# The US West Coast Ocean Forecast System: skill assessments and analyses of anomalous oceanic conditions in 2014

**Alexander Kurapov,**
**College of Earth, Ocean and Atmospheric Sciences, Oregon State University**
**/ support: NOAA WCOFS project**

**West Coast Ocean Forecast System (WCOFS):** based on Regional Ocean Modeling System (ROMS, www. myroms.org)

Horizontal resolution: 2-km
Vertical resolution: 40 terrain-following layers

Forcing:

- Surface winds and heat flux (12-km NOAA NAM)
- @open boundary: global model (HYCOM/RTOFS)
  + tides (Oregon State Tidal Inverse Soft.)
- River inputs: Columbia R., Fraser R., small rivers in Puget Sound


***Goal:*** 3-7 day forecasts of oceanic conditions (coastal sea level, currents, oceanic fronts, etc.), constrained by data assimilation (DA)

*Processes: (larger scale) N. Pac Current splits into Alaskan Stream (WA, BC) and California Current System; (coastal) wind-driven upwelling-downwelling (CA-OR-WA), CTW, poleward slope undercurrent, internal tides*

## **Motivation for operational prediction:**


- national security,
- navigation,
- search and rescue,
- environmental hazard response (oil spills, marine debris, etc.),
- fisheries,
- coastal weather prediction,
- beach erosion,
- recreation,
- new business opportunities,
- public health,
- education,
- local community involvement,
- new technology development, etc.

Credit : Eric Mortenson, Doug Beghtel /The Oregonian, [www.naturalbuy.com](http://www.naturalbuy.com), USCG, [http://i.livescience.com/](http://i.livescience.com/), Grantham et al. (2002)

**WCOFS: Present status**

(1) Hindcast simulations: Oct 2008 – Dec 2014 (no DA)

Skill assessment: comparisons

- sea level (coastal tide gauges, altimetry),
- surface velocities (HF radar)
- SST (satellite)
- T and S profiles (Argo floats, glider, ship CTD profiles)

(2) Process studies: alongshore sea level coherence, subsurface variability along the continental slope, basin scale warm Pacific Ocean in 2014-15

(3) Real-time application without assimilation (w/ Jiangtao Xu, NOAA/CO-OPS): testing phase

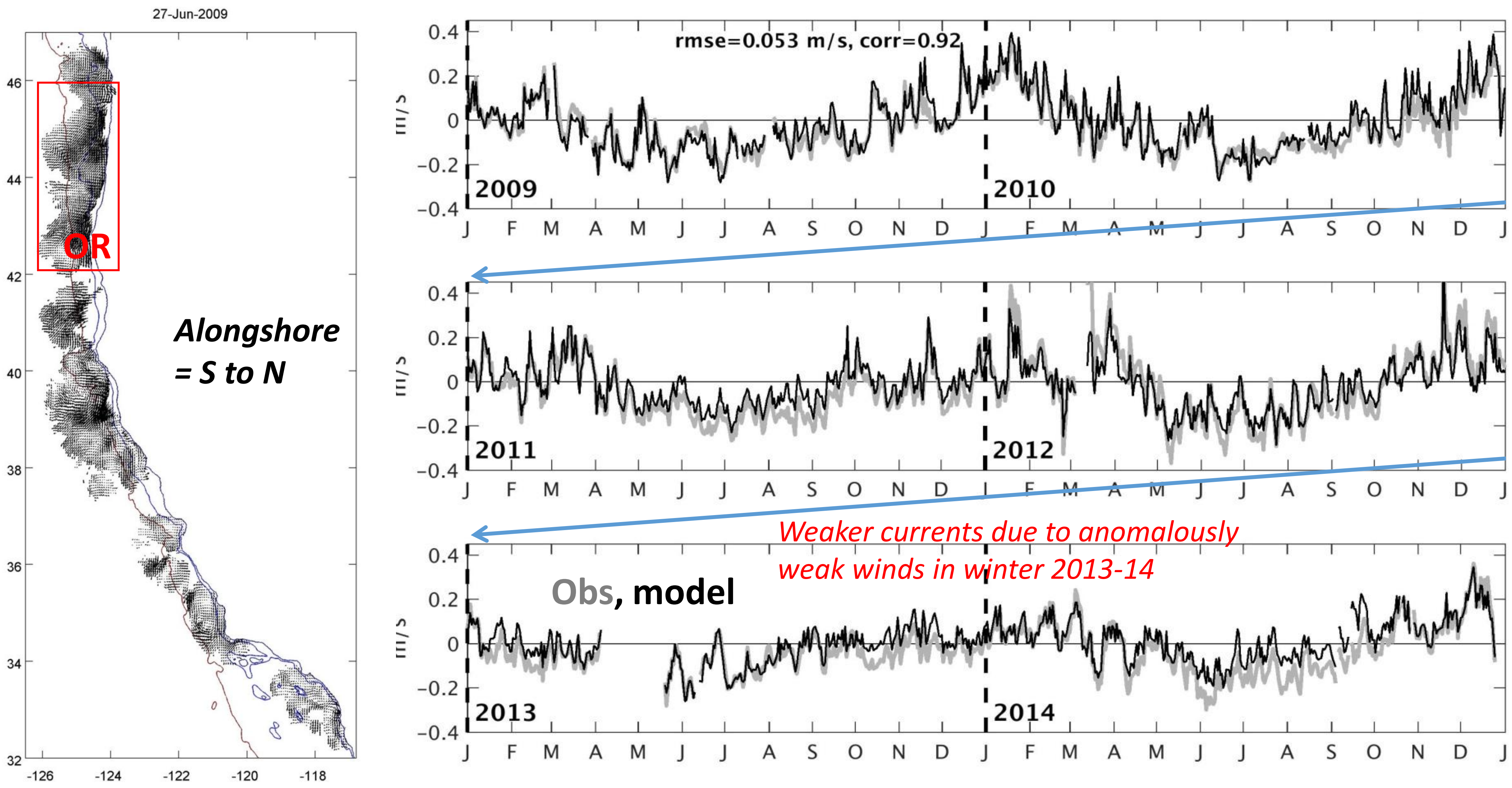
(4) DA: Hindcast tests of ROMS 4DVAR, 4-km resolution (alongtrack altimetry and SST)

1. Skill assessments

Kurapov, A.L., S. Y. Erofeeva, and E. Myers, 2017a: Coastal sea level variability in the US West Coast Ocean Forecast System (WCOFS), Ocean Dynamics, 67: 23. doi:10.1007/s10236-016-1013-4, http://link.springer.com/article/10.1007/s10236-016-1013-4

Kurapov, A. L., N. Pelland, and D. L. Rudnick, 2017b: Seasonal and interannual variability in oceanic properties along the US West Coast continental slope: inferences from a high-resolution regional model, J. Geophys. Res., submitted (the draft is available here: http://ingria.coas.oregonstate.edu/publications.html)

**HF radar vs. WCOFS surface currents (area-averaged, daily-averaged alongshore currents…** *sim. to Durski et al. Oc. Dyn. 2015*): variability is predicted on temporal scales from several days to seasonal and interannual



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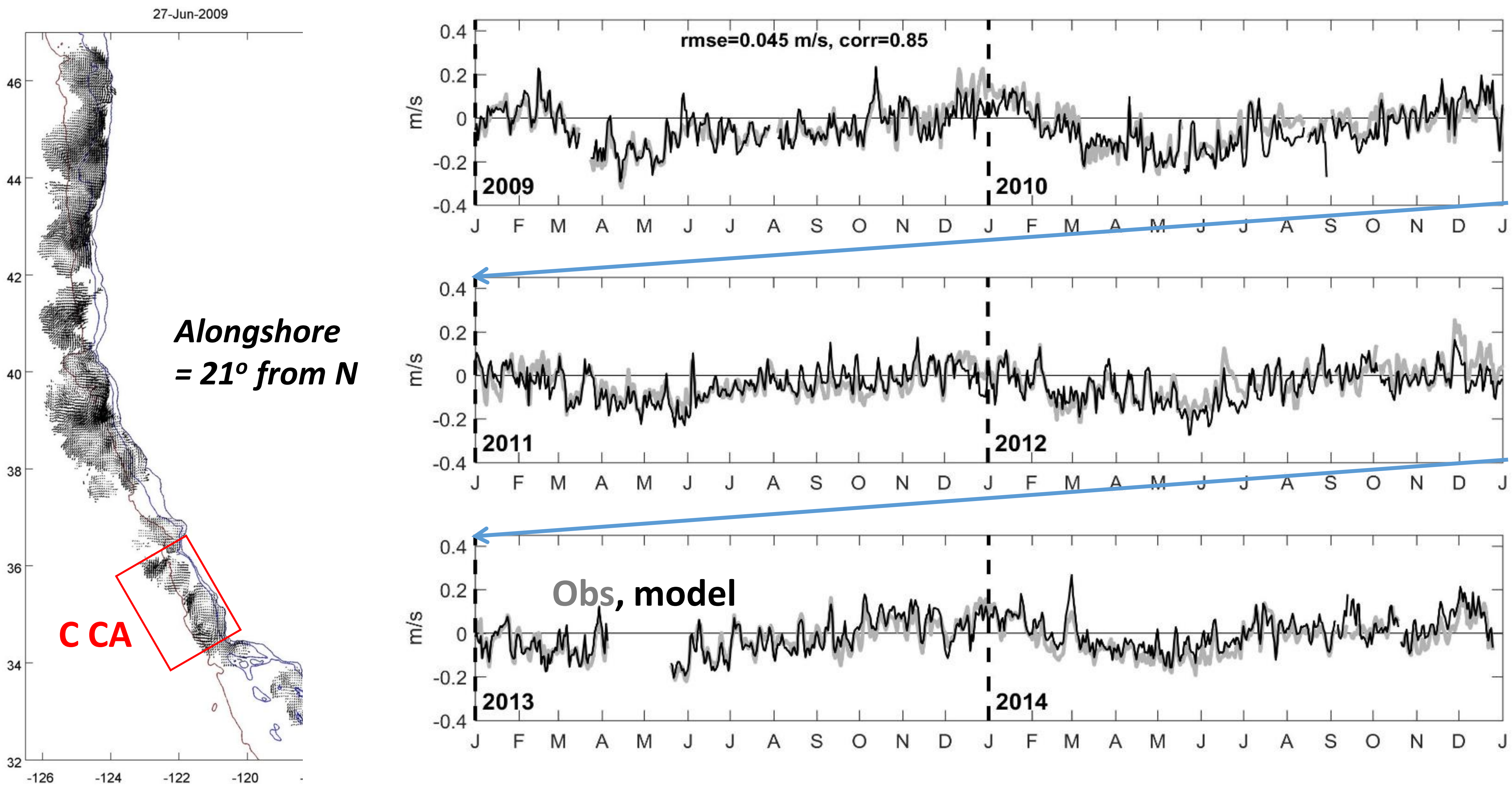

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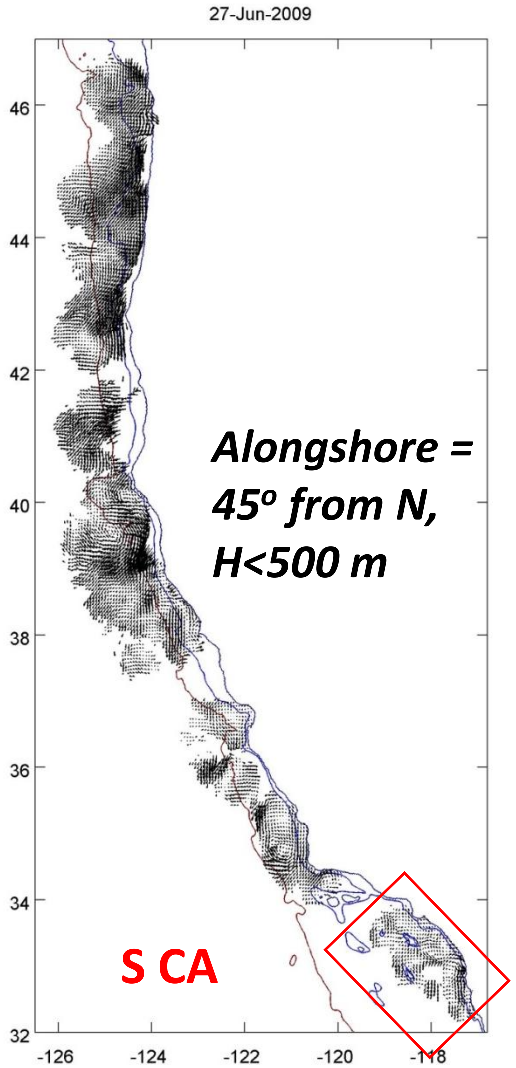
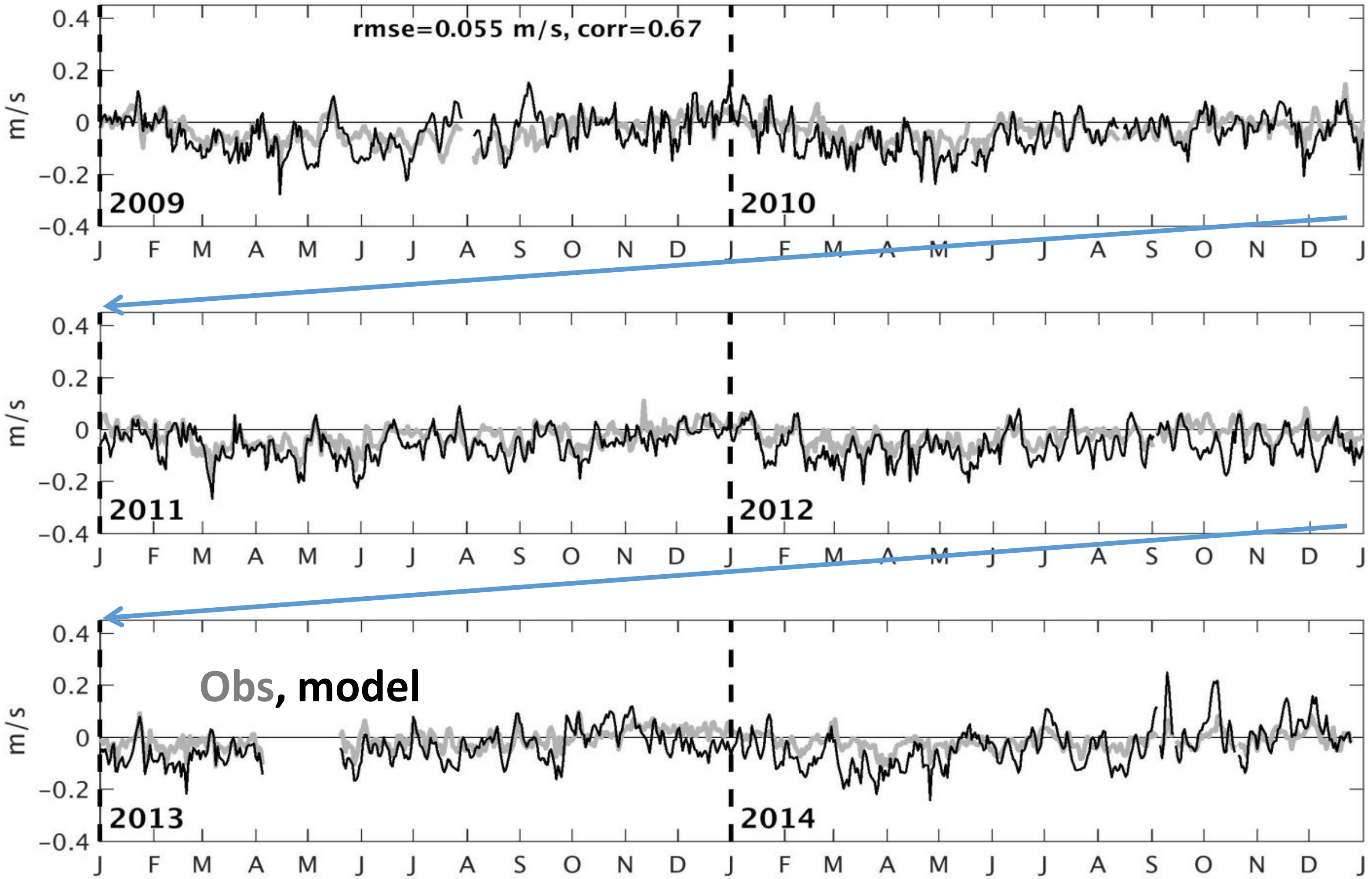


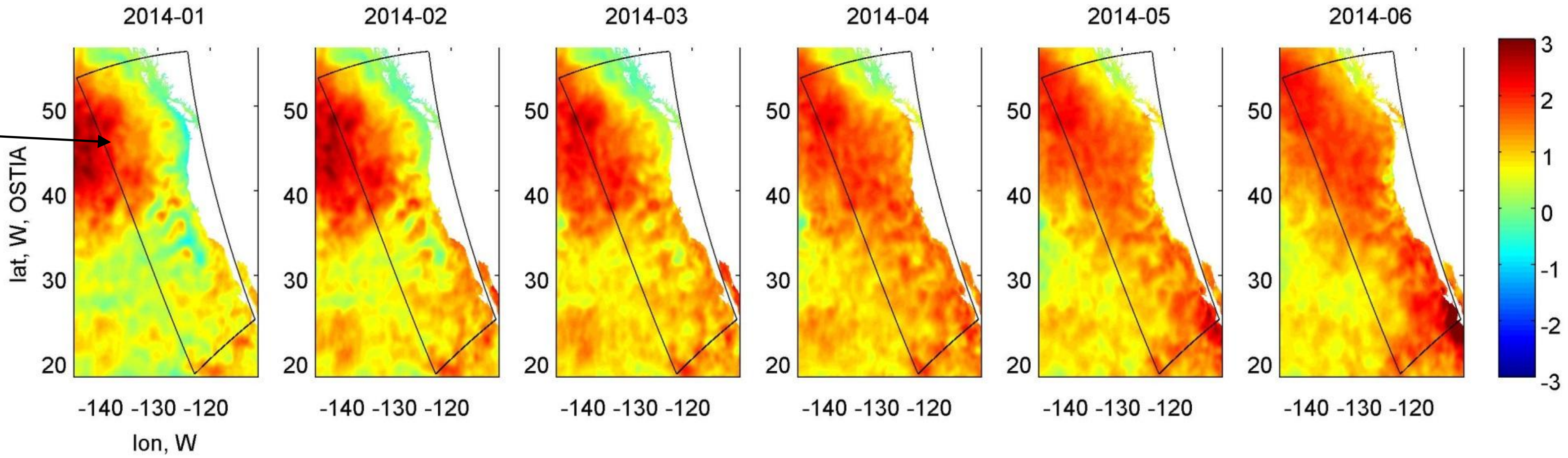



**Strong temperature anomalies emerge in NEP 2014** (and these would persist until the end of 2015)

**Satellite OSTIA SST anomaly, w /respect to 2009-2013 climatology (OSTIA)**

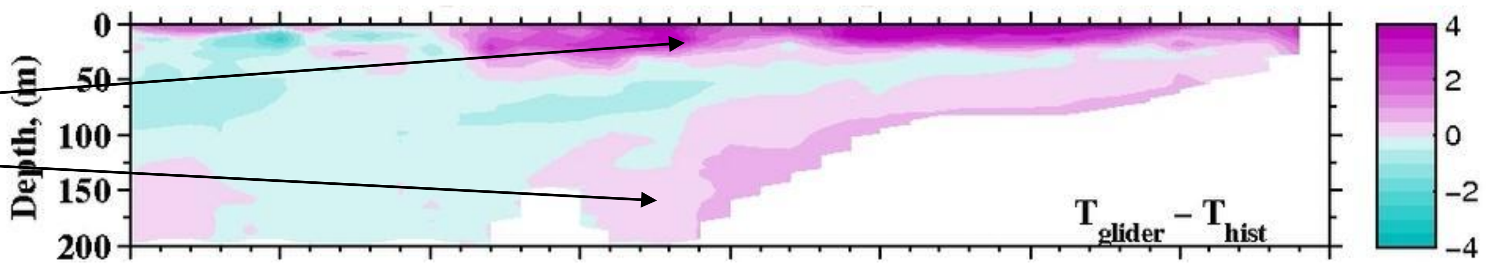
“Warm blob”

(*Bond et al.* 2015)

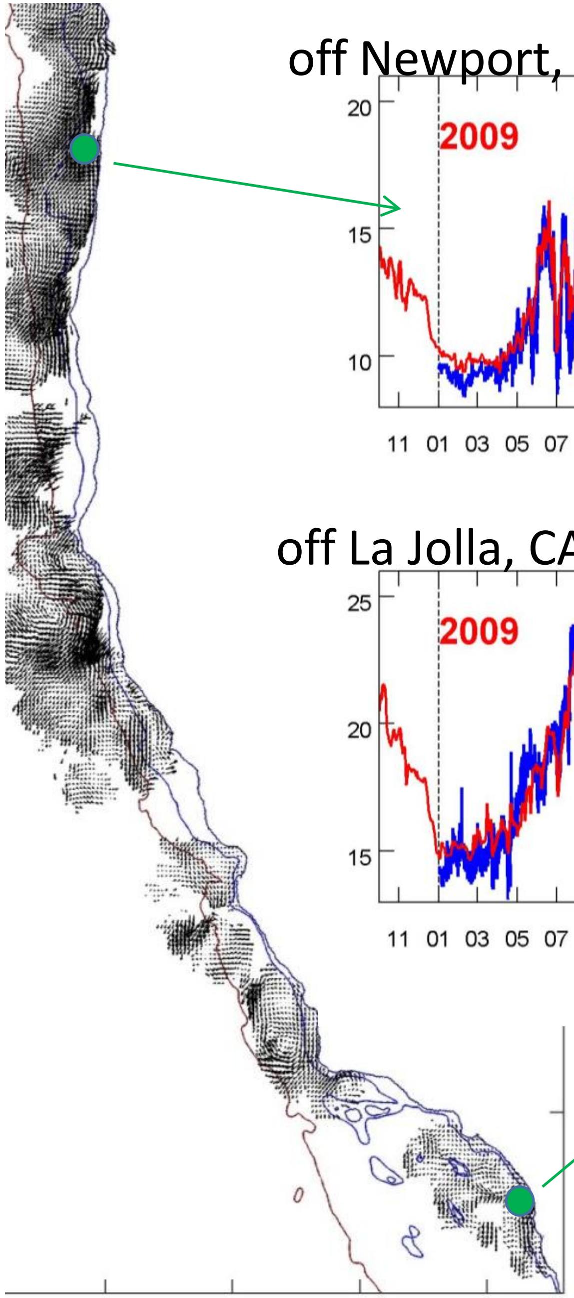


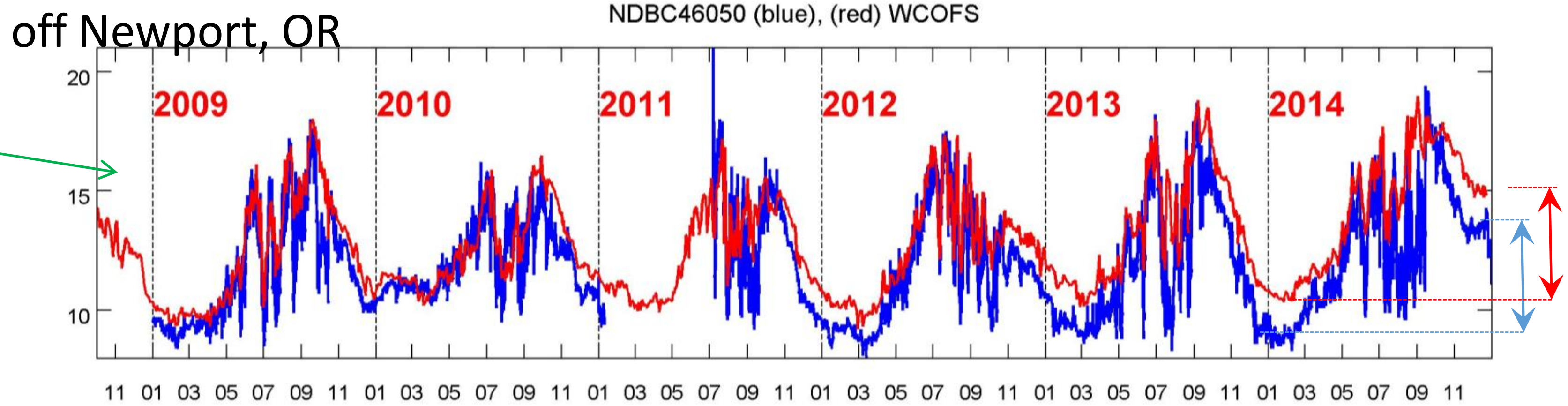

**Glider temperature anomaly off Oregon, 44.6N (September 2014) [Barth, OSU]**

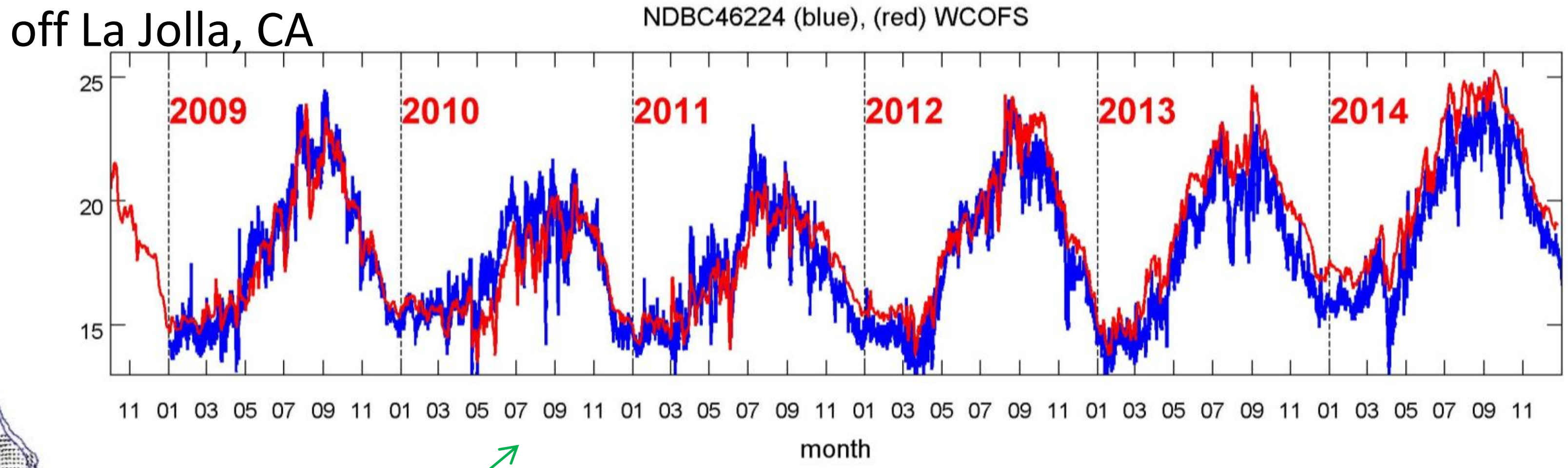
Strong anomalies at the surface and over the slope



# Near-surface T (NDBC shelf moorings) / WCOFS comparison:





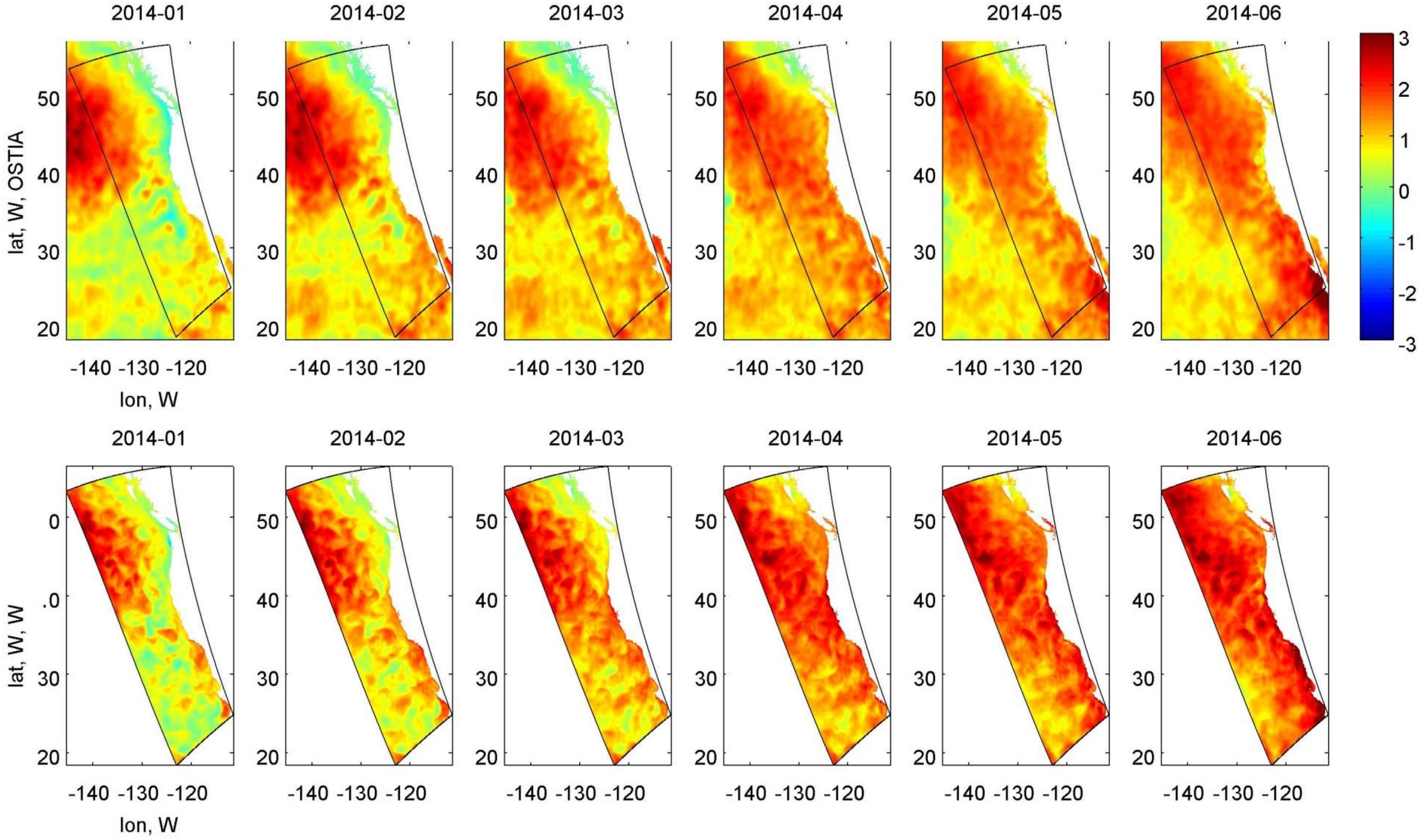




WCOFS has predicted correctly the warming trend (from Dec 2013 to Dec 2014)

## Compared to sat. SST anomaly, WCOFS predicts the appearance of the warm blob by Jan 2014, and wide-spread warming along the US Coast by summer 2014

**Satellite SSTA (OSTIA)**

**Model SSTA (WCOFS)**




*Anomaly w/ respect to 2009-2013 climatology (computed similarly for sat. and model)*

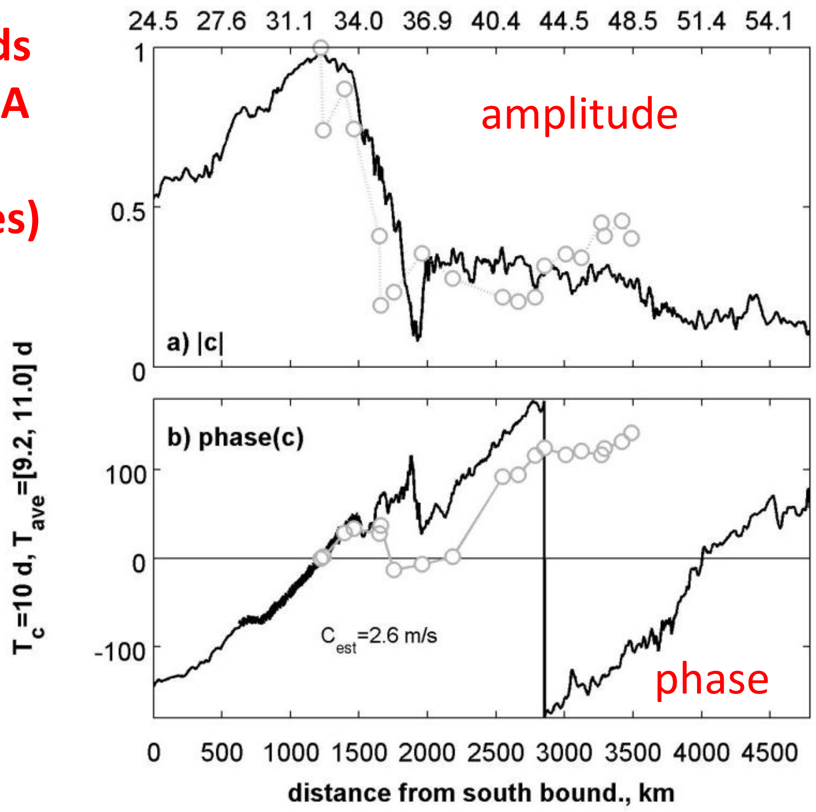
**Coastal trapped waves express themselves, e.g., in the along-coast coherence in the coastal sea level**

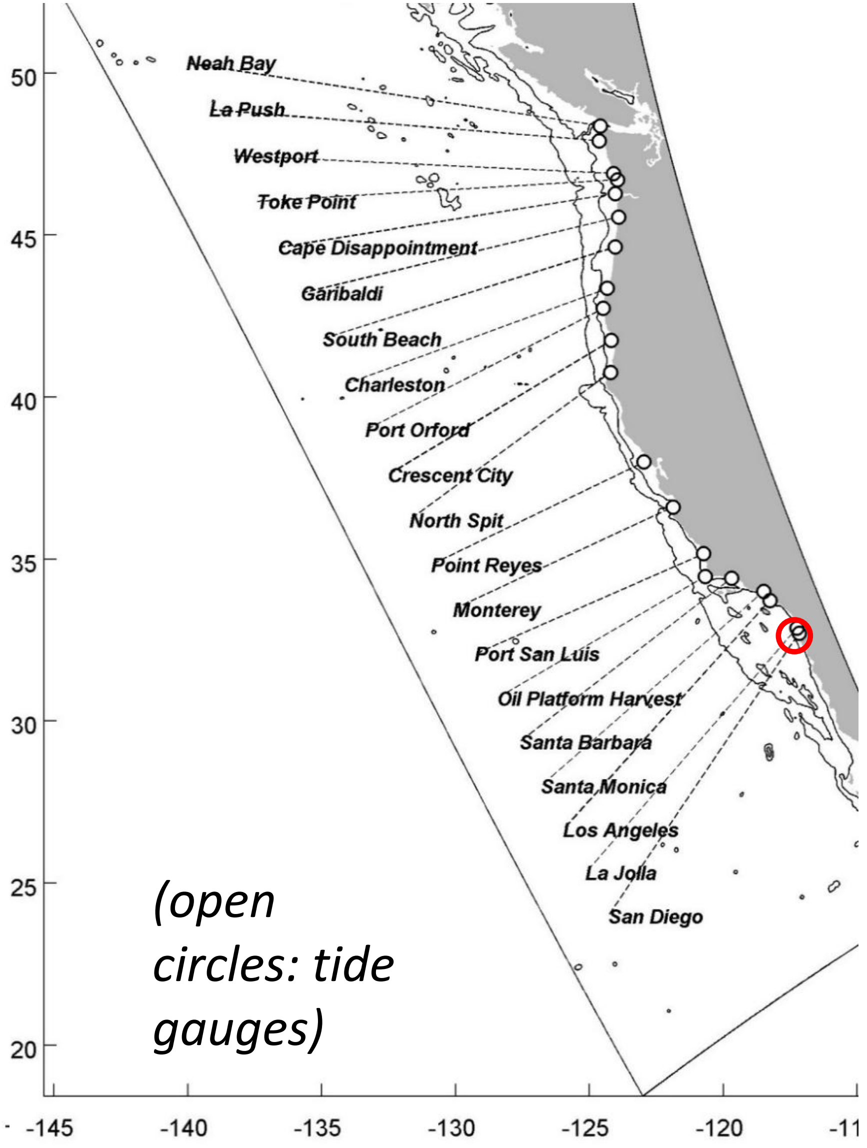
$$c(x,x_0)=|c|e^{i\varphi}=\frac{\langle Z(x,\omega)Z^*(x_0,\omega)\rangle}{\langle Z(x_0,\omega)Z^*(x_0,\omega)\rangle^{1/2}\langle Z(x,\omega)Z^*(x,\omega)\rangle^{1/2}},$$

where $Z(x,\omega)$ is the Fourier coeff. of $\zeta(x,t)$

**9-11 day range of periods w/ resp. to San Diego, CA**

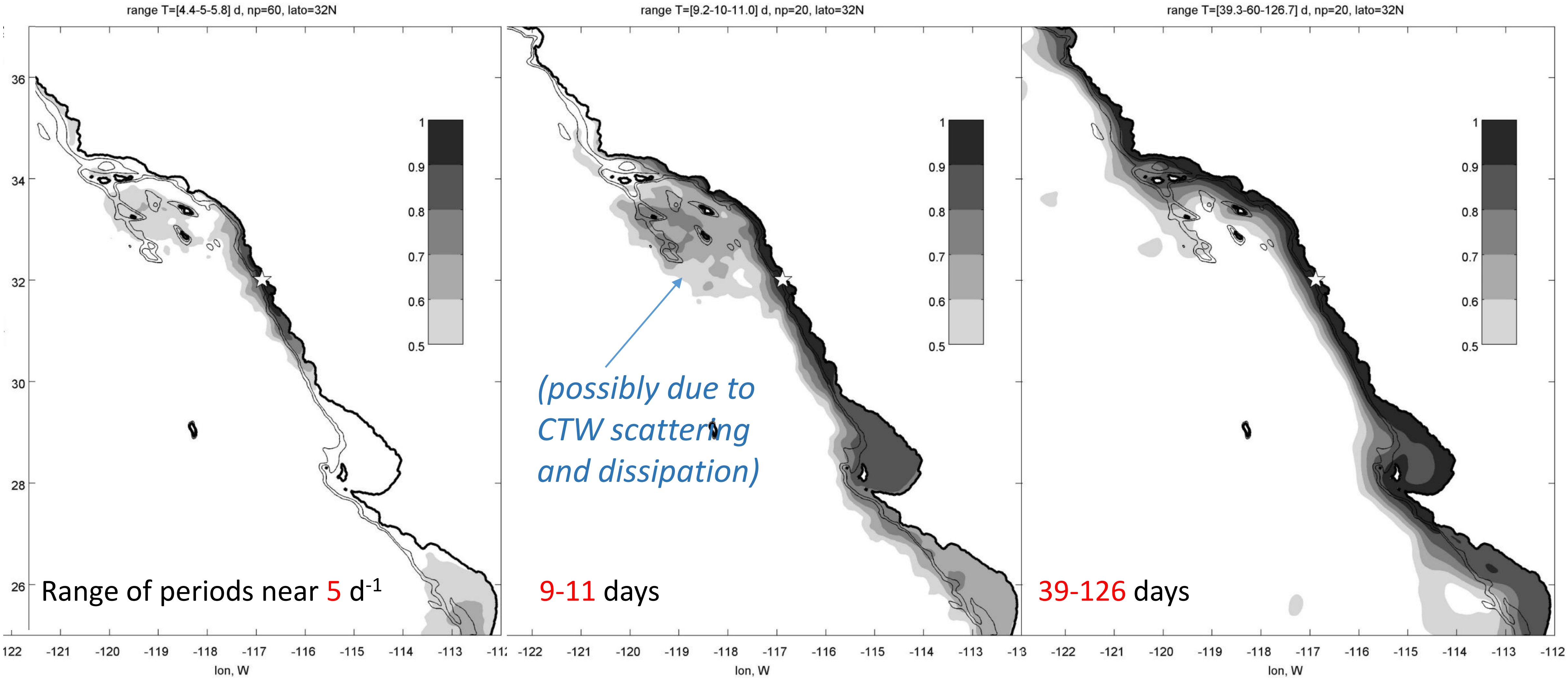
**(open circles: tide gauges)**
**(black line: model)**



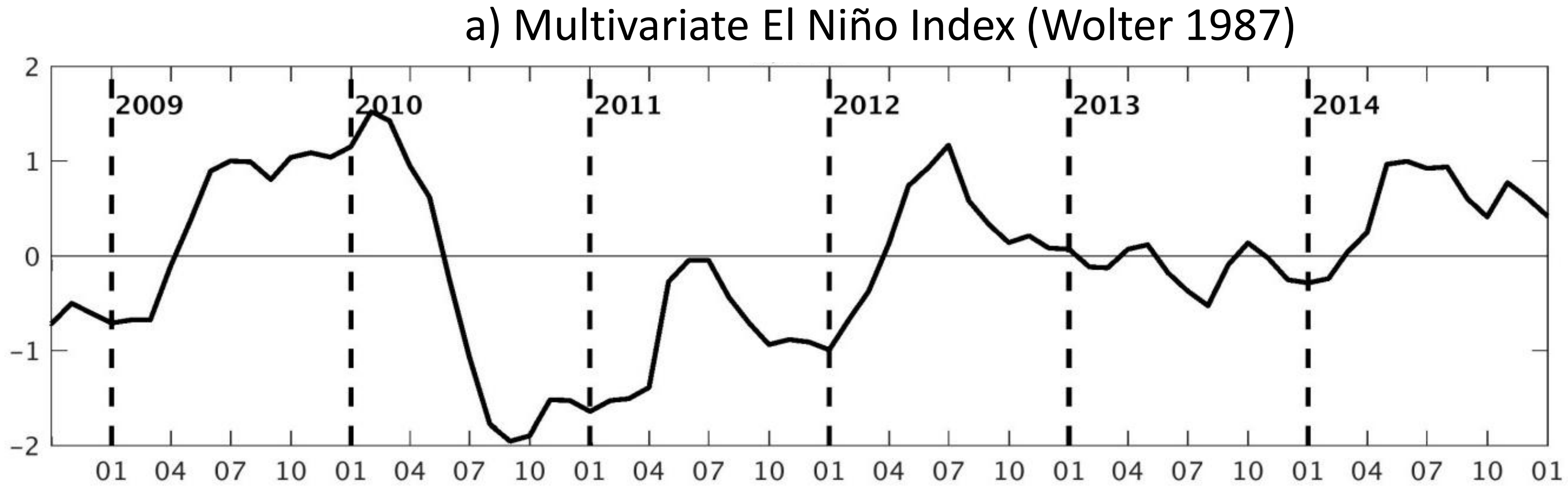



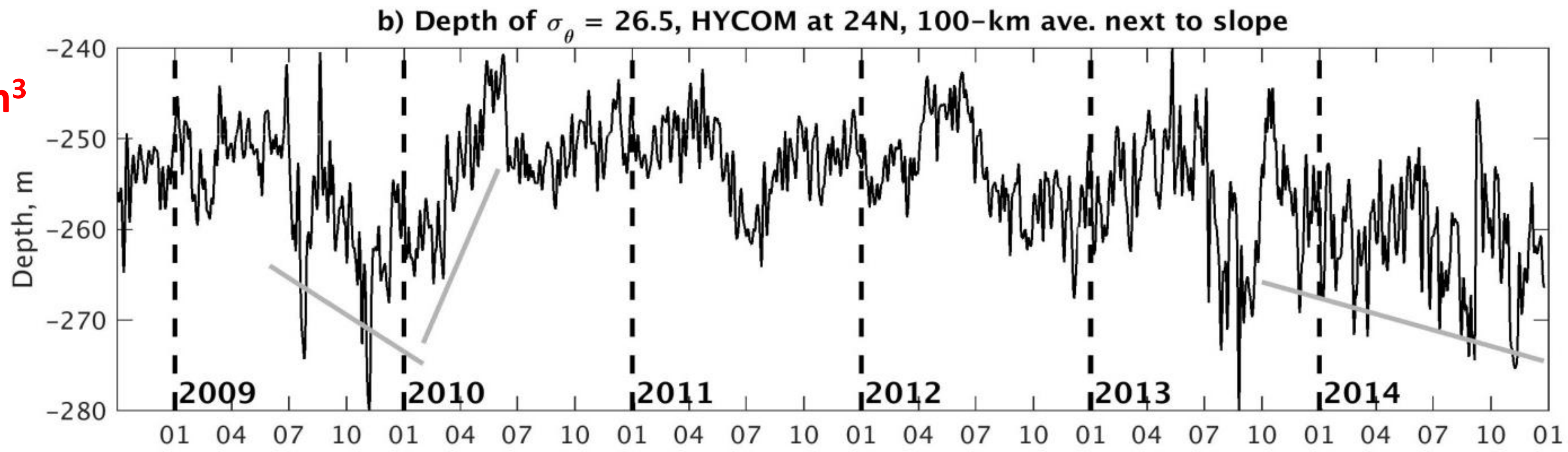

(Kurapov et al., 2017a)

# Using the 6-year model solution, we can compute 2-dimensional SSH coherence amplitude maps



**What kind of signal is found in the southern boundary conditions?**




**Depth of $\sigma_\theta$=26.5 kg/m$^3$ HYCOM at 24N**
(averaged between 0-100 km from cont. slope)

WCOFS: T and S are nudged to the global HYCOM solution in a 100-km wide band around the WCOFS open boundary

**Properties on the isopycnal surface 26.5**

In the entire domain, for each day, at each grid point we obtain

- depth of the isopycnal surface, *z*(x,y,t)
- T, S, u, v on this surface, PV

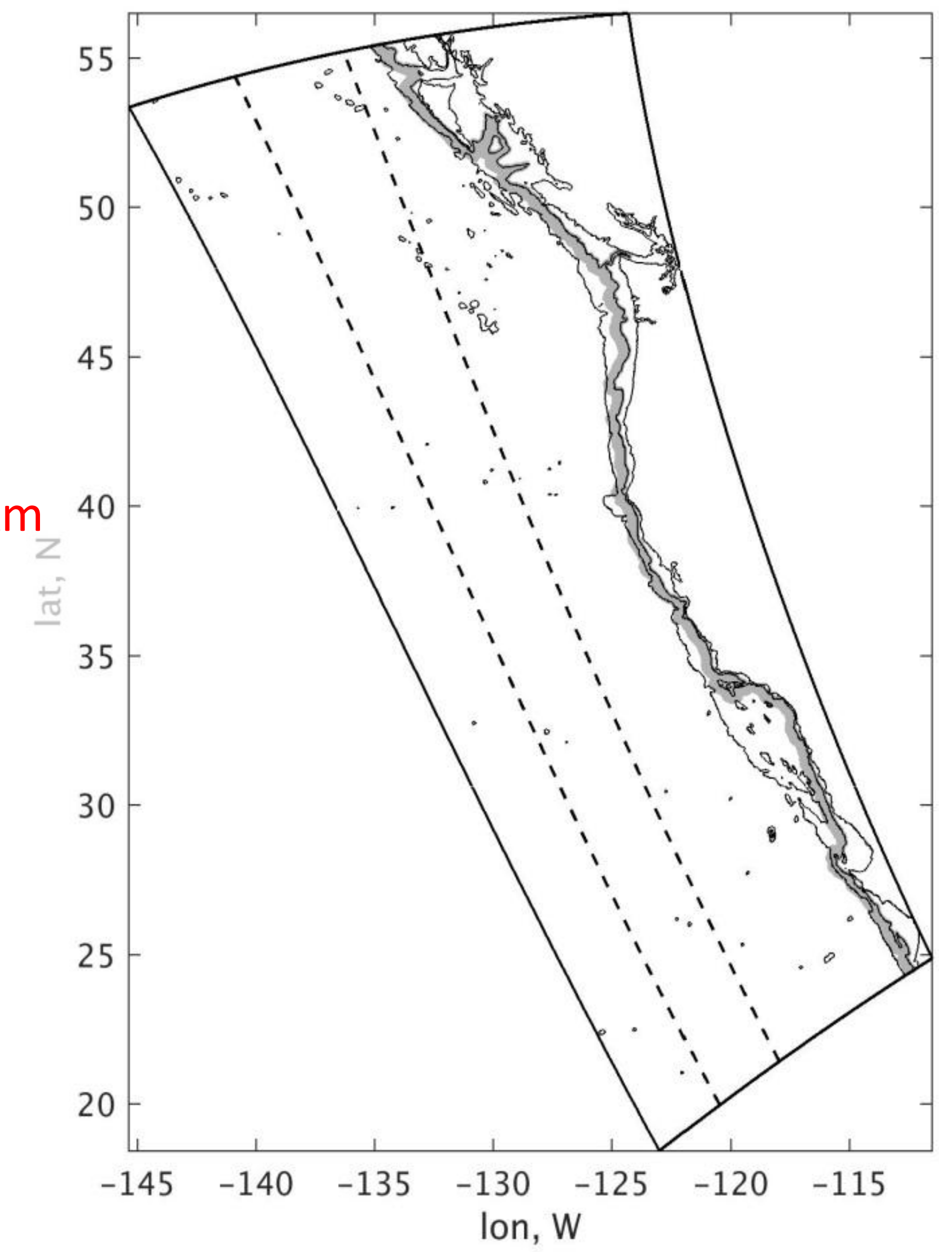
Average properties in cross-shore direction between 0-30-km offshore of the 200-m isobath (see gray shade in the figure)

⇒ e.g., *z*(s,t), *T*(s,t) where s = distance from southern boundary

T(s,t)= time_ave_T(s) + seasonal_T(s,t)+anomaly_T(s,t)

seasonal_T = harmonic fit (annual + semi-annual)

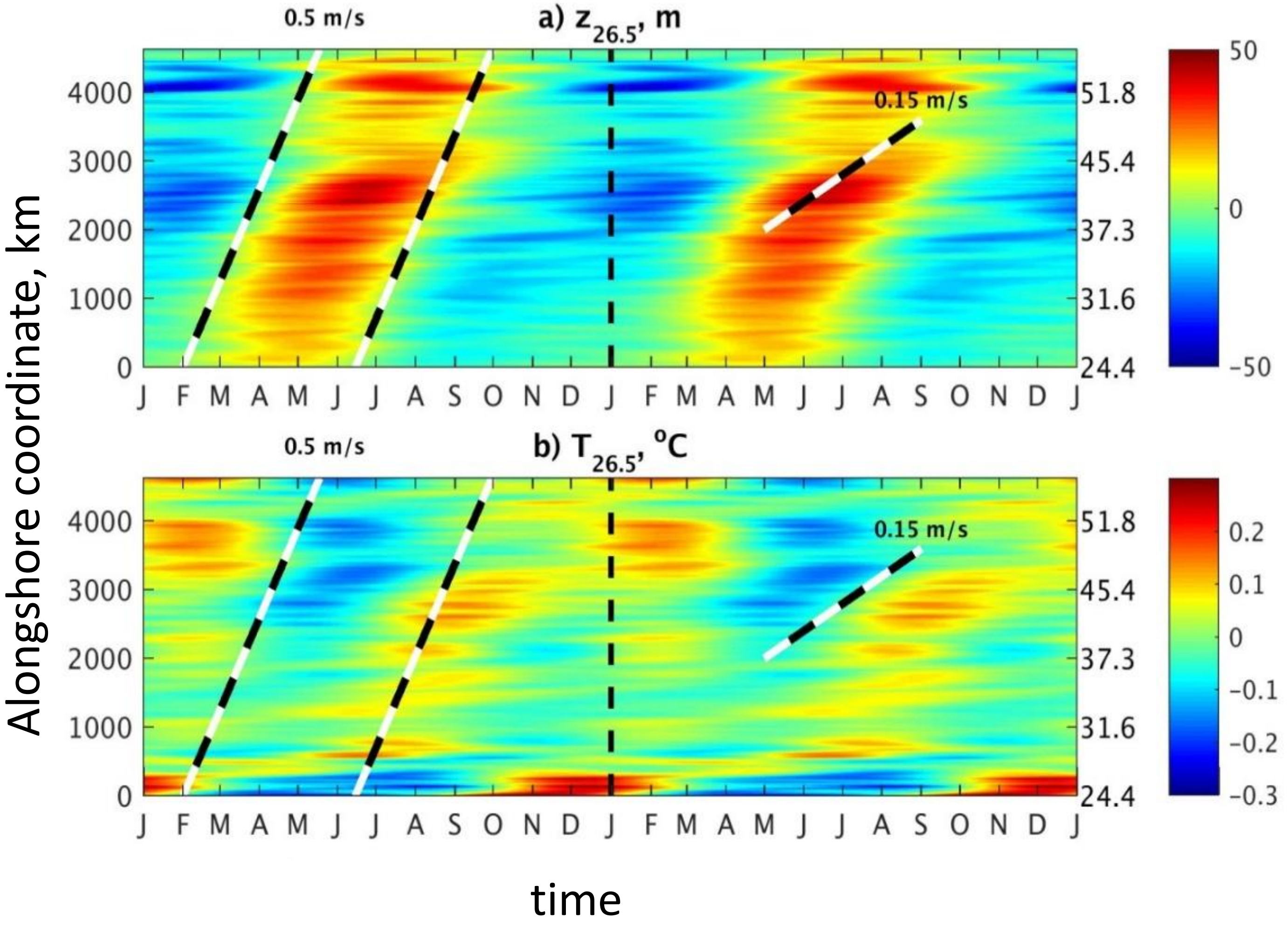
*Effect of CTW? Effect of undercurrent?*
*Climatology, anomalies?*



Seasonal patterns
(2 identical years shown):

Isopycnal depth: ±30 m, propagating pattern (0.5 m/s)

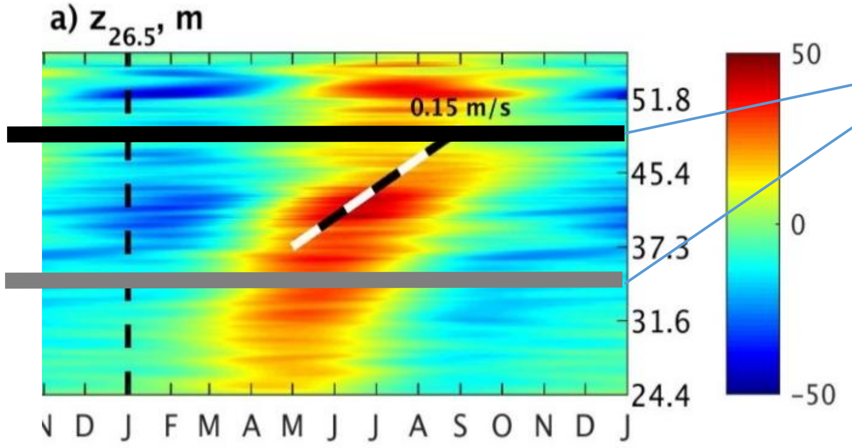
Temperature: subarctic waters are displaced by undercurrent waters (0.15 m/s), apparent in CA-OR-WA

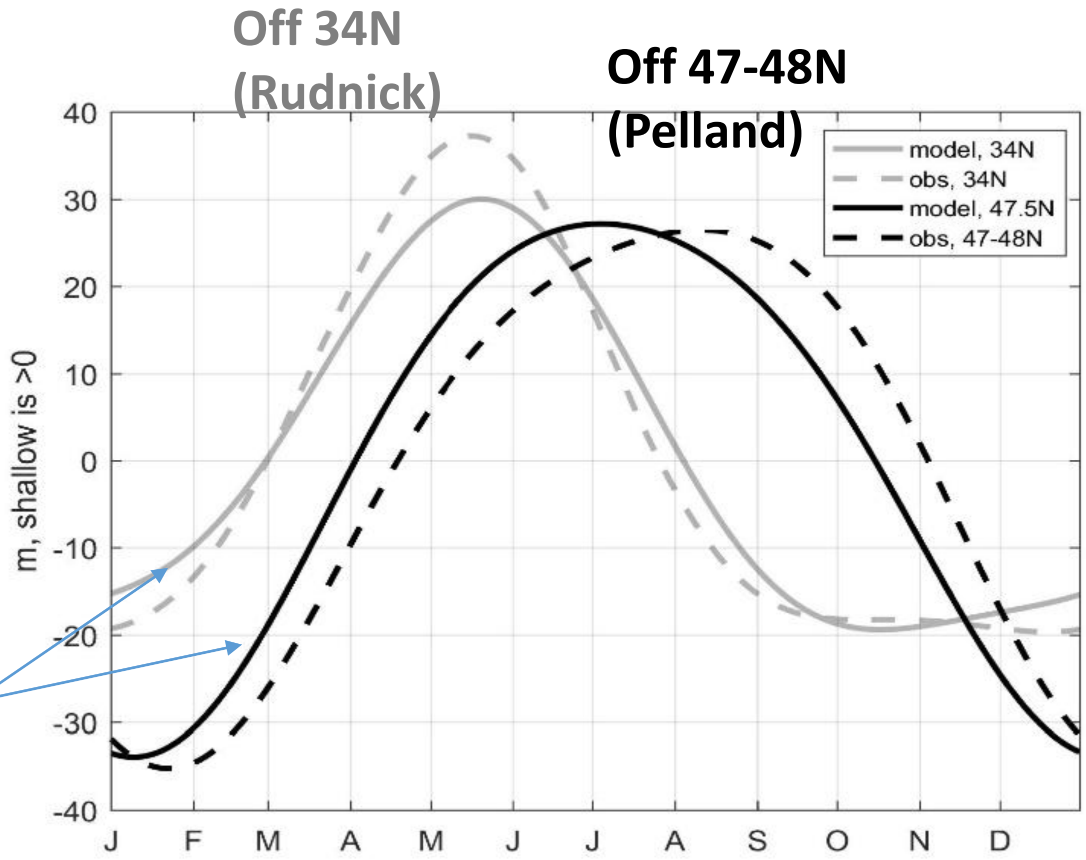


**Annual cycle in the depth of $\sigma_\theta$=26.5 over the continental slope:**

**model (solid lines) is compared to glider (dashed)** (Rudnick, Peland)

Glider data analysis confirms that seasonal $z_{26.5}$ does propagate along the slope



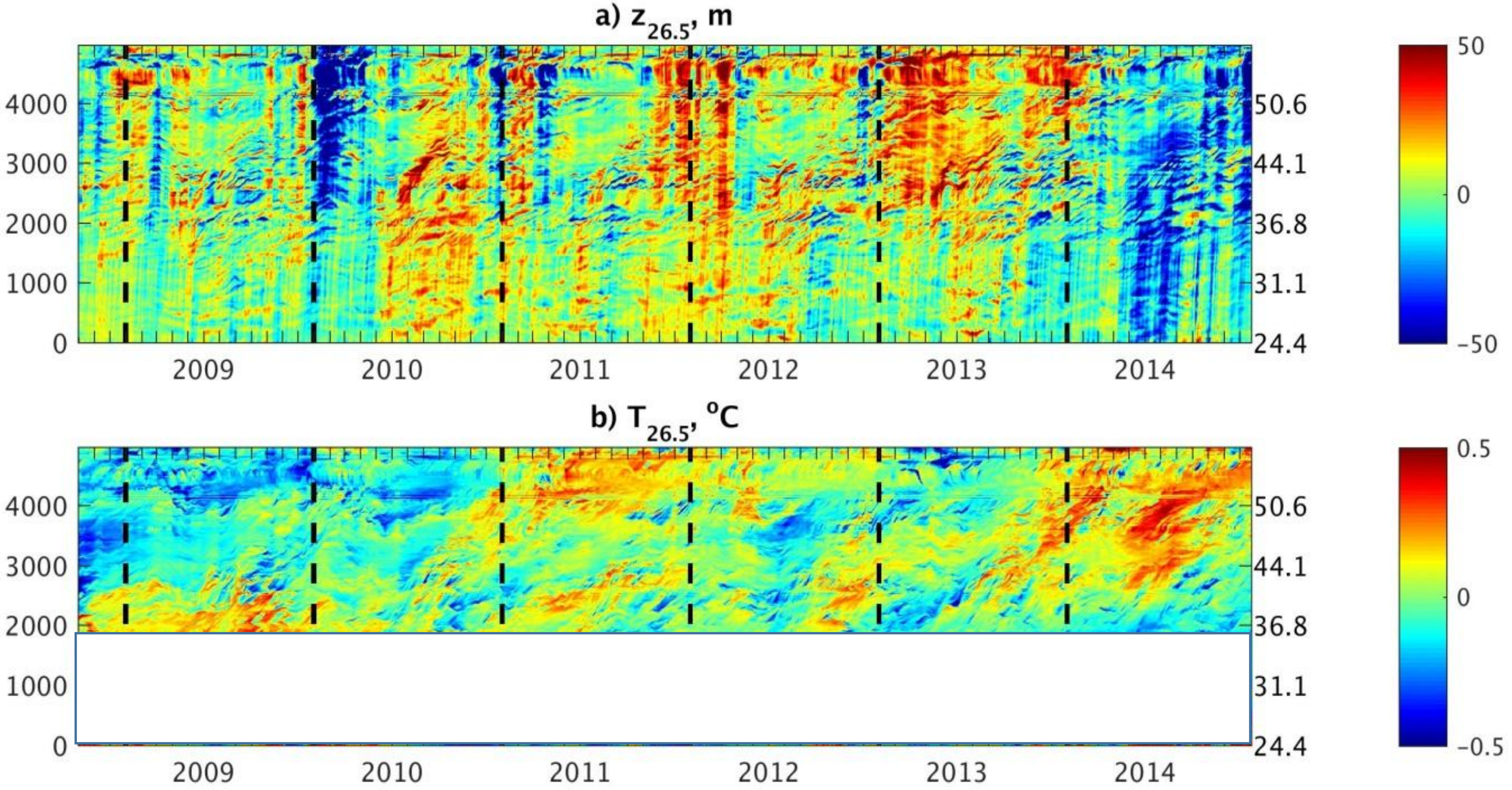



**Anomalies in the properties on the 26.5 isopycnal over the continental slope:**

z:

- fast propagating CTW
- El Niño effect in winter 2010 (atm. teleconnection)
- El Niño effect in summer 2014: propagation from the southern boundary

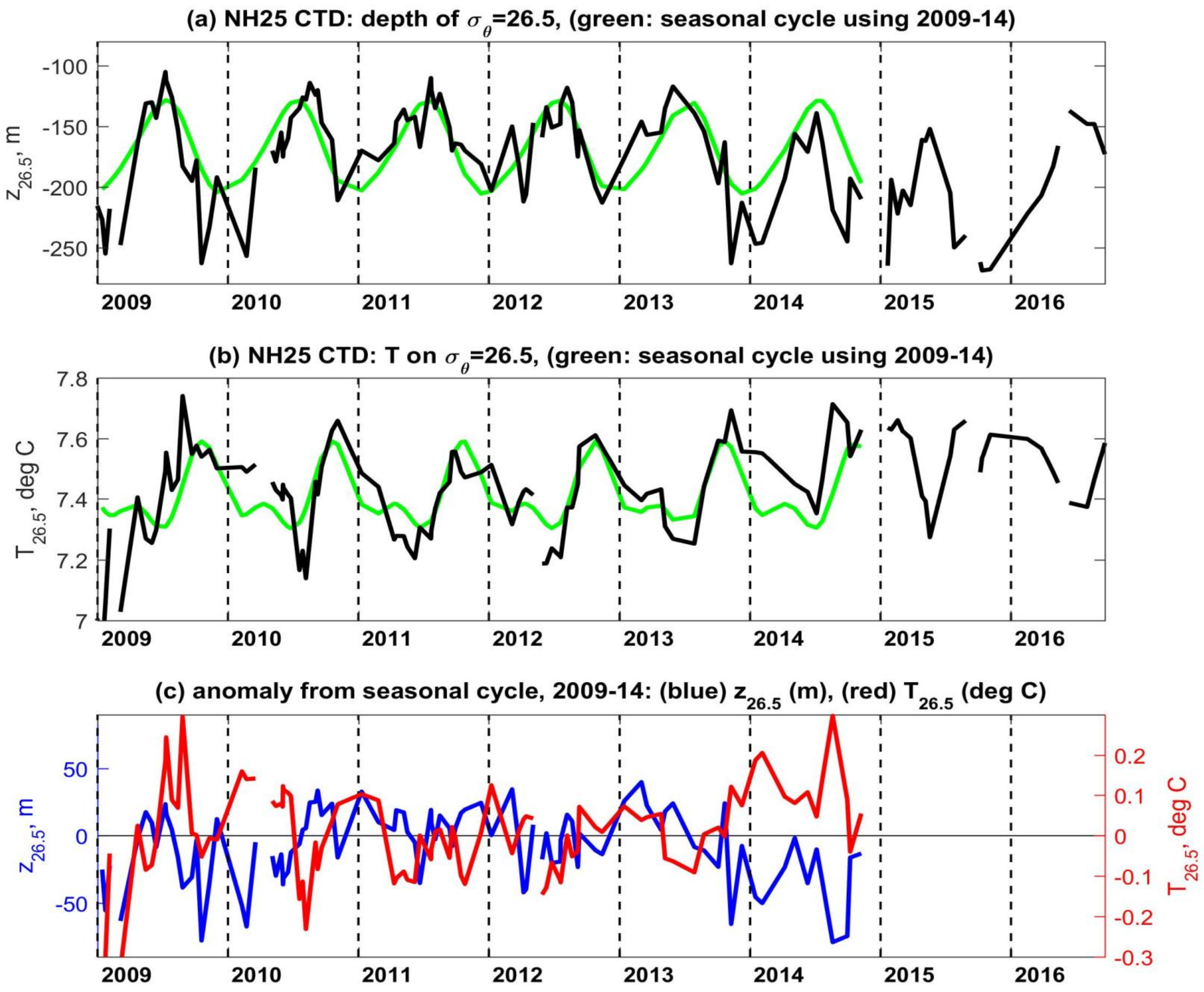
T: warmer in OR-WA-BC



Anomalously deeper $z_{26.5}$ and warmer $T_{26.5}$ is found in the CTD profile data off Oregon (H=300 m)

(data courtesy W. Peterson and J. Fisher)

(green: seasonal cycle based on 6 years of data)



2. DA tests, 4-km WCOFS, ROMS 4DVAR

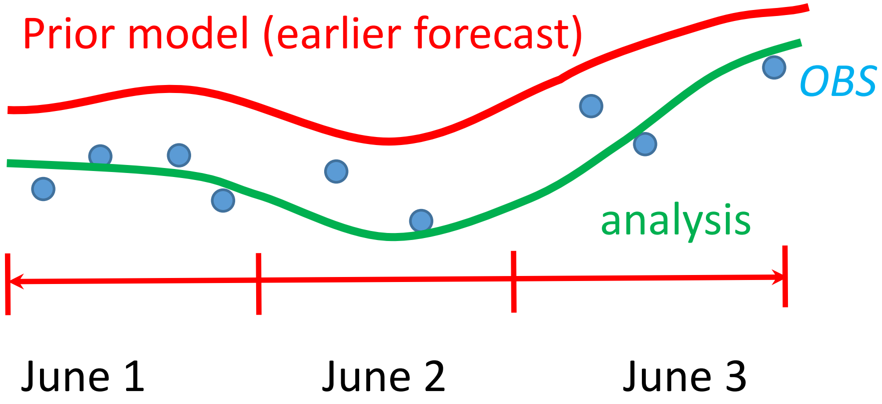
WCOFS4 DA Test, 3-day assimilation window

Observations:

- SST: JPSS VIIRS L3U (Ignatov et al., NOAA/NESDIS/STAR)
- SSH: Alongtrack altimetry, (1Hz/6 km alongtrack resolution, Jason, Cryosat, Altika)

*(satellite SSHA+model MSL)*

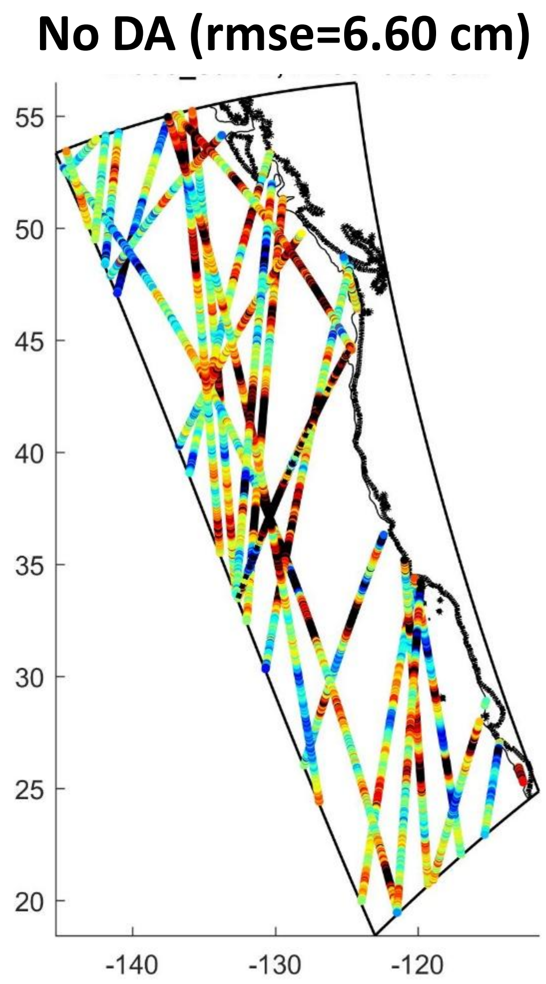
Assimilation methodology, 4DVAR:

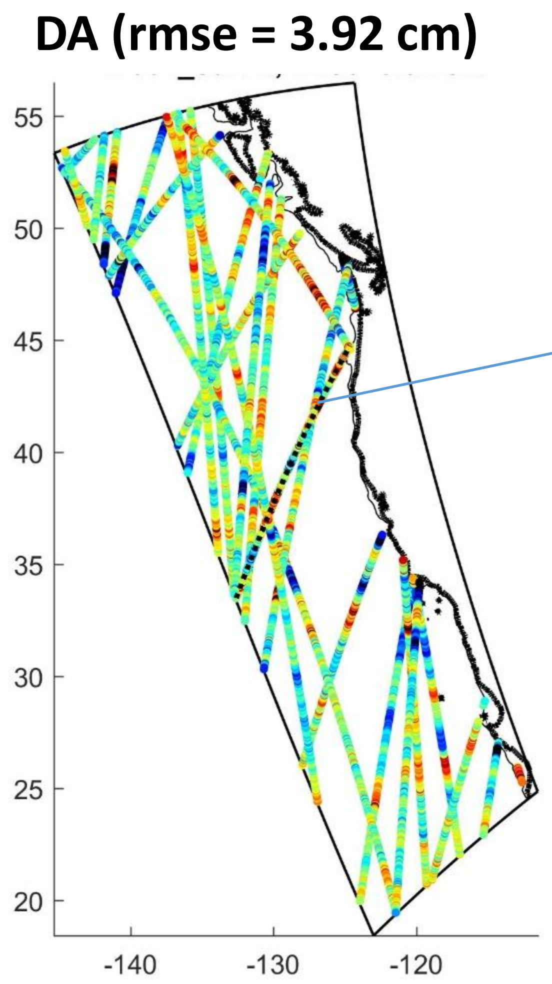


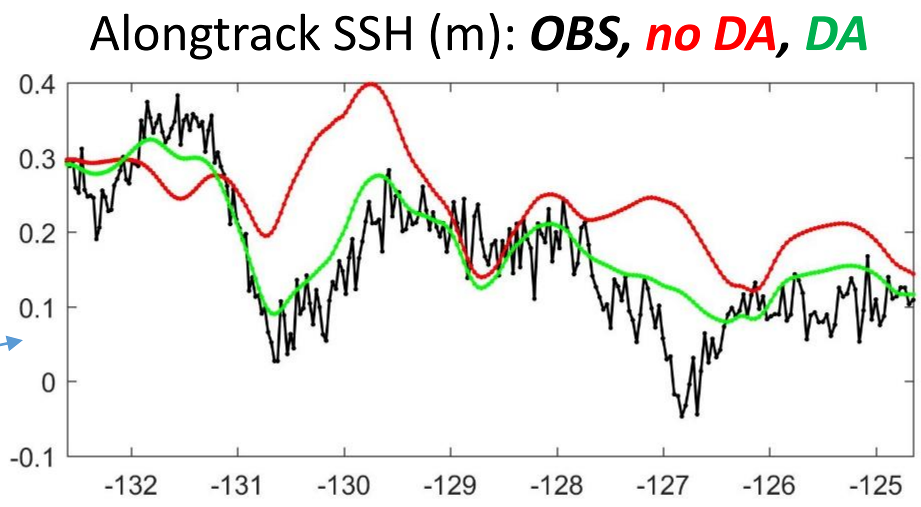

(a) Over a given time interval (here, 3 days) use available observations and adjoint model to correct initial conditions for the analysis

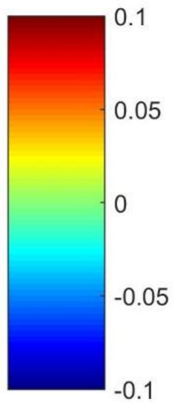
(b) Analysis provides improved initial conditions for future forecasts

# Data fit, SSH (non-tidal, model-observation difference, m)



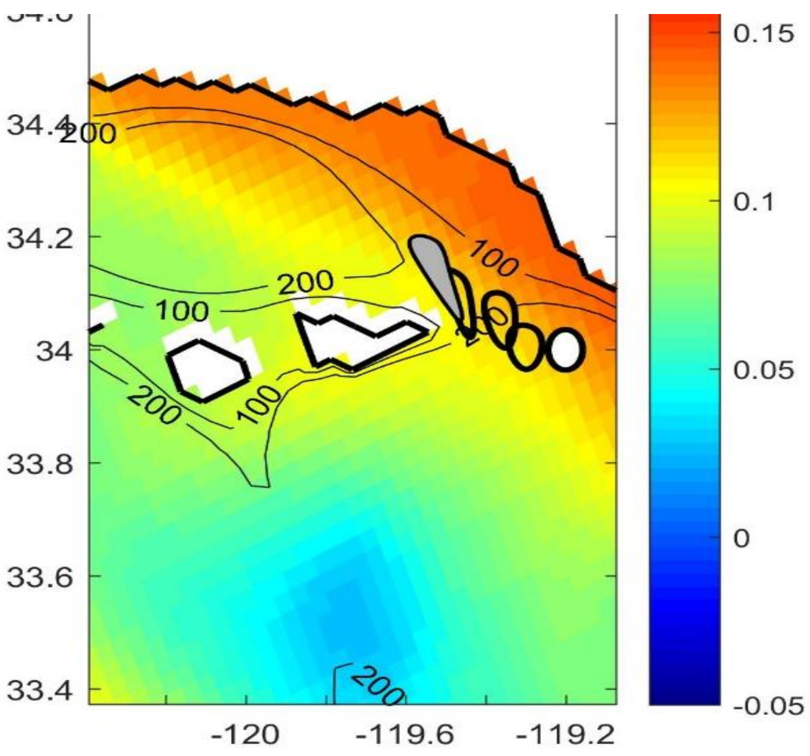



## DA Impact, “oil slick” dispersion in Santa Barbara Channel

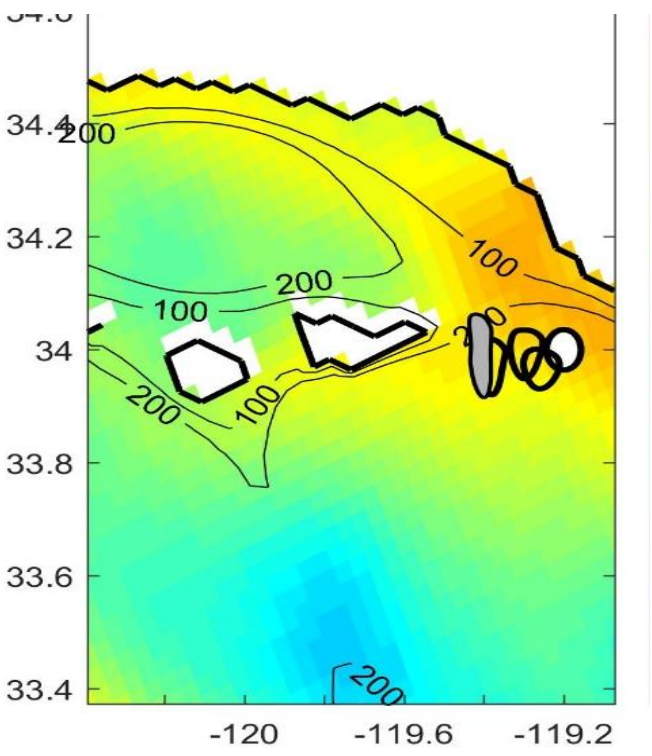
***Background color: <u>SSH</u> (shown on Jun 3, 2016)***

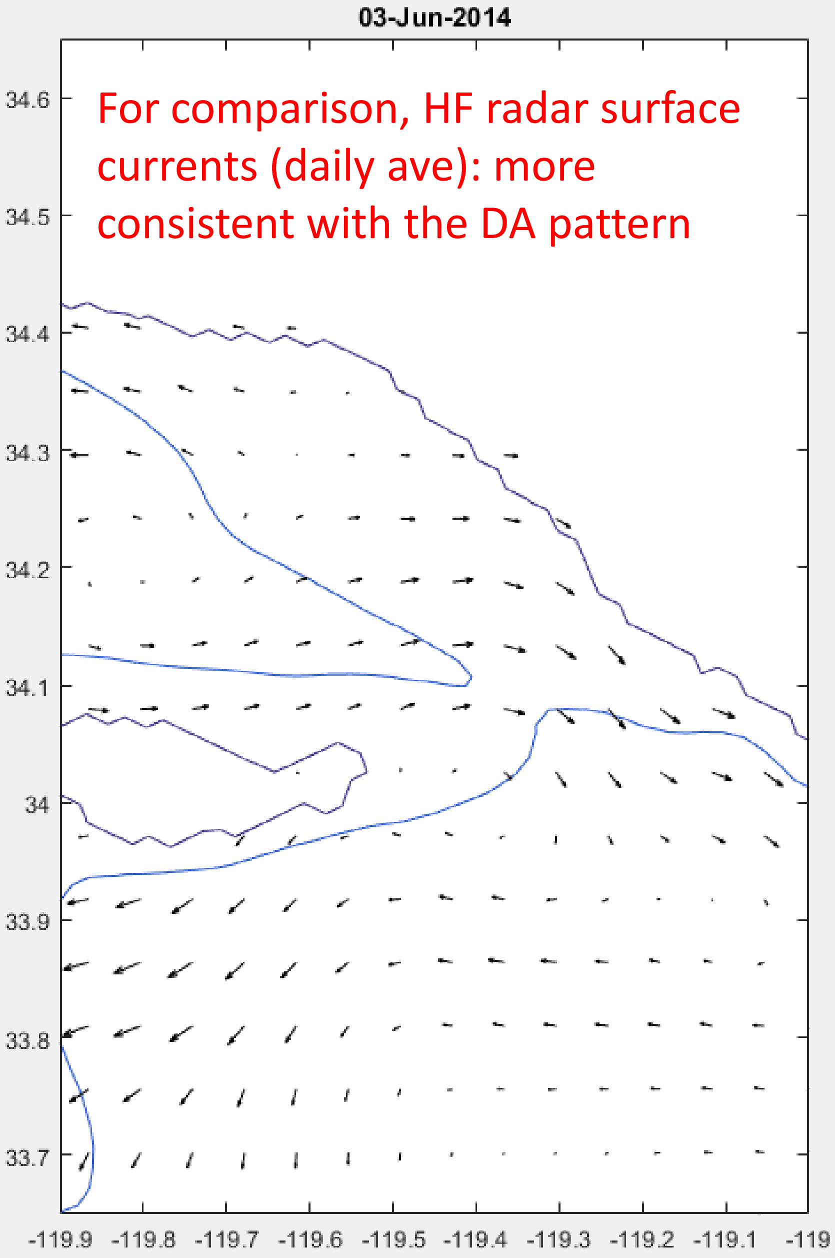
A patch is released on the surface and its contour is tracked using model (uv) for 2 days (6/2-3)
WHITE: beginning (4-km radius disk), GRAY: 48 hours later

No DA




DA




For comparison, HF radar surface currents (daily ave): more consistent with the DA pattern

**DA Impact, oil slick dispersion in Santa Barbara Channel**
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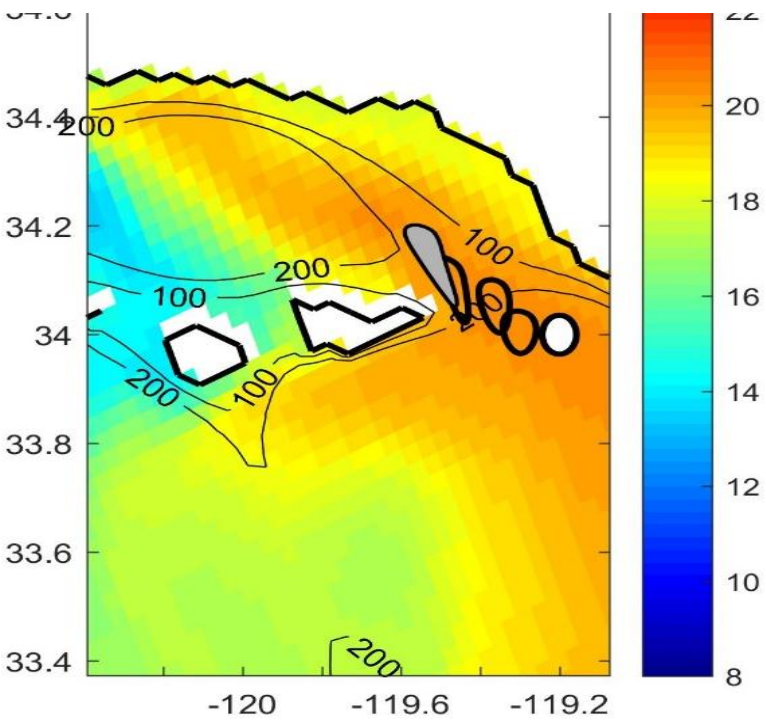


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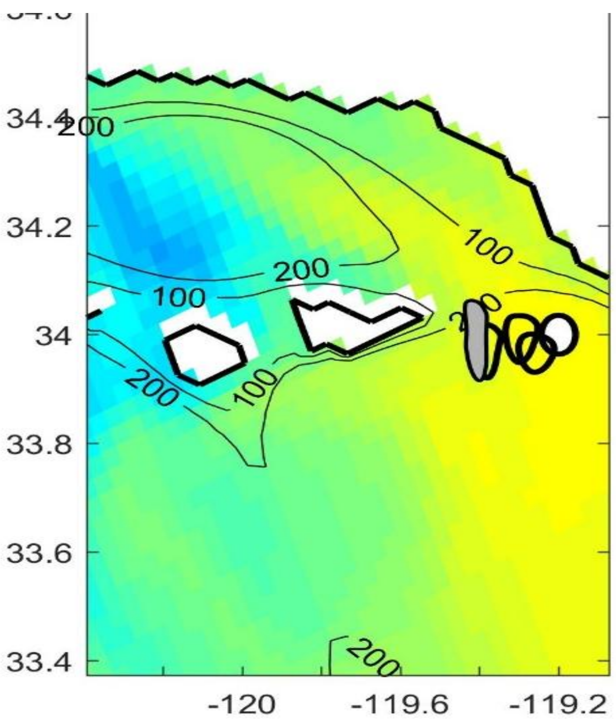


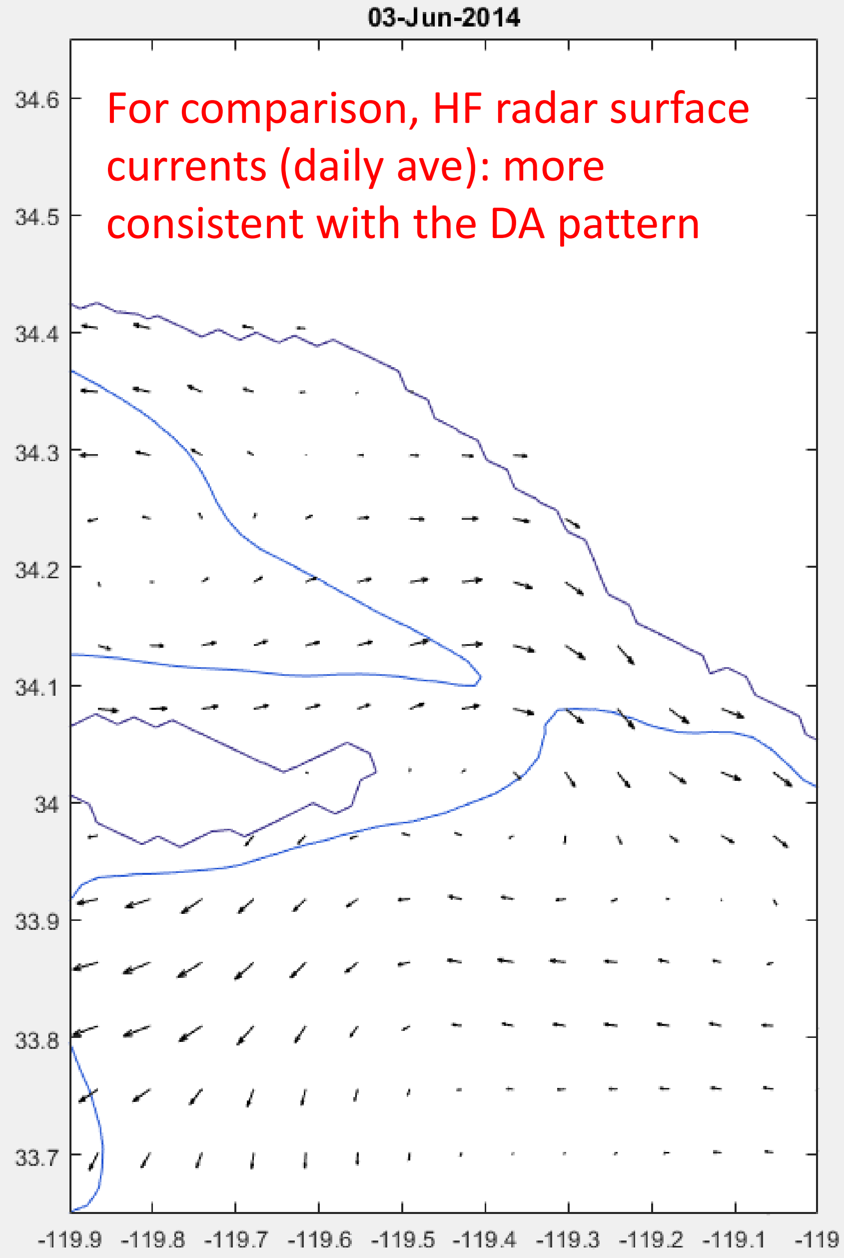

SUMMARY:

- A 2-km resolution regional ocean model of the West Coast from Mexico to BC has been developed as the base component of the NOAA West Coast Ocean Forecast System (WCOFS)

- Alongshore sea level coherence: a useful tool to understand CTW effects at different temporal scales

- The seasonal cycle in the depth of the 26.5-kg/m$^3$ isopycnal surface shows a south-to-north propagating pattern over the slope, with the speed of 0.5 m/s. Temperature and PV show patterns characteristic of advection by the undercurrent (0.1-0.15 m/s)

- Availability of long-term glider transect and profile data helps us verify the accuracy of the seasonal cycle in subsurface properties over the shelf and slope and discuss anomalies

- Assimilation of altimetry and SST makes an impact on Lagrangian transport