Teleconnections and Topography:
How the Use of Sea Surface Temperature Data to Predict Snow Water Equivalent Varies within Small Watersheds in the Western US

Jeremy Barroll, Ben Livneh
University of Colorado, Boulder Civil, Environmental and Architectural Engineering

Introduction:

- For much of the Western United States, spring snow-water equivalent depth (SWE) in mountain areas is the best predictor of water supply through the summer months.[6]
- Water agencies would like to predict SWE in advance so that they can choose how to operate their facilities to optimize water storage and flood protection.[1]
- Traditionally, El Niño Southern Oscillation (ENSO) has been used to predict SWE in advance in the Western United States.[2]
- However, areas of the Western United States between roughly 36 and 41 North latitude have lower and more variable correlations with ENSO.[7]
- The predictive skill of sea surface temperature (SST) can be higher in small, high elevation areas, however the relationship varies across small distances.[4]
- Additionally, SST data from alternate prediction centers (oceanic regions that correlate strongly with SWE at a given location) in both the Pacific[8] and North Atlantic[7] Ocean Basins can have higher predictive skill than ENSO for this region.

Objectives:

- This study aims to relate the variations in SST prediction of SWE to elevation, location relative to prominent crests, and latitude/longitude within the larger region.
- We will use the study period of water years 1985 through 2021.

Data Used:

- For SWE data: Western United States UCLA Daily Snow Reanalysis[3] in 16 arc-seconds.
- For SST data: NOAA Extended Reconstructed Sea Surface Temperature[5] in 2-degree lat/lon cells.

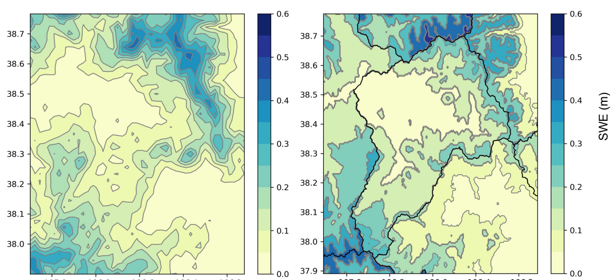

Figure 2: Average April 1 SWE (m) over the study period of water years 1985-2021 (left), and grouped by watershed and 400 meter elevation band (right).

Key Takeaways:

- SWE prediction using SSTs can be improved for small watersheds by custom selecting SST regions for the individual watershed, and even the individual elevation band in some cases.
- Teleconnections vary according to a complex interplay of topography and regional relationships.

References:

1. Anghileri et. al. 2016: Value of long-term streamflow forecasts to reservoir operations for water supply in snow-dominated river catchments. Water Resources Research. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2015WR017864
2. Cayan et. al. 1999: ENSO and Hydrologic Extremes in the Western United States. Journal of Climate. https://journals.ametsoc.org/view/journals/clim/12/9/1520-0442_1999_012_2881_eaheit_2.0.co_2.xml
3. Fang, Y., Y. Liu. and S. A. Margulis. 2022. Western United States UCLA Daily Snow Reanalysis, Version 1. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/PP7T2GBI52I2.
4. Hidalgo et. al. 2003: ENSO and PDO Effects on Hydroclimatic Variation of the Upper Colorado River Basin. Journal of Hydrometeorology. journals.ametsoc.org/view/journals/hydr/4/1/1525-7541_2003_004_0005_eapeoh_2_0_co_2.xml
5. Boyin Huang, Peter W. Thorne, Viva F. Banzon, Tim Boyer, Gennady Chepurin, Jay H. Lawrimore, Matthew J. Menne, Thomas M. Smith, Russell S. Vose, and Huai-Min Zhang (2017): NOAA Extended Reconstructed Sea Surface Temperature (ERSST), Version 5. [indicate subset used]. NOAA National Centers for Environmental Information. doi:10.7289/V5T72FNM. Obtain at NOAA/ESRL/PSD at their website esri.noaa.gov/psd
6. Serreze et. al. 1999: Characteristics of the western United States snowpack from snowpack telemetry (SNOTEL) data. Water Resources Research. agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/1999WR900090
7. Stone, Luke and Strong, Courtenay 2023: Atlantic-Pacific influence on western U.S. hydroclimate and water resources. Nature. nature.com/articles/s41612-023-00471-7
8. Zhao et. al. 2021: Long-Lead Seasonal Prediction of Streamflow over the Upper Colorado River Basin: The Role of the Pacific Sea Surface Temperature and Beyond. Journal of Climate. journals.ametsoc.org/view/journals/clim/34/16/JCLI-D-20-0824.1.xml

Funding Acknowledgment:

NOAA grant # NA20OAR4310420 Identifying Alternatives to Snow-based Streamflow Predictions to Advance Future Drought Predictability, and NOAA grant titled “Physically-based evaluation of CMIP6 hydrologic projections for the western United States (NA19OAR4310284)

April 1 snow-water equivalent (m) correlation with previous December sea-surface temperature anomaly (+/- C) in the North Temperate Pacific Ocean.

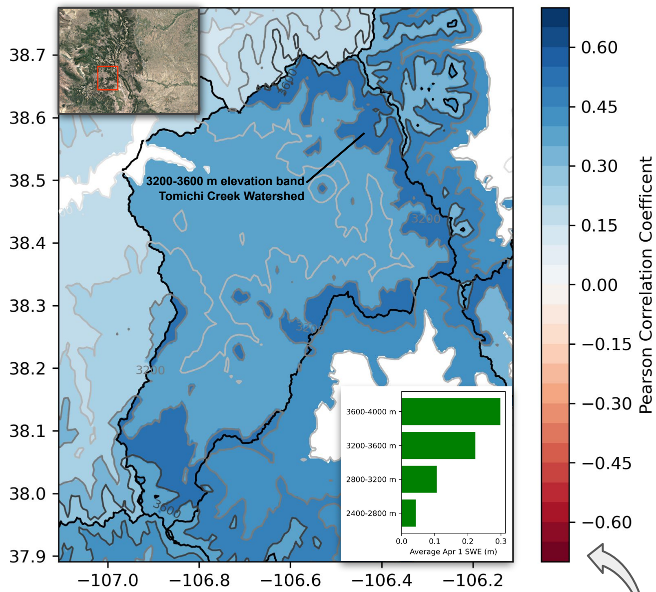

Figure 3: Pearson Correlation Coefficient between December SST anomalies averaged over the North Temperate Pacific (see **Figure 4**, bottom) and Apr 1 SWE in the Tomichi Creek Watershed in the Colorado Rockies, grouped by watershed and 400 meter elevation band. The upper left shows location within Colorado, US. The lower right shows average April 1 SWE for each elevation band of the Watershed.

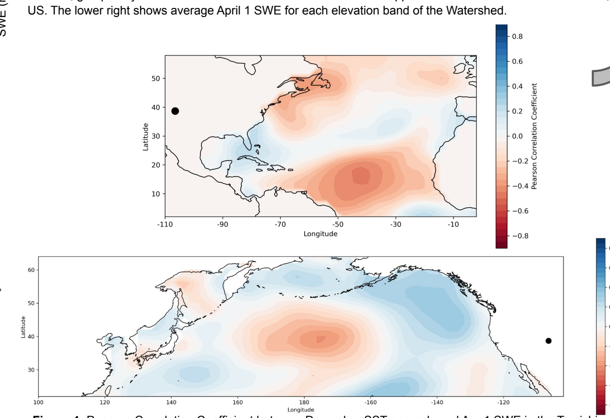

Figure 4: Pearson Correlation Coefficient between December SST anomaly and Apr 1 SWE in the Tomichi Creek Watershed for the North Atlantic Ocean (top) and North Temperate Pacific Ocean (bottom). Blue is positive correlation, red is negative. December SST anomalies were taken as the average of positively correlated locations minus the average of the negatively correlated locations. This combined SST anomaly list was then correlated with SWE at our chosen watershed, which is shown as a black dot.

Methods:

The pearson correlation coefficient (correlation or R) is mapped across the oceans (see **Figure 4**). We take the average SST anomaly of positively correlated locations minus the average SST anomaly of negatively correlated regions. Prediction center relationships are then mapped across land. We can relate SST at a given prediction center with SWE at a given elevation band with the following linear fit:

$$SWE_{predicted} = intercept + covariance * SST_{PC}$$

Where $SWE_{predicted}$ is SWE (m), intercept is $SWE_{predicted}$ when SST anomaly is zero, $covariance$ is covariance (m/C) and SST_{PC} is the SST anomaly at our prediction center in +/- C.

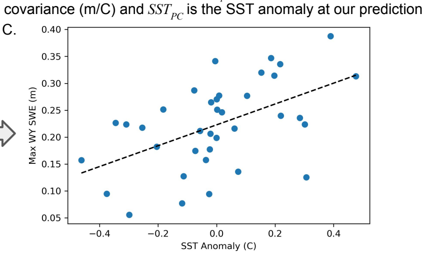

Figure 5: Scatter plot showing SST anomaly averaged over the North Temperate Pacific Ocean on the x-axis and April 1 SWE for the 3200-3600 m elevation band of the Tomichi Creek Watershed on the y-axis. Intercept= 0.22 m, Covariance= 0.19 m/C Correlation= 0.52.

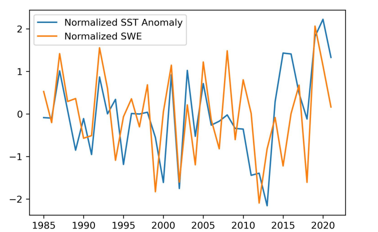

Figure 5: Line graph showing standardized time series of the above SST anomaly and SWE (units of standard deviation) over the study period of water years 1985-2021.

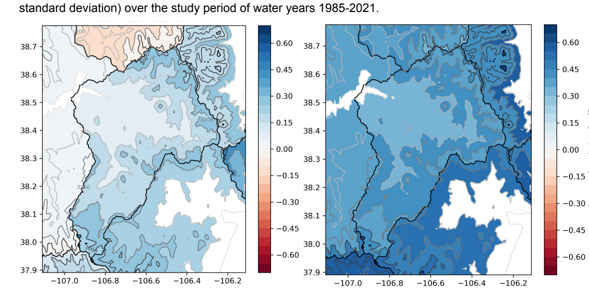

Figure 6: Pearson Correlation Coefficient between December Nino 3.4 Index (left), December SST anomaly averaged over the North Atlantic Ocean (right) and Apr 1 SWE in the Tomichi Creek Watershed. We can see the North Temperate Pacific is more useful for this watershed than the ENSO Region, and so it makes sense to combine that prediction center with the one in the North Atlantic for optimal prediction.

Questions:

- Which other land regions we should test?
- What are the physical mechanisms of the prediction centers i.e. how does each prediction center affect storm tracks, and how does that relate to topography?
- Is there statistical significance to choosing different prediction centers (positively and negatively correlated ocean regions) for adjacent locations?