CW3E Research and Applications Development on Southwest U.S. Extreme Precipitation

F. Martin Ralph and Forest Cannon
Center for Western Weather and Water Extremes
Scripps Institution of Oceanography, UC San Diego

Southwest Extreme Precipitation Symposium
March 27, 2019
Snowfall and desert flooding in Agua Caliente Canyon on 22 February 2019; credit: Jeff Wheeland
**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.  
**Website:** cw3e.ucsd.edu

**Strategies:** Observations, physical processes, modeling, decision support

**Scope:** A diverse group of ~40 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

**CW3E’s Core Efforts**

- **Forecast-Informed Reservoir Operations**
- **Tools for California Water Extremes**
- **“West-WRF” Weather Model**
- **Climate Science**
- **Subseasonal-to-Seasonal Outlooks**
SOUTHWEST U.S. PRECIPITATION IS UNIQUELY VARIABLE

This talk will describe precipitation climatology in the Southwest, discuss the remarkable 2019 water year, and highlight regional forecast challenges.

Lamjiri et al. 2018 – Hourly Precipitation
Cannon et al. 2018 – Precipitation Mechanisms
Atmospheric River Reconnaissance
Upper Colorado Basin Extreme Precipitation
Extreme Precipitation in Monsoon Region
Monsoons, ARs and TCs (Mike Sierks Talk on Lake Mead)

Dettinger et al. 2011, Water
In general, northern California receives a higher number of rainfall events with larger event-totals and longer durations, but lower event-maximum and average rainfall intensities compared to southern California.
Southern California Extreme Precipitation

Left: median number of hours generating 50% of annual total rainfall, 1995–2016

Right: median fraction of annual total rainfall from the largest rainfall event, 1995–2016.

A large portion of annual rainfall in California falls during only a few hours, highlighting that California’s large interannual variability of annual rainfall totals strongly depends on a few big storms.
• Meteorological Analysis for Forecast Informed Reservoir Operations (FIRO) at Prado Dam
• Use an “ingredients-based” approach to evaluate precipitation processes in Southern California
Development of Hazardous Precipitation Rates in a Weak AR

A schematic of the Meteorological Conditions in the 9 Jan 2018 Montecito Debris Flow Event

Meteorological and climatological conditions associated with the 9 January 2018 post-fire debris flows in Montecito and Carpinteria, California, USA

Development of a narrow cold frontal rainband (NCFR) led to extreme precipitation rates (0.59” in 5min)

Oakley, N.S., F. Cannon, R. Munroe, J.T. Lancaster, D. Gompberg, F.M. Ralph
Natural Hazards and Earth System Sciences
Observation campaigns support the understanding of physical processes in extreme events and are essential to the development of numerical weather prediction, Including West-WRF
West-WRF is a configuration of a mesoscale numerical weather prediction model that has been developed at CW3E for optimal performance in West Coast forecasting challenges. Here, we demonstrate the model's ability to simulate NCFR development.

West-WRF Ensemble uses varied physics and perturbations to the model initial conditions and dynamics to account for uncertainty. While the physical processes are well-resolved, there remains uncertainty in forecast timing and intensity, as demonstrated by variability in ensemble members. Ensemble based on changing initial conditions and model representation of physical processes.

Comparison of West-WRF with NEXRAD for 18 Feb 2017 Event
Center time for dropsondes: 0000 UTC 27 Jan 2018

Number of dropsondes planned: 27, 26, 36 (C-130 H, C-130 C, G-IV)

- Mission Director: F. Martin Ralph (PI; Scripps/CW3E)
- Co-PIs: Vijay Tallapragada (NWS/NCEP), Andy Edman (NWS/Western Region)
- C-130 Flight Planning lead: Jon Rutz (NWS)
- G-IV Flight Planning Lead: Chris Davis (NCAR)
- Forecasting Lead: Jay Cordeira (Plymouth St. Univ.)
- Moist Adjoint Lead: Jim Doyle/Carolyn Reynolds (NRL)
- GPS sensor lead: Jennifer Haase (Scripps/IGPP and CW3E)
- AR Recon Coordinator: Anna Wilson (Scripps/CW3E)
- Flight Track Coordinator: Forest Cannon (Scripps/CW3E)
- Air Force C-130 Flight Director: Ashley Lundry (AF/53rd Weather Recon)
- NOAA G-IV Flight Director: Jack Parrish (NOAA/AOC)

Modeling Partners
NWS/NCEP     US NAVY
ECMWF          NCAR

Forecaster      Chad Hecht (Scripps/CW3E)       Moist Adjoint support        Reuben Demirdjian (CW3E)
Forecaster      David Lavers (ECMWF)            Flight Planning ("alternate") Tom Galarneau (Univ. AZ)
Forecaster      Philippe Papin (NRL)            Onboard Scientist            Jon Rutz (NWS)
Forecaster      Aneesh Subramanian (Scripps/CW3E) Onboard Scientist Reuben Demirdjian (CW3E)

Onboard Scientist (GPS) Bing Cao (Scripps/IGPP)
AR Rekon Forecasting Challenges

AR Landfall Forecast uncertainty at 0-4 days lead time is a major challenge to emergency management

96-h TIVT Analysis and Forecast Verification: Valid 00Z 20 Mar. – 00Z 24 Mar. 2018
AR Recon Forecasting Challenges

CNRFC QPF

22-23 Mar 2018
Day -3 Forecast

Frontal Wave didn’t just shift timing.
Also changed orientation and moisture supply.

AR Recon observations target errors in forecast initial conditions ahead of landfall in an effort to improve simulation of AR evolution and landfall.
2019 AR Recon IOP-1: An Impactful Southern California Atmospheric River

IOP-1 Case Study: Predictability of Hazard Precipitation Rates in S. CA atmospheric rivers (in preparation)
A Scale to Characterize the Strength and Impacts of Atmospheric Rivers

F. Martin Ralph (SIO/CW3E), J. J. Rutz (NWS), J. M. Cordeira (Plymouth State), M. Dettinger (USGS), M. Anderson (CA DWR), D. Reynolds (CIRES), L. Schick (USACE), C. Smallcomb (NWS); Bull. Amer. Meteor. Soc. 269-289 (2019); DOI/10.1175/BAMS-D-18-0023.1

The AR CAT level of an AR Event* is based on its **Duration** and max **Intensity (IVT)**.

- AR Cat 5 – Primarily hazardous
- AR Cat 4 – Mostly hazardous, also beneficial
- AR Cat 3 – Balance of beneficial and hazardous
- AR Cat 2 – Mostly beneficial, also hazardous
- AR Cat 1 – Primarily beneficial

**IMPACTS**

Determining AR Intensity and AR Category

**Step 1:** Pick a location

**Step 2:** Determine a time period when IVT > 250 (using 3 hourly data) at that location, either in the past or as a forecast. The period when IVT continuously exceeds 250 determines the start and end times of the AR, and thus also the AR Duration for the AR event at that location.

**Step 3:** Determine AR Intensity

- Determine max IVT during the AR at that location
- This sets the AR Intensity and preliminary AR CAT

**Step 4:** Determine final value of AR CAT to assign

- If the AR Duration is > 48 h, then promote by 1 Category
- If the AR Duration is < 24 h, then demote by 1 Category

*An “AR Event” refers to the existence of AR conditions at a specific location for a specific period of time.

**How long IVT>250 at that location. If duration is <24 h, reduce AR CAT by 1, if longer than 48 h, add 1.

***This is the max IVT at the location of interest during the AR.

The Oroville Event AR

On the Web: CW3E.UCSD.EDU
On Twitter: @CW3E_Scripps
During 25-27 Feb, the San Francisco Bay Area experienced AR Cat 3 conditions and the remainder of coastal Northern and Central CA experienced an AR Cat 2 event.
The Inland Penetration of Atmospheric Rivers over Western North America: A Lagrangian Analysis

J.J. Rutz, J. W. Steenburgh and F.M. Ralph


Schematic showing the primary pathways for the penetration of 950-hPa AR-related trajectories into the interior of western North America. Regions associated with frequent AR decay are shaded in red.

However, we work on a number of meteorological and climate phenomena impacting the interior of the West.

Mike Sierks to cover summertime precip. In the Lake Mead Watershed
Ralph et al. 2017 (Chiracahua Gap Monsoon Moisture Transport)
Yampa River Basin
January 29th, 2019

Comparing the Storms

Bluebird forever today. It was glorious and amazing to see such deep, dark blue skies. After 14 days of epic winter, having the sun come out is actually nice. Not that we want it out for long, but today it was worthy. As we dig out from one of our deepest snow cycles in years, it’s interesting to compare the historical significance of what we just witnessed. These past 14 days we were blessed with 91” of snow. That’s 7.5 feet of snow. That’s a lot of snow. But how does this compare to other 2-week storm cycles in the past?

We’ve been keeping solid snow records since 2000 at our cabin and in our upper zones in Soda Mountain. The deepest 2 week period we had was December 18-January 2 during our 02/03 season where we received 133” in that 16-day timeframe. That’s 11 feet of snow. Yikes. In January of 2008 and January of 2016 we had 2-week storms that tallied 114” and in December 2008 and December 2012 we had storms of 101”. 2008 was an EPIC year with 2 storms over 100”. WOW!

This cycle ranks 8th deepest since 2000. But we believe this storm was the most important because it’s now and as powderhounds we live in the moment. Every day, every second, every turn, right now is the best ever and most meaningful.

As always, thanks for playing and we hope you enjoy these bluebird images from today.

Powdercat Kent
(Kent Vertrees; Owner of Steamboat Powdercats since 2000)
40% of Peak Seasonal SWE accumulated in 2 weeks; 28 Feb to 13 Mar
Seasonal Inflow Forecasts

Lake Powell inflow forecast issued on March 1 indicated a “near average” season as the most probable scenario.

The maximum inflow forecast as of March 1 was for 96% of climatological average.

Precipitation over the next two weeks added ~40% of climatological average annual maximum SWE to the basin.

The next inflow forecast will be substantially higher.
Impact of Individual Events on Seasonal SWE Accumulation

Snow water equivalent is well above average over much of the West

The gains in SWE across the season are attributable to a few large events

Some events are shared regionally, including those sampled by AR Recon

Flagstaff all-time daily snowfall record (31”) on 20-21 Feb

Legend:
- Blue: Snow Water Equivalent (in) Start of Day Values
- Black: Precipitation Accumulation (in) Start of Day Values
The Landfall and Inland Penetration of a Flood-Producing AR in Arizona

P.J. Neiman, F.M. Ralph, B.J. Moore, M. Hughes, K.M. Mahoney, J.M. Cordeira, M.D. Dettinger

*Journal of Hydrometeorology*
Impact of Extreme Events on Arizona Precipitation: Differing Mechanisms

Fastest start to the water year on record

http://cirrus.ucsd.edu/~pierce/staweb/?npanels=2
ARs, TCs and the Monsoon

A single post tropical cyclone event in early October set the stage for the rest of the year to be above average

http://cw3e.ucsd.edu/iwv-and-ivt-forecasts/
If virga occurs in the West...

and someone isn’t there to photograph it...

did it really happen?

Rain gauges say no!

Radar says yes...

(if there’s one within a few hundred km, which there probably isn’t)
RAWS Station Data in Vicinity of Angry Virga: Photo Taken ~11:00 Local Time

Photo: FM Ralph April 2018 near Craig CO

- **RAWS Station**
- **Grand Junction Sounding**
- **Photo Location (Craig, CO)**

![Graphs showing wind direction, temperature, and relative humidity over time.](image)
Summary

• Major collaborative efforts underway that integrate data collection, analysis, and modeling to achieve the overarching goal: **Improve relevant forecasts of phenomena at all appropriate time-scales for the west. This broad objective is key for water supply reliability, flood risk mitigation, ecosystem health, and emergency preparedness.**

• Initial results help us to target future efforts – e.g. AR Recon adjoint; new field sites in locations where observations will allow us to better understand physical processes and represent them in models.
Thank You!

Snowfall and desert flooding in Agua Caliente Canyon
On 22 February 2019; credit: Jeff Wheeland