

Formulating the ARkStorm Meteorology

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BIOGRAPHICAL SKETCH

Dr. Michael Dettinger is a research hydrologist for the U.S. Geological Survey, Branch of Western Regional Research, and a research associate of the Climate, Atmospheric Sciences and Physical Oceanography Division at Scripps Institution of Oceanography, La Jolla, California. Dettinger has monitored and researched the hydrology, climates, and water resources of the West for almost 30 years, focusing on regional surface water and groundwater resources, watershed modeling, causes of hydroclimatic variability, and climatic-change influences on western water resources. He has authored over 75 scientific articles in scholarly journals and books, 20 government reports, and another 70 articles in outreach and less formal outlets.

Among other activities, he was the physical-sciences team leader for DOI-DOD ecosystem planning in the Mojave Desert, founding member of the multi-institutional CIRMONT Western Mountain Climate Sciences Consortium, climate advisor to the CALFED Bay-Delta Restoration Program, member of the Climate Change Technical Advisory Group for California Dept. of Water Resources' 2009 Water Plan Update and ongoing Central Valley Flood Protection Program workgroup, member of the external Science Steering Group for the federal Global Water Cycle Program, research advisor for USGS Surface-Water Discipline, and a member of the USGS Global Change Science Strategic Planning Team. He has degrees from the University of California, San Diego, Massachusetts Institute of Technology, and a Ph.D. from the University of California, Los Angeles (Atmospheric Sciences).

ABSTRACT

The USGS Multi-Hazards Project is working with numerous agencies and experts to evaluate hazards that would be associated with a scientifically plausible series of extreme winter storms in California. The scenario consists of a storm sequence that impacts both Southern and Northern California in rapid succession, and that is more severe overall than any single 20th century storm, but that may rival the extreme storms of 1861-62. The atmospheric and hydrological characteristics of the storms are quantified to provide the basis for other teams to estimate human, infrastructure, economic, and environmental impacts. The scenario will be used to design emergency preparedness and flood planning exercises by federal, state and local agencies.

Recent storm episodes were "stitched" together to describe a rapid sequence of several major storms over the state, yielding precipitation totals and runoff rates beyond any that occurred during the individual (unstitched) historical events. This stitching approach is a new strategy that allowed the scenario-design team to avoid arbitrary scalings to achieve much greater-than-historical storm and flood totals, by instead allowing for the very real occasions when storms stall over parts of the state and when extreme storms have followed each other into the state over short periods of time. The scenario—called the ARkStorm—is quantified by a dynamical (regional weather-model) downscaling of historical observations of extreme winter storms of January 1969 and February 1986 to 6-km and 2-km grids over California. The weather model outputs were used to force a hydrologic model to estimate runoff, for comparison with historical runoff. The methods used to build this scenario, and key results, could also be applied to other, nonemergency or non-California applications.



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Mike Dettinger (USGS) and Marty Ralph (NOAA)

Mimi Hughes (NOAA), Tapash Das (SIO),
Paul Neiman (NOAA), Dale Cox (USGS)





USGS MULTI-HAZARDS DEMONSTRATION PROJECT

- **The Great Southern California Shakeout:** A week-long series of events to inspire SoCalifornians to improve earthquake readiness; >6 million participants thus far
- A scientifically plausible & detailed scenario of a major southern San Andreas earthquake was designed by the USGS scientists (and collaborators) and used as basis for California Office of Homeland Security's Golden Guardian exercises, Nov 2008, Oct 2009, Oct 2010, ...



Shake
Out

Our objective in the present study was to develop a scientifically defensible, spatially and temporally detailed, and very challenging scenario of a major winter storm episode for use in emergency planning and preparedness exercises.

ARkStorm METEOROLOGY TEAM

In a new MutiHazards effort, we were tasked recently with formulating a similarly detailed & defensible scenario for an extreme-winter storm/flood episode(s) in California—eventually dubbed “ARkStorm”

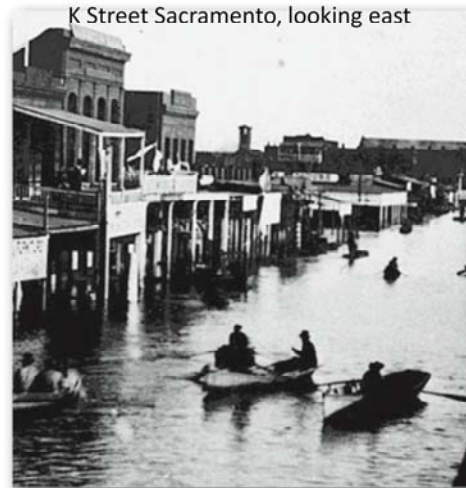
Name	Affiliation	Position
Storm Design Team		
F. Martin Ralph	NOAA/ESRL, Boulder	Team leader, Research meteorologist
Michael Dettinger	USGS, Scripps Institution of Oceanography, La Jolla	Team leader, Research hydrologist
Daniel Cayan	Scripps Institution of Oceanography, La Jolla	Research climatologist
David Danielson	NWS, Los Angeles	Hydrologist
Tapash Das	Scripps Institution of Oceanography, La Jolla	Postdoctoral researcher
Gary Estes	California Extreme Precipitation Symposium, Auburn	Scientist
Robert Hartman	NOAA/NWS CA-NV RFC, Sacramento	Hydrologist in charge
Mimi Hughes	NOAA/ESRL, Boulder	Postdoctoral researcher
Paul Neiman	NOAA/ESRL, Boulder	Research meteorologist
Jan Null	Golden Gate Weather	Consulting Meteorologist
David Reynolds	NWS, Monterey	Meteorologist in charge
Review Team		
Mark Jackson	NWS, Los Angeles	Meteorologist in charge
John Monteverdi	San Francisco State University, San Francisco	Meteorologist
Kelly Redmond	Western Regional Climate Center, Reno	Research climatologist
Maurice Roos	California Department of Water Resources, Sacramento	State hydrologist
Project Management		
Lucy Jones	USGS, Pasadena	Program chief
Dale Cox	USGS, Sacramento	Project chief
Suzanne Perry	USGS, Pasadena	Research geologist

ARkStorm meteorology was a real team effort, and drew ideas from meetings of a cast of many local and national experts.



THE 1861-1862 FLOODS

- December 24, 1861 through Jan 21, 1862: nearly unbroken rains
- Central Valley flooding over about 300 mi long, 12 – 60 mi wide
- Most of LA basin reported as “generally inundated”
- San Gabriel & San Diego Rivers cut new paths to sea
- 420% of normal-January precipitation in Sacramento in Jan 1862
- 300% of normal-January precipitation in San Diego in Jan 1862
- 500% of normal-January in San Francisco



Another view of K Street from 4th Street looking east during the 1862 flood.

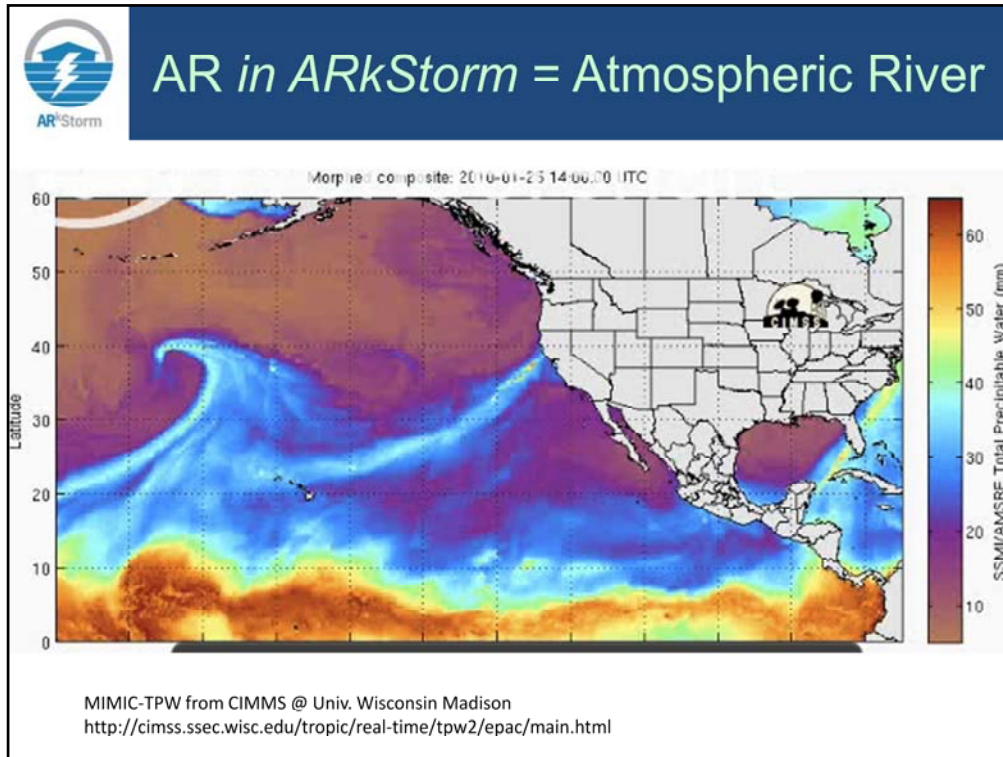
The storms and flooding of 1861-1862 always loomed as an example of how nasty ARkStorm could be without leaving the realm of historical veracity as we began the task of formulating the ARkStorm scenario. We didn't try to recreate that episode but rather learned some lessons from it that went into the design of ARkStorm while also taking solace from the fact that even the ARkStorm we came up with probably wasn't as punishing overall as the 1862 events.



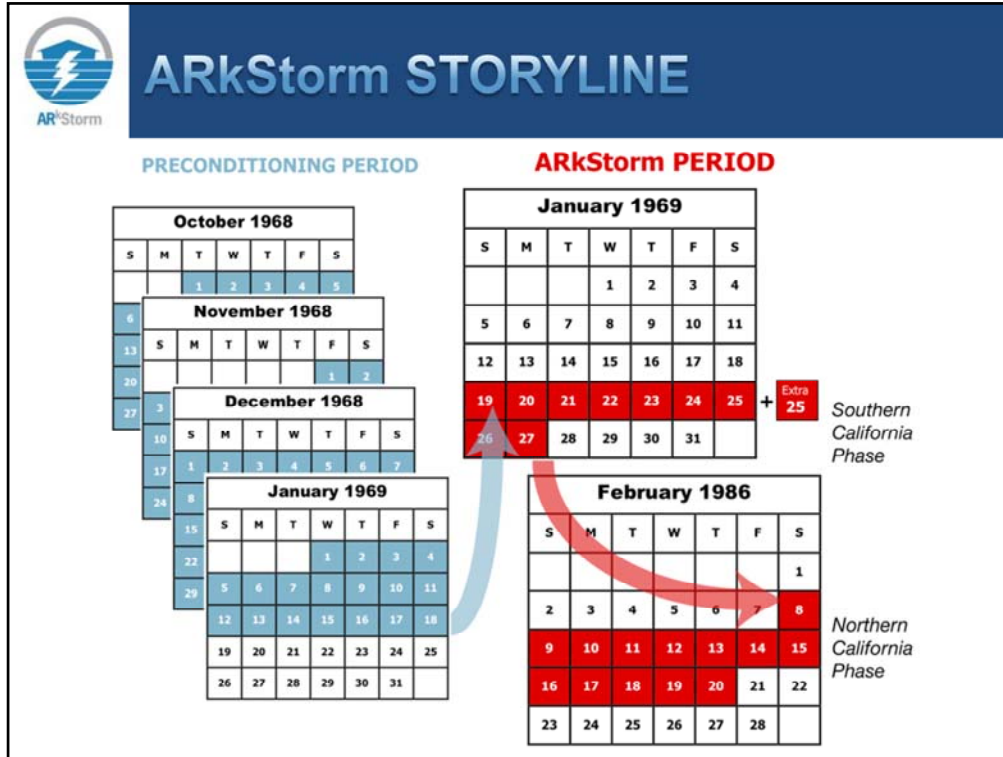
THE 1861-1862 FLOODS

- No way of knowing how intense the rains were, but they were exceptionally large in total and prolonged.
- Lesson: Prolonged storm episodes are a plausible mechanism for winter-storm disaster conditions in California
- Lesson: **A combined NorCal+SoCal extreme event is plausible.** 12 days separated the flood crest in Sacramento from the crest in Los Angeles in Jan 1862

We had no good way of recreating the storms of 1862, so instead they served as examples of how large storms had gotten in earlier historical times as well as providing several key lessons about how to make a storm sequence particularly challenging.



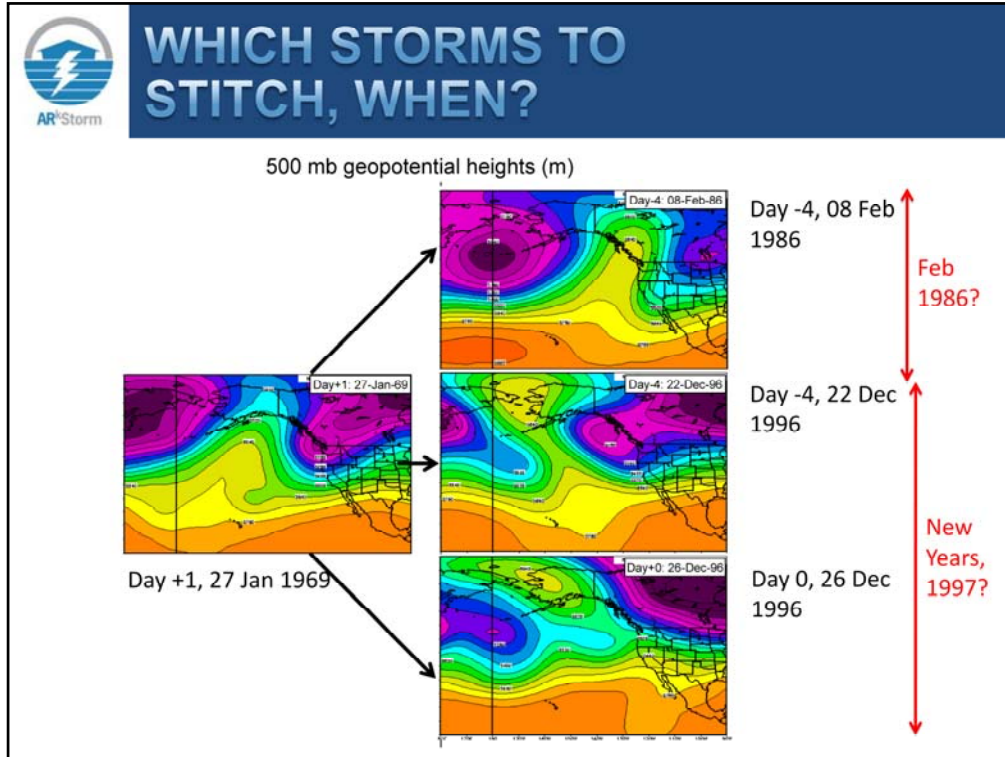
Our formulation of ARkStorm was also informed by the most recent scientific advances recognizing a major storm and flood mechanism on the West Coast, the atmospheric rivers embedded in midlatitude cyclone systems. These ARs conduct most of the water vapor moving around in the midlatitudes within narrow corridors thousands of km long and only a few 100 kms wide. When ARs make landfall in California, they often yield intense rains, warm-storm conditions, and have caused essentially all declared winter floods in many of California rivers. We now recognize that California's worst and most widespread storm episodes may be attributed closely to the arrivals, sequencing and intensities of these major atmospheric features.



Our strategy for formulating ARkStorm was NOT to try to directly recreate the storms of 1862, nor to simply scale up precipitation values from some more recent storm. Rather we decided to take the preceding two implications/lessons from 1862 and construct a storm sequence that was modern in its intensities, of longer duration than a couple of modern storms (one focused in south and one focused in north), with a short interval separating the two storm phases. We also decided that the runoff to the storms of 1969 were wet enough across enough of the state to ensure that watersheds were already wet when the ARkStorm sequence arrived.

In order to ensure that the southern California phase of the storm was more challenging than the original January 1969 events, the wettest day in that storm sequence (25 Jan 1969) was stalled or repeated in the ARkStorm sequence. This day historically yielded about 30+% of the total January 1969 precipitation, so that continuing those storm conditions for two days instead of one, was a sizeable increase in overall storm totals in southern California.

No such stalling was required for the northern California phase of ARkStorm because the January 1969 events, although focused in southern California, also spilled into northern California sufficiently so that having Feb 1986 immediately following, yielded large increases in runoff from ARkStorm (relative to the already large runoff totals from February 1986).

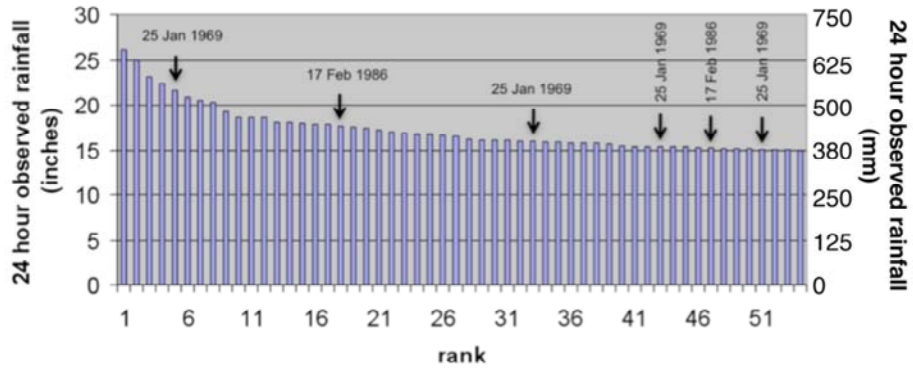


Comparing the weather patterns immediately after the southern-California-focused January 1969 storms to those in the runup to two modern storms focused in northern California, we found dates when there was a relatively small leap involved in stitching January 1969 storms together with quickly following set of storms from February 1986. No such close matches were found between late January 1969 and the runup to the New Years storm of 1997.



LARGEST HISTORICAL REPORTS OF DAILY PRECIPITATION IN CALIFORNIA

ALL reports of precipitation > 15 in/day at sites in California, 1871-1998

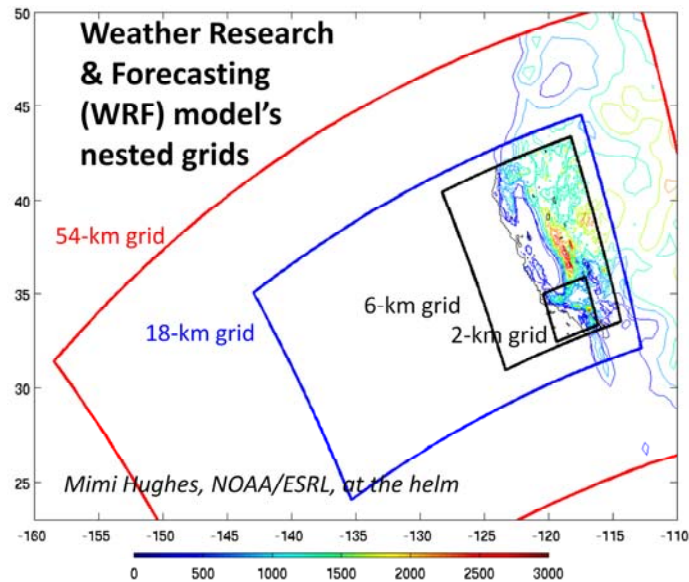


Courtesy, Jim Goodridge, 2008

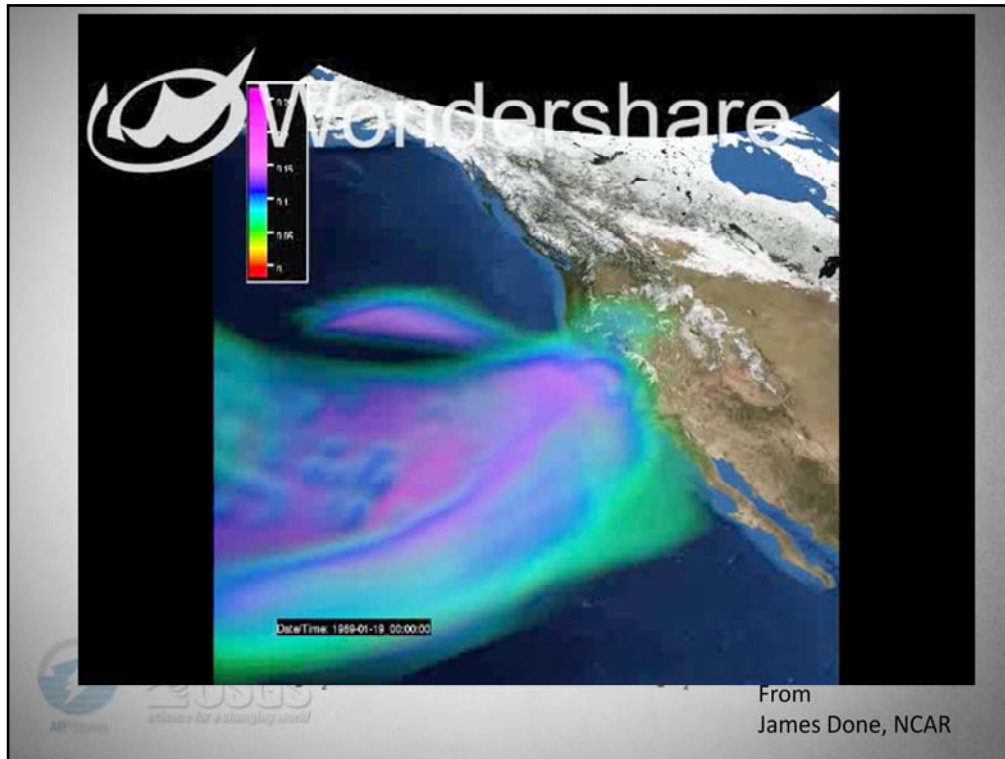
The largest 54 historical reports of daily precipitation in California are shown here. Reports from the peak of the January 1969 storms and from the February 1986 storms are among these largest daily reports. The New Years 1997 storm was very large but did not yield precipitation intense enough to rank among the historical highest values here.



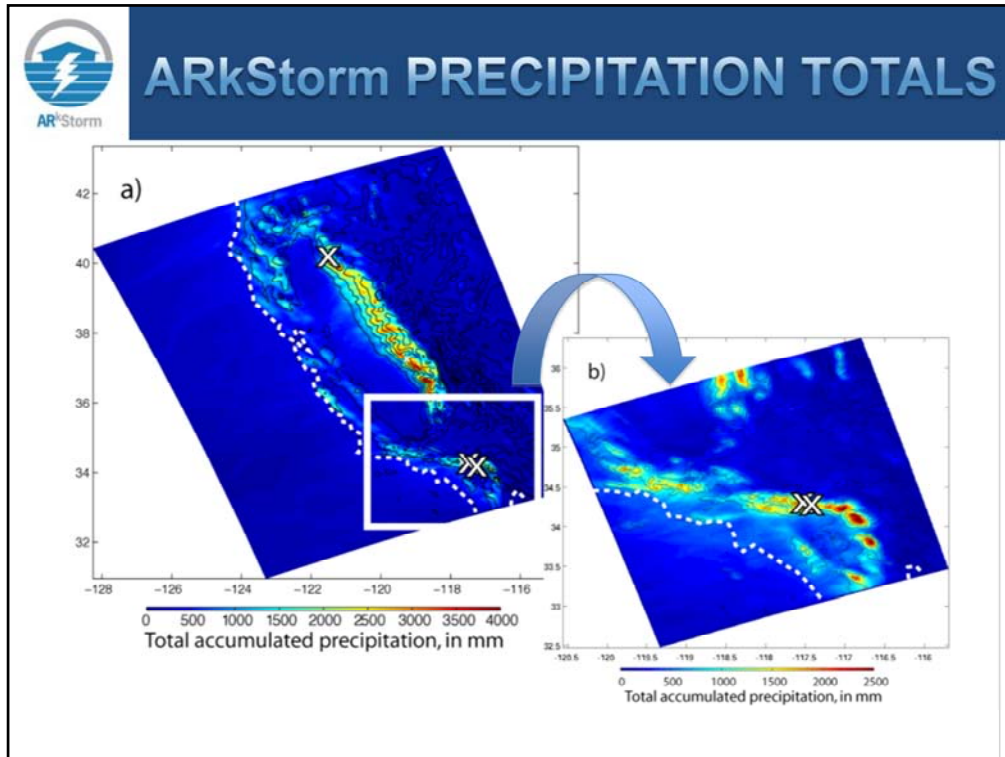
SIMULATING THE SCENARIO



In order to fill in the meteorological details of the ARkStorm sequence with hourly “observations” and on 6-km and 2-km grids, we simulated the ARkStorm events by embedding the WRF weather model in reanalysis of global conditions from each day of the ARkStorm storyline.



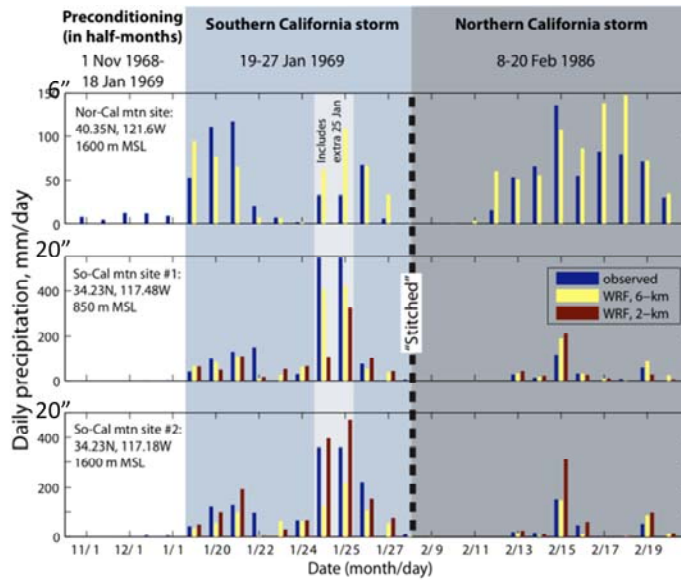
An animation of water-vapor fluxes into the west coast during the course of the ARkStorm sequence illustrates how persistent the storm conditions were, and gives a sense of the level of detail obtained by using WRF to create the ARkStorm meteorology.



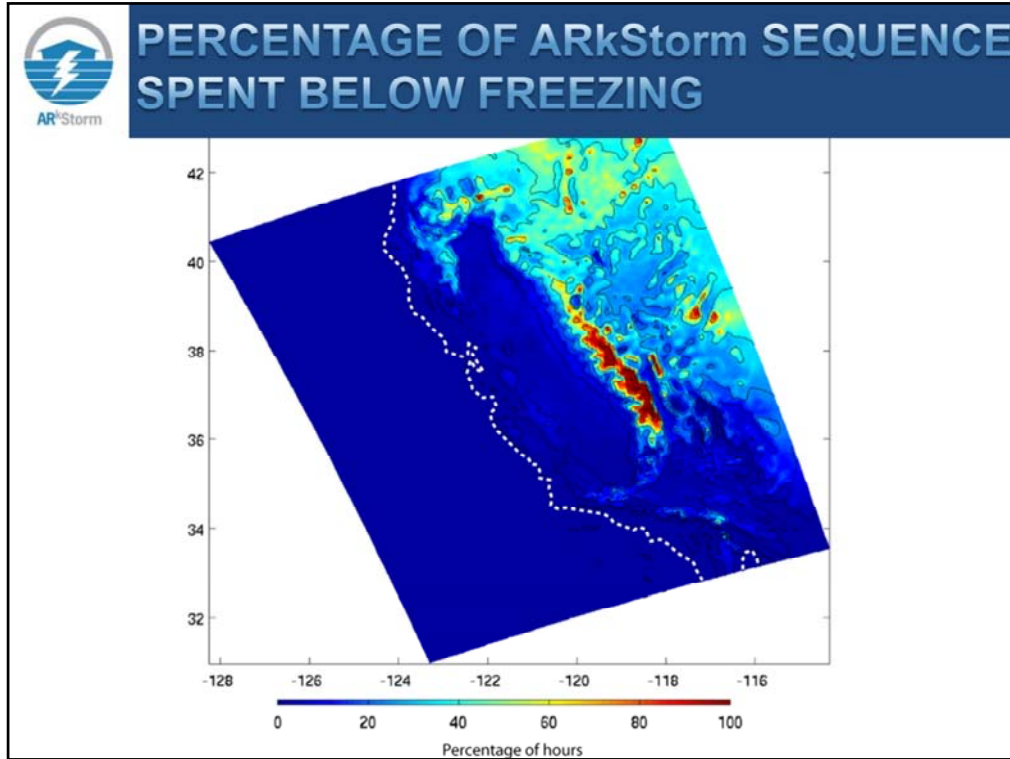
Over 3 meters of precipitation came from the simulated-ARkStorm episode in some places. X's locate sites for which the precipitation sequences are illustrated a few slides from now.



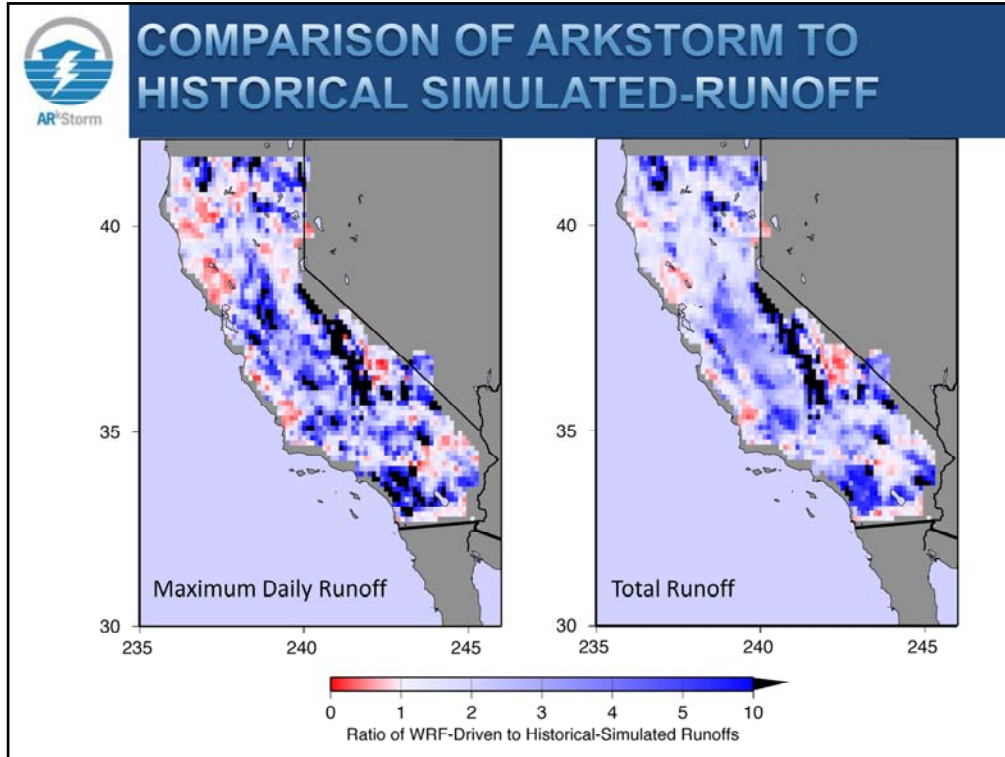
DAILY PRECIPITATION AT THREE SITES



Storm (precipitation) sequences involved several main pulses of precipitation in both northern and southern California. Simulated rainfall rates did not always track directly with observations, but maximum rates and overall rates were reasonably well comparable.

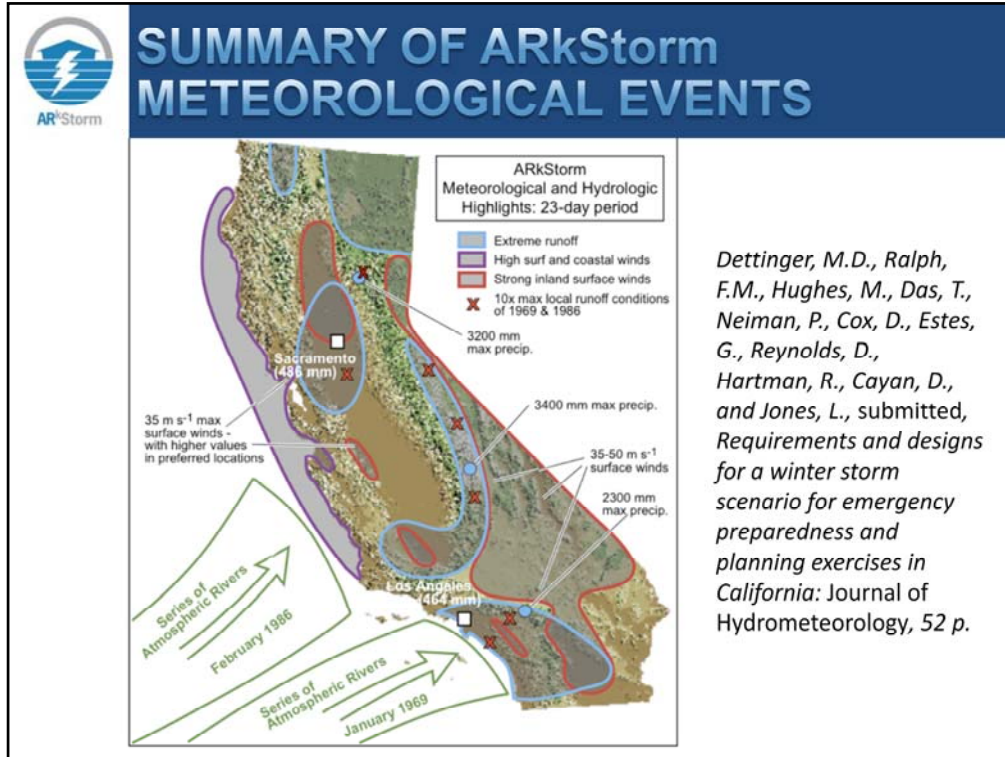


ARkStorm is a warm-storm sequence. Only in the high, southern Sierra was much freezing weather and therefore snowfall generated. Over the rest of the state, ARkStorm precipitation fell mostly as rain, with attendant rapid runoff generation.

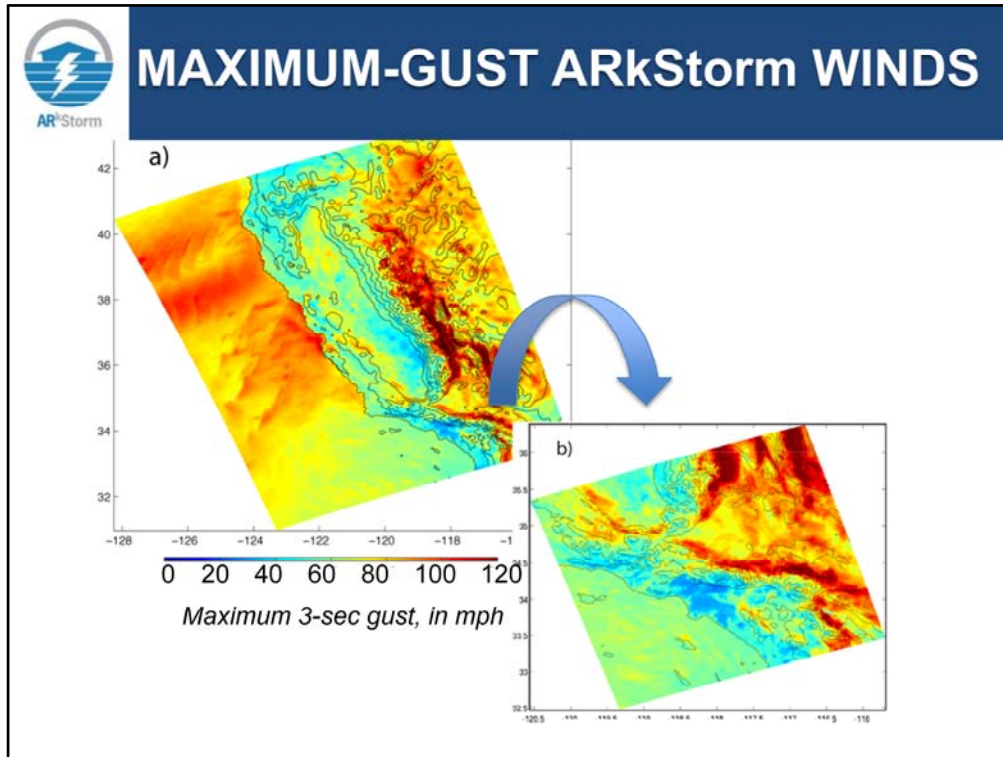


The WRF-simulated daily meteorology was run through the VIC hydrologic model (12-km resolution) and daily runoff rates simulated in response to ARKStorm are compared here to corresponding runoff rates from VIC simulated responses to observed historical events from January 1969 and February 1986.

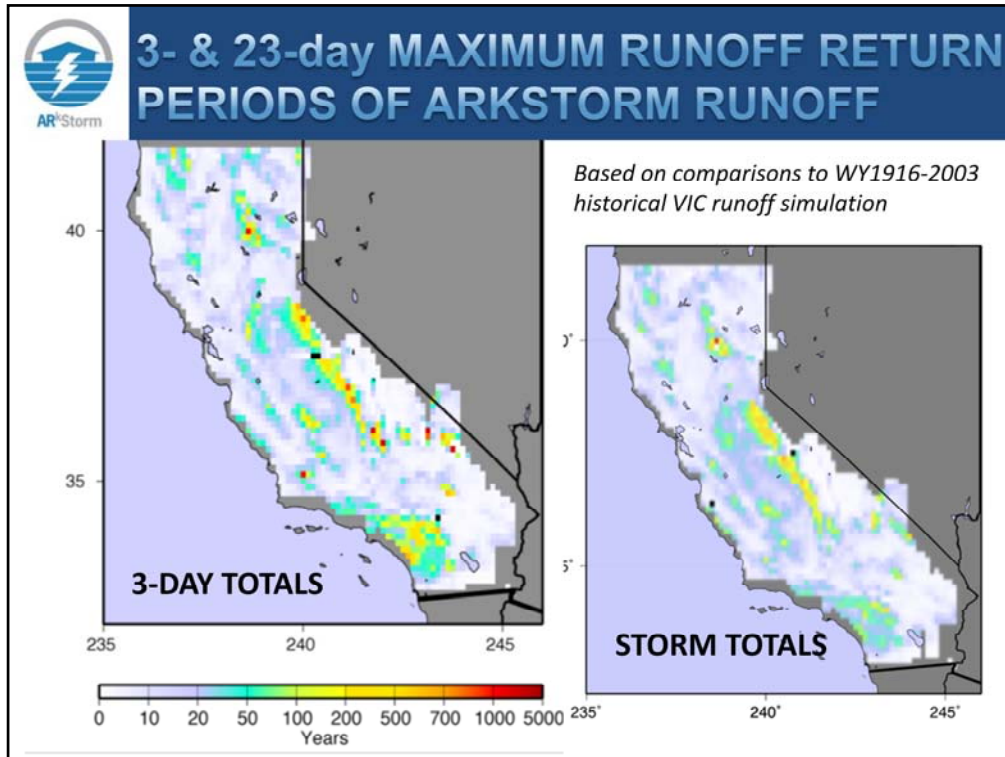
The stitching of storms into rapid succession, and the stalling of the peak January 1969 storm, resulted in significant increases in the amount of runoff from areas like the southern California coastal division, central and southern Sierra, and from catchments above Oroville.



Summary of results, and a paper in journal review that will provide more background and details.



Winds gusted up to over 100 mph offshore, along ridge lines and in the high desert. Even those yellow, 60-80 mph gusts also would result in significant structure damages in many other parts of the state.



Finally (for this talk), the VIC-simulated runoff rates were compared to a much longer observations-driven VIC simulation to estimate recurrence intervals, using standard flood return-interval methods. ARkStorm runoff rates rose to > 500 yr levels in places in the Sierra Nevada, to > 200 yr levels in much of the central and southern Sierra and across much of the southern California coastal plain, and approached 100 yr levels in many settings in southern California and around the Central Valley. These return-interval estimates steered some eventual ad-hoc estimates of flooding and inundations that were generated by others on the Multi-hazards Project team.

