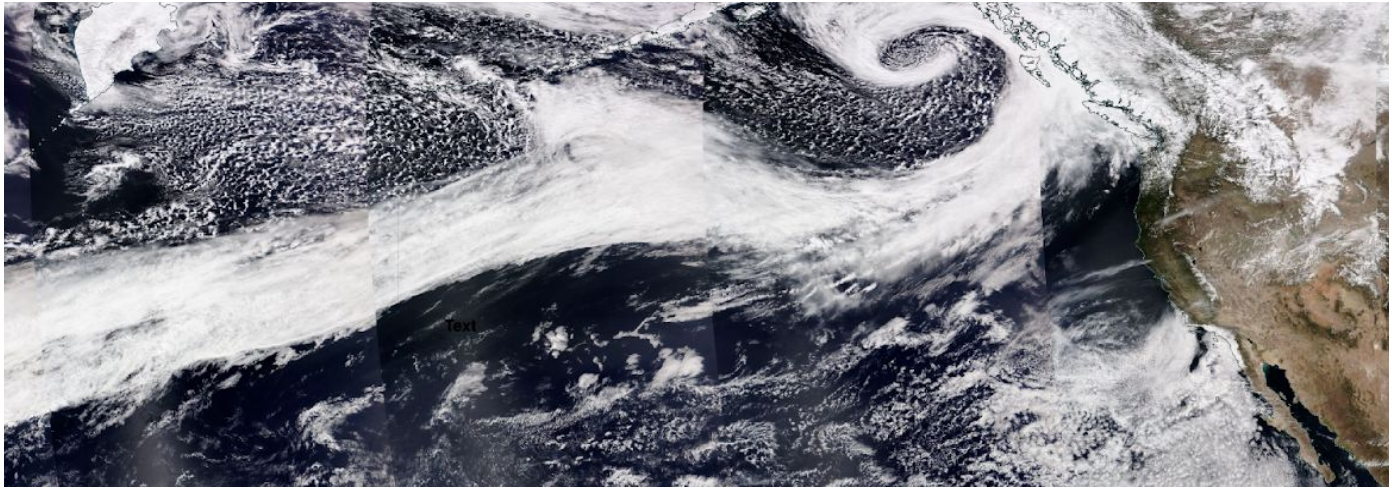


The upper ocean's response to Northeast Pacific atmospheric rivers under climate change:

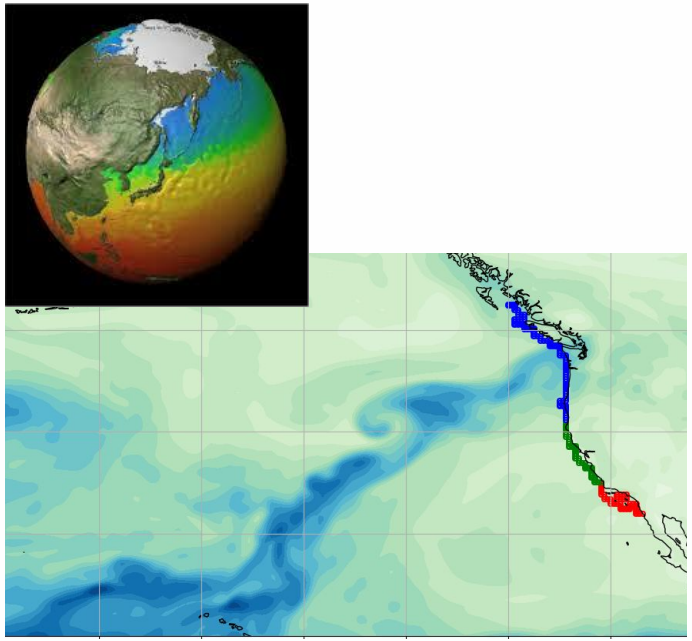
Eddy-resolving oceans matter

Credit: worldview.earthdata.nasa.gov, https://www.pmel.noaa.gov/
Atmospheric river, April 2022

Christine A. Shields, Hui Li, NSF NCAR

Frederic S. Castruccio (NSF NCAR), Dan Fu (Texas A&M), Kyle Nardi (PSU), Xue Liu (Texas A&M), Colin Zarzycki (PSU)

Eddy resolving CESM simulations



- CESM1.3, iHESP version, ~0.25º atmosphere/land and 0.1º ocean/ice
- Transient climate change simulations, 2 members completed available
- Analysis years: 1960-2005; 2060-2100
- Regional focus: Eastern Pacific and landfalling Pacific NW, California, Southern California
- ARDTs: ARTMIP contributors Shields/Kiehl, Mundhenk/Nardi, and IPART
- Results shown as consensus ARs

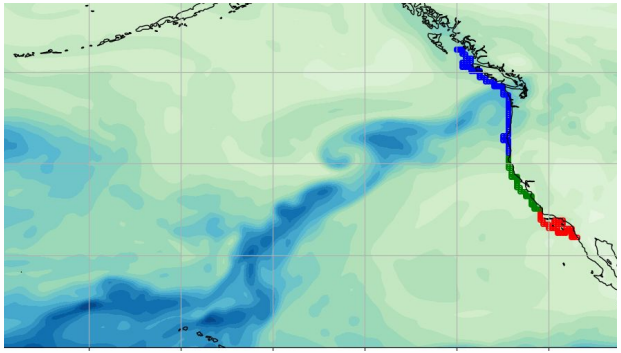
Model reference: Chang et al., JAMES, 2020, 10.1029/2020MS002298

Identifying ARs in gridded or model data with Atmospheric River Detection Tools (ARDTS)

Shields/Kiehl ARDT:
- ✔ Spatial relative methodology
- ✔ Time varying
- ✔ Very restrictive, favors strongest ARs

Mundhenk/Nardi ARDT:
- ✔ Temporal relative methodology
- ✔ Fixed-relative percentile based
- ✔ Less restrictive; comparable to ARTMIP mean

IPART ARDT:
- ✔ Threshold-free methodology
- ✔ Image recognition of IVT plumes
- ✔ Moderately restrictive compared to ARTMIP mean



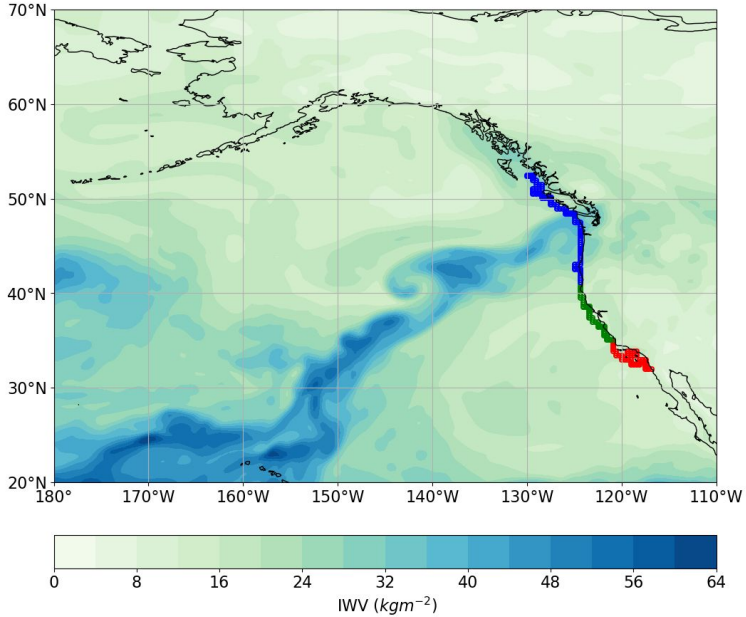
$$IWV = -\frac{1}{g}\int_{Pb}^{Pt} (q)\, dp$$

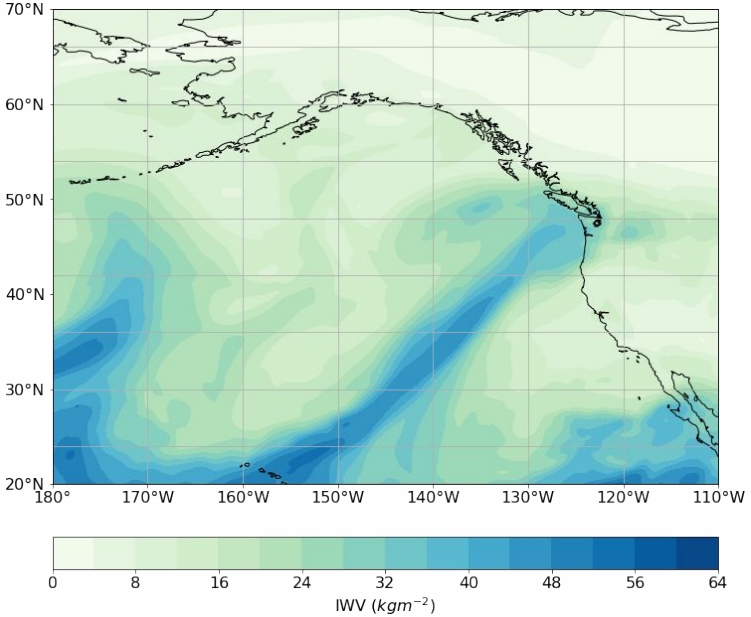
$$IVT = -\frac{1}{g}\int_{Pb}^{Pt} (q\, \boldsymbol{V}_h)\, dp$$

Pt = 300mb and Pb = 1000mb, q= specific humidity, $\boldsymbol{V}_h$ = vector form of wind, g = gravity

High (~0.1) vs standard (~1º) resolution

Integrate Water Vapor



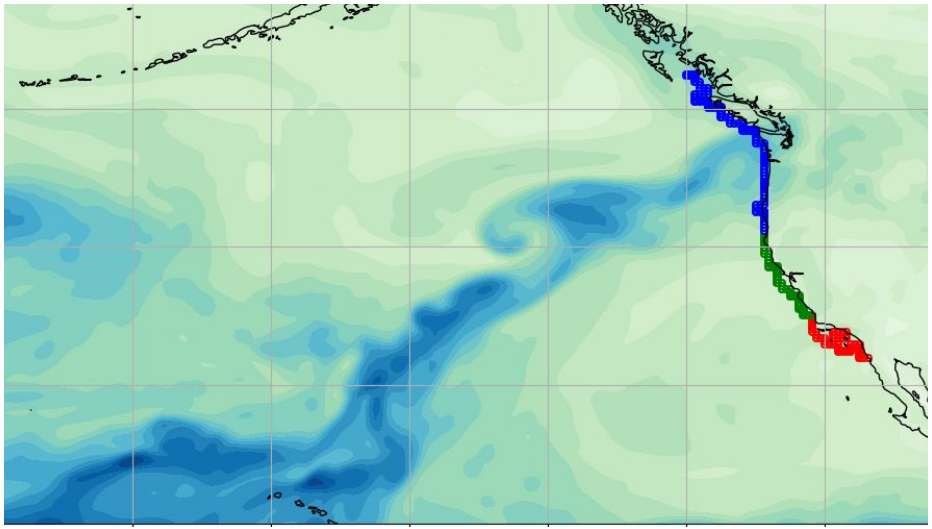


High resolution captures eddies reflection from the 0.1º ocean

Composite Analysis for upper ocean response to ARs

***Consensus** agreement across ARDTs is used in all composite plots*

Fingerprint = 3 days after (1 for SSH) AR onset minus 3 days before AR



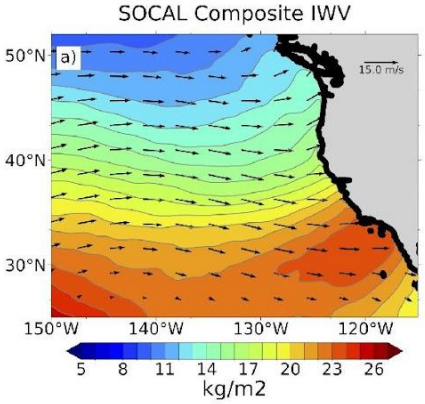
Blue = Pacific Northwest
Green = California
RED = Southern California

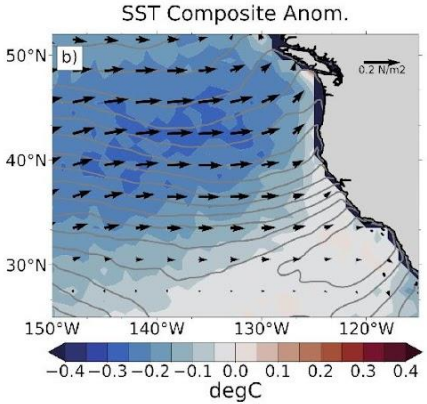
Upper ocean variables evaluated

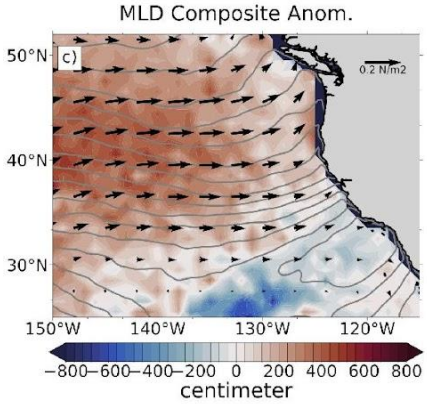
MLD = Mixed layer depth (cm)
SSH = Surface surface height (cm)
SST = Sea surface temperature (^{o}C)
SHF = Surface heat flux (Wm^{-2})
SENH = Sensible heat flux (Wm^{-2})
EVAP = Evaporative heat flux (Wm^{-2})

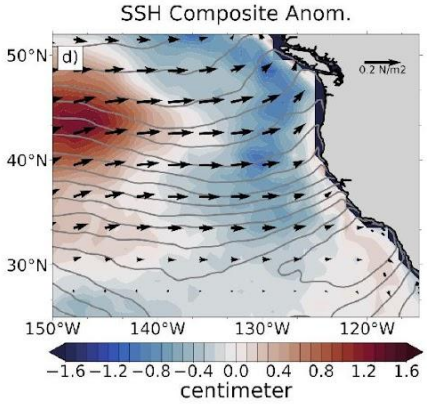
Anomalies from long-term climatology

SoCal Historical Simulations



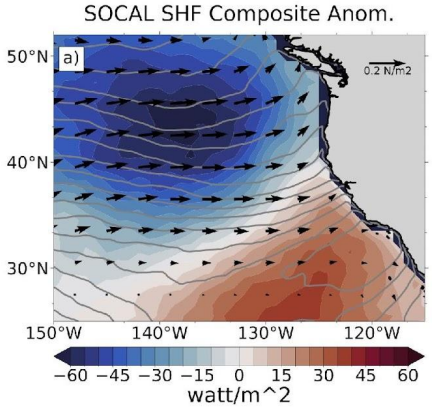


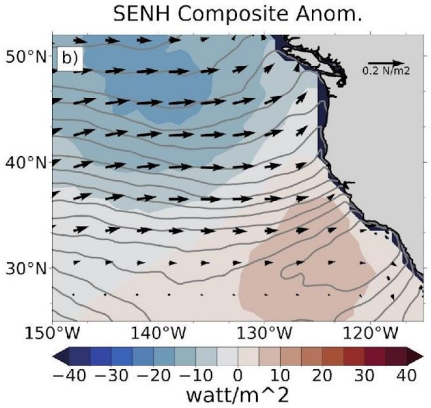


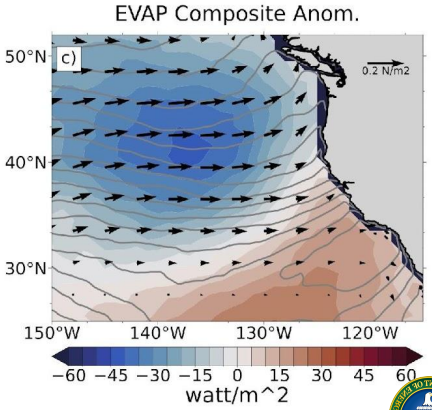


IWV composite AR climatology

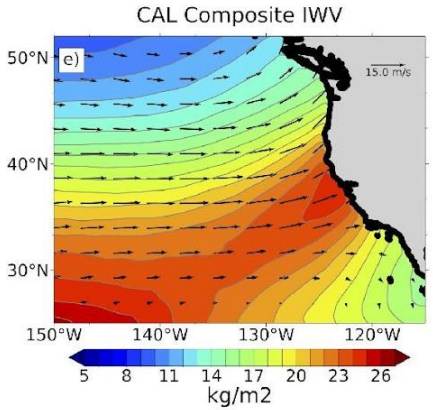
SST, MLD, SST, SHF, SENH, EVAP anomalies from long term climatology

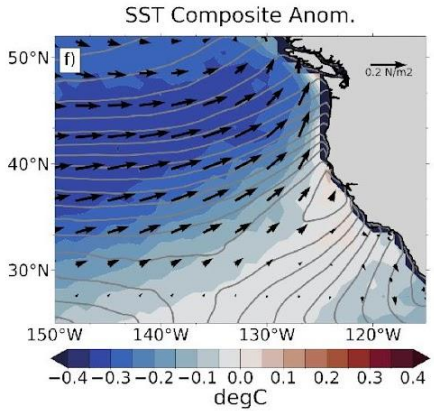


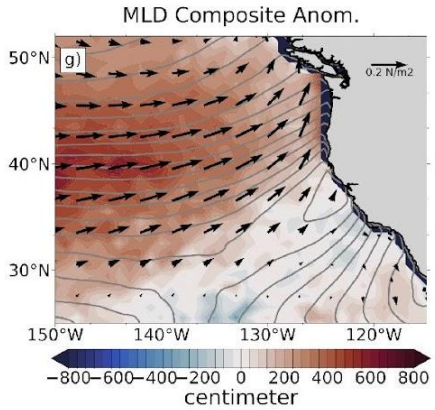


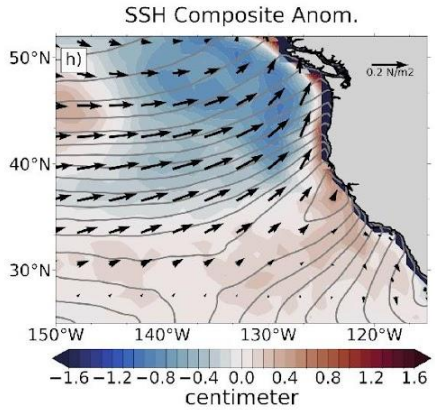


Cal Historical Simulations



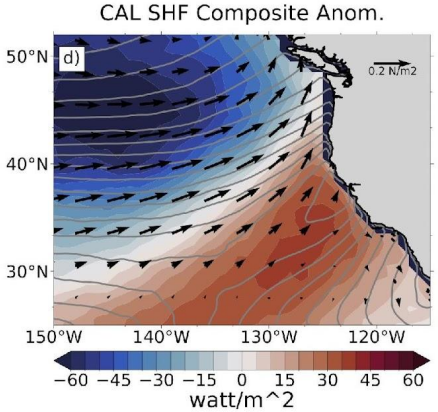


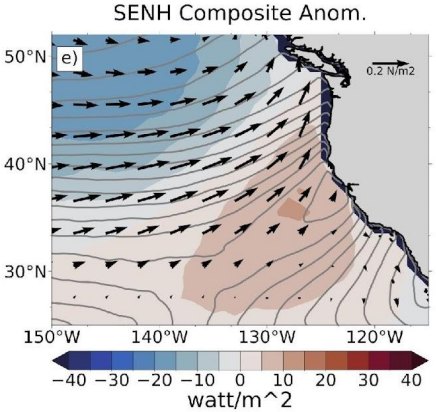


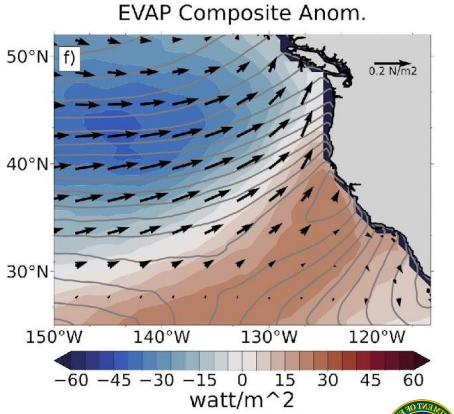


IWV composite AR climatology

SST, MLD, SST, SHF, SENH, EVAP anomalies from long term climatology

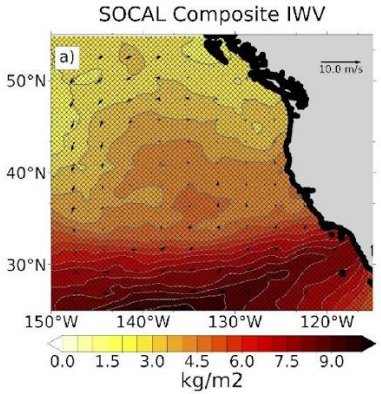


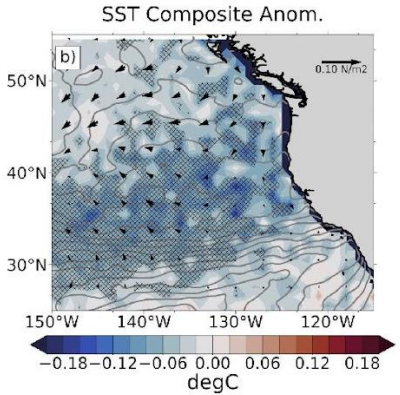


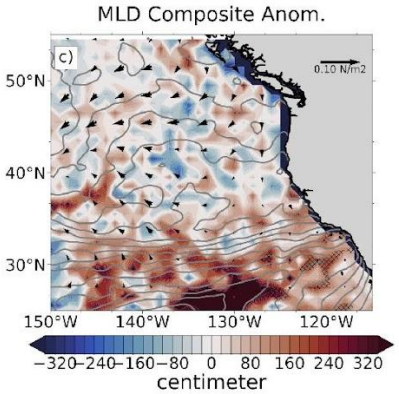


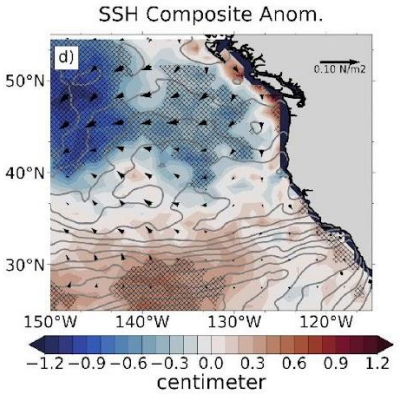
SoCal Climate Change Signal

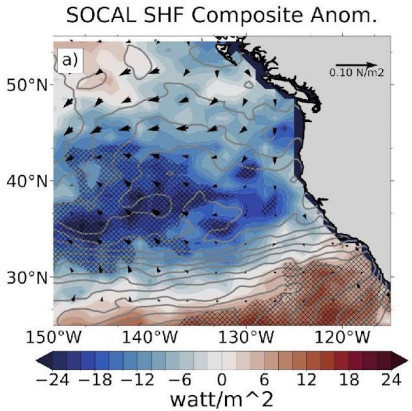
RCP8.5 minus Historical

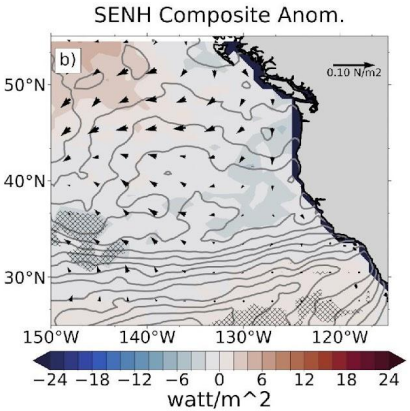


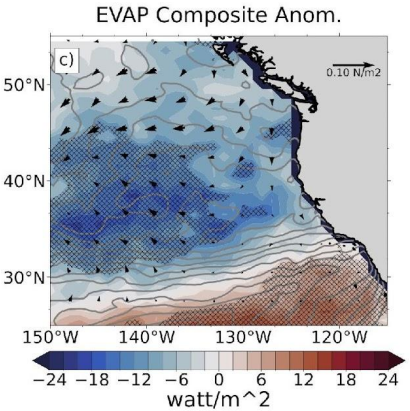




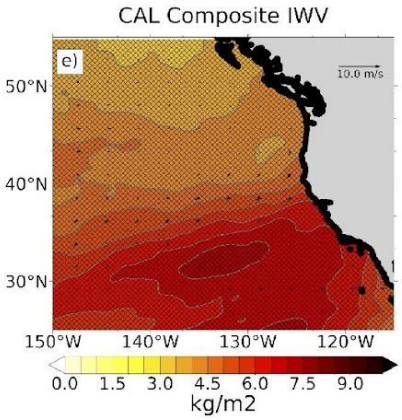


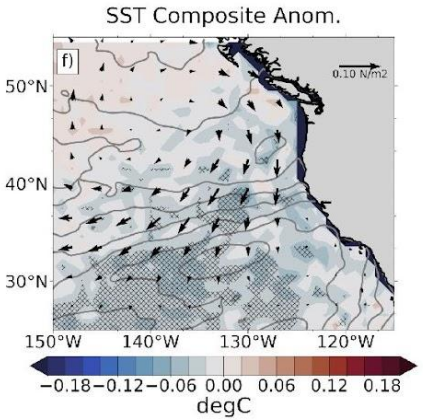


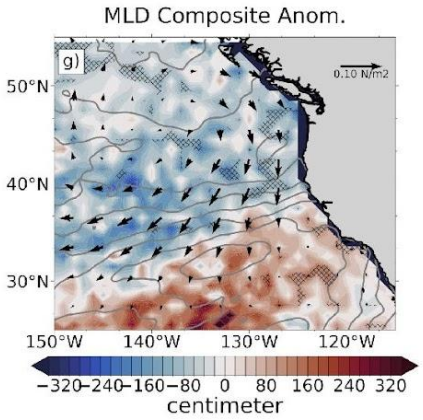


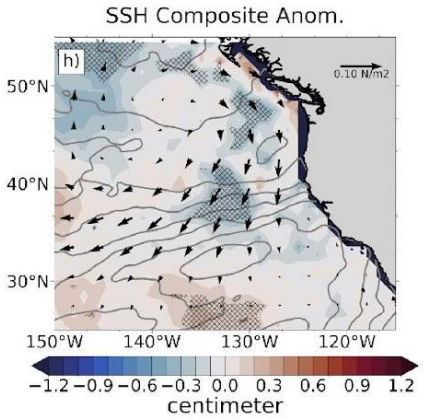


Cal Climate Change Signal

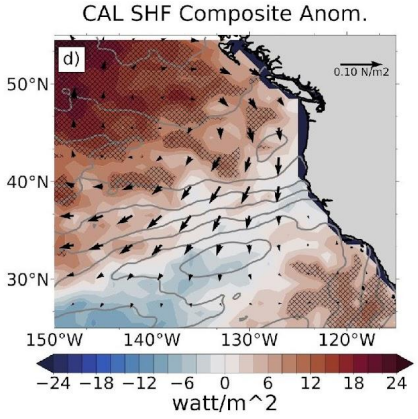


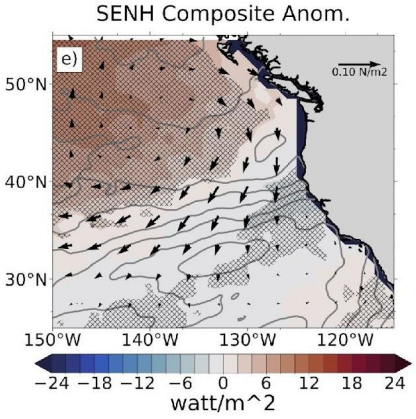


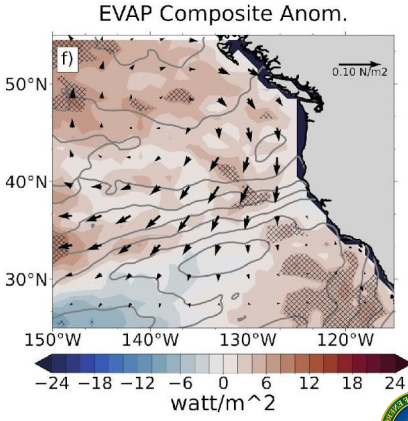


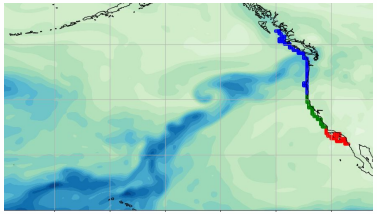


RCP8.5 minus Historical





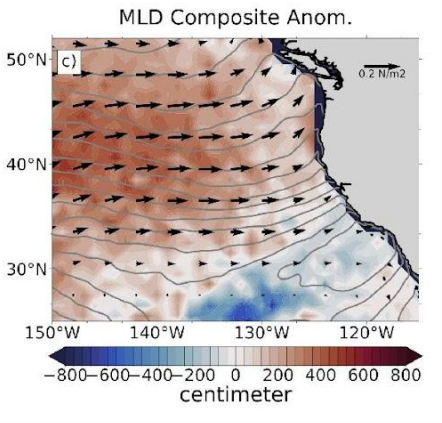




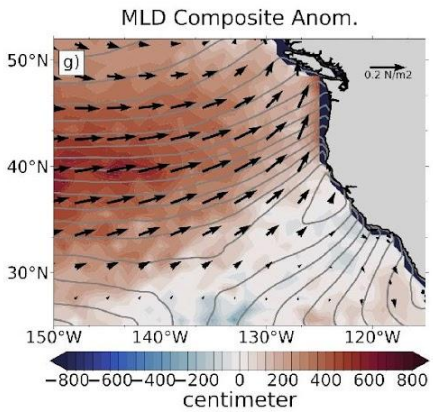
Putting it all together…

- ARs and their strong winds cause significant upper ocean responses in a high-resolution eddy-resolving climate model

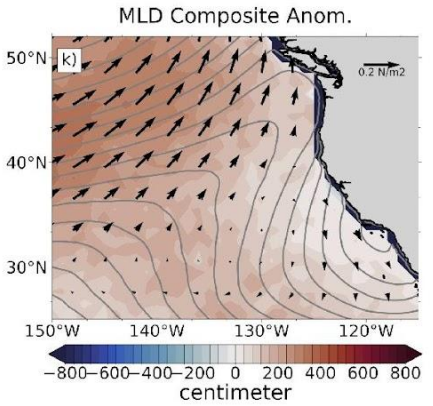
SoCal Historical



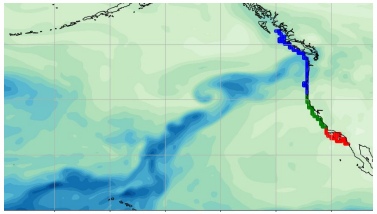
Cal Historical



PNW Historical

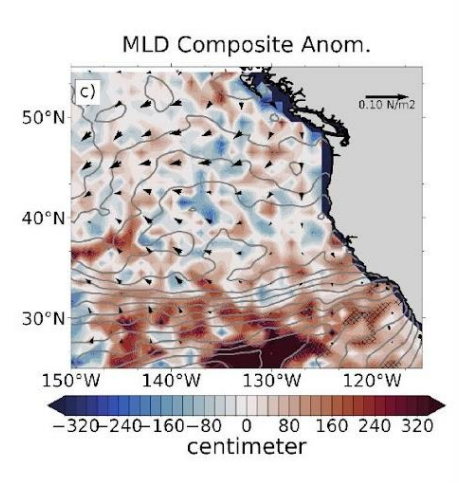


Putting it all together…

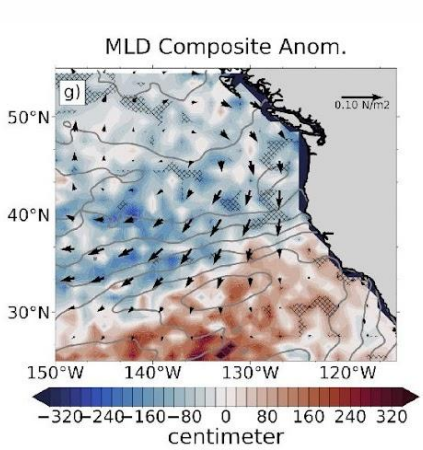


- Mixed layers are generally deeper/shallower upstream/downstream of AR passage (due to wind and heat fluxes). This response is subdued with climate change and less shallowing downstream of the AR.

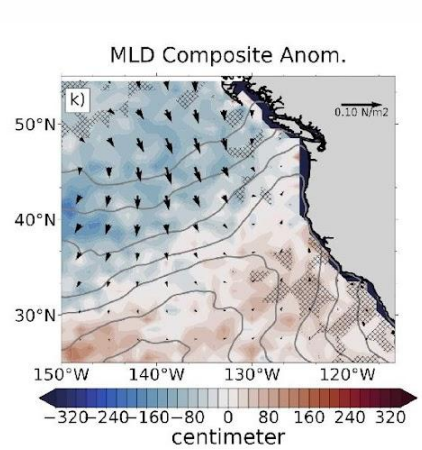
SoCal Climate Change



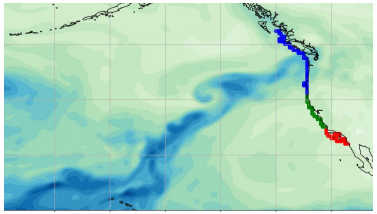
Cal Climate Change



PNW Climate Change

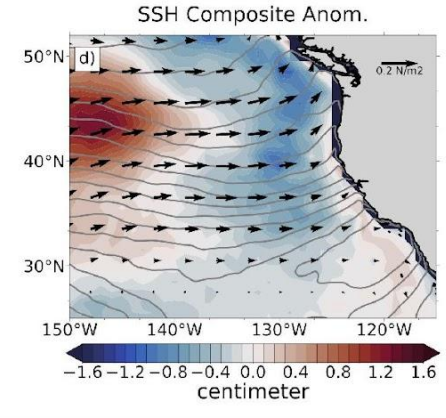


Putting it all together…

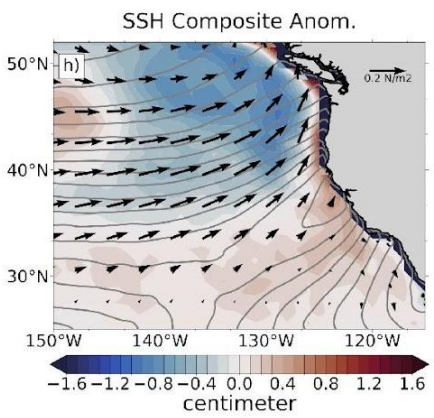


- ARs push ocean water towards the coast as measured by SSH. This will be amplified under climate change.

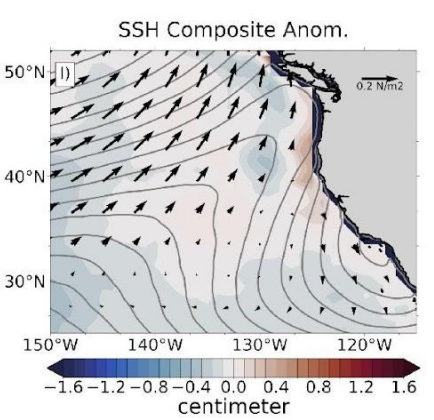
SoCal Historical



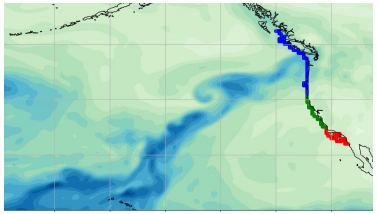
Cal Historical



PNW Historical

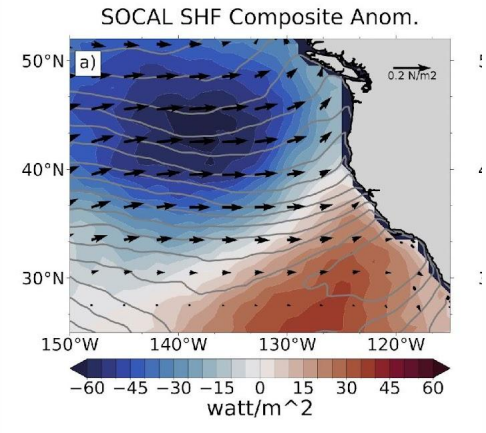


Putting it all together…

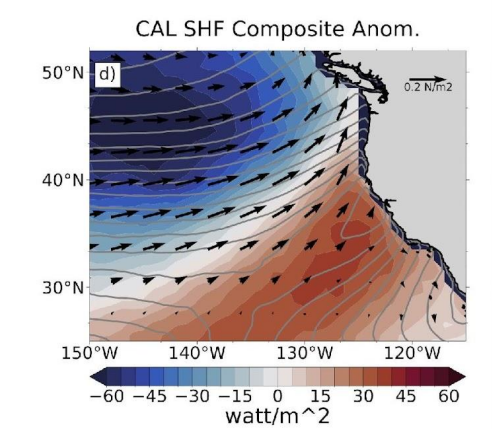


- AR strong winds impact heat fluxes, which promote cooling/warming upstream/downstream of AR passage

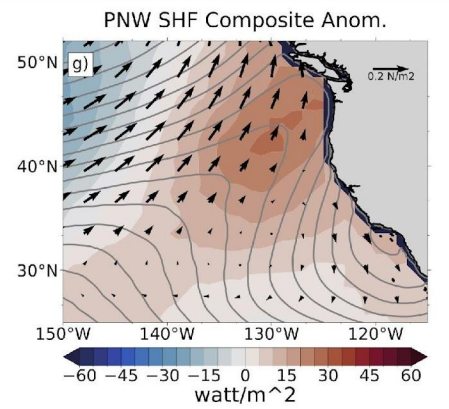
SoCal Historical



Cal Historical



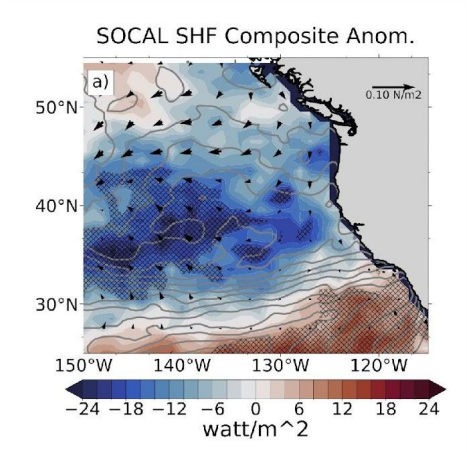
PNW Historical



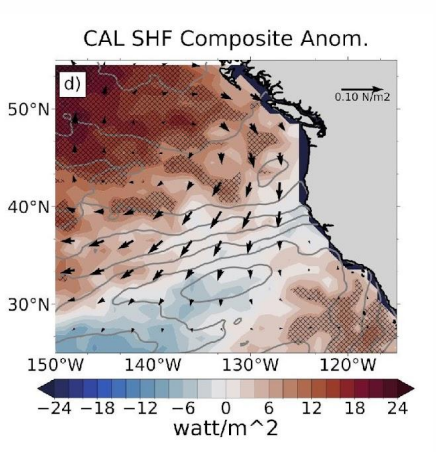
Putting it all together…

- Heat fluxes have a different climate change response in Southern California compared to latitudes north due to different processes at play (wind, sensible vs latent contributions)

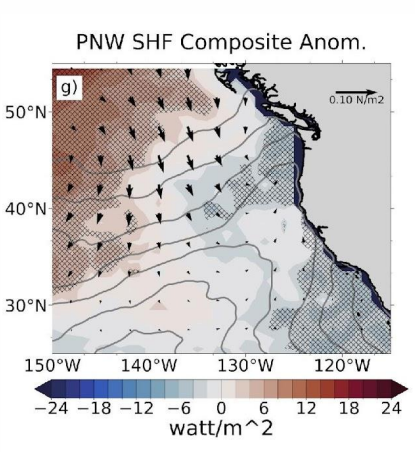
SoCal Climate Change



Cal Climate Change



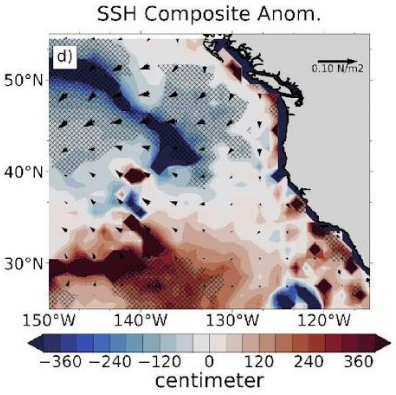
PNW Climate Change



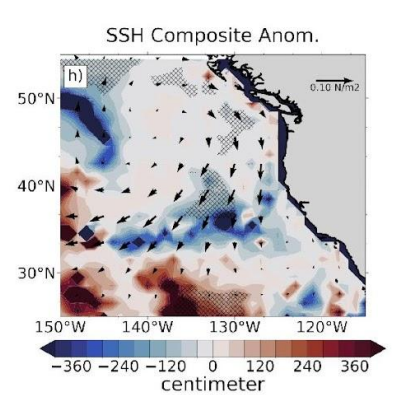
Yes, atmospheric rivers feedback onto the ocean!

Questions?

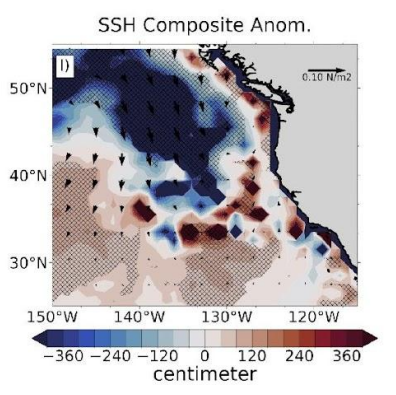
SoCal Climate Change



Cal Climate Change



PNW Climate Change



SSH climate change response in % change relative to historical

Shields, Li, Castruccio, Fu, Nardi, Liu, Zarzycki, The upper ocean's response to Northeast Pacific atmospheric rivers under climate change, Communications Earth and Environment, in revision.