Revisiting the summer Relationship Between the North Pacific High and Upwelling Winds Along the West Coast of North America in the Present and Future climate

Hui Ding[1,2], Michael Alexander[2], and Mingfang Ting[3]

1. CIRES, University of Colorado Boulder
2. NOAA/PSL, Boulder, Colorado
3. Columbia University

CIRES

University of Colorado Boulder

NOAA

Coastal upwelling is a key factor in maintaining a productive marine ecosystem and regulating local air-sea interaction.

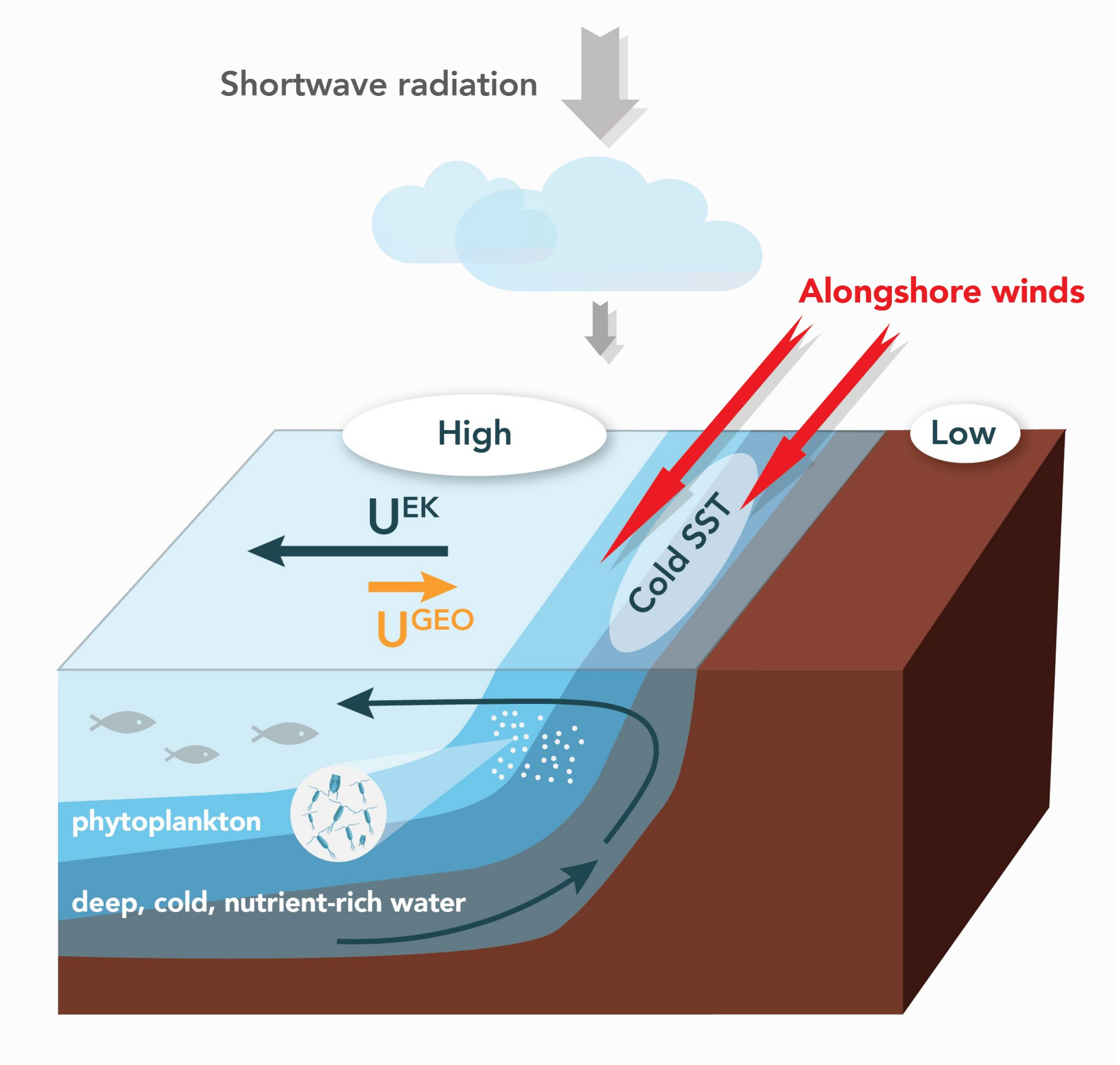
Background

Coastal upwelling is a key factor to maintain a productive ecosystem along the U.S. west coast through delivering cold nutrient-rich water to the surface layer, which serves as a fertilizer for phytoplankton and subsequently feeds higher trophic levels

Wind-driven offshore Ekman transport is an important driver of the coastal upwelling besides geophysical transport (Jacox et al., 2018)

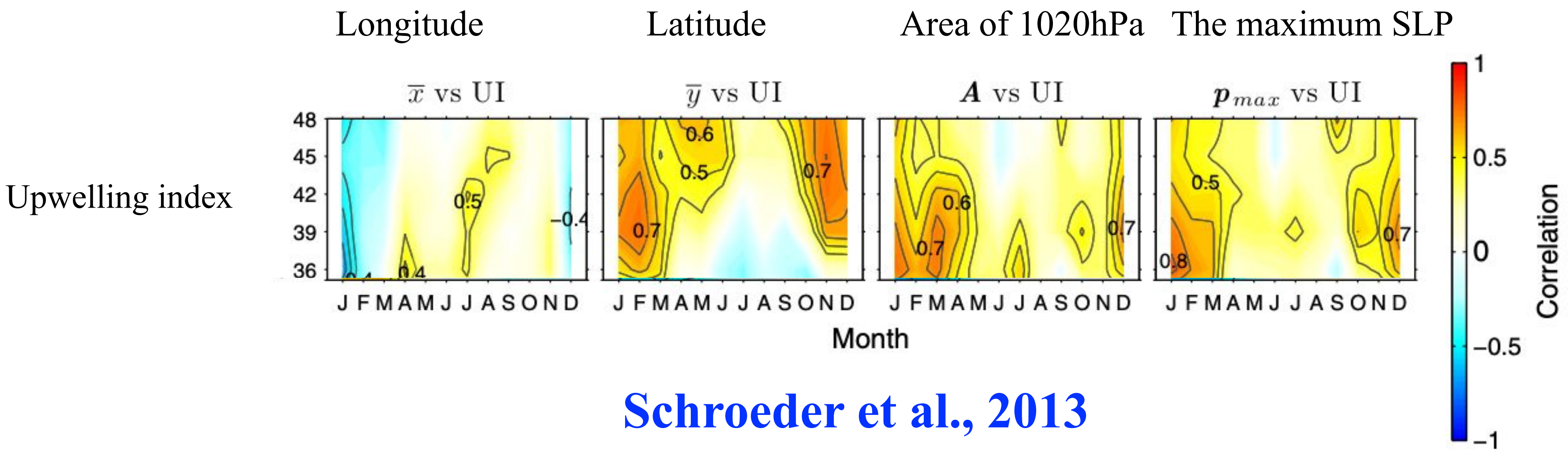
The North Pacific High (NPH) is the dominant atmospheric phenomenon in the subtropical North Pacific in summer.

Here, we examine the impact of the NPH on upwelling winds along the North American west coast using 500hPa subsidence to represent the NPH



A Schematic for the upwelling system in the California Current System (CCS)

Message: the NPH-related surface high-pressure cell exerts only minor effect on the coastal region in summer (Schroeder et al., 2013)

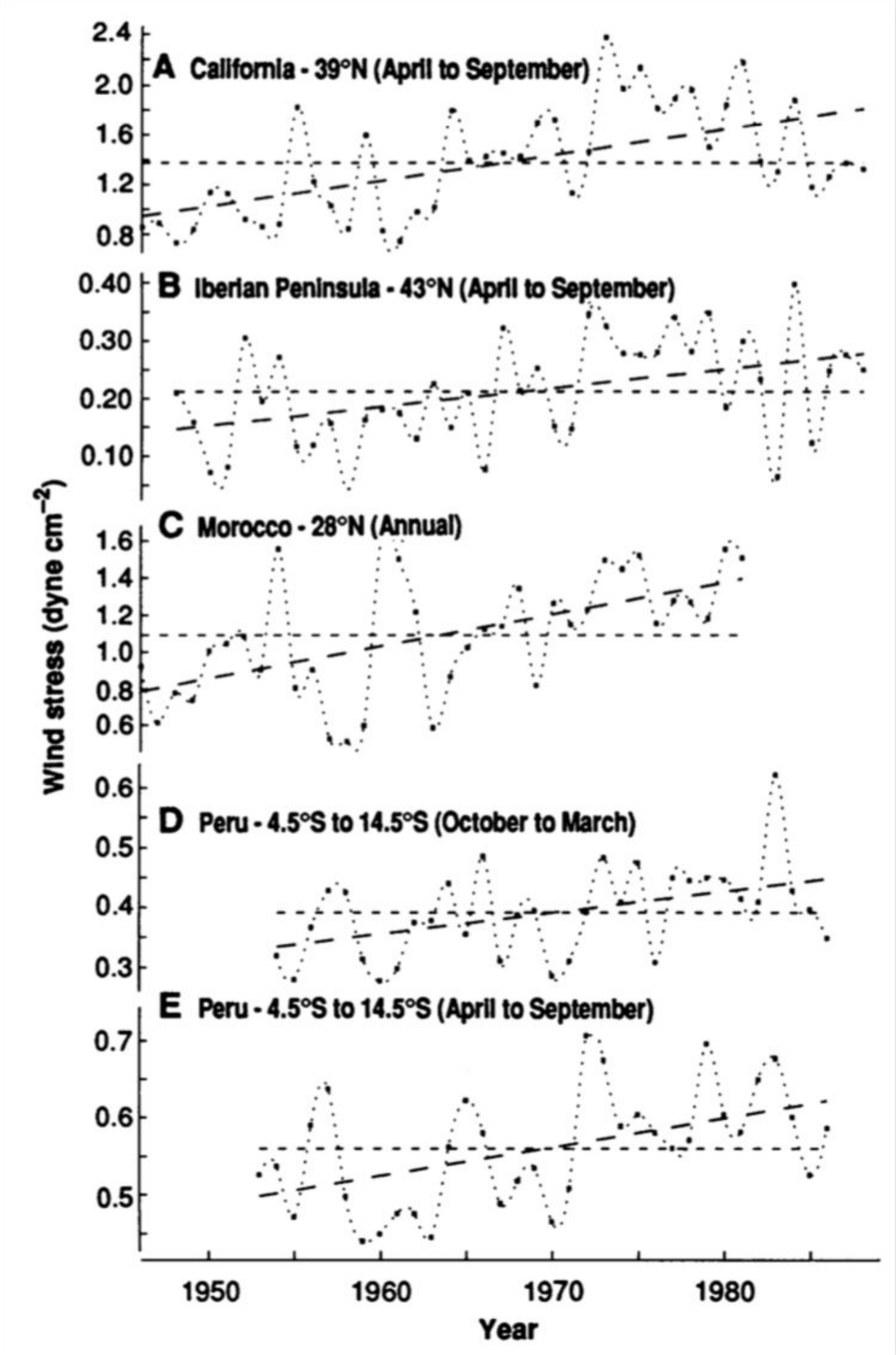


Schroeder et al., 2013

In this work, we will show the NPH-related subsidence in the mid-troposphere strongly affects the interannual variability and future changes of upwelling winds in summer.

Motivation: future changes in coastal upwelling is an important concern

- Bakun (1990) pioneered the study of examining the long-term changes in coastal upwelling. This study found the increasing trend in upwelling over the years of 1946-1988, which was argued to be anthropogenic climate change.
- Further, Bakun (1990) suggest the coastal upwelling will continue to intensify in response to ongoing greenhouse warming because surface air temperature will increase to a larger extent in continent than in the oceans. The increased surface temperature difference increases onshore-offshore pressure gradient and thus intensify the upwelling-favorable alongshore wind stress and thus coastal upwelling.
- The Bakun's hypothesis has stimulated many investigations of wind forcing in a changing climate (e.g., Cardone et al., 1990; Hsieh & Boer 1992; Mote & Mantua 2002; Garcia-Reyes & Largier 2010; Narayan et al., 2010; Garcia-Reyes & Largier (2010); Sydeman et al., 2014; Garcia-Reyes et al., 2015; Wang et al., 2015; Rykaczewski et al., 2015).



Bakun, 1990

ERA5 reanalysis monthly mean are employed to examine interannual variability and verify against the CESM-LE

1920 Historical radiative forcing **2005** RCP8.5 radiative forcing **2100**

CESM1 large ensemble (CESM-LE; Kay et al., 2015)

- There are forty ensemble members, differing only slightly in their initial atmospheric conditions in January 1920.
- One benefit of using the CESM-LE is that anthropogenic-forced signals, given by the ensemble mean, can be separated from internal climate variability.
- We use (2071-2100) minus (1925-1954) to indicate greenhouse gas-forced changes.

Message: upwelling-favorable winds occurs with strong subsidence above

The near-surface equatorward winds (i.e., upwelling favorable) occur in the region with strong subsidence above

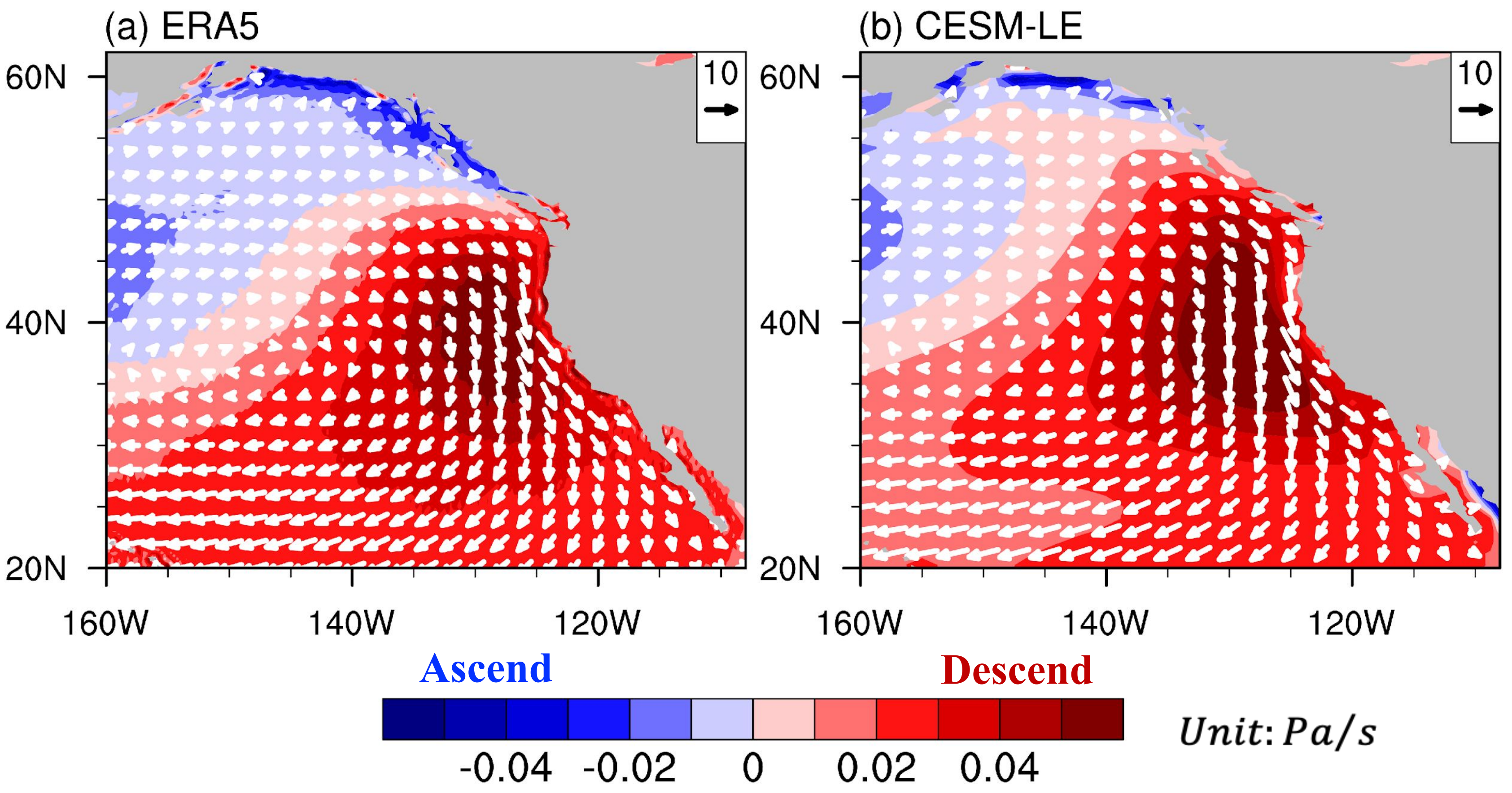
This is consistent with the vorticity balance in the atmosphere ($\beta v = f\omega$; Rodwell and Hoskins, 2001)

In this work, we employ 500hPa pressure vertical velocity to measure the NPH in summer

CESM-LE has an excellent performance in the summer mean state

Data are from 1919-2020

Summer mean 500hPa pressure vertical velocity and 1000hPa winds



Positive pressure vertical velocity indicates descending motion

Message: upwelling-favorable winds occurs with strong subsidence above along the North American west coast

The near-surface equatorward winds (i.e., upwelling favorable) occur in the region with strong subsidence above

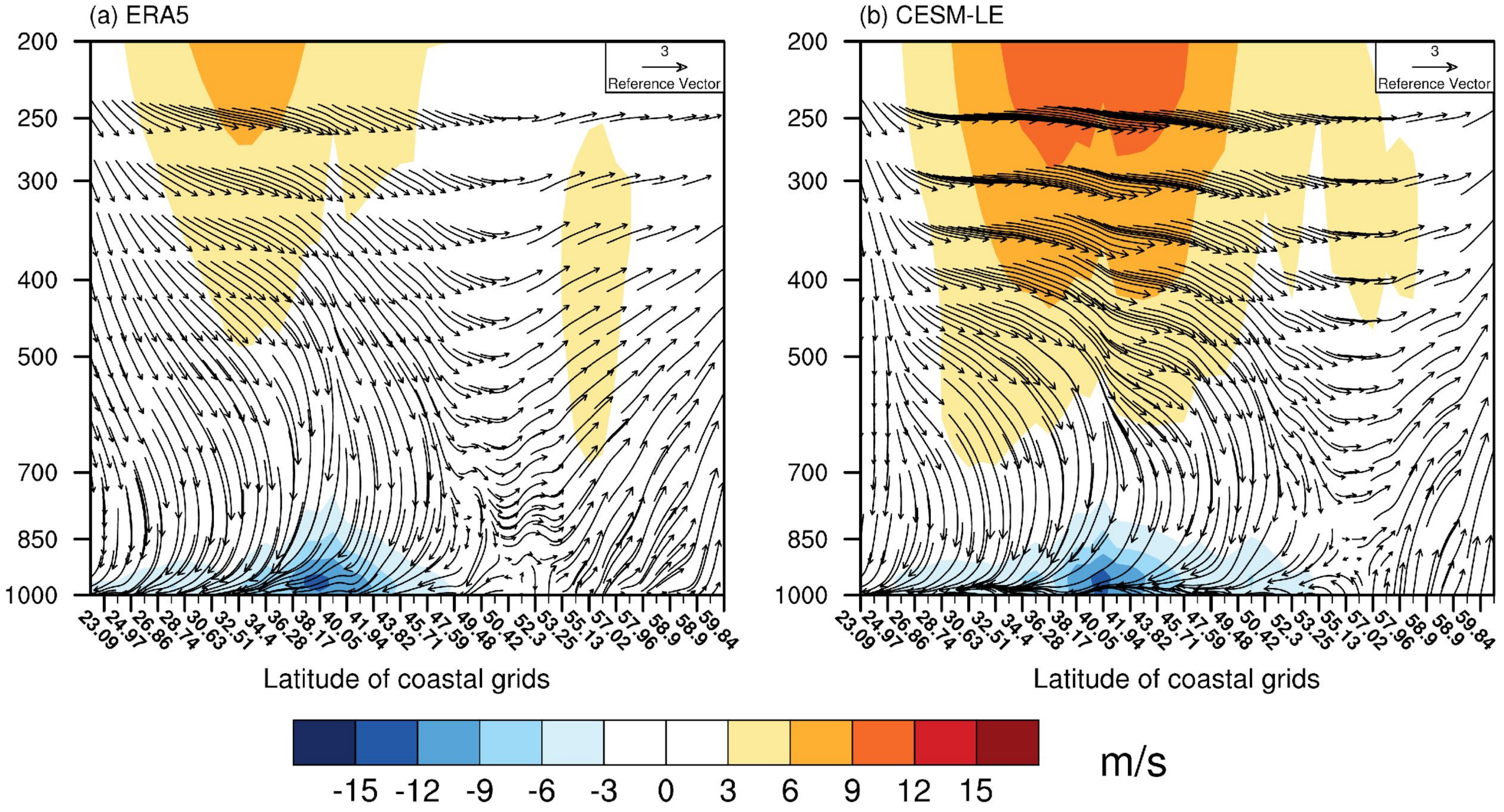
This is consistent with the vorticity balance in the atmosphere ($\beta v = f\omega$; Rodwell and Hoskins, 2001)

In this work, we employ 500hPa pressure vertical velocity to measure the NPH in summer

CESM-LE has a nearly excellent performance in the summer mean state

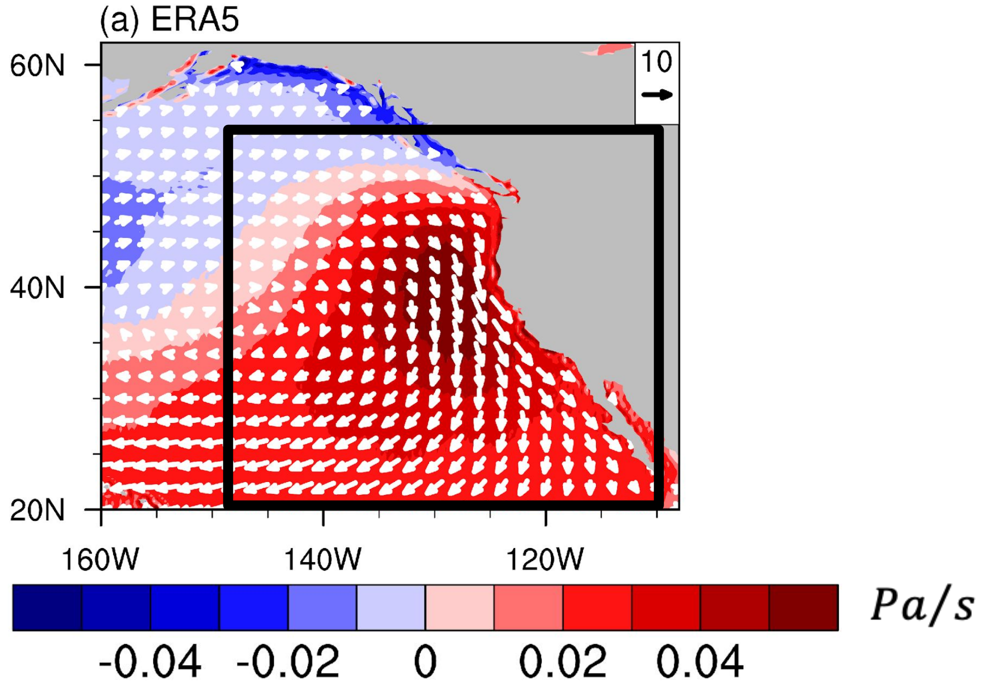
Data are from 1919-2020

Summer mean meridional and vertical winds along North American west coast

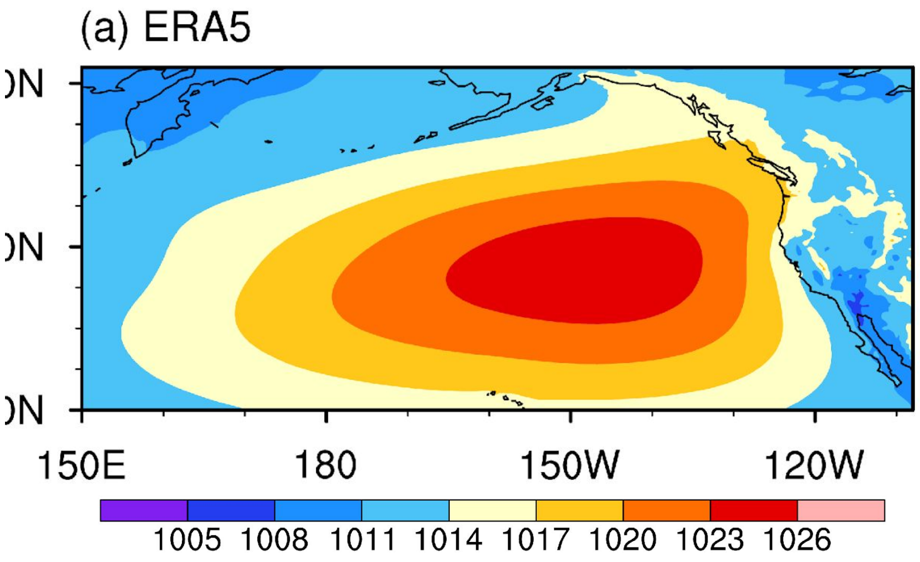


The summer North Pacific High (NPH) index

- In this study, an omega500 index $= \frac{\sum_i^n \omega}{n}$, mean value of 500hPa pressure vertical velocity (omega500) within the contour of 0.03Pa/s in a domain bounded by 150W-100W, 15N-60N near California coast.



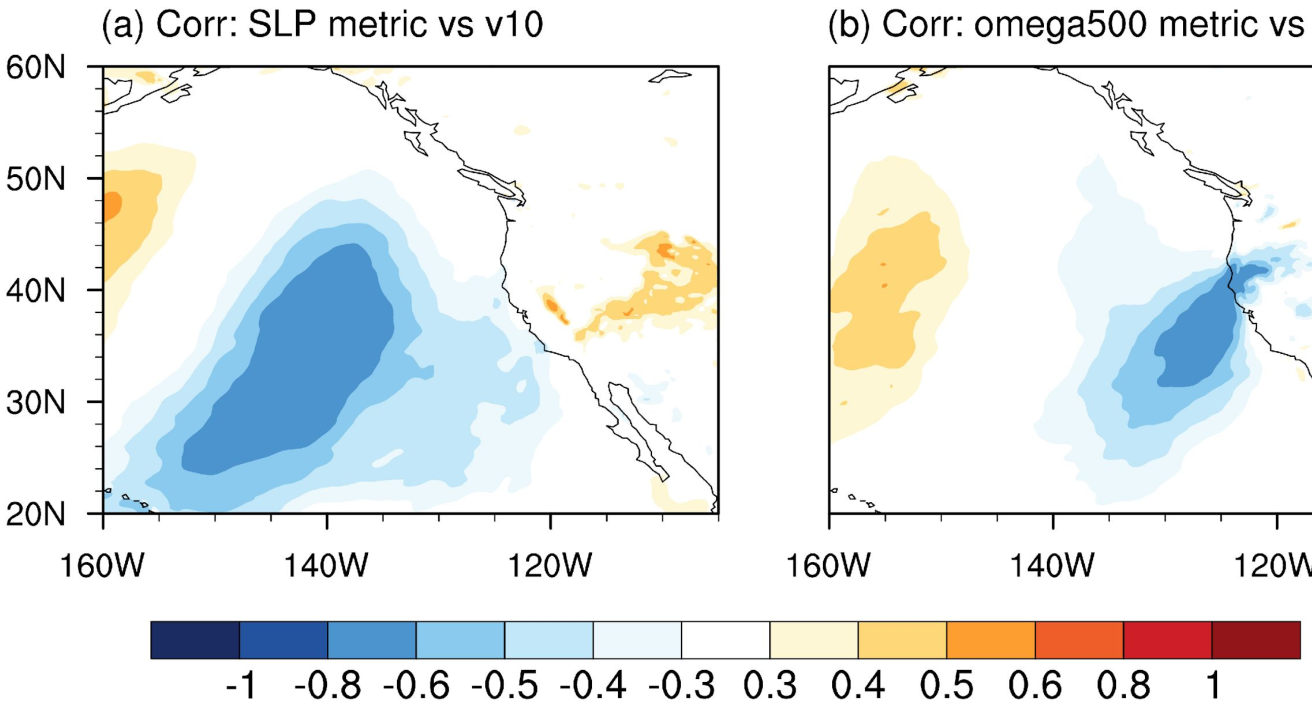
For a comparison, following previous studies, we also define a SLP index= $\frac{\sum_i^n slp_t^i}{n}$, mean value of sea level pressure within the 1020 hPa contour.



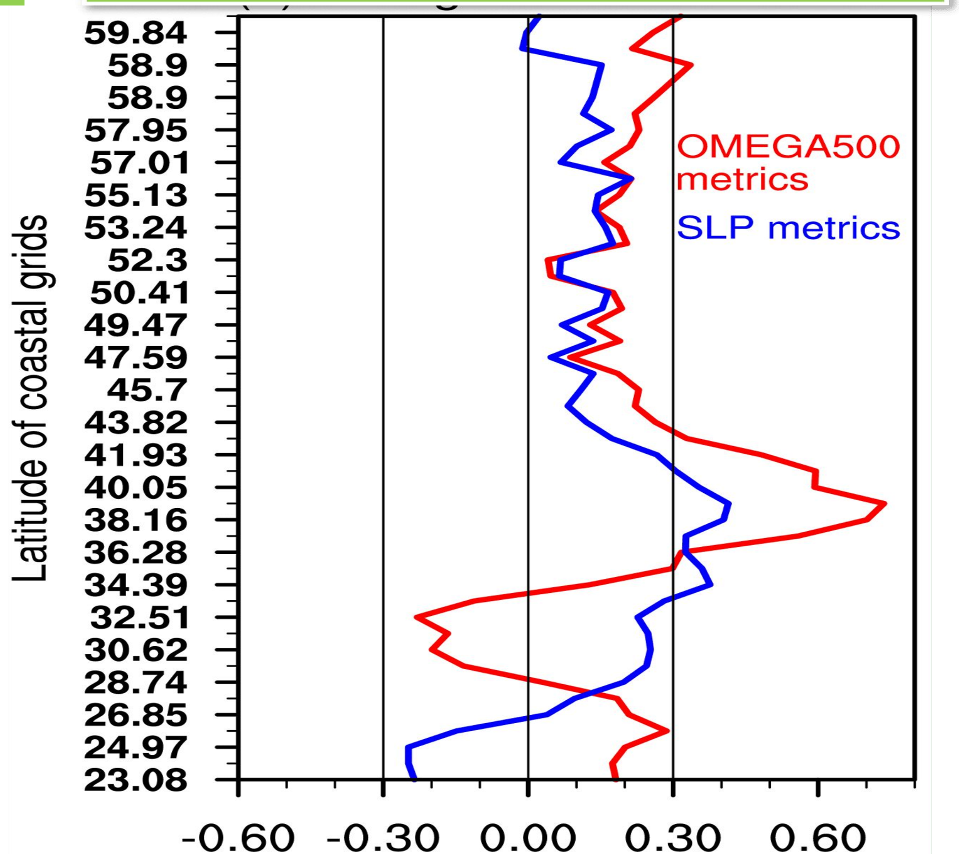
Message: the NPH-related subsidence has a much larger impact on upwelling winds near the California coast than the surface high-pressure cell

ERA5 reanalysis data over 1979-2020 are employed in this slide

Correlating (a) SLP (b) omega500 indices with surface meridional wind



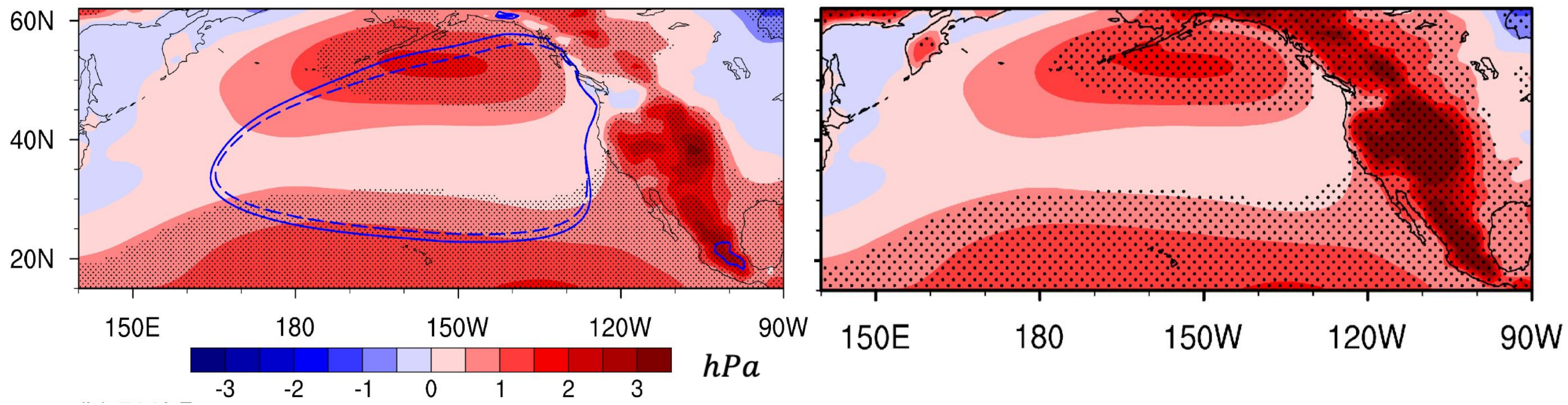
NPH vs upwelling-favorable winds



The following slides are about future changes in the NPH and upwelling winds by the the ensemble mean epoch difference (2071-2100 minus 1925-1954)

Message: the NPH-related surface high-pressure cell changes only slightly in the future climate

Epoch difference (2071-2100 minus 1925-1954) in SLP (left) and surface pressure (right)



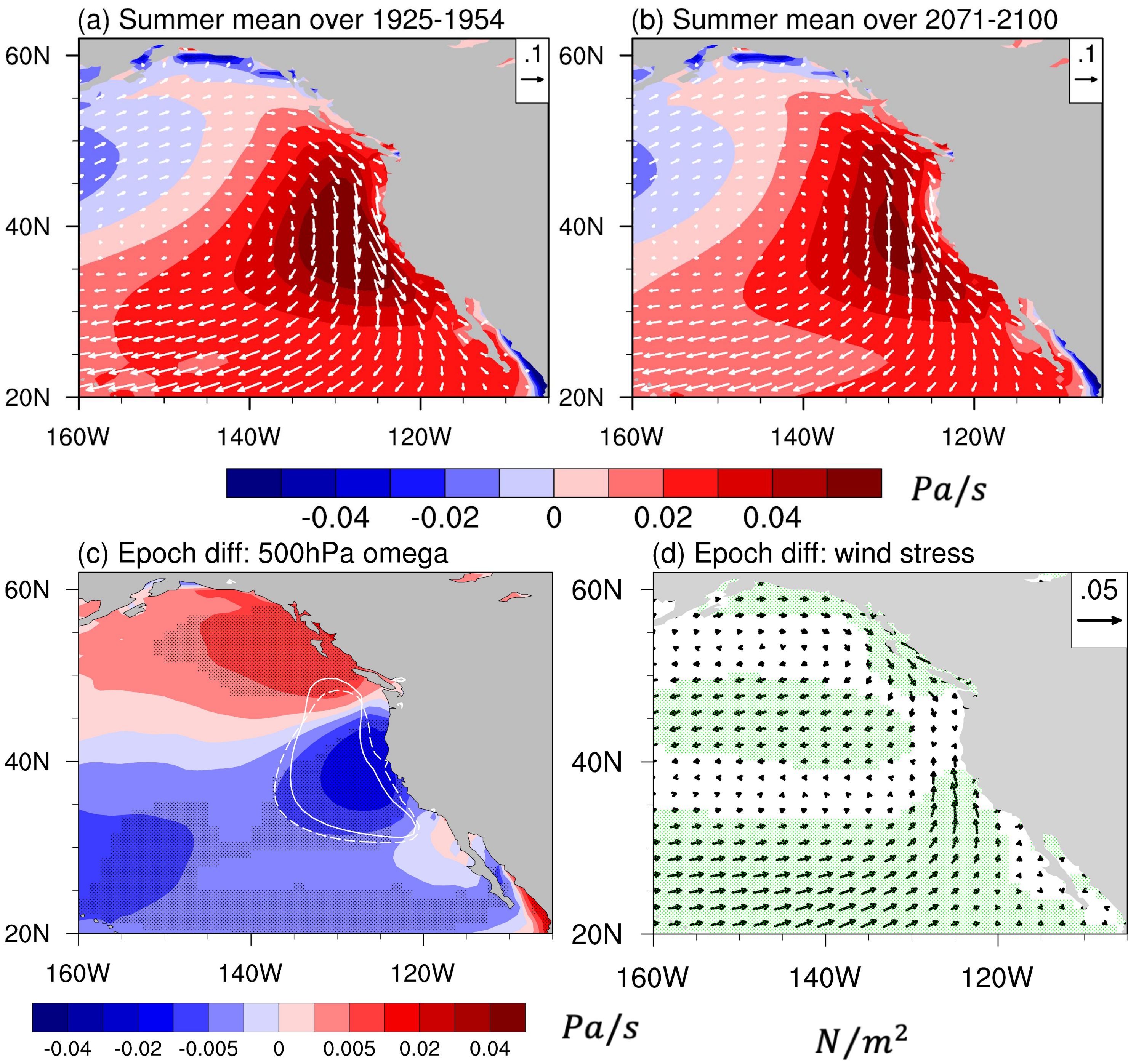
Dashed and solid lines show the contours of 1020hPa for summer mean over 1925-1954 and 2071-2100, respectively

Dots indicates 95% significance

	Epoch difference (2071-2100 minus 1925-1954)
SLP index	
Omega500 index	

Asterisk (*) denotes 95% significance

Message: the NPH-related subsidence and winds in the coastal region both change significantly in the future climate



Dashed and solid lines show the contours of 0.03 Pa/s for summer mean over 1925-1954 and 2071-2100, respectively

Dots and hatching indicate 95% significance

	Epoch difference (2071-2100 minus 1925-1954)
SLP index	
Omega500 index	

Epoch difference (2071-2100 minus 1925-1954) along North American west coast

A height and latitude cross section along the west coast of North America

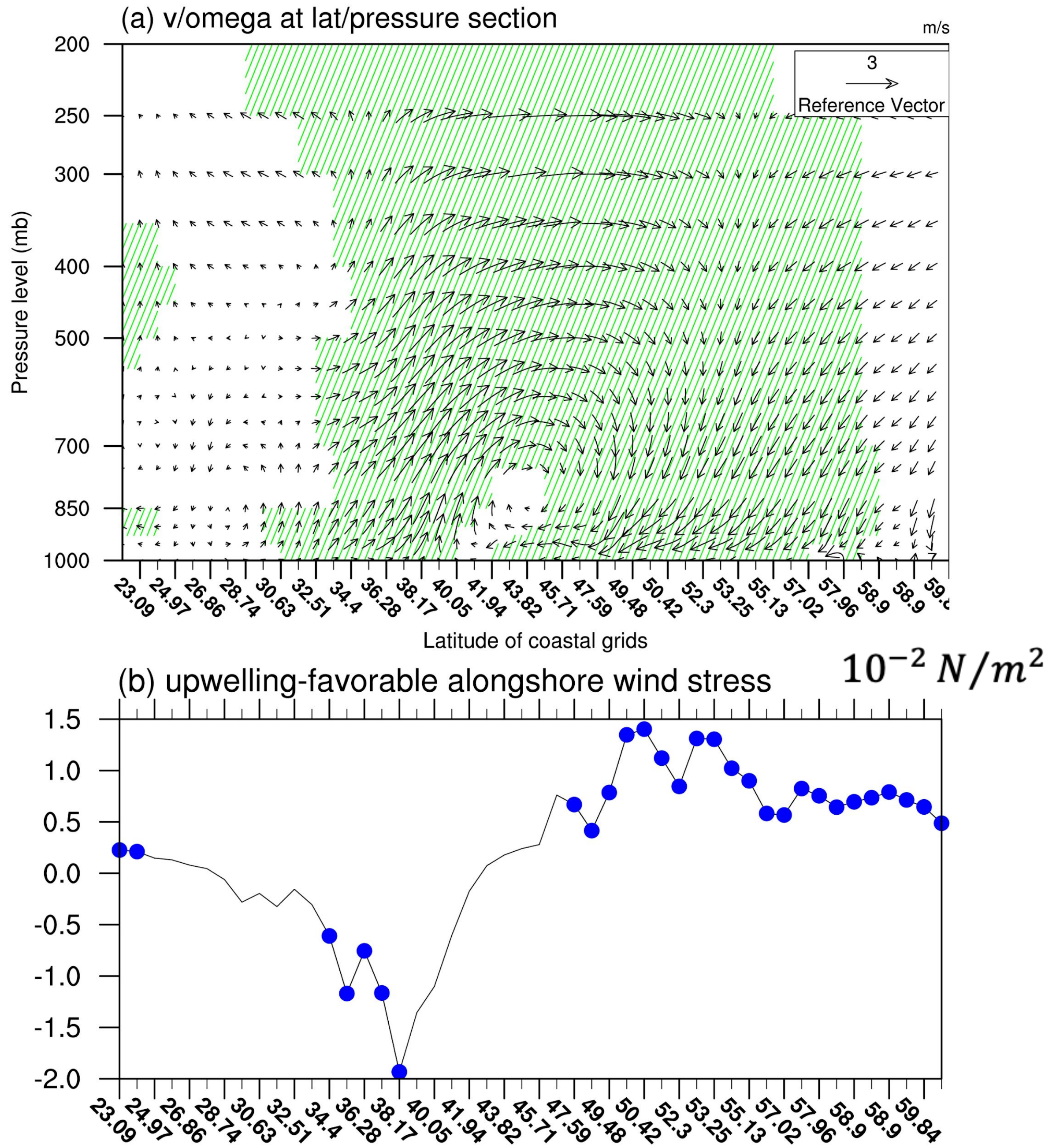
This figure illustrate the link between the forced changes in 500 hPa pressure vertical velocity and meridional wind using

Southerly wind (i.e., unfavorable for upwelling) and ascending anomalies are located between 32°N and 40°N.

Further north, northerly wind (i.e., favorable for upwelling) and descending anomalies occur from 43°N to 59°N.

Together they form an anomalous clockwise circulation

Hatching and dots indicate 95% significance

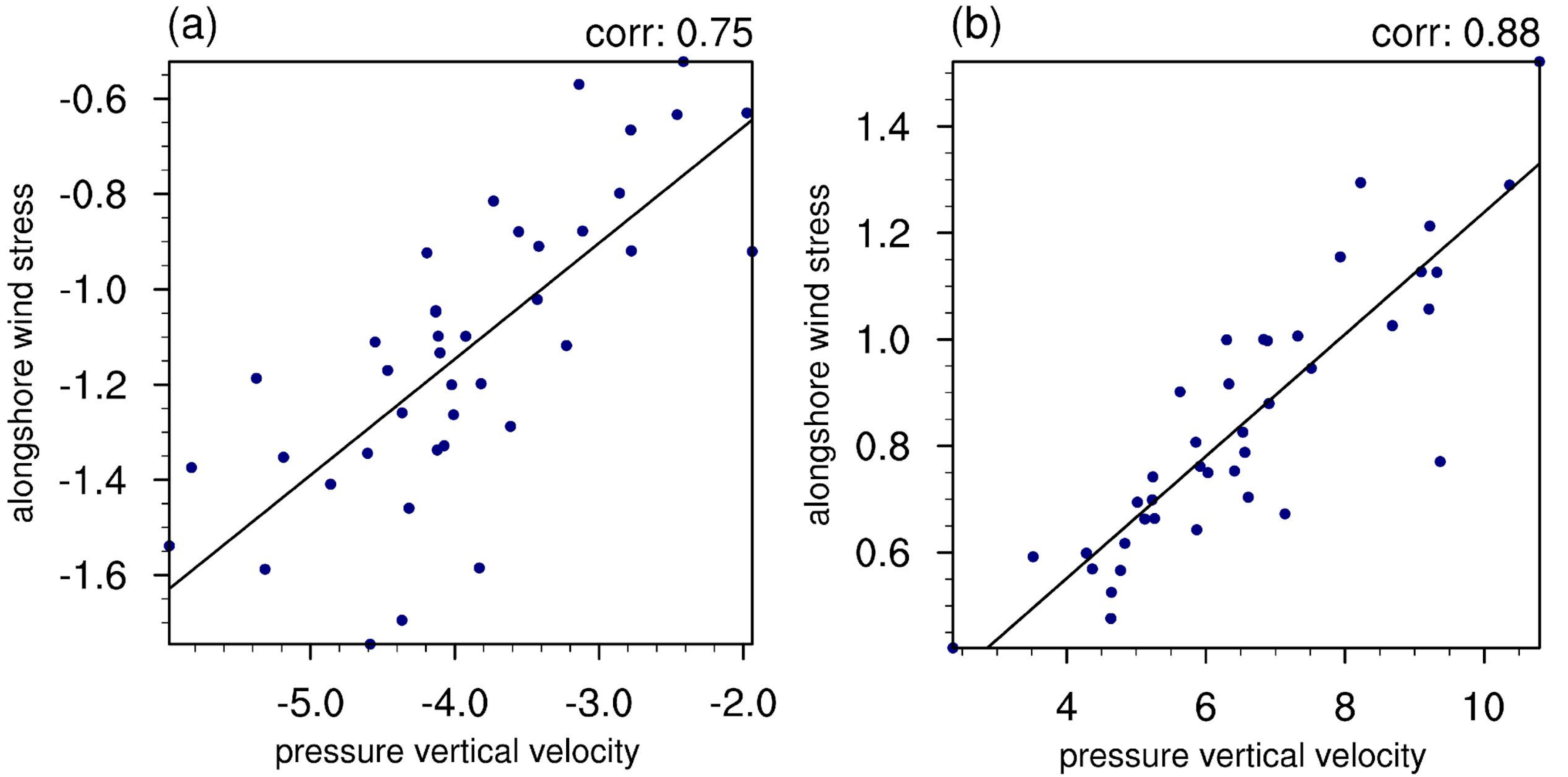


Message: the future changes in 500hPa pressure vertical velocity strongly modulates the future changes in upwelling-favorable alongshore wind stress along the North American west coast

One dot represents one ensemble member, and there are 40 ensemble members

Units are $10^{-2}\ Pa/s$ for the velocity and $10^{-2}\ N/m^2$ for the wind stress

Inter-member scatters between omega and upwelling winds in the south (left) and north (right)



Summary

- We examined the impact of the NPH on the upwelling winds along the North American west coast during summer, using the ERA5 and the CESM1 large ensemble of simulations
- The subsidence at 500 hPa is used to assess the NPH and its variability in addition to the surface high-pressure cell
- The strength of subsidence has a much larger effect on the interannual variability of upwelling winds than the surface high-pressure cell, although both are related to the winds
- Based on the mean of the 40 CESM simulations,
    - Future changes in upwelling winds more strongly coincide with changes in subsidence than in surface high-pressure cell
    - Subsidence and southward upwelling-favorable winds increase off the Canadian coast, with the reverse occurring off the US west coast, by the end of the 21st century
    - In particular, the inter-member correlation between the changes in the near-shore surface winds and the 500 hPa pressure vertical velocity reaches 0.75 and 0.87 in the southern and northern portion of the northeast Pacific, respectively

Thank you!

Summer mean upwelling-favorable alongshore wind stress