

Atmospheric Wind Relaxations and the Oceanic Response in the California Current Large Marine Ecosystem

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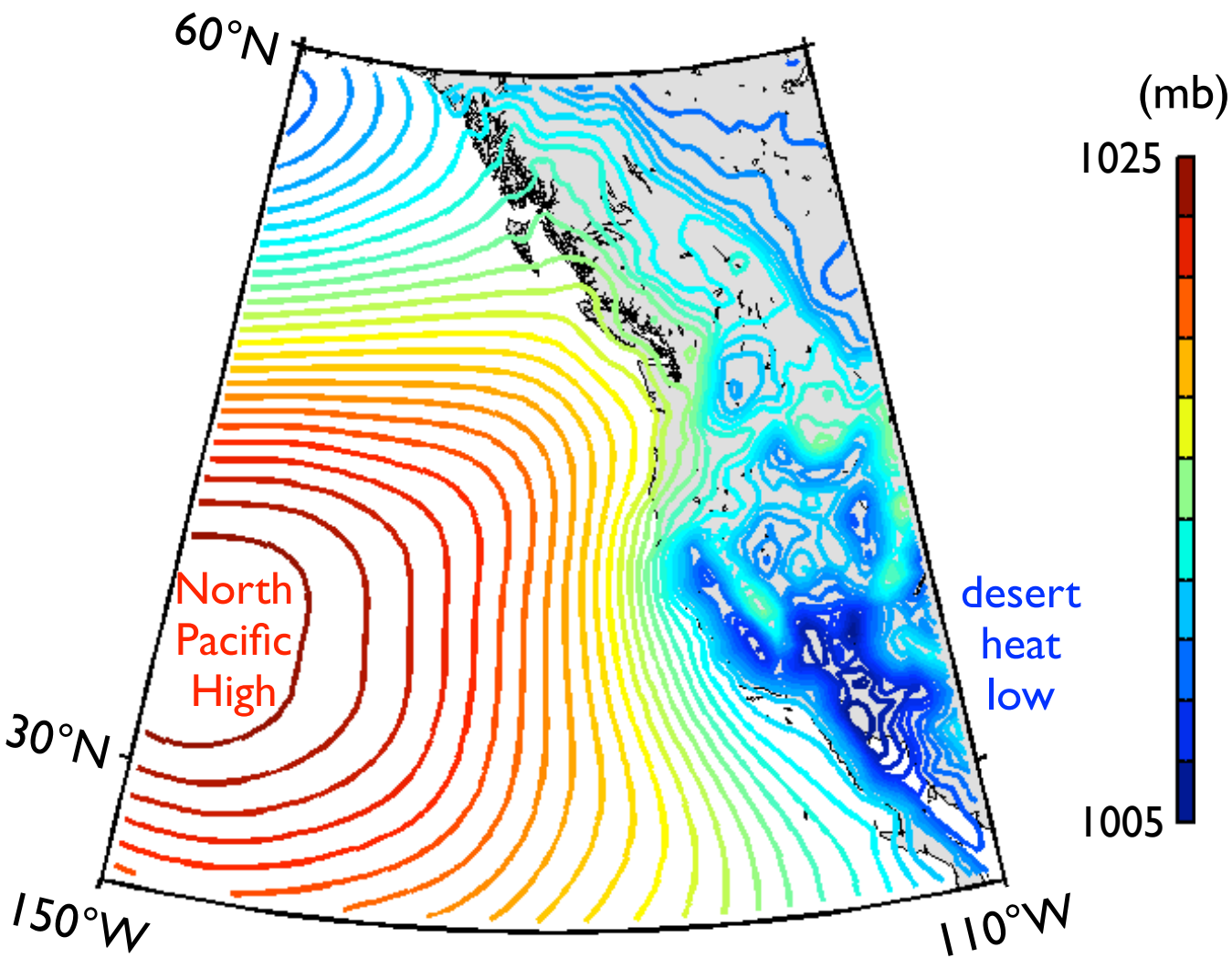
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NorthWest Research Associates / CoRA Division

In summer off the West Coast of North America, the wind stress is southward because the North Pacific High strengthens in the atmosphere.

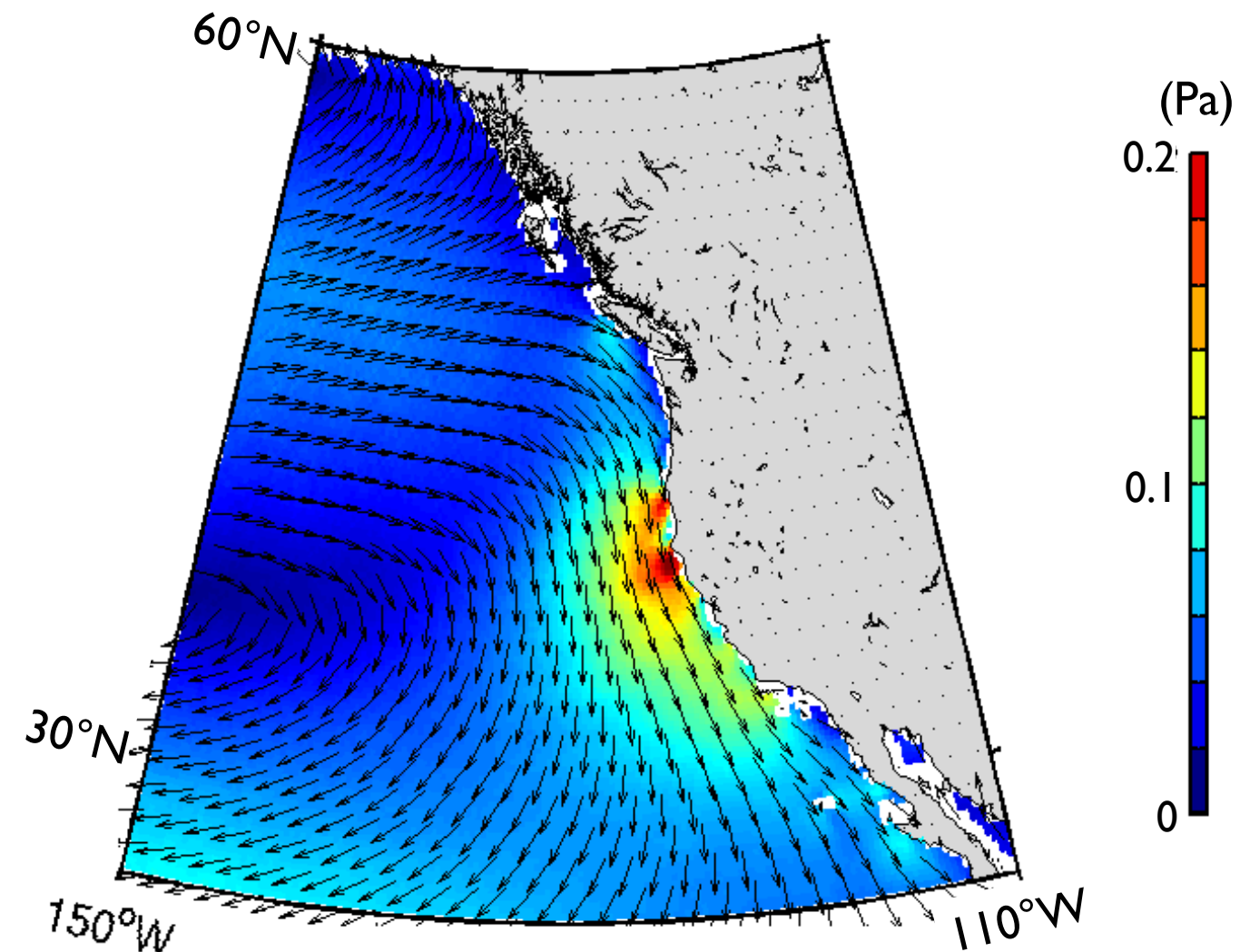
mean sea-level pressure

June-Sept



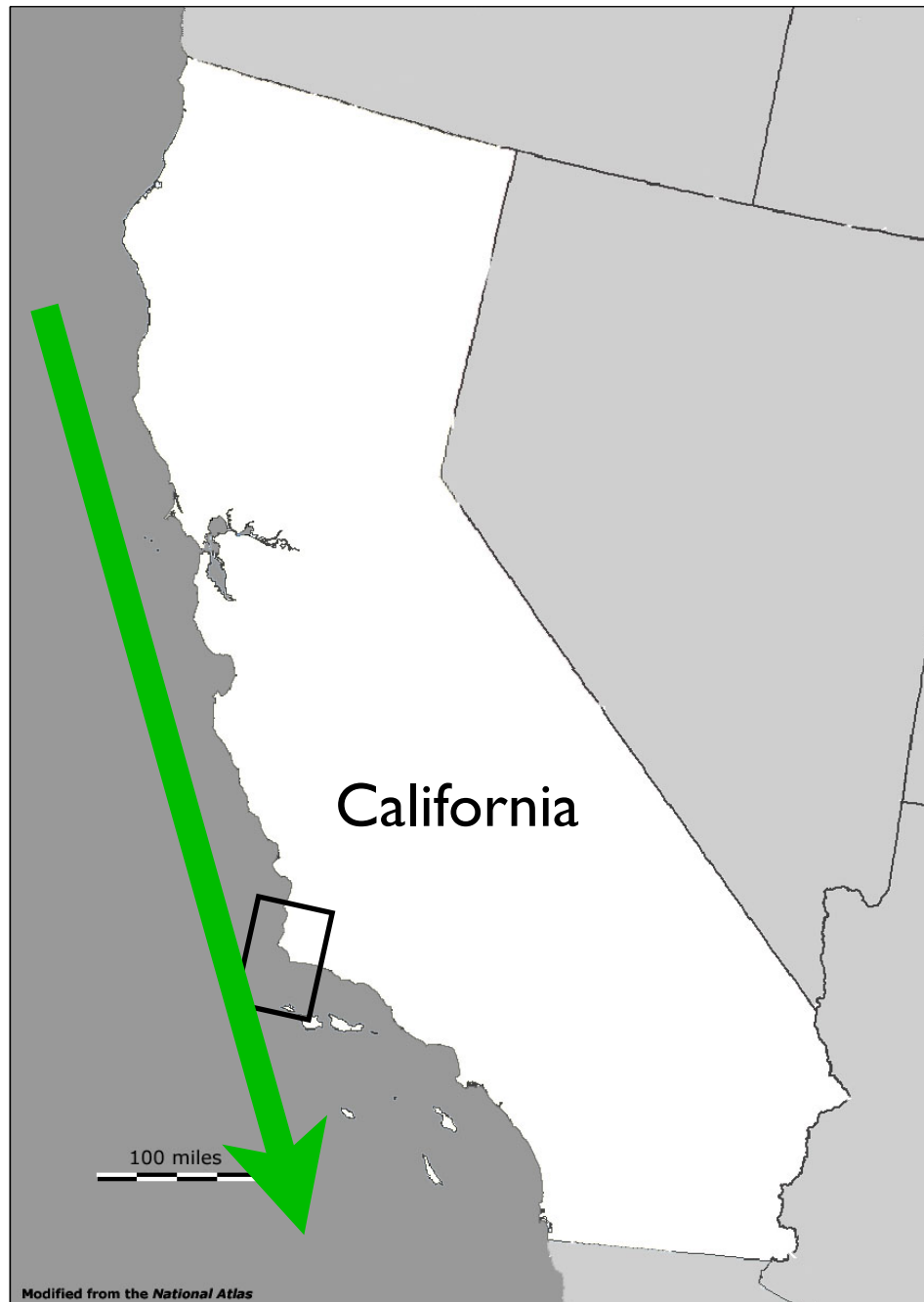
mean wind stress

June-Sept



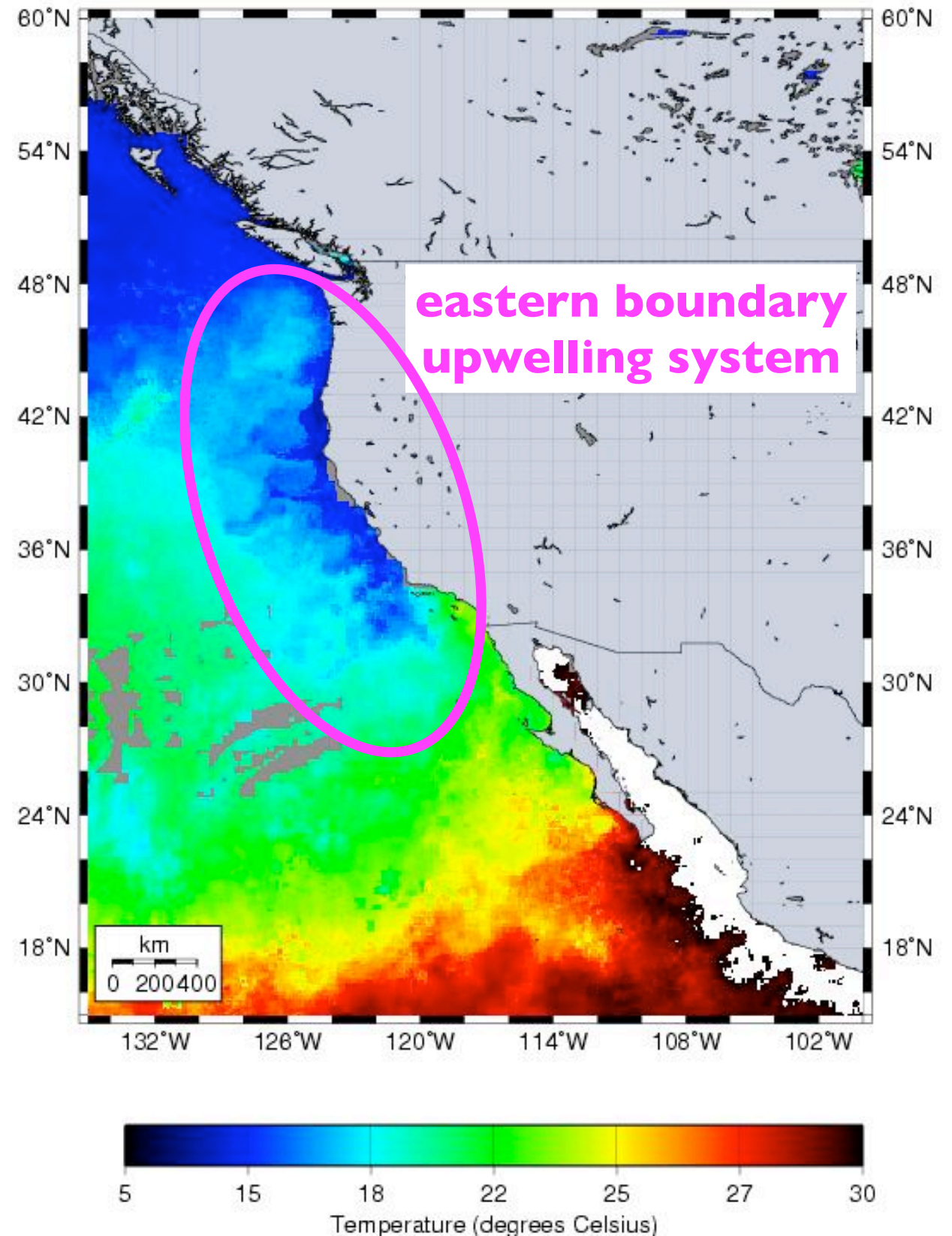
That southward wind stress causes coastal upwelling that brings deep, cold water to the surface.

upwelling-favorable wind



sea-surface temperature

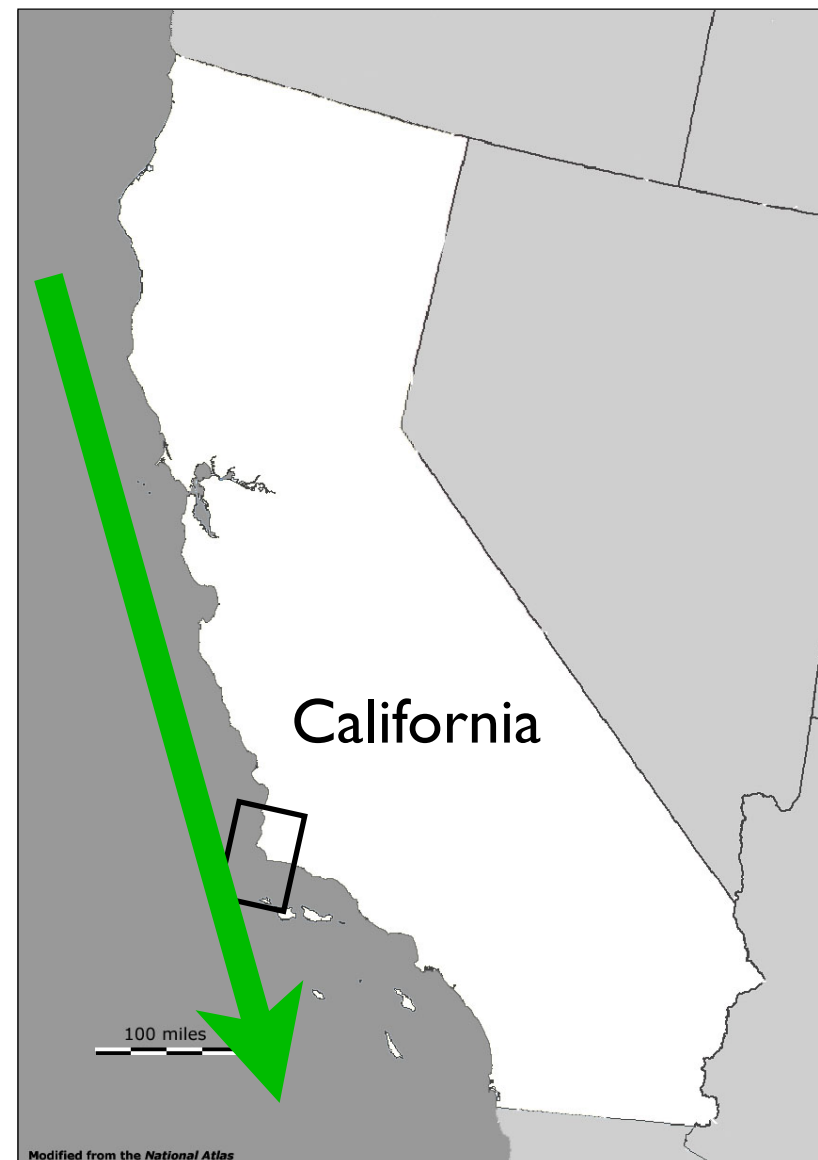
AVHRR-GAC SST from 16 Jul 2006 to 18 Jul 2006



The upwelled water is nutrient-rich and can be oxygen-poor.

- upwelling of nutrients supports high fisheries productivity in the California Current Large Marine Ecosystem
- upwelling of hypoxic water contributes to fish and invertebrate die-off

**upwelling-favorable
wind**



rockfish



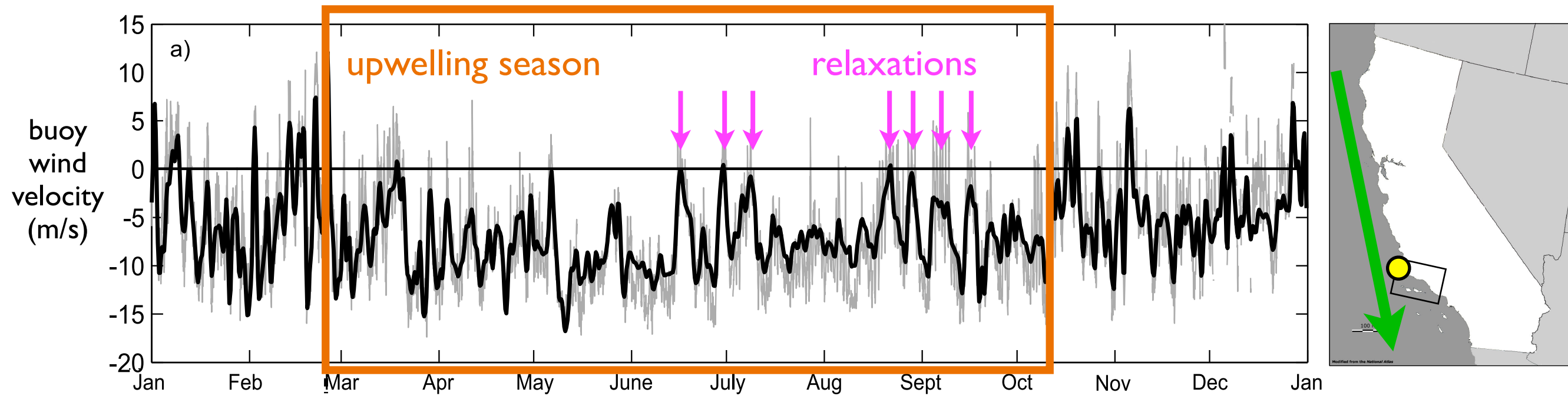
spiny lobster



kelp bass



The upwelling-favorable winds periodically weaken or “relax”.



The coastal ocean responds with buoyant poleward flows.

cold upwelled water replaced
by warm water from south of Pt. C

important for larval transport

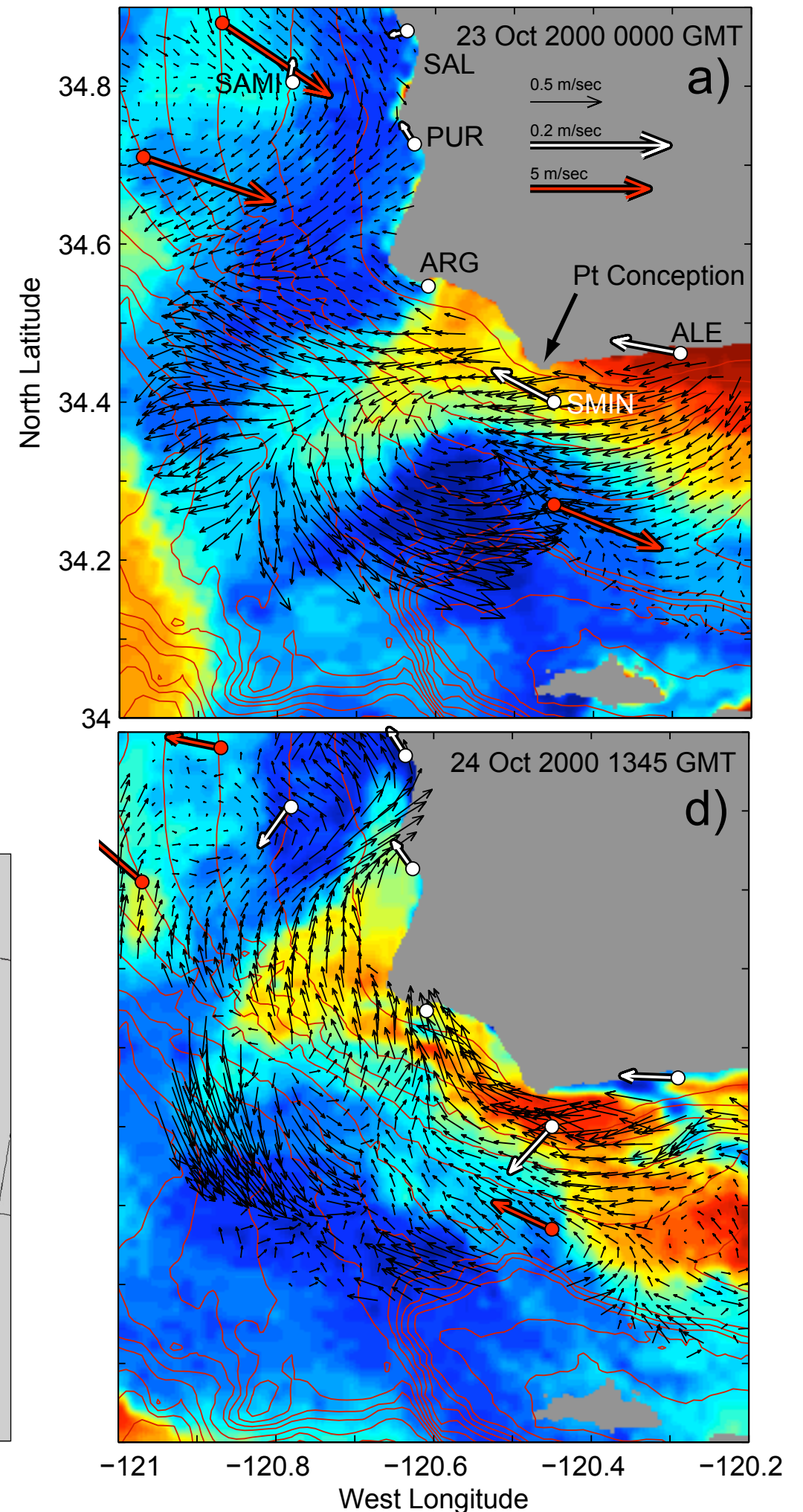
similar flows in other upwelling systems

Iberia:

García-Lafuente et al, 2006,
Relvas & Barton, 2002, 2006

Benguela:

Fawcett et al. 2008



What atmospheric conditions lead to wind relaxations?
Are the relaxations confined to California?
What is the regional ocean response?



Data

Wind

QuikSCAT wind stress
Level 3 daily gridded, $1/4^\circ$

Atmospheric pressure

NCEP North American Regional Reanalysis
32-km grid, 8x daily

Sea-Surface Temperature

MODIS 1-km daily binned (Kahru)

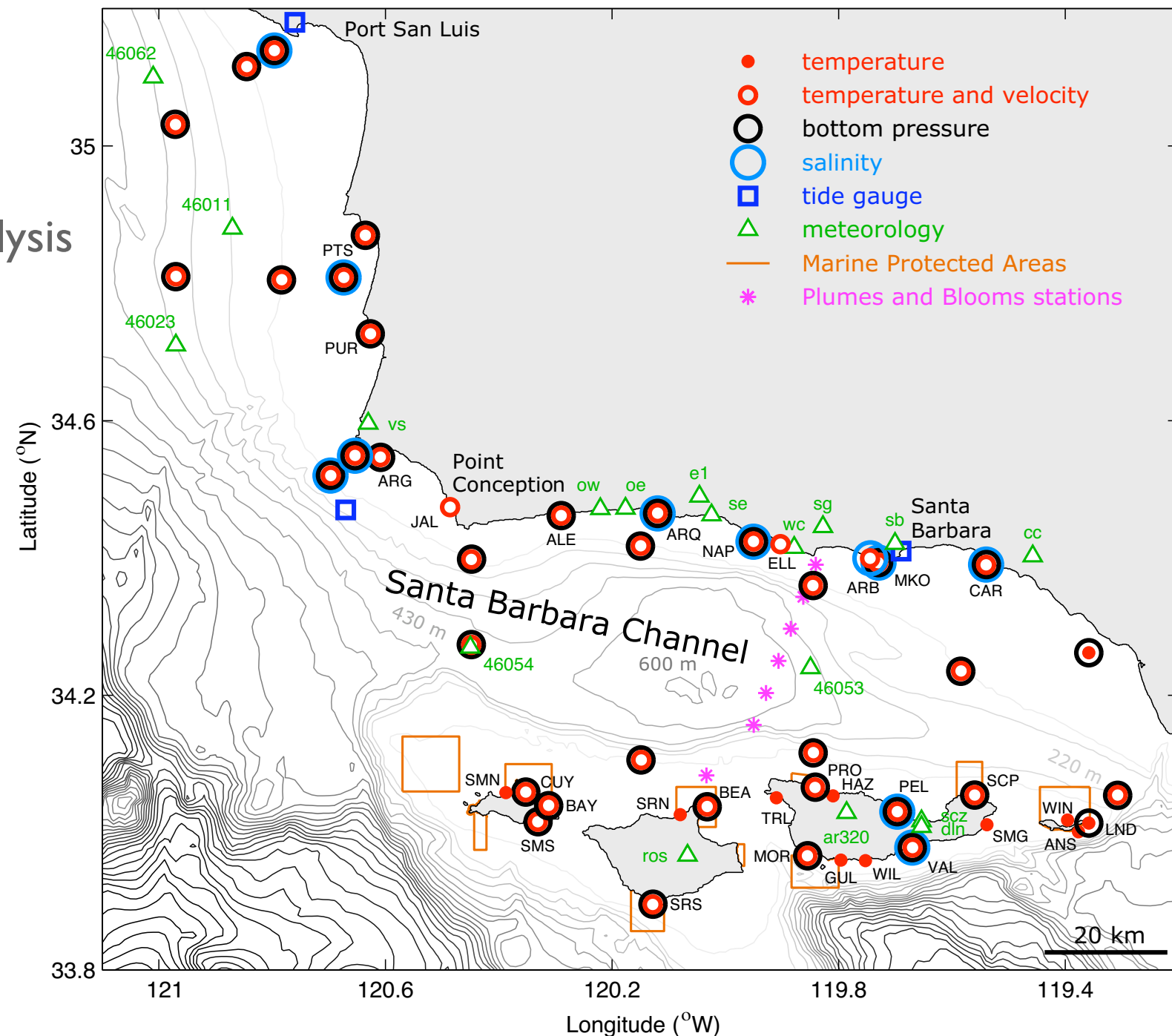
Chlorophyll

Merged SeaWiFS/MODIS Aqua
Level 3 daily binned, 9 km

Surface Ocean Currents

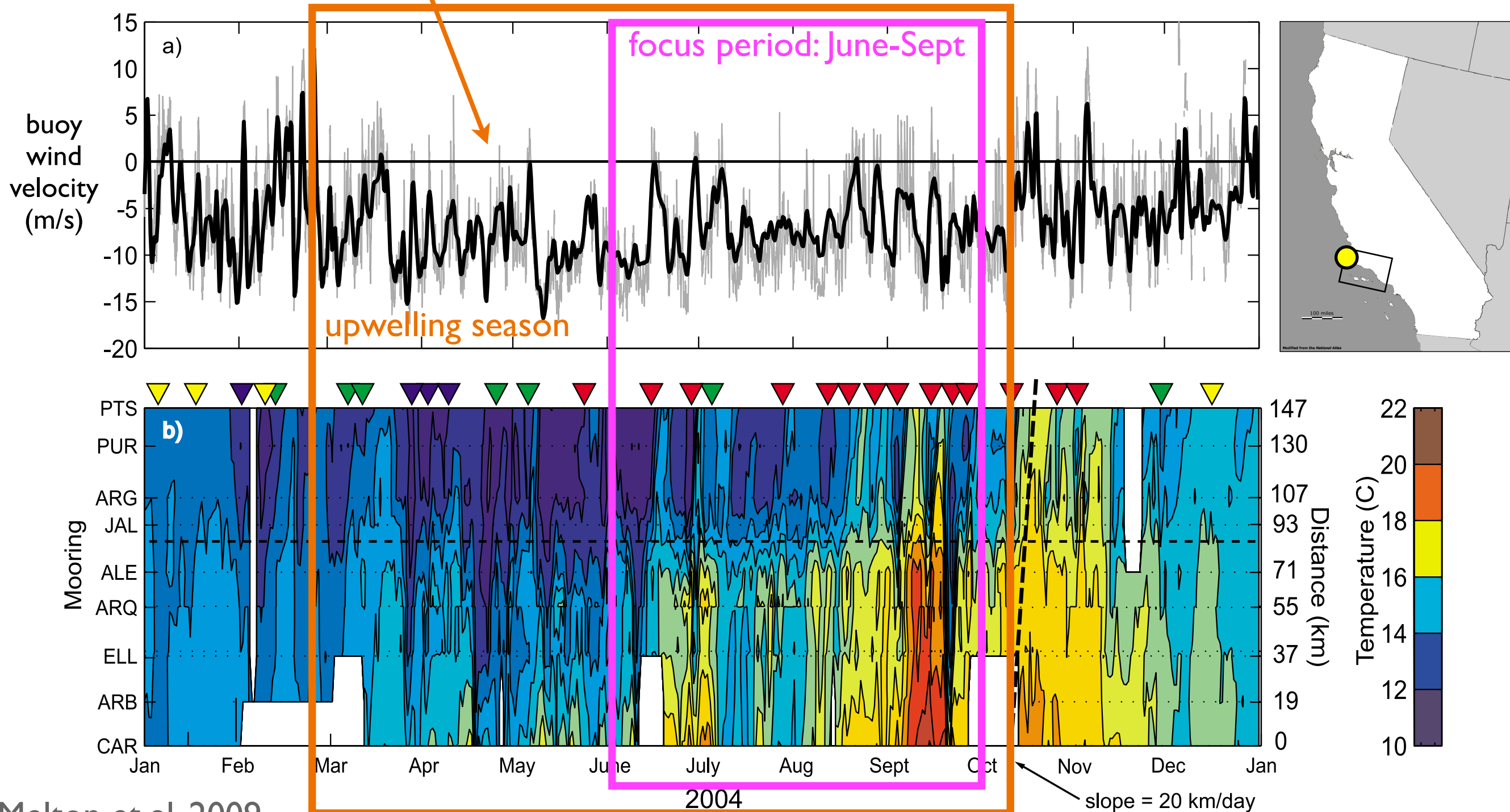
high-frequency radar
hourly, 2 km

Subsurface Water Temperature, Velocity
moorings @ 15, 50, 100, 250 m depth



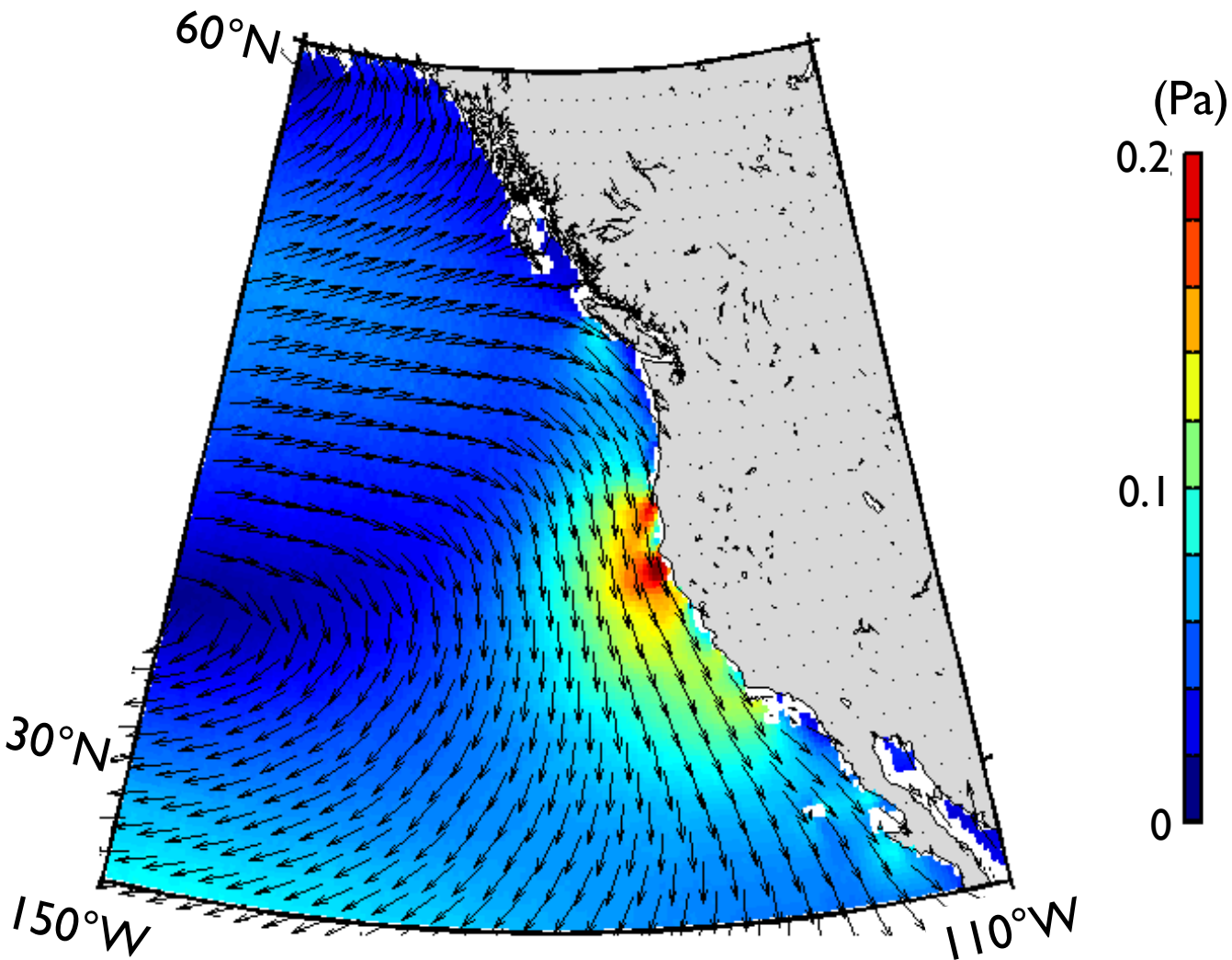
We identify relaxation times using coastal buoy data, then select satellite data before, during, and after each relaxation.

wind does not reverse direction

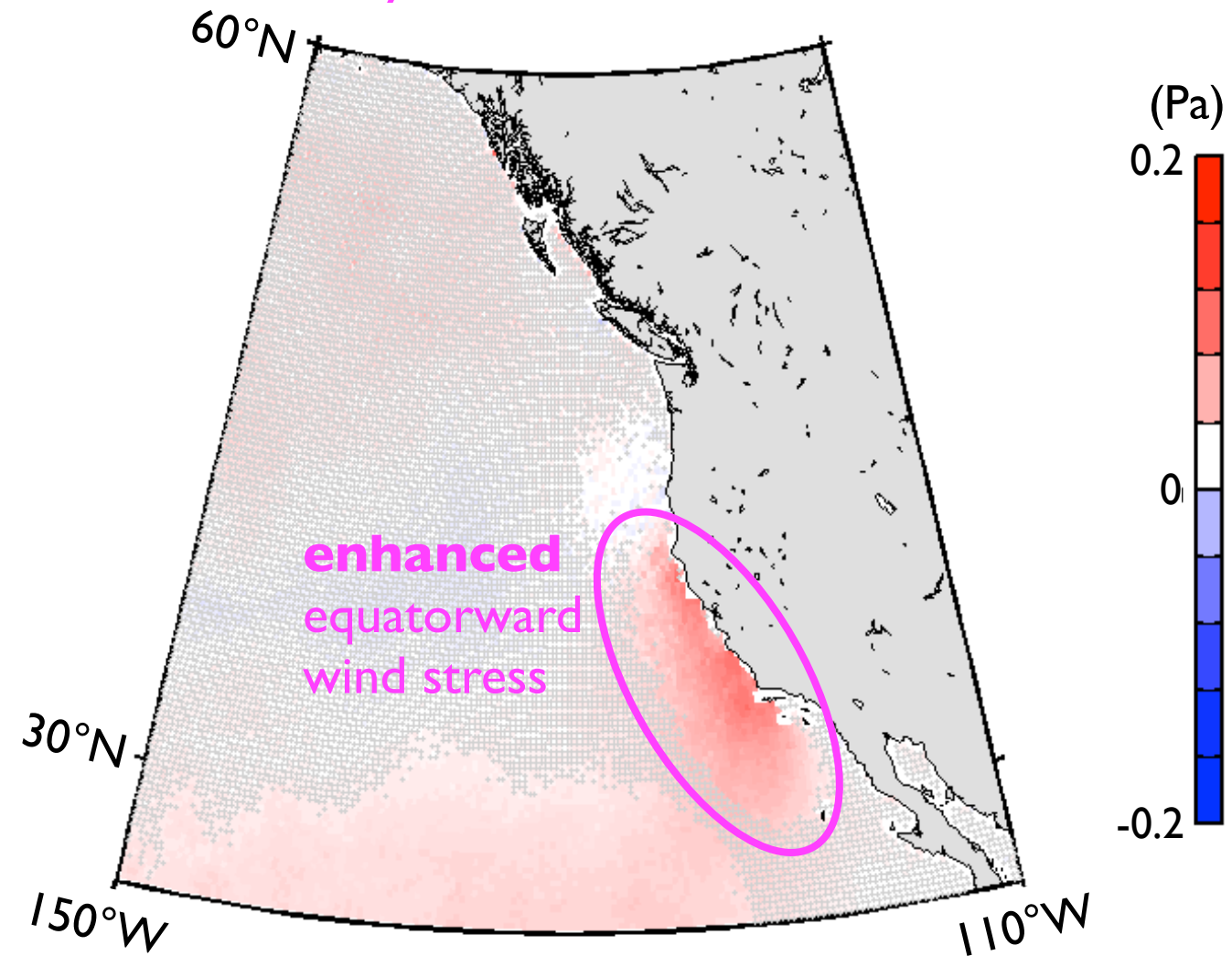


The upwelling-favorable wind stress **INCREASES**
prior to the relaxation.

mean wind stress
June-Sept



wind stress anomaly
average over ~100 events
along mean direction
1 day before relaxation

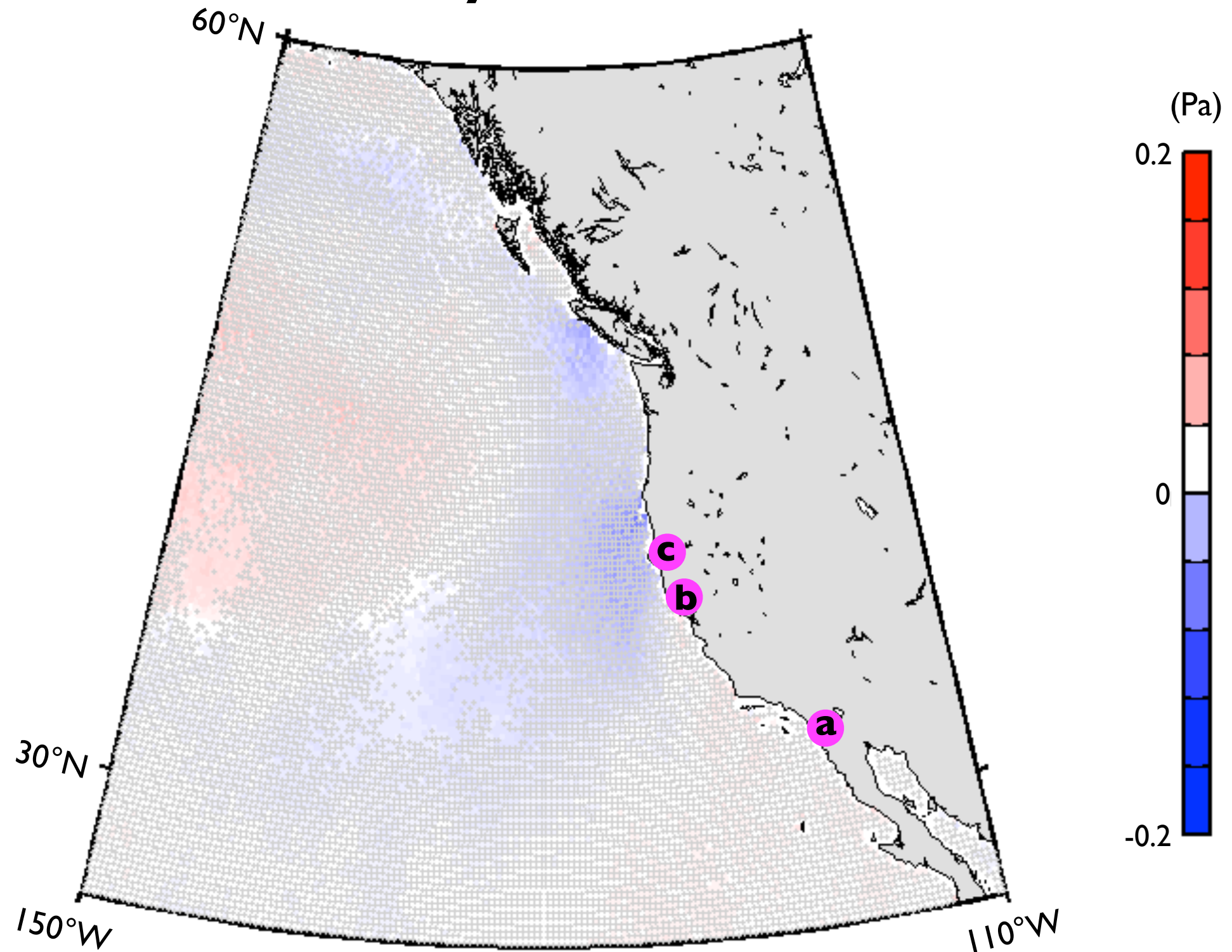


The relaxation propagates northward.

wind stress anomaly
average over ~100 events

along mean direction

day -5

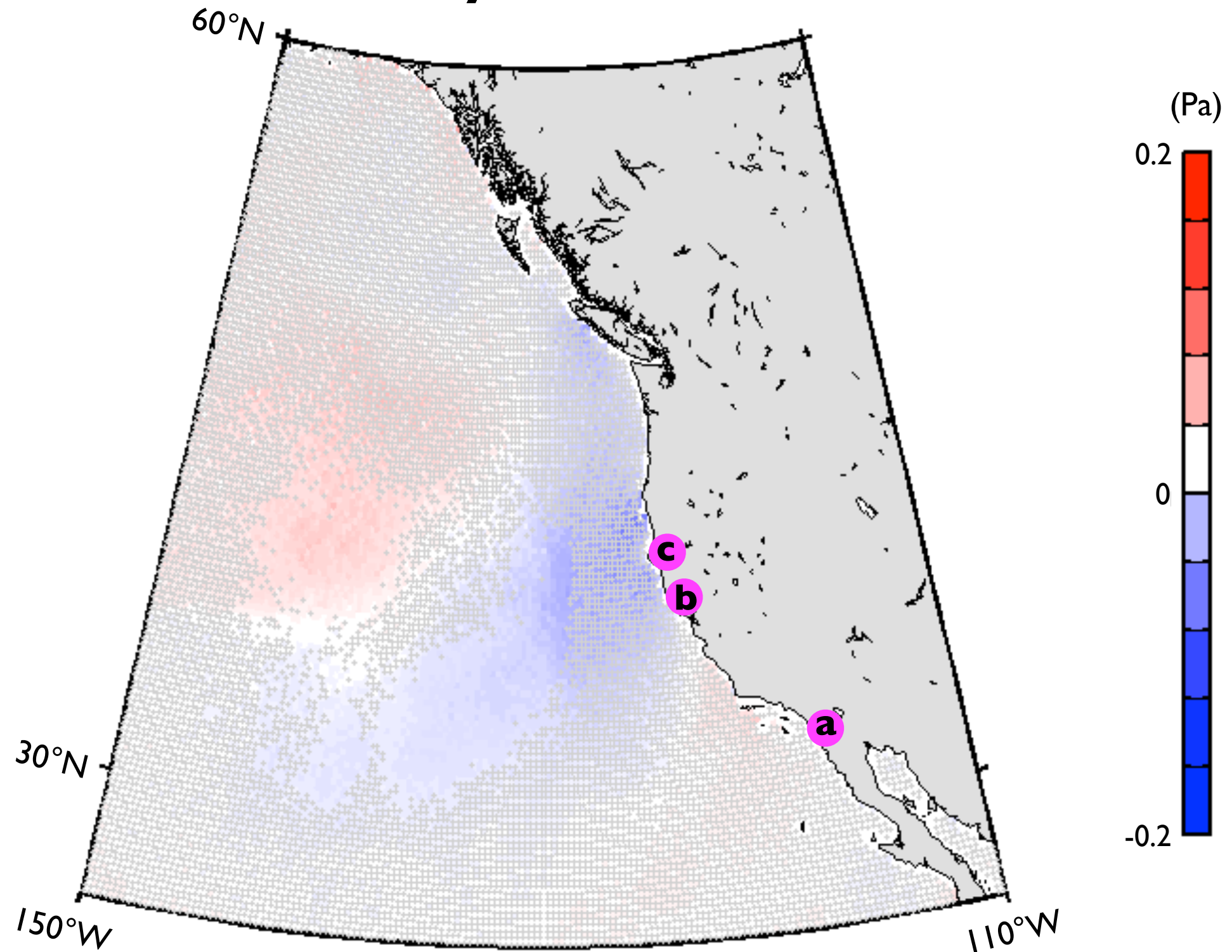


The relaxation propagates northward.

wind stress anomaly
average over ~100 events

along mean direction

day -4

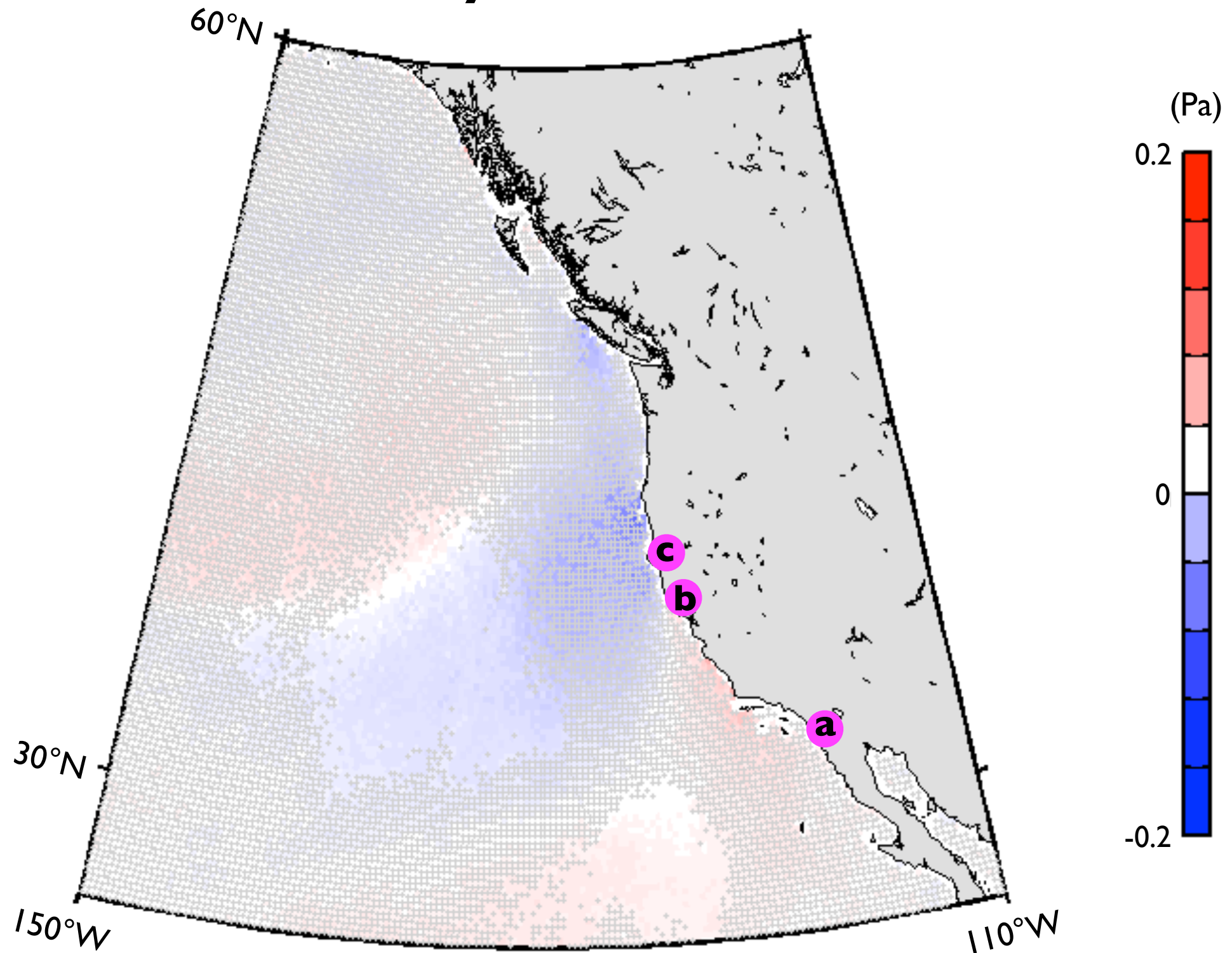


The relaxation propagates northward.

**wind stress anomaly
average over ~100 events**

along mean direction

day -3

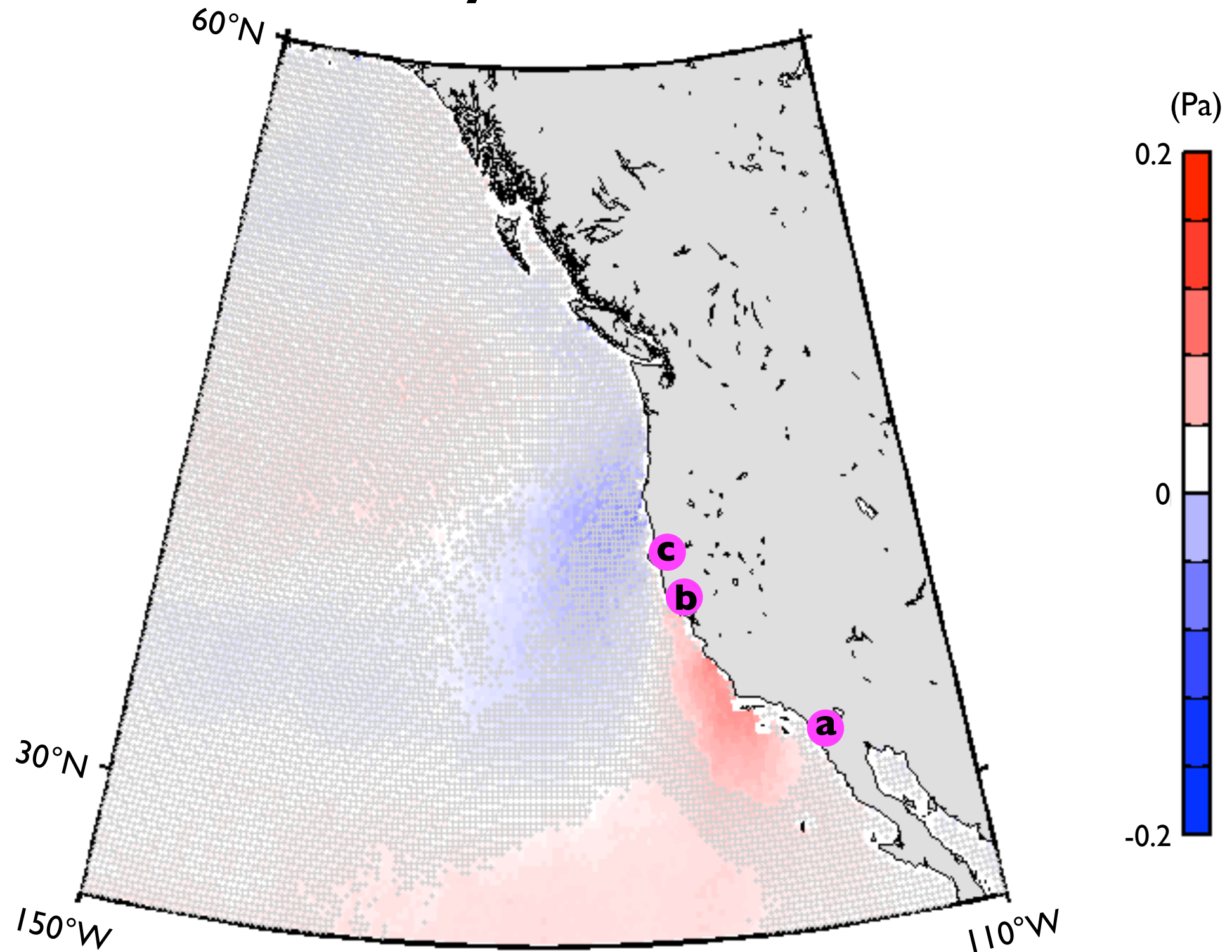


The relaxation propagates northward.

**wind stress anomaly
average over ~100 events**

along mean direction

day -2

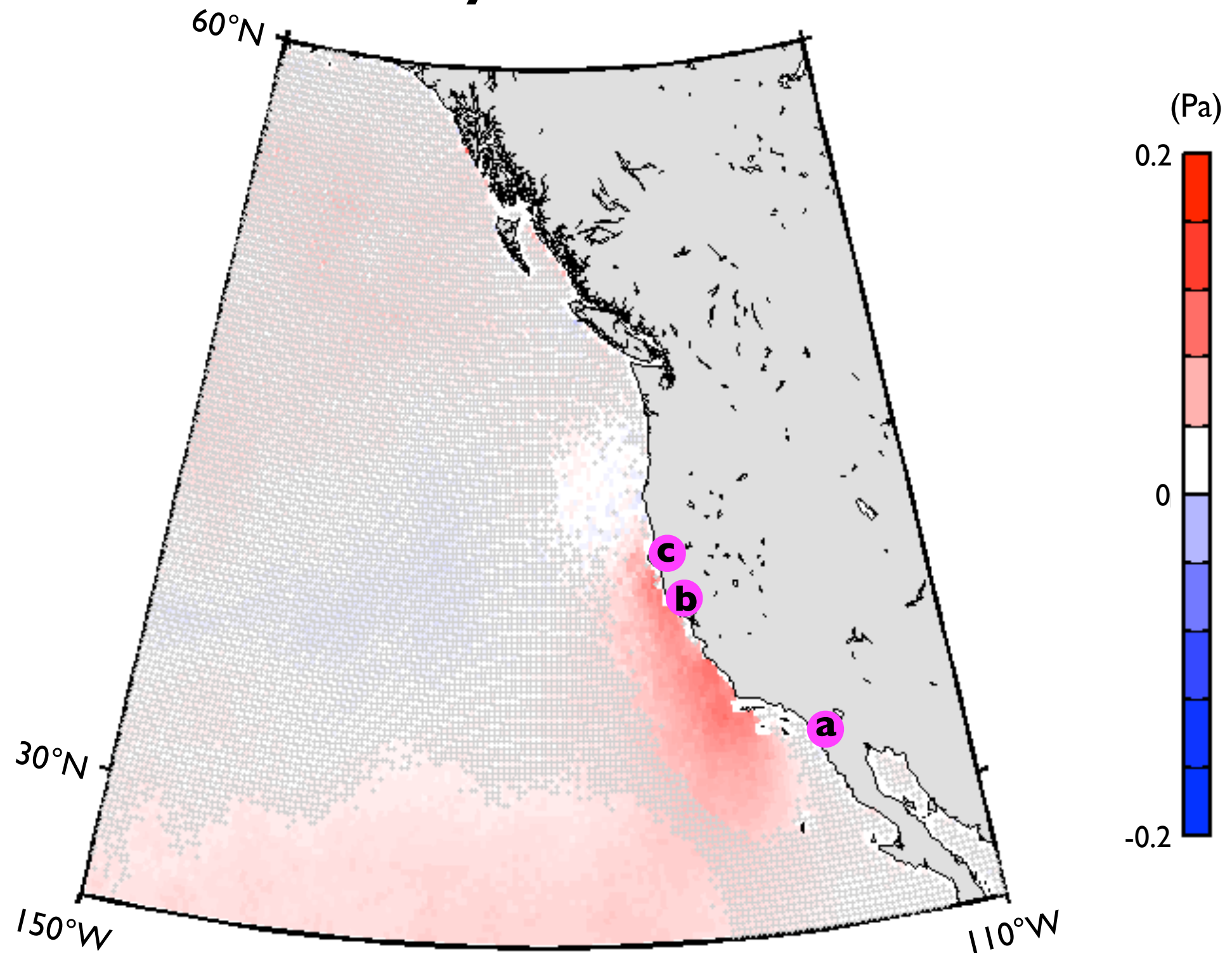


The relaxation propagates northward.

**wind stress anomaly
average over ~100 events**

along mean direction

day -1

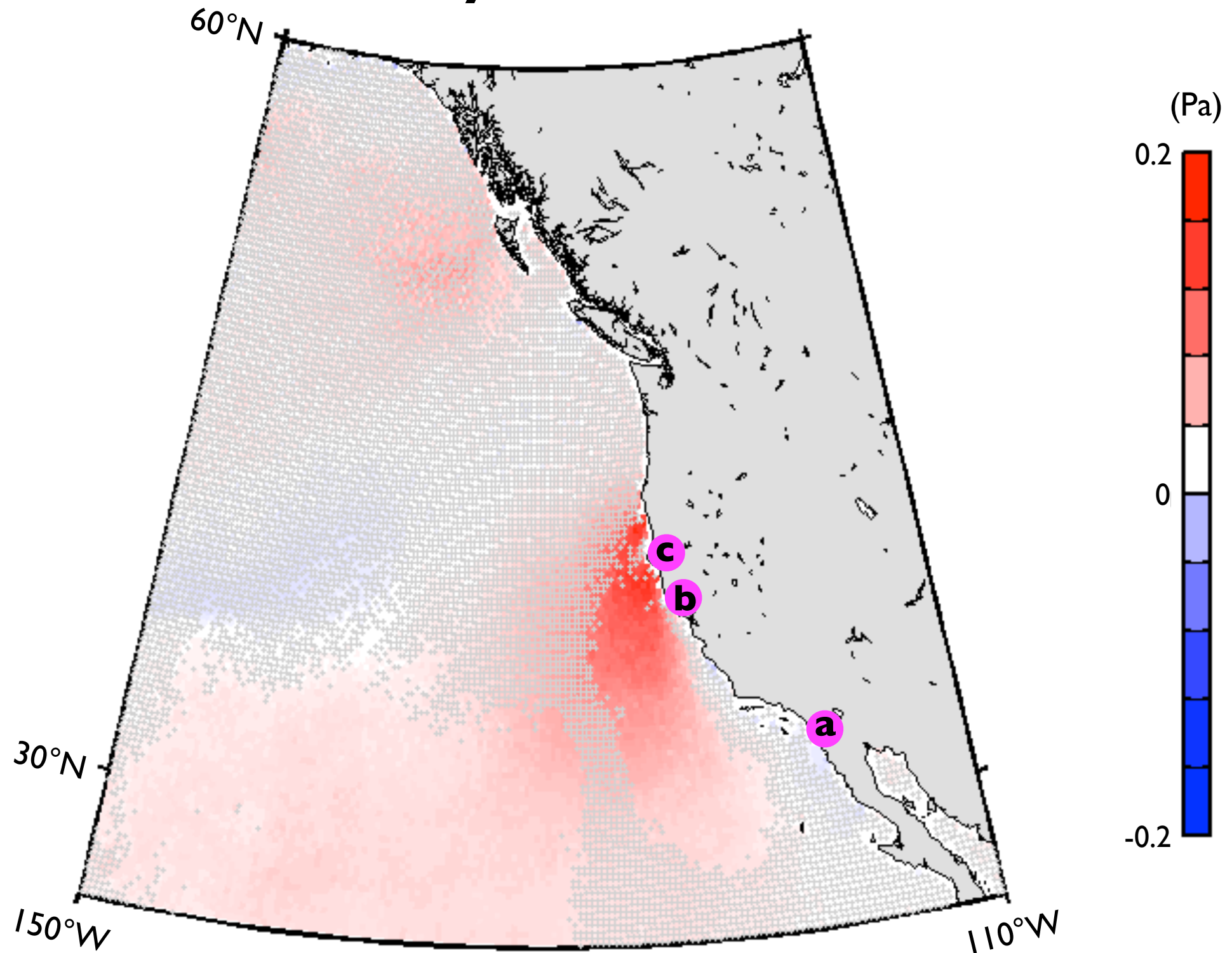


The relaxation propagates northward.

wind stress anomaly
average over ~100 events

along mean direction

day 0

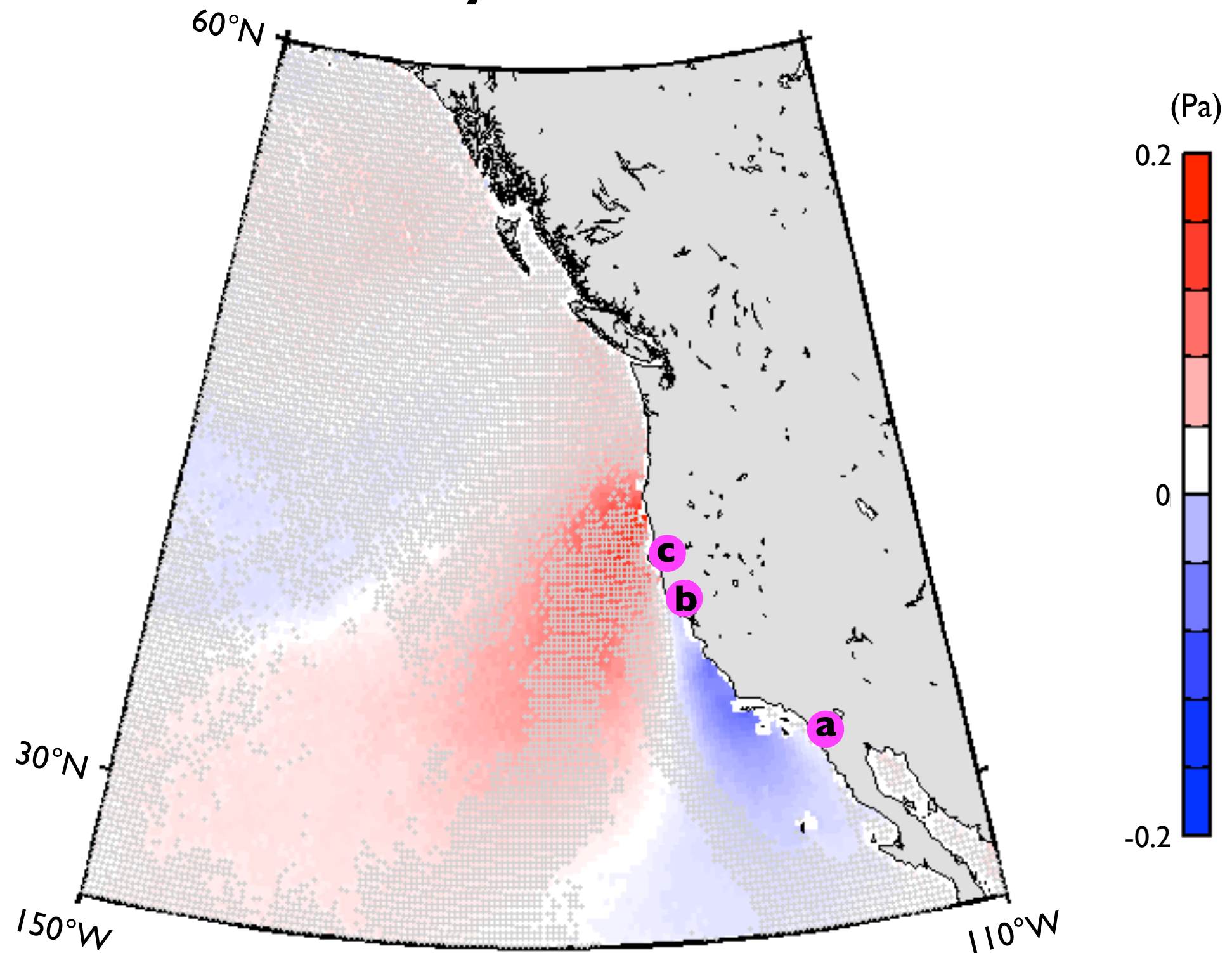


The relaxation propagates northward.

wind stress anomaly
average over ~100 events

along mean direction

day 1

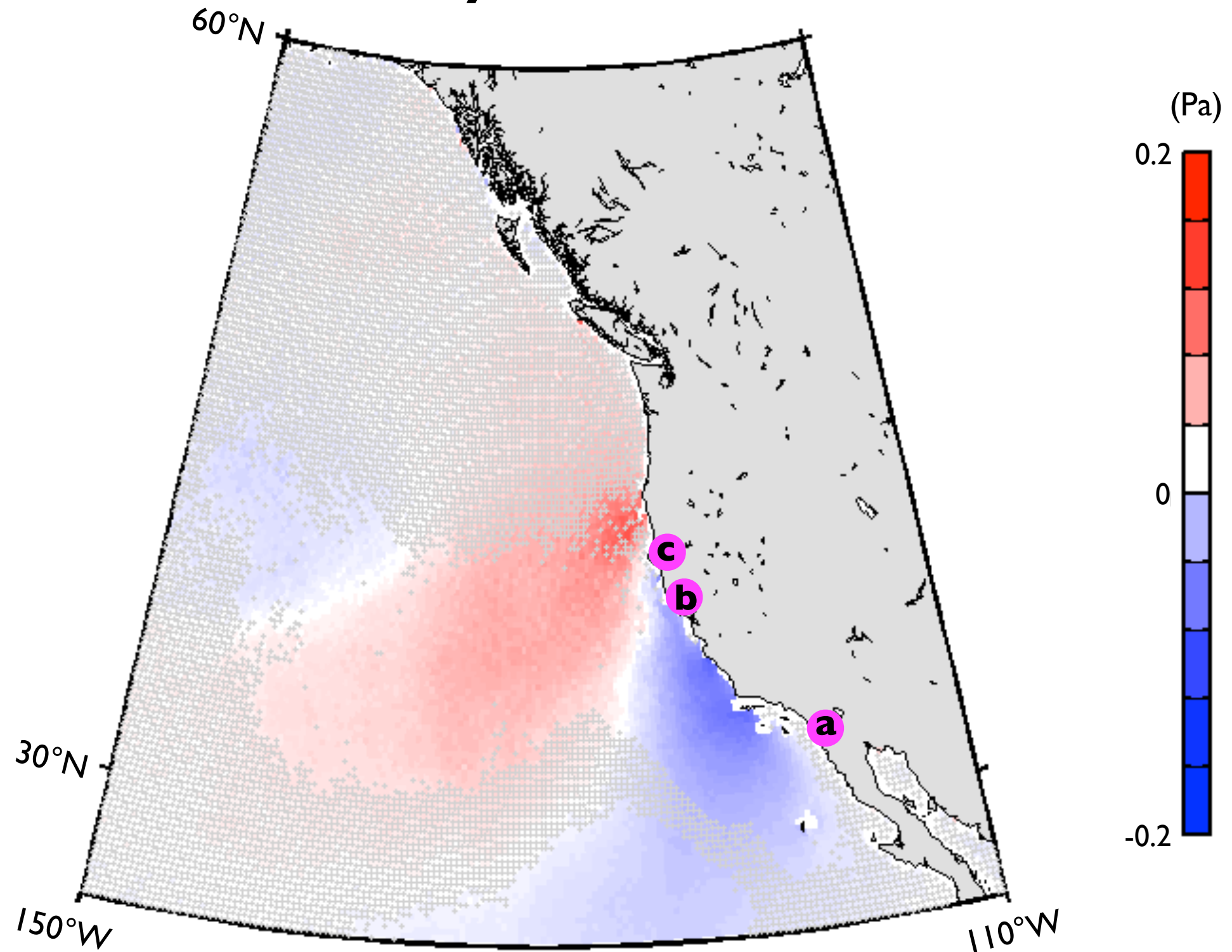


The relaxation propagates northward.

**wind stress anomaly
average over ~100 events**

along mean direction

day 2

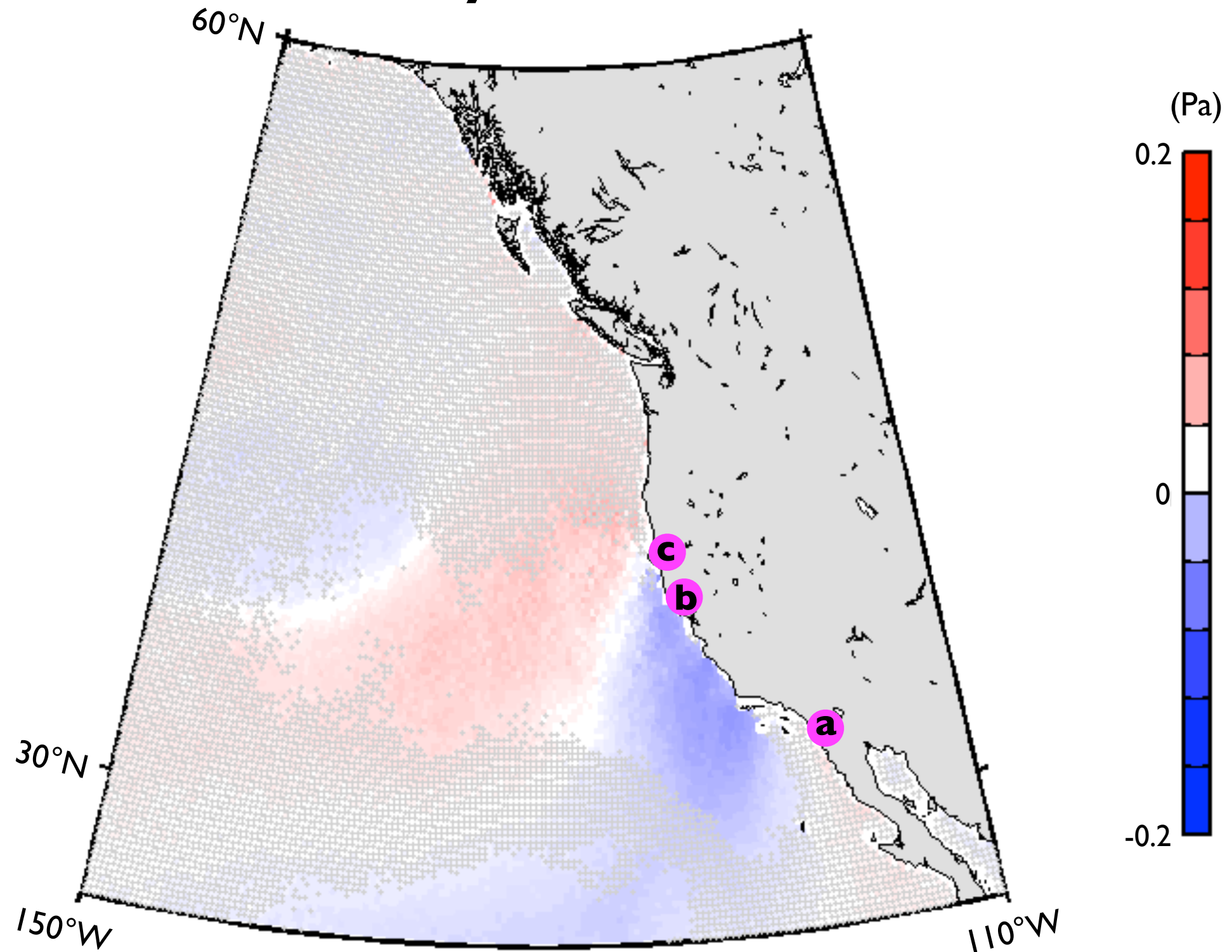


The relaxation propagates northward.

**wind stress anomaly
average over ~100 events**

along mean direction

day 3

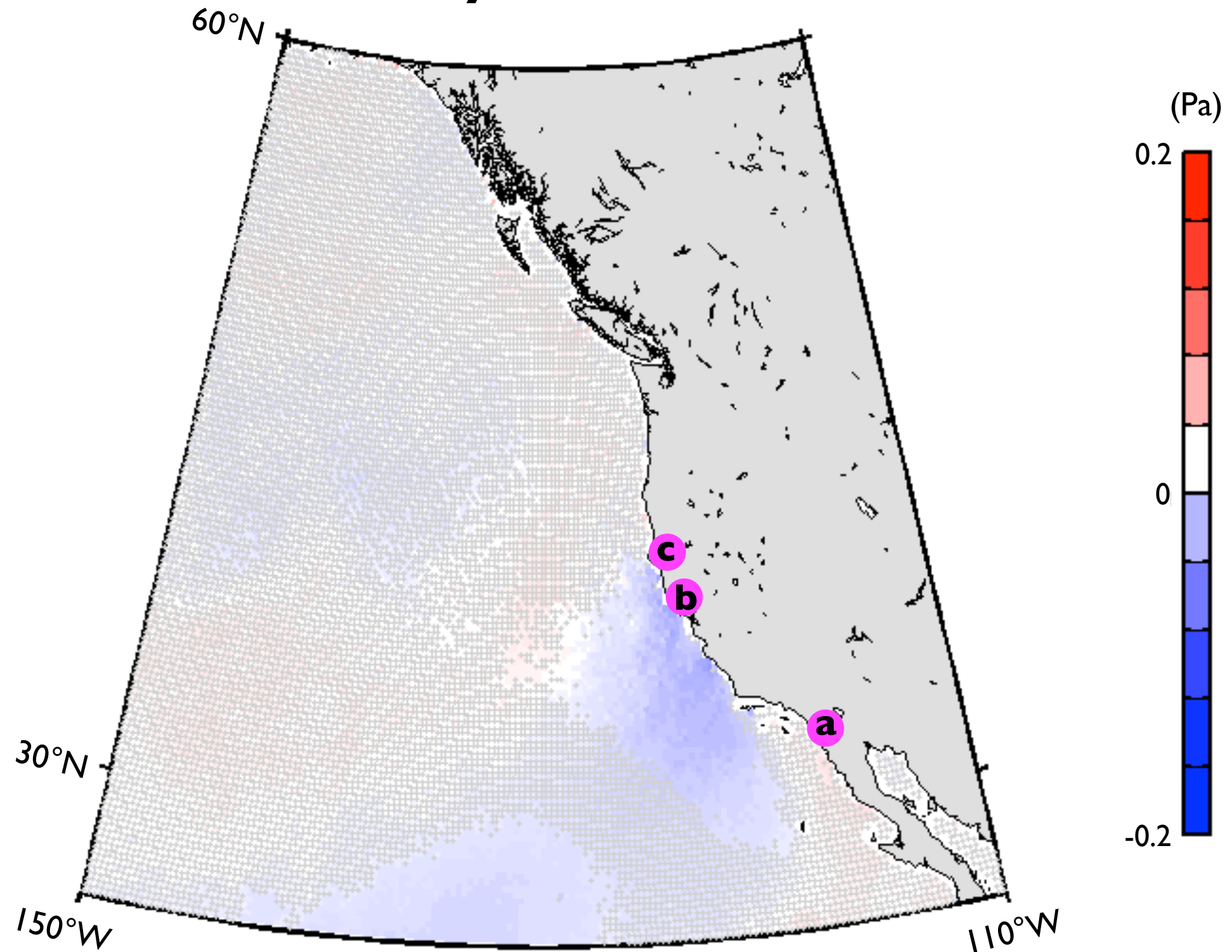


The relaxation propagates northward.

**wind stress anomaly
average over ~100 events**

along mean direction

day 4

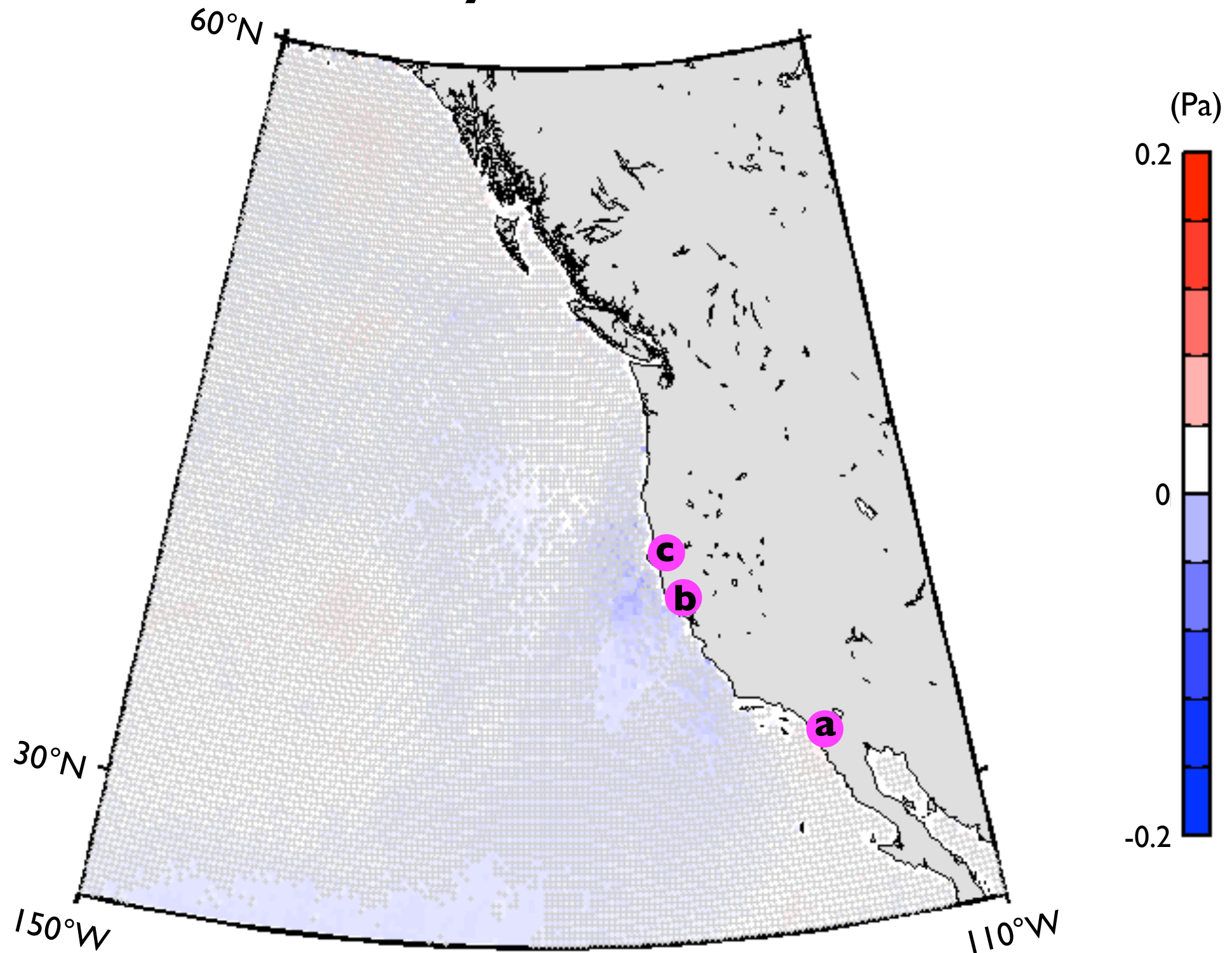


The relaxation propagates northward.

**wind stress anomaly
average over ~100 events**

along mean direction

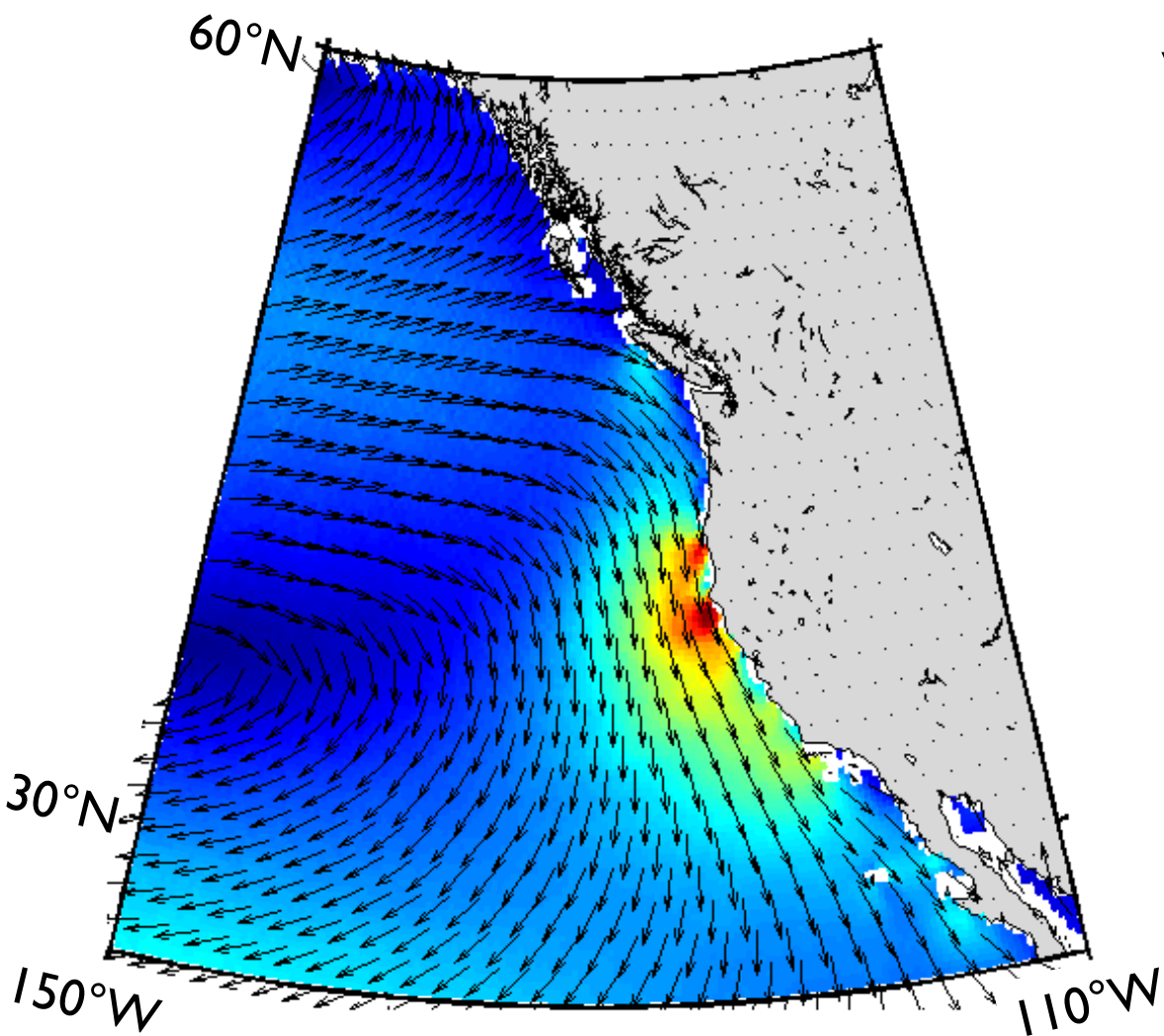
day 5



The average wind relaxation at Pt. Conception extends from the N. California border to Baja and ~500 km offshore.

mean wind stress

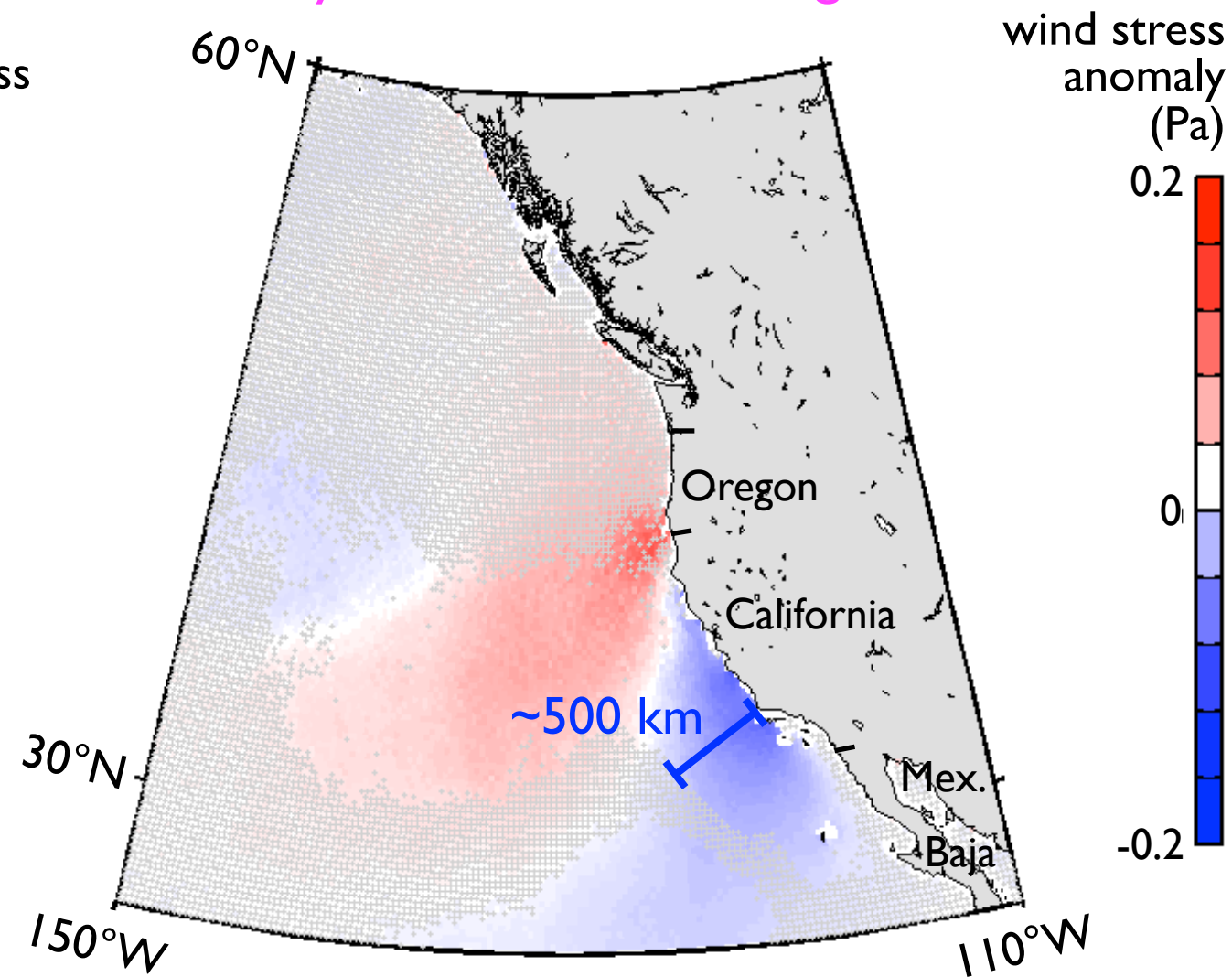
June-Sept



**wind stress anomaly
average over ~100 events**

along mean direction

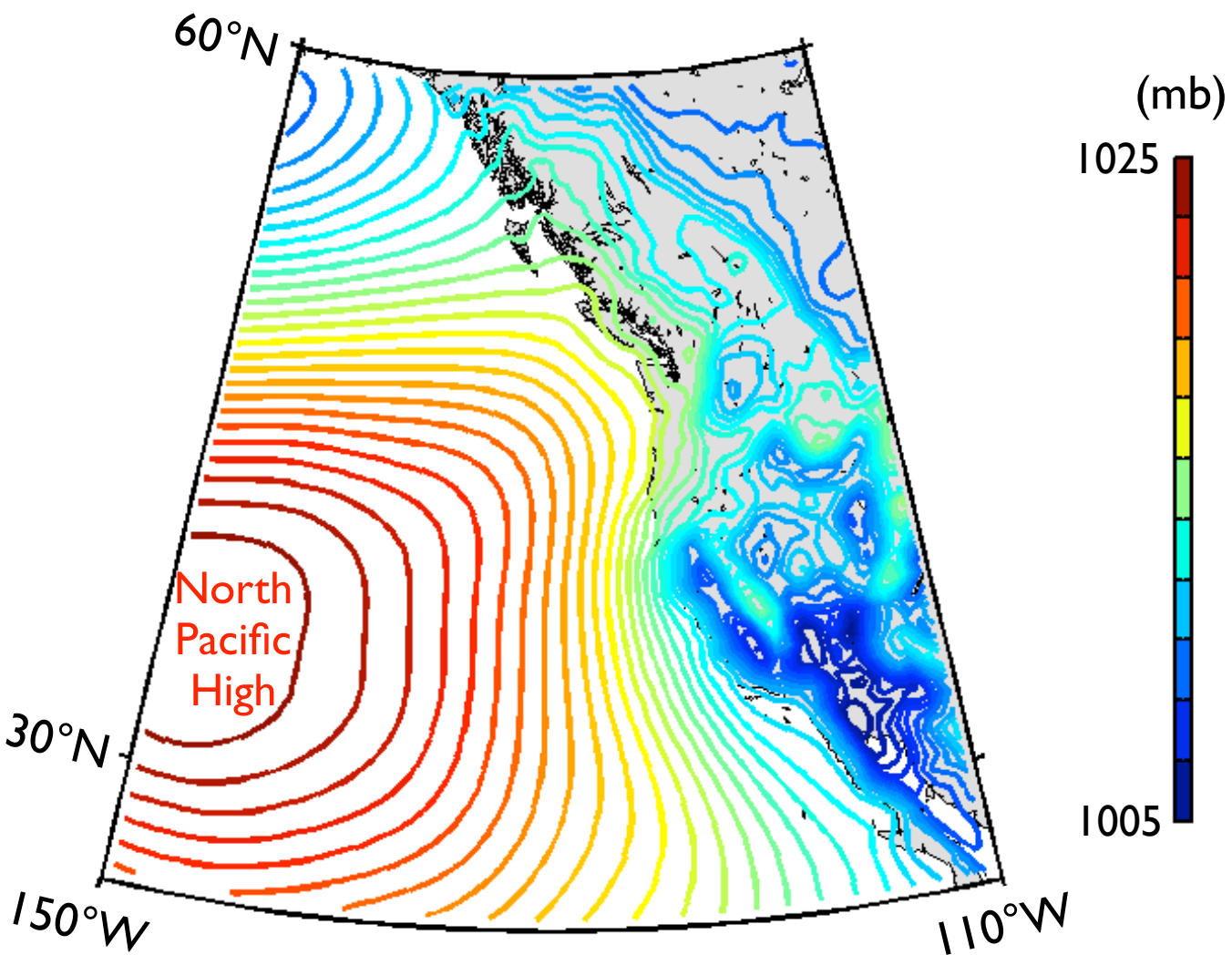
2 days after relaxation begins



The wind relaxations involve
a northeast extension of the North Pacific High.

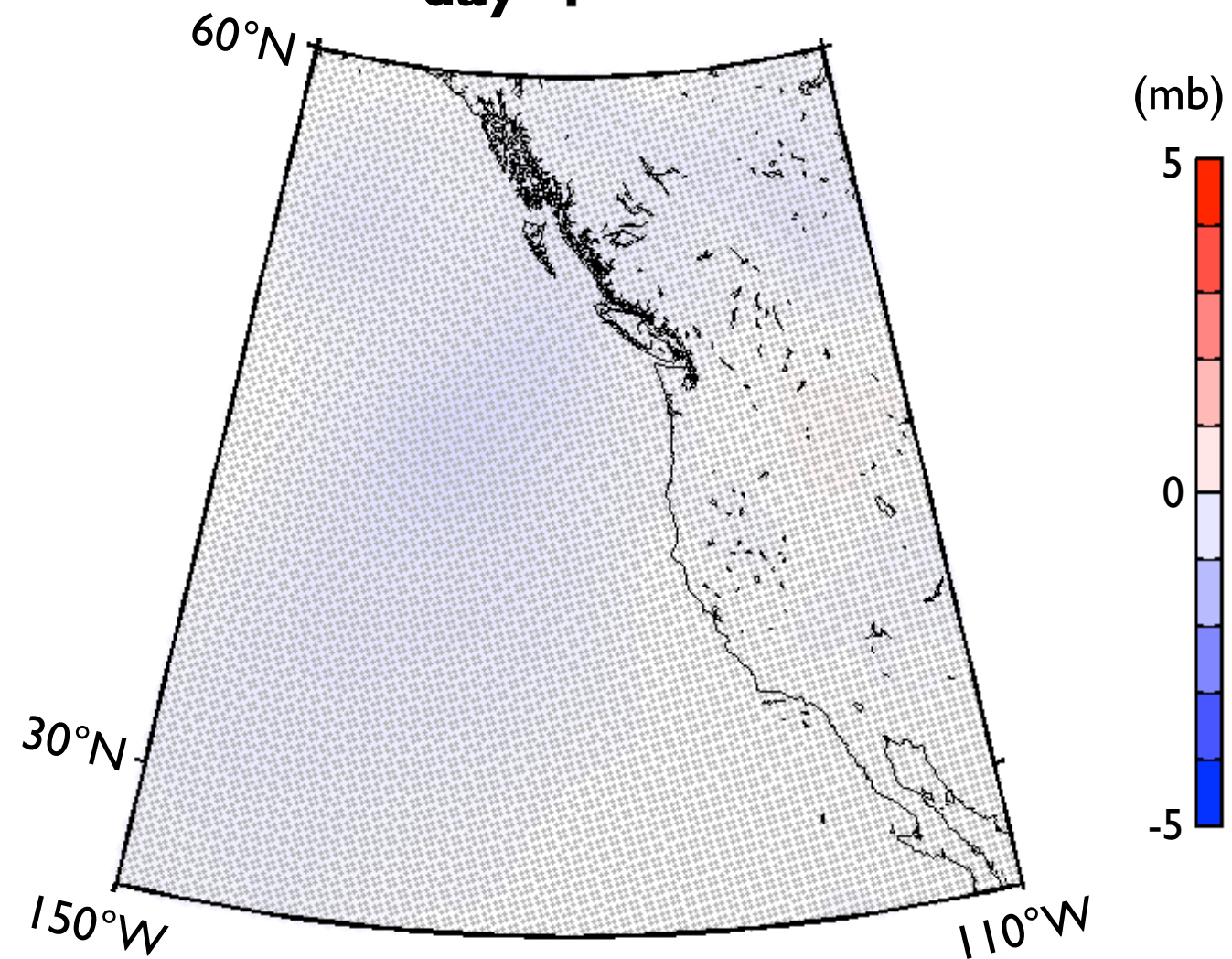
mean sea-level pressure

June-Sept



**sea-level pressure anomaly
average over ~100 events**

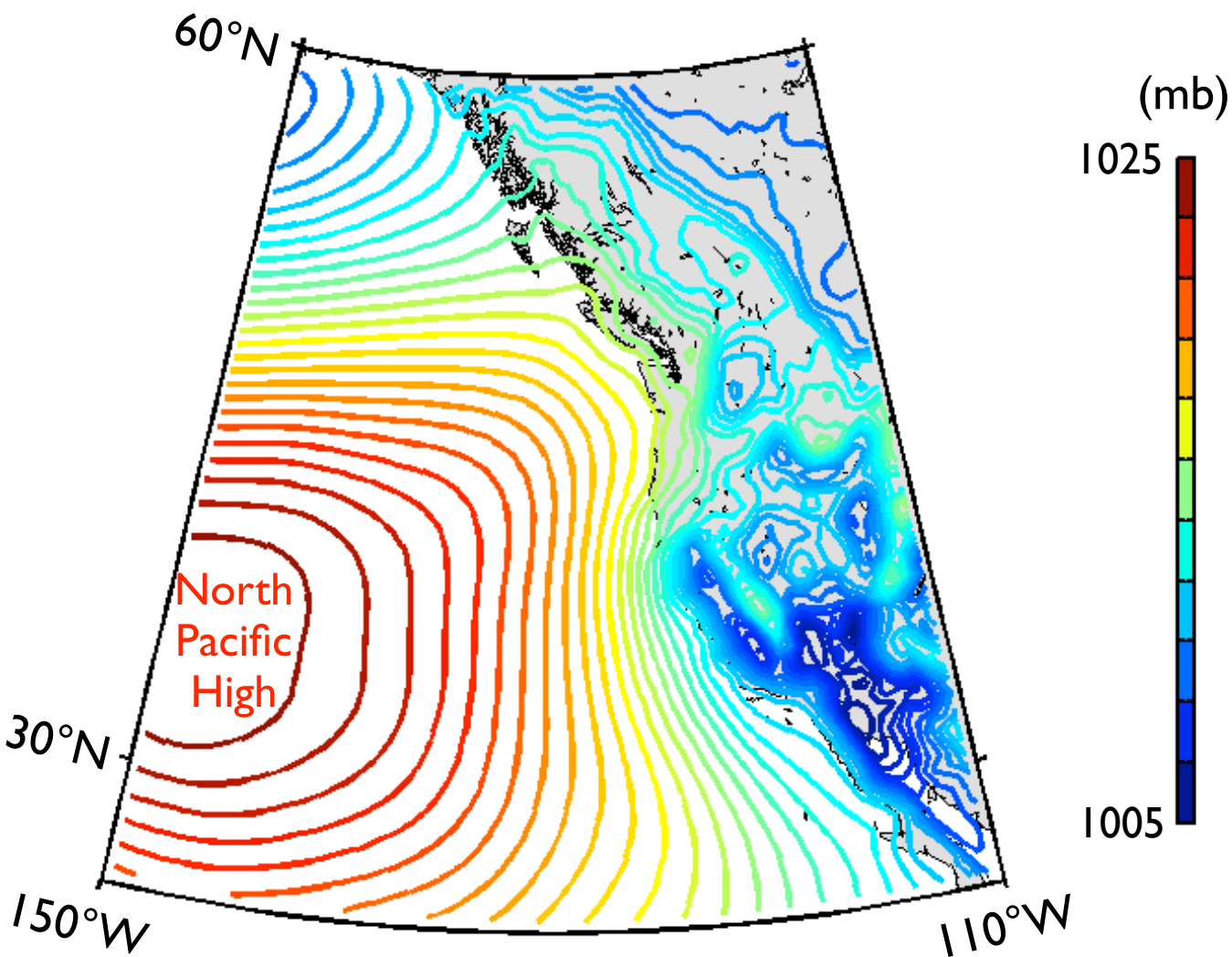
day -7



The wind relaxations involve
a northeast extension of the North Pacific High.

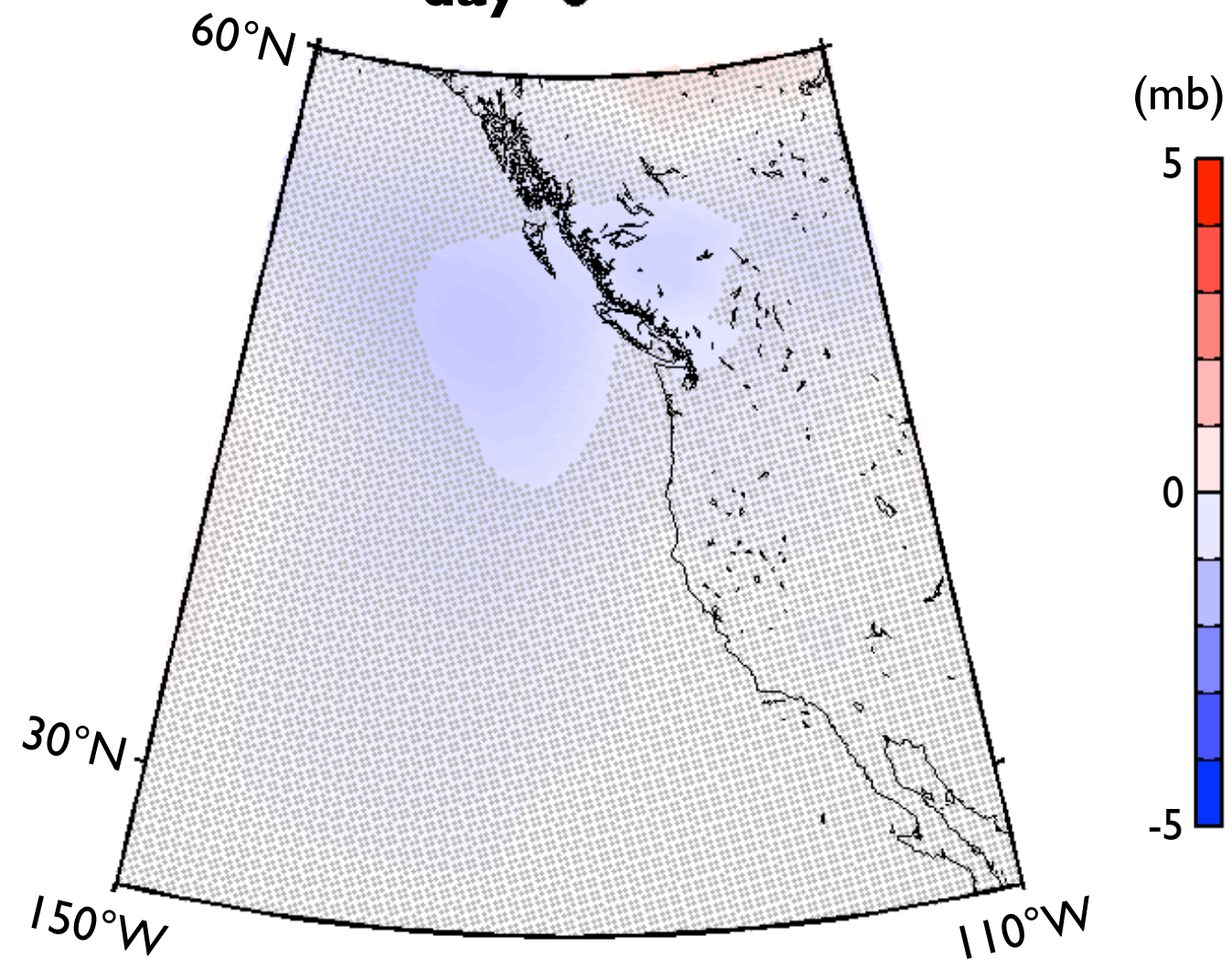
mean sea-level pressure

June-Sept



sea-level pressure anomaly
average over ~100 events

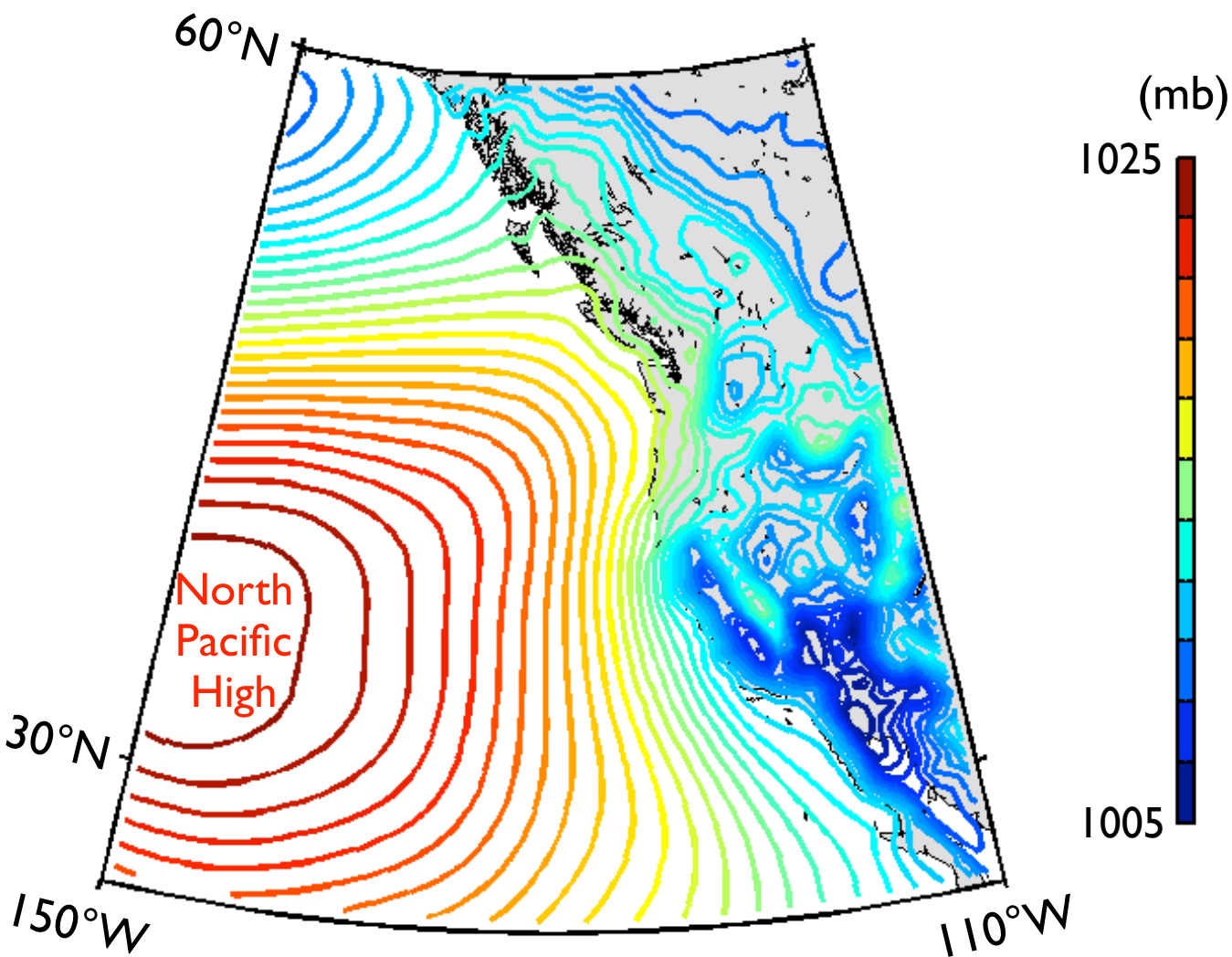
day -6



The wind relaxations involve
a northeast extension of the North Pacific High.

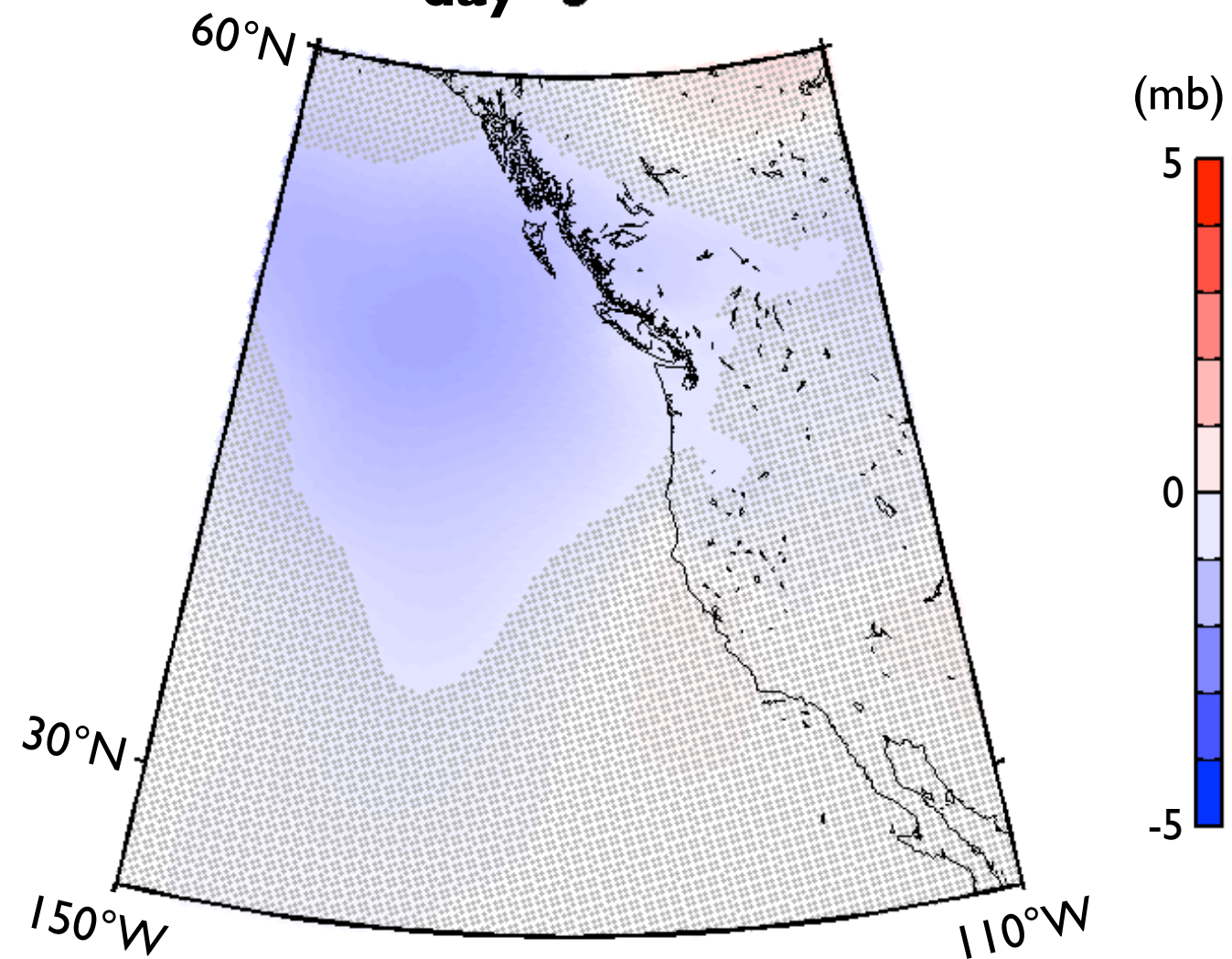
mean sea-level pressure

June-Sept



**sea-level pressure anomaly
average over ~100 events**

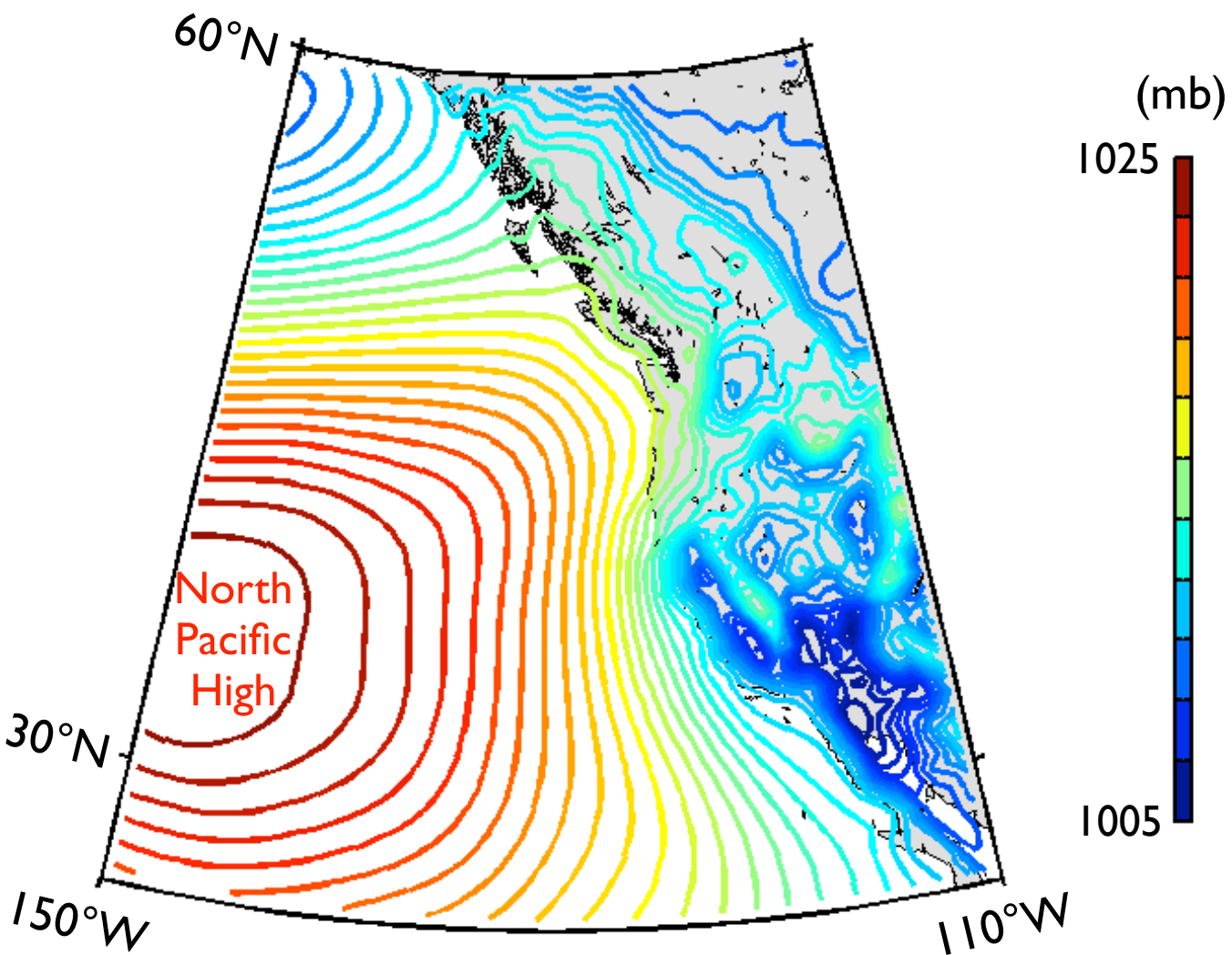
day -5



The wind relaxations involve
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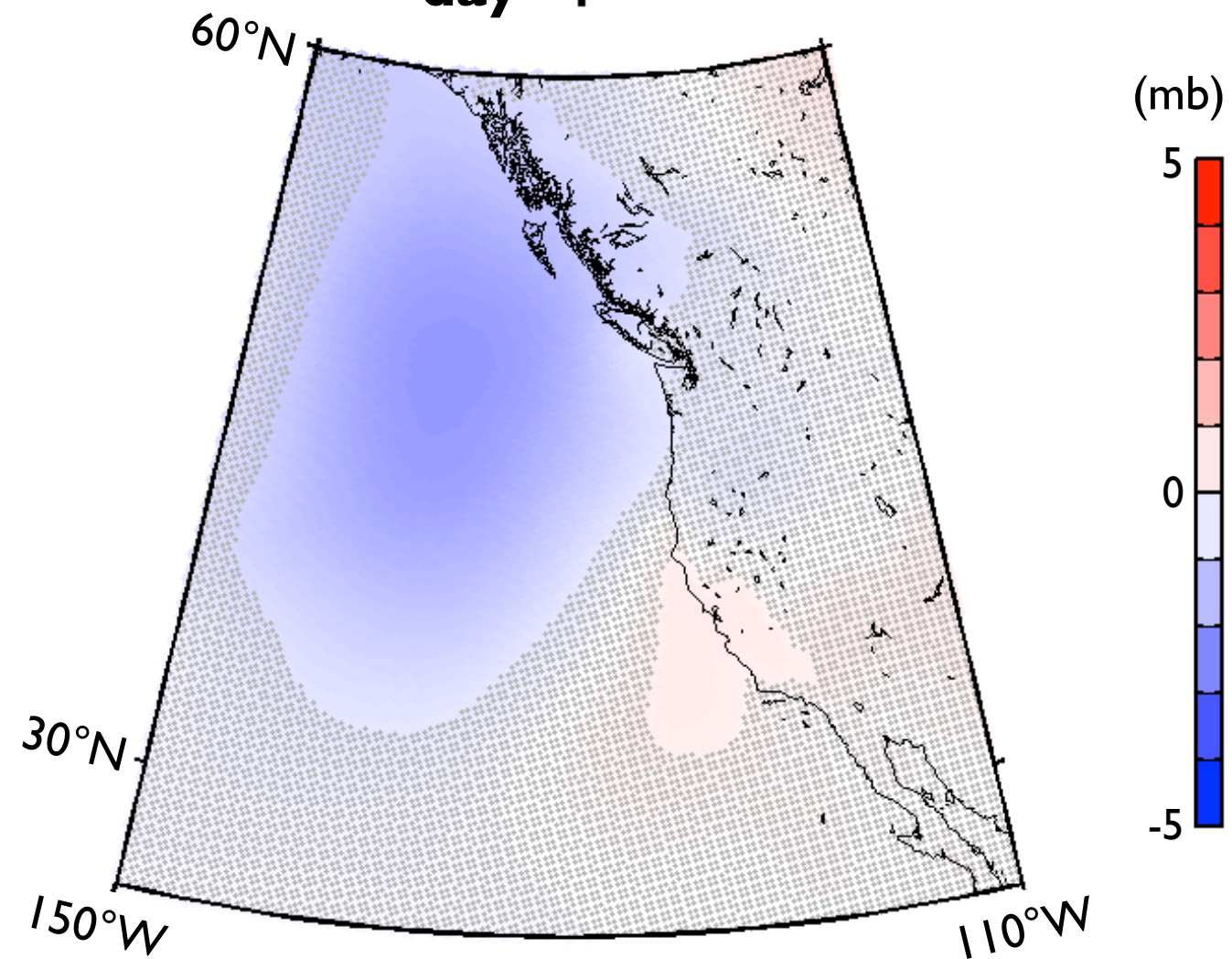
mean sea-level pressure

June-Sept



**sea-level pressure anomaly
average over ~100 events**

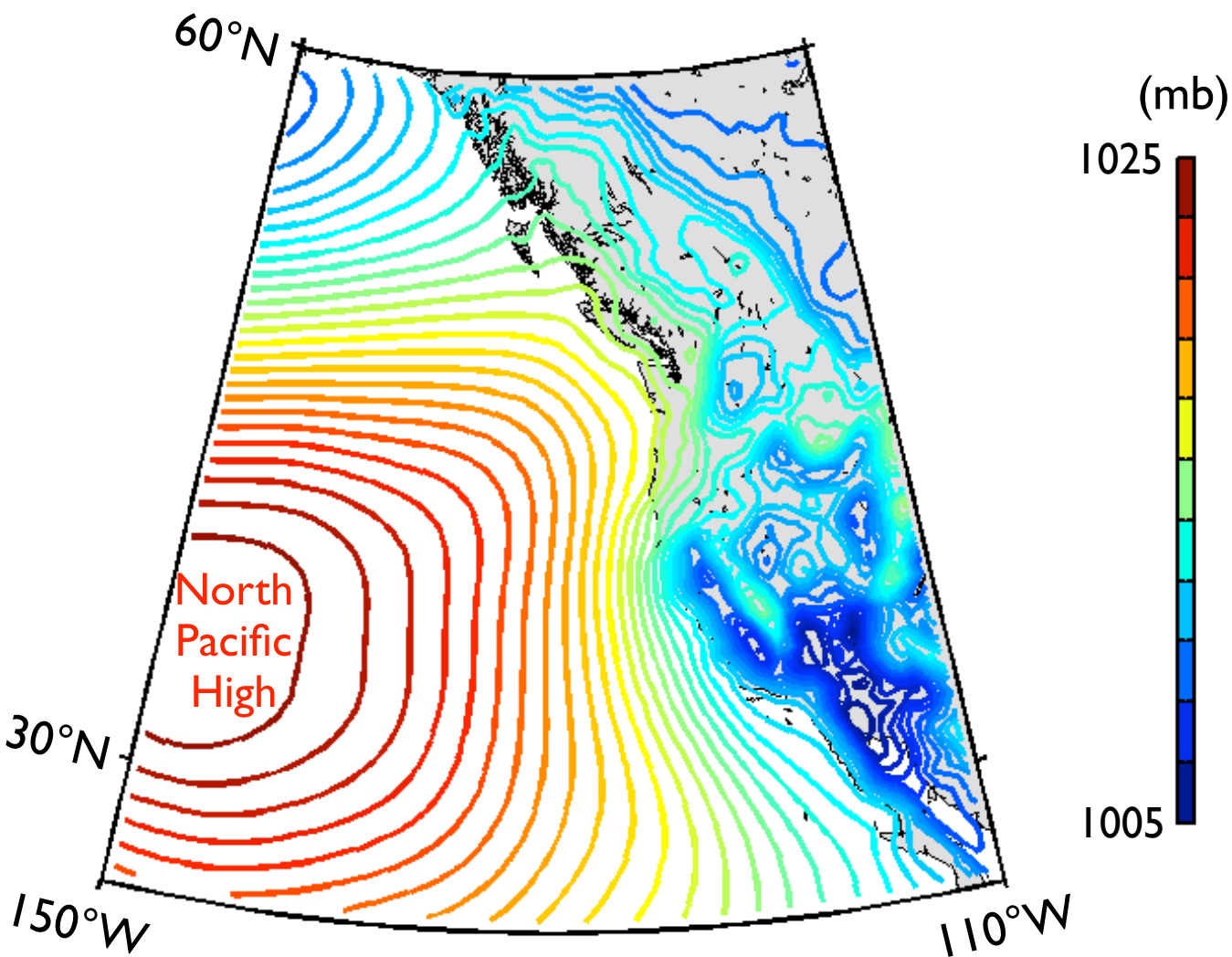
day -4



The wind relaxations involve
a northeast extension of the North Pacific High.

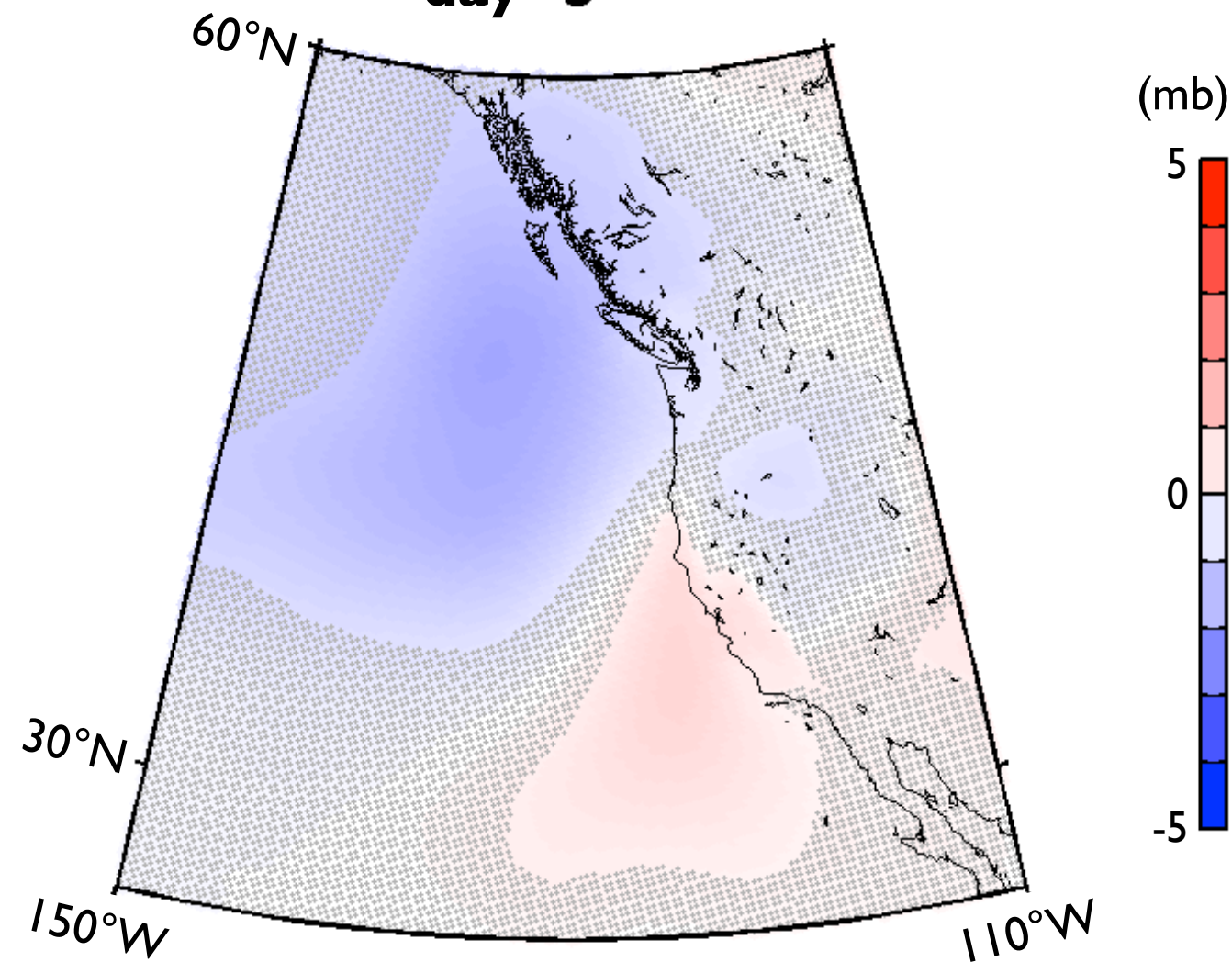
mean sea-level pressure

June-Sept



**sea-level pressure anomaly
average over ~100 events**

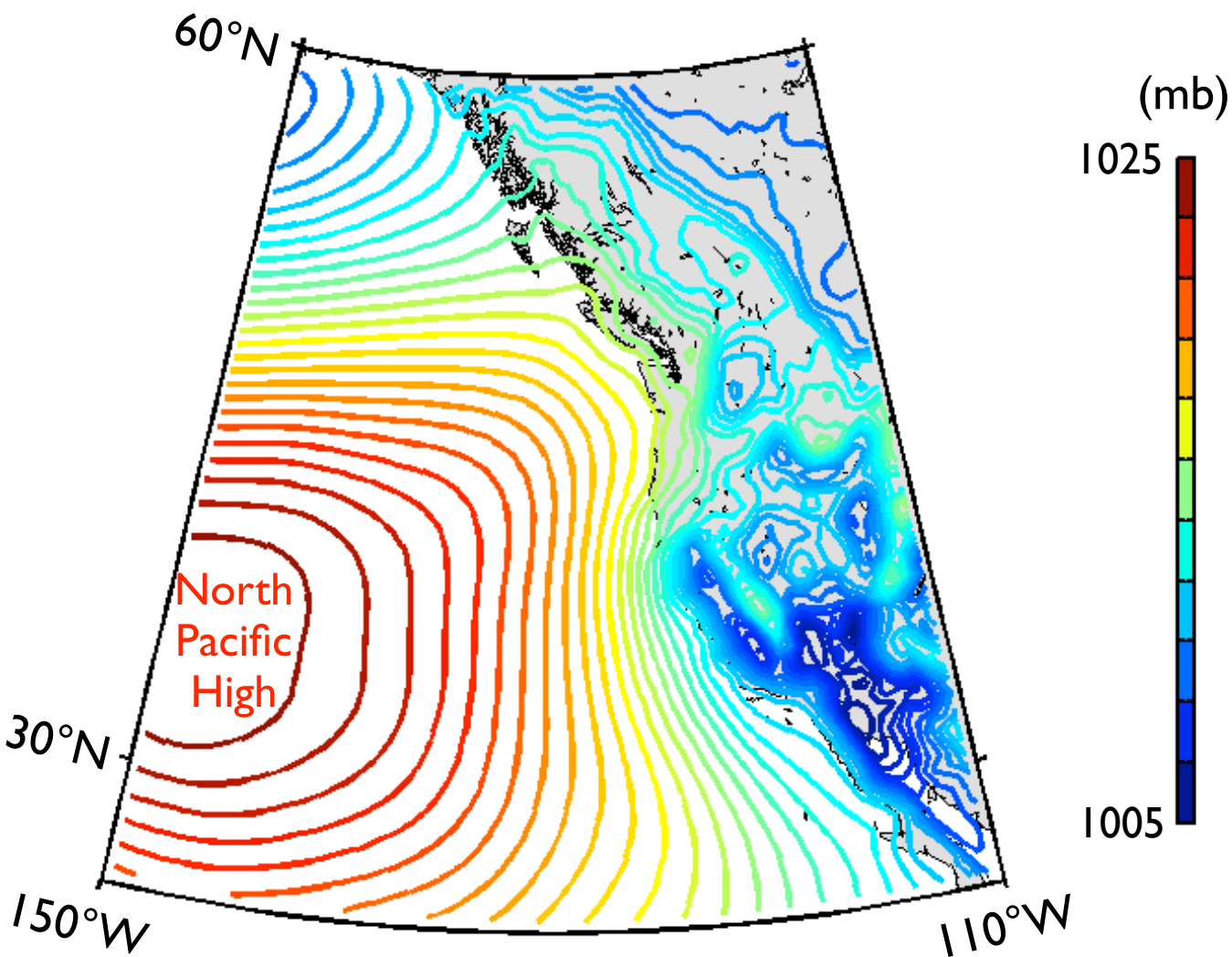
day -3



The wind relaxations involve
a northeast extension of the North Pacific High.

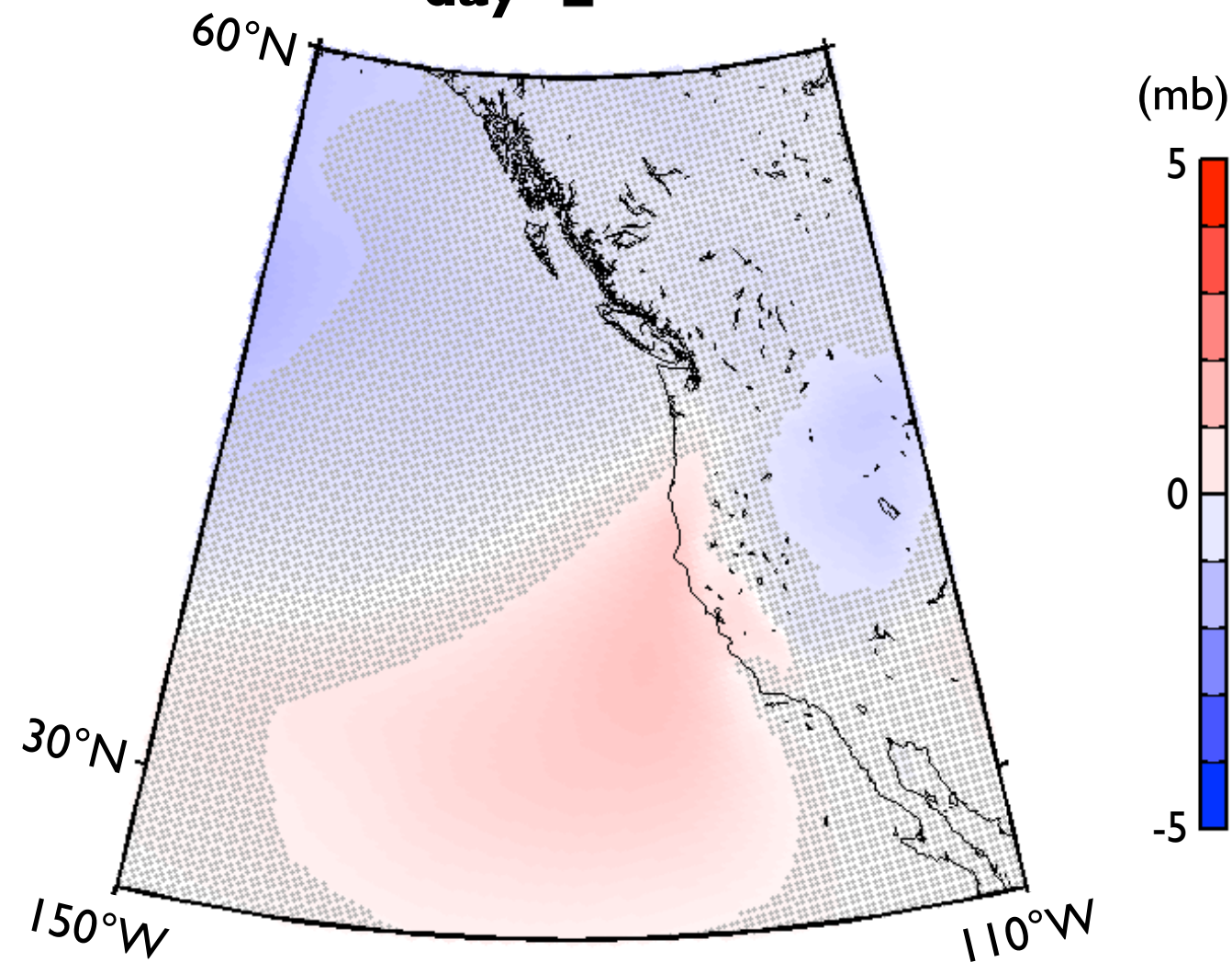
mean sea-level pressure

June-Sept



**sea-level pressure anomaly
average over ~100 events**

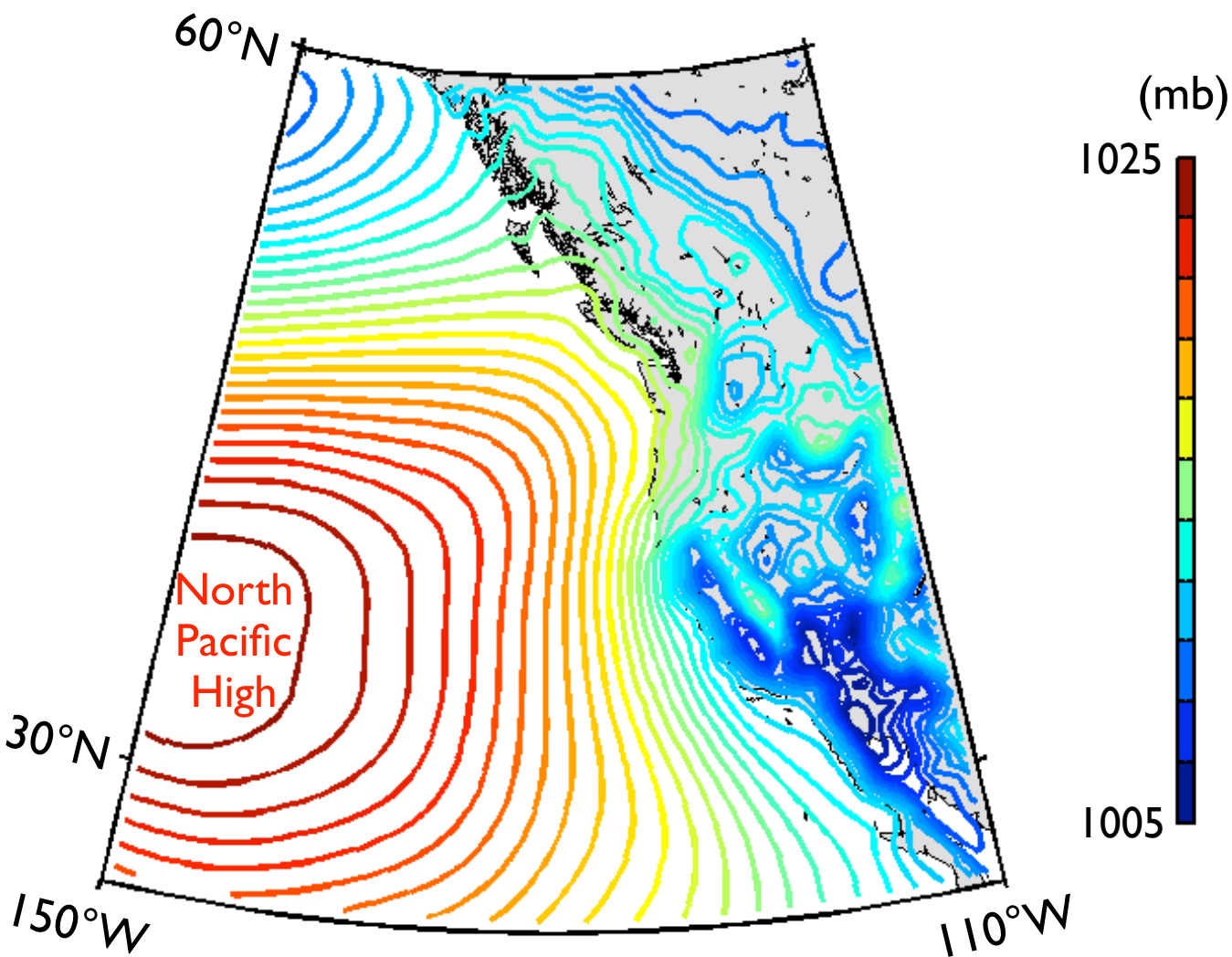
day -2



The wind relaxations involve
a northeast extension of the North Pacific High.

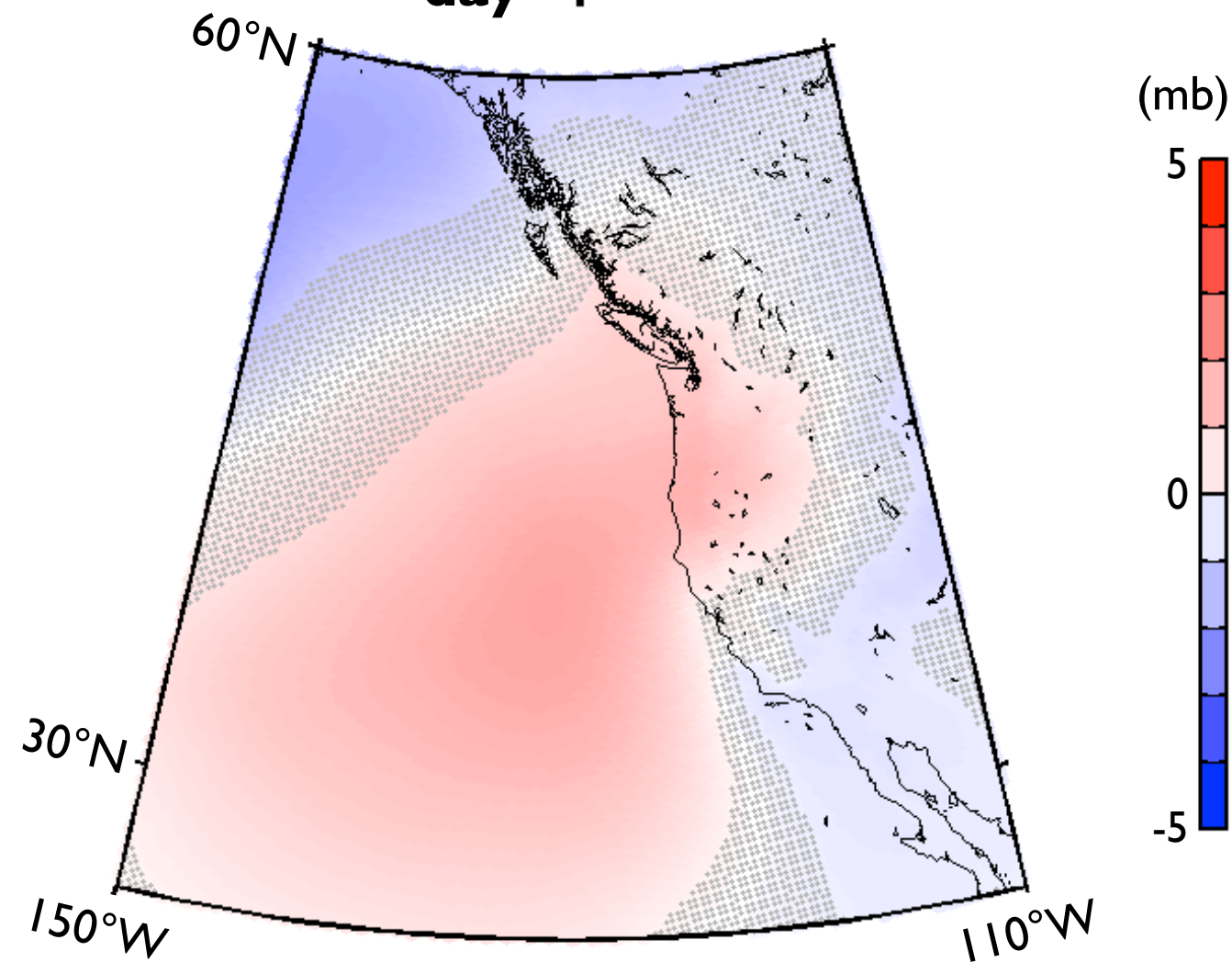
mean sea-level pressure

June-Sept



**sea-level pressure anomaly
average over ~100 events**

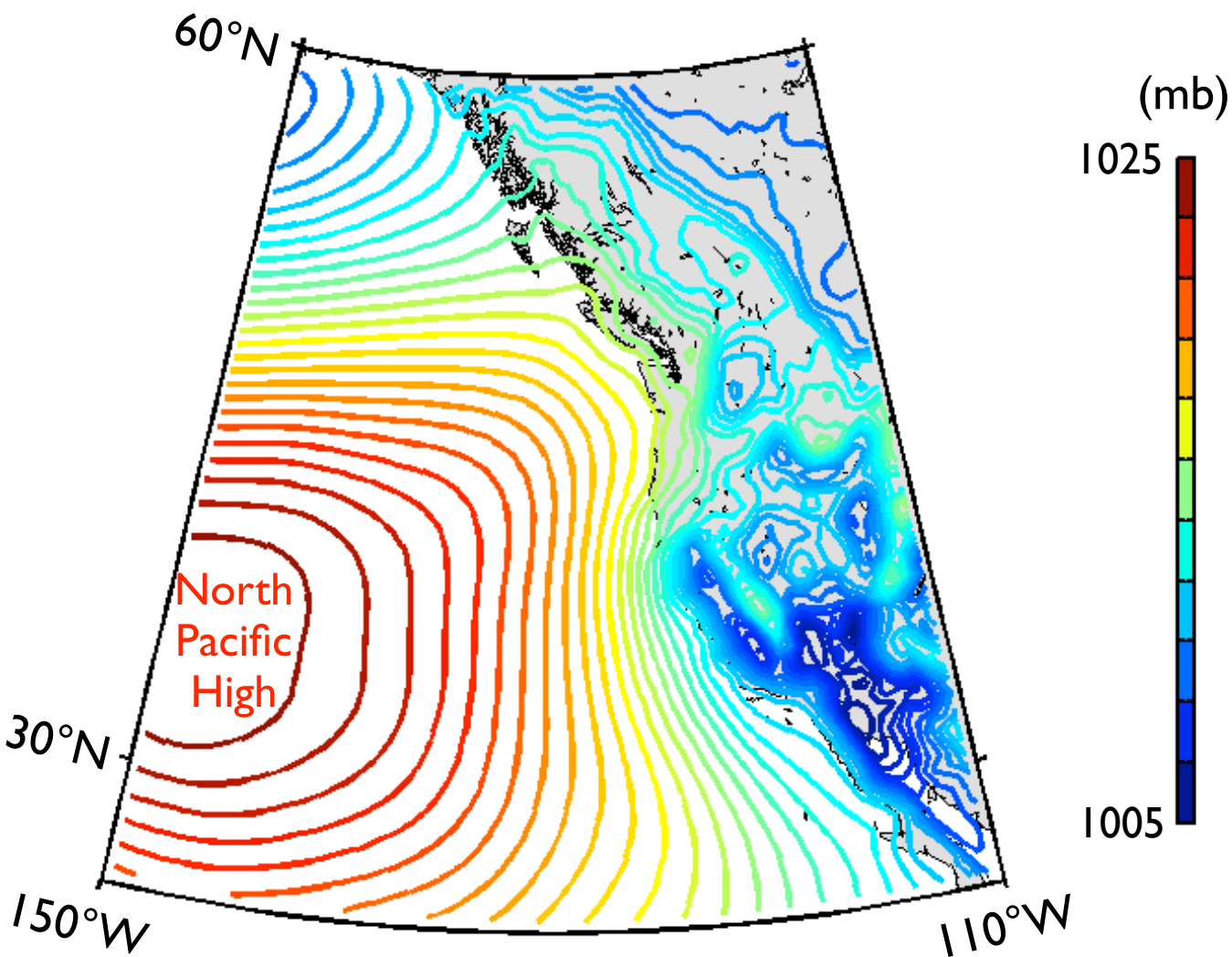
day -1



The wind relaxations involve
a northeast extension of the North Pacific High.

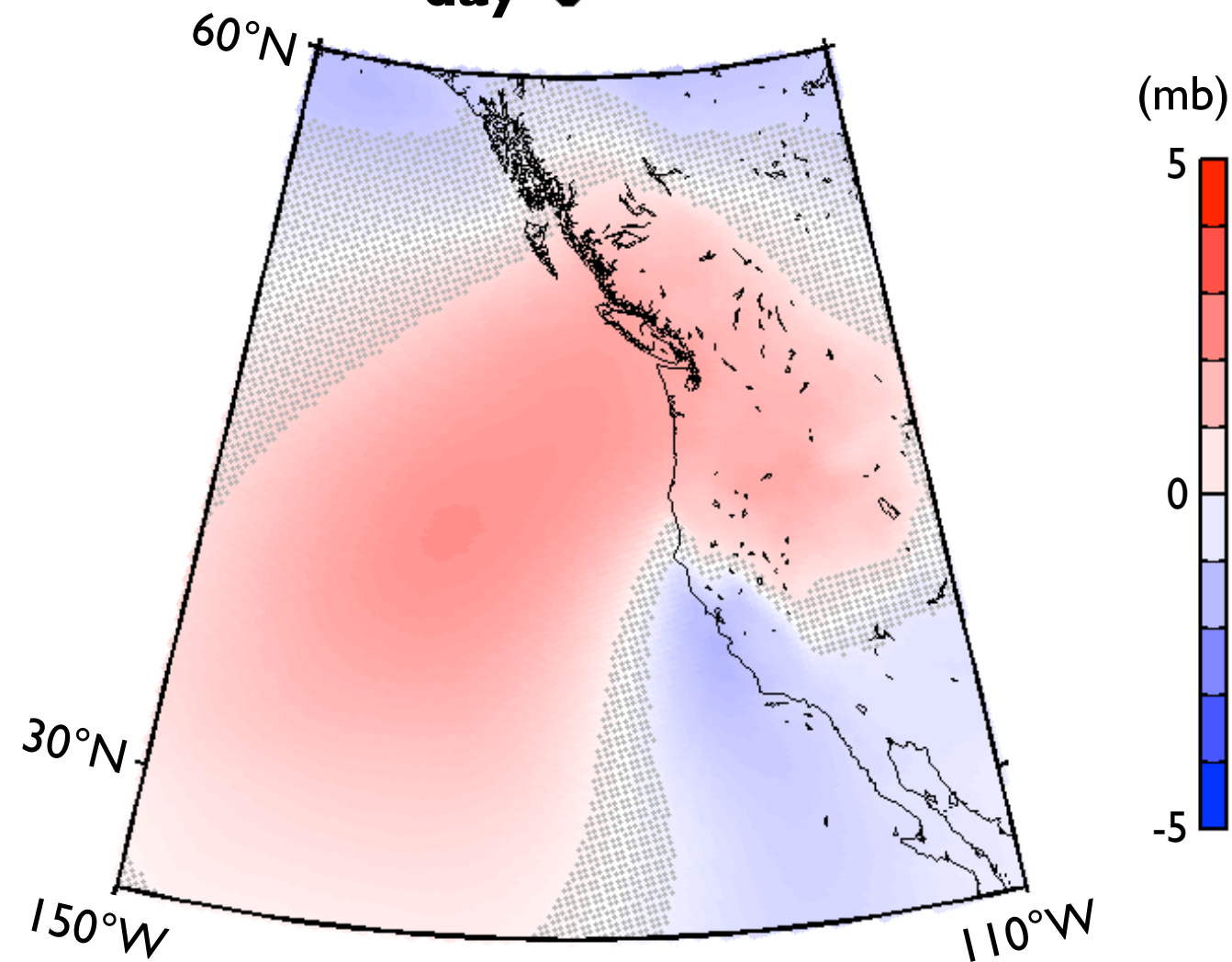
mean sea-level pressure

June-Sept



**sea-level pressure anomaly
average over ~100 events**

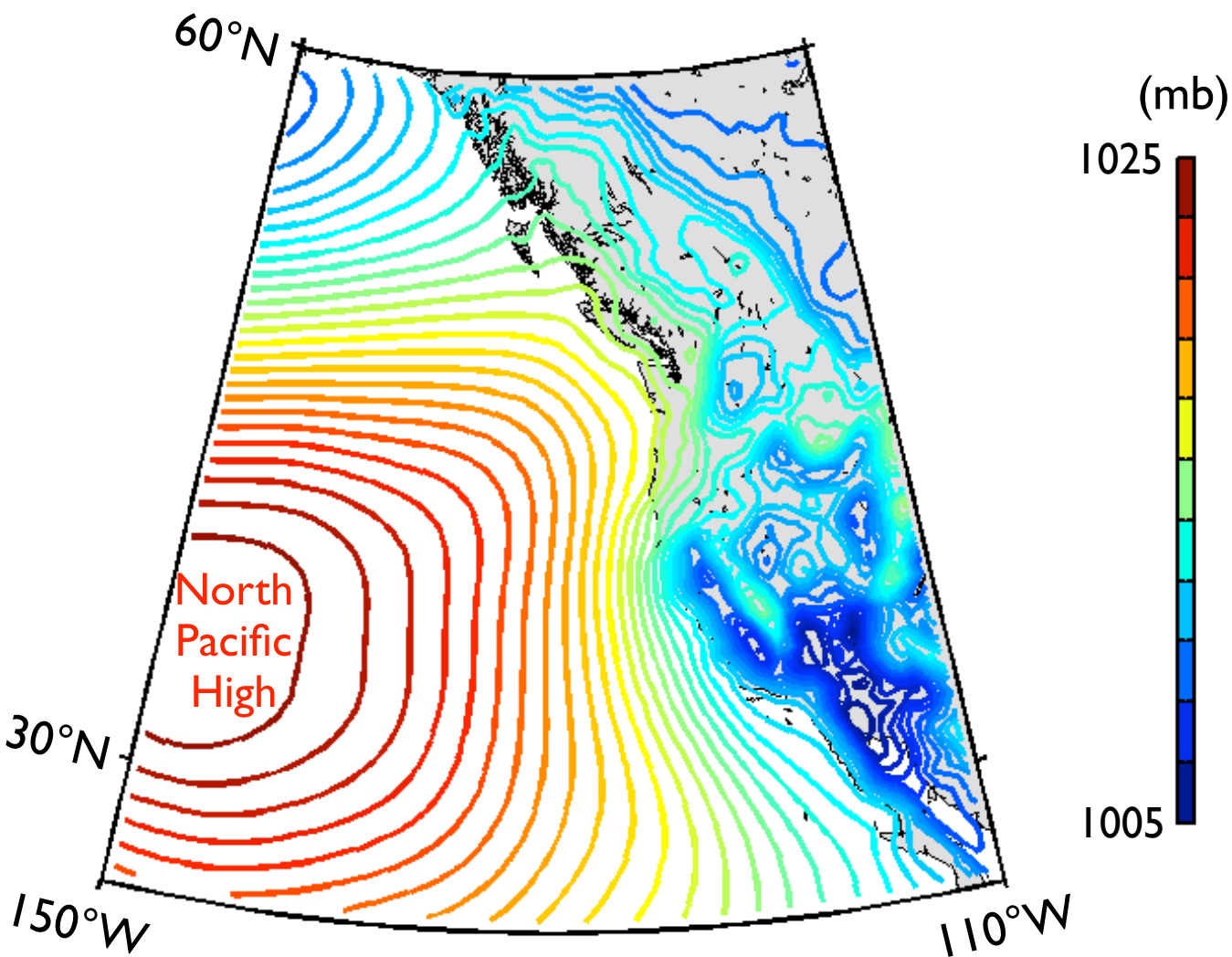
day 0



The wind relaxations involve
a northeast extension of the North Pacific High.

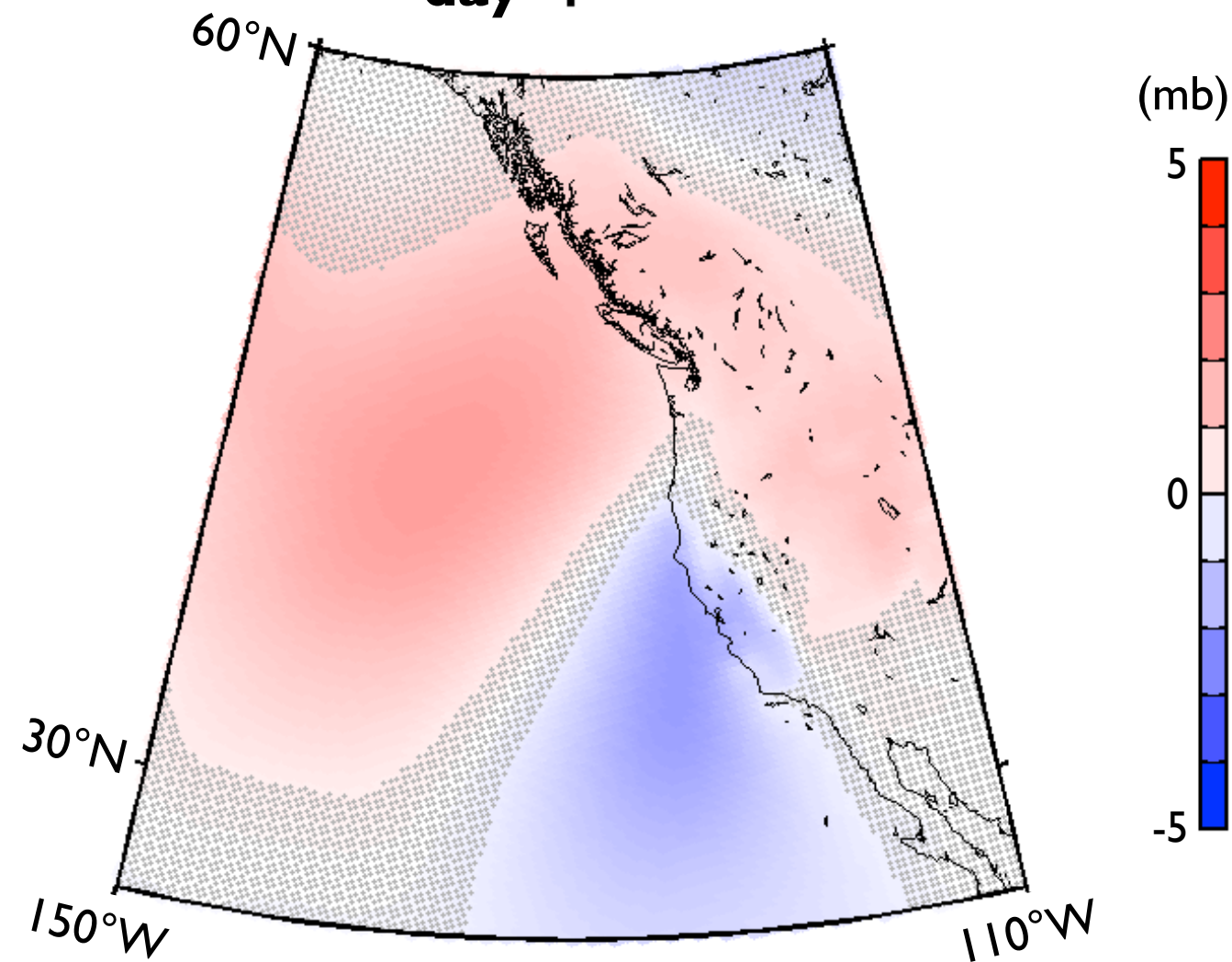
mean sea-level pressure

June-Sept



**sea-level pressure anomaly
average over ~100 events**

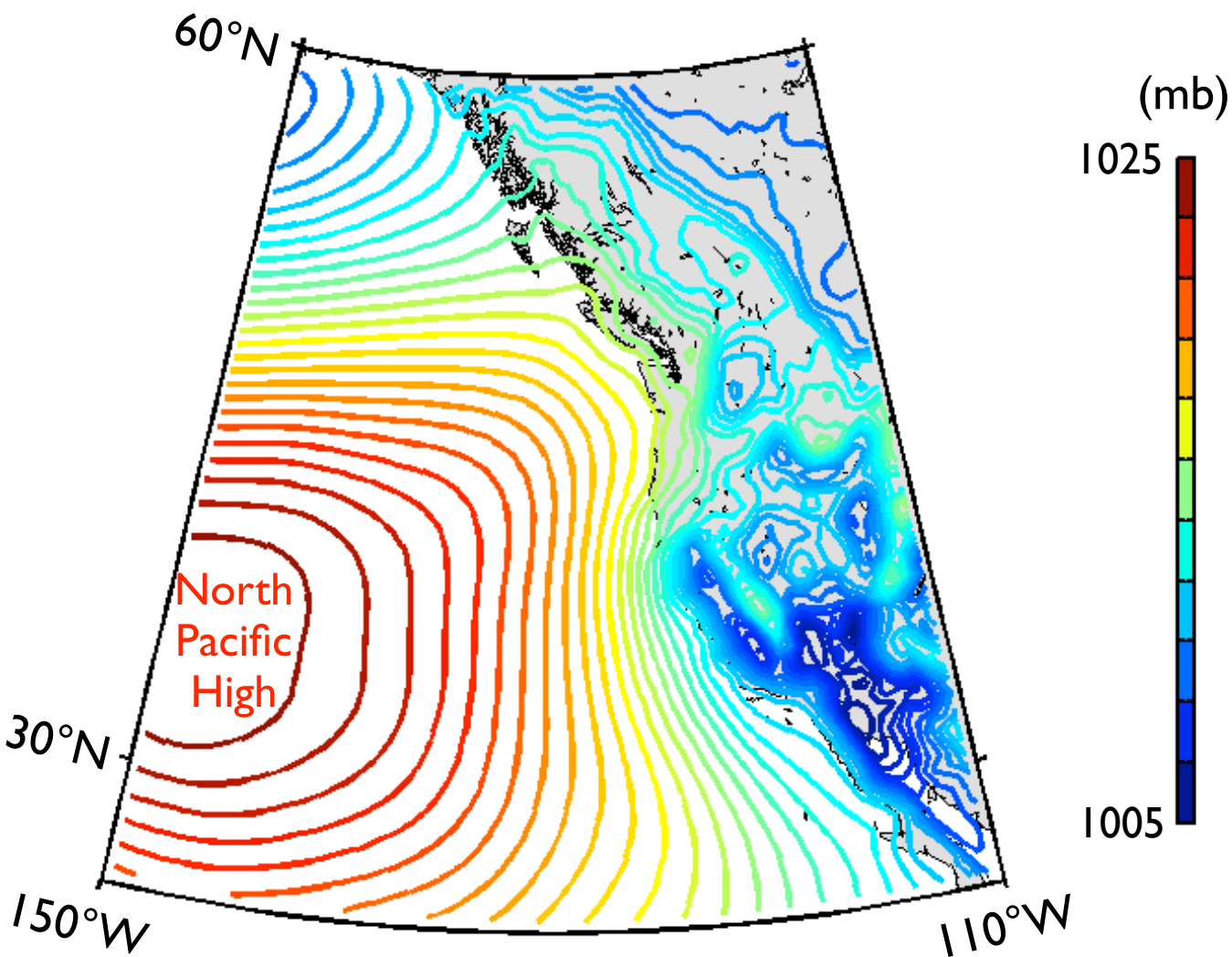
day 1



The wind relaxations involve
a northeast extension of the North Pacific High.

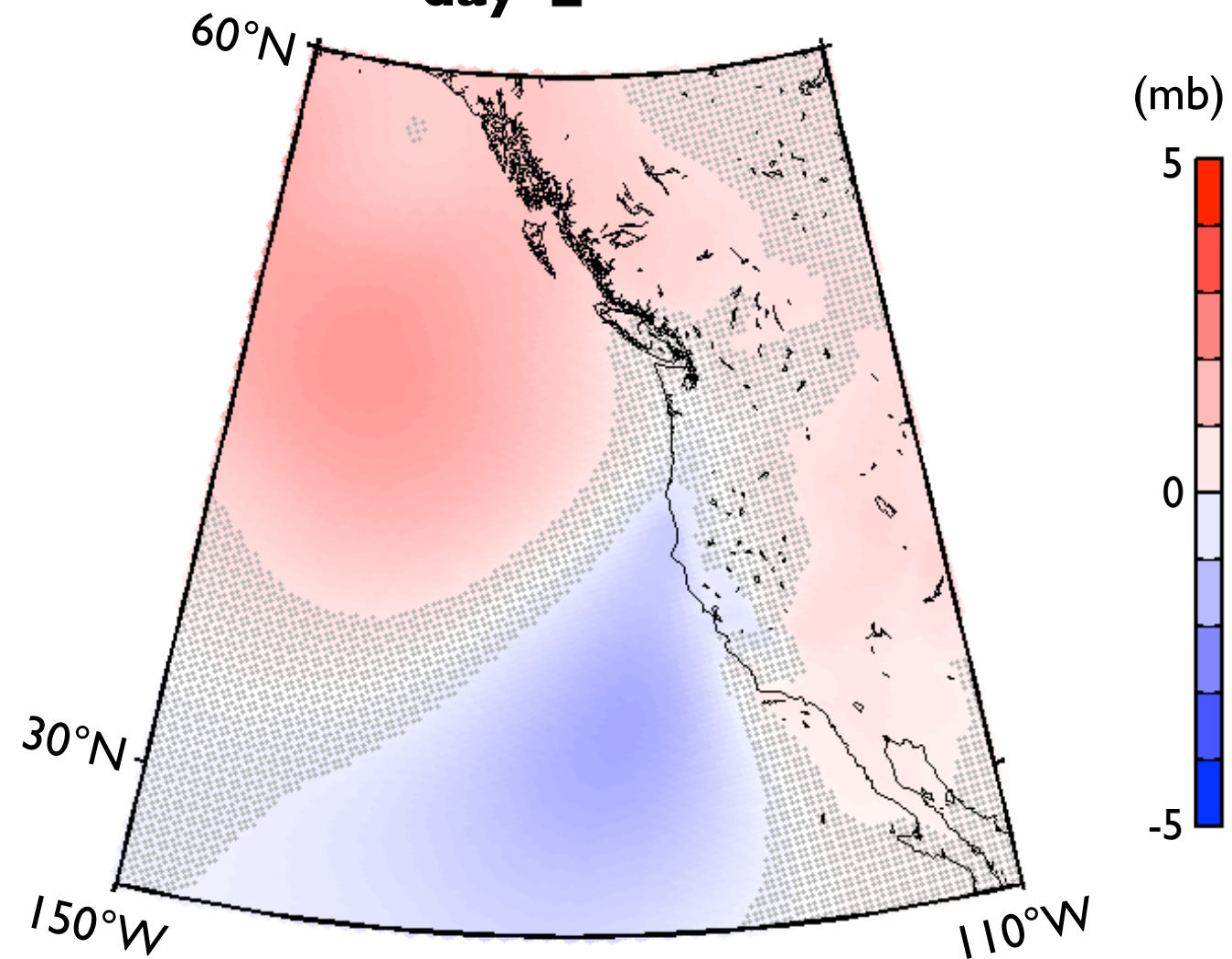
mean sea-level pressure

June-Sept



**sea-level pressure anomaly
average over ~100 events**

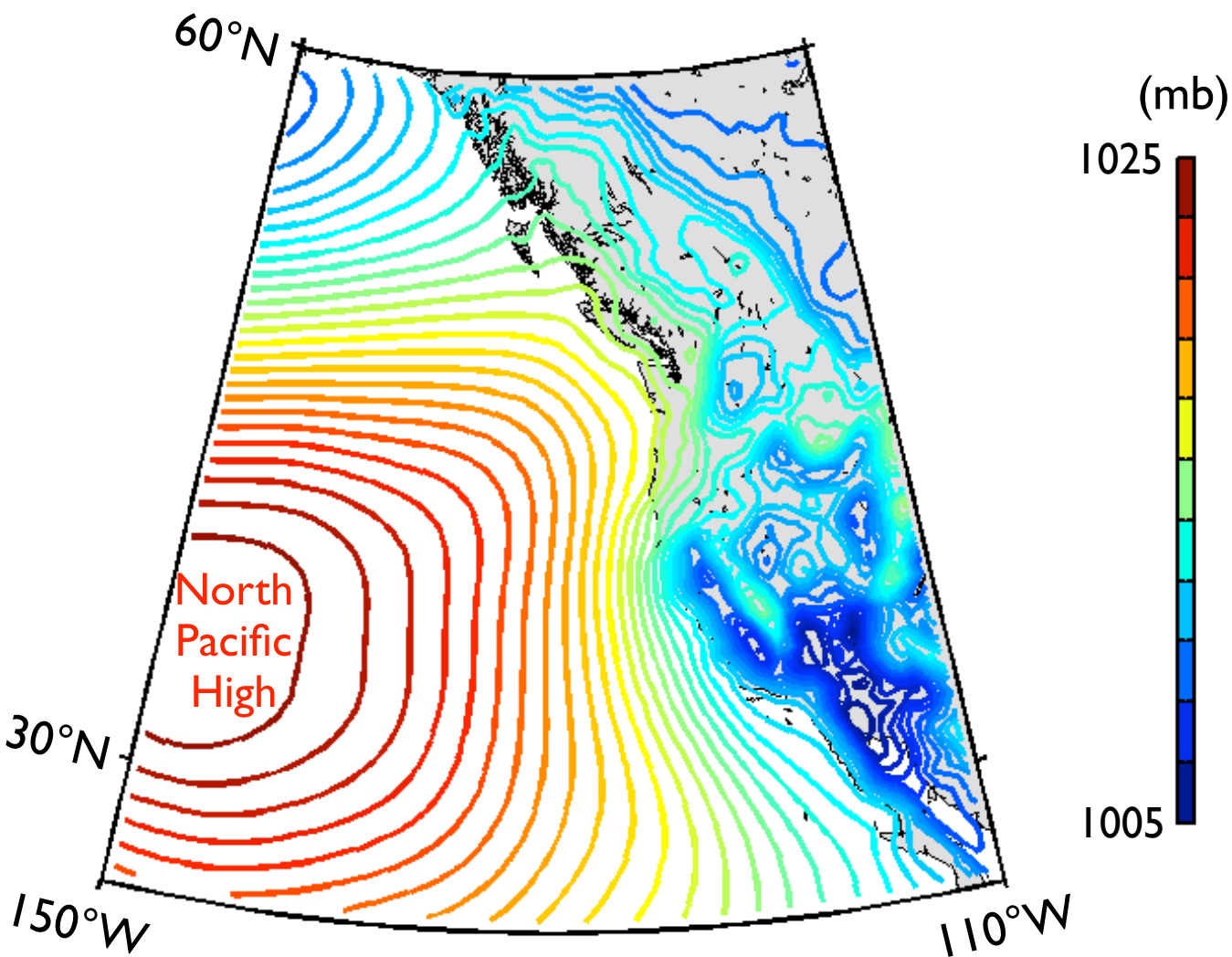
day 2



The wind relaxations involve
a northeast extension of the North Pacific High.

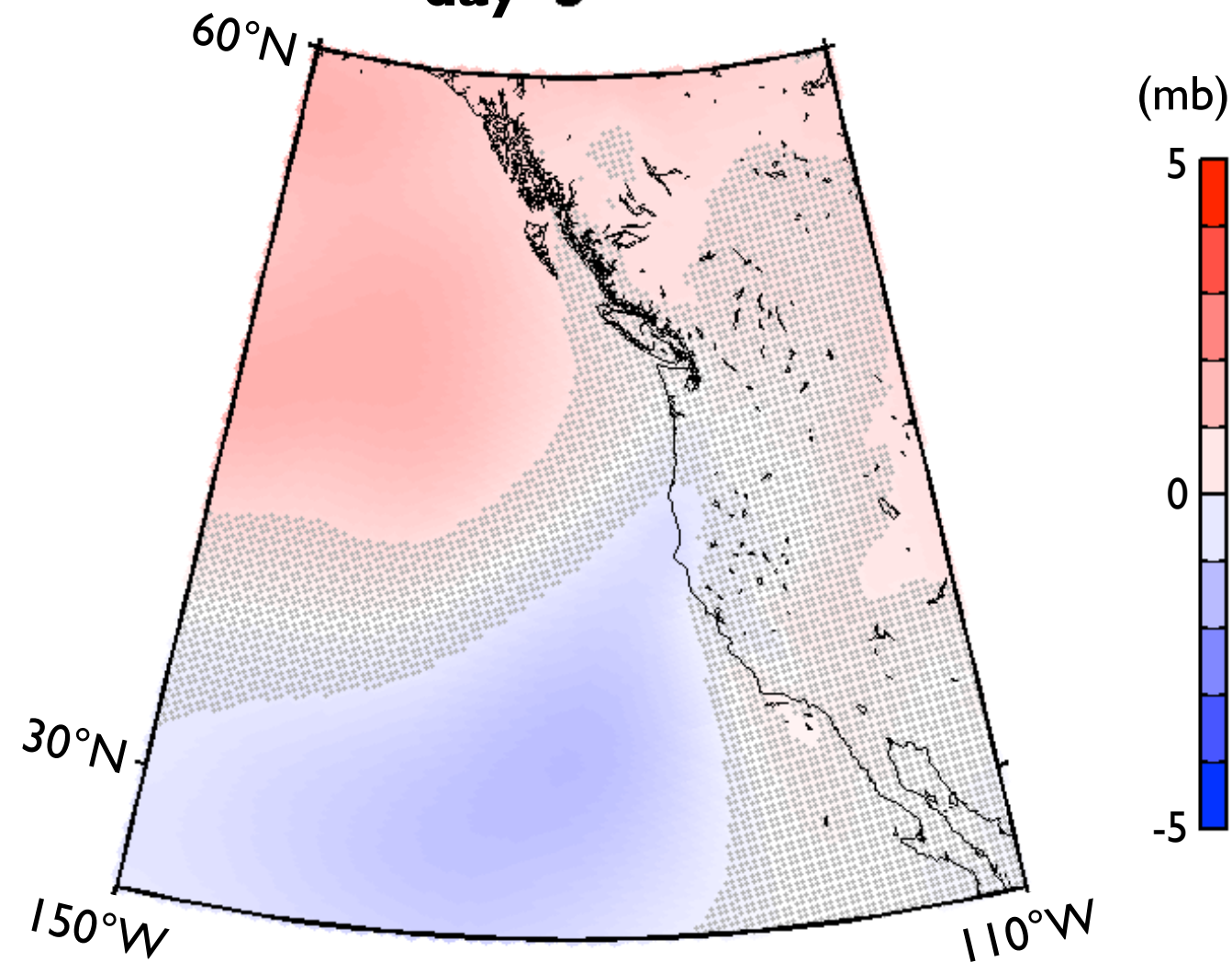
mean sea-level pressure

June-Sept



**sea-level pressure anomaly
average over ~100 events**

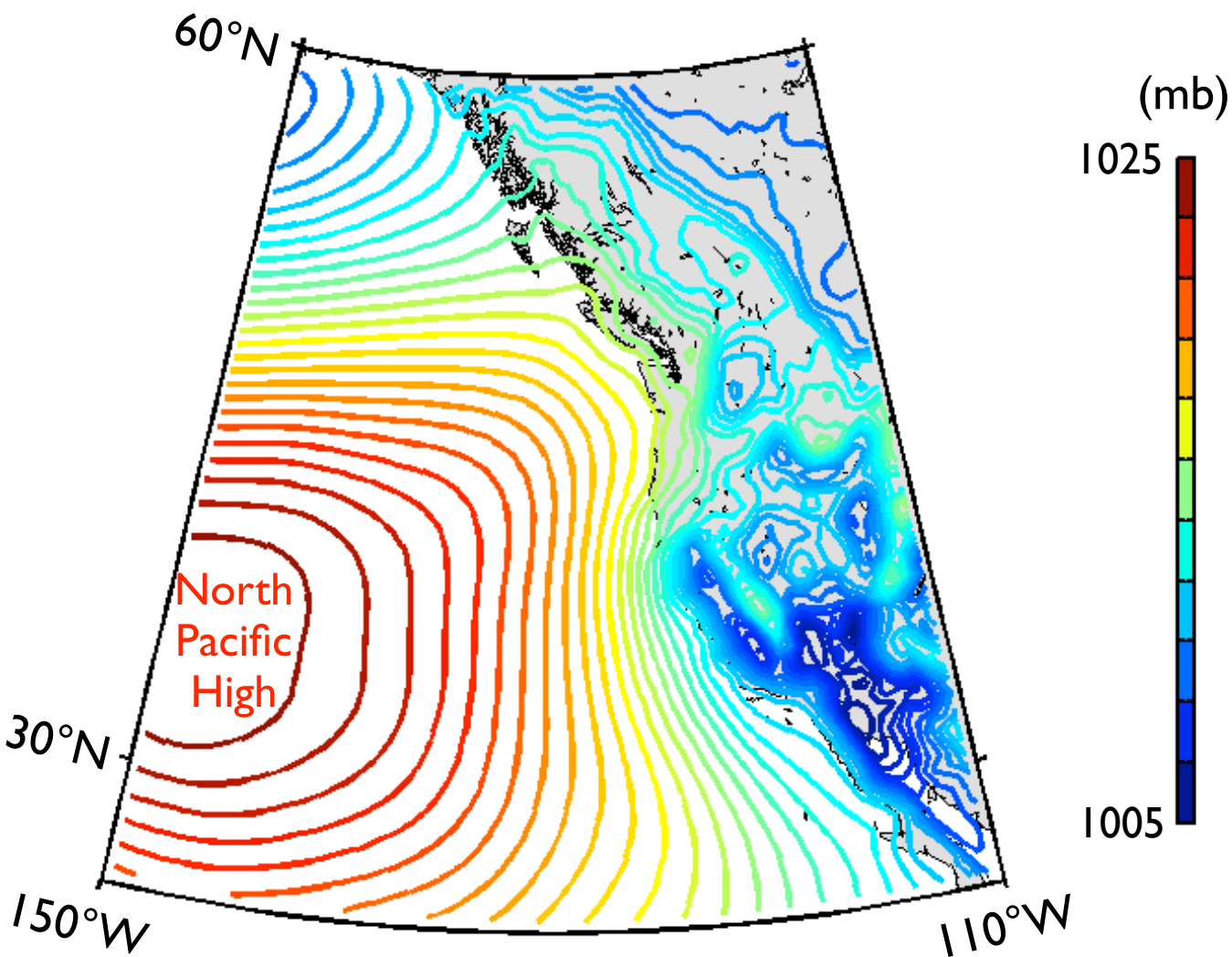
day 3



The wind relaxations involve
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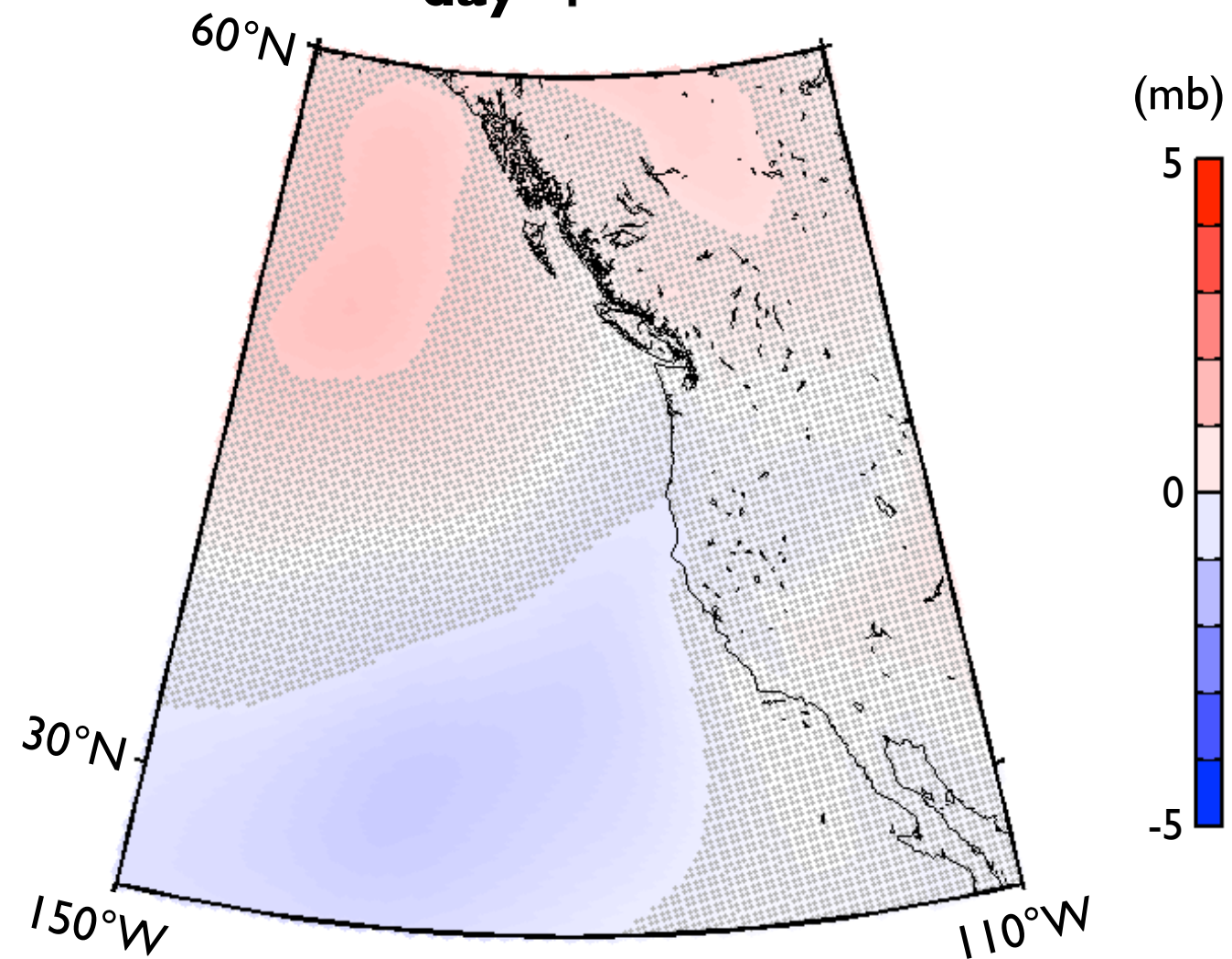
mean sea-level pressure

June-Sept



**sea-level pressure anomaly
average over ~100 events**

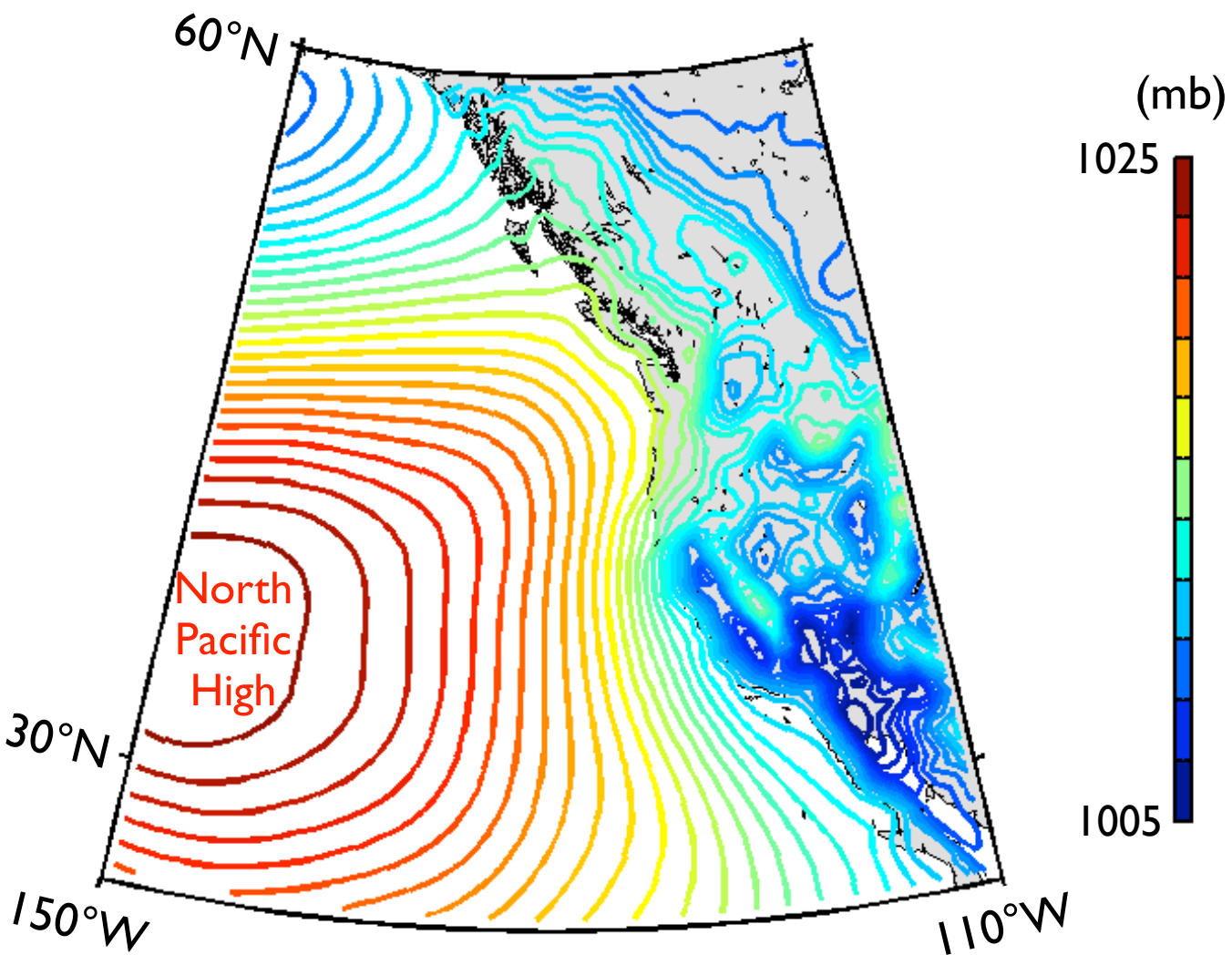
day 4



The wind relaxations involve
a northeast extension of the North Pacific High.

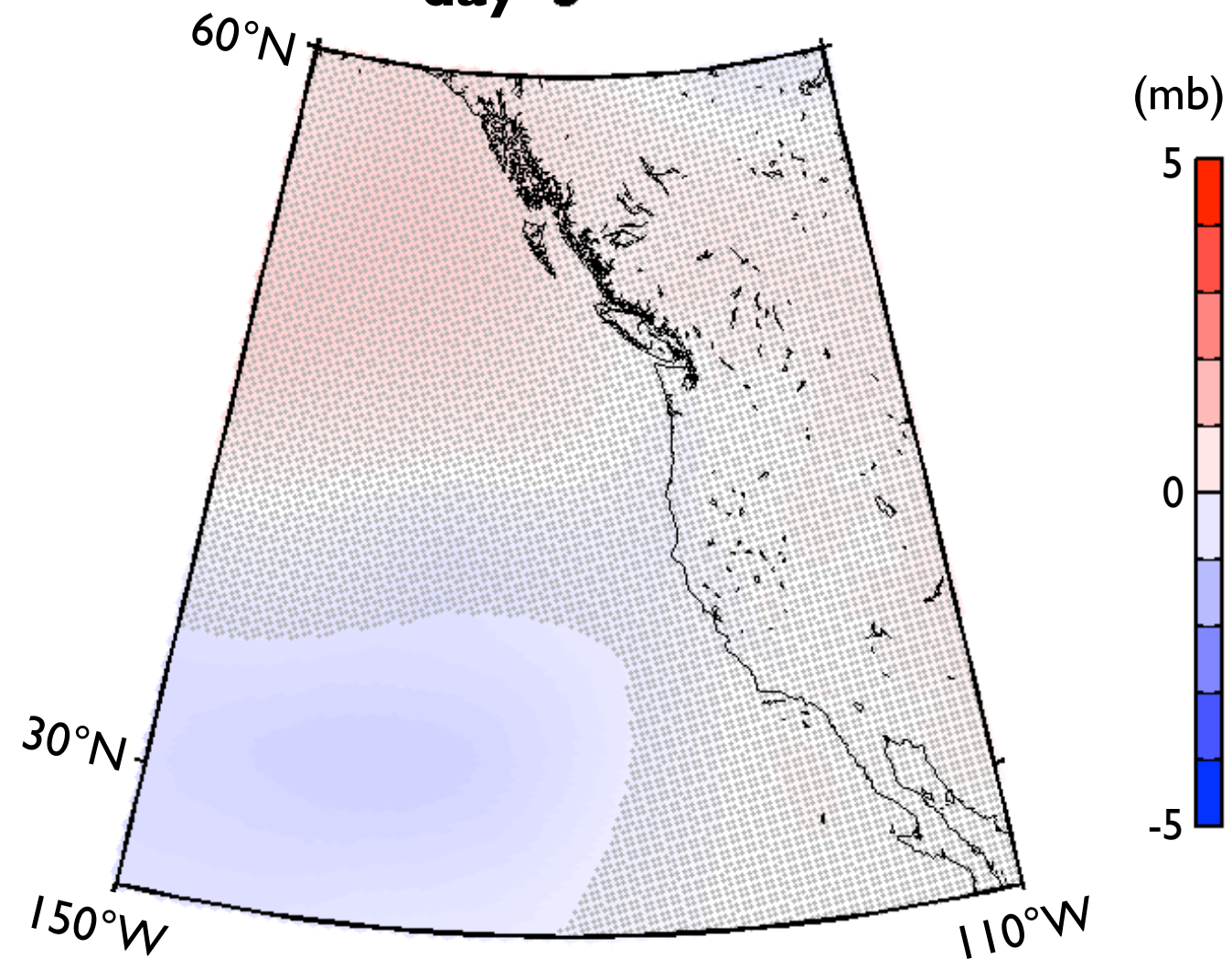
mean sea-level pressure

June-Sept



**sea-level pressure anomaly
average over ~100 events**

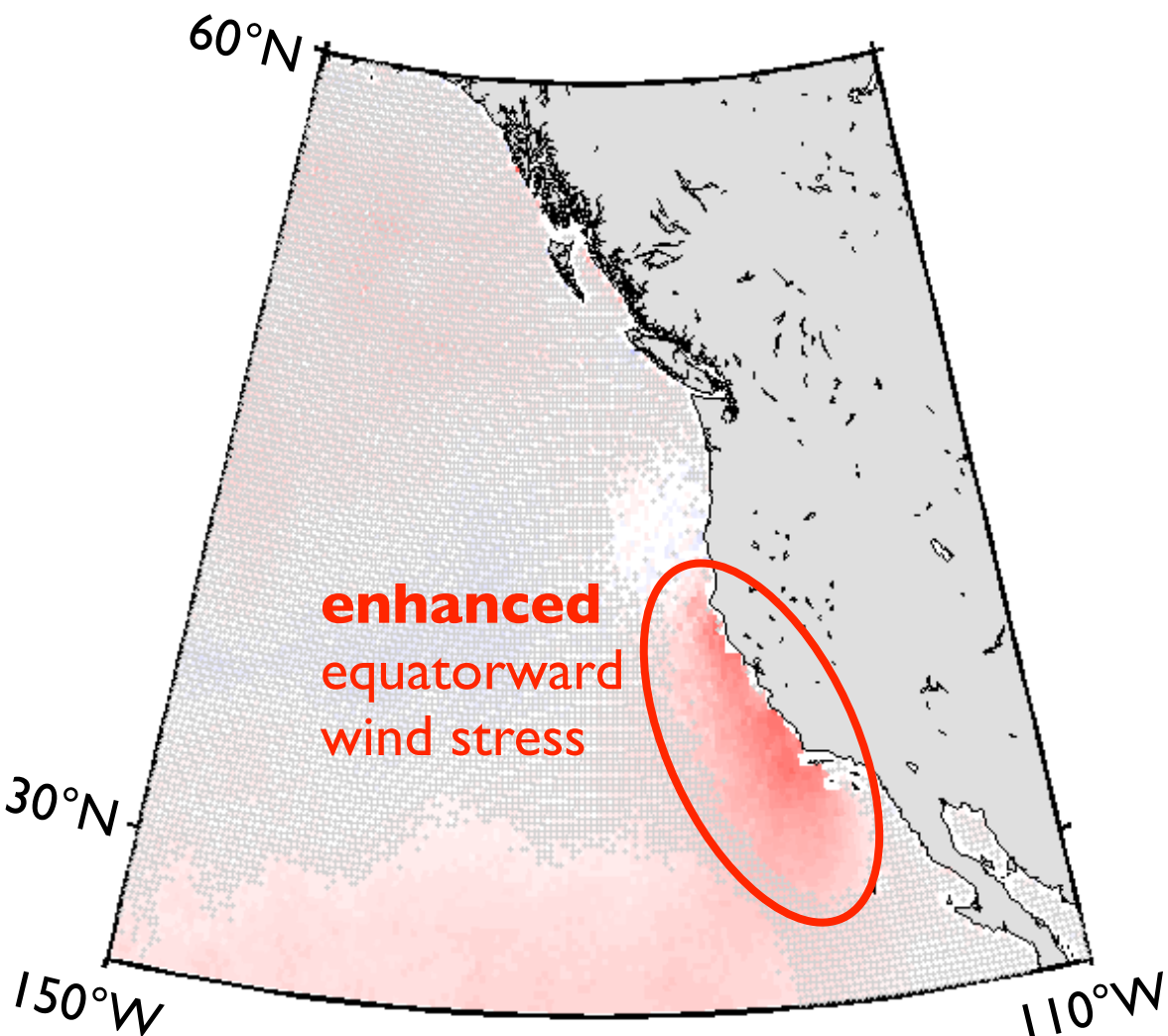
day 5



The wind relaxations involve a northeast extension of the North Pacific High.

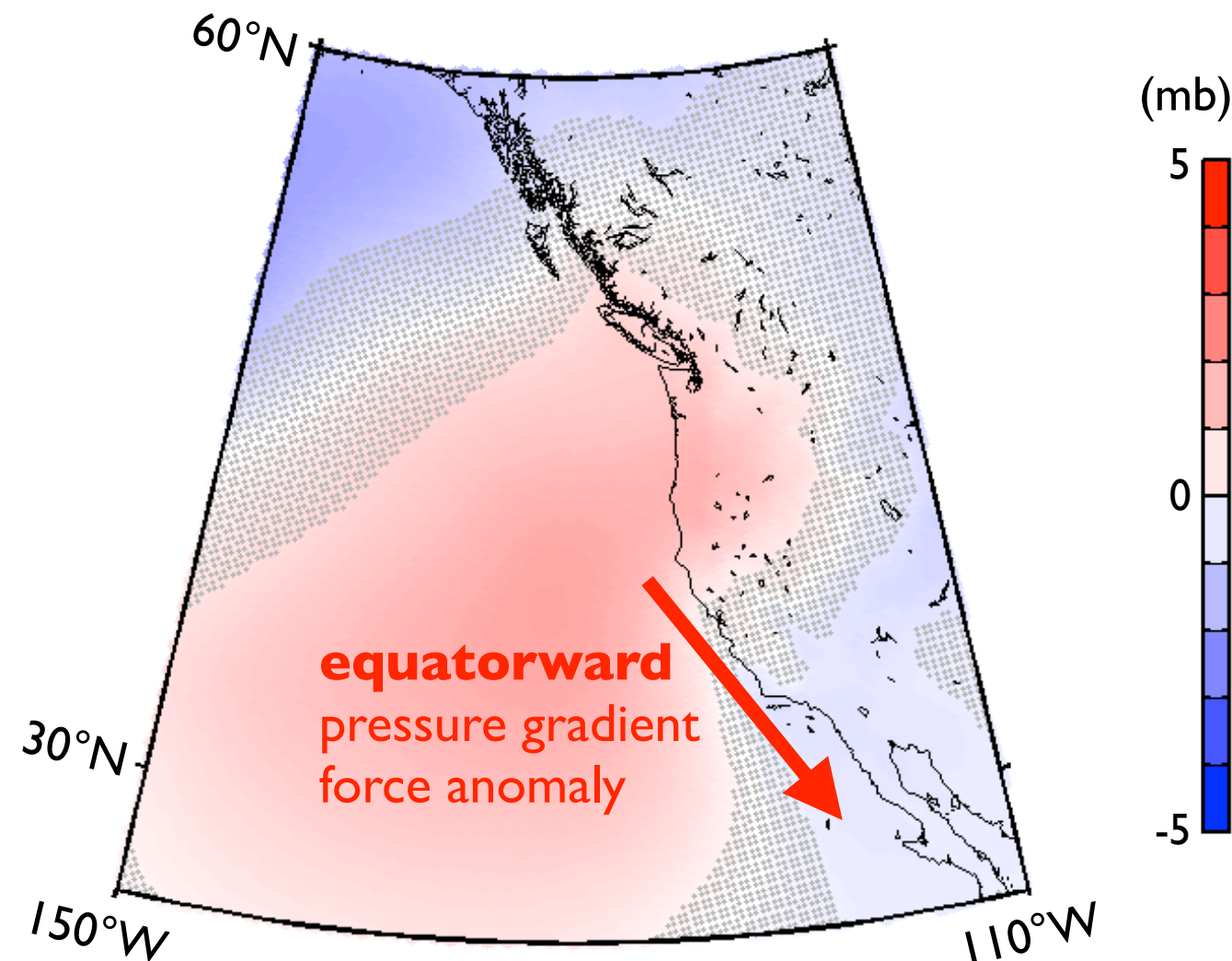
The sea-level pressure anomalies
first strengthen, then weaken the along-coast pressure gradient force,
which strengthens, then weakens the upwelling-favorable wind.

wind stress anomaly
along mean direction



sea-level pressure anomaly

1 day before relaxation



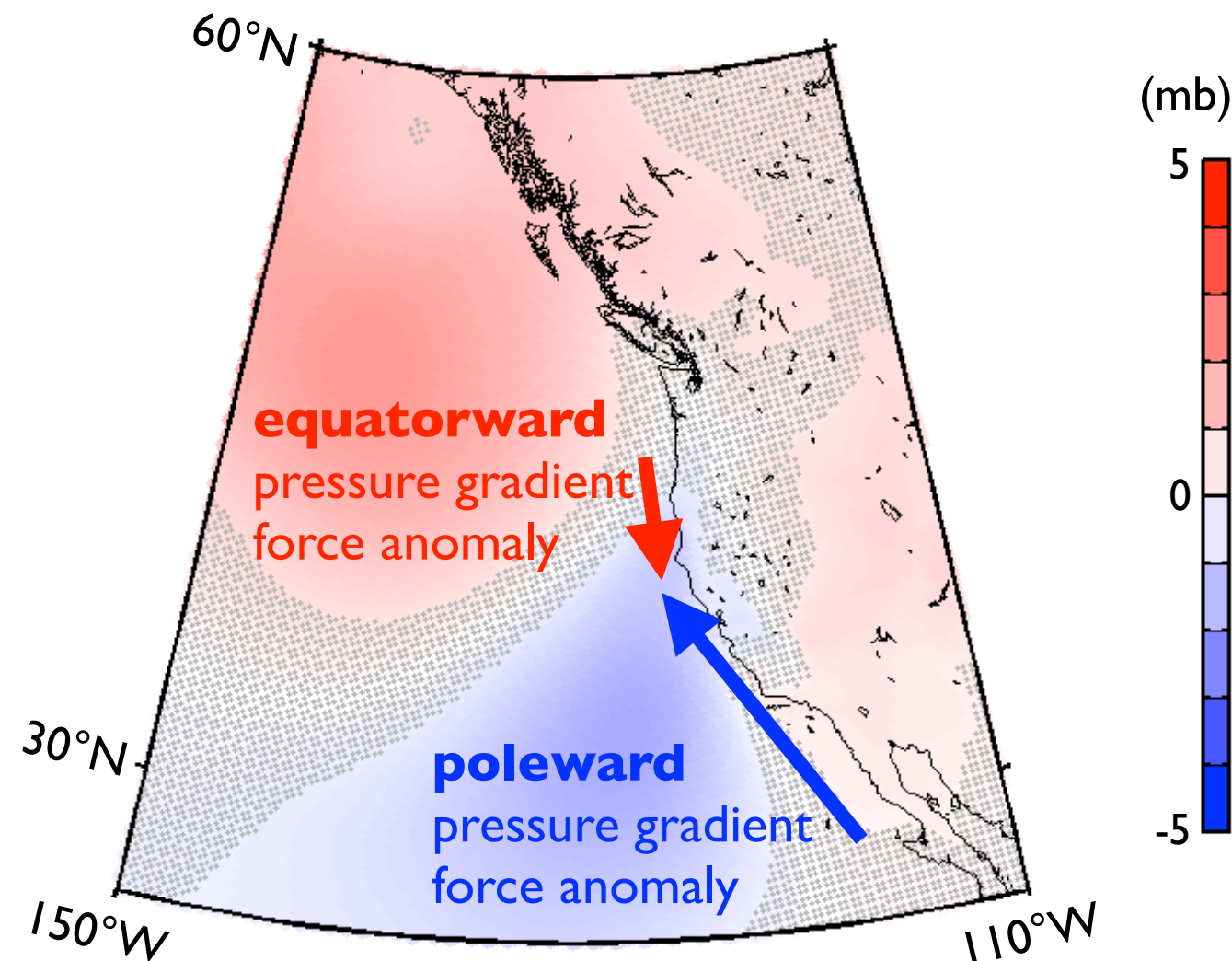
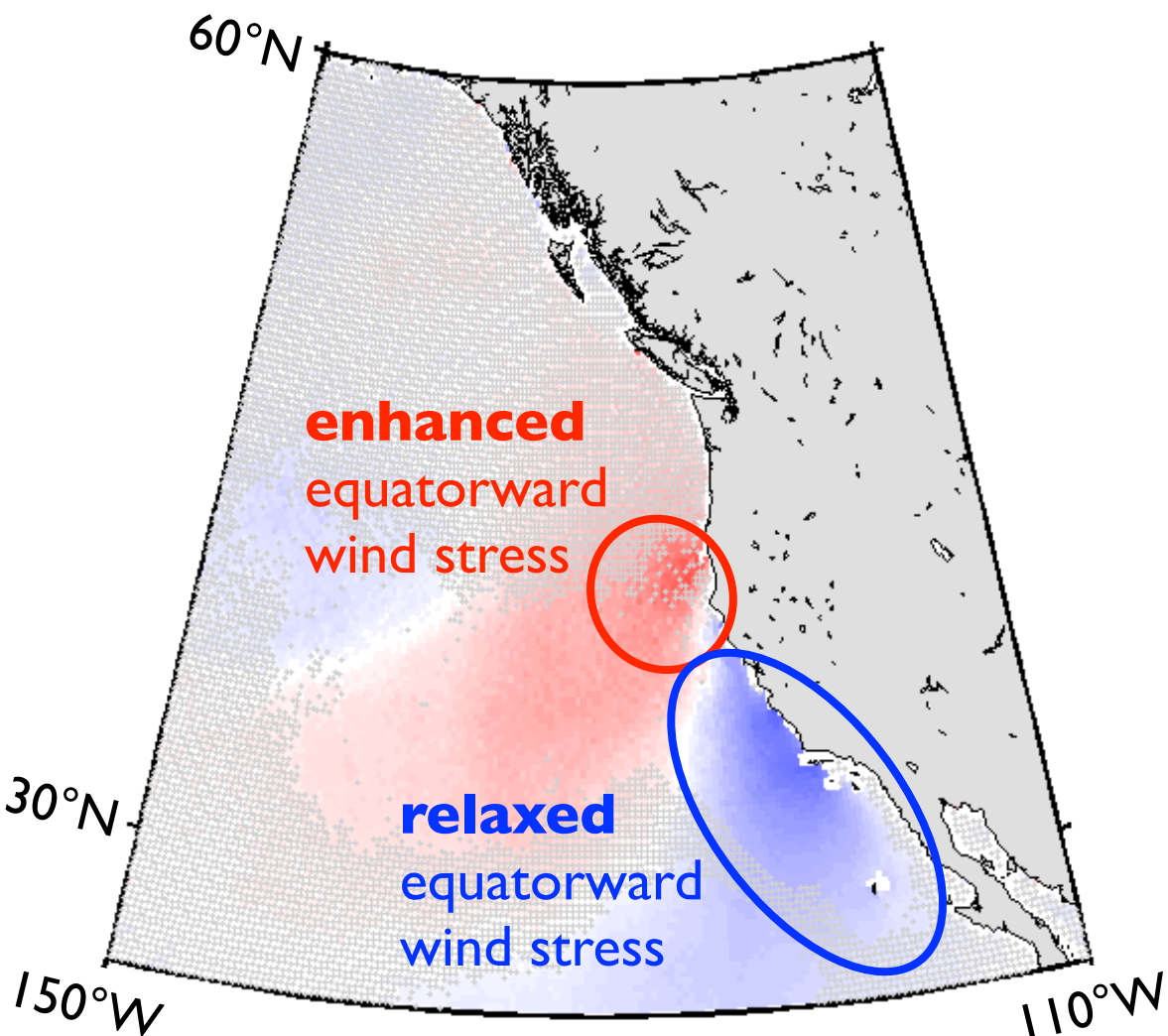
The wind relaxations involve a northeast extension of the North Pacific High.

The sea-level pressure anomalies
first strengthen, then weaken the along-coast pressure gradient force,
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wind stress anomaly
along mean direction

sea-level pressure anomaly

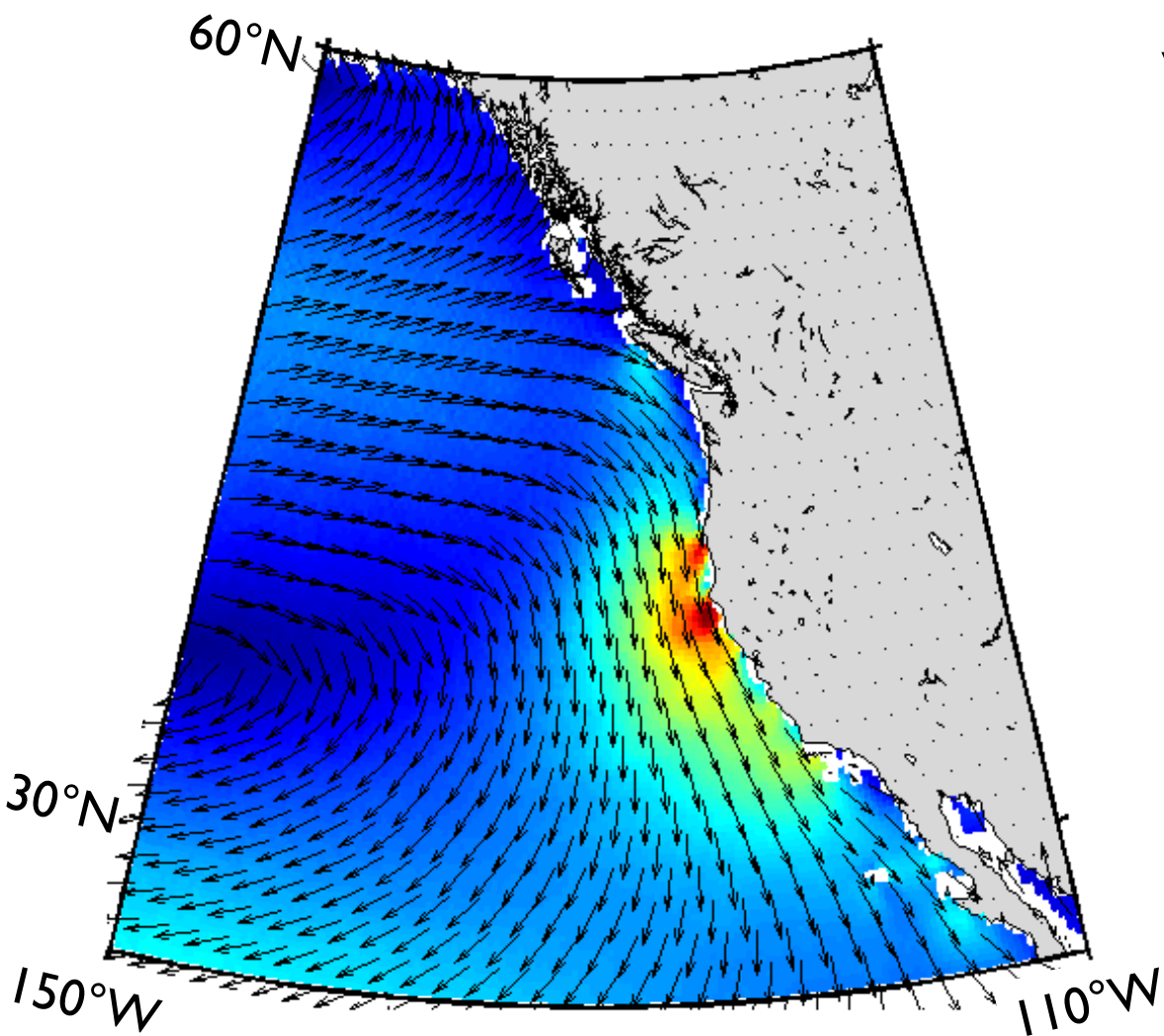
2 days after relaxation



Recall: the average wind relaxation
extends from the N. California border to Baja.

mean wind stress

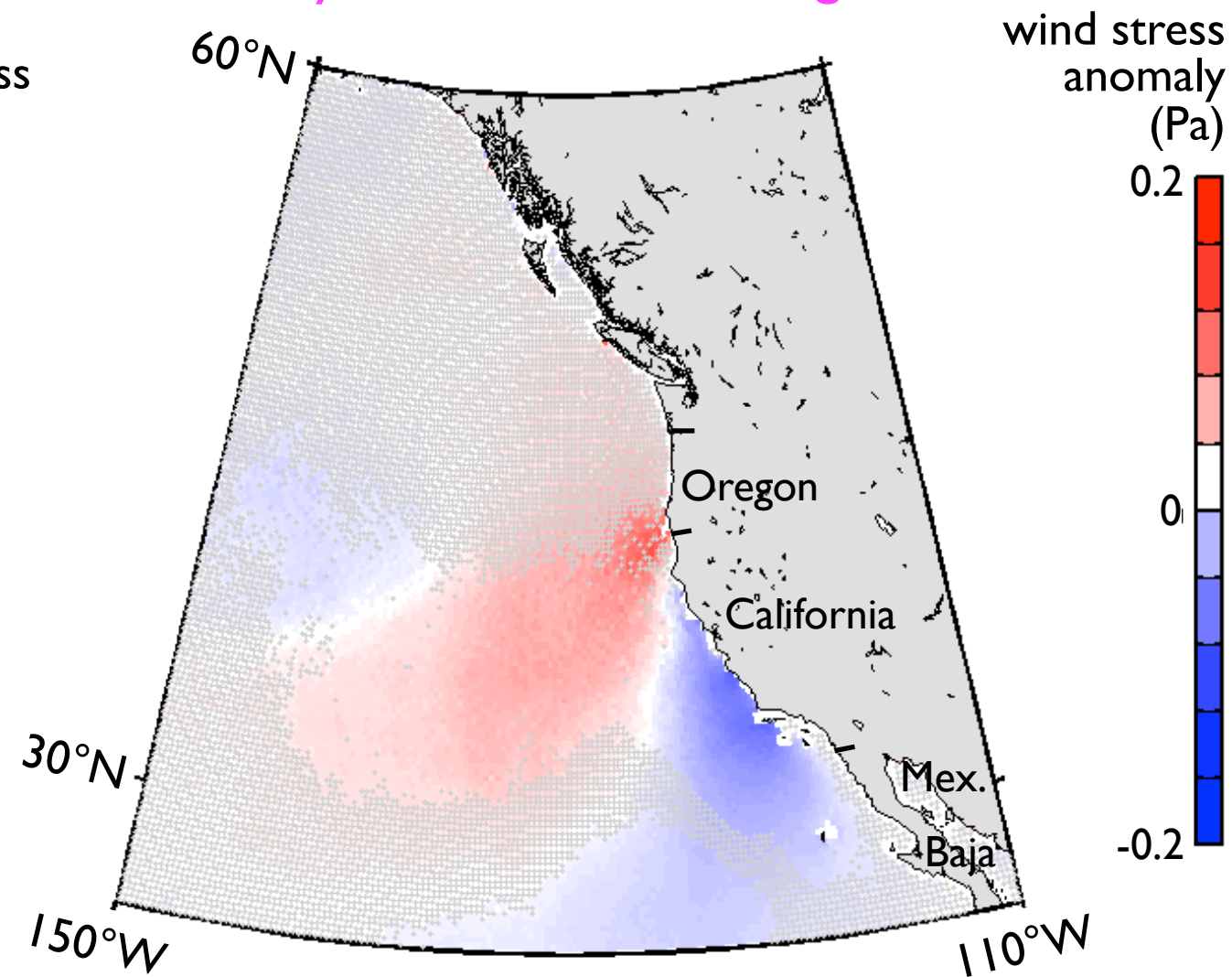
June-Sept



**wind stress anomaly
average over ~100 events**

along mean direction

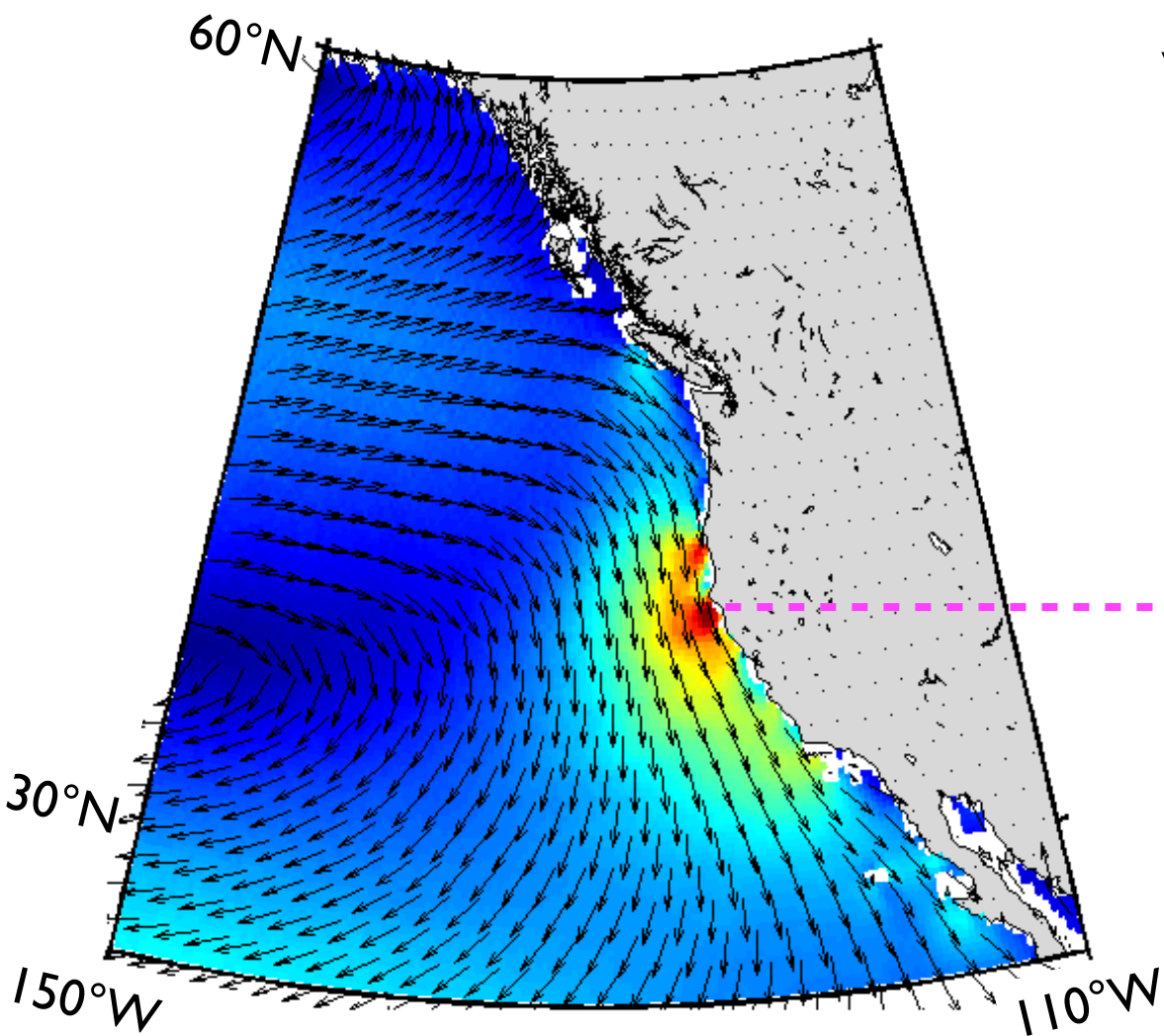
2 days after relaxation begins



We suggest the upwelling system has 2 parts:
north and south of the latitude of maximum winds

mean wind stress

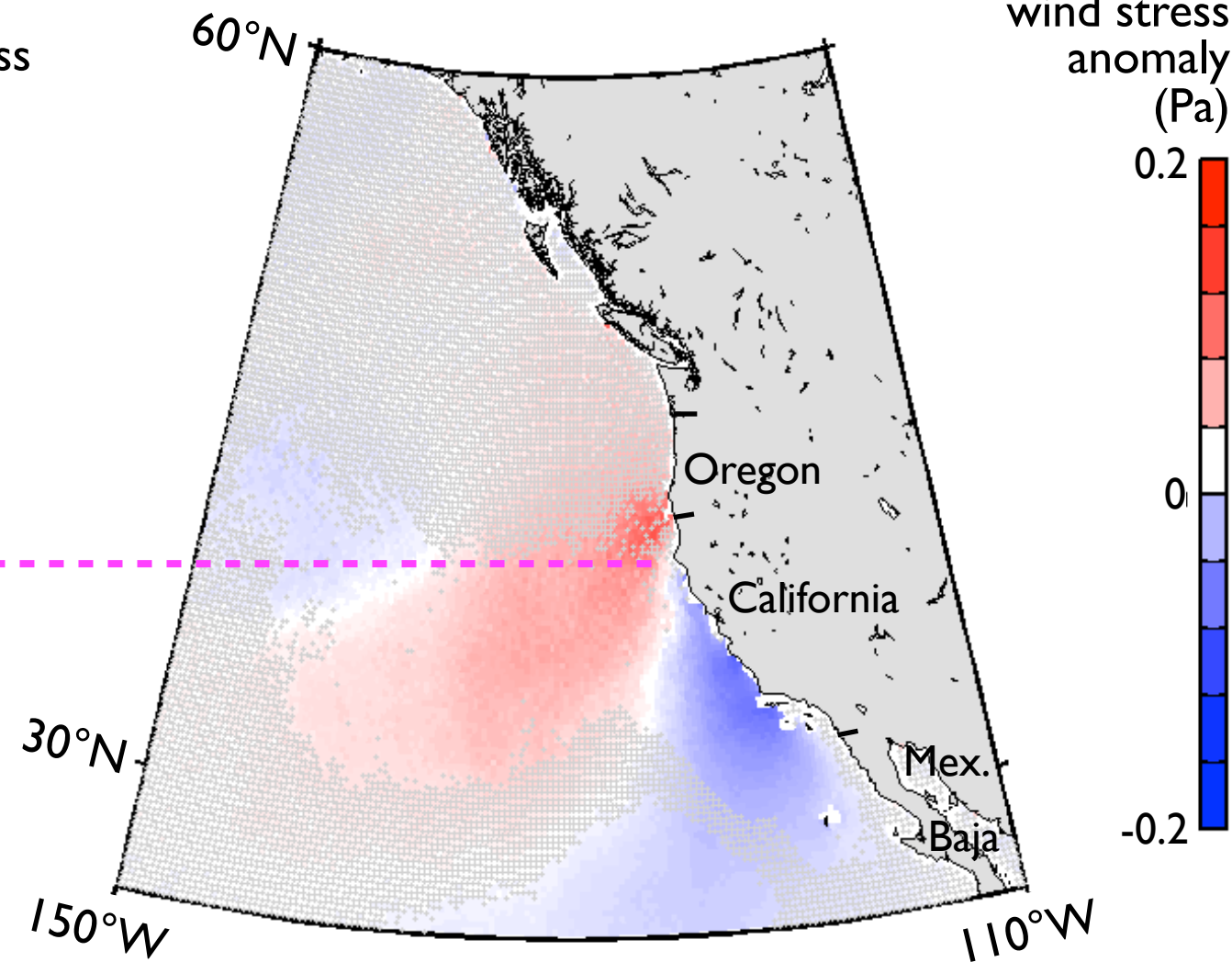
June-Sept



wind stress anomaly
average over ~100 events

along mean direction

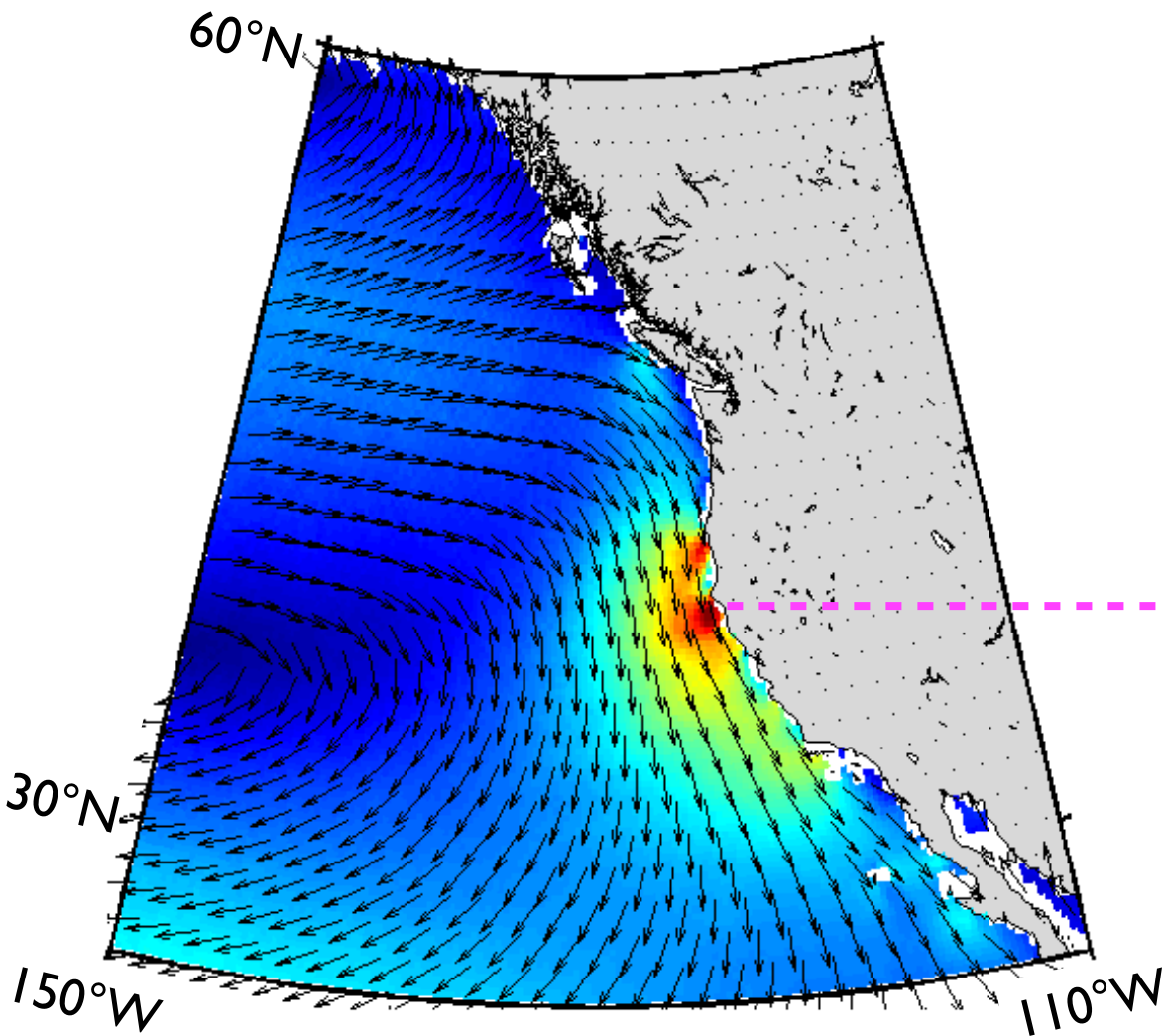
2 days after relaxation begins



We suggest the upwelling system has 2 parts:
north and south of the latitude of maximum winds
...or of the anticyclone.

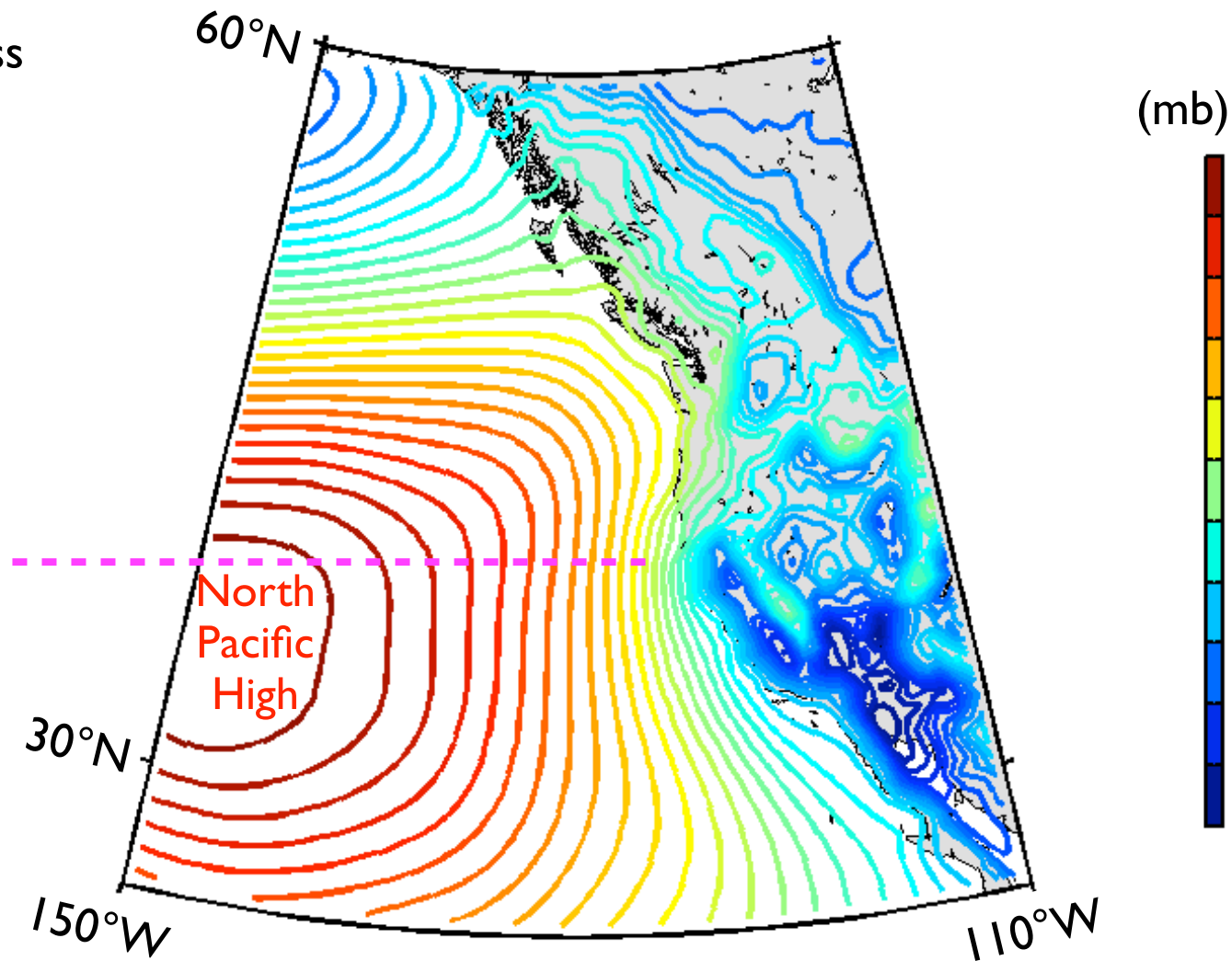
mean wind stress

June-Sept



mean sea-level pressure

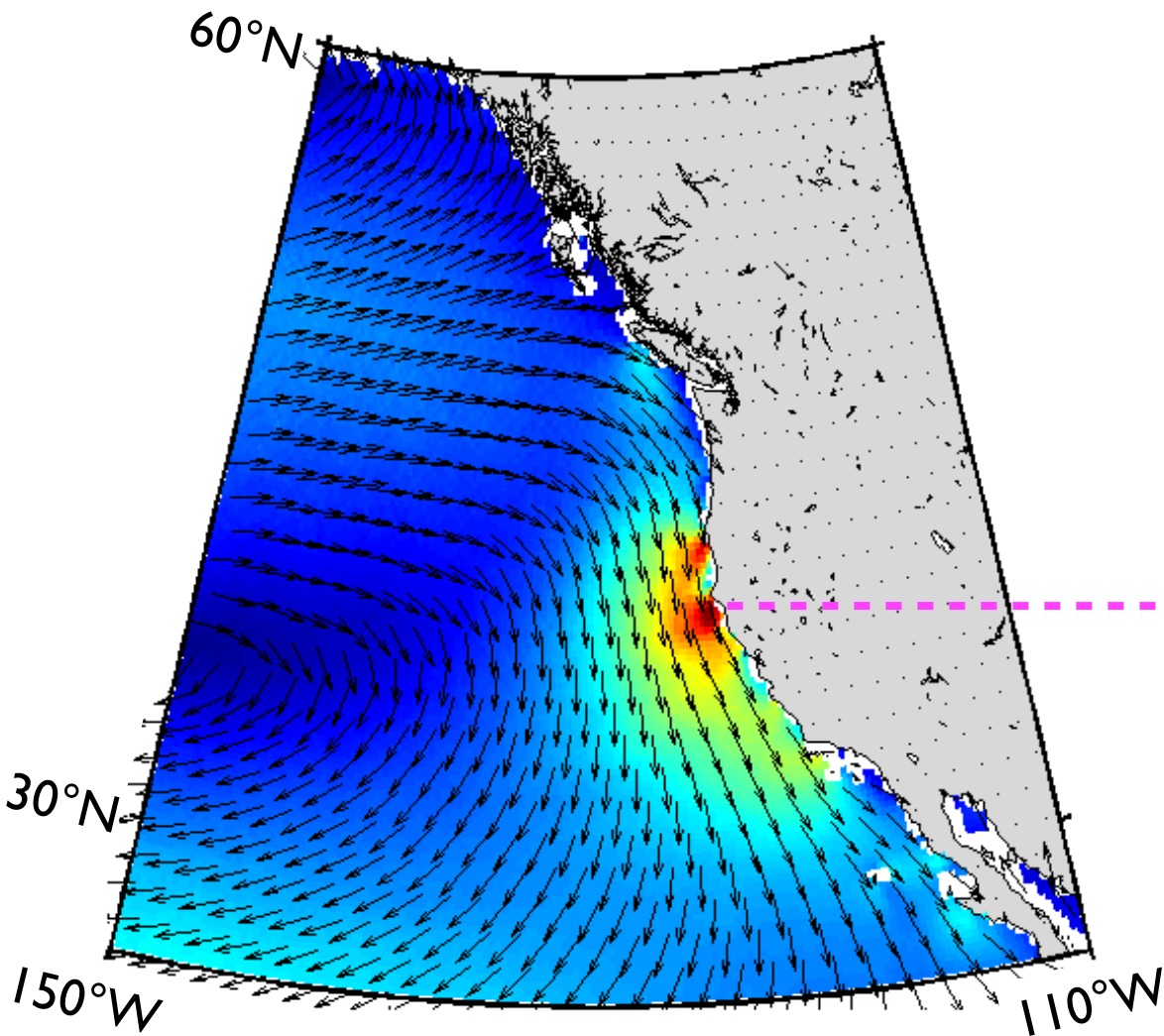
June-Sept



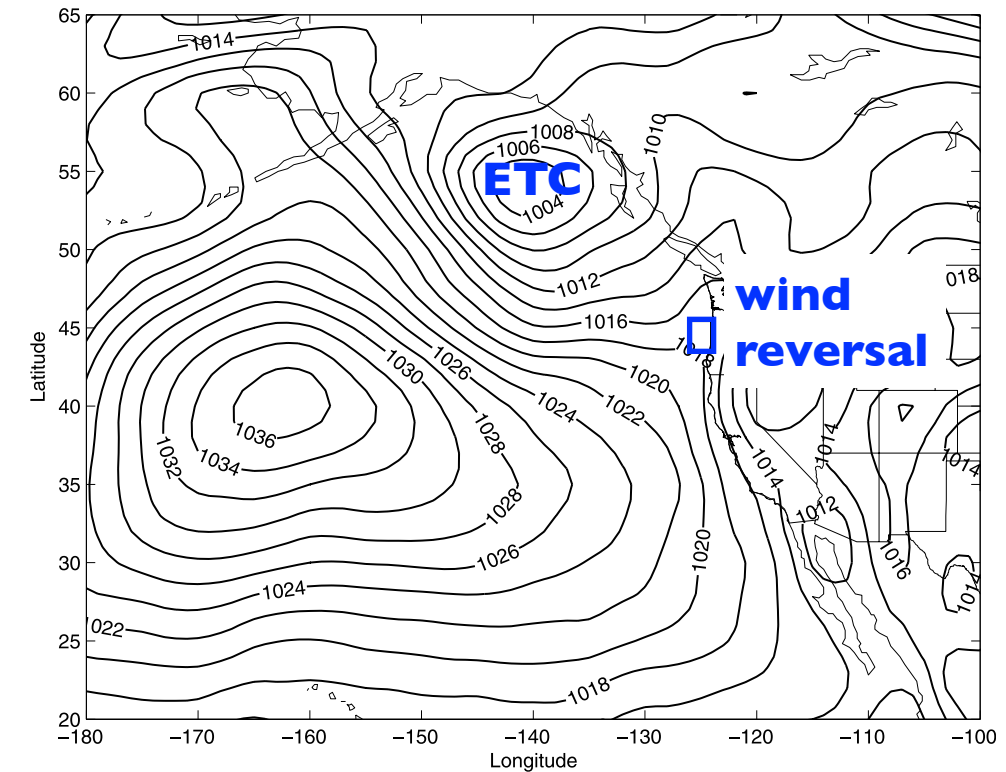
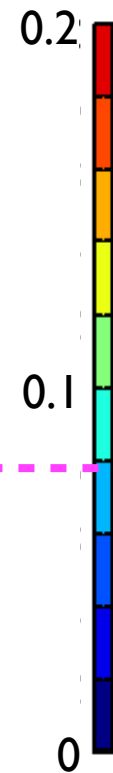
The 2 parts have different wind relaxation dynamics.

Bane et al. 2001

mean wind stress
June-Sept



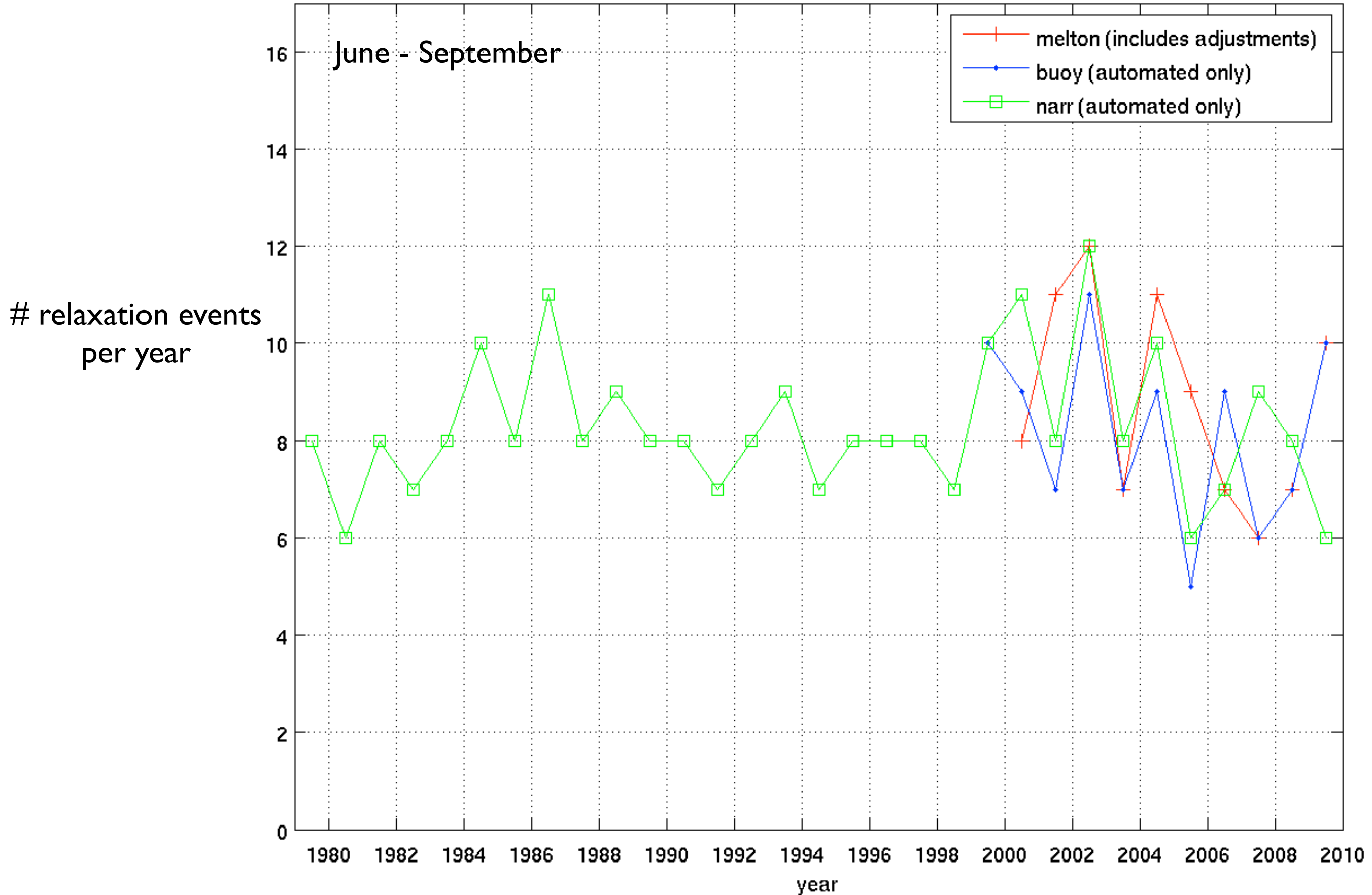
wind stress
(Pa)



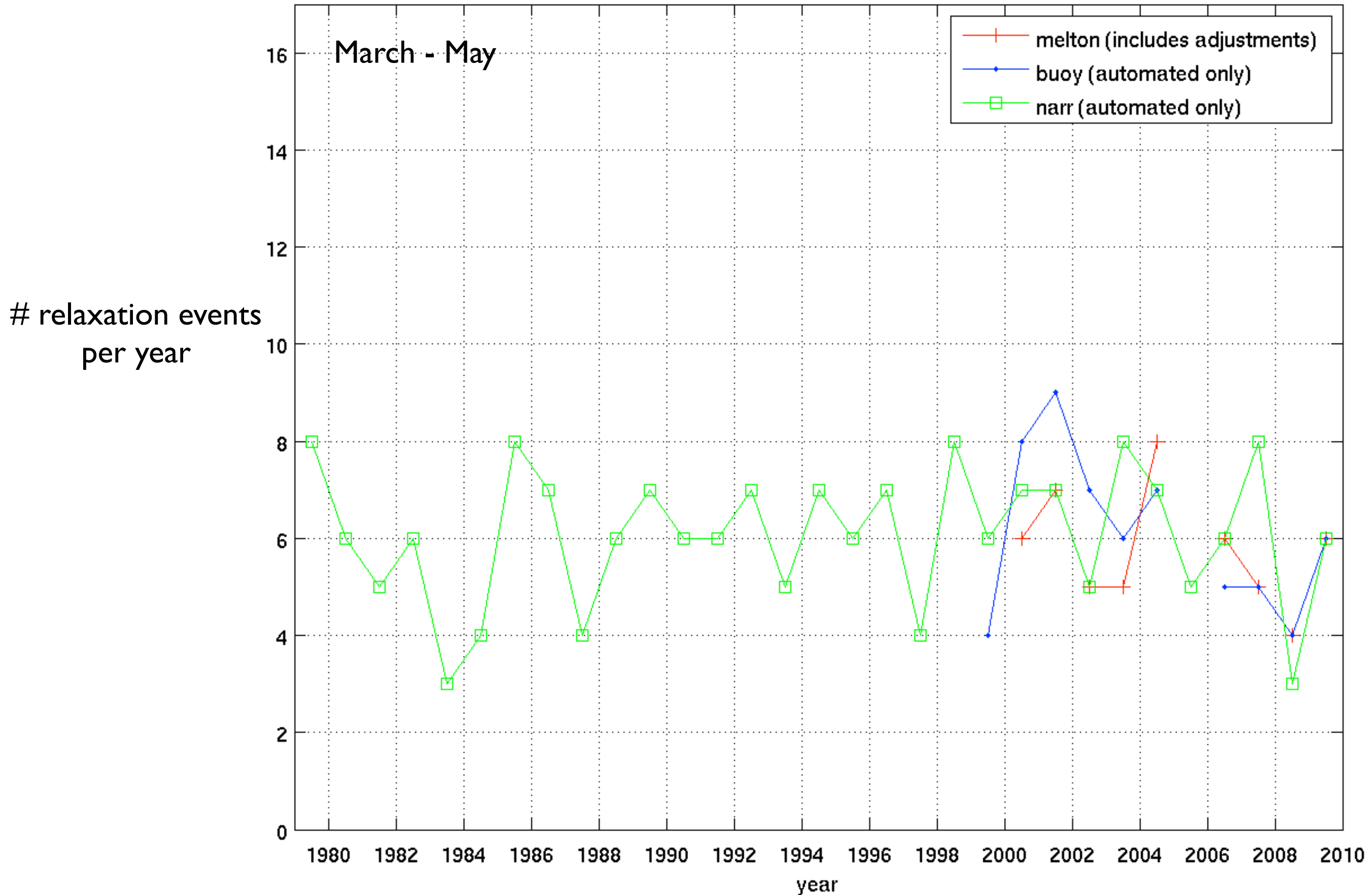
relaxations in north caused by
extra-tropical cyclones
& southward shift of jet stream
(Bane et al. 2001, 2007)

relaxations in south caused by
movement of North Pacific High

A new 30-yr wind relaxation index from NARR shows no trend in the number of relaxations.



A new 30-yr wind relaxation index from NARR shows no trend in the number of relaxations.



Conclusions

Northeastward movement of the North Pacific High causes upwelling-favorable wind stress off California to INCREASE, then RELAX.

The wind relaxations at Pt. Conception
have northward phase propagation
extend ~500 km offshore
do not extend north of California.

The upwelling system has 2 parts with different wind relaxation dynamics.

Ongoing and Future Work

Climate variability and wind relaxations (DSR special issue)

30-yr index of relaxations:

is strength or frequency of relaxations related to ENSO or other climate indices?

Regional ocean response

spatial extent, time evolution, ocean-atmosphere coupling dynamics

water temperature, velocity, pressure

chlorophyll, backscatter, CDOM, phytoplankton productivity

Future changes in wind relaxations

with relaxation index from atmospheric pressure gradient,

predict changes in frequency & intensity of relaxations under future climate scenarios

Acknowledgments

NASA Ocean Vector Winds Science Team Grant

NARR output provided by the NOAA/OAR/Earth System Research Laboratory,

Physical Sciences Division, Boulder, Colorado, USA, <http://www.esrl.noaa.gov/psd/>

Brian Emery, UCSB (NARR output acquisition)

