The effect of vertical displacement of the California Undercurrent and alongcoast advection on the Pacific Northwest shelf

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PICES 2016

November 8, 2016

PNWTOX

CMG

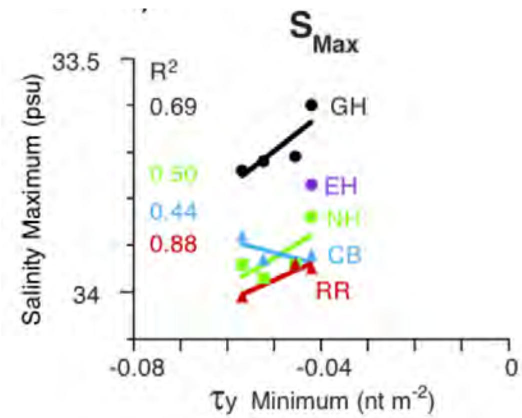
UW Coastal Modeling Group

IGERT PROGRAM ON OCEAN CHANGE

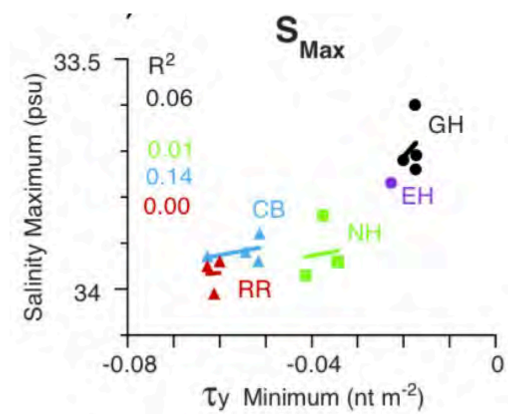
Drivers of Variability in the NCCS

- Importance of winds in NCCS:
  - Remote winds (39˚N) and weaker local winds drive upwelling and downwelling.
  - Remote winds drive propagation of coastal trapped waves that enhance alongcoast flows, including the CUC.
- California Undercurrent (CUC) variability in:
  - Depth
  - Composition
  - Velocity
- Variability in large-scale alongcoast advection
  - Intrusions of northern water
  - Influence of NPGO, PDO, ENSO on source of water in NCCS.

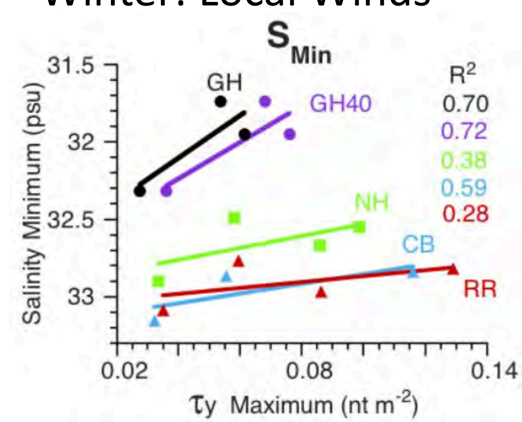
Summer: Remote Winds



Summer: Local Winds



Winter: Local Winds



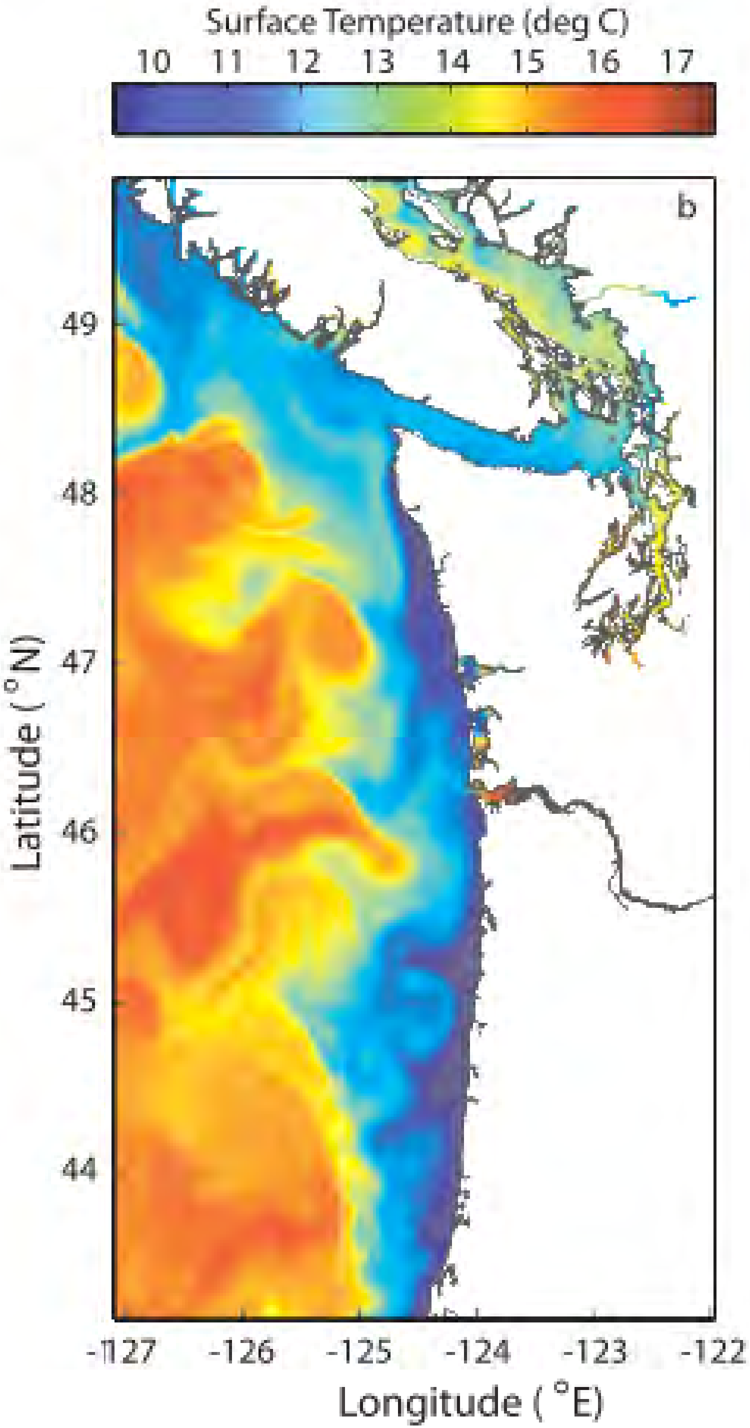
From Hickey, et al., *JGR,* in press

Questions

- How does variability in the depth and composition of the CUC affect mid-shelf bottom water variability?
- How does large-scale alongcoast advection affect the source of water on both upper slope and subsurface shelf?
- How might these mechanisms affect shelf water chemistry?

Methods: Overview

- Analyzed both Eulerian and Lagrangian analyses from the *Cascadia* model, a ROMS hindcast model developed by UW Coastal Modeling Group.
- Eulerian: water properties on the mid-shelf bottom and upper slope.
- Lagrangian: water origin on the subsurface shelf and upper slope.



Cascadia Model

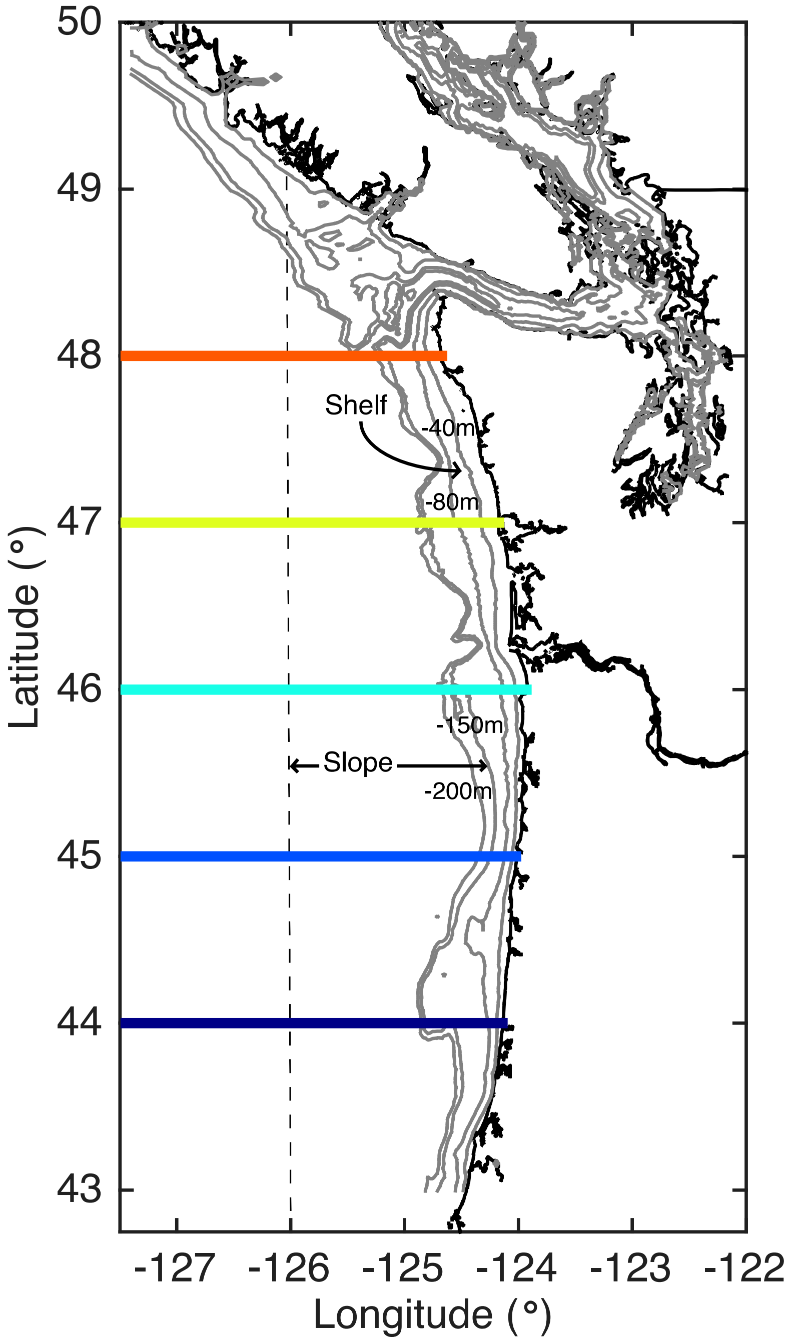
- PNWTOX-Cascadia model developed under PNWTOX (Giddings et al, *JGR*,2014) by the UW Coastal Modeling Group.
  - Utilizes Regional Ocean Modeling System (ROMS)
  - 8 year physical hindcast (2002-2009).
  - Includes the Salish Sea and coastal oceans and estuaries of WA, OR, VI, and BC.
  - Horizontal resolution: 1.5 km over shelf and slope; 4.5 km offshore.
  - Vertical resolution: 40 σ-layers.
- Giddings, et al., 2014 used observational data to validate the model.
  - Coastal upwelling, the position, strength, and seasonality of the CUC, and coastal-trapped waves are well represented by the model.
- Caveat: deep salinity bias (0.2 fresher) inherited from NCOM.
  - Expected bias in f_{PEW} : ~0.05.
  - Impact limited by removal of seasonal cycle.

Model Forcing

- Ocean:
  - Southern and Western boundaries initialized and forced by the global Navy Coastal Ocean Model (NCOM)
  - Northern Boundary is closed at Johnstone Strait.
- Tides:
  - Tidal regimes from the 1/4° TPXO7.2 inverse global tidal model (Egbert and Erofeeva, 2002).
- Rivers:
  - Daily discharge data for all 16 major rivers from US Geological Survey and Environment Canada.
- Atmosphere:
  - All atmospheric initial conditions and forcings are from the MM5 regional forecast model (Mass et al, 2003).
- More information can be found in Giddings, et al., *JGR*, 2014.

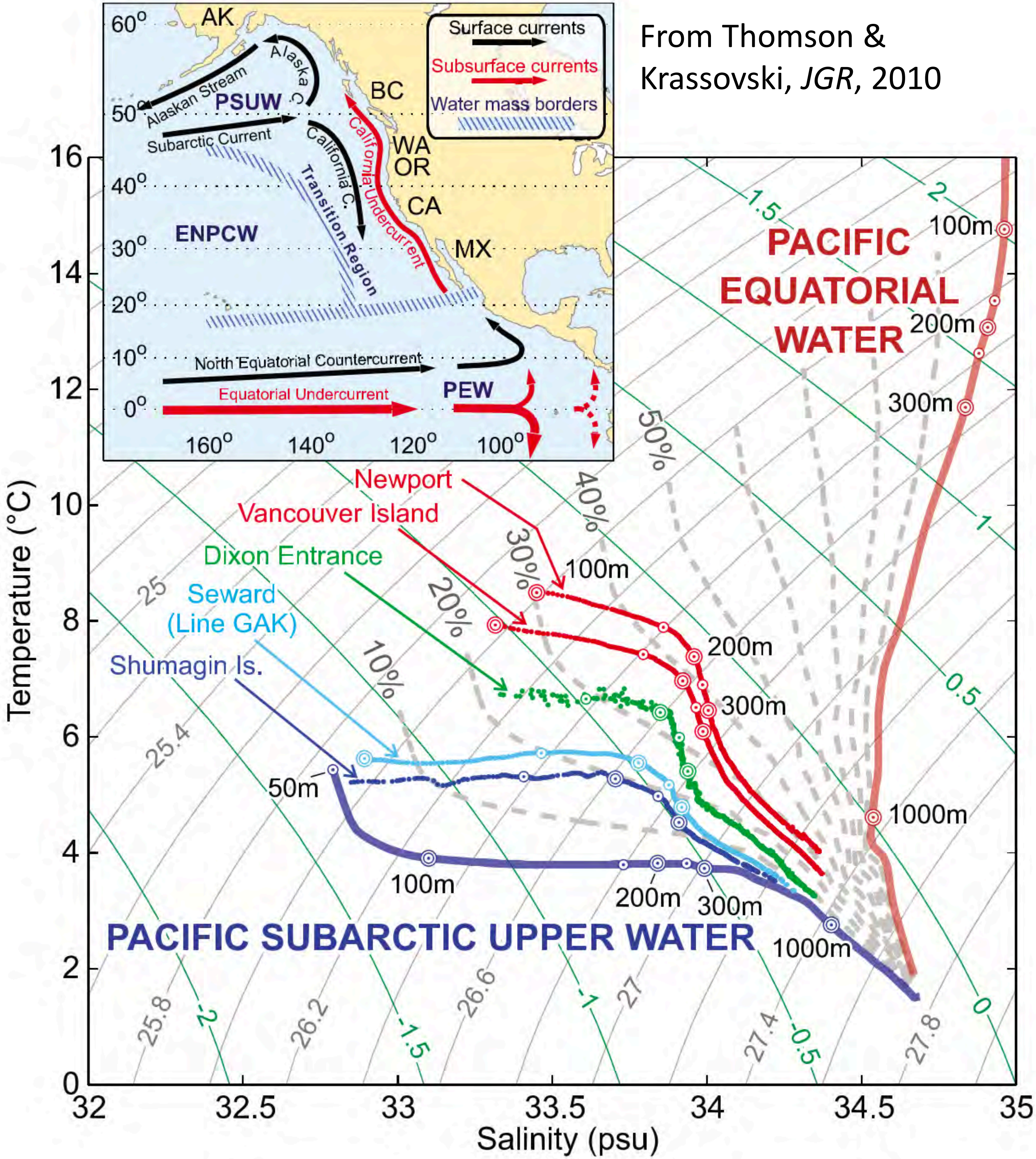
Eulerian Analysis

Q1: How does variability in the depth and composition of the CUC affect mid-shelf bottom water variability?



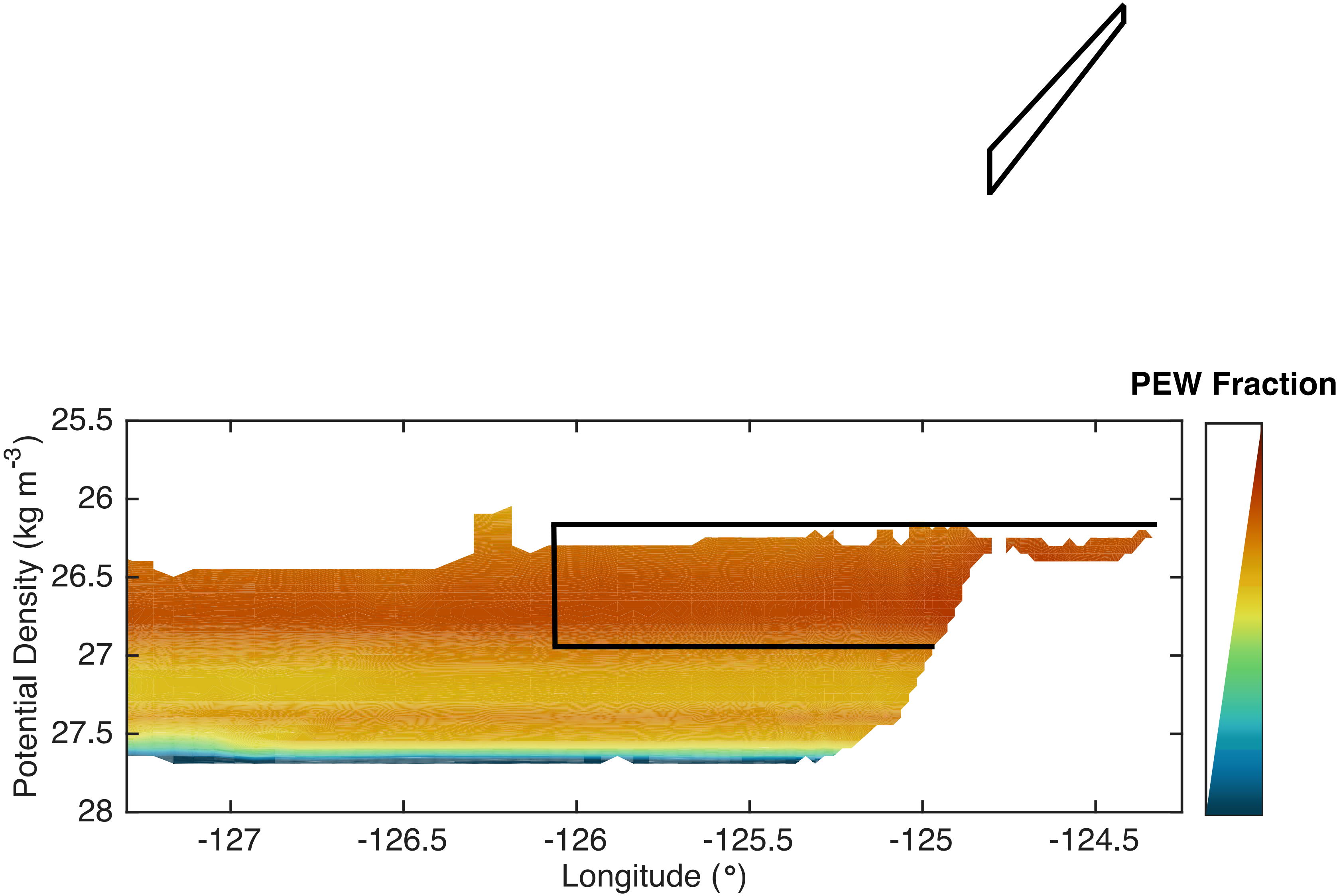
Model Output

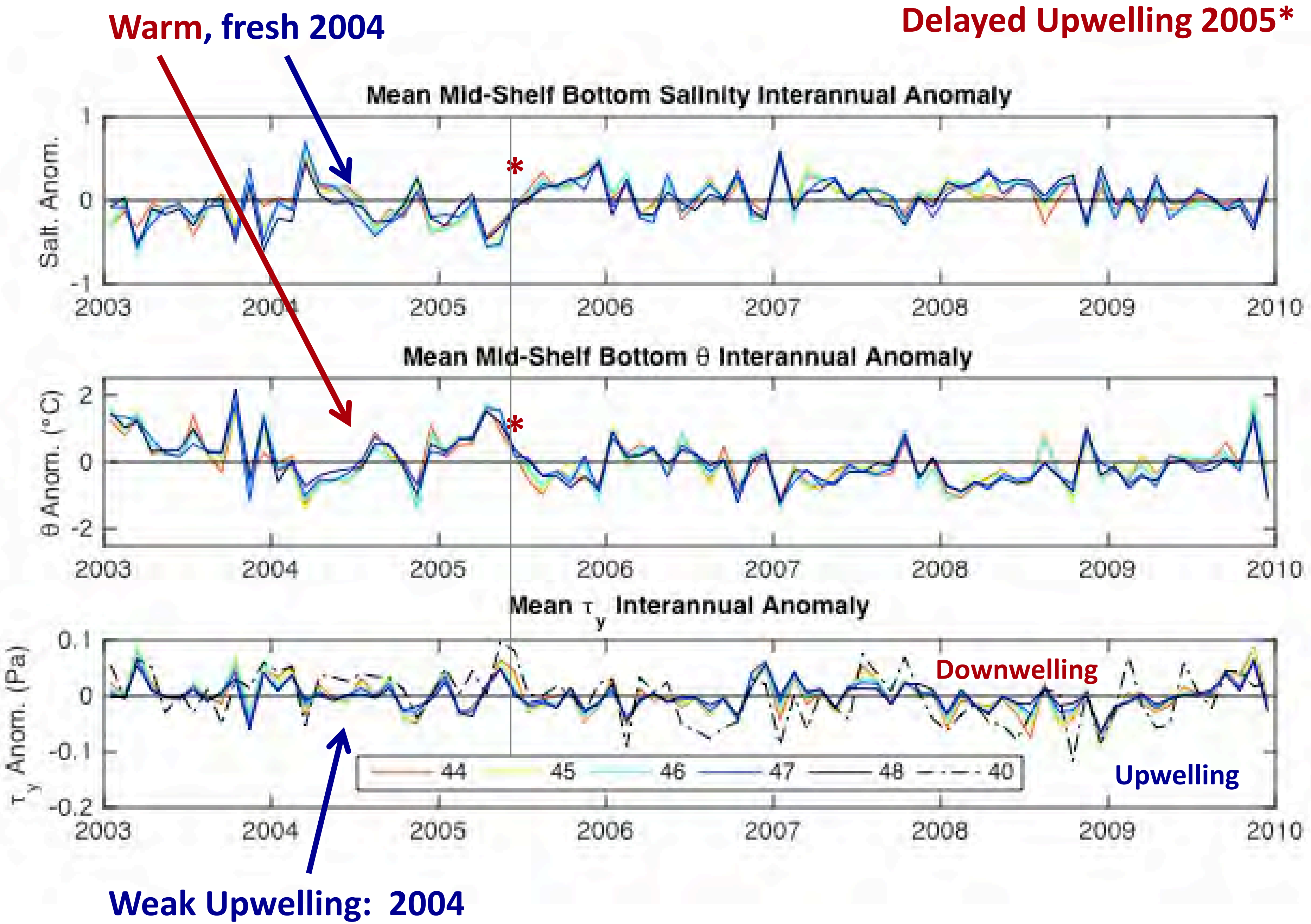
- Analysis spans 2003 through 2009.
  - Removed 2002 as spin-up year.
- A 30-day Hanning filter was applied to the model's daily output to get monthly values.
- Interannual anomalies were calculated by removing the seasonal cycle (mean monthly value).
- Analysis focused on mid-shelf bottom and upper slope water along each latitude from 44˚N – 48˚N.
  - Shelf water properties: salinity, temperature.
  - Slope water properties: temperature, salinity, Pacific Equatorial Water Fraction (f_{PEW}), depth of the σ_t = 26.5 kg m^{-3} isopycnal ($z_{26.5}$).
- Alongshore wind stress also used, and is from model forcing (MM5).



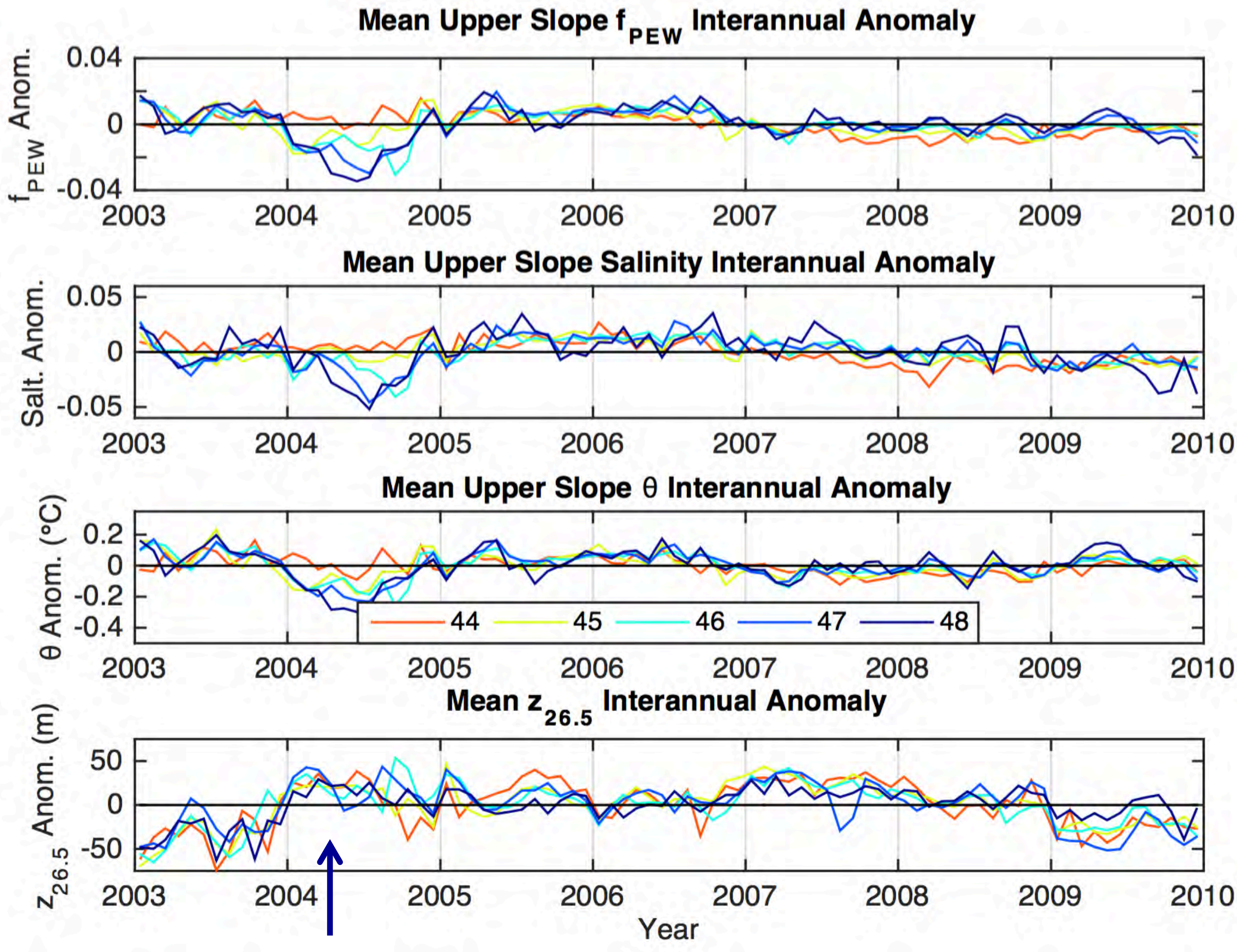
From Thomson & Krassovski, *JGR*, 2010

- Pacific Equatorial Water (PEW):
  - Warm (7˚C – 23˚C)
  - Salty (34.5 – 36.0)
- Pacific Subarctic Upper Water (PSUW):
  - Cold (3˚C – 15˚C)
  - Fresher (32.6 – 33.6)
- % PEW declines as CUC flows poleward as PEW mixes with PSUW.


PEW Fraction
Potential Density (kg m^{-3})
25.5
26
26.5
27
27.5
28
-127
-126.5
-126
-125.5
-125
-124.5
Longitude (°)

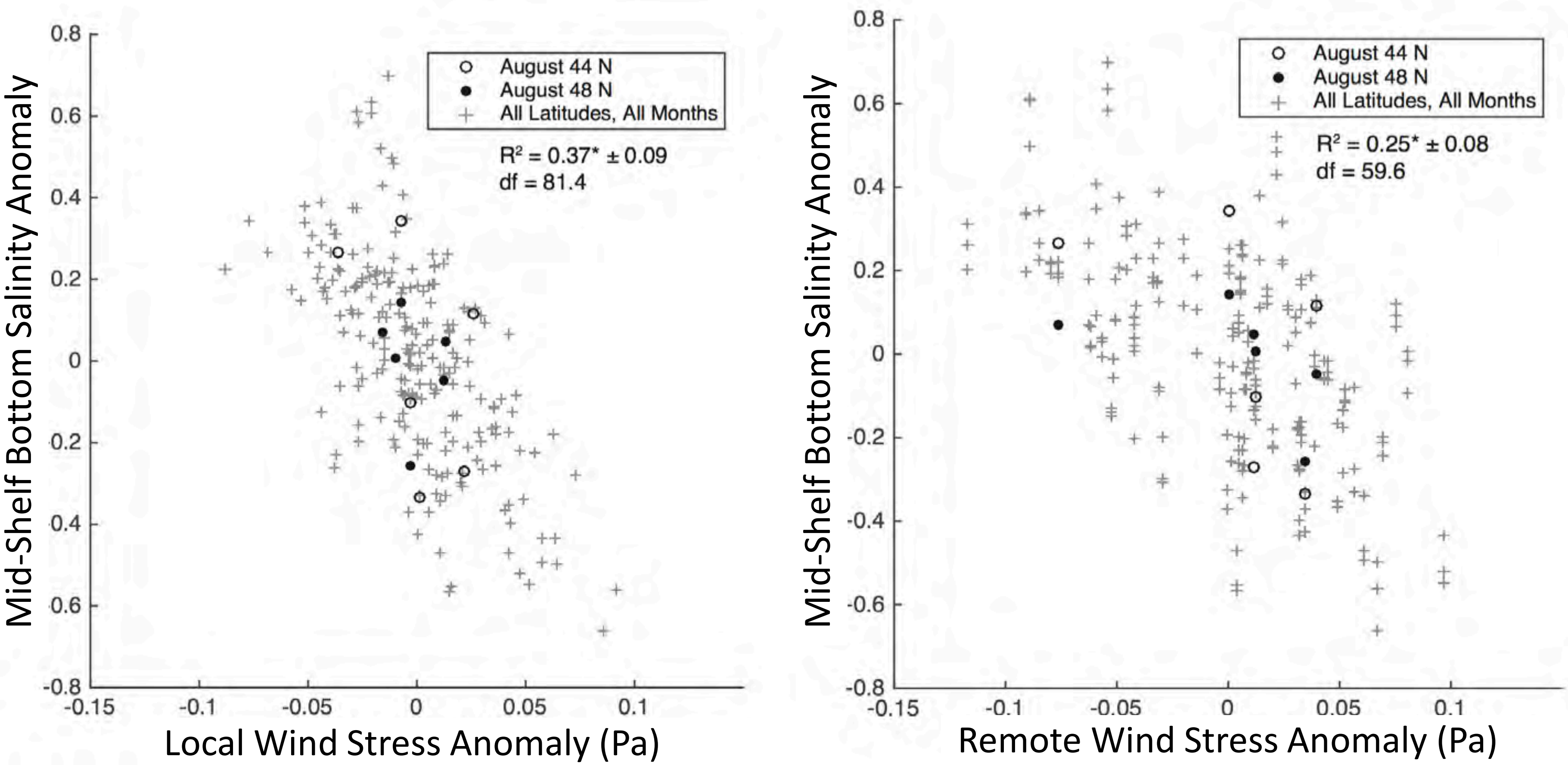


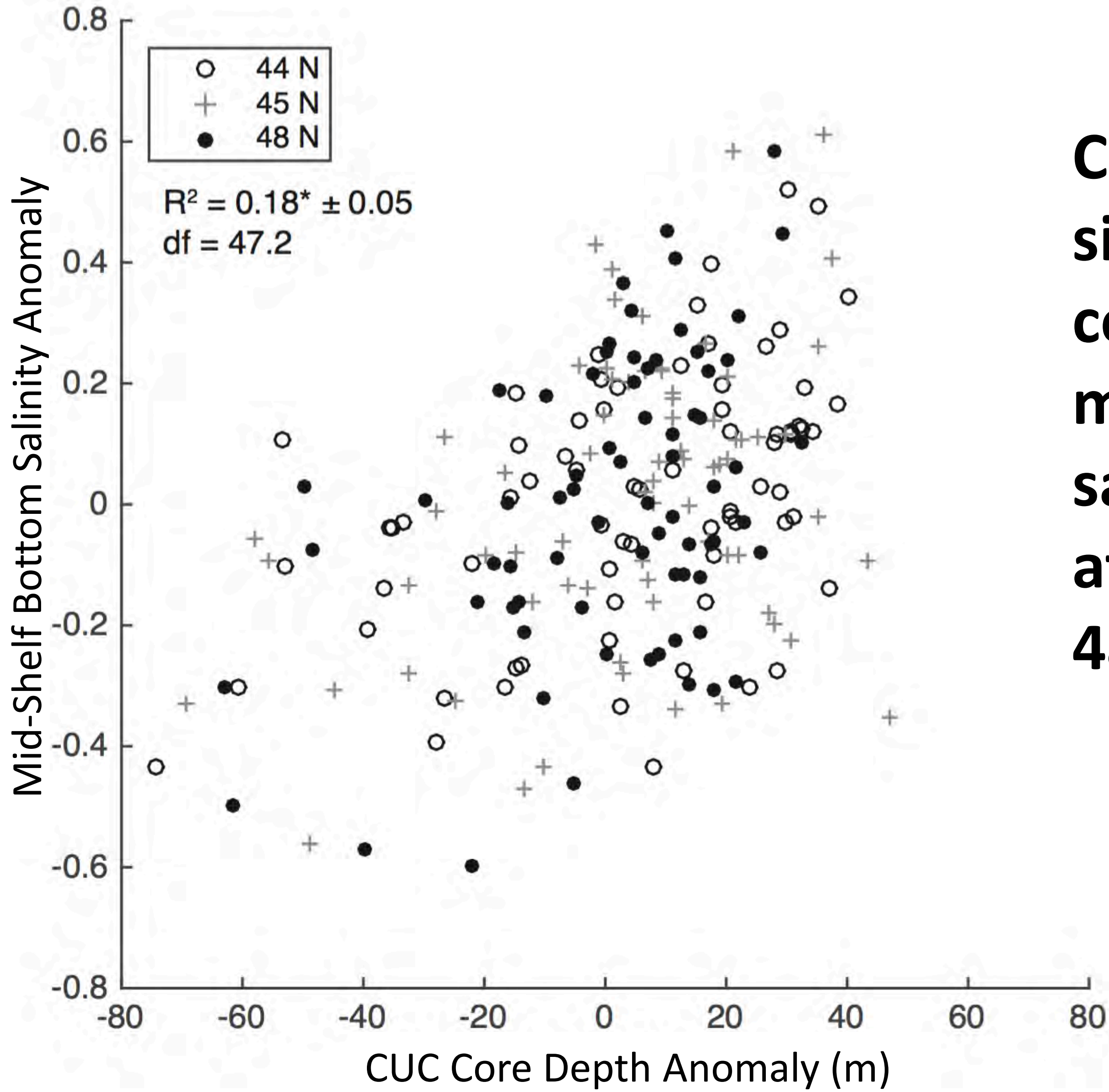
Warm, fresh 2004
Delayed Upwelling 2005*
Mean Mid-Shelf Bottom Salinity Interannual Anomaly
Salt. Anom.
Mean Mid-Shelf Bottom θ Interannual Anomaly
θ Anom. (°C)
Mean τy Interannual Anomaly
τy Anom. (Pa)
Downwelling
Upwelling
44
45
46
47
48
40
Weak Upwelling: 2004



Mean Upper Slope f_{PEW} Interannual Anomaly
f_{PEW} Anom.
0.04
0
-0.04
2003
2004
2005
2006
2007
2008
2009
2010
Mean Upper Slope Salinity Interannual Anomaly
Salt. Anom.
0.05
0
-0.05
Mean Upper Slope θ Interannual Anomaly
θ Anom. (°C)
0.2
0
-0.2
-0.4
44
45
46
47
48
Mean $z_{26.5}$ Interannual Anomaly
$z_{26.5}$ Anom. (m)
50
0
-50
Year
Shallower CUC: 2004

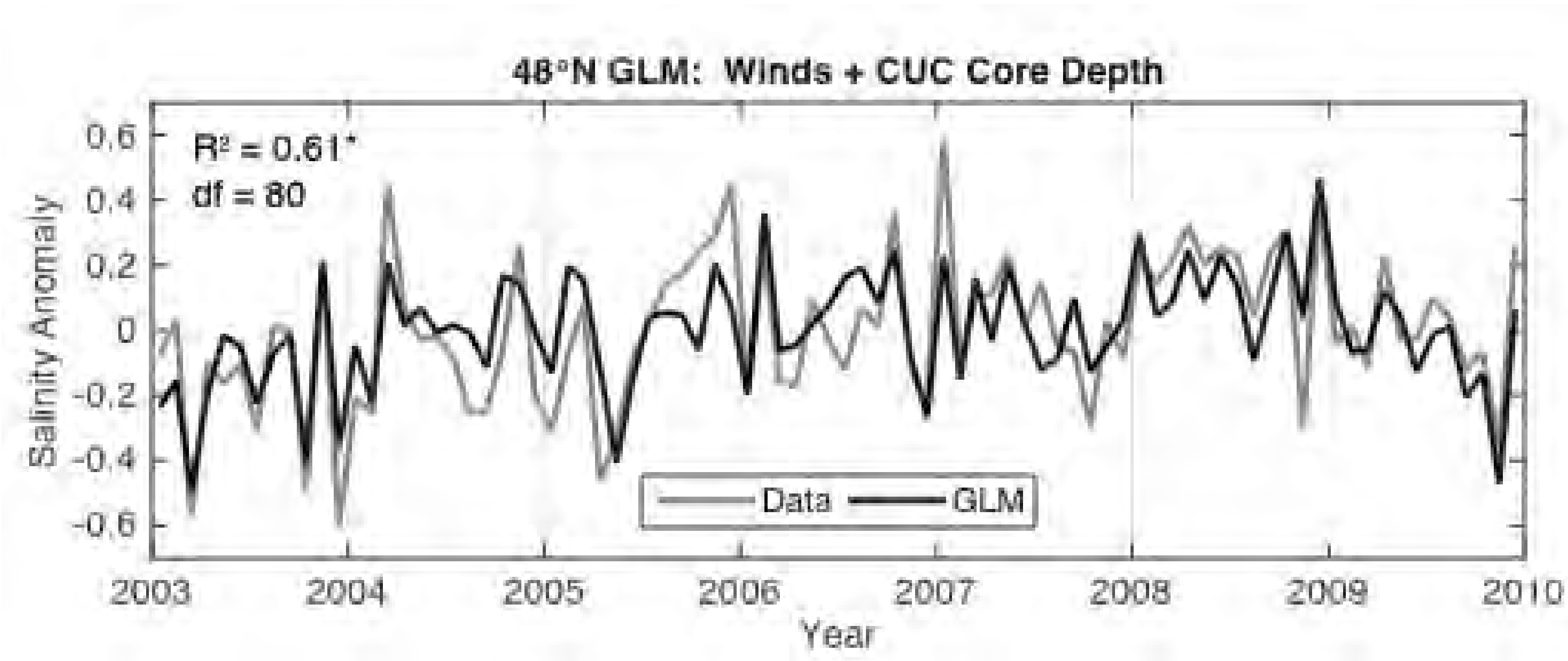
Mid-shelf bottom salinity is correlated with local and remote wind stress.





CUC core depth is significantly correlated with mid-shelf bottom salinity anomalies at 44˚N, 45˚N, and 48˚N.

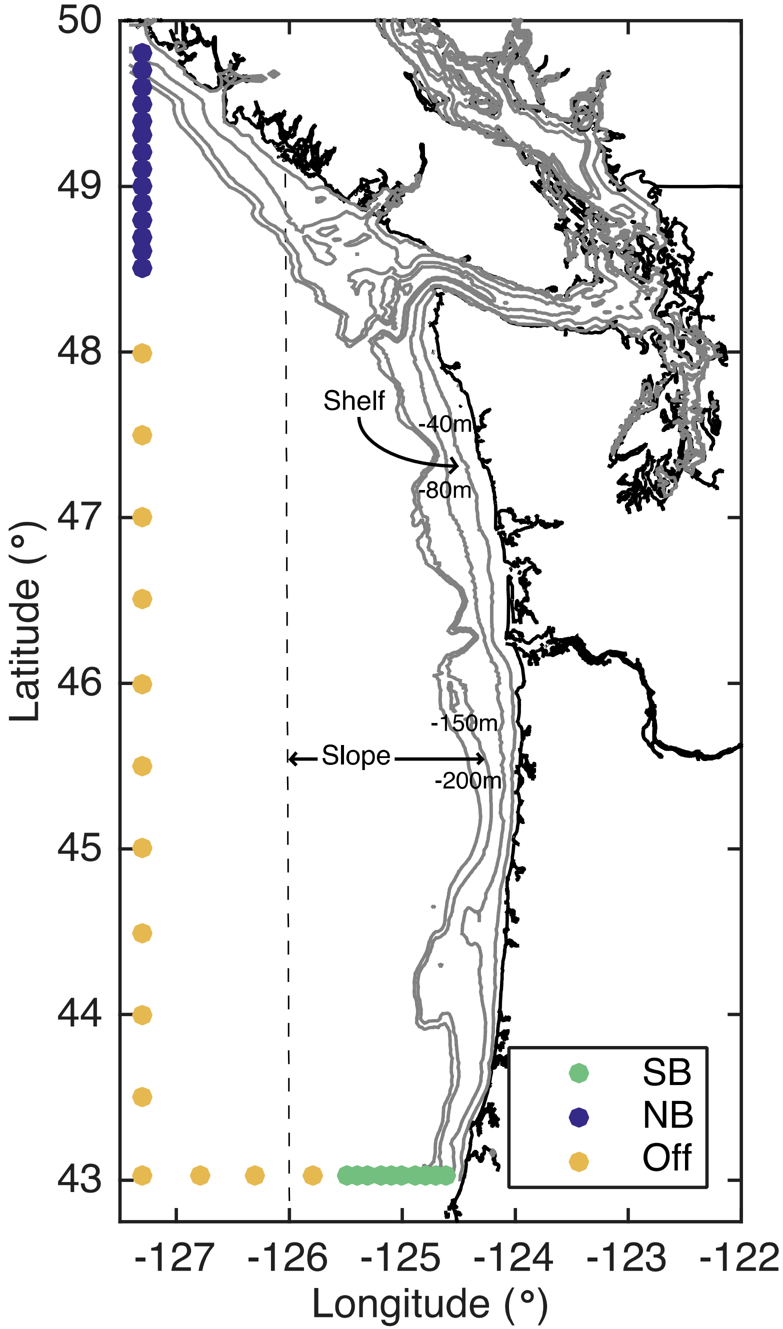
Together, winds and CUC depth explain 50% of shelf salinity variability.



- Created a GLM composed of local and remote wind stress anomalies and anomalies in CUC core depth to reconstruct mid-shelf bottom salinity anomalies.
- Mean R^2 = 0.50; best fit at 48˚N (R^2 = 0.61).

Lagrangian Analysis

Q2: How does large-scale alongcoast advection affect the source of water on both upper slope and subsurface shelf?



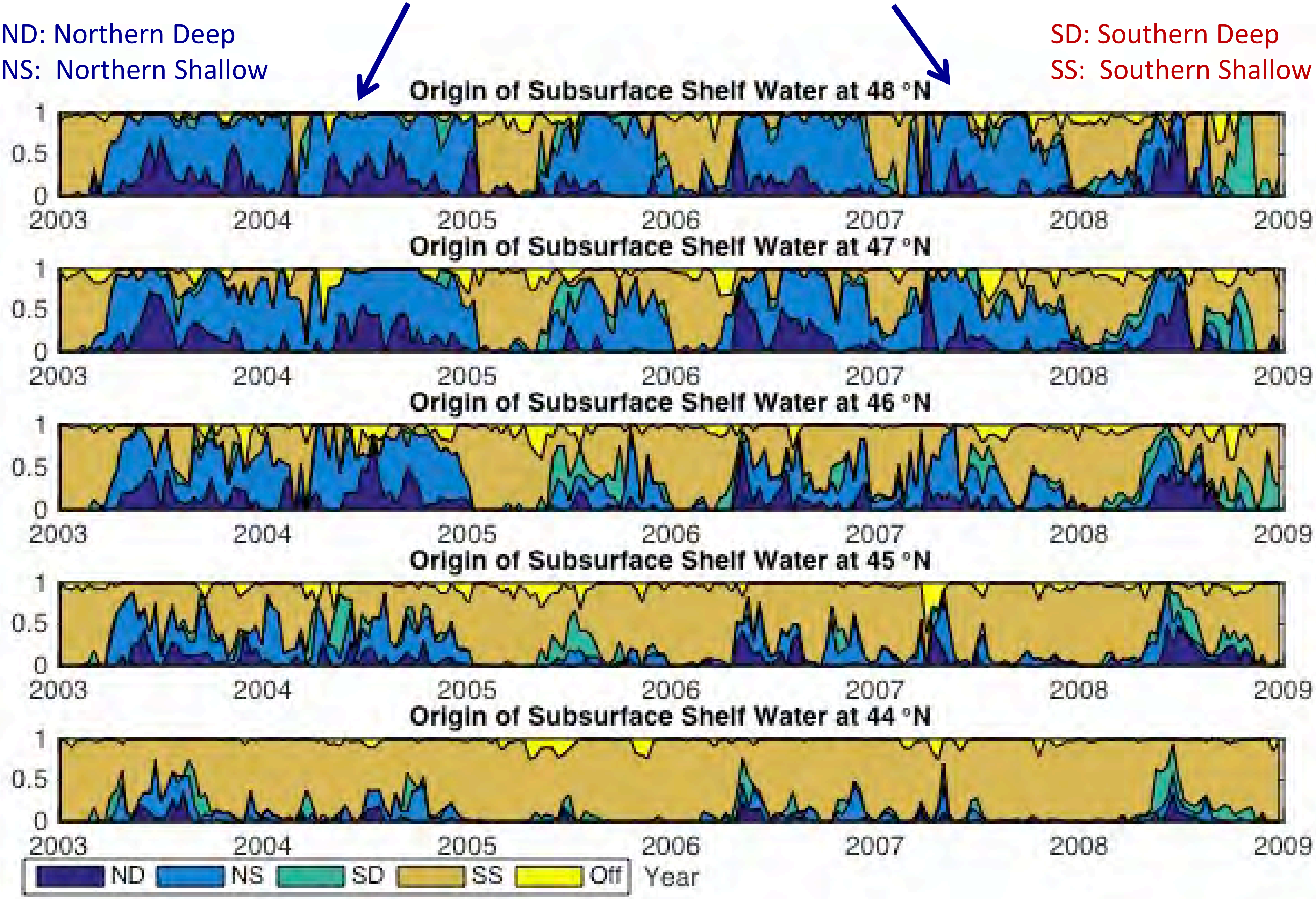
Lagrangian Analysis

- Jan 2002 – Nov 2008: 3 million particles released at 38 points along model boundaries at every tenth of the water column depth.
  - Particles tracked in three dimensions until move outside domain or are "beached".
  - Excluded particles:
    - That exit within first three days of release.
    - That are released when flow was outward.
    - Once they enter the Salish Sea.
  - Remaining: 400,000 particles.
- Particle Origins:
  - Southern Boundary (SB): Green
  - Northern Boundary (NB): Blue
  - Offshore (Off): Yellow
  - SB & NB divided into "shallow" (released above 150 m) and "deep" (released below 150 m).
- Analysis focuses on particles that are found over the upper slope (150 m – 500 m, 126˚W to shelf break) and subsurface shelf (between 40 m and 80 m isobaths; bottom ½ of water column) at any time.
  - Divided into 1˚ latitude-wide bands.
- Calculated fraction of water origin at each time step.

Intrusions of Northern Boundary Deep Water

ND: Northern Deep
NS: Northern Shallow

SD: Southern Deep
SS: Southern Shallow



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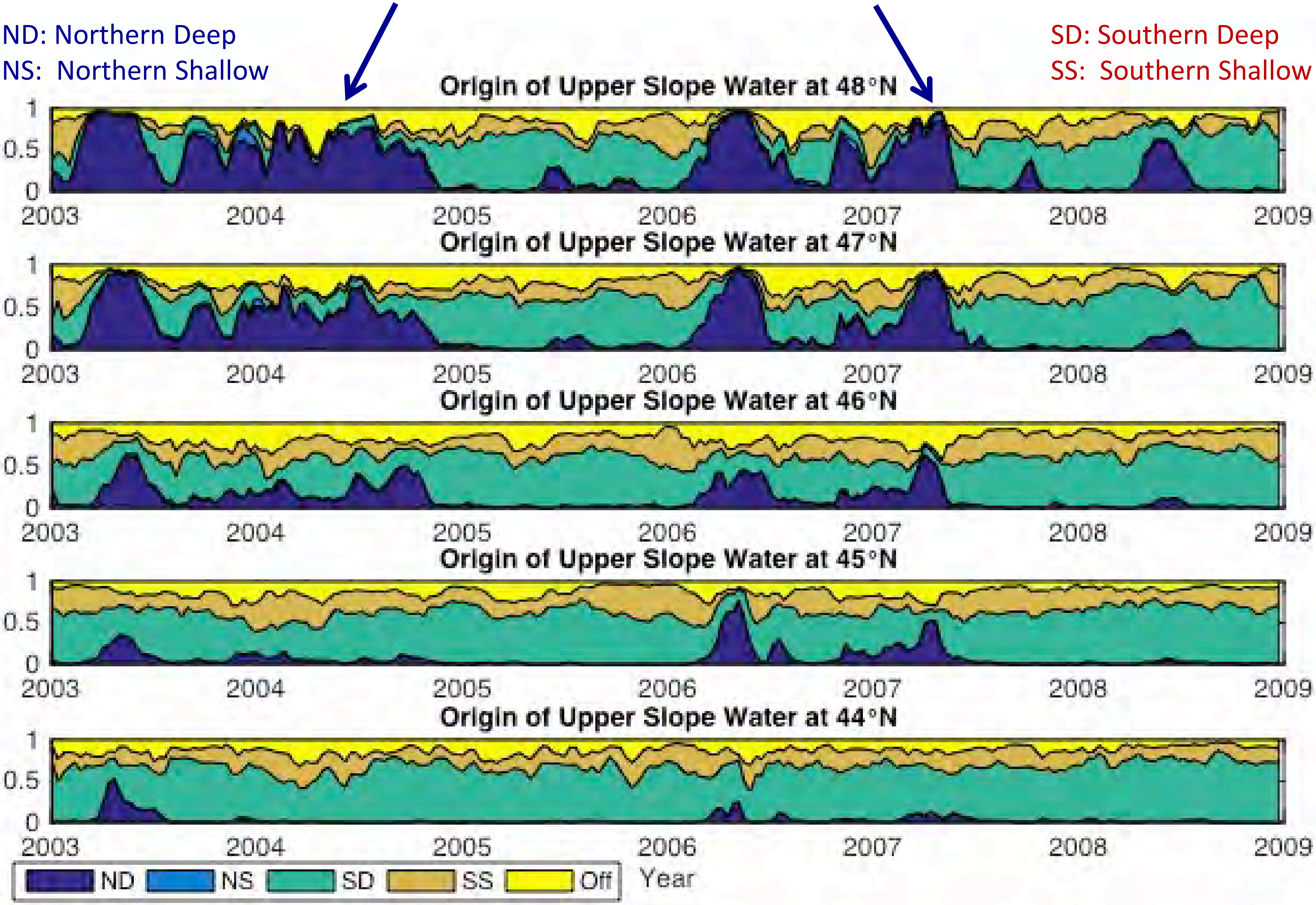
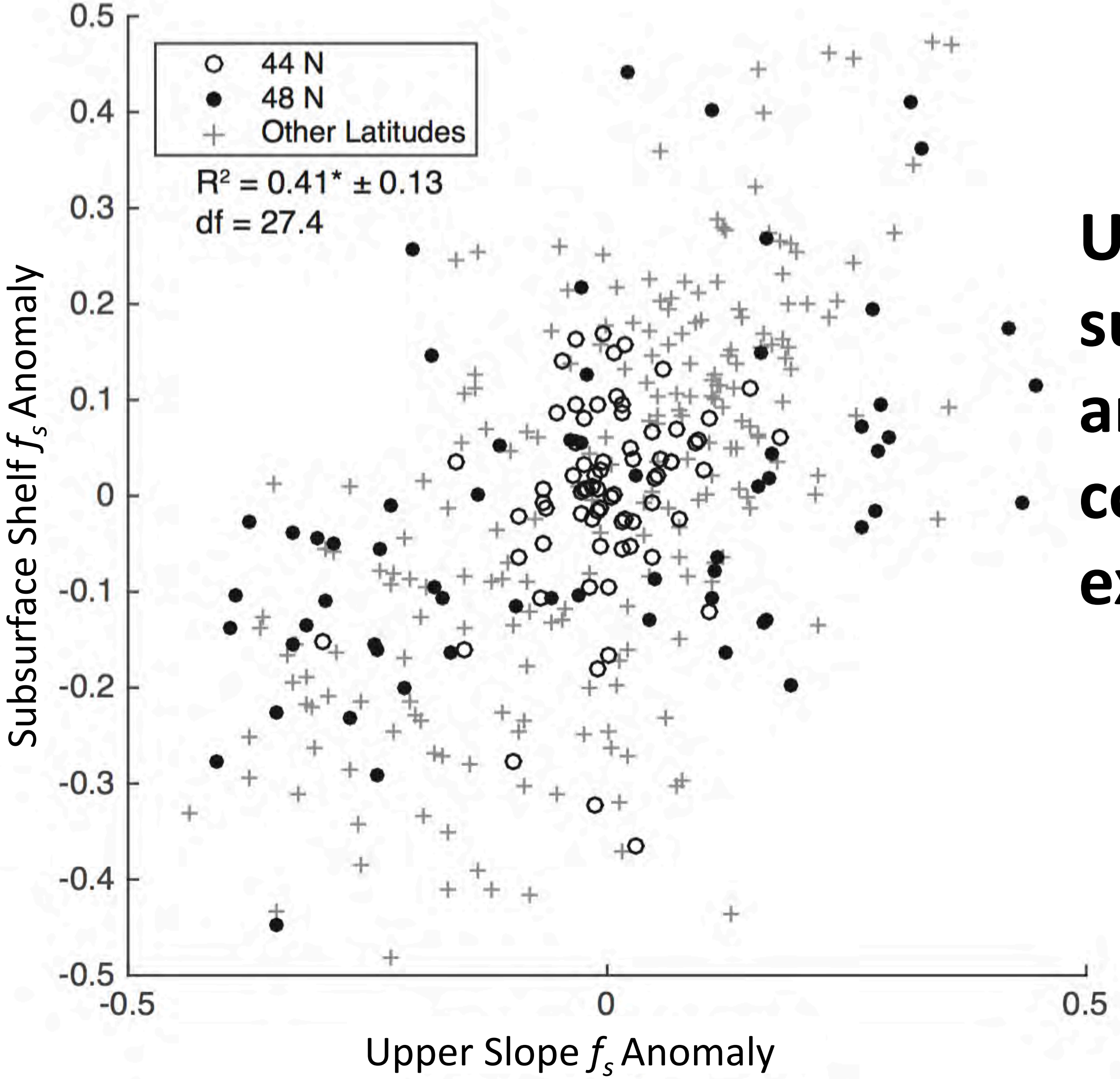


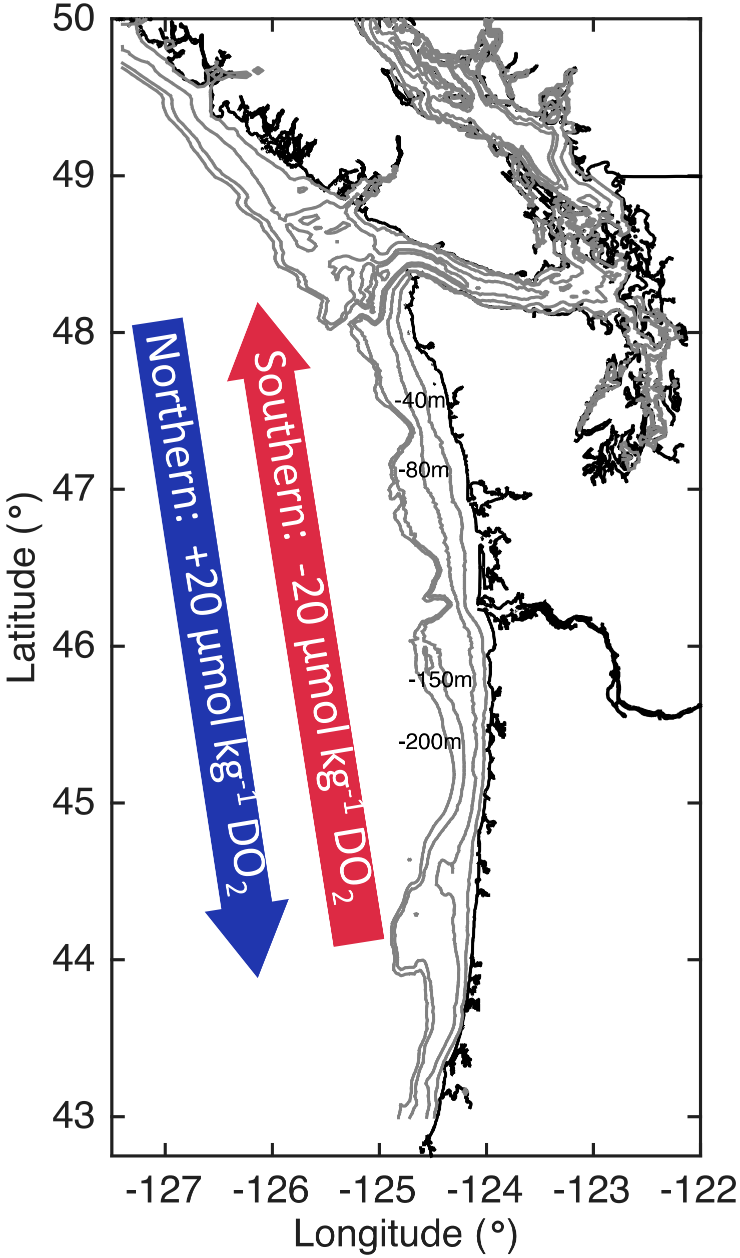


Upper slope and subsurface shelf f_s are significantly correlated, excluding 44˚N.

Application to Chemistry

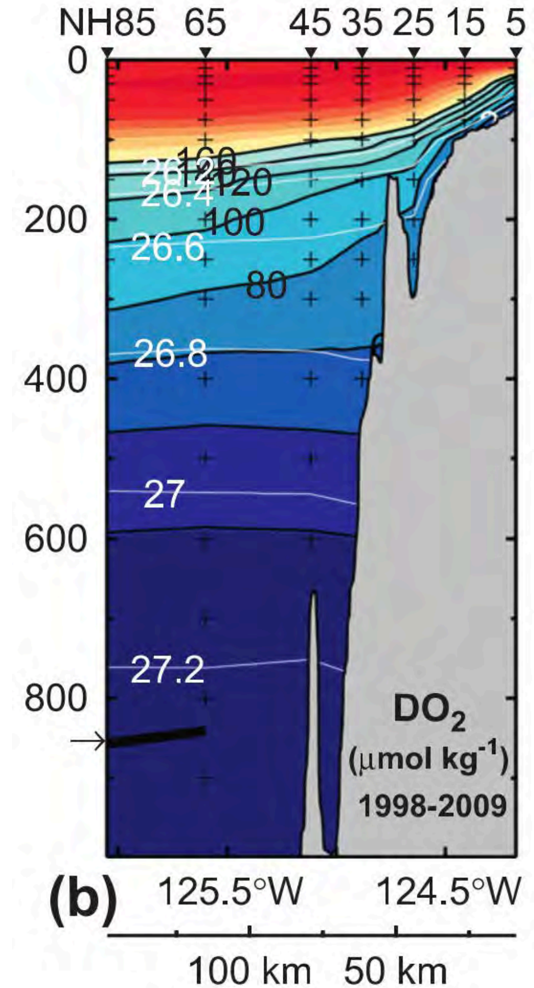
Q3: How might these mechanisms affect shelf water chemistry?

Implications for Oxygen:



Based on WOA DO_2 fields (Garcia, et al., 2014)

- Shoaling of the CUC core by 50 m corresponds to a decrease in DO_2 by ~20 μmol kg^{-1}.
- Difference of ~20 μmol kg^{-1} in DO_2 along the σ_t = 26.5 kg m^{-3} isopycnal within the model domain.
  - Southern Boundary water carries less DO_2.



From Pierce, et al., *JPO*, 2012

These changes are comparable to interannual anomalies in DO_2 on the shelf (Siedlecki, et al., 2015).

Conclusions

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