

Future Changes in Atmospheric River Sequences over California

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01-04-2023 | 00:00:20 UTC | GOES-18 | GeoColor

Background and Motivation

U.S. Selected Significant Climate Anomalies and Events for January 2023

Jan was warmer than average for the state of AK. Anchorage was 7°F above normal – its warmest Jan since 2006.

On Jan 31, about 42.7% of the contiguous U.S. was in drought, down about 3.6% from the beginning of Jan. Drought conditions expanded or intensified across portions of the southern Plains, the FL Peninsula and parts of the Rockies, Pacific Northwest, Midwest and HI. Drought contracted or was eliminated across large parts of the West and Midwest, and portions of the Plains, Southeast, Northeast and PR.



On Jan 16, two tornadoes were confirmed by the National Weather Service in IA – the state's first Jan tornadoes in more than 50 years.

A tornado outbreak occurred in IL with nine confirmed tornadoes on Jan 3 – the highest number of tornadoes in Jan, for the state, since 1989.

Much of the Northeast saw record warmth in Jan. ME, CT, MA, NH, NJ, RI and VT had their warmest Jan on record.

NYC remained snowless through the end of Jan, setting a new latest first measurable snowfall record that was previously set on Jan 29, 1973.

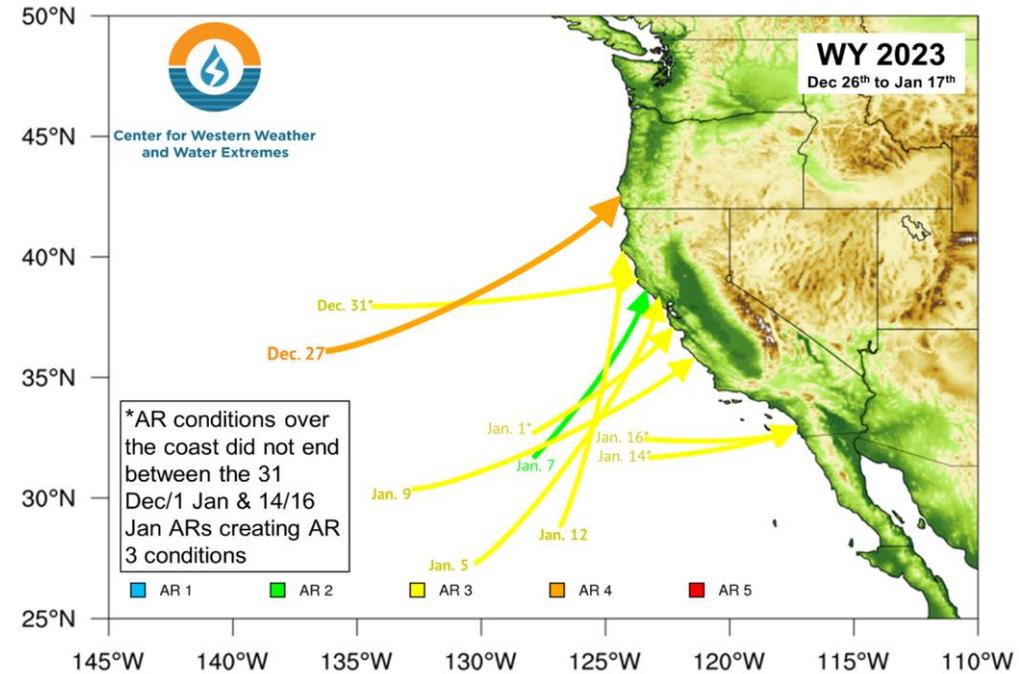
From Dec 26 to Jan 17, a series of nine atmospheric river events caused significant flooding, power outages and mudslides in CA that resulted in at least 21 deaths, 1,400 rescues and 700 landslides.

During late Jan, a strong low pressure system brought flooding, landslides and wind-toppled trees to portions of HI. Islands of Maui and Molokai reported 20-31 in. of rainfall over a five-day period.

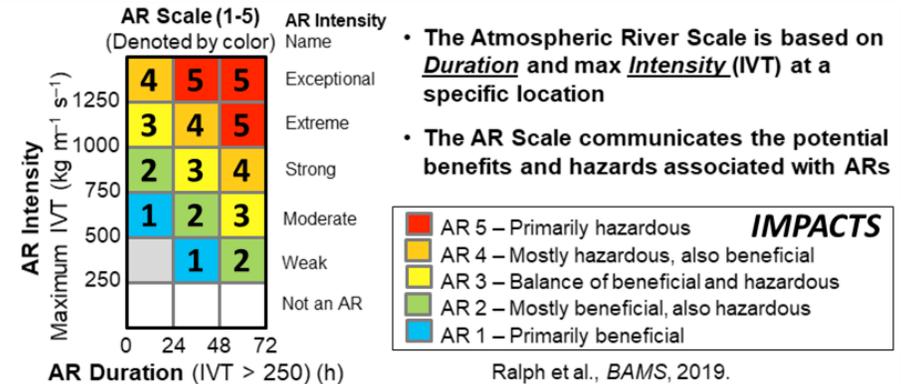
About 50 million people were under winter weather alerts in late Jan as a slow-moving storm brought freezing rain and accumulating ice to parts of the southern Plains.

The average U.S. temperature for Jan was 35.2°F, 5.1°F above average, ranking sixth warmest in the 129-year record. The U.S. precipitation average for Jan was 2.85 in., 0.54 in. above average, ranking in the wettest third of the record.

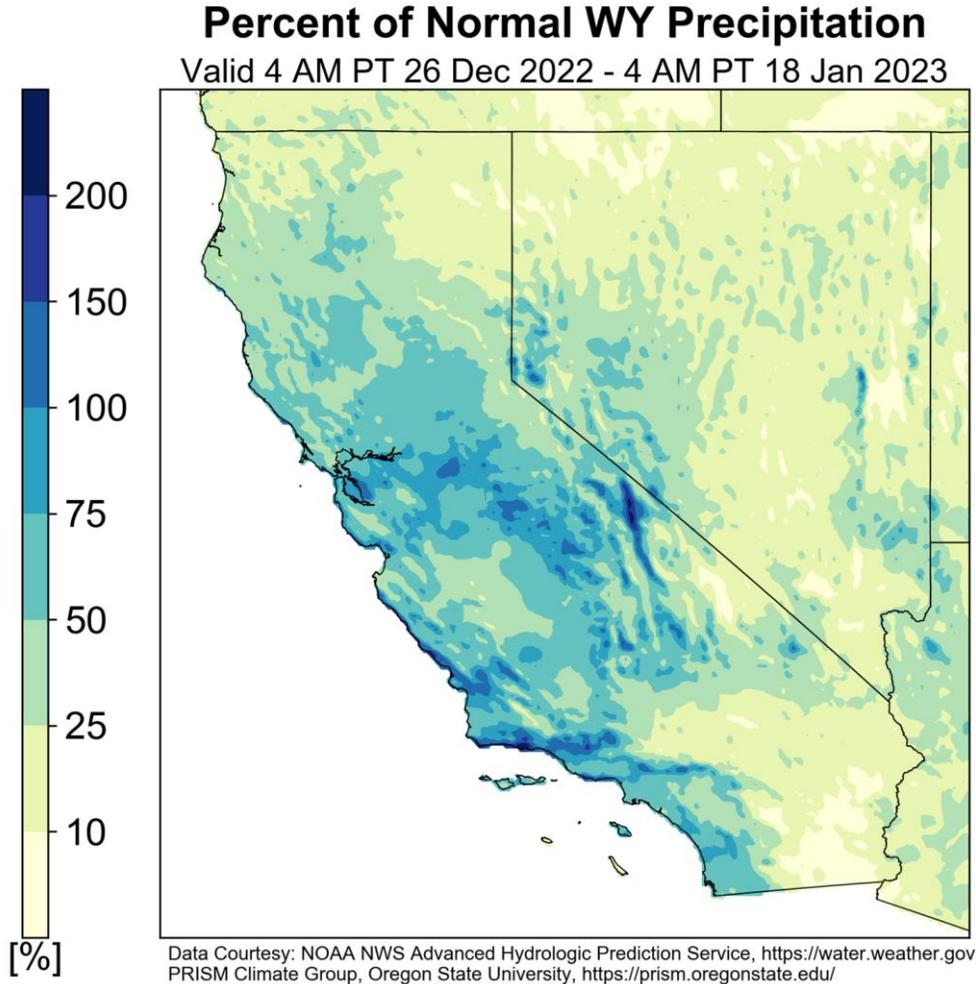
Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: <https://www.ncei.noaa.gov/access/monitoring/monthly-report/>



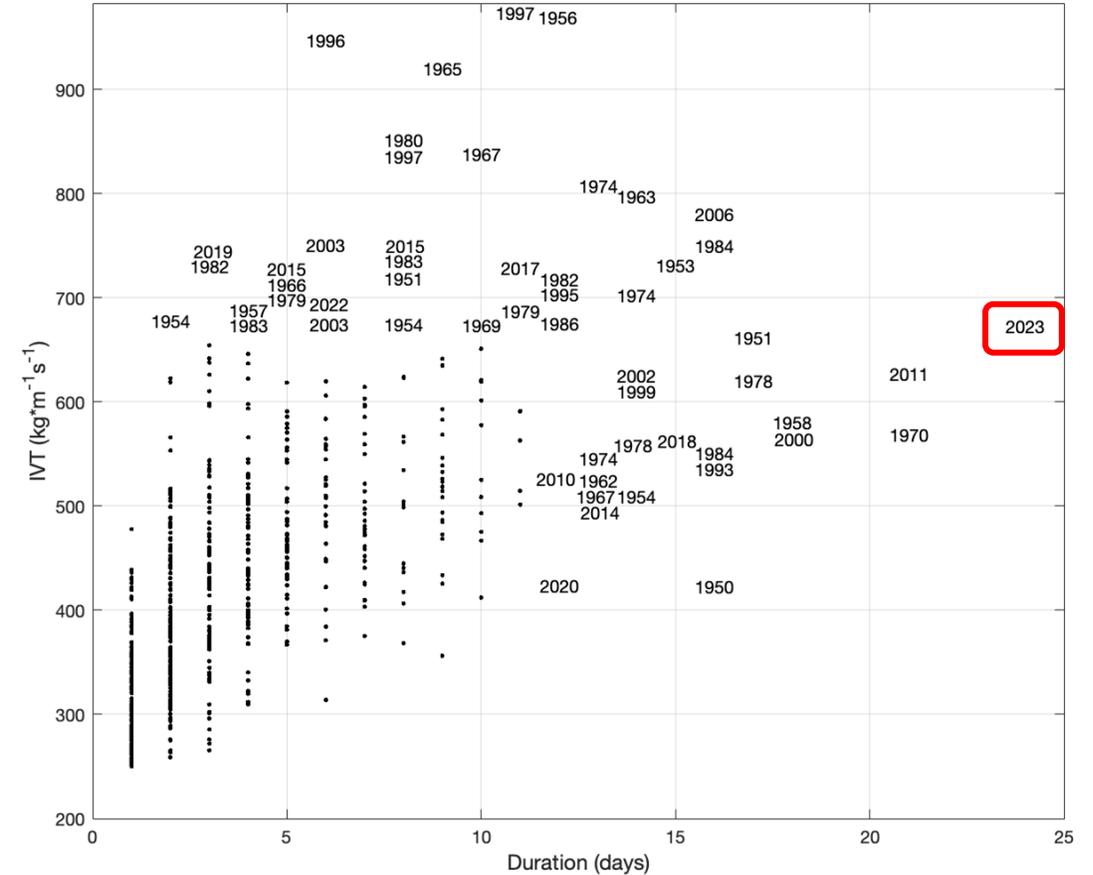
Credit: C. Hecht, UCSD/SIO/CW3E



Background and Motivation



Duration and Magnitude of AR Families



AR families identified using SIO/CW3E's AR detection algorithm based on NCEP/NCAR reanalysis

Credit: K. Guirguis, UCSD/SIO/CW3E

Data Sources

- Daily mean IVT and IWV from ERA5 reanalysis and 18 CMIP6 models
- Historical evaluation: 1950–2014
- Future projections: 2015–2100 (ssp245, ssp370, ssp585)

**IVT and IWV data are re-gridded to a common $0.5^\circ \times 0.5^\circ$ grid*

Model	Resolution	Ensemble Size
ACCESS-CM2	$1.25^\circ \times 1.875^\circ$	3
BCC-CSM2-MR	$1.125^\circ \times 1.125^\circ$	1
CanESM5	$2.8^\circ \times 2.8^\circ$	3
CNRM-CM6-1	$1.4^\circ \times 1.4^\circ$	6
CNRM-CM6-1-HR	$0.5^\circ \times 0.5^\circ$	1
CNRM-ESM2-1	$1.4^\circ \times 1.4^\circ$	1
EC-Earth3	$0.7^\circ \times 0.7^\circ$	2
EC-Earth3-Veg	$0.7^\circ \times 0.7^\circ$	1
GFDL-CM4	$2^\circ \times 2.5^\circ$	1
HadGEM3-GC31-LL	$1.25^\circ \times 1.875^\circ$	1
INM-CM4-8	$1.5^\circ \times 2^\circ$	1
INM-CM5-0	$1.5^\circ \times 2^\circ$	1
MIROC6	$1.4^\circ \times 1.4^\circ$	3
MIROC-ES2L	$2.8^\circ \times 2.8^\circ$	1
MPI-ESM1-2-HR	$0.9375^\circ \times 0.9375^\circ$	2
MPI-ESM1-2-LR	$1.875^\circ \times 1.875^\circ$	10
MRI-ESM2-0	$1.125^\circ \times 1.125^\circ$	5
UKESM1-0-LL	$1.25^\circ \times 1.875^\circ$	4

AR Detection

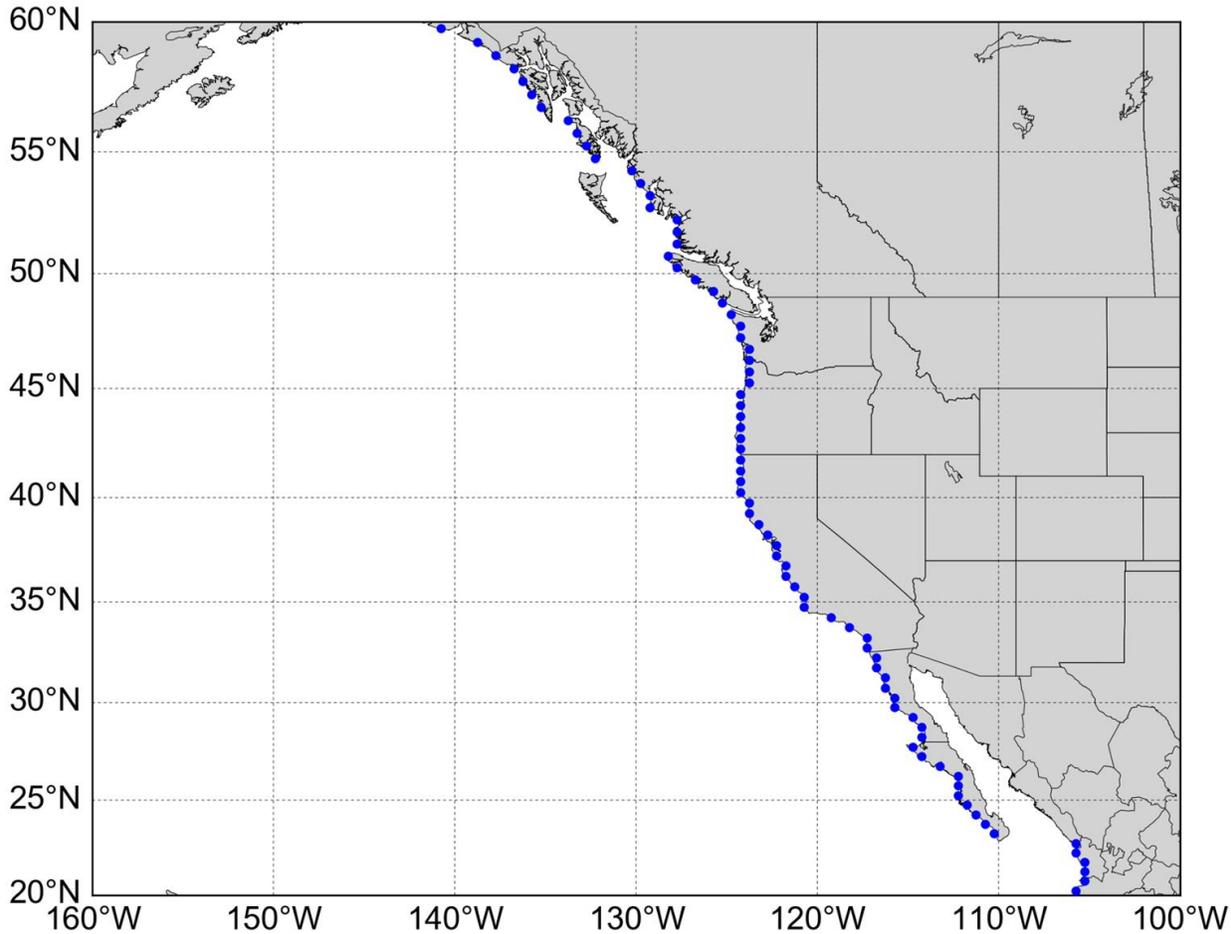
- Landfalling ARs are detected using minimum IVT ($250 \text{ kg m}^{-1} \text{ s}^{-1}$), IWV (15 mm), and length (1,500 km) criteria defined in [Gershunov et al. \(2017\)](#)

AR Sequences

- AR sequences during Oct–Apr are identified following the methodology in [Bowers et al. \(2023\)](#)
 1. Identify continuous periods when 5-day running mean IVT $>$ 75th percentile of climatology
 2. A period is considered an AR sequence if maximum 5-day running mean IVT $\geq 250 \text{ kg m}^{-1} \text{ s}^{-1}$ and an AR footprint exists on two or more days

Data and Methodology

Coastal Grid Points for AR Detection



Schematic: Identifying AR Sequences

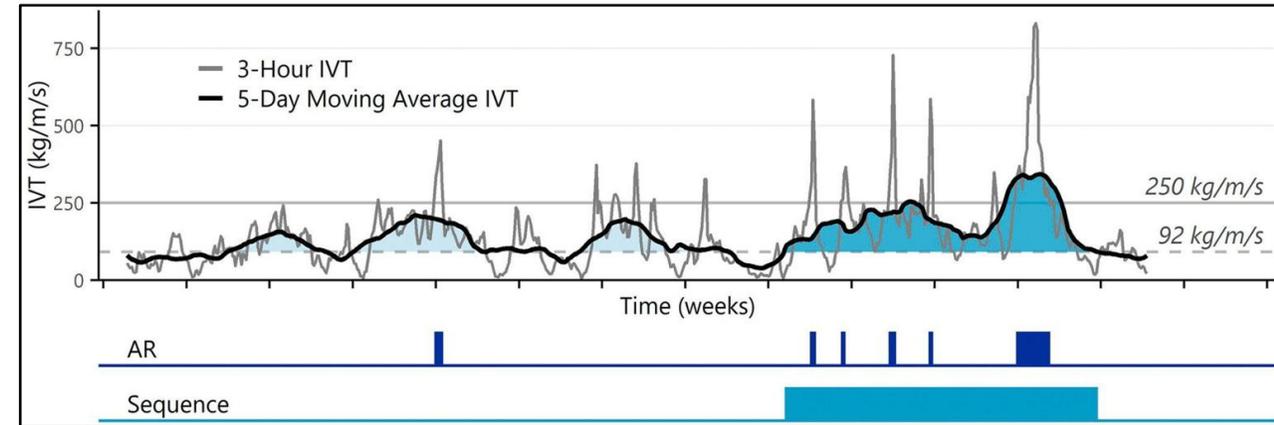


Figure 1 from Bowers et al. (2023)

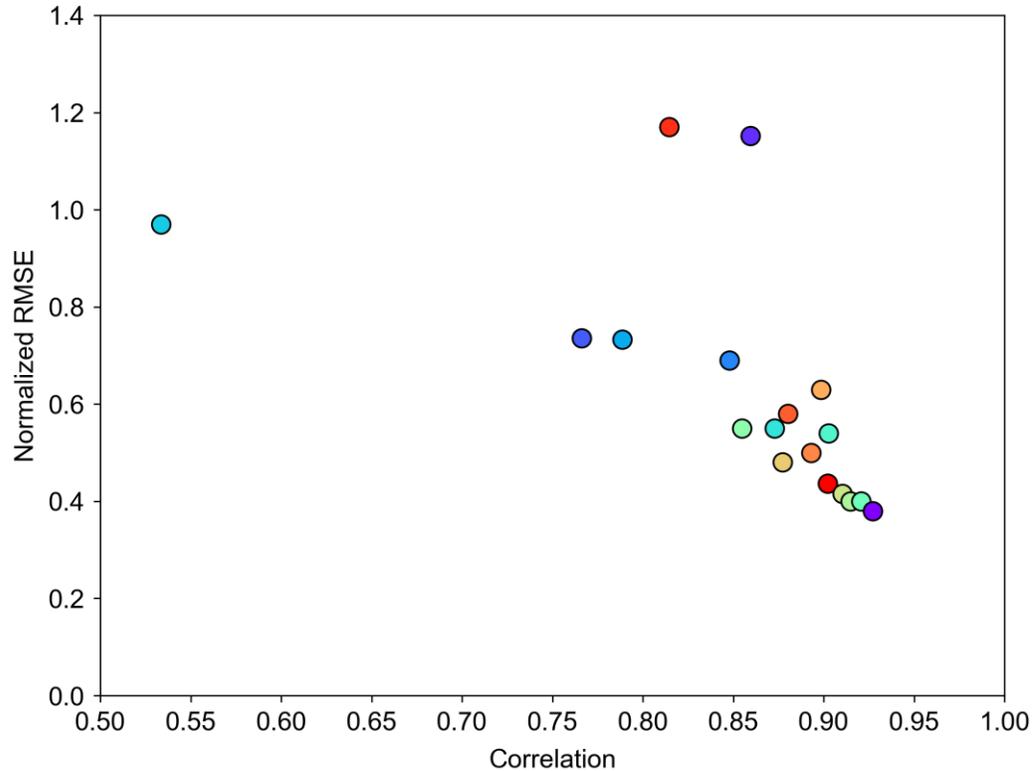
Dashed line = median of IVT climatology

Dark blue shading = AR sequences

Light blue shading = potential AR sequences that do not meet additional criteria

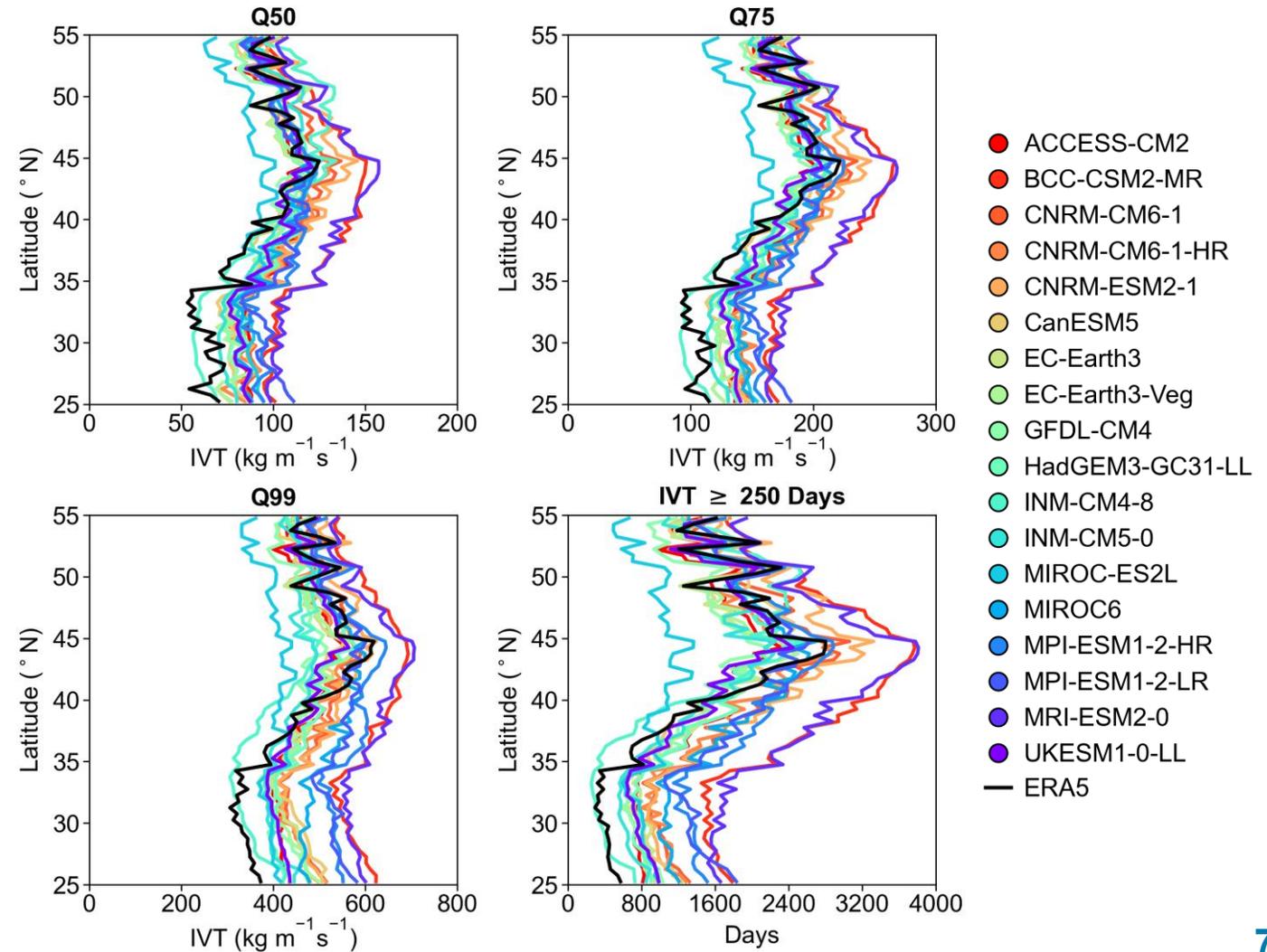
CMIP6 Historical Evaluation

Monthly AR Days



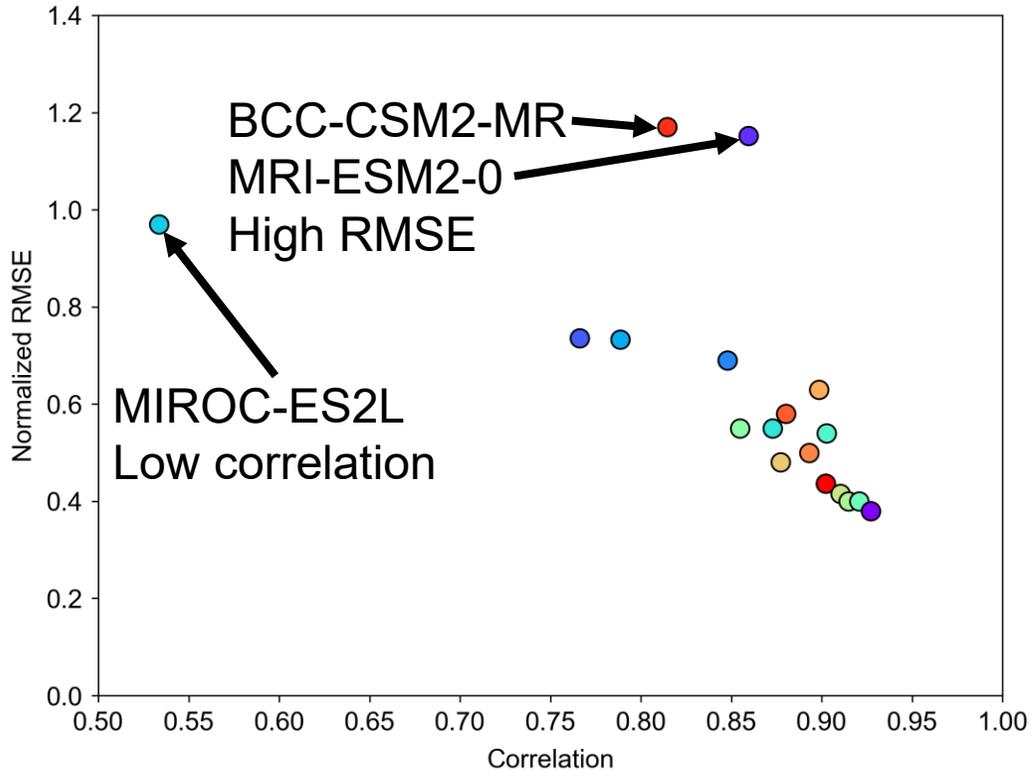
A subset of “realistic” models was identified by computing the RMSE and pattern correlation of simulated monthly AR days and monthly AR TIVT with respect to ERA5

Oct–Apr IVT Climatology



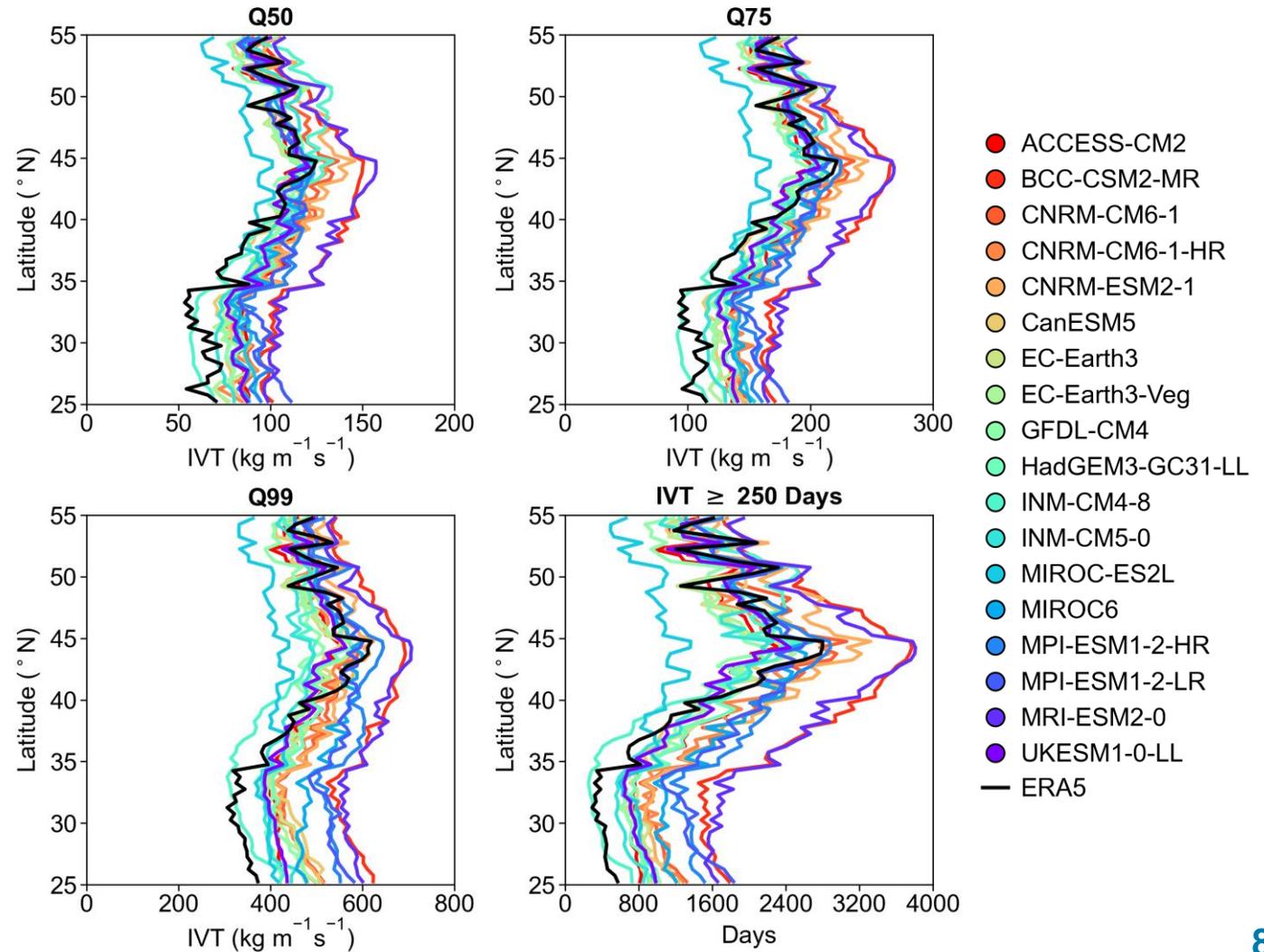
CMIP6 Historical Evaluation

Monthly AR Days



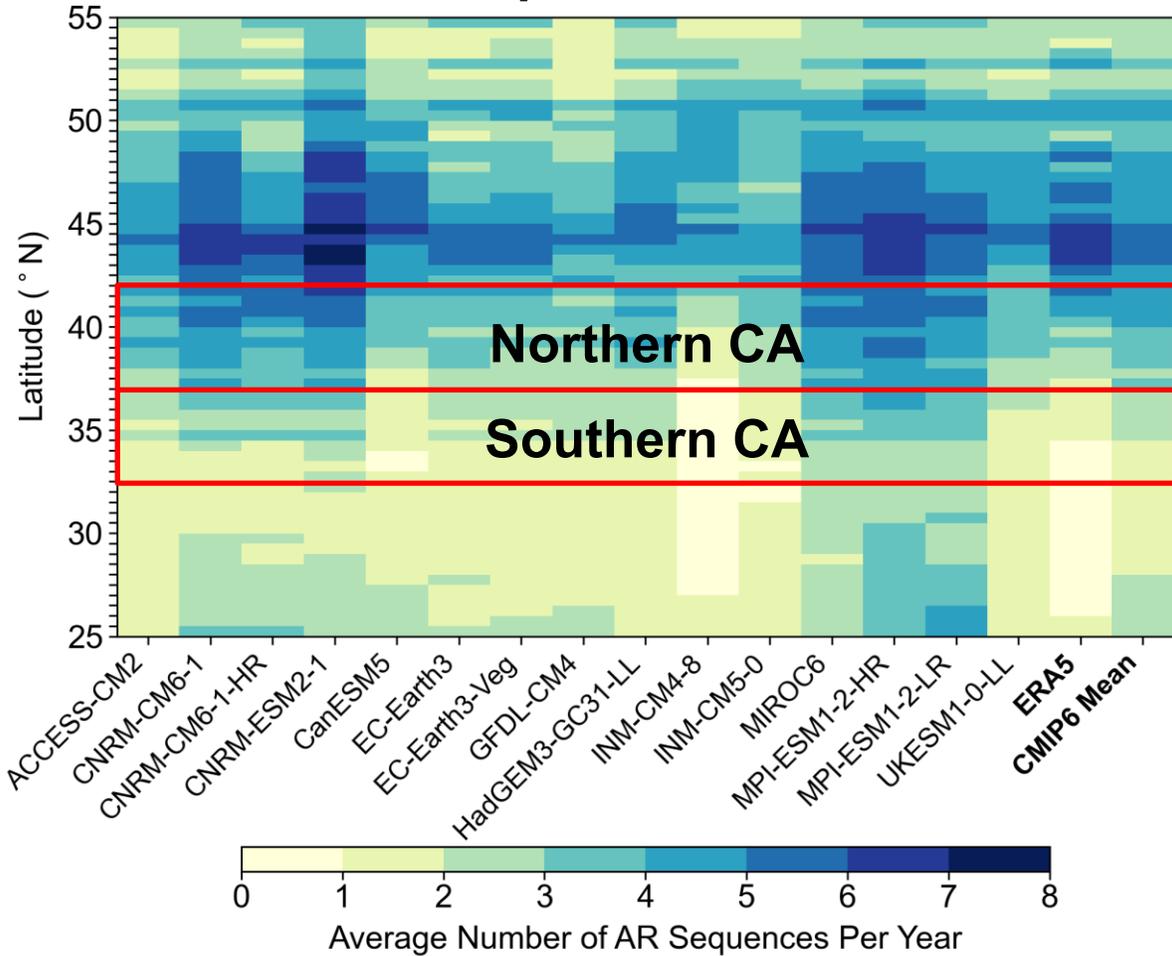
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Oct–Apr IVT Climatology

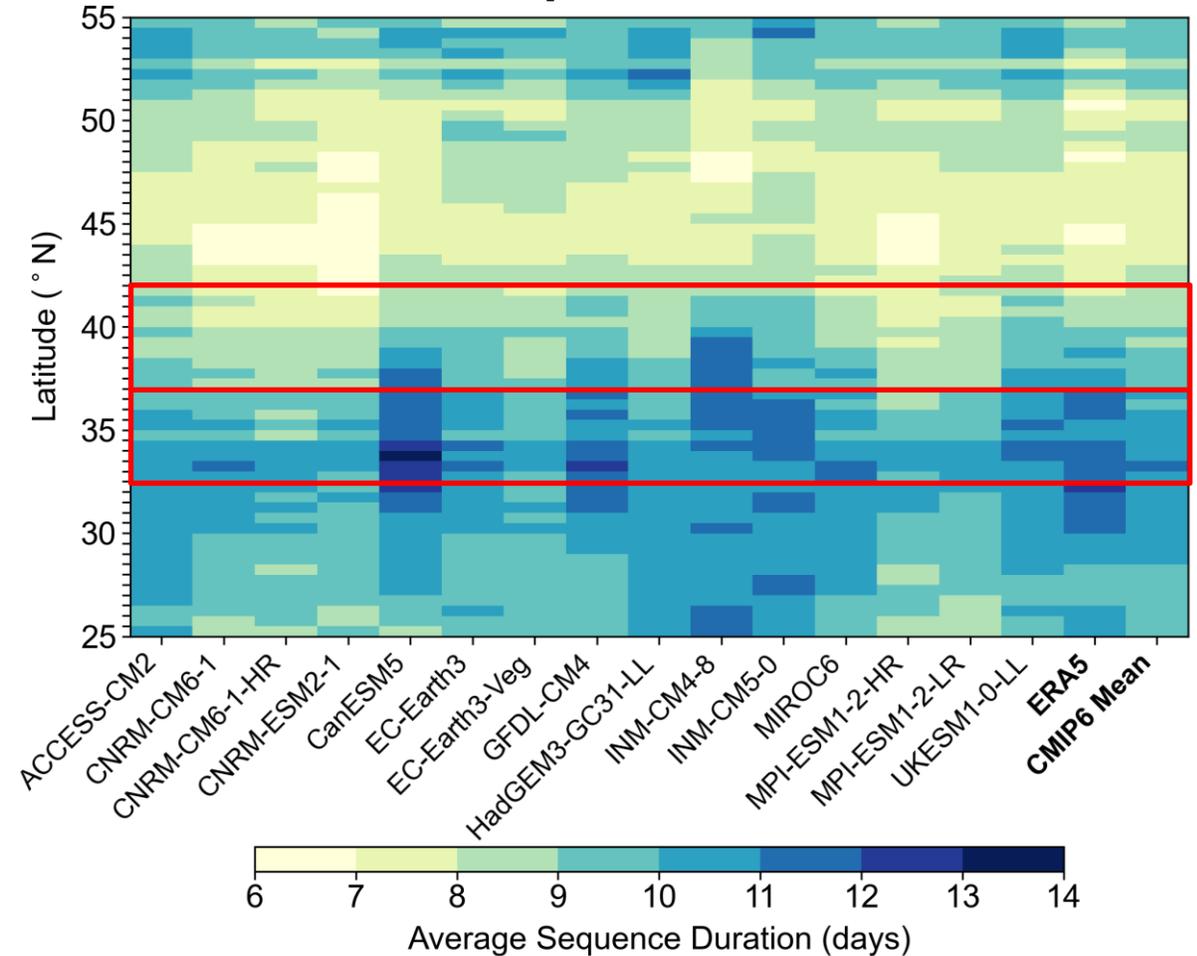


CMIP6 Historical Evaluation of AR Sequences

AR Sequences Per Year

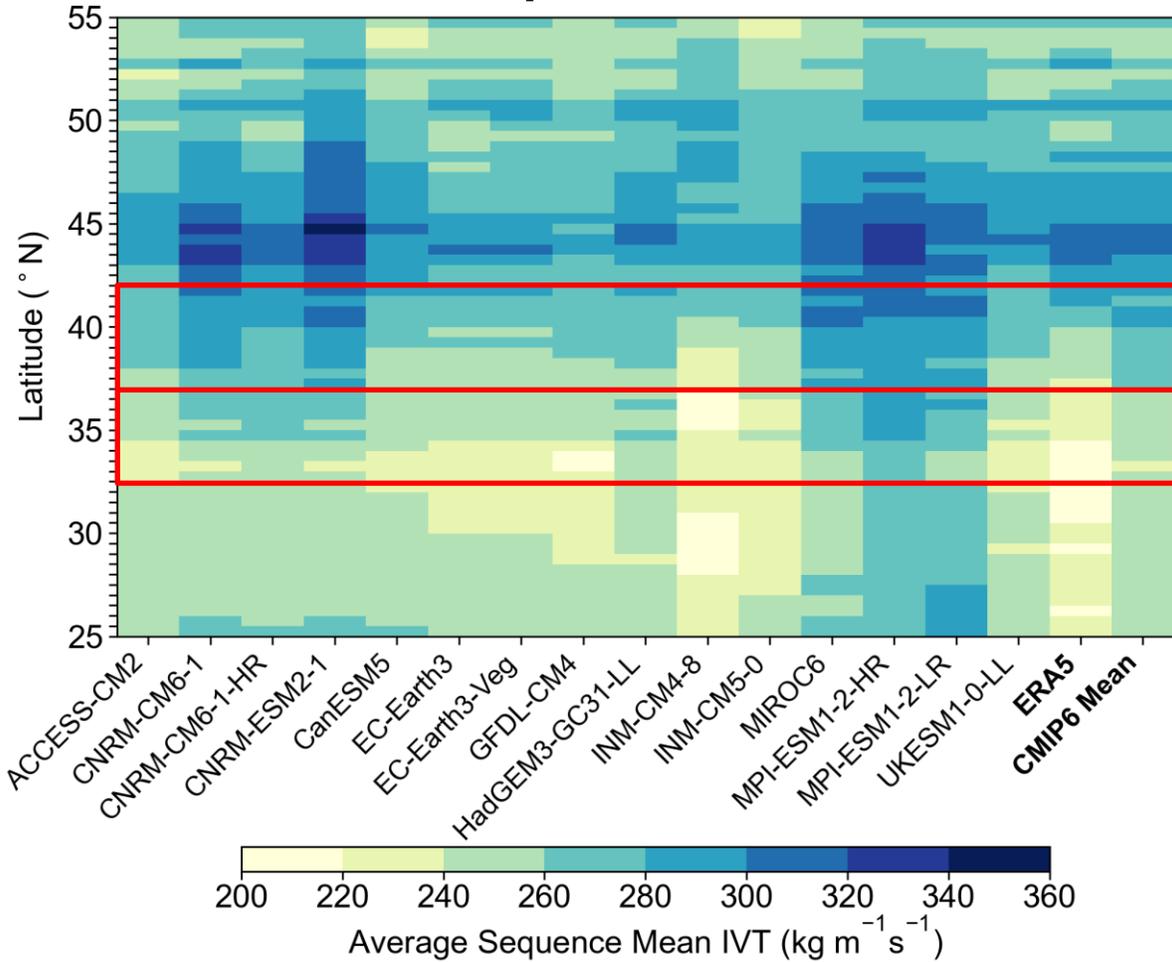


AR Sequence Duration

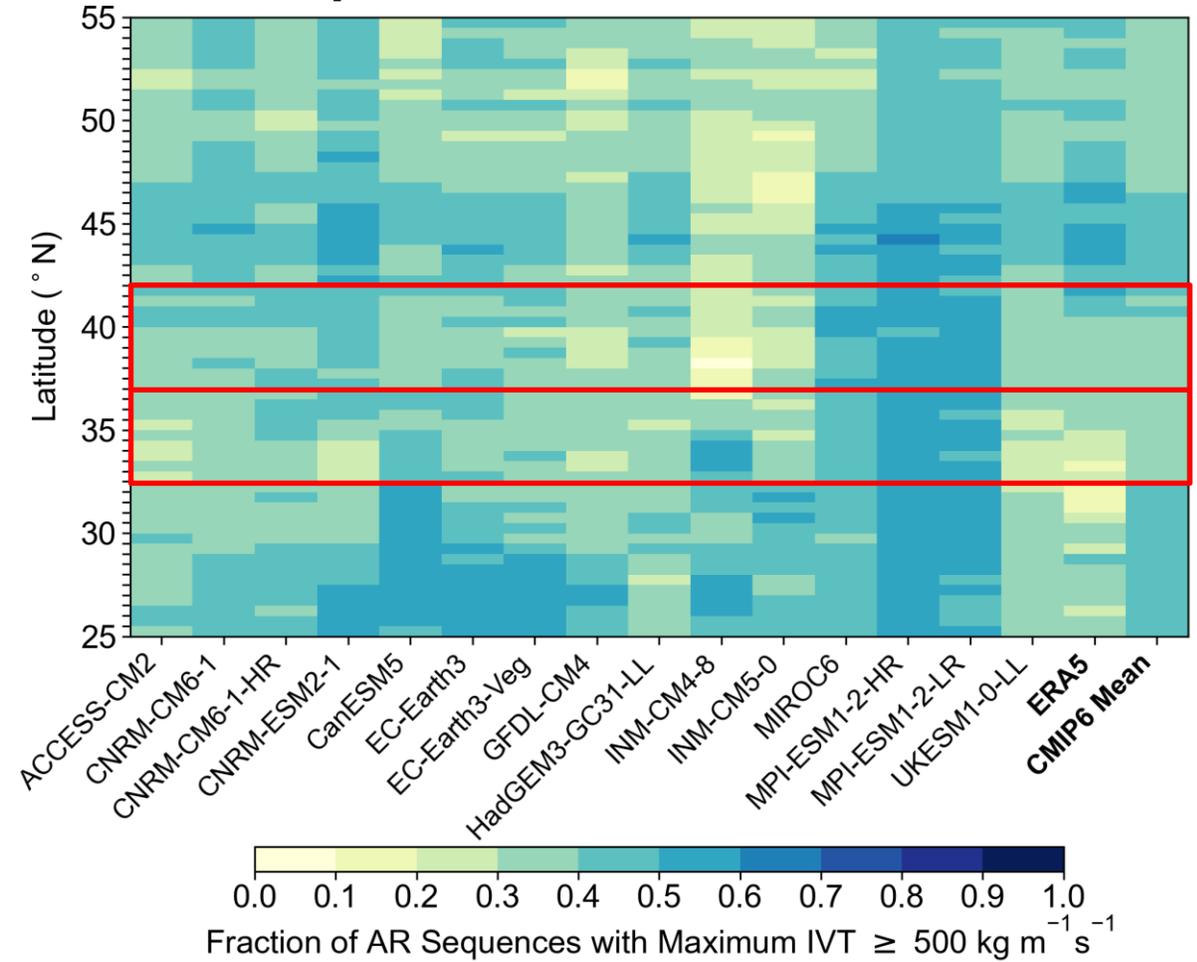


CMIP6 Historical Evaluation of AR Sequences

AR Sequence Mean IVT

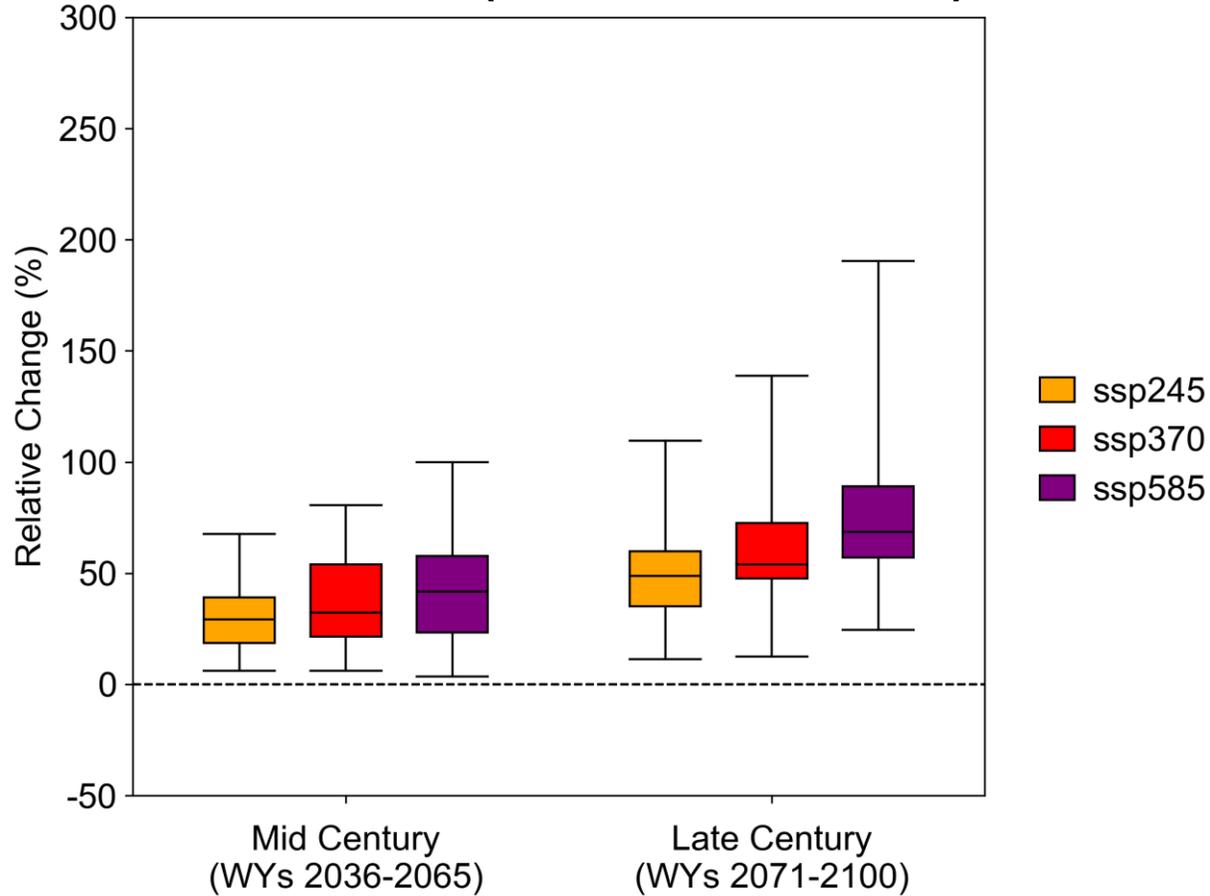


AR Sequences with Max IVT ≥ 500 Units

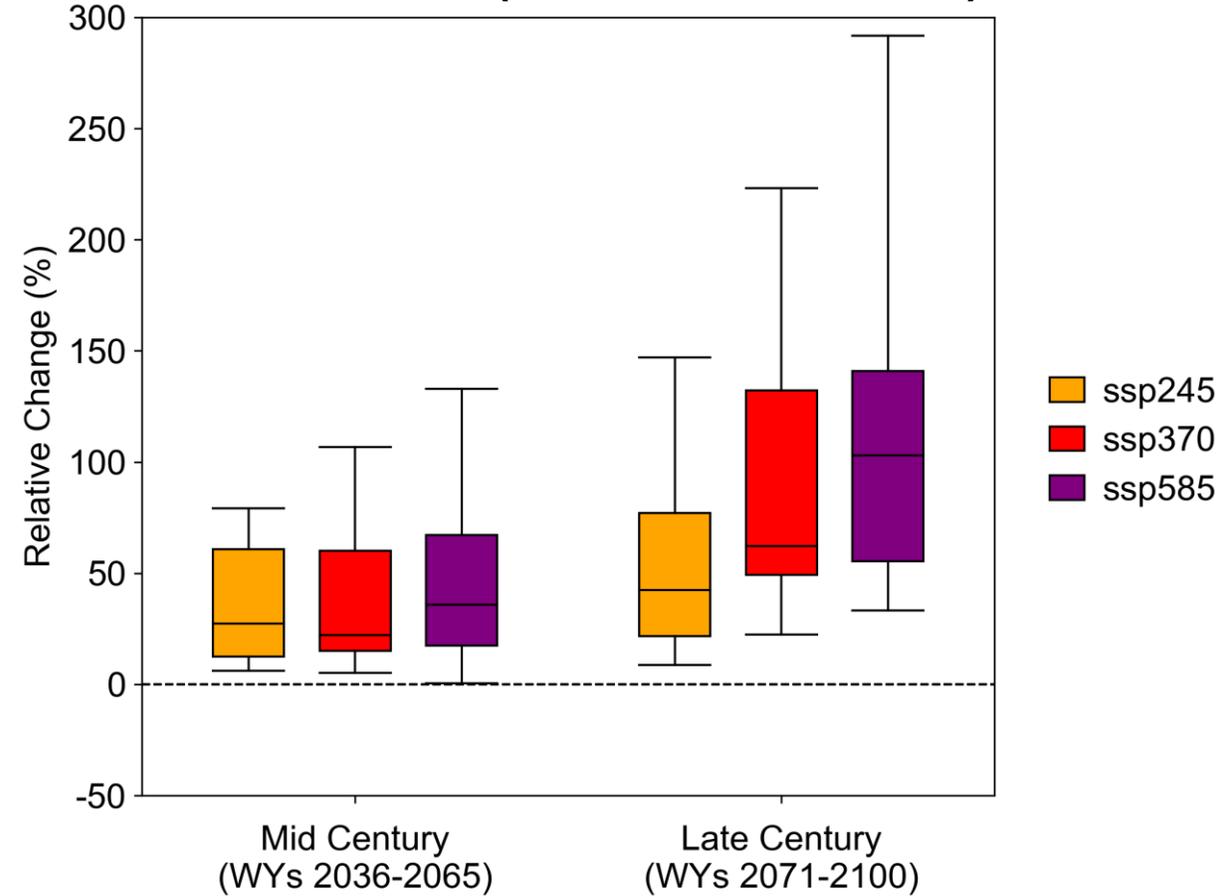


Projected Changes in AR Sequences: Frequency

Northern CA (38.25°N, 122.75°W)



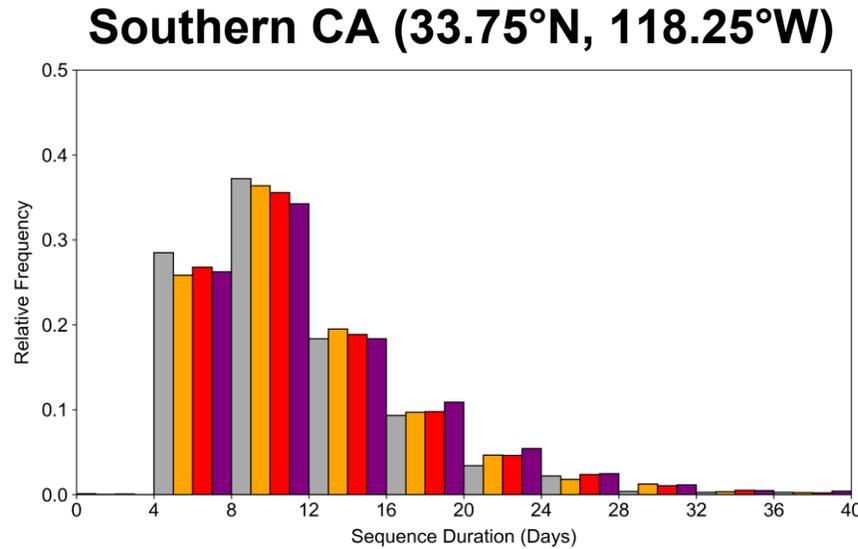
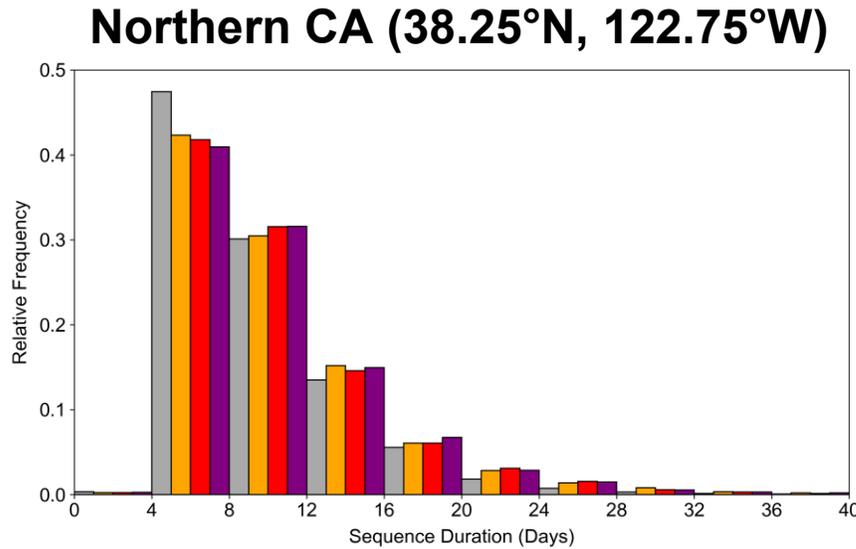
Southern CA (33.75°N, 118.25°W)



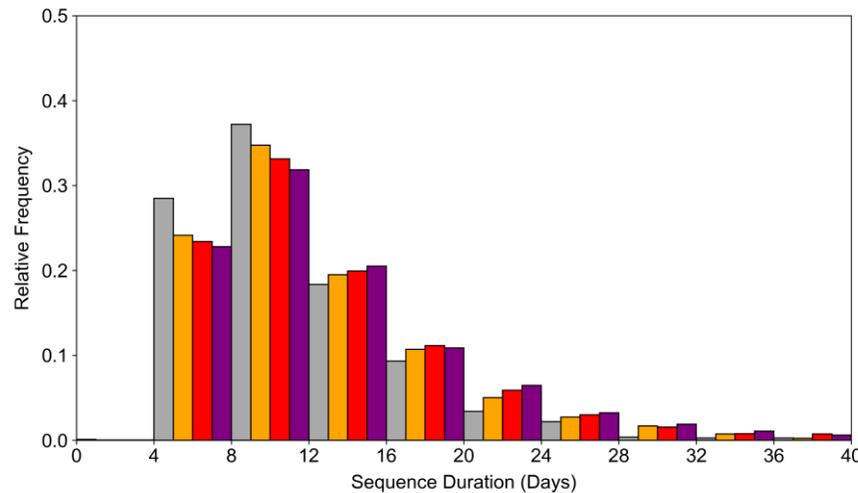
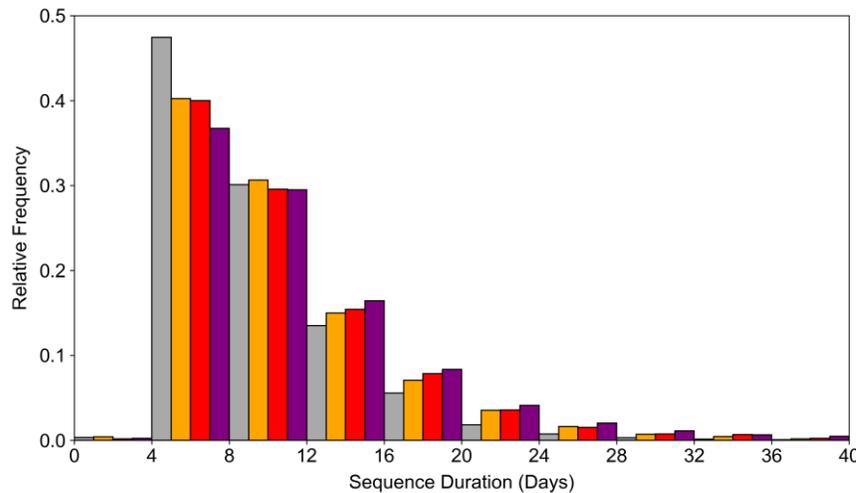
Each boxplot consists of n values (n = number of models). Relative changes are calculated with respect to WYs 1981–2010.

Projected Changes in AR Sequences: Duration

**Mid Century
WYs 2036–2065**



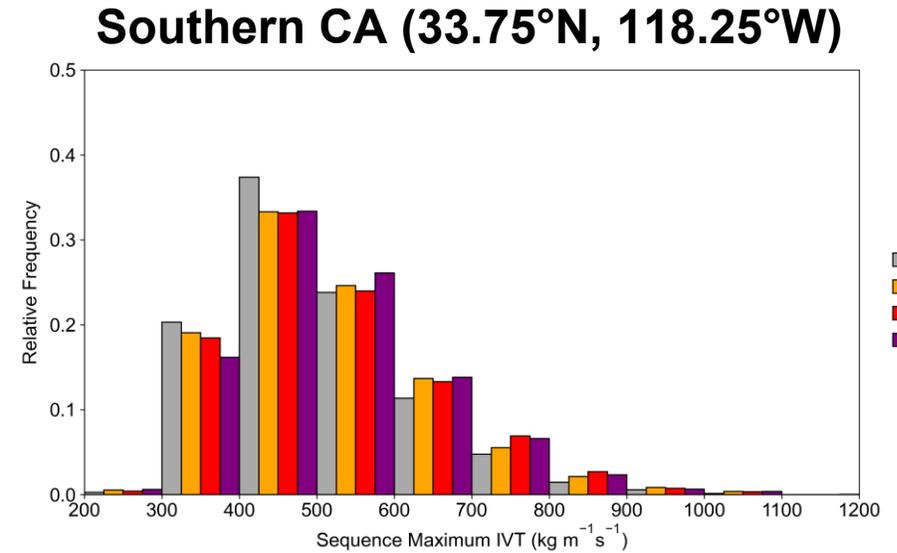
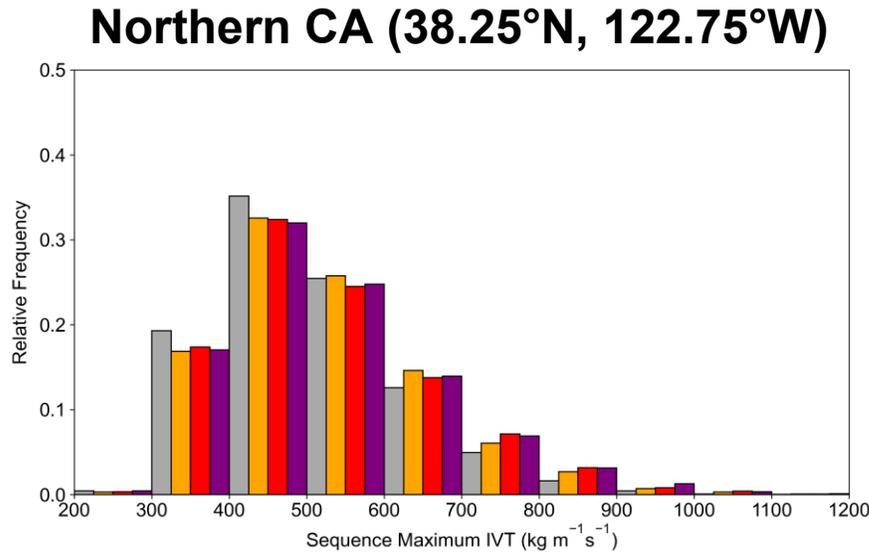
**Late Century
WYs 2071–2100**



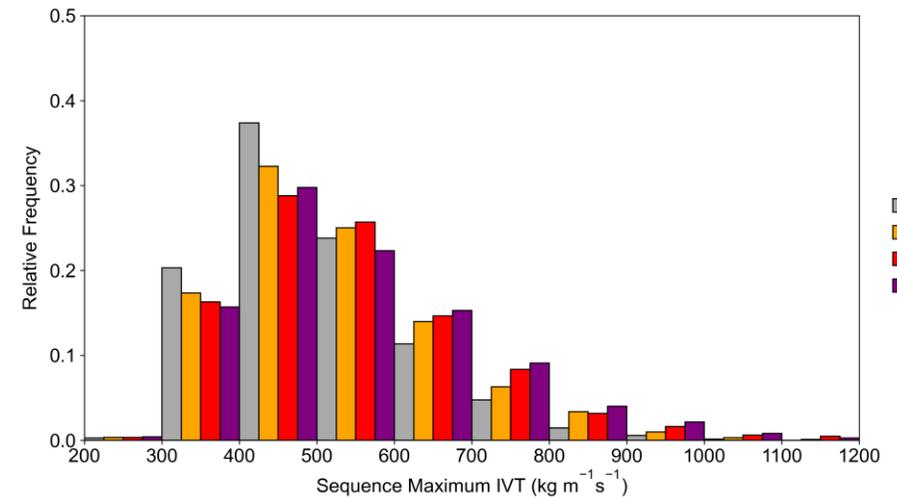
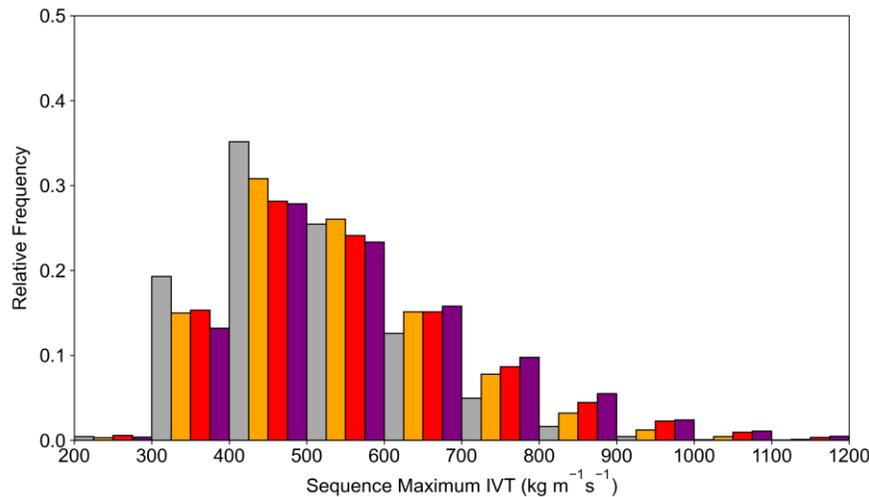
Each histogram represents the distribution of values across all simulated AR sequences

Projected Changes in AR Sequences: Maximum IVT

Mid Century
WYs 2036–2065



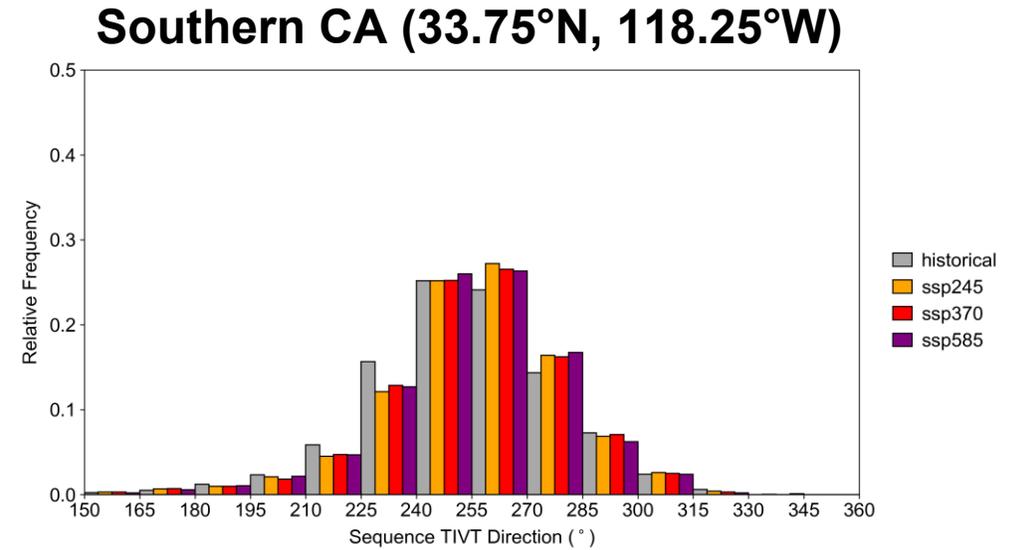
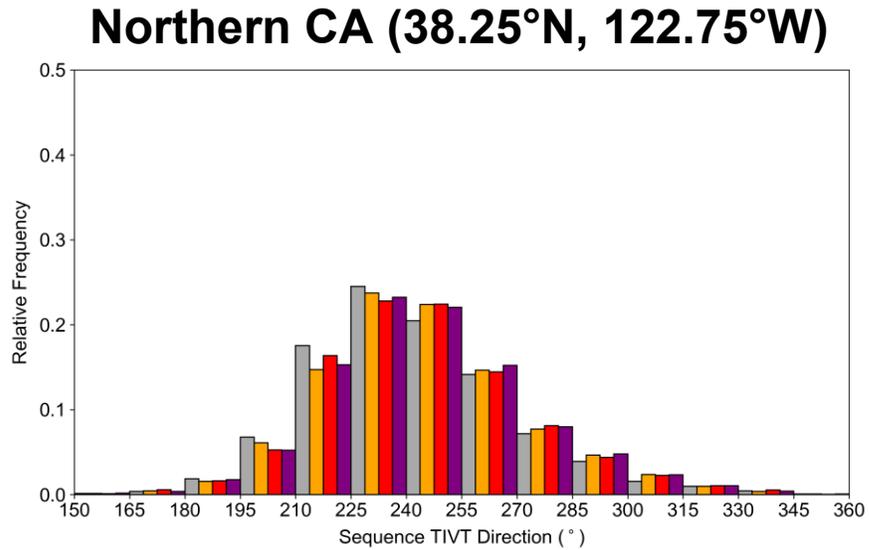
Late Century
WYs 2071–2100



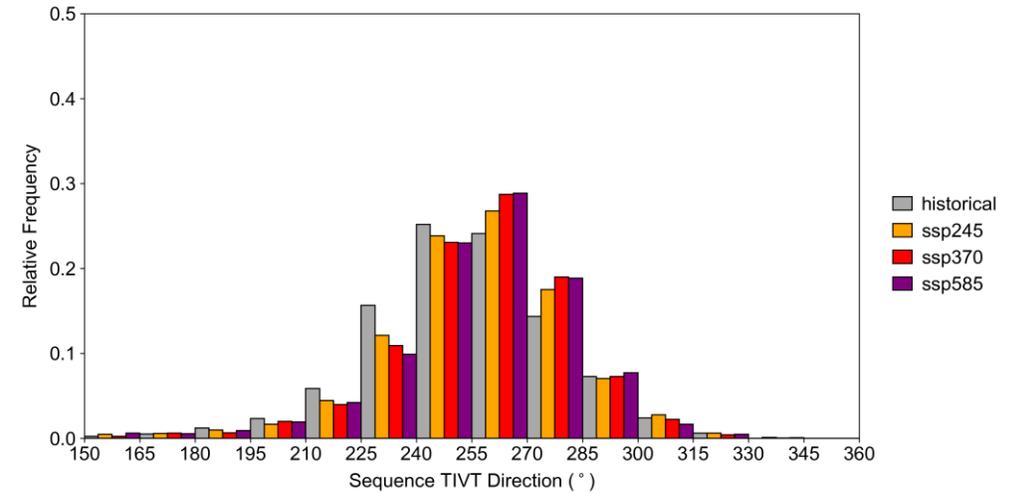
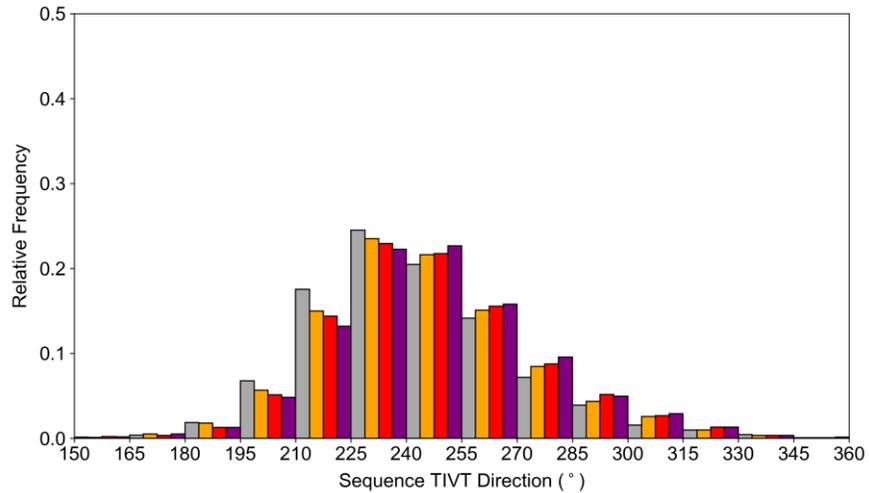
Each histogram represents the distribution of values across all simulated AR sequences

Projected Changes in AR Sequences: TIVT Direction

**Mid Century
WYs 2036–2065**



**Late Century
WYs 2071–2100**



Each histogram represents the distribution of values across all simulated AR sequences

Summary

- CMIP6 models do a reasonably good job of simulating AR sequences, but overestimate their frequency and intensity over Southern CA
- Models predict large increases in the frequency of AR sequences during the late 21st century, especially over Southern CA under the ssp370 and ssp585 scenarios
- Models predict relatively modest increases in AR sequence duration, but show a shift toward stronger AR sequences (i.e., higher maximum IVT) during the late 21st century, particularly under the ssp370 and ssp585 scenarios
- Models show a shift toward more westerly moisture transport in AR sequences during the late 21st century, especially over Southern CA

- **Investigate the relationship between AR sequences and North Pacific circulation regimes ([Guirguis et al. 2020](#))**
 - Do AR sequences preferentially occur under certain weather regimes?
 - How do weather regimes modulate the characteristics of landfalling ARs (e.g., location, duration, intensity, orientation) within AR sequences?
- **Investigate projected changes in the relationship between AR sequences and precipitation in the western US**
 - How might the contribution of AR sequences to total precipitation and extreme precipitation days change in the future?

References and Acknowledgement

Bowers, C., Serafin, K. A., Tseng, K.-C., & Baker, J. W. (2023). Atmospheric river sequences as indicators of hydrologic hazard in historical reanalysis and GFDL SPEAR future climate projections. *Earth's Future*, 11(12), e2023EF003536. <https://doi.org/10.1029/2023EF003536>

Gershunov, A., Shulgina, T., Ralph, F. M., Lavers, D. A., & Rutz, J. J. (2017). Assessing the climate-scale variability of atmospheric rivers affecting western North America. *Geophysical Research Letters*, 44(15), 7900–7908. <https://doi.org/10.1002/2017GL074175>

Guirguis, K., Gershunov, A., DeFlorio, M. J., Shulgina, T., Delle Monache, L., Subramanian, A. C., et al. (2020). Four atmospheric circulation regimes over the North Pacific and their relationship to California precipitation on daily to seasonal timescales. *Geophysical Research Letters*, 47(16), e2020GL087609. <https://doi.org/10.1029/2020GL087609>

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