# Marine heat waves
# in
# eastern boundary upwelling systems


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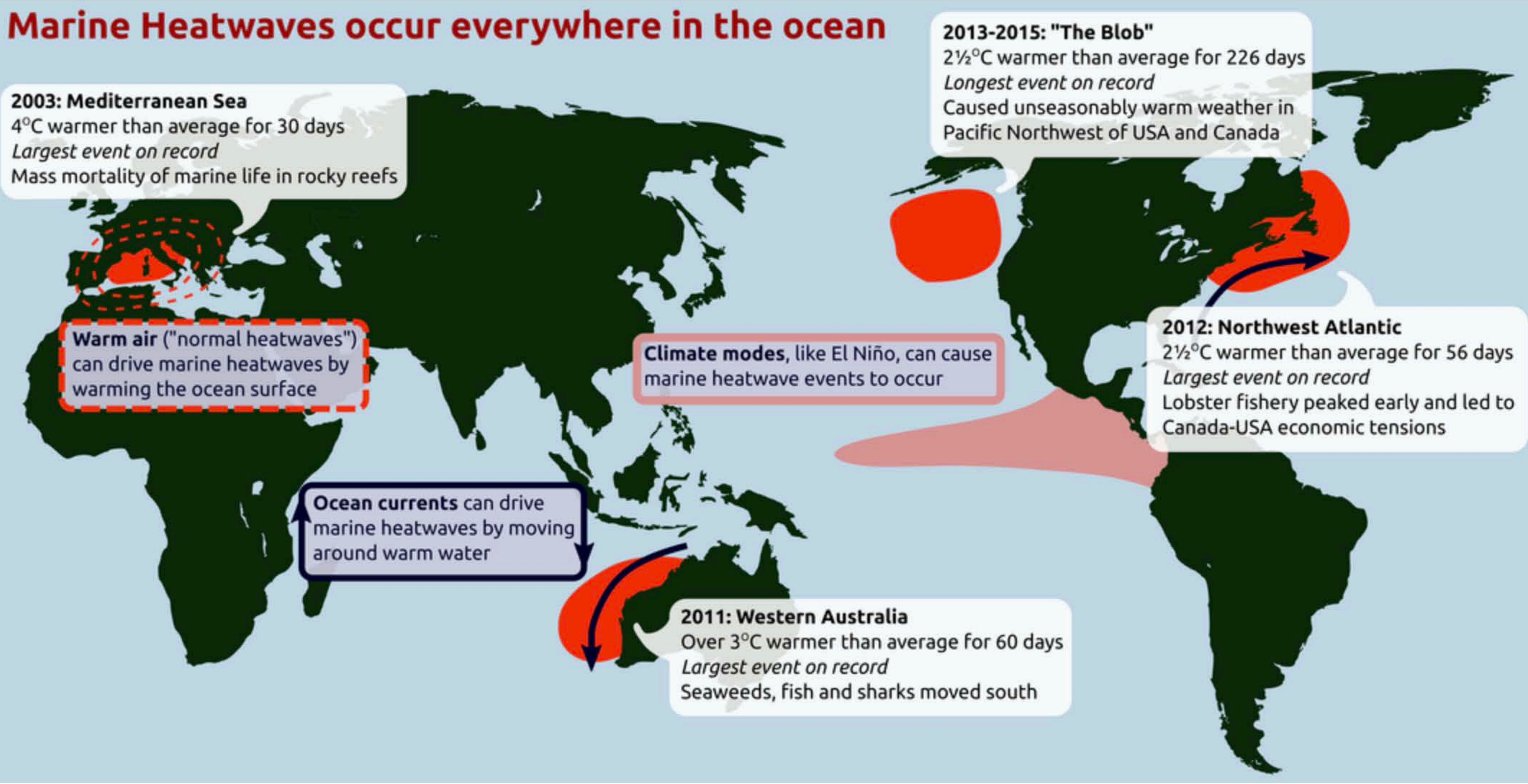
# Marine heat waves:
# warm water episodes cause environmental and economic damage




marineheatwaves.org

# Why study eastern boundary upwelling systems (EBUS)?

- **highly productive systems:**

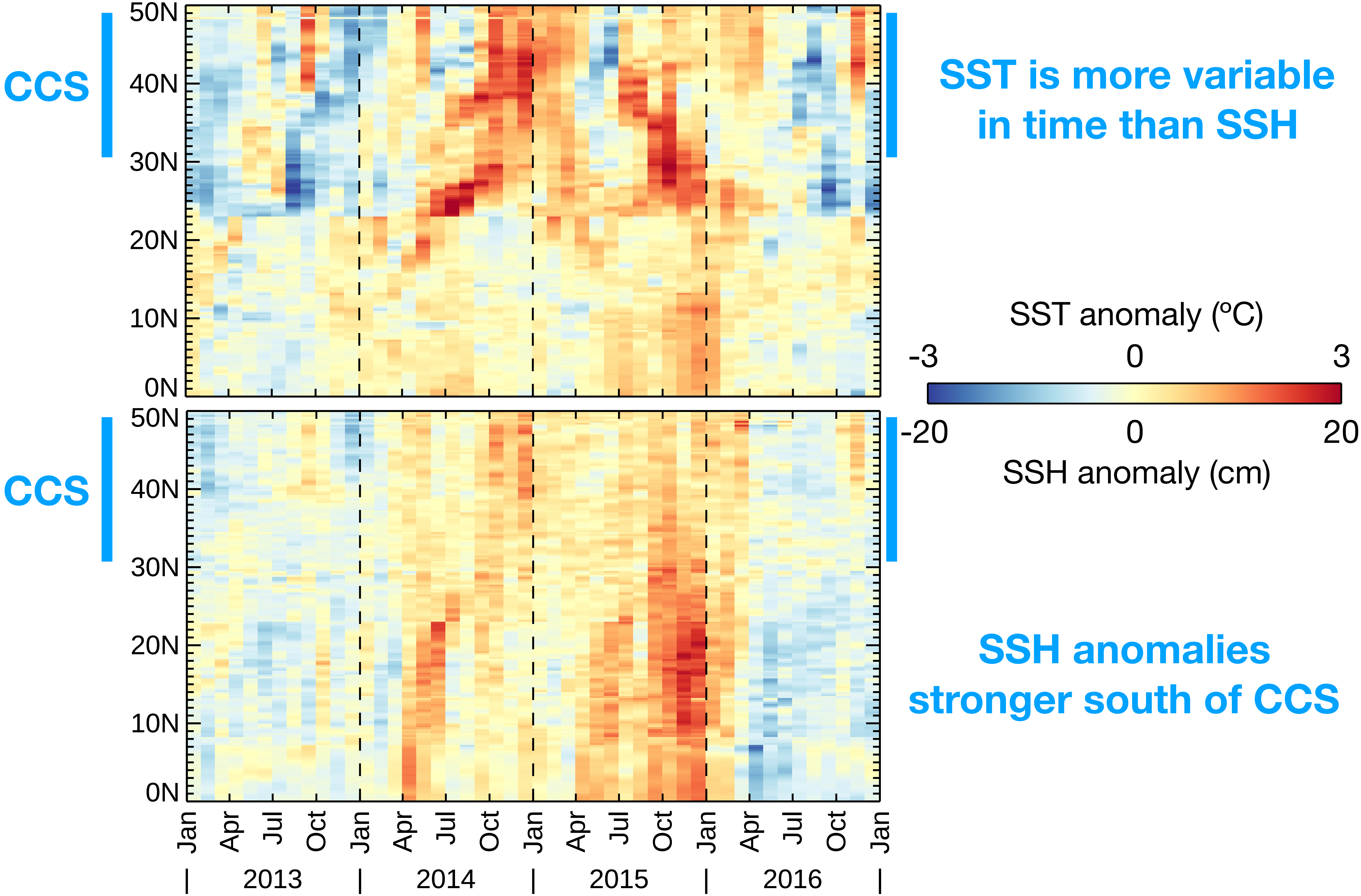
only ~3% of the global ocean surface area, but

**25-40% of the reported global fish catch**
(Pauly and Christiansen, 1995; Capone and Hutchins, 2013)

- **severely affected by MHWs:**

California EBUS (CCS) 2014–16 MHW:
- delays and closures in $100Ms Dungeness crab fishery
- coastwide toxic algal bloom (McCabe et al. 2016)
- extensive species shifts: spatial and phenological — mistiming of prey and predators

# Altimetry shows basin-scale oceanic connection to tropics

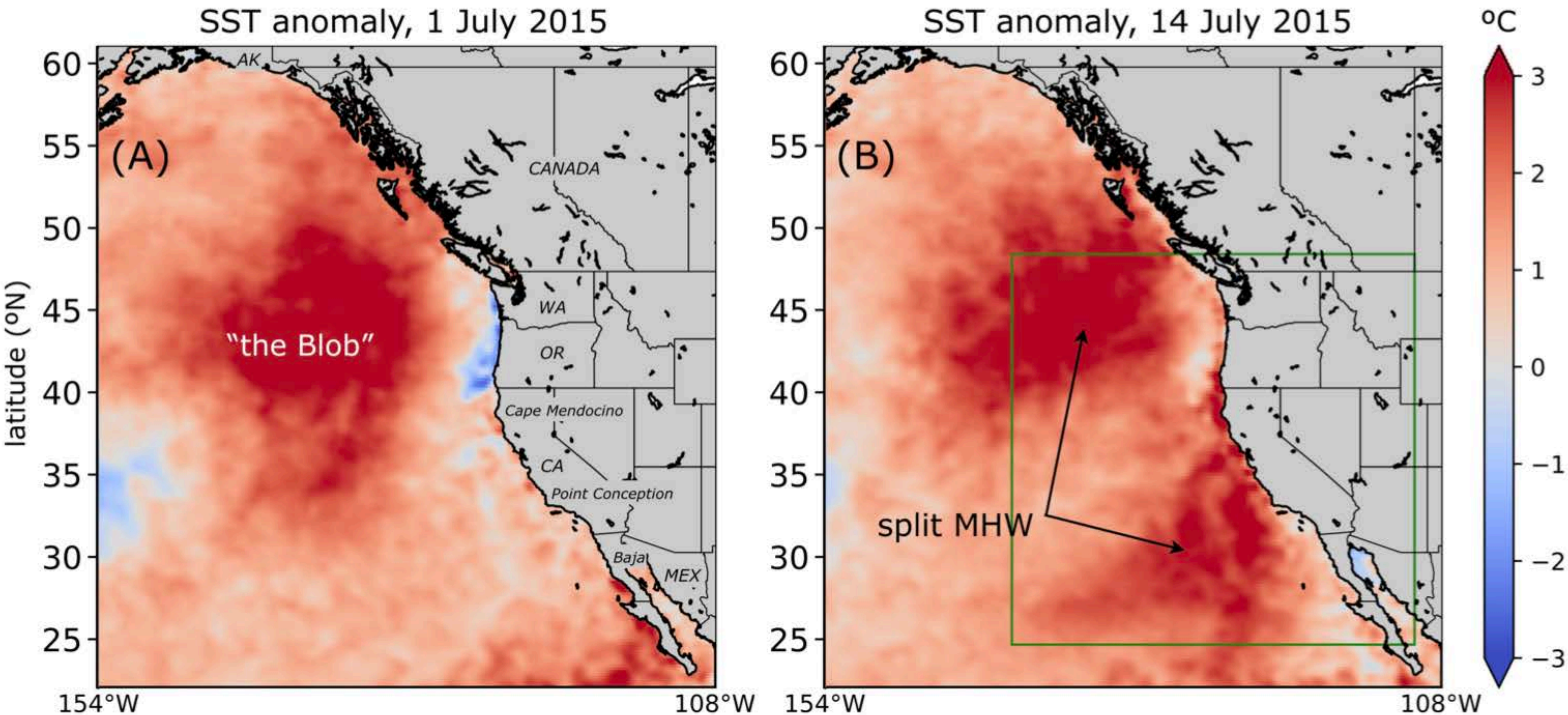



**SST is more variable in time than SSH**

**SSH anomalies stronger south of CCS**

Figure by Corinne James and Ted Strub

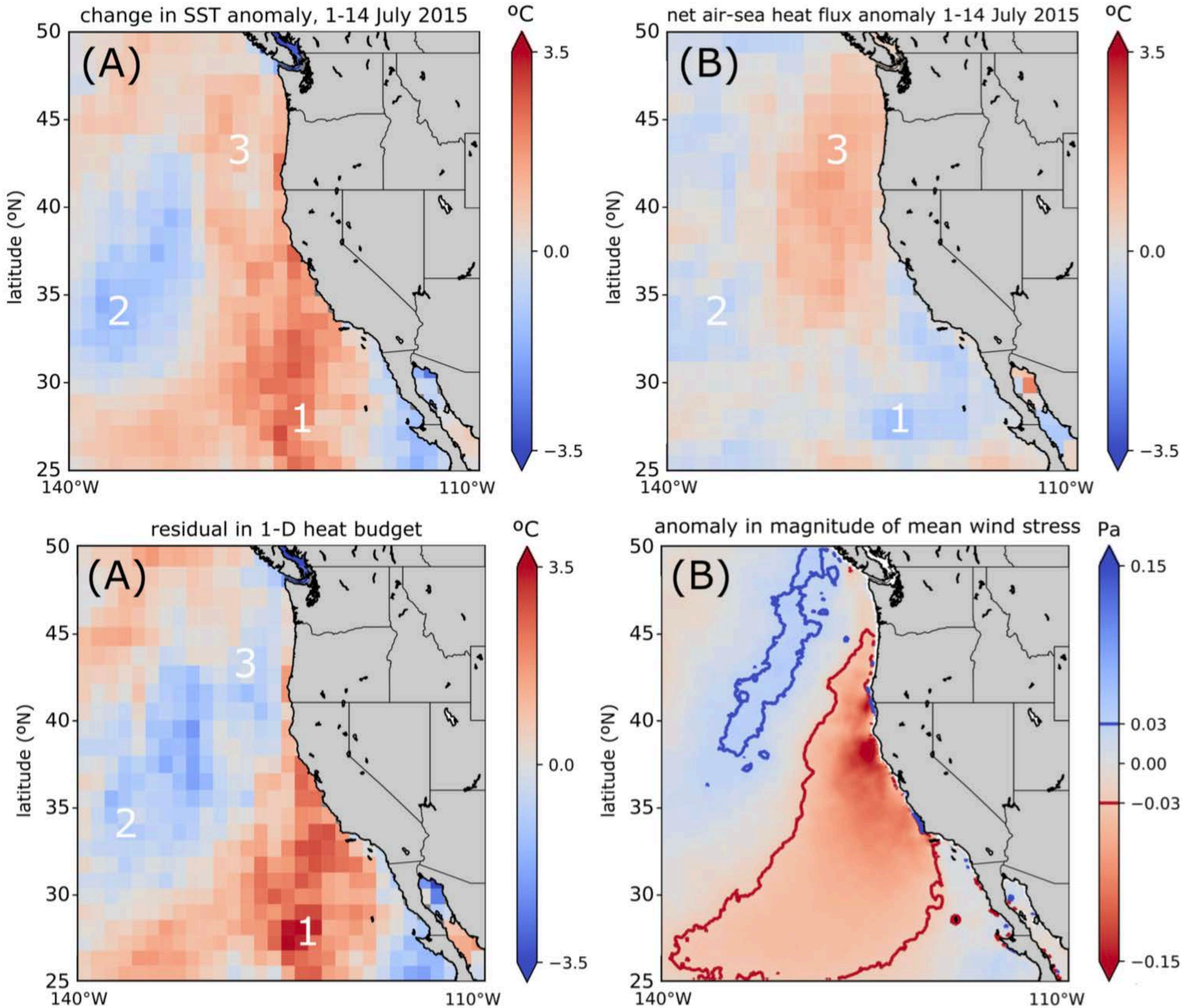
# An example of regional structure within a MHW in the CCS




This spatial variability during an extreme event (MHW) is due to an unusually persistent version of a "normal" weather event.

Fewings and Brown, 2019

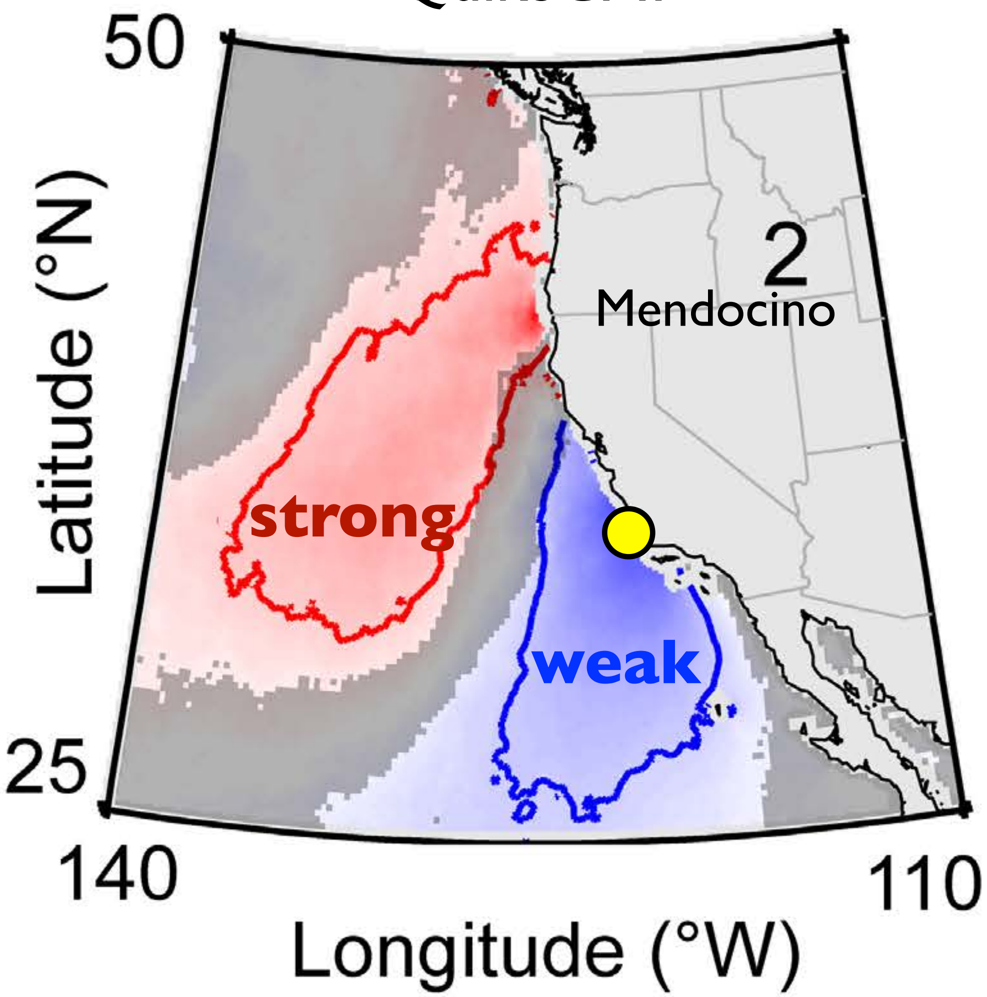
# In California EBUS, regional wind patterns enhanced the MHW



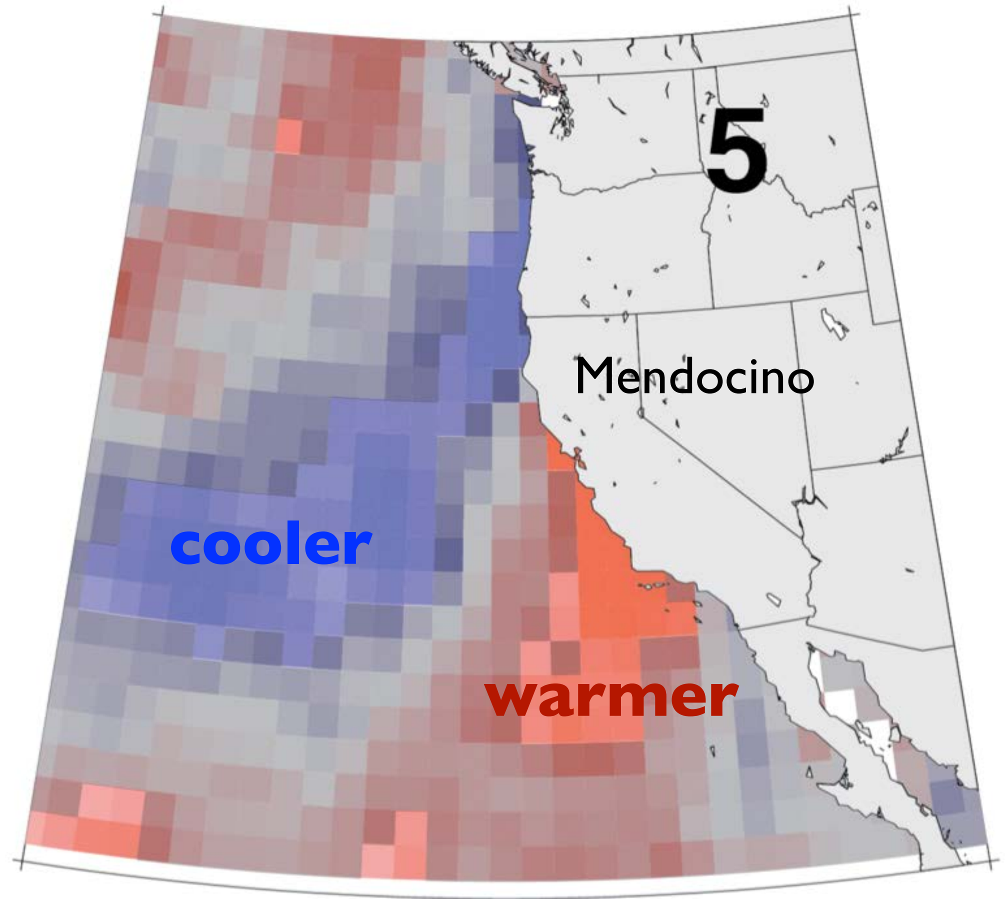

Fewings and Brown 2019

# There are SST anomalies associated with summer wind relaxations

**wind stress anomaly**
composite of 69 wind relaxations
QuikSCAT




**change in SST**
composite of 44 wind relaxations
OAFlux

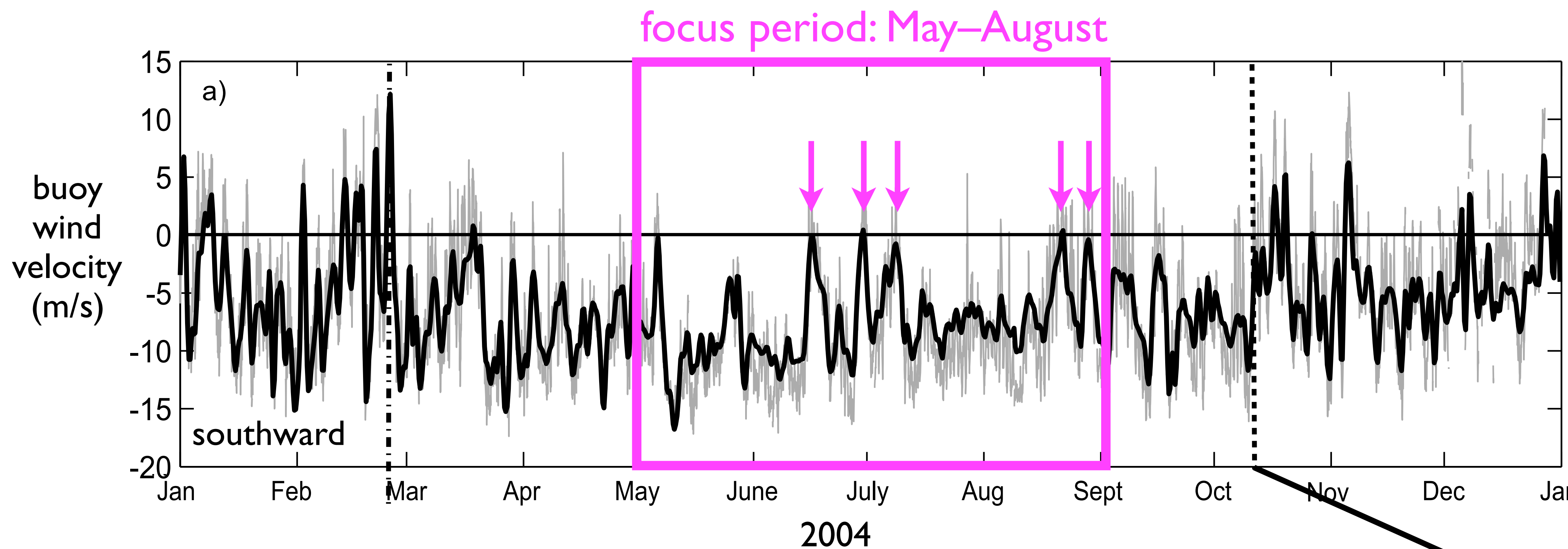


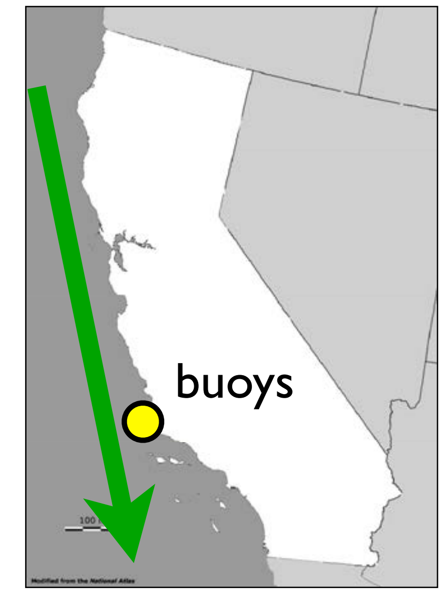

**60% of variability in summer is in this quasi-dipole mode**

➡ to understand extreme events, first understand typical events.

Fewings et al. 2016, Fewings 2017, Flynn et al., 2017, Fewings and Brown 2019

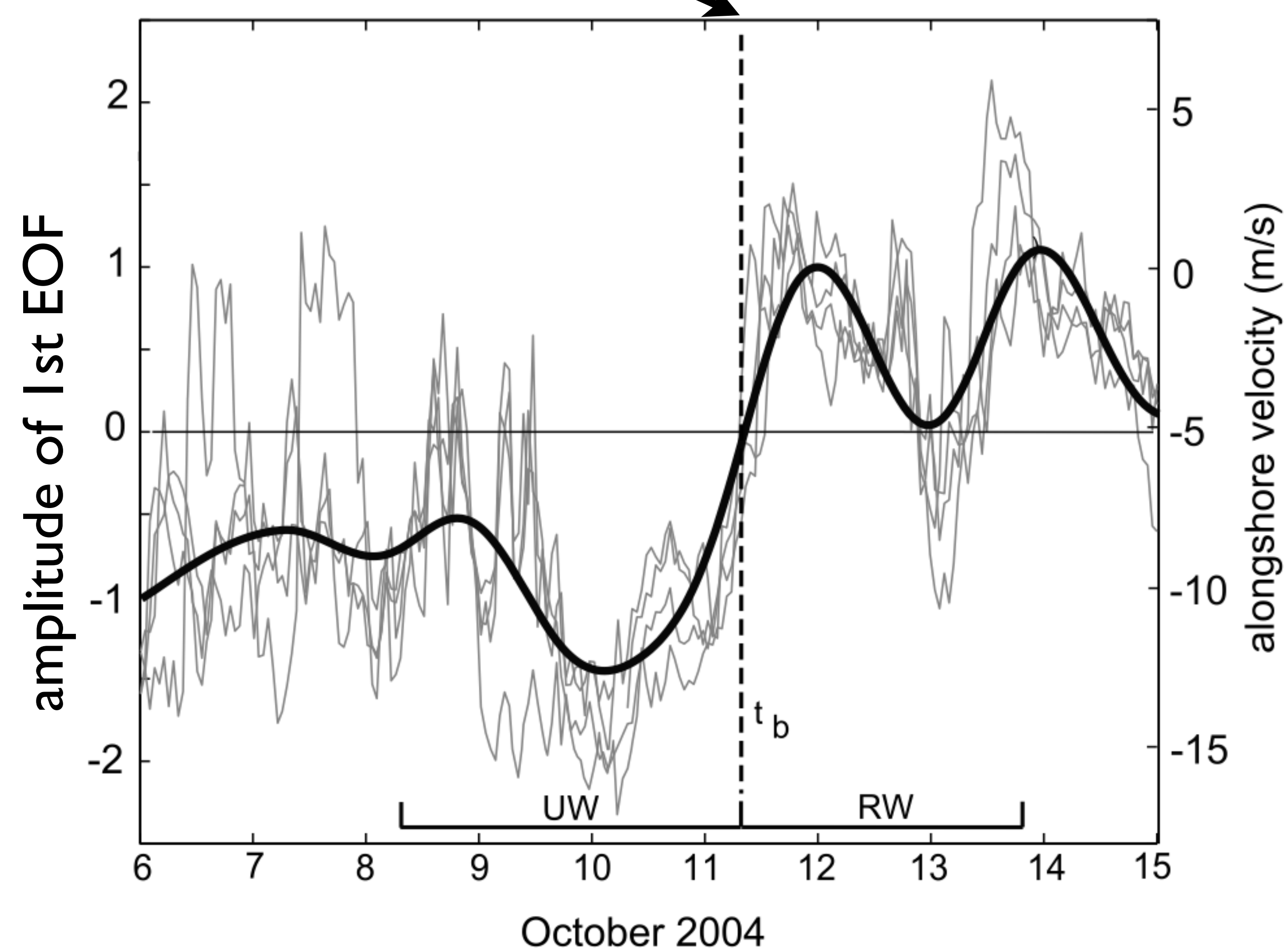
# We identify wind relaxation times at Pt. Conception using buoy data, then select satellite data before, during, and after each relaxation.




- **analysis years: 2000–present**

- relaxation times identified with Melton et al. 2009 method: zero crossings of 1st EOF of wind velocity at 4 buoys near Pt. Conception




figures based on Melton et al. 2009

# Composite satellite data reveal 3 connected wind events

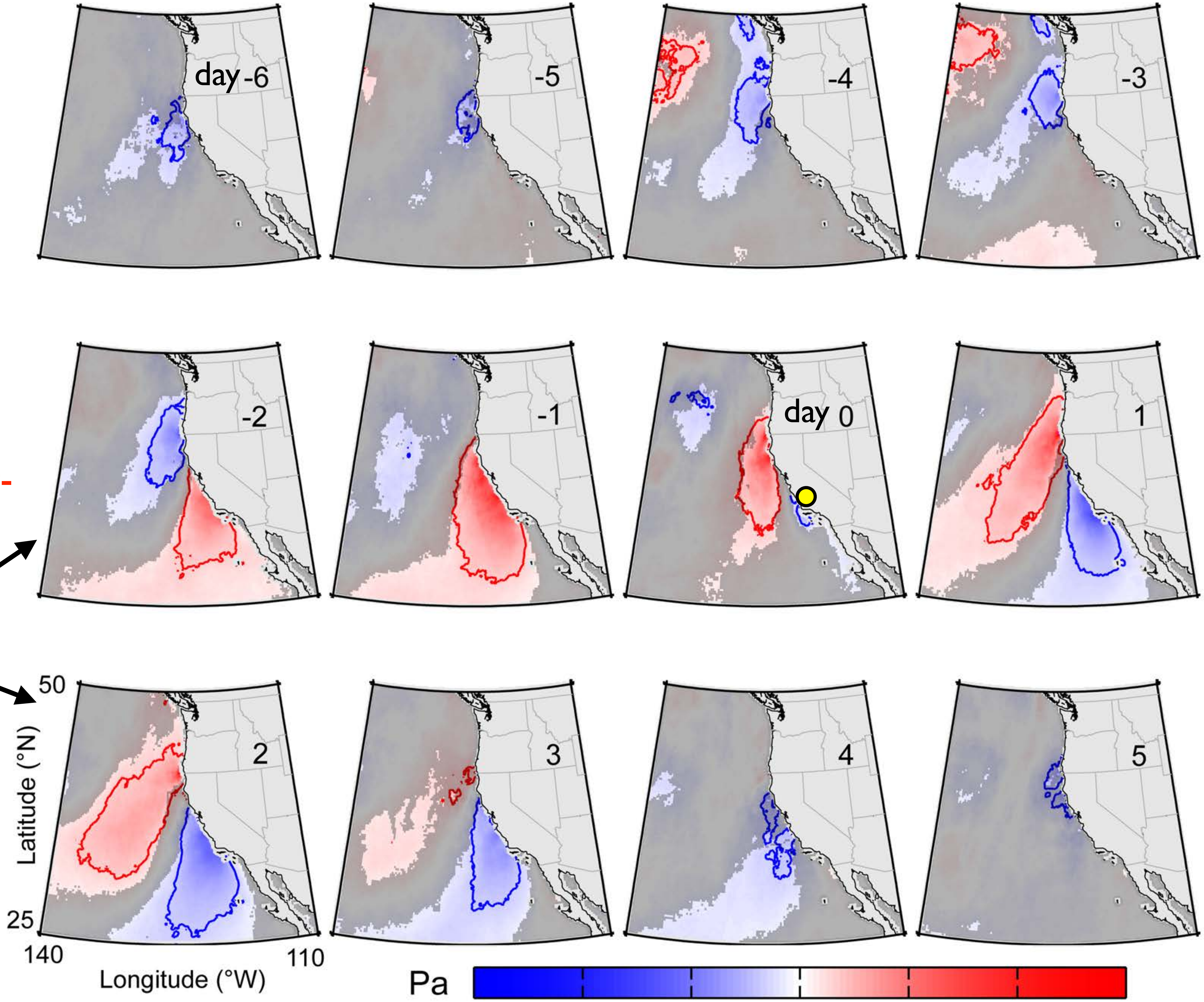
**wind stress anomaly** from QuikSCAT satellite
composited over ~70 relaxations at Pt. Conception in summer 2000-2009

stage 1:
relaxation/reversal off Oregon

stage 2:
intensified upwelling-favorable wind

**quasi-dipole**
60% of vel. variance

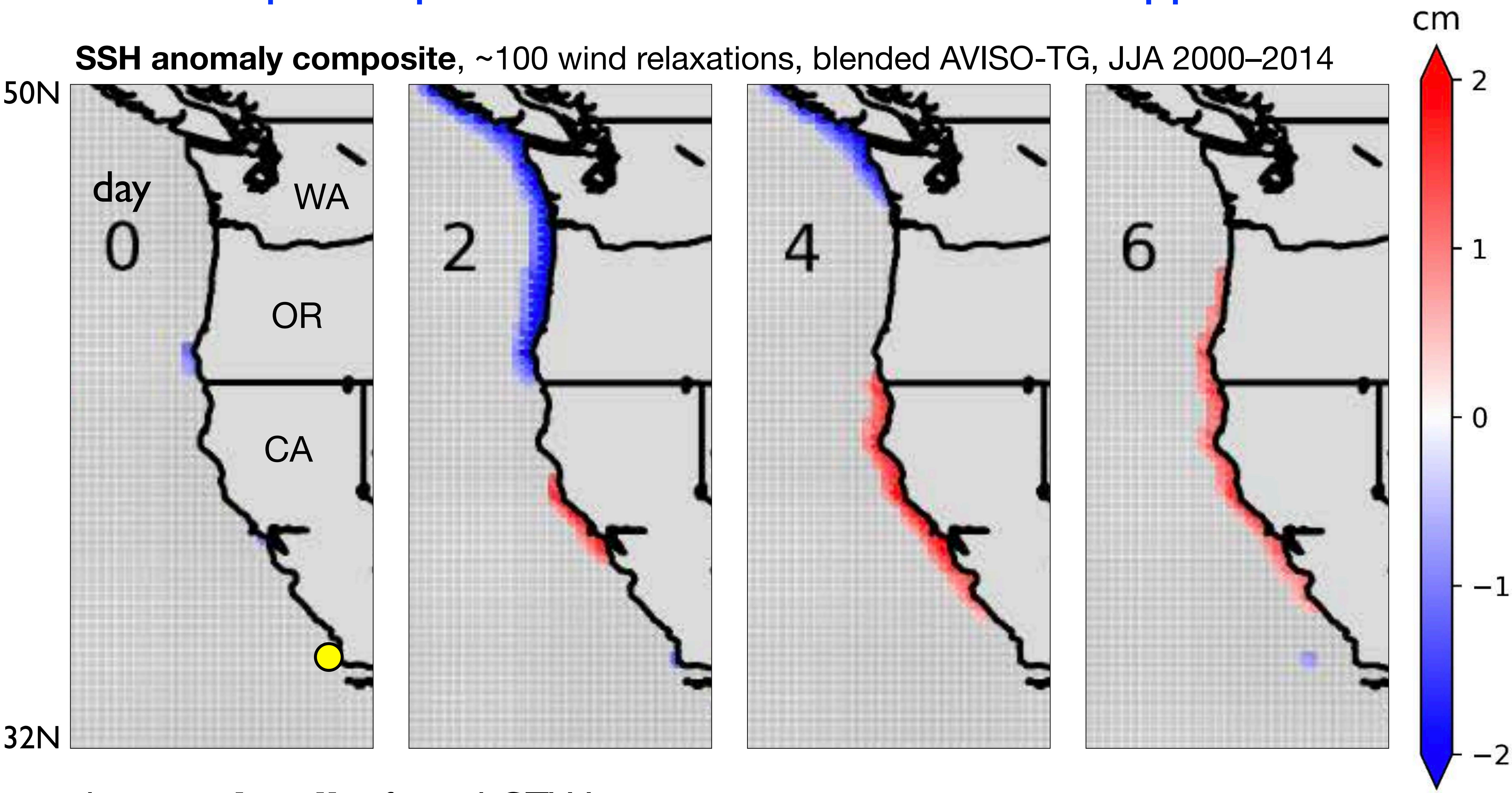
stage 3:
relaxation off central California




Fewings et al. 2016, Fewings 2017

What SSH anomalies are associated with this wind event cycle?

# The wind quasi-dipole is associated with coastal-trapped waves




- these are **locally-**forced CTW
- only detectable because remotely-generated CTW are averaged out by composite
- progression speed consistent with **mode-1 baroclinic CTW**: 200-300 km/day
- combined **forced/freely-propagating** waves
- wind variability is as large as mean, so **many events have SSH anomaly 4-6 cm**

# Implications for understanding MHW in productive EBUS

- context about distant forcing, time scales months to years

    — equatorial connection

    — **help define large-scale MHW** to separate from regional variability

- estimate **ocean advection contribution to regional MHW formation**

    — combine altimetry & satellite SST: along-coast advective heat flux divergence
    — important in **upwelling zone** and for **extreme events** (relaxations of ~weeks)
    — globally, where coastal HF radar velocities and tide gauges not available

    — future: composite **along-track** altimeter data near coast
    — goal: **enable better predictions of regional variability** in MHW (Jacox et al. 2019)

# Implications for the SWOT mission

- **SWOT will alias these propagating SSH signals** of wind events
  — SSH anomalies *O*(2-6 cm) for typical *locally-driven* events
  — typical wind events last 3-5 days, making a ~12-day cycle
  — SWOT sampling will alias or miss features with 5-10 day time scales

- **need to model these CTWs for SWOT**
  — need to model the locally- **and remotely**-driven CTW
  — it is possible to model CTW SSHs accurately: extensive literature on dynamics
  (CCS: Allen, Denbo, Enfield, Battisti, Hickey, Chelton, Brink, Pringle, … Kurapov recent papers)
  — computationally expensive to model globally
  — need high-res bathymetry
  — need stratification
  — need high-resolution wind stress, local and remote

# We are analyzing other MHW during 2000–~~2017~~ ~~2018~~ 2019 and comparing to the Chile-Peru system

With Co-PI Carlos Moffat (U. Delaware)

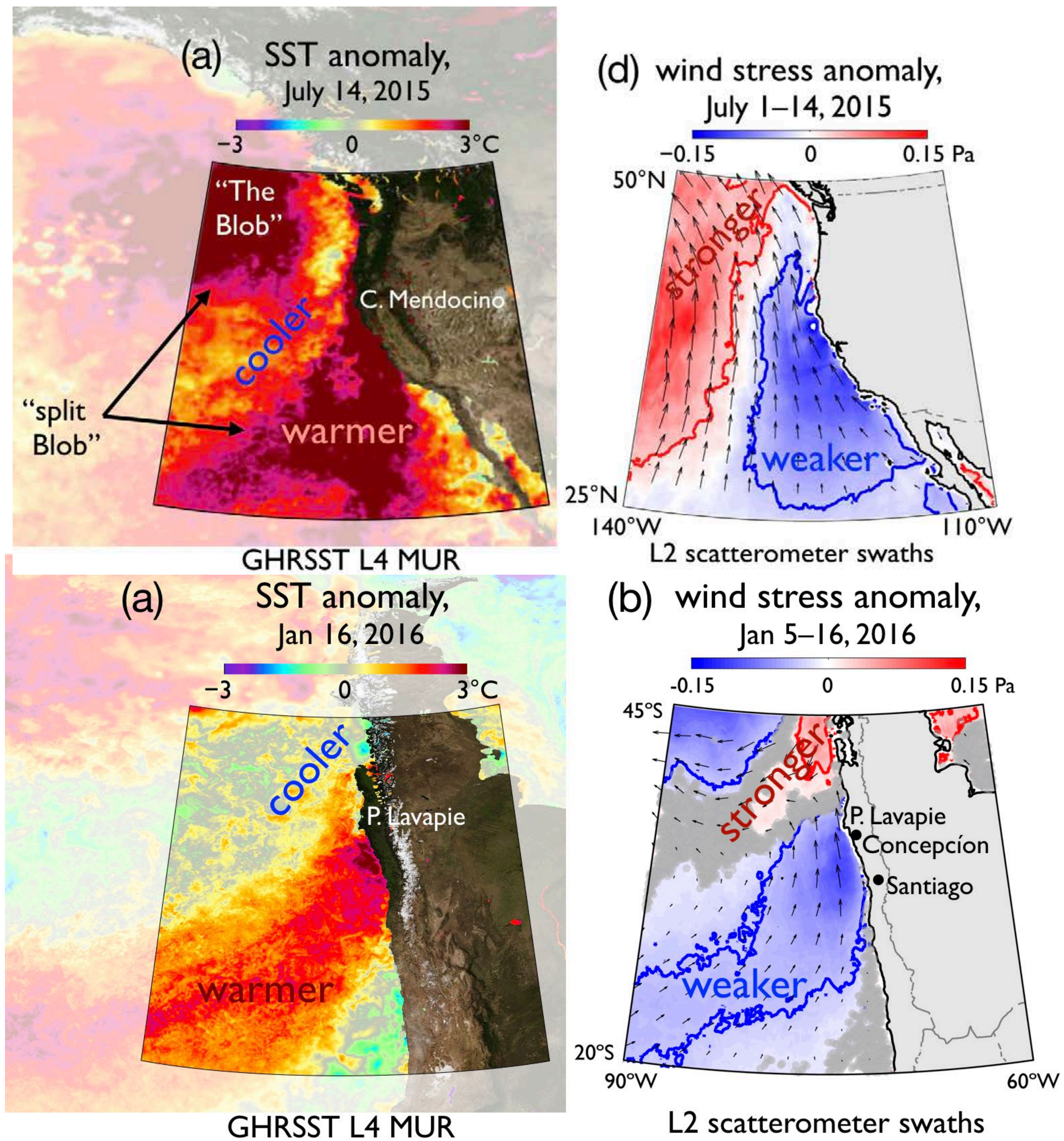
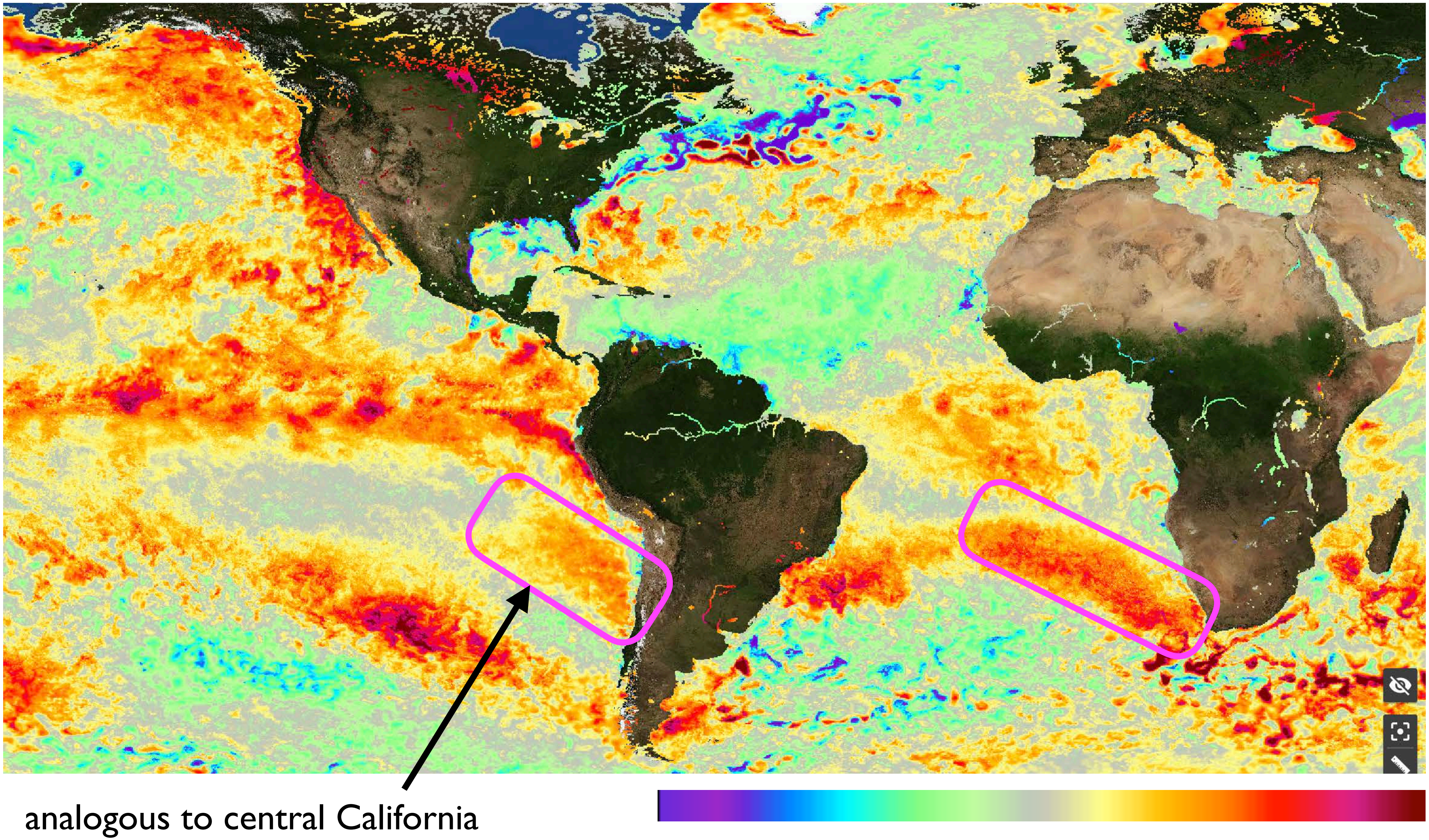



Fig. 2: **SST and wind stress anomalies off Chile during the 2016 southeast Pacific MHW.** (a) SST anomaly, similar to Fig. 1(a). (b) Wind stress anomaly, similar to Fig. 1(d). Note the figures are flipped vertically, i.e. north is downward, to facilitate comparison with the NAmer figures.

# Suggestion of similar SST patterns in Benguela and Chile-Peru EBUS

SST anomaly, 21 December 2018




analogous to central California expansion fan?

NASA State of the Ocean, podaac-tools.jpl.nasa.gov/soto