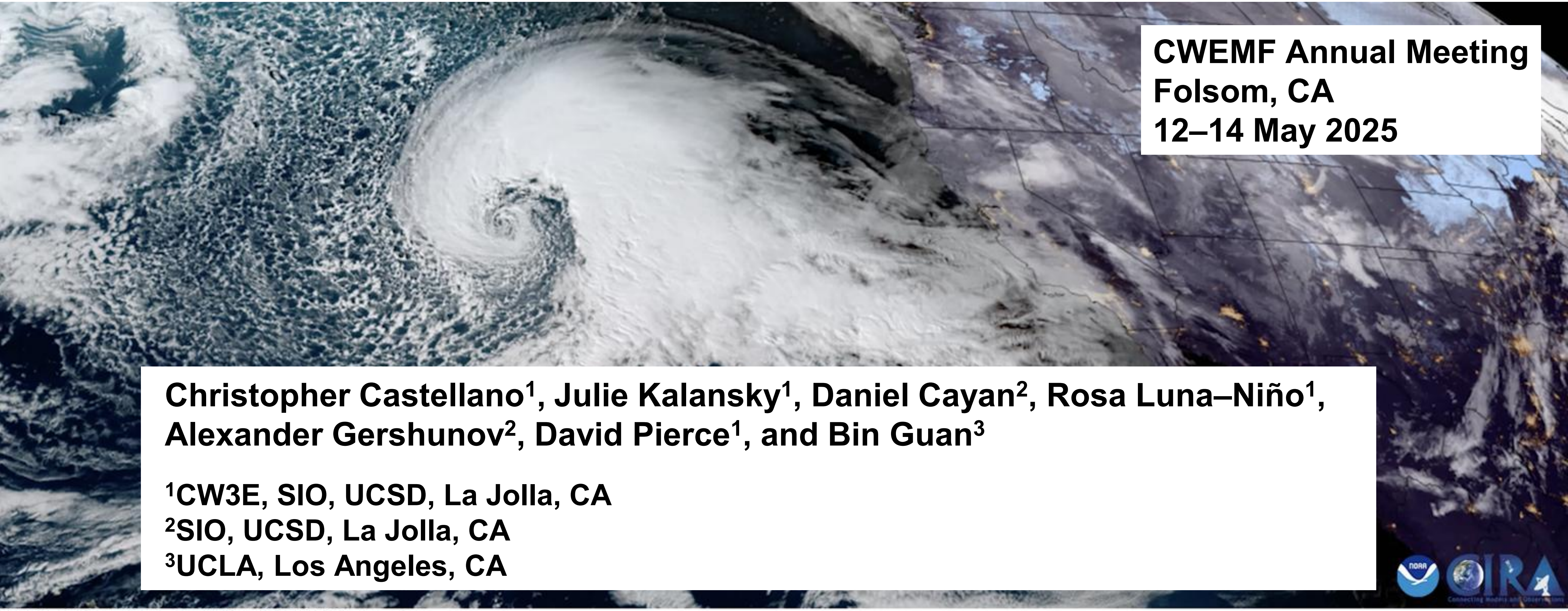
Future Changes in Atmospheric River Sequences over California



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CWEMF Annual Meeting
Folsom, CA
12–14 May 2025

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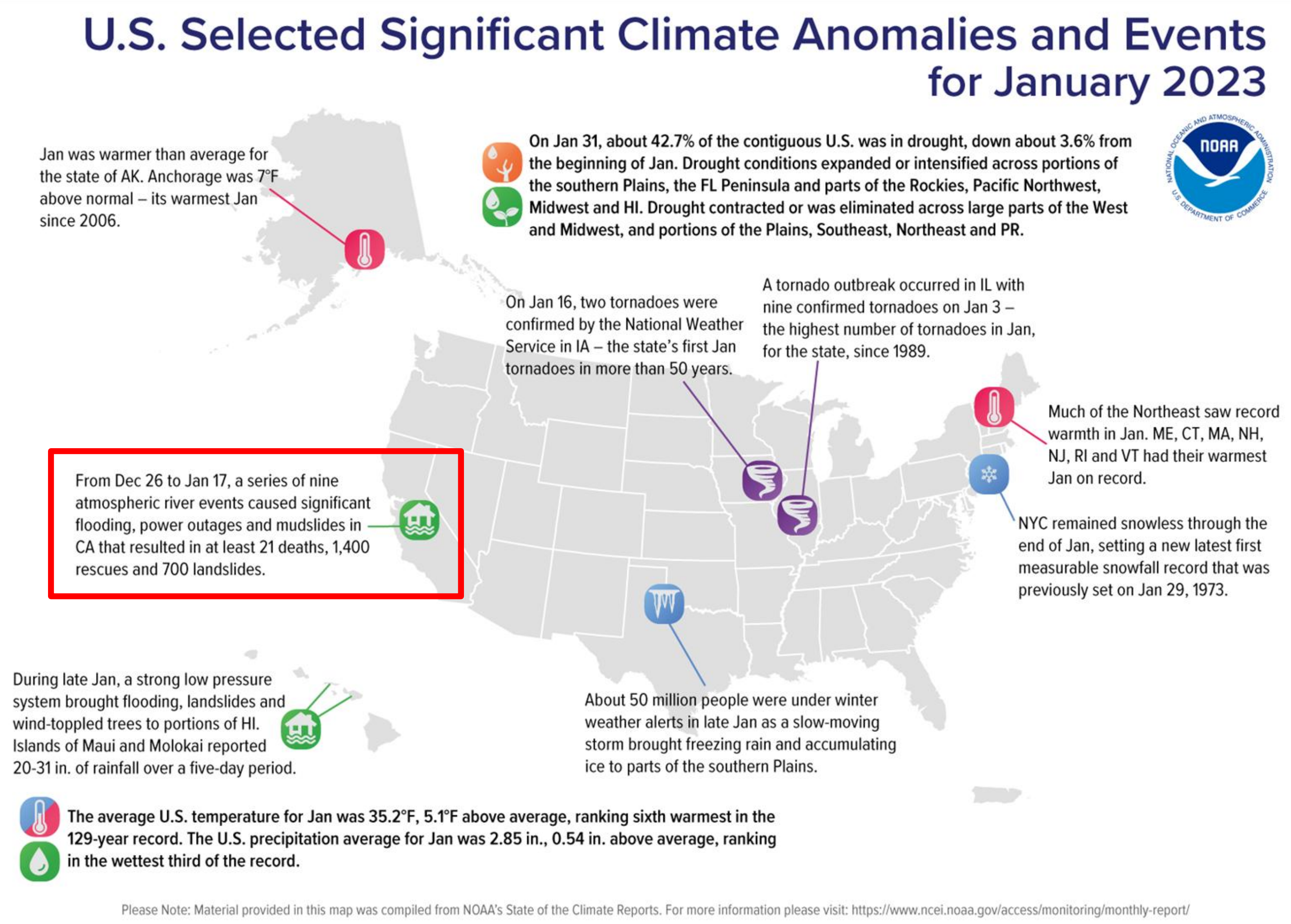
[3]UCLA, Los Angeles, CA

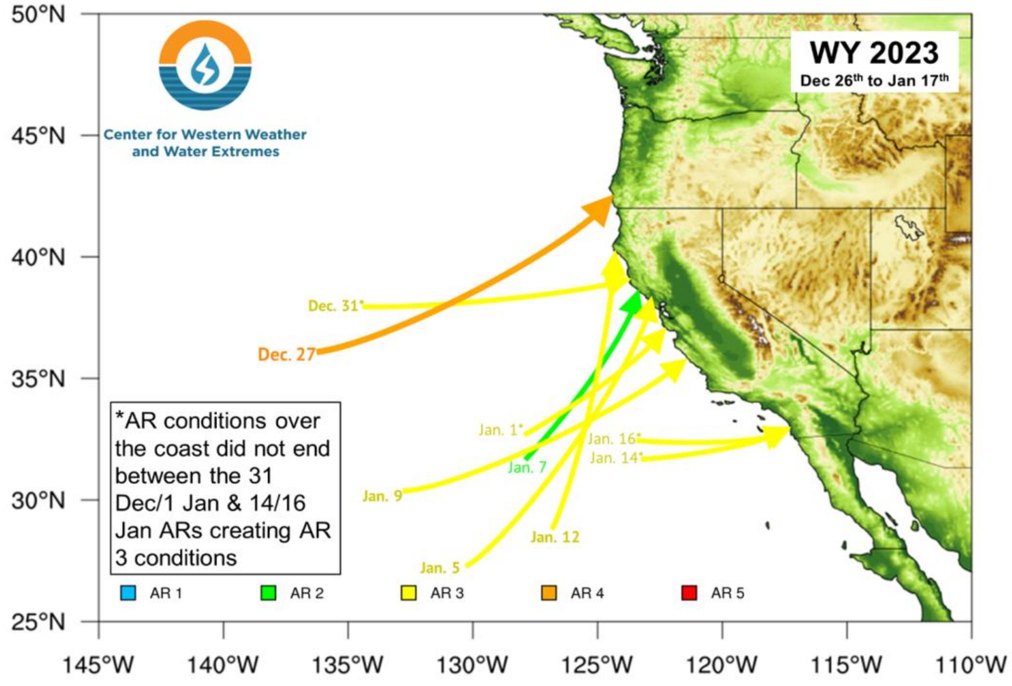
CW3E Center for Western Weather and Water Extremes

UC San Diego

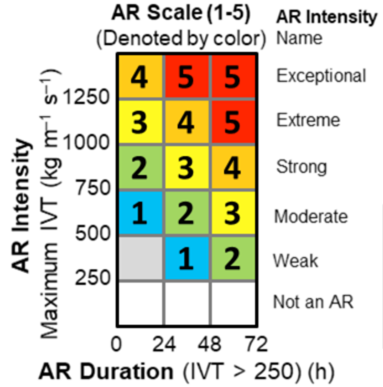
SCRIPPS INSTITUTION OF OCEANOGRAPHY

Background and Motivation





Credit: C. Hecht, UCSD/SIO/CW3E

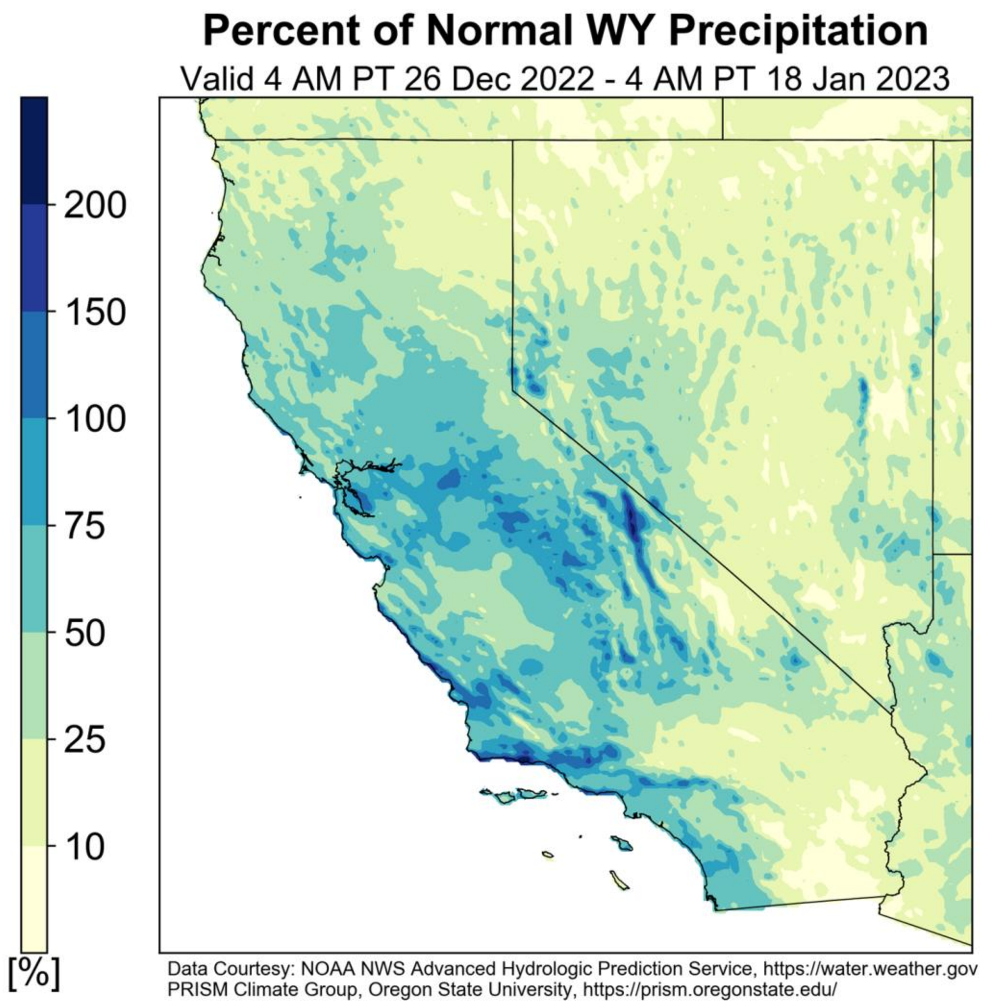


- **The Atmospheric River Scale is based on *Duration* and max *Intensity* (IVT) at a specific location**
- **The AR Scale communicates the potential benefits and hazards associated with ARs**

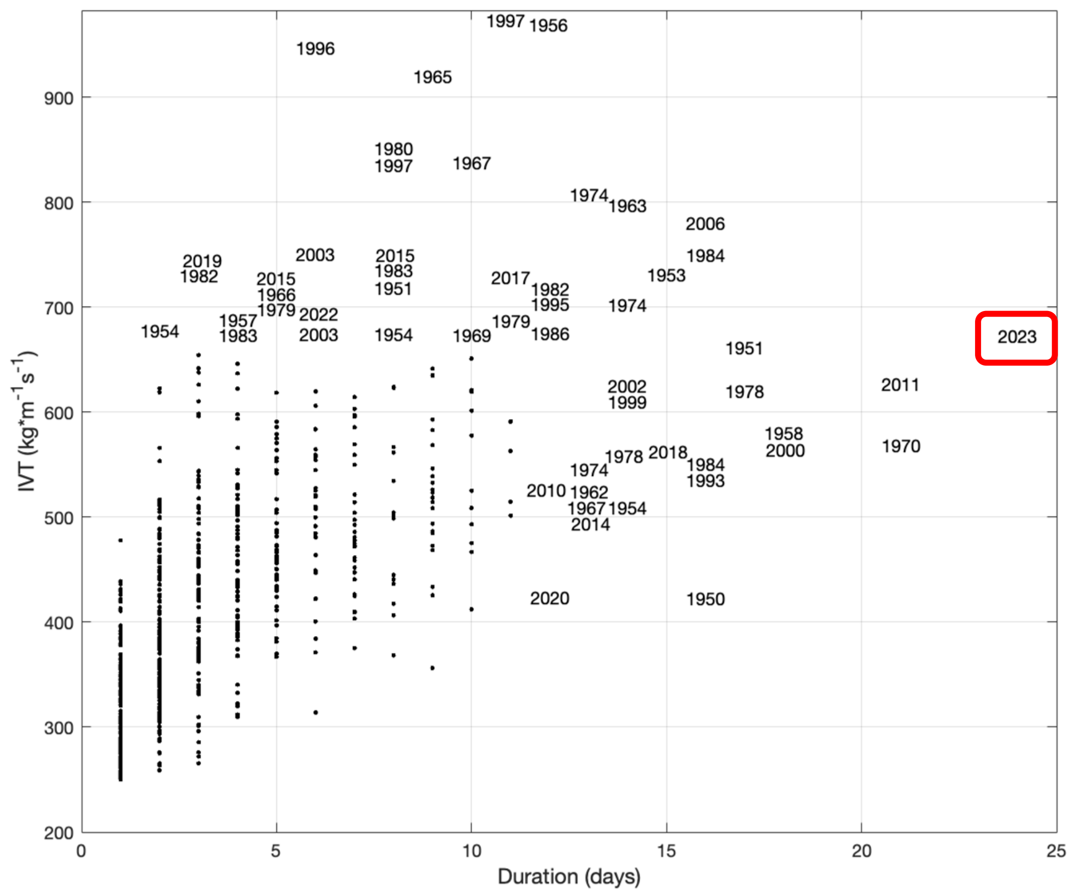
IMPACTS
- AR 5 – Primarily hazardous
- AR 4 – Mostly hazardous, also beneficial
- AR 3 – Balance of beneficial and hazardous
- AR 2 – Mostly beneficial, also hazardous
- AR 1 – Primarily beneficial

Ralph et al., *BAMS*, 2019.

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 and Methodology

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° × 0.5° grid*

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

Data and Methodology

AR Detection

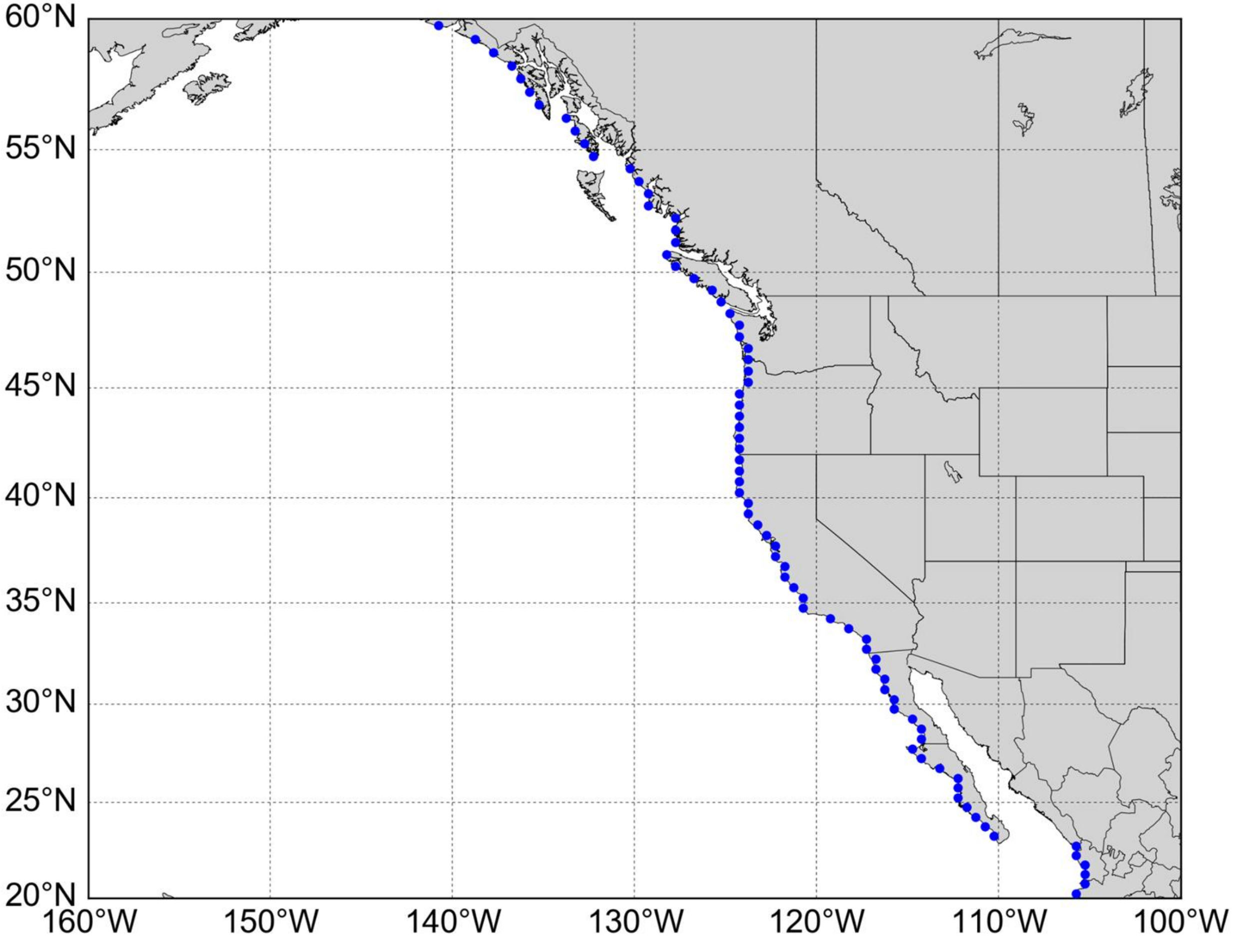
- Landfalling ARs are detected using minimum IVT (250 kg m^{-1} s^{-1}), IWV (15 mm), and length (1,500 km) criteria defined in Gershunov et al. (2017)

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 ≥ 250 kg m^{-1} 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

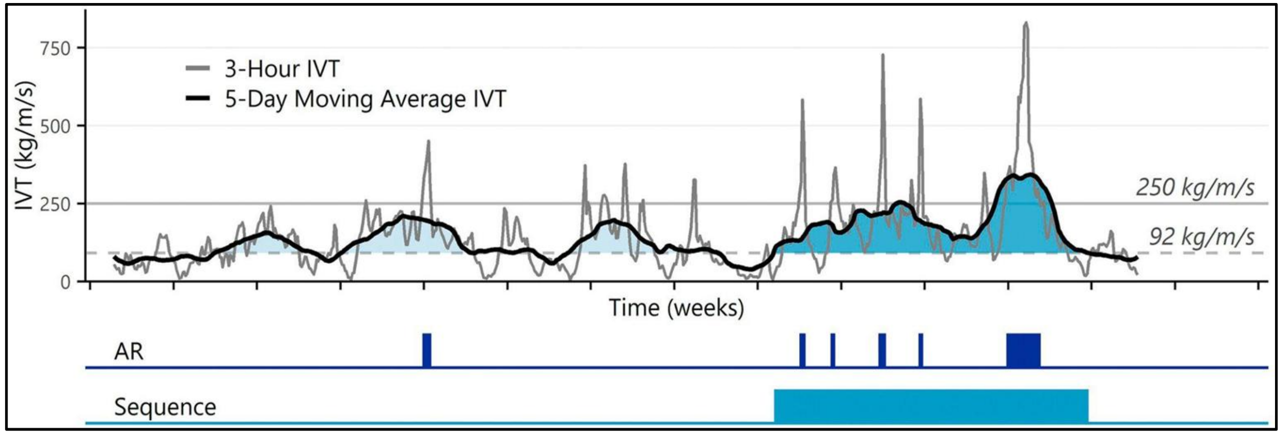


Figure 1 from Bowers et al. (2023)

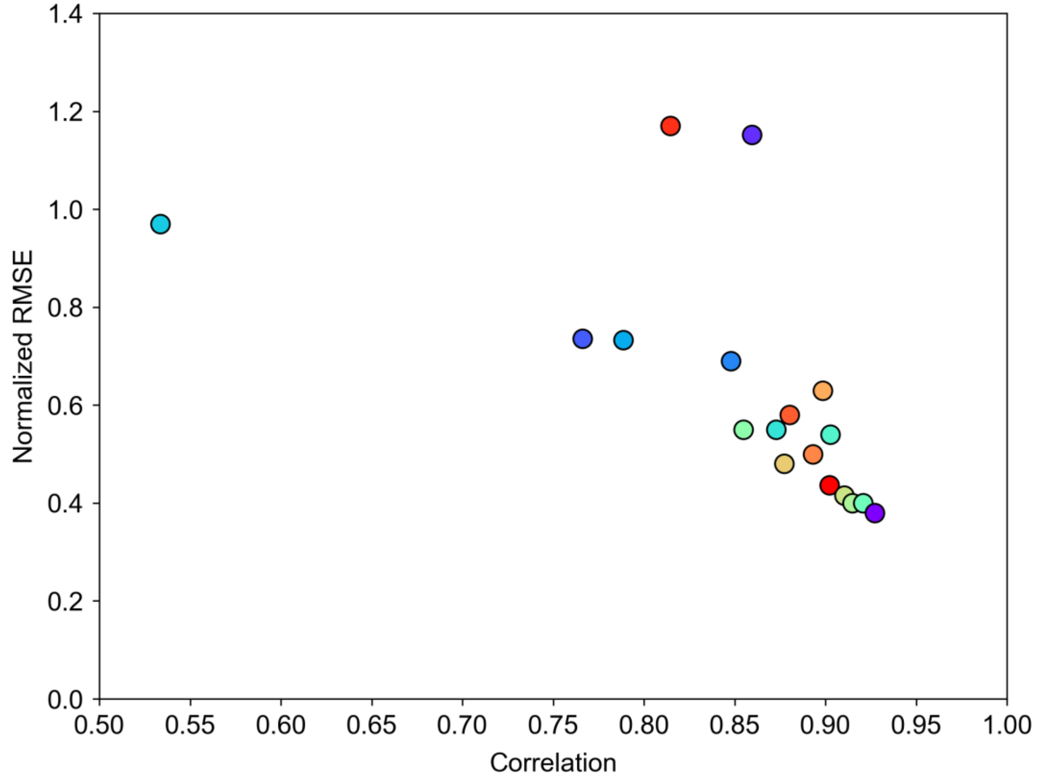
Dashed line = median of IVT climatology

Dark blue shading = AR sequences

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

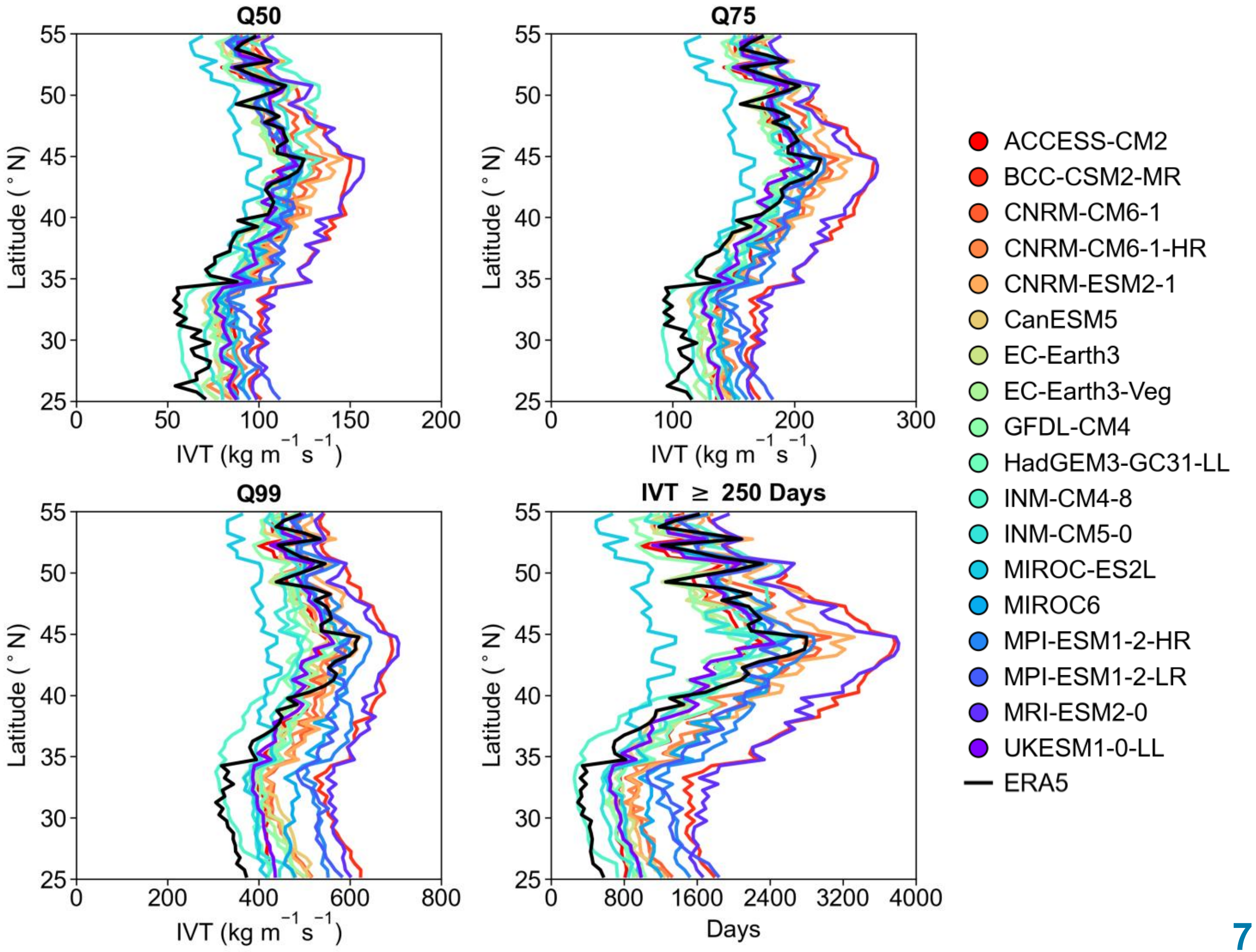
CMIP6 Historical Evaluation

Monthly AR Days



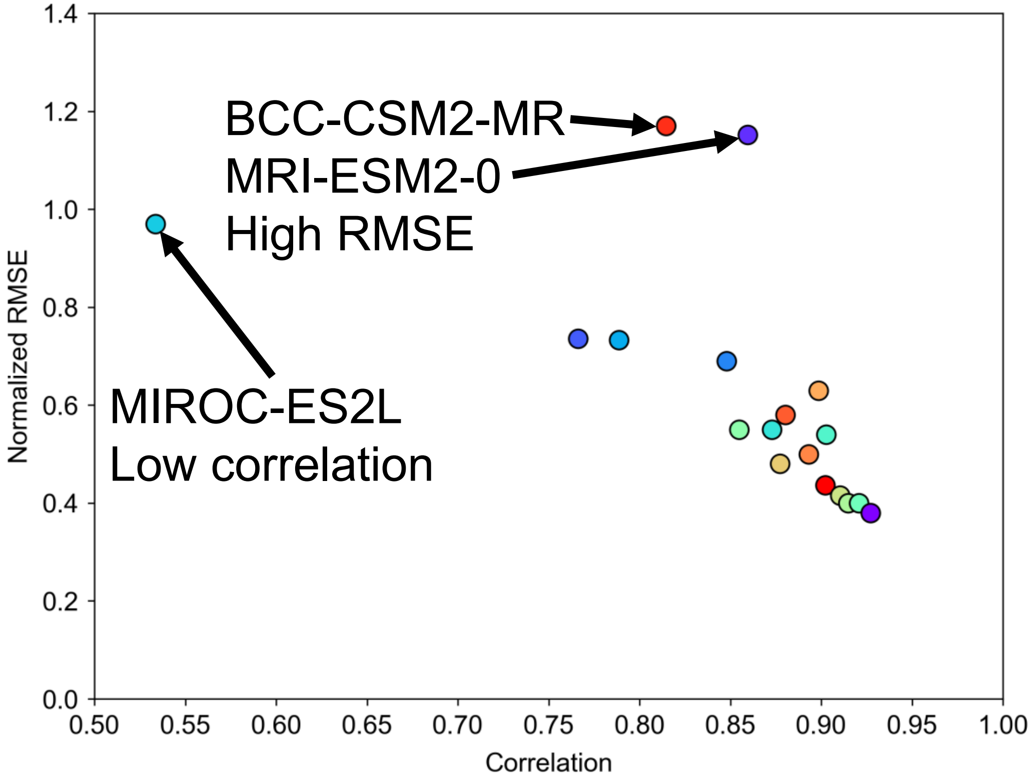
A subset of “realistic” models was identified by computing the RMSE and pattern correlation of simulated monthly AR days and monthly AR TIVT with respect to ERA5

Oct–Apr IVT Climatology



CMIP6 Historical Evaluation

Monthly AR Days



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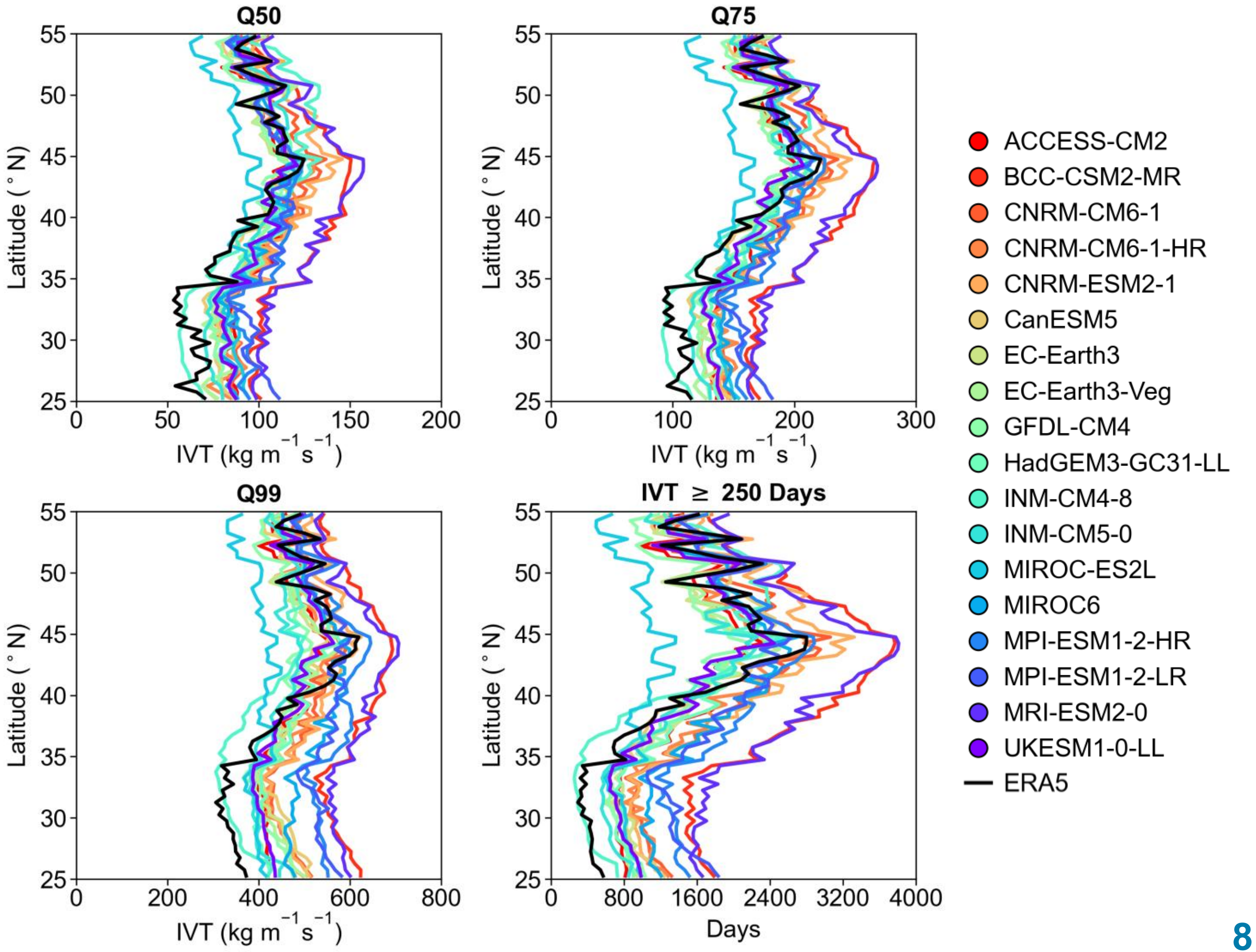
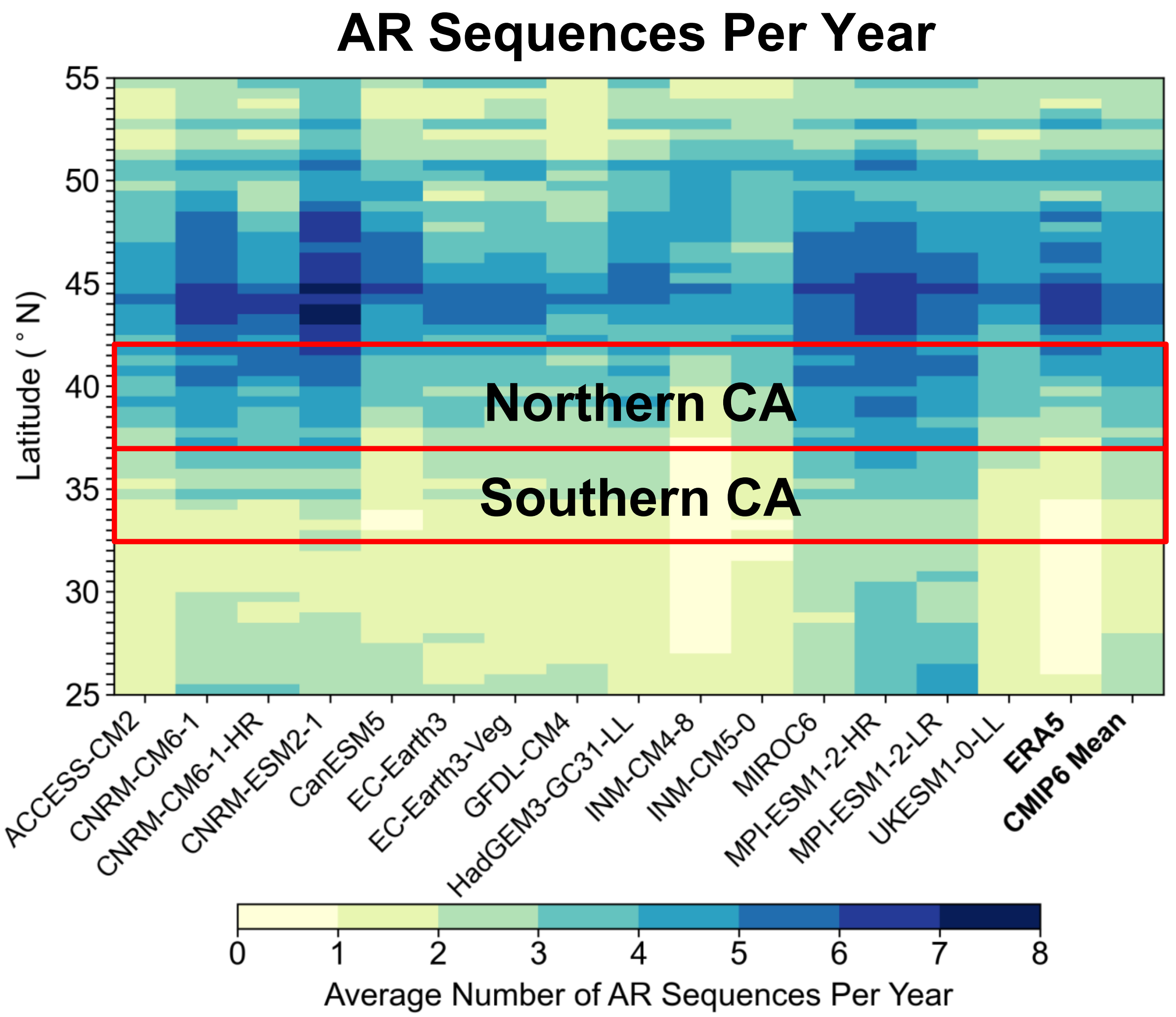
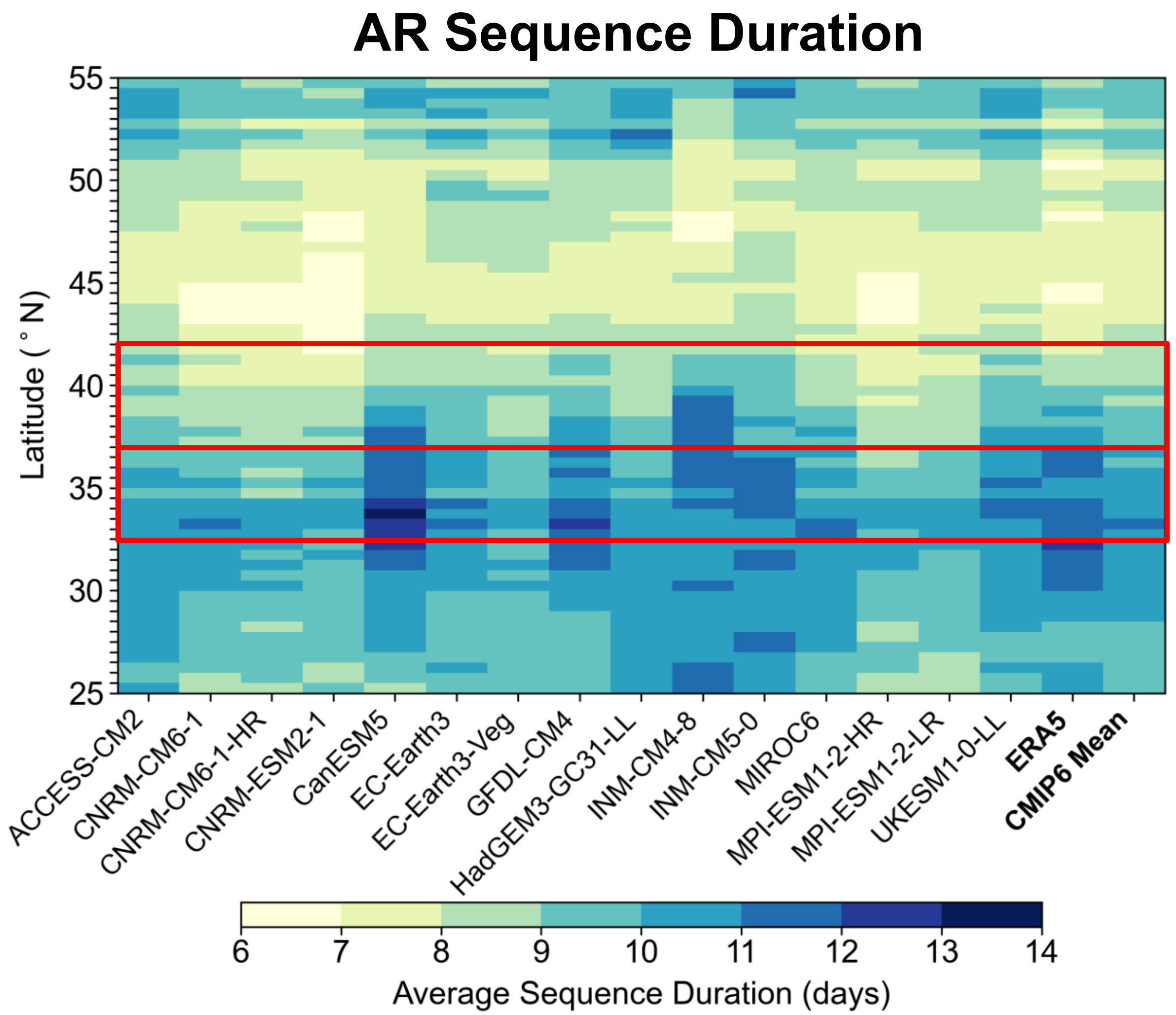
Oct–Apr IVT Climatology

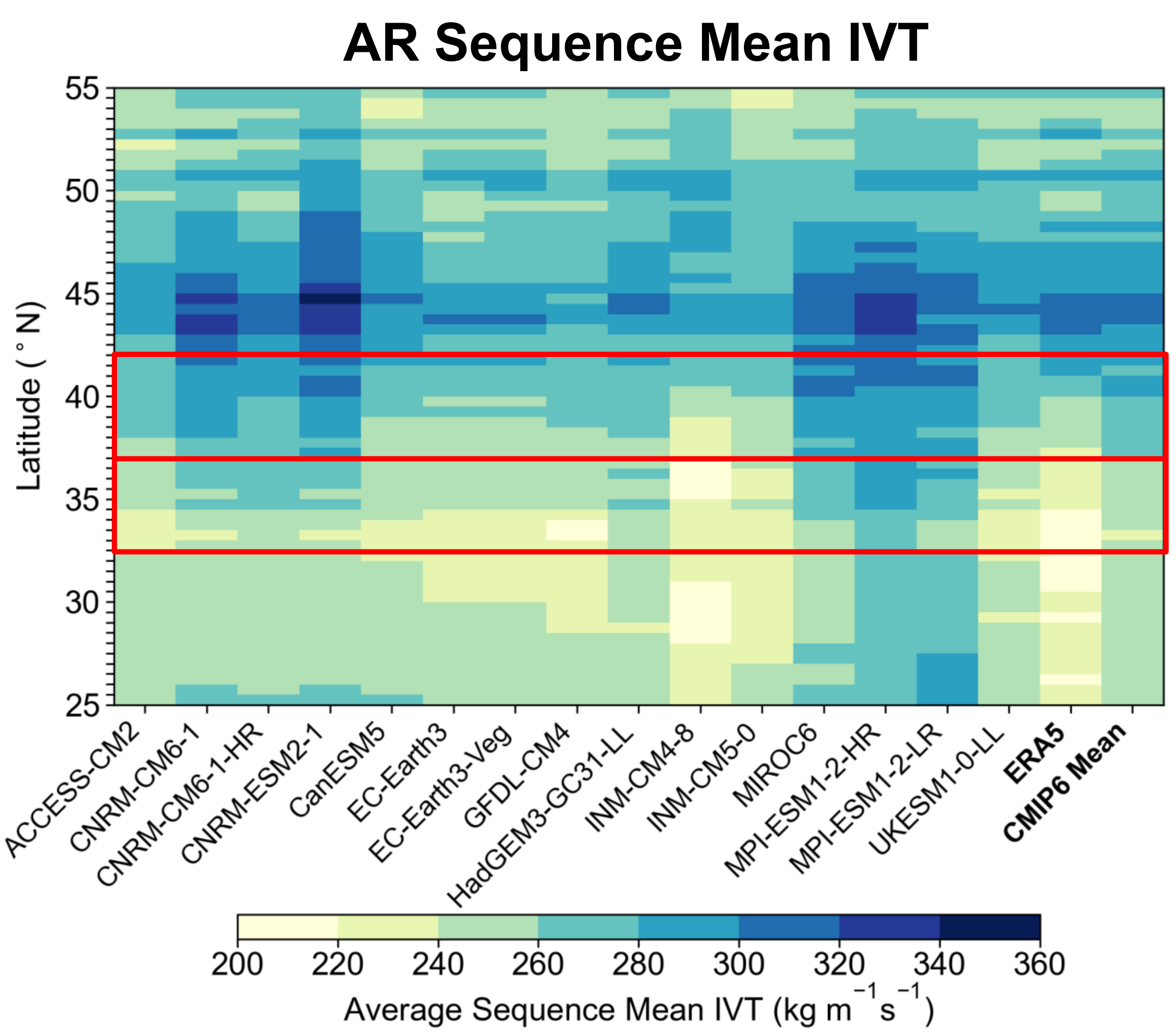


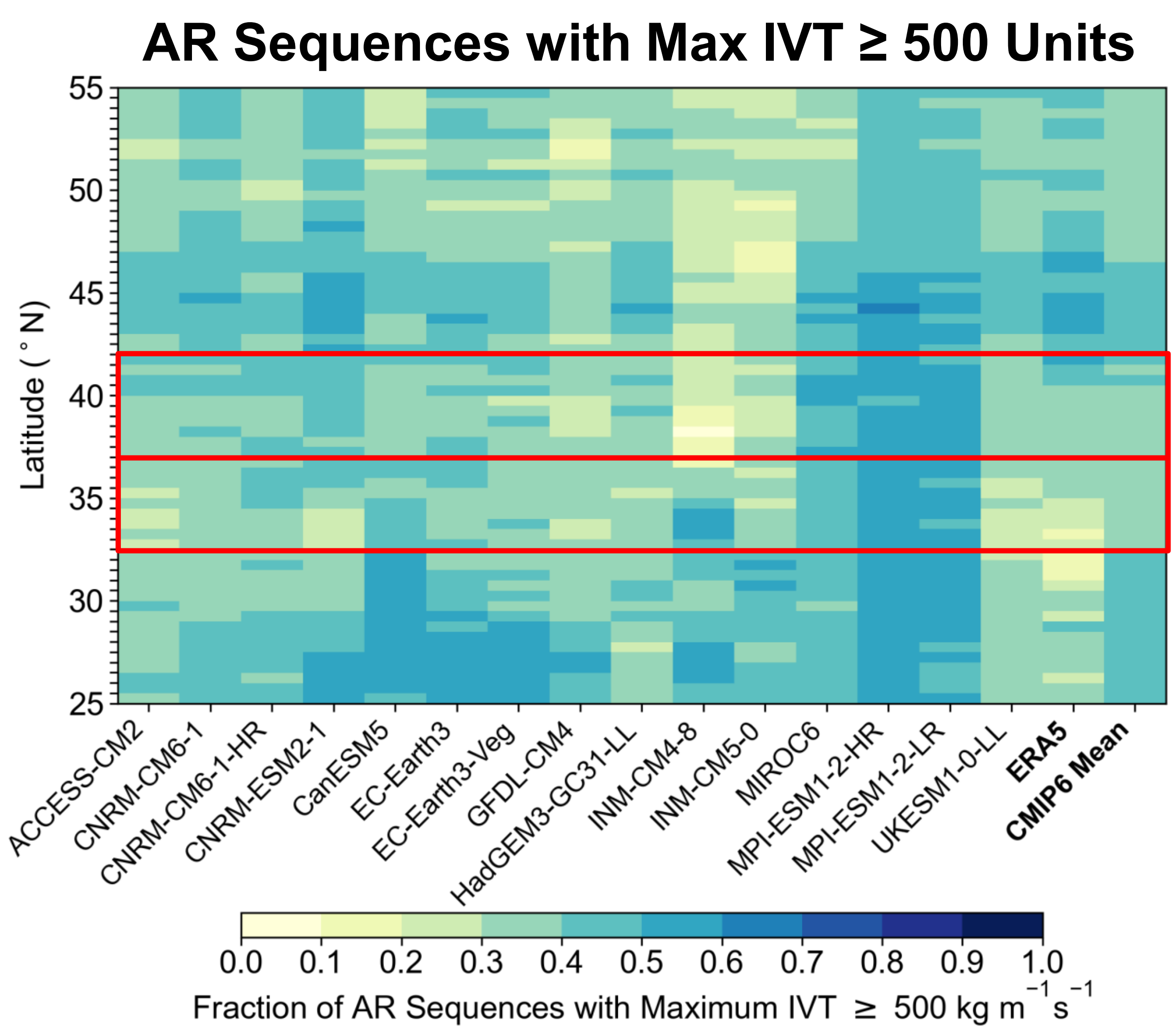
CMIP6 Historical Evaluation of AR Sequences



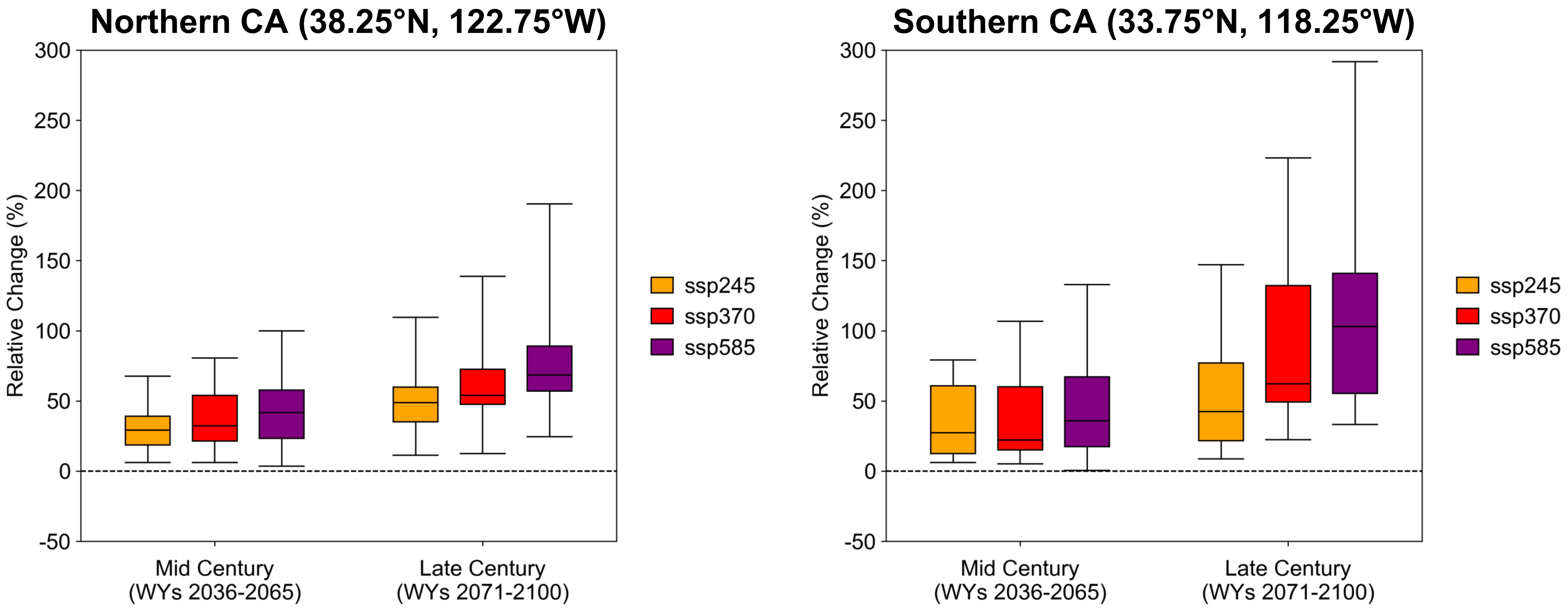


CMIP6 Historical Evaluation of AR Sequences





Projected Changes in AR Sequences: Frequency

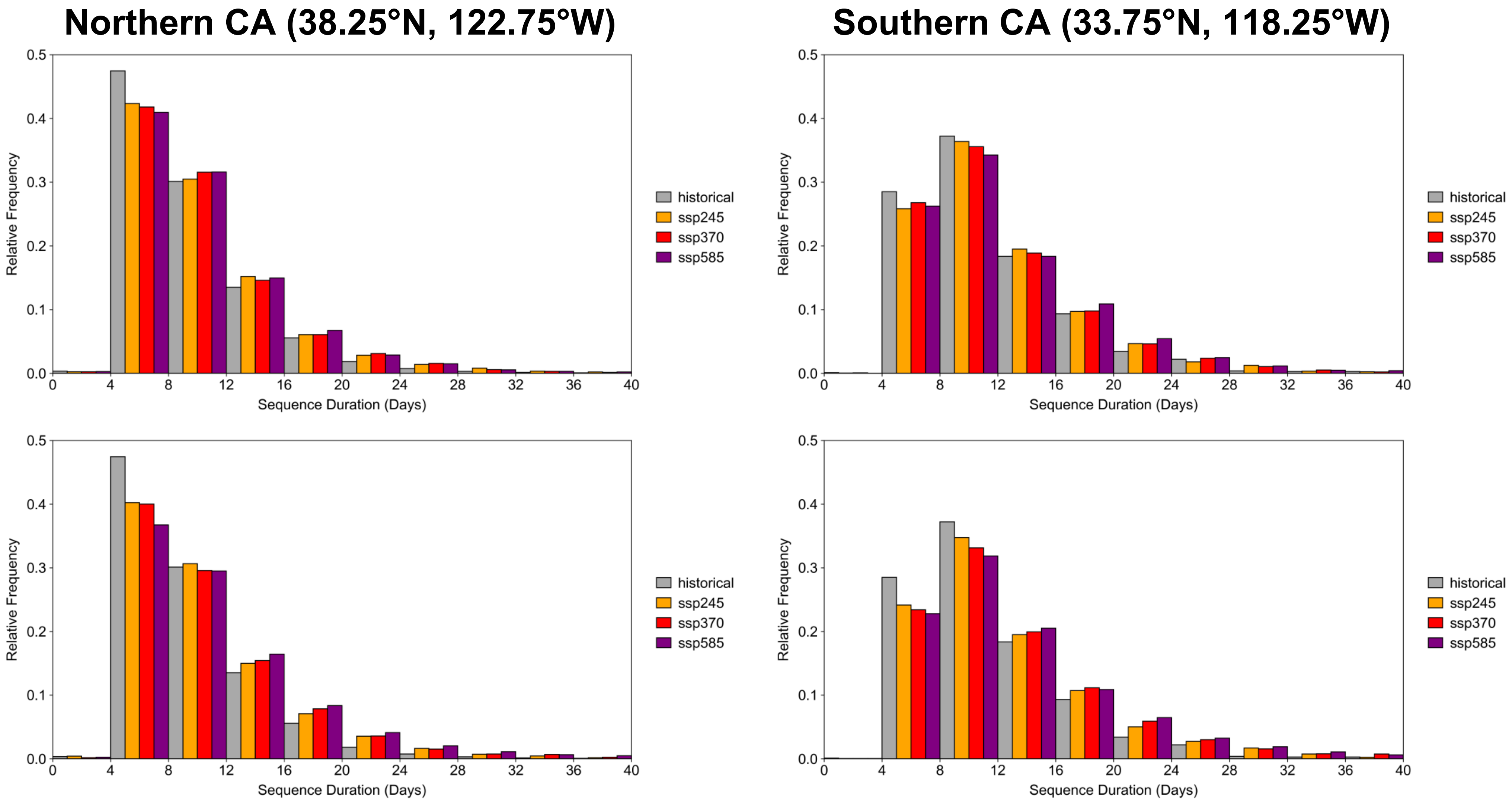


Each boxplot consists of n values (n = number of models). Relative changes are calculated with respect to WYs 1981–2010.

Projected Changes in AR Sequences: Duration

Mid Century
WYs 2036–2065

Late Century
WYs 2071–2100

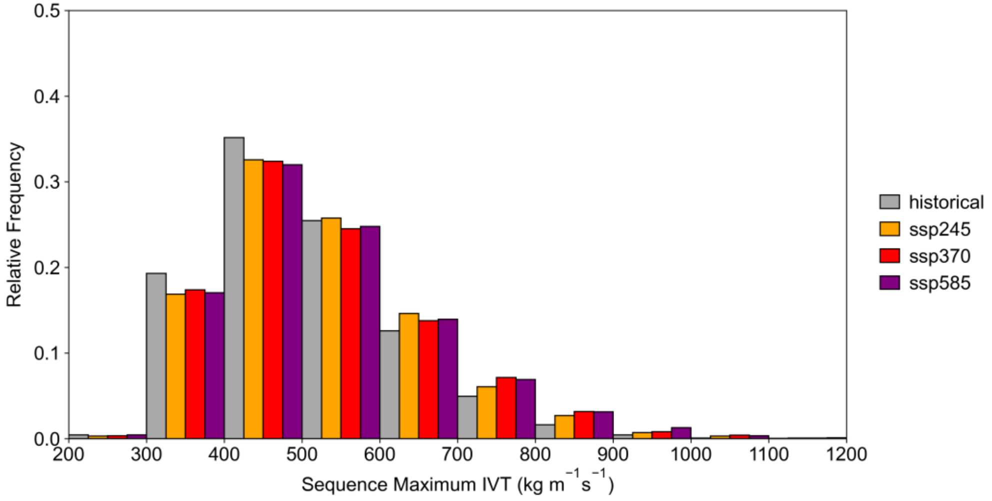


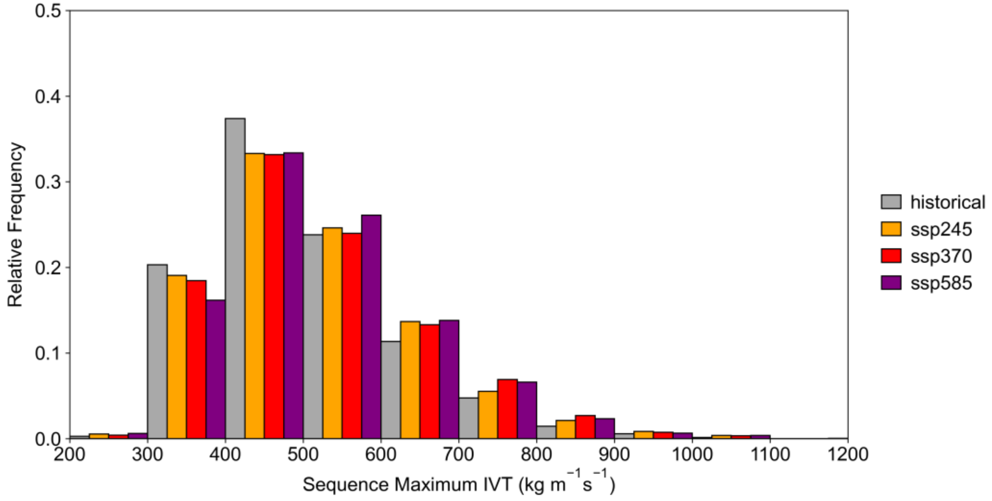
Each histogram represents the distribution of values across all simulated AR sequences

Projected Changes in AR Sequences: Maximum IVT

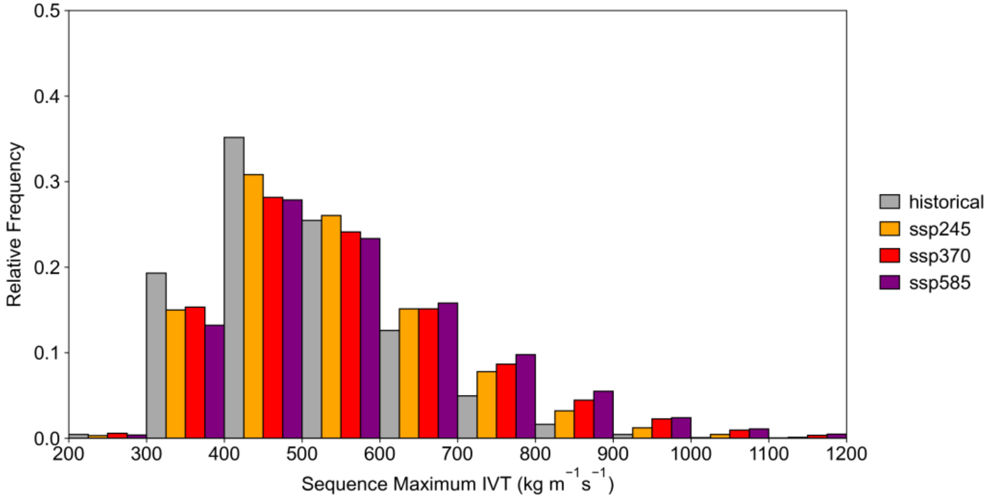
Northern CA (38.25°N, 122.75°W) | Southern CA (33.75°N, 118.25°W)

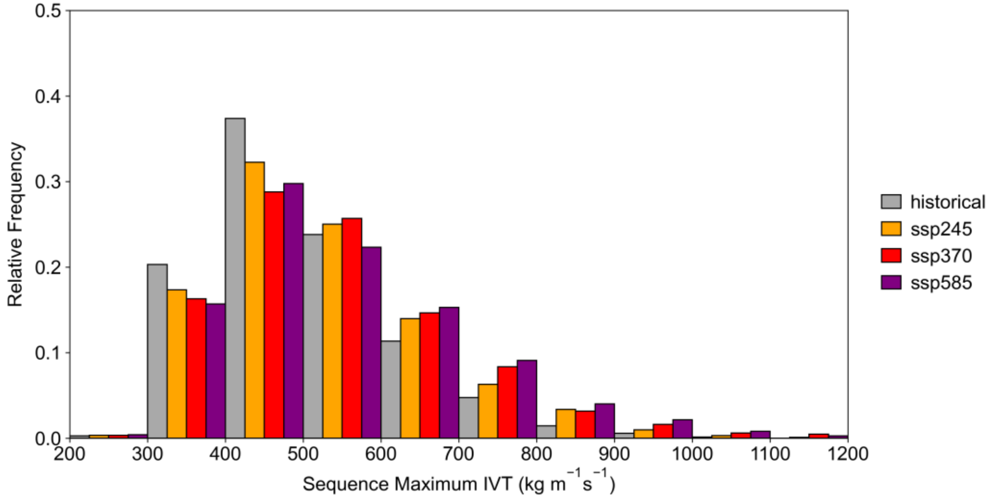
Mid Century
WYs 2036–2065





Late Century
WYs 2071–2100



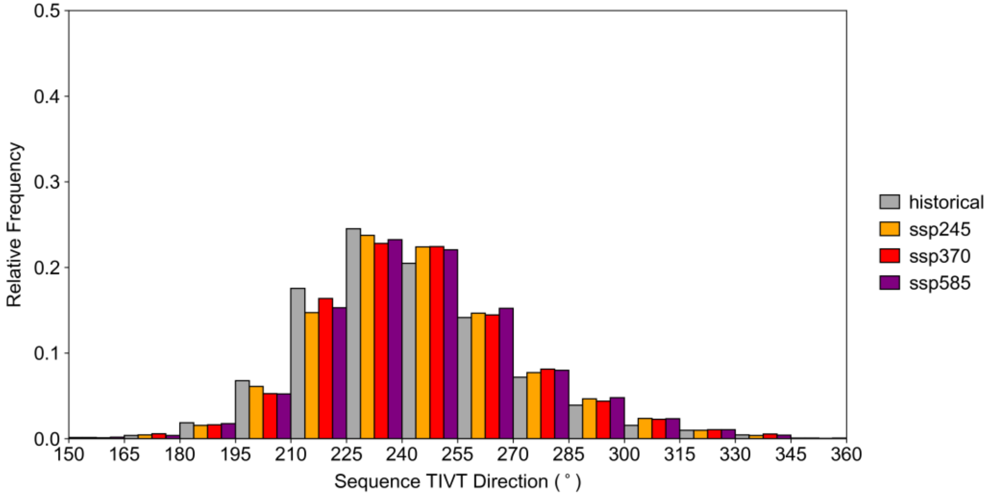


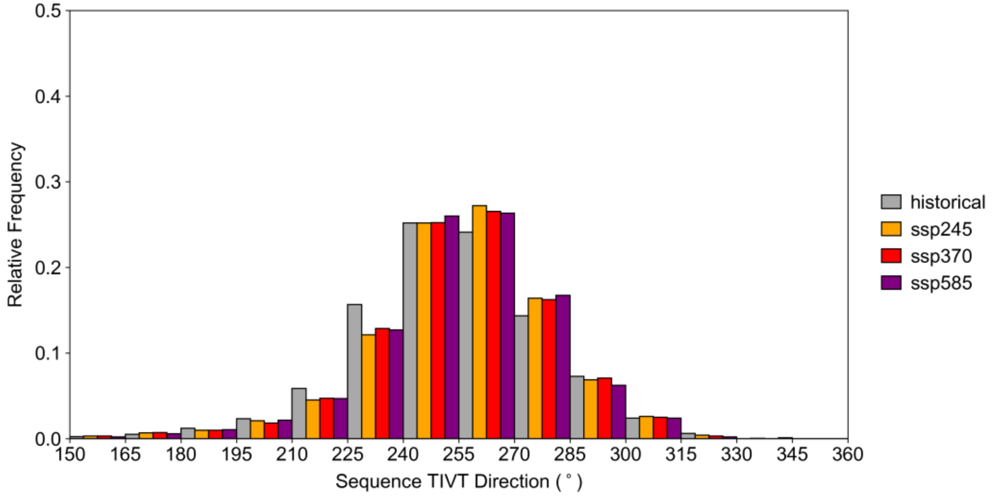
Each histogram represents the distribution of values across all simulated AR sequences

Projected Changes in AR Sequences: TIVT Direction

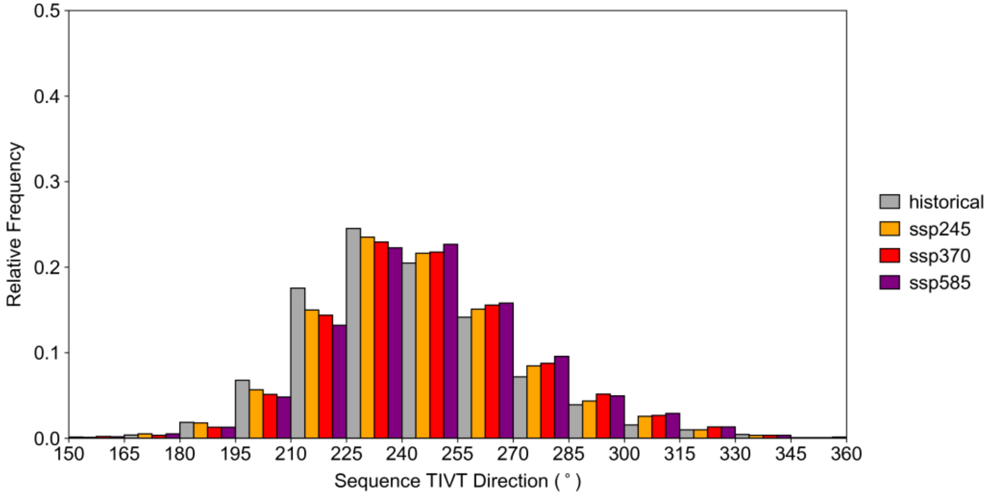
Northern CA (38.25°N, 122.75°W) | **Southern CA (33.75°N, 118.25°W)**

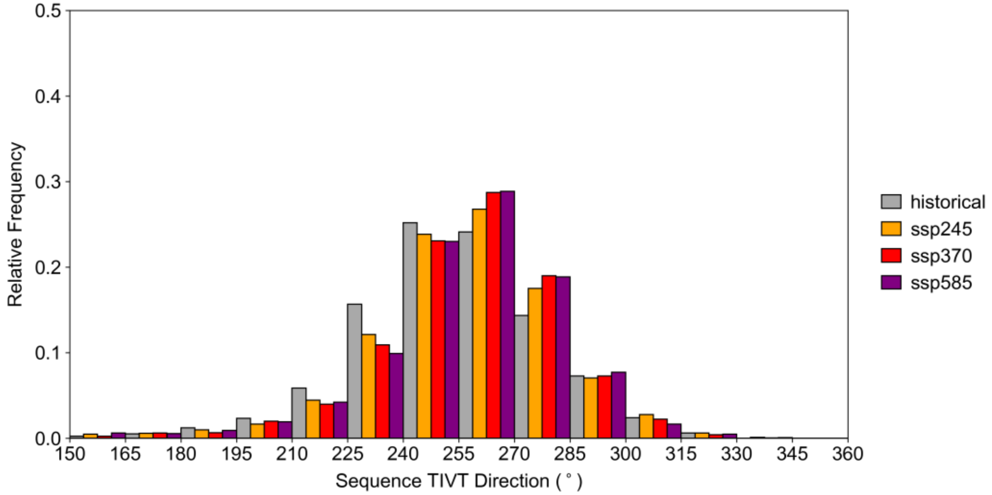
Mid Century
WYs 2036–2065





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

Future Work

- **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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