Subseasonal-to-Seasonal (S2S) Forecasting of Atmospheric Rivers and Precipitation

Mike DeFlorio¹, Marty Ralph¹, Luca Delle Monache¹, Duane Waliser²,³, Bin Guan²,³, Peter Gibson², Alexander Goodman², Zhenhai Zhang¹, Tamara Shulgina¹, Kristen Guirguis¹, Sasha Gershunov¹, Aneesh Subramanian⁴, Frederic Vitart⁵ … and others!

2019 Floodplain Management Association Meeting; San Diego, CA; 5 September 2019

¹Center for Western Weather, Water and Extremes, University of California, San Diego, Scripps Institution of Oceanography; La Jolla, CA
²NASA Jet Propulsion Laboratory/California Institute of Technology; Pasadena, CA
³Joint Institute for Regional Earth System Science and Engineering, University of California, Los Angeles; Los Angeles, CA
⁴University of Colorado, Boulder; Boulder, CO
⁵European Centre for Medium Range Weather Forecasts; Reading, UK
CW3E Provides 21st Century water cycle science, technology and practices that address the impacts of extreme weather and water events on the environment, people and the economy of Western North America.

cw3e.ucsd.edu
Mission
Provide 21st Century water cycle science, technology and outreach to support effective policies and practices that address the impacts of extreme weather and water events on the environment, people and the economy of Western North America.

Goal
Revolutionize the physical understanding, observations, weather predictions and climate projections of extreme events in Western North America, including atmospheric rivers and the North American summer monsoon as well as their impacts on floods, droughts, hydropower, ecosystems and the economy.

Director: F. Martin Ralph, Ph.D.
Strategies: Observations, physical processes, modeling, decision support
Scope: A group involving roughly 50 people with 10 major projects
Partners: California DWR, Sonoma County Water Agency, CNAP, USGS, San Diego Supercomputing Center
Sponsors: CA DWR, USACE/ERDC, NOAA, SCWA, NASA, USBR
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**

*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.

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.
What is subseasonal-to-seasonal (S2S) forecasting?

“S2S” lead time range: 2 weeks to ~3-4 months or longer. A critical decision-making window for many stakeholders.
How does an S2S forecast differ from a weather forecast?
Weather Forecasts (0-14 Days)

Hurricanes

Atmospheric Rivers
Rather than try to predict the occurrence or evolution of a single atmospheric river at such long leads, should we predict the likelihood of an atmospheric river or expected frequency of atmospheric rivers?

Can we do that? How do we do that?
More on 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

Source: NASA JPL
Fundamentally, the “S2S” lead time represents a transition from short-term weather forecasts, which aspire to predict individual, discrete events, towards probabilistic longer-term forecasts which still depend on initial conditions but are influenced by slower-varying modes of climate variability (e.g. El Niño-Southern Oscillation [ENSO]).

Additionally, an S2S forecast is often compared to a climatological forecast in order to predict “above” or “below” normal conditions.
Weather forecast: “An AR will make landfall near Coronado Island in 84-96 hours.”

S2S forecast: “There is a 20% chance for above-average AR activity in the vicinity of San Diego County at week-3** lead time.”**and longer!
BUT... we already know that the limit of prediction skill of dynamical models in forecasting discrete AR events over the western U.S. within 500km accuracy is ~7-8 days (Wick et al. 2013; DeFlorio et al. 2018).

So why might we think there is hope for predicting ARs/precipitation skillfully at lead times beyond 7-8 days?
Answer: we don’t try to predict individual events at these longer lead times. Instead, we switch to evaluating forecasts at S2S lead times in a probabilistic framework. i.e., trading forecast precision for increased lead time.
Experimental S2S Forecasting of Atmospheric Rivers over the Western U.S.

Michael J. DeFlorio¹, Duane E. Waliser²³, F. Martin Ralph¹ et al. (2019, in revision)

¹UCSD/SIO/CW3E, ²NASA JPL/CalTech, ³UCLA

[Images of heat maps showing the distribution of Atmospheric River days per week (0 AR days/week, 1 to 2 AR days/week, 3 to 7 AR days/week) across the Western U.S.]

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. DeFlorio¹, Duane E. Waliser²,³, F. Martin Ralph¹ et al. (2019, in revision)

¹UCSD/SIO/CW3E, ²NASA JPL/CalTech, ³UCLA

Central California

- Observed AR
- Forecast AR

Hit

Miss

False Alarm

Correct Rejection

15-20% reduction in False Alarms for AR activity (#AR days per week) at week-2 lead time when MJO is in Phase 8 at time of forecast... a "forecast of opportunity"
Overview of Experimental Subseasonal and Seasonal Outlooks of ARs, Precipitation, and Atmospheric Ridging Events
Experimental Multi-Model Atmospheric River Forecast*

Week-3: issued on February 7, 2019; Week-2: issued on February 14, 2019; Week-1: issued on February 21, 2019

Contents:

Slide 1: “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

Slides 2-3: “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.

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.
Experiment AR forecast issued on Thursday, February 7, 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-2 (8-day to 14-day lead)

<table>
<thead>
<tr>
<th>NCEP</th>
<th>ECMWF</th>
<th>ECCO</th>
</tr>
</thead>
</table>

**Experimental AR Forecast** issued on Thursday, February 14, 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

Contact: Mike DeFlorio (mdeflorio@ucsd.edu)
***EXPERIMENTAL AR FORECAST***

- **NCEP**
- 2019-02-21:
  - 1-day forecast
  - 3-day forecast

- **ECMWF**
- 2019-02-21:
  - 1-day forecast
  - 3-day forecast

- **ECCC**
- 2019-02-21:
  - 1-day forecast
  - 3-day forecast

Experimental AR forecast issued on Thursday, February 21, 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

Contact: Mike DeFlorio (mdeflorio@ucsd.edu)
AR-related IVT example: Alaska region

54 new locations (blue dots) in Alaska
AR and IVT Forecasts for Week3 (08/01/2019 - 08/07/2019) from ECCC issued at 07/18/2019

**Left:** AR occurrence (number of AR days in a week) at week-3 for the 21 ECCC ensemble members (1-21, sorted according to total AR occurrence), ensemble mean (EM), and boxplot (All AR). Different colors indicate different AR intensity categories (Ralph et al. 2019). The horizontal dashed line is the model climatology.

**Right:** Time-integrated IVT ($10^7$kg/m in a week) at week-3 for 21 ECCC ensemble members (1-21, sorted according to total IVT), ensemble mean (EM), boxplot for all IVT (All IVT), and boxplot for IVT associated with AR (AR IVT). Red indicates the IVT associated with AR and the blue indicates the IVT not associated with AR. The horizontal dashed line is the model climatology of total IVT.
Development of Statistically-Based Seasonal Prediction of Precipitation over the Western U.S.

Key CW3E-related personnel: Tamara Shulgina, Alexander Gershunov, Kristen Guirgius

**Predictand:** Precipitation (PR): 1949 – 2012, 1/16°× 1/16°, [20-52N, 125-110W]

**Predictor:** Sea Surface Temperature (SST, NOAA Extended Reconstructed SST V4): 1948-2011, 2°× 2°, [20S-64N, 260-100W]

**Method:** Canonical Correlation Analysis (CCA) (Model training period: 1950 – 2012 (63 years))
Experimental Seasonal Forecast of January-March 2019 precipitation anomalies over the western US via December 2018 SST

Prediction of total precipitation anomalies, January-March, 2019

CCA prediction approach:
Predictor: December Pacific SST [20S – 65N]
Predictand: JFM precipitation anomalies (%)
Model training period: 1950 – 2012

**EXPERIMENTAL SEASONAL FORECAST IN DECEMBER 2018 OF JFM 2019 PRECIPITATION BASED ON PACIFIC SST**
Observed Precipitation Anomaly for January 2019 – March 2019

Provided by B. Kawzenuk

Data courtesy: PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu
Ridging events often occur (and sometimes persist) in winter off the west-coast of USA.
These ridge events divert important rain-bearing systems away from California.

From NASA Terra satellite – August 7 2018
Ridge detection algorithm

- Applied on daily z500 anomalies from MERRA-2
- Reports the magnitude, extent, location, persistence of large z500 anomalies > 50m
- Outputs information with respect to 3 regions: N, S, W
- Ridge occurrence is ‘counted’ for region if anomaly covers > 50% of domain

Ridging events over the Western U.S.
Experimental S2S Ridging Outlooks

North Ridge

Predicted Ridge Occurrence

Chance of precipitation pattern associated with given ridge type

South Ridge

West Ridge

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

Jet Propulsion Laboratory
California Institute of Technology
Experimental S2S Ridging Outlooks

Predicted Ridge Occurrence

North Ridge

South Ridge

West Ridge

Chance of precipitation pattern associated with given ridge type
Experimental S2S Ridging Outlooks

Predicted Ridge Occurrence

North Ridge

South Ridge

West Ridge

Chance of precipitation pattern associated with given ridge type

66% overall likelihood

46% overall likelihood
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, AR intensity, ridging, and precipitation 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
Future directions

• Implement post-processing methods (e.g. bias correction, superensemble prediction) into multi-model experimental forecast product pipeline (DeFlorio, Zhang, Delle Monache)

• Continue development of experimental seasonal precipitation forecasting model using Canonical Correlation Analysis based on Pacific SST and other variables (Shulgina, Guirguis, Gershunov)

• Extension of Chapman et al. (2019) methodology to S2S timescales, in combination with Analog Ensemble methods (Chapman, Gibson, Delle Monache)

• Evaluate intrinsic limit of S2S AR predictability in multimodel hindcast framework (DeFlorio, Waliser, Delle Monache et al.)

• … and many others!
Thank you!

mdeflorio@ucsd.edu

cw3e.ucsd.edu