Empirical Prediction of Atmospheric Rivers on Subseasonal Timescales

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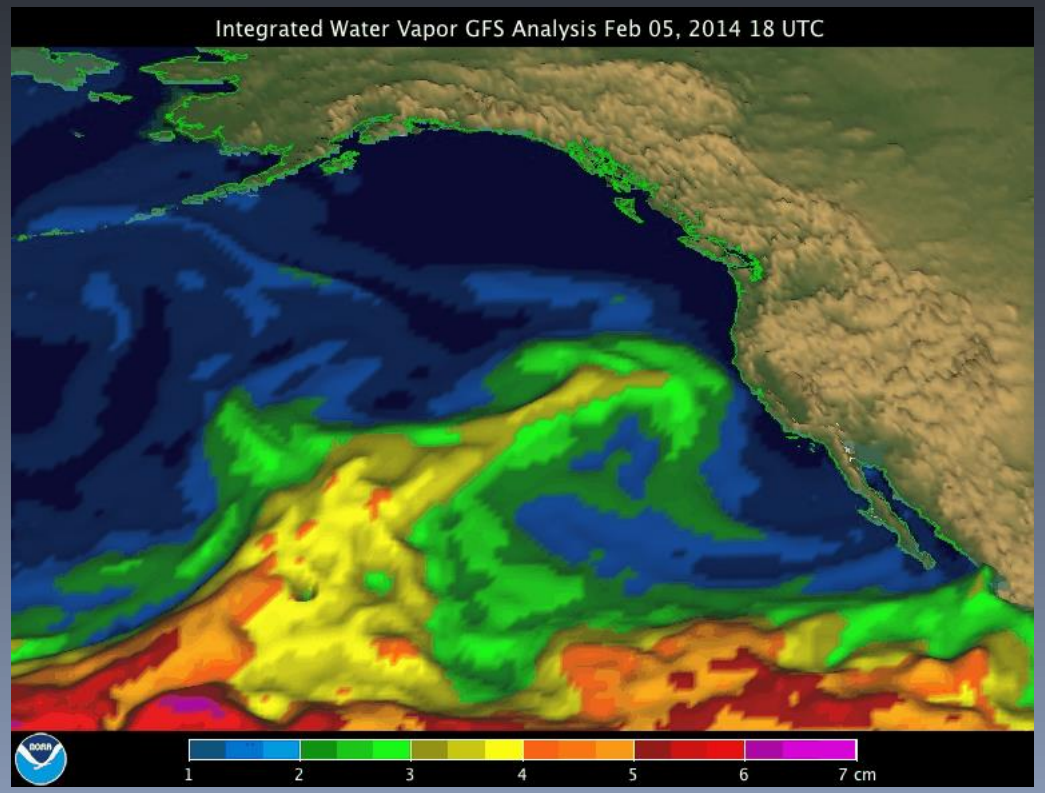
45th Climate Diagnostics and Prediction Workshop
October 22, 2020

Background: What are Atmospheric Rivers (ARs)?

- *"Intense synoptic scale plumes of tropospheric water vapor" (Barnes et al 2018, CTB proposal)*
- Can be destructive→ extreme precipitation and flooding at landfall
- But also beneficial→ provides up to 50% of the water supply to the regions of the western US (Dettinger et al 2011)



Source: NOAA PSL Climate Repository

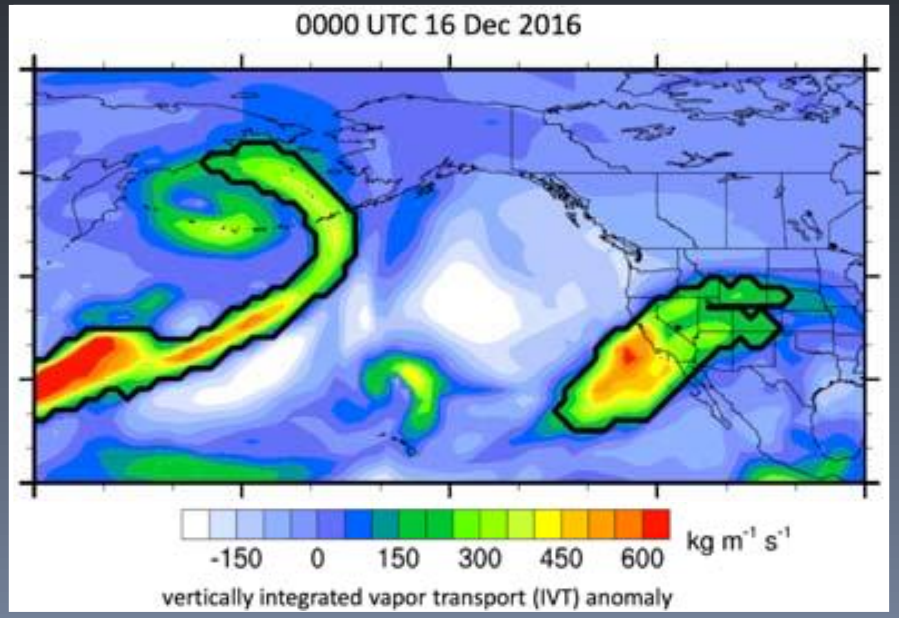
Detection of Atmospheric Rivers (ARs)

Two key criteria

1. Intensity threshold:
   - Vertically integrated water vapor transport (IVT) OR
   - Integrated water vapor (IWV)
2. Geometry (plume-like):
   - total area
   - length
   - length-to-width (LTW) ratio

Mundhenk et al (2016) detection algorithm

- Intensity: 94th percentile of all season distribution of IVT values over North Pacific
- Geometry: feature at least 2000 km in length with LTW~1.4

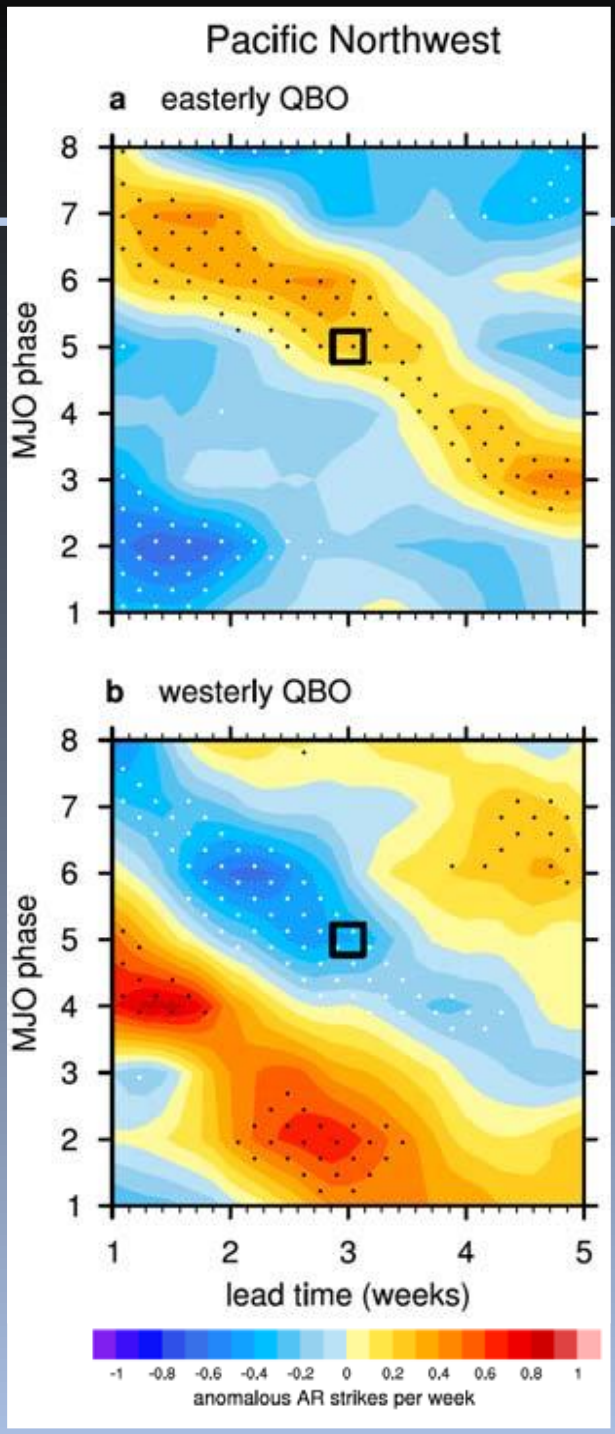


Atmospheric Rivers (black outlines) that impacted the US west coast in Dec 2016. Source: Barnes et al 2018 CTB proposal

Predicting ARs: Large-Scale Influences

Baggett et al (2017)

- Modulation of Madden Julian Oscillation (MJO) by the Quasibiennial Oscillation (QBO; Yoo and Son 2016; Son et al 2017)
  - Easterly (westerly) QBO→ stronger (weaker) MJO amplitude in boreal winter
- AR activity linked to MJO-QBO
  - Anomalous AR activity 4 weeks ahead due to MJO propagation
  - Sign of anomalous AR activity seems to be a function of QBO phase
- Can MJO/QBO information be leveraged to predict anomalous AR activity? → empirical model

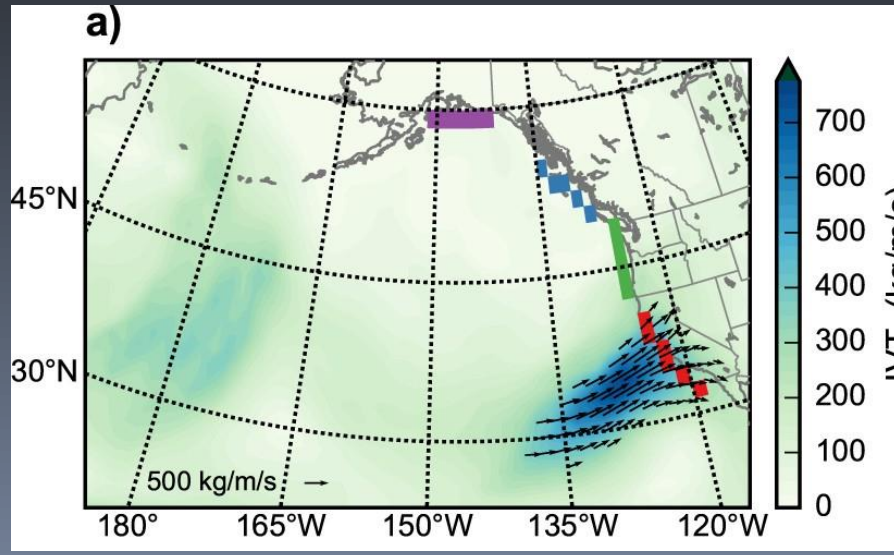


ERA-Interim composites of anomalous AR occurrences peak week following days when MJO was in a particular phase during easterly and westerly QBOs

Empirical AR model

Mundhenk et al 2018

- Similar methodology to CPC Phase Model (Johnson et al 2014)
- Predictors:
  - QBO: westerly vs easterly
  - MJO: 8 active phases and 1 inactive phase
- Predictand:
  - Anomalous AR activity at various lead times
  - Two categories (above or below)
- Domain: west coast of US and southern AK
- Cross validated results (1979-2014): forecasts of opportunity → empirical model forecasts more skillful than ECMWF reforecast predictions

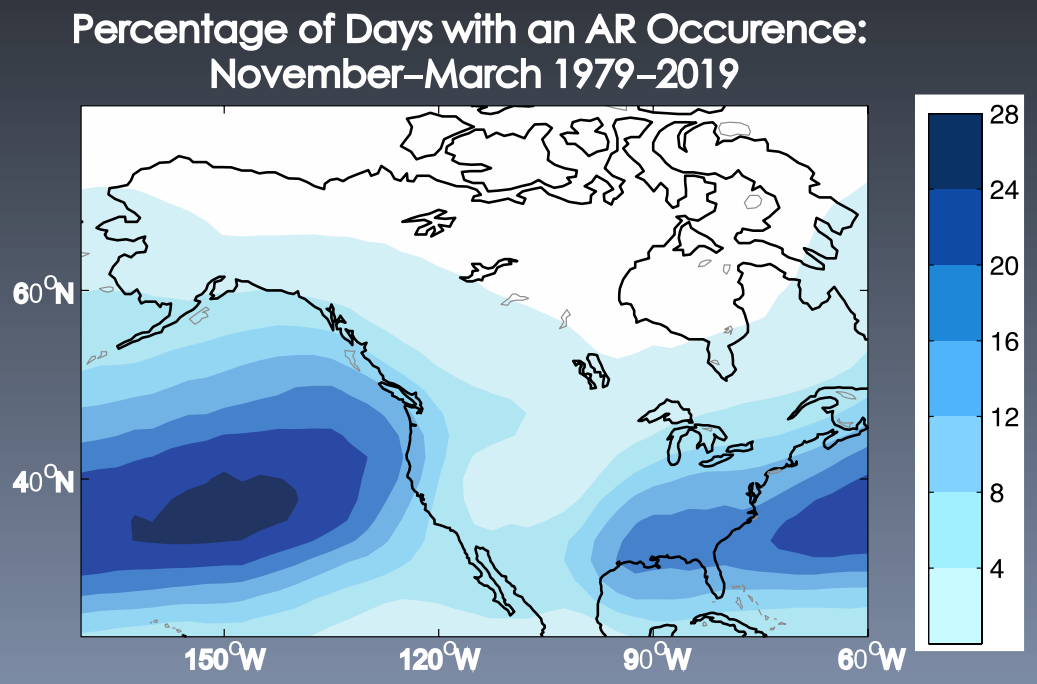


Location of the Alaska (purple), British Columbia (BC; blue), Washington/Oregon (green), and California (CA; red) landfall boundaries overlaying the daily mean integrated water vapor transport (IVT; shaded) from 20 February 2017. The black IVT vectors highlight an AR that impacted the CA boundary on that date . Source: Mundhenk et al (2018)

Objective: Implementing AR guidance at CPC

- Climate Testbed Proposal (PI: Libby Barnes)
  - Transition the empirical model from Mundhenk et al (2018) to CPC operations

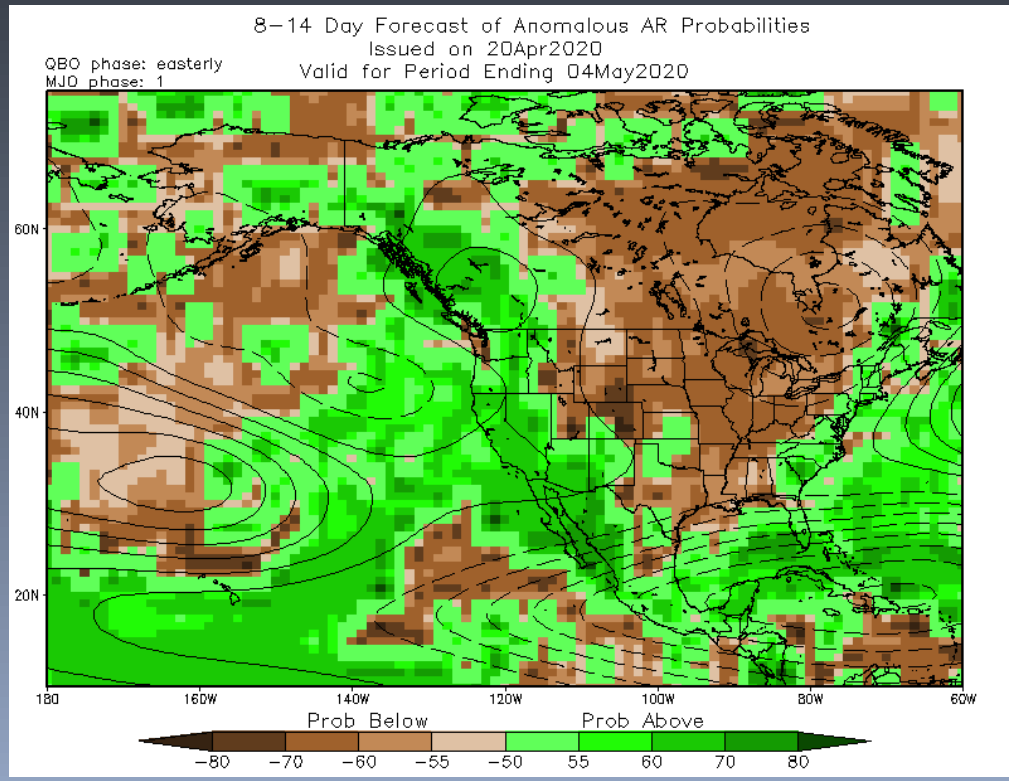
- Changes from the original model
  - Realtime data available at CPC
  - Add forecasted 500-hPa height anomalies
  - Extend beyond west coast to entire CONUS/AK



CPC Empirical AR Forecast Guidance Tool

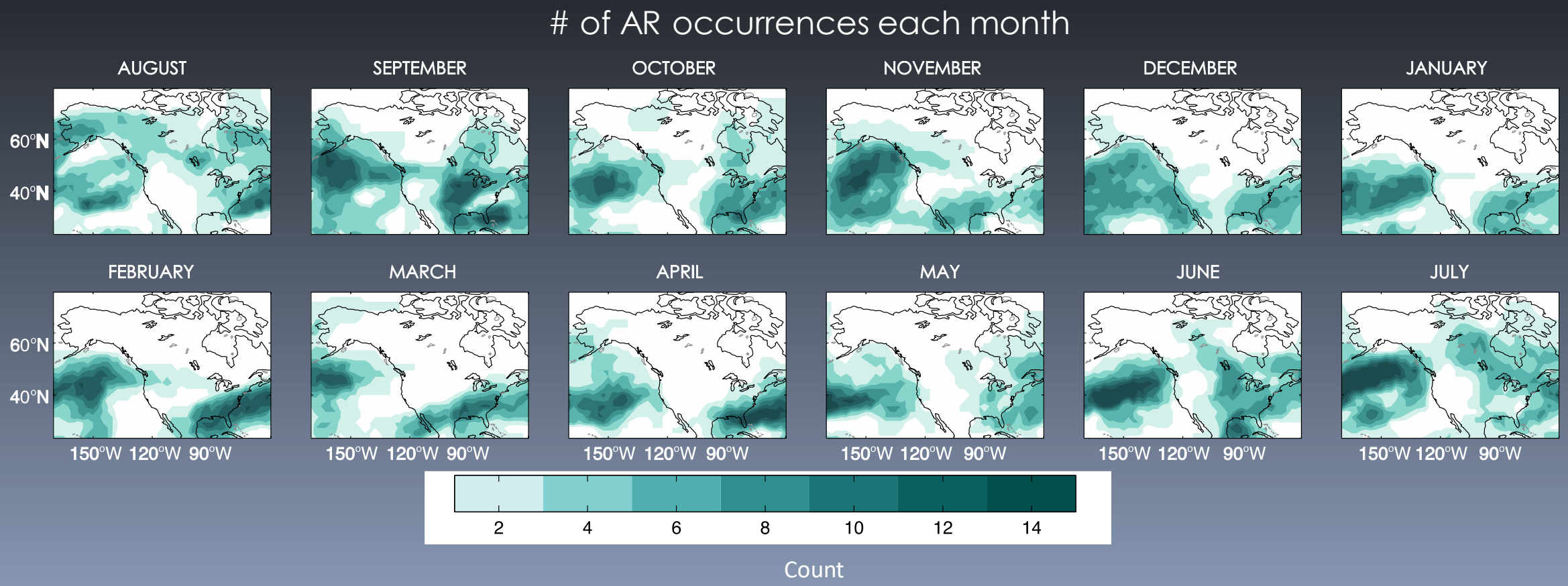
- Product: Daily probabilistic AR forecast to support CPC precipitation forecasts
  - Days 8-14
  - Weeks 3-4
- Training Period: 1979-2014 (also period for cross-validated historical skill)
- Verification Metric: Heidke Skill Score (HSS) calculated across the CONUS and AK (sorry Hawaii)
- How did the model perform for the first year?
  - Results August 1 2019 – July 31 2020

Example of Day 8-14 AR Forecast



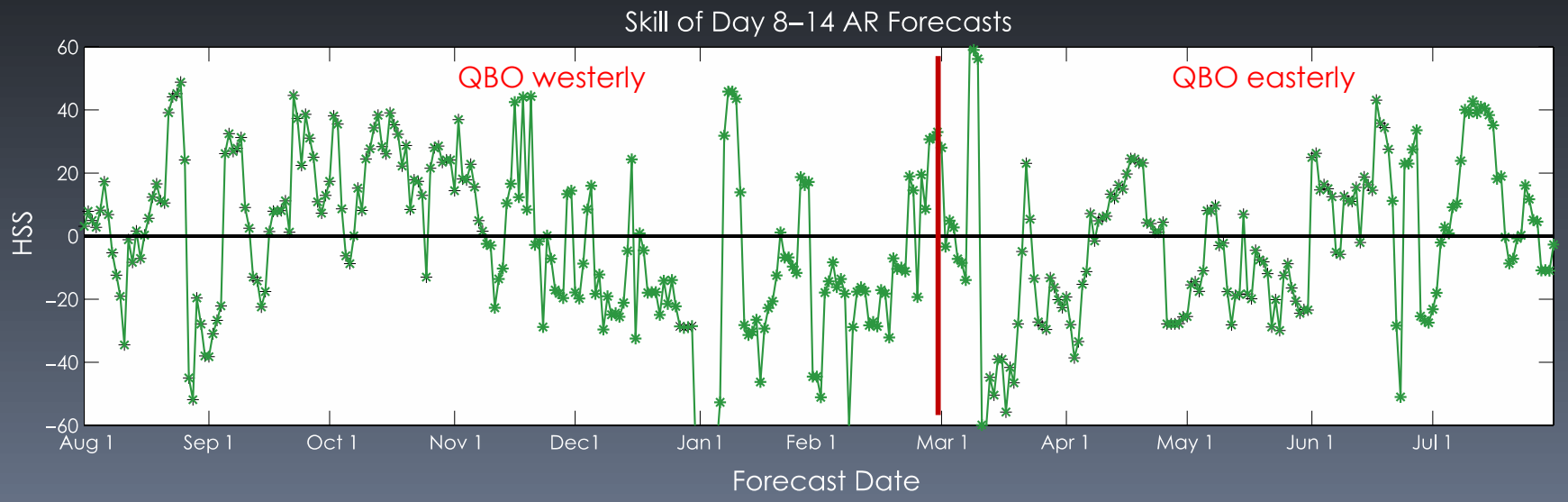
Shading: AR forecast probability
Contours: forecasted Z500 anomalies

Observed AR Detection: 2019-2020 Season



- Alaska: later summer/fall
- West coast: mostly winter
- East coast: year-round (more than I expected?)

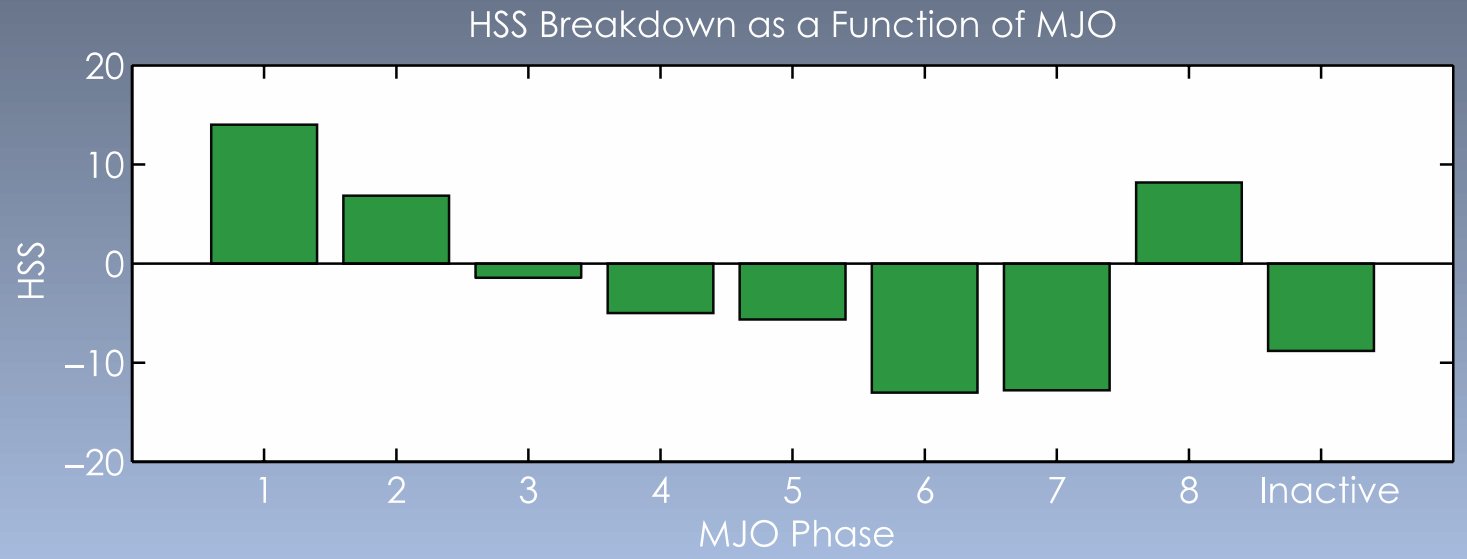
Day 8-14 Outlooks: 2019-2020 Verification Summary



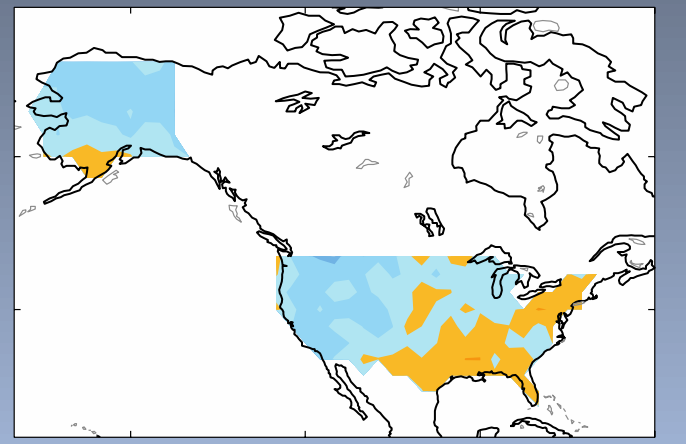
HSS (all categories) = -1.23

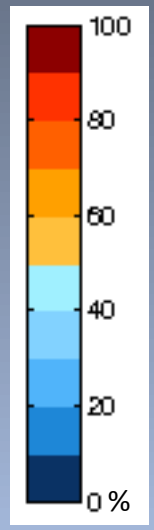
HSS (above)= -6.8

HSS (below)= 8.06



Percentage of Hits at each Gridpoint



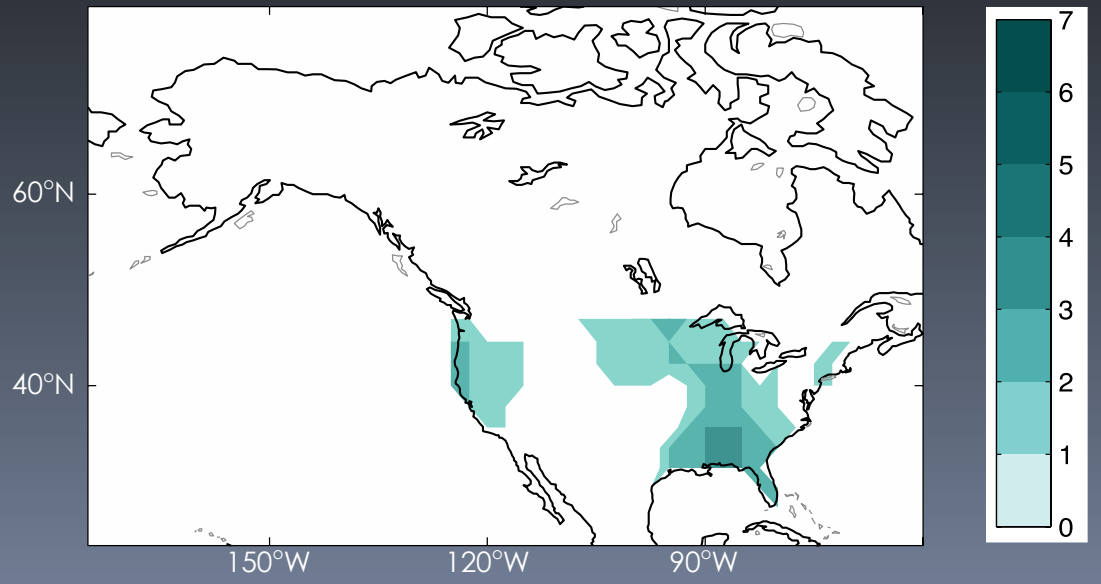


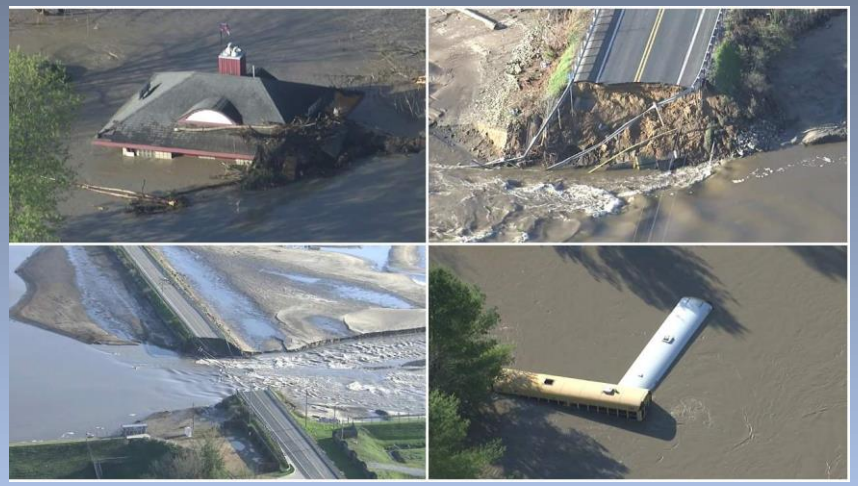
Day 8-14 Outlook: Forecasting an AR event

- May 16-19 2020--> Two events
  - West Coast(AR1 conditions Source: CW3E)
  - But also across the Midwest, coming up from the Gulf and causing massive flooding in Michigan (7in + in Midland, MI)

- Did the empirical model capture these events?

Number of US AR Occurrence Days: May 16-22, 2020

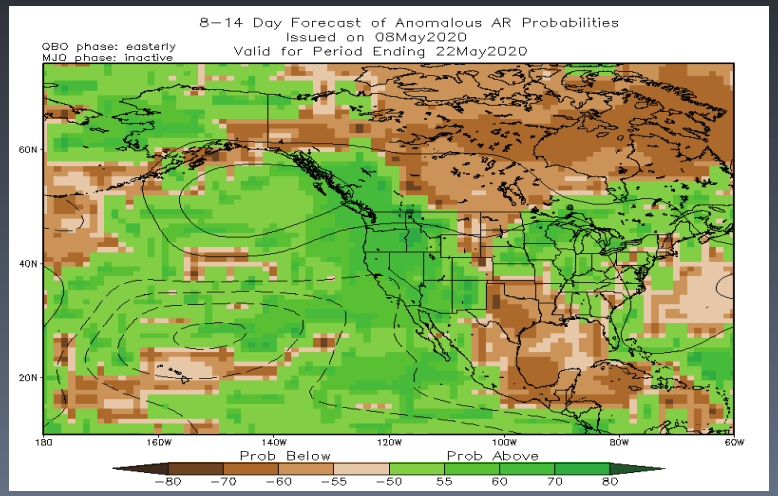




Midland Co, MI. Various flooding damage photos as a result of the Edenville and Sanford dam failures. Credit: WDIV. Source: NWS

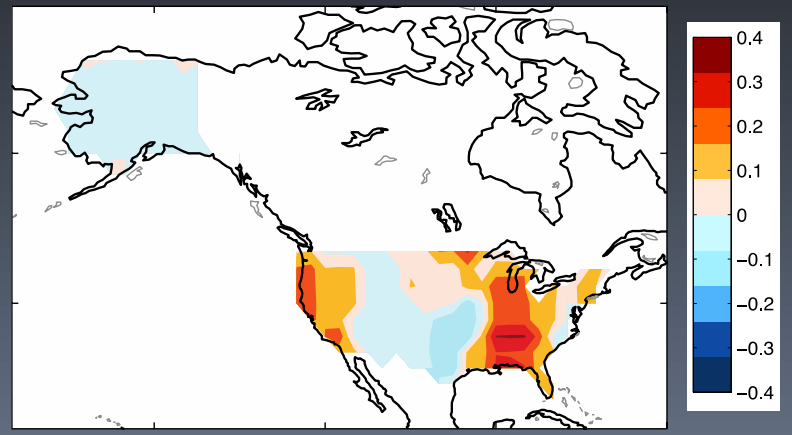
Day 8-14 Outlook Issued May 8 2020
Valid for May 16 – 22 2020

What was forecasted?



What was observed?

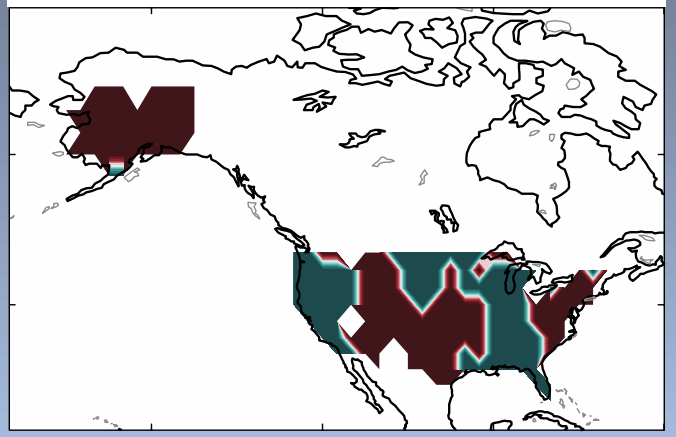
AR anomalies over 8-14 day period



- Model captures ARs on west coast and Midwest
- Overall CONUS pattern is reasonably captured (but shifted)

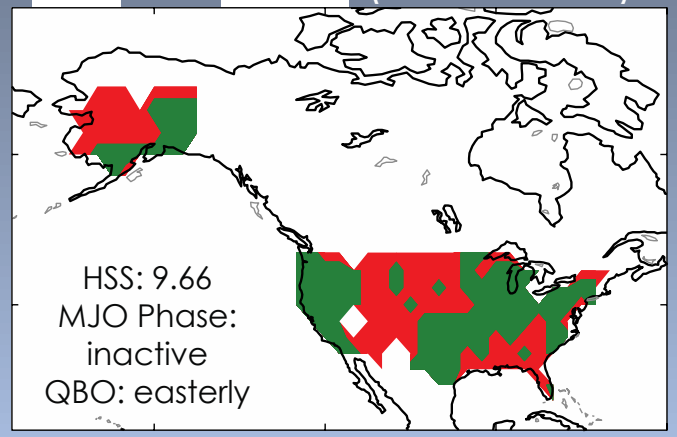
Verification Category

Above Normal Below Normal

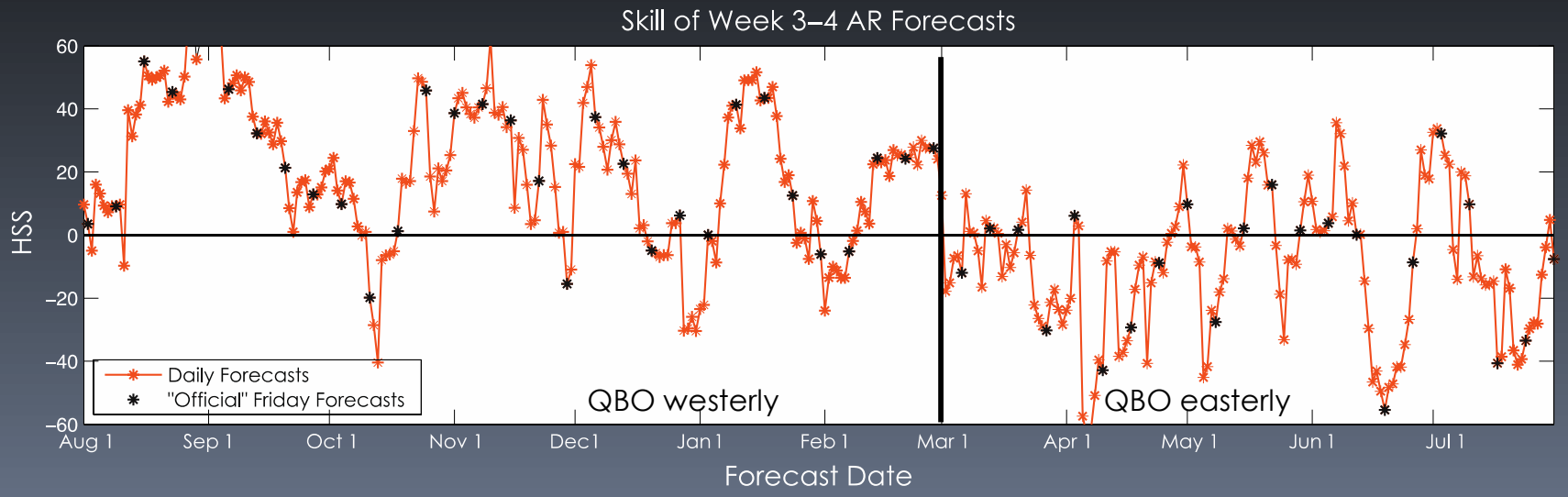


What did we get right?

Hits and Misses (to calc HSS)



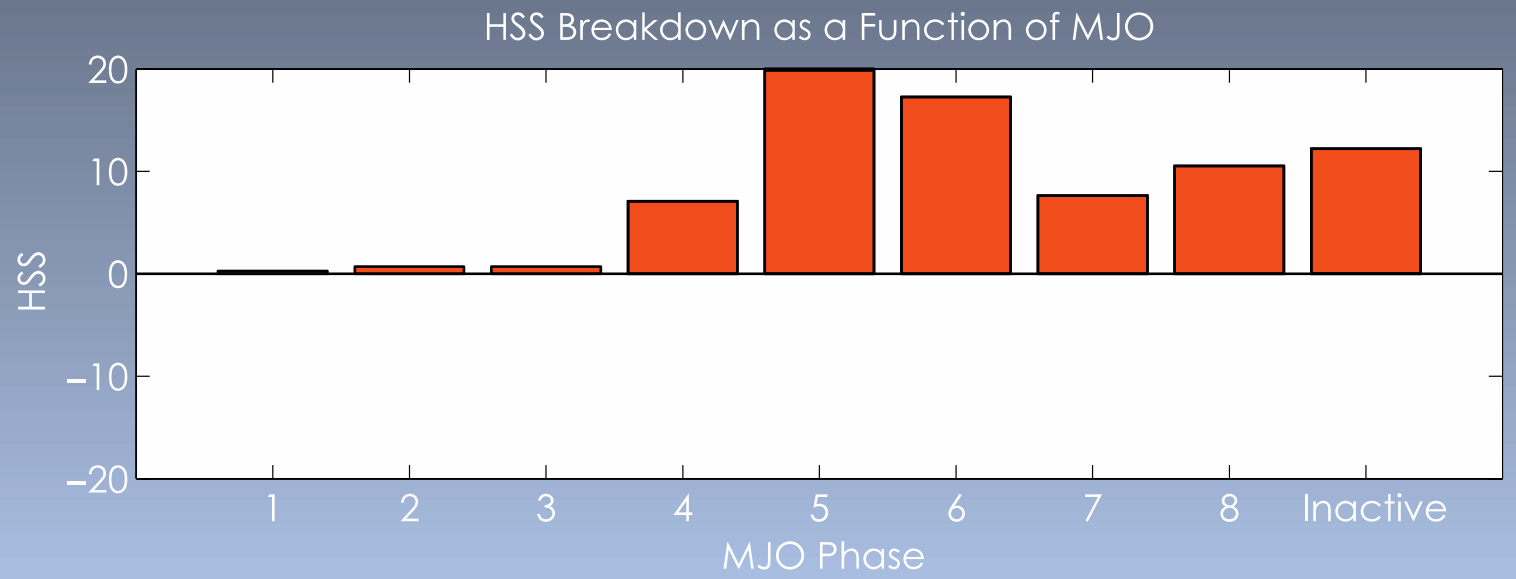
Week 3-4 Outlook: 2019-2020 Verification Summary

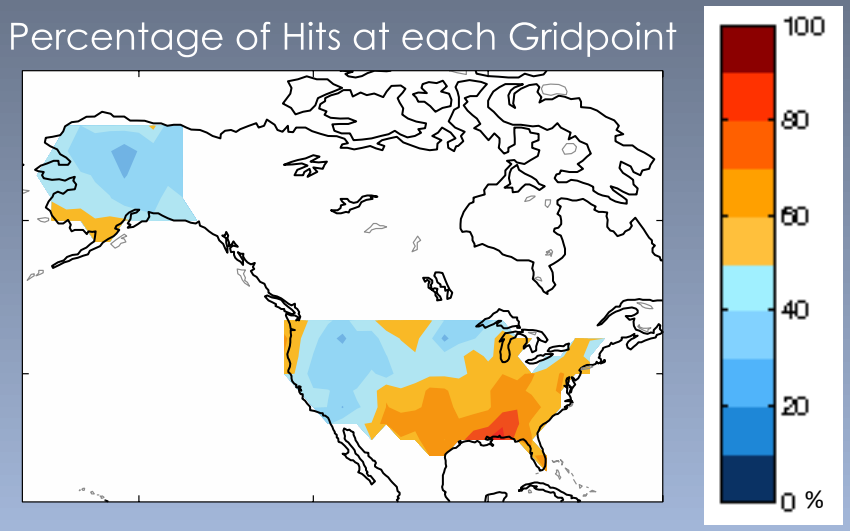


HSS (all categories): 8.55

HSS (above): 10.77

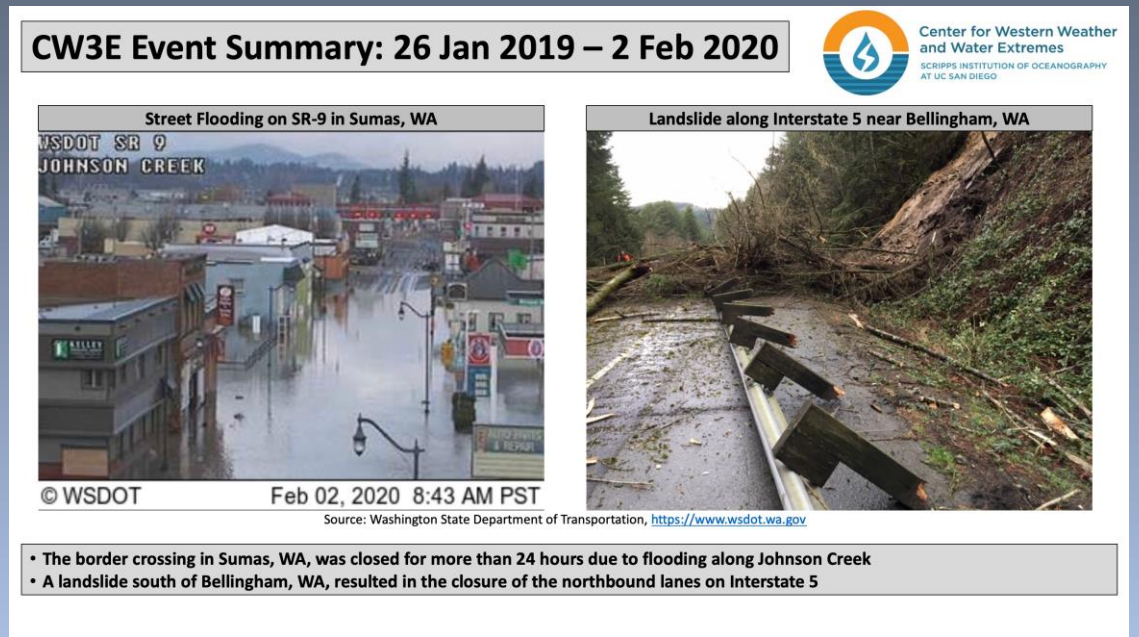
HSS (below): 3.72



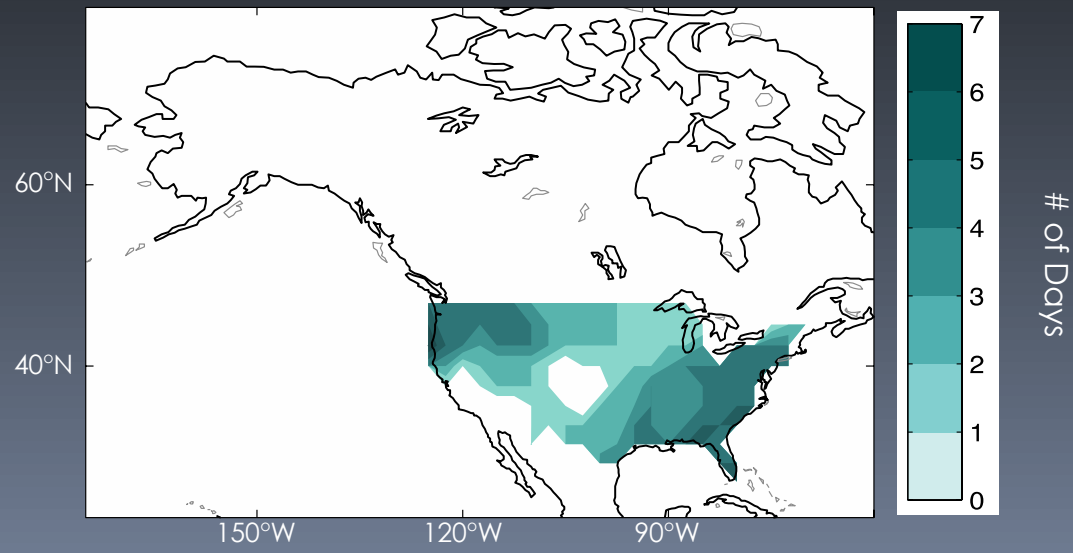


Week 3-4 Outlook: Forecasting an AR Event

- West coast AR event: Jan 26- Feb 2 2020
- WA/OR: AR 3 conditions (moderate; Source CW3E)
- 7-day precip totals ~7in

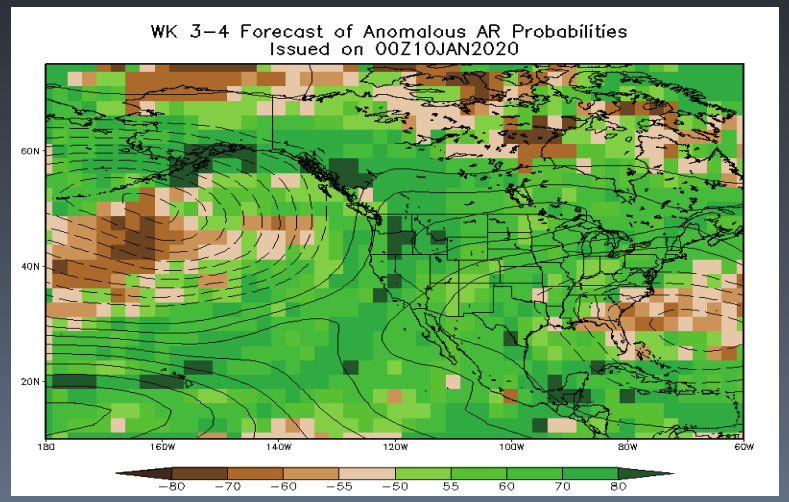


Number of US AR Occurrence Days: Jan 25 - Feb 07 20



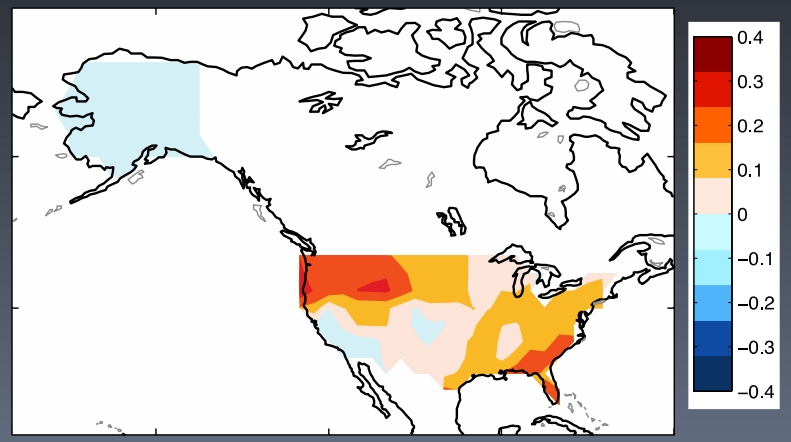
Week 3-4 Outlook Issued Jan 10 2020
Valid for Jan 25 - Feb 7 2020

What was forecasted?



What was observed?

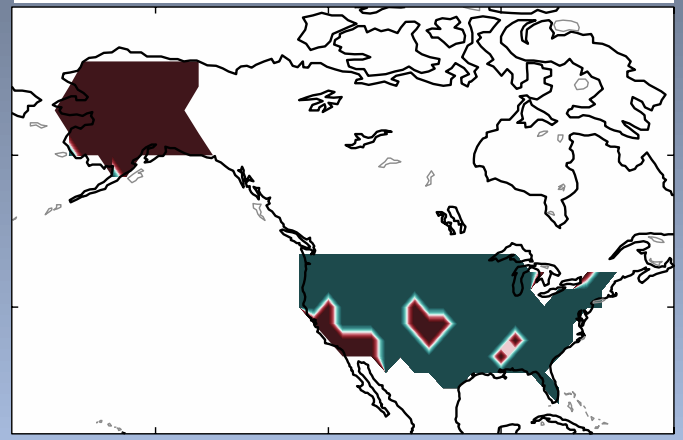
AR anomalies over 8-14 day period



- Captures ARs in Pacific NW but not in the Southeast

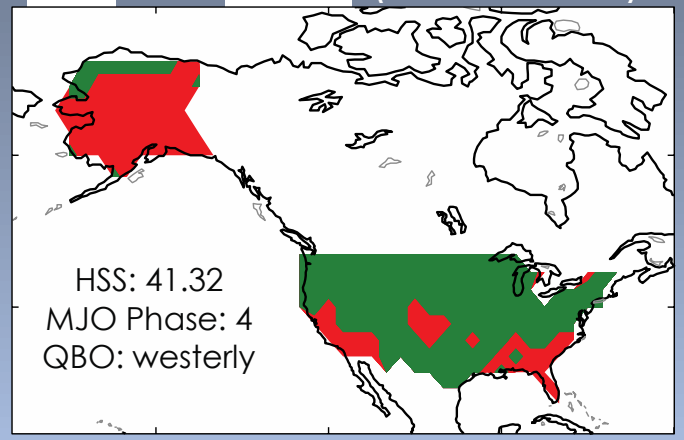
Verification Category

Above Normal Below Normal



What did we get right?

Hits and Misses (to calc HSS)



Summary

- One year of results so not much to “conclude”
- Day 8-14: not adding much skill
  - Was able to capture the Michigan flooding event May 2020
- Week 3-4: more skillful west coast and southeast
  - Tends to forecast above normal AR activity in Alaska which doesn’t pan out
- Starting to be used more in forecast process
- Potential Changes
  - Add neutral QBO (currently only westerly or easterly)
  - Does IVT threshold need to change (currently based on IVT distributions from North Pacific)