# AR Prediction for Western US

## *In the Context of Global Weather/Climate Models*


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*With significant collaboration / support from the*

*Center for Western Weather and Water Extremes (M. Ralph et al.)*

*CA Department of Water Resources (J. Jones)*

*NASA Energy and Water Cycle Research Program (J. Entin)*


**Western States Water Council**

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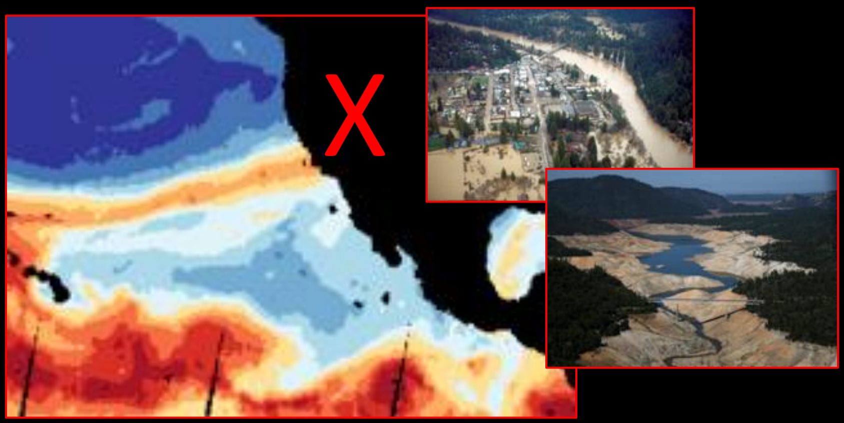
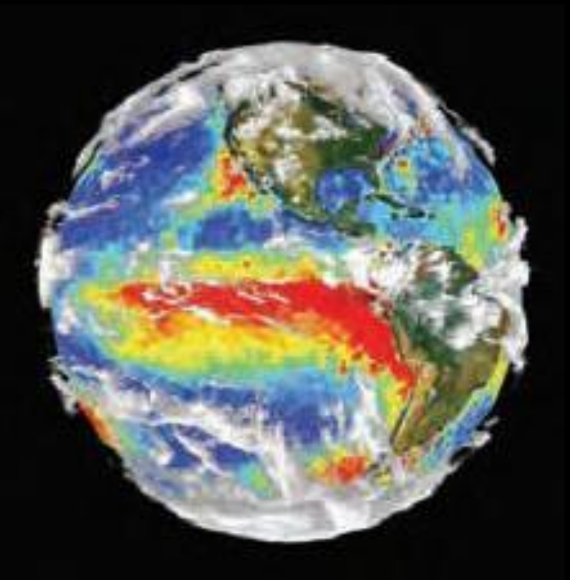
# A Global Approach to ARs



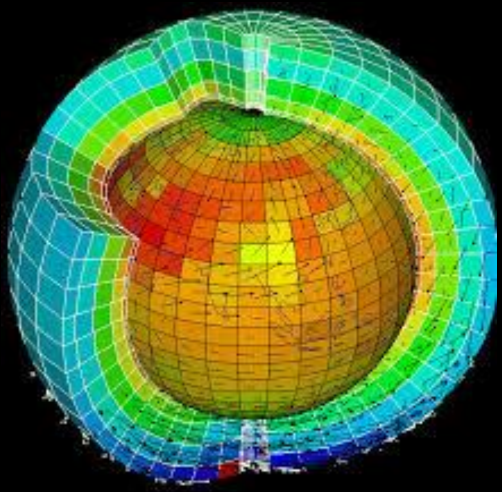
**Objective**:
Western US Water Predictions

“Think Regionally”



**Key Considerations:**
Long-Leads -> Global Circulation, Climate Modes

”Model & Forecast Globally”



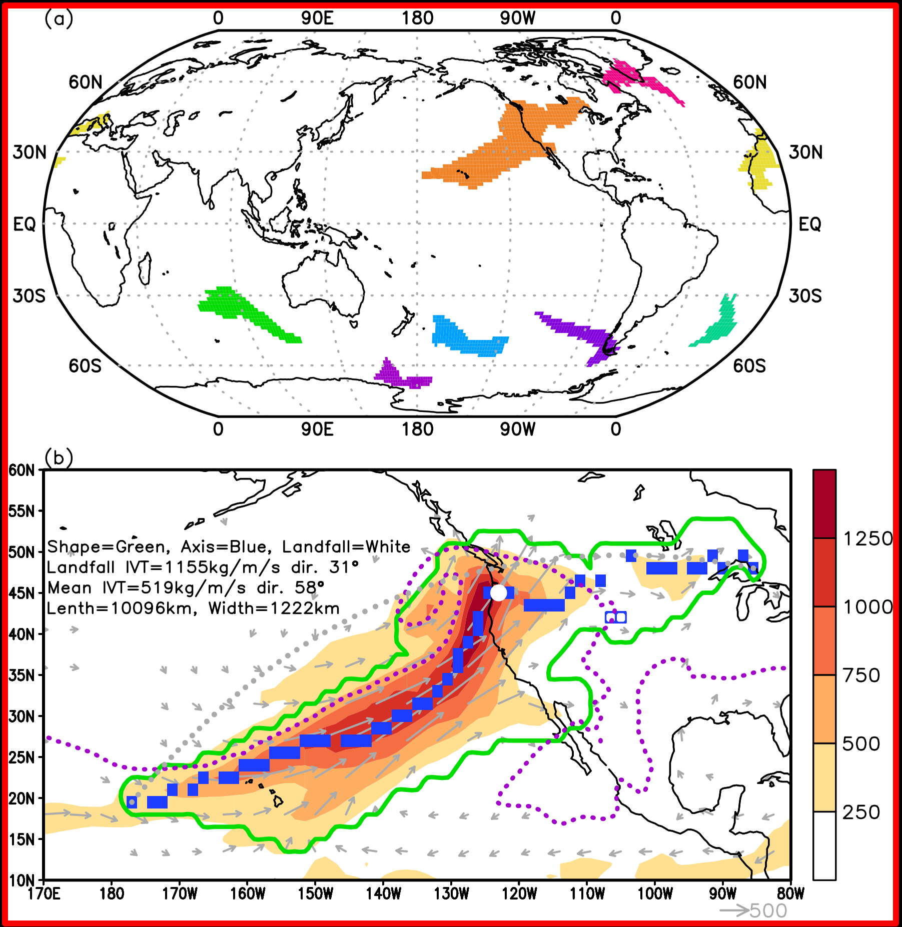
# Outline

I. Background and Resources
- *Global AR Detection Algorithm*
- *Climate Mode Modulations of ARs*
- *WCRP/WWRP S2S Project & Database*

II. AR Predictions
- *Weather predictions of Individual ARs  (e.g. 0-15 days)*
- ***Subseasonal predictions (e.g. 2-6 weeks)***
- *Climate change projections (e.g. 50-100 years)*

III. AR Global Model Evaluation & Improvement
- *Global/Regional & Bulk AR Characteristics*

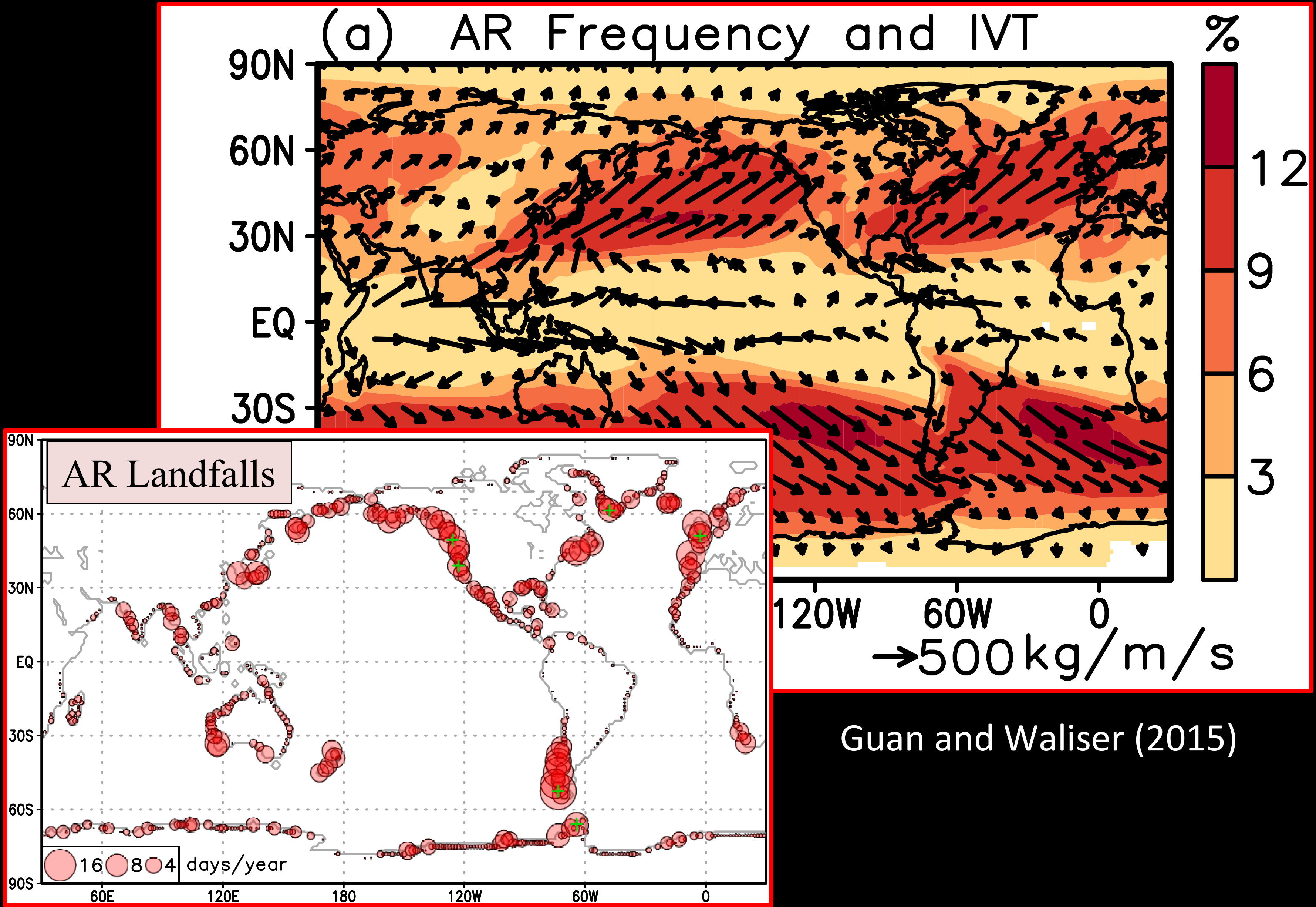
# Global AR Detection Algorithm




Guan and Waliser (2015)

- Based on Integrated Vapor Transport (IVT) fields and a number of common AR criteria (e.g. Ralph et al. 2004).
- Developed for global studies and for observations/reanalysis and models.
- Applied to:
  - ERA-I, MERRA-2, CFSR, NCEP/NCAR
- Code and databases available at:
  - https://ucla.box.com/ARcatalog
- Databases include AR Date, $IVT_{x,y}$, Shape, Axis, Landfall Location, etc.

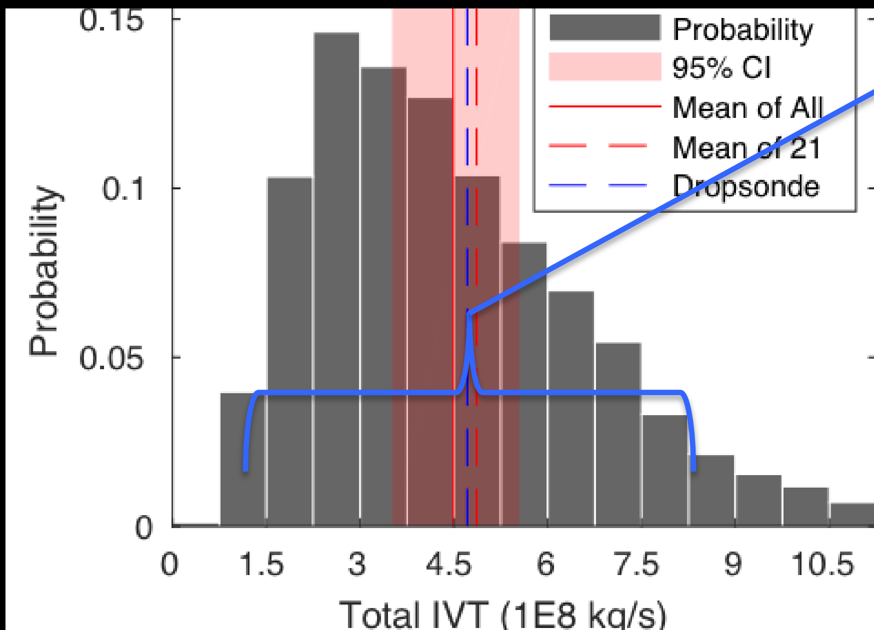
# Global AR Frequency, IVT & Landfalls




Guan and Waliser (2015)

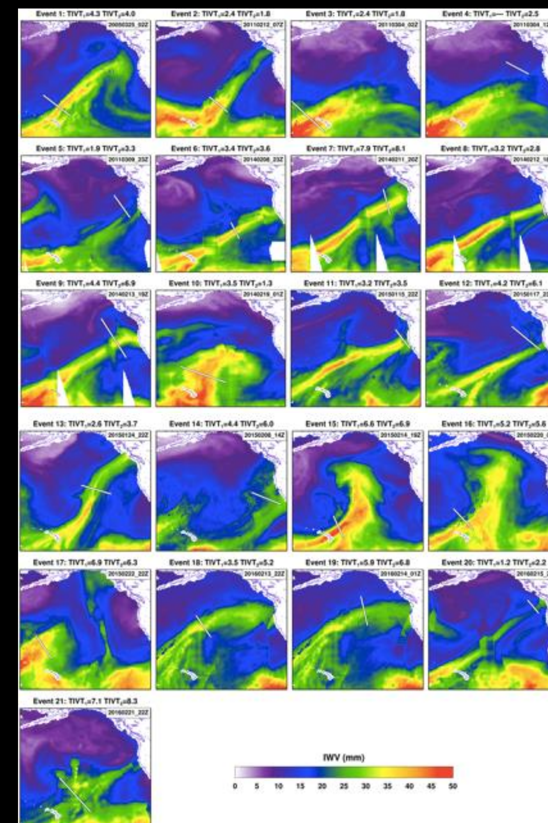
# CalWater Validation Support of Algorithm

IVT Histogram Based On
5636 NE Pacific ARs
*125-163W, 23-46N*
*Jan 15-Mar 25 1979-2016*




Guan, Waliser and Ralph (2017, In Prep)

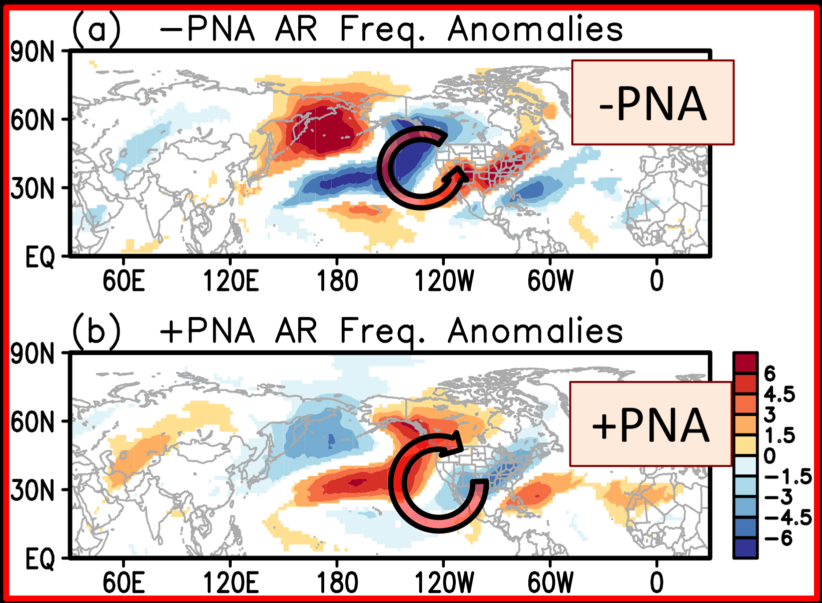
21 AR Event Transects
4.7 +/- 1.9kg/s
Min 1.3; Max 8.3



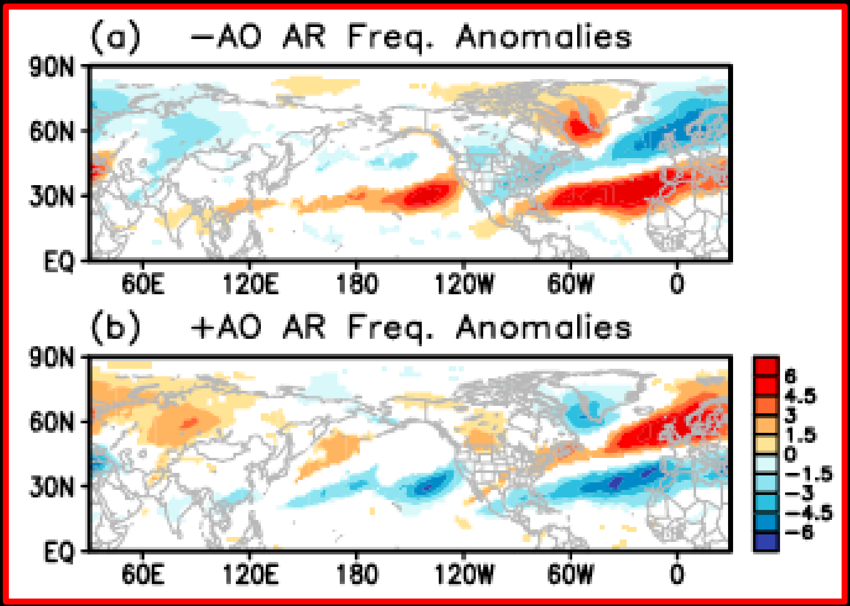
Ralph et al. (2017, Under Revision)

# Climate Patterns and ARs

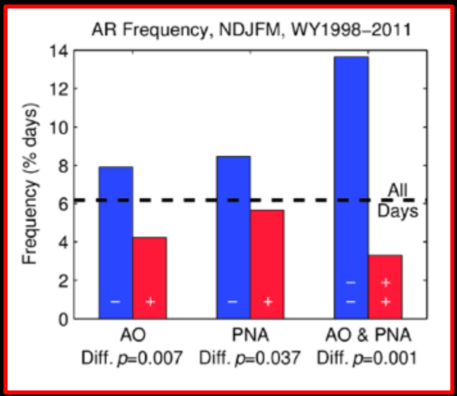
## Pacific-North American (PNA)




## Arctic Oscillation (AO)




Guan and Waliser (2015)

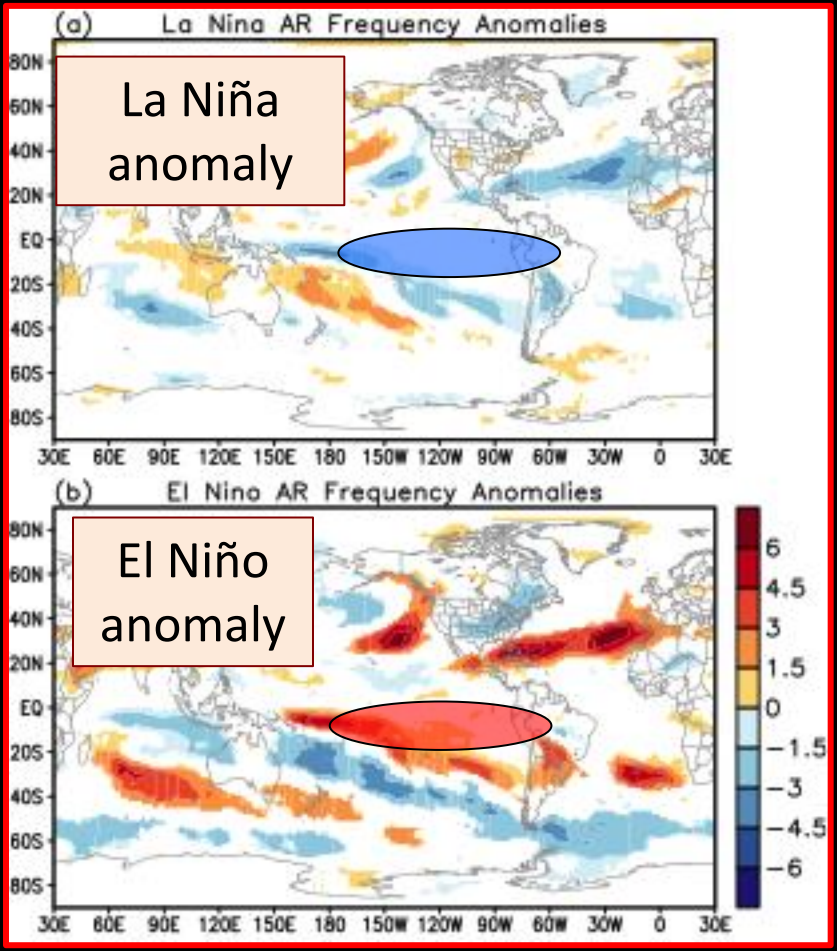



When PNA & AO are both in "negative" phases, there is a doubling of the frequency of ARs.

*Guan et al. 2013; using Neiman et al., 2008 AR database*

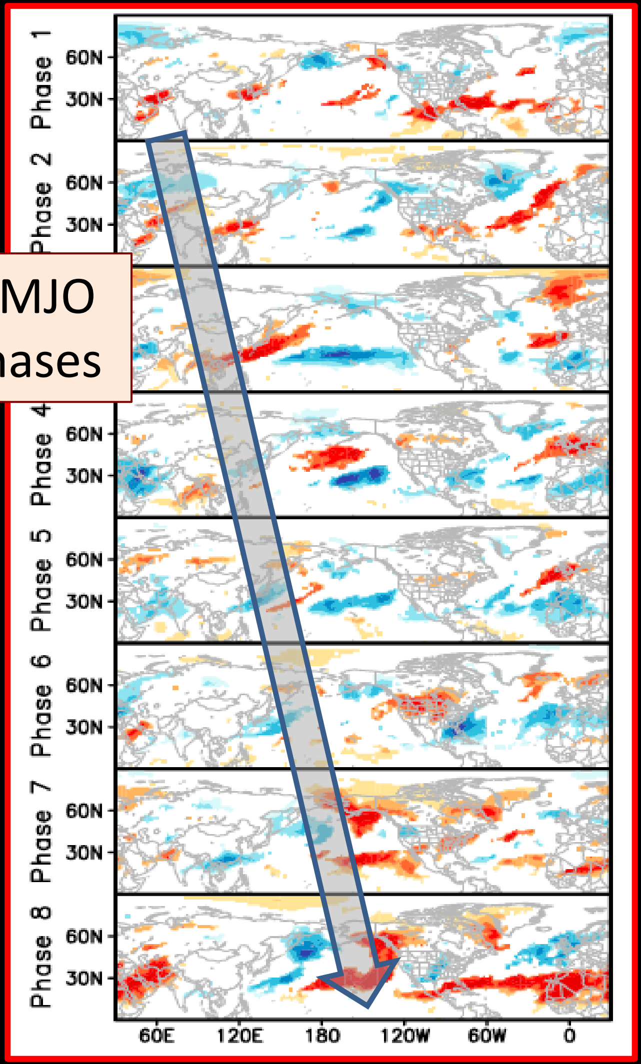
# Climate Patterns and ARs

## El Nino Southern Oscillation (ENSO)




Guan and Waliser (2015)

## Madden-Julian Oscillation (MJO)

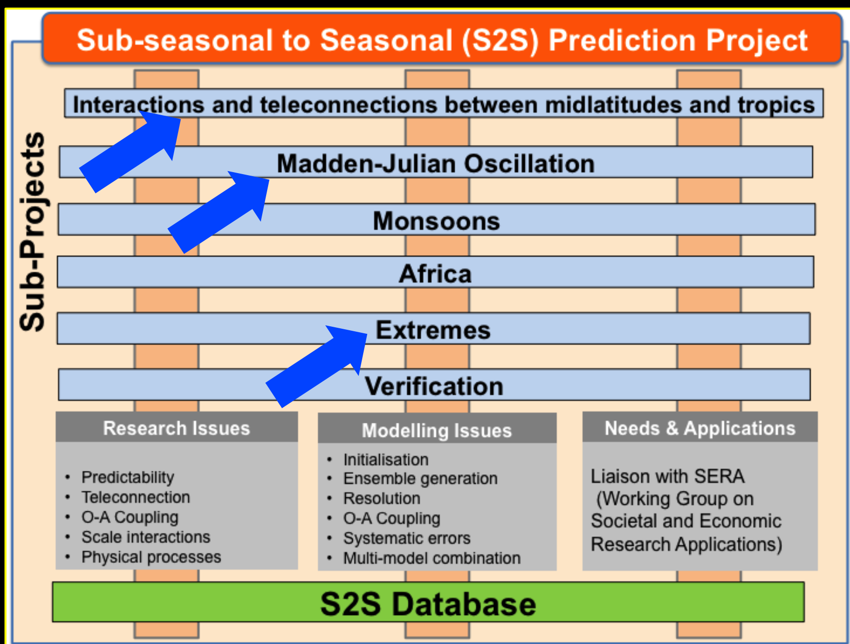



See also Guan et al. (2012)

# Subseasonal Forecast Database

*WCRP-WWRP S2S Project*

## International Program for S2S Research




## S2S Database

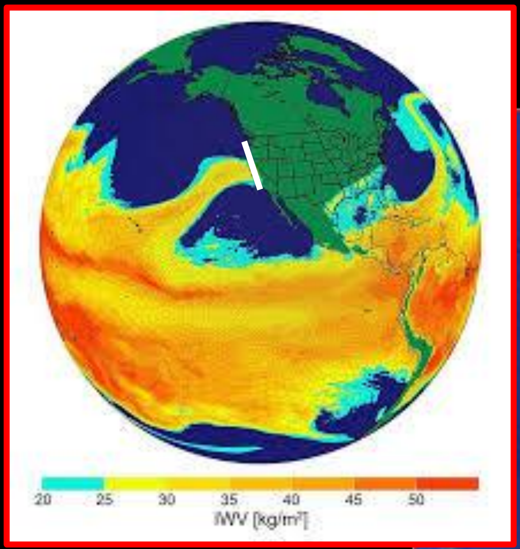

| | Time-range | Resol. | Ens. Size | Freq. | Hcsts | Hcst length | Hcst Freq | Hcst Size |
|---|---|---|---|---|---|---|---|---|
| ECMWF | D 0-46 | T639/319L91 | 51 | 2/week | On the fly | Past 20y | 2/weekly | 11 |
| UKMO | D 0-60 | N216L85 | 4 | daily | On the fly | 1996-2009 | 4/month | 3 |
| NCEP | D 0-44 | N126L64 | 4 | 4/daily | Fix | 1999-2010 | 4/daily | 1 |
| EC | D 0-32 | 0.6x0.6L40 | 21 | weekly | On the fly | 1995-2014 | weekly | 4 |
| CAWCR | D 0-60 | T47L17 | 33 | weekly | Fix | 1981-2013 | 6/month | 33 |
| JMA | D 0-34 | T319L60 | 25 | 2/weekly | Fix | 1981-2010 | 3/month | 5 |
| KMA | D 0-60 | N216L85 | 4 | daily | On the fly | 1996-2009 | 4/month | 3 |
| CMA | D 0-45 | T106L40 | 4 | daily | Fix | 1886-2014 | daily | 4 |
| CNRM | D 0-32 | T255L91 | 51 | Weekly | Fix | 1993-2014 | 2/monthly | 15 |
| CNR-ISAC | D 0-32 | 0.75x0.56 L54 | 40 | weekly | Fix | 1981-2010 | 6/month | 1 |
| HMCR | D 0-63 | 1.1x1.4 L28 | 20 | weekly | Fix | 1981-2010 | weekly | 10 |

- Downloaded U,V,Q fields from all models' multi-decade subseasonal hindcasts.
- Computed IVT and Applied AR Detection on ECMWF, others in progress.
- Utilizing for AR forecast assessments, including model sensitivity.

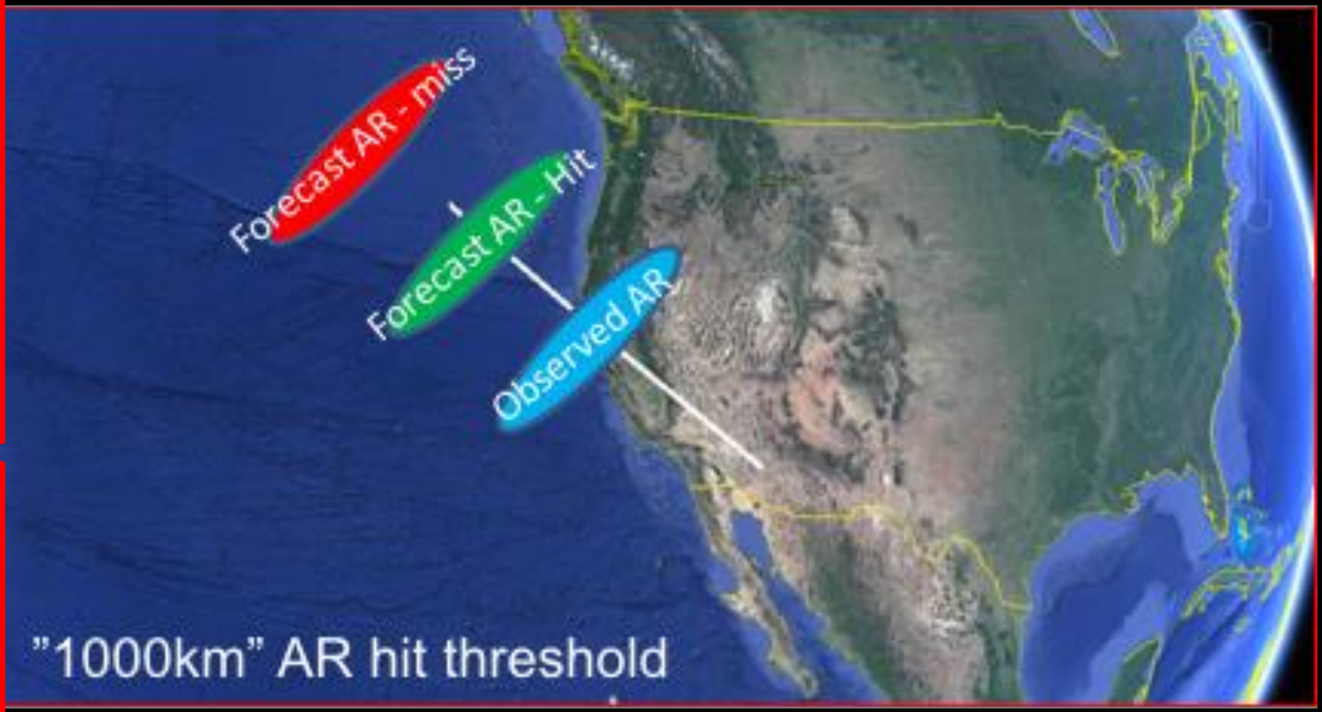
Vitart, F., et al. (2017), The Sub-seasonal to Seasonal Prediction (S2S) Project Database, BAMS.

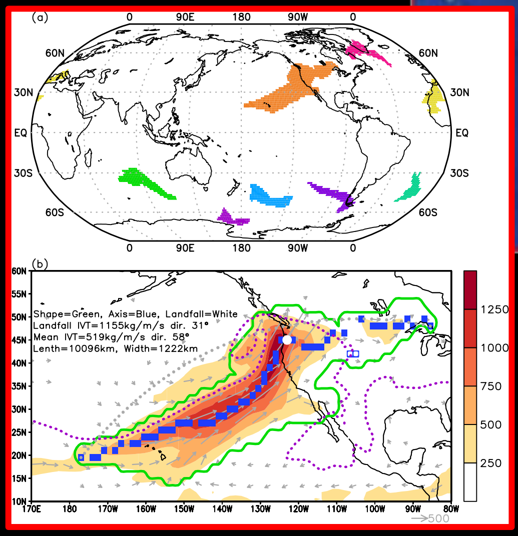
# AR Event Prediction Skill

*DeFlorio, Waliser, Guan, Lavers, Ralph, Vitart (2017, In Revision)*



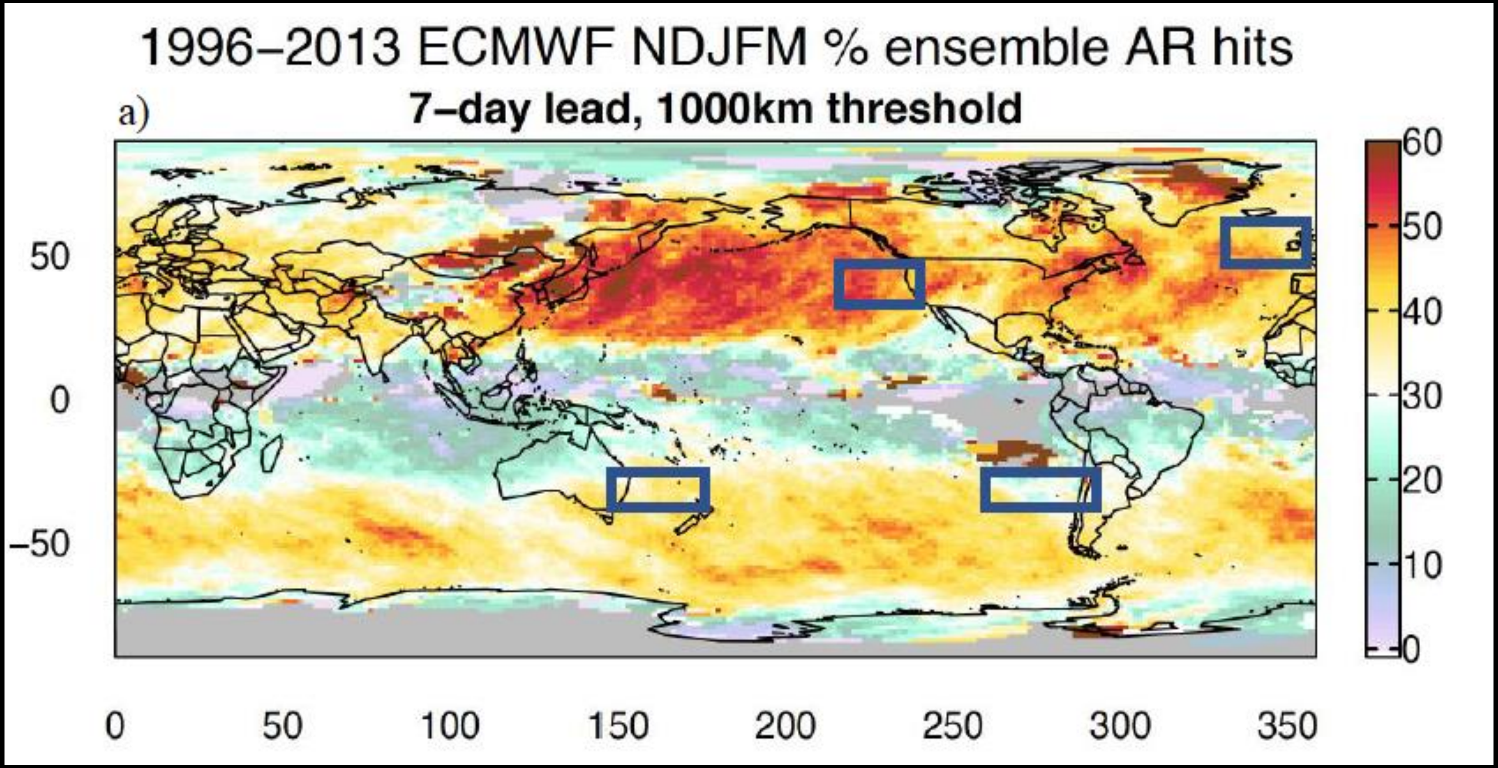

*Builds on CA Regional study by Wick et al. 2013*




How well do our global S2S models – ECMWF in this case - predict AR occurrence/position?

# Global AR Prediction Skill

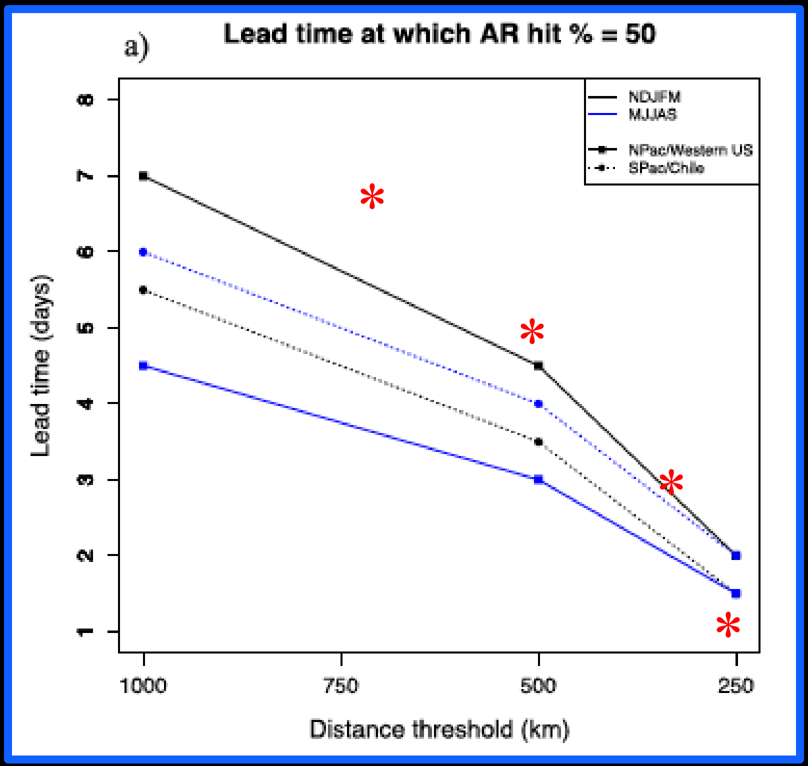


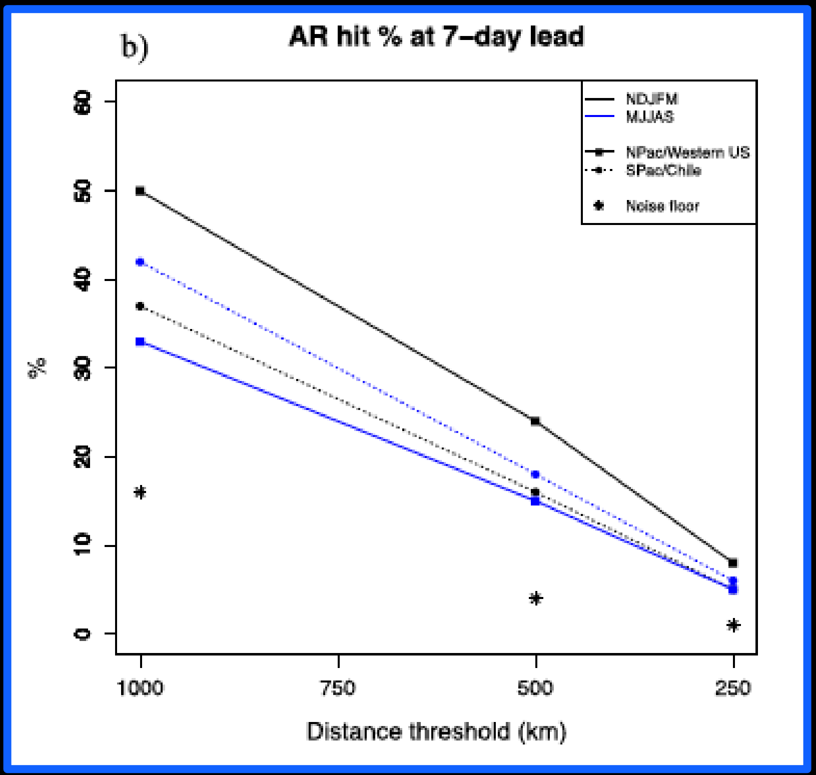

Including sensitivity of prediction skill on season, lead time, distance threshold and climate mode variations.

*DeFlorio, Waliser, Guan, Lavers, Ralph, Vitart (2017, In Revision)*

# AR Landfall Predictions & Water/Flood Management

When do I need to know, and with what confidence?



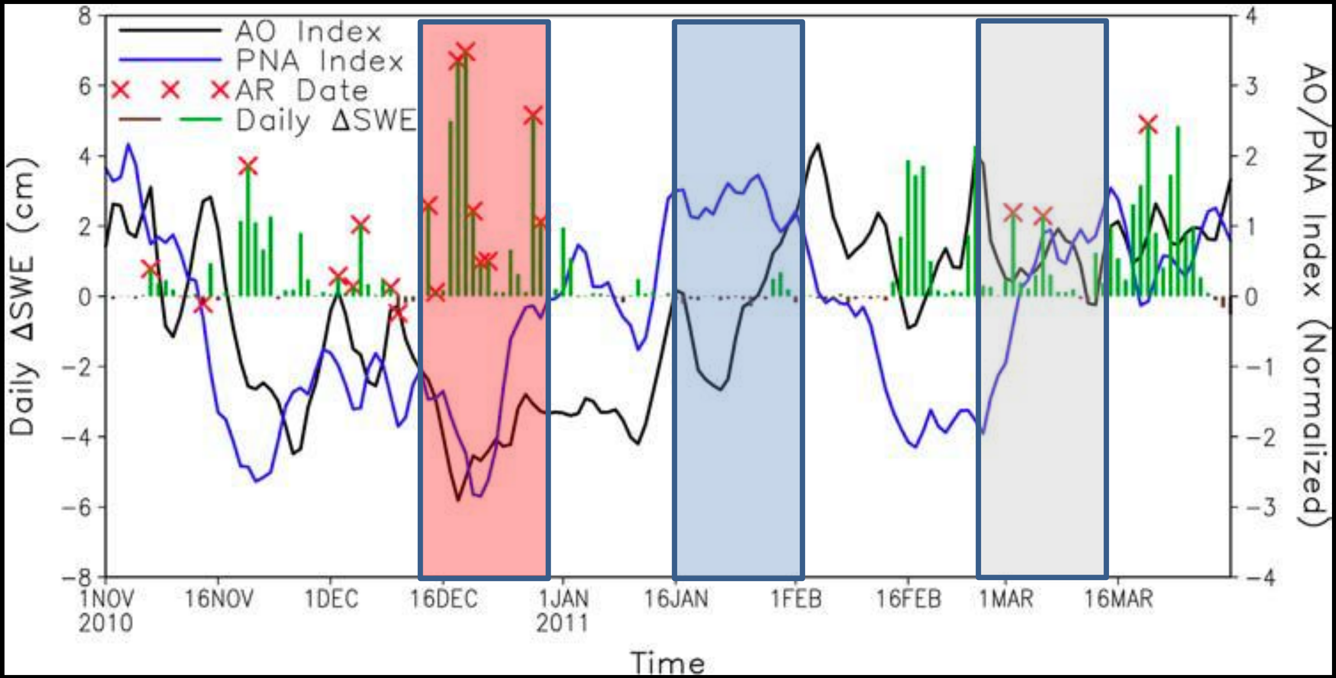




*DeFlorio, Waliser, Guan, Lavers, Ralph, Vitart (2017, In Revision)*

Ensemble / probabilistic information complements the AR landfall prediction study of Wick et al. 2013 (*)

# Subseasonal AR Prediction

*DeFlorio, Waliser, Guan, Ralph…. (2017, In Prep)*



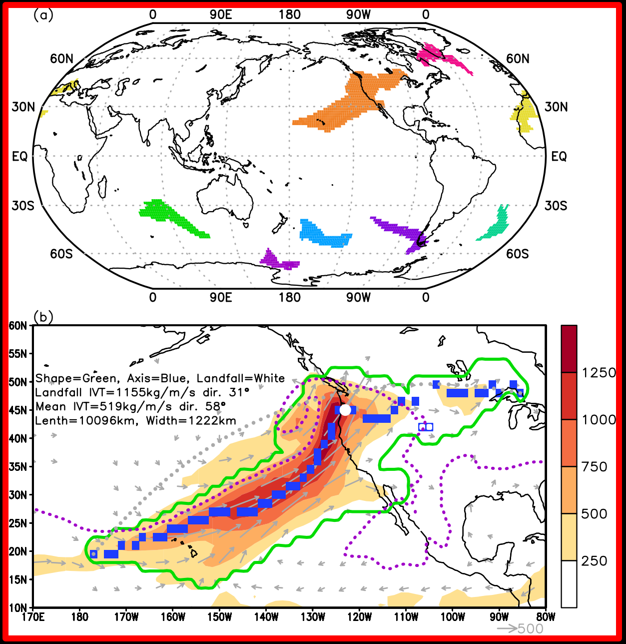

How well do our global S2S models

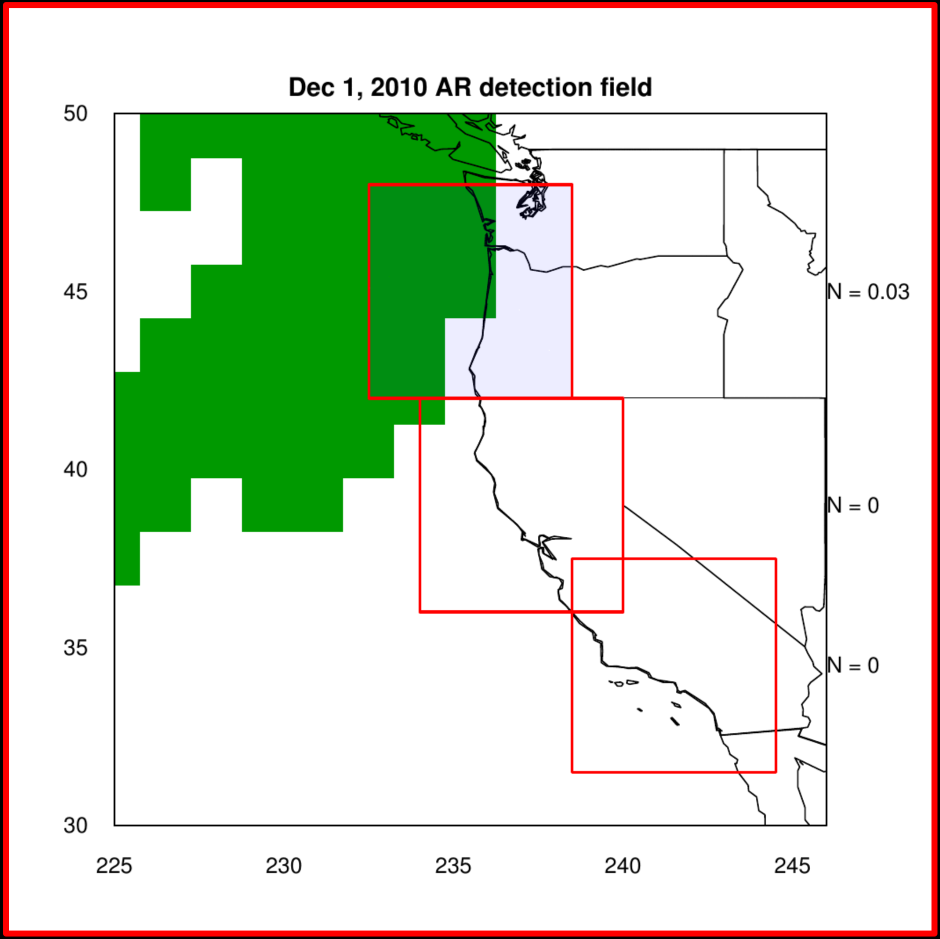
– ECMWF in this case –

predict high & low AR periods at subseasonal time scales?

# Subseasonal AR Prediction

*DeFlorio, Waliser, Guan, Ralph, Barbour…. (2017, In Prep)*

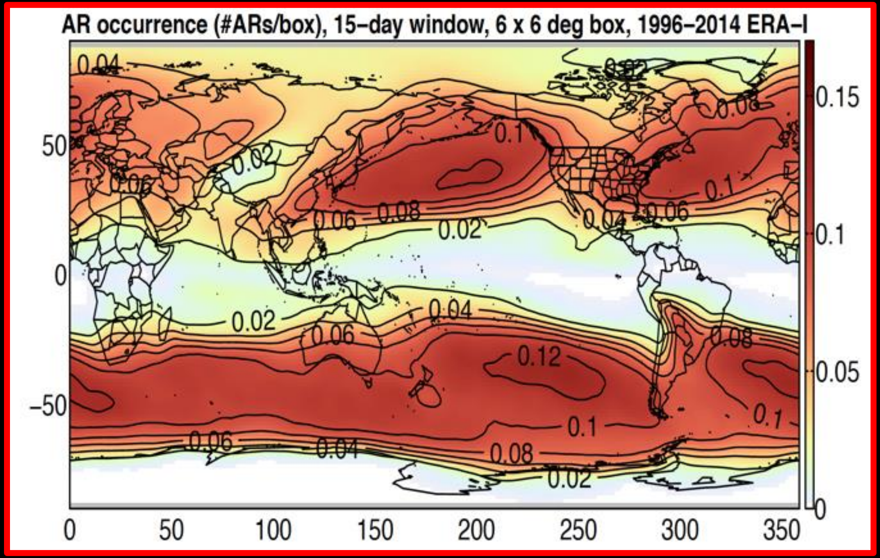


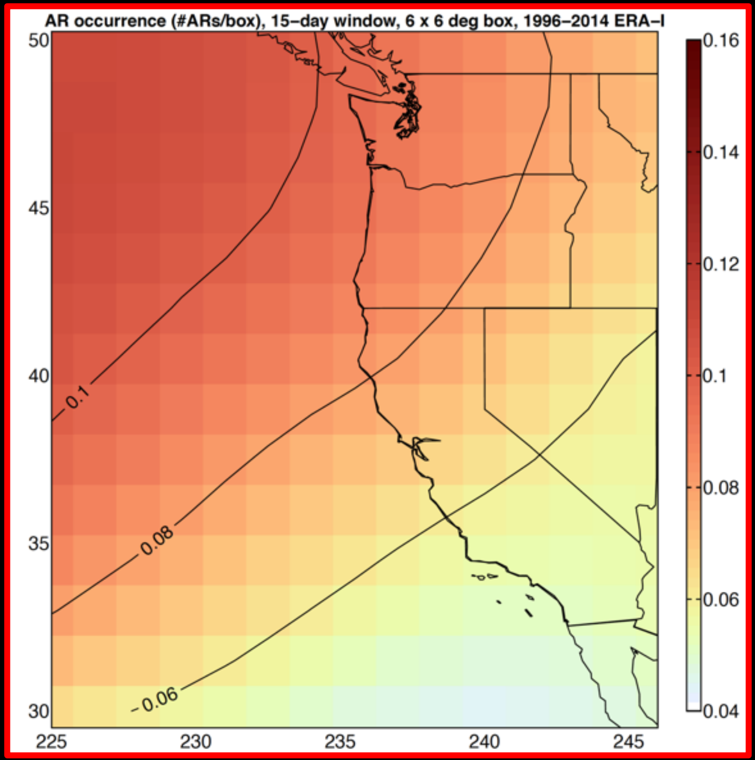




Compute fraction of space & time a given region has an AR for a 2 week period

# Subseasonal AR Prediction

*(for 2-week averages of AR frequency)*



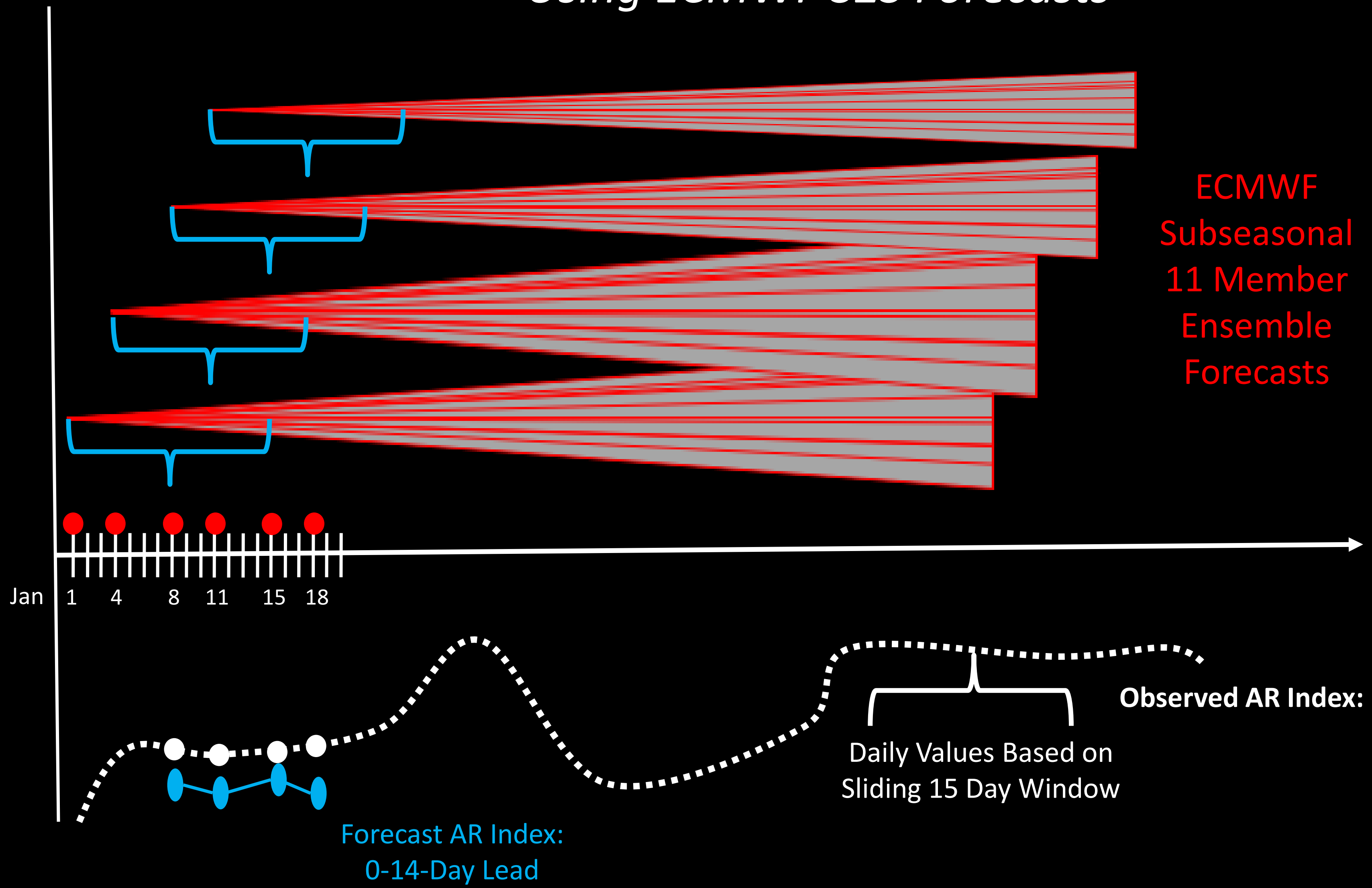




Fraction of space & time a given region has an AR occurrence, when considering a 2 week period and the surrounding 6$^o$x6$^o$ degree area.

*DeFlorio, Waliser, Guan, Ralph, Barbour…. (2017, In Prep)*

# Subseasonal AR Prediction

*Using ECMWF S2S Forecasts*

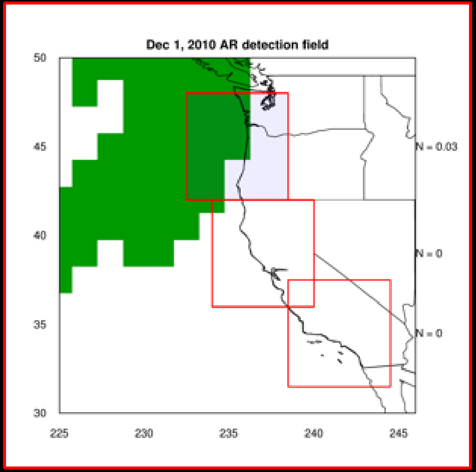


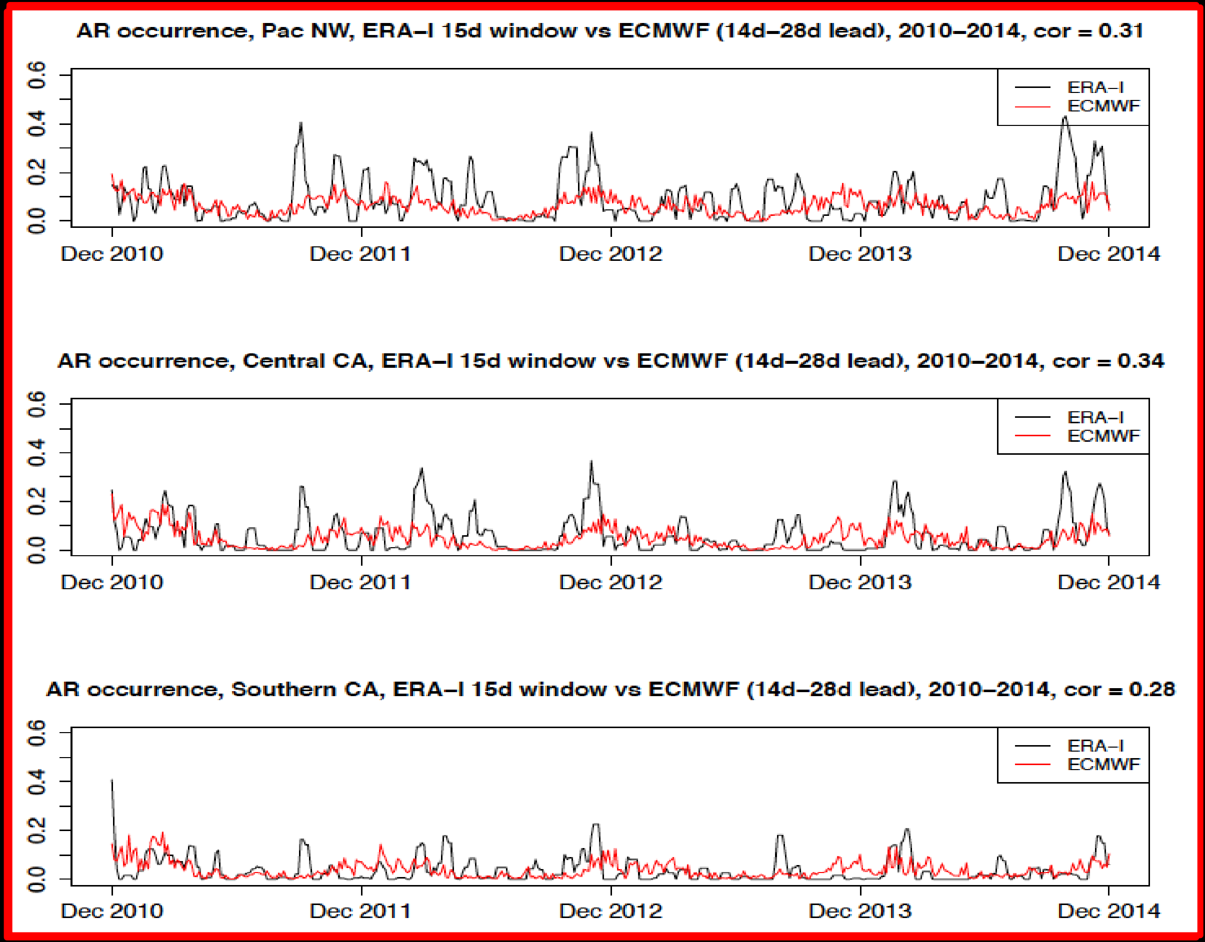

*DeFlorio, Waliser, Guan, Ralph, Barbour…. (2017, In Prep)*

# Subseasonal AR Prediction

*DeFlorio, Waliser, Guan, Ralph, Barbour…. (2017, In Prep)*

US West Coast



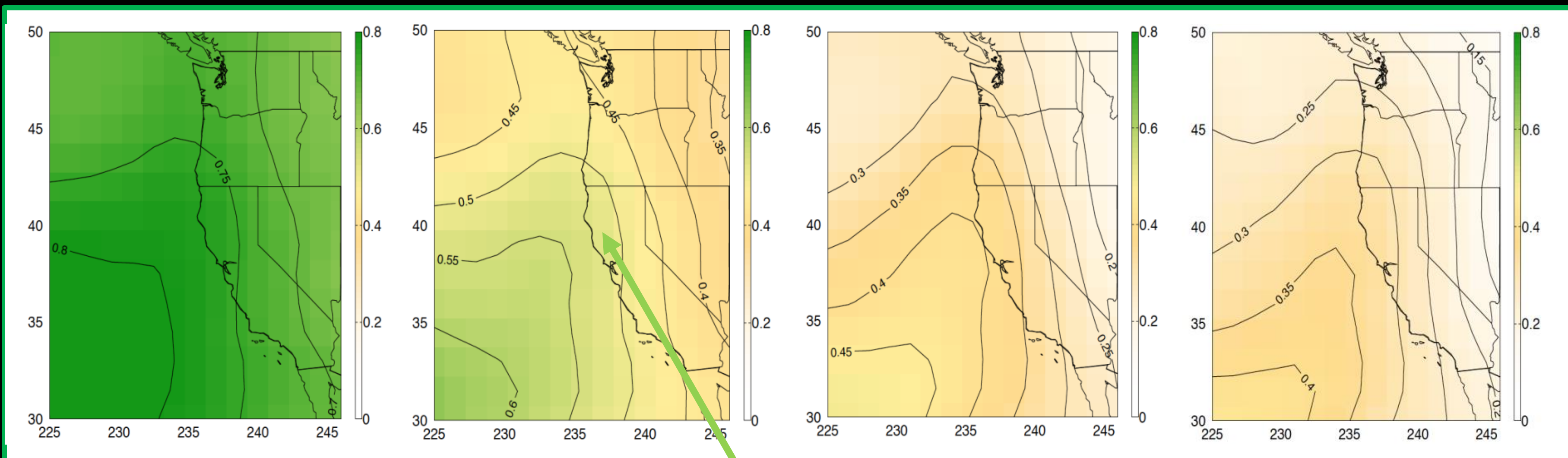

How well do our global S2S models

– ECMWF in this case –

predict high & low AR periods at subseasonal time scales?

# Western US AR Prediction Skill

## Forecast vs Observation Time Series Correlations




0-14 Days

7-21 Days

14-28 Days

21-35 Days

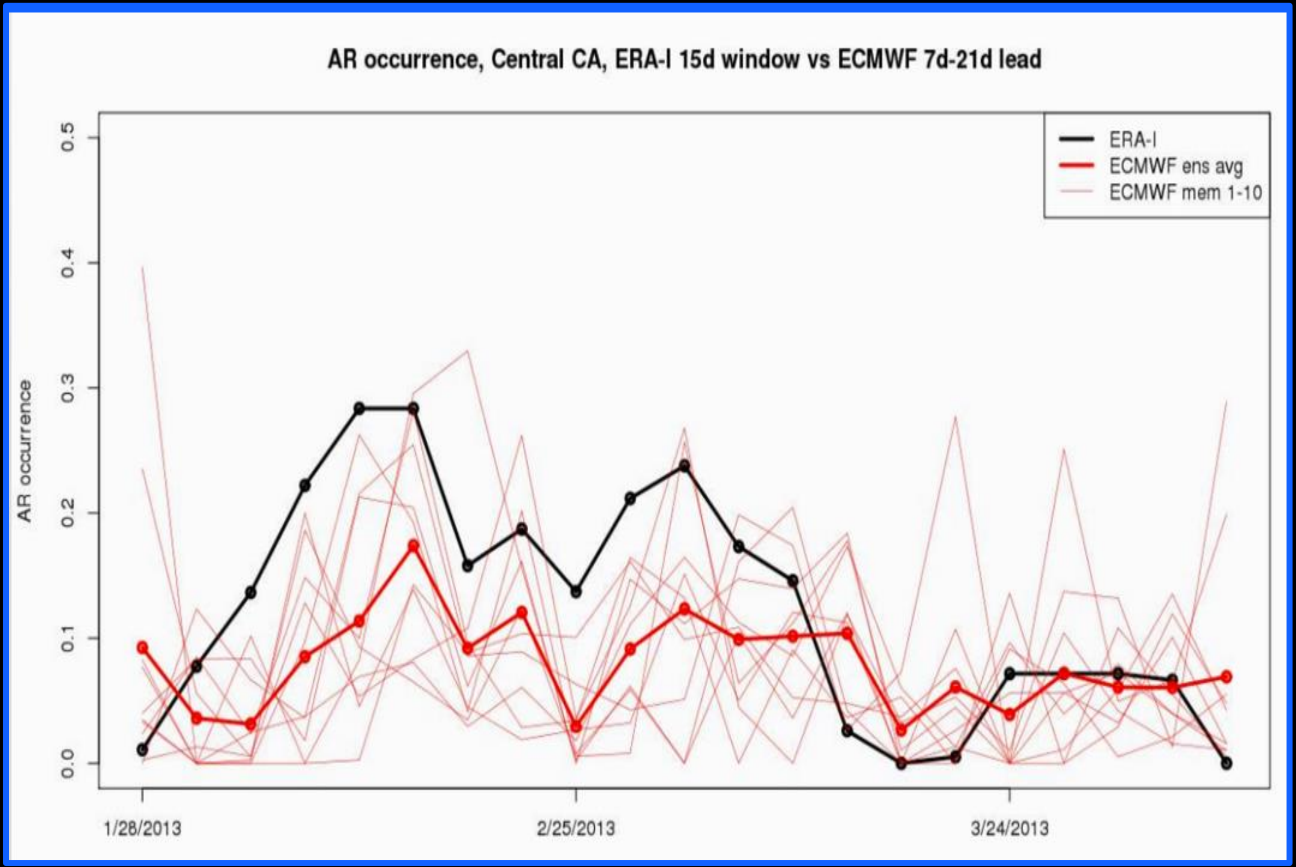
e.g. 0.5 for 2 week average for week 2 & 3

*DeFlorio, Waliser, Guan, Ralph, Barbour…. (2017, In Prep)*

Jet Propulsion Laboratory
California Institute of Technology

# AR Landfall Predictions & Water/Flood Management

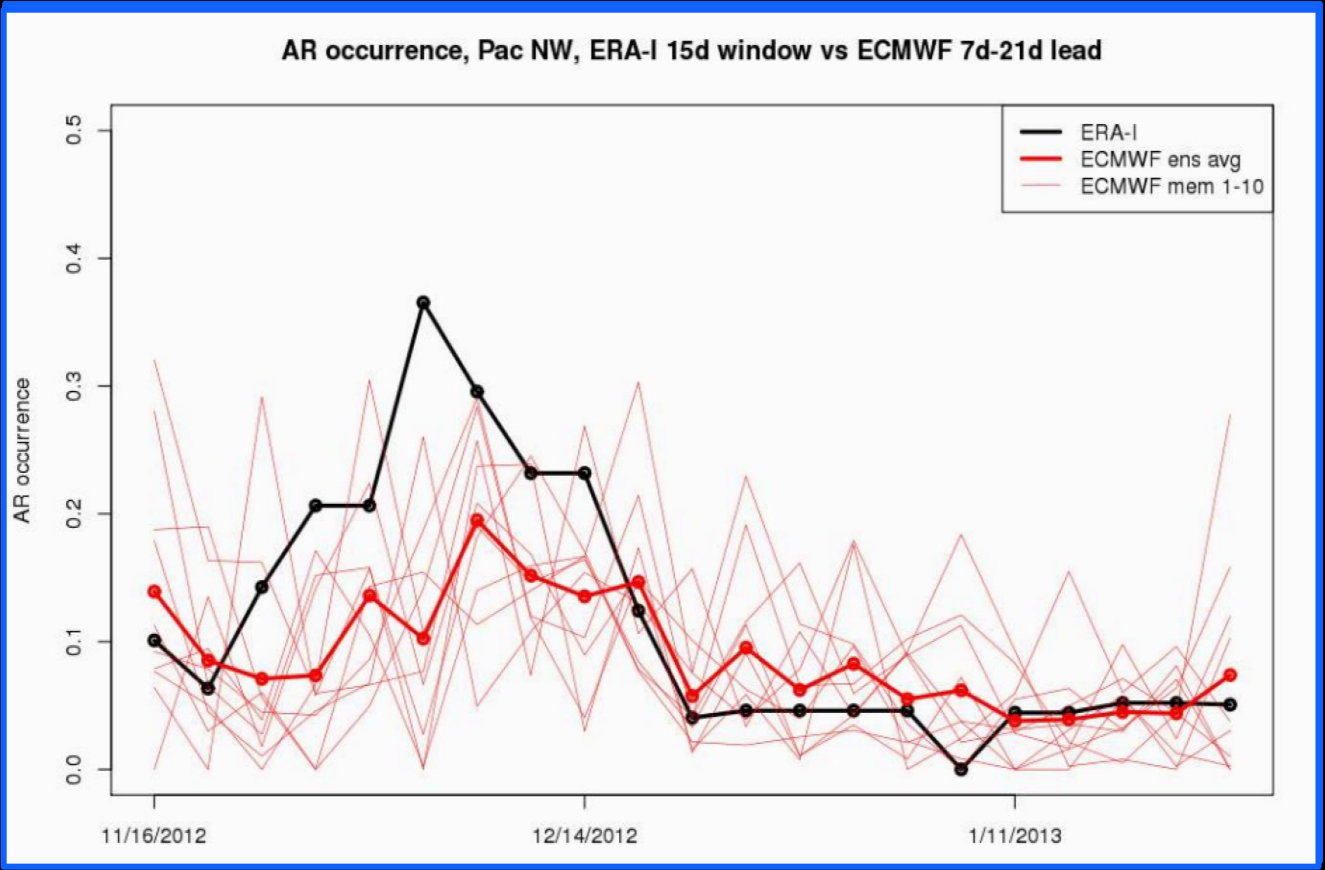
## *Experimental Forecasts?*




*DeFlorio, Waliser, Guan, Ralph, Barbour…. (2017, In Prep)*

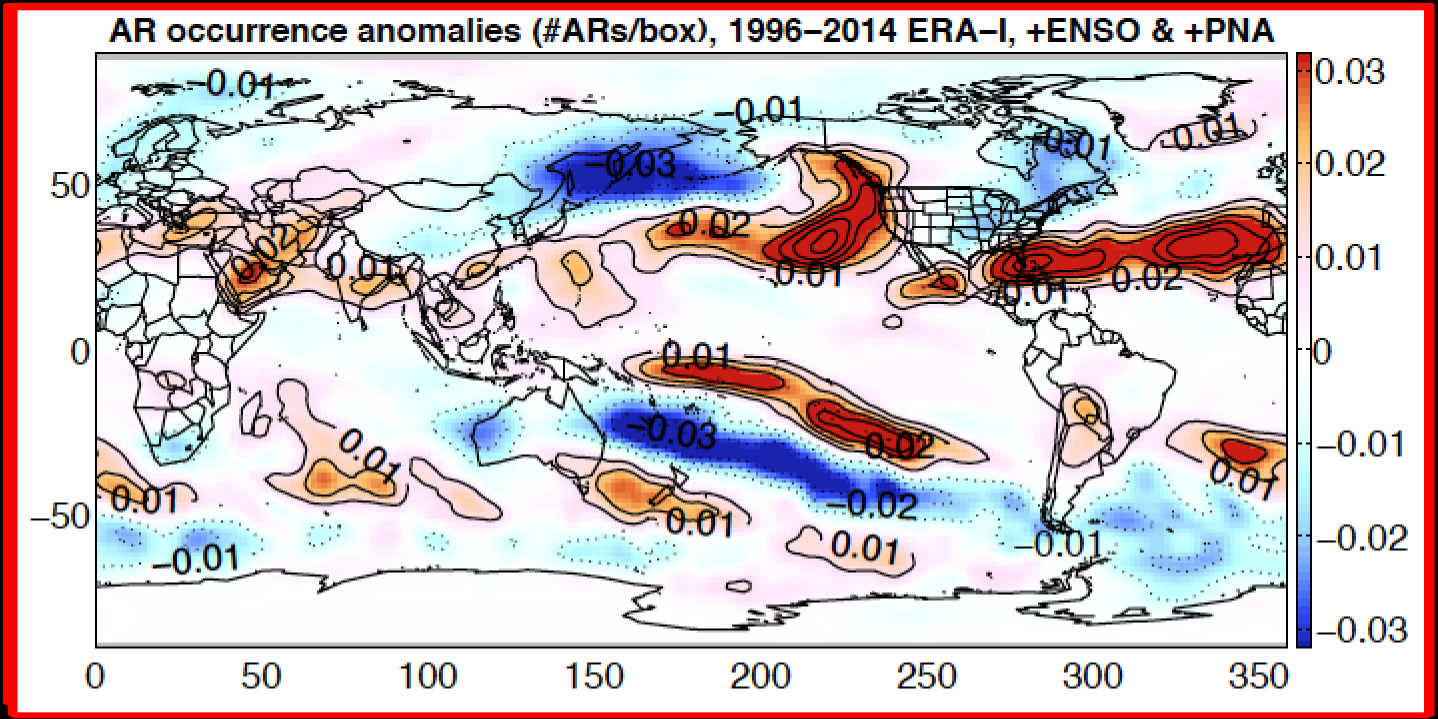
# AR Landfall Predictions & Water/Flood Management

## *Experimental Forecasts?*




*DeFlorio, Waliser, Guan, Ralph, Barbour…. (2017, In Prep)*

# Climate Modes & "Forecasts of Opportunity"




Both +PNA and +ENSO increase the subseasonal AR frequency measure, particularly when combined.

*Such periods yield a stronger signal and possibly better skill, TBD*

*DeFlorio, Waliser, Guan, Ralph, Barbour…. (2017, In Prep)*

# Summary

- We're leveraging global AR databases, S2S Predictions, and climate variations to explore/quantify AR prediction capabiilites.
- We're quantifying skill in the present-day ECMWF forecast for:
    - *Individual AR Detection*
    - *Subseasonal AR Frequency of Occurrence*
- We'd like to leverage this research work to explore the development and use of an experimental product.

- We have some comprehensive global weather /climate model evaluation results (24 models, 17 metrics) to help identify model weaknesses and guide improvements (Guan and Waliser, 2017)
- We have produced the first global analysis of projected 21$^{ST}$ century climate changes in ARs (Espinoza et al. 2017, In prep)

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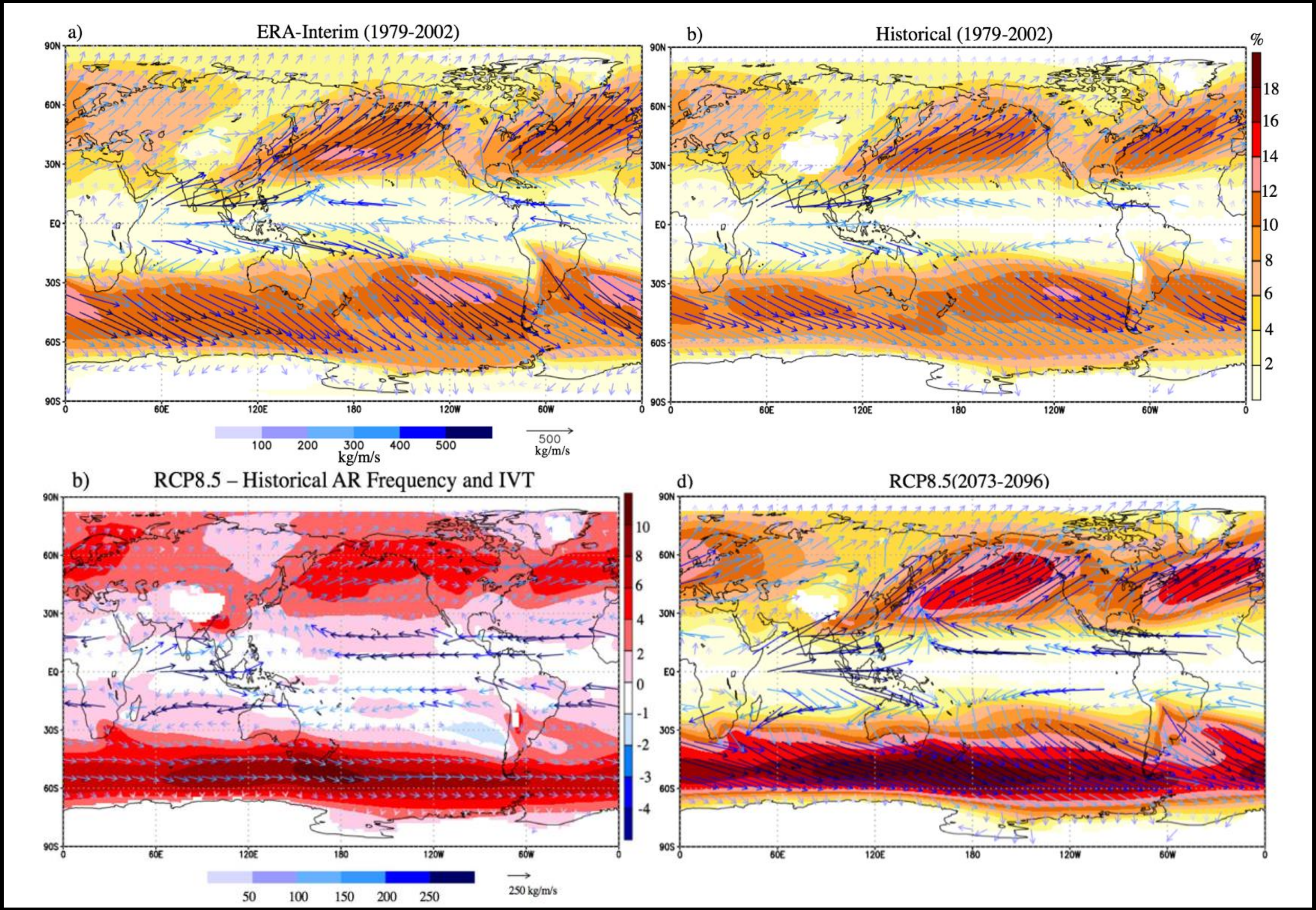
Wick, G. A., P. J. Neiman, F. M. Ralph, and T. M. Hamill (2013), Evaluation of Forecasts of the Water Vapor Signature of Atmospheric Rivers in Operational Numerical Weather Prediction Models, Weather and Forecasting, 28(6), 1337-1352.

# Climate Change & ARs

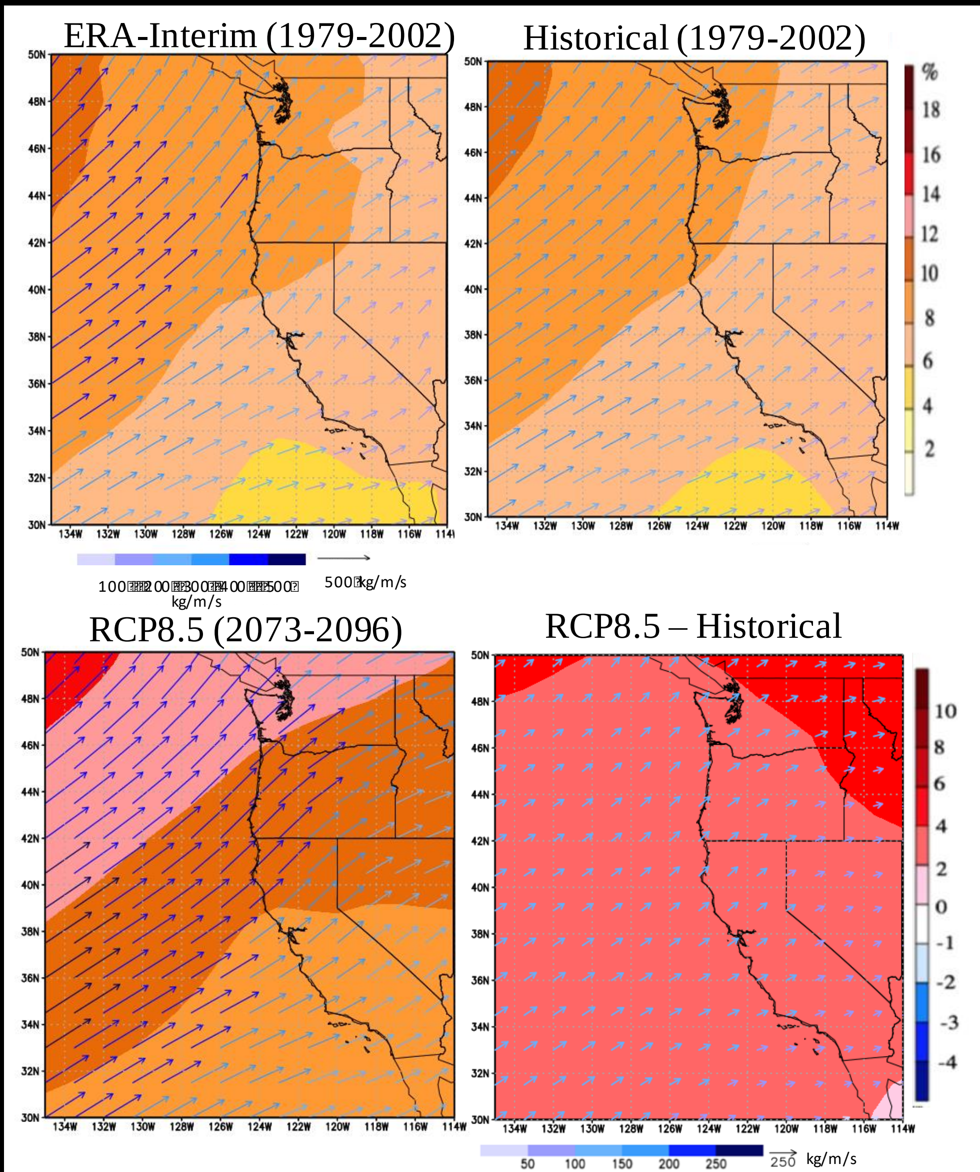
*AR Frequency & Transport: 21 CMIP5 Models*




*Espinoza, Waliser, Guan, Lavers, Ralph (2016, In Prep)*

# Climate Change & ARs

*AR Frequency & Transport: 21 CMIP5 Models*




**% AR Frequency for Western US**

- Historical/ERA-Interim AR Frequency: 7-9%
- RCP8.5 (2073-2096) AR Frequency: 9-13%
- AR Frequency Increase: 2-4%;
- Relative Increase 30-40%

**IVT Increase for Western US**

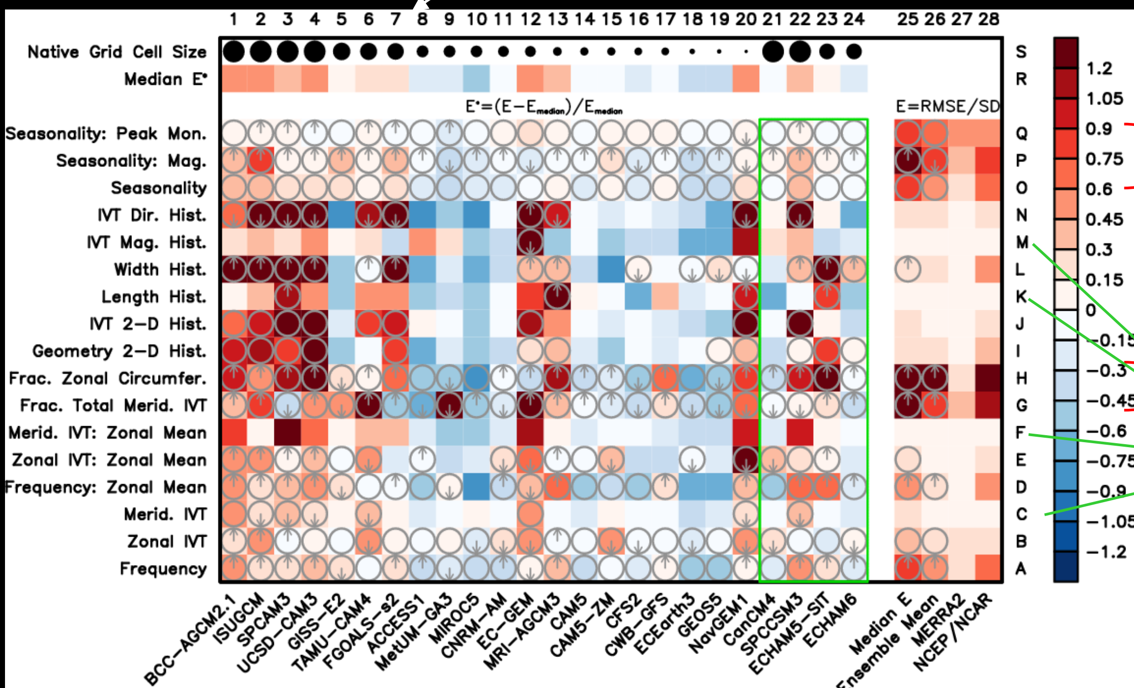
- Historical IVT ~250kg/m/s
- RCP8.5 IVT ~350 kg/m/s
- Relative Increase ~40%.

What does this imply about total precipitation?

*Espinoza, Waliser, Guan, Lavers, Ralph (2016, In Prep)*

# Weather/Climate Simulations of ARs

Models fidelity is resolution dependent, suggesting about 1.5 degree or better is a necessary but not sufficient condition [i.e. mostly red (blue) to the left (right)].




7 AR metrics relatively challenging:

- Seasonality (3 metrics)
- Fractional zonal circumference
- Fractional total meridional IVT
- Zonal IVT
- Frequency

4 AR metrics relatively good:

- IVT magnitude histogram
- Length histogram
- Meridional IVT, and its zonal mean

***CAPTION**: Portrait diagram showing evaluation result for 17 metrics, with cool (warm) colors indicating better(worse)-than-average models, gray circles (arrows) indicating large RMSE (bias) relative to observation. Green outline marks 4 coupled models. Top row indicates model horizontal resolution, with biggest (smallest) circle about 280 (40) km.*

Evaluation based on 20-year simulations from 24 global weather/climate models from the GASS-YOTC Physical Processes Experiment

Guan and Waliser (2017)