Experimental Subseasonal Forecasting of Atmospheric Rivers During Winter 2017-2018 and 2018-2019

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Contains key figures/concepts from:

1. DeFlorio et al. 2018a, **Global assessment of atmospheric river prediction skill**, J. Hydromet., **19**, 409-426, doi:https://doi.org/10.1175/JHM-D-17-0135.1.
2. DeFlorio et al. 2018b, **Global evaluation of atmospheric river subseasonal prediction skill**, Clim. Dyn., doi:10.1007/s00382-018-4309-x.
3. DeFlorio et al. 2018c, **Experimental real-time forecasting of atmospheric river occurrence over California during Winter 2017-2018 and 2018-2019**, BAMS, in prep.
4. Guan and Waliser 2015, **Detection of atmospheric rivers: Evaluation and application of an algorithm for global studies**, J. Geophys. Res., **120**, 12514-12535.

Key Research Question

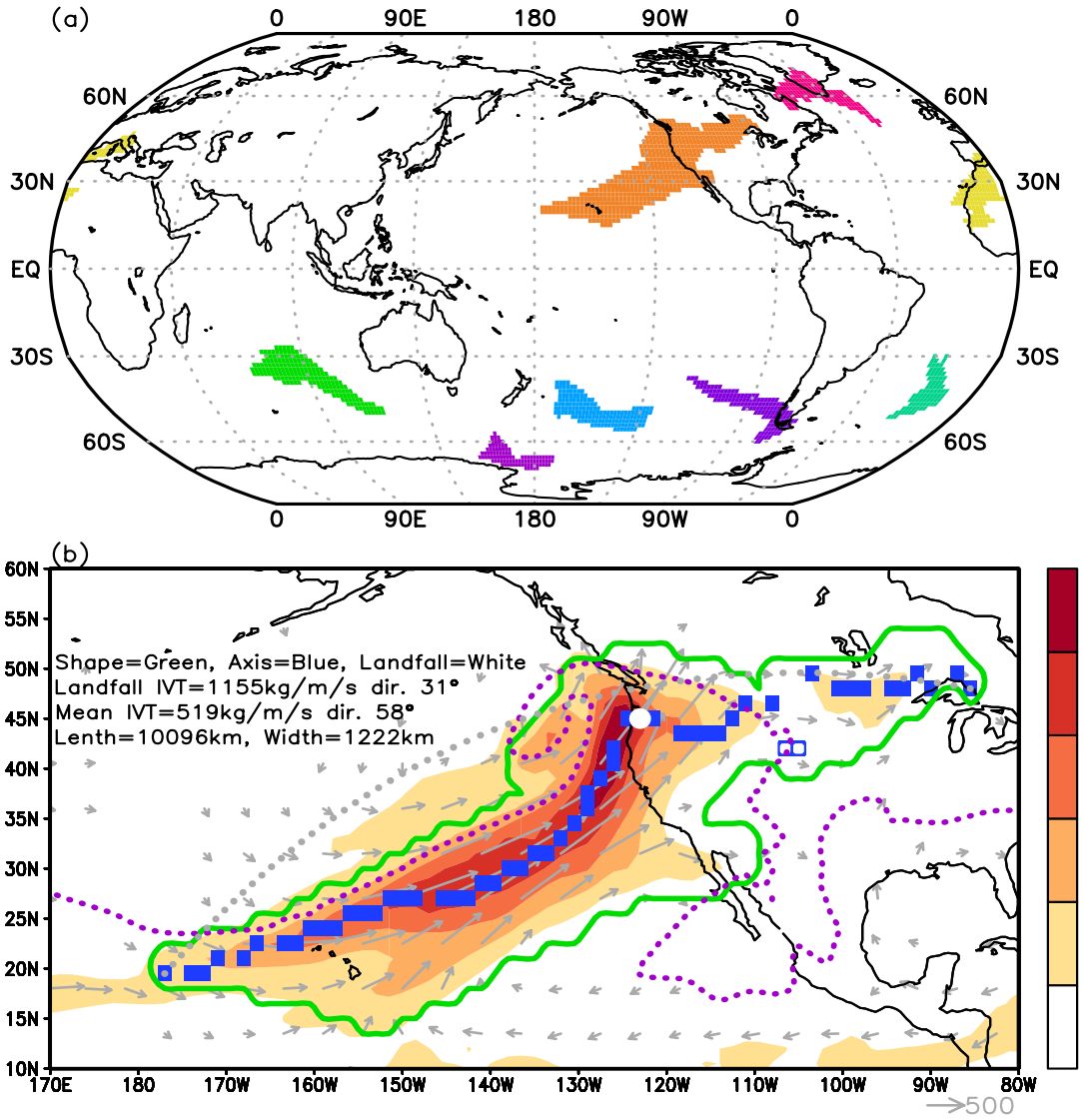
What is the limit of global synoptic (1-day to 14-day) and subseasonal (1-week to 1-month) prediction skill of atmospheric river occurrence, and how does each vary as a function of season, region, and certain large-scale climate conditions?

Key Applications Question

Can present-day subseasonal-to-seasonal (S2S) forecast systems provide benefit to CA water resource management decision makers?

A global, objective algorithm for AR identification

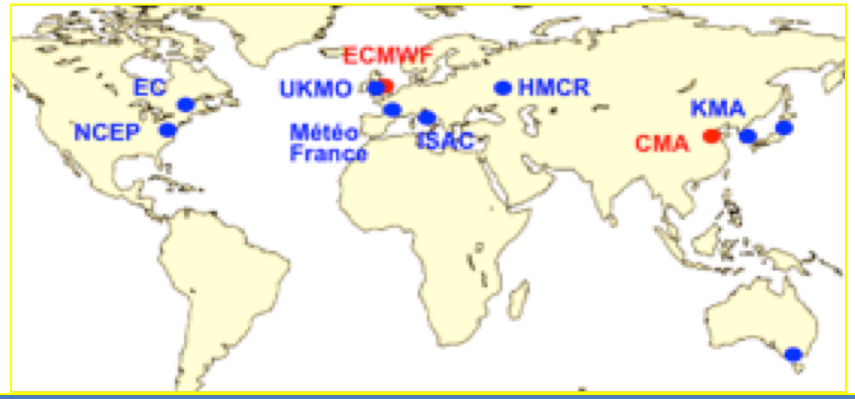
(Guan and Waliser 2015)



- Based on Integrated Vapor Transport (IVT) fields and a number of common AR criteria (e.g. Ralph et al. 2004)
- Applied to global hindcast/forecast systems and reanalysis datasets
- Code and databases available at: https://ucla.box.com/ARcatalog
- Databases include AR Date, $IVT_{x,y}$, Shape, Axis, Landfall Location, etc.
- Used for GCM evaluation (Guan and Waliser 2017), climate change projections (Espinoza et al. 2018), & forecast skill assessment (DeFlorio et al. 2018a and 2018b)

The S2S Project Database (s2sprediction.net)

- Suite of real-time forecasts and several decades of hindcasts from 11 operational forecast models
- Maximum lead time ranging from 32 days to 60 days
- Hindcast ensemble size ranging from 1 to 33
- Variety of forecasting configurations and other model parameters (heterogeneity amongst models)
  - "dataset of opportunity"



	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

Vitart et al. 2017

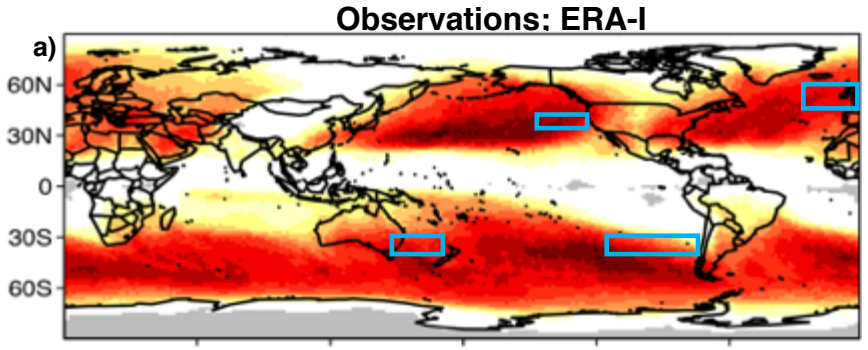
Global Evaluation of Atmospheric River Subseasonal Prediction Skill

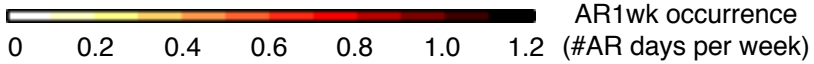
Michael J. DeFlorio[1], Duane E. Waliser[1], Bin Guan[1,2], F. Martin Ralph[3], and Frederic Vitart[4]; (*Climate Dynamics* 2018)
[1]NASA Jet Propulsion Lab., [2]UCLA, [3]UCSD/SIO/CW3E, ECMWF[4]

Purpose of Study

- Evaluate global ECMWF hindcast prediction skill of 1-week AR occurrence (AR1wk; number of AR days per week) at 1-week to 1-month lead times
- Quantify interannual variability of AR1wk magnitude, and identify conditions of climate variability which exhibit higher/lower AR1wk prediction skill

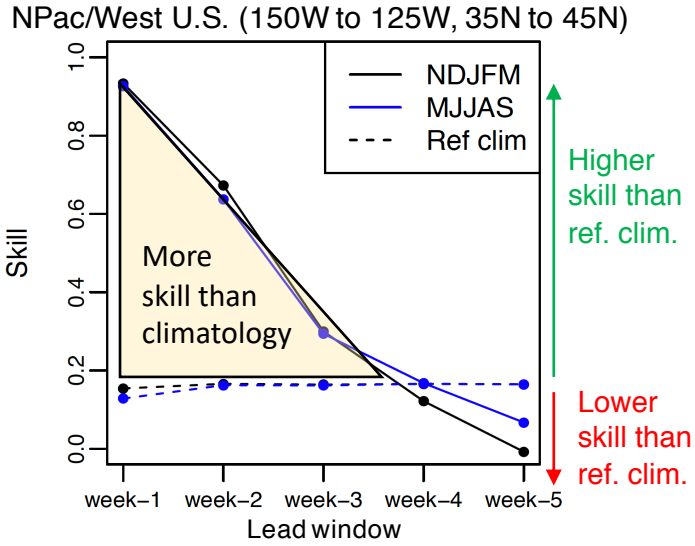
Global climatology of wintertime AR1wk, 1996-2015





- AR1wk is largest in midlatitude storm track regions

Does ECMWF AR1wk skill exceed climatological skill? Is AR1wk skill modulated by large-scale climate mode activity?



- (left) ECMWF AR1wk occurrence forecast skill outperforms a reference forecast based on monthly climatology of AR1wk occurrence at week-3 (14d-20d) lead over the North

Experimental S2S AR forecasting for winter 2017-18 and 2018-19

Duane Waliser
Mike DeFlorio
Alex Goodman

Bin Guan

Marty Ralph
Aneesh Subramanian
and others

Frédéric Vitart

Jay Cordeira

Jeanine Jones
Mike Anderson

Review of winter 2017-2018 activities and winter 2018-2019 goals

Winter 2017-2018: what we did

- Create an automated pipeline to:
  - detect atmospheric rivers from ECMWF, ECCC, and NCEP forecast systems
    - Twice-a-week for ECMWF
    - Weekly or bi-monthly for ECCC, NCEP
  - calculate forecast skill of "number of AR days per week" for week-1, week-2, and week-3 lead windows and compare to hindcast skill benchmarks [DeFlorio et al. 2018b; DeFlorio et al. 2018c (in prep)]
- Disseminate experimental forecasts and solicit feedback during S2S telecons and JPL-DWR meetings
- Develop verification statistics using MERRA2 reanalysis data for winter 2017-2018 outlooks (nearly completed) and for winter 2018-2019 outlooks (next spring/summer)

Winter 2018-2019: what we're doing

- Produce near real-time week-3 AR1wk occurrence forecasts for ECMWF, ECCC, and NCEP forecast systems, stratified by mean AR intensity (>250 kg/ms, >500 kg/ms)
- Display week-3 outlooks on protected CW3E website
- Engage in NCEP CPC week-3/week-4 Friday discussions (POC: Jon Gottschalck, NCEP/NOAA)
- Working to add NASA GMAO experimental forecasts to this effort (POC: Deepthi Achuthavarier, NASA Goddard)

Experimental ECMWF Atmospheric River Forecast*

Issued on Thursday, October 18, 2018

Contents:

Slides 1 and 2: "Weather" - Typical presentation of US west coast weather/precipitation forecast over lead times of 1 to 14 days considering only the likelihood of an atmospheric river (AR) occurring on a given forecast day. *Novelty – a weather forecast presented only in terms of AR likelihood.*

Slide 3: "Subseasonal" - US west coast weather/precipitation forecast for week 3 considering the likelihood of an atmospheric river occurring in the given forecast week.
Novelty – as above, but also specifically for week 3, an extended/long-range or "subseasonal" prediction

**This is an experimental activity for the 2017-18 and 2018-19 winters. Methodologies and hindcast skill are documented in DeFlorio et al. (2018a,b). Further validation of the real-time forecast results is required and underway. This phase of the research includes gathering stakeholder input on the presentation of information – feedback is welcome.*

POC: Michael J. DeFlorio (michael.deflorio@jpl.nasa.gov)

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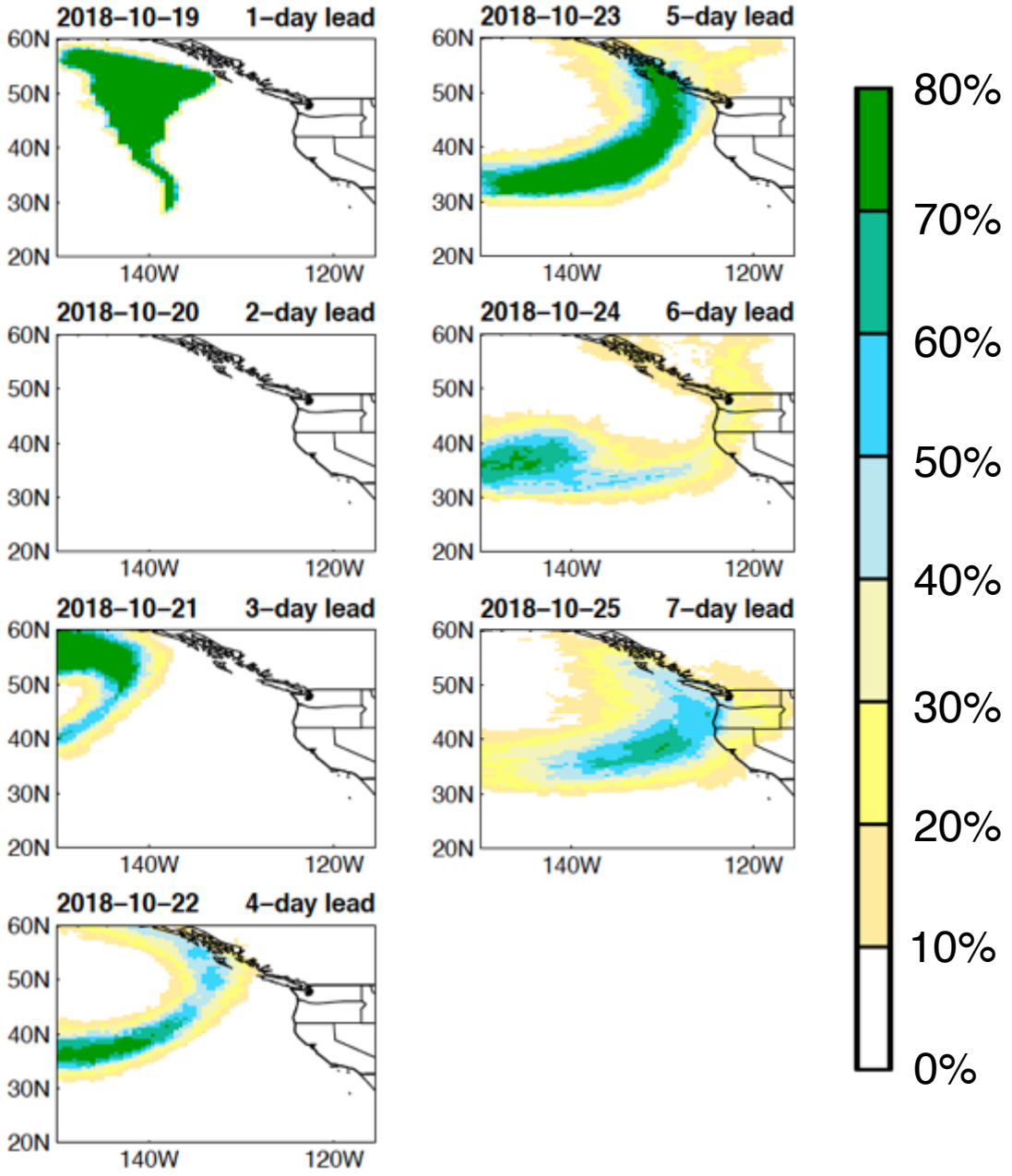
EXPERIMENTAL AR FORECAST

October 18, 2018 forecast: probability of AR occurrence during week-1



Week-1

(1-day to 7-day lead)

Experimental AR forecast issued on Thursday, October 18, 2018 by M. DeFlorio, D. Waliser, A. Goodman, B. Guan, A. Subramanian, Z. Zhang, and M. Ralph using 51-member real-time ECMWF data for an Experimental AR Forecasting Research Activity sponsored by California DWR

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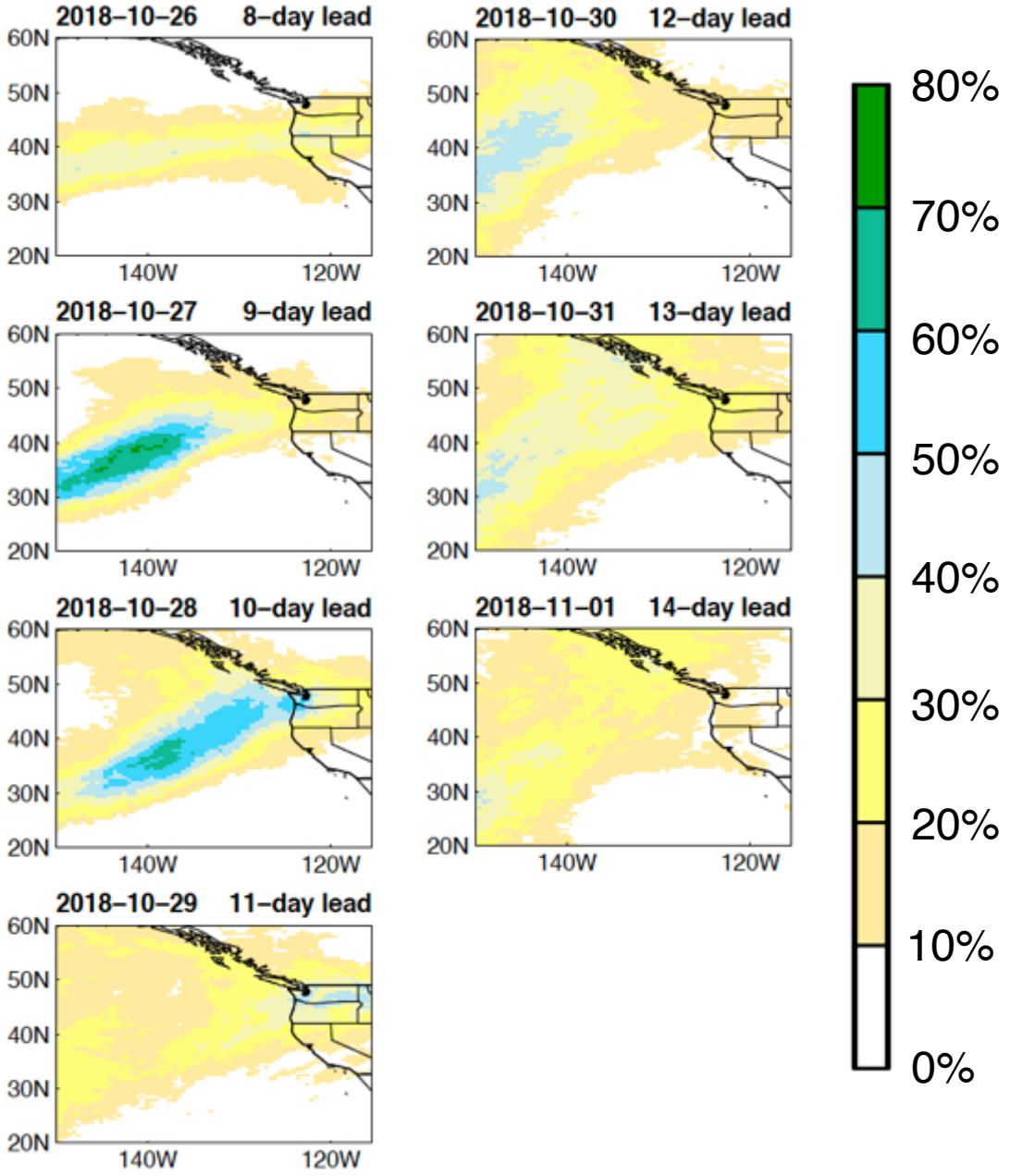
EXPERIMENTAL AR FORECAST

October 18, 2018 forecast: probability of AR occurrence during week-2



Week-2

(8-day to 14-day lead)

Experimental AR forecast issued on Thursday, October 18, 2018 by M. DeFlorio, D. Waliser, A. Goodman, B. Guan, A. Subramanian, Z. Zhang, and M. Ralph using 51-member real-time ECMWF data for an Experimental AR Forecasting Research Activity sponsored by California DWR

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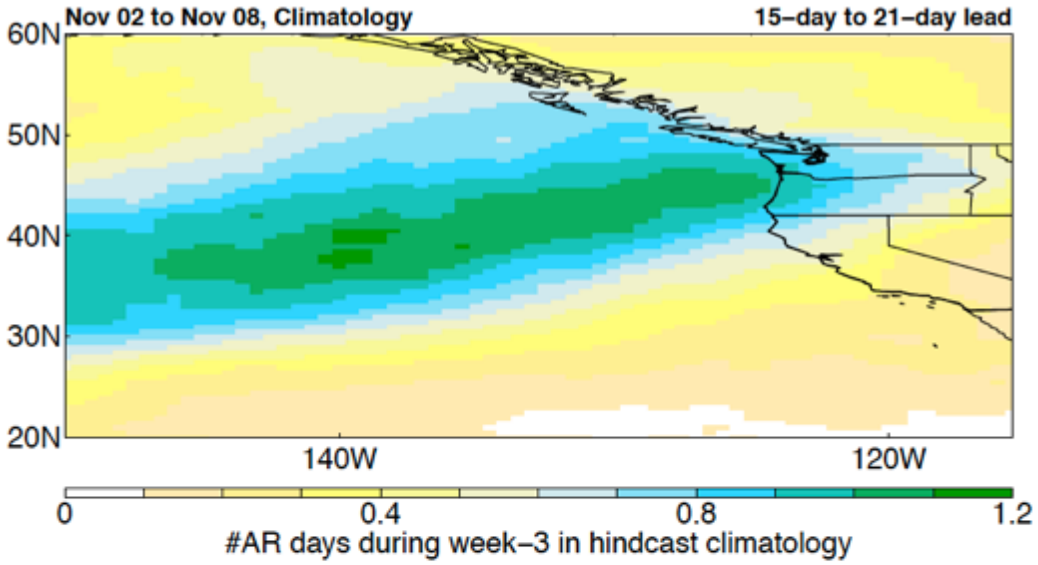
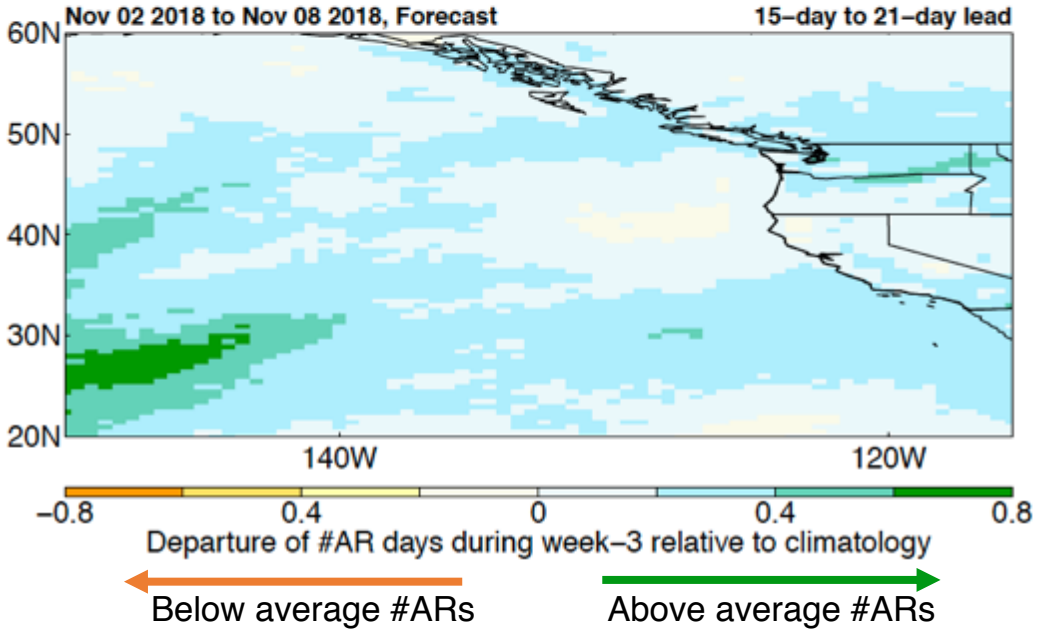
EXPERIMENTAL AR FORECAST

October 18, 2018 forecast: number of AR days during week-3





ECMWF

Week-3

(Combined 15-day to 21-day lead)

Top row: hindcast climatology (ECMWF 1996-2015 data)
Bottom row: real-time forecast minus climatology (ECMWF 51-member ensemble)

Experimental AR forecast issued on Thursday, October 18, 2018 by M. DeFlorio, D. Waliser, A. Goodman, B. Guan, A. Subramanian, Z. Zhang, and M. Ralph using 51-member real-time ECMWF data for an Experimental AR Forecasting Research Activity sponsored by California DWR

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Multi-model Experimental S2S Atmospheric River Forecast*

Issued on Thursday, October 18, 2018

Contents:

Definition of "Subseasonal" - US west coast weather/precipitation forecast for week 3 considering the number of atmospheric river days predicted to occur in the given forecast week.
Novelty – an S2S forecast presented only in terms of AR likelihood - specifically for week 3, an extended/long-range or "subseasonal" prediction

Slide 1: ECMWF (European Centre for Medium-Range Weather Forecasts) forecast system
Slide 2: NCEP (National Centers for Environmental Systems) forecast system
Slide 3: ECCC (Environment and Climate Change Canada) forecast system

**This is an experimental activity for the 2017-18 and 2018-19 winters. Methodologies and hindcast skill are documented in DeFlorio et al. (2018a,b). Further validation of the real-time forecast results is required and underway. This phase of the research includes gathering stakeholder input on the presentation of information – feedback is welcome.*

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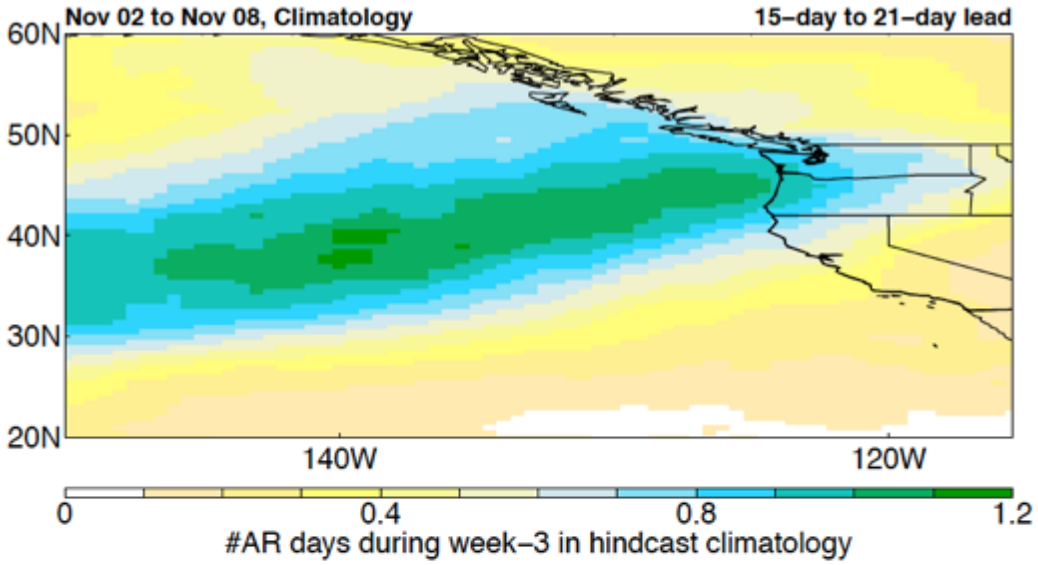
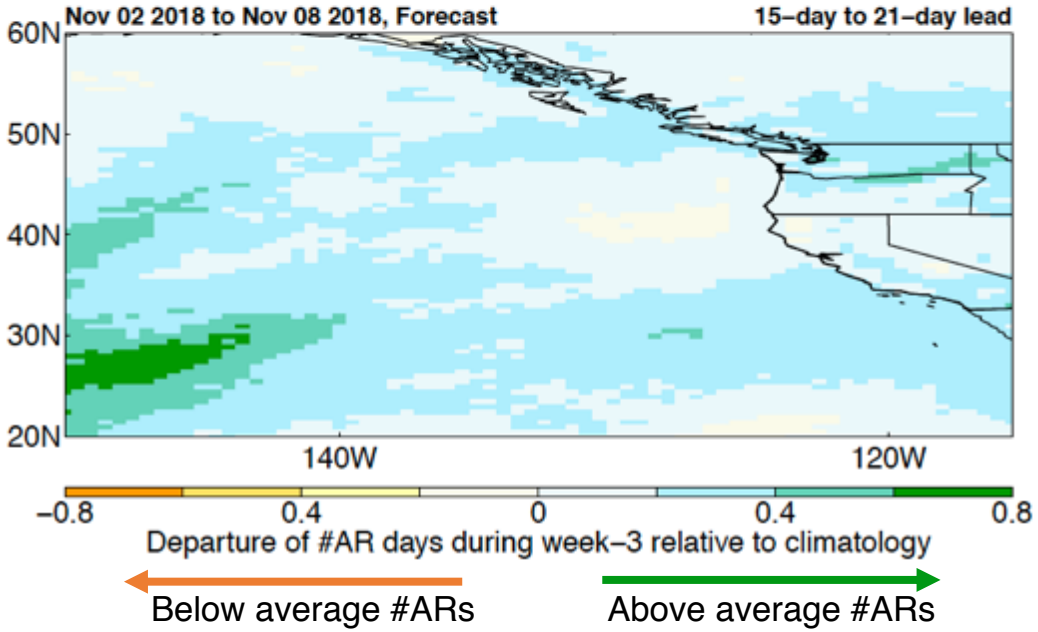
EXPERIMENTAL AR FORECAST

October 18, 2018 forecast: number of AR days during week-3





ECMWF

Week-3

(Combined 15-day to 21-day lead)

Top row: hindcast climatology (ECMWF 1996-2015 data)
Bottom row: real-time forecast minus climatology (ECMWF 51-member ensemble)

Experimental AR forecast issued on Thursday, October 18, 2018 by M. DeFlorio, D. Waliser, A. Goodman, B. Guan, A. Subramanian, Z. Zhang, and M. Ralph using 51-member real-time ECMWF data for an Experimental AR Forecasting Research Activity sponsored by California DWR

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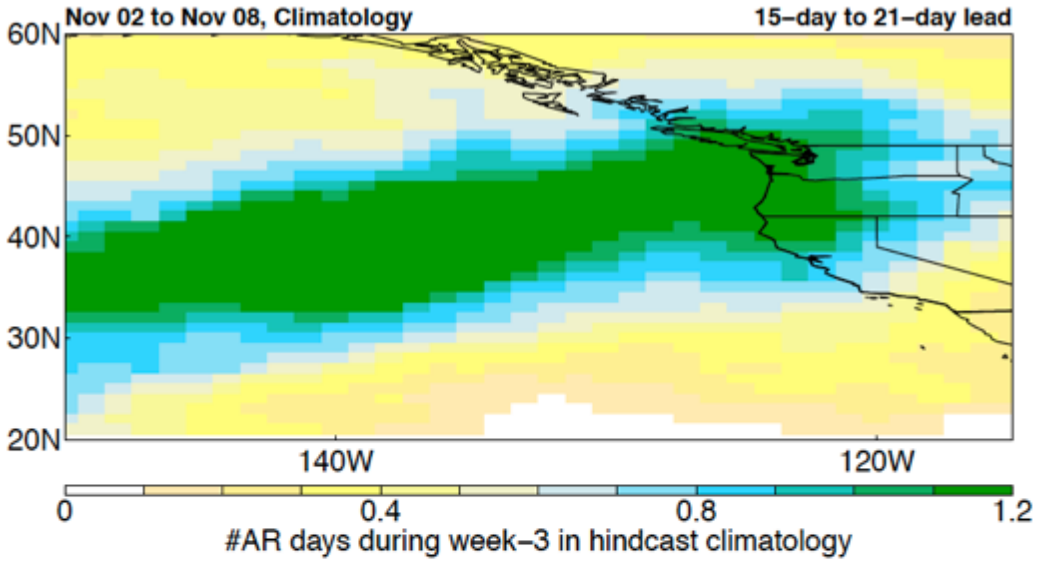
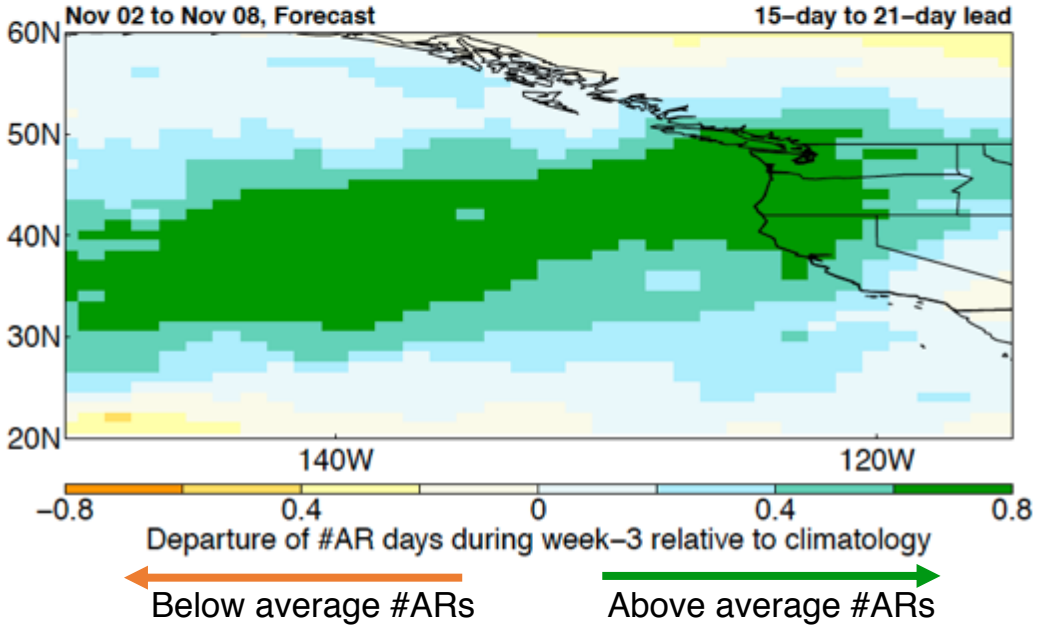
EXPERIMENTAL S2S AR FORECAST

October 18, 2018 forecast: number of AR days during week-3





NCEP

Week-3

(Combined 15-day to 21-day lead)

Top row: hindcast climatology (NCEP 1999-2010 data)
Bottom row: real-time forecast (NCEP 16-member ensemble)

Experimental AR forecast issued on Thursday, October 18, 2018 by M. DeFlorio, D. Waliser, A. Goodman, B. Guan, A. Subramanian, Z. Zhang, and F. M. Ralph using 16-member real-time NCEP data for an Experimental AR Forecasting Research Activity sponsored by California DWR

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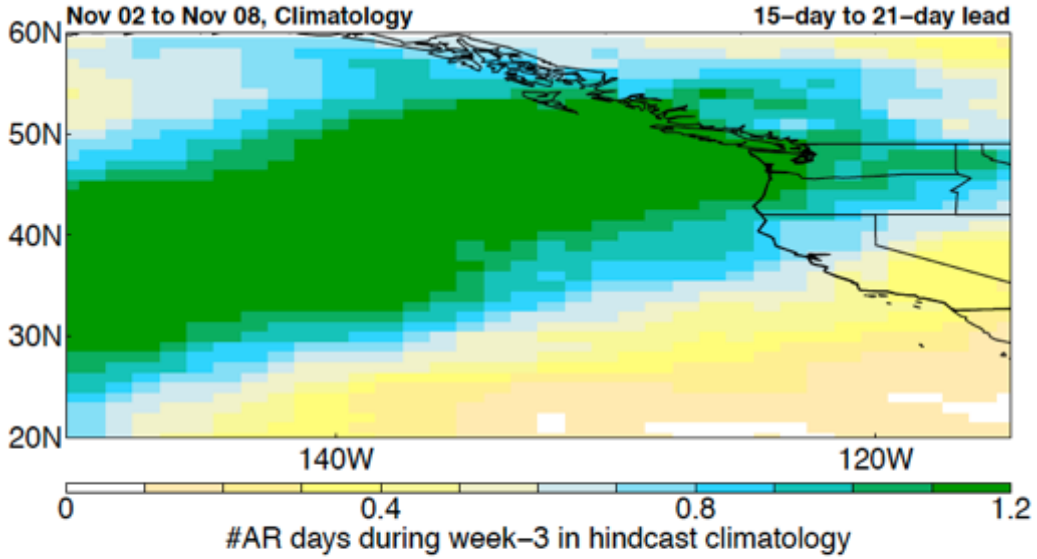
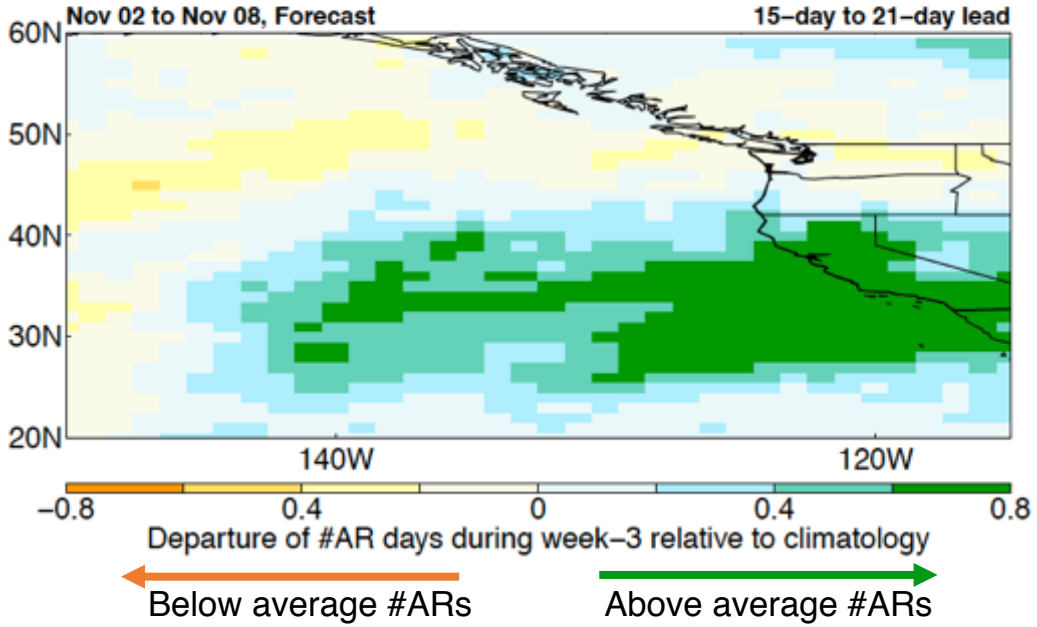
EXPERIMENTAL S2S AR FORECAST

October 18, 2018 forecast: number of AR days during week-3





ECCC

Week-3

(Combined 15-day to 21-day lead)

Top row: hindcast climatology (ECCC 1995-2014 data)
Bottom row: real-time forecast (ECCC 21-member ensemble)

Experimental AR forecast issued on Thursday, October 18, 2018 by M. DeFlorio, D. Waliser, A. Goodman, B. Guan, A. Subramanian, Z. Zhang, and F. M. Ralph using 21-member real-time ECCC data for an Experimental AR Forecasting Research Activity sponsored by California DWR

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Ongoing verification efforts for winter 2017-2018 atmospheric river occurrence experimental forecasts

Strategy: verify week-3 AR occurrence experimental forecasts categorically

- forecast metric: “number of AR days per week” (AR1wk)
- define categories of AR occurrence (subject to change):
  - ”0 days” - no AR activity
  - ”1 day” - low AR activity
  - “2 days” - moderate AR activity
  - ”3-7 days” - high AR activity
- calculate average Brier Skill Score (BSS) over forecast period for each category

Brier Skill Score (BSS) overview

- Brier Skill Score (BSS) verifies accuracy of probabilistic forecasts of a binary event that can be grouped into categories
  - in our case, whether there were a given number (0, 1, 2, 3-7) of AR days in a given week
- $BSS = 1 - (BS/BS_{ref})$

where BS = Brier score for forecast $= \frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)^2$

BS_{ref} = Brier score for reference climatology $= \frac{1}{N}\sum_{i=1}^{N}(P_{i,clim} - O_i)^2$

N = number of forecasts

P = forecast probability

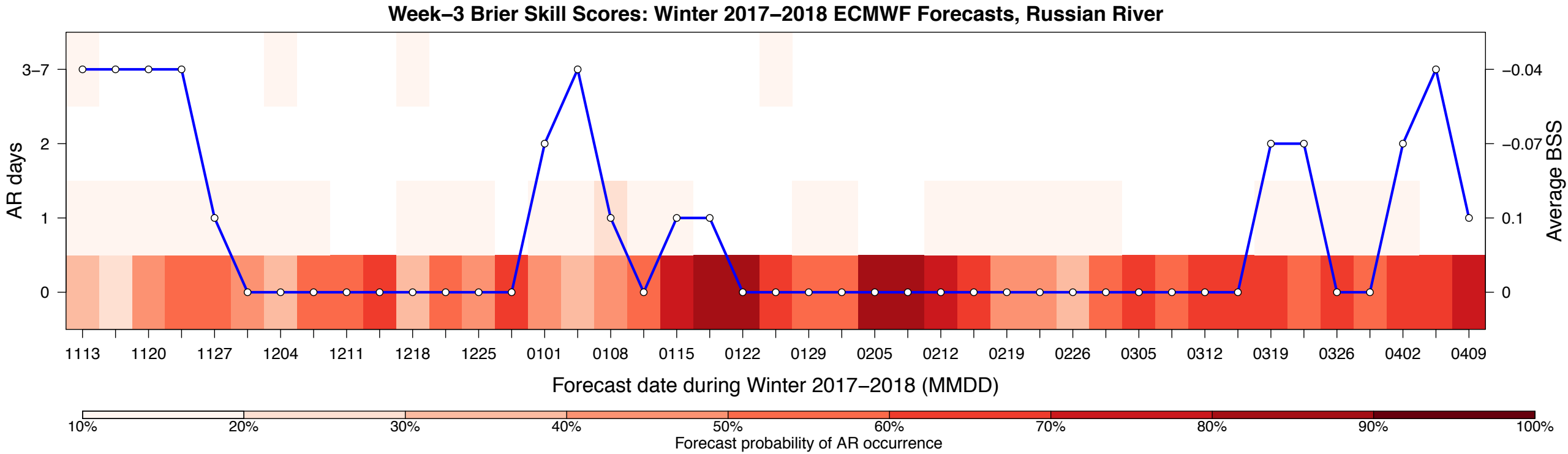
O = observations (AR = 1, no AR = 0)

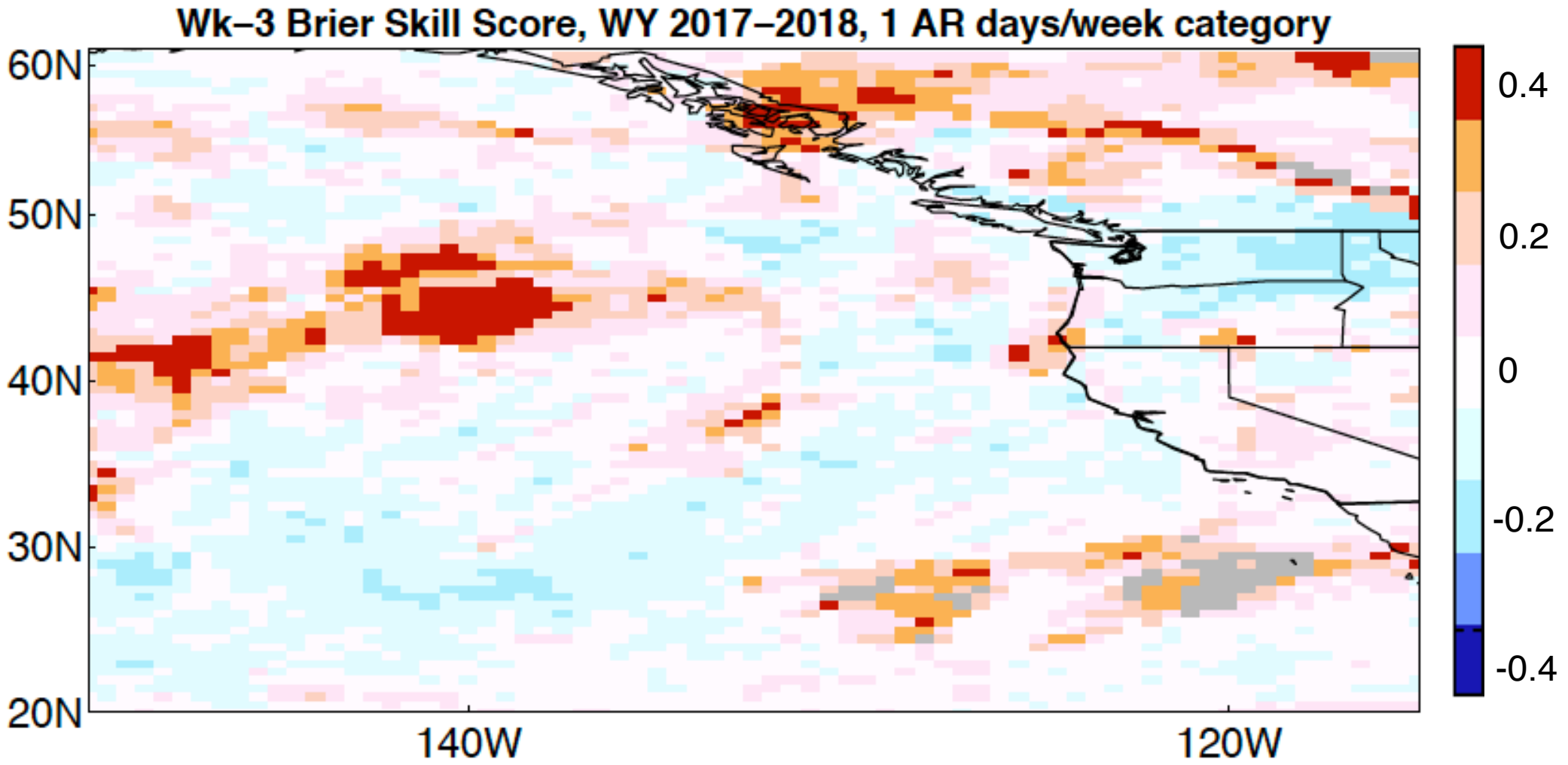
P_{clim} = reference climatology ("long term" observations)

- Compute BSS for each AR day category

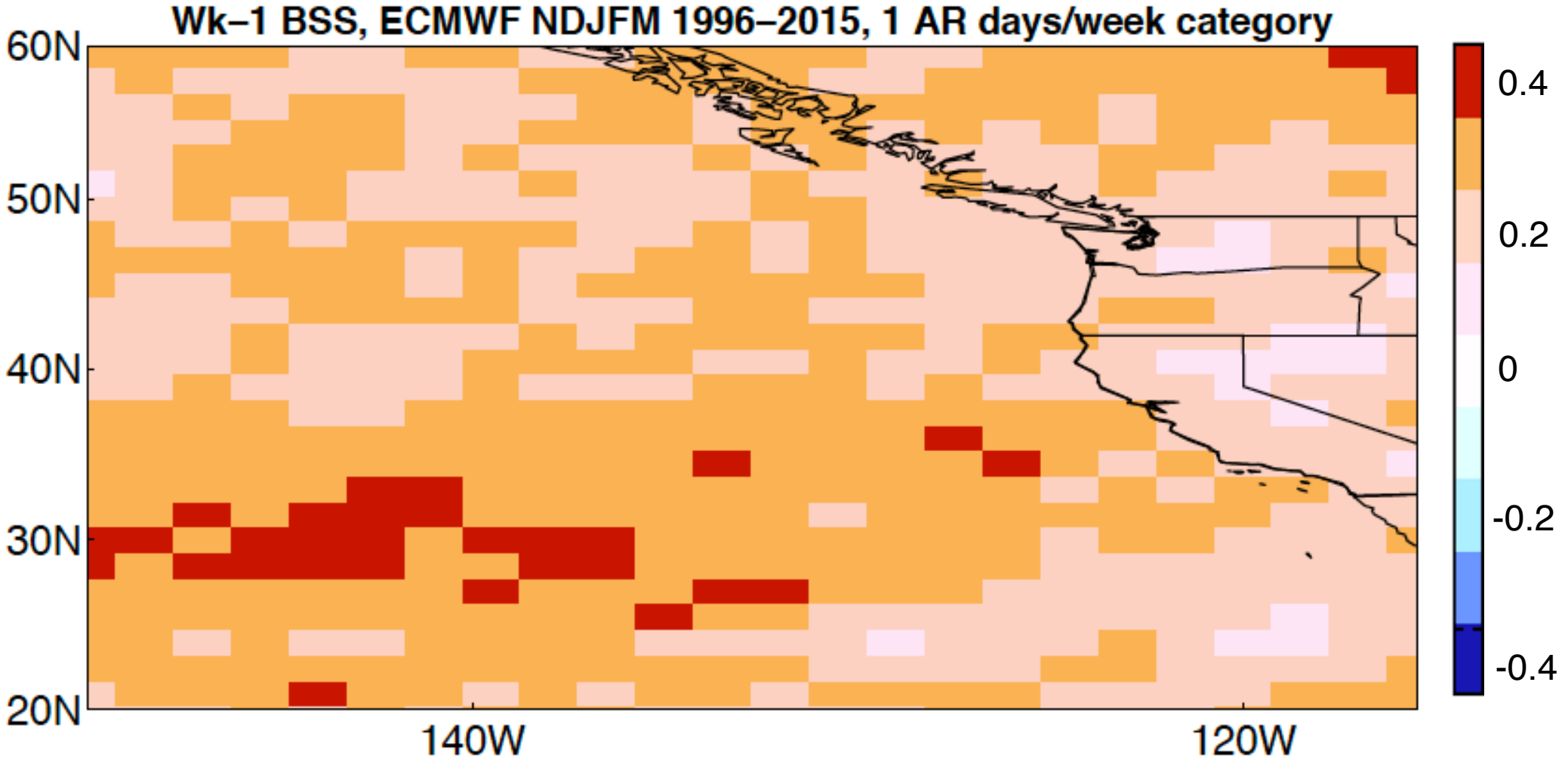
<u>Interpretation</u>

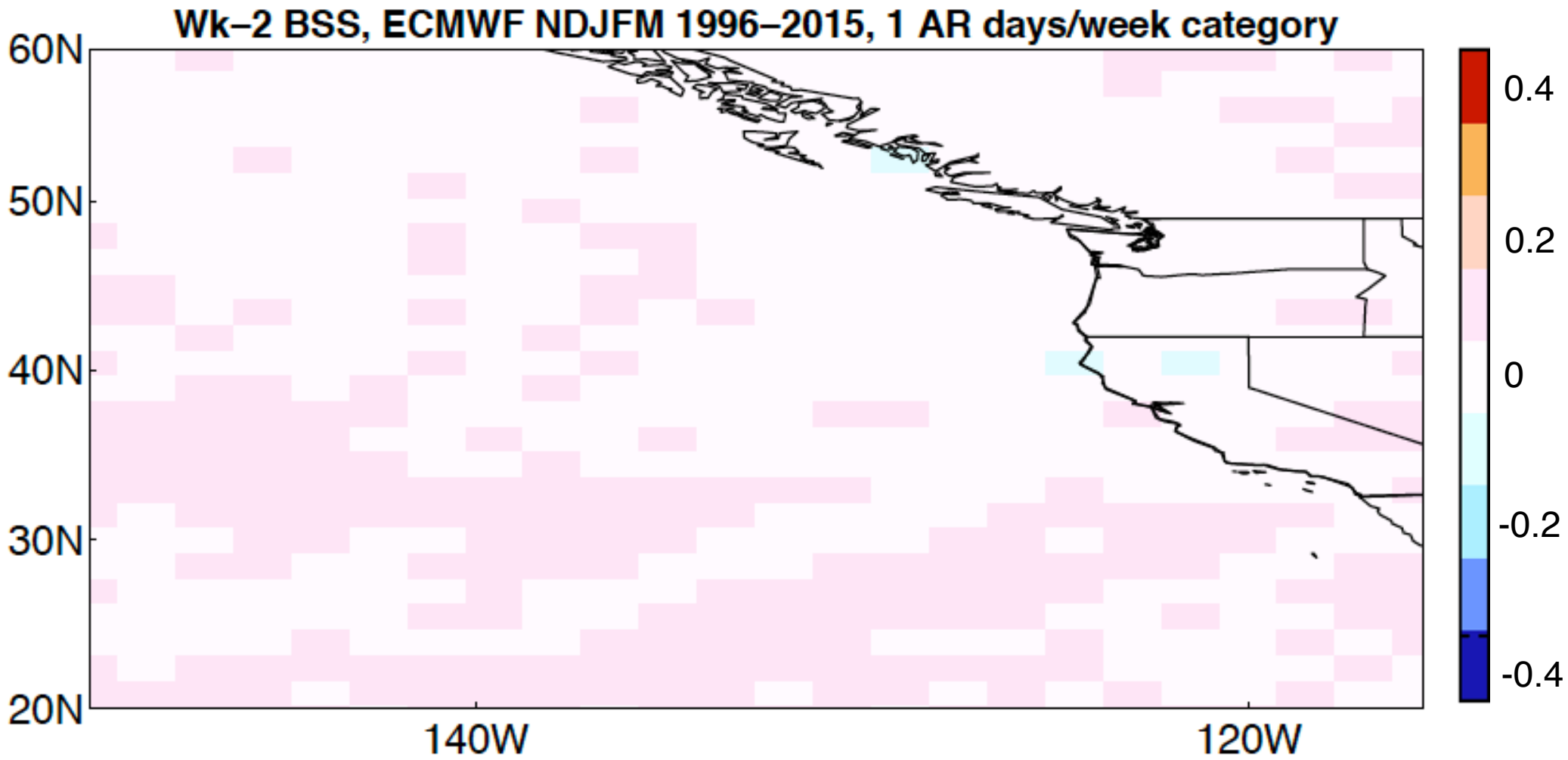
- BSS < 0 → forecast skill is lower than a forecast made using climatology
- BSS = 0 → forecast skill is equal to a forecast made using climatology (i.e. no skill)
- BSS = 1 → forecast skill is perfect compared to a forecast made using climatology


Week–3 Brier Skill Scores: Winter 2017–2018 ECMWF Forecasts, Russian River
AR days
3–7
2
1
0
Average BSS
−0.04
−0.07
0.1
0
1113
1120
1127
1204
1211
1218
1225
0101
0108
0115
0122
0129
0205
0212
0219
0226
0305
0312
0319
0326
0402
0409
Forecast date during Winter 2017–2018 (MMDD)
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Forecast probability of AR occurrence

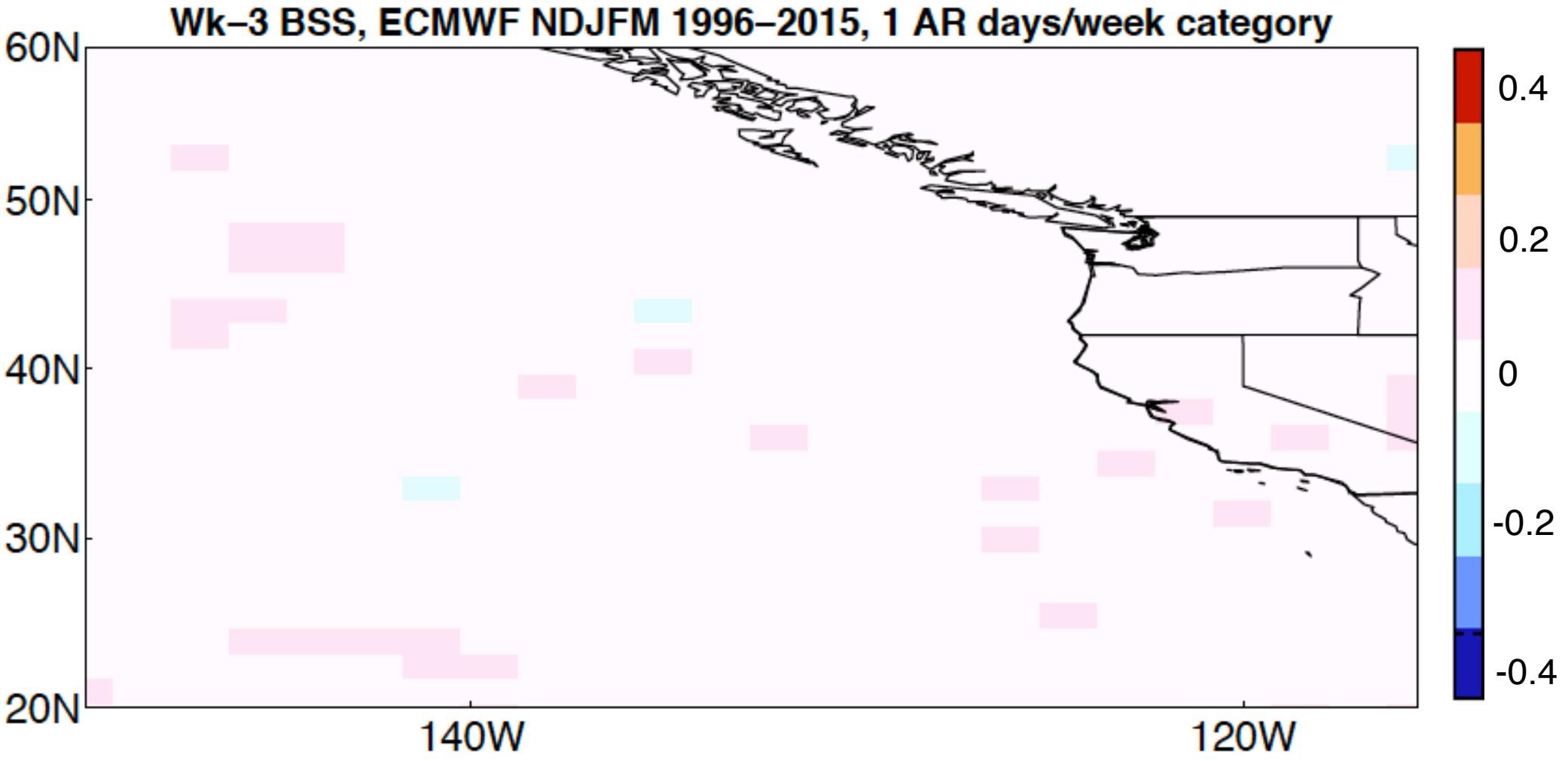

Wk–3 Brier Skill Score, WY 2017–2018, 1 AR days/week category
60N
50N
40N
30N
20N
140W
120W
0.4
0.2
0
-0.2
-0.4

Comparison to categorical hindcast skill benchmarks for the 1 AR day/week category

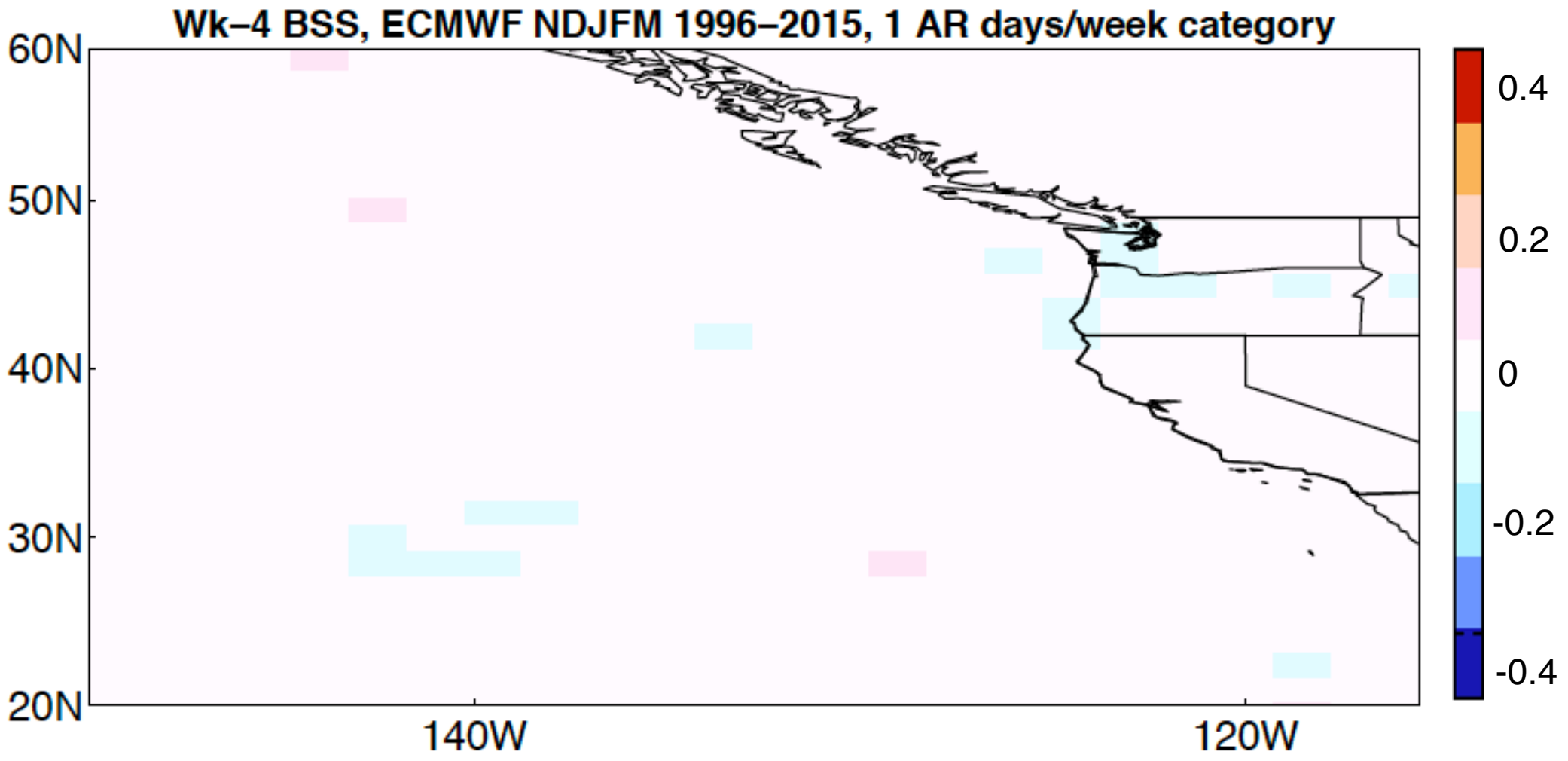

Wk–1 BSS, ECMWF NDJFM 1996–2015, 1 AR days/week category
60N
50N
40N
30N
20N
140W
120W
0.4
0.2
0
-0.2
-0.4


Wk–2 BSS, ECMWF NDJFM 1996–2015, 1 AR days/week category
60N
50N
40N
30N
20N
140W
120W
0.4
0.2
0
-0.2
-0.4

Slightly positive skill in some places, but mostly zero skill almost everywhere by week-3



Zero to negative skill almost everywhere by week-4



Summary: subseasonal-to-seasonal (S2S) forecasting of atmospheric rivers

- Atmospheric rivers occur globally and influence weather and water extremes.
- Total amount of annual precipitation over the western U.S. is strongly influenced by occurrence or absence of atmospheric rivers.
- Subseasonal-to-seasonal (S2S) forecasting lead times for atmospheric rivers represent a critical decision-making time window for water resource managers.
- Real-time experimental AR occurrence forecasting effort (and verification) using ECMWF, NCEP, and ECCC data is ongoing (collaboration between JPL, UCSD-Scripps CW3E, and DWR).