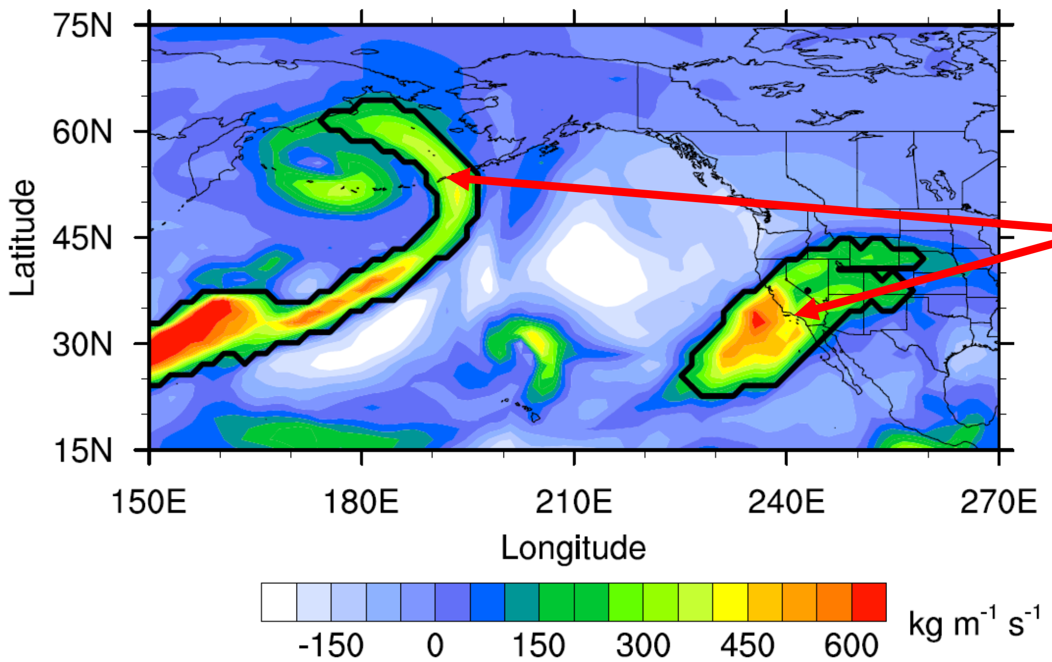
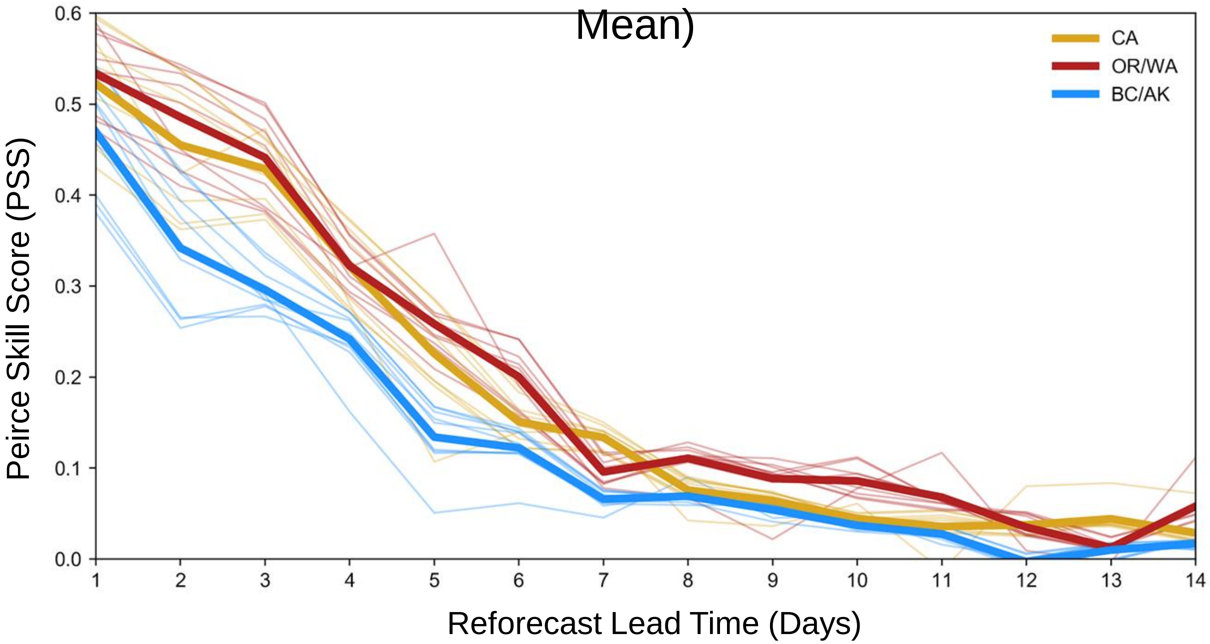
Snapshot of integrated vapor transport



We identify atmospheric rivers in weather models and observations (ERA-Interim reanalysis data) using fields of water vapor transport (IVT) (Mundhenk et al. 2016).

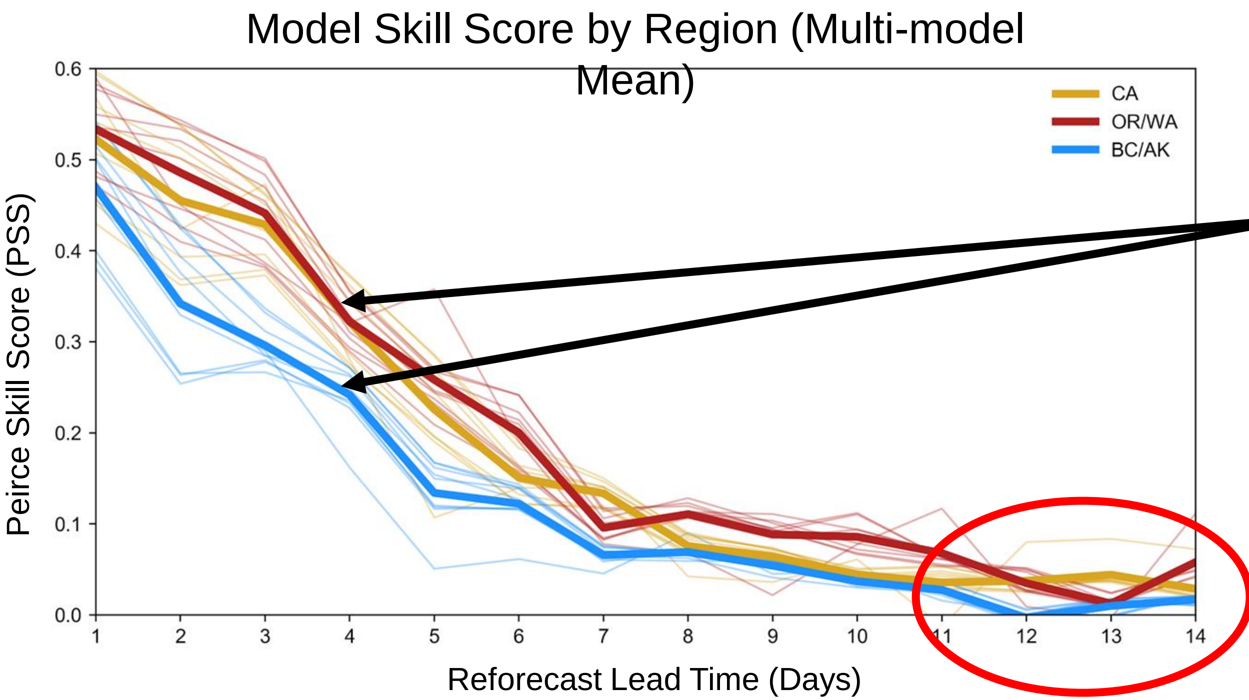
Atmospheric River Activity - Model Skill Scores

Model Skill Score by Region (Multi-model Mean)



Reforecasts from: BOM, CMA, CNRM, ECCC, ECMWF, HMCR, JMA, NCEP, UKMO

Atmospheric River Activity - Model Skill Scores

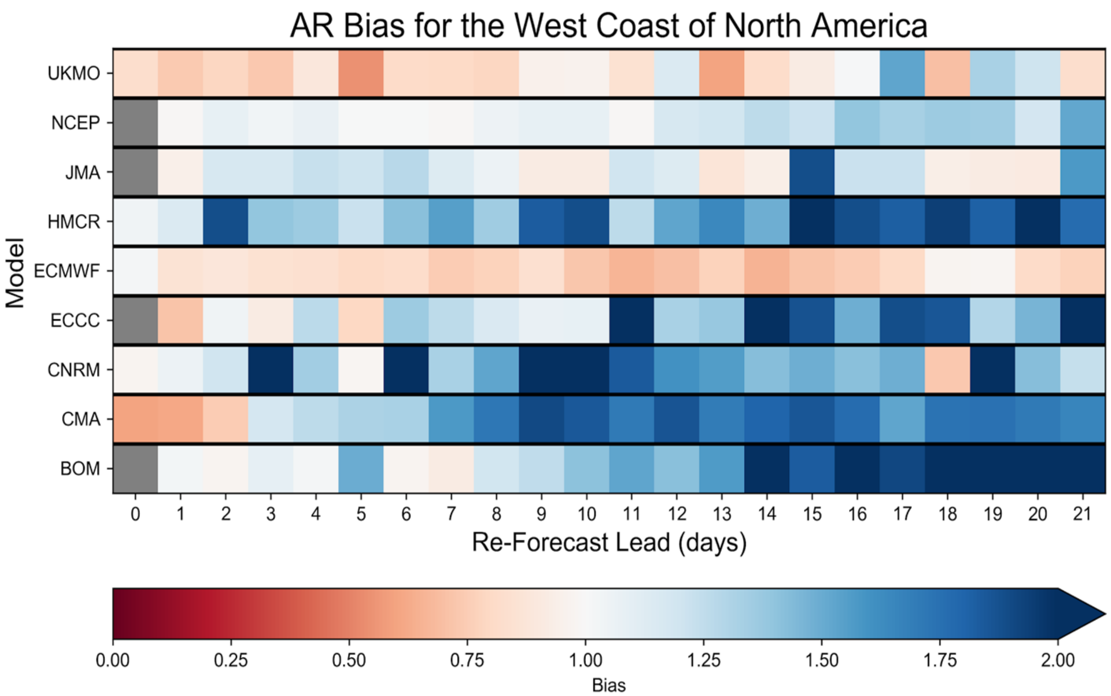


Model skill varies by region, with lower skill in BC/AK compared to CA and OR/WA

At lead times approaching 14 days, models have no additional skill compared to a climatological forecast

Reforecasts from: BOM, CMA, CNRM, ECCC, ECMWF, HMCR, JMA, NCEP, UKMO

Atmospheric River Activity - Model Bias



Blue indicates <u>more</u> ARs forecasted than observed

Red indicates <u>less</u> ARs forecasted than observed

$$\text{Model Bias} = \frac{\text{\# of Forecasted ARs}}{\text{\# of Observed ARs}}$$

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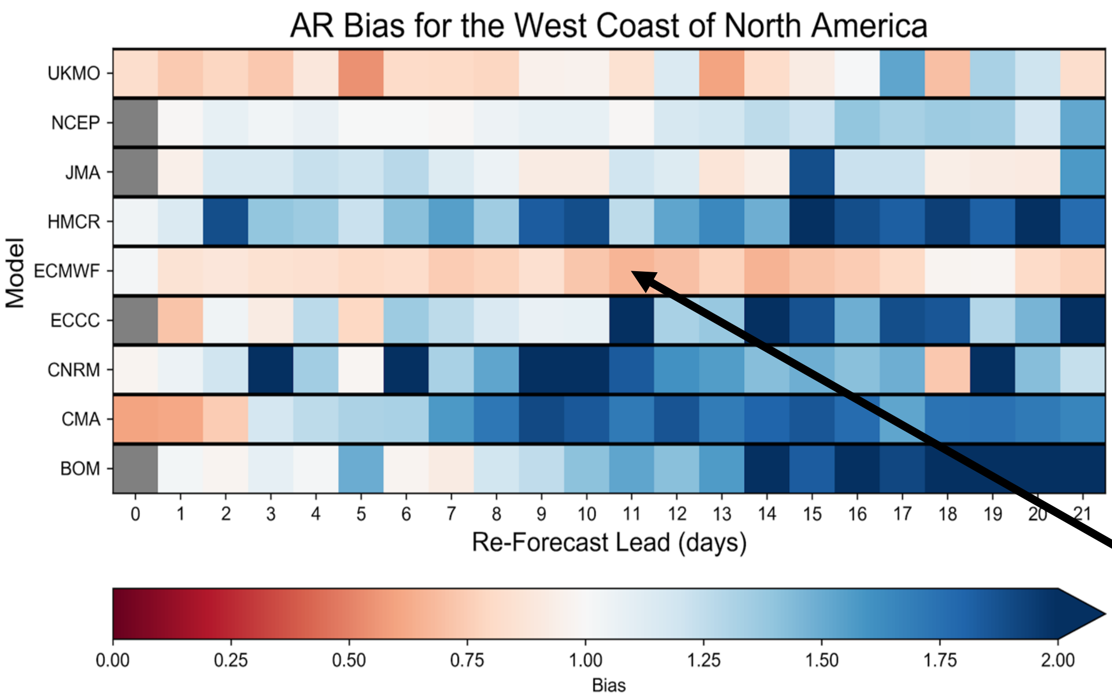

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ECMWF has a “quiet” bias

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Apparently no, the models have skillful lead times only extending to ~14 days, in agreement with prior studies (Wick et al. 2013; Nayak et al. 2014; DeFlorio et al. 2018).

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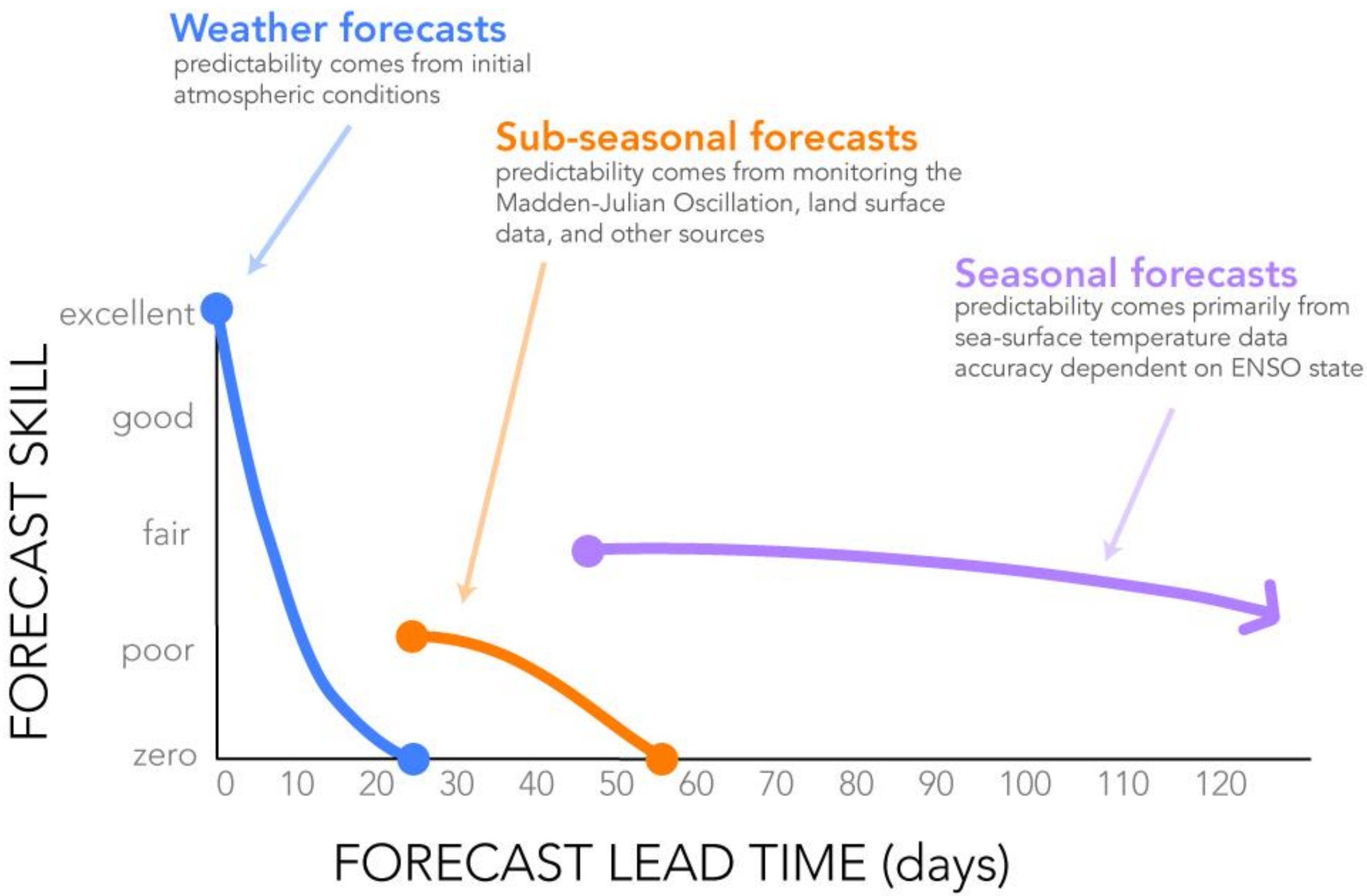

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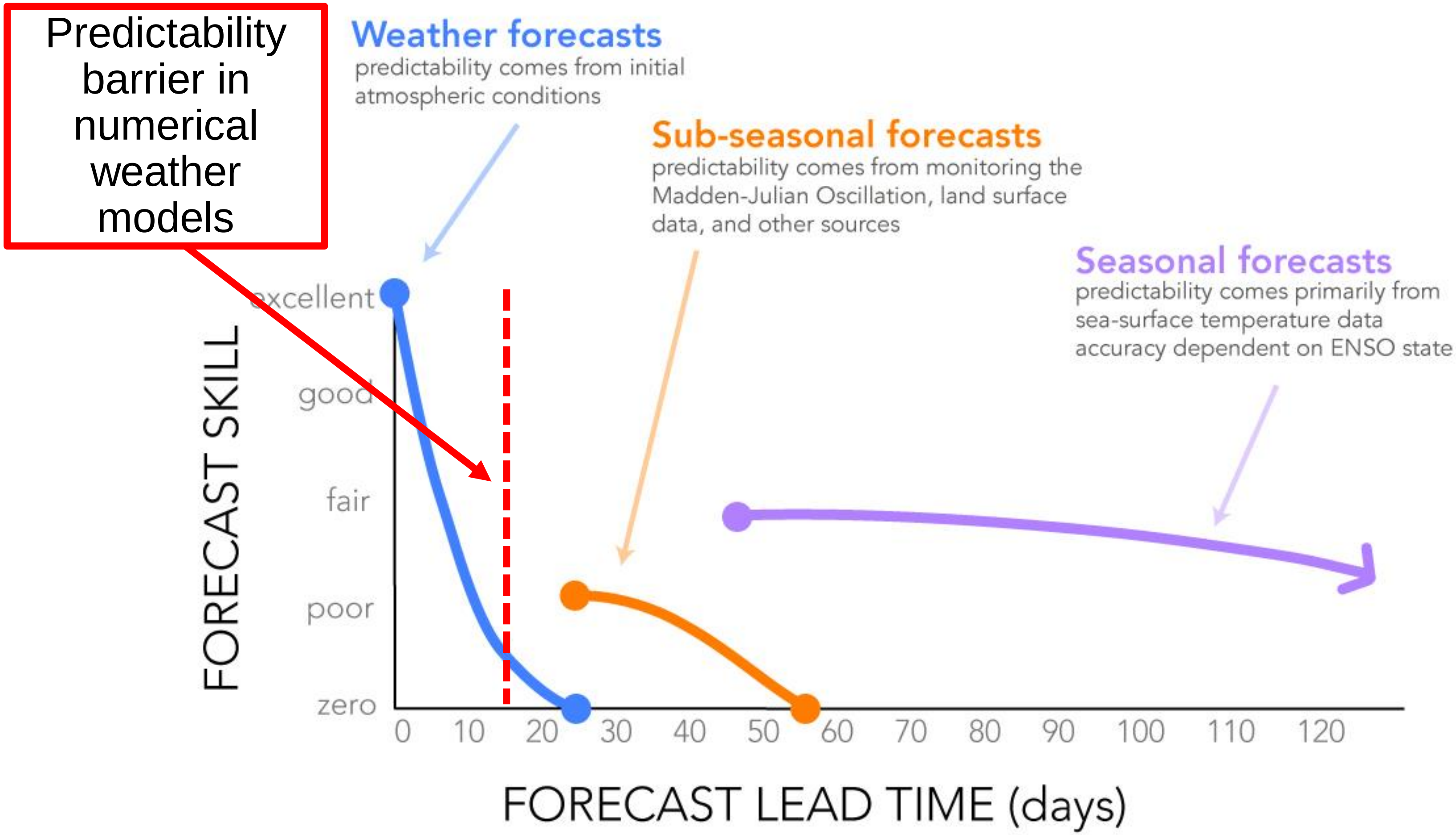

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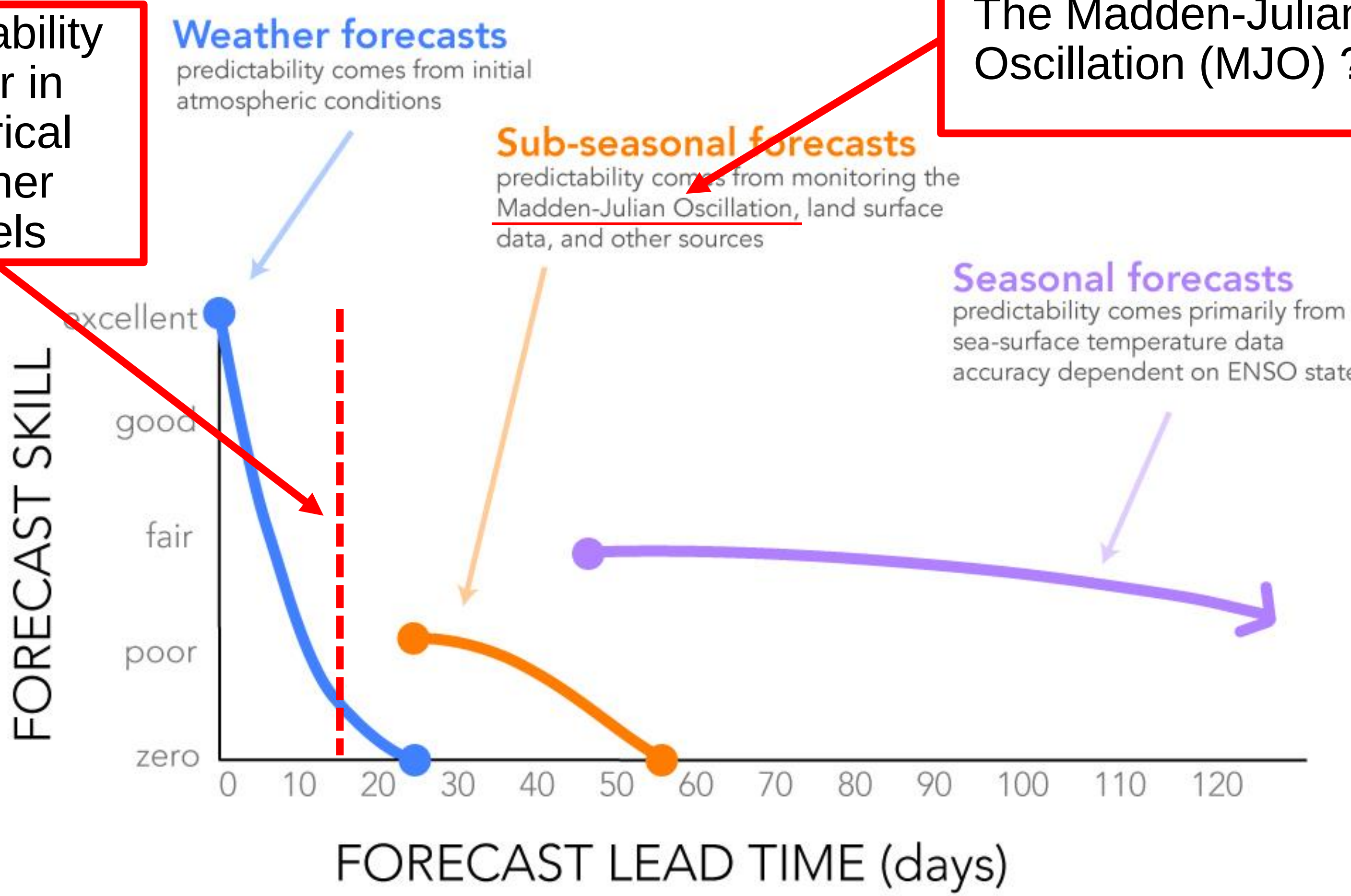
Predictability barrier in numerical weather models

The Madden-Julian Oscillation (MJO) ?



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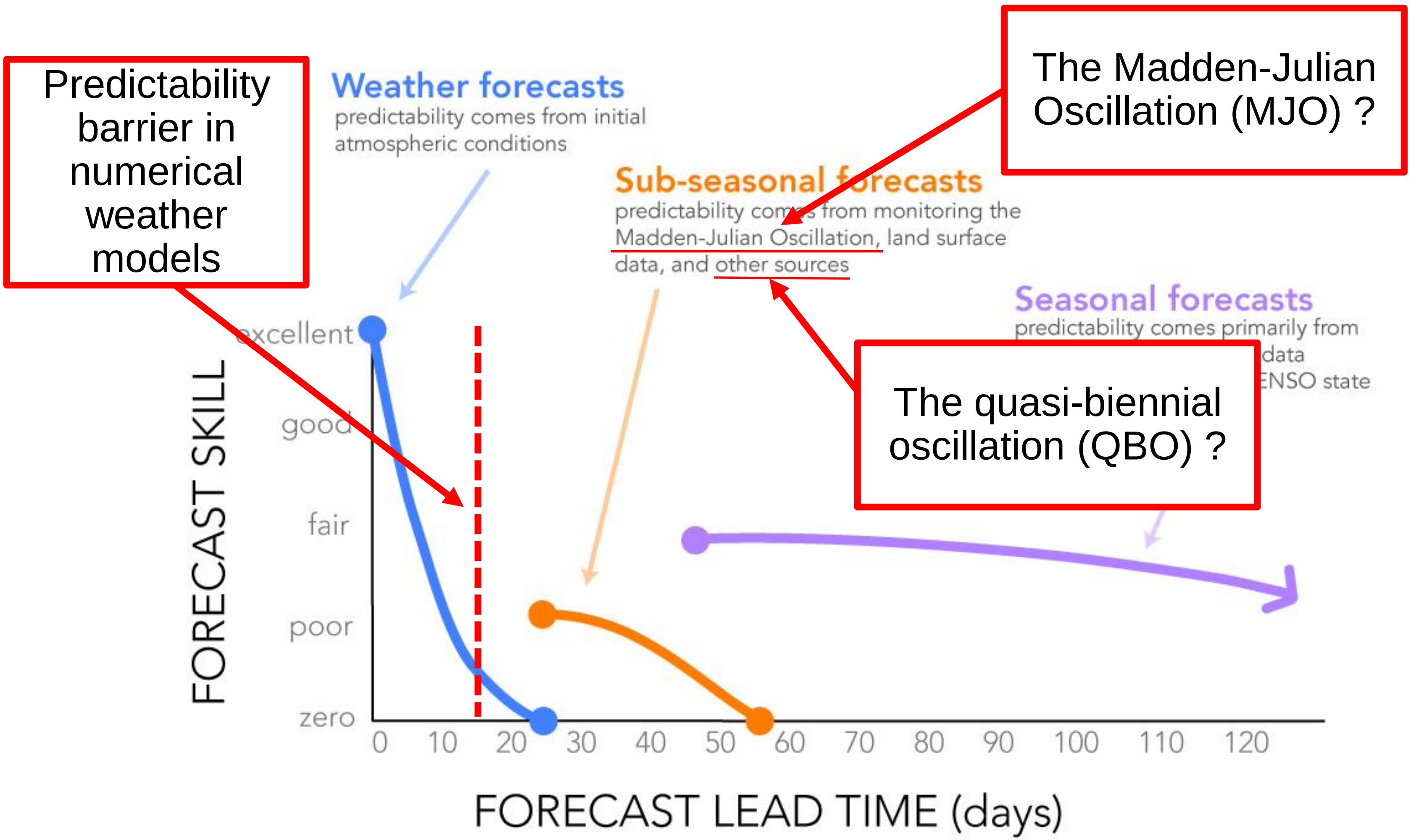

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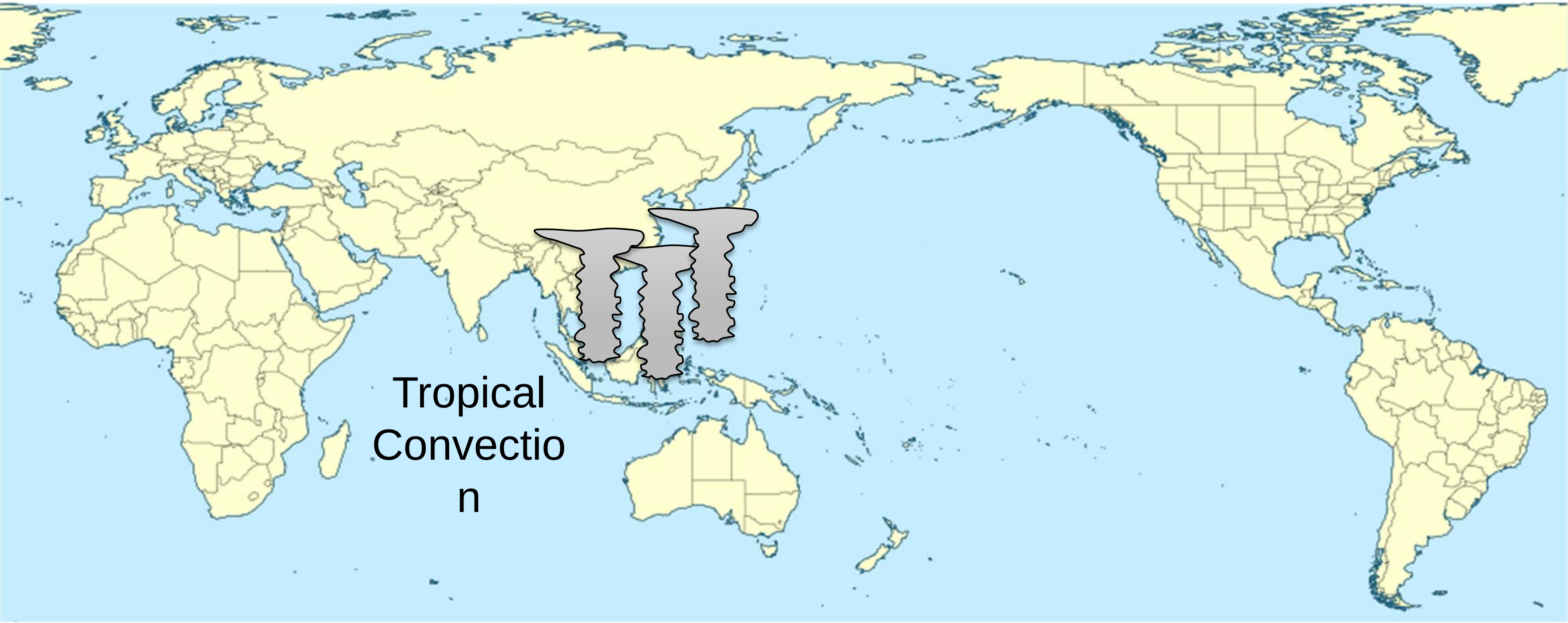
The Madden-Julian Oscillation – a source of predictability at S2S lead times

Since the 1980s, we have known…



Hoskins and Karoly (1981); Simmons et al. 1983; Sardeshmukh and Hoskins

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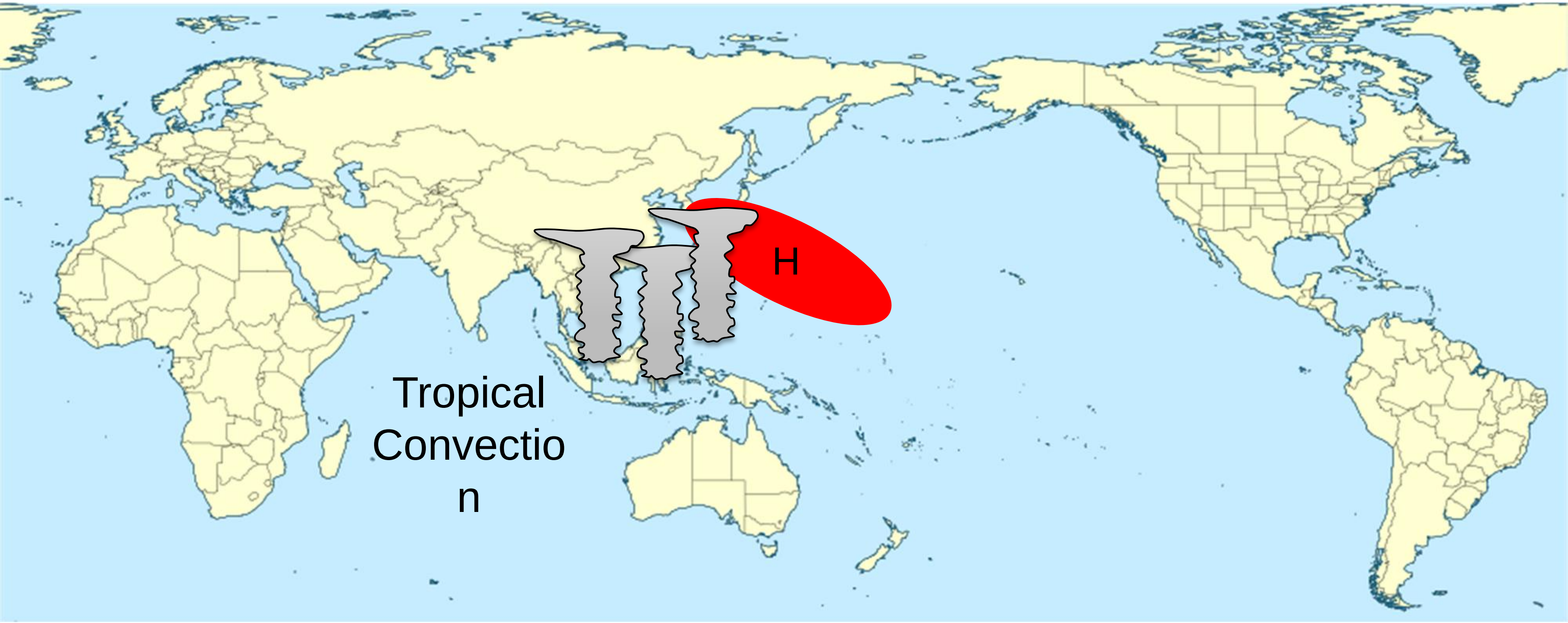

Like creating ripples in a pond, tropical convection can produce atmospheric waves that reach North America in ~7 to 10 days

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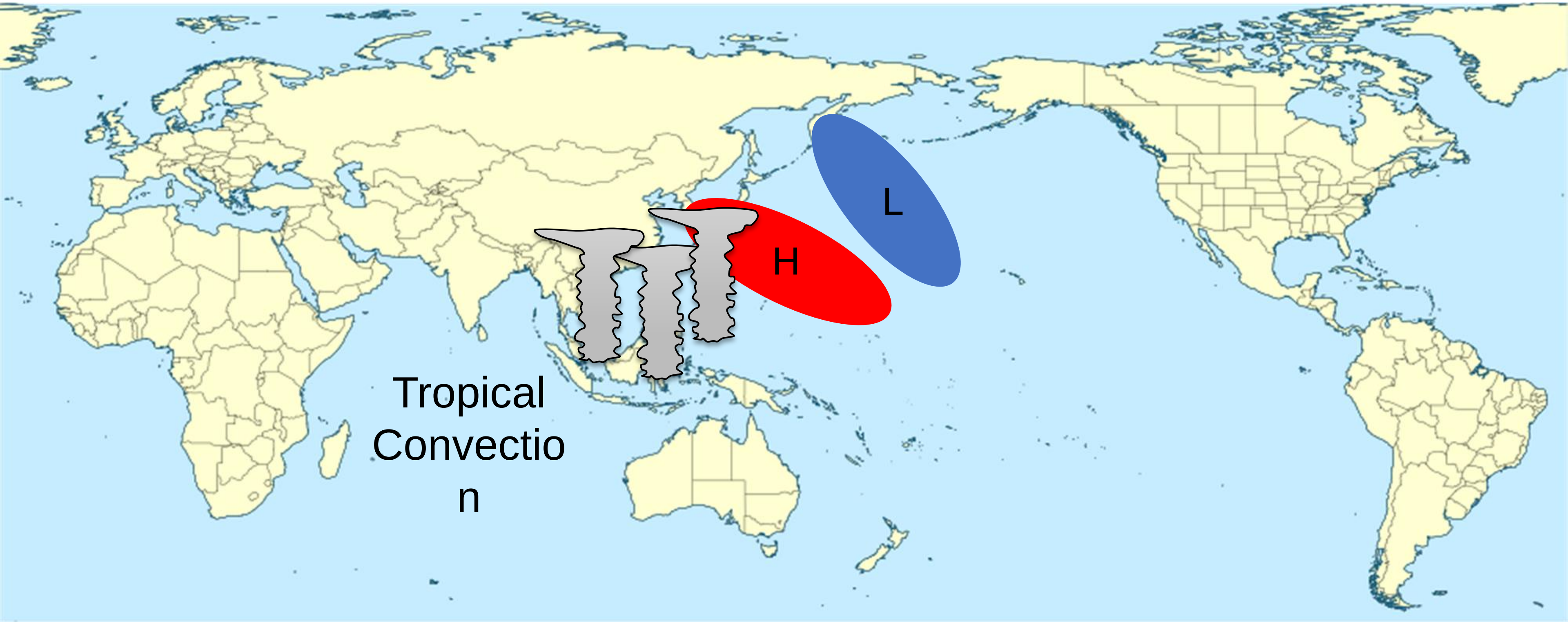

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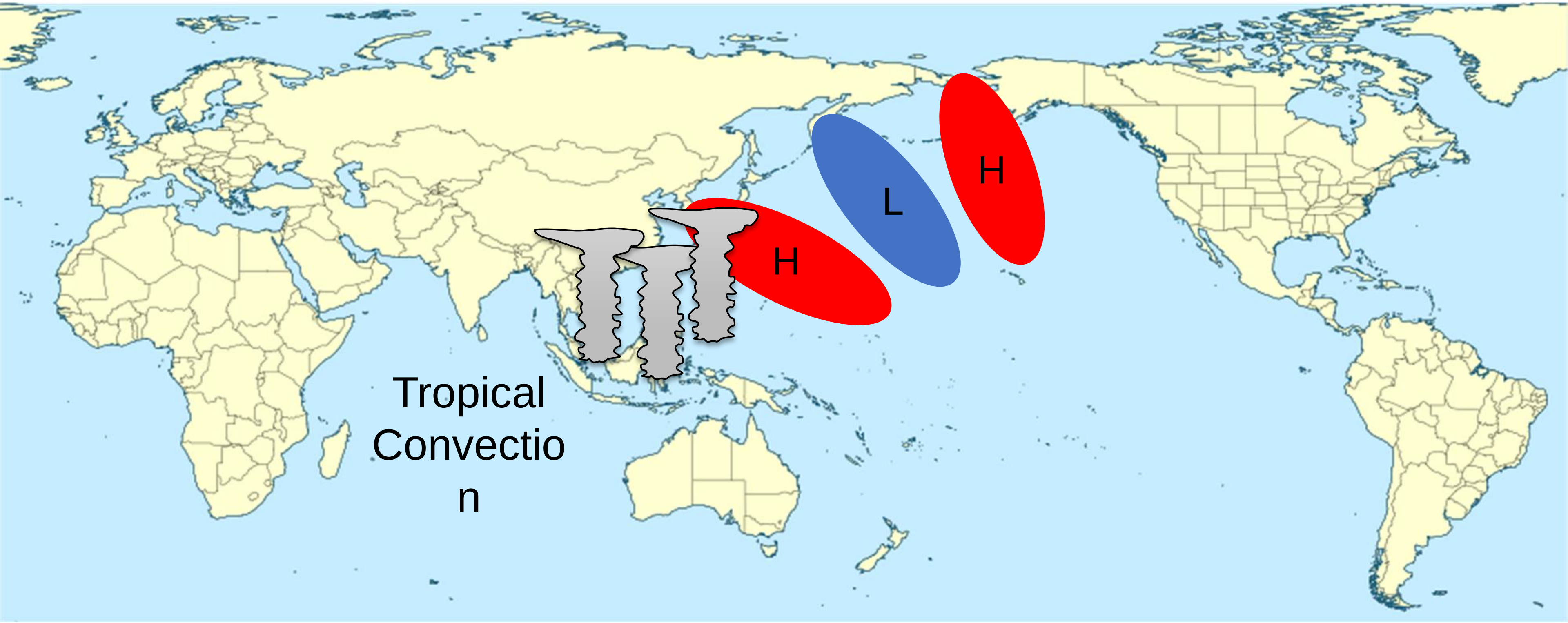

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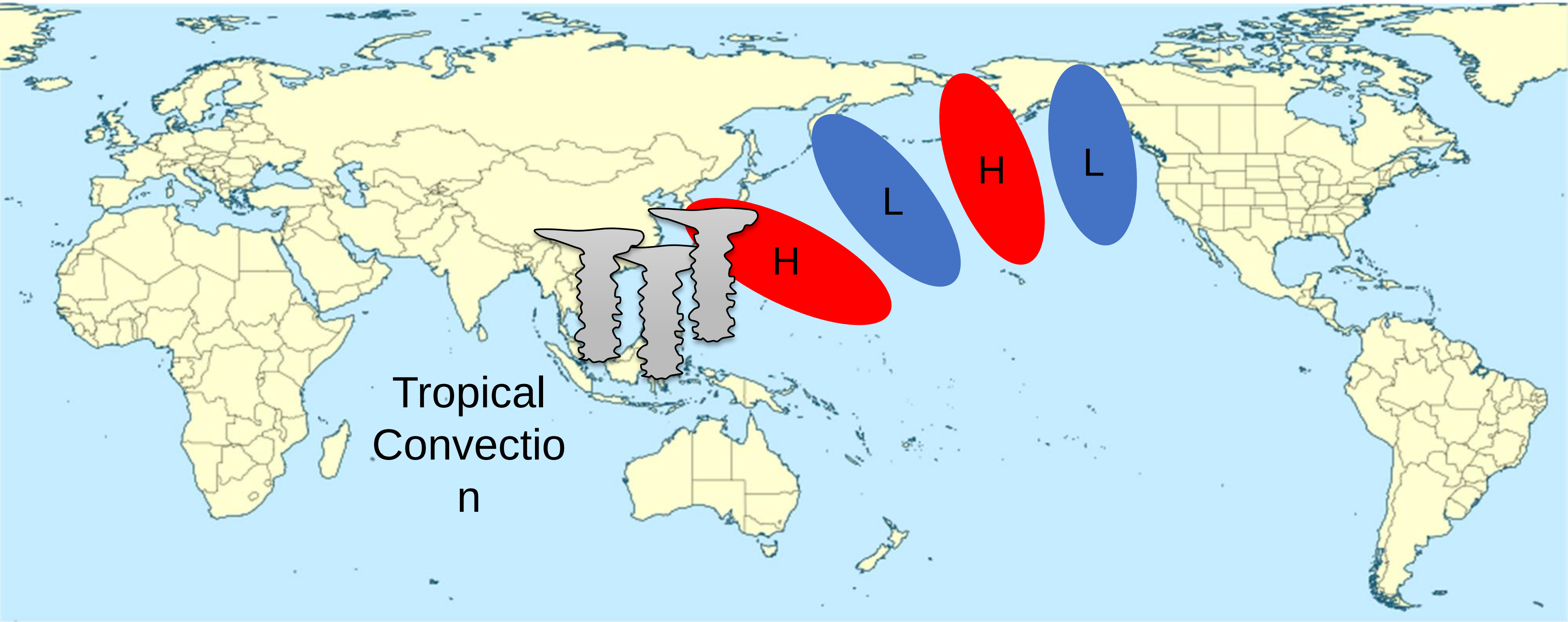

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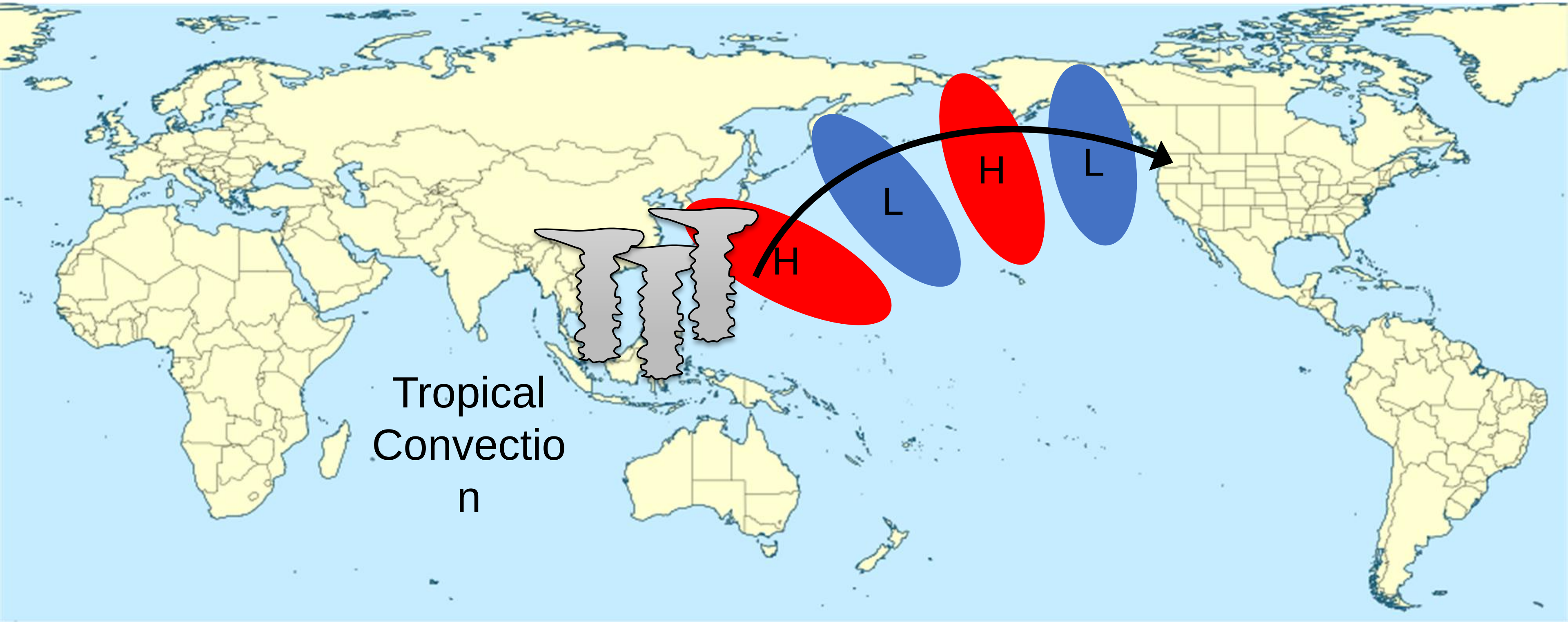

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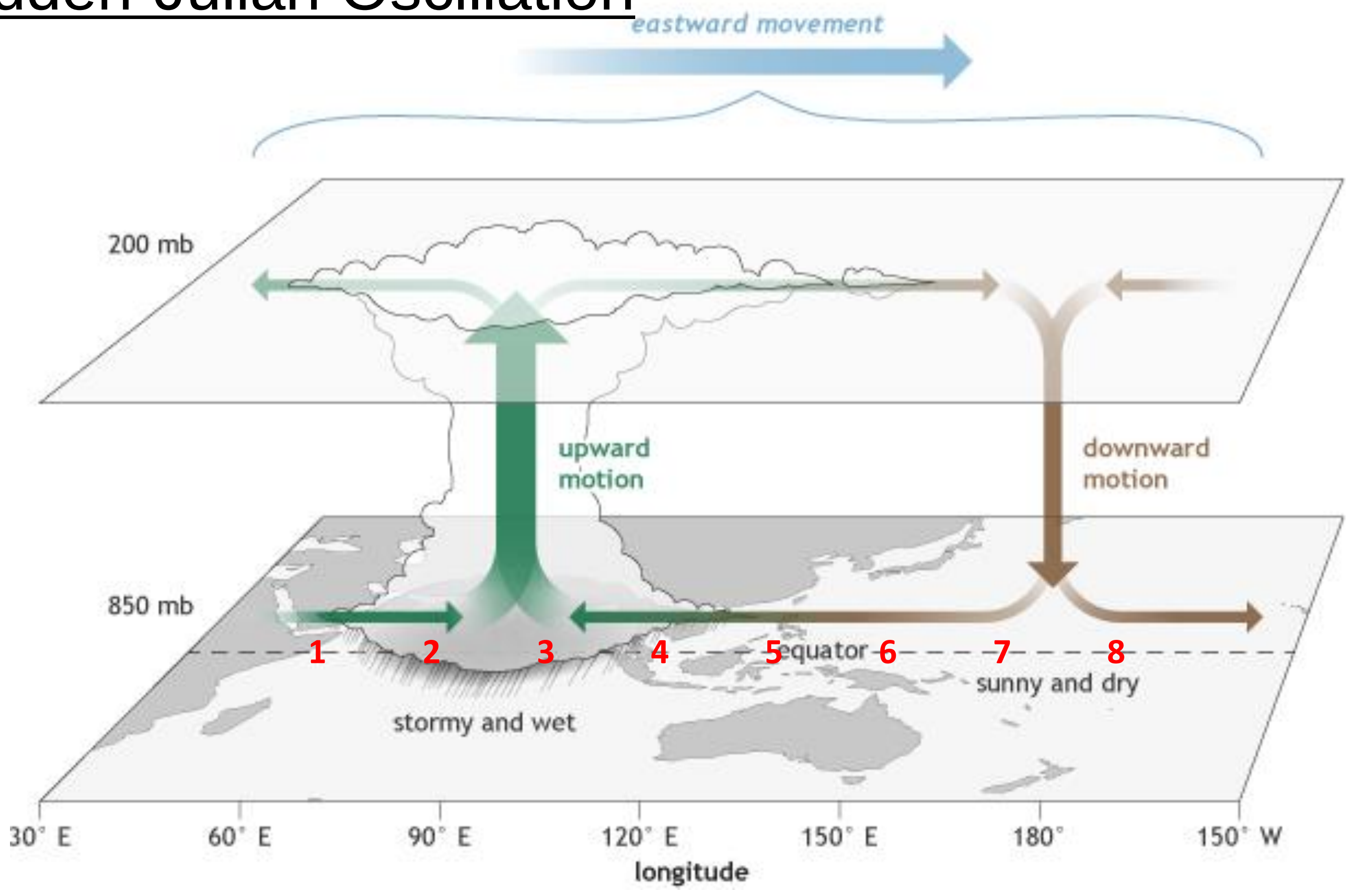

The Quasi-biennial Oscillation – modulates the MJO?

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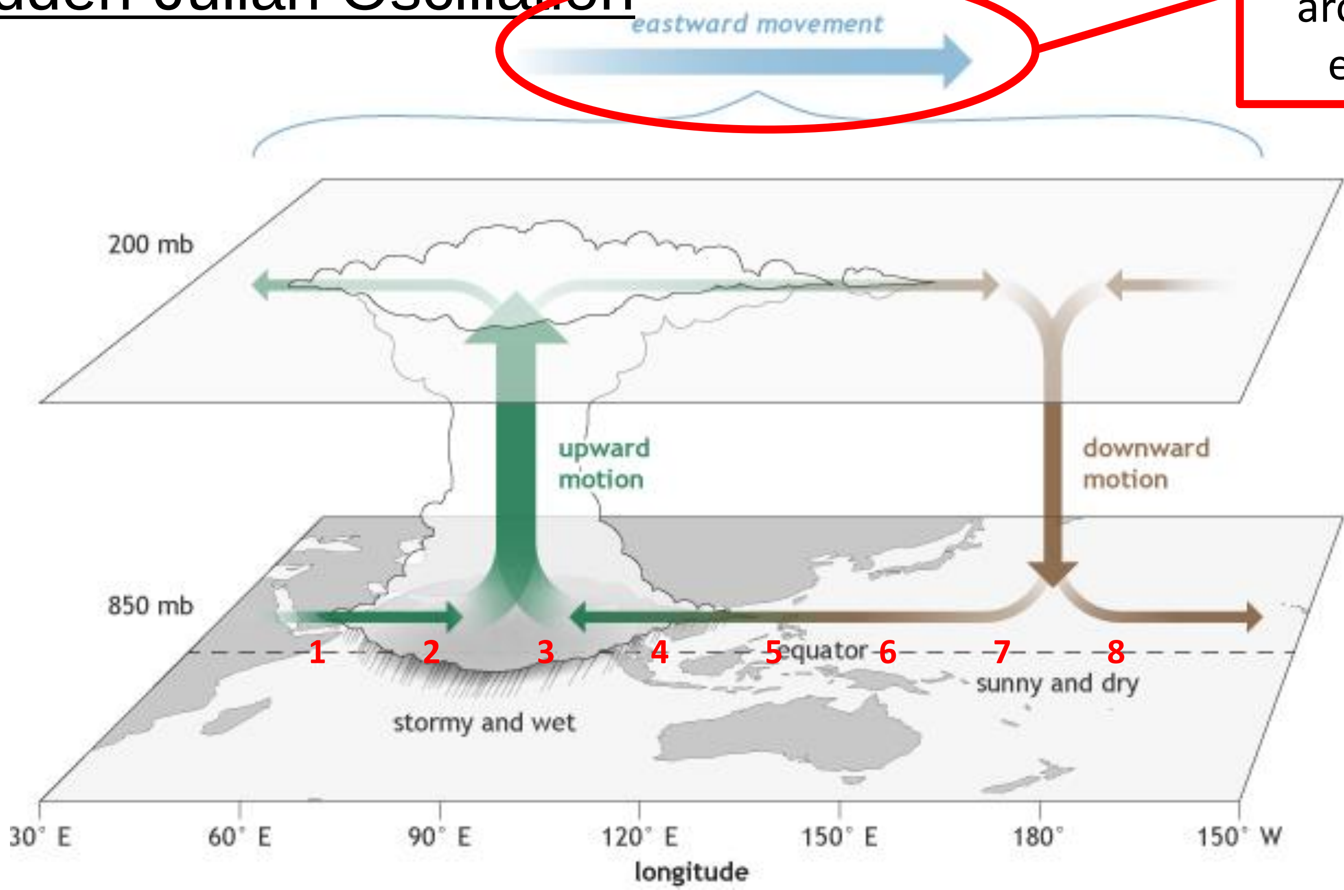
<u>Madden-Julian Oscillation</u>

~30 to 90 days to travel around the equator



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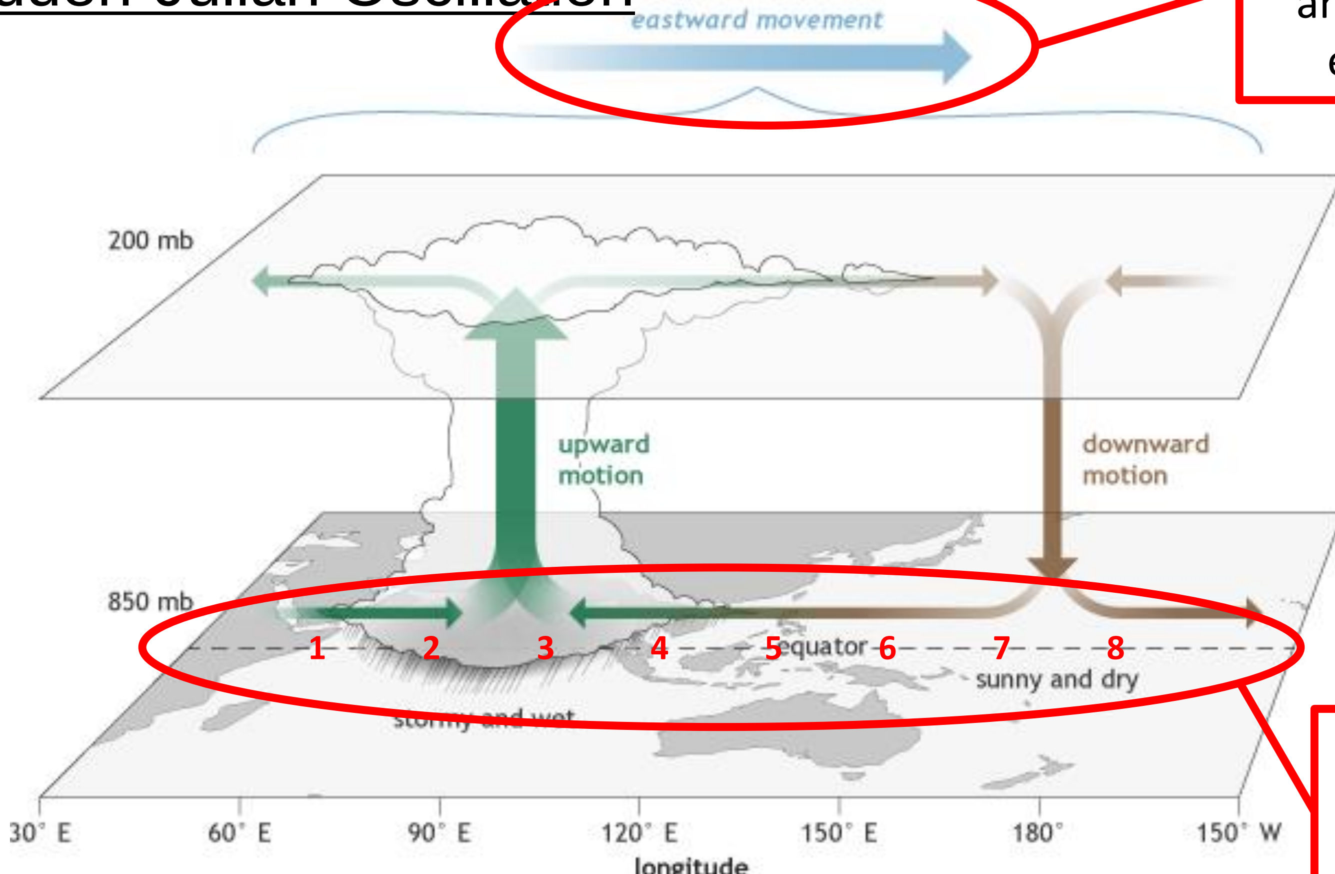

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Location of MJO along the equator is divided into 8 phases

The Quasi-biennial Oscillation – modulates the MJO?

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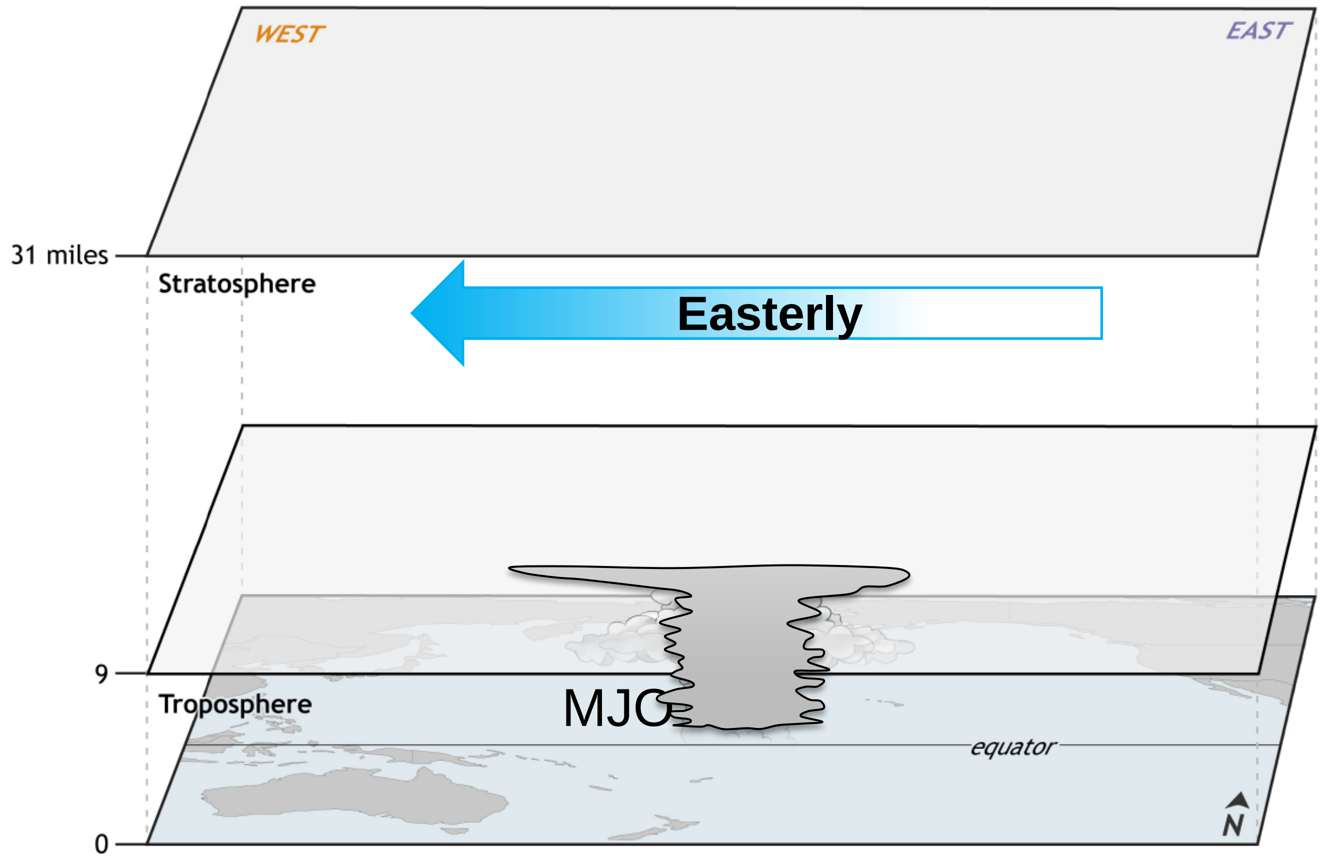

The QBO is characterized by stratospheric zonal winds that cycle between easterly and westerly phases every 2 to 3 years

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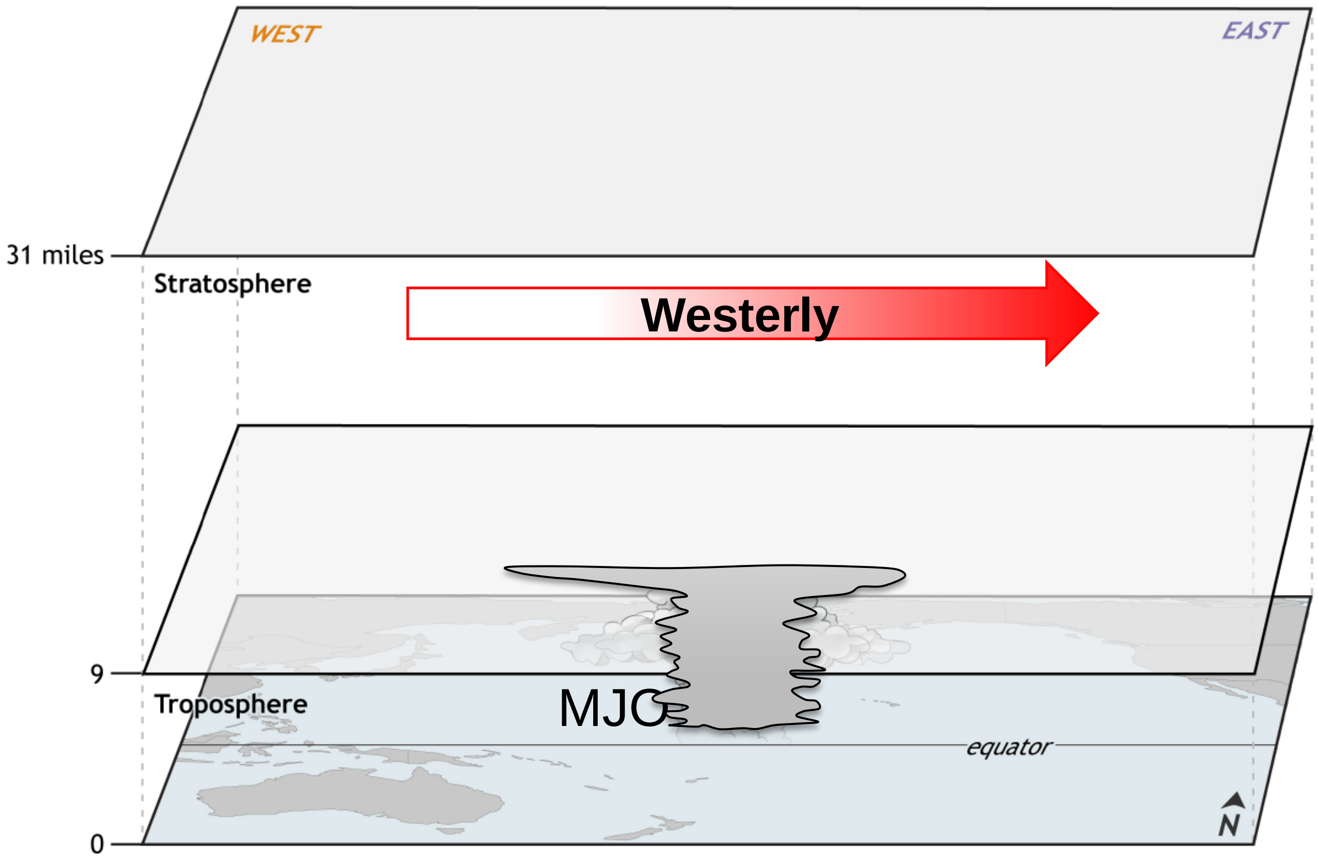

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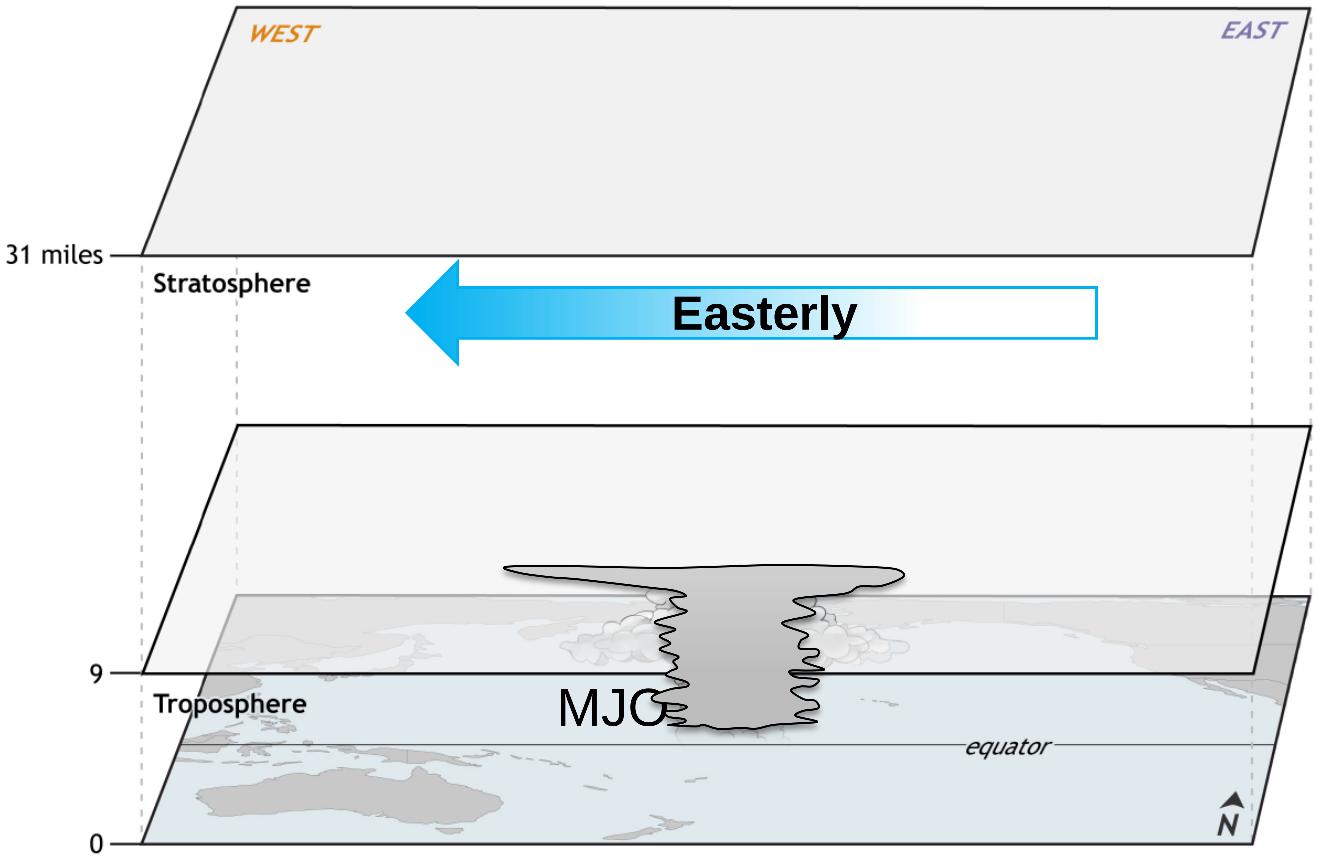

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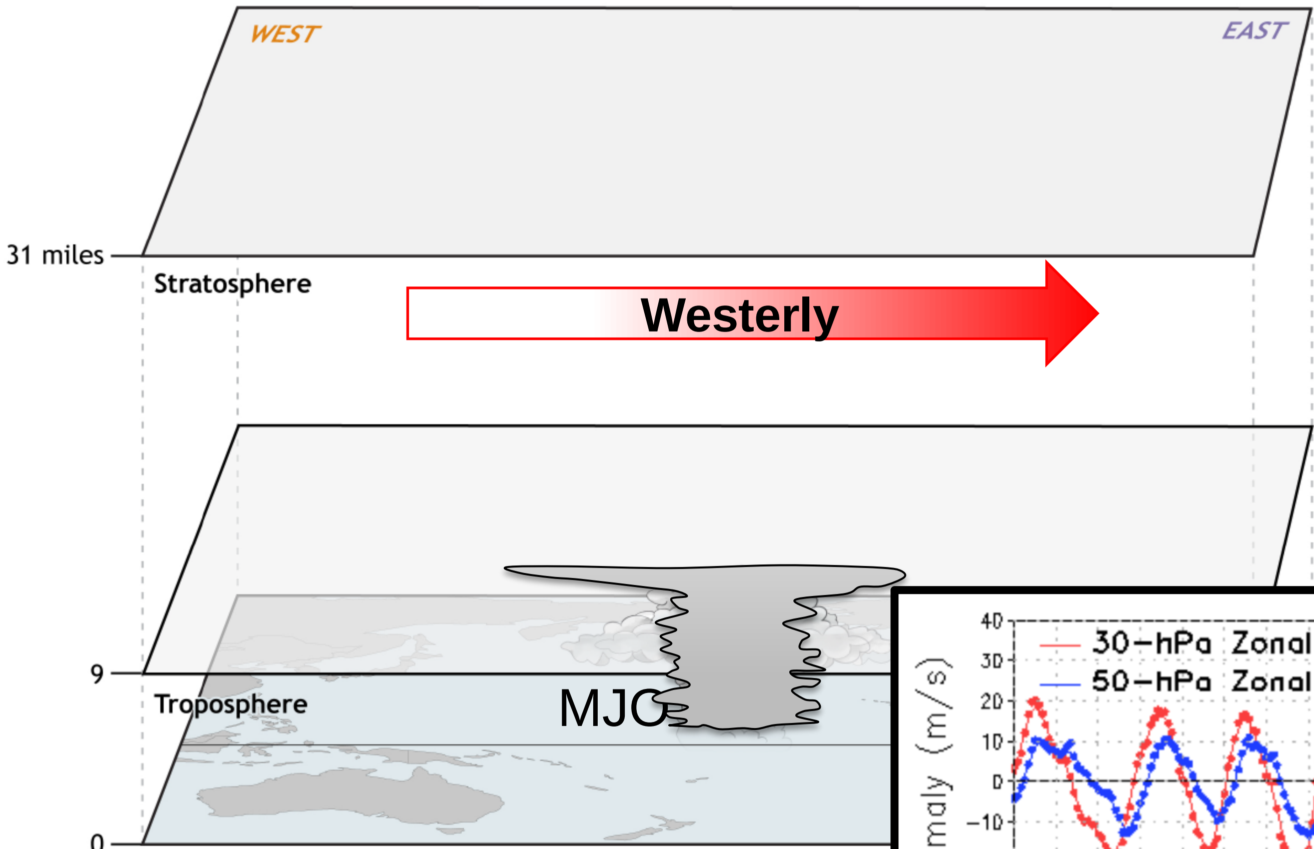

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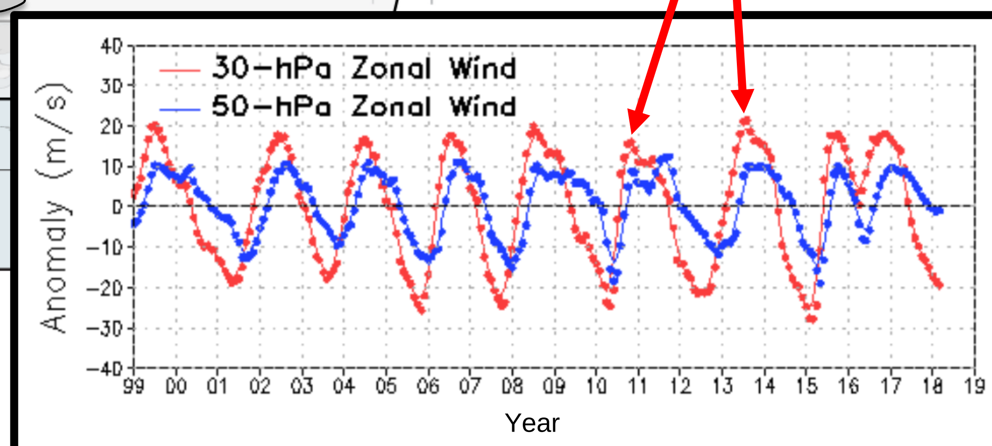

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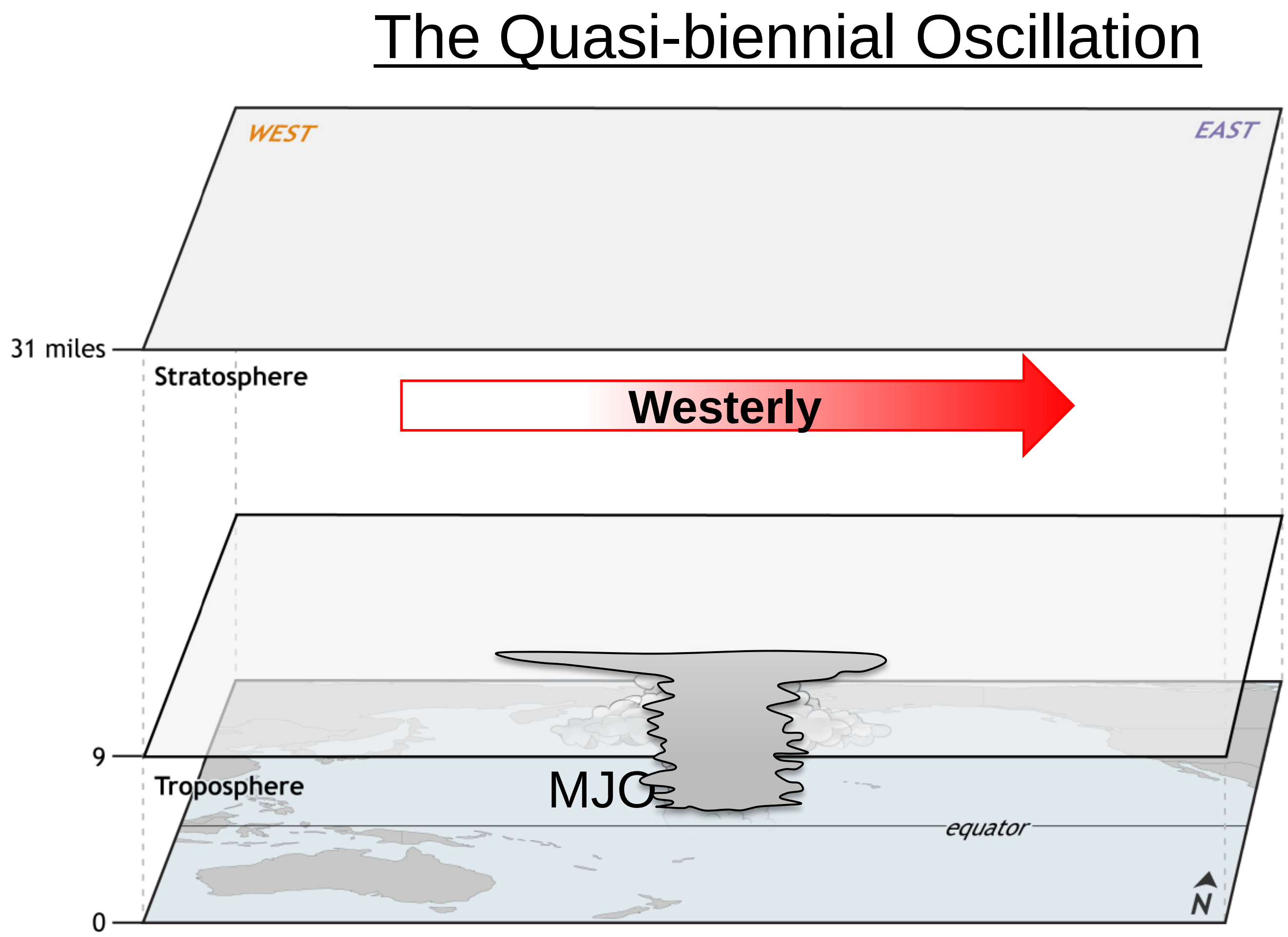

Recent work has shown that the QBO has an impact on the MJO and its teleconnections, but the mechanism is still a subject of ongoing research (Yoo and Son 2016; Son et al. 2017; Zhang and Zhang 2018)

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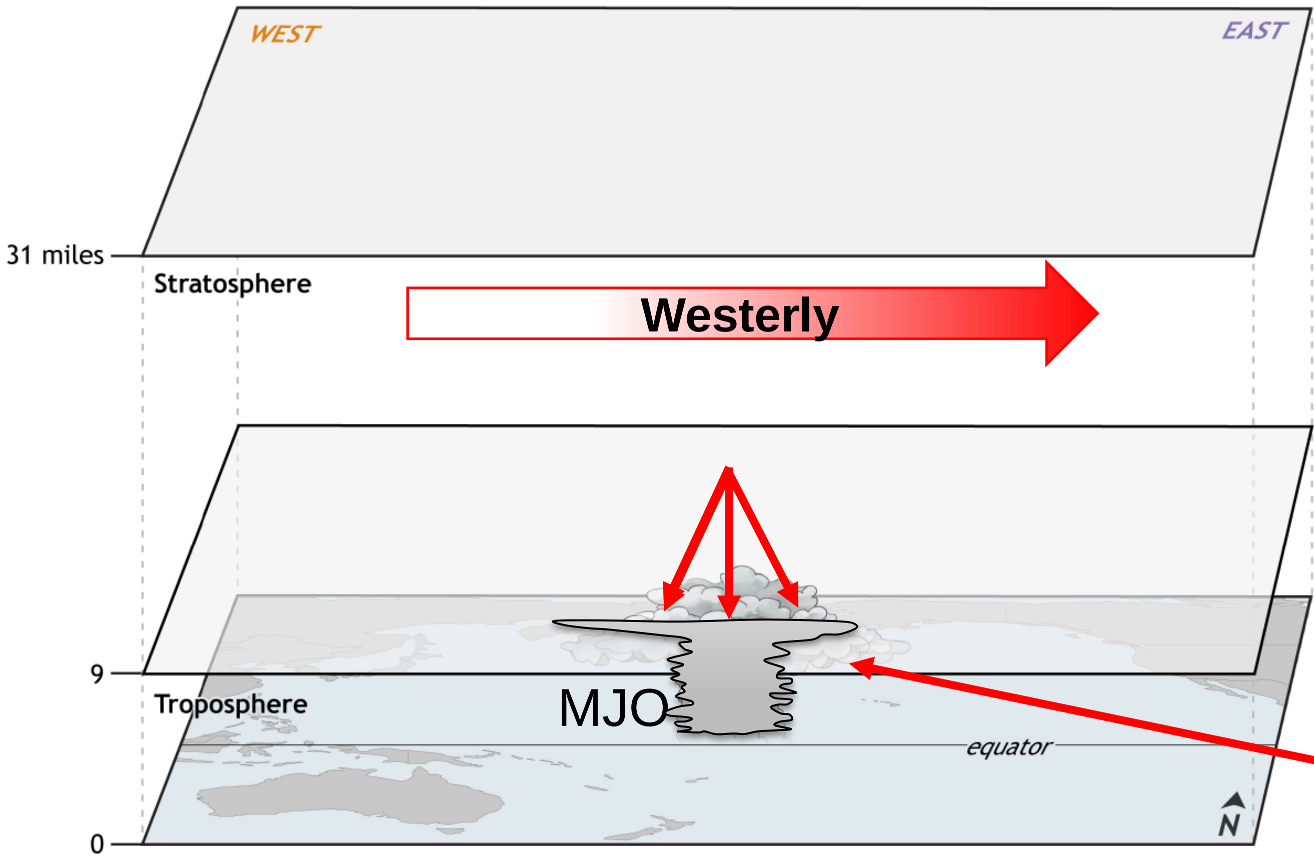

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MJO is *suppressed* during the westerly phase of the QBO

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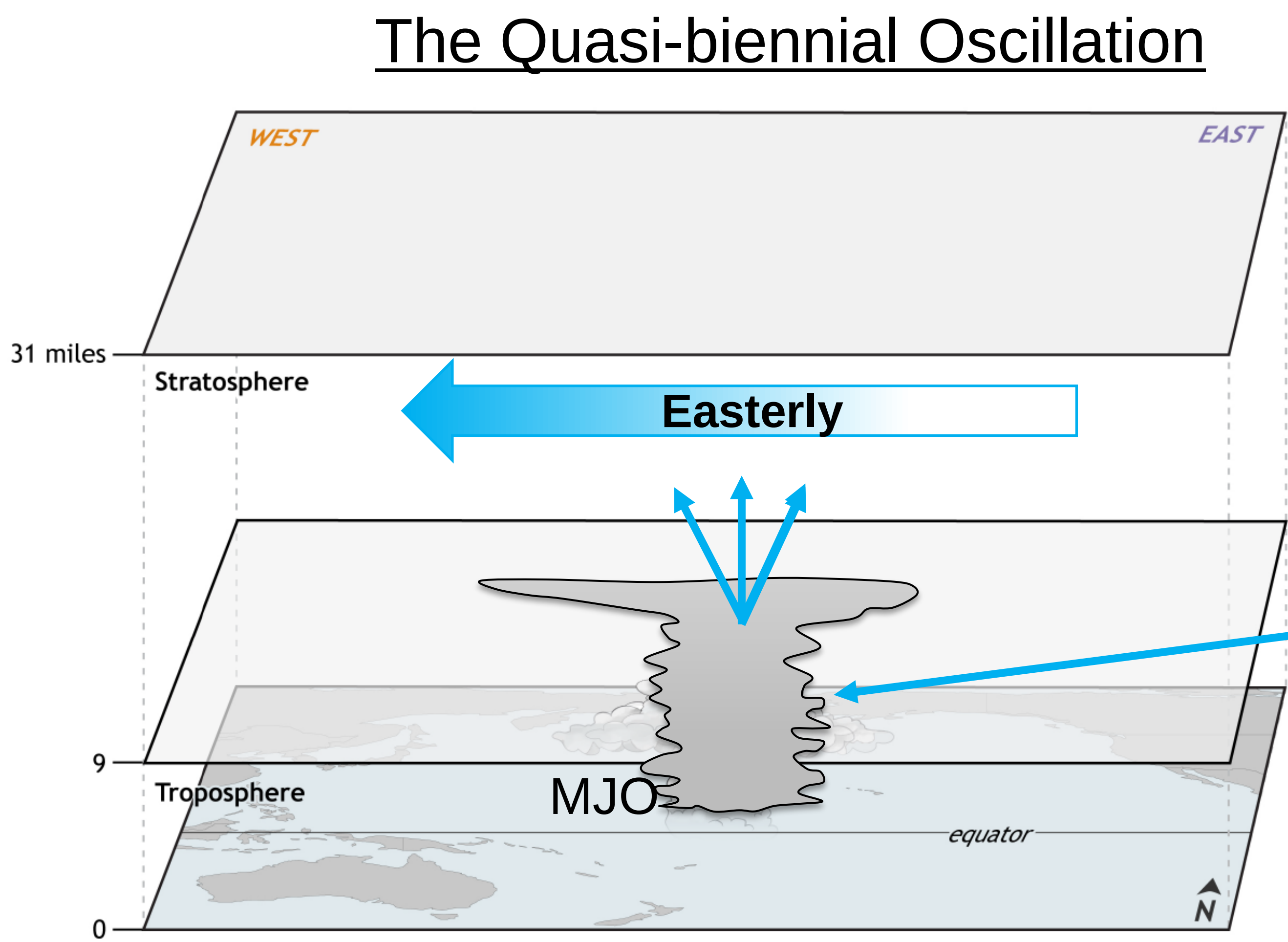

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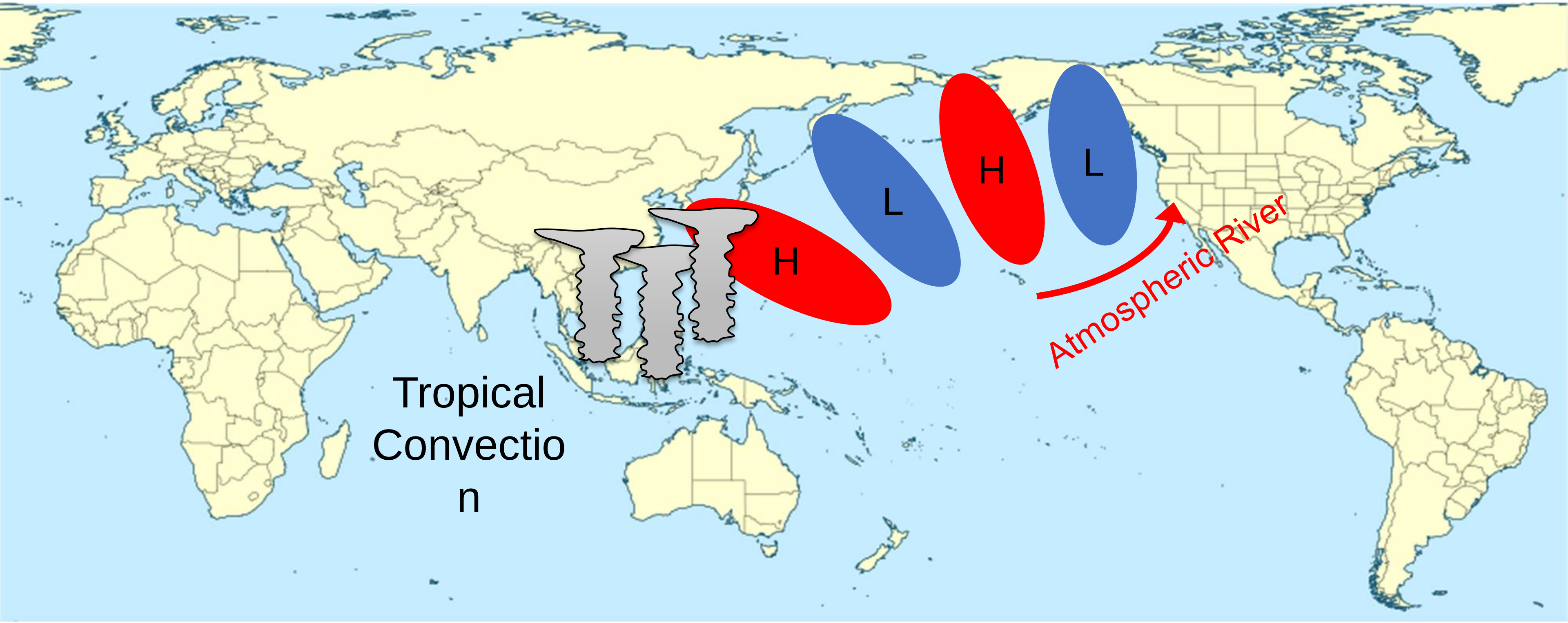
MJO is *enhanced* during the easterly phase of the QBO

The Madden-Julian Oscillation – a source of predictability at S2S lead times

So, why do the MJO and QBO matter?



Because the pressure and wind patterns they produce over the North Pacific impact if and where atmospheric rivers make landfall along the U.S. West Coast.

Hoskins and Karoly (1981); Simmons et al. 1983; Sardeshmukh and Hoskins

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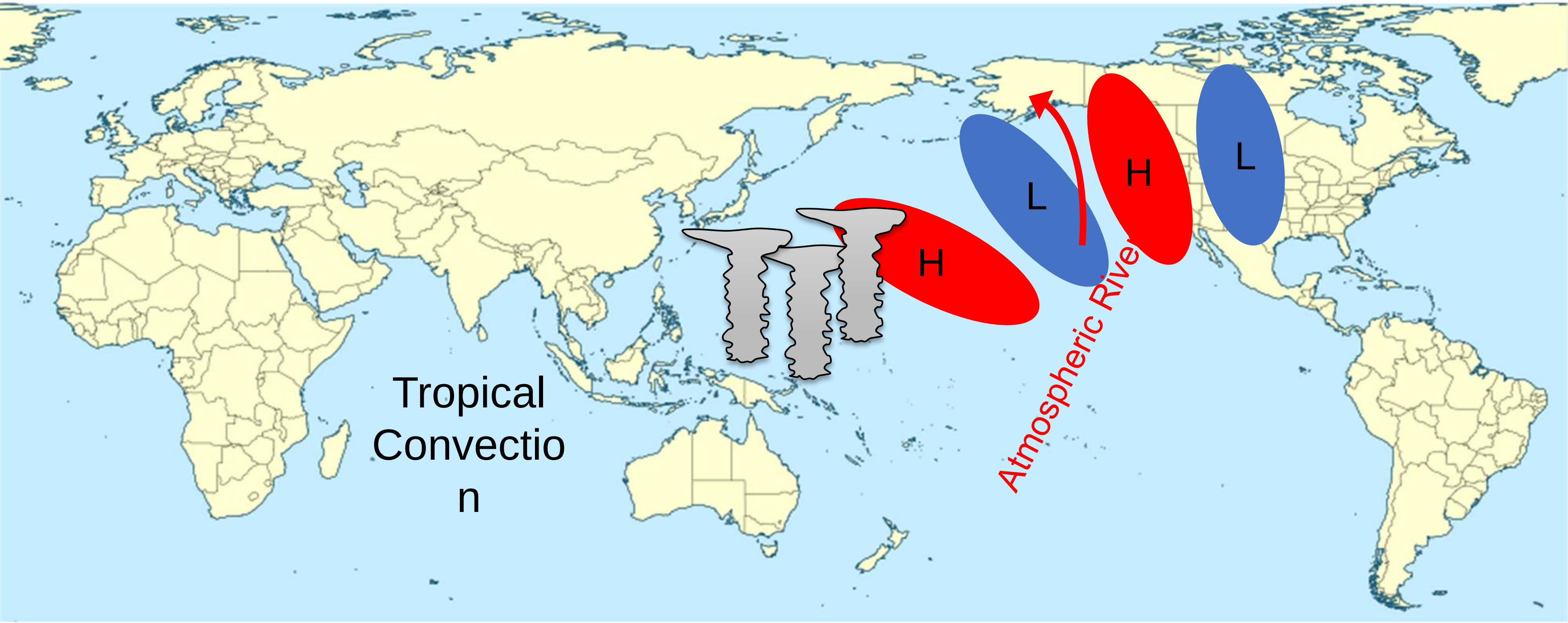

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The MJO and the QBO are potential sources of predictability.

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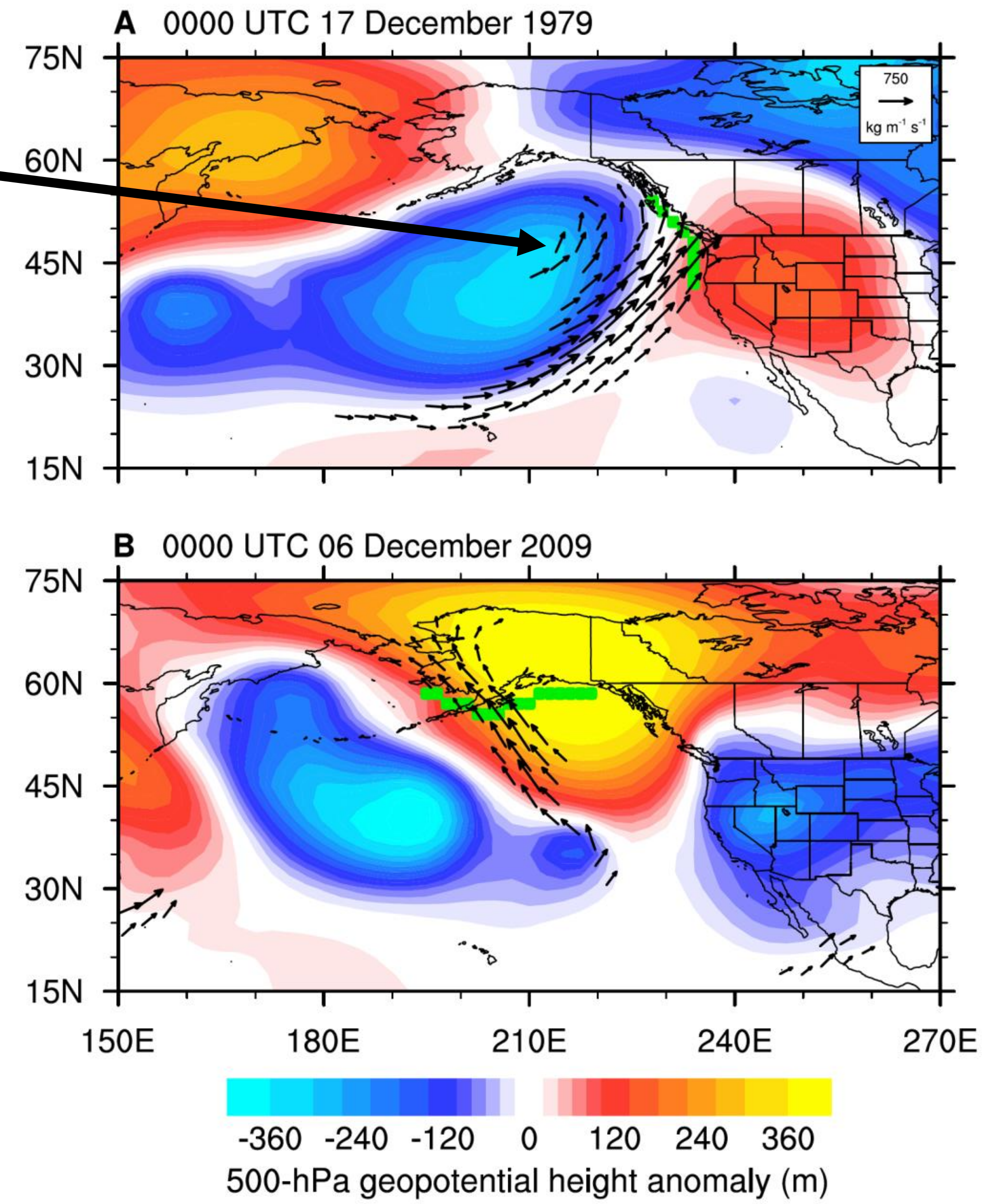
The MJO and the QBO are potential sources of predictability.

Does the *current state* of the MJO and QBO offer information about *future* atmospheric river activity along the U.S. West Coast?

If yes, can we use the *current state* of the MJO and QBO to skillfully forecast atmospheric river activity at subseasonal-to-seasonal lead times (~3 to 6 weeks in advance)?

Observational Work - AR Landfall Events

Black arrows outline the location of an atmospheric river



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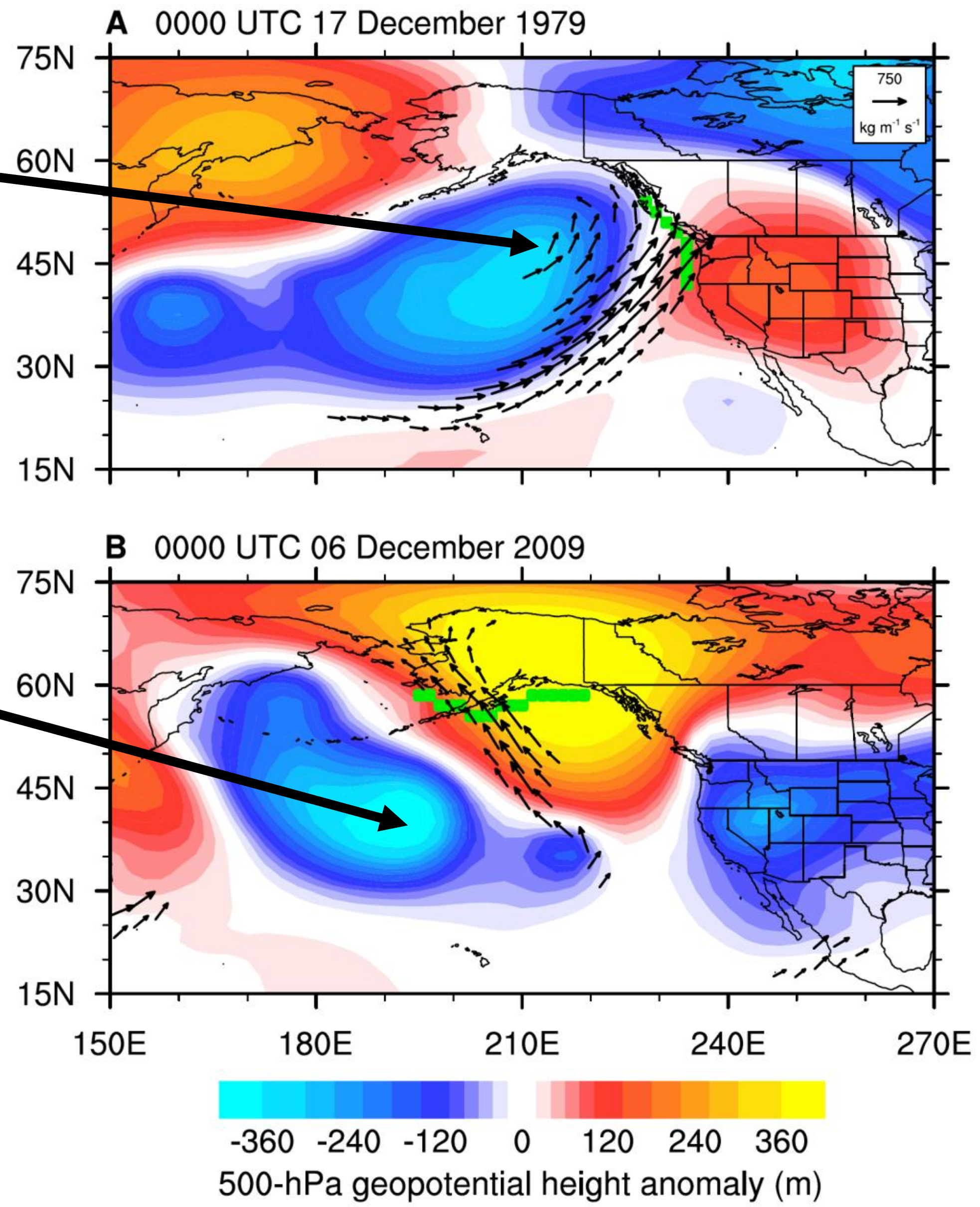
Black arrows outline the location of an atmospheric river

Shaded regions represent 500-mb geopotential height anomalies



Observational Work - AR Landfall Events

Black arrows outline the location of an atmospheric river

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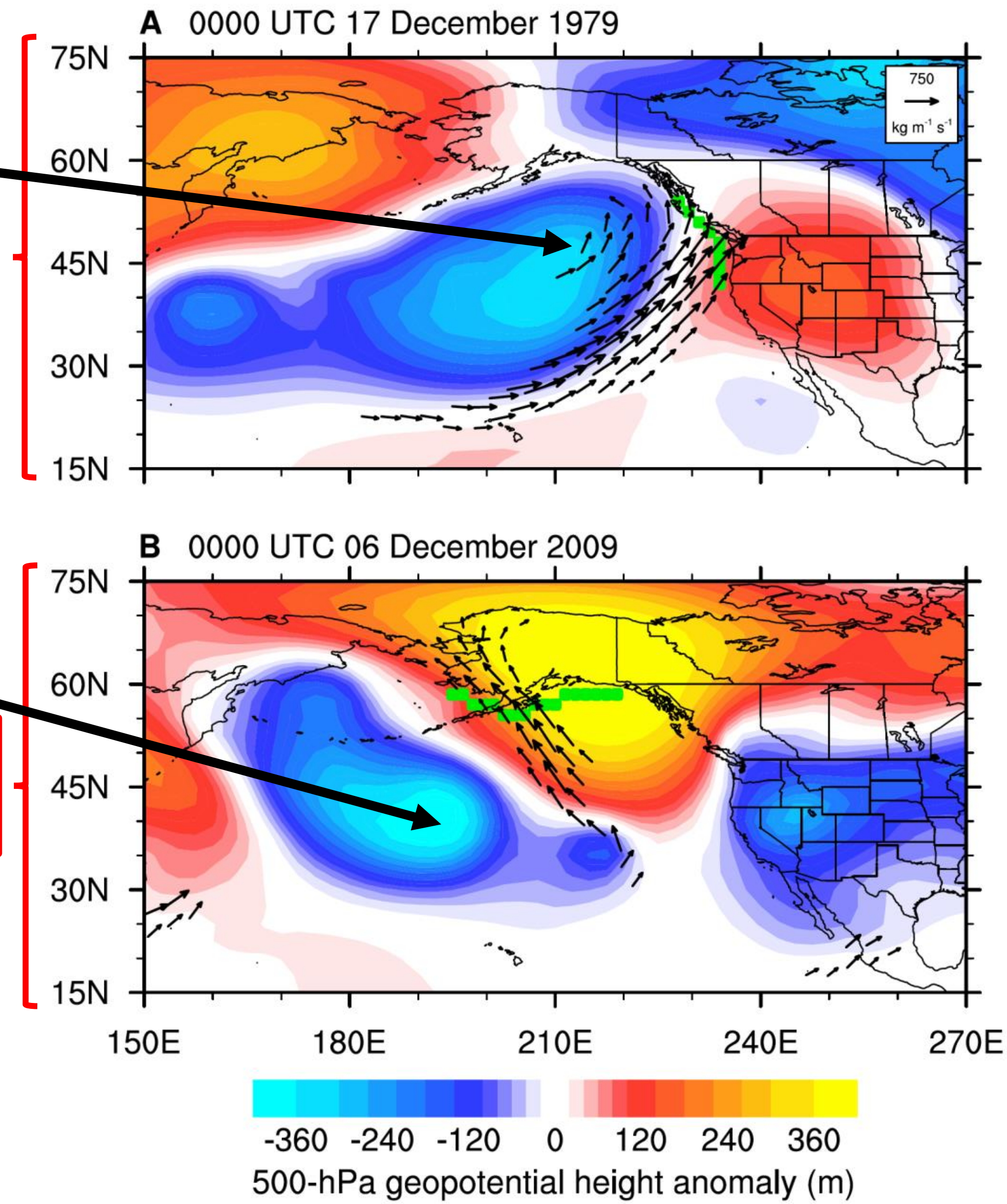
Both events occurred in the <u>third week</u> following MJO phase 5, but during opposite QBO phases

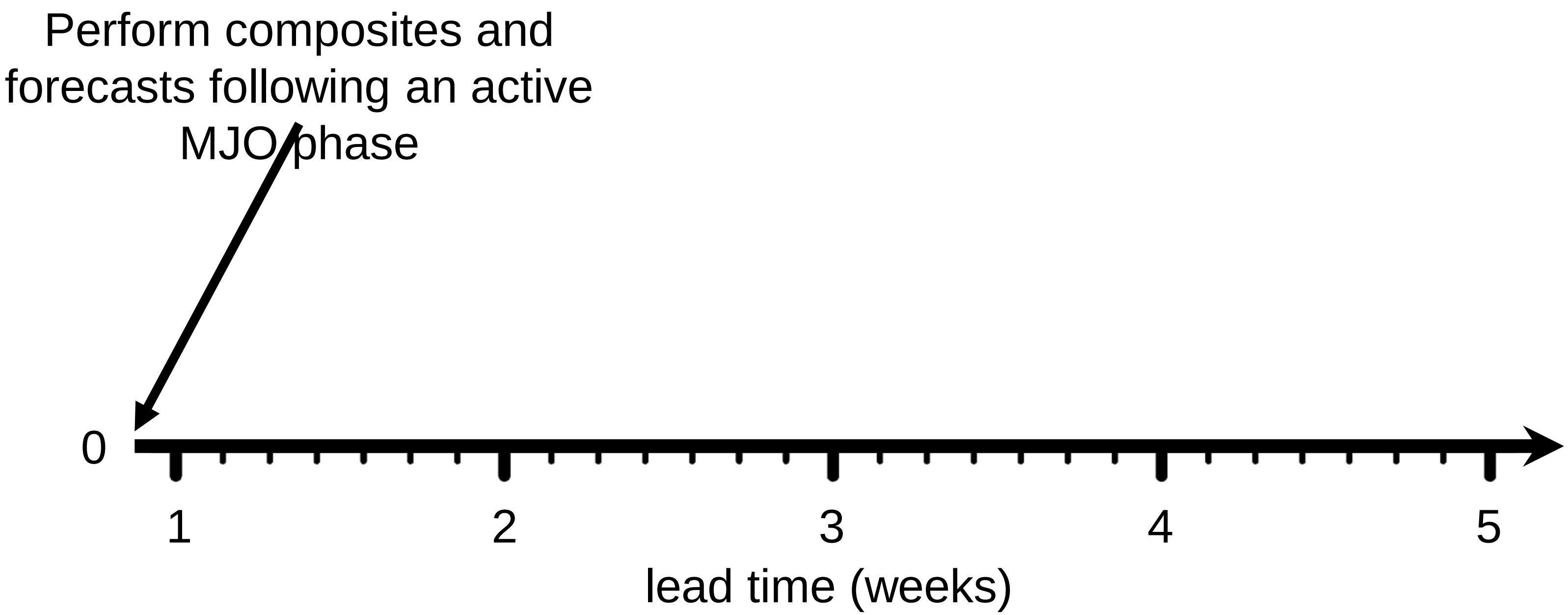
Easterly QBO

versus

Westerly QBO



Weekly Composites of Anomalous Atmospheric River Activity



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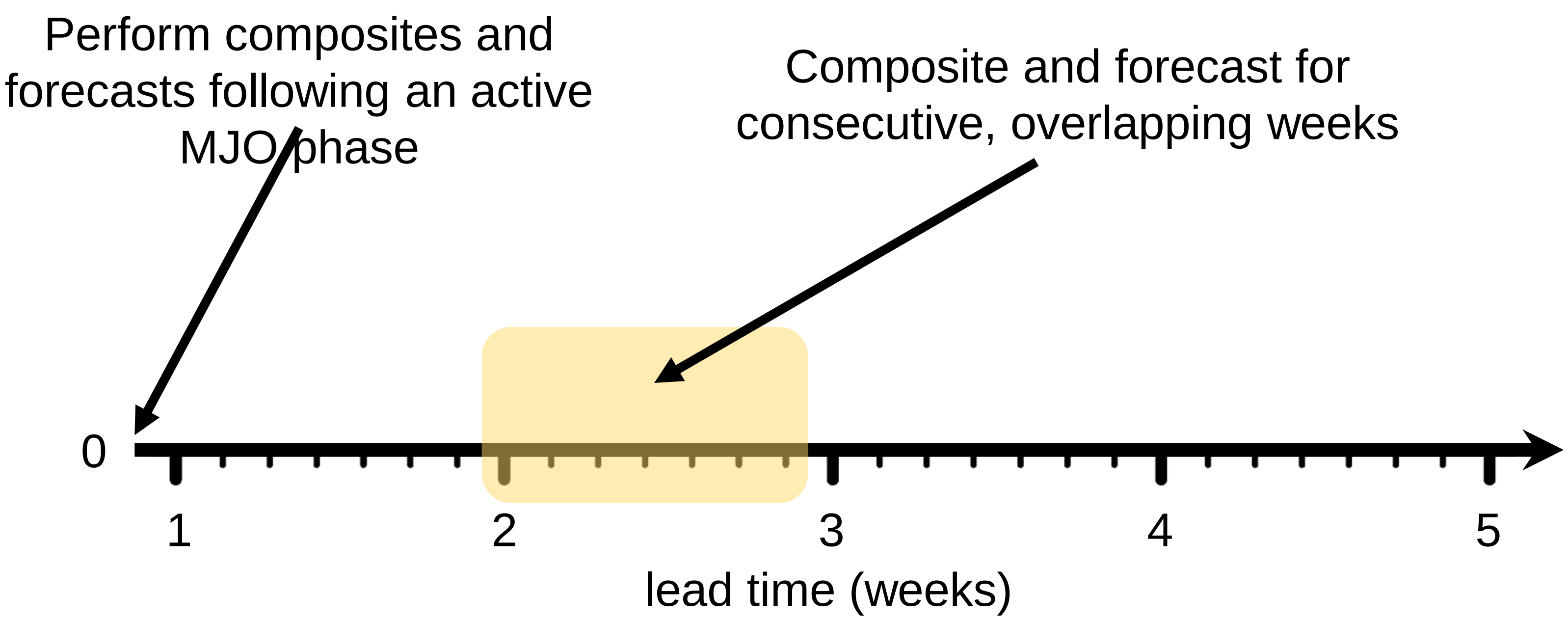

Days 8 to 14

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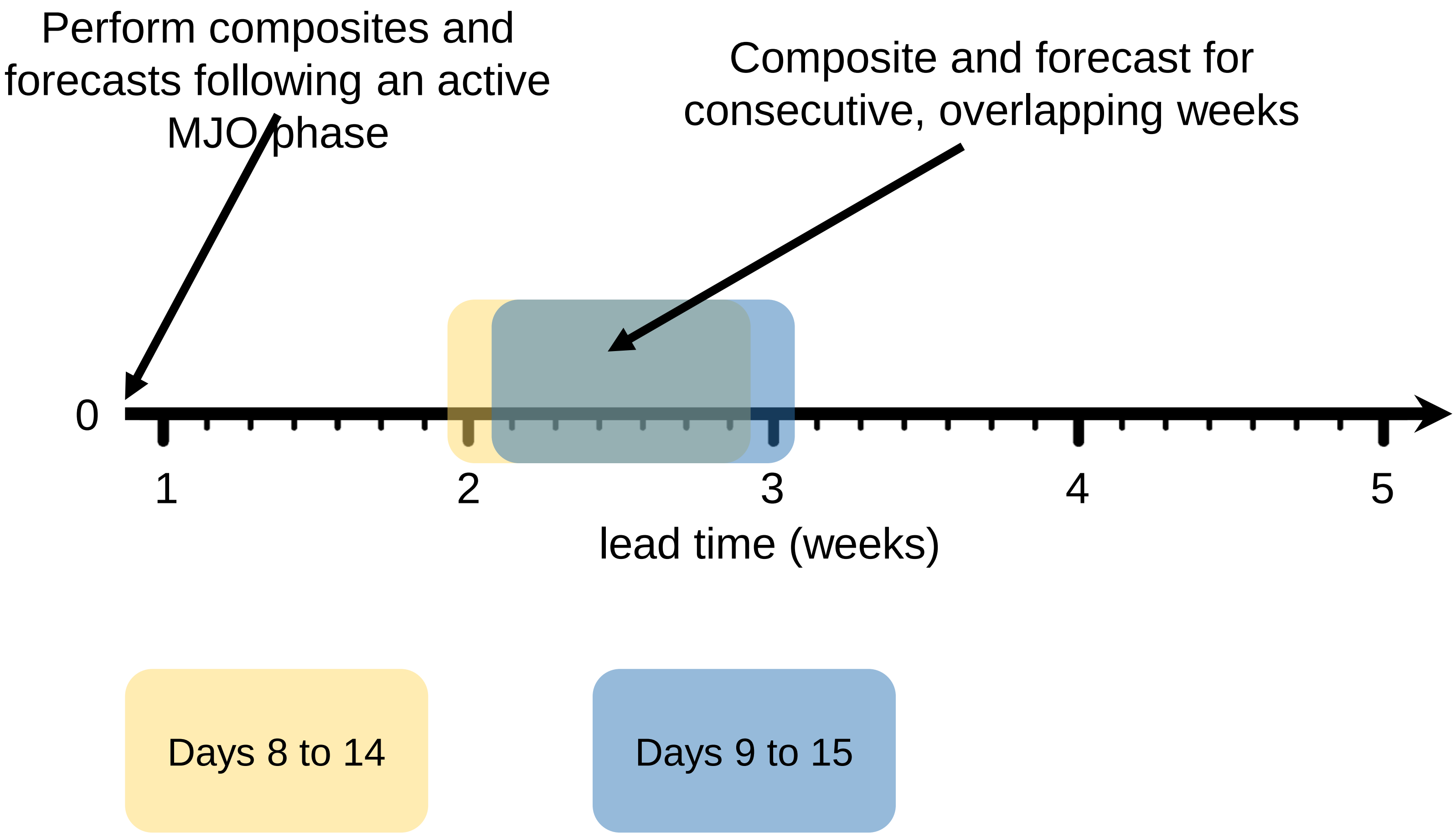

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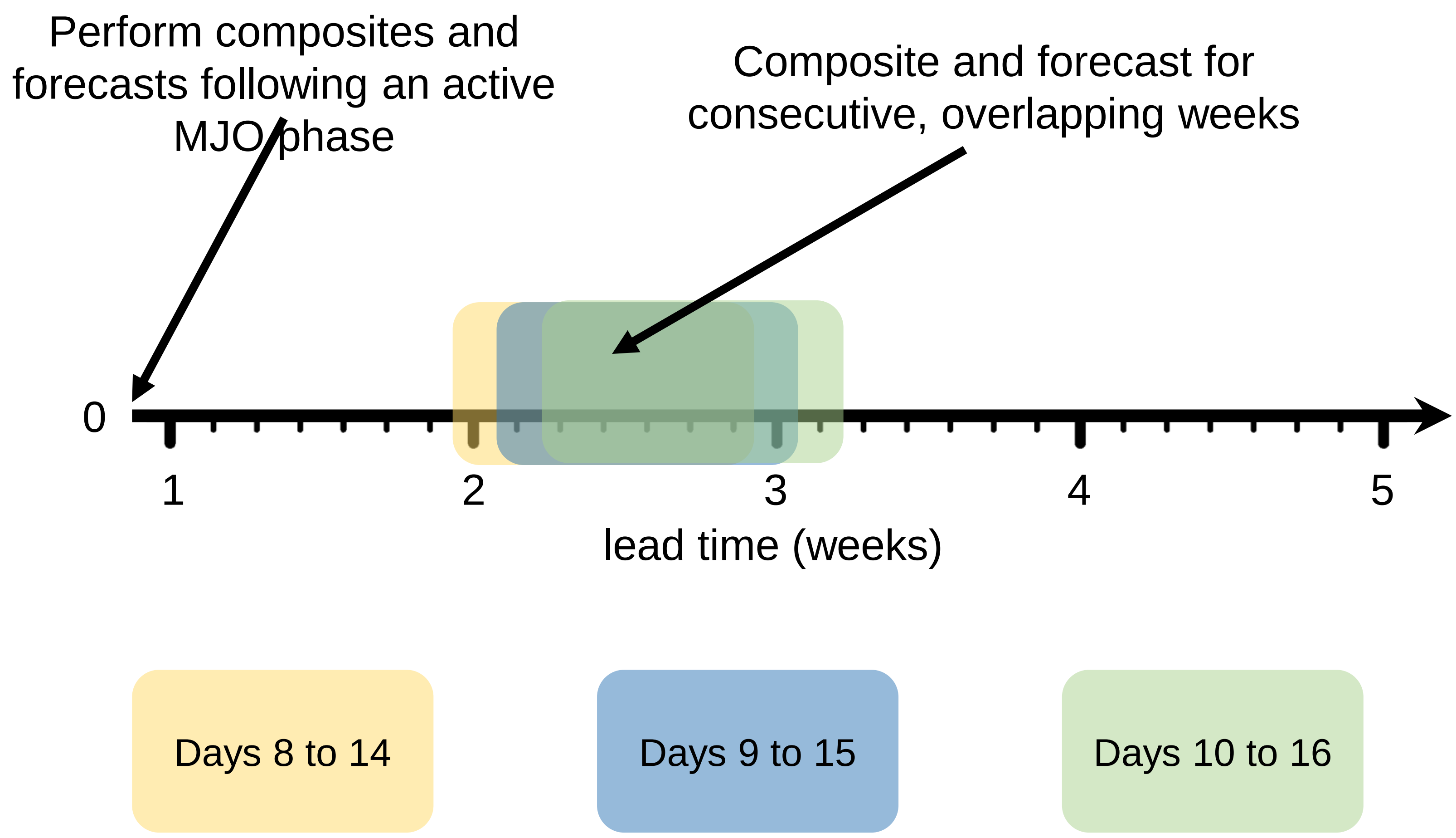
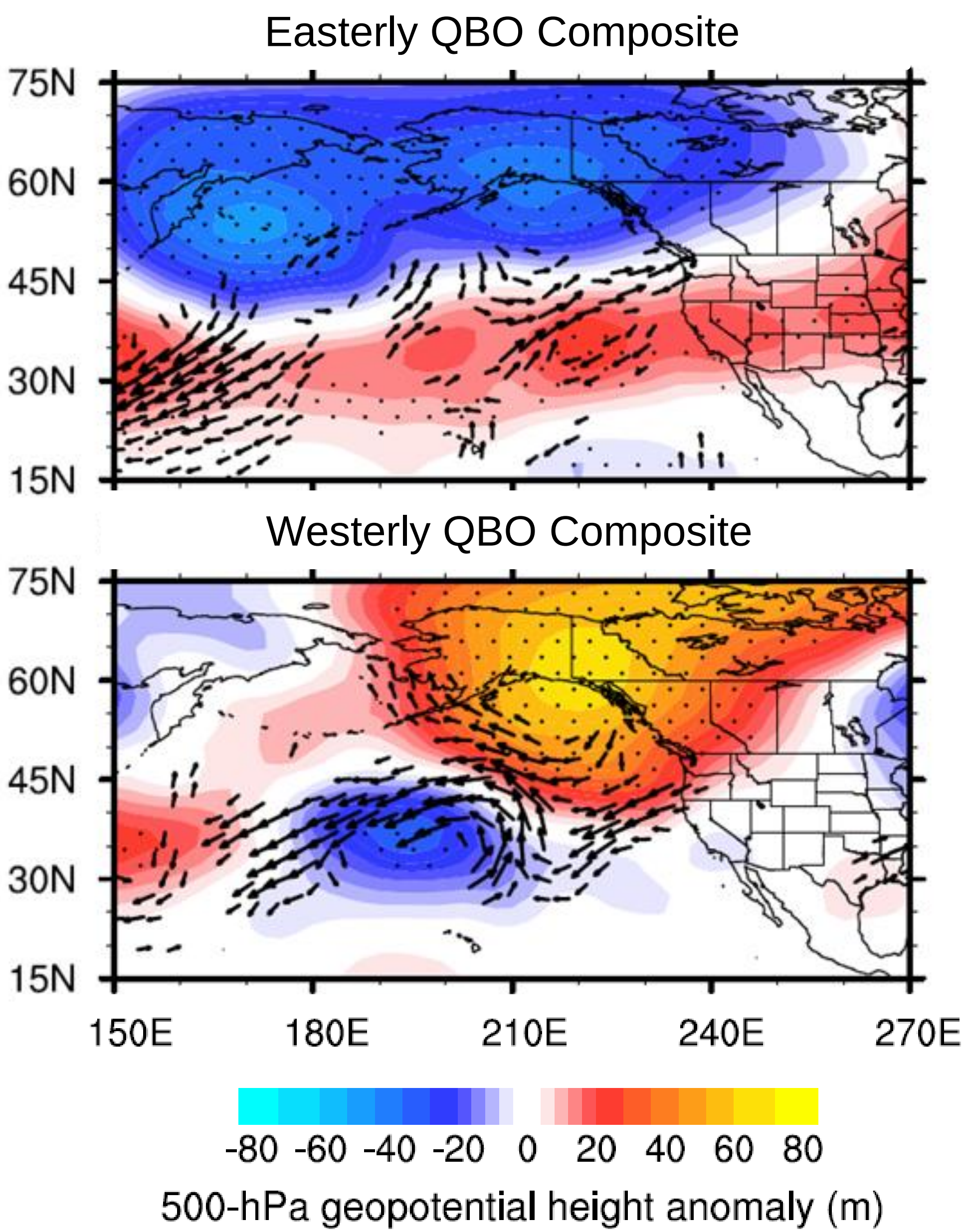
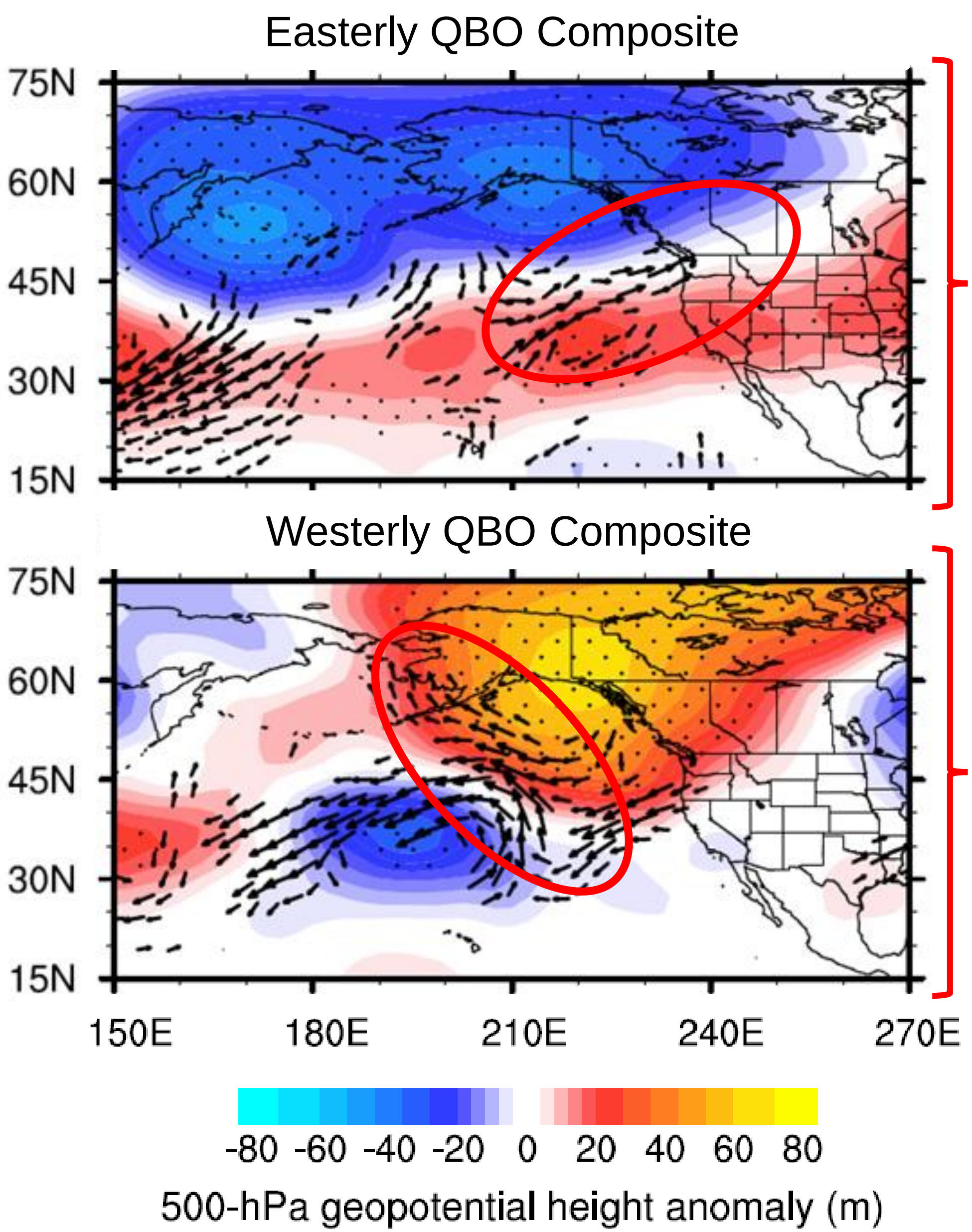


Observational Work - Composites



Averaging the third week following each MJO phase 5 event, we obtain vastly different composites when the phase of the QBO is considered.

Observational Work - Composites



Easterly QBO: favors OR/WA AR landfalls

versus

Westerly QBO: favors AK AR landfalls

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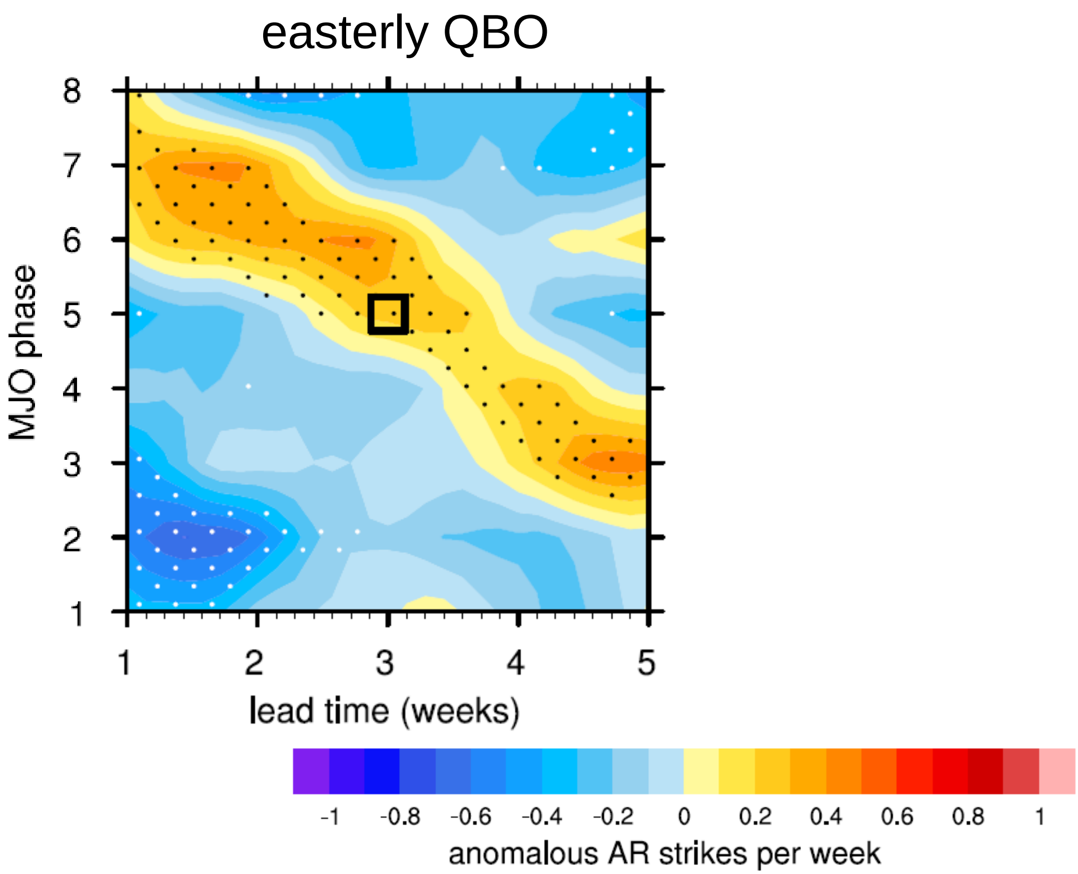
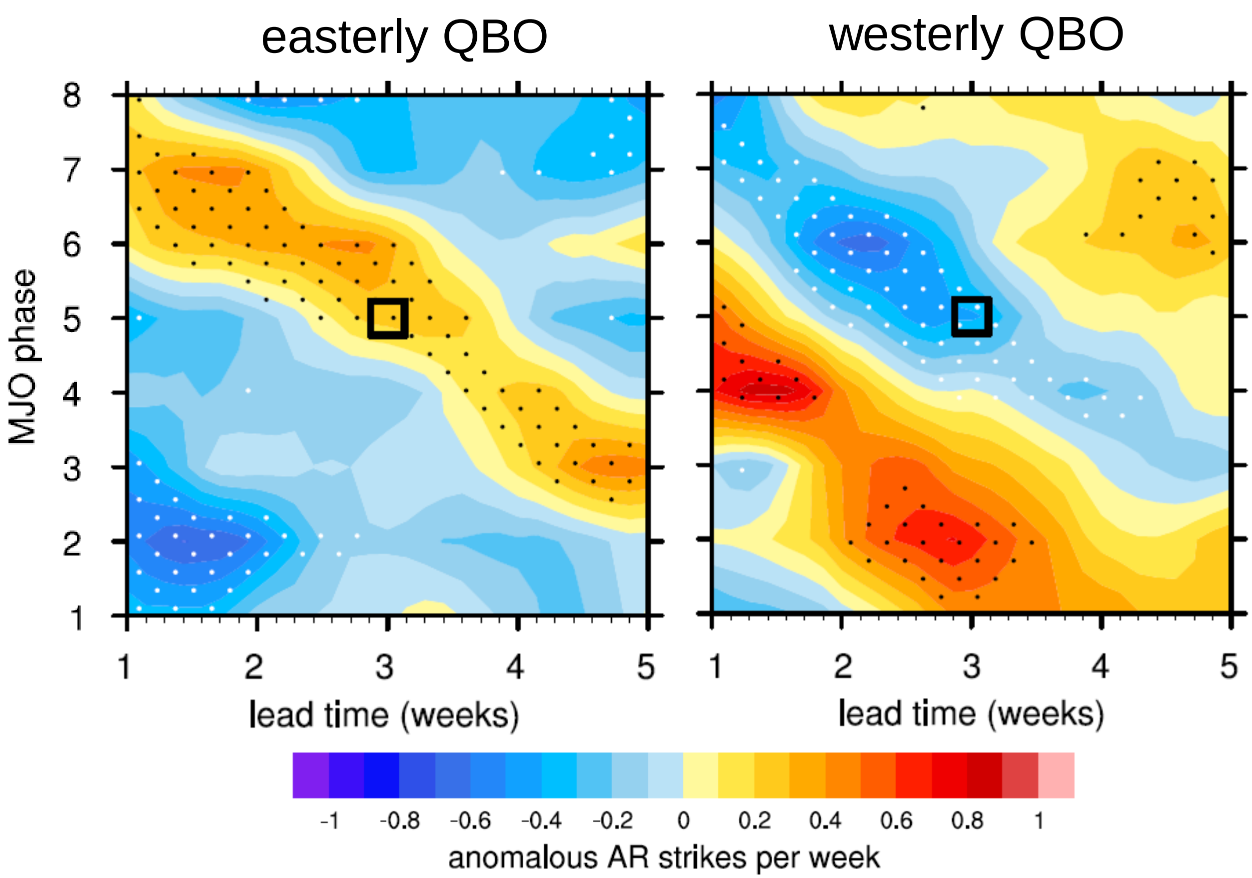
Observational Work –
Pacific Northwest Composites

Pacific Northwest

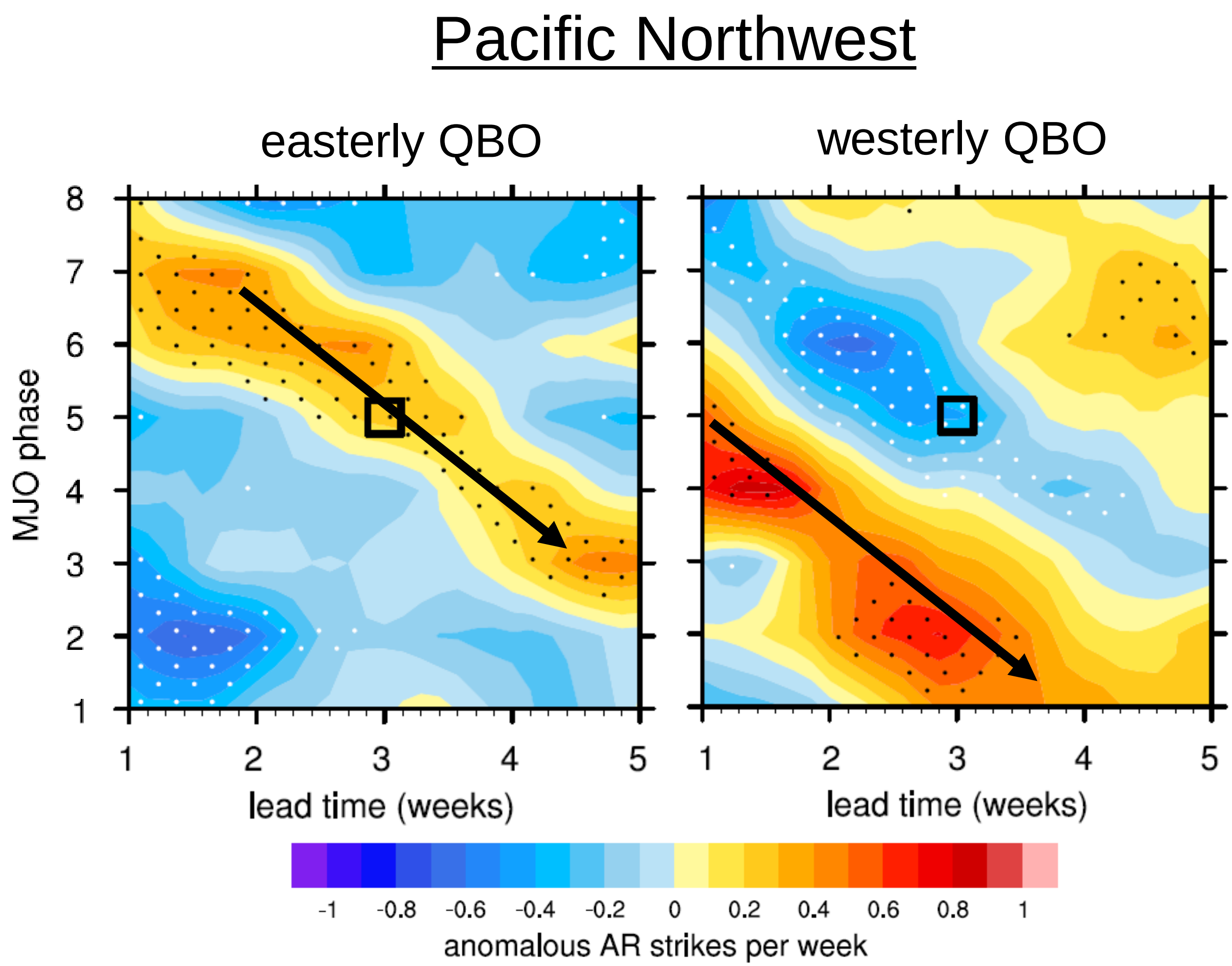


Observational Work – Pacific Northwest Composites

Pacific Northwest



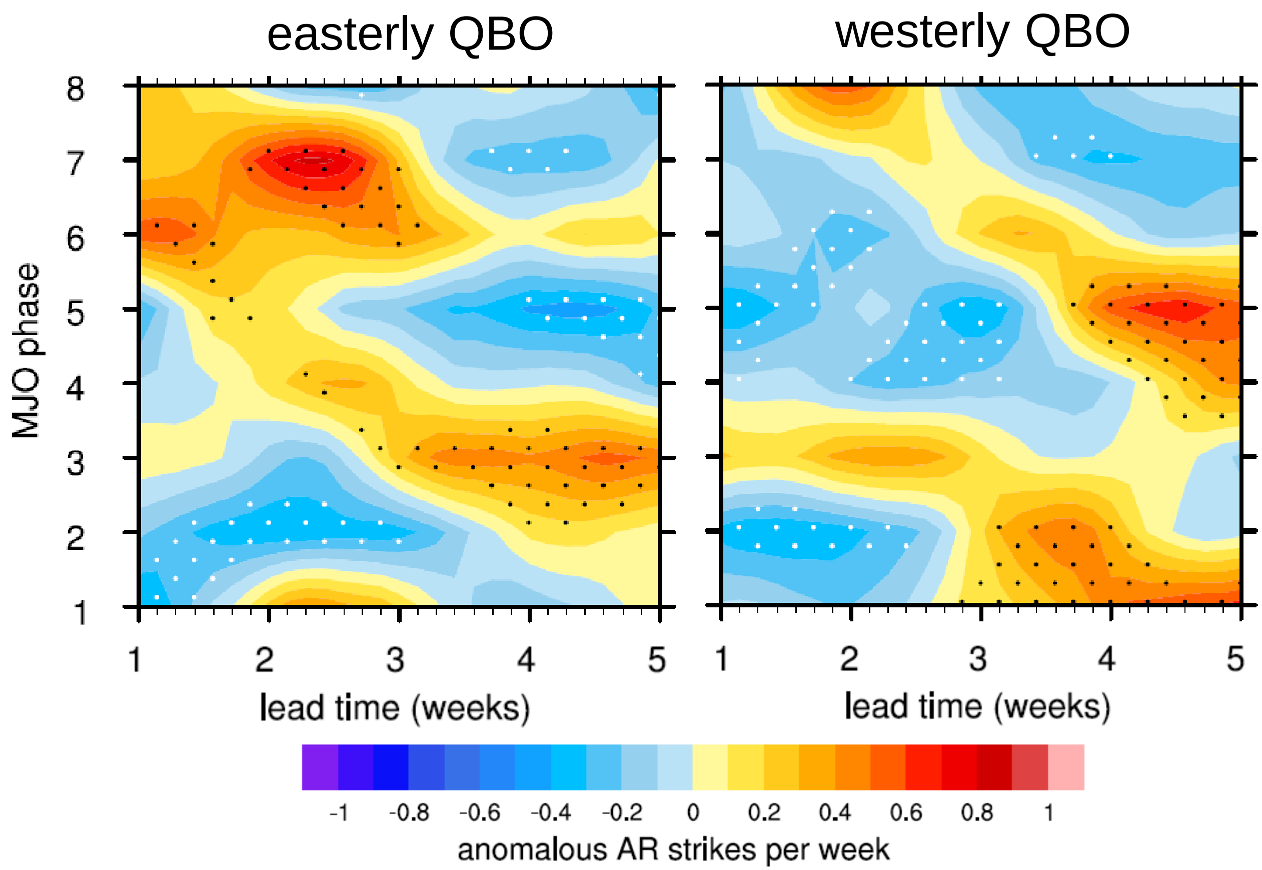
Observational Work – Pacific Northwest Composites



The signals propagate across lead time and MJO phase but vary strongly according to the phase of the QBO.

Observational Work – California Composites

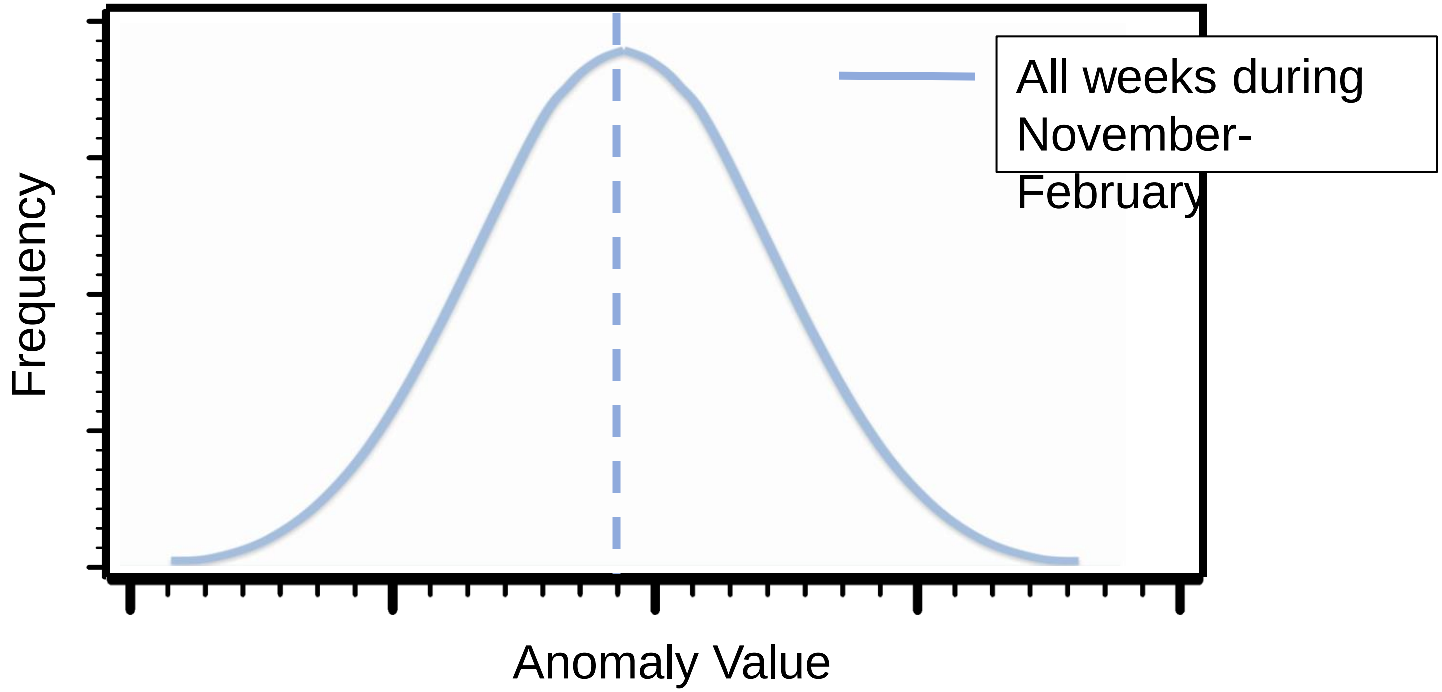
California



The signals are not as clear in California as in the Pacific Northwest, but modulation by QBO phase is still evident.

Empirical Forecast Work - Description of the Forecast Method

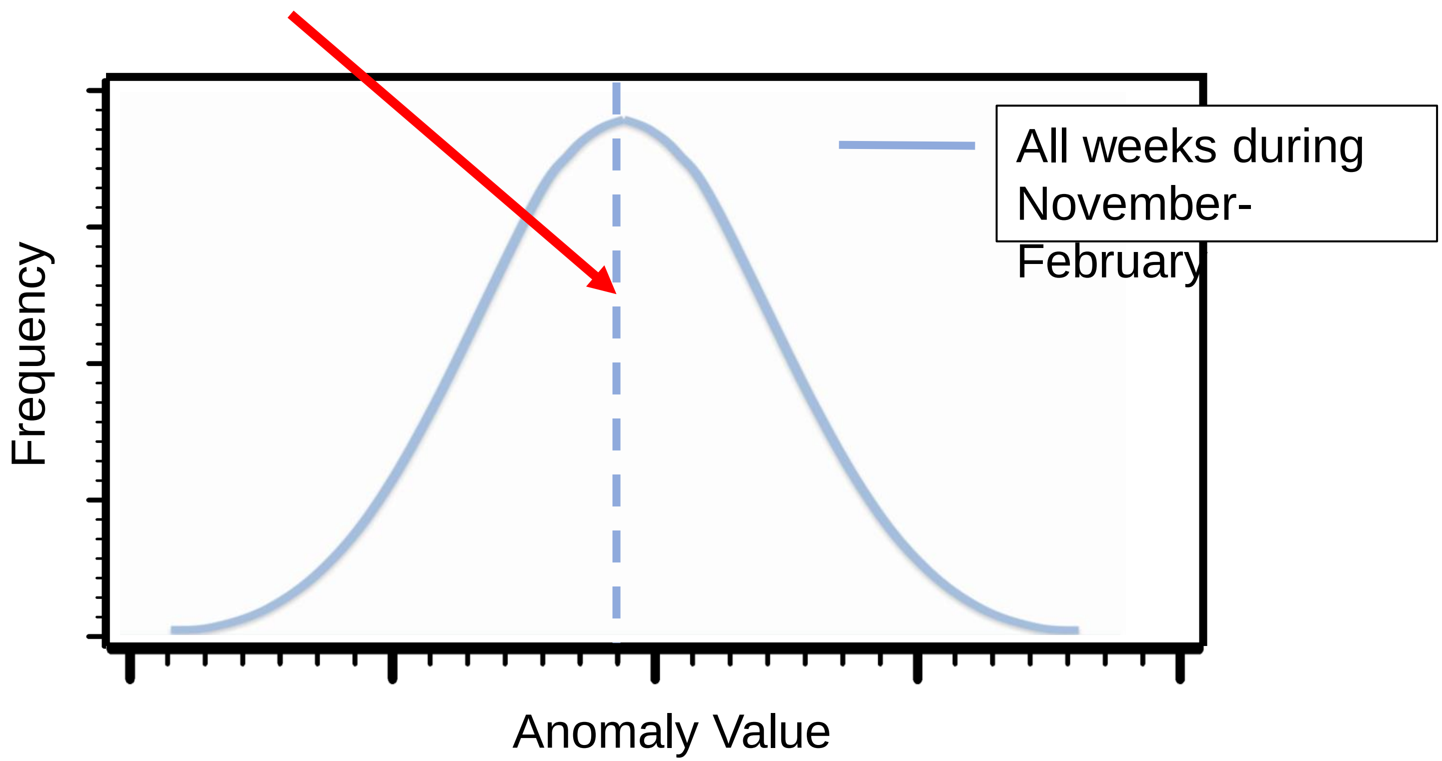
How do we construct an atmospheric river activity forecast using the current state of the MJO and QBO, e.g., in California?



Empirical Forecast Work - Description of the Forecast Method

How do we construct an atmospheric river activity forecast using the current state of the MJO and QBO, e.g., in California?

Normal AR activity during any given week



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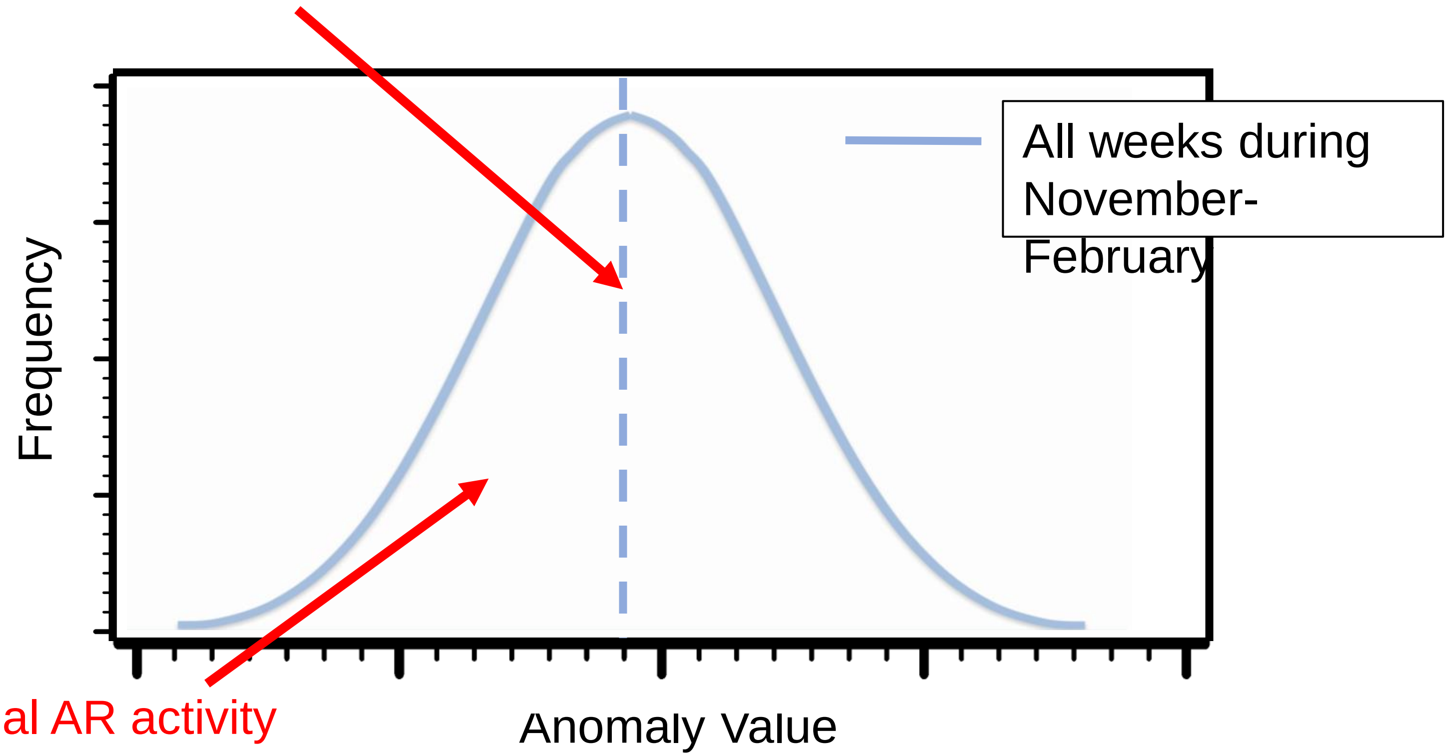

Below normal AR activity during any given week

Empirical Forecast Work - Description of the Forecast Method

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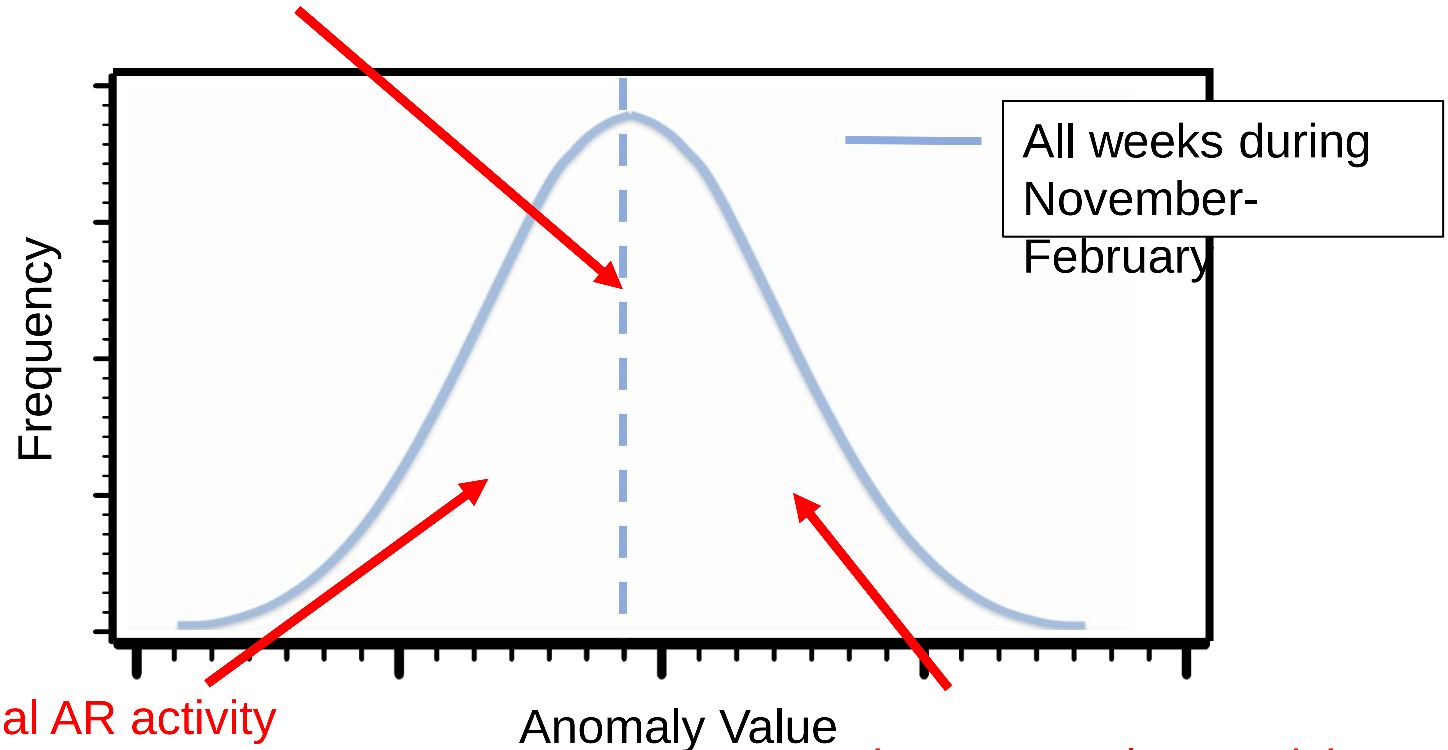
Normal AR activity during any given week



Below normal AR activity during any given week

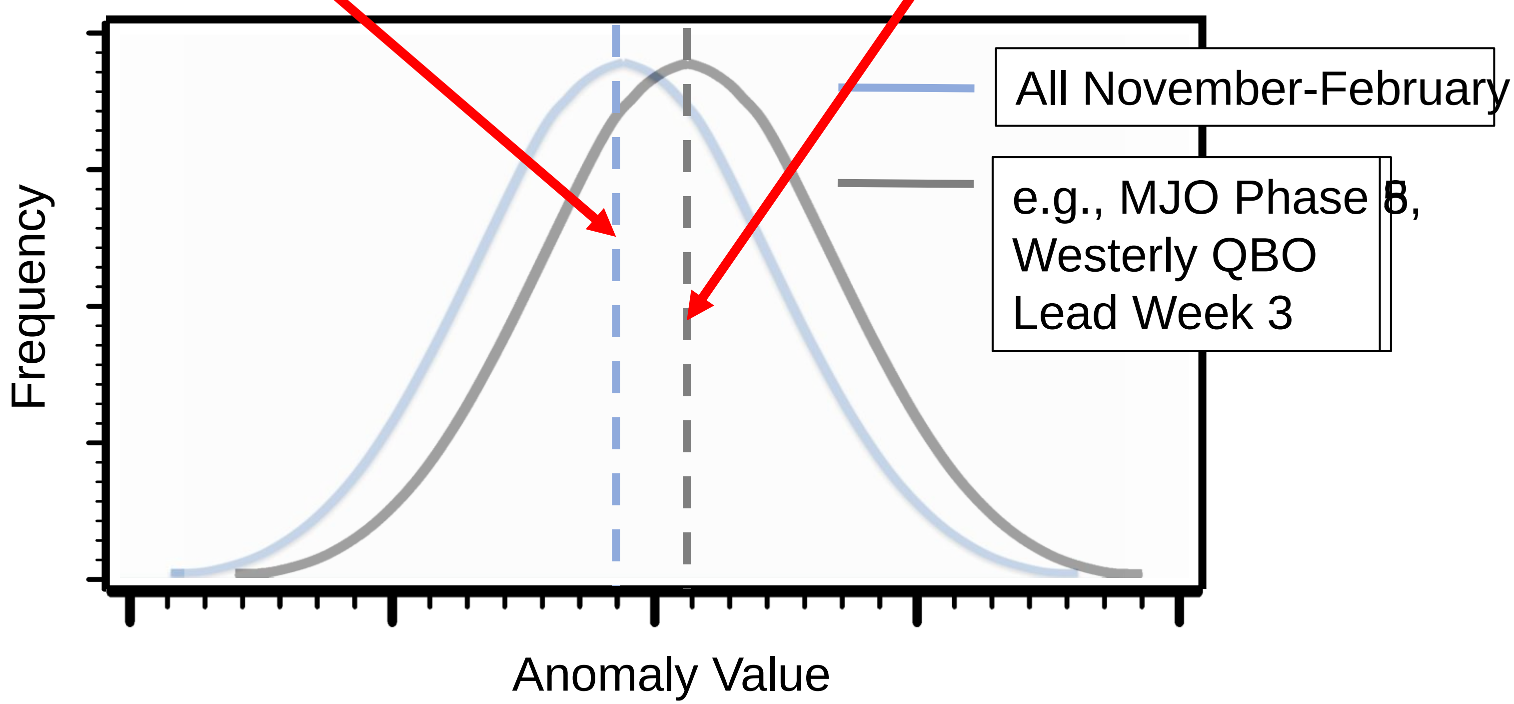
Above normal AR activity during any given week

Empirical Forecast Work - Description of the Forecast Method

How do we construct an atmospheric river activity forecast using the current state of the MJO and QBO, e.g., in California?

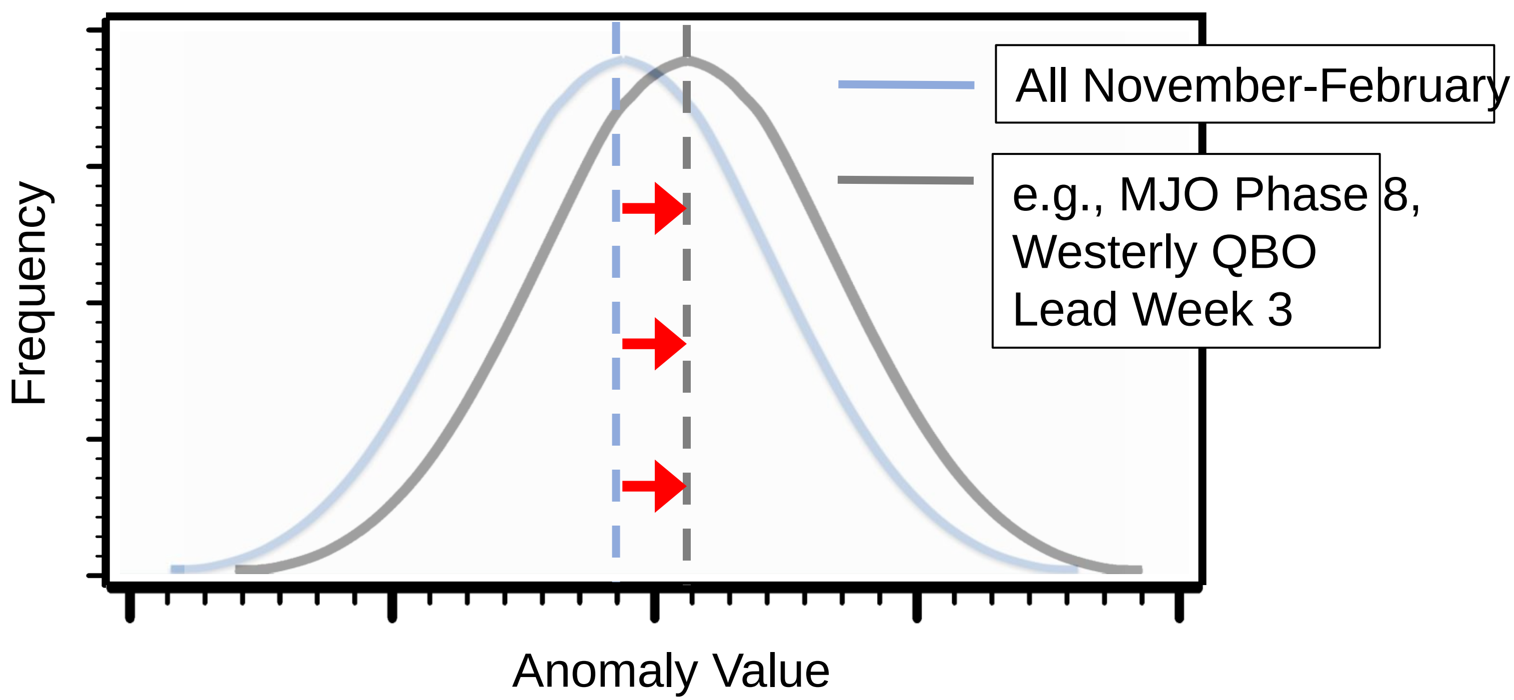
Normal AR activity during any given week

Normal AR activity during the third week following MJO phase 8 in a Westerly QBO



Empirical Forecast Work - Description of the Forecast Method

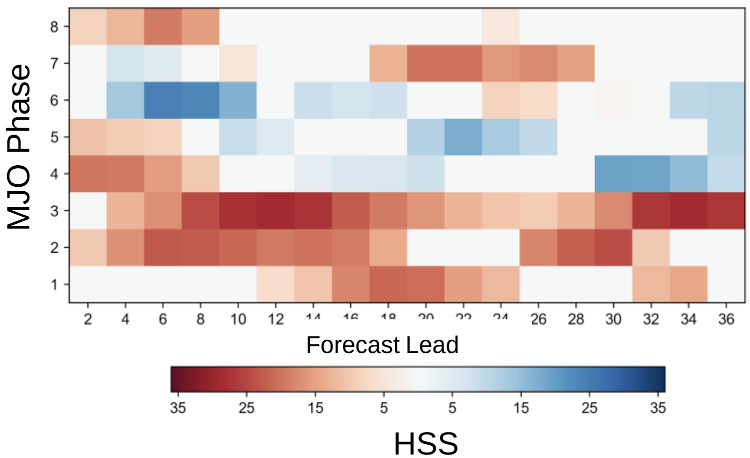
Normal shifts to the right, so we forecast above normal atmospheric river activity during the third week following MJO phase 8 in a Westerly QBO.



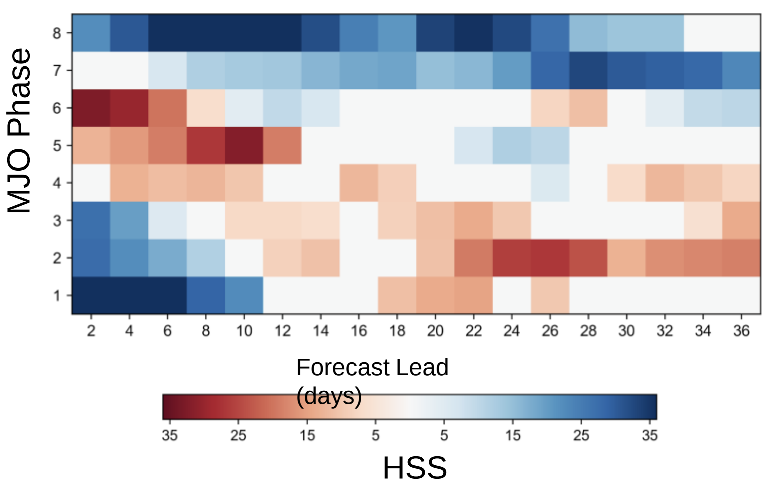
Empirical Forecast Work - Heidke Skill Score for California Forecasts of AR Activity

AR Activity Forecasts

HSS for AR activity in CA, during the easterly QBO



HSS for AR activity in CA, during the westerly QBO



We generate forecasts for all combinations of MJO phase, QBO phase, and lead time.

Heidke Skill Score (HSS)

of correct forecasts

$$HSS = \frac{(H - E)}{(T - E)} \times 100,$$

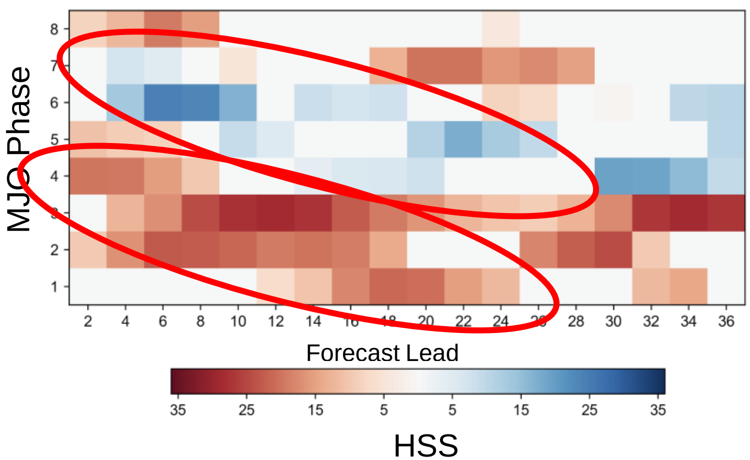
# of total forecasts

# of correct by chance = T/2

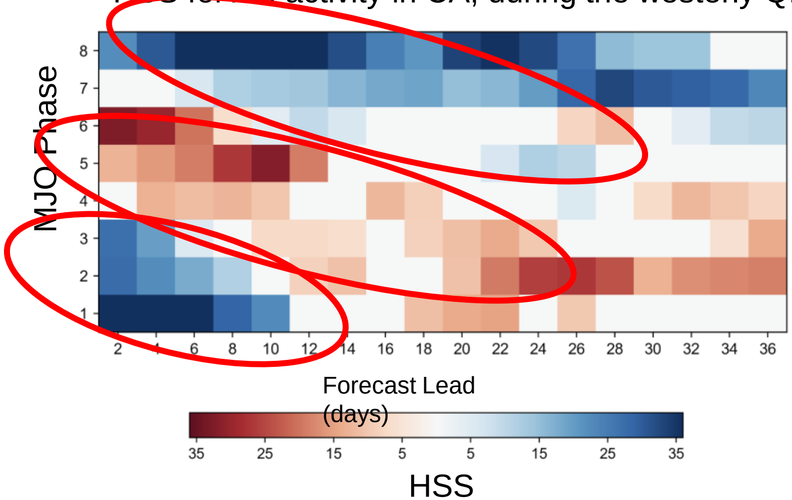
Empirical Forecast Work - Heidke Skill Score for California Forecasts of AR Activity

AR Activity Forecasts

HSS for AR activity in CA, during the easterly QBO



HSS for AR activity in CA, during the westerly QBO



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Heidke Skill Score (HSS)

of correct forecasts

$$HSS = \frac{(H - E)}{(T - E)} \times 100,$$

# of total forecasts

# of correct by chance = T/2

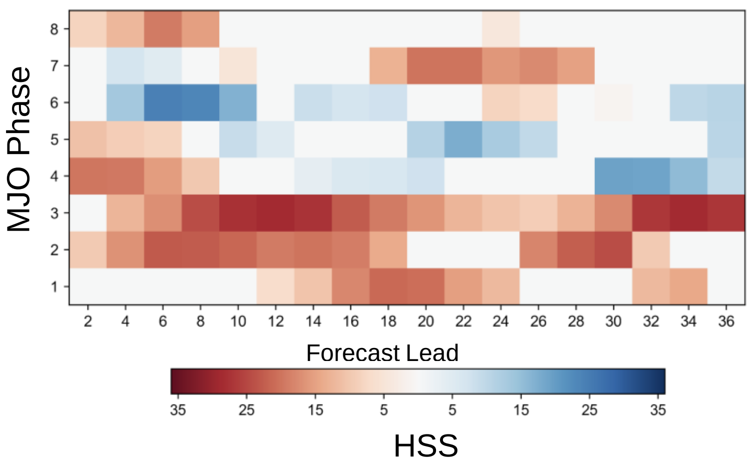
- Skillful forecasts out to 5+ weeks
- Skills propagate across lead time and MJO phase, consistent with the composites

Empirical Forecast Work -
Comparing the HSS for California Forecasts of AR Activity and IVT

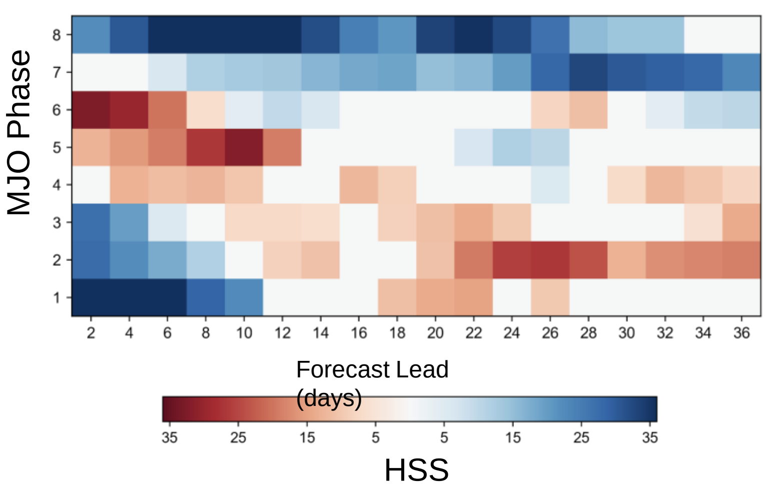
Colorado State University

AR Activity Forecasts

HSS for AR activity in CA, during the easterly QBO

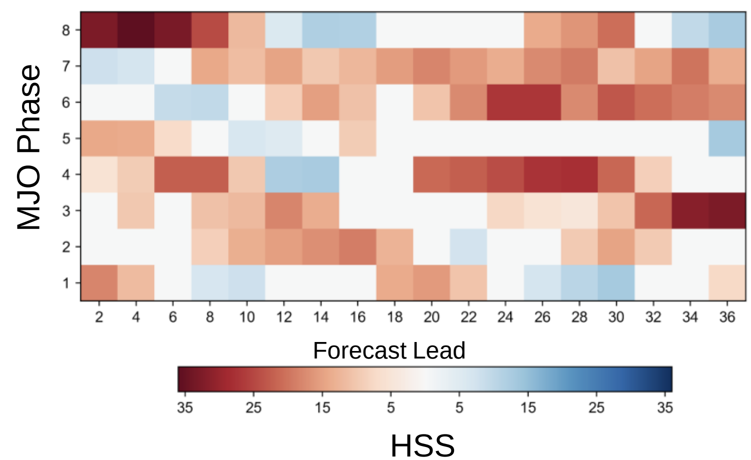


HSS for AR activity in CA, during the westerly QBO

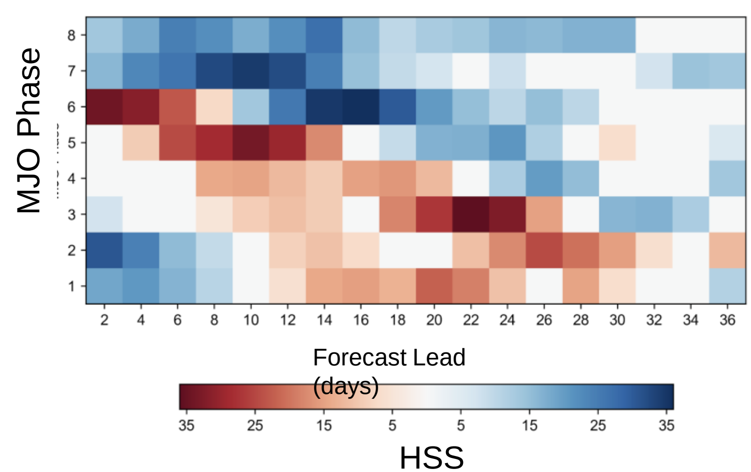


IVT Forecasts

HSS for IVT in CA, during the easterly QBO

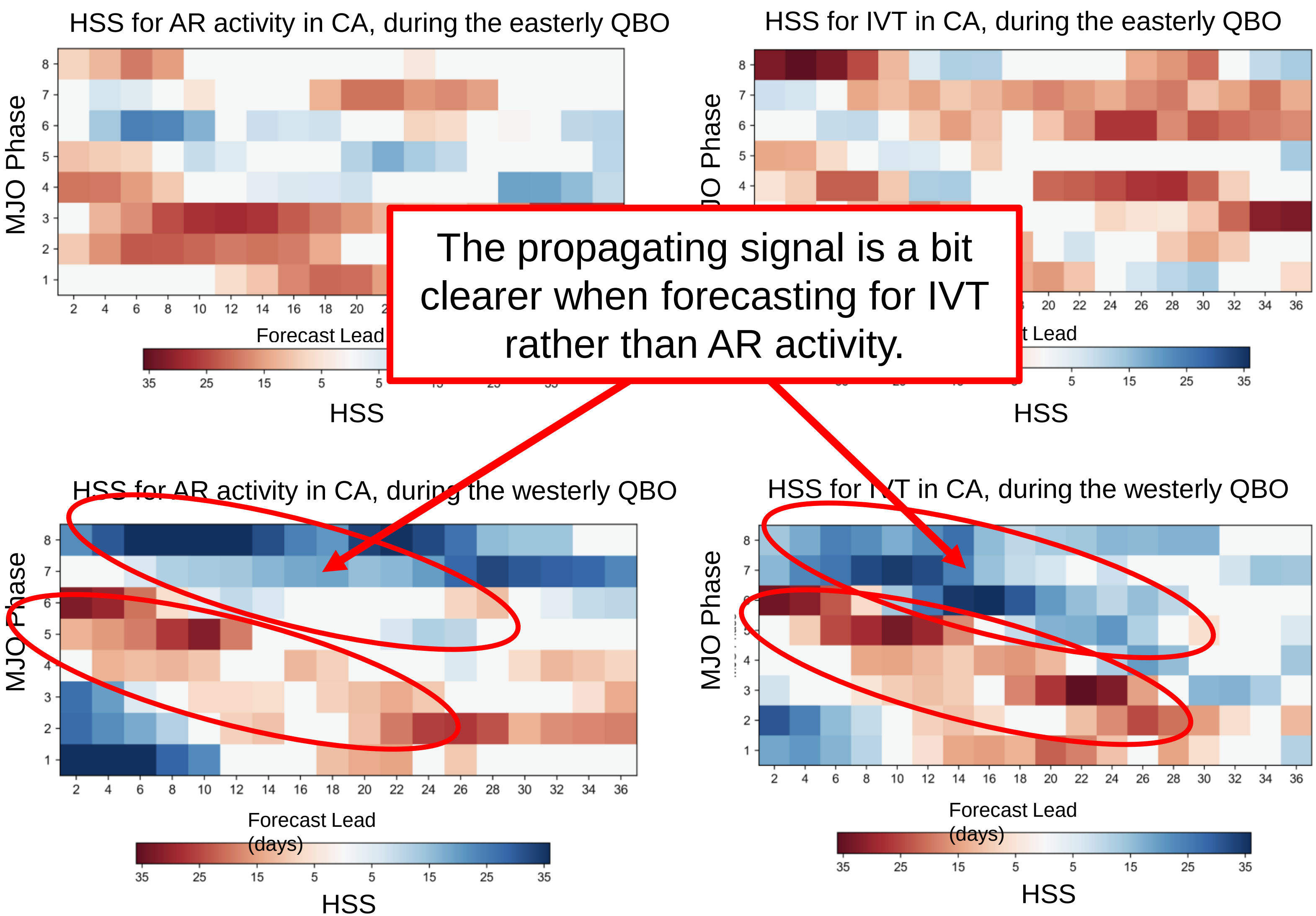


HSS for IVT in CA, during the westerly QBO



Empirical Forecast Work - Comparing the HSS for California Forecasts of AR Activity and IVT

AR Activity Forecasts | IVT Forecasts



Question

Does the *current state* of the MJO and QBO offer information about *future* atmospheric river activity along the U.S. West Coast?

Yes, 3 to 6 weeks in advance.

If yes, can we use the *current state* of the MJO and QBO to skillfully forecast atmospheric river activity at subseasonal-to-seasonal lead times (~3 to 6 weeks in advance)?

Yes, skillful forecasts of opportunity exist 3 to 6 weeks in advance.

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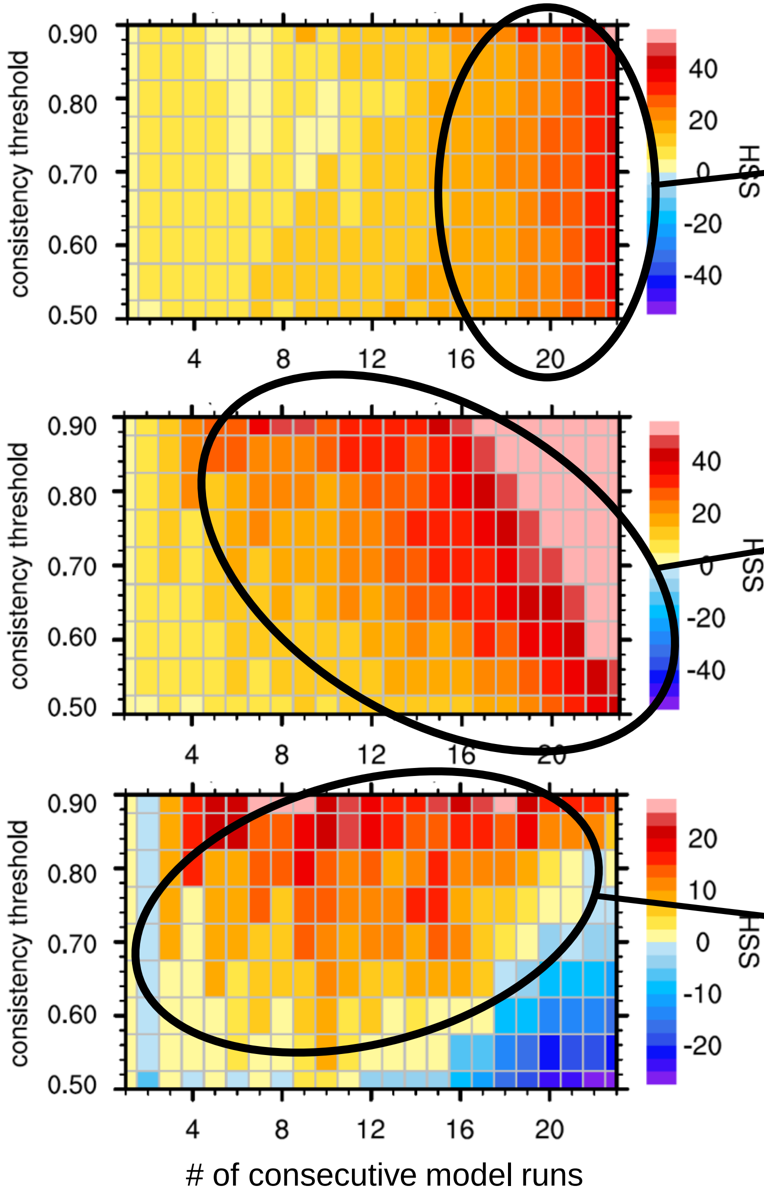
Yes, skillful forecasts of opportunity exist 3 to 6 weeks in advance.

<u>TEASER of work in progress:</u>

Back to the numerical models. Are they really hopeless beyond 14 days? What if we remove the bias? Or use a lagged ensemble approach to forecast based on model run to model run consistency?

TEASER Slide
ECMWF - Bias Correction and Consistency Forecasting

ECMWF ensemble mean AR forecasts for CA



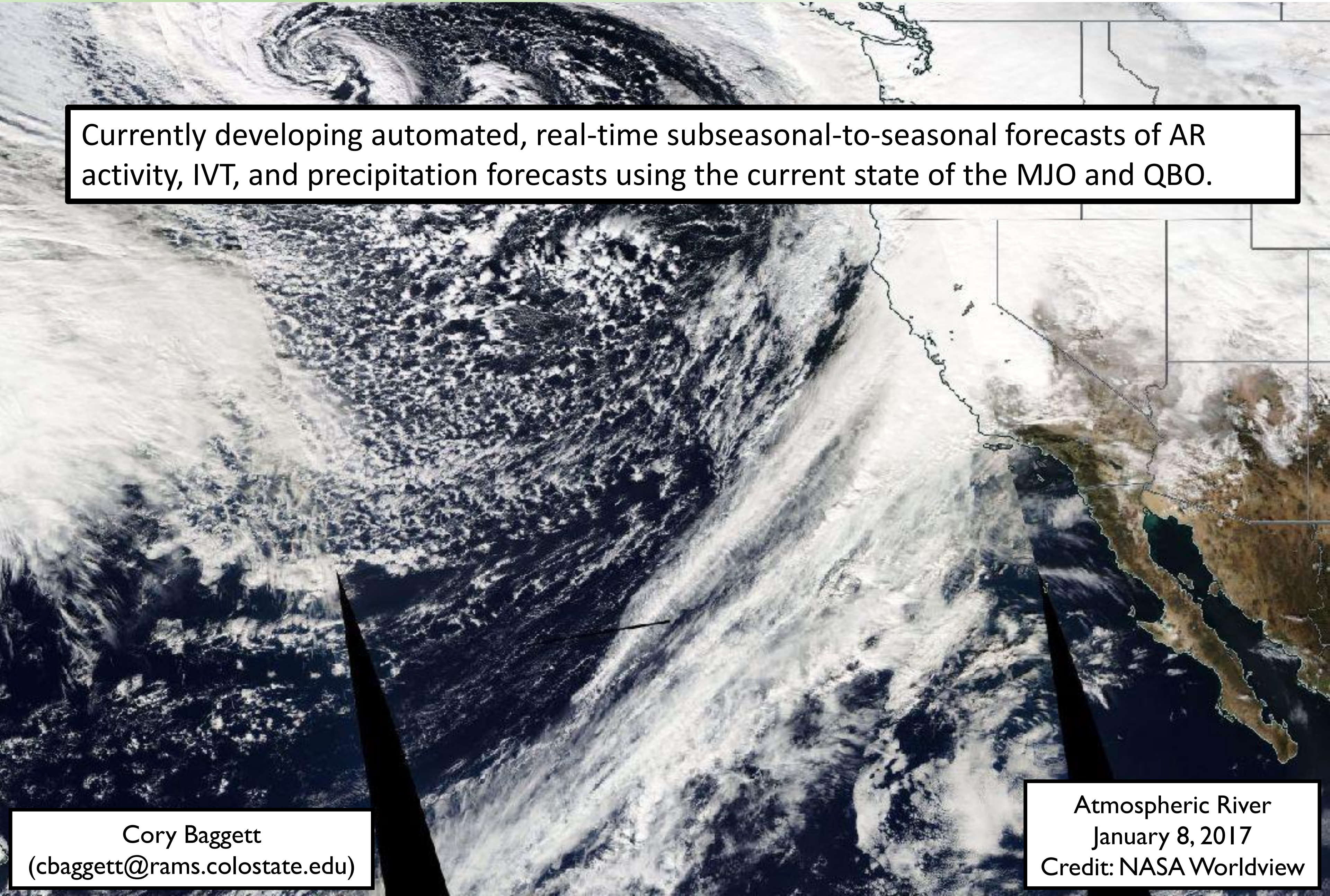
Bias not removed forecast
Consistency forecasting is generally most skillful with lead times of less than 3 weeks.

Bias removed forecast
Skill scores are much improved and increase as the consistency threshold is increased.

But how does the bias removed forecast compare to simply using the most recent model run?
There is a period of time when using the most recent model run is better, but at longer leads consistency forecasting has higher skill, especially at higher consistency thresholds

Current and Future Efforts

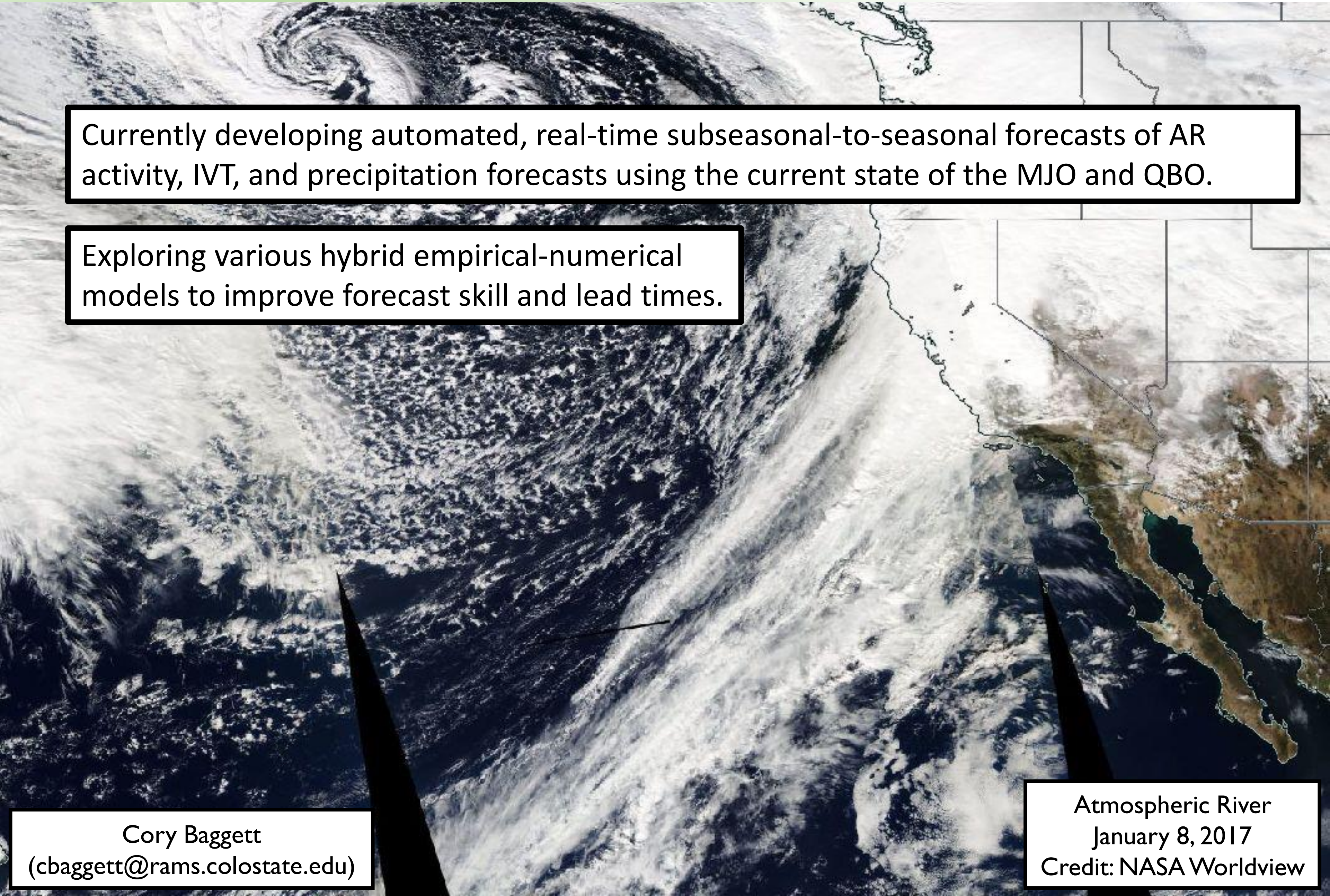
Currently developing automated, real-time subseasonal-to-seasonal forecasts of AR activity, IVT, and precipitation forecasts using the current state of the MJO and QBO.



Atmospheric River
January 8, 2017
Credit: NASA Worldview

Cory Baggett
(cbaggett@rams.colostate.edu)

Current and Future Efforts



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Exploring various hybrid empirical-numerical models to improve forecast skill and lead times.

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Current and Future Efforts

Currently developing automated, real-time subseasonal-to-seasonal forecasts of AR activity, IVT, and precipitation forecasts using the current state of the MJO and QBO.

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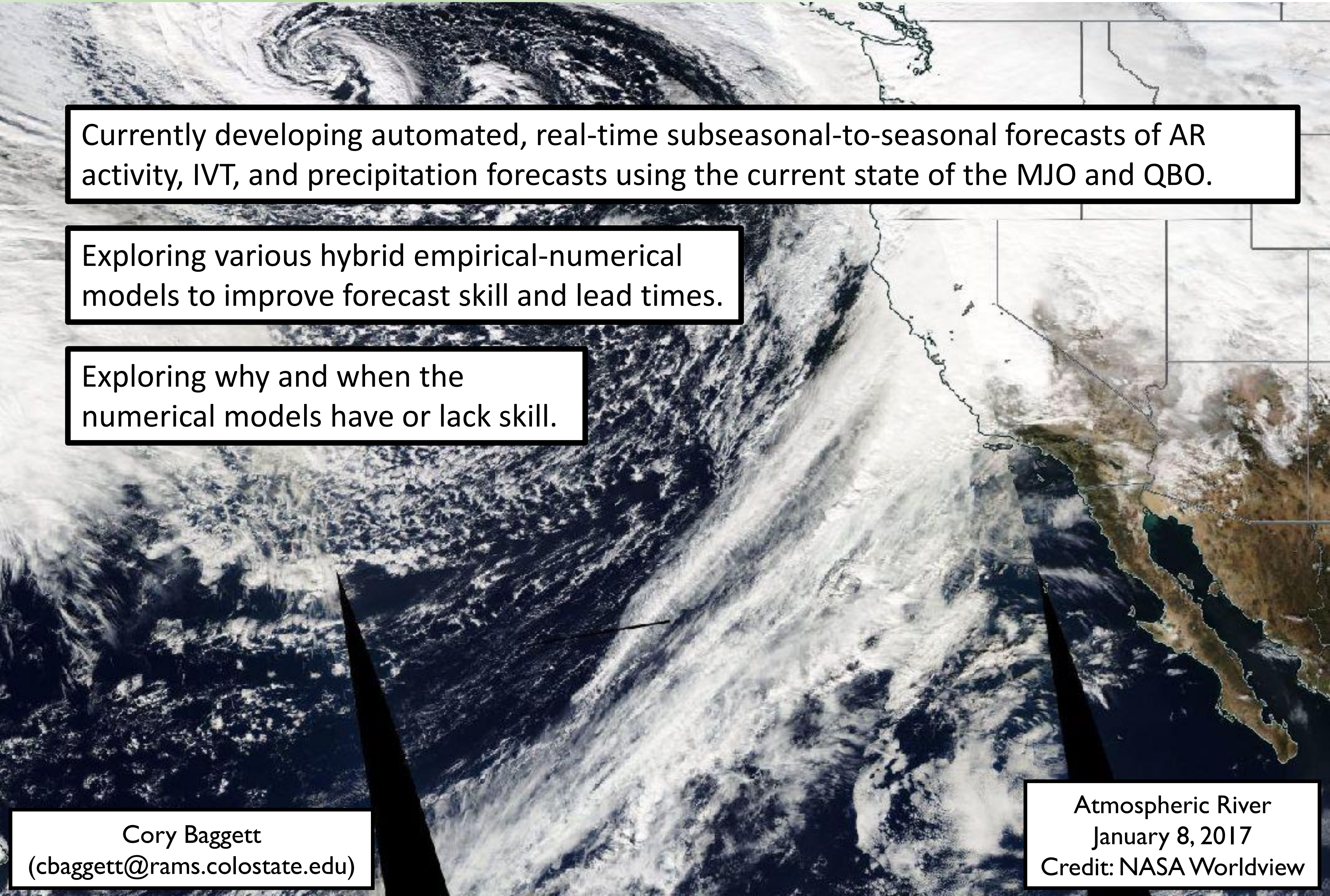
Exploring why and when the numerical models have or lack skill.



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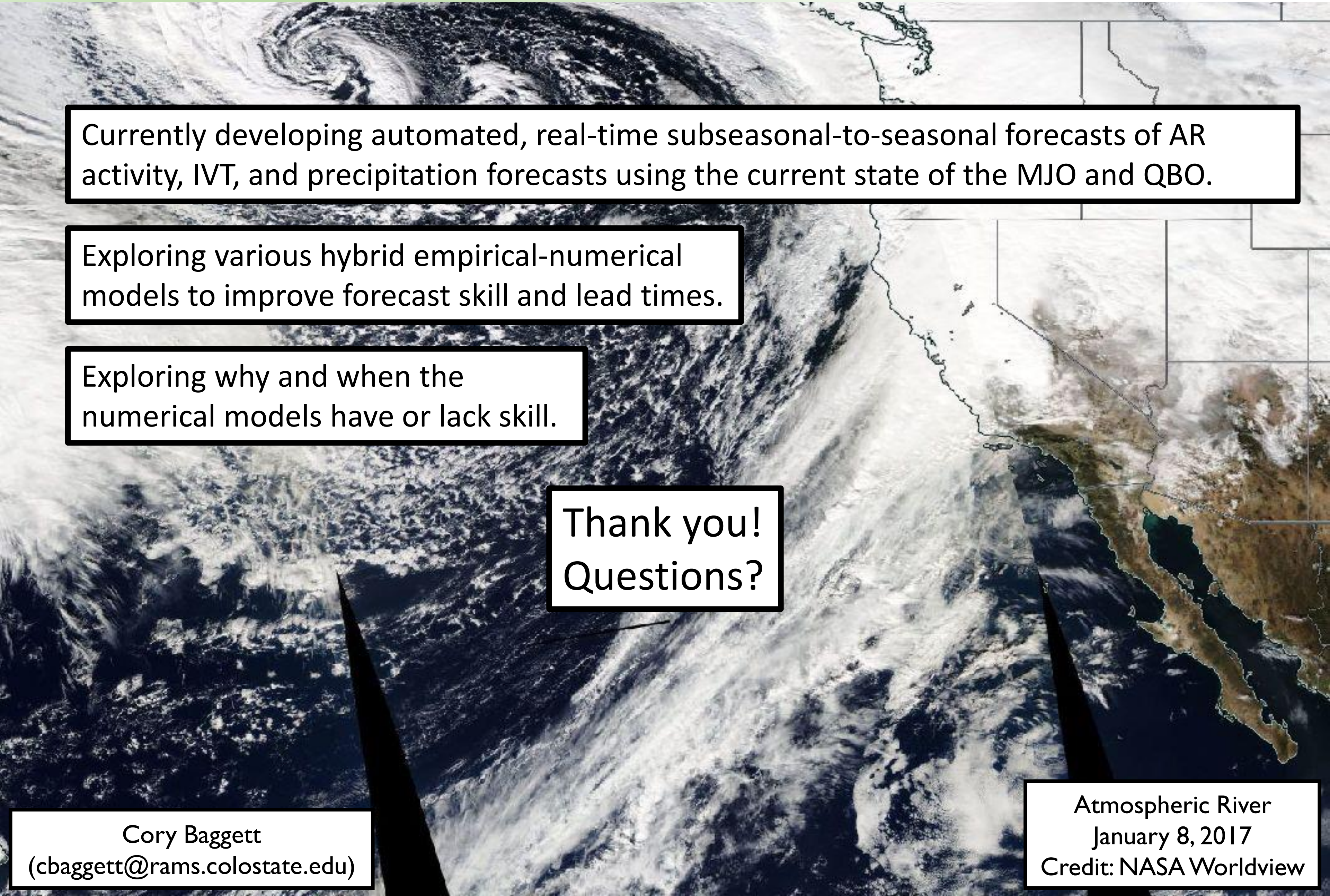

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Thank you!
Questions?

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Atmospheric River
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References

Baggett, C. F., E. A. Barnes, E. D. Maloney, and B. D. Mundhenk, 2017: Advancing Atmospheric River Forecasts into Subseasonal-to-Seasonal Timescales. *Geophys Res Lett*.

DeFlorio, M. J., D. E. Waliser, B. Guan, D. A. Lavers, F. M. Ralph, and F. Vitart, 2018: Global assessment of atmospheric river prediction skill. *J Hydrometeorol*.

Dettinger, M. D., 2013: Atmospheric Rivers as Drought Busters on the U.S. West Coast. *J Hydrometeorol*, **14,** 1721-1732.

Dettinger, M. D., F. M. Ralph, T. Das, P. J. Neiman, and D. R. Cayan, 2011: Atmospheric Rivers, Floods and the Water Resources of California. *Water*, **3,** 445-478.

Hoskins, B. J., and D. J. Karoly, 1981: The Steady Linear Response of a Spherical Atmosphere to Thermal and Orographic Forcing. *J Atmos Sci*, **38,** 1179-1196.

Mundhenk, B. D., E. A. Barnes, and E. D. Maloney, 2016: All-Season Climatology and Variability of Atmospheric River Frequencies over the North Pacific. *J Climate*, **29,** 4885-4903.

Mundhenk, B. D., E. A. Barnes, E. D. Maloney, and C. F. Baggett, 2018: Skillful empirical subseasonal prediction of landfalling atmospheric river activity using the Madden–Julian oscillation and quasi-biennial oscillation. *npj Climate and Atmospheric Science*, **1**.

Nayak, M. A., G. Villarini, and D. A. Lavers, 2014: On the skill of numerical weather prediction models to forecast atmospheric rivers over the central United States. *Geophys Res Lett*, **41,** 4354-4362.

Sardeshmukh, P. D., and B. J. Hoskins, 1988: The Generation of Global Rotational Flow by Steady Idealized Tropical Divergence. *J Atmos Sci*, **45,** 1228-1251.

Simmons, A. J., J. M. Wallace, and G. W. Branstator, 1983: Barotropic Wave Propagation and Instability, and Atmospheric Teleconnection Patterns. *J Atmos Sci*, **40,** 1363-1392.

Son, S. W., Y. Lim, C. H. Yoo, H. H. Hendon, and J. Kim, 2017: Stratospheric Control of the Madden-Julian Oscillation. *J Climate*, **30,** 1909-1922.

Wick, G. A., P. J. Neiman, F. M. Ralph, and T. M. Hamill, 2013: Evaluation of Forecasts of the Water Vapor Signature of Atmospheric Rivers in Operational Numerical Weather Prediction Models. *Weather Forecast*, **28,** 1337-1352.

Wilks, D. S., 2006: *Statistical methods in the Atmospheric Sciences.* 2 ed. Academic Press.

Yoo, C., and S. W. Son, 2016: Modulation of the boreal wintertime Madden-Julian oscillation by the stratospheric quasi-biennial oscillation. *Geophys Res Lett*, **43,** 1392-1398.

Zhang, C., and B. Zhang, 2018: QBO-MJO Connection. *Journal of Geophysical Research: Atmospheres*.

Extra Slides

Regions of interest

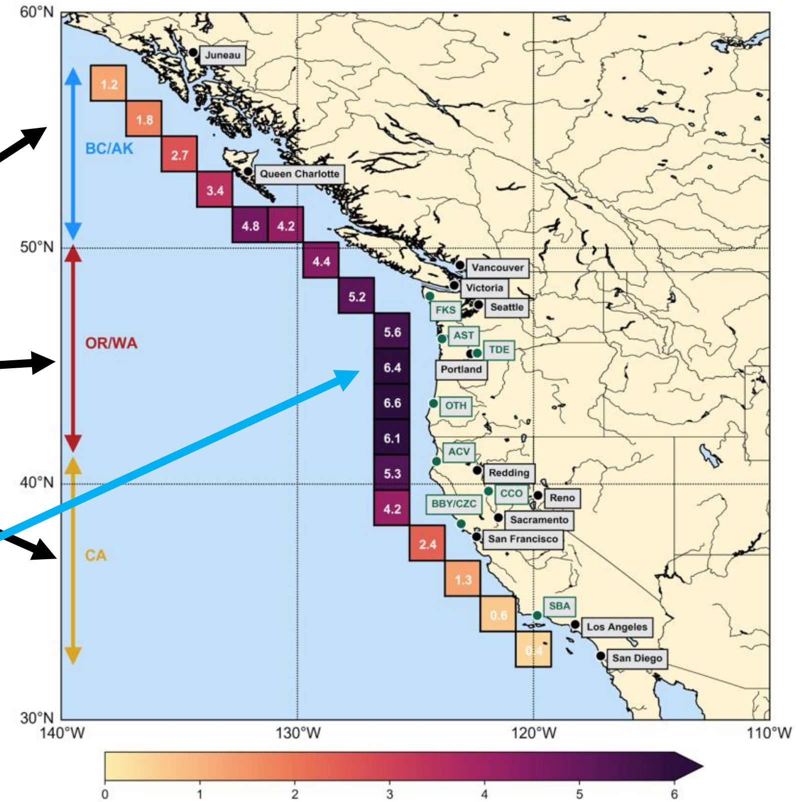
ERA-Interim Reanalysis data is the "truth" by which the models are judged.

The detection region is divided into 3 sub-regions with different atmospheric river climatologies:

- British Columbia / Alaska
- Oregon / Washington
- California

Atmospheric river frequencies are highest in the Pacific Northwest

Atmospheric River November-February Frequencies



Atmospheric River Days per Season

Atmospheric River Occurrence – Skill Metrics

2 x 2 Contingency Table (Wilks 2016)

Observed?

Forecast?		Yes	No
	Yes	Hits	False Alarms
	No	Misses	Correct Rejections

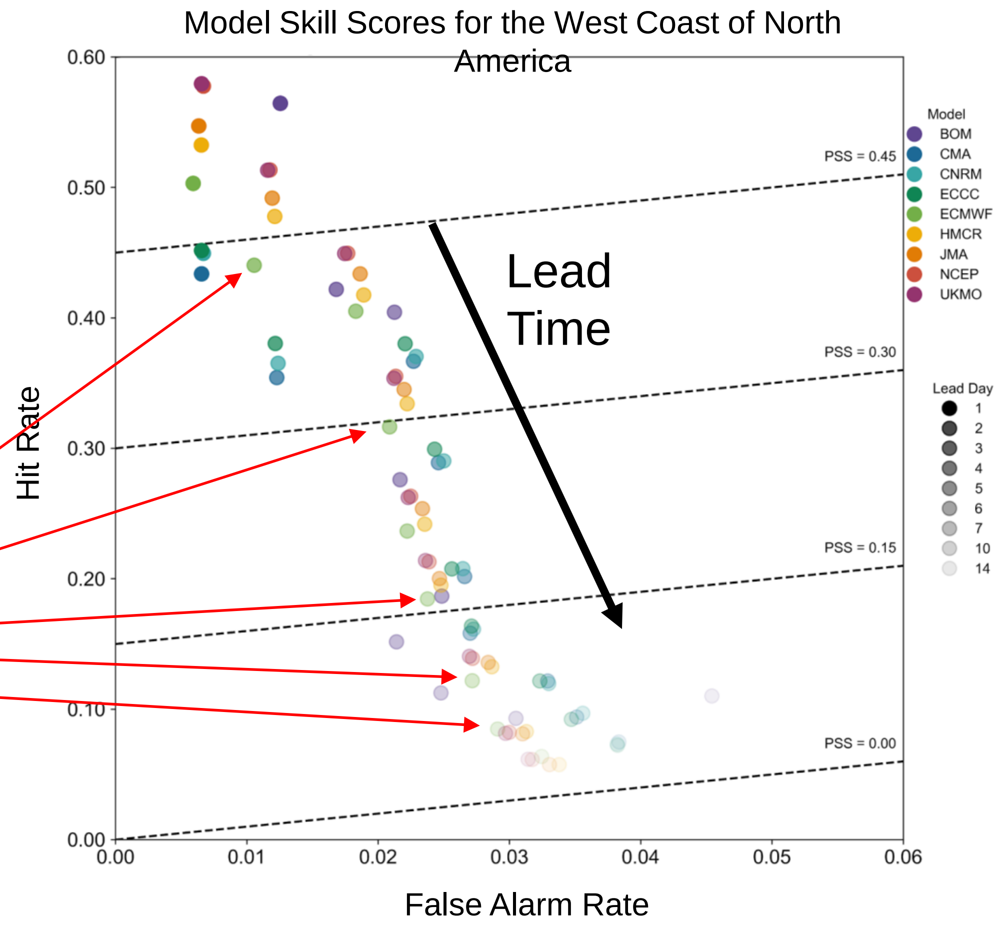
Allows for the calculation of

- Bias,
- Hit Rate,
- False Alarm Rate
- Peirce Skill Score (PSS).

Atmospheric River Occurrence - Hit and False Alarm Rates

Hit Rate decreases and False Alarm Rate increases as lead time increases.

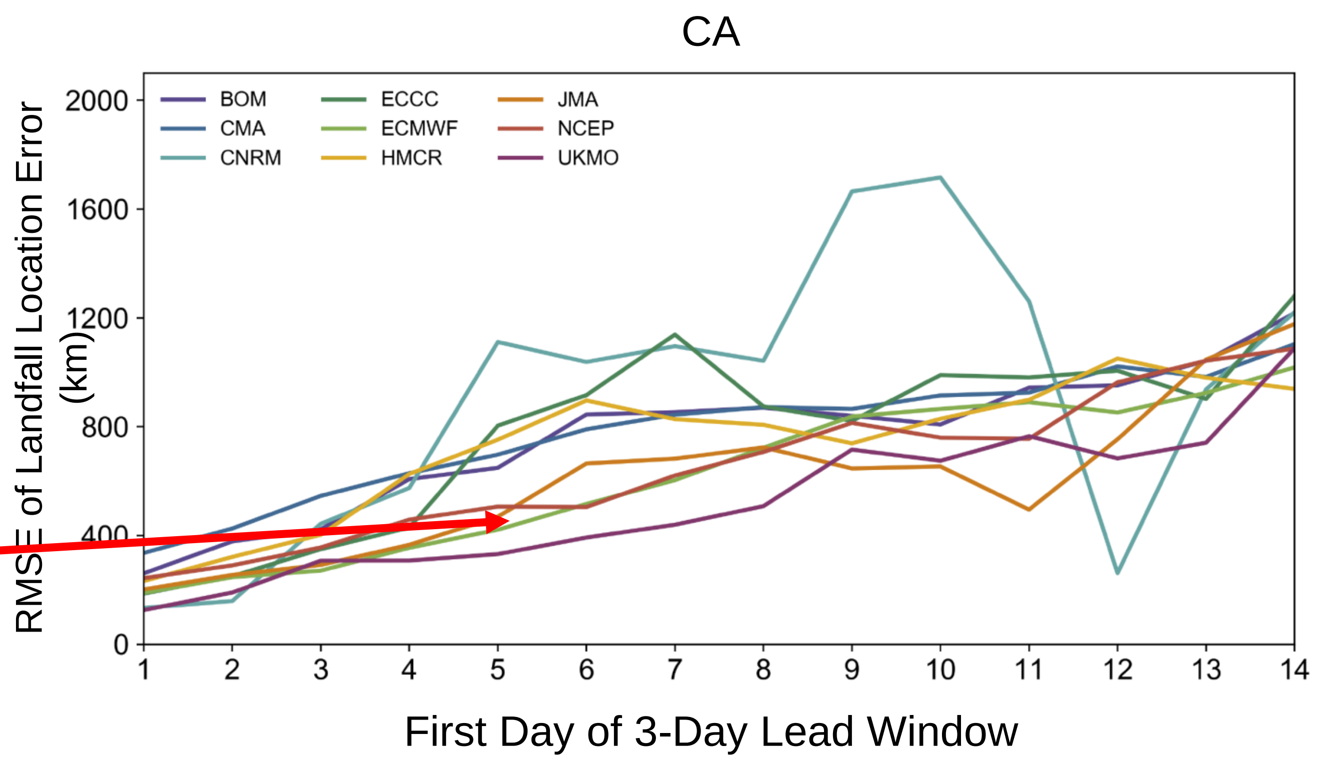
ECMWF consistently has the lowest False Alarm Rate, consistent with its “quiet” bias



Atmospheric River Landfall Location Errors

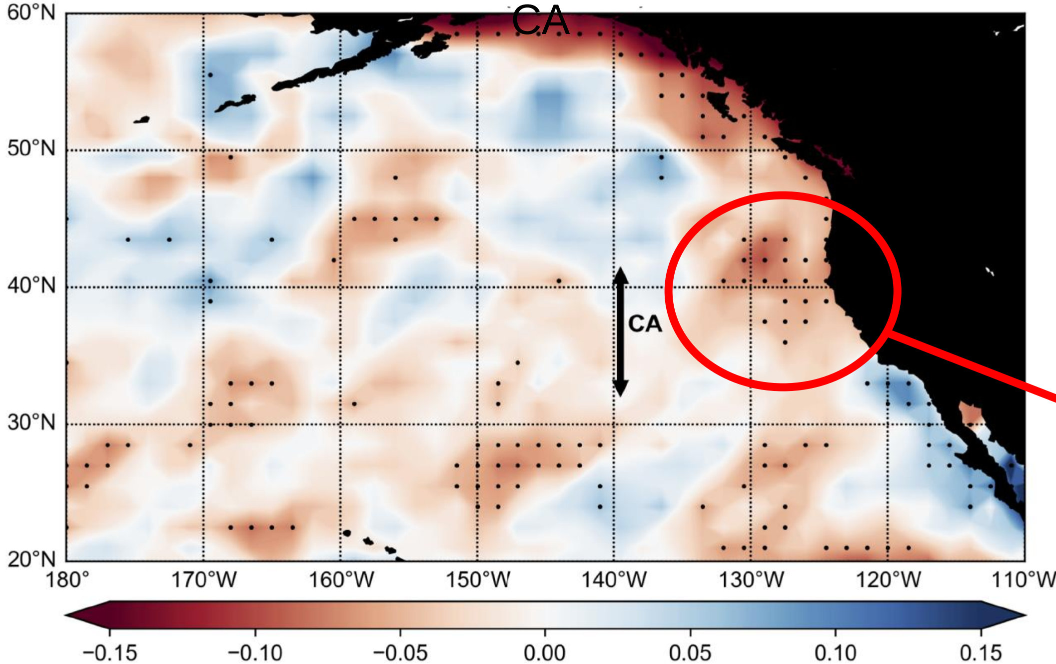
Landfall errors develop quickly in the models and approach 1000 km by day 14.

ECMWF is no exception.



Atmospheric River IVT Errors

Composite of ECMWF IVT Error for “Hits” on CA



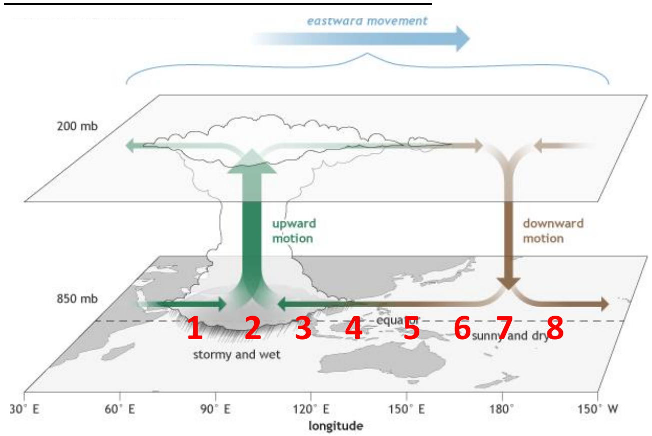
Relative Difference between ECMWF and ERA-Interim

Red colors indicate that the model, on average, re-forecasts lower IVT values compared to reanalysis.

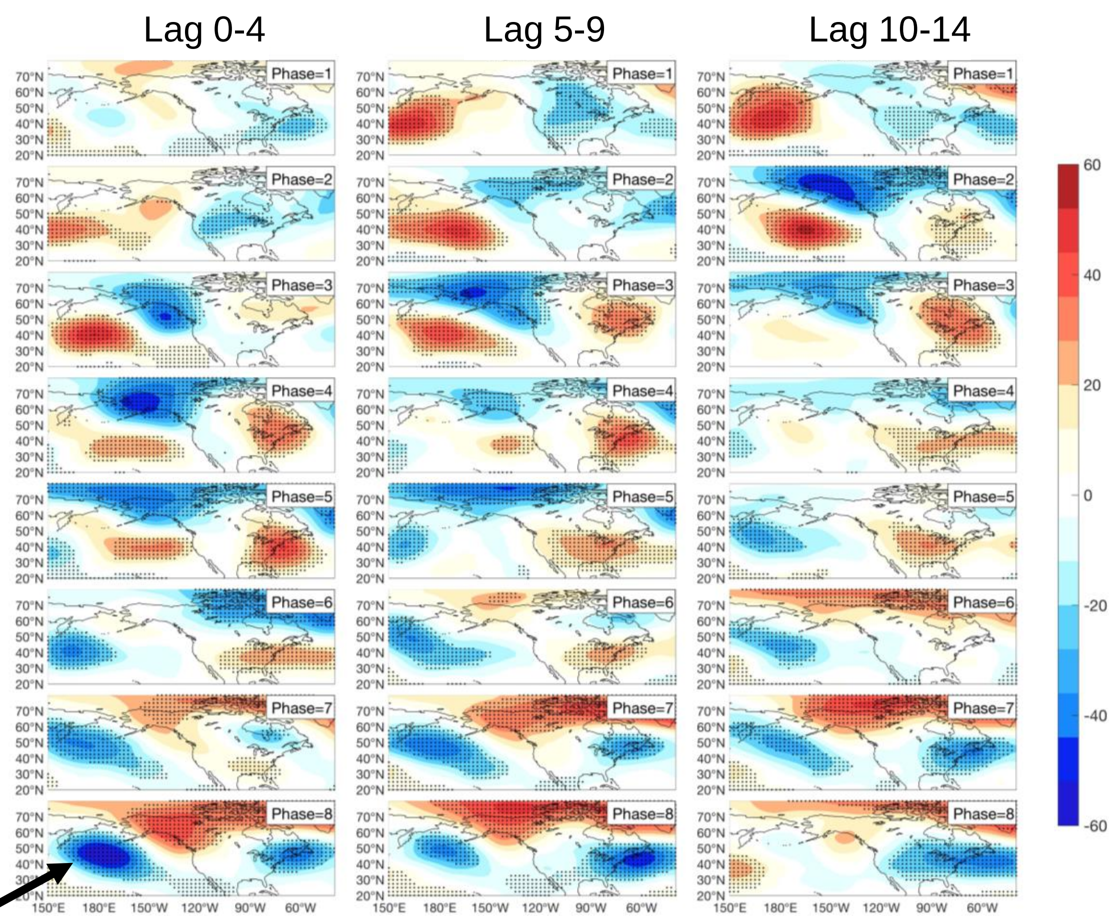
ECMWF shows, on average, offshore low-IVT errors.

The Madden-Julian Oscillation – a source of predictability at S2S lead times

Madden-Julian Oscillation



Teleconnection



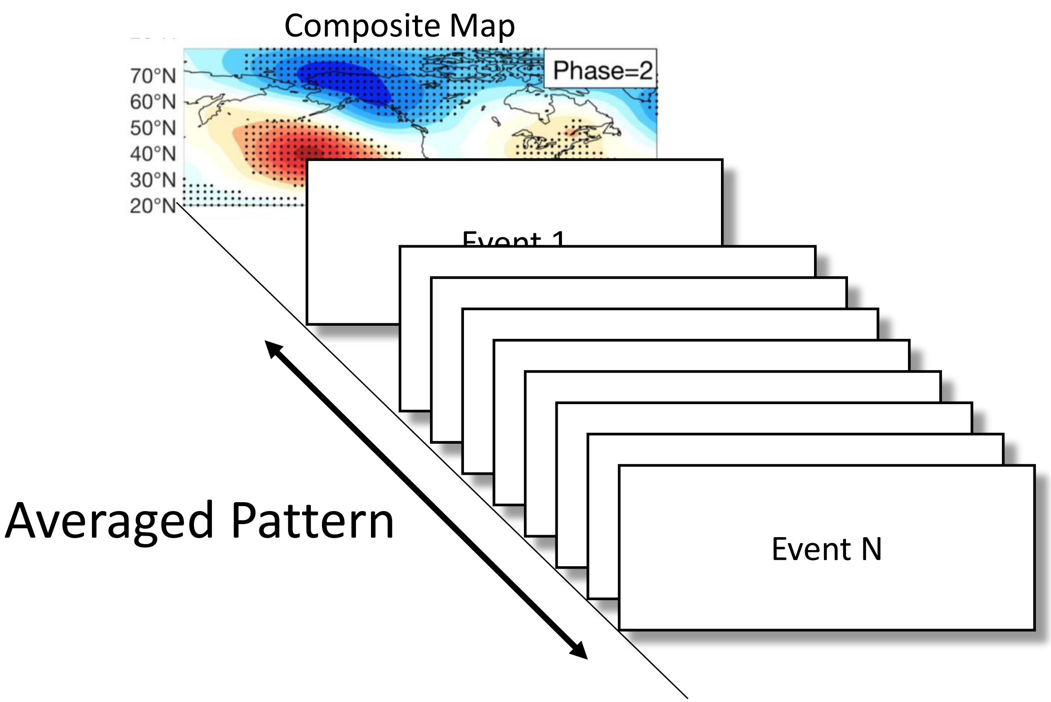
Shaded regions represent 500-mb geopotential height anomalies, according to MJO phase

Can we use the MJO to forecast atmospheric river activity along the U.S. West Coast at S2S lead times of ~3 to 6 weeks?

Pattern Consistency

At least two reasons can result in a strong MJO teleconnection signal:

- A few strong events dominate the signal
- Or similar teleconnections continually occur

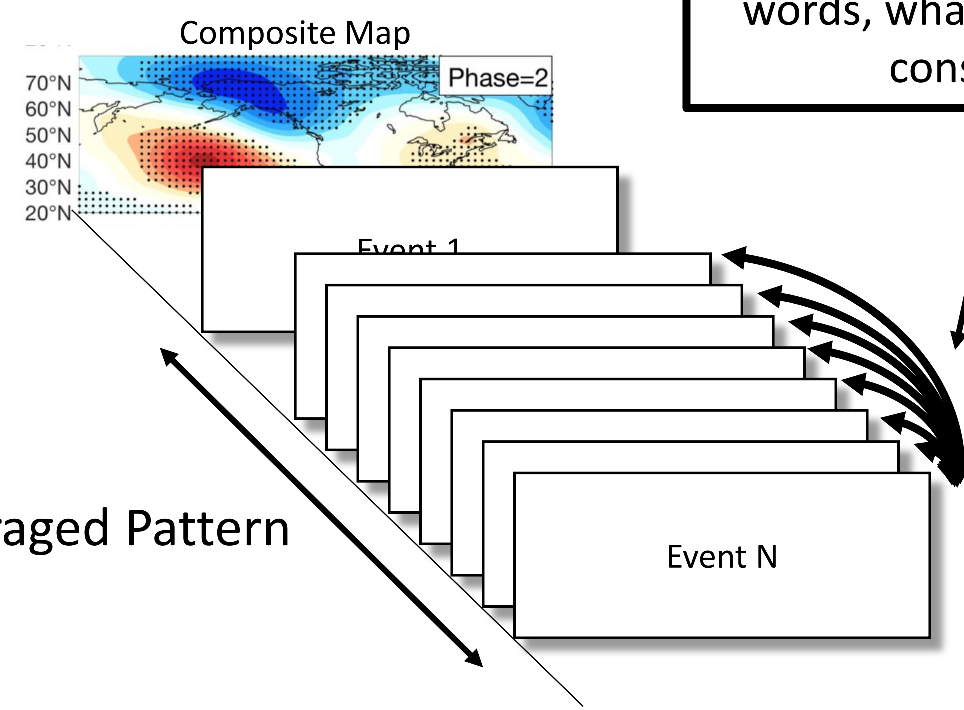


Pattern Consistency of Events per MJO phase

At least two reasons can result in a strong MJO teleconnection signal:

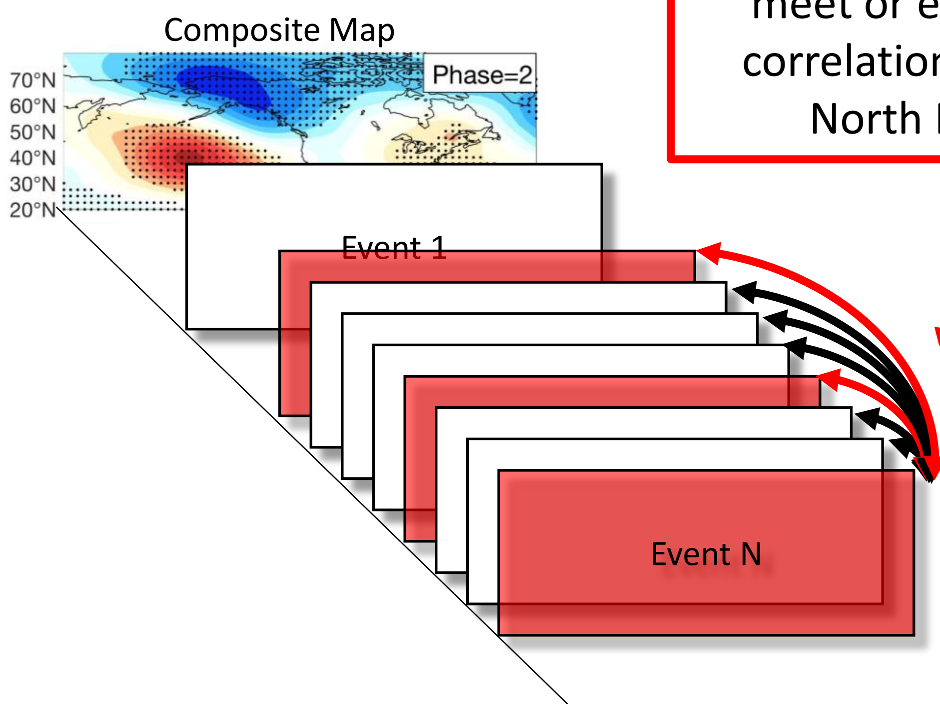
- ~~A few strong events dominate the signal~~
- Or similar teleconnections continually occur

We will test the second idea by asking, how similar are individual events to each other per MJO phase? In other words, what is their pattern consistency?



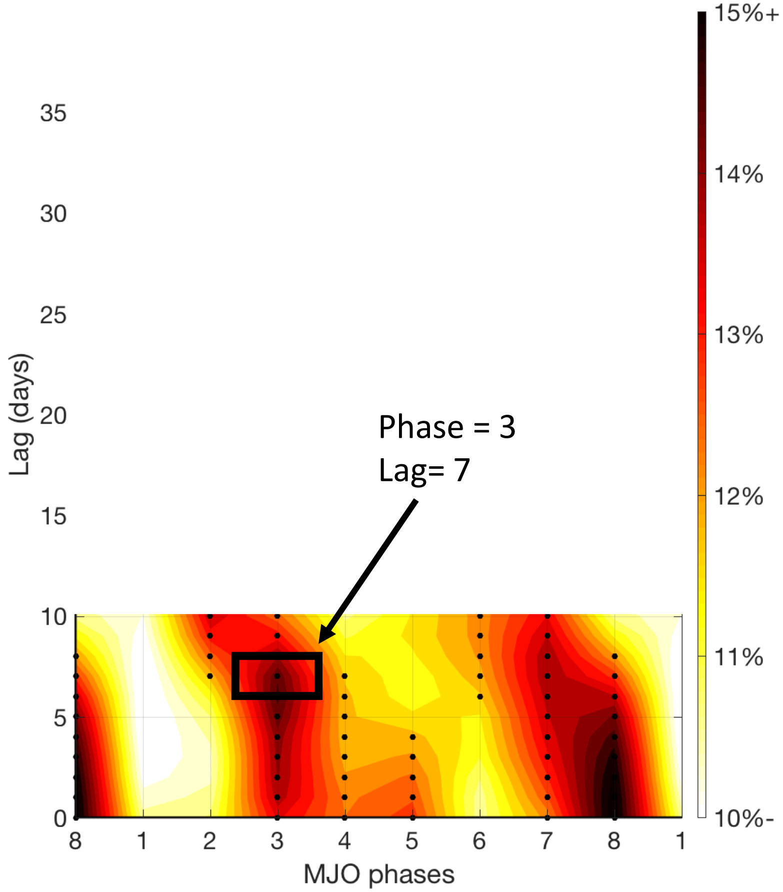
Averaged Pattern

Pattern Consistency of Events per MJO phase



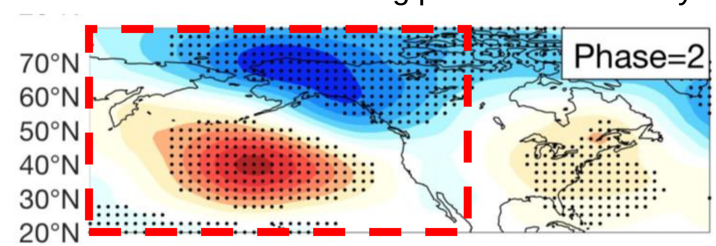
We quantify pattern consistency by counting the number of pairs of events the meet or exceed a pattern correlation of 0.5 over the North Pacific basin.

Pattern Consistency of Events per MJO phase



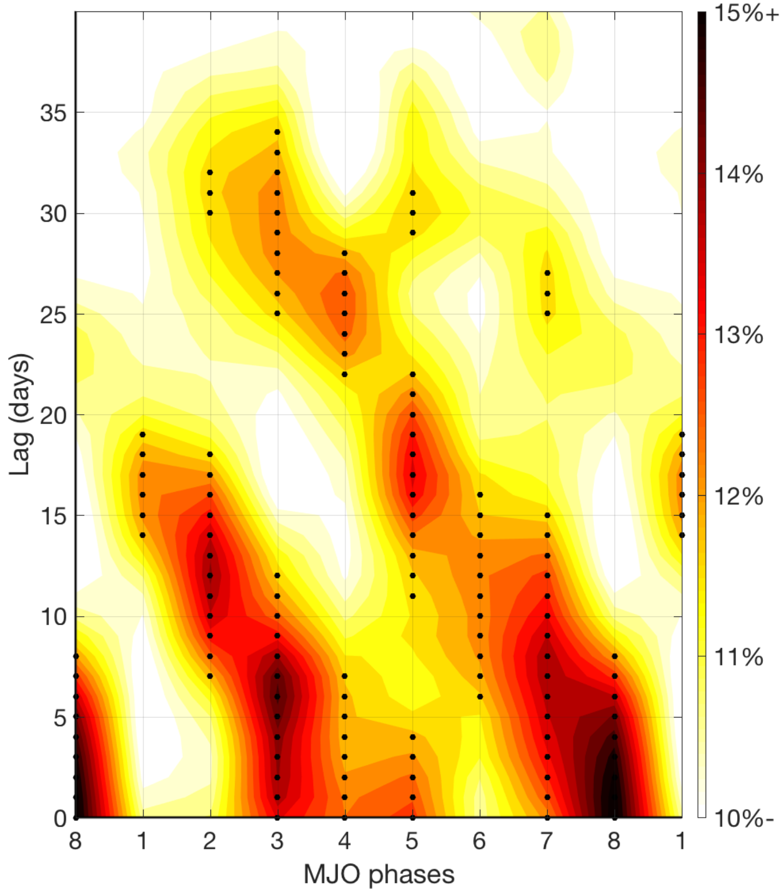
High Pattern Consistency

Domain for calculating pattern consistency



Low Pattern Consistency

Pattern Consistency of Events per MJO phase



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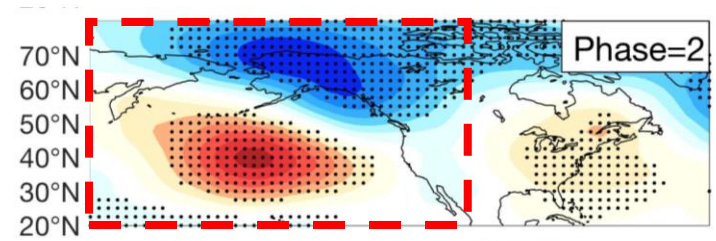
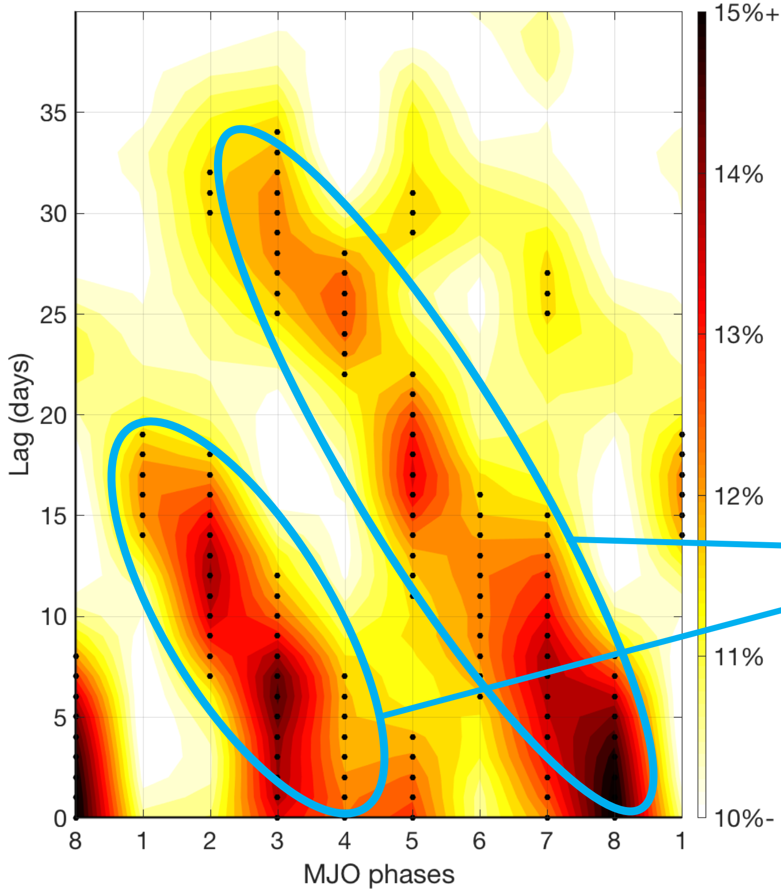


Low Pattern Consistency

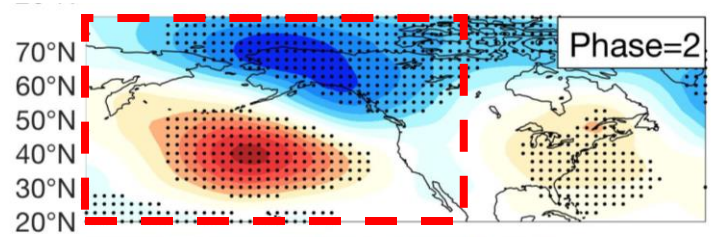
Pattern Consistency of Events per MJO phase



High Pattern Consistency

Low Pattern Consistency

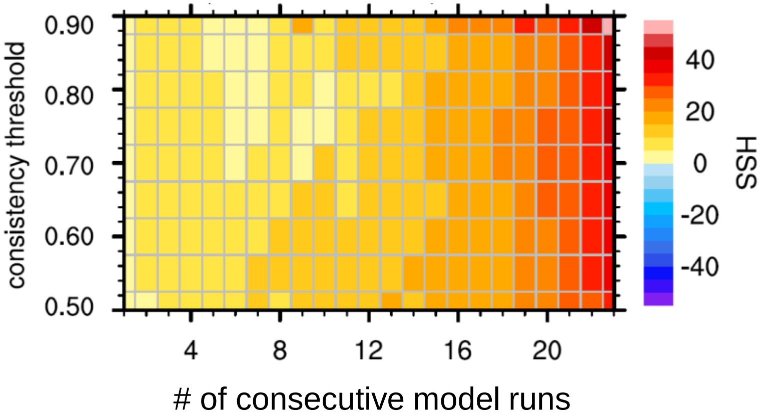
Domain for calculating pattern consistency



The pattern consistency is a function of MJO phase and time lag.

ECMWF - Bias Correction and Consistency Forecasting

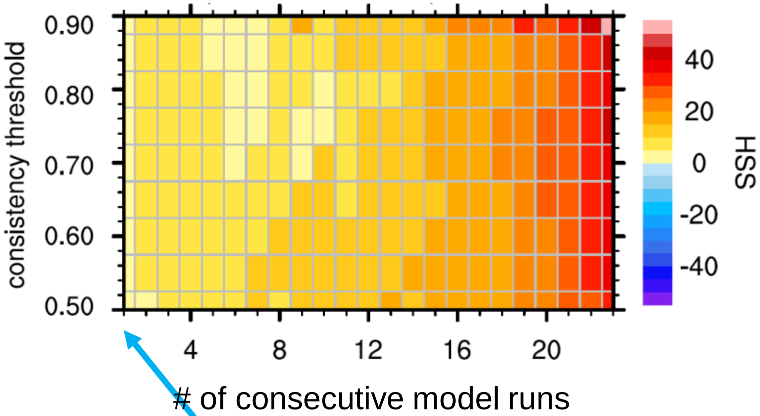
CMWF ensemble mean AR forecasts for CA



Skill scores of consistency forecasts are calculated across the parameter space of 1) number of consecutive model runs used and 2) consistency threshold

ECMWF - Bias Correction and Consistency Forecasting

CMWF ensemble mean AR forecasts for CA



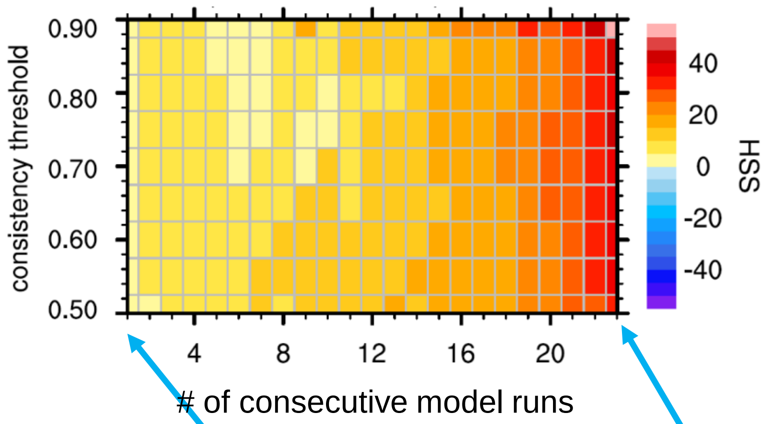
Skill scores of consistency forecasts are calculated across the parameter space of 1) number of consecutive model runs used and 2) consistency threshold

Longest lead time forecast (~6 weeks). Only one model run has seen the forecast valid date.

ECMWF - Bias Correction and Consistency Forecasting

Colorado State University

CMWF ensemble mean AR forecasts for CA



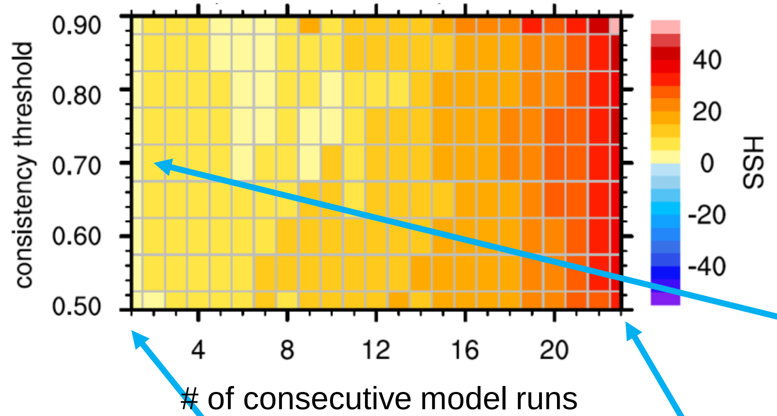
Skill scores of consistency forecasts are calculated across the parameter space of 1) number of consecutive model runs used and 2) consistency threshold

<u>Longest lead time forecast (~6 weeks).</u> Only one model run has seen the forecast valid date.

<u>Shortest lead time forecast (< 1 week).</u> Maximum number of model runs have seen the forecast valid date.

ECMWF - Bias Correction and Consistency Forecasting

CMWF ensemble mean AR forecasts for CA



Skill scores of consistency forecasts are calculated across the parameter space of 1) number of consecutive model runs used and 2) consistency threshold

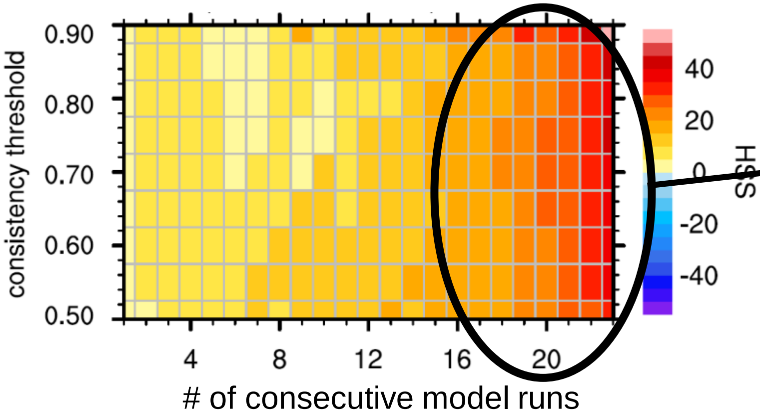
Threshold = the fraction of consecutive model runs that agree on the sign of the AR anomaly. E.g., 0.70 implies 70% agree on the sign of the anomaly.

<u>Longest lead time forecast (~6 weeks).</u> Only one model run has seen the forecast valid date.

<u>Shortest lead time forecast (< 1 week).</u> Maximum number of model runs have seen the forecast valid date.

ECMWF - Bias Correction and Consistency Forecasting

CMWF ensemble mean AR forecasts for CA



Bias not removed forecast
Consistency forecasting is generally most skillful with lead times of less than 3 weeks.

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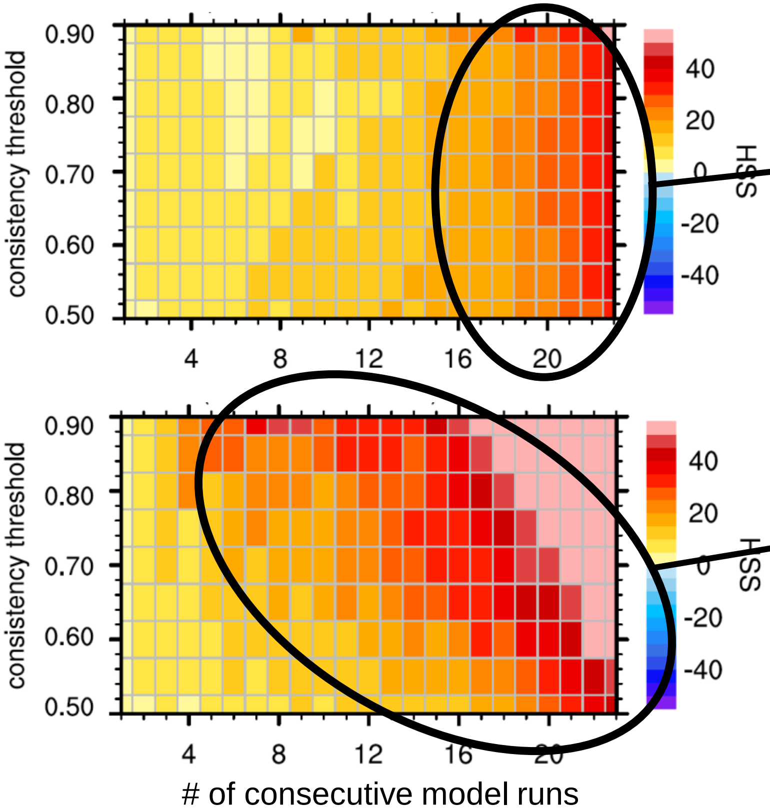

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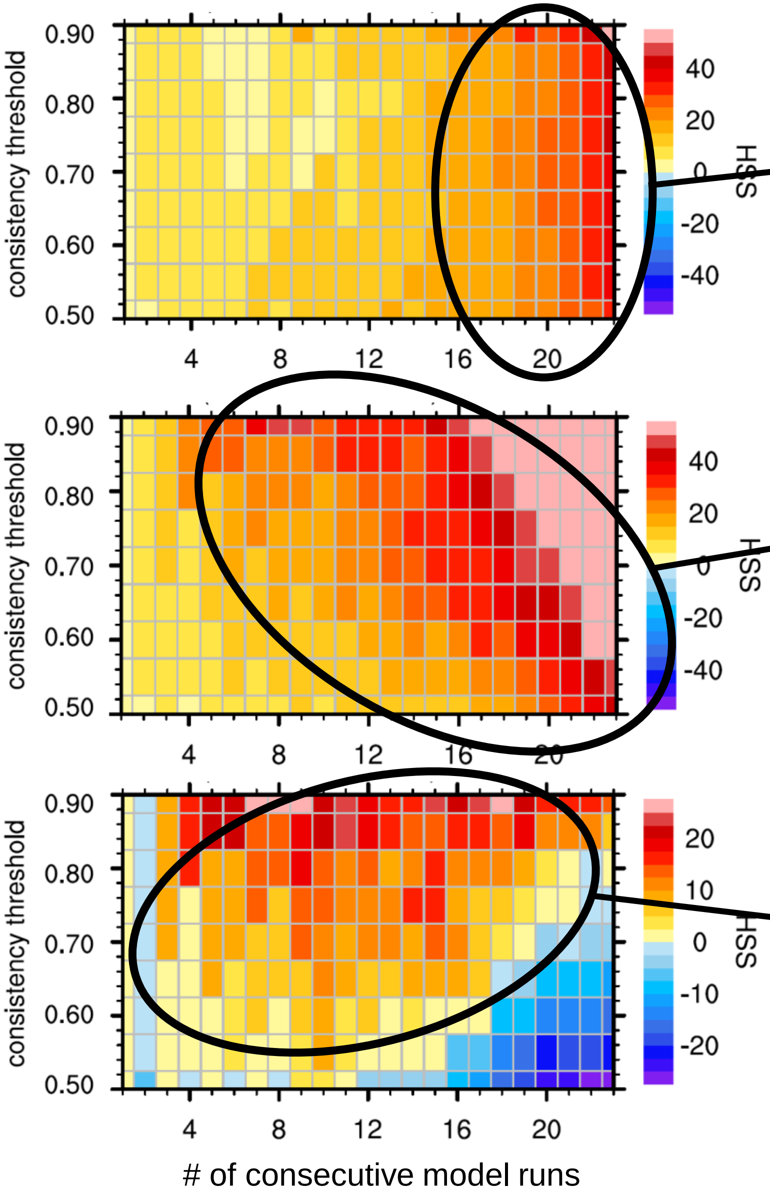

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But how does the bias removed forecast compare to simply using the most recent model run?
There is a period of time when using the most recent model run is better, but at longer leads consistency forecasting has higher skill, especially at higher consistency thresholds