Nonlinear Ekman pumping and coastal upwelling off the Oregon coast

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Take home messages

The "spin" (vorticity) associated with surface currents in the coastal jet off the Oregon coast is strong enough to affect the spatial patterns of wind-driven upwelling and downwelling

Downwelling can occur over parts of the shelf during periods of upwelling-favorable winds. This may bring phytoplankton to lower light levels or concentrate buoyant particles

Questions

Where does upwelling occur (inshore/offshore)?

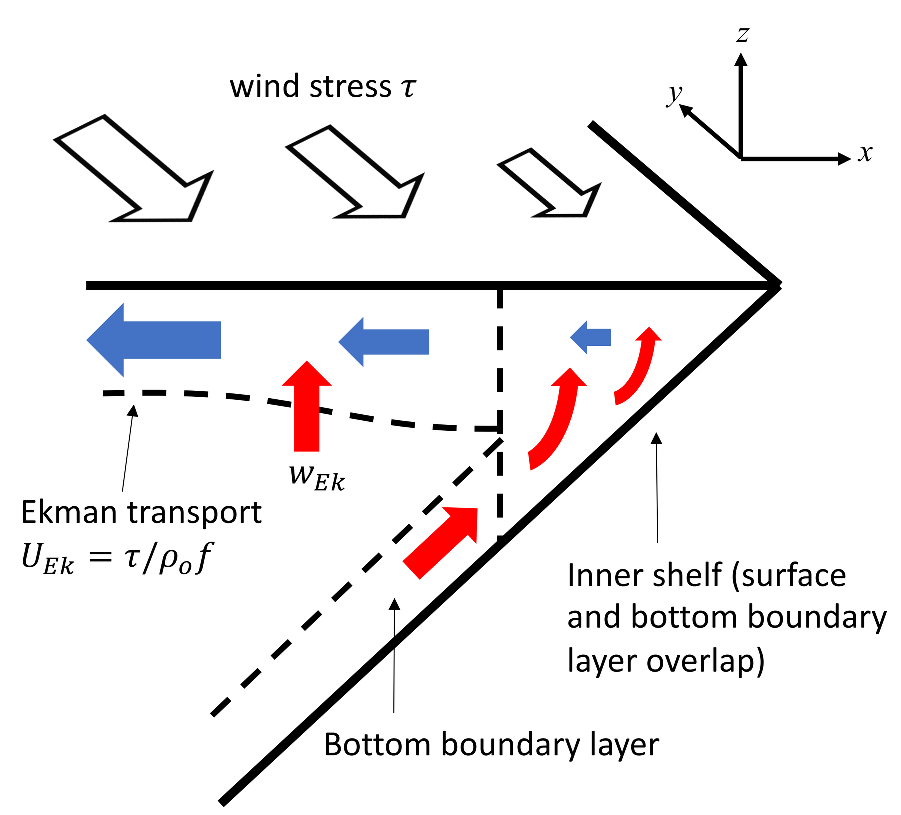
What processes drive upward motion?

Three potential mechanisms for wind-driven upward motion (w):

- Inner shelf upwelling
- Curl-driven Ekman pumping

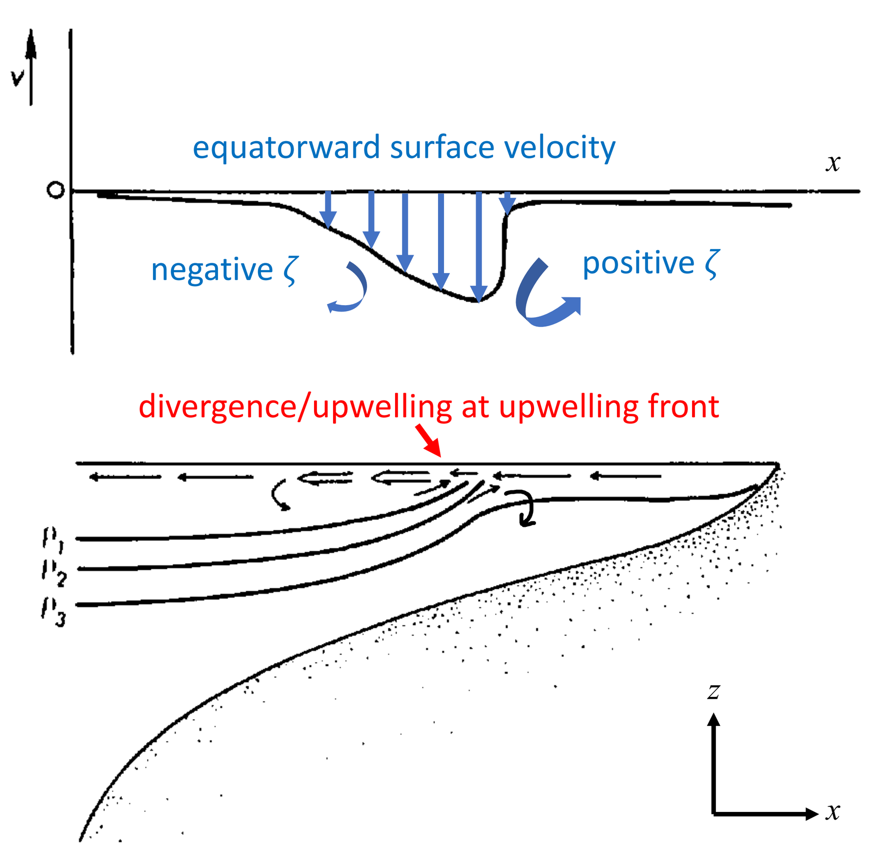
$$w_{Ek} = \nabla \times \left(\frac{\vec{\tau}}{\rho_o f}\right)$$

- Nonlinear Ekman pumping



Cartoon inspired by Jacox and Edwards (2012), Upwelling source depth in the presence of nearshore wind stress curl, *JGR*

Background: Nonlinear Ekman pumping



Cartoon adapted from Brink (1987) Upwelling fronts: implications and unknowns

Upwelling or downwelling can occur even if there is no wind stress curl if the relative vorticity ζ is comparable to f

$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

Nonlinear Ekman upwelling velocity:

$$w = \nabla \times \left[\frac{\vec{\tau}}{\rho_o (f + \zeta)}\right]$$

curl (spatial gradient)

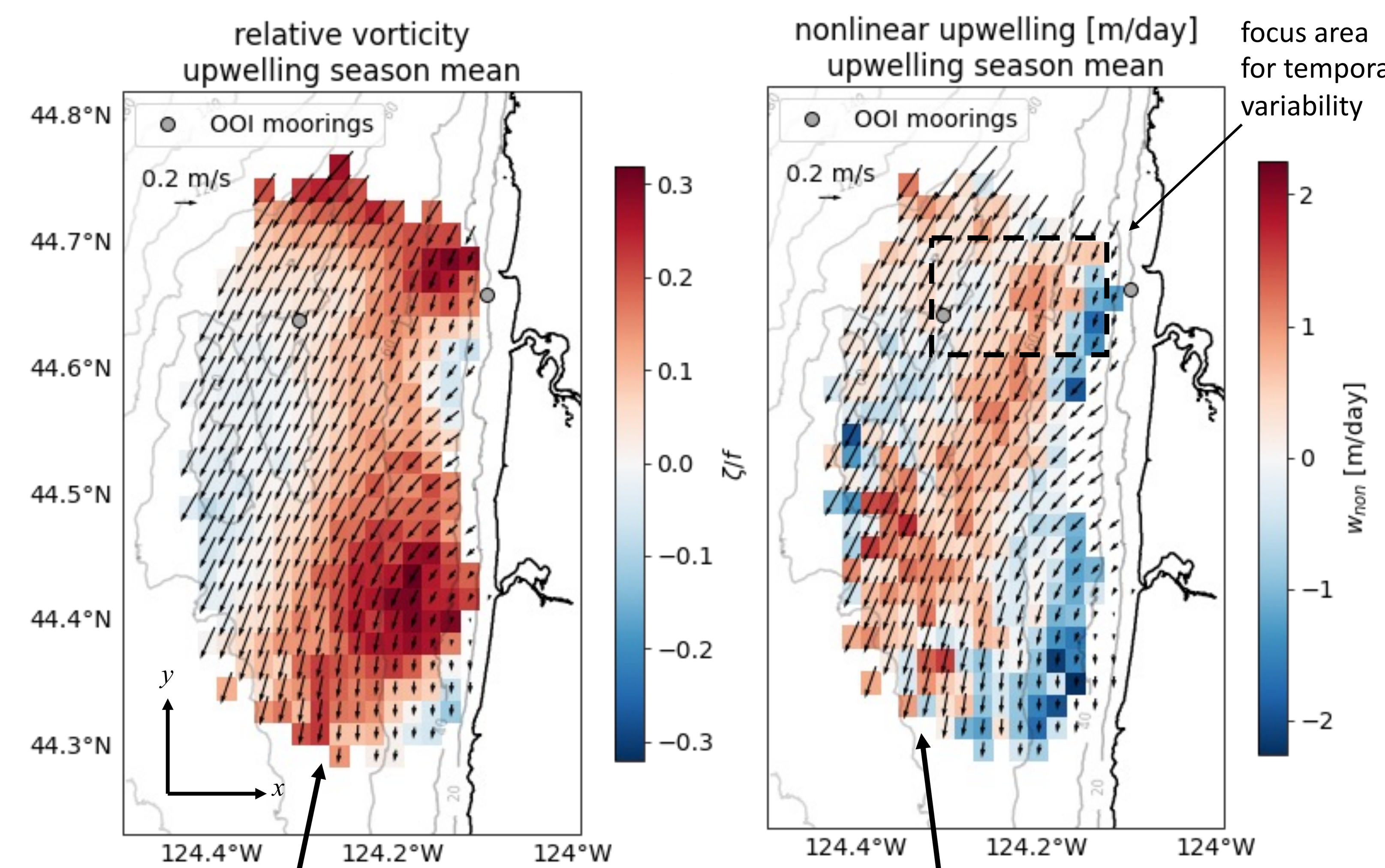
buoy wind stress (time-varying, spatially uniform)

Coriolis parameter (based on latitude)

relative vorticity from HF radar surface currents

Stern (1965) Interaction of a uniform wind stress with a geostrophic vortex. *Deep Sea Res.*

Spatial patterns



Strong positive (cyclonic) vorticity on inshore side of coastal jet

Range of ζ is a significant fraction of f (submesoscale dynamics)

HF radar observations reveal small-scale variability in the coastal jet (e.g. Kosro et al. 1997)

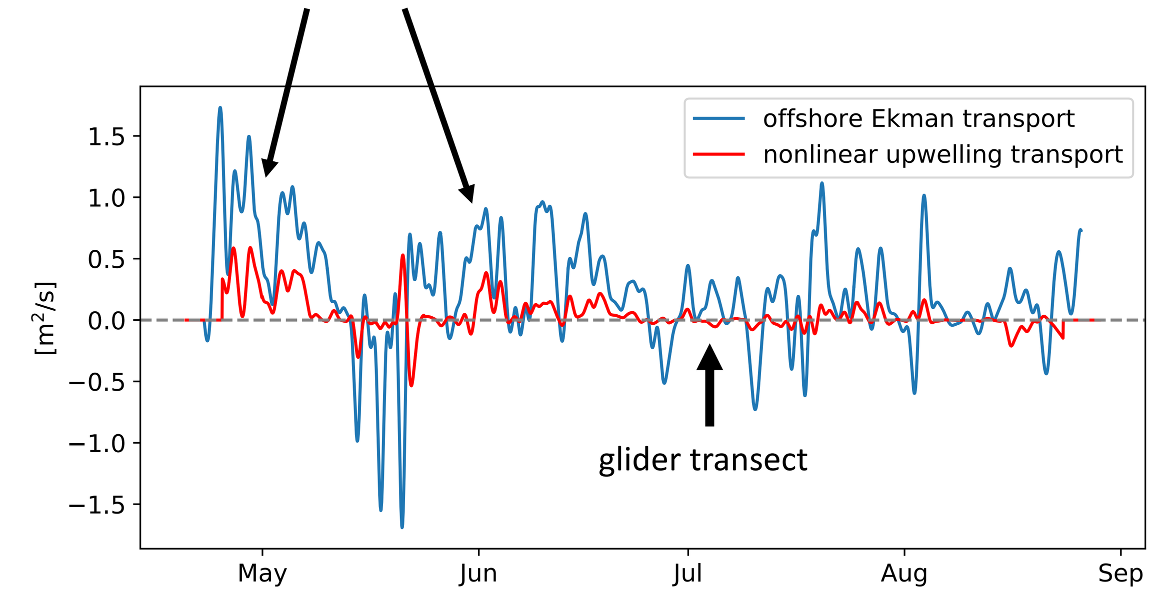
Theory indicates broad region of upwelling following coastal jet

Downwelling inshore of jet core

Kosro et al. (1997) The coastal jet: Observations of surface currents over the Oregon continental shelf from HF Radar, *Oceanography*

Temporal variability

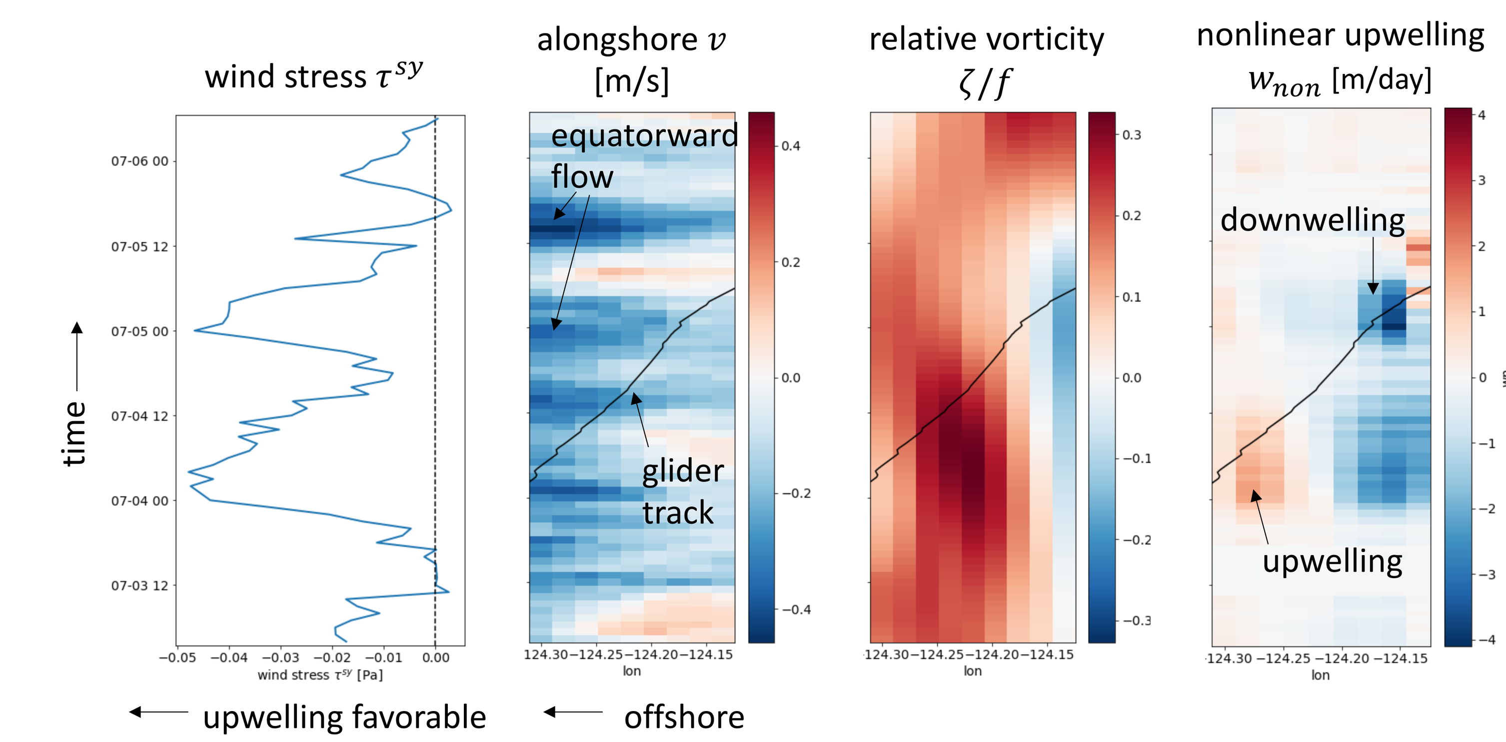
Upwelling transport (per m coastline) can be a substantial fraction of Ekman transport



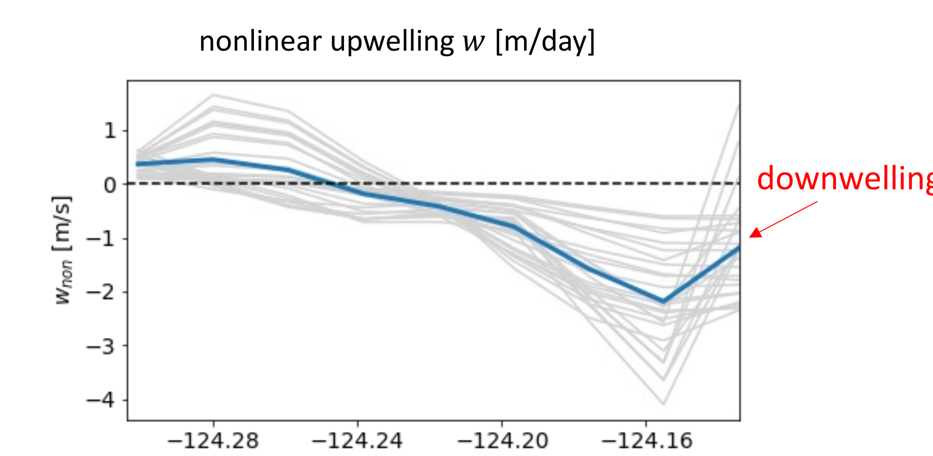
Contribution diminishes over course of upwelling season

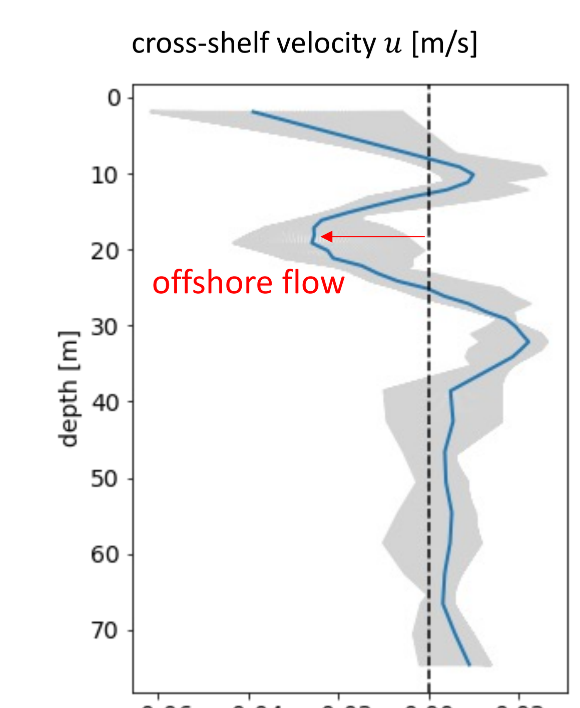
Detailed look at an equatorward wind event

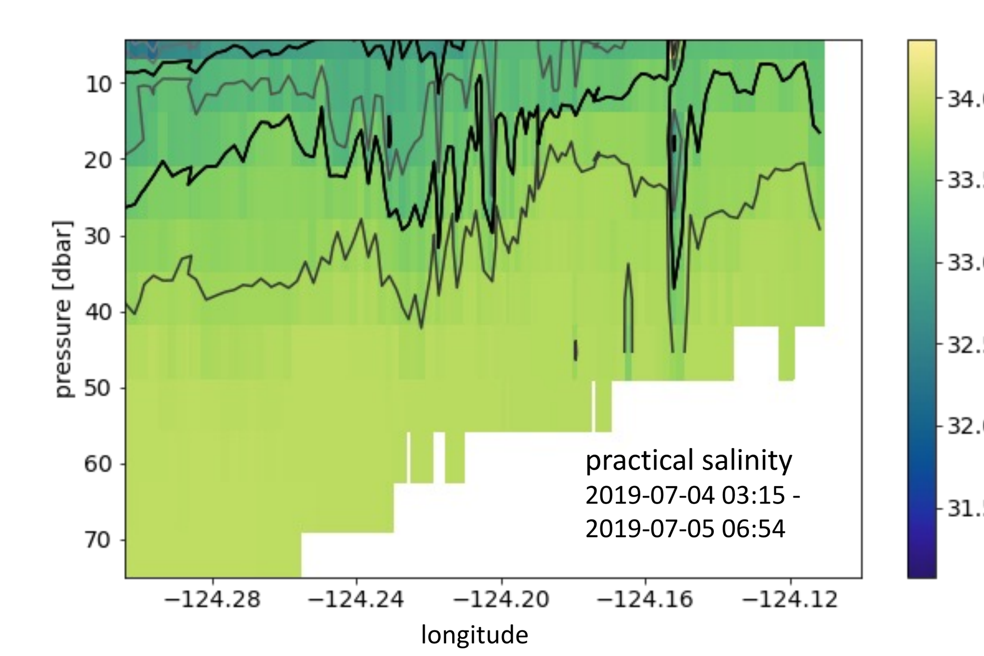
OOI glider transect extends inshore during a period of equatorward wind stress



Average vertical and cross-shelf velocities during glider transect







Complex offshore/offshore cross-shelf velocity profiles are consistent with theoretical upwelling/downwelling at similar salinity values.

Data sources

2019 upwelling season, as defined by Pierce and Barth (April 19 – August 28)

HF radar – 2km product provided by UCSD Coastal Observing Research and Development Center

Wind and ADCP current velocity and glider data from Ocean Observatories Initiative Oregon Shelf site

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