Key Points
- Interannual upwelling variability is studied in a regional ocean model that assimilates available satellite and in situ hydrographic data.
- Model vertical velocities elucidate upwelling variability not captured by traditional upwelling indices and proxies.
- Nearshore (<50km) and offshore (50-200km) upwelling variability are out of phase.
- Cross-shore upwelling structure is highly correlated with large-scale climate variability. Positive NPGO and negative PDO/ENSO favor nearshore upwelling, while negative NPGO and positive PDO/ENSO favor offshore upwelling.

Model Configuration
Regional Ocean Modeling System with 4-dimensional variational data assimilation (ROMS 4D-Var)
- United States west coast, 1988-2010
- 42 vertical levels
- 1/10° horizontal resolution
- ECMWF interim reanalysis forcing with Cross-Calibrated Multi-Platform wind
- Assimilated data:
  - Sea Surface Temperature (AHRM/Pathfinder, AMSR-E and MODIS-Terra)
  - Sea Surface Height (Aviso)
  - In situ temperature and salinity (XBTs, MMTs, CTDs and Argo profiling floats from EN3 data set)
For analysis, the domain is divided into northern, central, and southern regions

A Comparison of Upwelling Estimates
- Wind-based estimates overestimate upwelling south of 39N.
- Pressure-based (black) and observation-based (blue) winds diverge substantially in the Southern California Bight.
- All three estimates capture similar trends except in the SC Bight, where the Upwelling Index misses a significant increase seen in the model.

Interannual Variability
- The first EOF of vertical velocity anomalies in the central and northern CCS indicates that interannual upwelling variability nearshore (<50km) and offshore (50-200km) are of opposite sign.
- Trends in central PC1 and northern PC2 describe significantly increased nearshore upwelling and decreased offshore upwelling from 1988 to 2010 between Pt. Conception and Cape Blanco.

Upwelling and Climate Variability
- PDO is negatively correlated with nearshore upwelling throughout the CCS.
- NPGO has a positive correlation with nearshore upwelling, but only in the northern CCS.
- PDO and NPGO are positively correlated, reinforcing the impact of large-scale climate variability on upwelling.