Understanding Central Arizona Precipitation

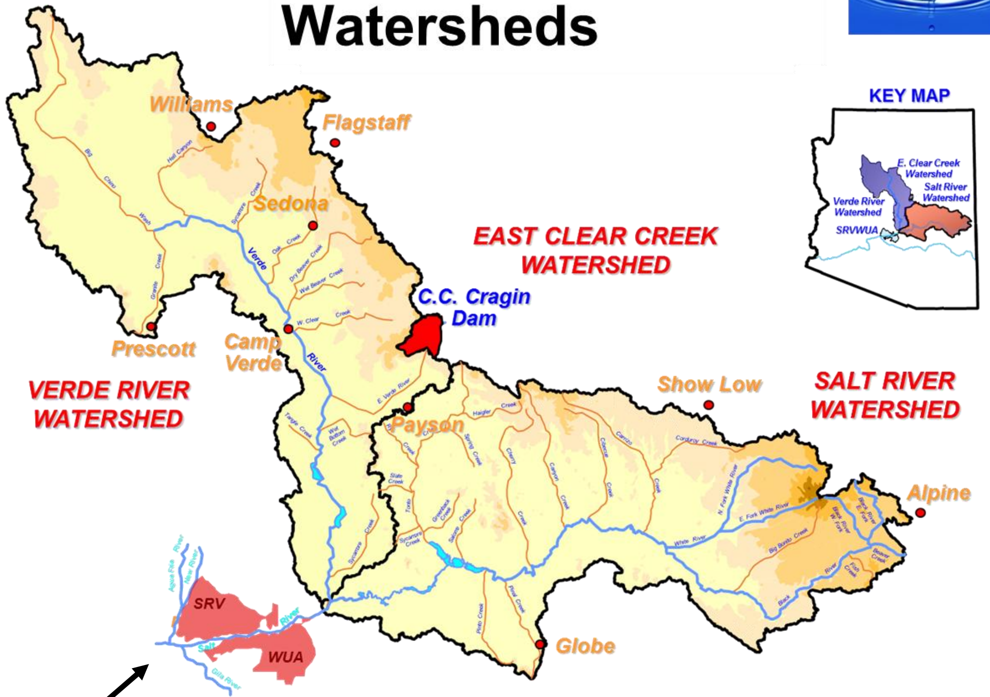
Bohumil M. Svoma, PhD
Principal Climate Scientist / Meteorologist

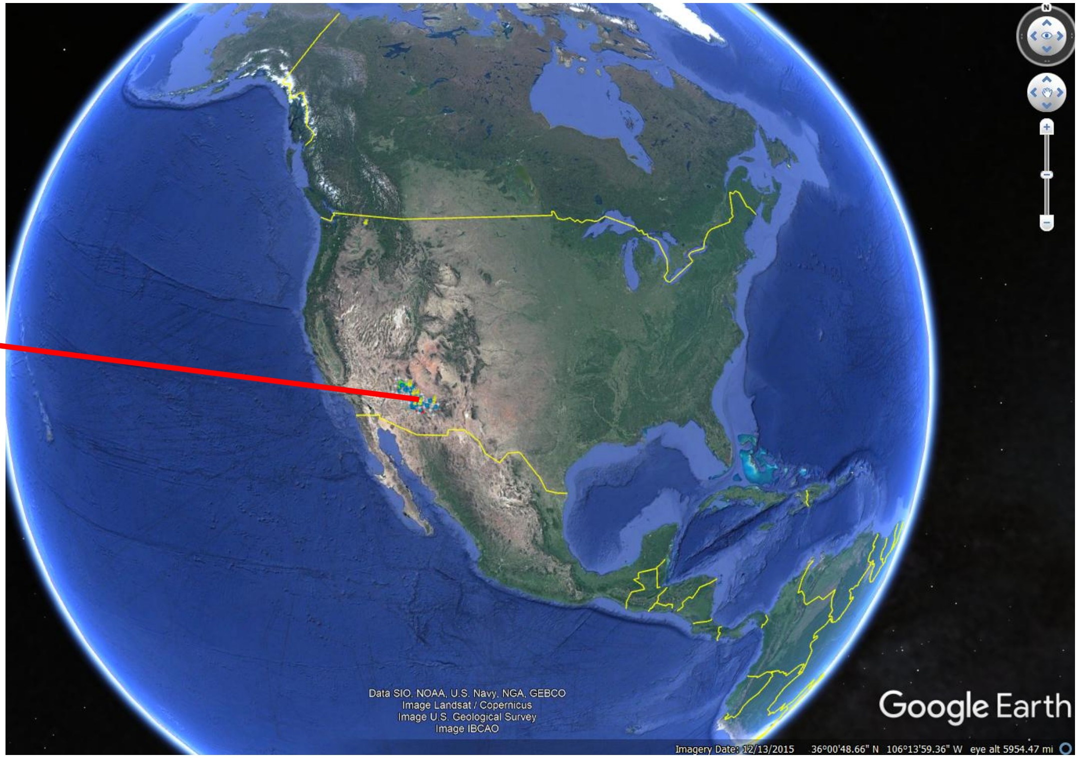
Delivering water and power™

Outline

- **Salt-Verde Overview**
- **Part 1: Importance of Temperature**
- **Part 2: Advancing understanding of central AZ precipitation**

Salt and Verde Watersheds





Annual deliveries of 1.0×10^9 m^3 to Phoenix, AZ, USA (population over 4 million)

- ~27,000 km^2, ~34.25°N, and ~600 km east of the Pacific Ocean
- Elevations from 400-3,800 m, annual precipitation from 250-900 mm yr^{-1}
- Runoff = 1.4×10^9 m^3 (52 mm) yr^{-1}
- As largest water supplier to the Phoenix Metro Area, the Salt River Project operates 7 reservoirs and ~270 wells

Delivering water and power™

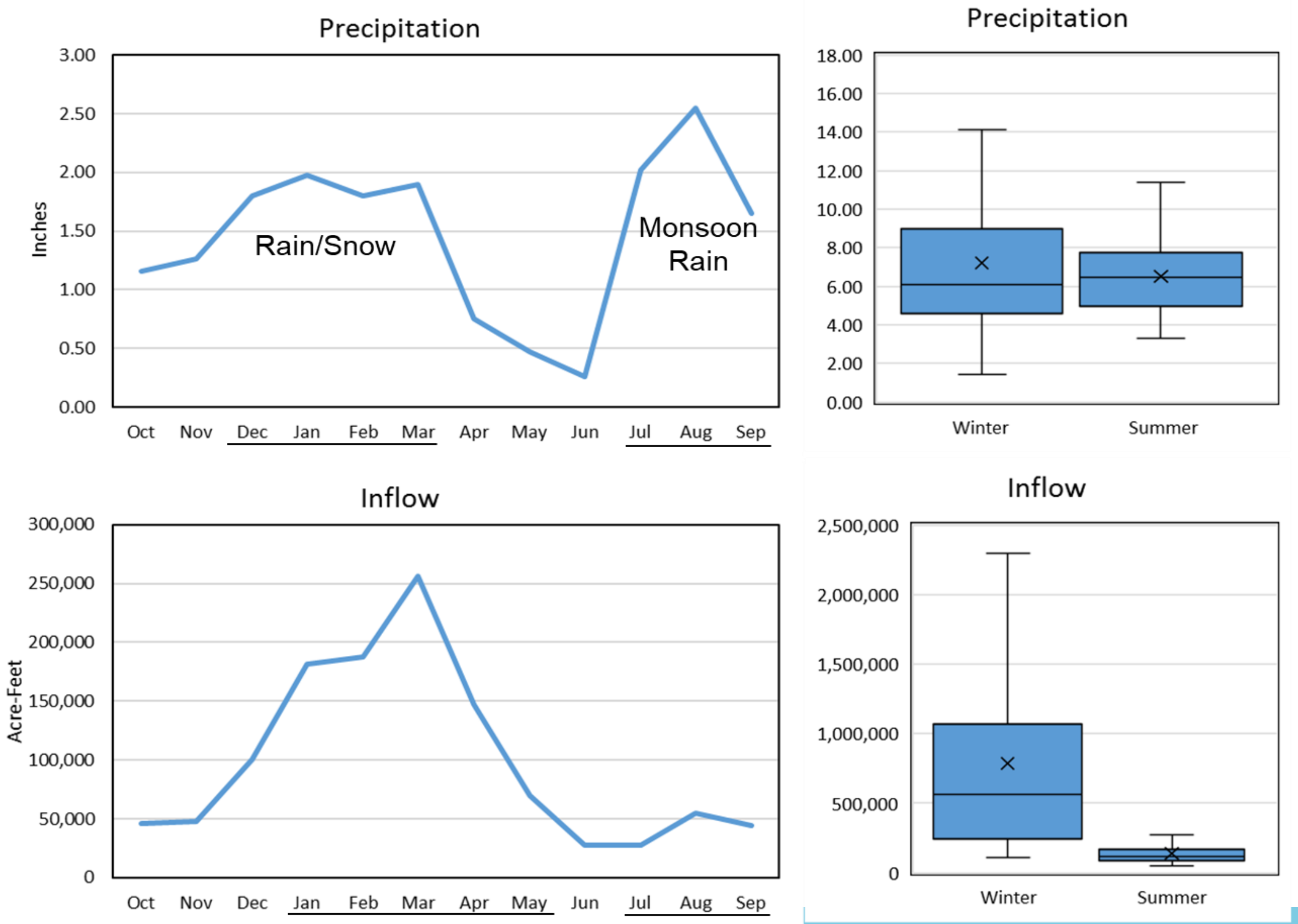
Verde – Steep Terrain, Flashy Runoff

Salt – Shallow Terrain, More Snowmelt, Less Flashy

Horseshoe Dam January 2010

Tempe Town Lake

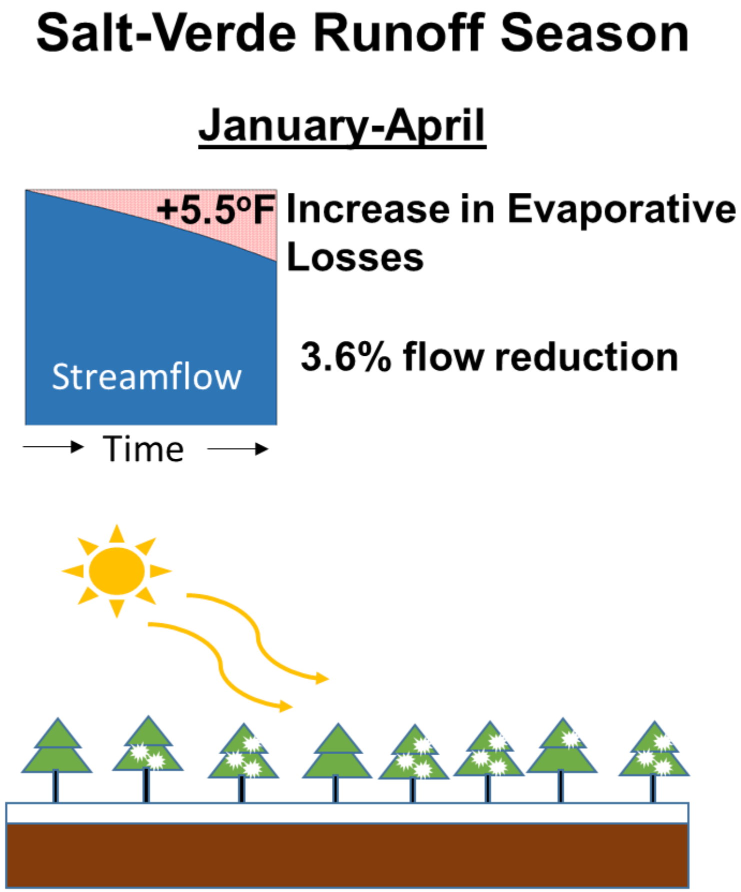
Salt-Verde Precipitation and Streamflow

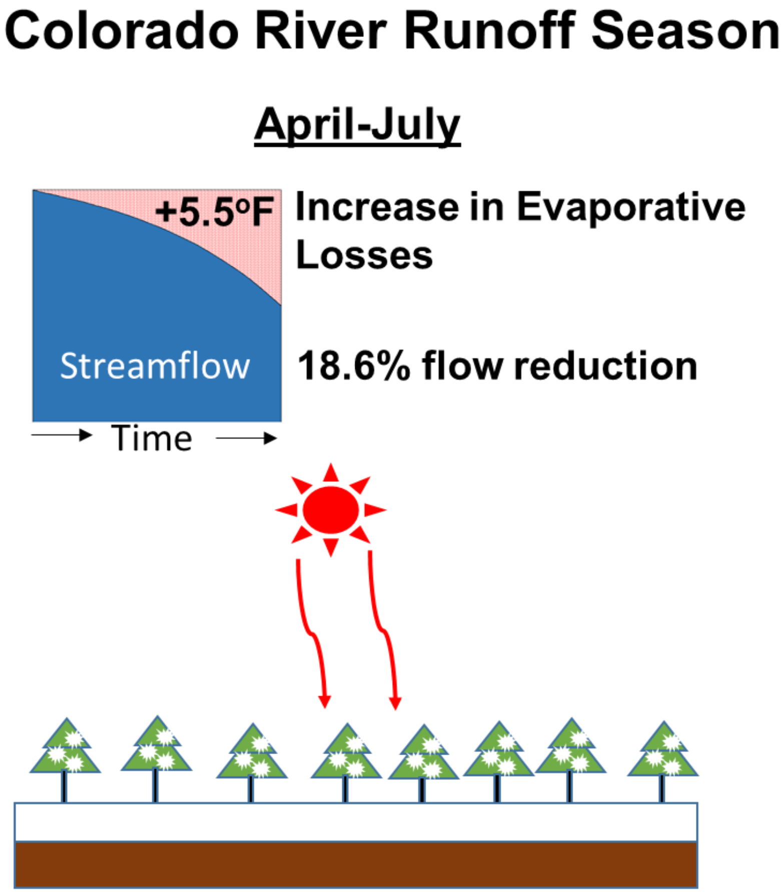


Climate Change: Salt-Verde vs Colorado River

The peak energy available for evaporative loss occurs 3 months after peak streamflow on the Salt-Verde (Robles et al. 2020).

This is not case for the UCRB partly contributing to a 5 times greater streamflow sensitivity to warming on the UCRB than the Salt-Verde (BOR 2020).

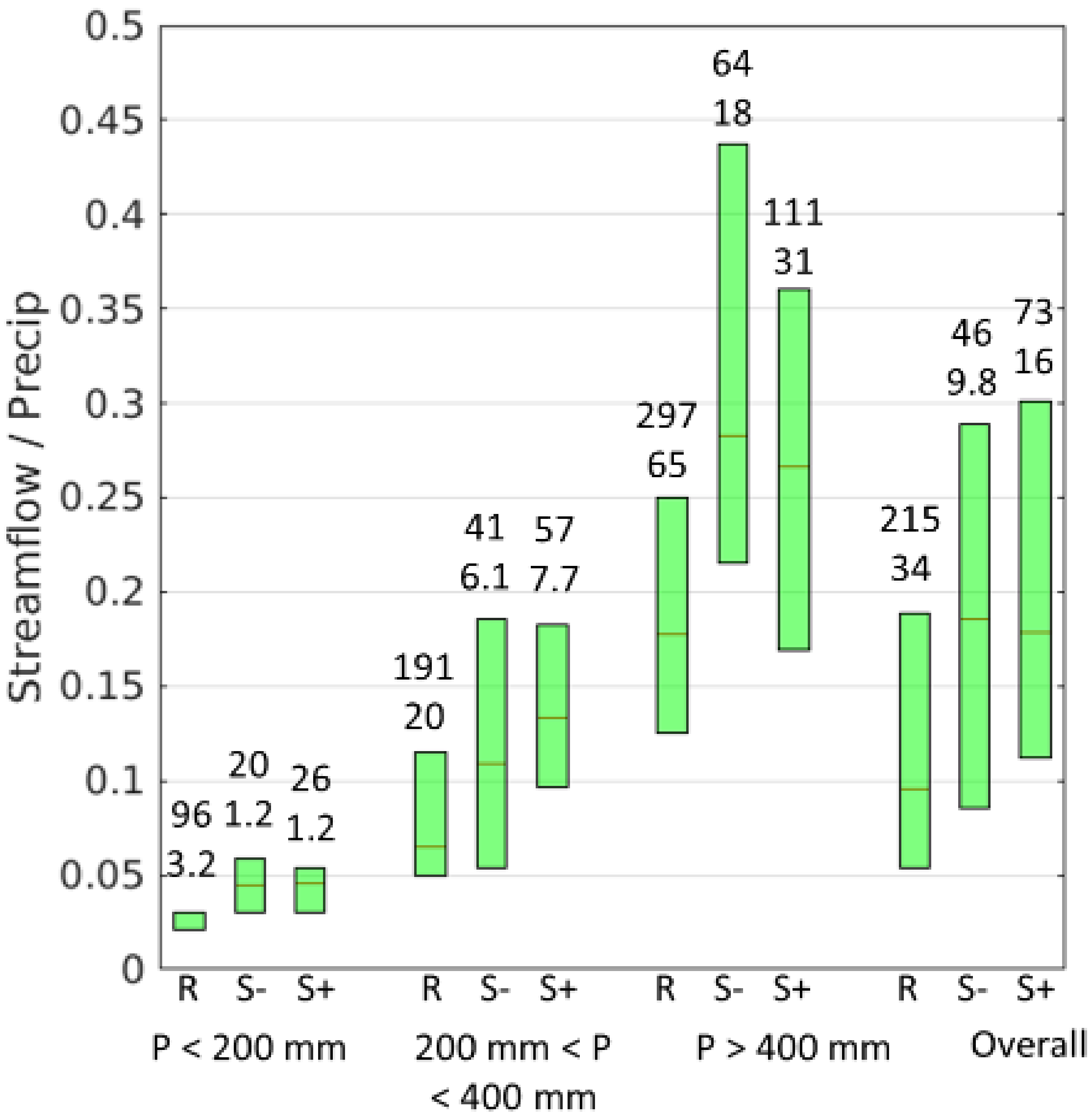




BOR 2020; https://www.usbr.gov/watersmart/pilots/docs/reports/Final_Reservoir_Operations_Pilot_Report-Salt_and_Verde_Az.pdf
Robles, M. et al. 2020: *Water* 2021, *13*(1), 3; https://doi.org/10.3390/w13010003
Woodhouse, C.A. and B. Udall. 2022. Upper Gila, Salt, and Verde Rivers: Arid land rivers in a changing climate. Earth Interactions 1, 1-14. https://doi.org/10.1175/EI-D-21-0014.1

Salt River Rain vs Snow

Average modeled runoff efficiencies for rainfall (R), snowmelt originating from elevations < 2250 m (S-), and snowmelt originating from elevations > 2250 m (S+) for years with different amounts of precipitation. The top (bottom) number is the average rain/melt input (and streamflow)



Although less efficient, rainfall generates more flow than snowmelt.

Experimental design not focused on responses to change, therefore, it is possible that snowmelt is more efficient because it generally occurs after rainfall.

RESEARCH ARTICLE

Subseasonal to seasonal streamflow forecasting in a semiarid watershed

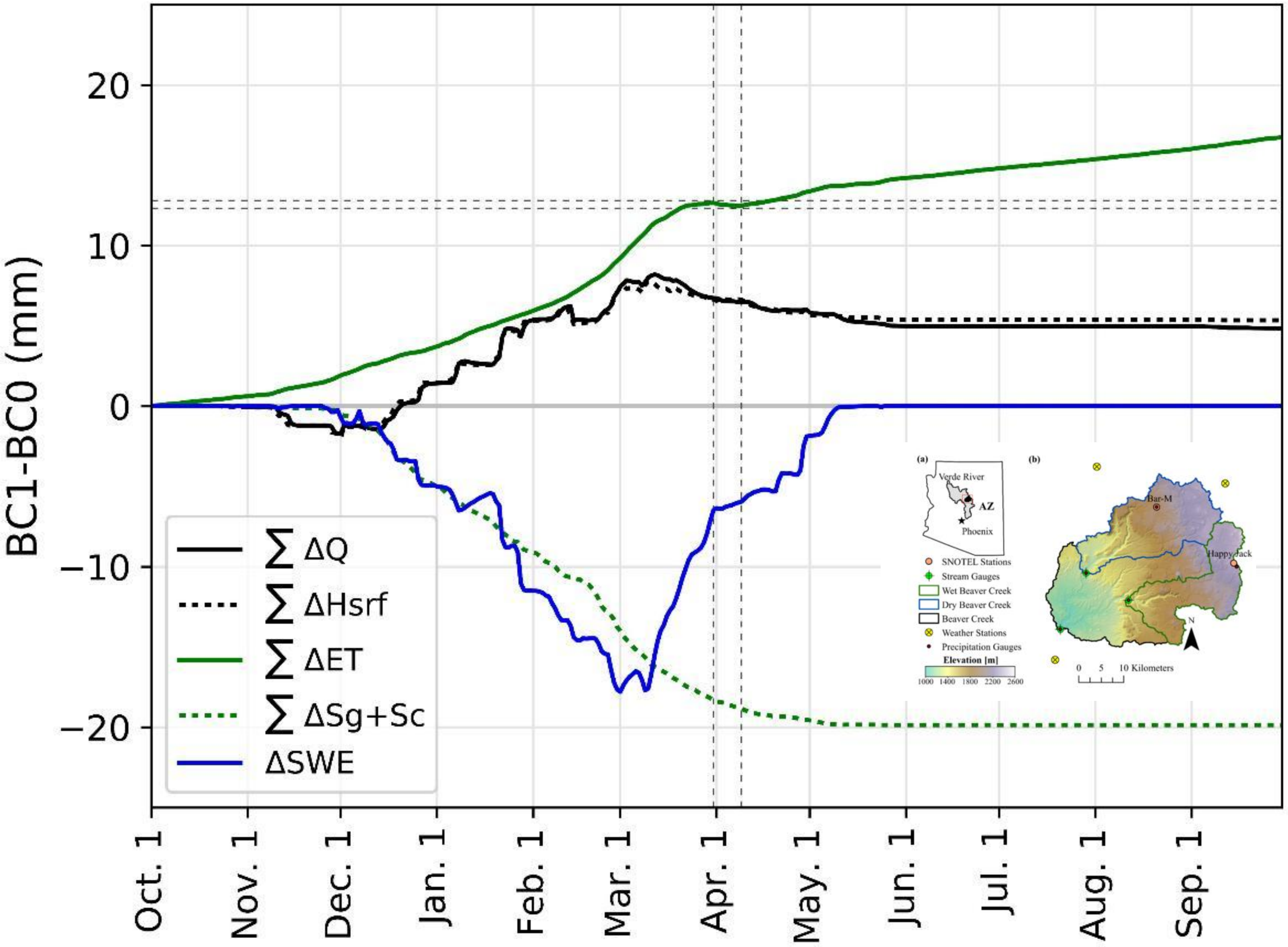
Patrick D. Broxton, Willem J. D. van Leeuwen, Bohumil M. Svoma, James Walter, Joel A. Biederman

First published: 25 July 2023 | https://doi.org/10.1111/1752-1688.13147

Change in Beaver Creek Water Budget +1°C

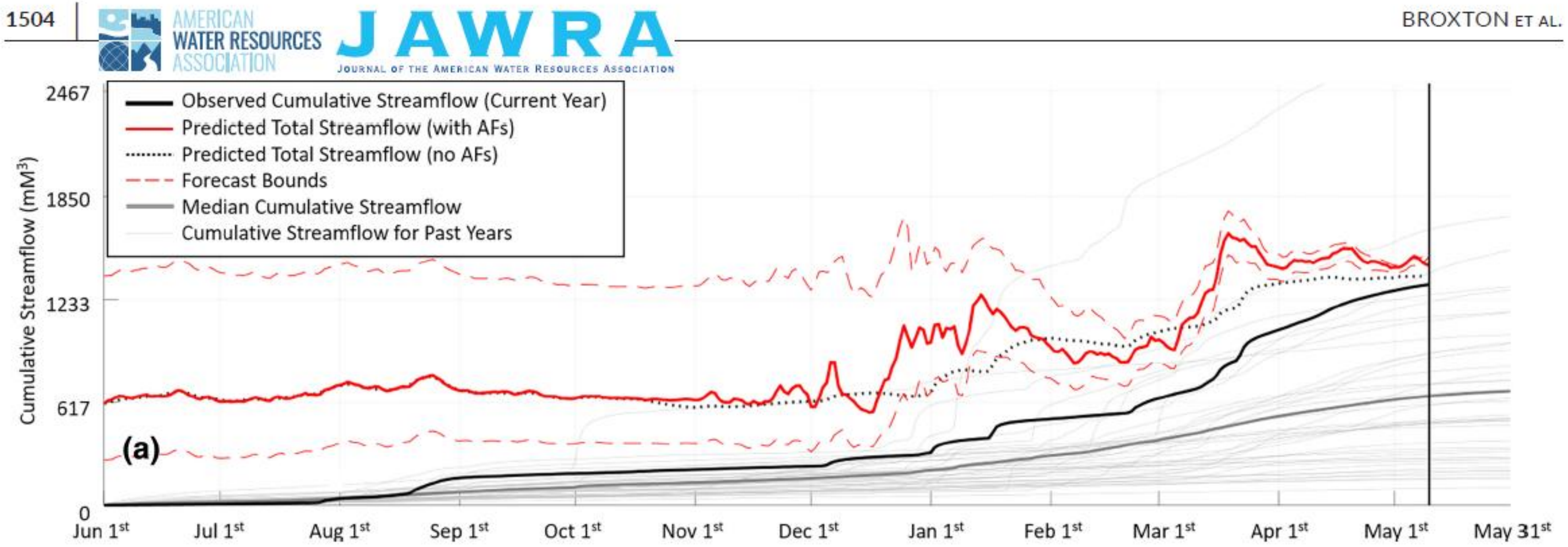
- **Streamflow increases with 1°C warming.**
    - **Snow sublimation (S_g+S_c) change overcomes Evapotranspiration (ET) change up to ~2°C warming**

    - **Exceptions are dry years when ET change overcomes S_g+S_c change**



Cederstrom, C., E. Vivoni, G. Mascaro, and B. Svoma (2023), Forest Treatment Effects on Watershed Responses Under Warming. Responses in Arizona under Warming Conditions, Water Resources Research, https://doi.org/10.1029/2023WR035627

SRP-UA Operational Forecast Tool for Additional Streamflow to June 1st

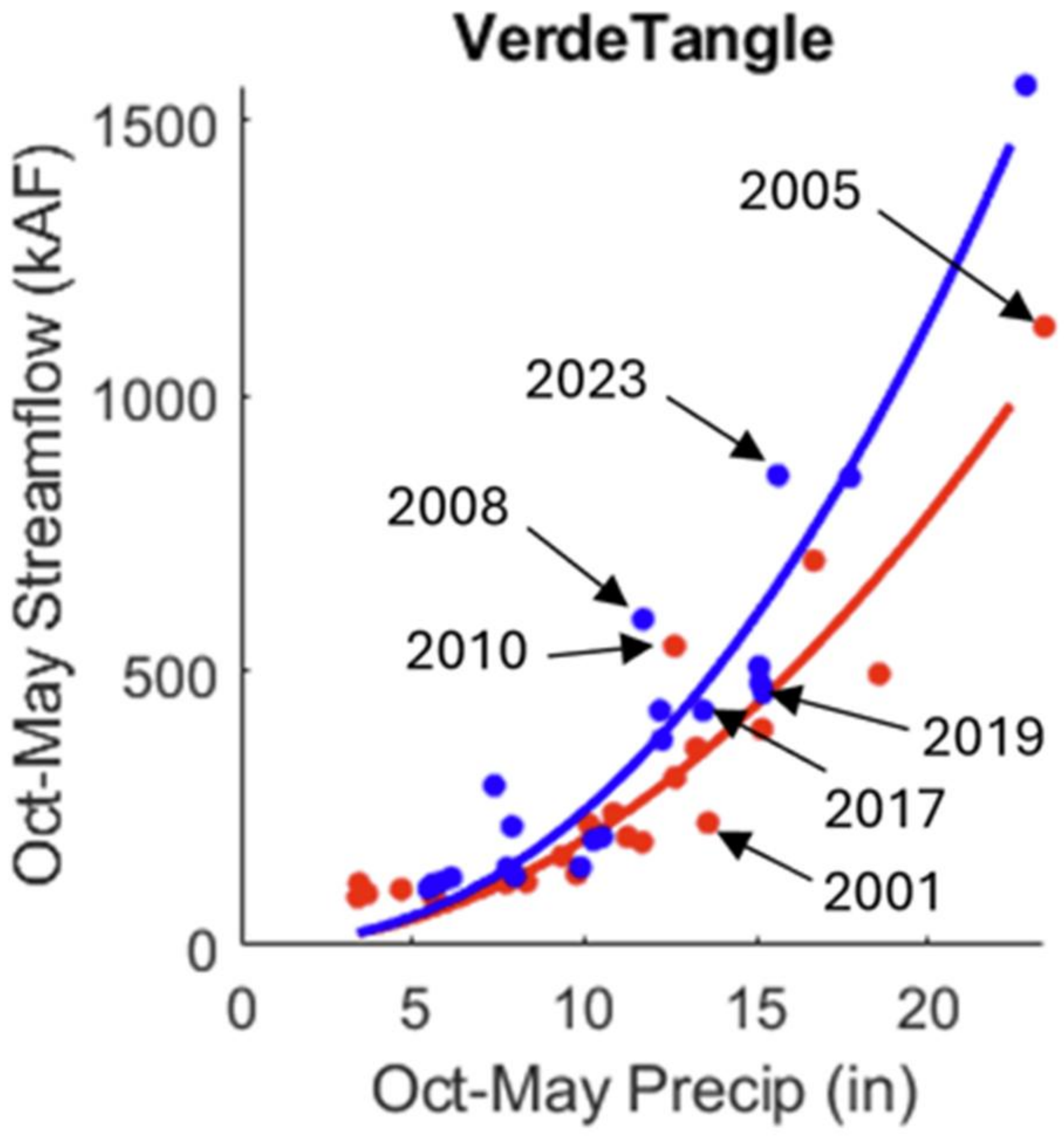


RESEARCH ARTICLE

Subseasonal to seasonal streamflow forecasting in a semiarid watershed

Patrick D. Broxton, Willem J. D. van Leeuwen, Bohumil M. Svoma, James Walter, Joel A. Biederman

First published: 25 July 2023 | https://doi.org/10.1111/1752-1688.13147



Blue = cool/wet summer prior

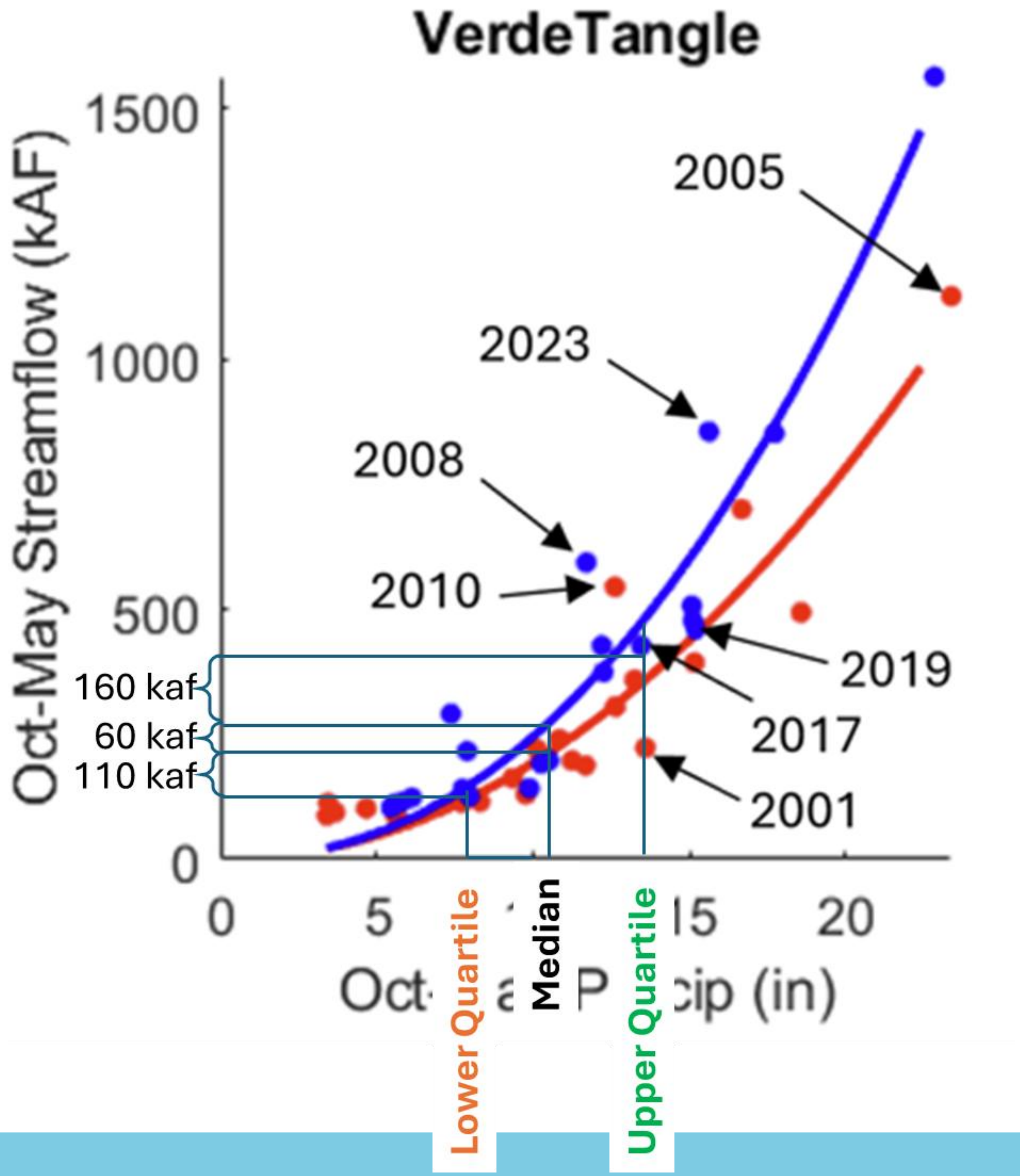
Red = hot/dry summer prior

RESEARCH ARTICLE

Subseasonal to seasonal streamflow forecasting in a semiarid watershed

Patrick D. Broxton, Willem J. D. van Leeuwen, Bohumil M. Svoma, James Walter, Joel A. Biederman

First published: 25 July 2023 | https://doi.org/10.1111/1752-1688.13147



Blue = cool/wet summer prior

Red = hot/dry summer prior

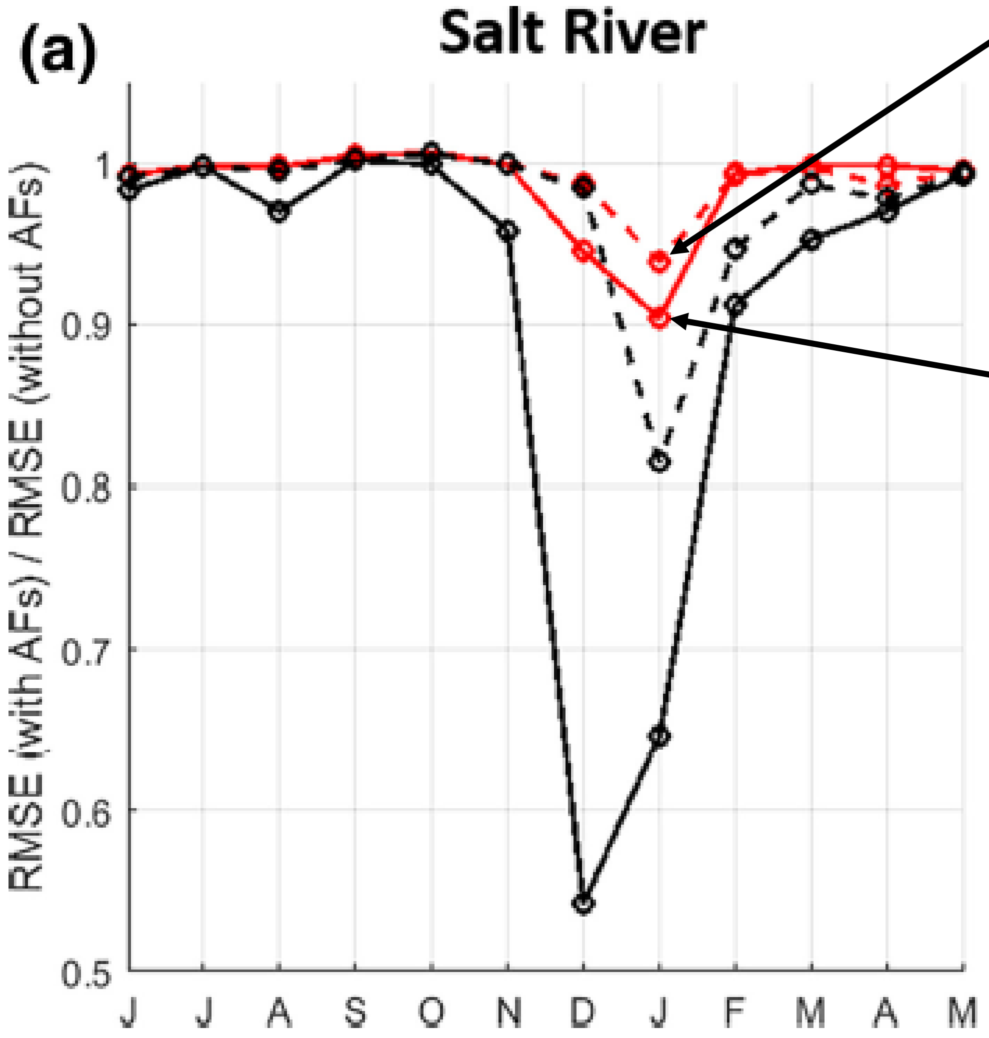
RESEARCH ARTICLE

Subseasonal to seasonal streamflow forecasting in a semiarid watershed

Patrick D. Broxton, Willem J. D. van Leeuwen, Bohumil M. Svoma, James Walter, Joel A. Biederman

First published: 25 July 2023 | https://doi.org/10.1111/1752-1688.13147

Value of Skillful Precipitation Forecasts Peaks in December-January



Incorporating 7-day precip forecasts in January reduces error by 5% (based on GEFS hindcasts)

Incorporating 35-day precip forecasts in January reduces error by 10% (based on GEFS hindcasts)

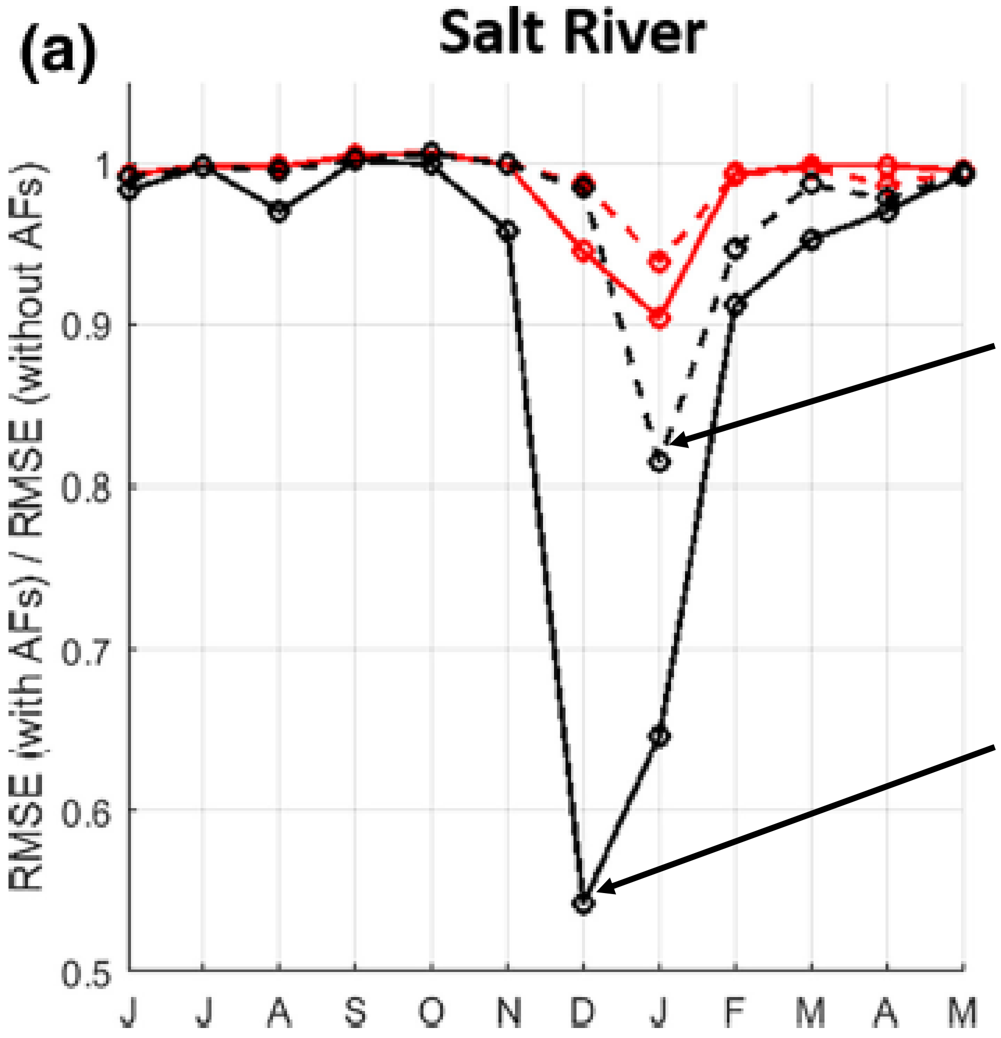
RESEARCH ARTICLE

Subseasonal to seasonal streamflow forecasting in a semiarid watershed

Patrick D. Broxton, Willem J. D. van Leeuwen, Bohumil M. Svoma, James Walter, Joel A. Biederman

First published: 25 July 2023 | https://doi.org/10.1111/1752-1688.13147

Value of Skillful Precipitation Forecasts Peaks in December-January



“Perfect” 7-day forecasts in January reduce error by nearly 20%

“Perfect” 35-day forecasts in December reduce error by nearly 50%

RESEARCH ARTICLE

Subseasonal to seasonal streamflow forecasting in a semiarid watershed

Patrick D. Broxton, Willem J. D. van Leeuwen, Bohumil M. Svoma, James Walter, Joel A. Biederman

First published: 25 July 2023 | https://doi.org/10.1111/1752-1688.13147

Conclusion of Part 1: Salt-Verde Streamflow Relatively Insensitive to Temperature = Precipitation Very Important

Part 2: Advancing understanding of central AZ precipitation

JGR Atmospheres

Research Article

Modeling Salt-Verde Watershed Winter Precipitation Using Convection-Permitting WRF-Simulations With Water Vapor Tracers

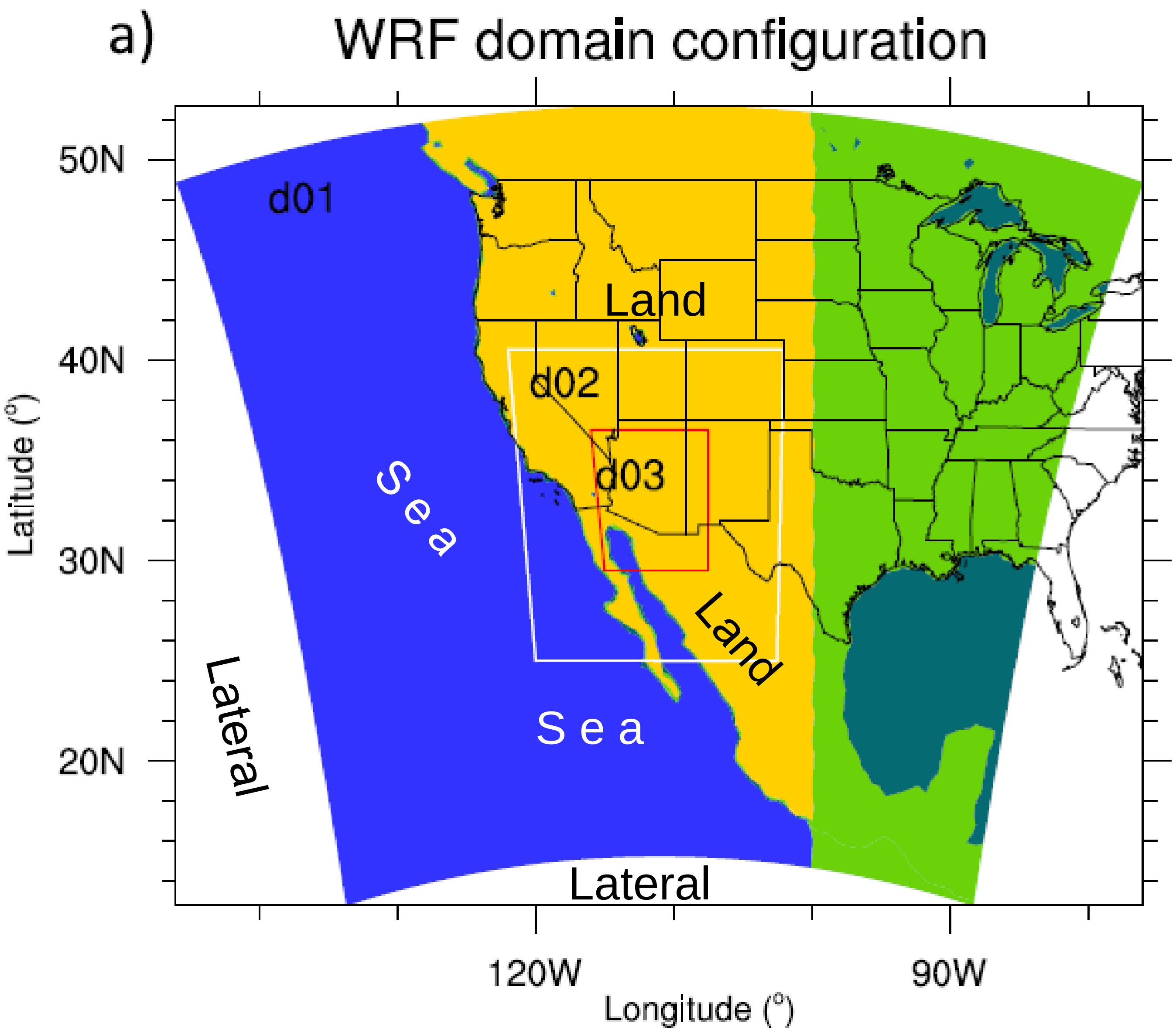
Francisco Salamanca-Palou, Bohumil Svoma, James Walter, Damian Insua-Costa, Gonzalo Miguez-Macho, Joseph Karanja, Matei Georgescu

First published: 19 June 2024 | https://doi.org/10.1029/2024JD041029

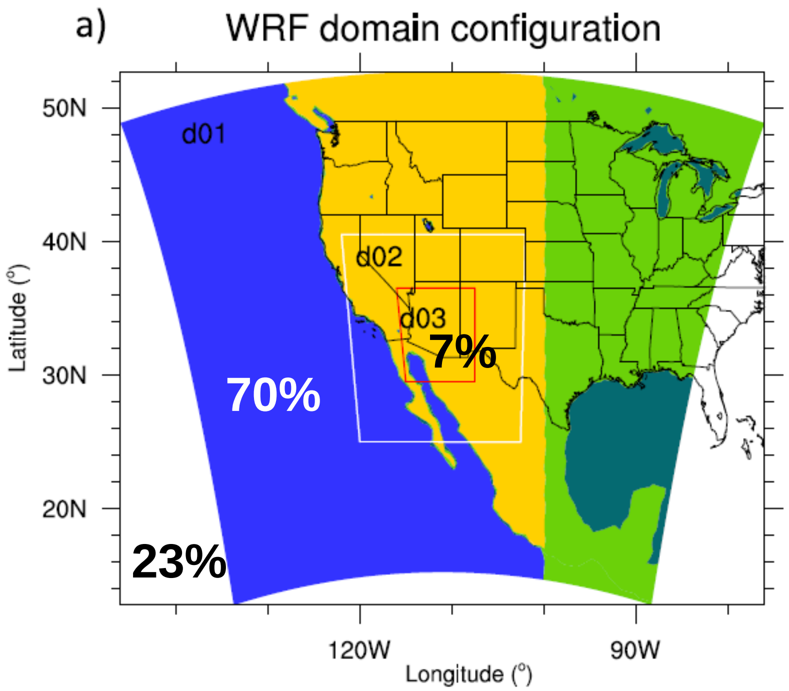
Simulations performed three winters:

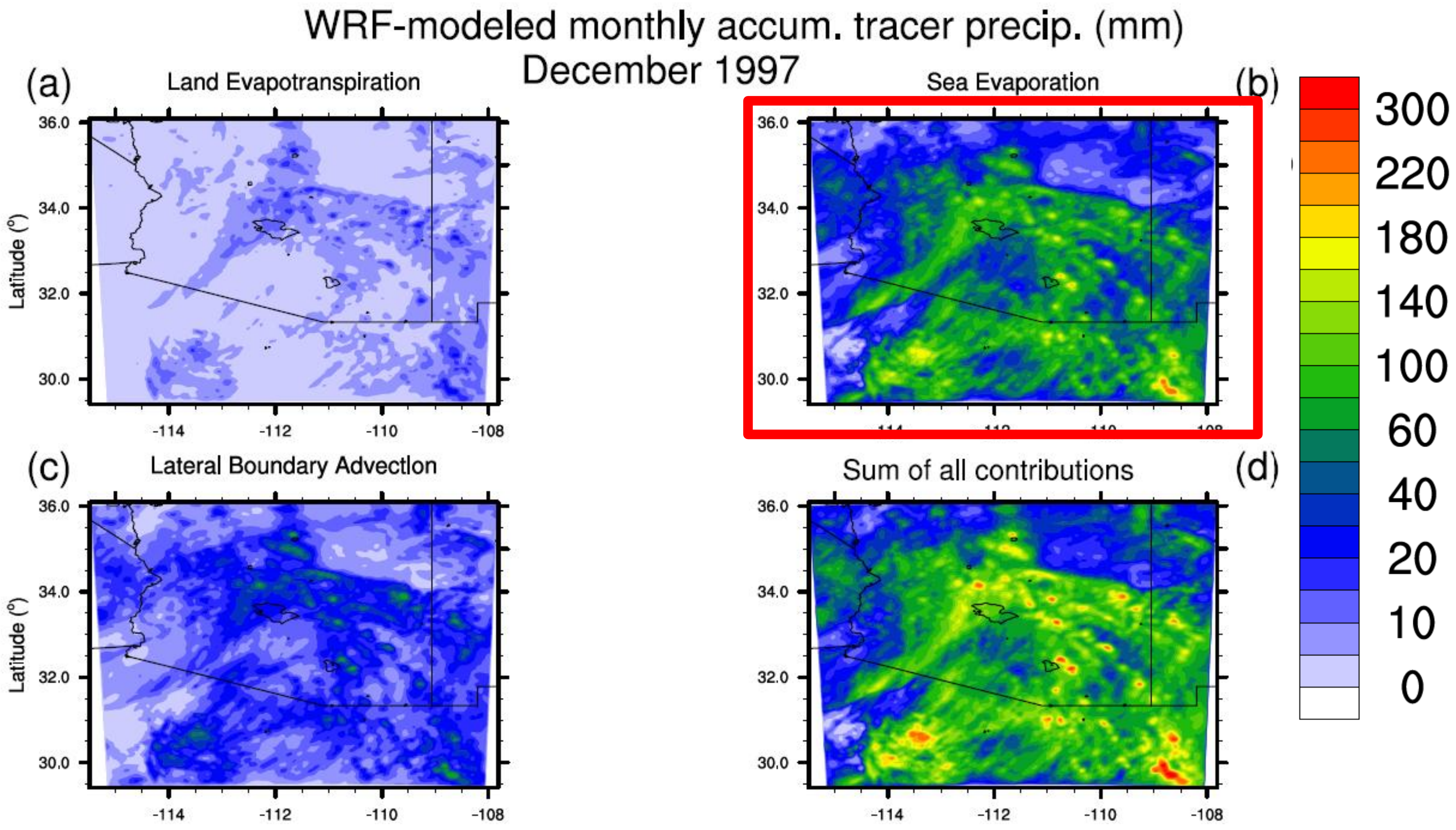
1. **Cold ENSO** (2000)
2. **Warm ENSO (1998)**
3. Neutral ENSO (2017)*

*2017 is weak Cold ENSO by some indices

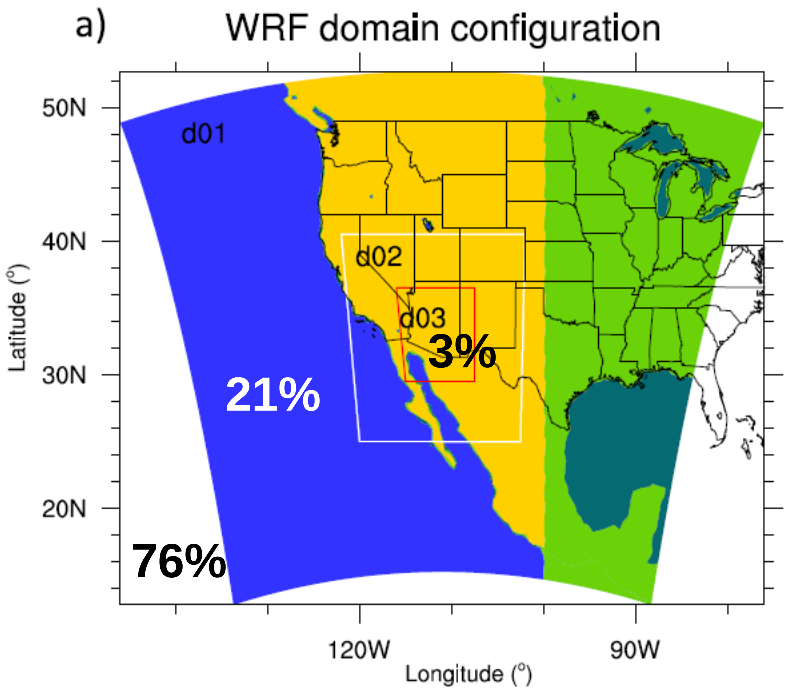

a)
WRF domain configuration
50N
40N
30N
20N
Latitude (°)
120W
90W
Longitude (°)
d01
d02
d03
Land
Land
Sea
Sea
Lateral
Lateral

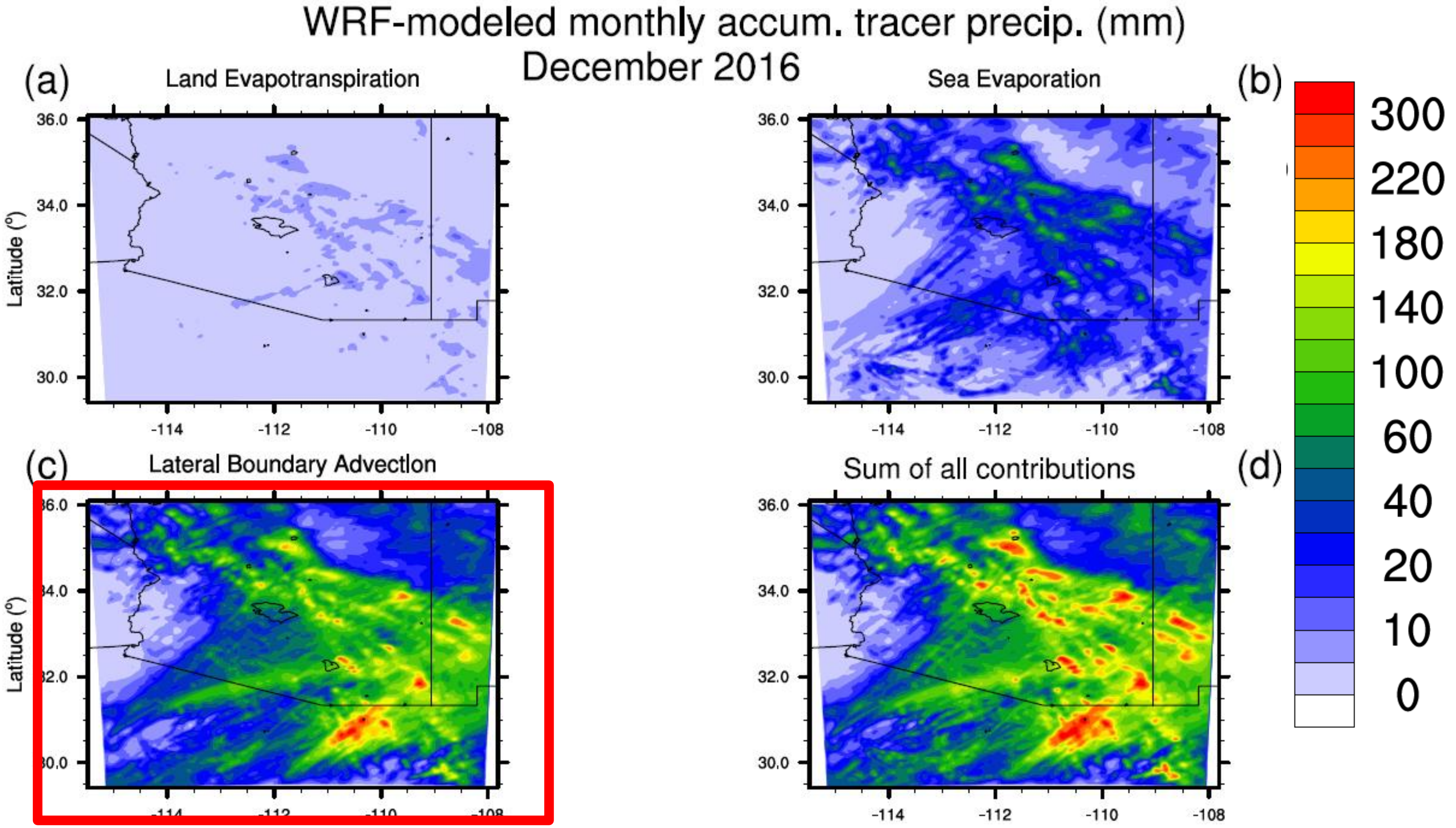
Warm ENSO: December 1997



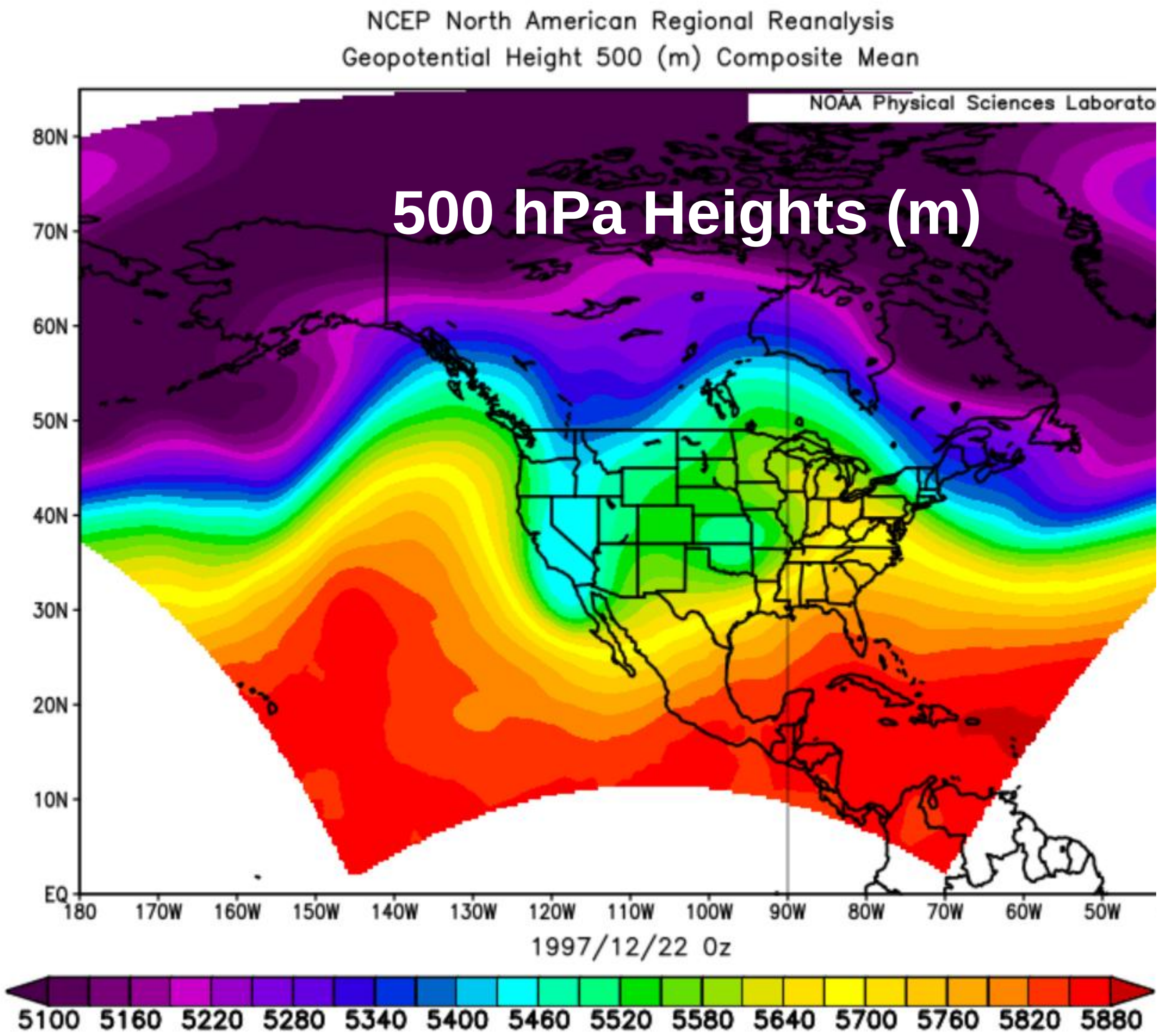


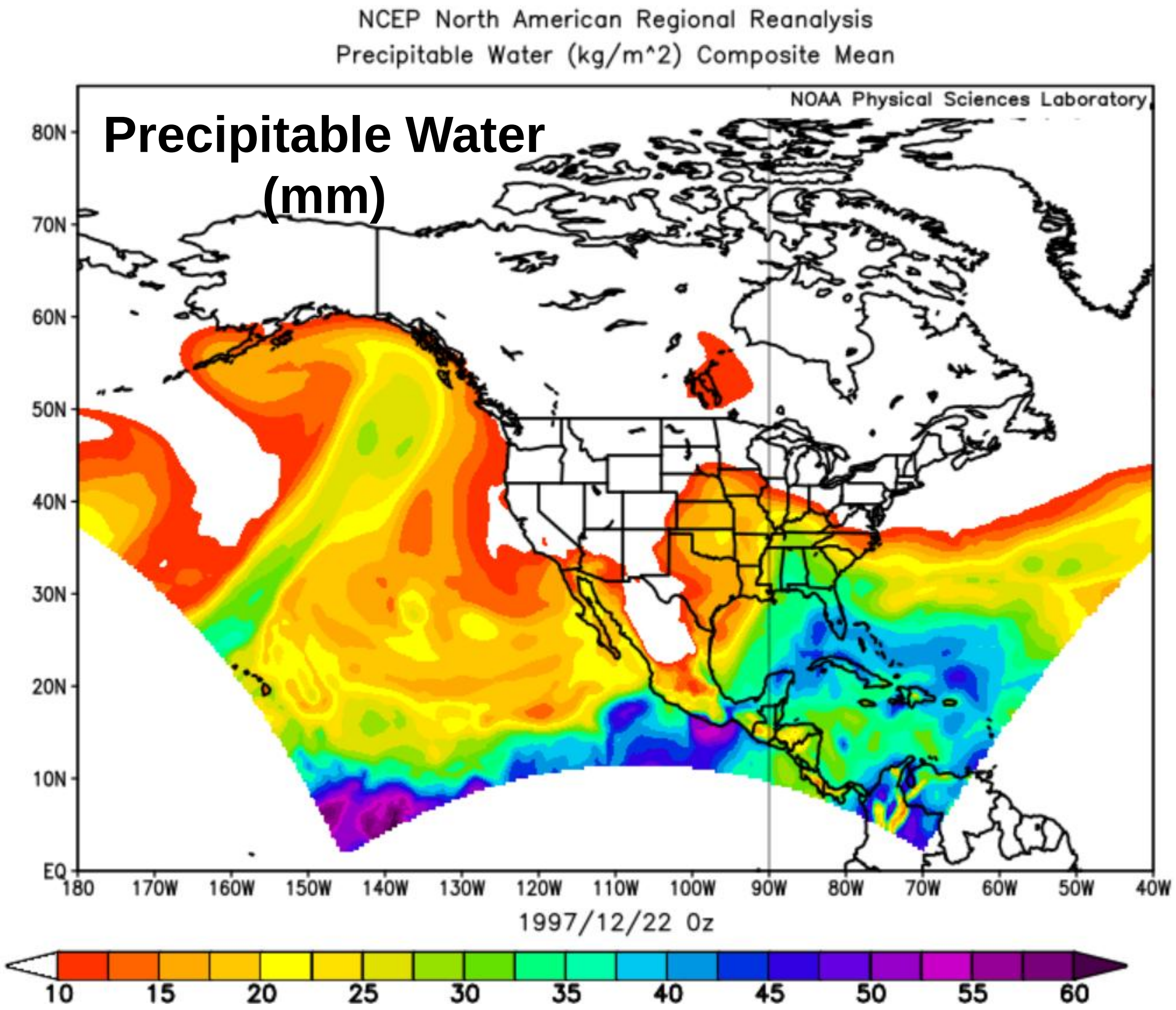
Neutral ENSO: December 2016



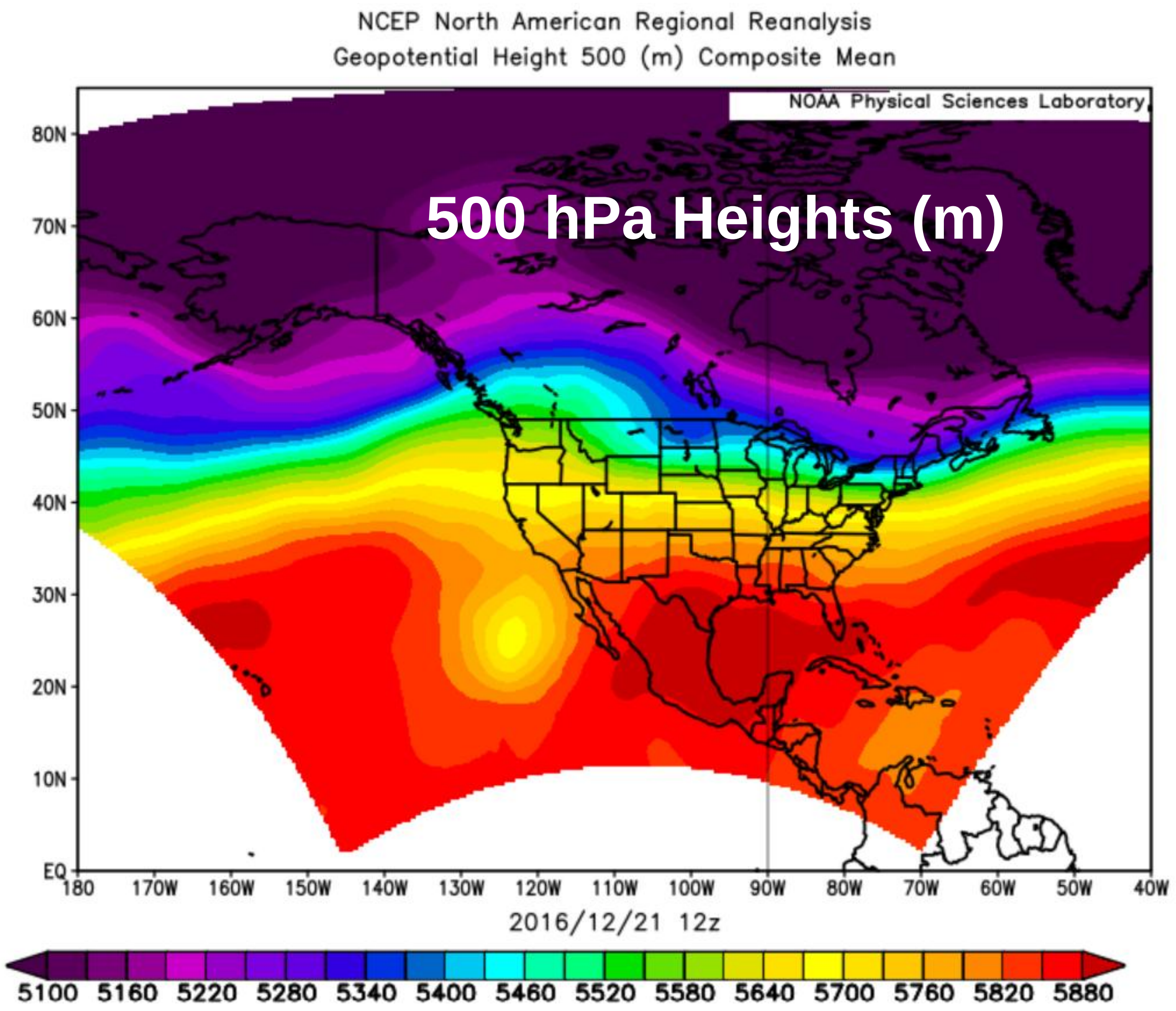


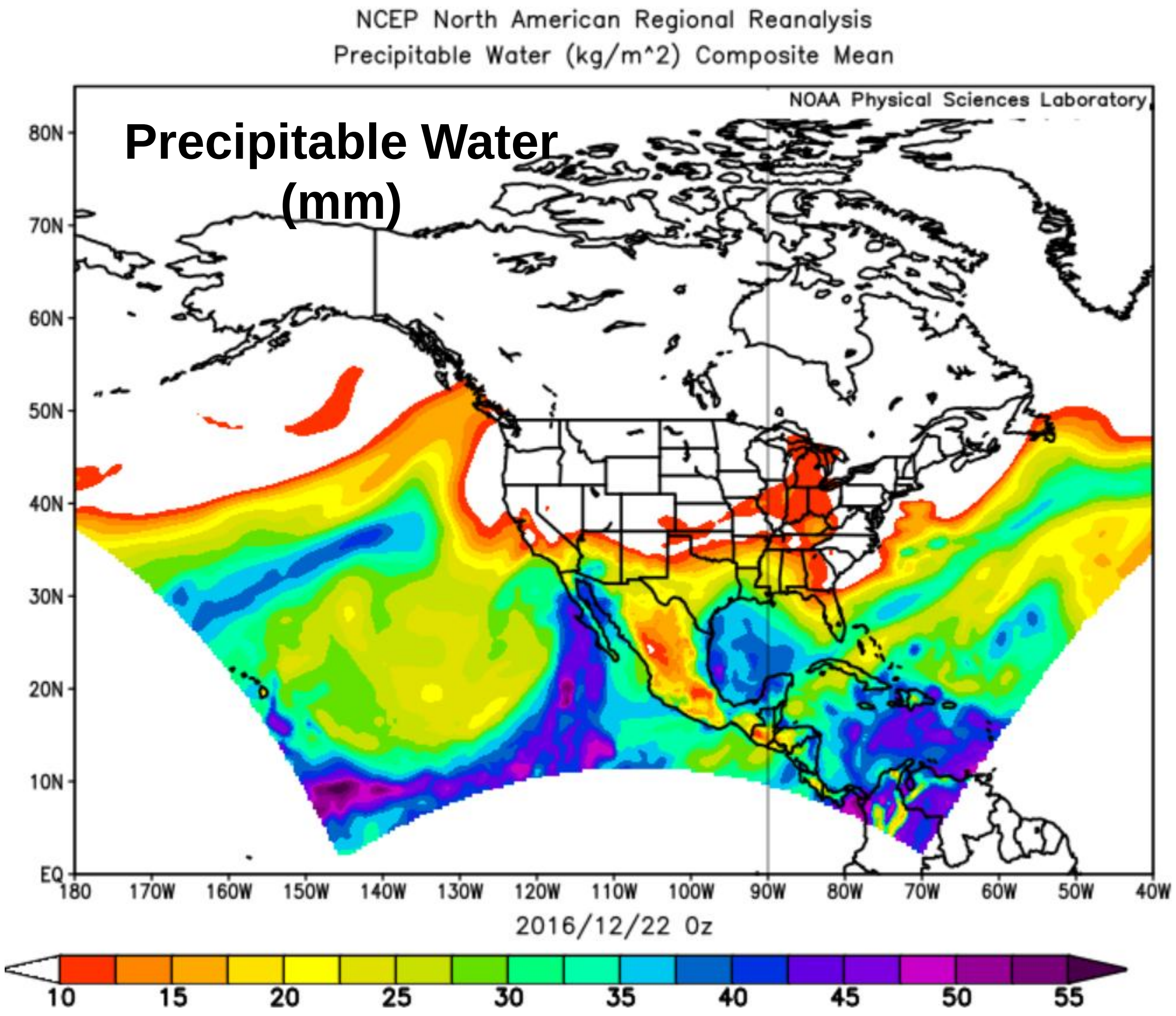
December 1997: Strong Mid-Latitude Cyclone

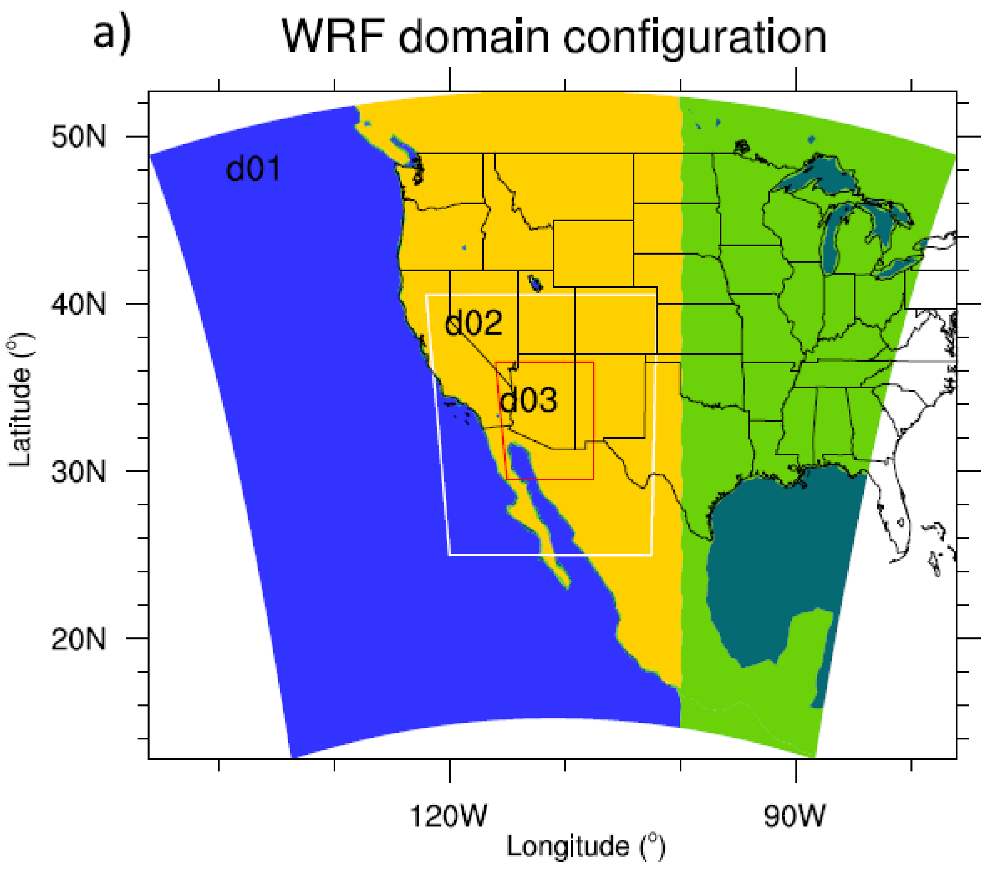


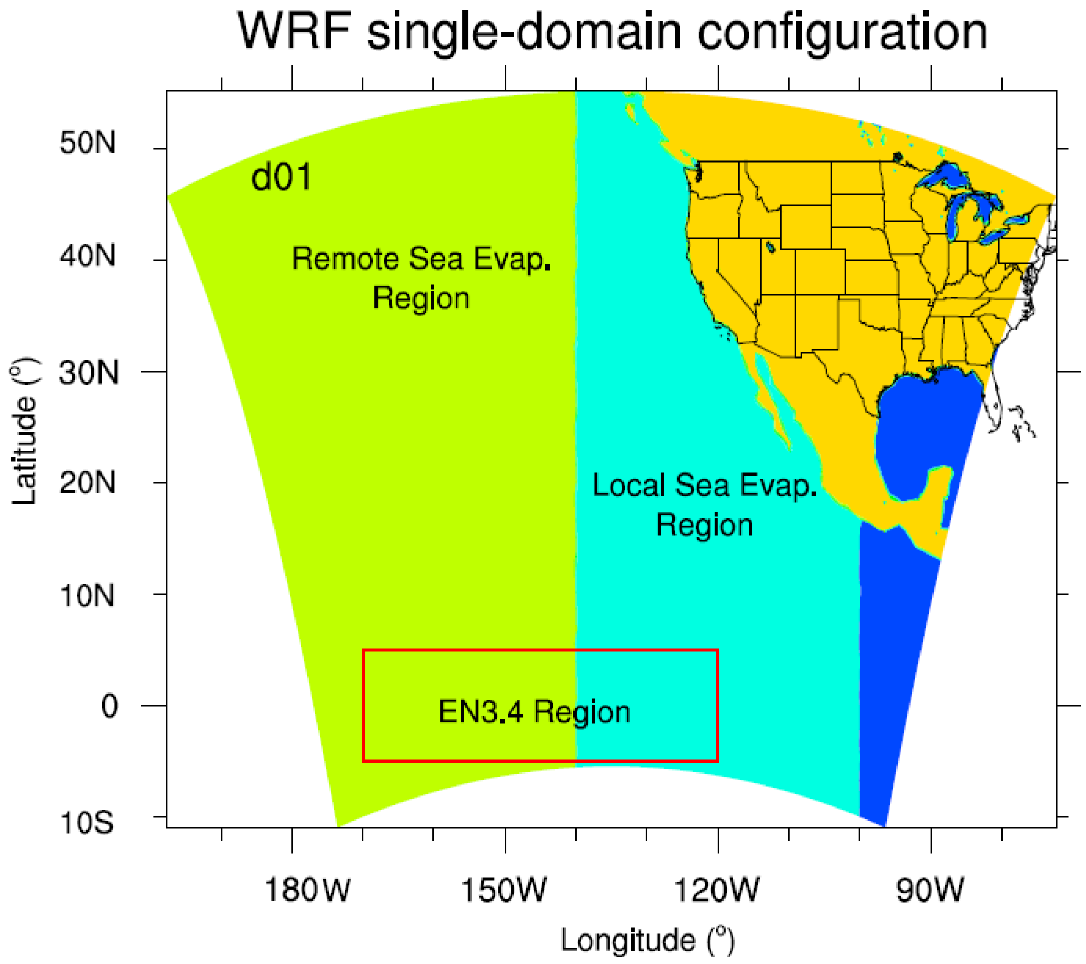


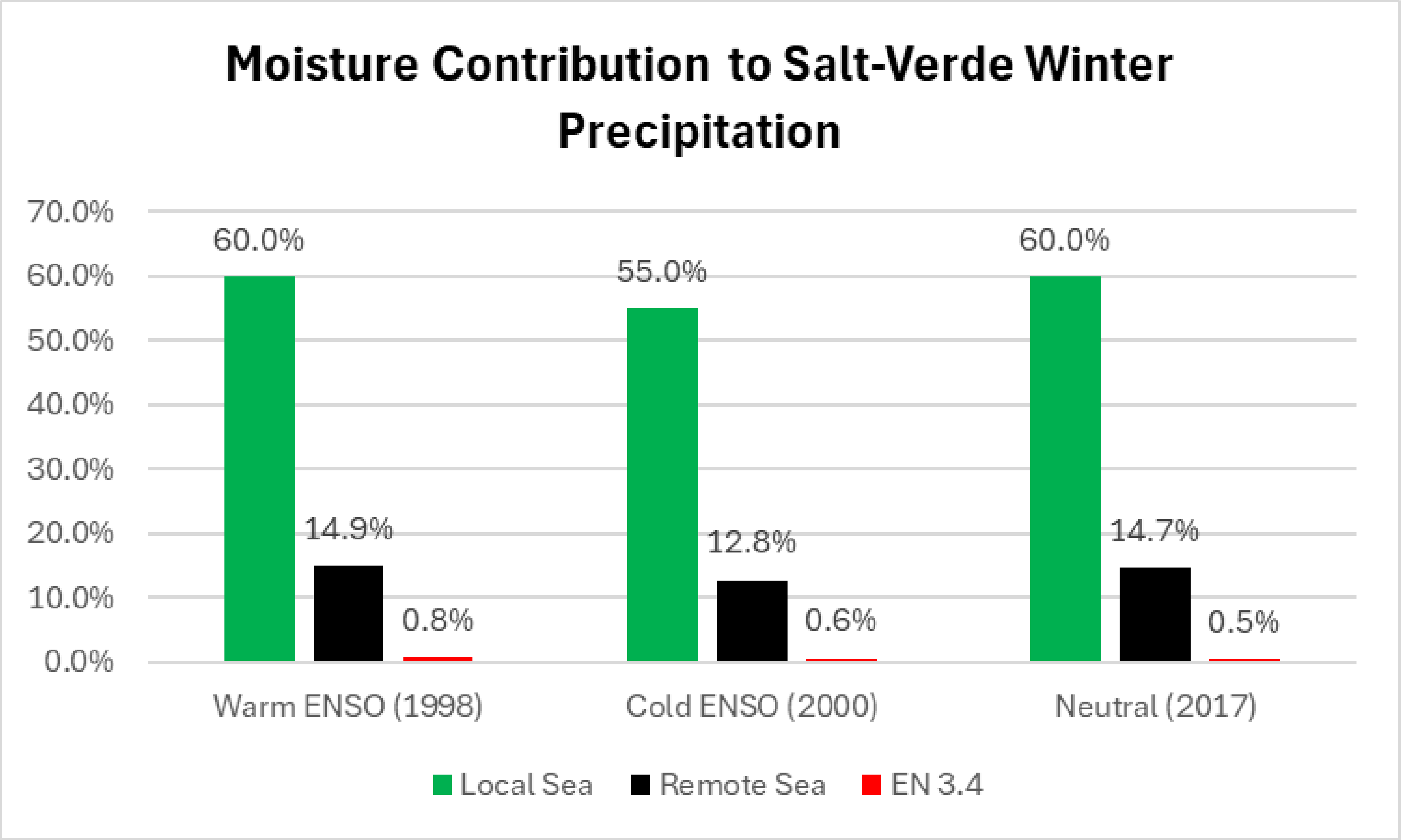
December 2016: Low Latitude Cutoff Low






a)
WRF domain configuration
50N
40N
30N
20N
d01
d02
d03
120W
90W
Longitude (°)
Latitude (°)


WRF single-domain configuration
d01
Remote Sea Evap.
Region
Local Sea Evap.
Region
EN3.4 Region
50N
40N
30N
20N
10N
0
10S
180W
150W
120W
90W
Longitude (°)
Latitude (°)



Moisture Contribution to Salt-Verde Winter Precipitation
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
60.0%
14.9%
0.8%
55.0%
12.8%
0.6%
60.0%
14.7%
0.5%
Warm ENSO (1998)
Cold ENSO (2000)
Neutral (2017)
Local Sea
Remote Sea
EN 3.4

JGR Atmospheres

Research Article

Modeling Salt-Verde Watershed Winter Precipitation Using Convection-Permitting WRF-Simulations With Water Vapor Tracers

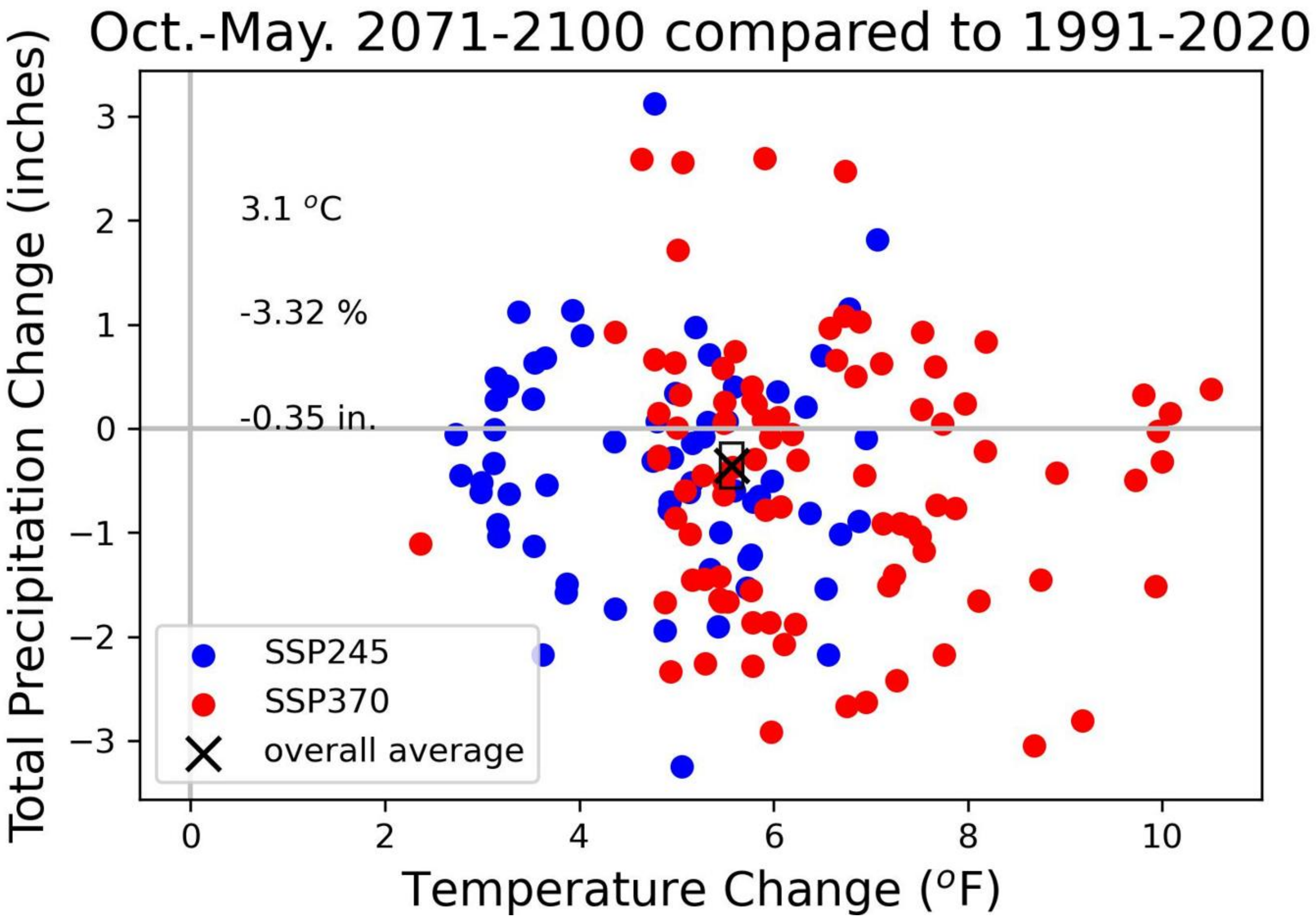
Francisco Salamanca-Palou, Bohumil Svoma, James Walter, Damian Insua-Costa, Gonzalo Miguez-Macho, Joseph Karanja, Matei Georgescu

First published: 19 June 2024 | https://doi.org/10.1029/2024JD041029

Conclusions:

1) Land is a relatively small contributor to moisture advection into central AZ
2) There is not an obvious moisture source region in the Pacific
3) EN 3.4 not a large contributor in any of the 3 seasons examined
4) Need to simulate more years to find systematic differences in moisture source by ENSO phase

CMIP6-LOCA2 Projections for Verde Watershed



Pierce et al. 2023: https://doi.org/10.1175/JHM-D-22-0194.1

IPCC AR6 Confidence in Projected Water Cycle Changes

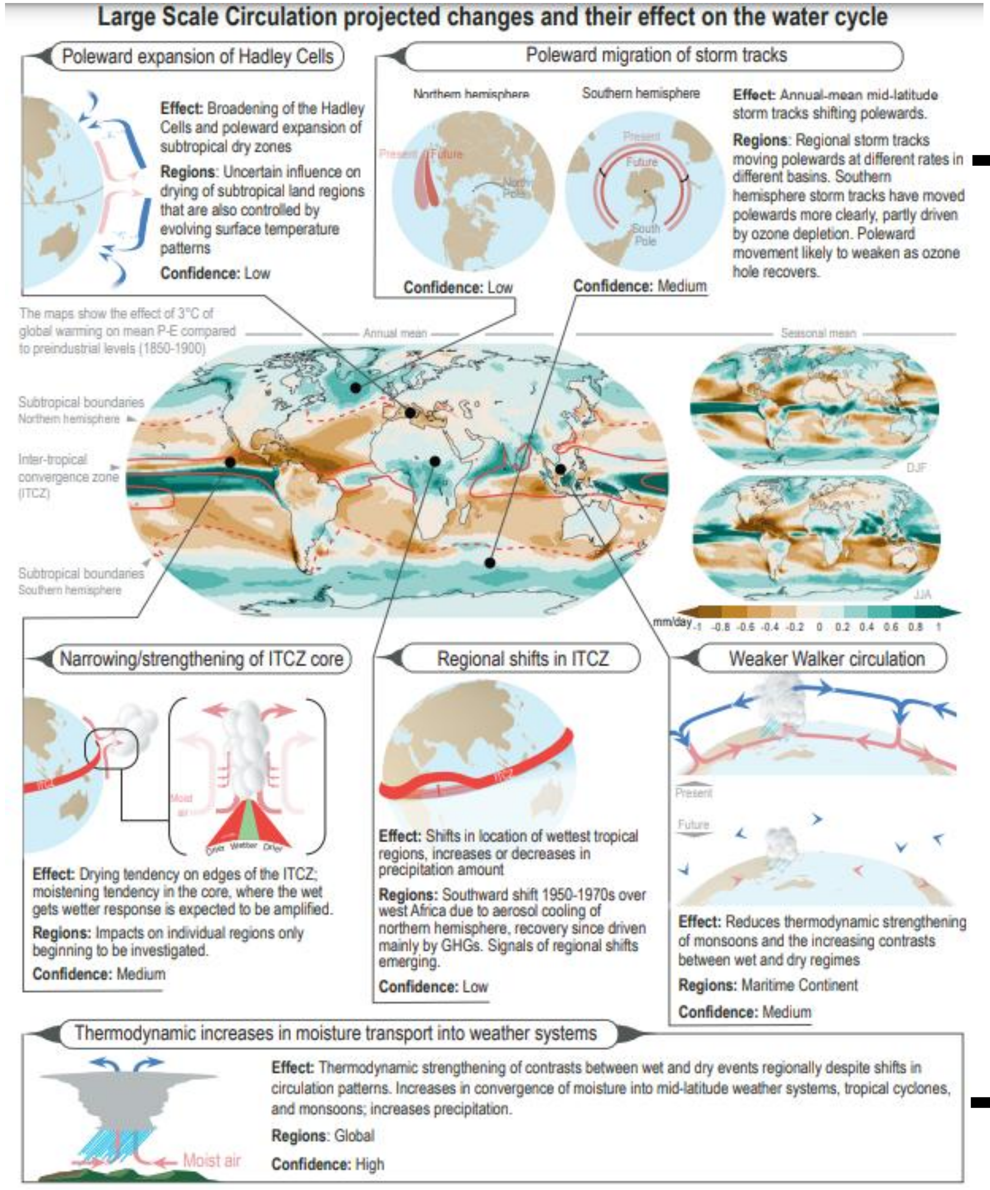


Figure 8.21 | Schematic depicting large-scale circulation changes and impacts on the regional water cycle. The central figures show precipitation minus evaporation (P–E) changes at 3°C or global warming relative to an 1850–1900 base period (mean of 23 CMIP6 SSP5-8.5 simulations). Annual mean changes (large map) include contours (ocean only) depicting control climate P–E = 0 mm day⁻¹ lines with the solid contour enclosing the tropical rain belt region and dashed lines representing the edges of subtropical regions. Confidence levels assess understanding of how large-scale circulation change affect the regional water.

Low confidence in storm track shift

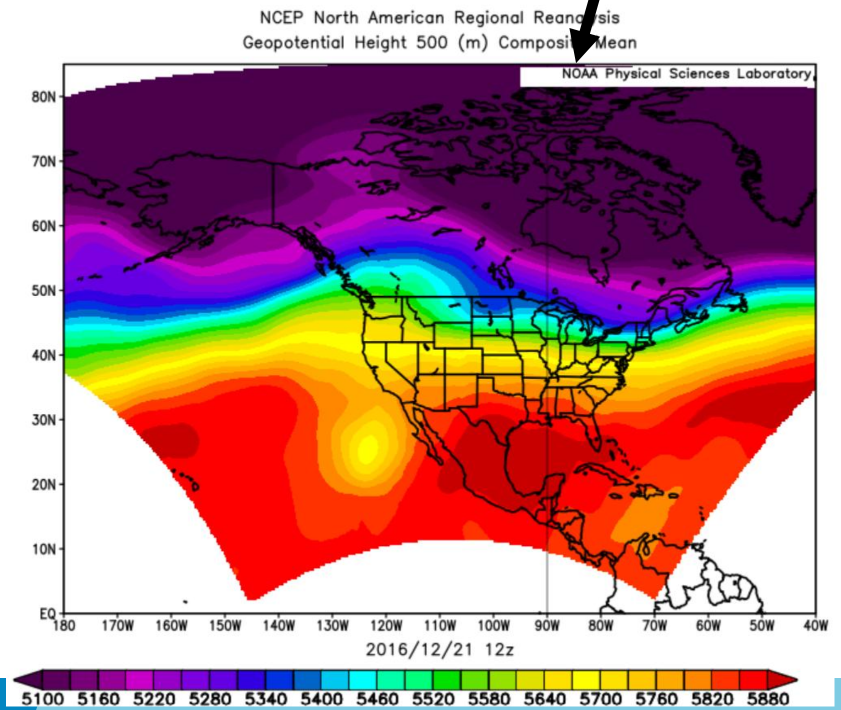
High confidence in increased humidity leading to increased storm intensity

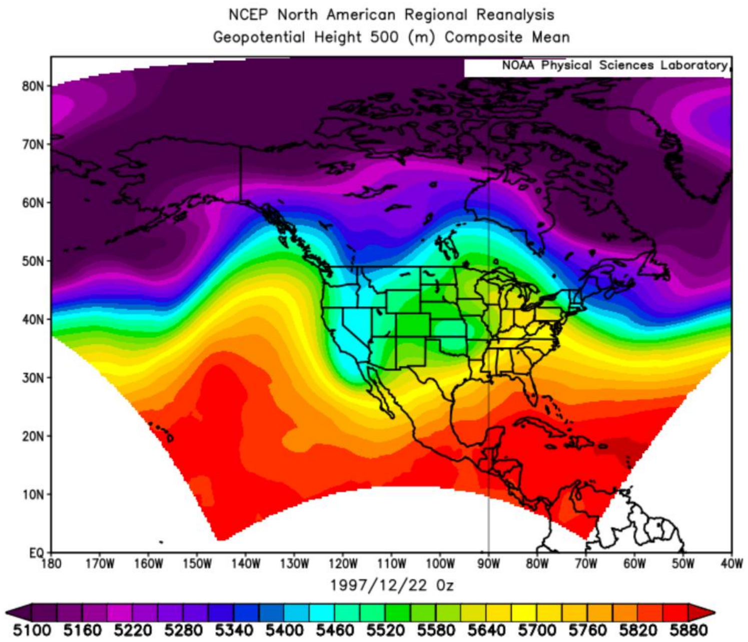
Douville, H., K. Raghavan, J. Renwick, R.P. Allan, P.A. Arias, M. Barlow, R. Cerezo-Mota, A. Cherchi, T.Y. Gan, J. Gergis, D. Jiang, A. Khan, W. Pokam Mba, D. Rosenfeld, J. Tierney, and O. Zolina, 2021: Water Cycle Changes. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1055–1210, doi:10.1017/9781009157896.010.

Future Central AZ Precipitation

- **Is the uncertainty in CMIP6 due to increased humidity offsetting decreased storm dynamics?**

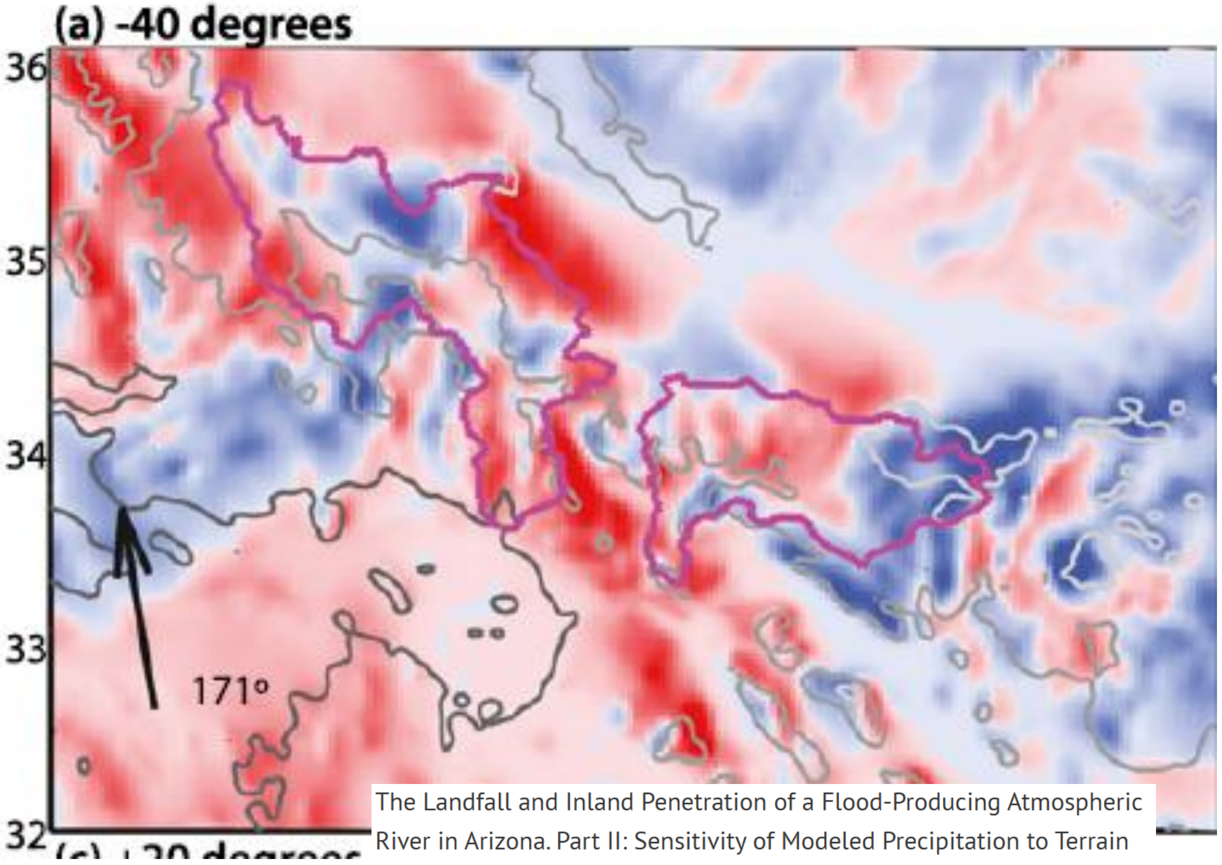
If so, can the mountain barriers in central AZ capitalize on the increased moisture advection in storm like this to overcome a lower frequency of storms like this?





Future Central AZ Precipitation

Given the high natural variability, modeling experiments to isolate the impacts of changing dynamics and thermodynamics in complex terrain may be required.



The Landfall and Inland Penetration of a Flood-Producing Atmospheric River in Arizona. Part II: Sensitivity of Modeled Precipitation to Terrain Height and Atmospheric River Orientation

Mimi R. Abel, Kelly M. Mahoney, Paul J. Neiman, Benjamin J. Moore, Michael Alexander, and F. Martin Ralph

Print Publication: 01 Oct 2014

DOI: https://doi.org/10.1175/JHM-D-13-0176.1

Summary

- **Reservoirs on the Salt-Verde support the largest water supply to the Phoenix Metro Area in Arizona.**

- **Salt-Verde Streamflow Relatively Insensitive to Temperature = Precipitation Very Important**

- **Not an obvious source of moisture from the Pacific that varies by ENSO phase**

- **Offsetting of dynamics and thermodynamics create uncertainty in CMIP6 projections?**
  - **Can orographic processes in central AZ tip the odds toward increased precipitation?**

thank you!