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RESEARCH LETTER
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Four Atmospheric Circulation Regimes Over the North Pacific and Their Relationship to California Precipitation on Daily to Seasonal Timescales

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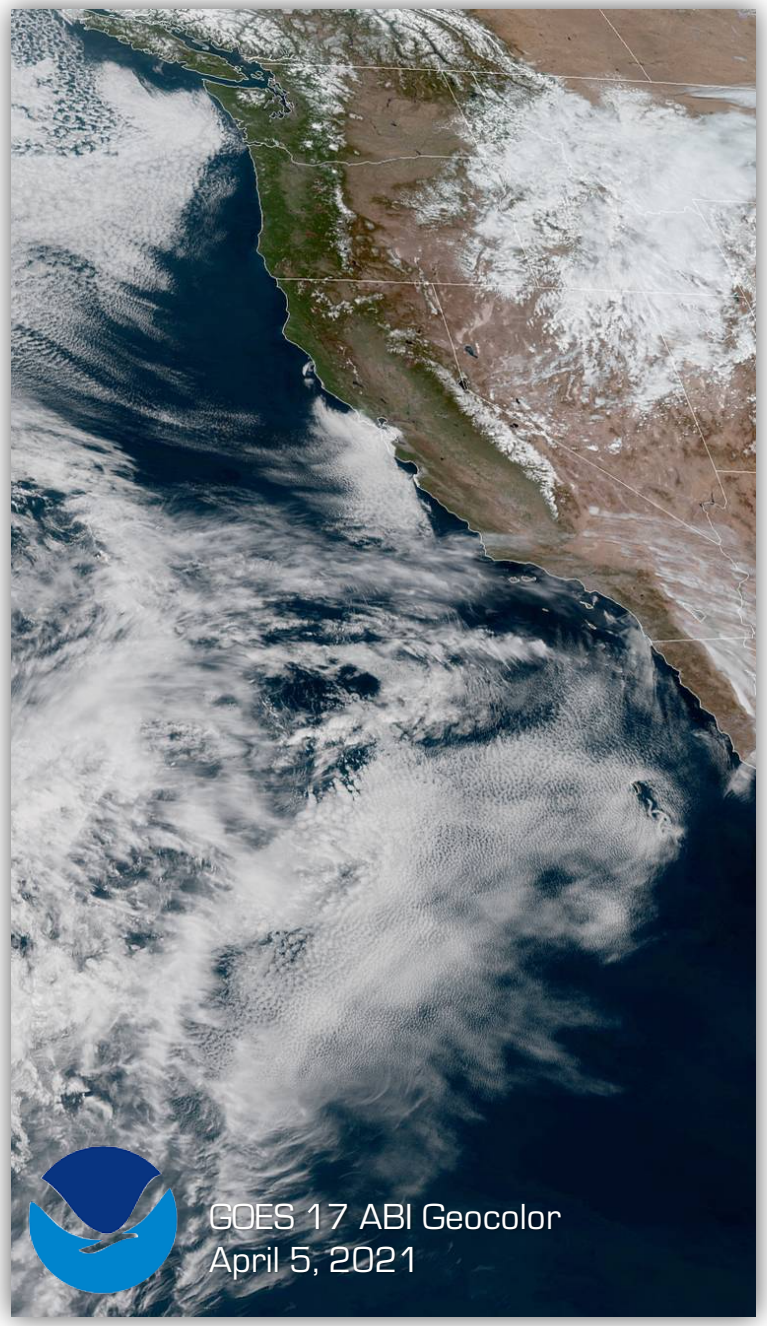
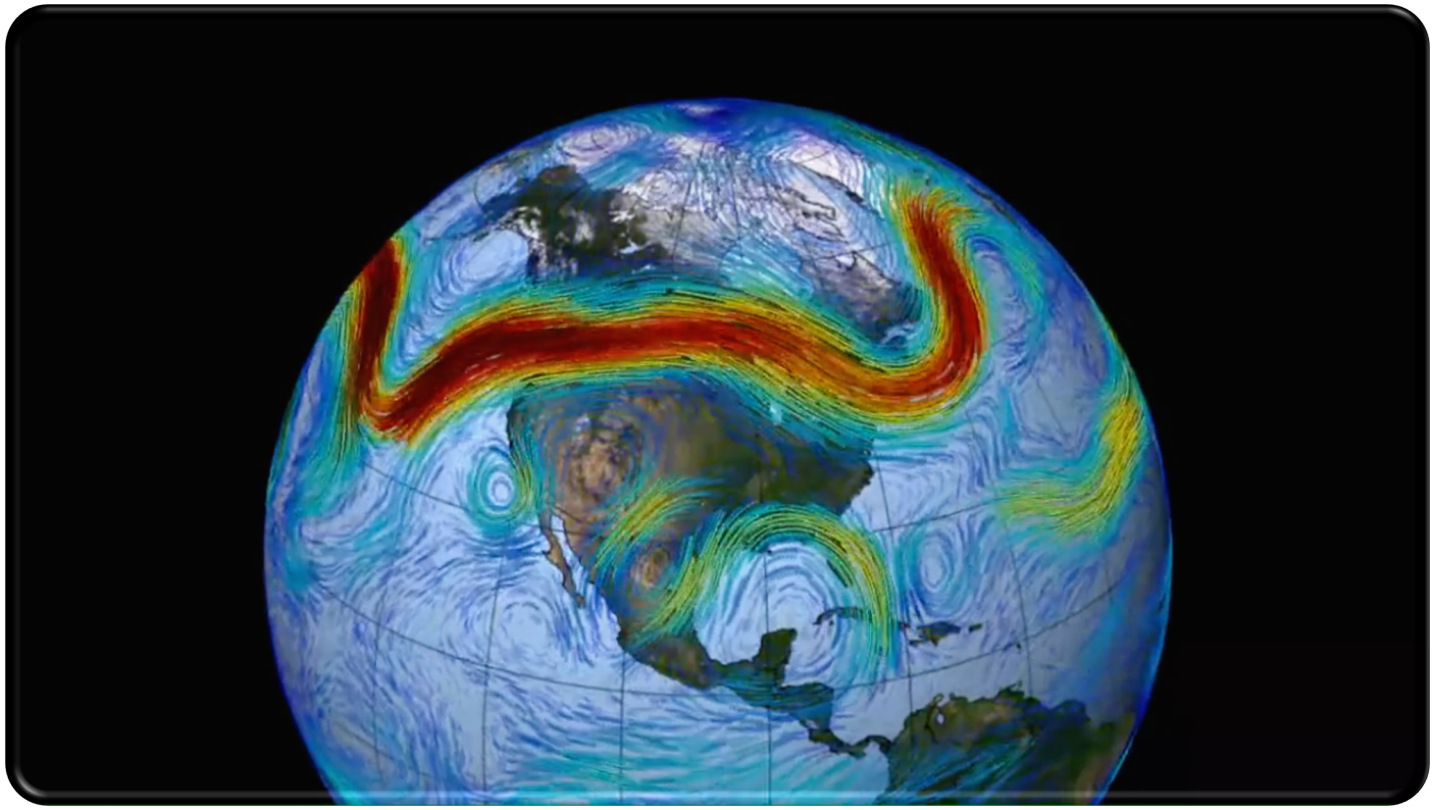


Introduction

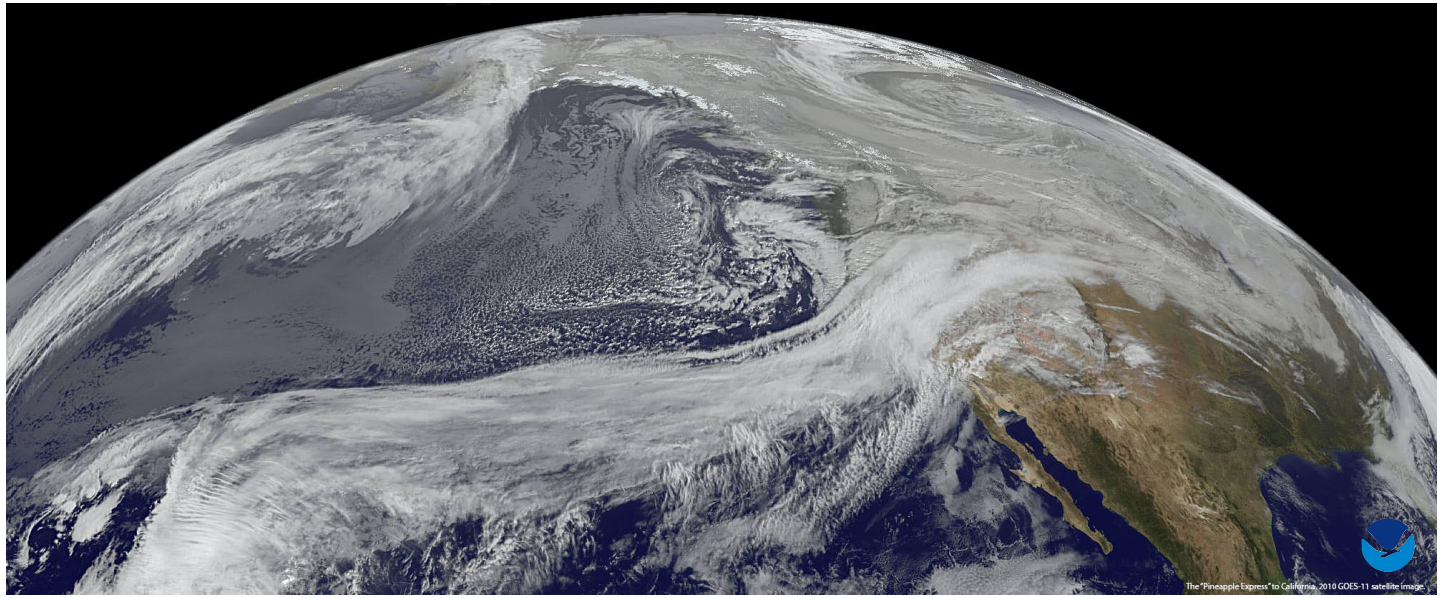
- Demand for skilled forecast beyond 2-week lead time is high to better optimize water resource management
- Dynamic and statistical forecast skill is low beyond 2-week lead time
- Teleconnection: a recurring and persistent, large-scale pattern of pressure and circulation anomalies that spans vast geographical areas.
- Teleconnections are associated with Rossby wave dynamics that influence the strength and position of troughs and ridges
- Rossby waves, aka planetary waves form in the Earth's atmosphere and ocean as a result of the rotation of the planet.



This animation from NASA's Goddard Space Flight Center shows both long and short atmospheric waves as indicated by the jet stream. The colors represent the speed of the wind ranging from slowest (light blue colors) to fastest (dark red).

Data and Methods
IWVT and AR Detection

- IWVT: as a measure of the horizontal transport of specific humidity, by integrating it for a vertical column of the troposphere
- AR catalog from Gershunov et al. (2017) – landfalling ARs 1948 to present using data from NCEP-NCAR global Reanalysis (Kalnay et al., 1996).
- AR detection
  - IWVT > 250 kg*$m^{-1}s^{-1}$
  - IWV > 250 mm
  - Geometric length > 1,500 km
- ARs associated with most of the horizontal transport of water vapor outside of the tropics.



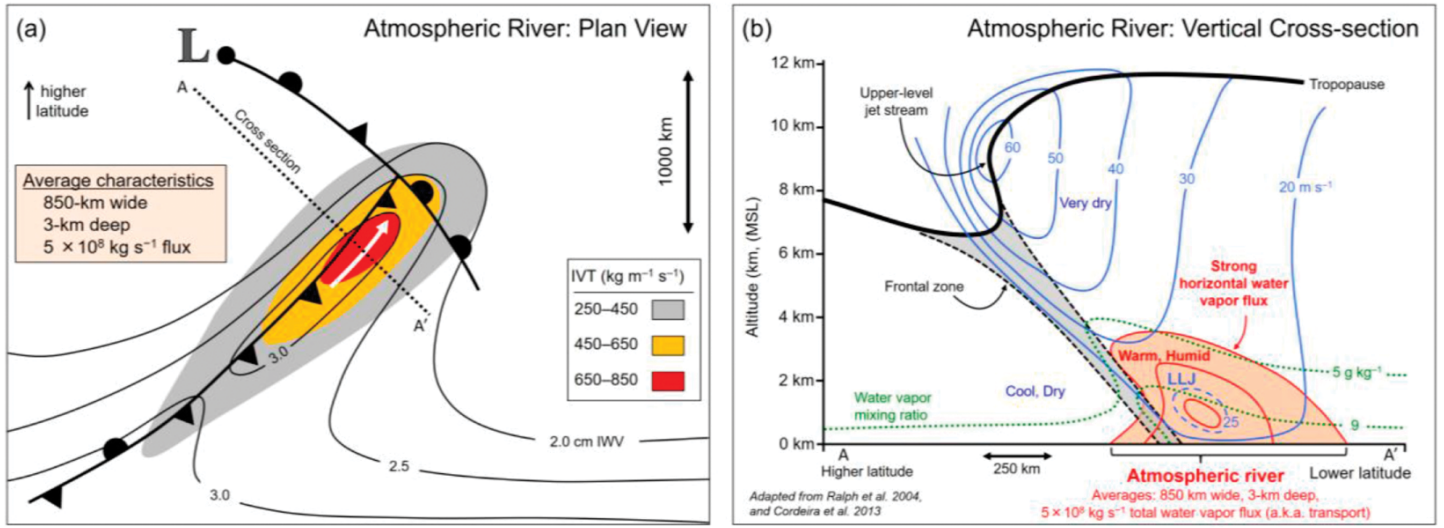


Figure (a) and (b) from; Ralph, F. Martin, et al. "DEFINING 'ATMOSPHERIC RIVER': How the Glossary of Meteorology Helped Resolve a Debate." *Bulletin of the American Meteorological Society*, vol. 99, no. 4, Apr. 2018, p. 837+.

Data and Methods

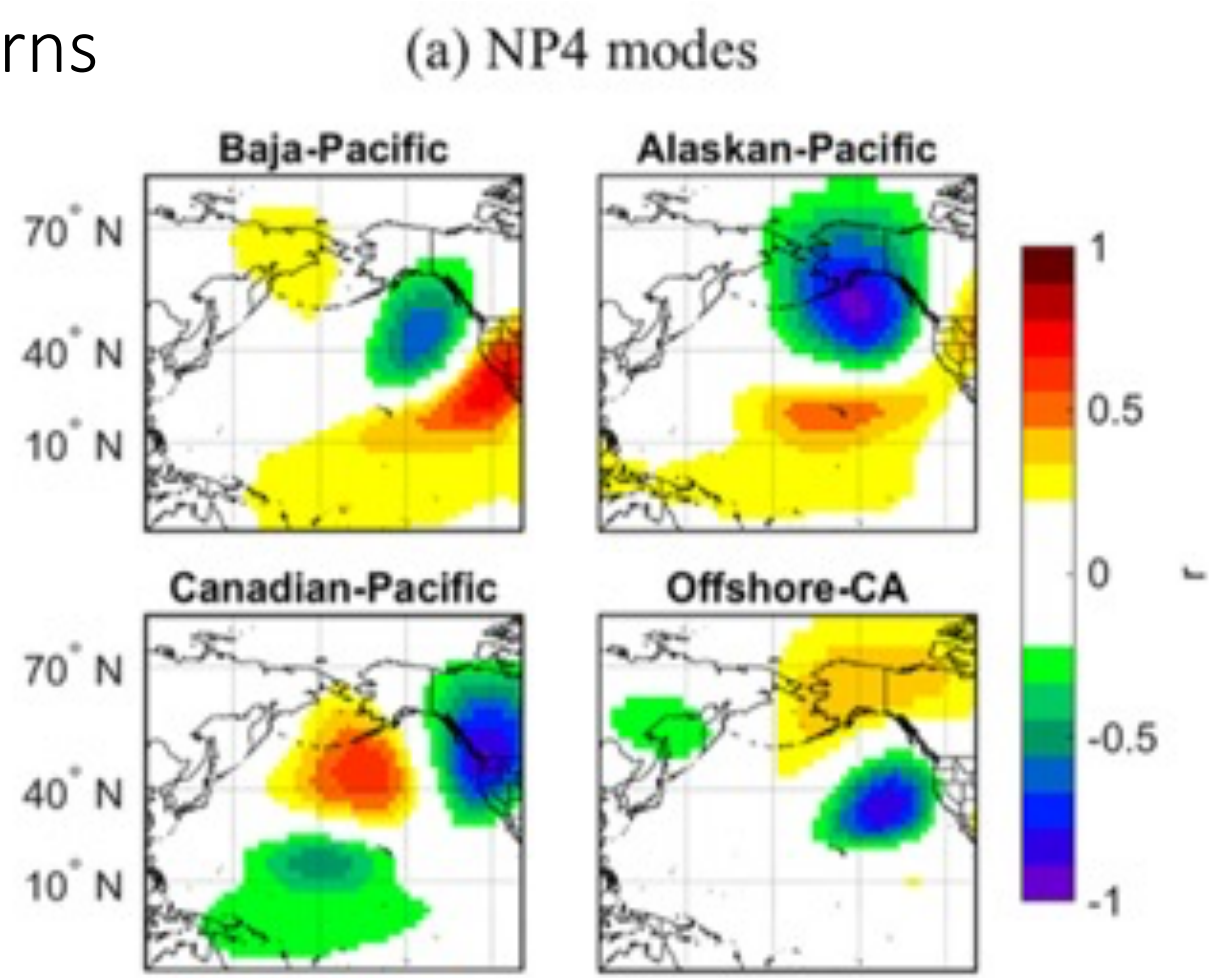
1) Atmospheric Variables
2) Daily Precipitation
3) Historical CA Flood Damages
4) El Niño Southern Oscillation (ENSO)

1) Atmospheric Variables
   - Daily 500 mb geopotential height from NCEP-NCAR global reanalysis
   - Daily grid-cell anomalies computed
2) Daily Precipitation
   - Gridded product from Livneh et al. (2013) interpolated to 1°/16 ° latitude-longitude grid
   - Source NCEI COOP supplemented by ASOS - NCDC
   - POR 1950 to 2013
3) Historical CA Flood damages
   - National Flood Insurance Program (NFIP) (1978 – 2017)
   - Most damaging floods: losses > $10 million (Corringham et al. (2019). Study is focused on Northern California.
4) El Niño Southern Oscillation (ENSO)
   - Monthly Niño 3.4 index (Climate Prediction Center)
   - Derived using Seas Surface Temperatures (SST)

Data and Methods

North Pacific Teleconnection Patterns

- GGR18’ – previous study investigating relationships between mid-tropospheric circulation, coastal vapor transport, and precipitation along California coast and western North America at daily to seasonal scales
- Rotated empirical orthogonal function (EOF) analysis applied to 500mb geopotential height anomalies
- Of the GGR18’ modes 4 were most important for AR activity over California
  - BP – Baja Pacific
  - AP – Alaskan Pacific
  - CP – Canadian Pacific
  - OC – Offshore California



Data and Methods
Multiple Linear Regression

- Relationship between precipitation NP4 modes
- Daily and Seasonal
- Regression to investigate correlation of daily and seasonal observed precipitation to NP4 modes
- For a given set of phasing between the NP4 modes, how correlated is the amount of precipitation?

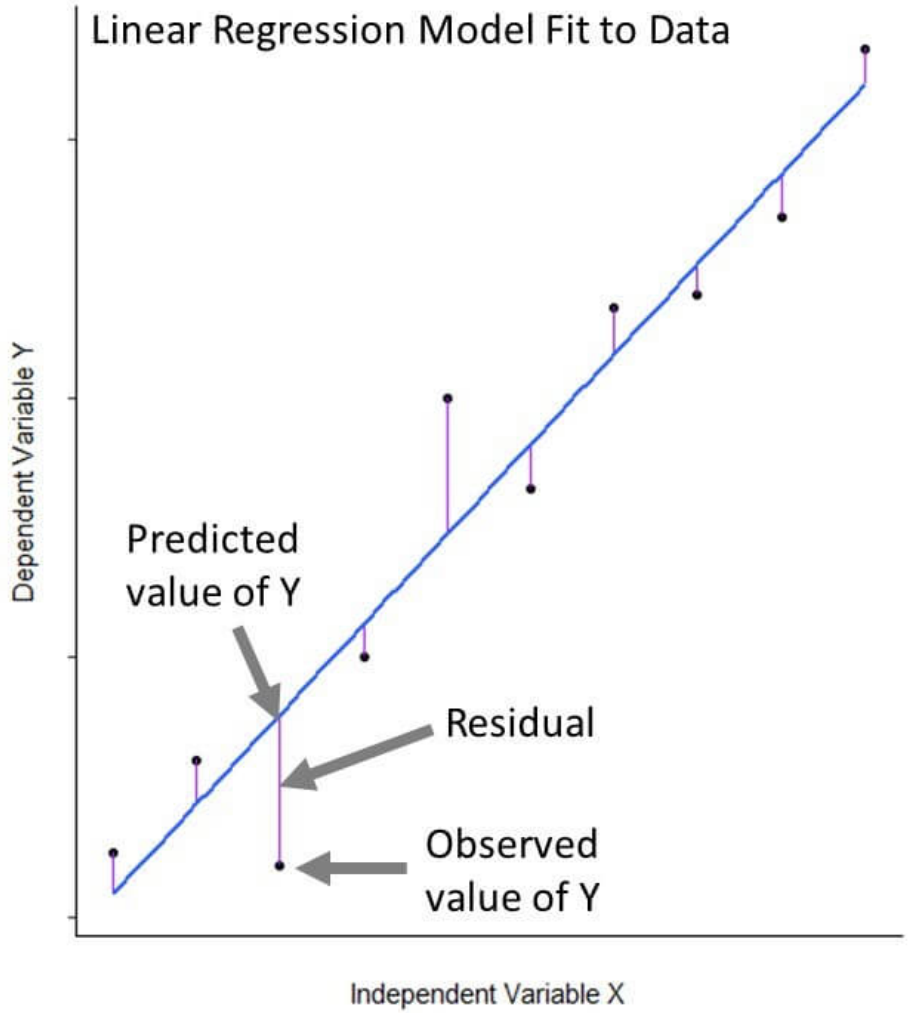
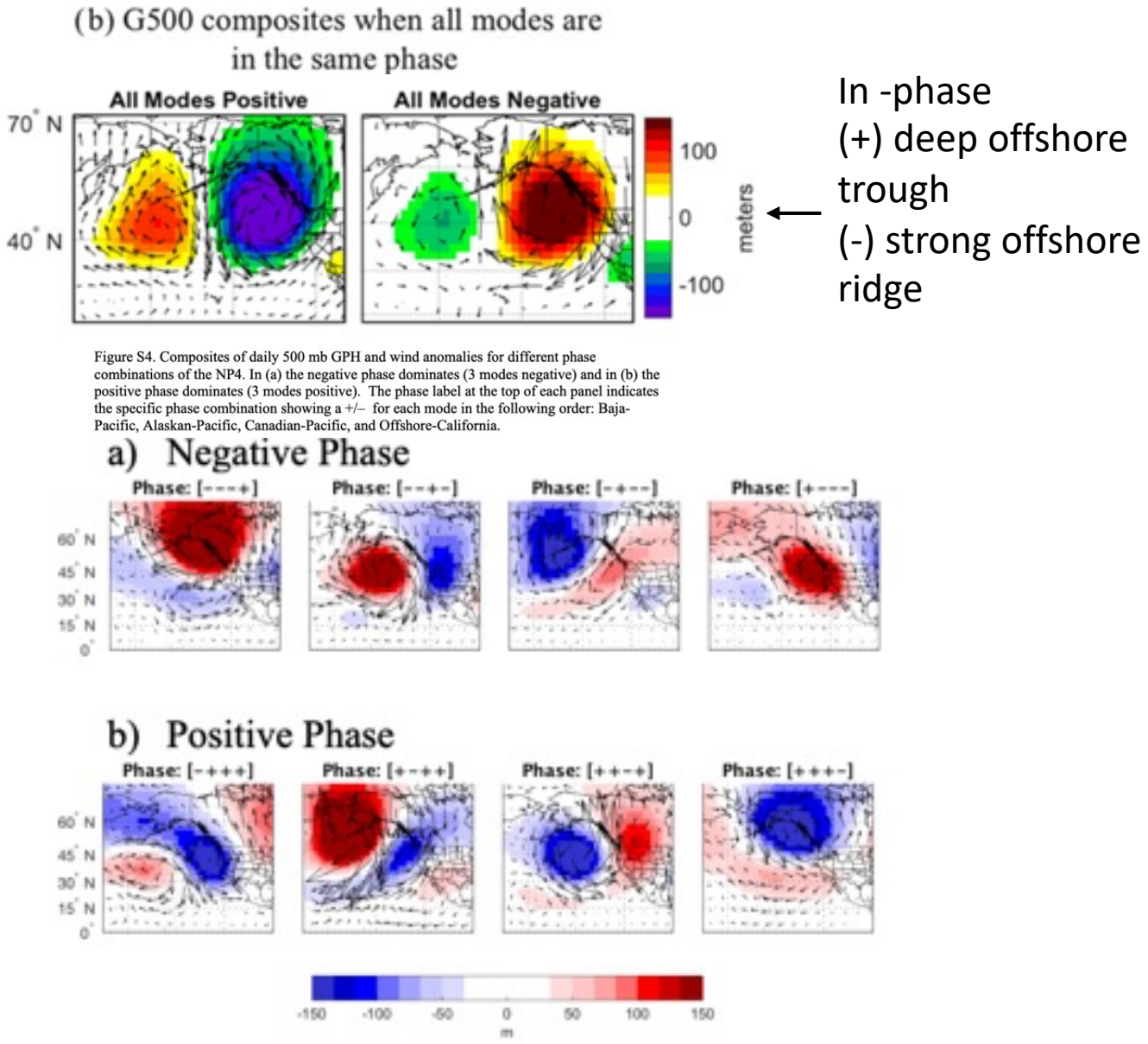


Figure from: https://www.dataquest.io/blog/statistical-learning-for-predictive-modeling-r/

Results

Circulation Interactions & Precipitation Extremes

- The NP4 patterns collectively explain 60 to 90% of the local variance in G500 anomalies over the N.E. Pacific and N. California.
- Therefore, NP4 explain much of the large-scale atmospheric flow that modulates vapor transport over the West Coast.
- Joint phasing is 3 or more modes all positive or negative
- Positive phase associated with anomalous onshore flow and elevated AR activity over N. California.
- Negative phase is associated with anomalous off-shore flow and reduced AR activity.
- Daily scale modes can become in-phase or oppose



In -phase
(+) deep offshore trough
(-) strong offshore ridge

Figure S4. Composites of daily 500 mb GPH and wind anomalies for different phase combinations of the NP4. In (a) the negative phase dominates (3 modes negative) and in (b) the positive phase dominates (3 modes positive). The phase label at the top of each panel indicates the specific phase combination showing a +/– for each mode in the following order: Baja-Pacific, Alaskan-Pacific, Canadian-Pacific, and Offshore-California.

Results
Circulation Interactions & Precipitation Extremes

- Example: Russian River basin (40°) latitude
- Probability of landfalling AR
  - 49% when 4 modes are jointly positive (hollow green circle)
  - 2% when 4 modes are jointly negative (hollow blue circle)
- 68% of AR days occurred with 3 or more days jointly positive
- 8% of AR days occurred with modes jointly negative

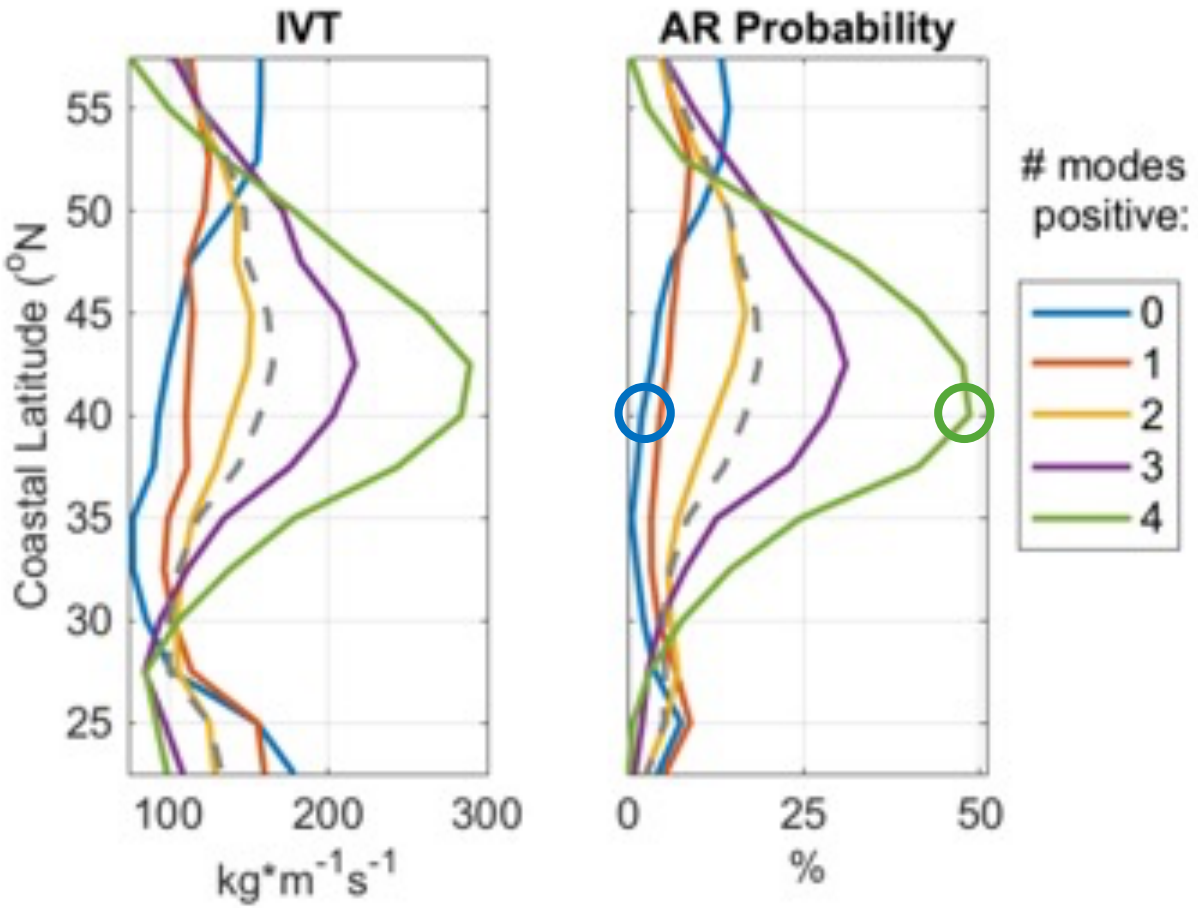
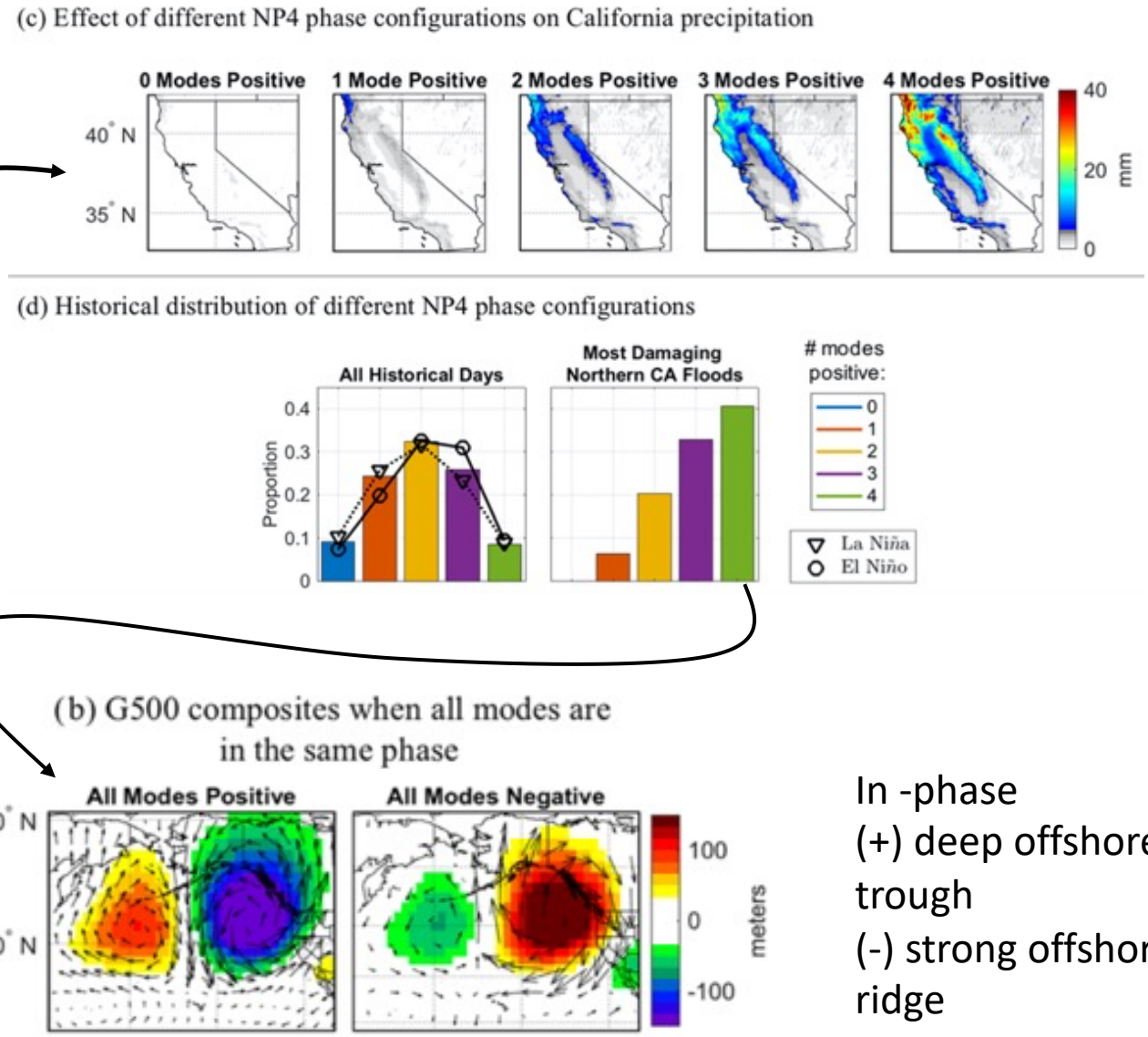


Figure S5. Mean IVT (left) and AR landfall probability (right) conditional on the joint phasing of the NP4 modes, where the legend gives the number of modes concurrently in the positive phase and climatology is shown in dashed gray.

Results
Circulation Interactions & Precipitation Extremes

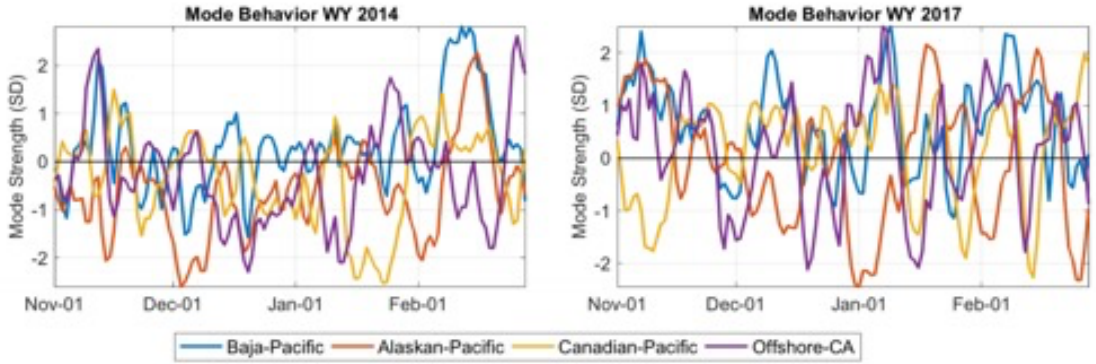
- Strong relationship between joint phasing of NP4 modes and California precipitation amount
- 57% of total statewide precipitation (1950 – 2013) occurred on days with 3 or more modes jointly positive compared to 13% when modes were jointly negative
- Relative fraction of historical flood damages associated with all NP4 modes positive (i.e., deep offshore trough)
  - 8% of all historical days
  - 41% of most damaging floods
  - Additional 33% with 3 NP4 modes positive

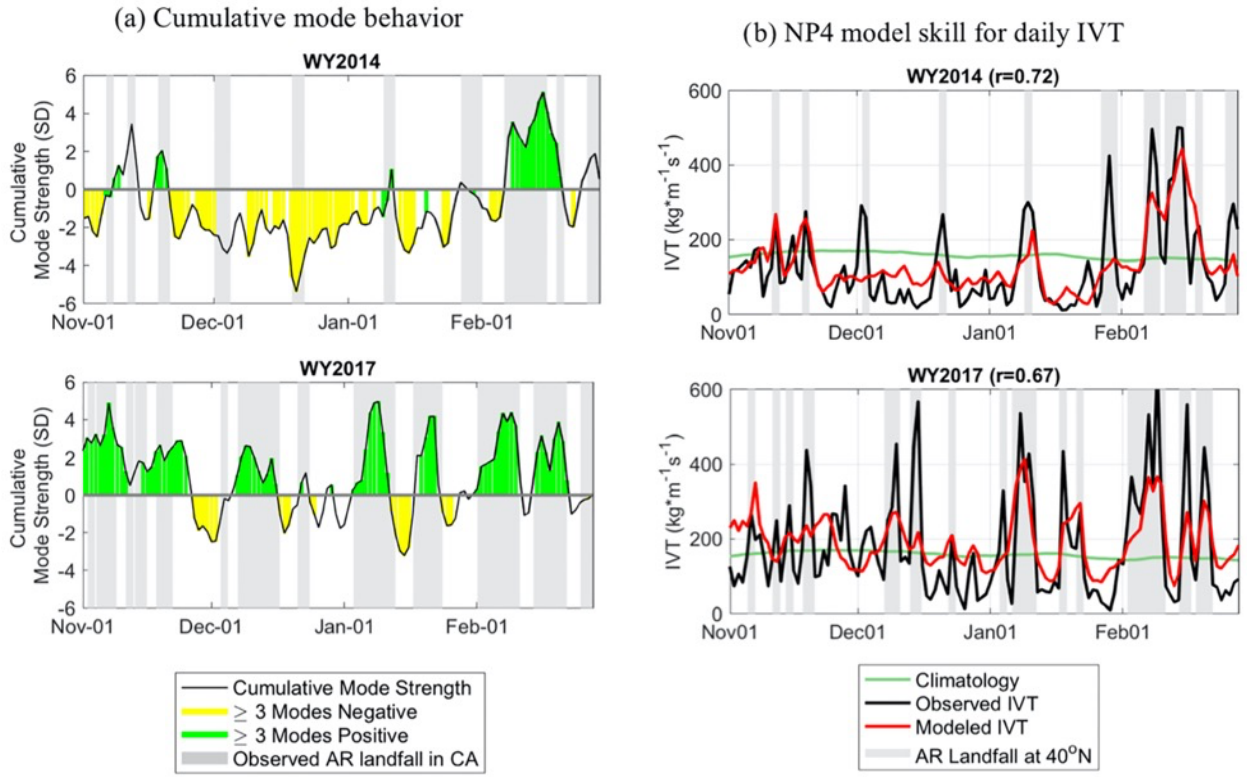


In -phase
(+) deep offshore trough
(-) strong offshore ridge

Results
Daily Weather Variability

- The NP4 modes fluctuate on weather time scales with an e-folding times on the order of a week or less
- WY 2014 (dry) and WY 2017 (historically wet)
  - WY 2017 – 93% of landfalling ARs at 40 ° N with 3 or more modes jointly positive and zero for jointly negative
  - WY 2014 – joint negative phasing 3 or more modes on 44% of days which was associated with blocking due to a persistent ridge. Notable flip to positive phasing Feb 7th associated with increased AR occurrence.
- NP4 regression model skill for 40 ° N (2b)
  - Regression model captures timing and dynamics of IVT and the timing of landfalling ARs

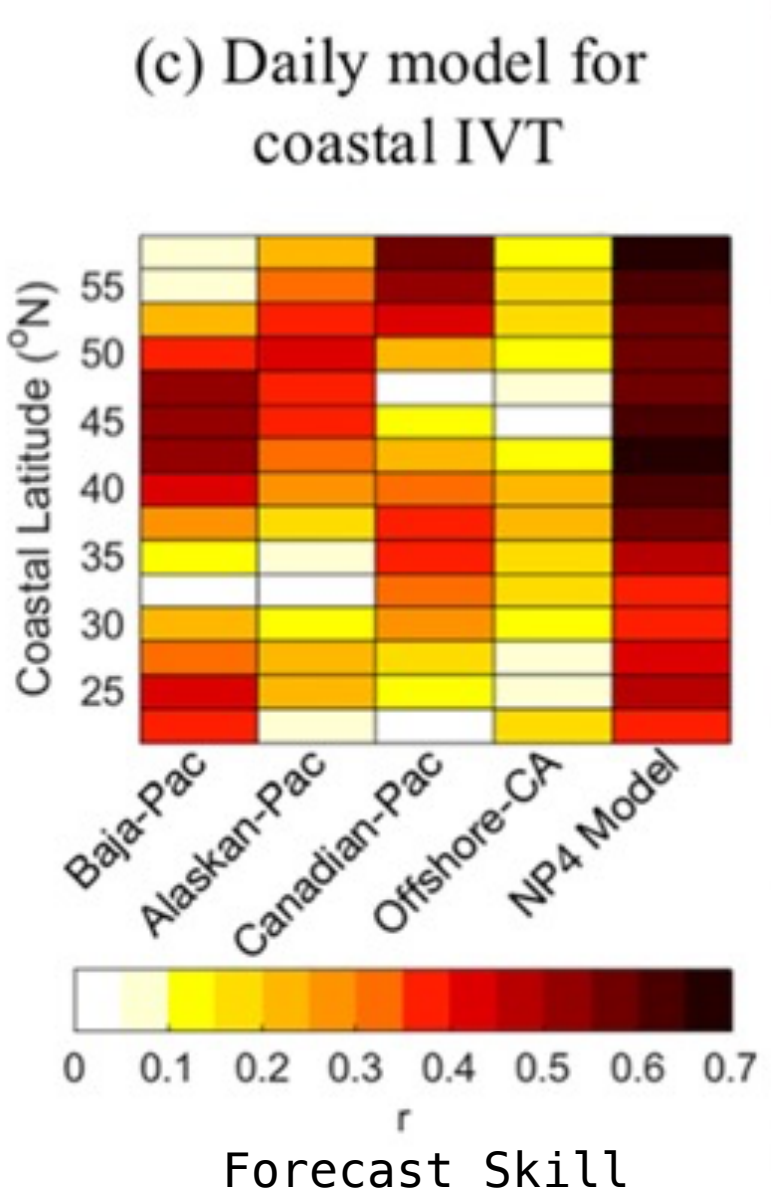




Results

NP4 Model Forecast Skill

- Correlation between daily modeled and observed IVT
- NP4 model entire west coast
- Skillful at all latitudes and is superior to any single model
- Highest skill in N. California, Pacific NW, and Canada
- Lowest skill for offshore California



Results

Seasonal Hydroclimate Variability

- Daily Mode Strength
  - Yellow – favors CA blocking
  - Green – favors CA AR landfalls
- Jointly positive phasing associated with wet and jointly negative with dry
- Not universal
  - Wet
    - WY 1998 – strong El Niño, positive phasing
    - WY 1956 – moderate La Niña, mixed phasing
    - WY 2017 – weak La Niña, mixed phasing
  - Dry
    - Similar non-universal to the wet
  - **Hypothesis:** positive or negative phase of one or more modes preferred possibly due to interannual-to-decadal forcing, producing seasonal phase preference and recurrent flow patterns resulting in anomalously wet or dry conditions

Dry WY

Wet WY

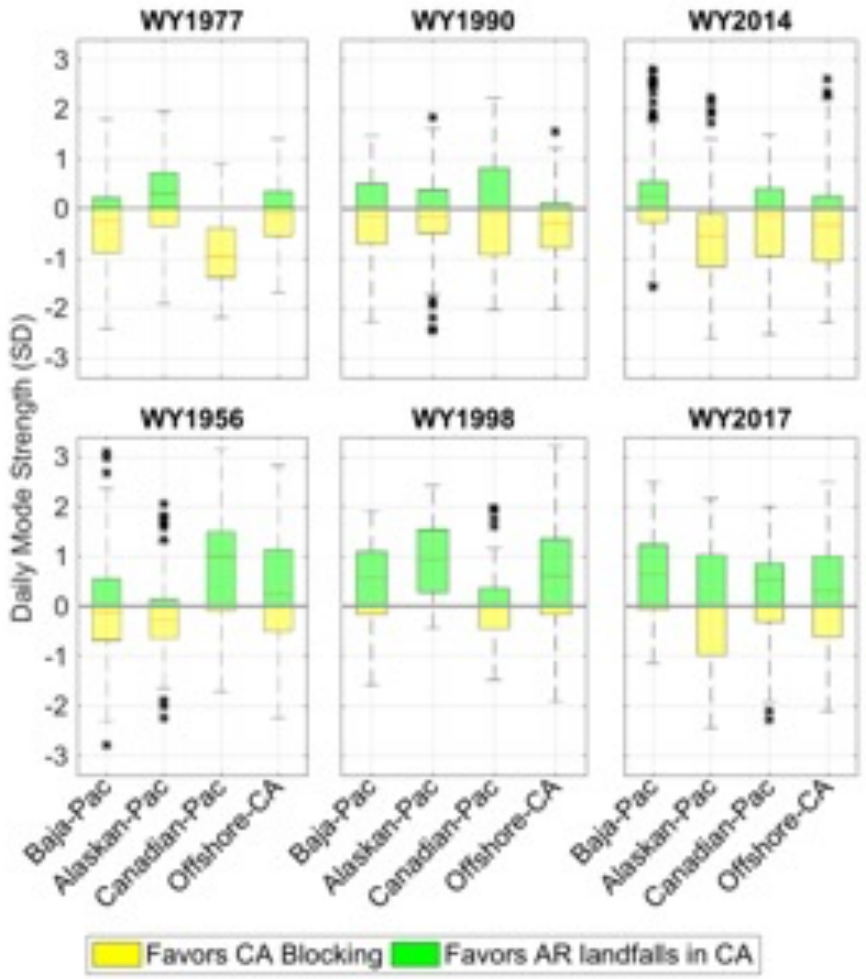
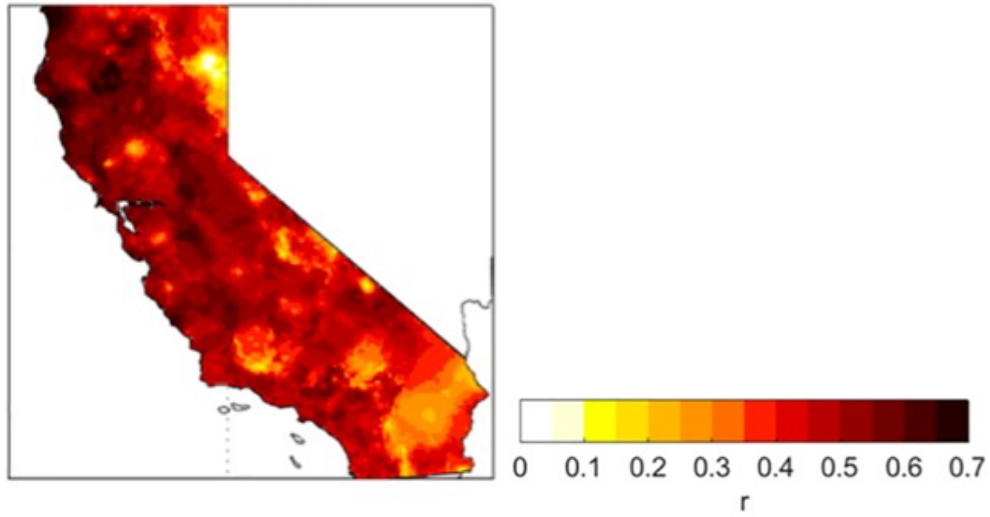


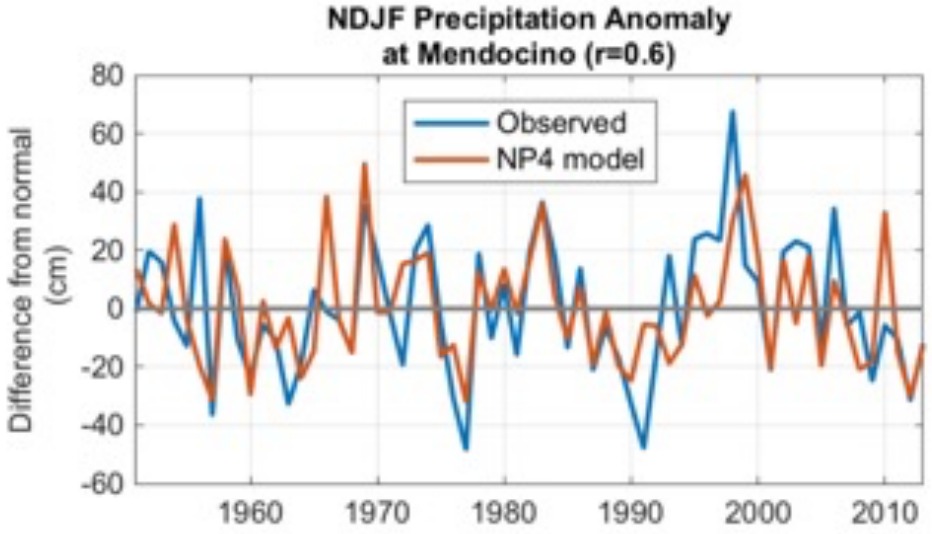
Figure S8. The distribution of daily magnitude and phase of the NP4 modes for historical dry years (1977, 1990, and 2014, top) and historical wet years (1956, 1998, and 2017, bottom). The yellow and green shading highlights favorable conditions for California blocking and AR landfalls, respectively.

Results

Seasonal Hydroclimate Variability

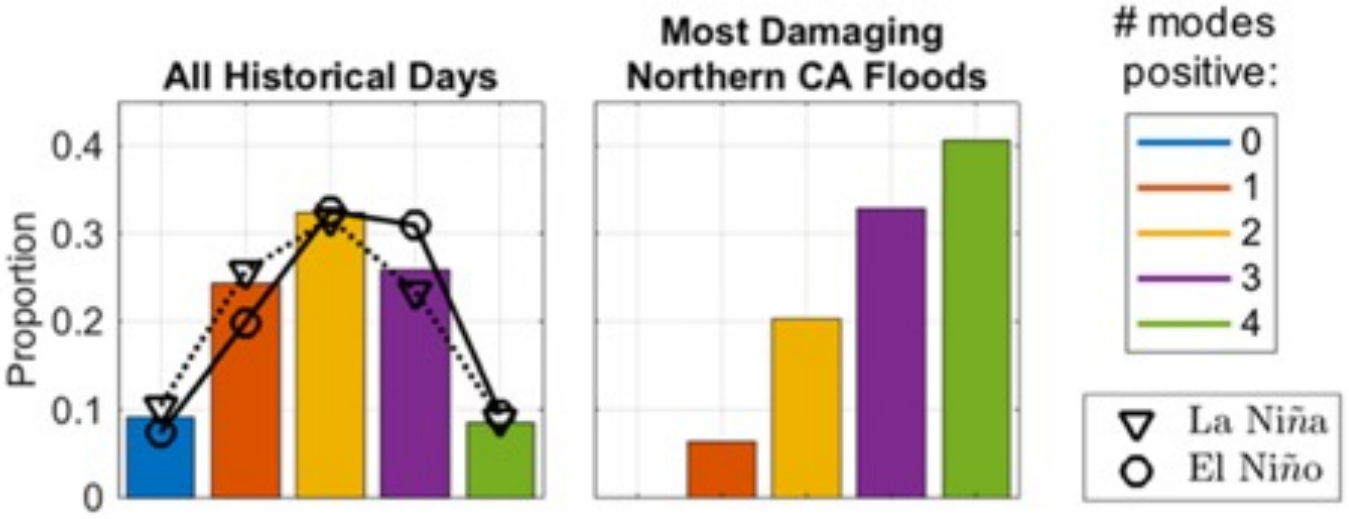
- Seasonal precipitation predictors: mode seasonal phase preference (# positive days minus # negative days)
- Temporal correlation between observed and predicted precipitation
- NP4 modes collectively account for 25% of the variance (r > 0.5) for much of California (~41% of the domain)
- For some Northern California locations 50% of the interannual precipitation variability (r > 0.7) is explained by the NP4 seasonal model
- Mendocino grid cell: 37% of the interannual precipitation variability (r > 0.6) is explained by the NP4 seasonal model. Above or below normal precipitation successfully predicted 78% of the 63-year period.





Results
The Role ENSO

- The most damaging flood conditions are associated with jointly aligned positive phasing of NP4 modes. Is this joint phasing influenced by the state of ENSO?
- Probability of joint phasing is slightly higher for El Niño than during La Niña
- The NP4 pattern most associated with N. California floods (i.e., 4 mode positive joint alignment) is unchanged by ENSO suggesting damaging floods are only modestly dependent on ENSO. S. California results showed ENSO more significant for floods.
- Mode phase combinations for S/N. California future investigation



Summary of Findings

- Coastal vapor transport and California precipitation are modulated by four North Pacific circulation regimes on daily to seasonal timescales
- The most damaging California floods have occurred when these modes were jointly aligned to reinforce onshore flow
- Seasonally, these modes are influenced by ENSO but much variability occurs within the constraints set by the larger-scale climate system