Arrival of 2014-2015 Warm Anomaly Waters off Oregon, U.S.A.

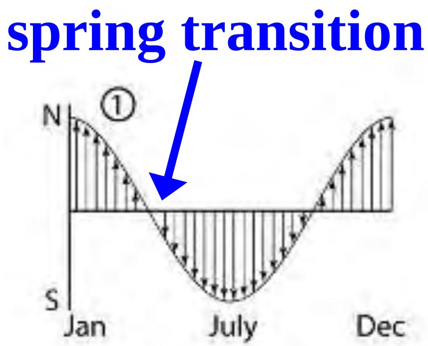
P. Michael Kosro, Craig Risien, John (Jack) Barth, Alexander Kurapov, R. Kipp Shearman and P. Ted Strub

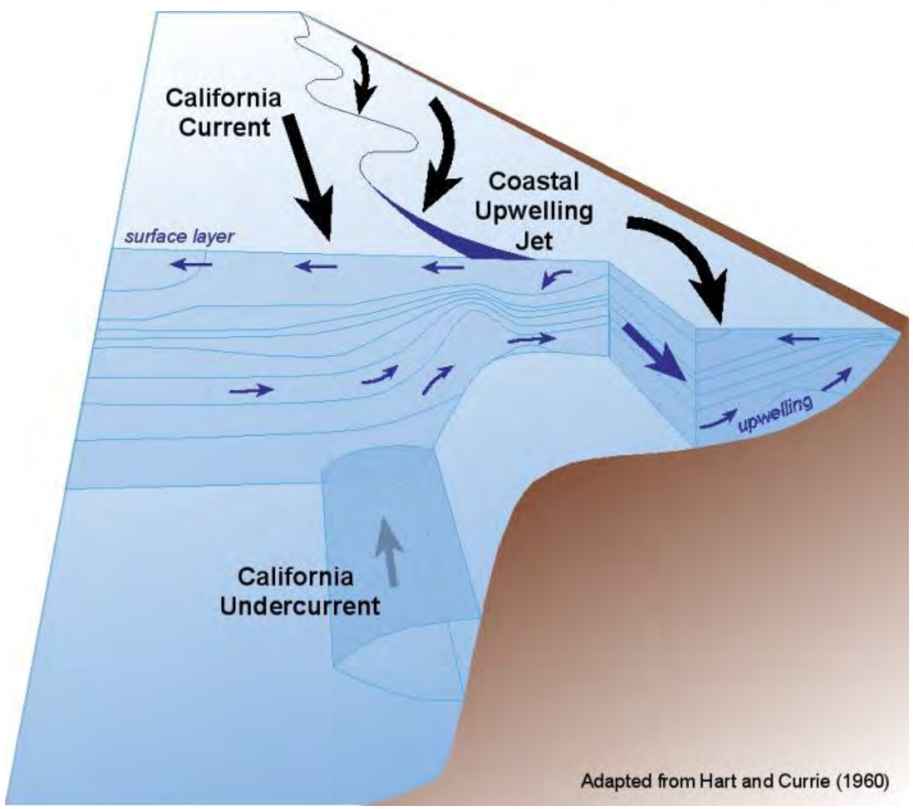
College of Oceanic and Atmospheric Sciences

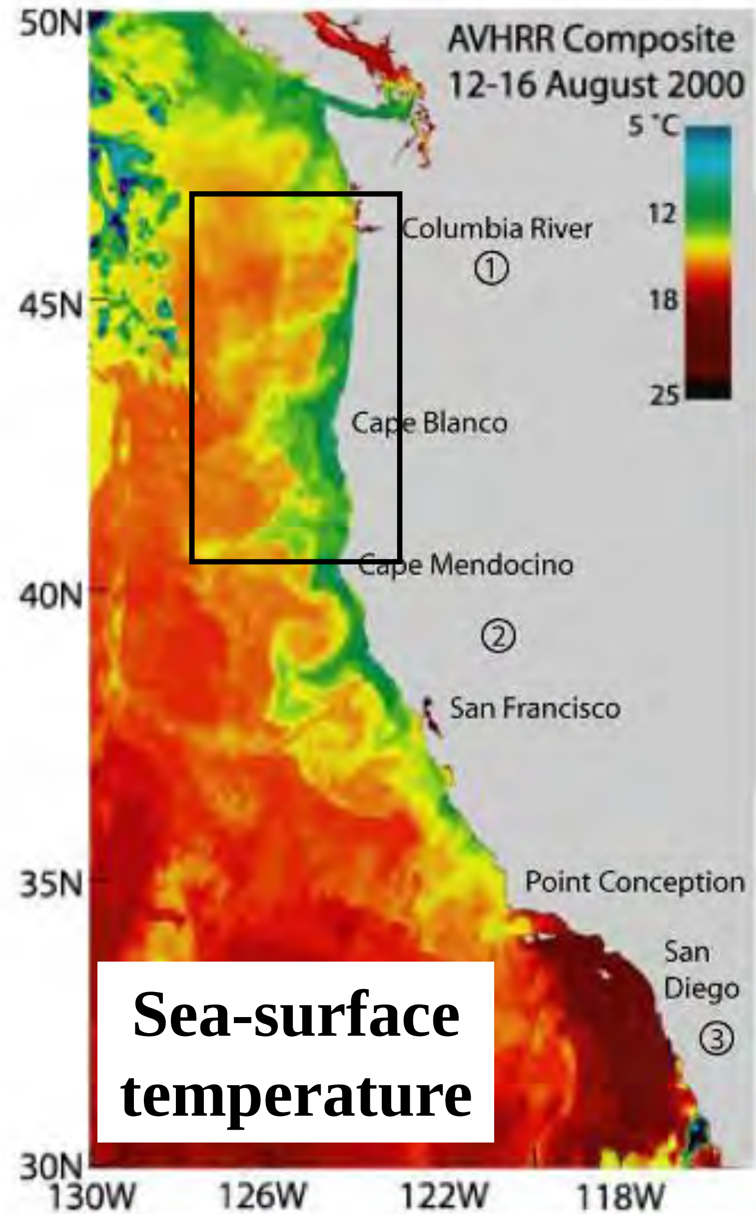
Oregon State University

Upwelling supports a productive marine ecosystem in the Northern California Current

Seasonal cycle of winds



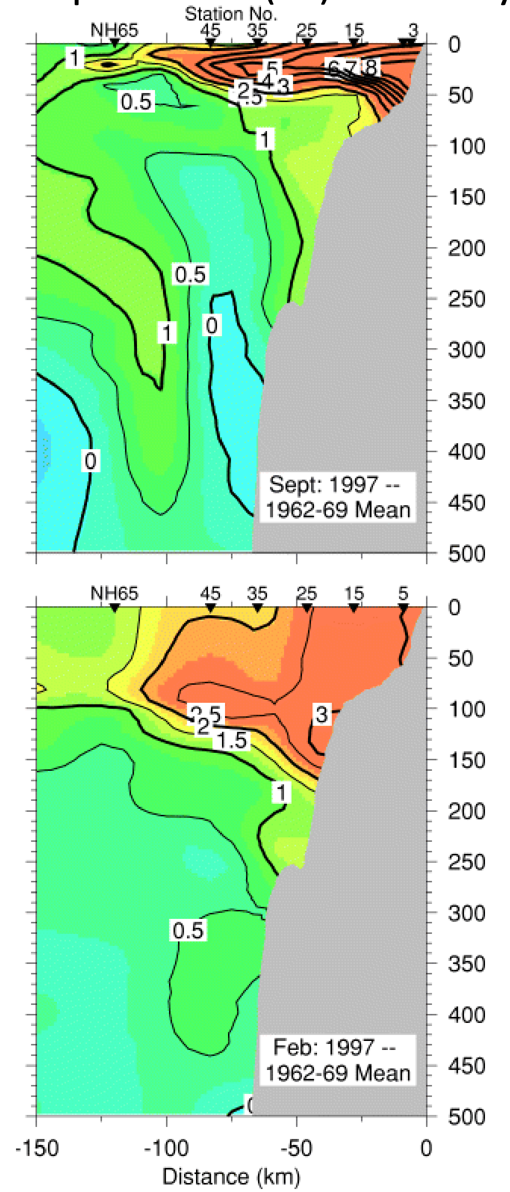




Warm water anomalies, changes in stratification, and changes in the water properties of the upwelling "source" waters (temperature, nutrients, dissolved oxygen) can profoundly influence the marine ecosystem.

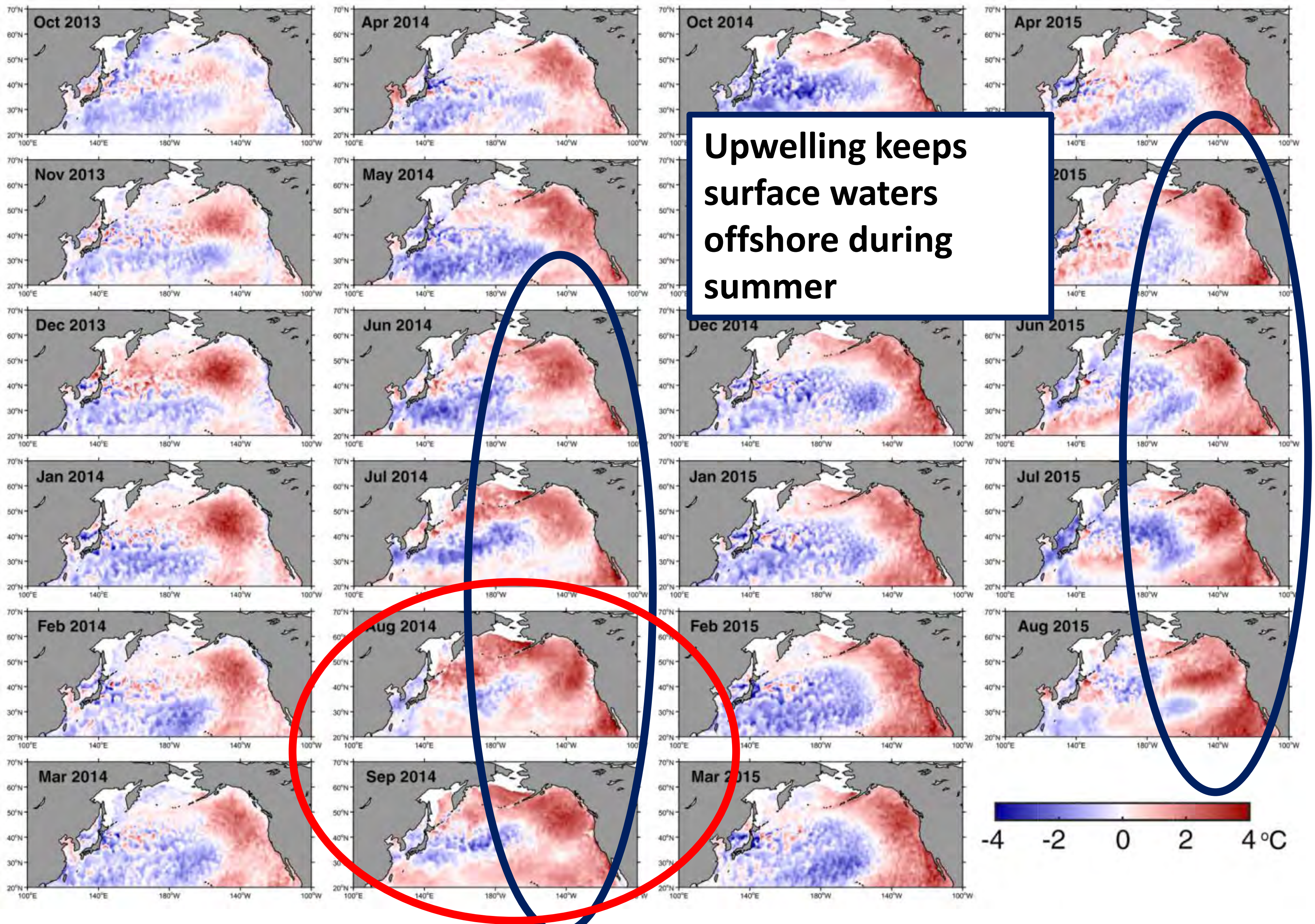
See talks in this PICES S2 session (Pena, Gomez-Ocampo, Koslow, Sastri, etc.)

Newport Hydrographic Line
44° 39'N
Temperature (°C) Anomaly

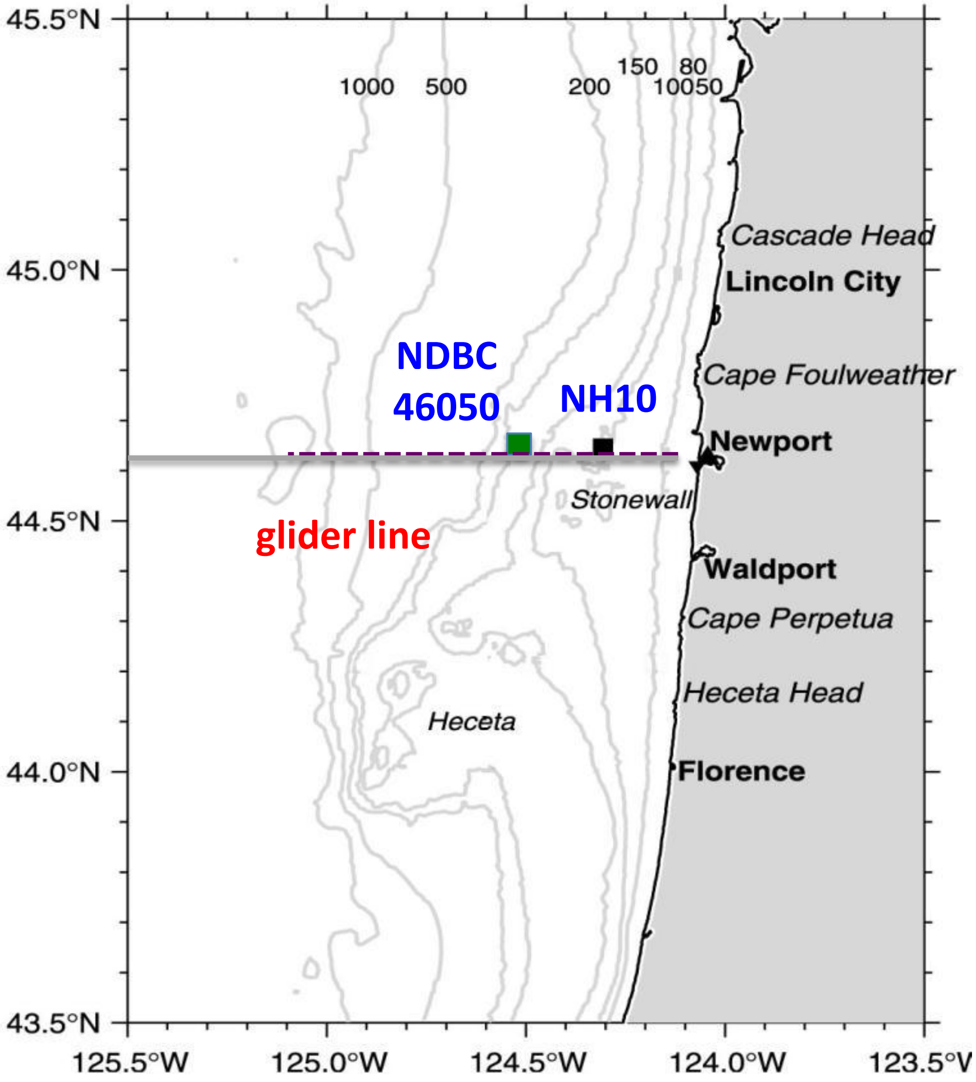


Huyer et al. (2002)

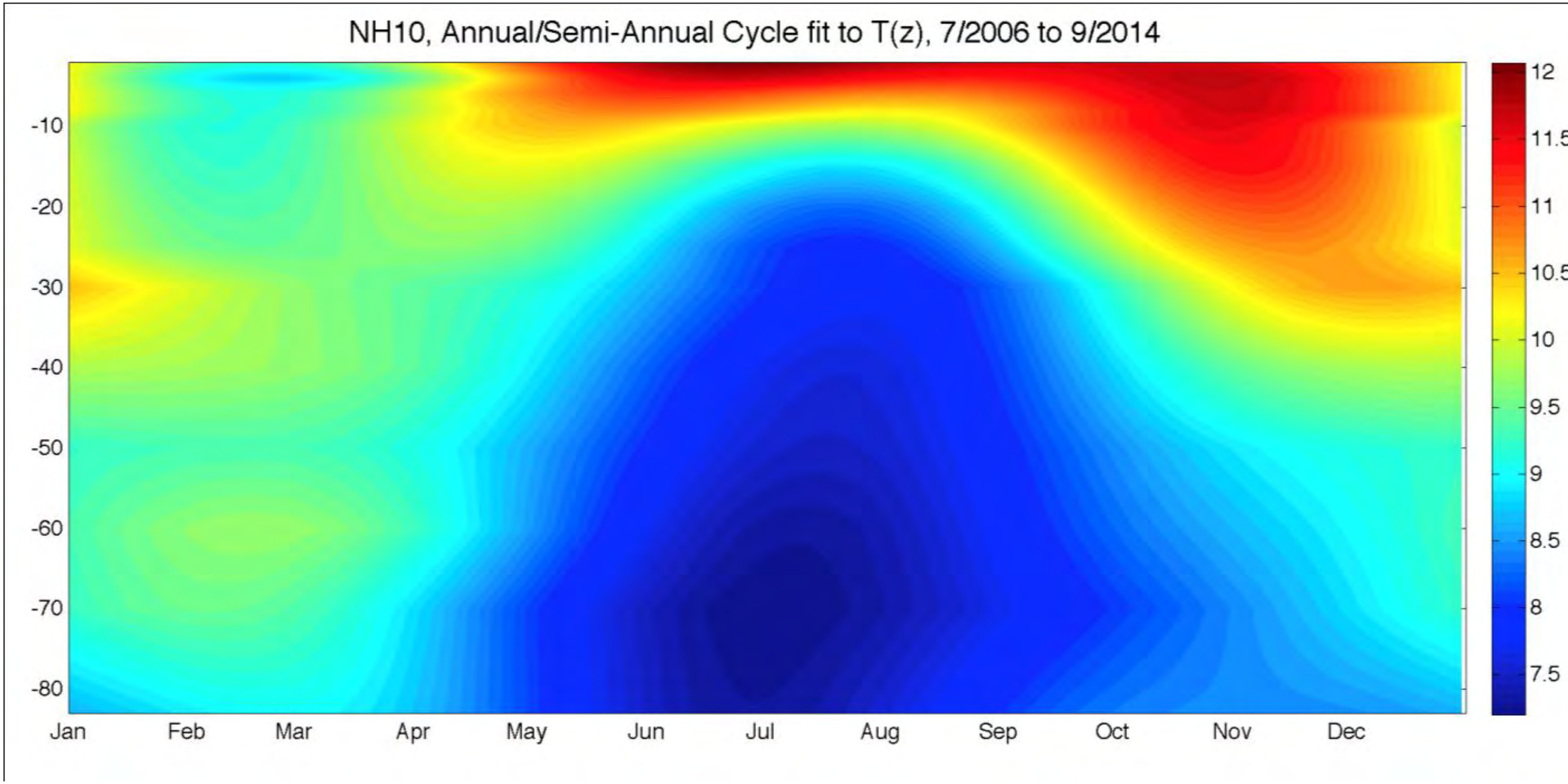
The "Warm Blob" of 2014-2015



Examine data from moorings and underwater gliders off central Oregon along the Newport Hydrographic Line (44° 39’N)

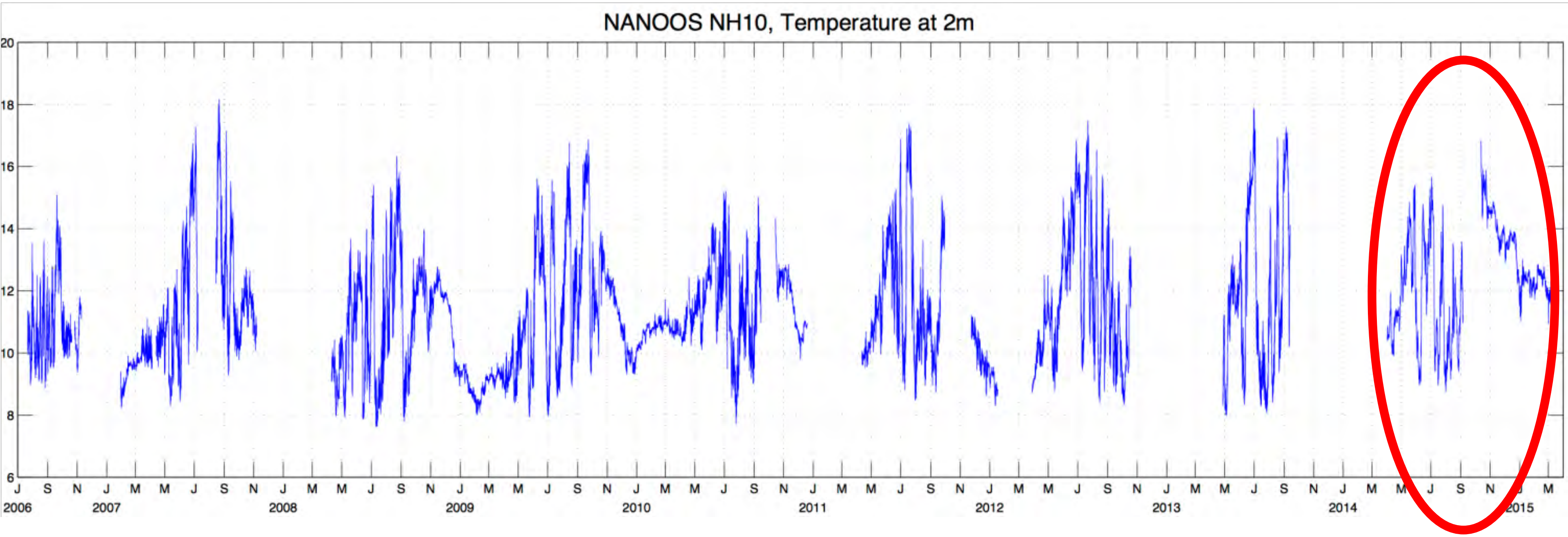


NH10 mooring: T(z,t), Seasonal Cycle (2006–2014



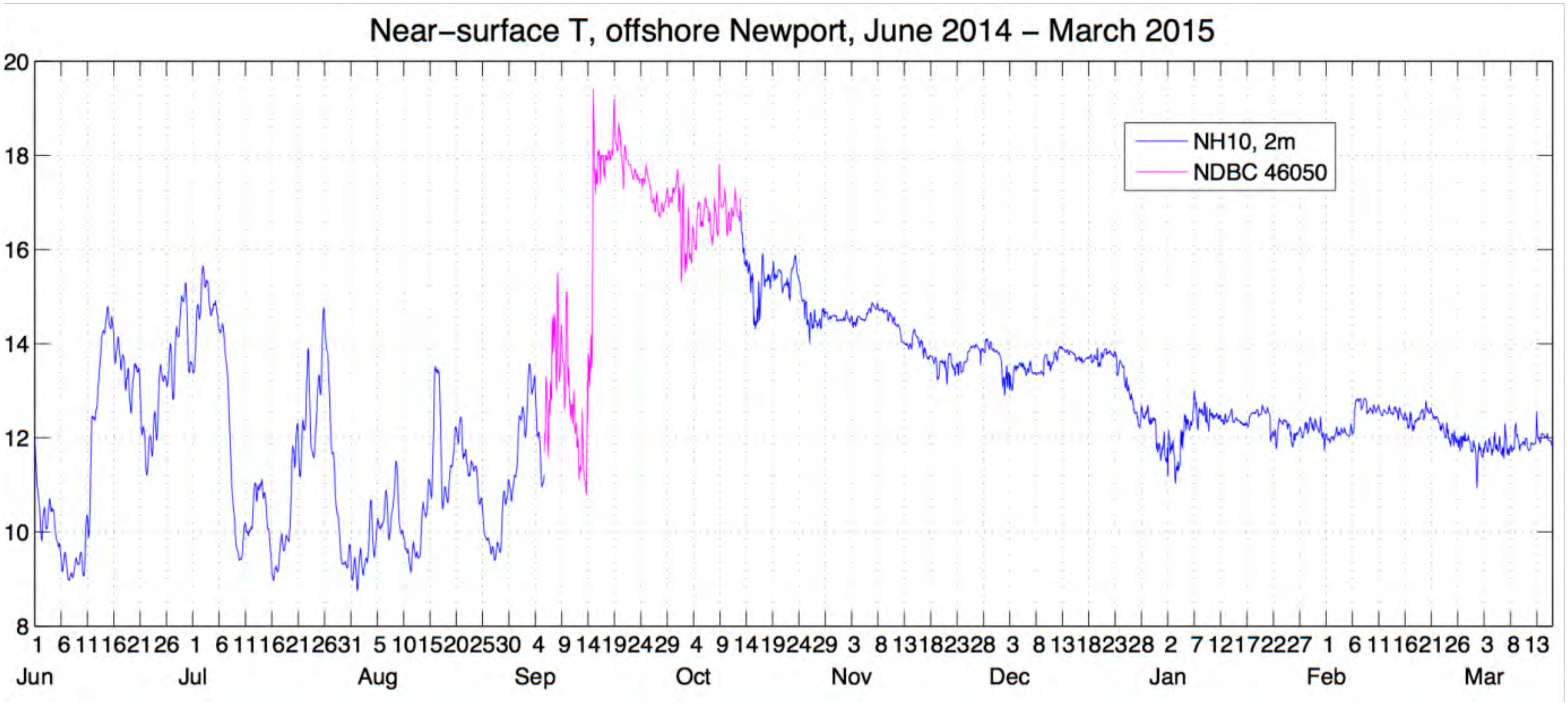
Very strong seasonal cycle
Stratified strongly spring – fall, weak or no stratification in winter
Cold temperatures near bottom first, rise through water column over spring
Fall: surface layer warms and deepens (downwelling)

2-m Temperature Time Series (10/2014-3/2015)



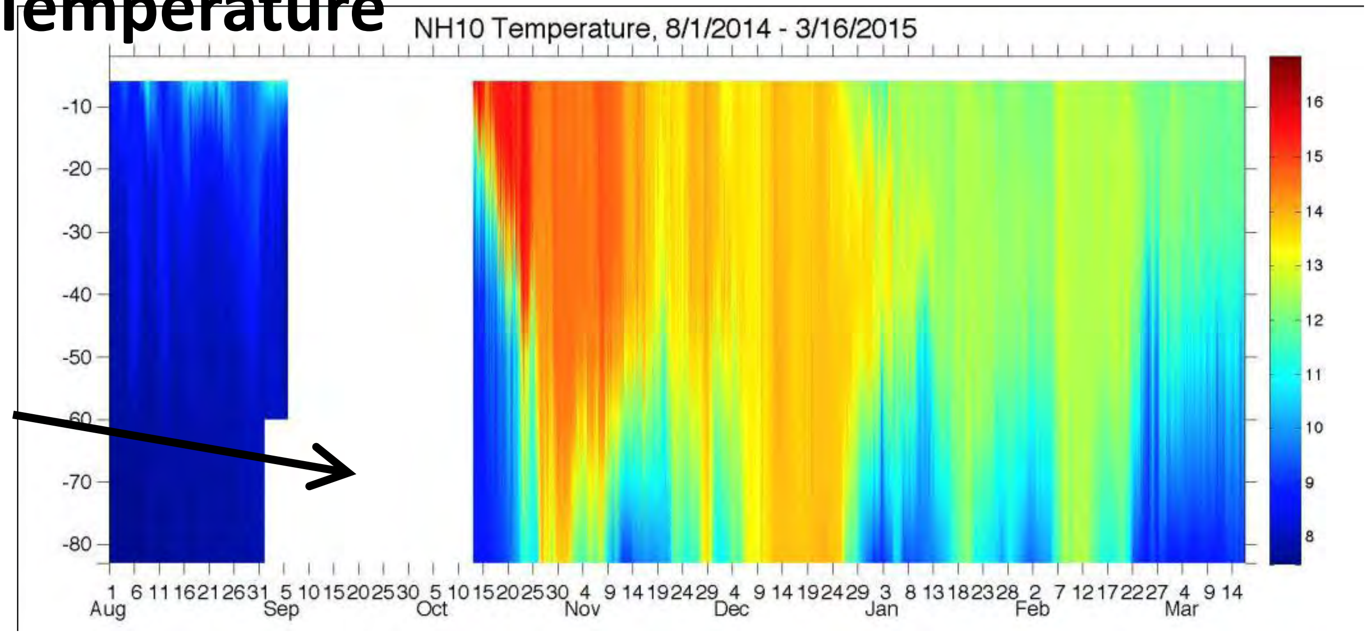
2007 2008 2009 2010 2011 2012 2013 2014

Surface Temperature, 6/1/2014 – 3/14/2015



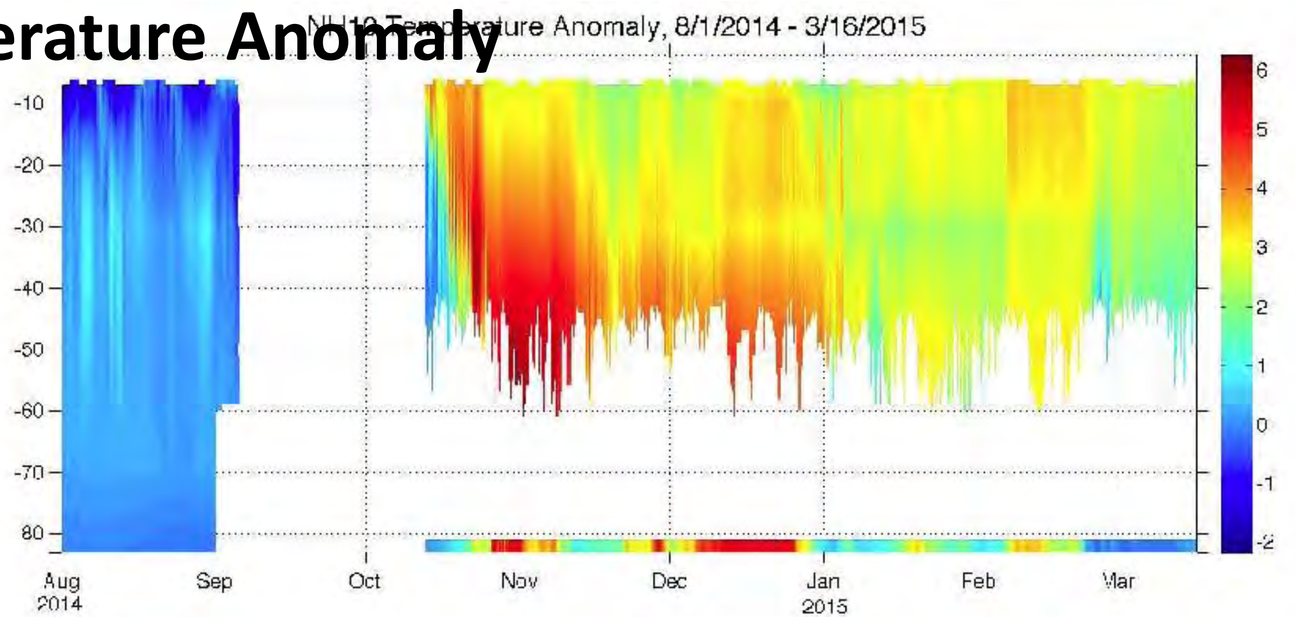
NH10 Temperature & Temperature Anomaly, 8/1/2014-3/16/2015

Temperature



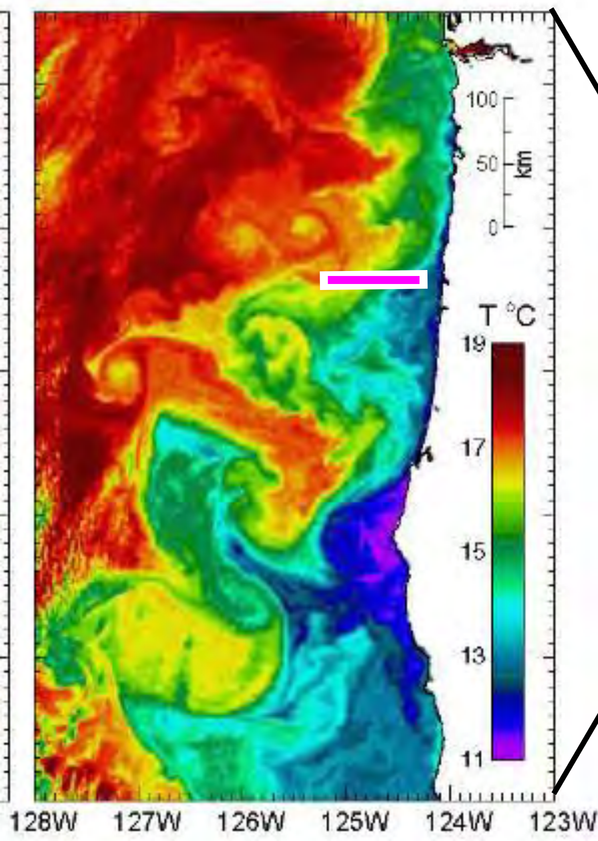
Mooring Servicing ☹

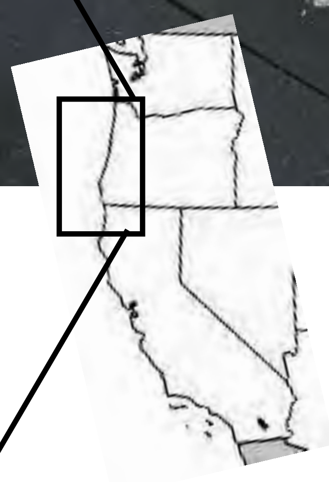
Temperature Anomaly



Autonomous Underwater Vehicle Gliders

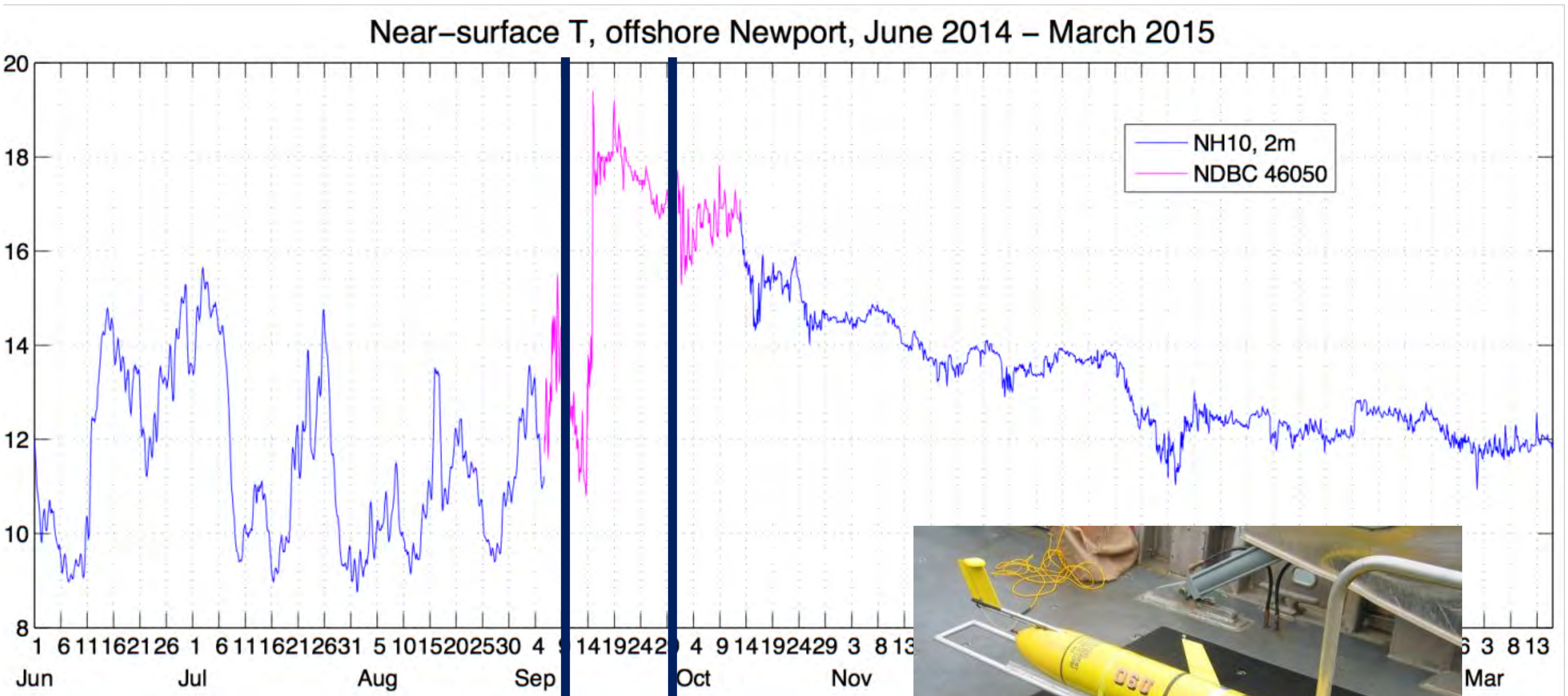
cross-margin transect twice per week since April 2006





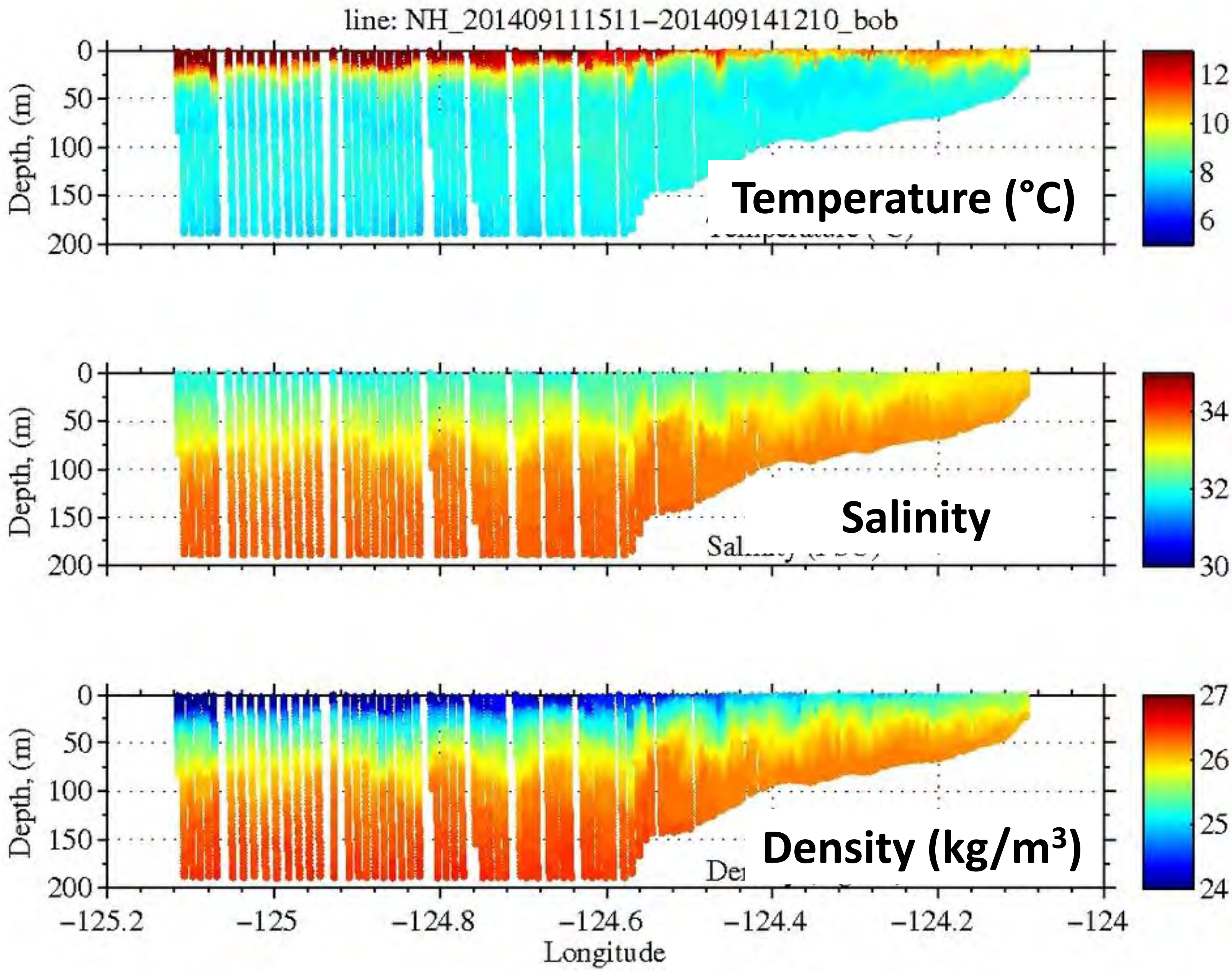
CTD
dissolved oxygen
chlorophyll fluorescence
CDOM fluorescence
light backscatter
depth-averaged velocity

Surface Temperature on the Oregon shelf, 6/1/2014 – 3/14/2015

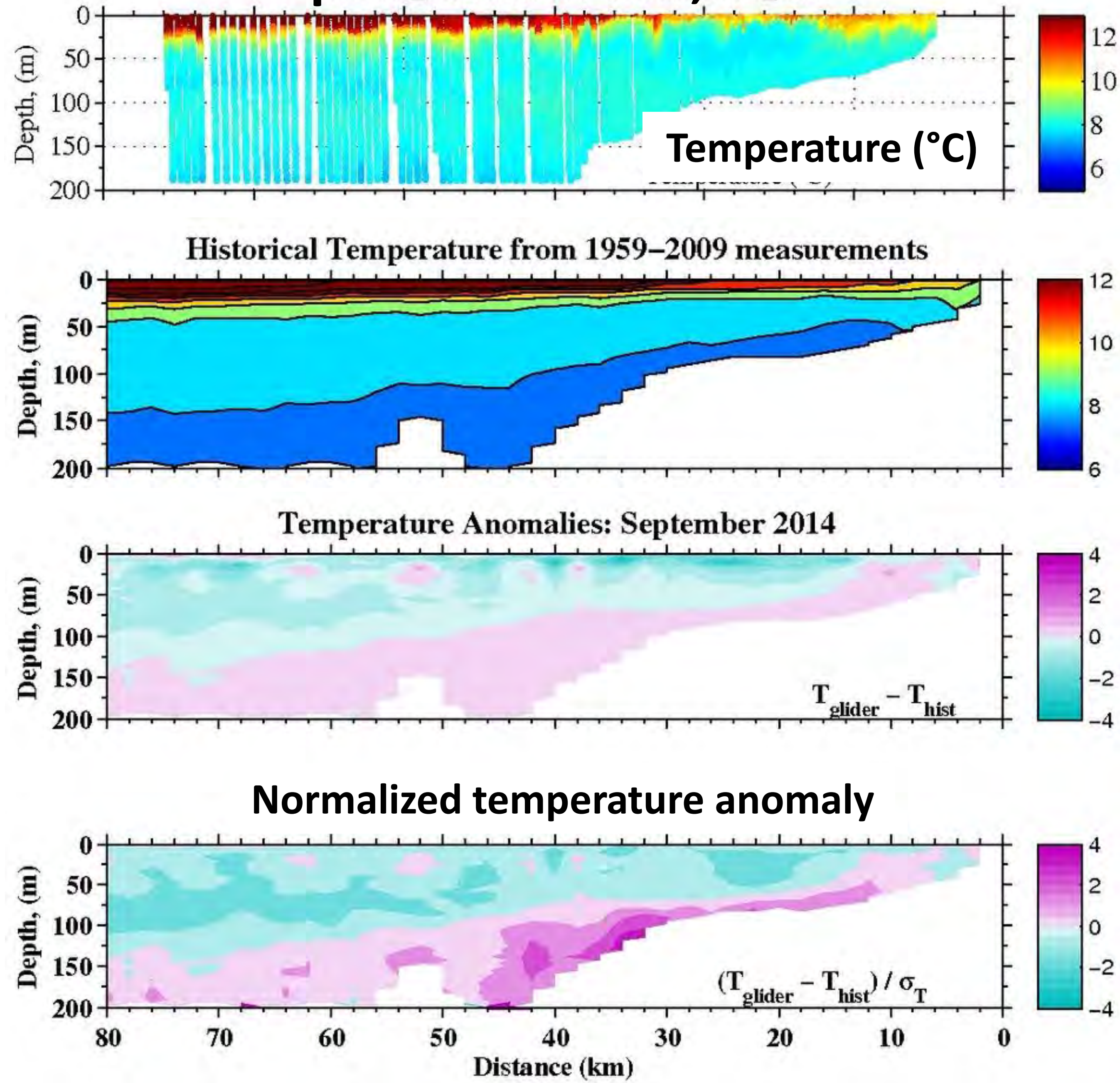


glider transects

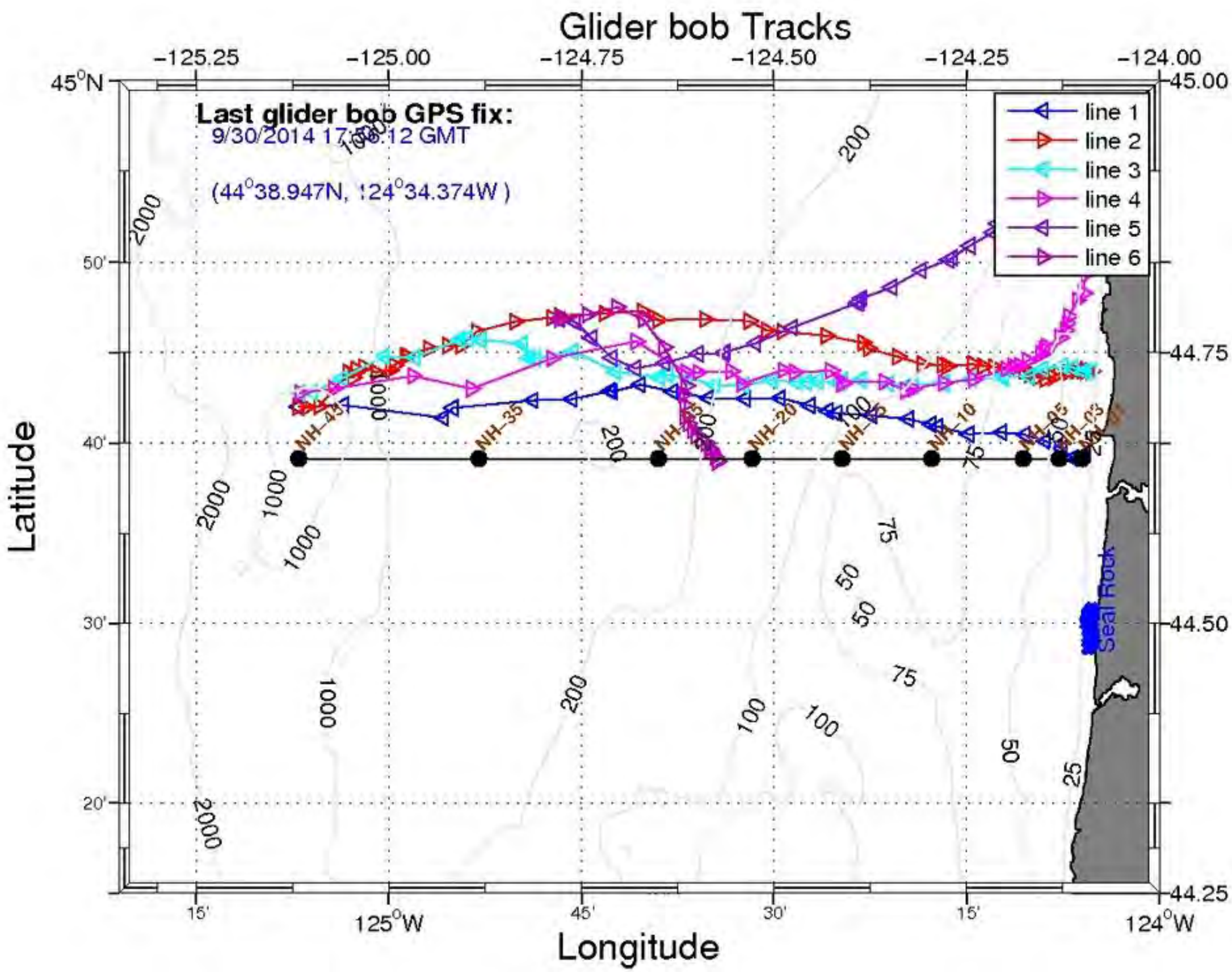
September 11-14, 2014



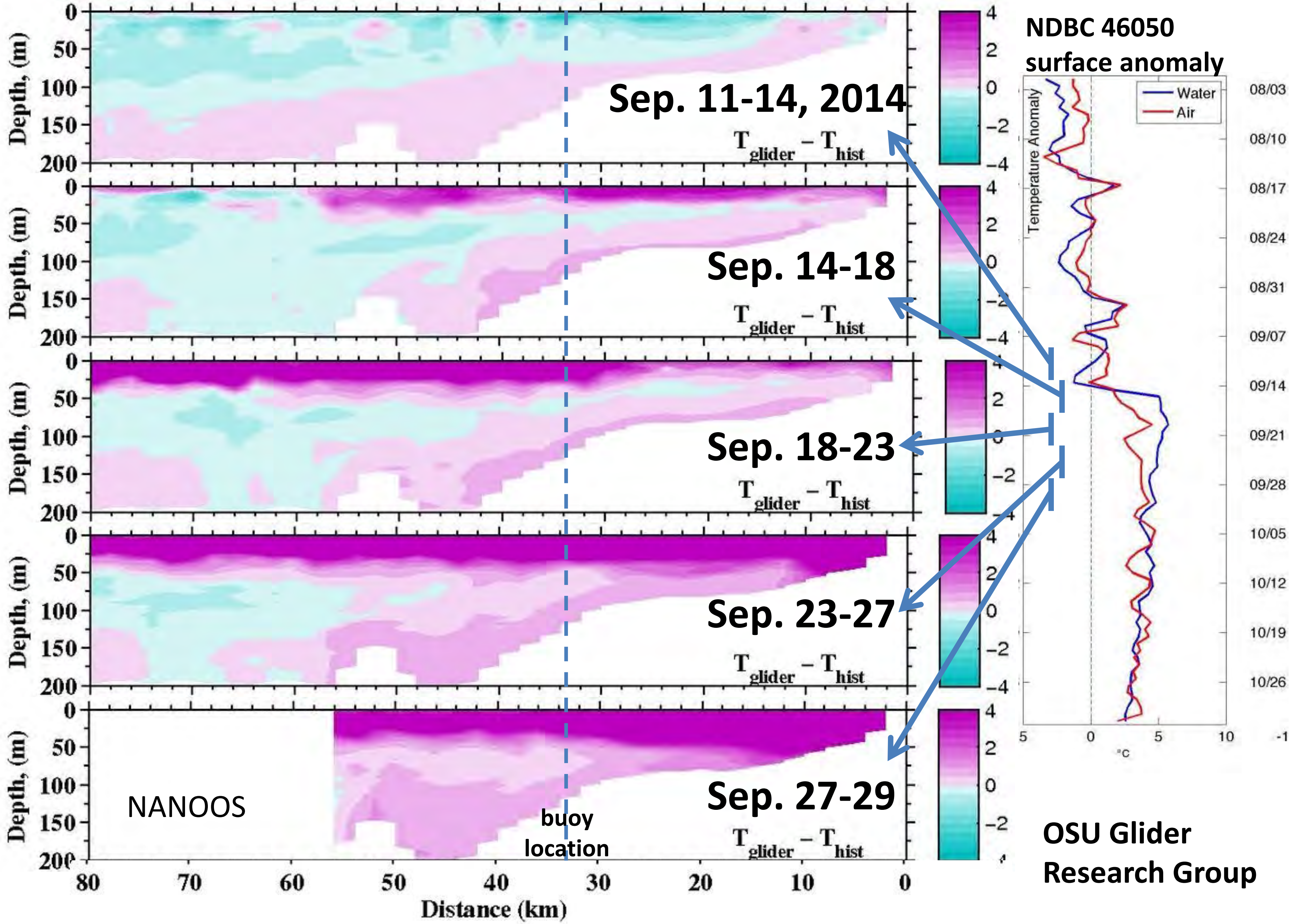
September 11-14, 2014



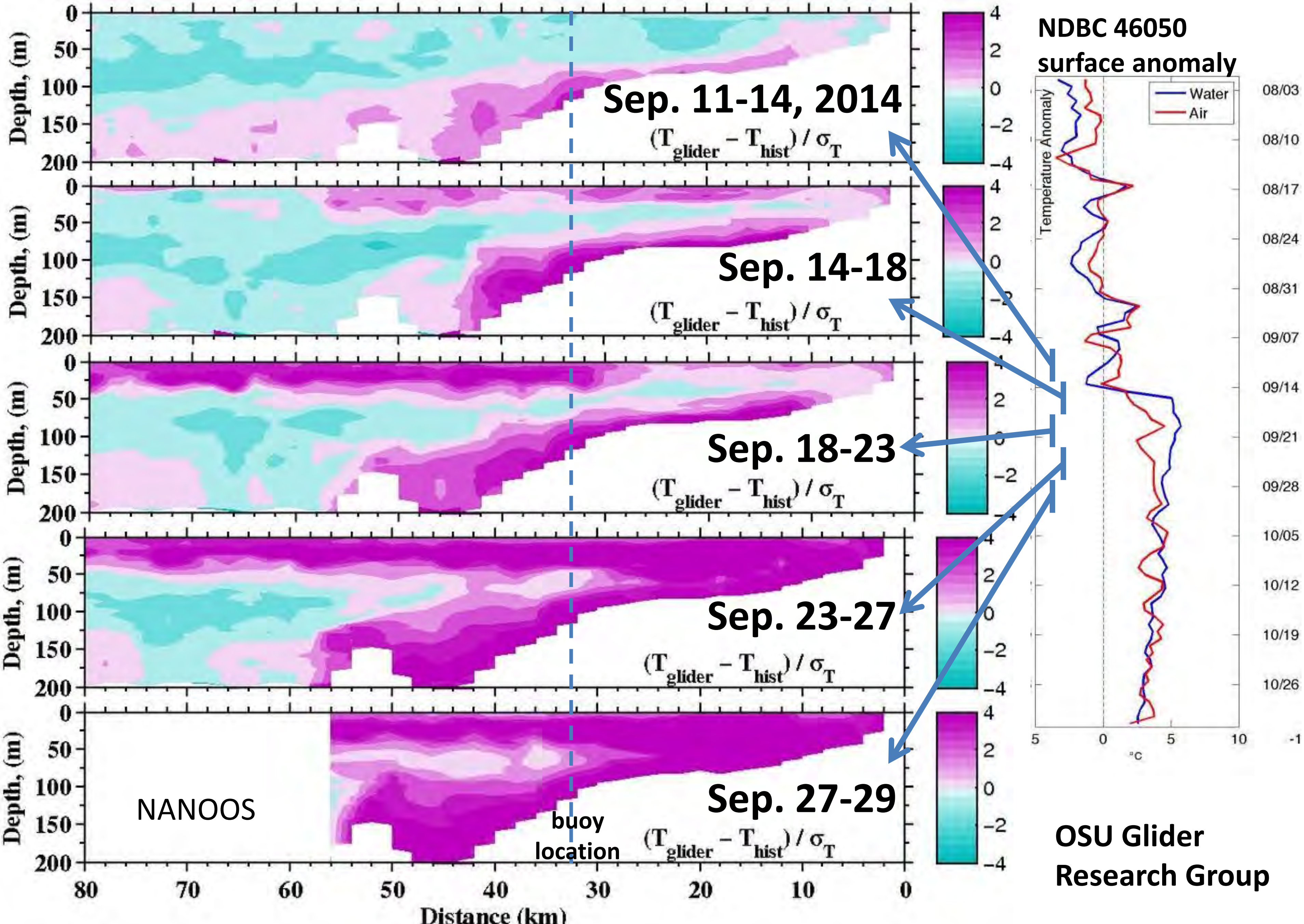
Now look at time series of cross-shelf glider transects in September 2014



Newport, Oregon, (44.65°N) Temperature Anomaly (°C)

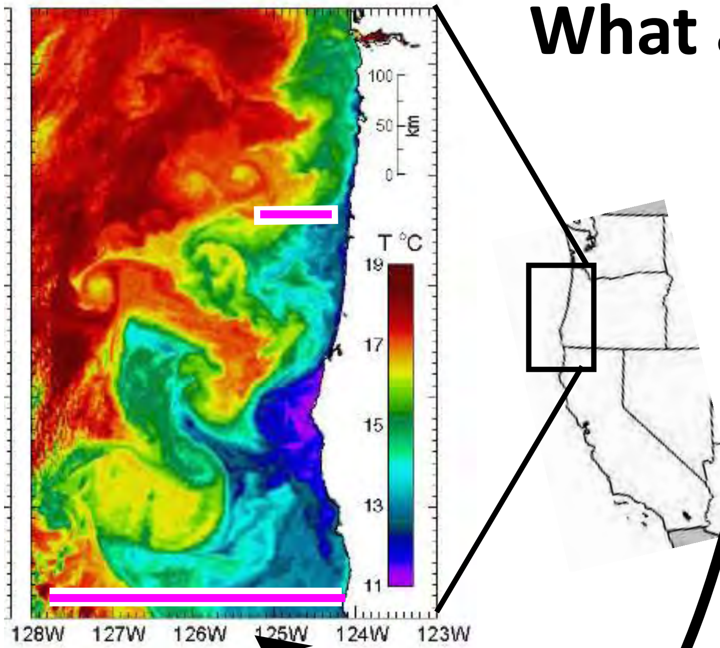


Newport, Oregon, (44.65°N) Normalized Temperature Anomaly

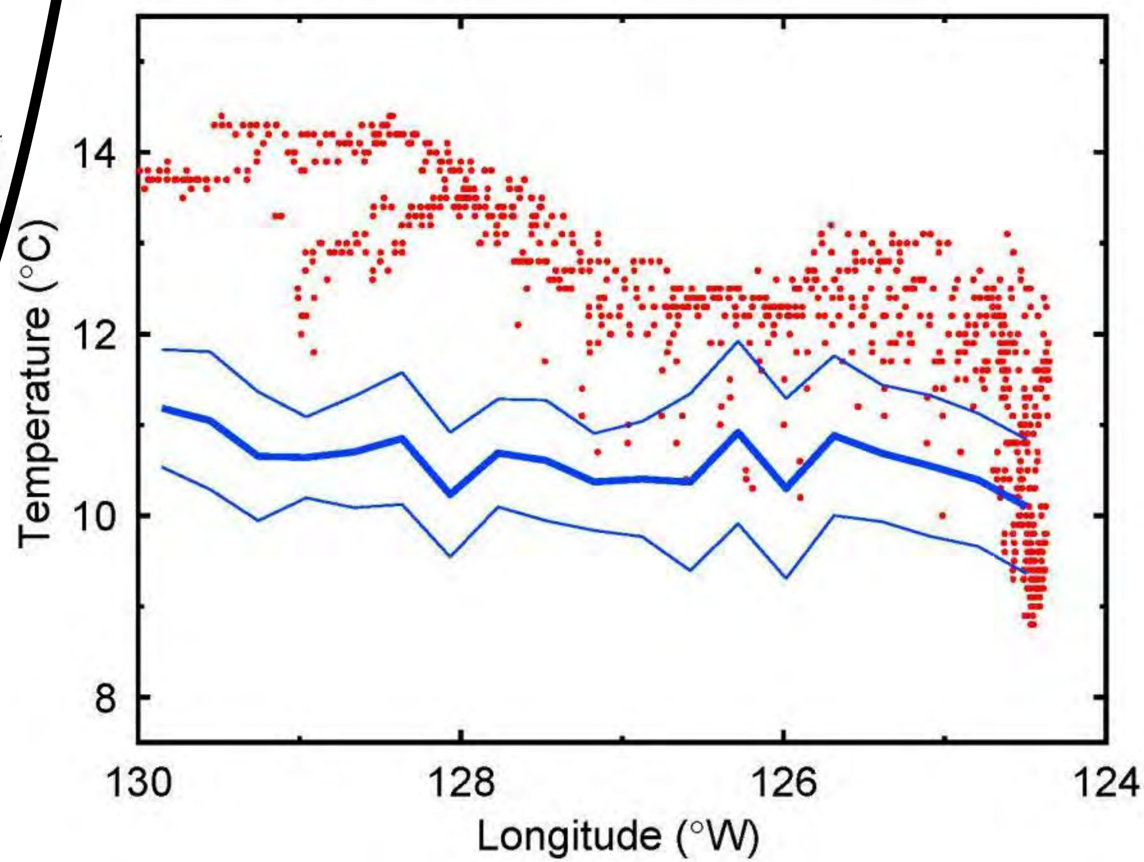


OSU Glider Research Group

What about farther south – the new Trinidad Head (41° 3'N) glider line

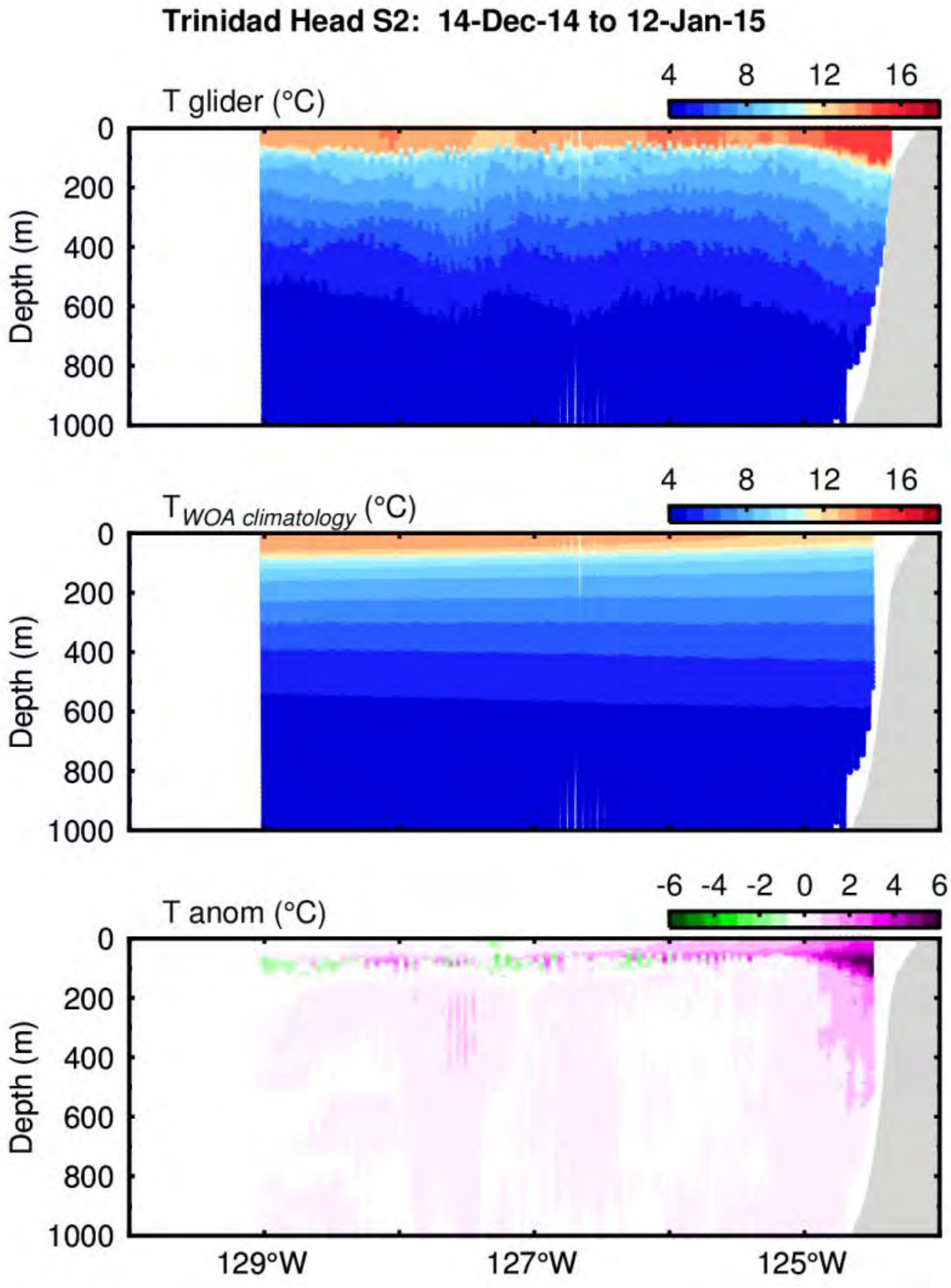


(Oregon State, CeNCOOS, NANOOS)

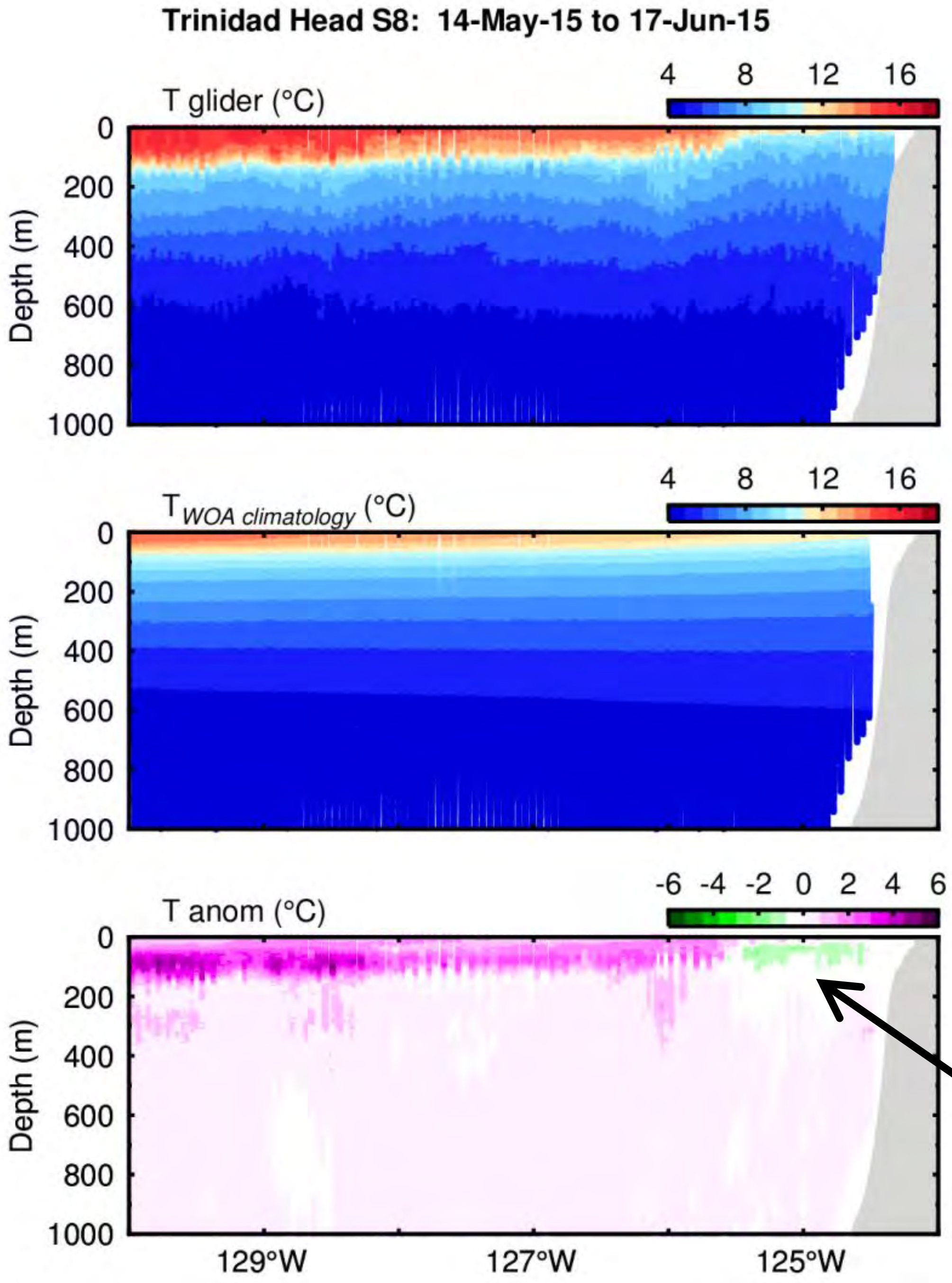


· Jan-Apr 2015 glider-measured temperatures at 50m

— Jan-Apr historical (1944-2013) 50m temperature, with one std. dev. envelope, from NODC search

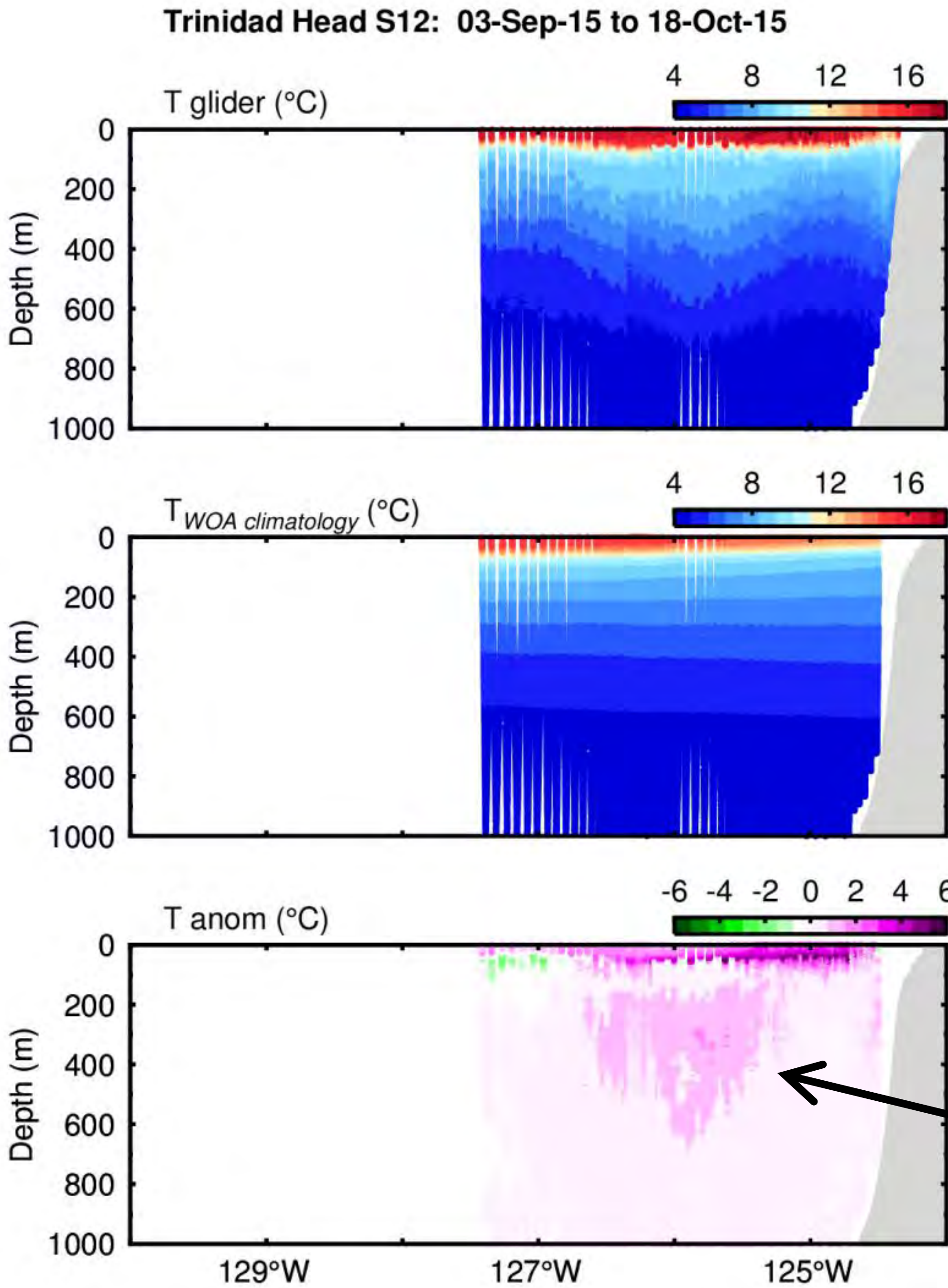


14 Dec 2014
To
12 Jan 2015



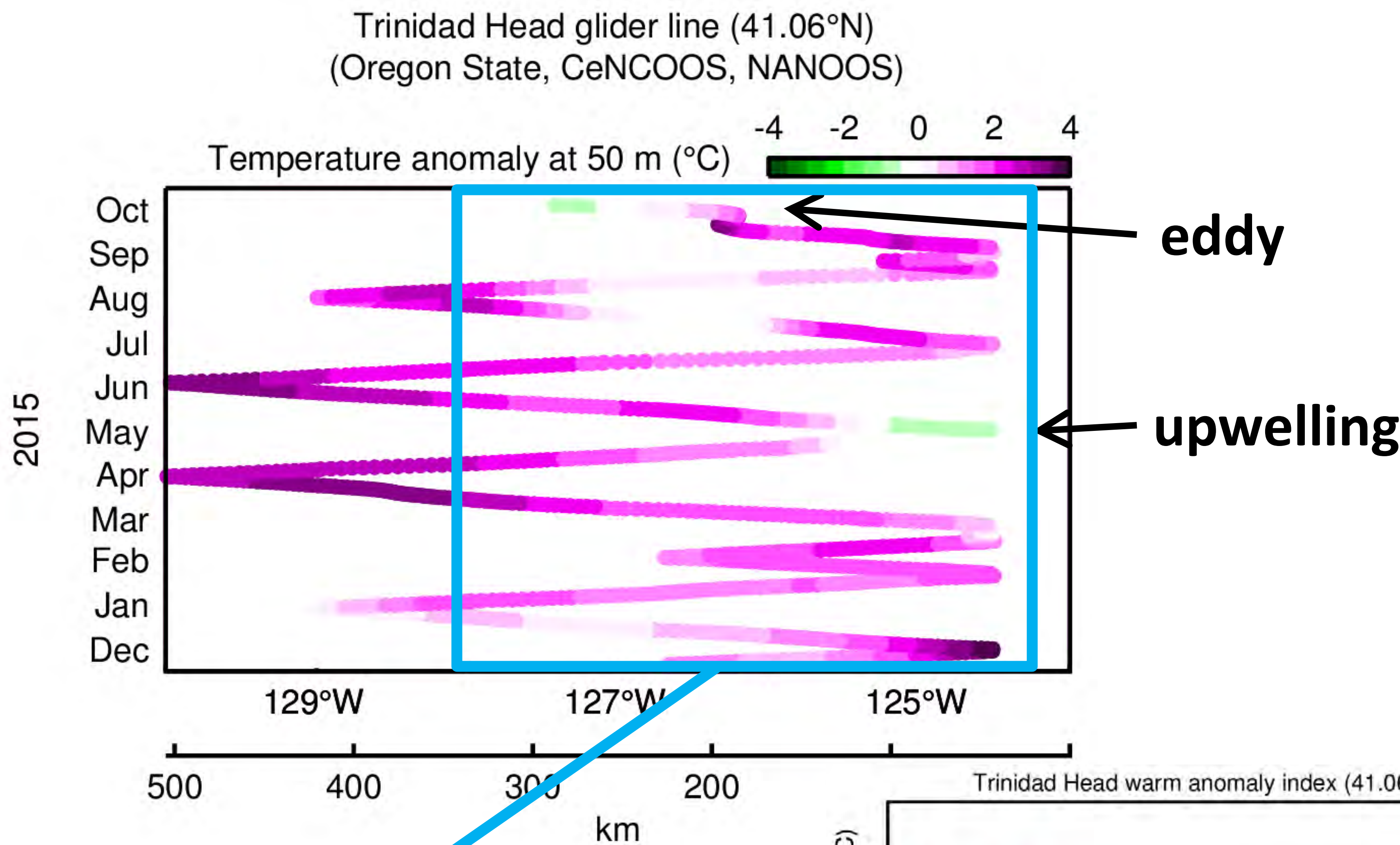
14 May 2015
To
17 Jun 2015

upwelling holds warm water offshore

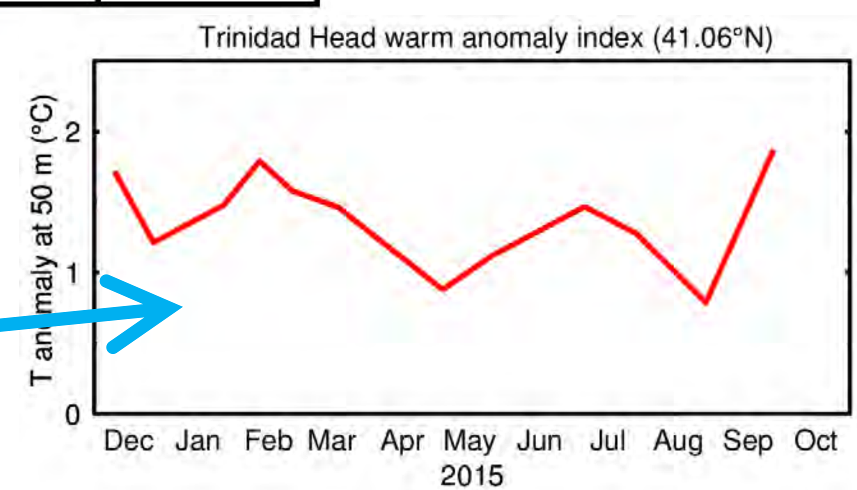


3 Sep 2015
To
18 Oct 2015
(last Sunday!)

California Undercurrent eddy



Integrate to get upper-ocean "warming" index



Now examine numerical model to explore heat budget

West Coast Operational Forecast System (WCOFS – OSU/NOAA, A. Kurapov et al.): comparing 2009-2011 to anomalous 2014

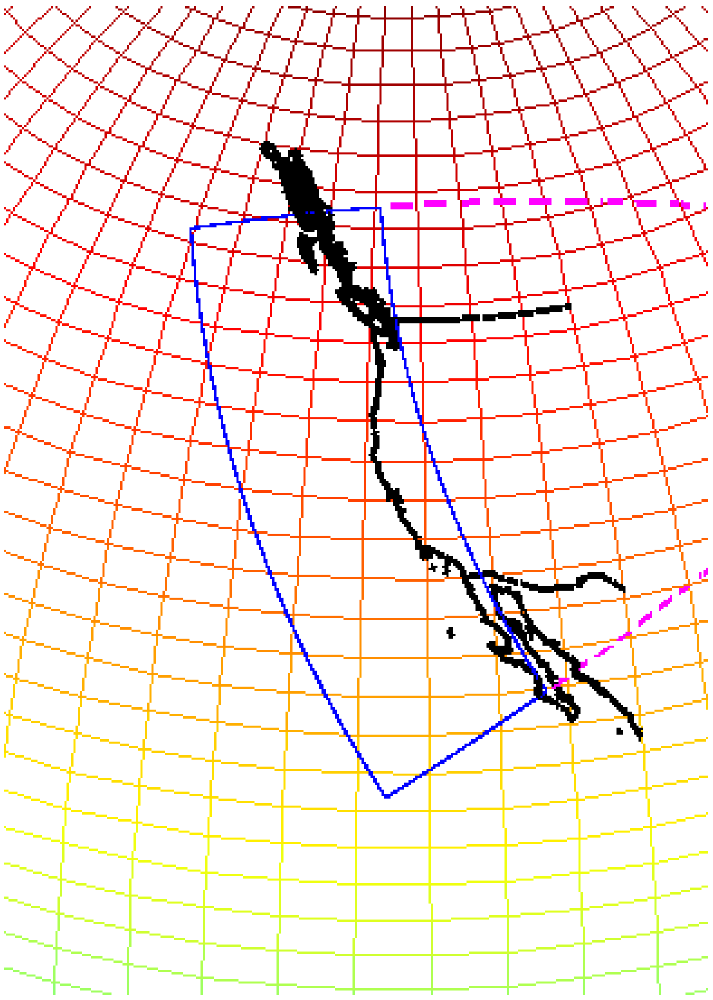
2-km ROMS

Ini C, Boundary C: 1/12th degr Navy HYCOM
Atm: 12-km res. NOAA NAM
Rivers: Columbia R., Fraser R., Puget Sound inputs
No tides in this simulation

NO DATA ASSIMILATION

Daily averaged outputs:
Oct. 2008 – Dec. 2011
Oct 2013 – Dec. 2014

(shown is the model boundary)

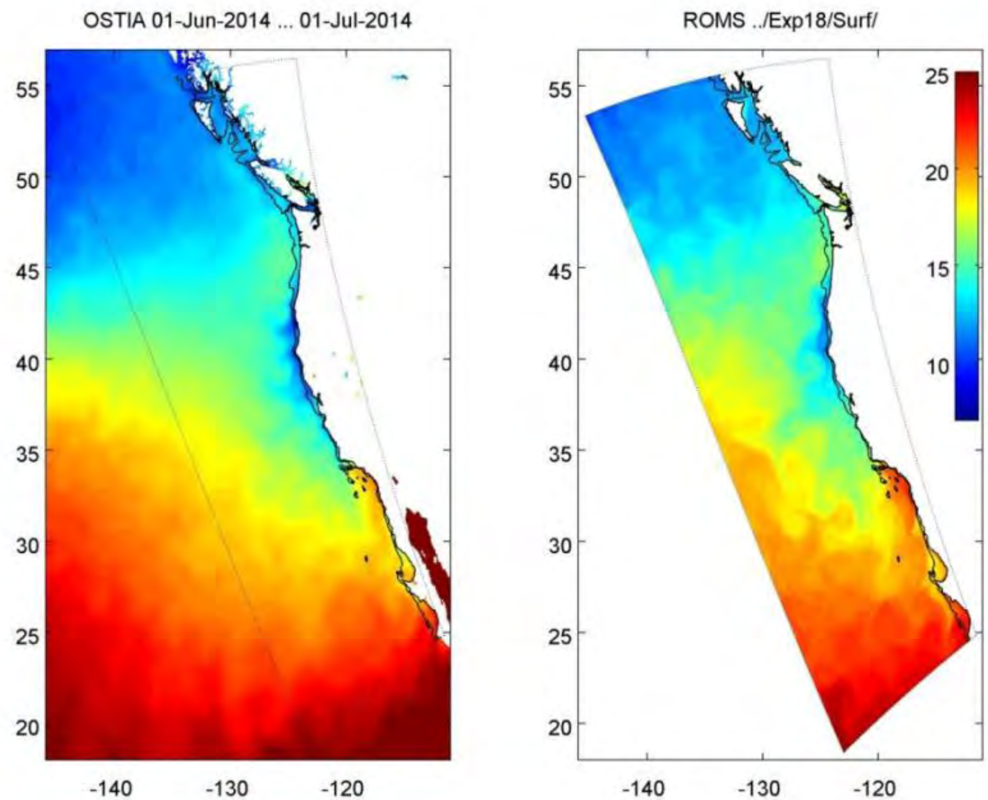


Does the model work?

Model verification against:

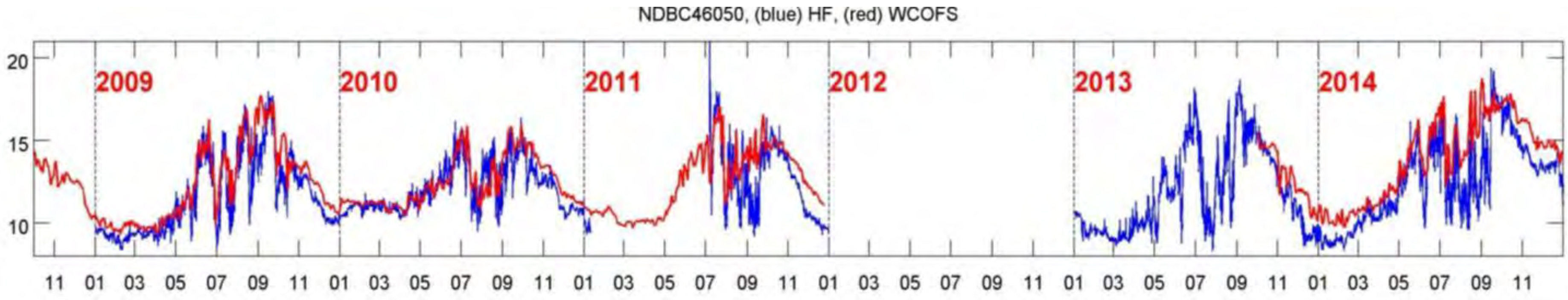
- **Satellite SST (*shown on this slide*)**
- HF radar surface currents
- Moored near-surface T
  (next slide)

Monthly averaged SST
June 2014
satellite (OSTIA) model



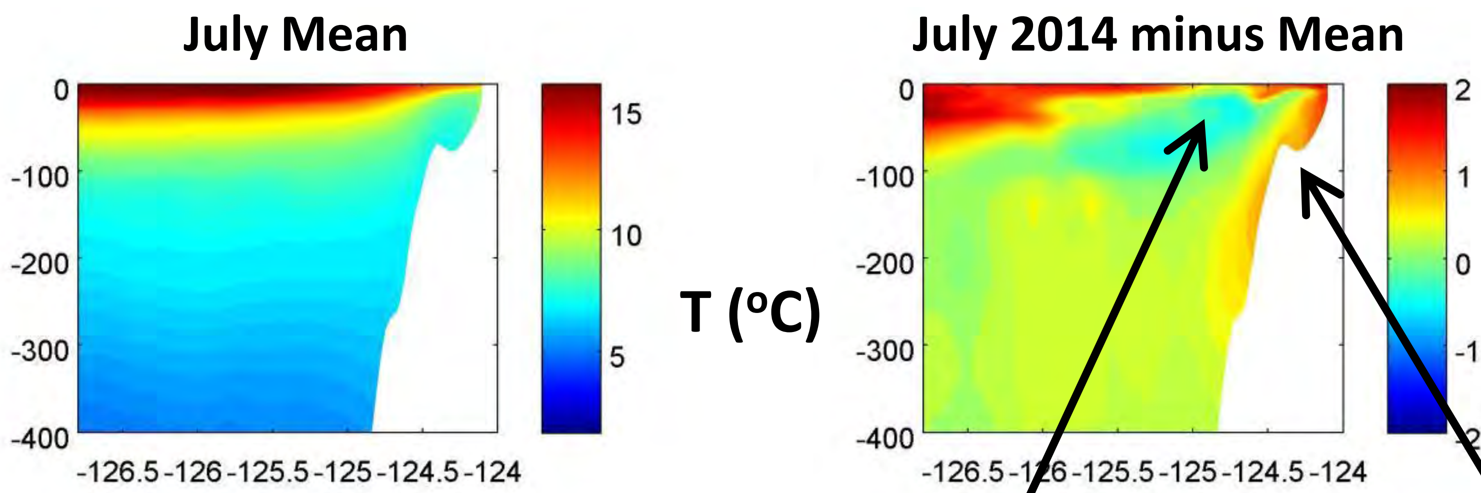
T at the mooring off Oregon (near-surface, buoy anchored at H=137 m):

WCOFS (daily-ave) vs. buoys (incl. high freq.)

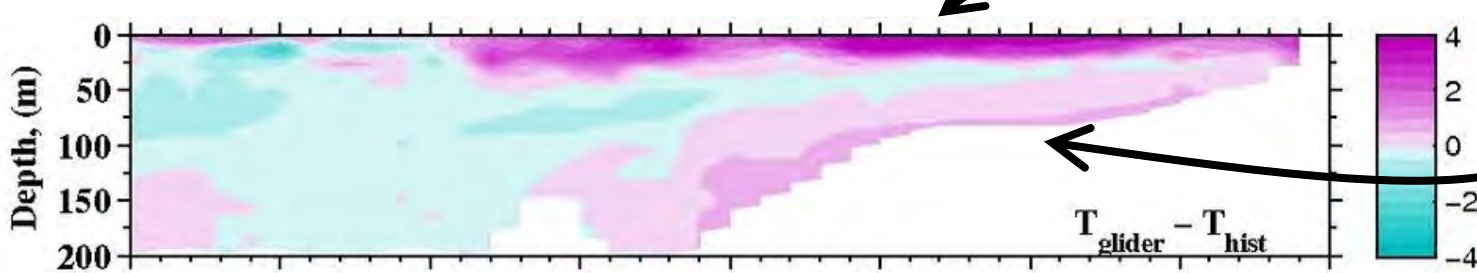


- Two runs shown (Oct. 2008-2011) and Oct 2013-2014
- The model reproduces seasonal cycle and interannual differences, including relatively warmer conditions in the 2nd half of 2014 (*NO DATA ASSIMILATION*)

Model cross-shore sections at 44.6N, July mean and 2014 anomaly



Note anomalous warming at surface and along bottom



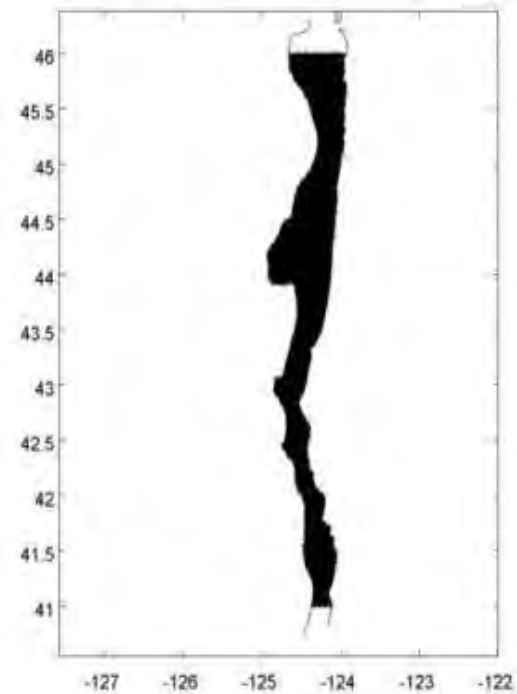
Glider temperature anomaly (September 2014)

Volume average temperature balance analysis

(following Durski et al., Oc. Dyn., 2015**):**

- to understand relative contributions of the atmospheric heat flux and ocean advection to rising the temperature on the Oregon shelf

Integrate heat equation in horizontal over a shelf area (41-47N, H<200 m), in vertical from bottom to surface

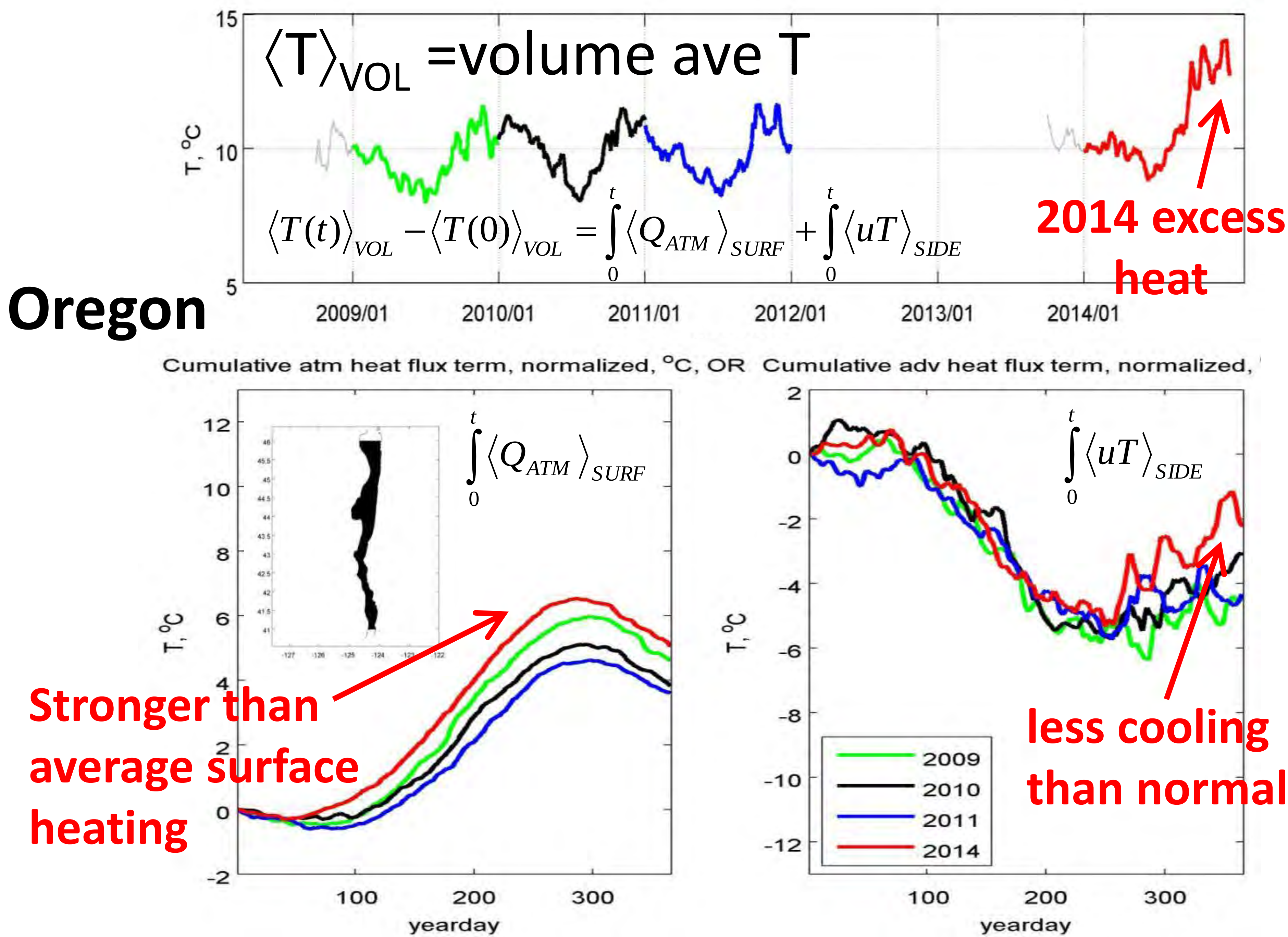


$\langle T\rangle_{VOL}$ =volume ave T

Integrate in time from Jan 1 to t (terms are appropriately normalized to obtain units of ^{o}C):

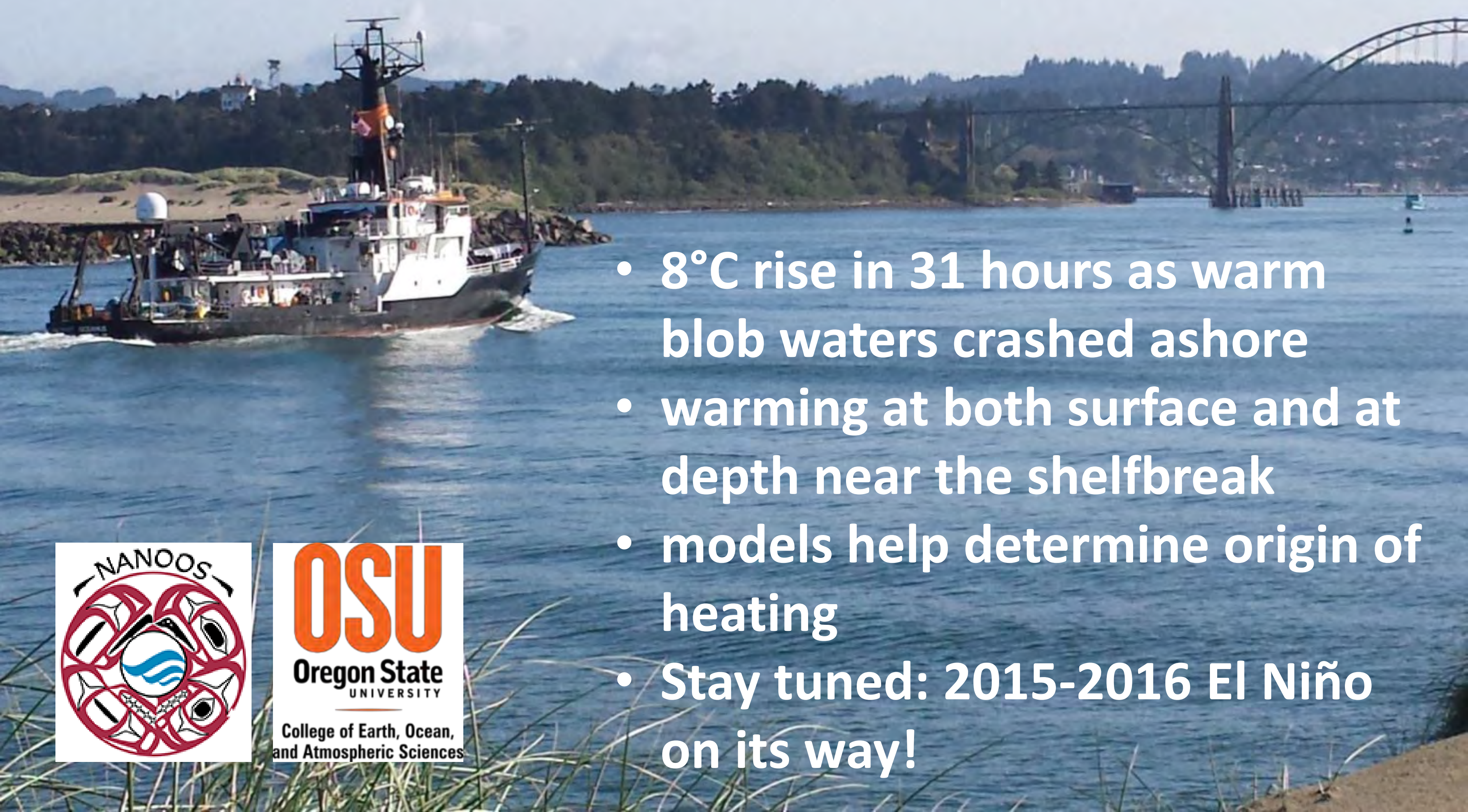
Surface heat flux **advection**

$$\langle T(t)\rangle_{VOL} - \langle T(0)\rangle_{VOL} = \int_0^t \langle Q_{ATM}\rangle_{SURF} + \int_0^t \langle uT\rangle_{SIDE}$$



⟨T⟩VOL =volume ave T
⟨T(t)⟩VOL − ⟨T(0)⟩VOL = ∫0t ⟨QATM⟩SURF + ∫0t ⟨uT⟩SIDE
T, °C
2009/01
2010/01
2011/01
2012/01
2013/01
2014/01
2014 excess heat
Oregon
Cumulative atm heat flux term, normalized, °C, OR
Cumulative adv heat flux term, normalized,
∫0t ⟨QATM⟩SURF
∫0t ⟨uT⟩SIDE
yearday
2009
2010
2011
2014
Stronger than average surface heating
less cooling than normal

2014-2015 Warm Anomaly off Oregon Summary



- 8°C rise in 31 hours as warm blob waters crashed ashore
- warming at both surface and at depth near the shelfbreak
- models help determine origin of heating
- Stay tuned: 2015-2016 El Niño on its way!

NANOOS

Oregon State University
College of Earth, Ocean, and Atmospheric Sciences