Experimental S2S Forecasting of Atmospheric Rivers Over the Western United States

Duane Waliser[1], **Mike DeFlorio[2]**, F. Martin Ralph[2], Bin Guan[1,3], Aneesh Subramanian[4], Alexander Goodman[1], Shakeel Asharaf[1], Peter G. Gibson[1], Luca Delle Monache[2], Zhenhai Zhang[2], Frédéric Vitart[5], Alexander Gershunov[2], Kristen Guirguis[2], Hai Lin[6], Arun Kumar[7]

ECMWF S2S Workshop; Reading, U.K.; 4 April 2019

[1]NASA Jet Propulsion Laboratory/California Institute of Technology; Pasadena, CA
[2]Center for Western Weather, Water and Extremes, University of California, San Diego, Scripps Institution of Oceanography; La Jolla, CA
[3]Joint Institute for Regional Earth System Science and Engineering, University of California, Los Angeles; Los Angeles, CA
[4]University of Colorado, Boulder; Boulder, CO
[5]European Centre for Medium Range Weather Forecasts; Reading, UK
[6]Environment and Climate Change Canada; Montreal, Canada
[7]Climate Prediction Center, NCEP/NWS/NOAA, College Park, Maryland

Contains key figures/concepts from:

1. DeFlorio et al. 2018, **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. 2019a, **Global evaluation of atmospheric river subseasonal prediction skill**, Clim. Dyn., doi:10.1007/s00382-018-4309-x.
3. DeFlorio et al. 2019b, **Multi-model hindcast skill assessment of atmospheric river prediction skill over the Western U.S.**, 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.

Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

A multi-institutional research effort sponsored by California DWR

Jet Propulsion Laboratory
California Institute of Technology

Overview of S2S AR Team

S2S AR Prediction Team

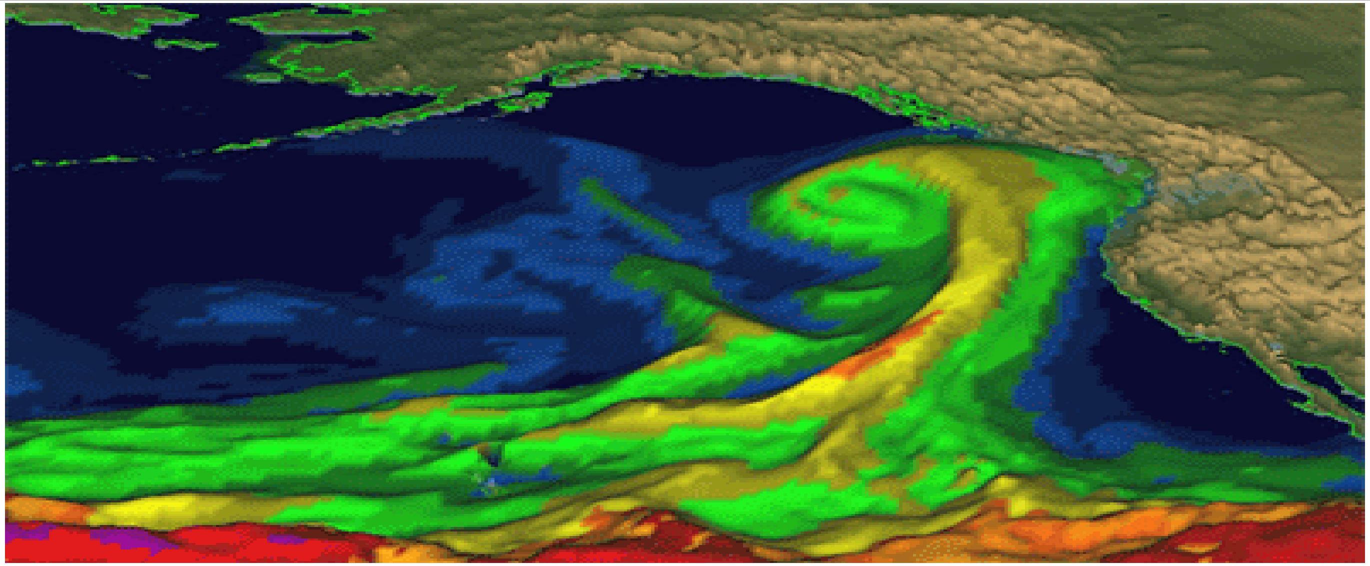
Duane Waliser[1], F. Martin Ralph[2] (co-PIs)

Mike DeFlorio*[2], Aneesh Subramanian*[3], William Chapman[2], Jason Cordeira[4], Luca Delle Monache[2], Alexander Gershunov[2], Peter Gibson[1], Alexander Goodman[1], Bin Guan[1], Kristen Guirguis[2], Brian Kawzenuk[2], Arun Kumar[5], Hai Lin[6], Tamara Shulgina[2], Rui Sun[2], Frederic Vitart[7], Anna Wilson[2], Zhenhai Zhang[2]

*denotes co-lead researcher

Affiliations: [1]NASA JPL/CalTech; [2]CW3E, SIO-UCSD; [3]University of Colorado Boulder; [4]Plymouth State University; [5]NCEP; [6]ECCC; [7]ECMWF

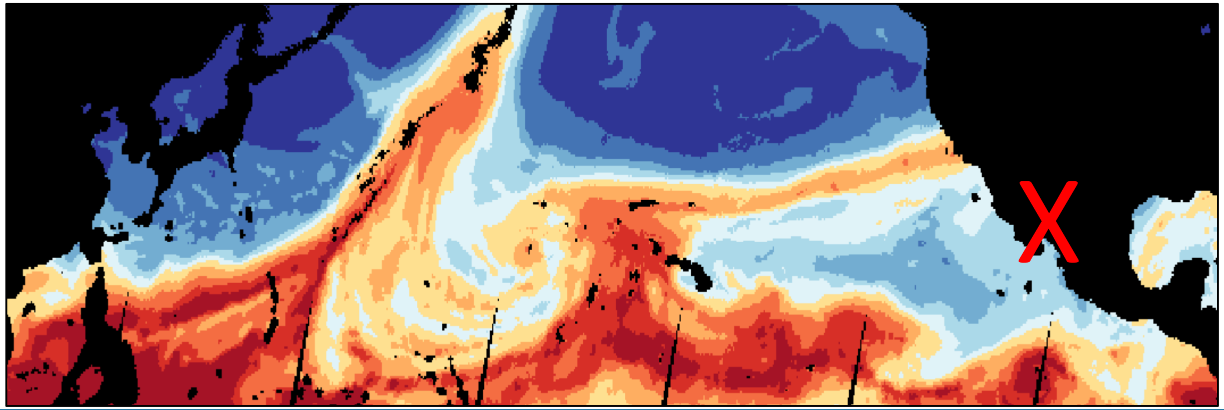
Atmospheric rivers and their associated flood and hazard risks occur globally and influence climate and water extremes.



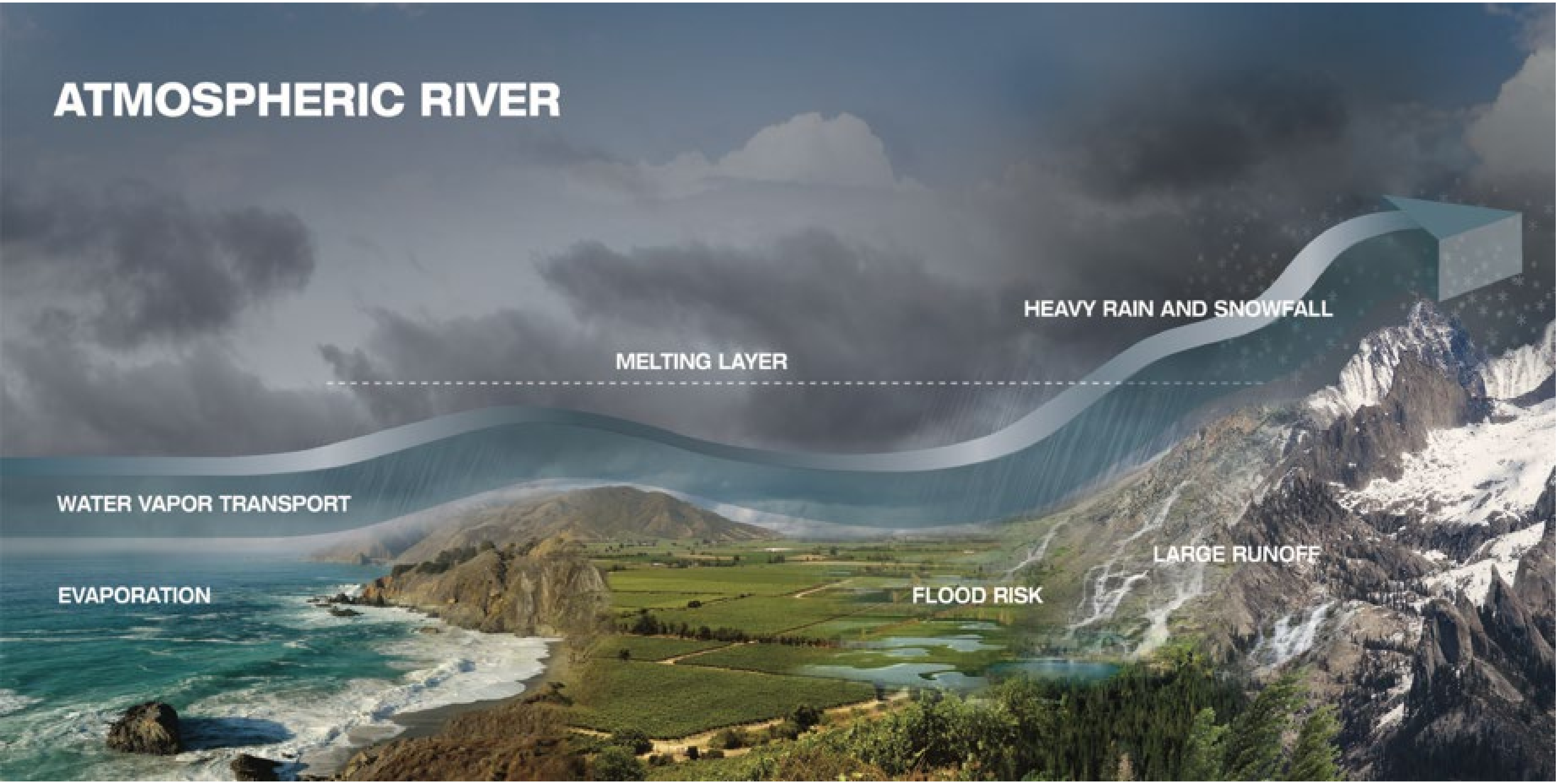
NOAA ESRL

Over 90% of poleward moisture transport at midlatitudes is by ARs that take up only ~10% of the zonal circumference.

In the west, ARs account for ~40% of annual precipitation and most floods.



Zhu and Newell 1998
Ralph et al. 2004



Source: NASA JPL

Atmospheric rivers:

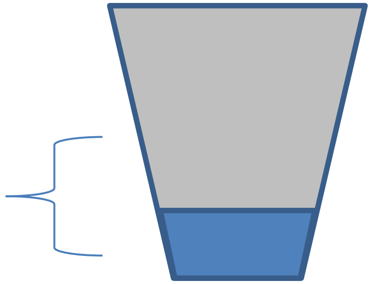
- can carry as much as water as 25 Mississippi Rivers, and can provide up to 50% of West Coast precipitation
- are about 500 miles wide (Ralph et al. 2017, Guan et al. 2018) and are located above the lowest mile of the atmosphere
- sometimes tap tropical moisture near Hawaii, transporting concentrated water vapor for thousands of miles

Why are our water challenges so unique in California?

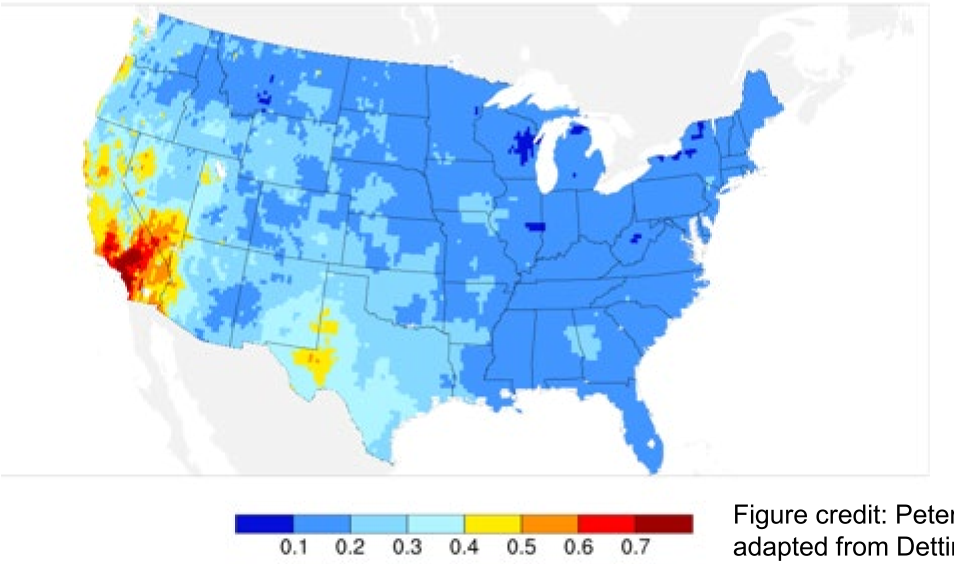
Precipitation is uniquely variable year-to-year in the western U.S.

Ratio of Year-to-Year Variation in Precipitation over Average Precipitation

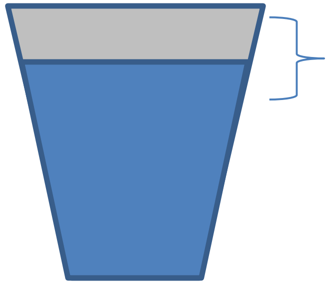
Annual precipitation "bucket" for southern California



Year-to-year variations ~70%



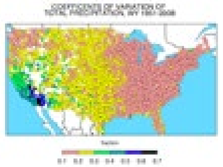
Annual precipitation "bucket" for eastern half of US



Year-to-year variations ~20%

Figure credit: Peter Gibson (NASA JPL/CalTech), adapted from Dettinger et al. 2011

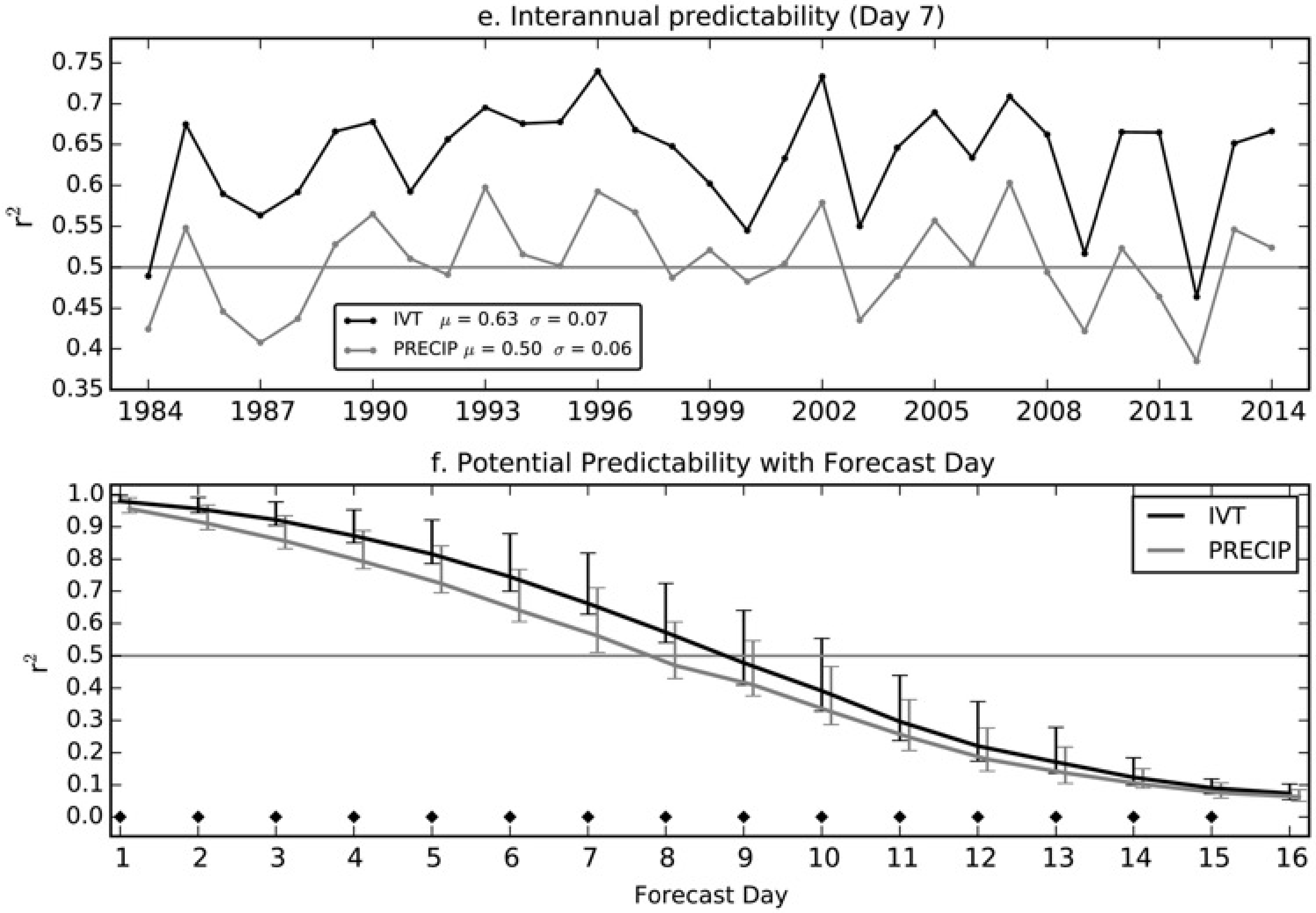
Caption: Map shows the ratio of the year-to-year variability in precipitation divided by the long-term mean precipitation (based on TRMM, 1998-2016). Thus, the eastern half of the country vary rarely experiences a significant variation from their typical precipitation totals (~1-1.5 m), about +/- 20% of the mean. Uniquely, in southern California, the year-to-year variations are nearly as big as the total annual precipitation (~0.2-0.3 m), i.e. +/- 70% of the mean.



Calculation using Tropical Rainfall Measuring Mission (TRMM) data, as originally performed by Dettinger et al. 2011 with station data

Relative to the rest of the U.S., southern California experiences the largest year to year swings in annual precipitation totals relative to its average values.

Potential Predictability of IVT vs. Precipitation



- 31 years of NCEP GEFS hindcast data (1984-2015) during DJF
- 30N-50N, 125-120W
- Potential predictability method treats each ensemble member as a surrogate observed realization (Waliser et al. 2003)
- Potential predictability of IVT exceeds that of precipitation at lead times of 1-15 days

Lavers, Waliser, Ralph and Dettinger, 2016 (GRL)

Key Research Question

Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

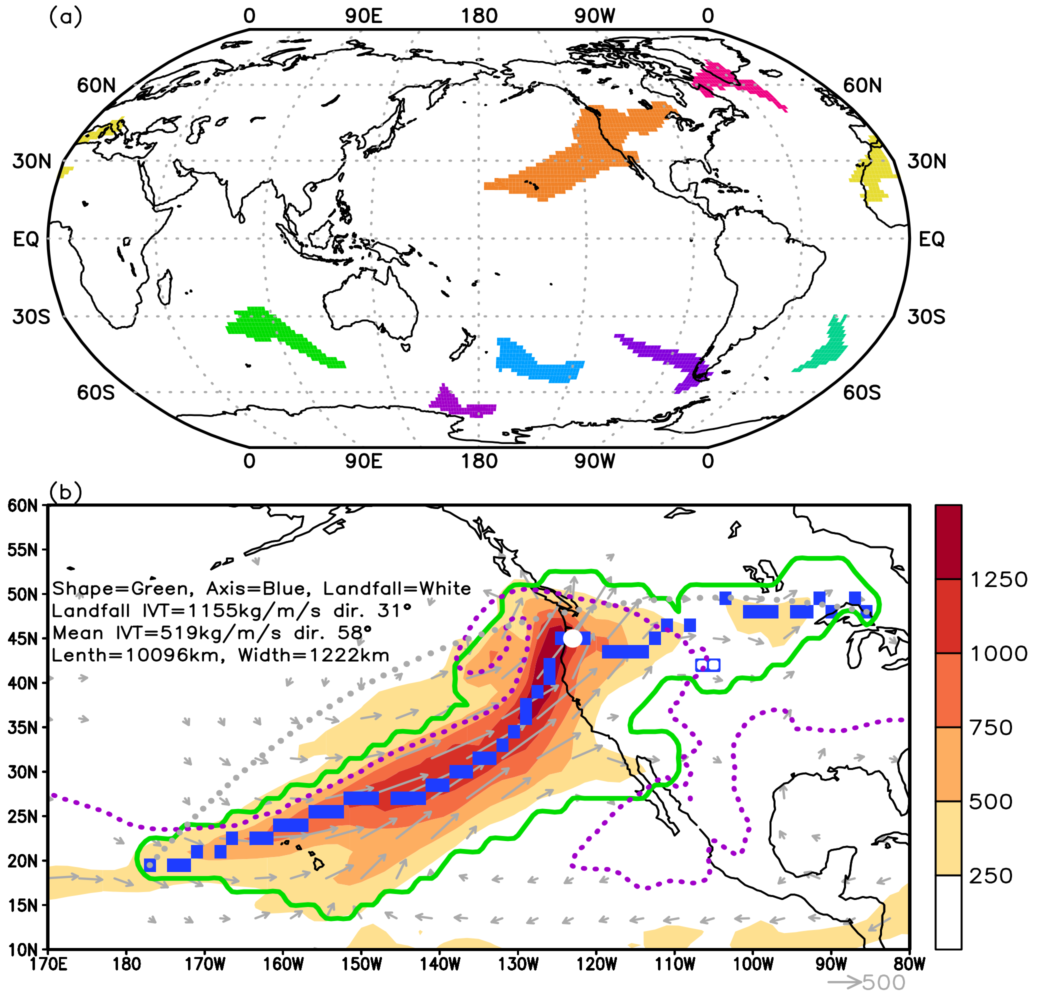
What is the limit of global subseasonal-to-seasonal (S2S) (here, 1-week to 1-month) prediction skill of atmospheric river occurrence, and how does it vary as a function of season, region, and certain large-scale climate conditions?

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

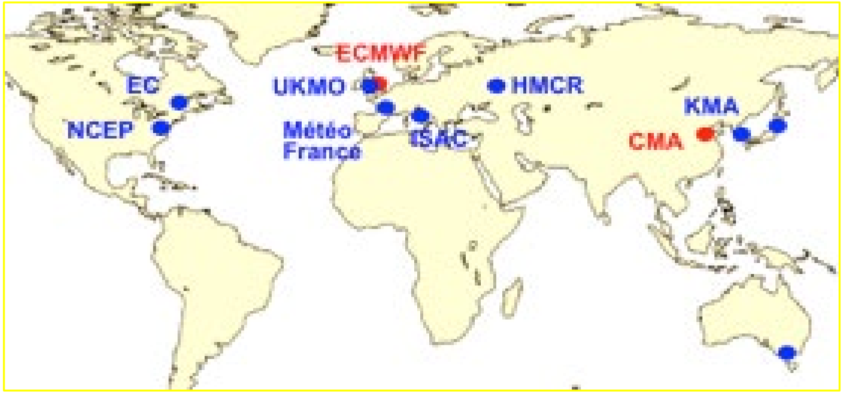
(Guan and Waliser 2015)



- AR detection involves thresholding 6-hourly fields of ERA-I IVT based on the 85th percentile specific to each season and grid cell and a fixed lower limit of 100 kg/ms and checking for the geometry requirements of length >2000 km, length/width ratio >2, and other considerations indicative of AR conditions
- Applied to global hindcast/forecast systems and reanalysis datasets (code and databases available at: https://ucla.box.com/ARcatalog)
- Parameter space AR Date, $IVT_{x,y}$, Axis, Landfall Location, etc.
- Used for GCM evaluation (Guan and Waliser 2017), comparison to dropsonde data (Ralph et al. 2017, Guan et al. 2018), climate change projections (Espinoza et al. 2018), extratropical and polar vapor transport (Nash et al. 2018), & hindcast/forecast skill assessment (DeFlorio et al. 2018, 2019a; and DeFlorio et al. 2019b [in prep])

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"



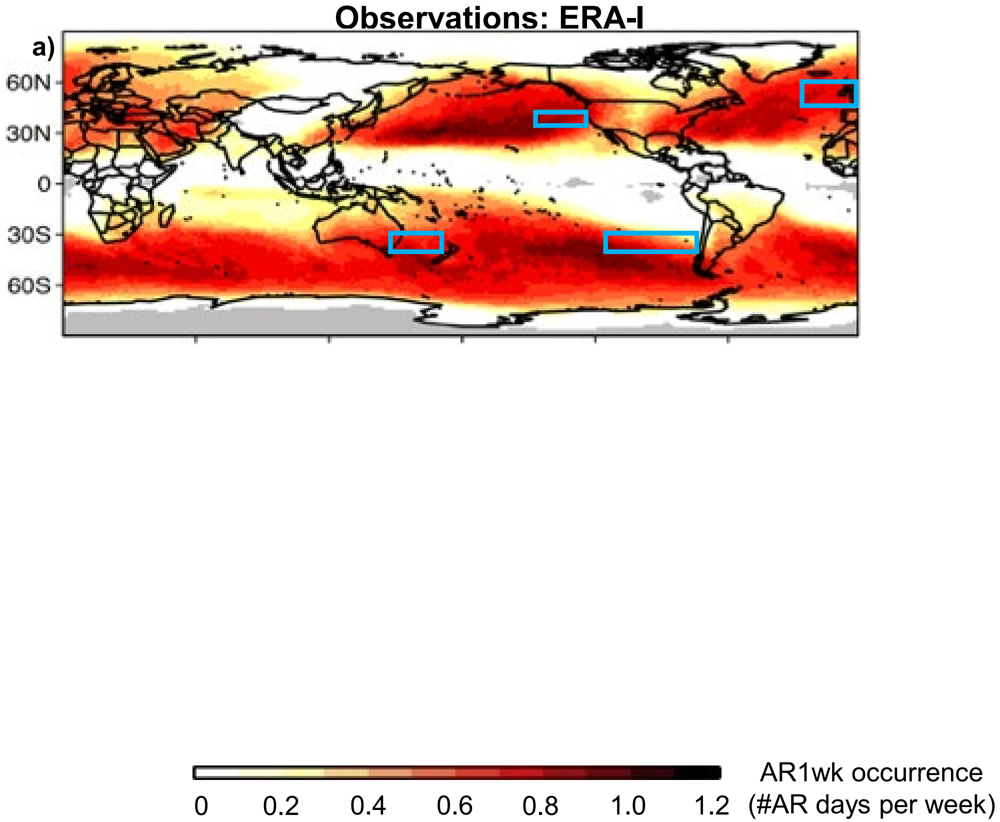
	Time-range	Resol.	Ens. Size	Freq.	Hcsts	Hcst length	Hcst Freq	Hcst Size
ECMWF	D 0-46	T639/319L91	51	2/week	On the fly	Past 20y	2/weekly	11
UKMO	D 0-60	N216L85	4	daily	On the fly	1996-2009	4/month	3
NCEP	D 0-44	N126L64	4	4/daily	Fix	1999-2010	4/daily	1
EC	D 0-32	0.6x0.6L40	21	weekly	On the fly	1995-2014	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

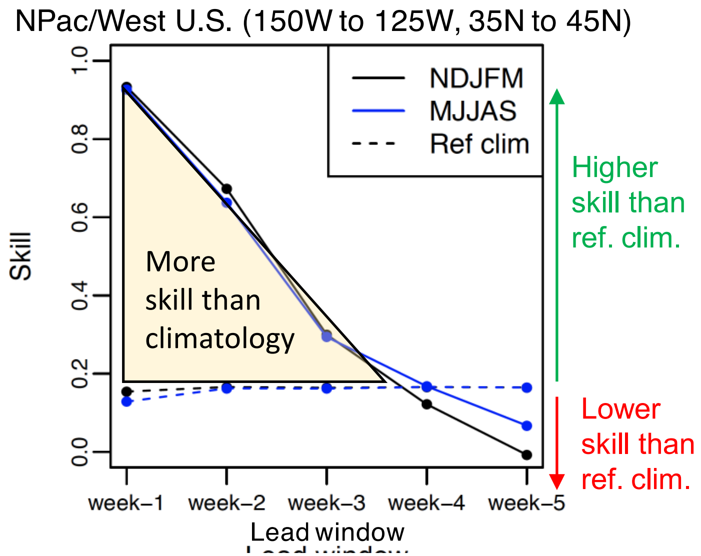
Michael J. DeFlorio[1], Duane E. Waliser[2,3], Bin Guan[2,3], F. Martin Ralph[1], and Frederic Vitart[4]; (*Climate Dynamics* 2019)
[1]UCSD/SIO/CW3E, [2]NASA JPL/CalTech, [3]UCLA, ECMWF[4]

Global climatology of wintertime AR1wk, 1996-2015



- AR1wk is largest in midlatitude storm track regions

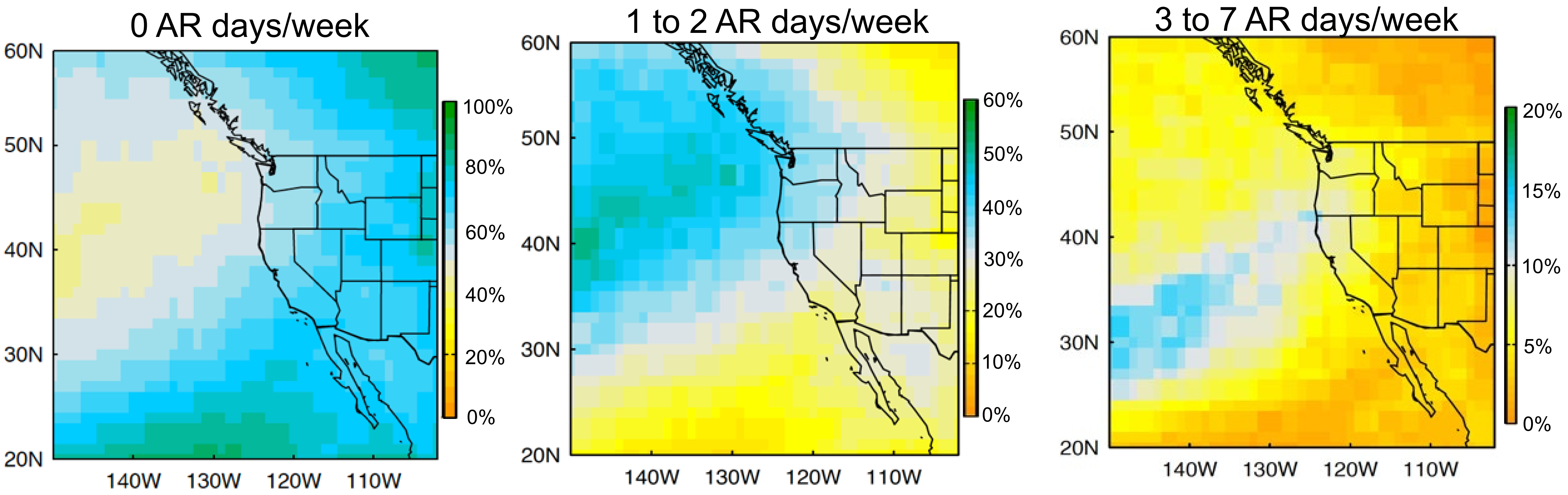
Does ECMWF AR1wk skill exceed climatological skill?
Is AR1wk skill modulated by large-scale climate mode activity?



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

Experimental S2S Forecasting of Atmospheric Rivers over the Western U.S.

Michael J. DeFlorio[1], Duane E. Waliser[2,3], F. Martin Ralph[1], Aneesh Subramanian, et al. (2019, in prep)
[1]UCSD/SIO/CW3E, [2]NASA JPL/CalTech, [3]UCLA, U Colorado[4]

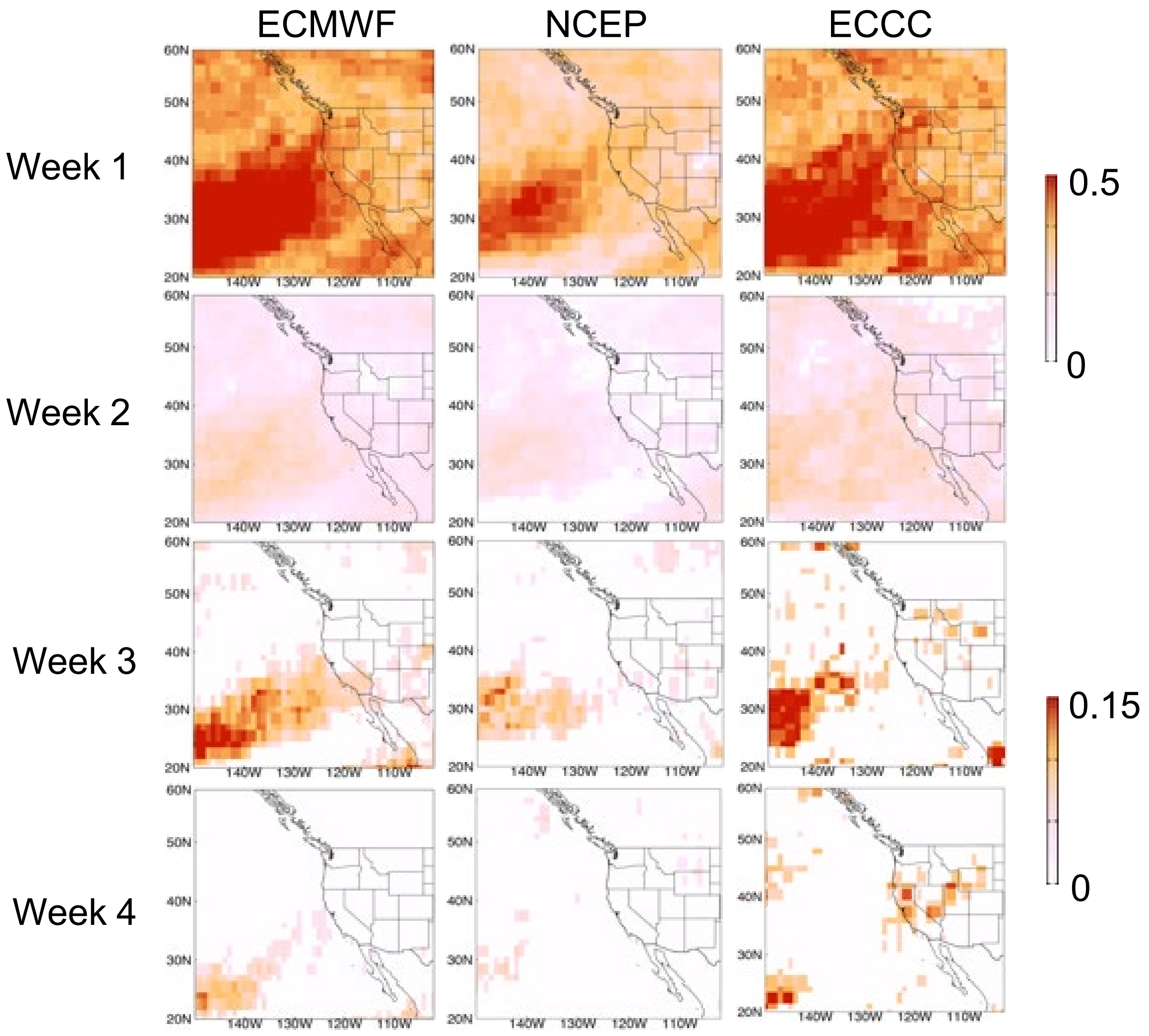


ERA-I NDJFM 1996-2015 average number of AR days per week (“AR1wk”) for 0, 1-2, 3-7 AR days/week

Experimental S2S Forecasting of Atmospheric Rivers over the Western U.S.

Michael J. DeFlorio[1], Duane E. Waliser[2,3], F. Martin Ralph[1], Aneesh Subramanian, et al. (2019, in prep)
[1]UCSD/SIO/CW3E, [2]NASA JPL/CalTech, [3]UCLA, U Colorado[4]

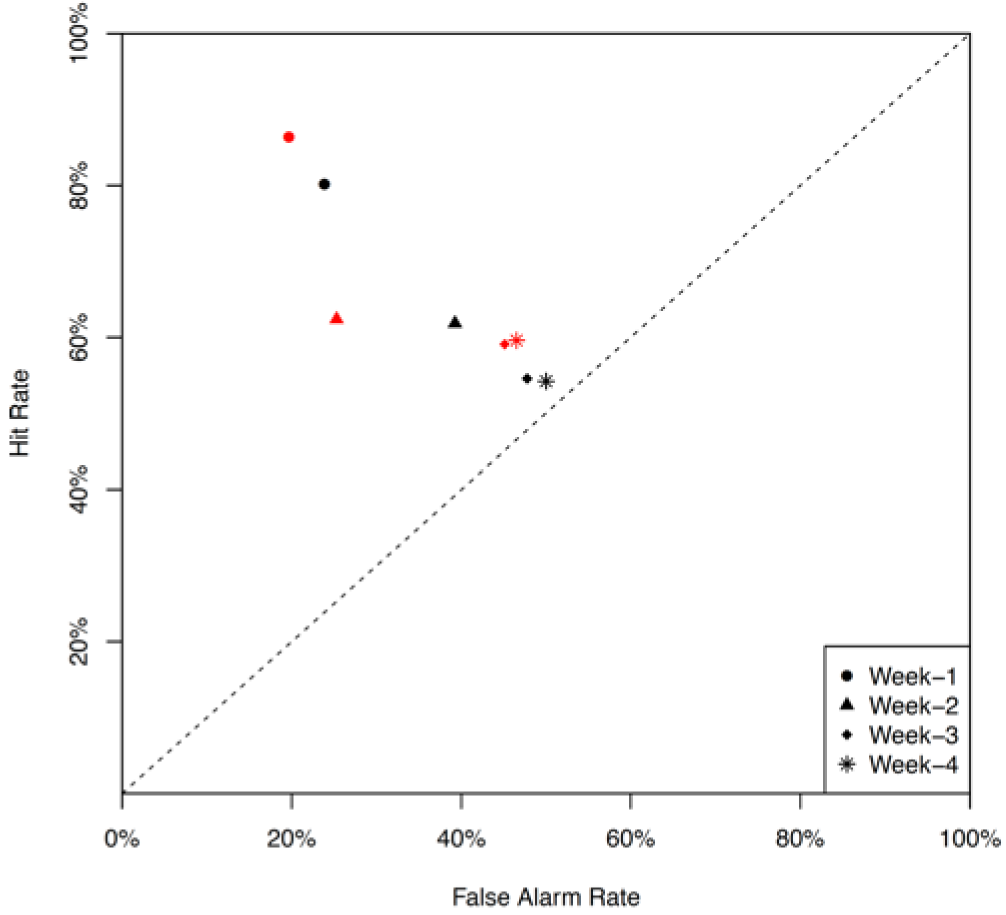
AR1wk NDJFM Brier Skill Scores:
"0 AR days/week" category



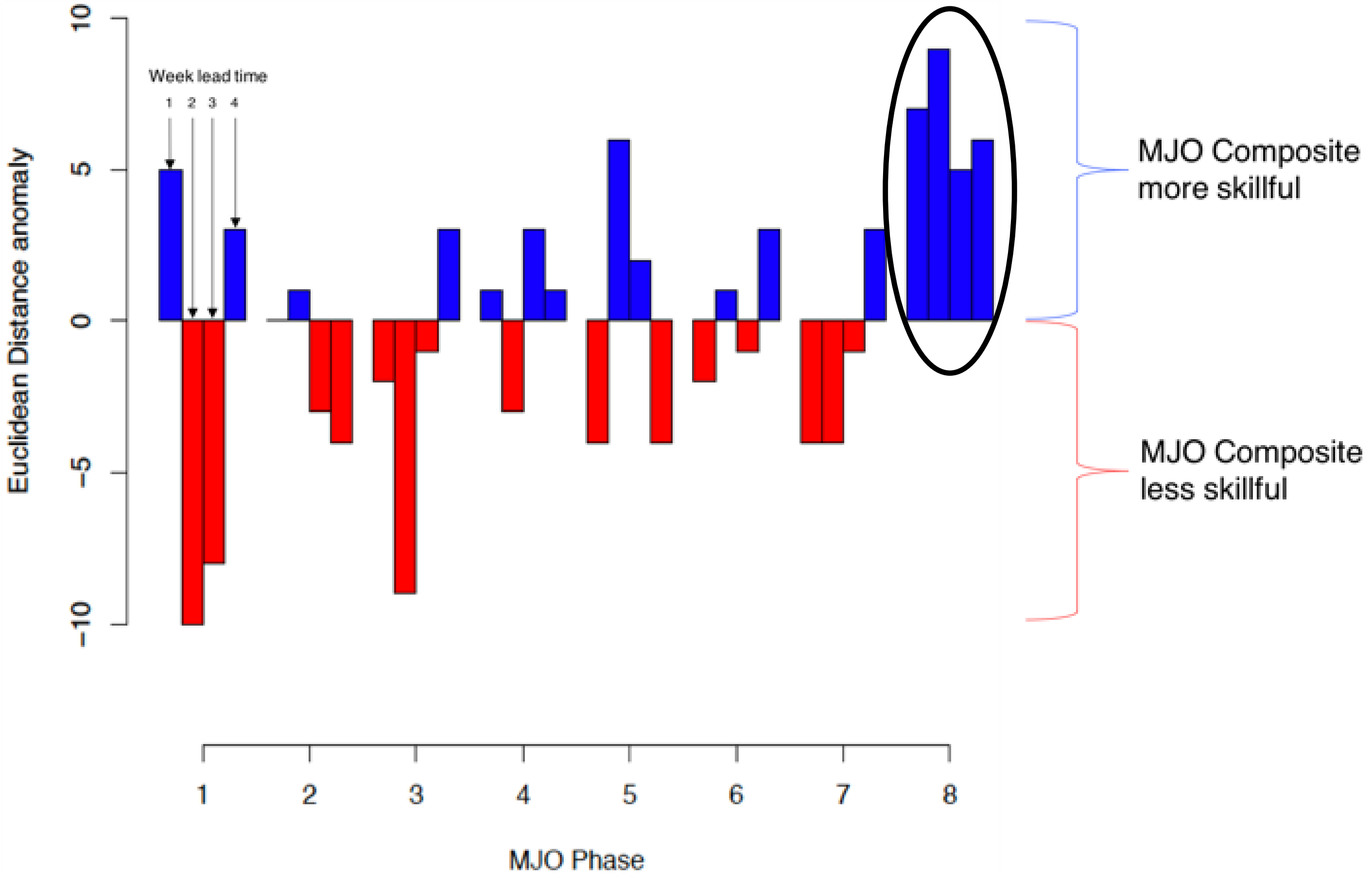
Experimental S2S Forecasting of Atmospheric Rivers over the Western U.S.

Michael J. DeFlorio[1], Duane E. Waliser[2,3], F. Martin Ralph[1], Aneesh Subramanian, et al. (2019, in prep)
[1]UCSD/SIO/CW3E, [2]NASA JPL/CalTech, [3]UCLA, U Colorado[4]

ROC Diagram; Central Cal; MJO Phase 8 IC (red) vs. all NDJFM days (black), ECMWF



Euclidean distance from perfect ROC score; Central California; All Days minus MJO Composite Days



Experimental Multi-Model Atmospheric River Forecast*

Issued on Thursday, March 28, 2018

Contents:

Slide 1-2: “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 3-5: “week-3” - 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

Ensemble Forecast Systems Used

ECMWF (European Centre for Medium-Range Weather Forecasts) forecast system

NCEP (National Centers for Environmental Systems) forecast system

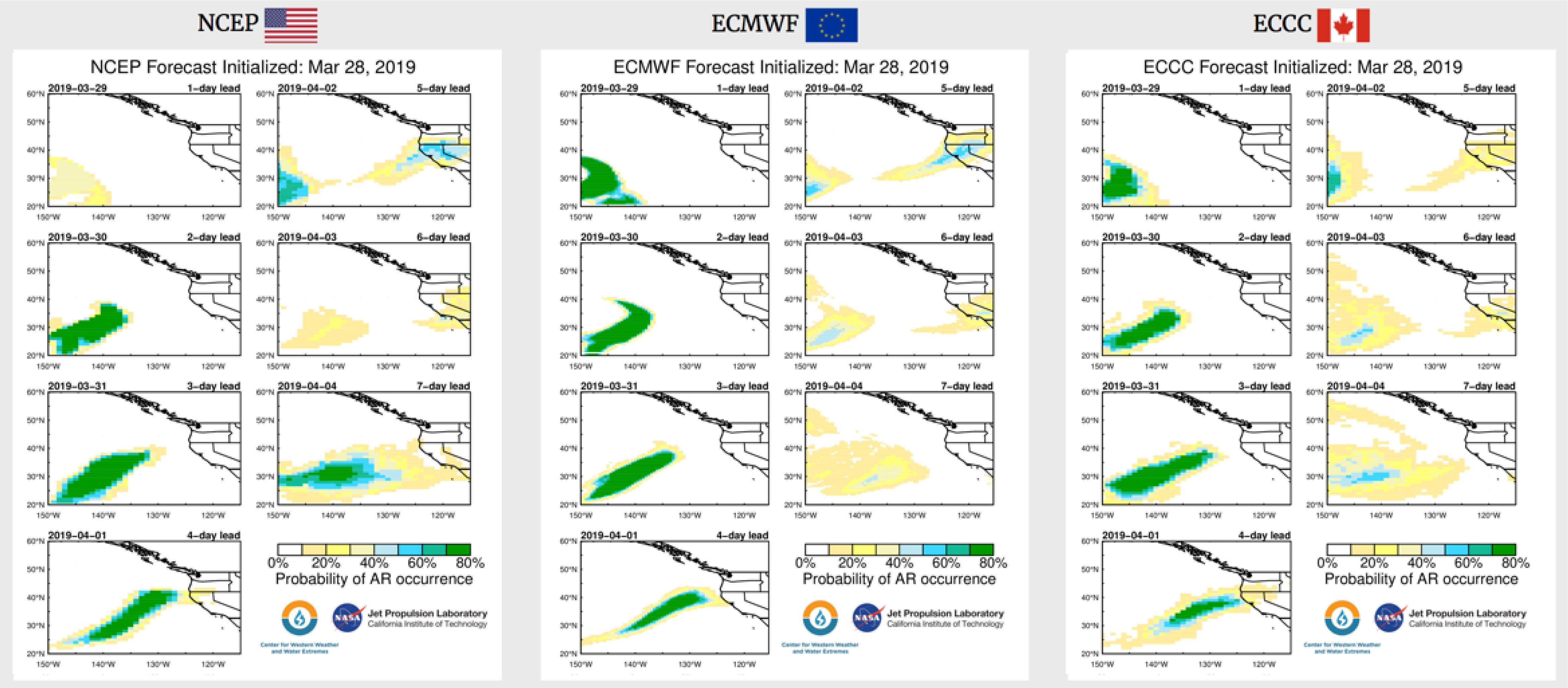
ECCC (Environment and Climate Change Canada) forecast system

**This is an experimental activity for the 2017-18 and 2018-19 winters. Methodologies and hindcast skill are documented in DeFlorio et al. (2018,2019a,2019b). 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: Mike DeFlorio (mdeflorio@ucsd.edu)

EXPERIMENTAL AR FORECAST

Week-1 (1-day to 7-day lead)



Experimental AR forecast issued on Thursday, March 28, 2019 by M. DeFlorio, D. Waliser, M. Ralph, A. Goodman, B. Guan, A. Subramanian, and Z. Zhang for an Experimental AR Forecasting Research Activity sponsored by California DWR

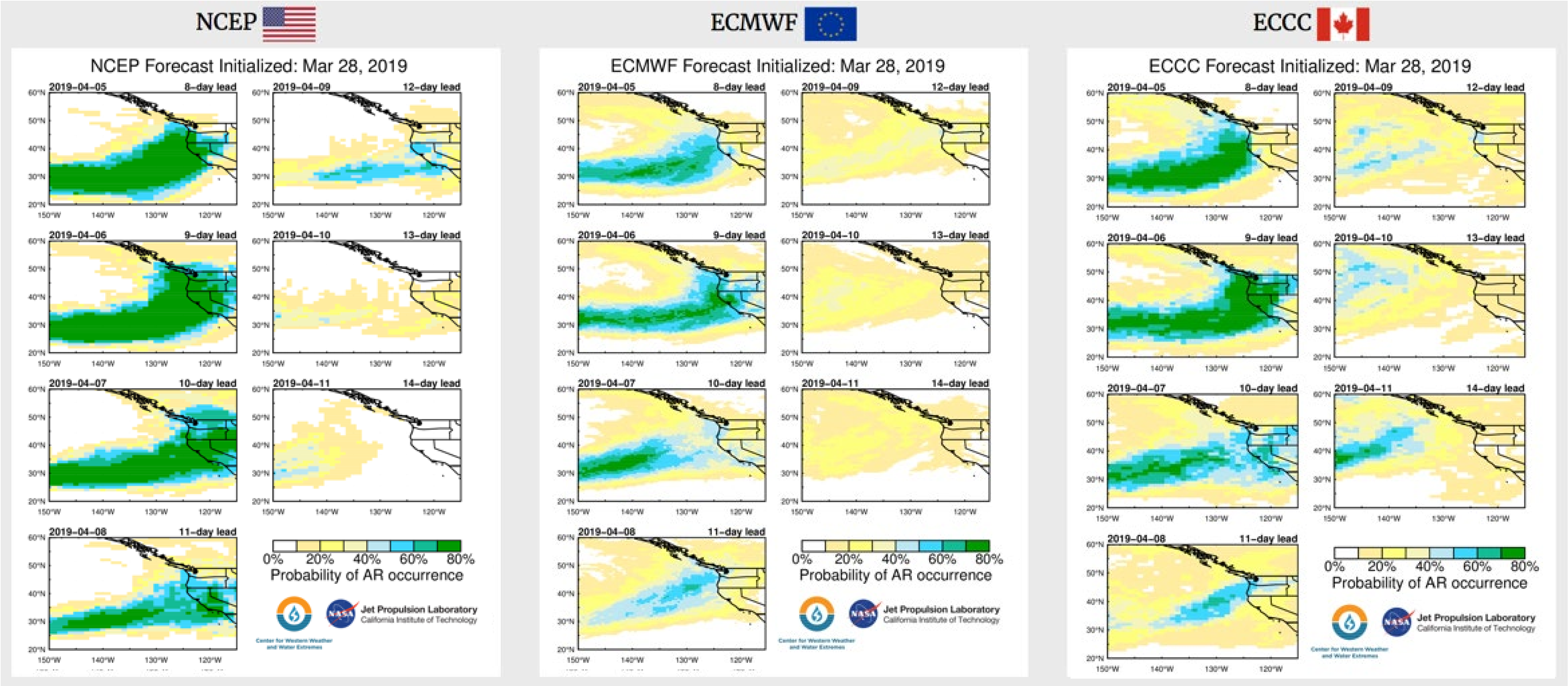
Center for Western Weather and Water Extremes

SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

Contact: Mike DeFlorio (mdeflorio@ucsd.edu)

EXPERIMENTAL AR FORECAST

Week-2 (8-day to 14-day lead)



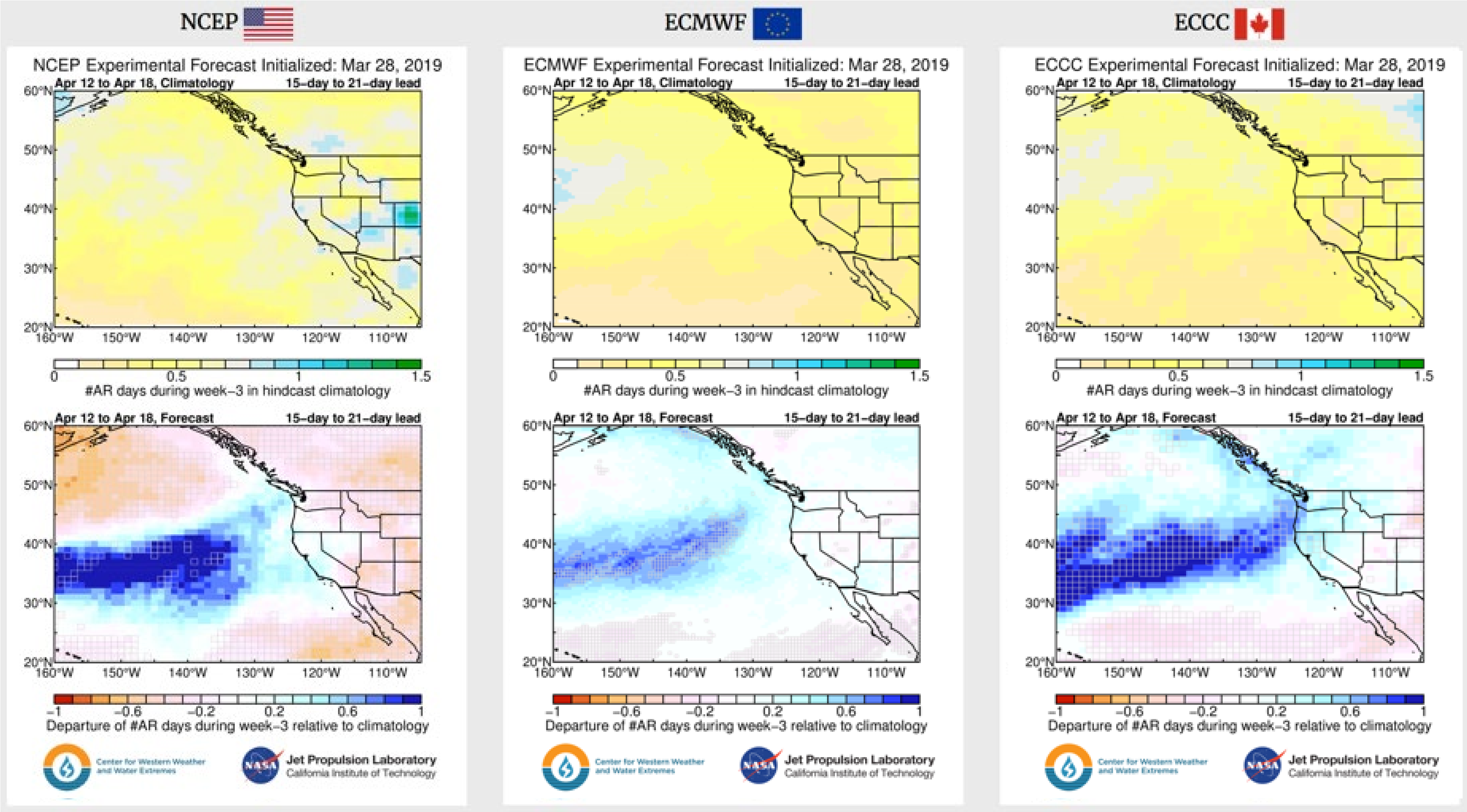
Experimental AR forecast issued on Thursday, March 28, 2019 by M. DeFlorio, D. Waliser, M. Ralph, A. Goodman, B. Guan, A. Subramanian, and Z. Zhang for an Experimental AR Forecasting Research Activity sponsored by California DWR

EXPERIMENTAL AR FORECAST

Week-3 (15-day to 21-day lead)

Hindcast Climatology

Forecast Minus Climatology



Experimental AR forecast issued on Thursday, March 28, 2019 by M. DeFlorio, D. Waliser, M. Ralph, A. Goodman, B. Guan, A. Subramanian, and Z. Zhang for an Experimental AR Forecasting Research Activity sponsored by California DWR

Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

Contact: Mike DeFlorio (mdeflorio@ucsd.edu)

Summary

- Atmospheric rivers occur globally and influence weather and water extremes.
- Total amount of annual California precipitation is uniquely variable from year to year and is strongly influenced by occurrence or absence of atmospheric rivers.
- S2S (here, week 3-4) forecasting of atmospheric rivers represents a critical decision-making time window for water resource managers.
- Real-time experimental AR occurrence forecasting effort using ECMWF, NCEP, and ECCC data is ongoing (CW3E/JPL partnership), with engagement from NCEP and addition of NASA GMAO data forthcoming
  - Pilot S2S Project for Applications
- Verification of S2S hindcasts of AR1wk (bias, BSS, ROC) is nearly complete (DeFlorio, Waliser, Ralph, Subramanian et al. 2019 in prep), and can be used as skill benchmarks for winter 2017-2018 and 2018-2019 experimental forecasts.
- Examining sources of increased prediction skill at longer lead times – e.g. atmospheric ridging events (Peter Gibson, Duane Waliser, Bin Guan, Alex Goodman et al., NASA JPL)

Thank you!

mdeflorio@ucsd.edu

Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

cw3e.ucsd.edu