The data assimilation approach in the US West Coast Ocean Forecast System (WCOFS)

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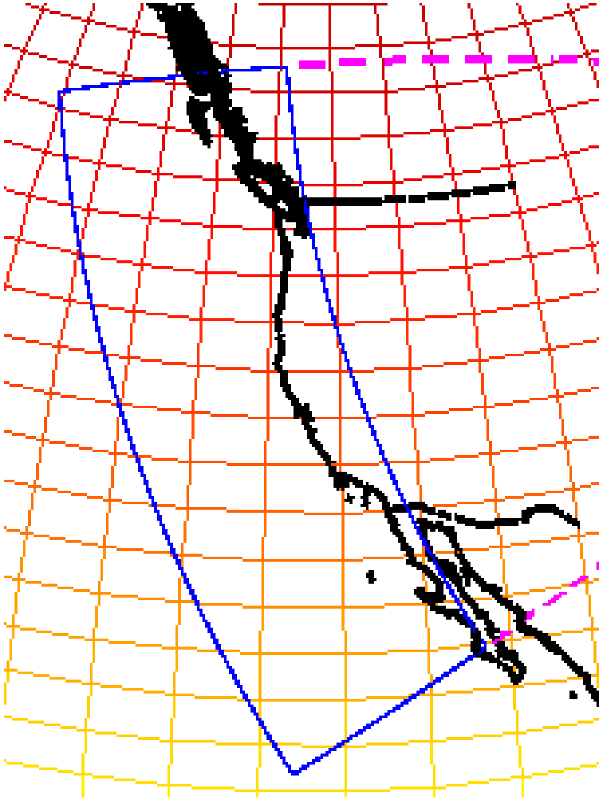
WCOFS:

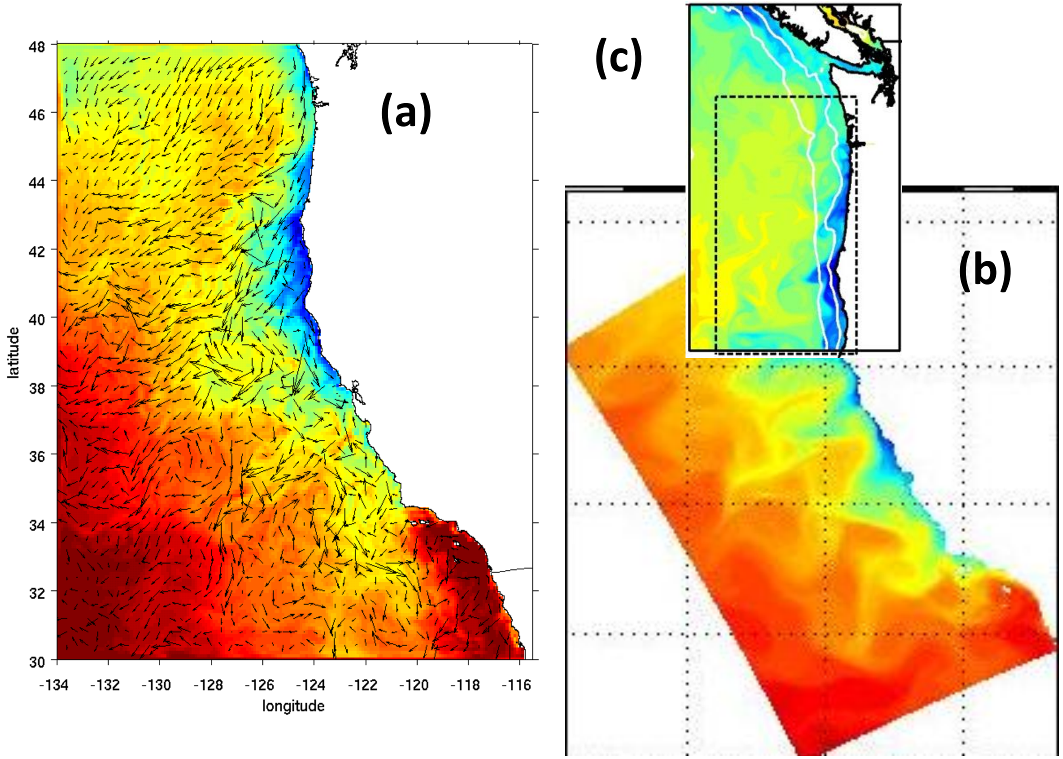
- Under development at NOAA (incl. NOS, NESDIS, JCSDA)
- Entire US West Coast
- Resolve shelf and slope processes everywhere
- Data assimilation
- Short-term forecasts of oceanic conditions

- Long non-da run for model skill assessment, model error covariance statistics, science analyses



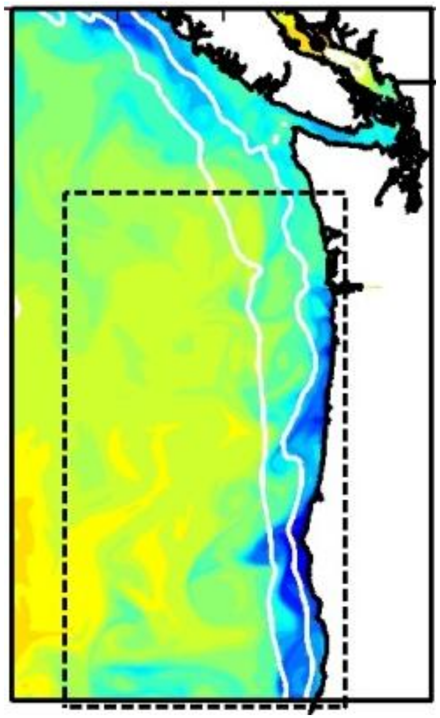
Credit : Eric Mortenson, Doug Beghtel /The Oregonian, www.naturalbuy.com, USCG, http://i.livescience.com/, Grantham et al. (2002)

Coastal Ocean Modeling Testbed (COMT project):
Transition of R&D to operations (WCOFS)



(a) UCSC/CenCCOOS (Edwards, Moore)	10-km res.,	4DVAR
(b) RSI/CenCCOOS/SCCOOS (Chao, Cornuelle, Chai)	3-km res. ,	3DVAR
(c) OSU/NANOOS (Kurapov)	2-km res.,	4DVAR

(d) UW (N. Banas, MacCready) .. domain sim. to (c), bio-phys. model



OSU DA system:

- Everyday updates of 3-day forecasts
- 4DVAR in 3-day windows (RADS SSH, hourly GOES SST, daily HF radar surface currents)

R&D: hybrid ensemble/4DVAR, assimilation in presence of the Columbia River plume (*Pasmans*)

- testsed with focus on the Columbia R. plume
- Effective method for covariance localization

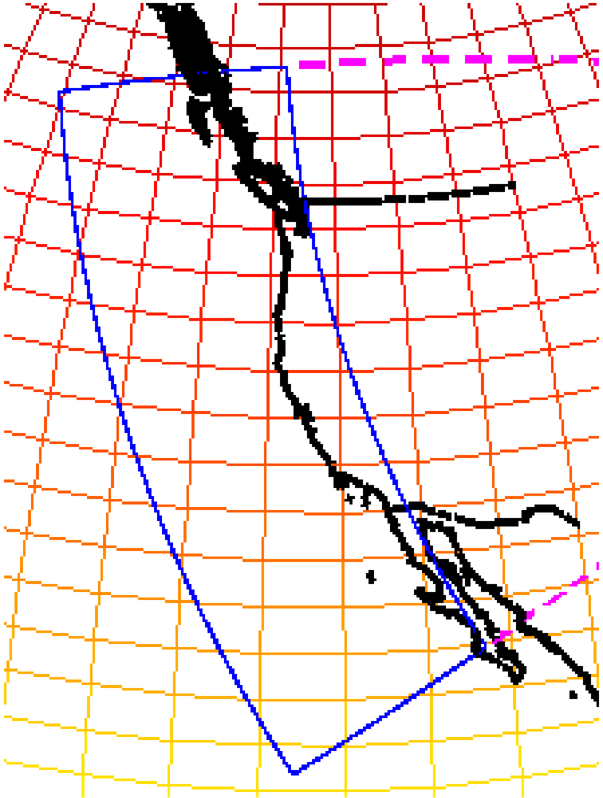
Problems with the ensemble-generated error covariance:

- T-S covariance has large variance along the front (since S changes from 10-33 psu)
- SST data cold bias + no constraint on S => DA increases S

WCOFS model: 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., Puget Sound (15 small rivers, clim.)



WCOFS: present status / skill assessment / initial data assimilation steps

Model-data comparisons:
- Coastal sea level (against tide gauge data)
- Alongshore coastal currents (against HF radar)
- SST (against moored time series, satellite)
- Subsurface stratification (Argo floats, gliders)

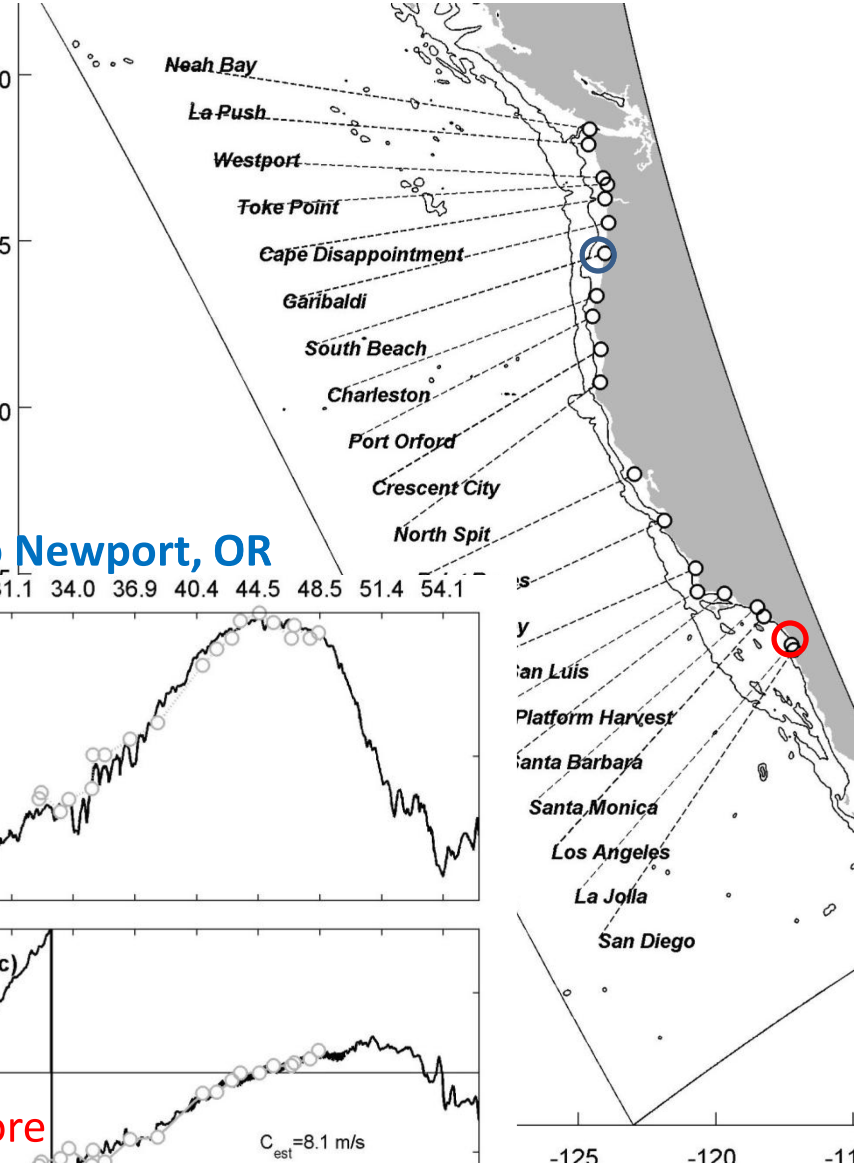
Scientific analyses (using a 6-year, 2009-2014, simulation without assimilation)
- Alongshore SSH coherence maps / esp. for ong-period motions
- Warm anomaly in the NEP in 2014-2015
- Seasonal and interannual variability in the slope properties (esp. undercurrent)

Initial DA efforts:
- learn to use the ROMS 4DVAR machine, first in a small domain

Along-coast coherence in the coastal sea level (tide gauge vs. model): close in amplitude and phase

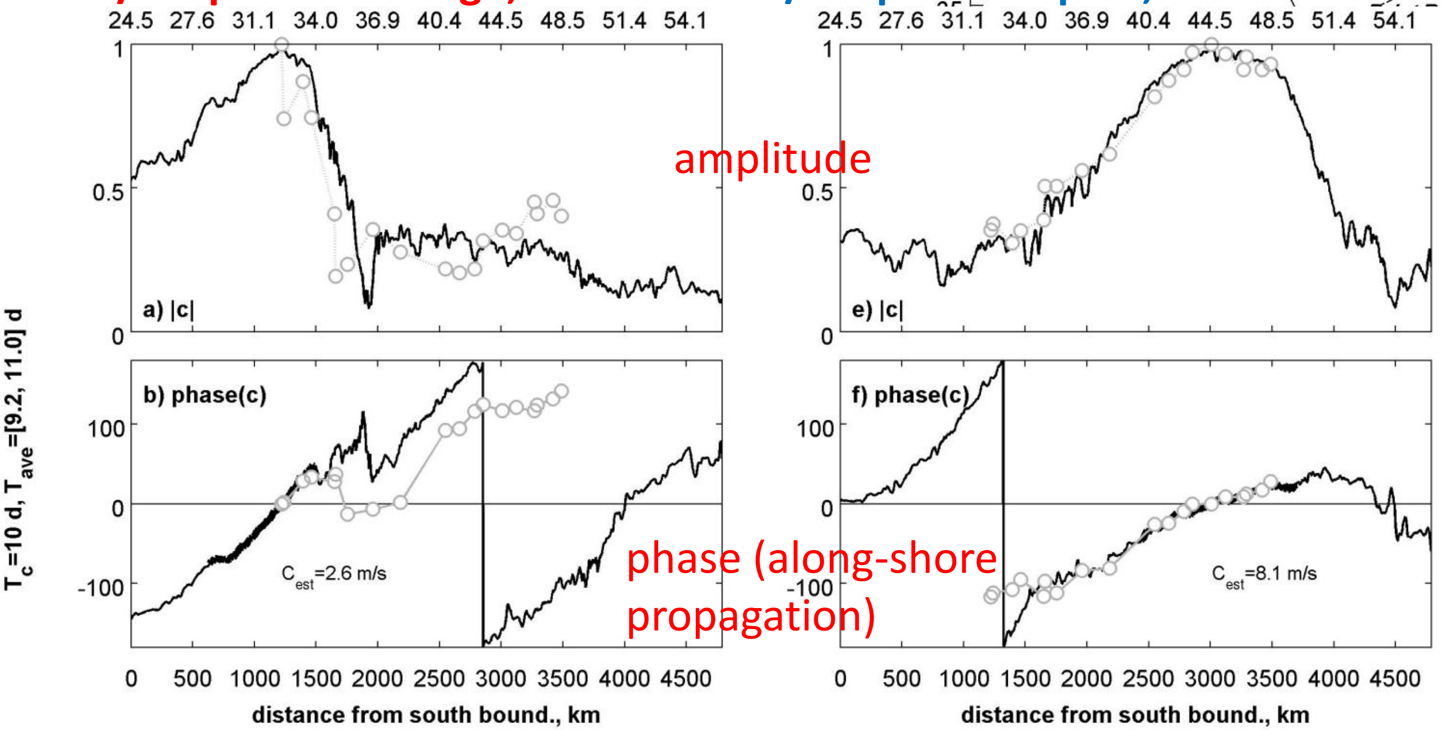
Coherence = spatial correlation for a specified frequency range

Shown here for the range of periods close to 10 days



w/ resp. to San Diego, CA

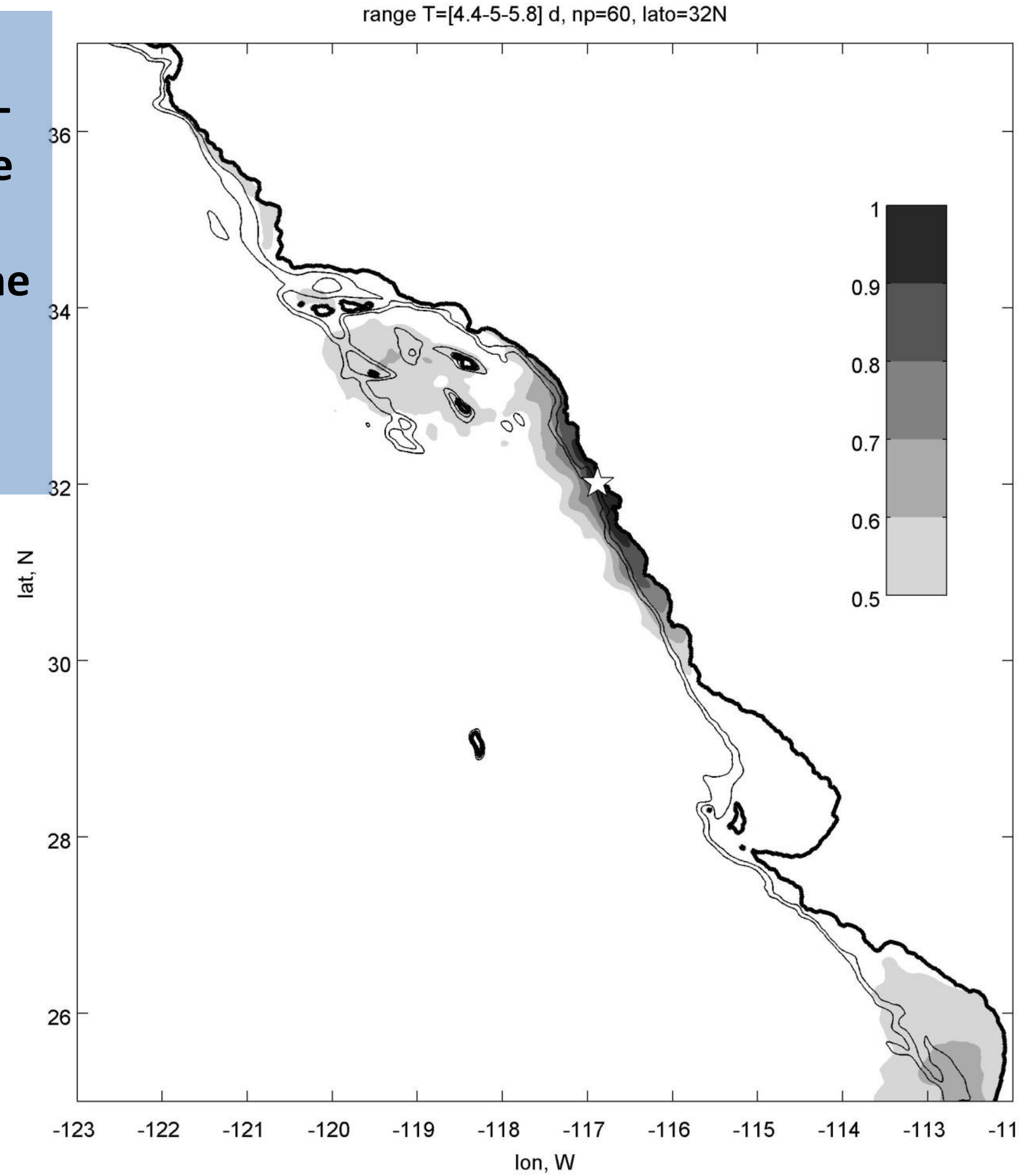
w/ resp to Newport, OR



amplitude

phase (along-shore propagation)

Using the 6-year model solution, we can compute 2-dimensional SSH coherence amplitude maps and learn about spatial structure of the long coastal trapped waves (conduits of the signal from south to north)

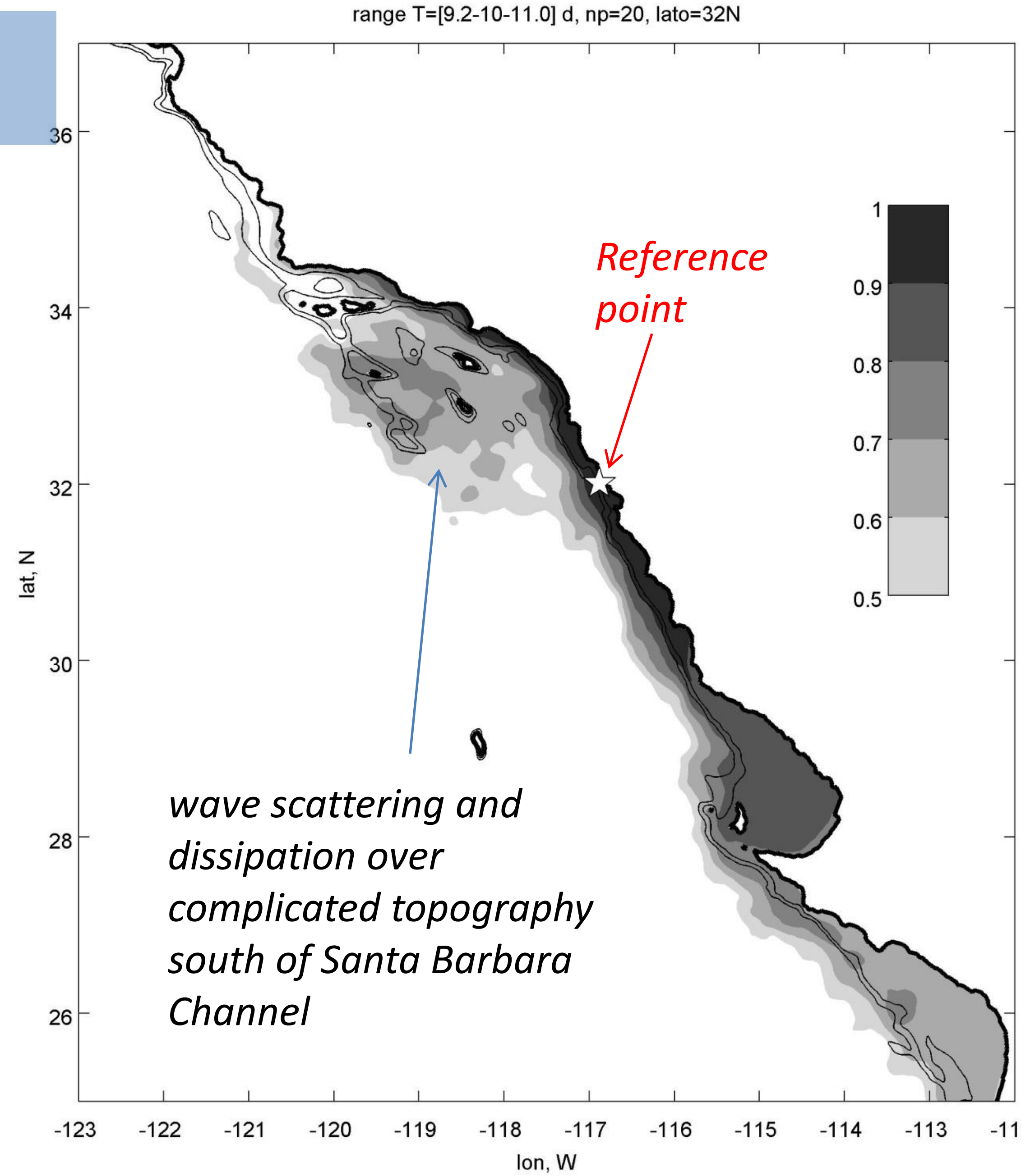


Frequency range centered on ω=1/5 d^{-1}

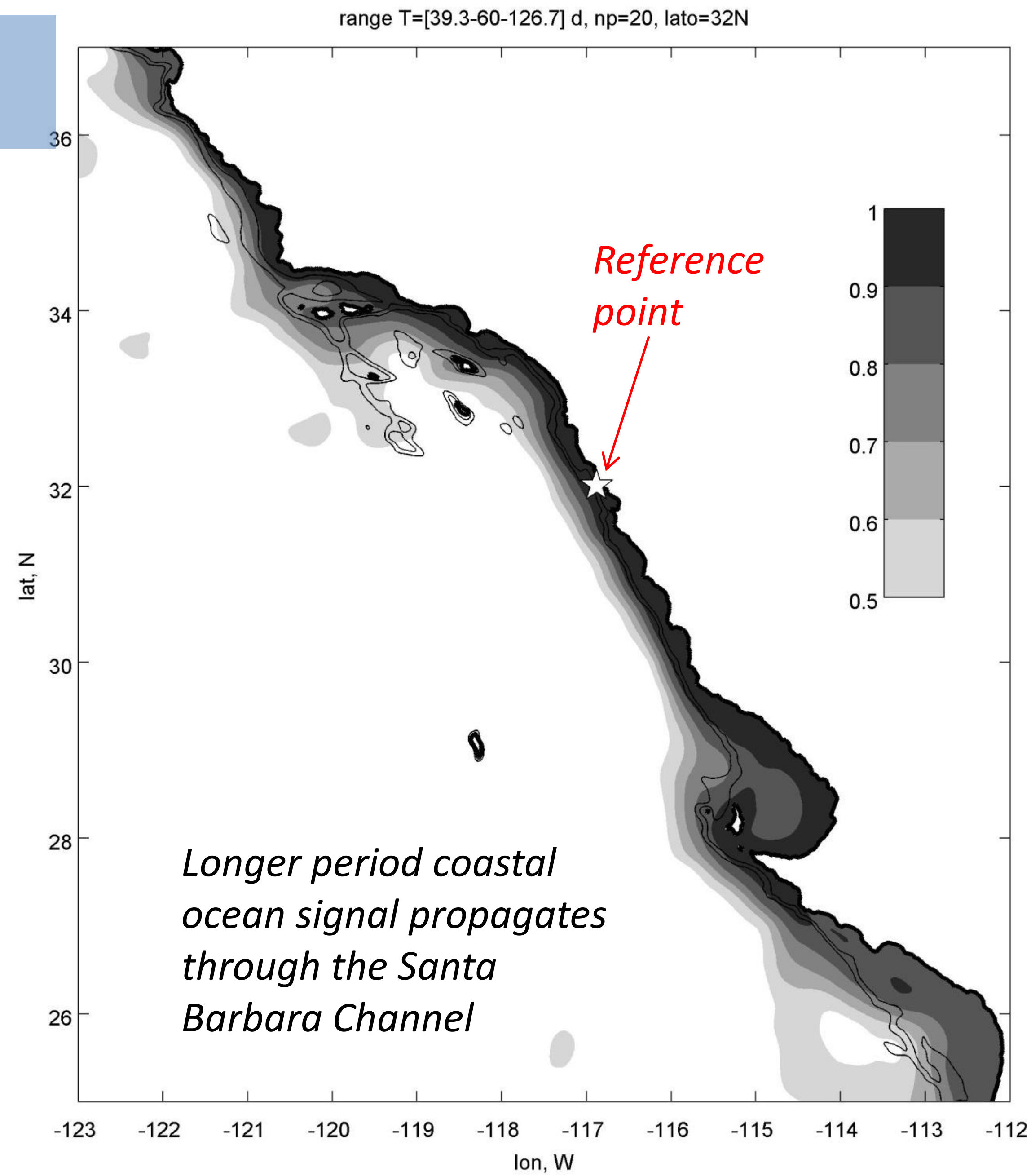
Kurapov et al., Oc. Dyn., submitted

The SSH coherence amplitude map

Frequency range centered on ω=1/10 d^{-1}



The SSH coherence amplitude map



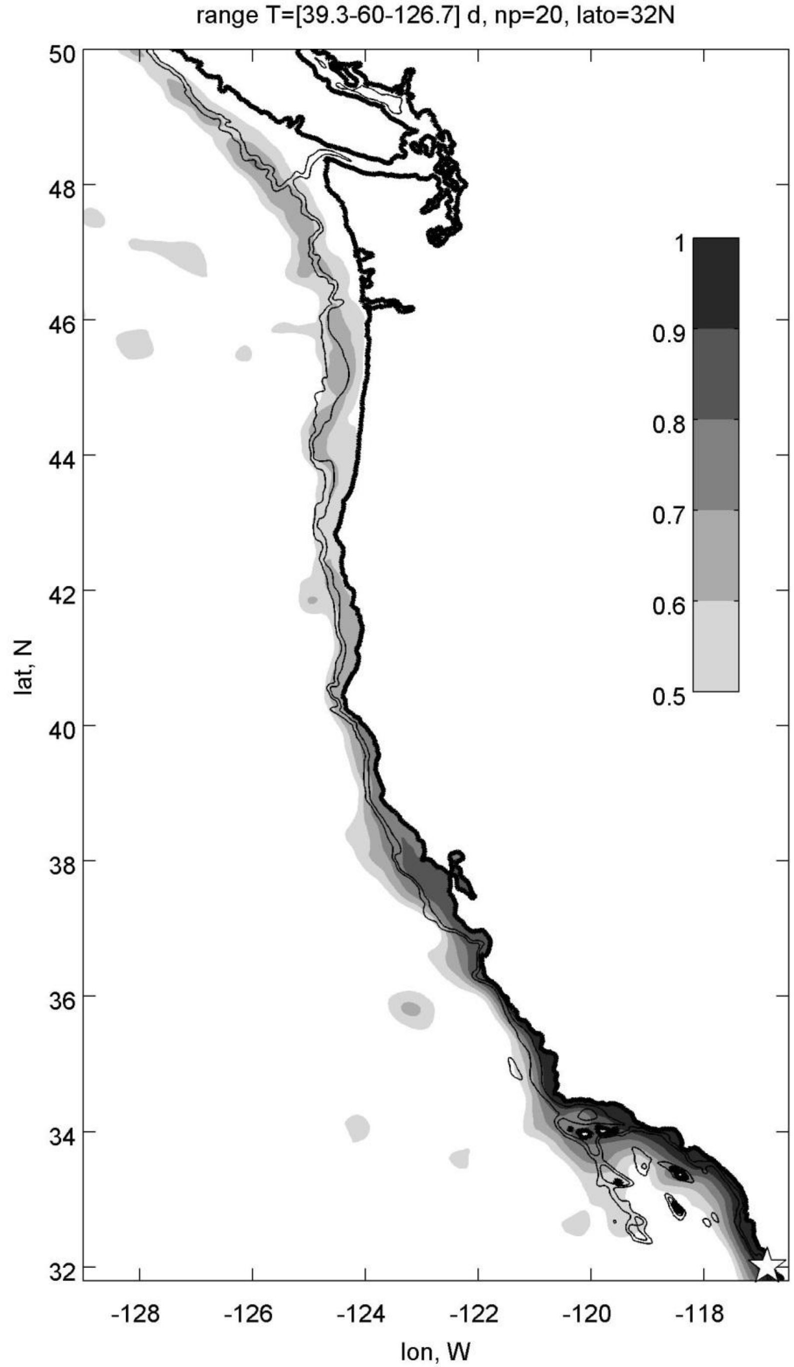
Frequency range centered on $\omega=1/60\ d^{-1}$

(40-126 days)

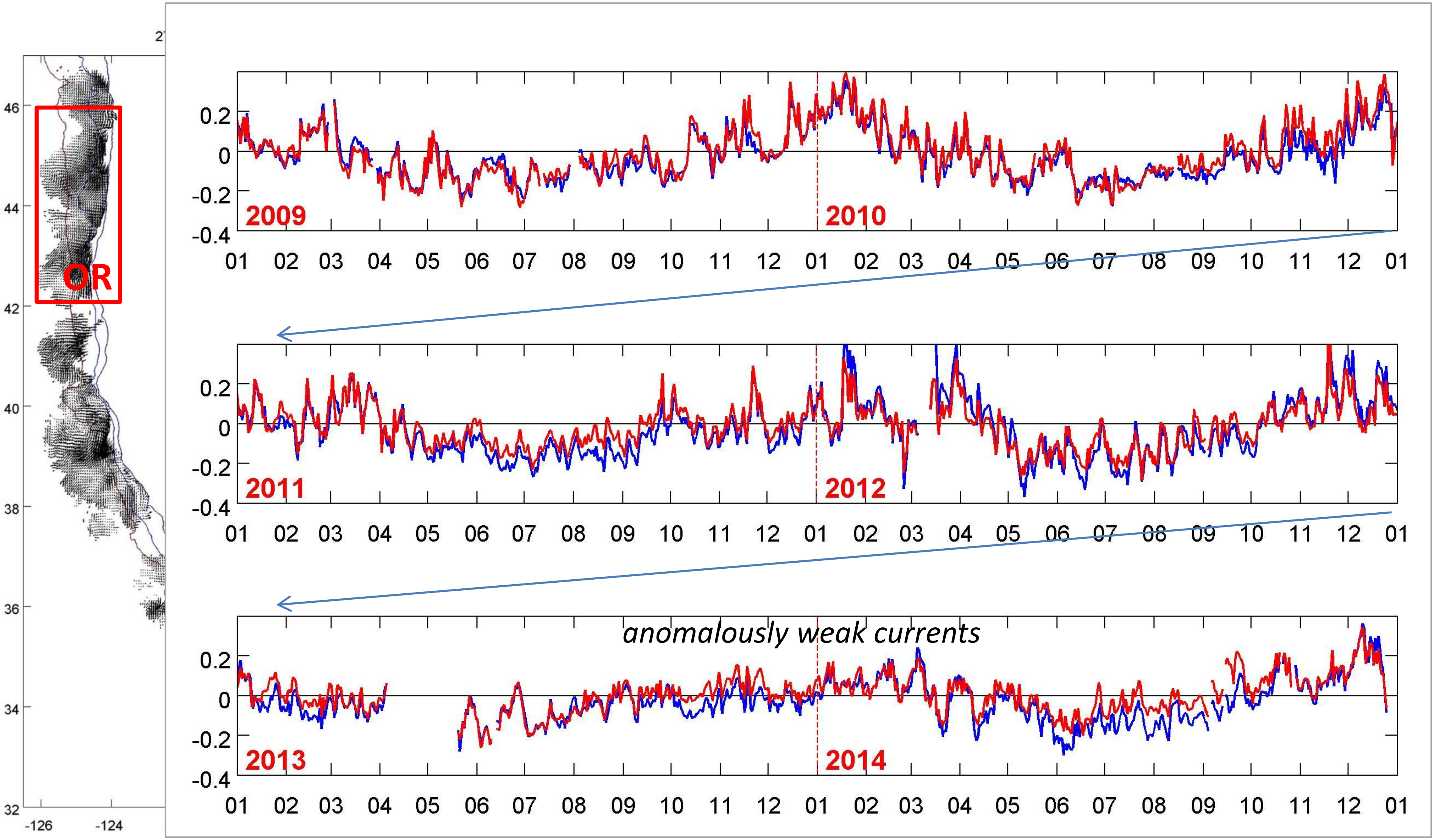
Frequency range centered on $\omega = 1/60\ d^{-1}$

(40-126 days)

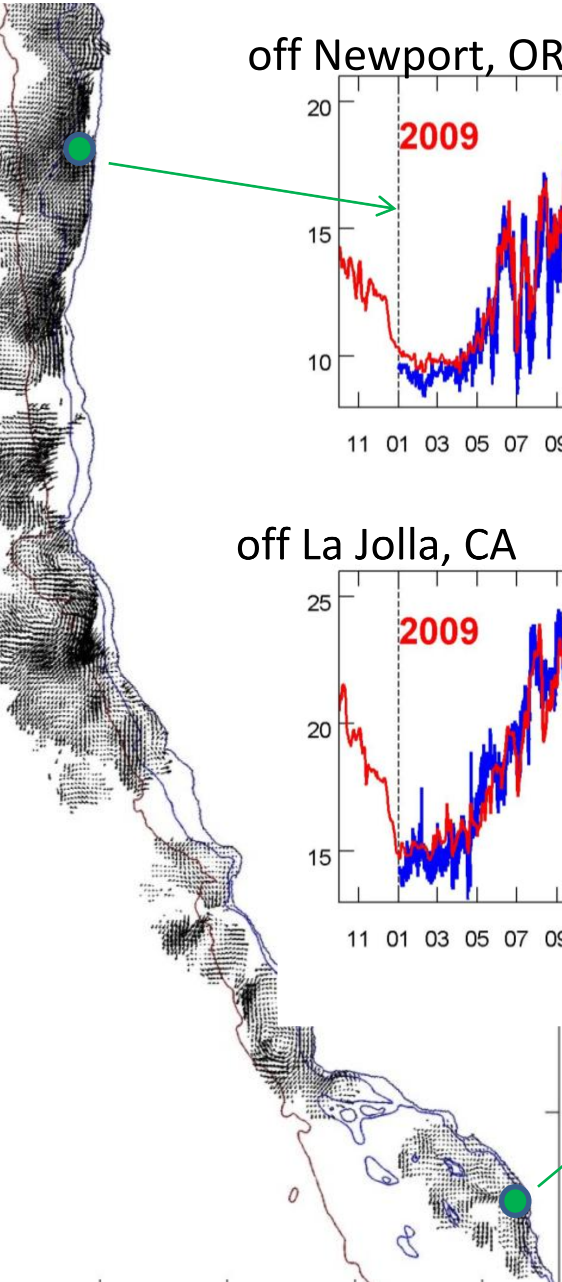
Coastal sea level at 32N is coherent with SSH along the shelf break in OR-WA-BC more than along the coast at the same latitudes



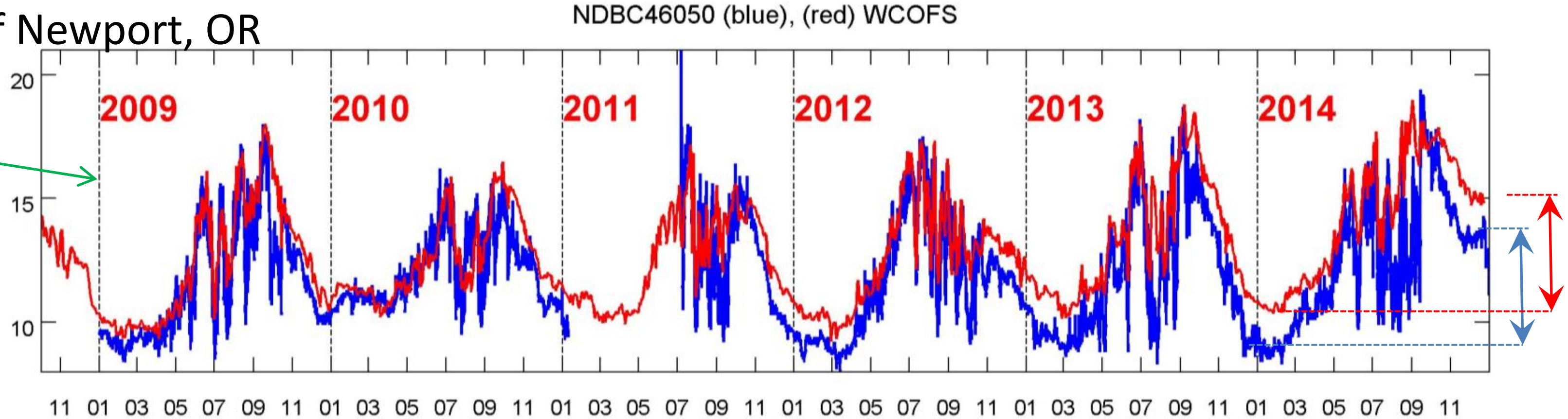
HF radar vs. WCOFS surface currents (area-averaged, daily-averaged alongshore currents… *sim. to Durski et al. Oc. Dyn. 2015***):** variability is predicted on temporal scales from several days to seasonal and interannual



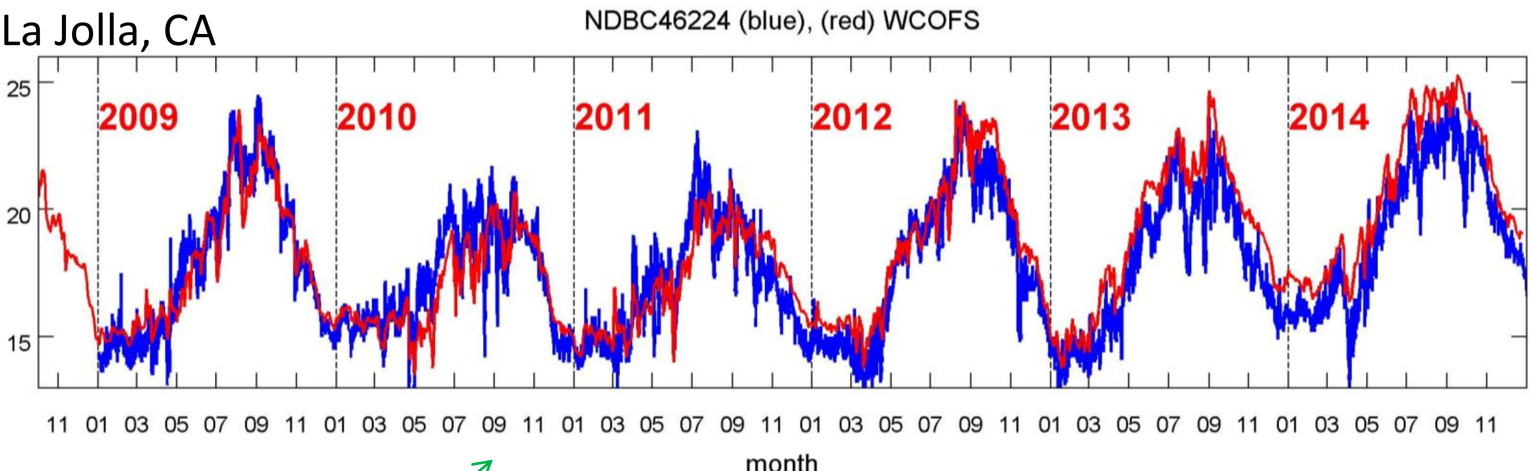
Near-surface T (NDBC shelf moorings) / WCOFS comparison:



off Newport, OR



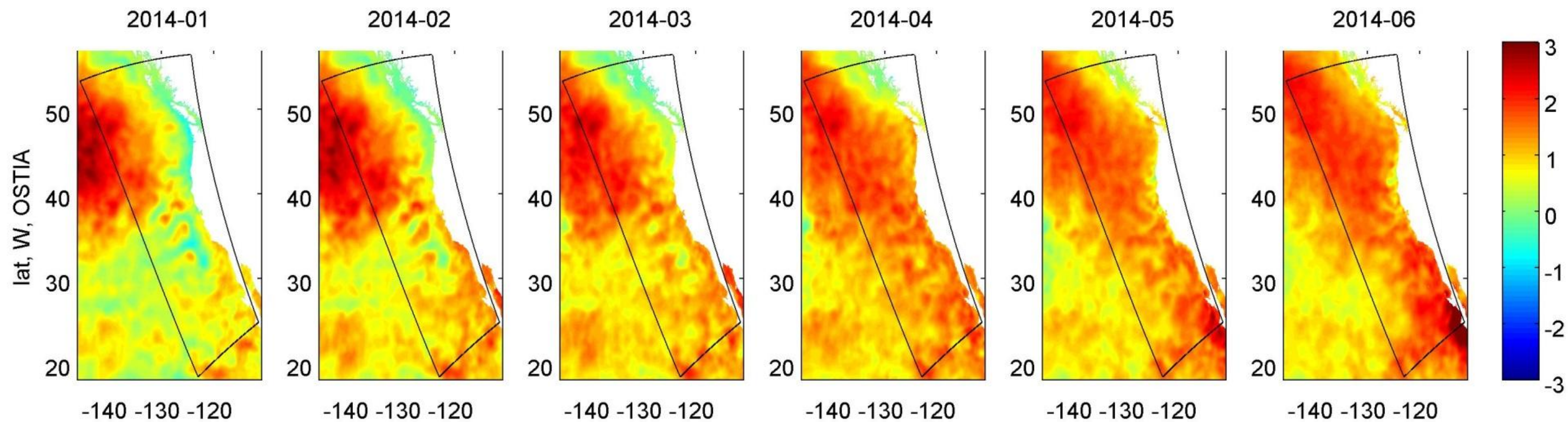
off La Jolla, CA



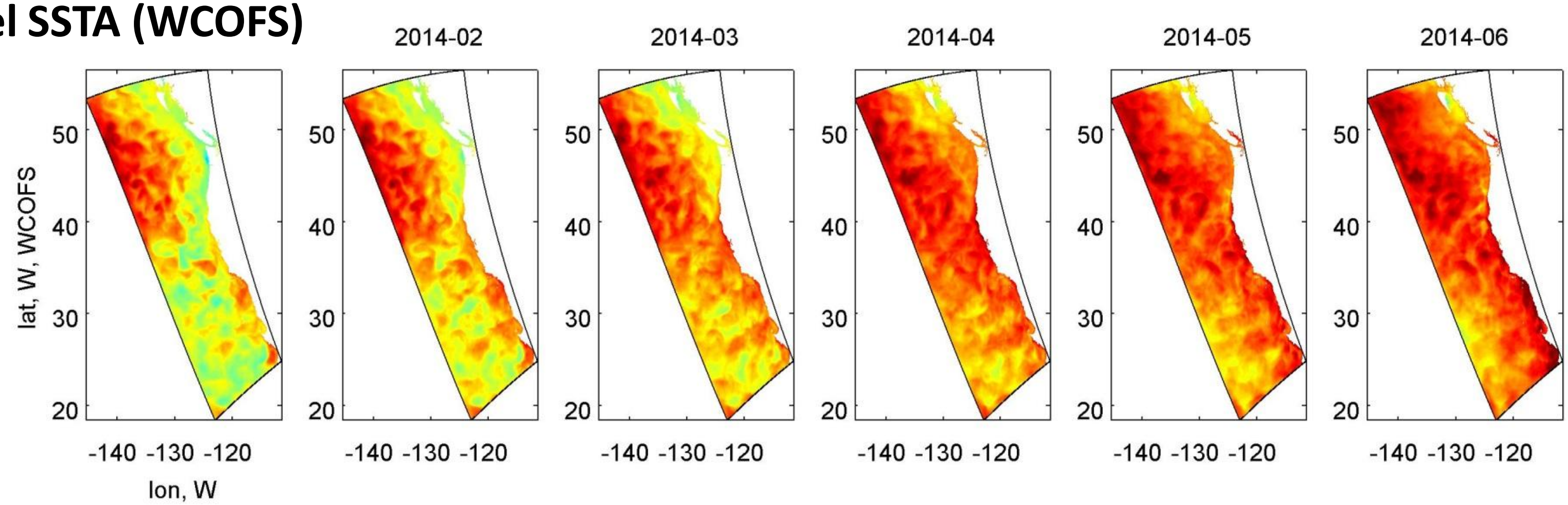
WCOFS has predicted correctly the warming trend (Dec 2013 – Dec 2014)

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)



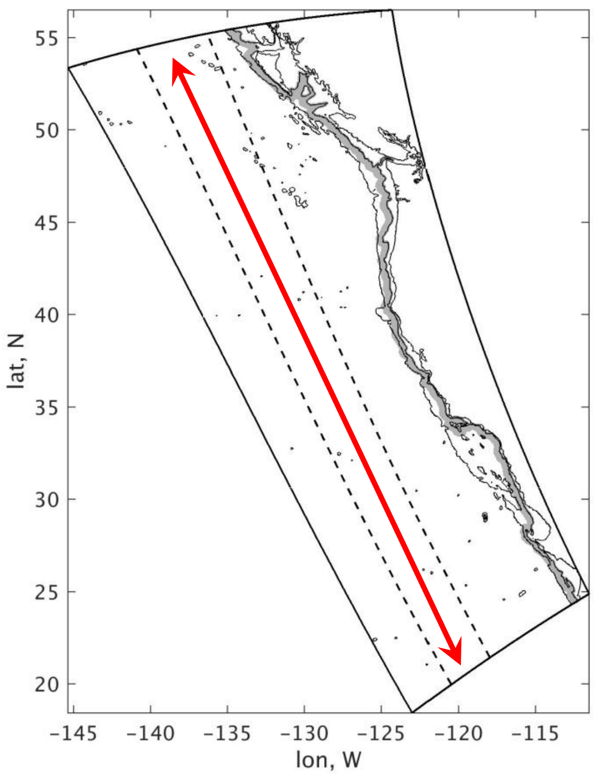
Model SSTA (WCOFS)

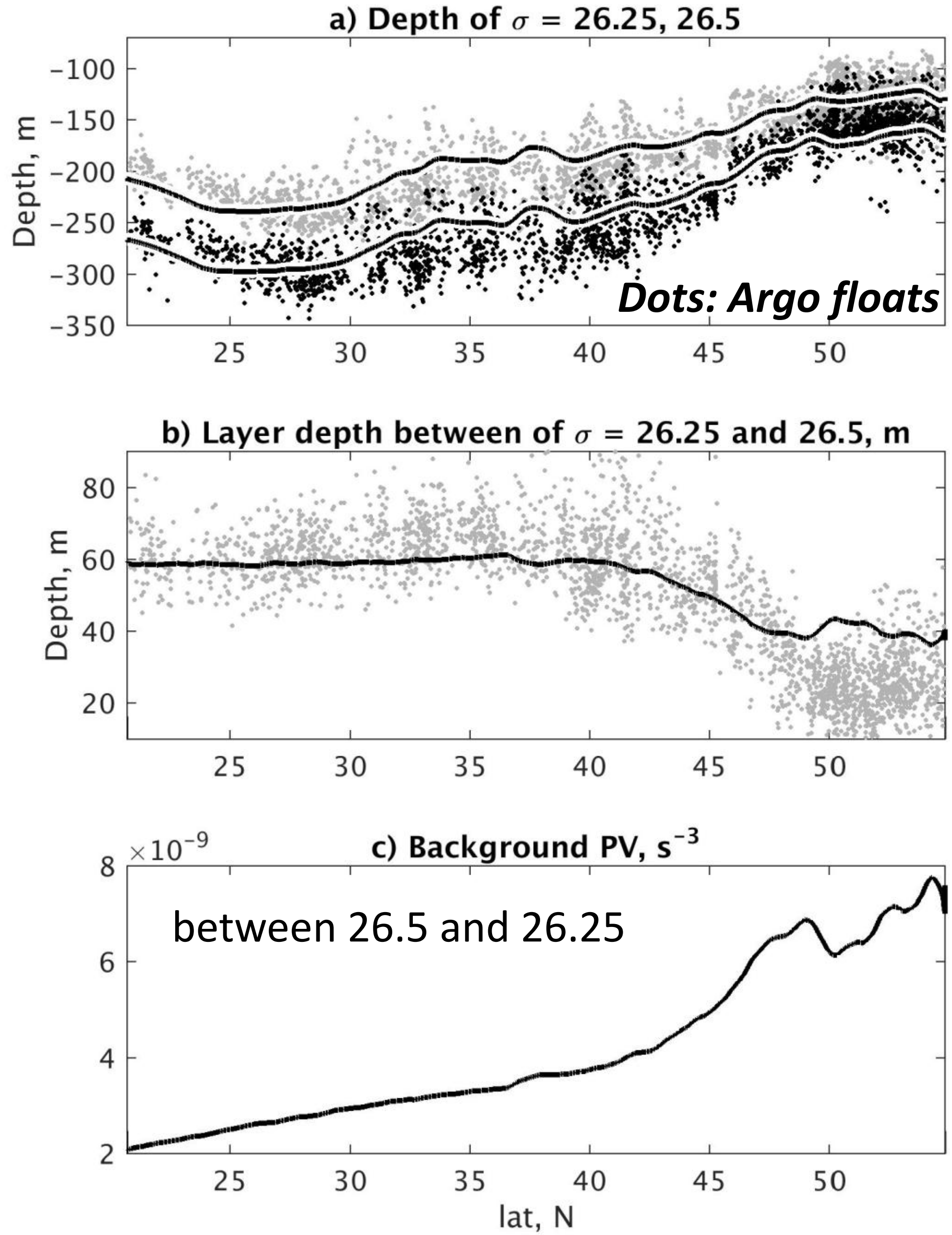


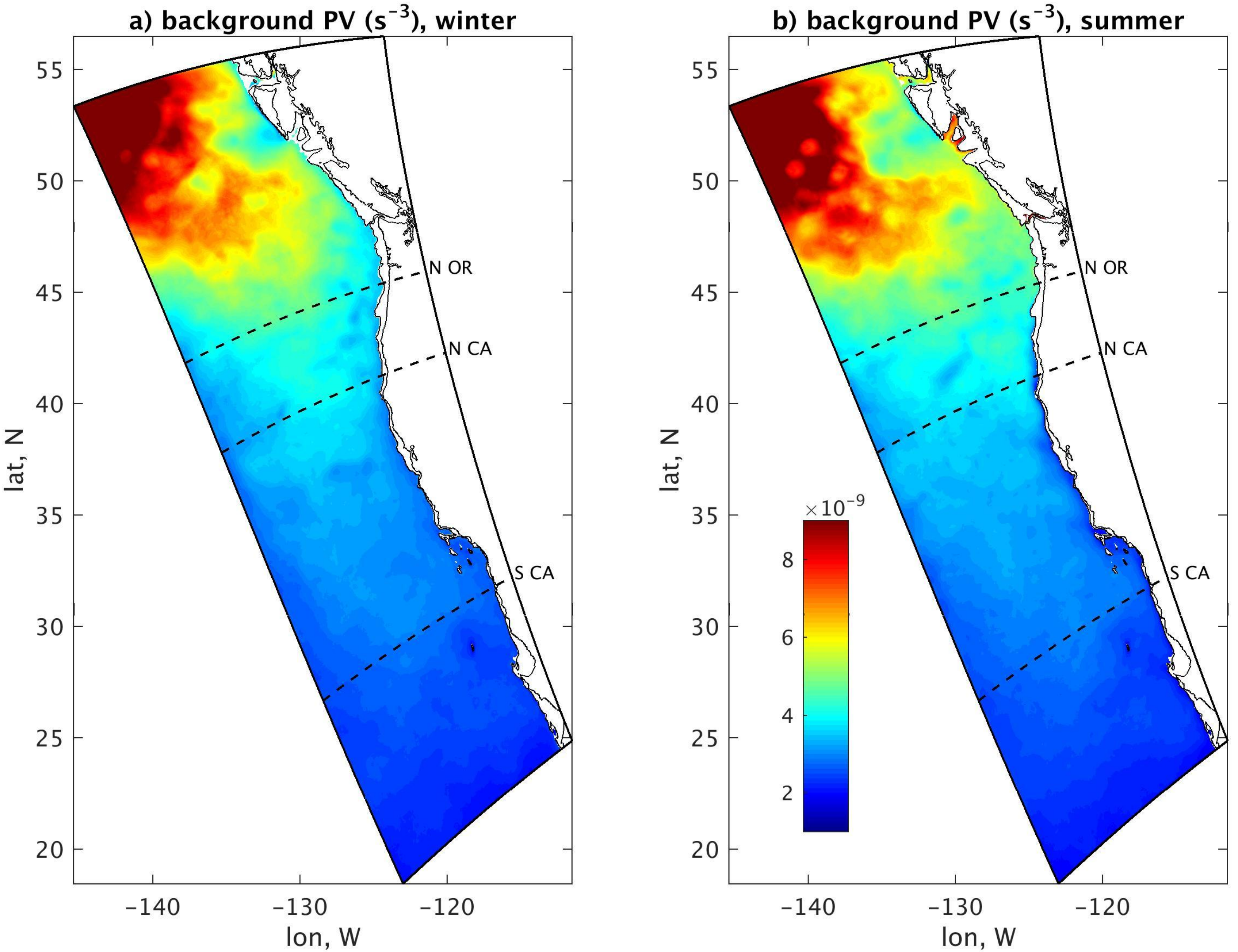
Anomaly w/ respect to 2009-2013 climatology (computed similarly for sat. and model)

Analyses on the σ=26.5 isopycnal surface

6-year averaged properties along the meridional section





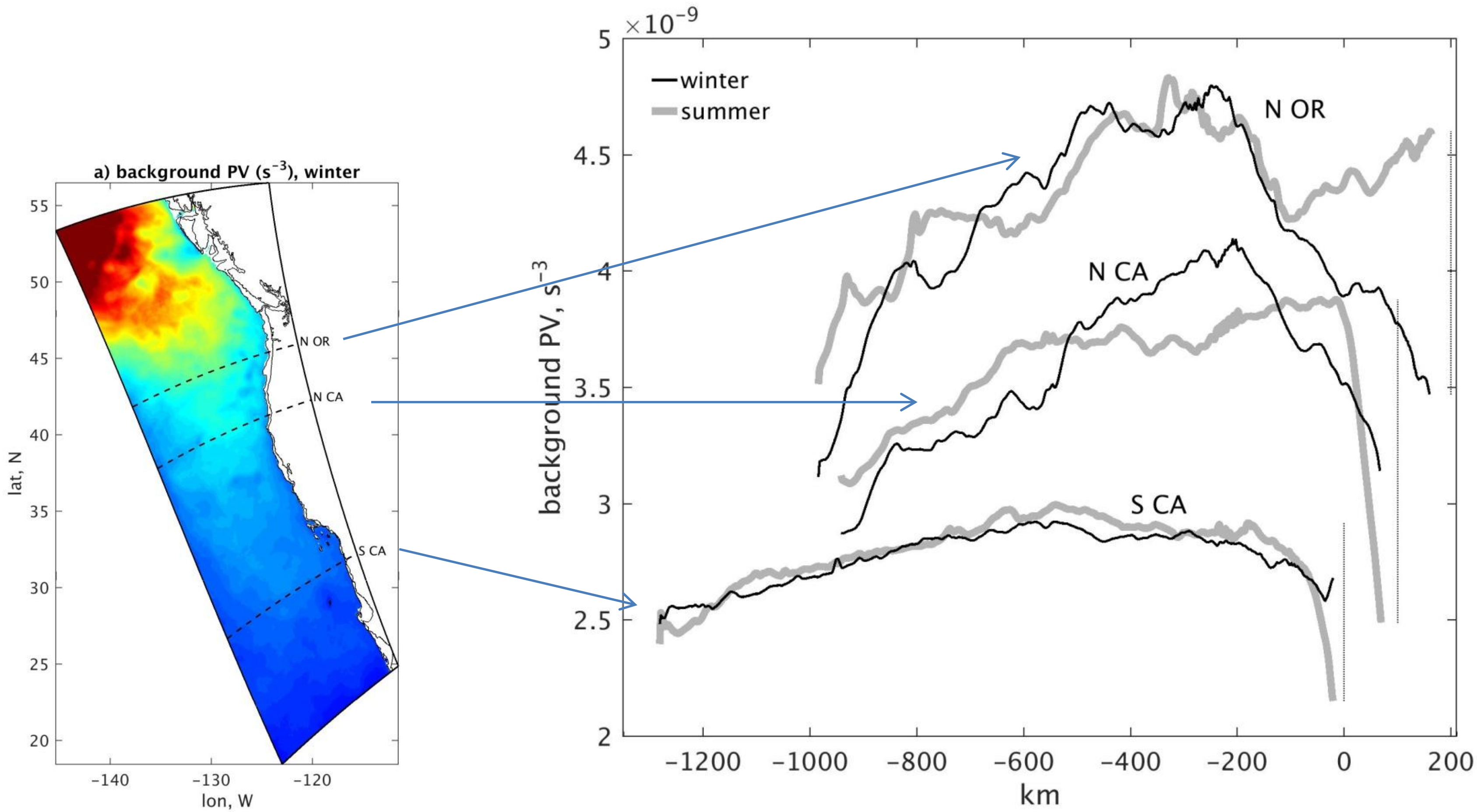


a) background PV (s^{-3}), winter
b) background PV (s^{-3}), summer
N OR
N CA
S CA
lat, N
lon, W
55
50
45
40
35
30
25
20
−140
−130
−120
×10^{-9}
8
6
4
2

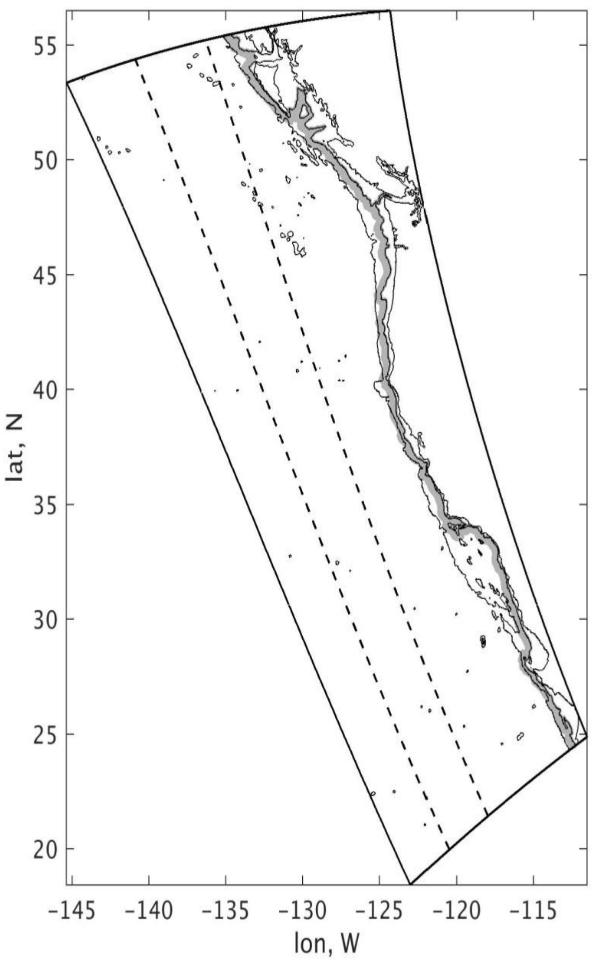
PV (26.5-26.25) in cross-shore sections: winter vs. summer.

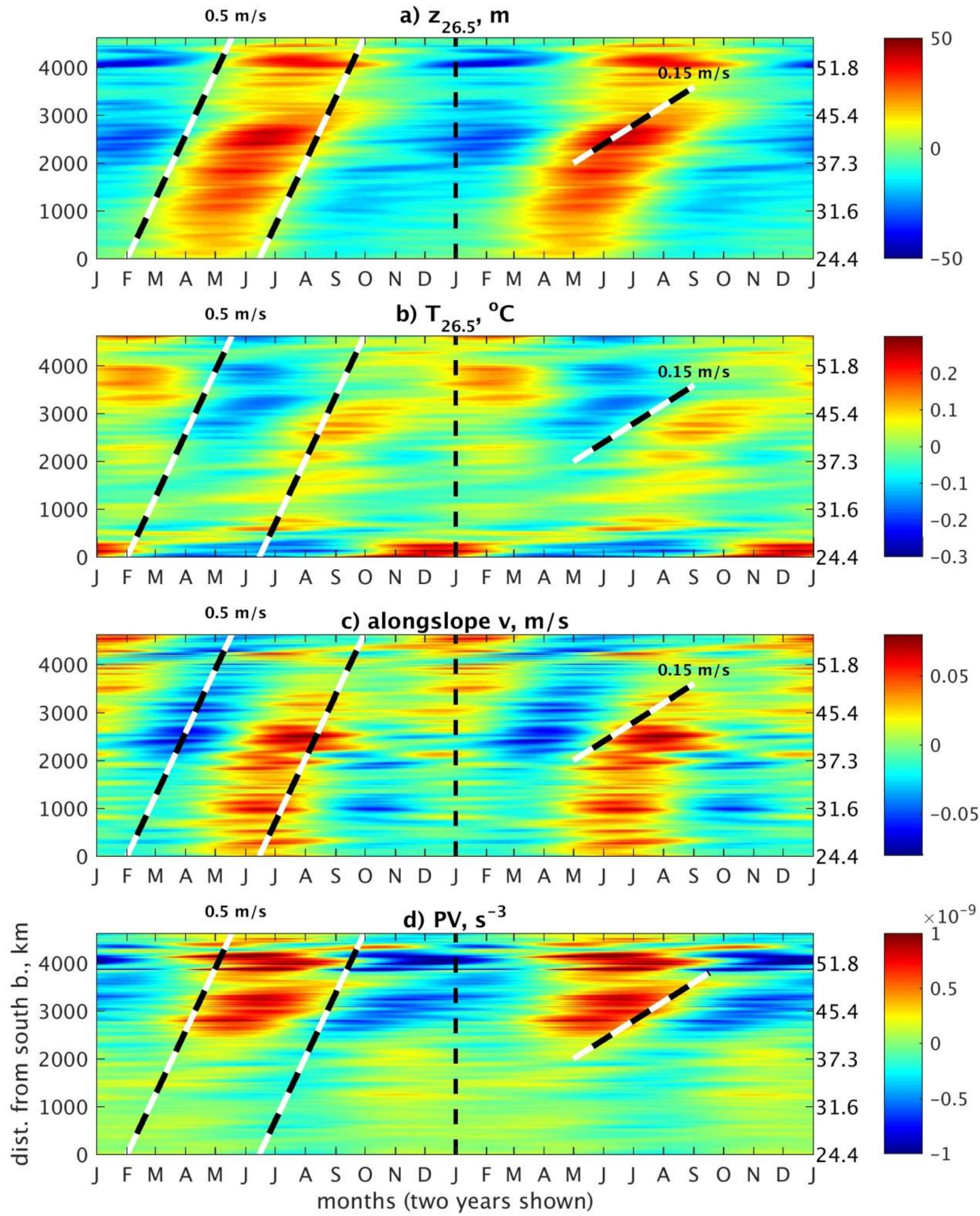
CA – S. OR: sharp drop in PV in summer (30-50 km wide)

N. OR – WA: no signature of undercurrent in summer PV. Different seasonality compared to south (PV larger in summer, smaller in winter)



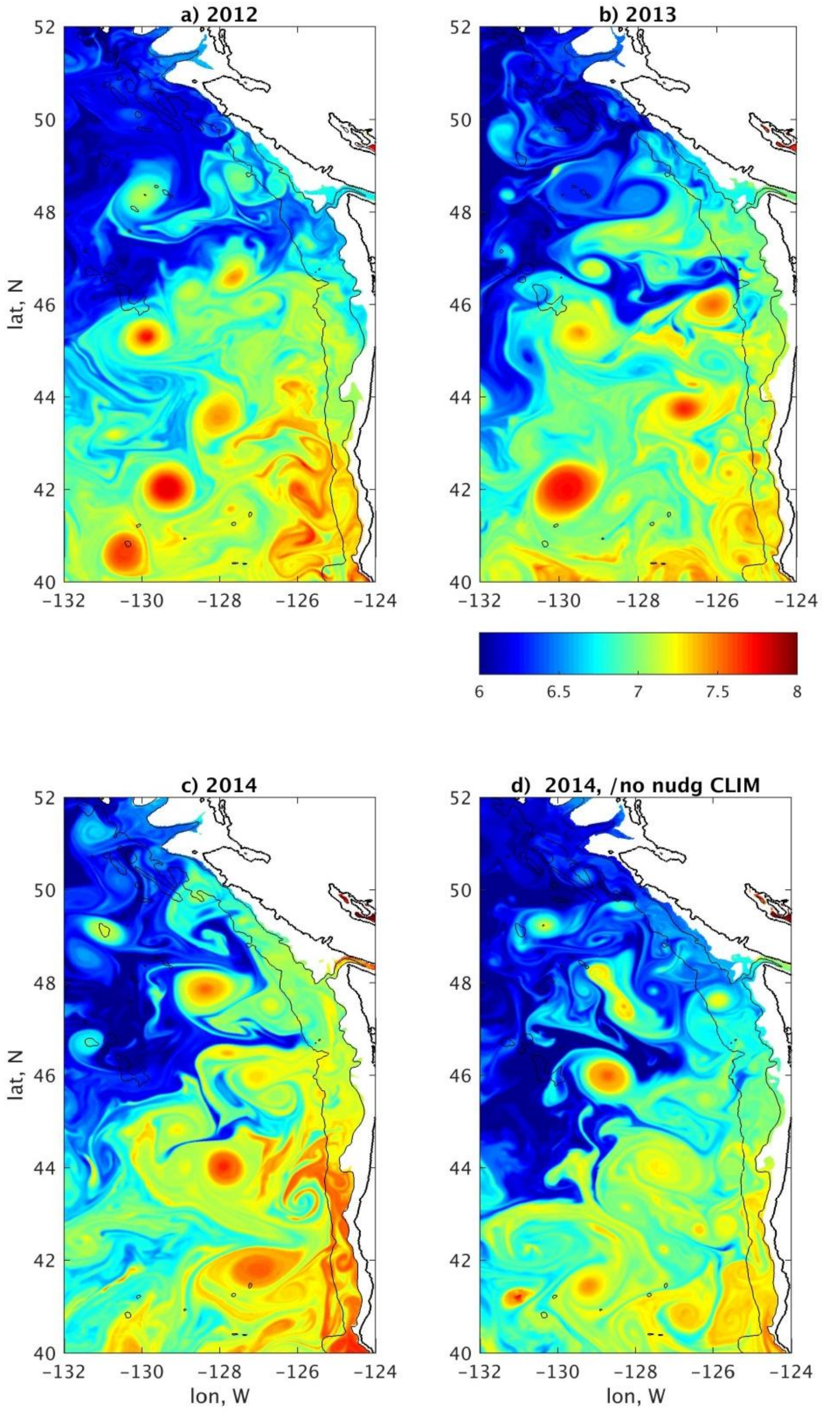
Seasonal cycles in properties on σ=26.5 kg/m^3, averaged along the continental slope (0-30 km offshore of the 200-m isobath)





If we provide enough resolution, we start to see eddy generation and material exchange between slope and interior ocean

Shown is a snapshot of temperature on σ=26.5. 1 June 2012 / 2013 / 2014.



WCOFS: DA approach

ROMS 4DVAR

- NL ROMS
- TL ROMS
- AD ROMS
- Error covariance
- Minimization method
- TL Data Functional (sample solution at obs loc.)
- AD Data Functional (impulse forcing of AD)

Obs: local in space in time (SSH, T, S, u, v)

OSU 4DVAR System: modular

- NL ROMS
- OSU TL
- OSU AD
- Error covariance
- Minimization method
- TL Data Functional
- AD Data Functional

Obs: any linear combination of SSH, T, S, u, v; averaging in space and time possible

ROMS 4DVAR

State space: all the fields at every time step

AD model impulse forcing and TL sampling: on a fly, inside the ROMS code

- Hard to implement time-averaged data
- Hard to contribute with new data types

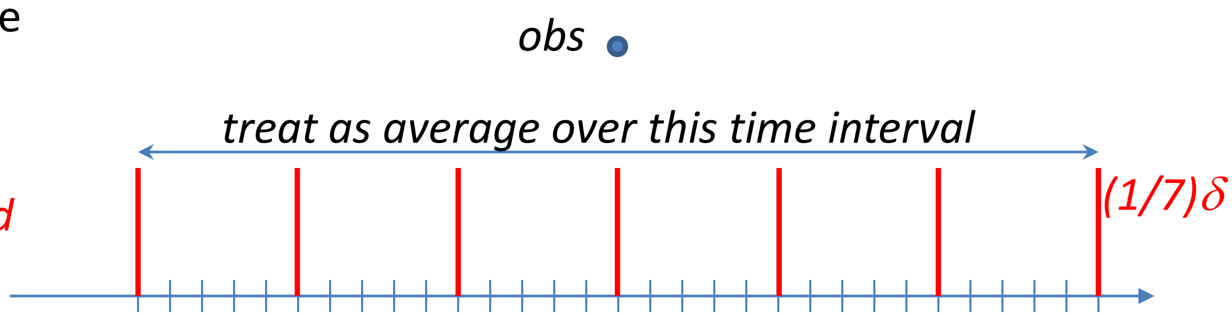
Ways around have been proposed; we have to see if these are acceptable in WCOFS

OSU 4DVAR System

State space: all variables (SSH, u, v, T, S) every NHIS times steps

The TL model sampling is done outside OSU TL & AD codes (using fields saved)

The AD model forcing is prepared outside the OSU TL & AD codes: formal Adj code of the TL model sampling code



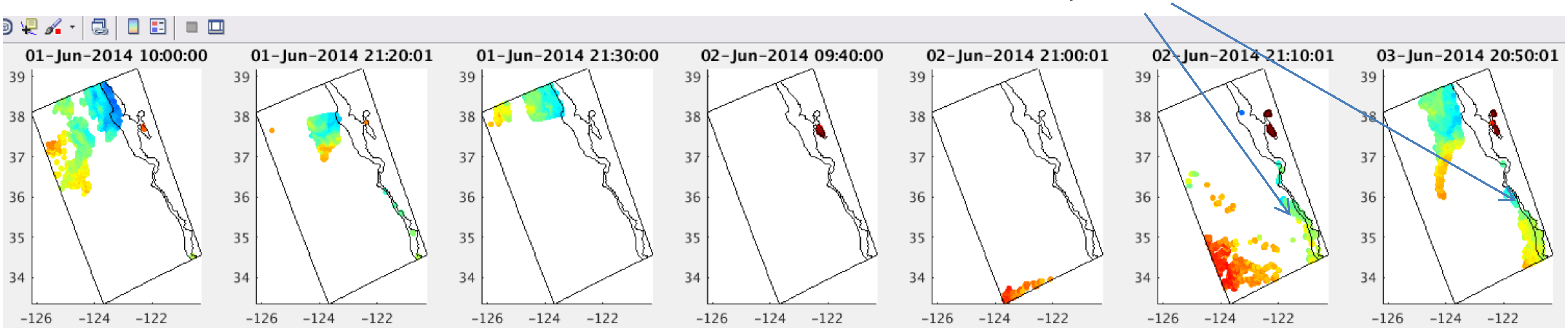
Time distributed impulse

NHIS=5

Test ROMS 4DVAR: CCA 4-km resolution

Assimilated observations (JPSS VIIRS L3U, combined in "superobs" = observations in each survey are averaged over 4x4-km model grid boxes)

colder SSTs observed only on day 2 and 3



day1 | day 2 | day 3

4DVAR algorithm propagates observed information back in time, to correct model initial conditions at the beginning of day 1

In particular, SST observations collected on day 3 are propagated (by model dynamics) back in time to influence correction at the beginning of day1

4DVAR

- is a dynamically based intepolator of sparse data sets
- combines observations of different type (SST, SSH, velocities, subsurface T and S, etc.)
- Allows obtaining improved forecasts

Data: Ignatov et al. NOAA/NESDIS/STAR

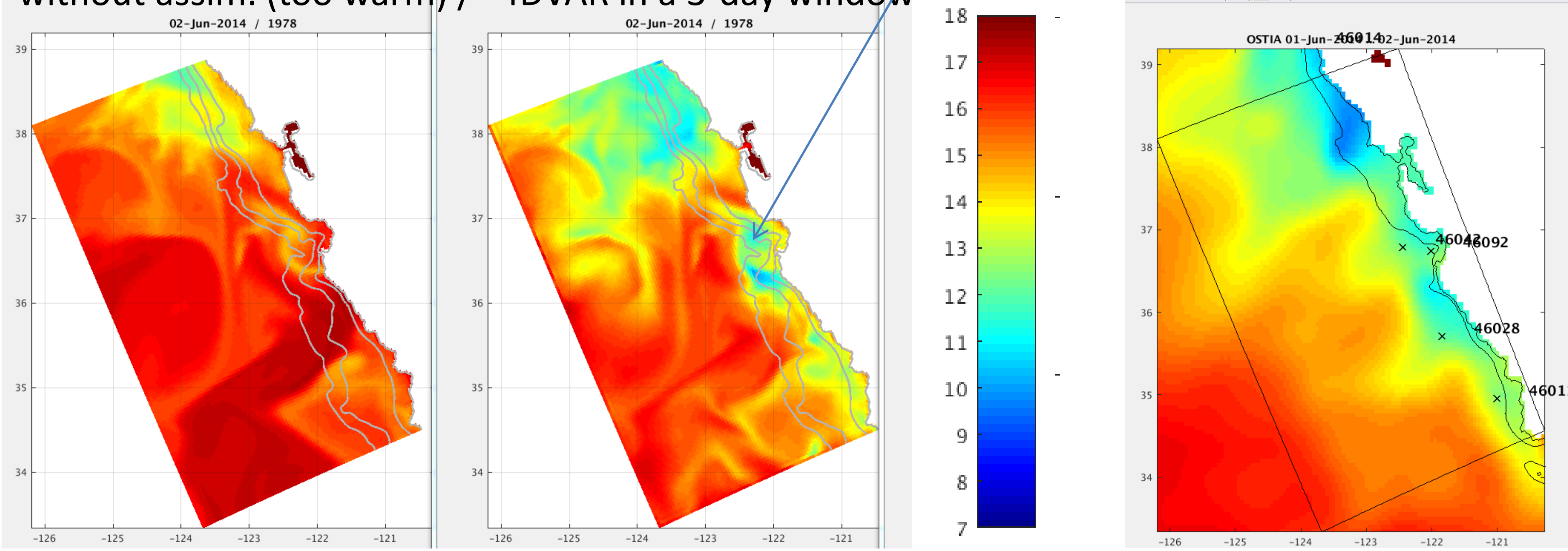
Example of the effect of SST assimilation on model SST:

Assimilation: corrects initial conditions at 06/01/16, 00:00:00 UTC

SST observations in the area of Monterey B. were not available on day 1, but available on days 2 and 3. In the 3-day window, the SST estimate on day 1 is influenced by the data on days 2-3, to make SST near Monterey B. colder (and more consistent with OSTIA SST)

Model at the end of day 1 (06/02/16 00:00:00)
without assim. (too warm) / 4DVAR in a 3-day window

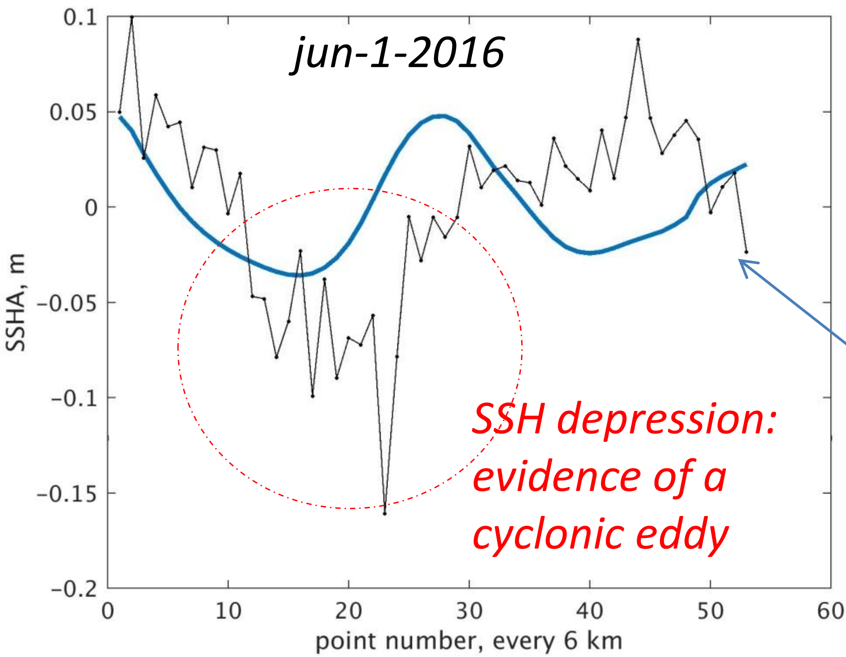
For qualitative comparison: multi-satellite OSTIA SST (6/1/16):

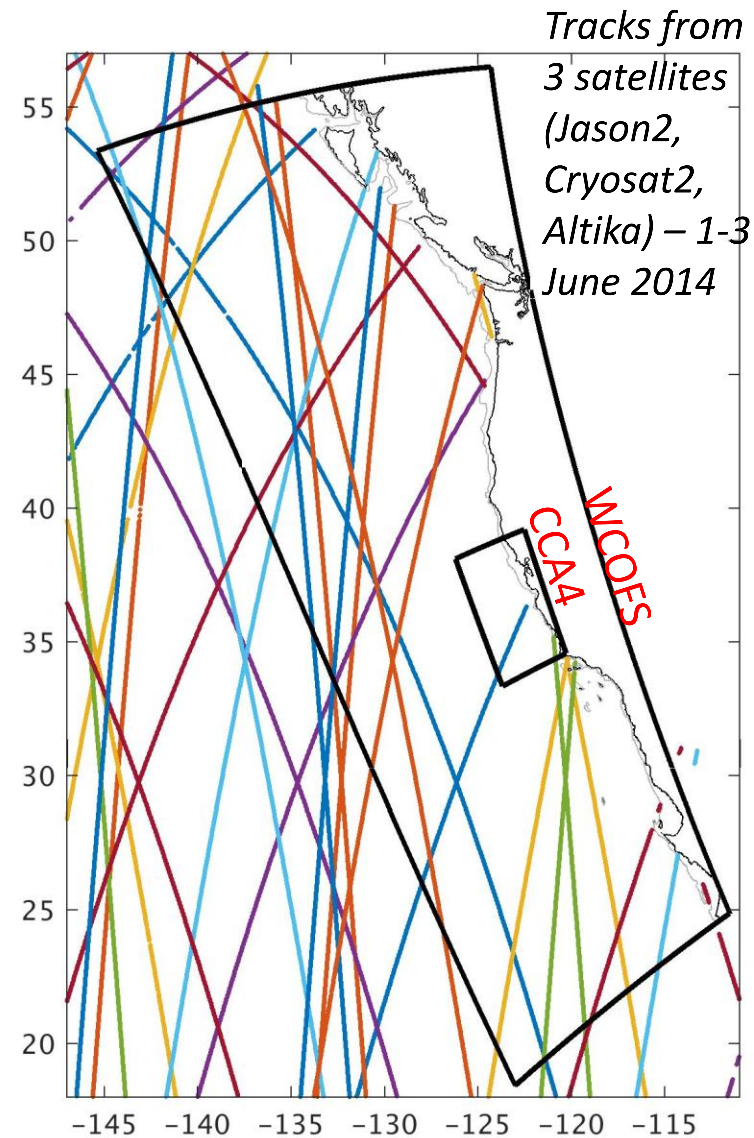


Next step: tests assimilating SST in combination with alongtrack altimetry

Data: RADS SSH (NESDIS/STAR, L. Miller et al.)

What does altimetry provide?
- the non-tidal sea surface slope on horizontal scales 50 km and larger provides information on the "geostrophic" currents (characteristic of eddies, coastal currents) in the direction across the satellite pass.





SSH anomaly along the satellite track inside the CCA4 domain

model SSH forecast along the same track

Outstanding DA issues:

- Covariance effect on unassimilated fields
- Assimilation of time-integrated data (daily HF radar in a tide-resolving model)
- Assimilation of area-average data (e.g., microwave T – 25x25 km)
- Mean SSH vs. SSH slope assimilation
- Spectral properties of the surface flow fields after long period of intergration
- Effect of a combination of observations vs. individual assimilation esp. on subsurface fields

$|\delta u|$, the color scale is between 0 … 0.2 m/s

(*Ivo Pasmans*)

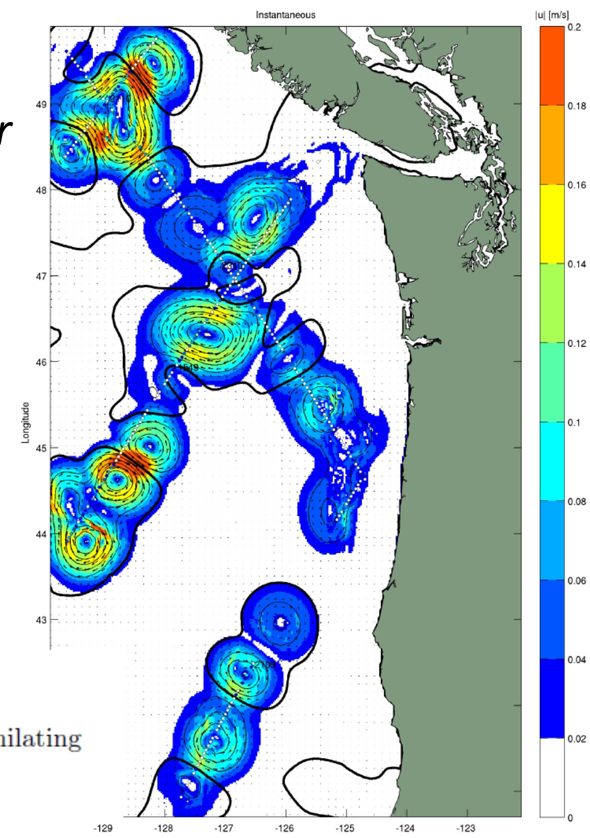


Figure 4: 4DVAR corrections to the sea-surface velocity field on 27 June 2011 generated by assimilating instantaneous SSH data. Contours mark the sea-surface height corrections.