

The US West Coast Component of the Coastal Ocean Modeling Testbed

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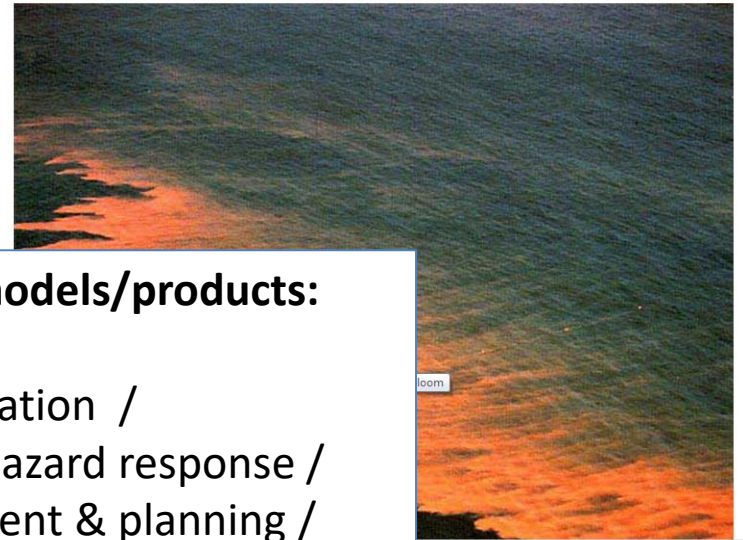
Federal Partners:

Edward Myers (NOAA NOS CSDL)

Eric Bayler (NOAA JCSDA)

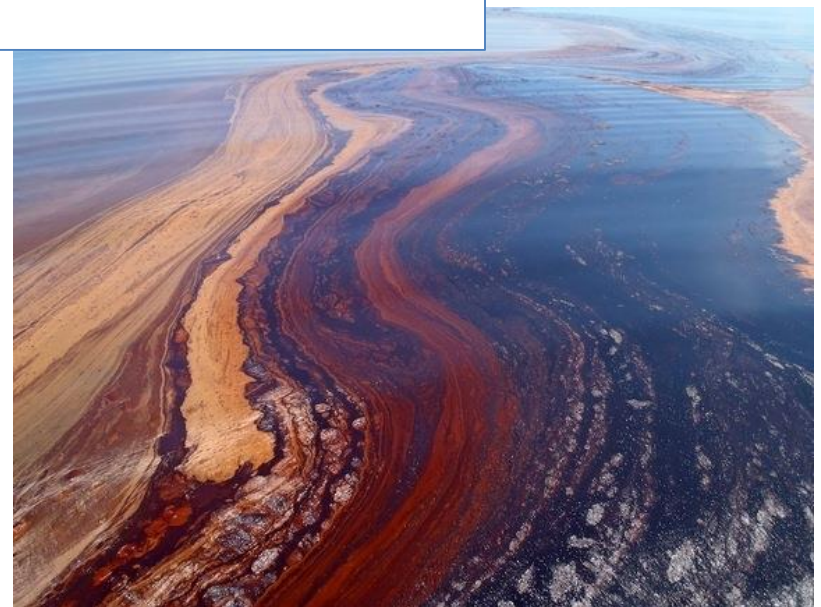
Avichal Mehra (NOAA NWS NCEP)

Igor Shulman (Naval Research Laboratory)

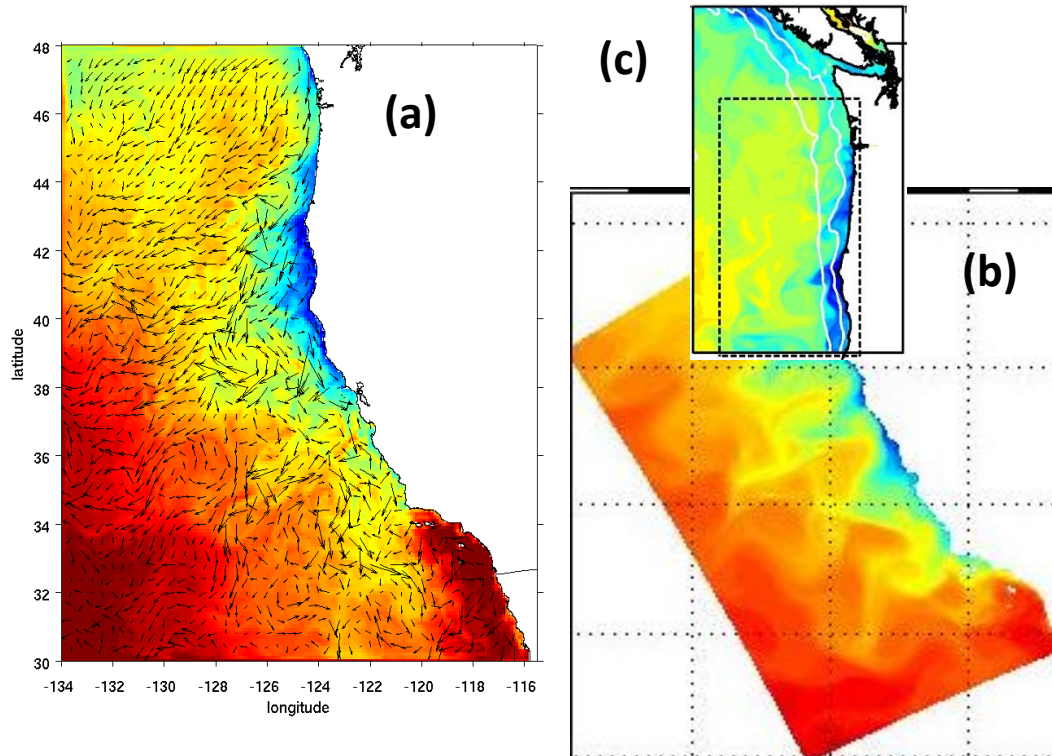


Uses and users of coastal ocean models/products:

Security of US borders / Safe navigation /
Search & rescue / Environmental hazard response /
Public health / Fisheries management & planning /
Recreation / Scientific research



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



(a) UCSC/CenCCOOS

(b) RSI/CenCCOOS/SCCOOS

(c) OSU/NANOOS

10-km res. ROMS,

3-km res. ROMS,

2-km res. ROMS,

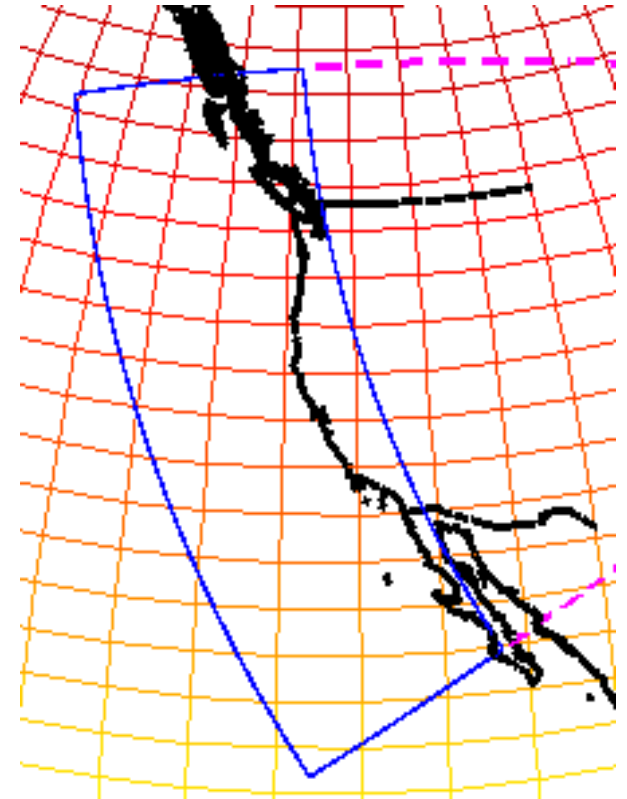
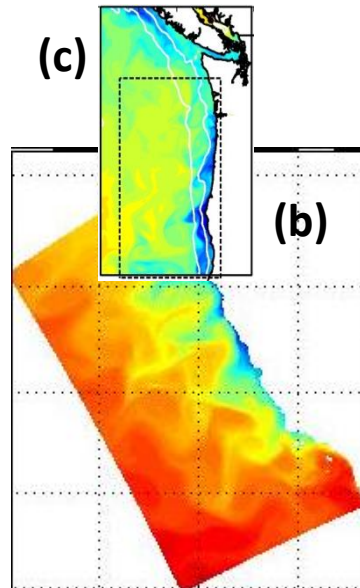
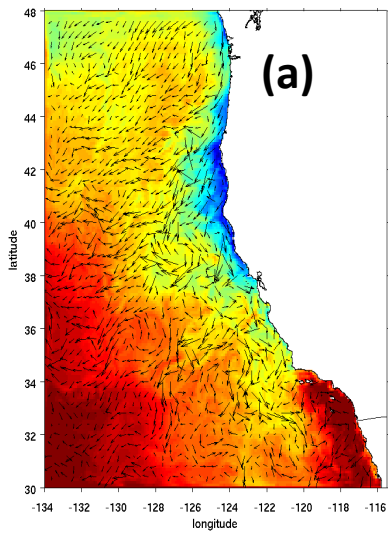
4DVAR

3DVAR

4DVAR

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

Transition to operations: NOAA West Coast Operational Ocean Forecast System



- Configurations for accurate prediction
- Metrics for skill assessment
- Data assimilation
- Coupled physical bio-chemical OFS

Research questions (Year 3):

- Does the **ensemble-variational hybrid approach to data assimilation** improve accuracy of state estimates and forecasts in dynamic coastal ocean regions, compared to a more traditional approach (a variational method with a static initial condition covariance)?
- Can **observation impact and observation sensitivity experiments** reveal elements of the west coast observation network that provide particularly critical or quantitatively redundant data for state estimation as gauged by particular metrics?
- Does added **ecosystem model** complexity provide benefits for modeling the CCS ecosystem?

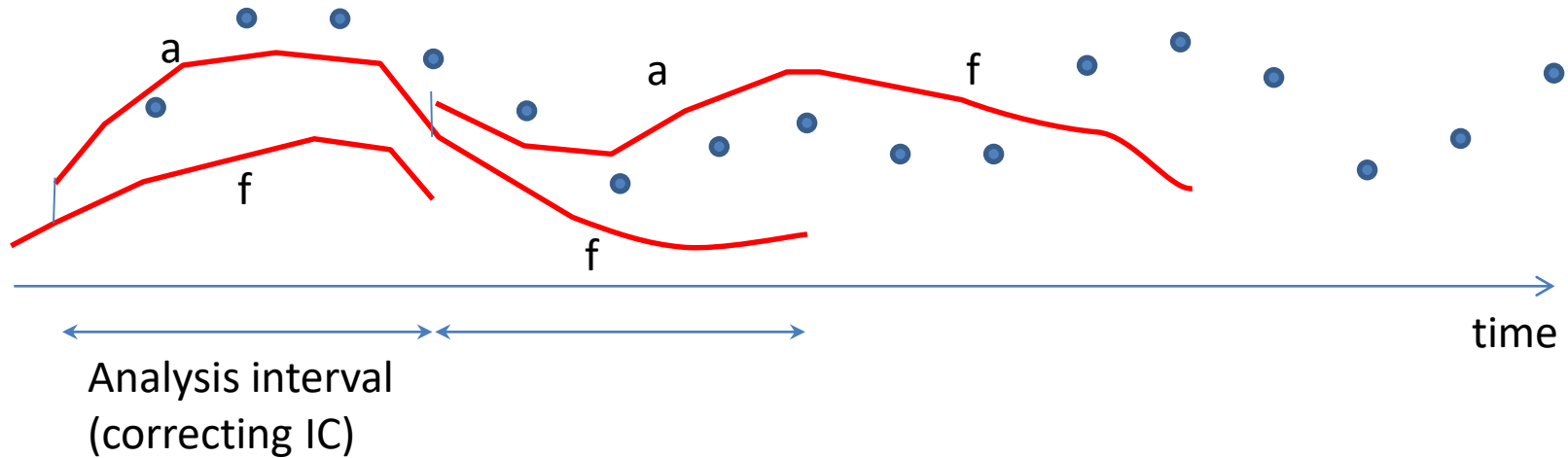
Milestones (year 3):

- Complete comparison of the three biochemical models coupled with the regional ocean circulation model
- Transfer tools for WCOFS model setup and evaluation to NOAA NOS CSDL
- Provide recommendations to NOAA about the choice of the assimilation method for WCOFS for based on comparison 4DVAR and hybrid methods, 3DVAR and EnKF

OR-WA model: traditional 4DVAR vs. ensemble-variational approach

(Kurapov and Pasmans)

4DVAR: dynamically-based smoothing over a larger time interval



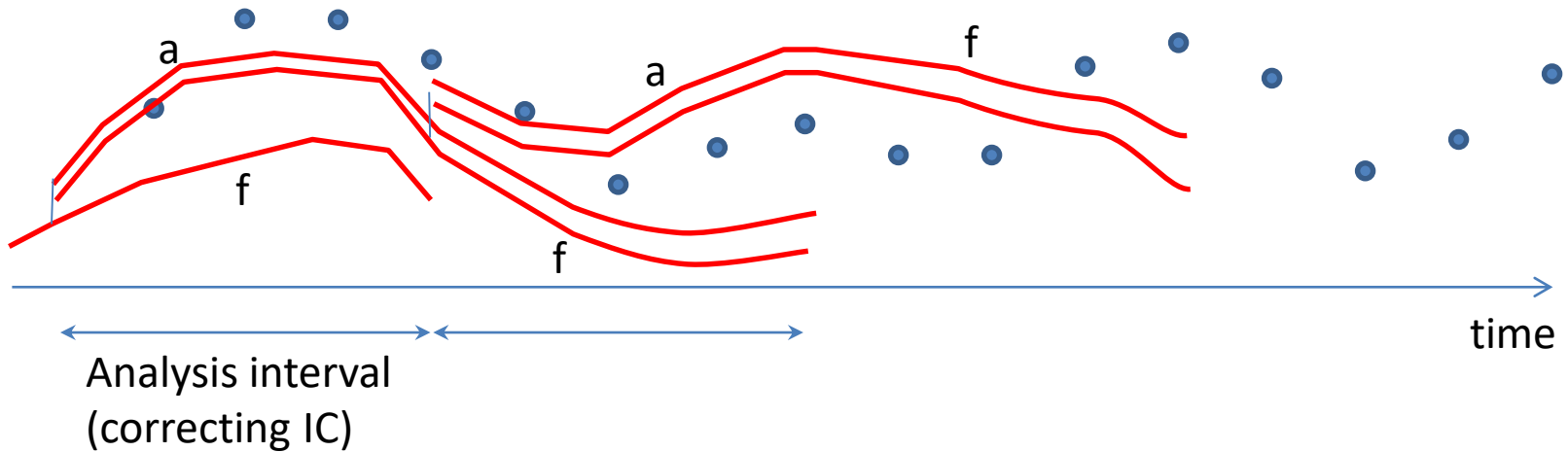
Pros:

- Transients are left in the past
- Data error is filtered in time
- Time-average data may be assimilated

Challenges:

- Requires development and repeated implementation of the adjoint model component
- The IC error covariance is static (the same in each analysis interval)

Hybrid Ensemble - 4DVAR (Kurapov and Pasmans)



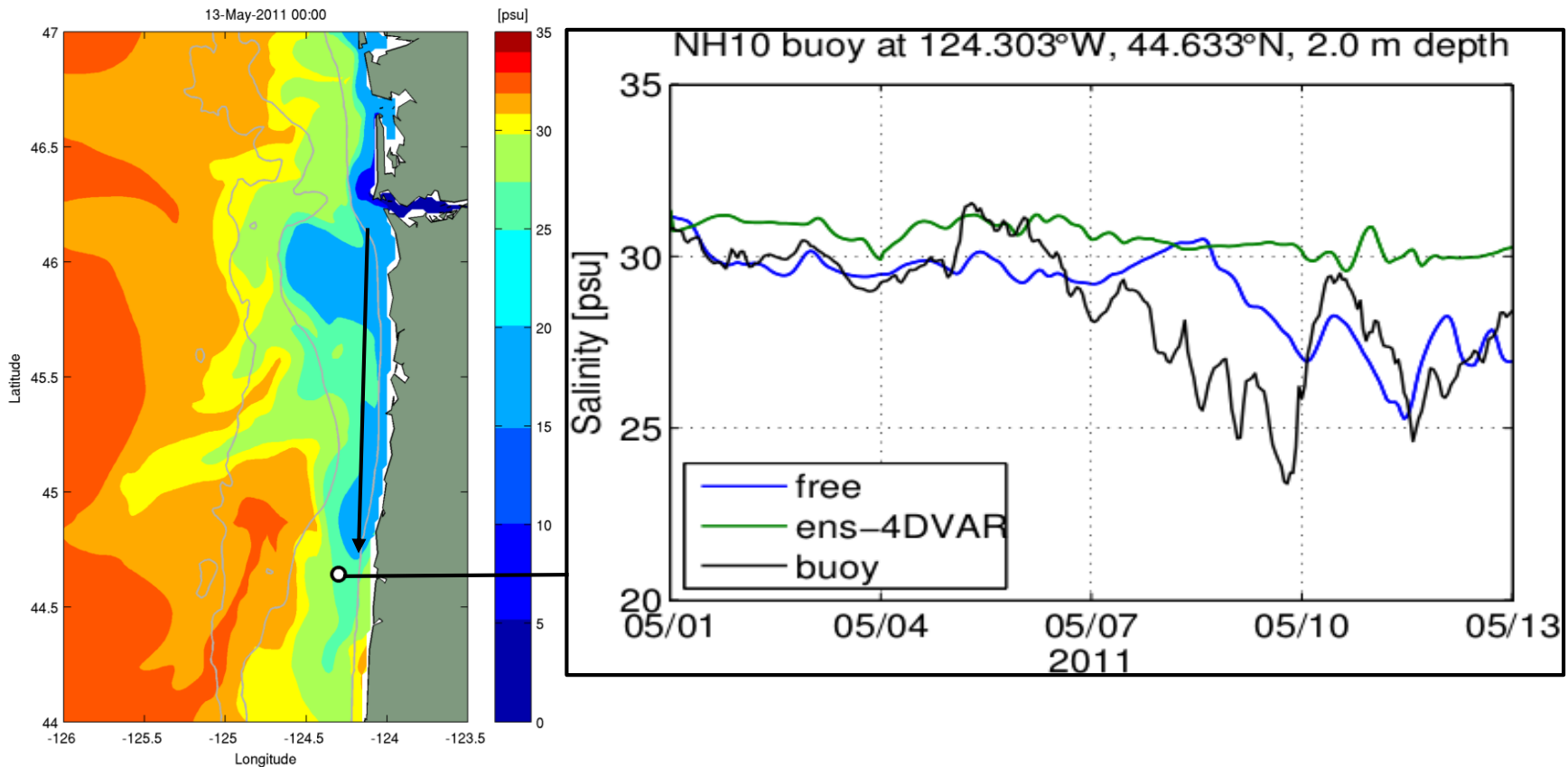
Obtain the IC error covariance from an ensemble of forecasts

Challenges:

- Ensemble generation
- Covariance localization (Pasmans & Kurapov, 2016, in prep.)

*(incorporate in EnKF – DART ? ..
Cornuelle et al.)*

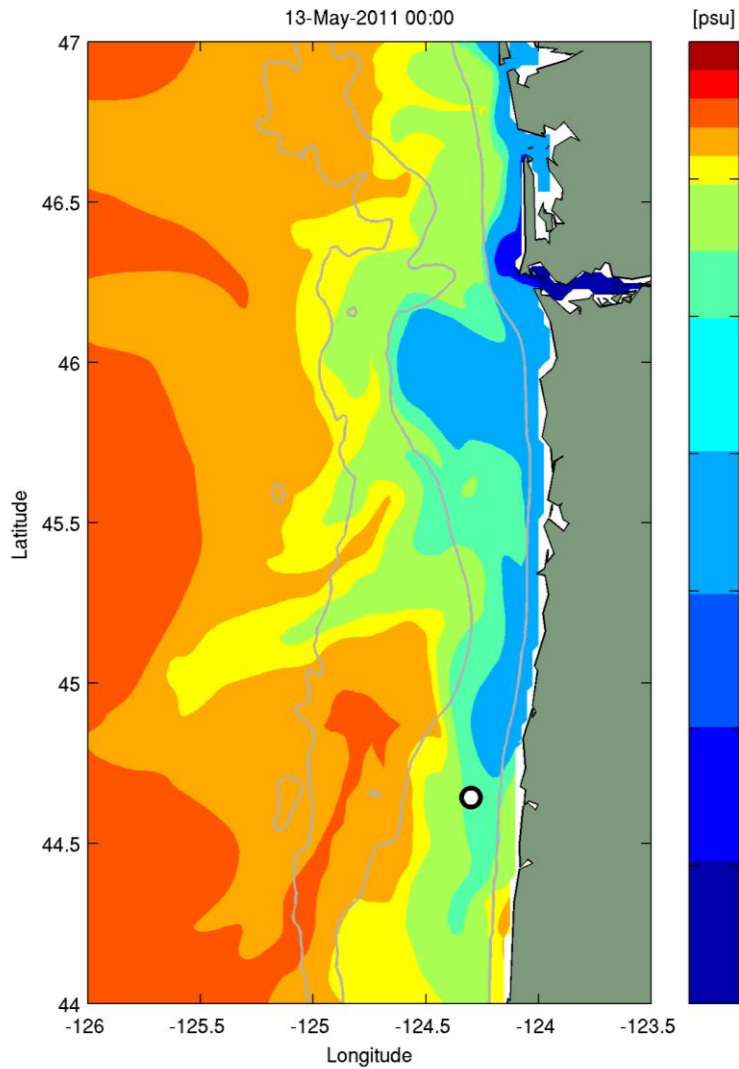
The ens-var method shows DA limitations predicting unassimilated fields, such as salinity in the far reach of the Columbia R. plume



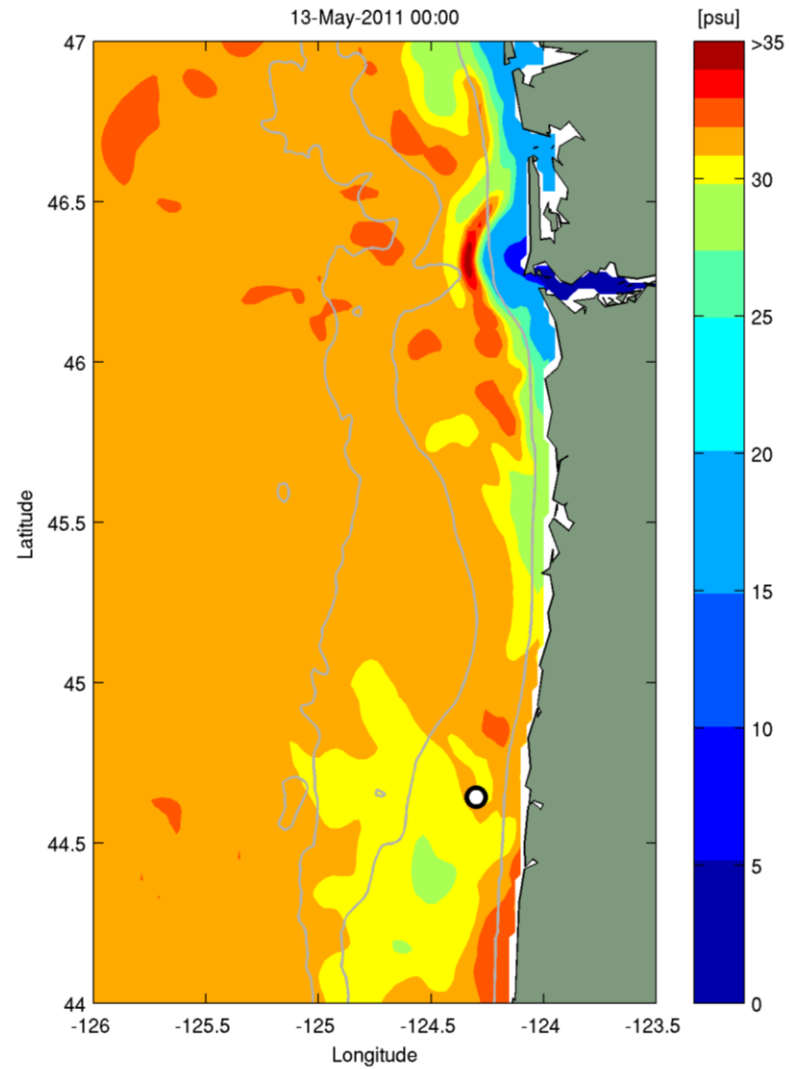
SSS on 05/13/2011 before assimilation

(DA: GOES SST, HF radar uv and altimetry are assimilated)

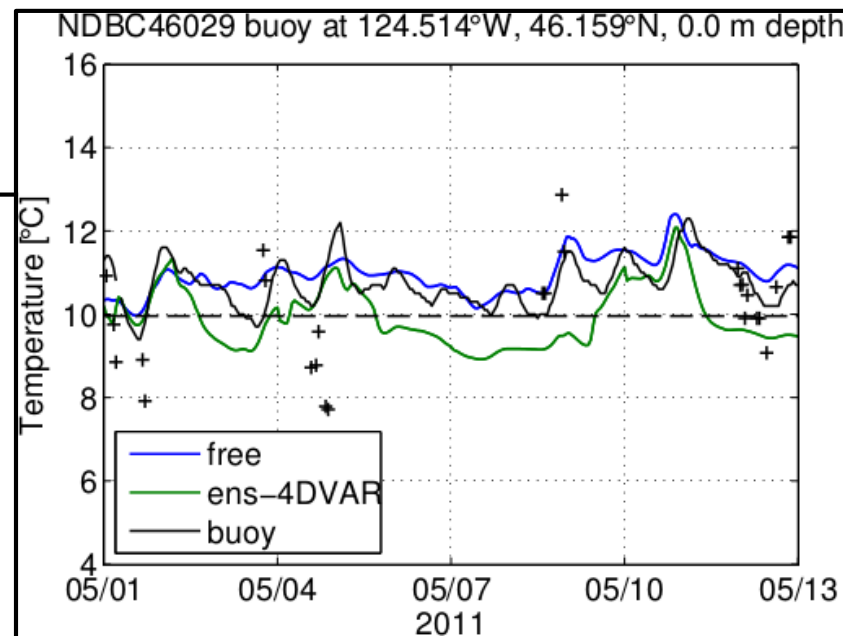
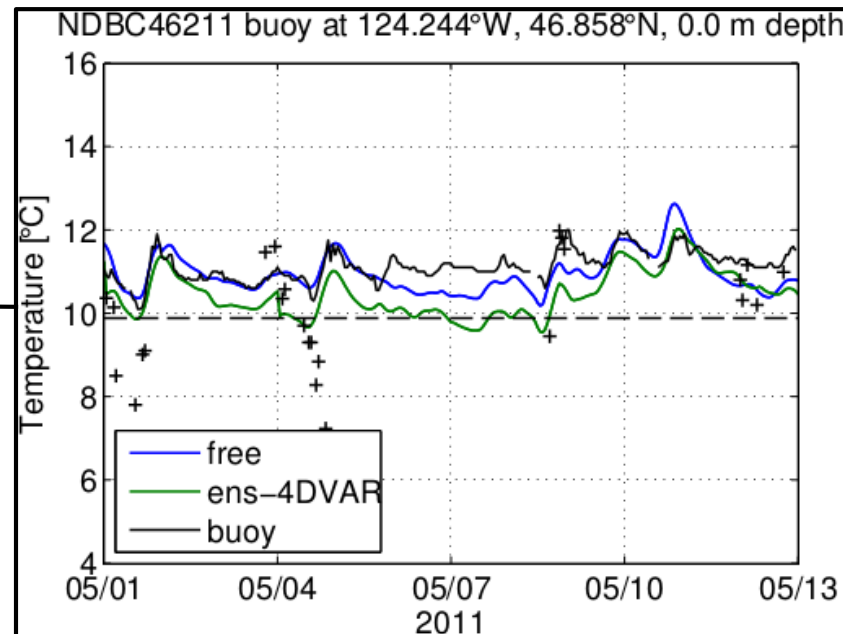
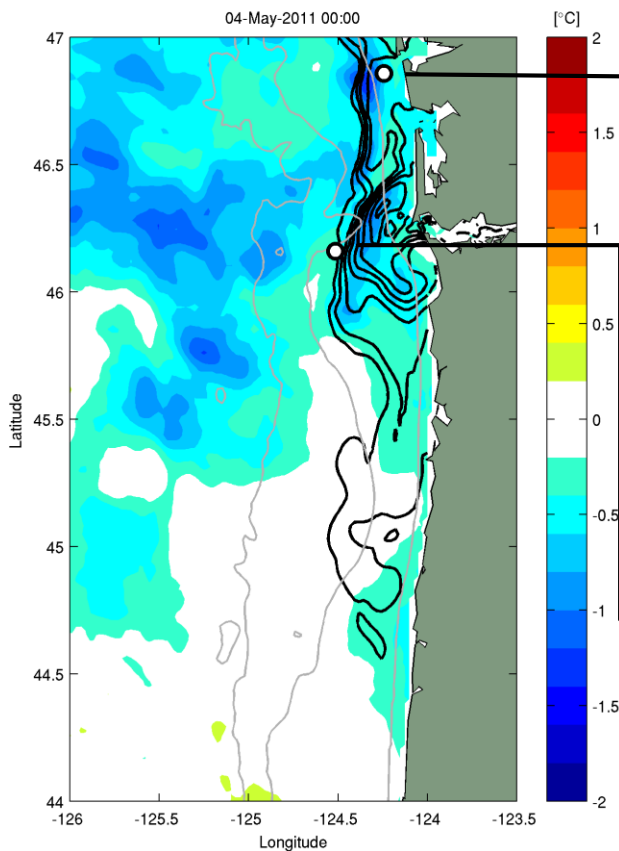
SSS on 05/13/2011
before assimilation



after assimilation



A negative 4DVAR correction (color)
(contours show SSS)
05/04/2011



Negative correction in SST => (given strong negative covar. of T and S in the plume)
positive SSS correction

Update on WCOFS

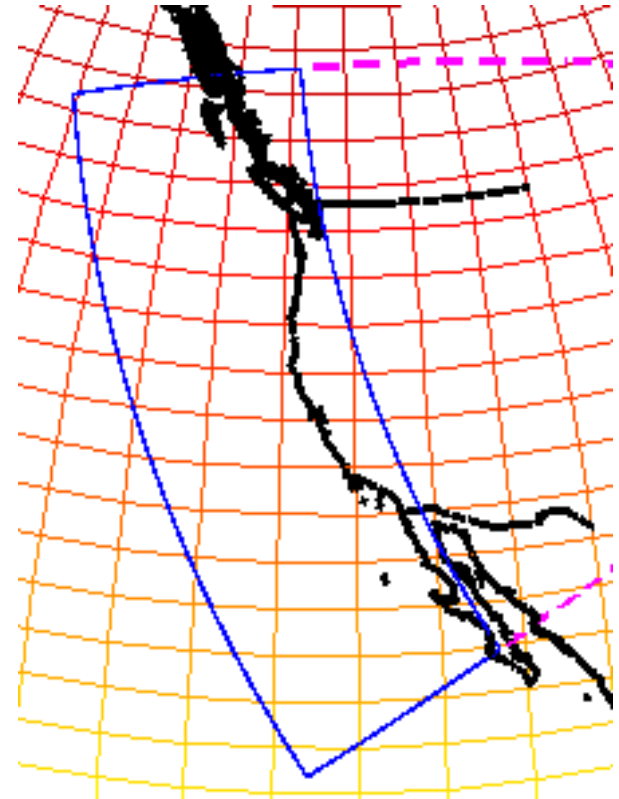
WCOFS model: based on Regional Ocean Modeling System (ROMS, [www. myroms.org](http://www.myroms.org))

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. long-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

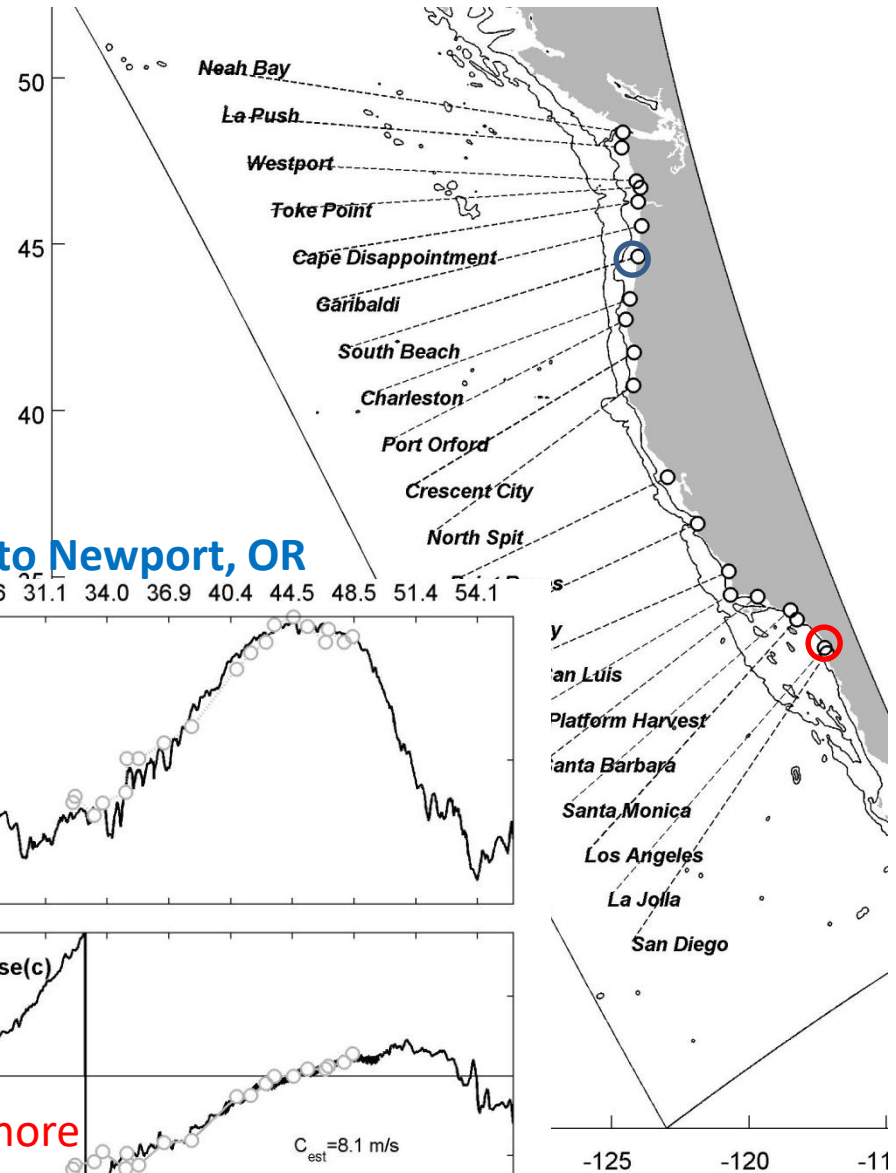
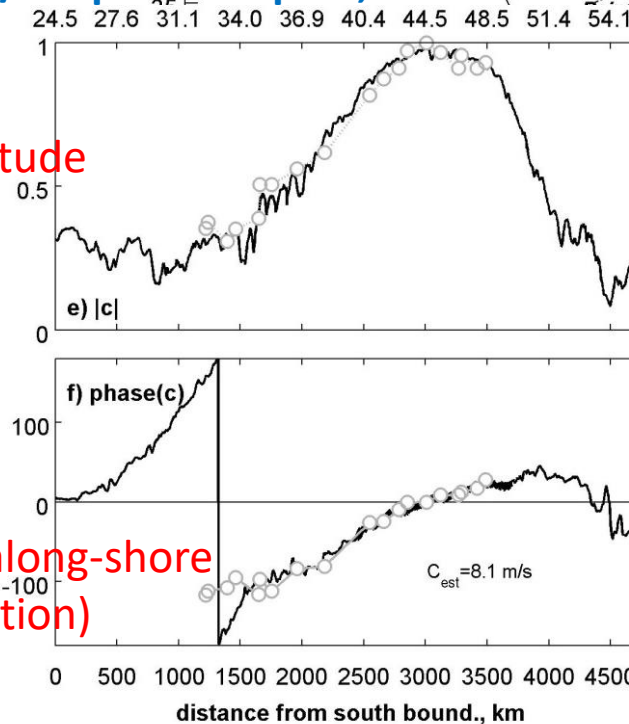
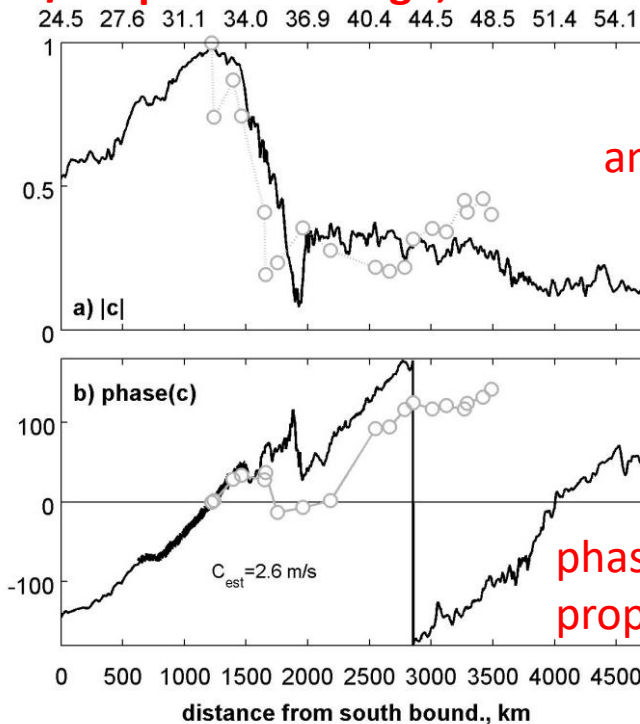
Coherence = spatial correlation for a specified frequency range

Shown here for the range of periods close to 10 days

w/ resp. to San Diego, CA

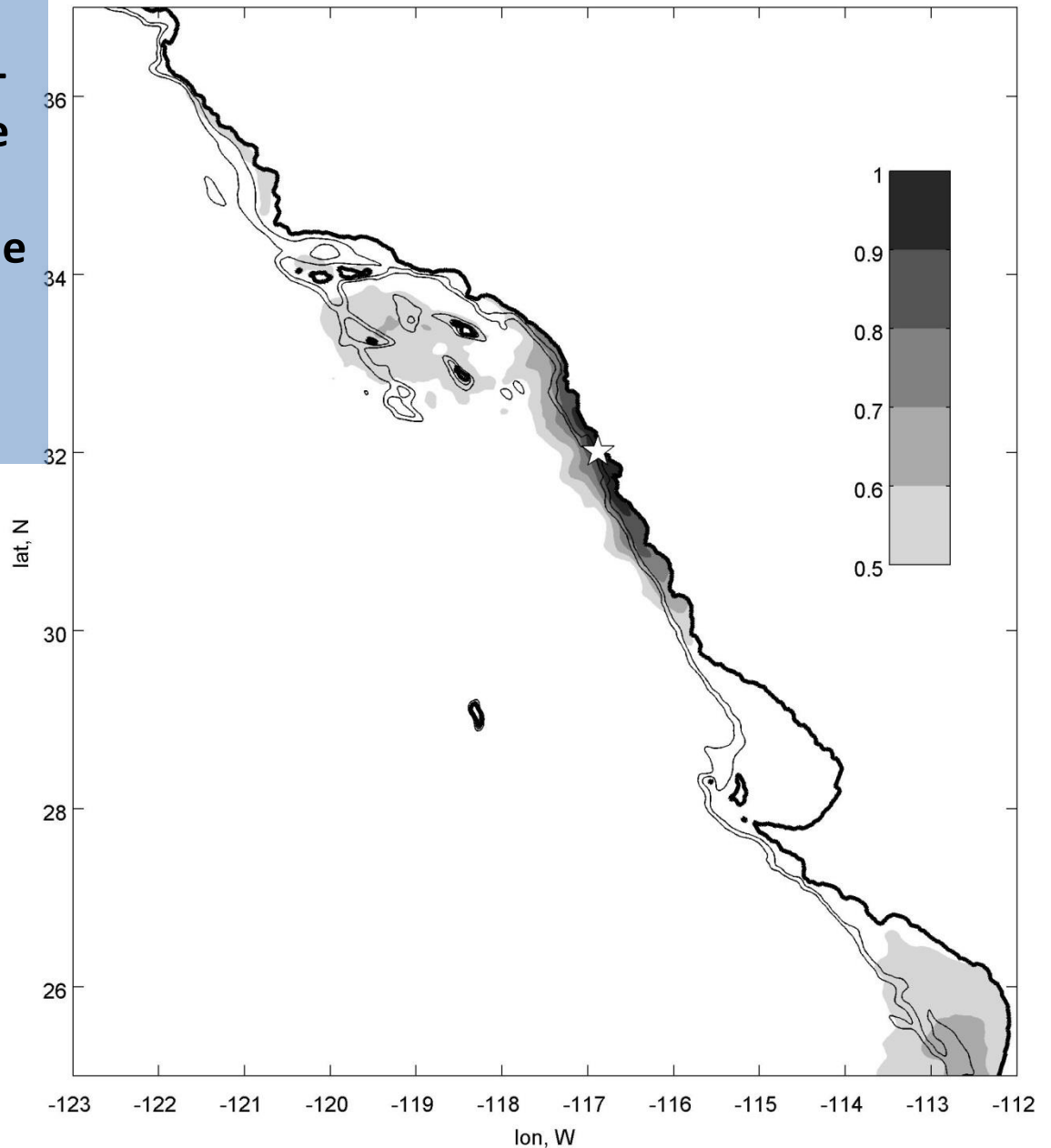
w/ resp to Newport, OR

$T_c = 10 \text{ d}, T_{ave} = [9.2, 11.0] \text{ d}$



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)

range T=[4.4-5-5.8] d, np=60, lato=32N

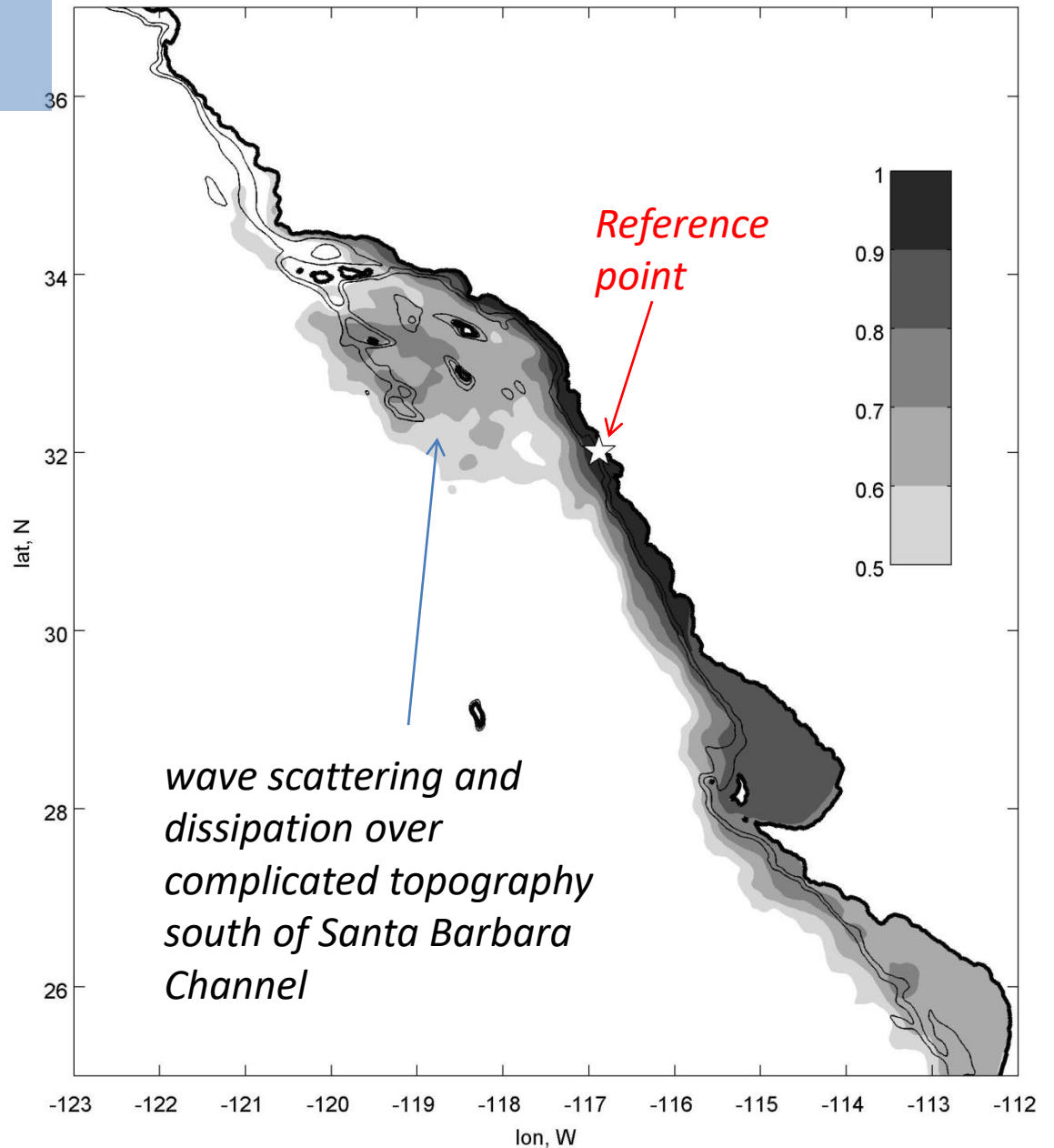


Frequency range
centered on $\omega=1/5 \text{ d}^{-1}$

*Kurapov et al., Oc. Dyn.,
submitted*

The SSH coherence amplitude map

range T=[9.2-10-11.0] d, np=20, lato=32N

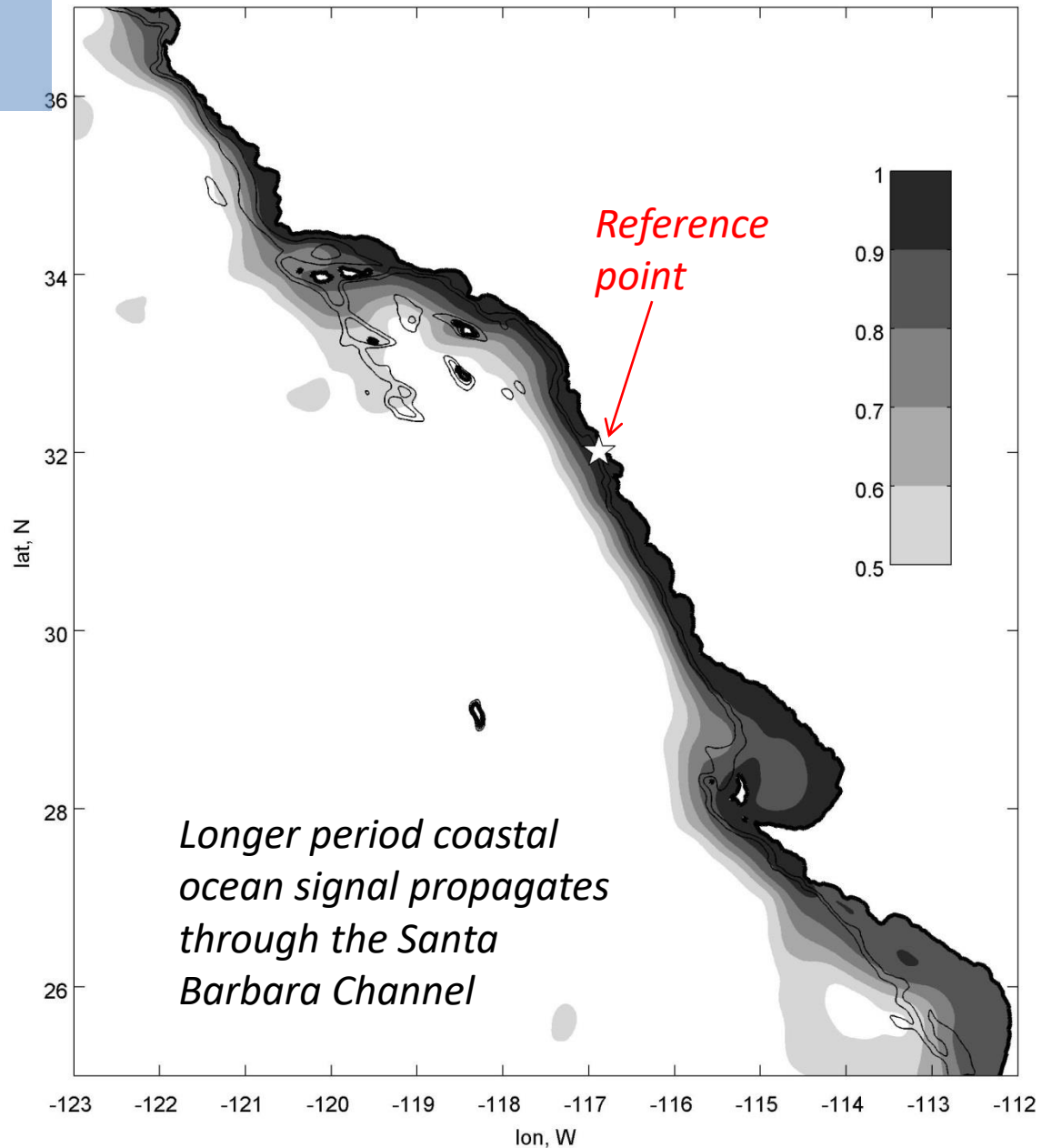


Frequency range
centered on $\omega=1/10$ d⁻¹

*wave scattering and
dissipation over
complicated topography
south of Santa Barbara
Channel*

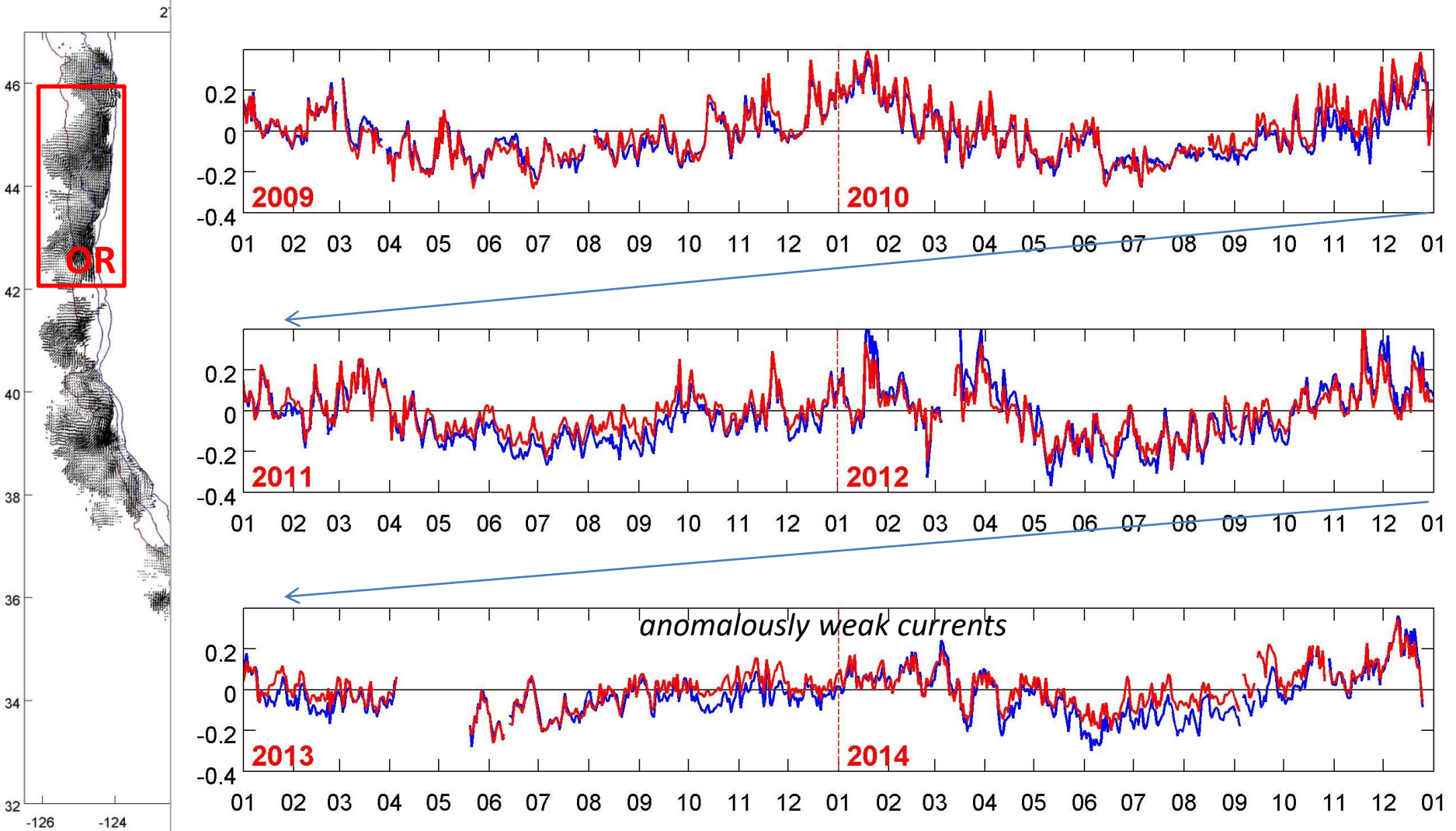
The SSH coherence amplitude map

range T=[39.3-60-126.7] d, np=20, lato=32N



Frequency range
centered on
 $\omega=1/60 \text{ d}^{-1}$
(40-126 days)

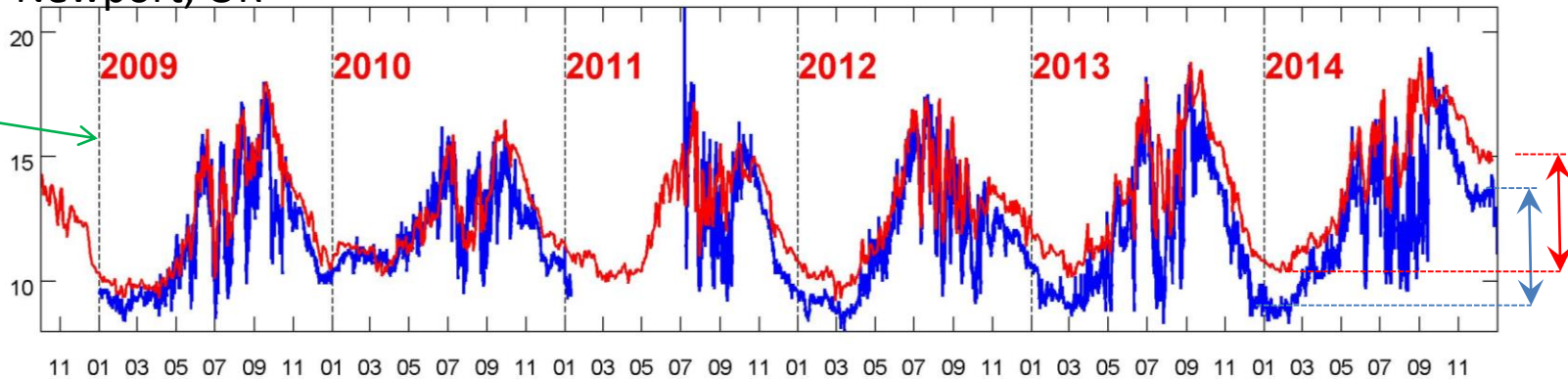
HF radar vs. WCOFS surface currents (area-averaged, daily-averaged alongshore currents... *sim. to Durski et al. Oc. Dyn. 2015*): variability is predicted on temporal scales from several days to seasonal and interannual



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

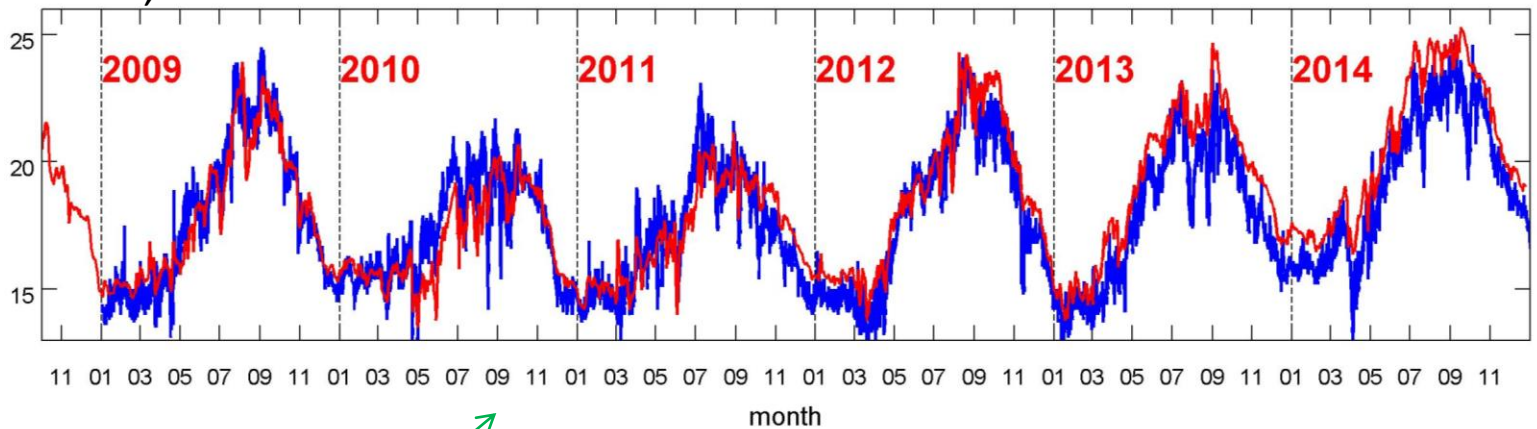
off Newport, OR

NDBC46050 (blue), (red) WCOFS



off La Jolla, CA

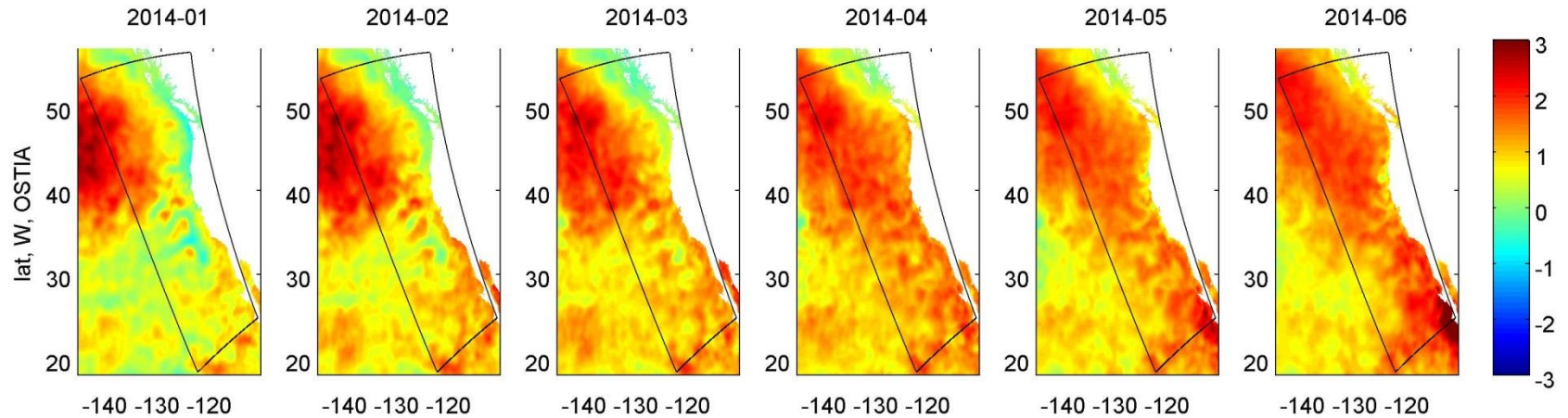
NDBC46224 (blue), (red) WCOFS



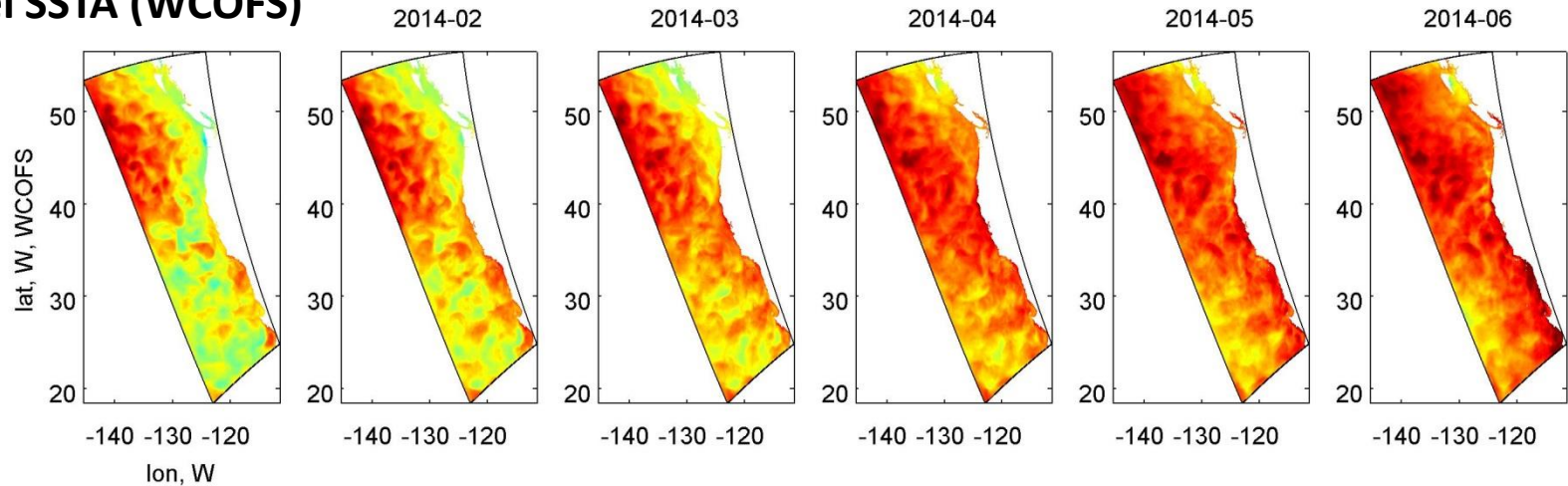
WCOFS has predicted correctly the warming trend (Dec 2013 – Dec 2014)

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)

Atm-Ocean heat flux exchange primer:

$$Q = \text{SWRAD} + \text{LWRAD} + \text{SENSIBLE} + \text{LATENT}$$

Radiation: $W = [\text{emissivity}] \times \sigma T^4$ (Stefan-Boltzmann)

SWRAD: the solar radiation

(a very hot body => max energy as short waves)

(net = downward – reflected)

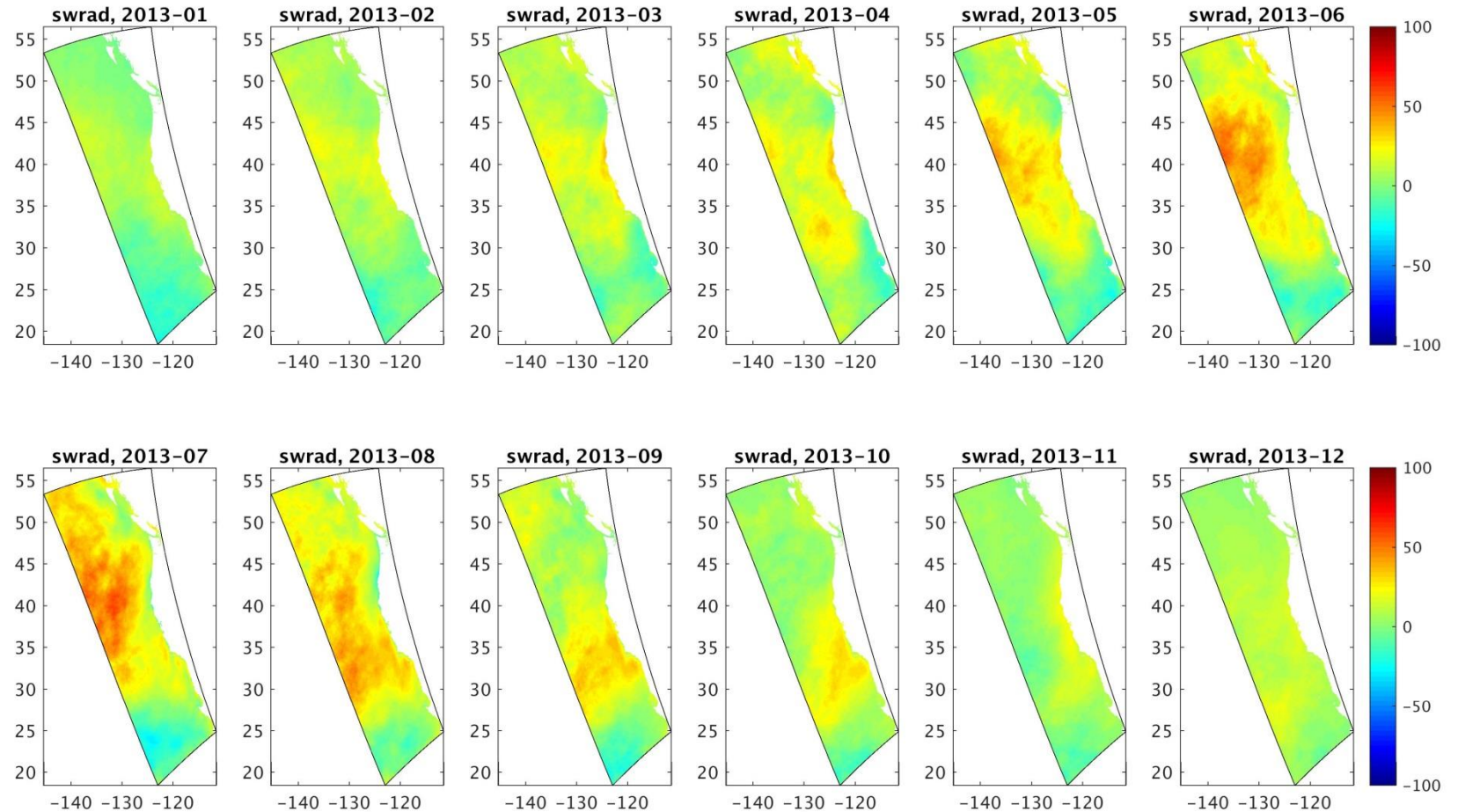
LWRAD: net = LW from air – LW from the ocean, generally <0 (cooling)

SENSIBLE ~ turbulent heat flux, $\langle w'T' \rangle \sim (\text{wind } U - \text{ocean } U) (T_{\text{AIR}} - T_{\text{ocean}})$

LATENT ~ turbulent water vapor flux $\langle w'q' \rangle$, where q is specific humidity

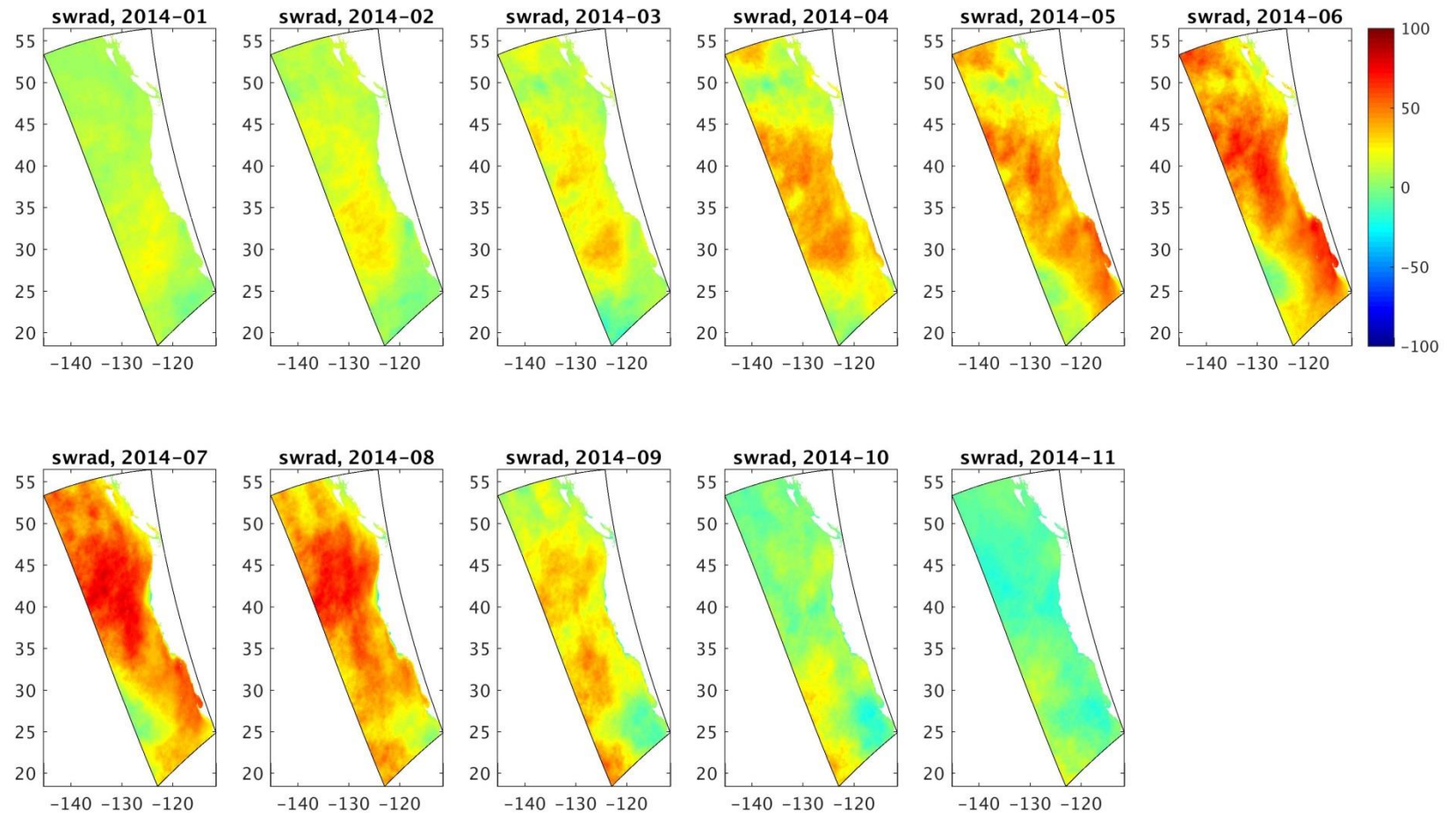
(ocean loses heat to evaporate water, water vapor is taken up by turbulence, heat is released up in the skies => clouds)

ROMS SWRAD anomaly 2013 w resp to 2009-2013 clim (using 3-mo running ave)



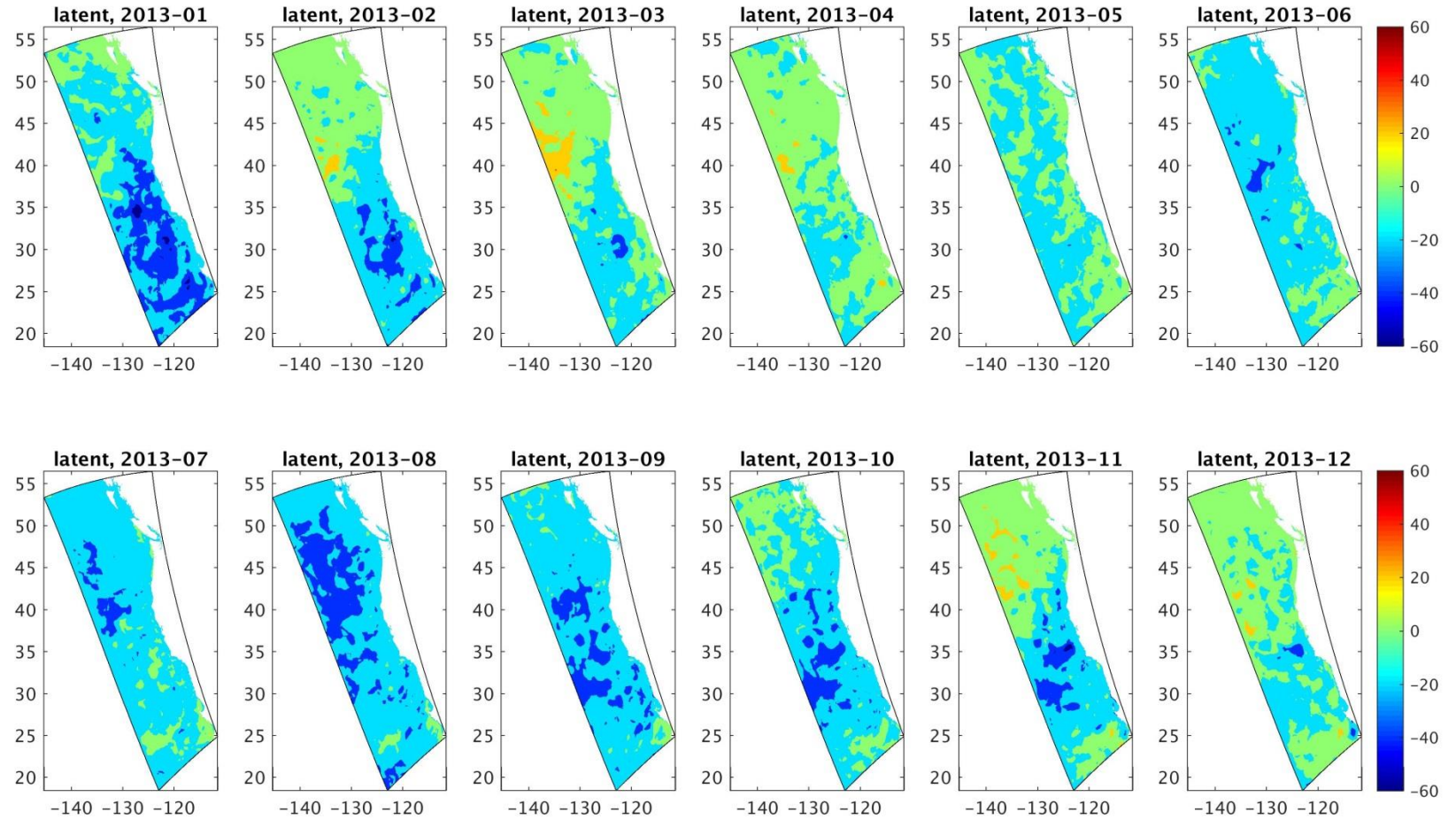
Winter 2013-14: SWRAD not anomalously large

ROMS SWRAD anomaly 2014 w respect to 2009-2013 clim (using 3-mo running ave)

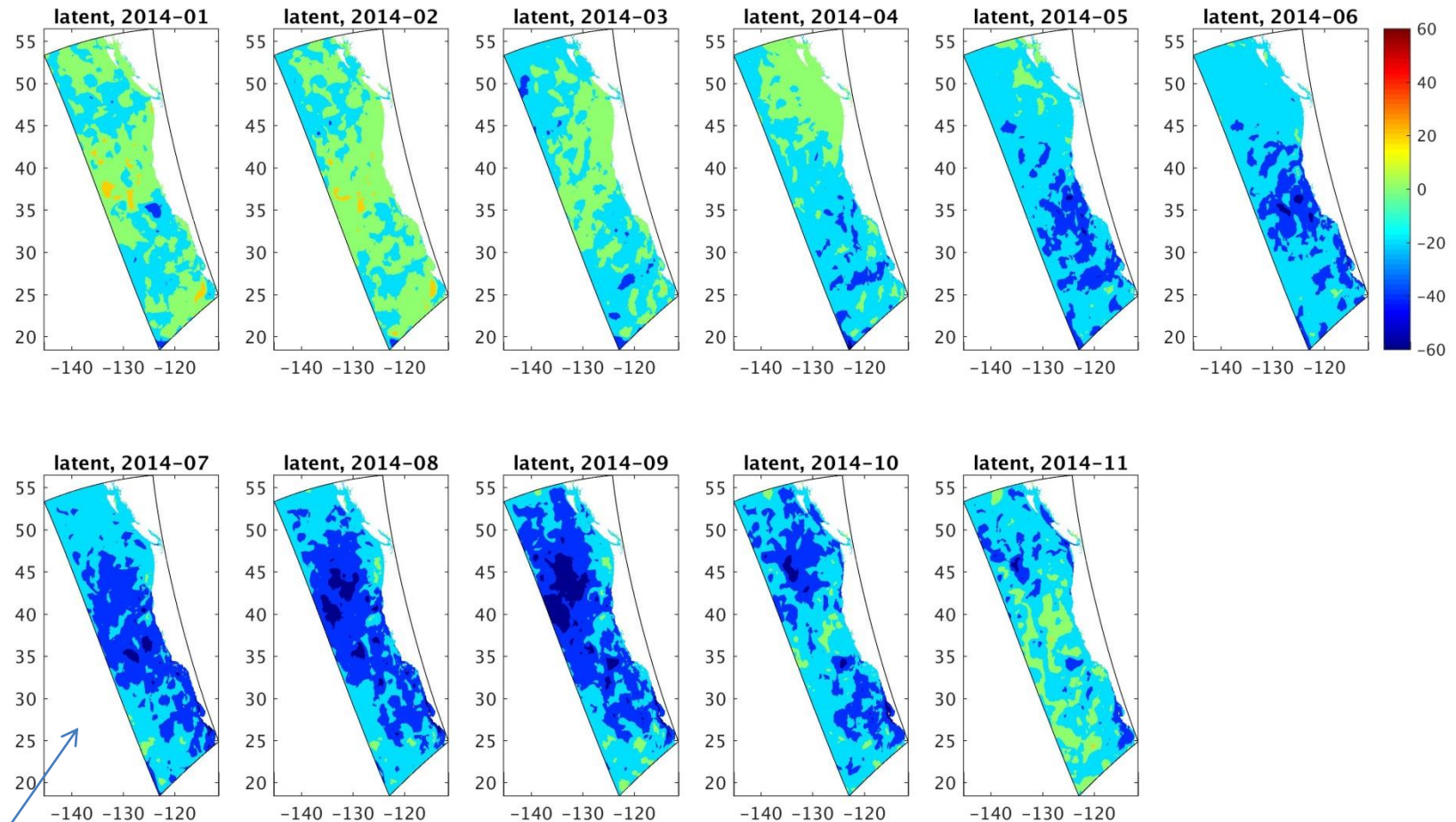


Anomalously large SWRAD
in summer 2014

Latent, 2013 anomaly



Latent, 2014 anomaly

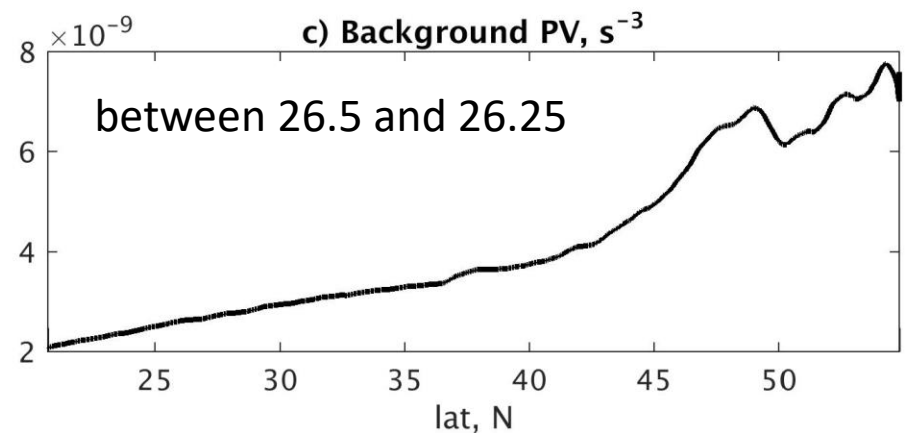
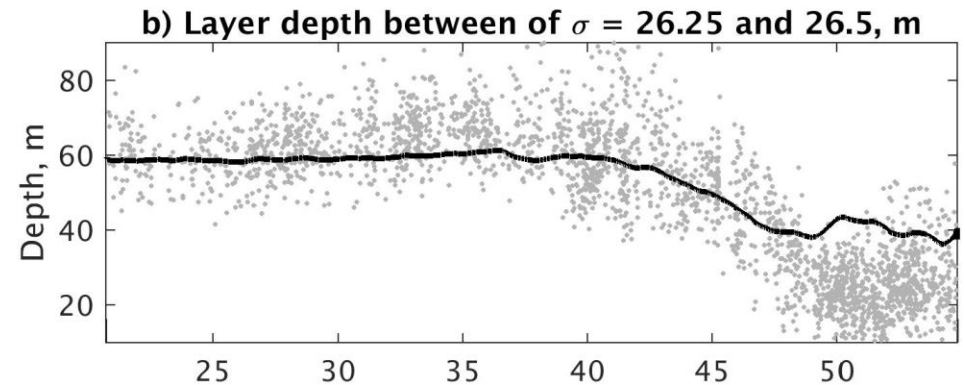
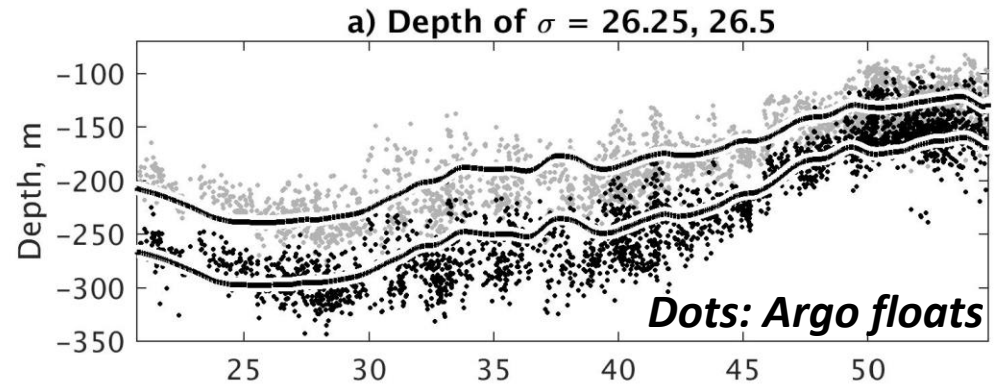
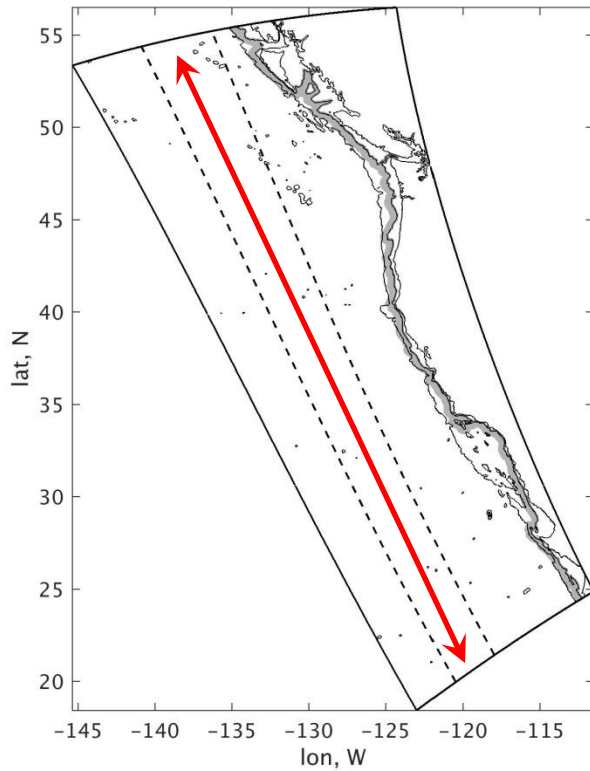


Non-negligible
($>40\text{W/m}^2$) negative
anomaly in late summer

Implication for WCOFS: presently, atm-oce salin. flux = 0.
Cooling by latent heat flux is associated with evaporation
(positive salinity flux). Can this cause convective mixing that
will help to cool the surface b. layer?

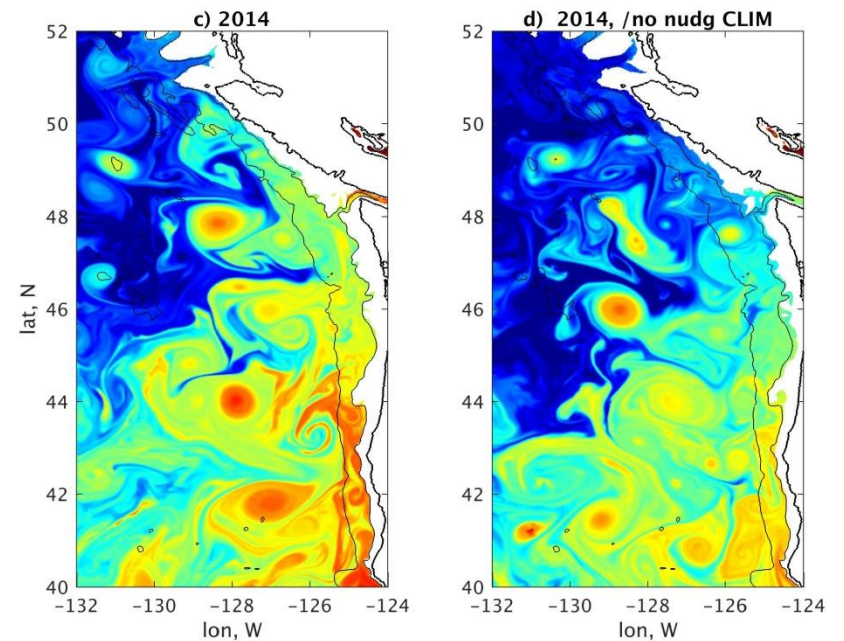
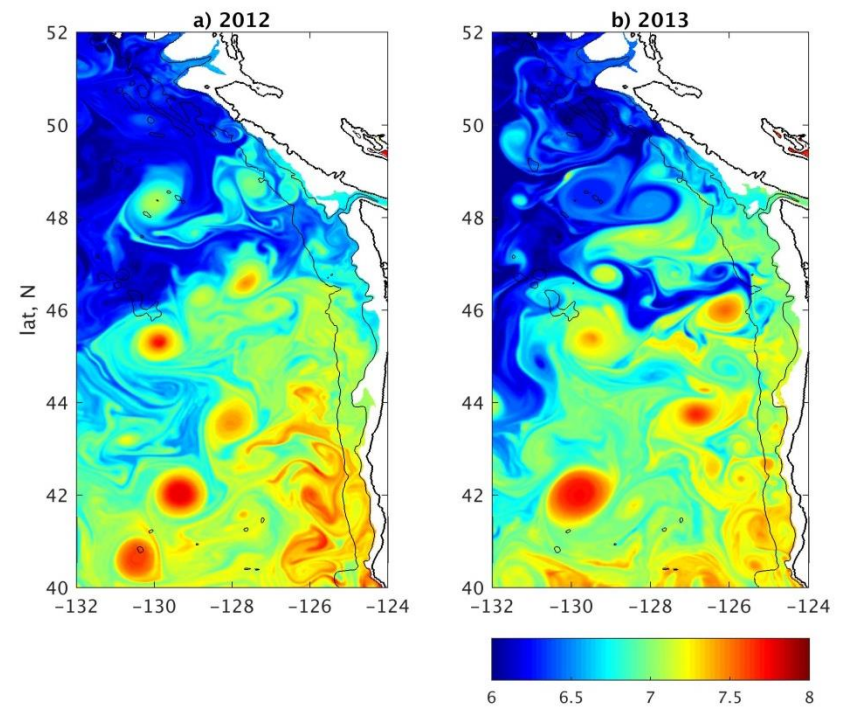
Analyses on the $\sigma=26.5$ isopycnal surface

6-year averaged properties along the meridional section



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 $\sigma=26.5$. 1 June 2012 / 2013 / 2014.



Analyses of slope properties on the isopycnal surface $\sigma=26.5 \text{ kg/m}^3$

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

Average properties in cross-shore direction offshore of the 200-m isobath (30-km wide)

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

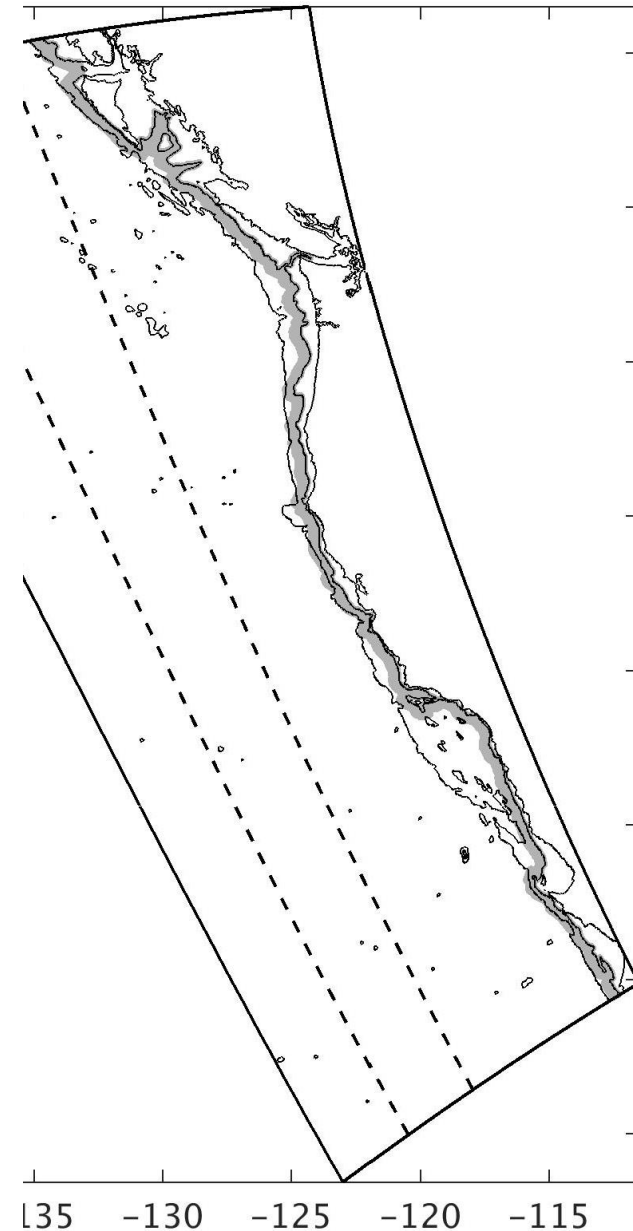
$T(s,t) = \text{time_ave_}T(s) + \text{seasonal_}T(s,t) + \text{anomaly_}T(s,t)$

seasonal_ T = harmonic fit (annual + semi-annual)

Effect of CTW?

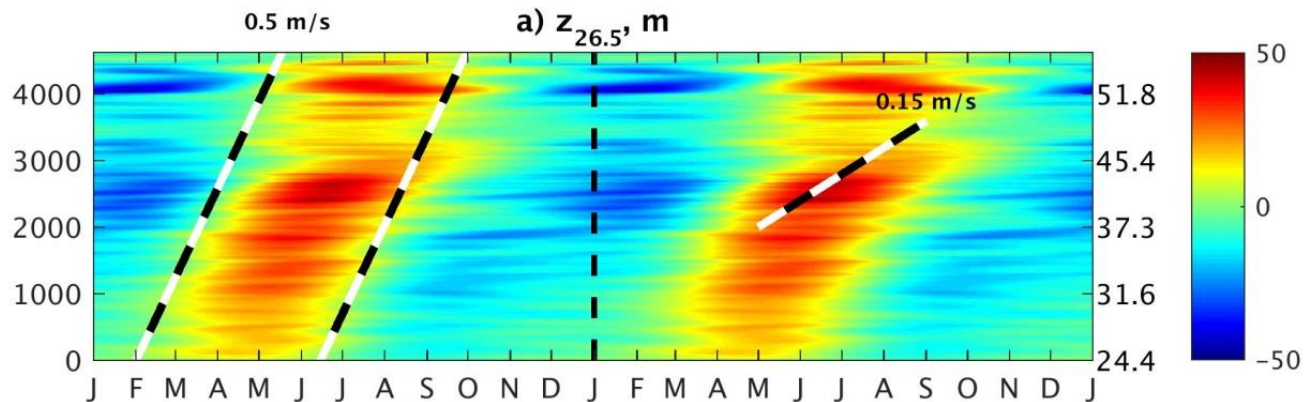
Effect of undercurrent?

Climatology, anomalies?

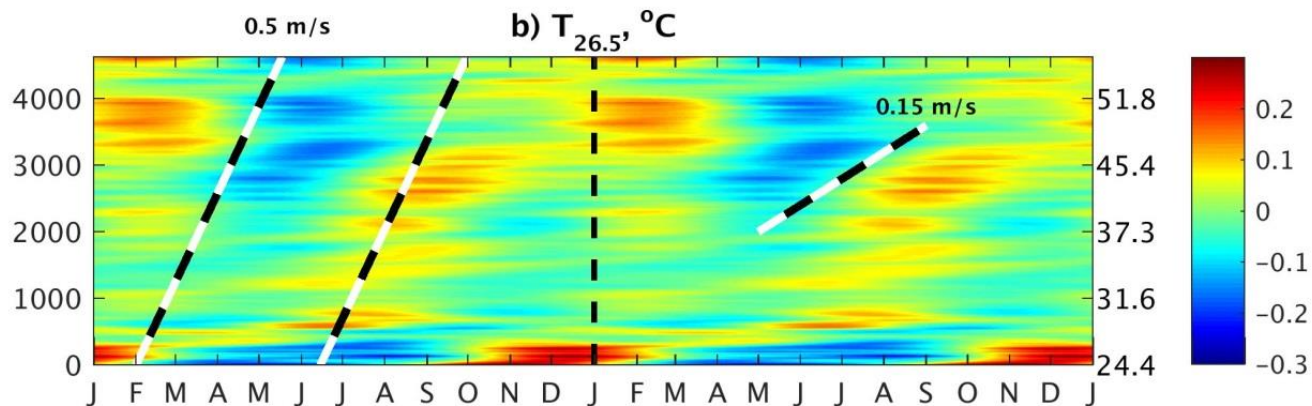


Annual cycle on $\sigma_\theta=26.5 \text{ kg/m}^3$ (two years shown)

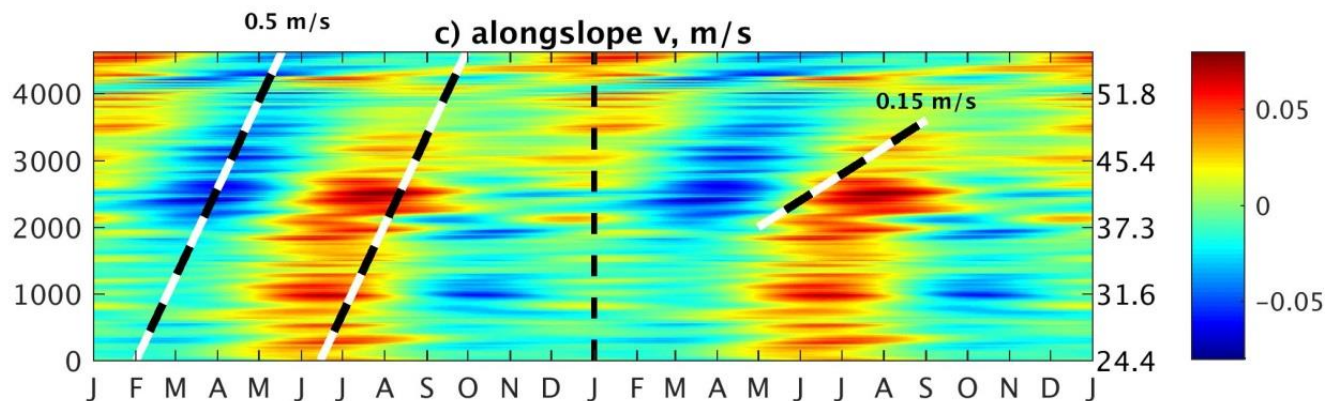
Depth of the isopycnal surface (m)



T on the isopycnal surface (C)

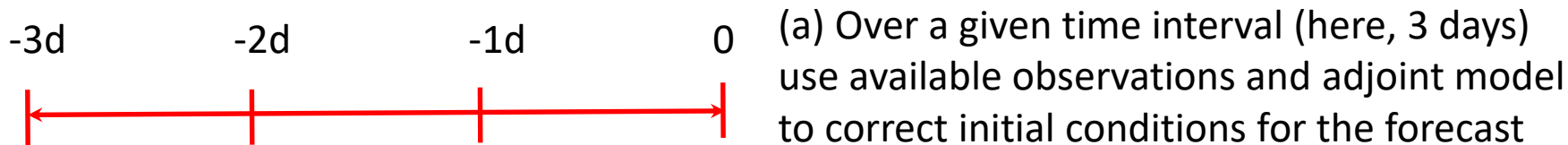


Alongslope velocity (m/c)



Initial assimilation tests: use JPSS VIIRS L3U, in the Central CA subdomain

Assimilation methodology, 4DVAR:



(b) Run the model forecast using improved initial conditions

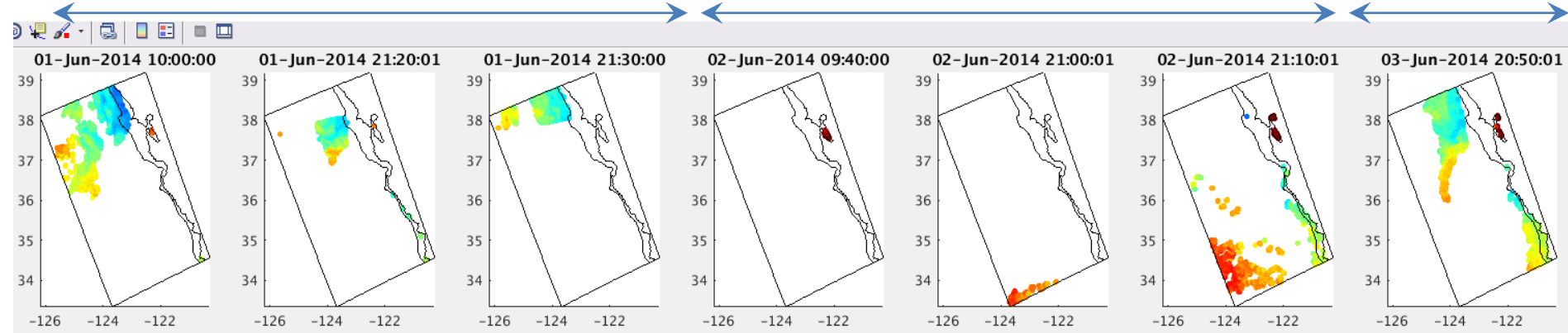


Example of SST coverage: JPSS L3U, in central CA, Jun 1-3 2014 (data: courtesy A. Ignatov)

1 Jun

2 Jun

3 Jun

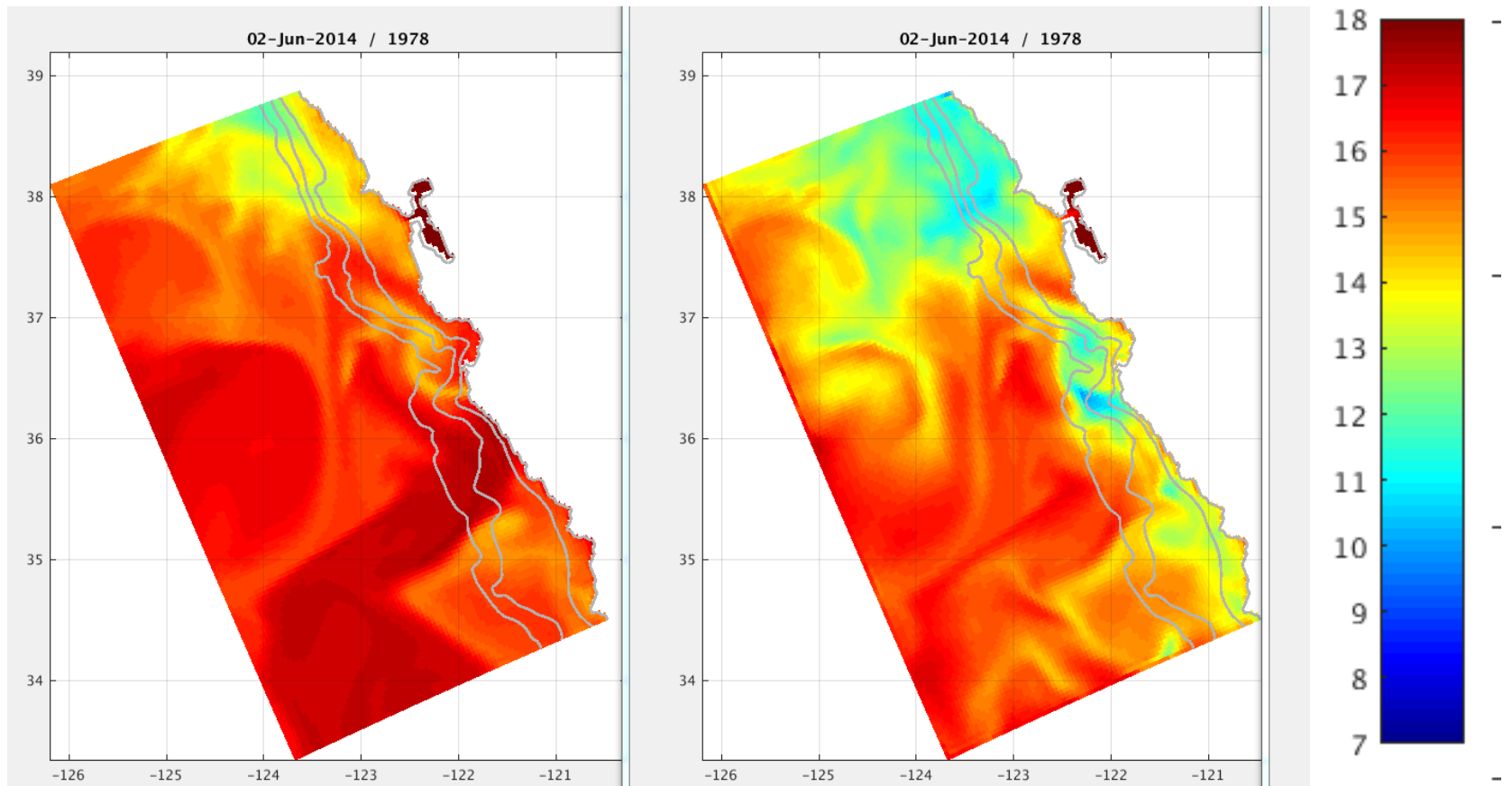


DA: **a dynamically based time-space interpolator** (fills between gaps, facilitates accurate forecasts)

The effect of SST assimilation on model SST:

06/02/16, 00:00:00 UTC

Model before assimilation / after assimilation

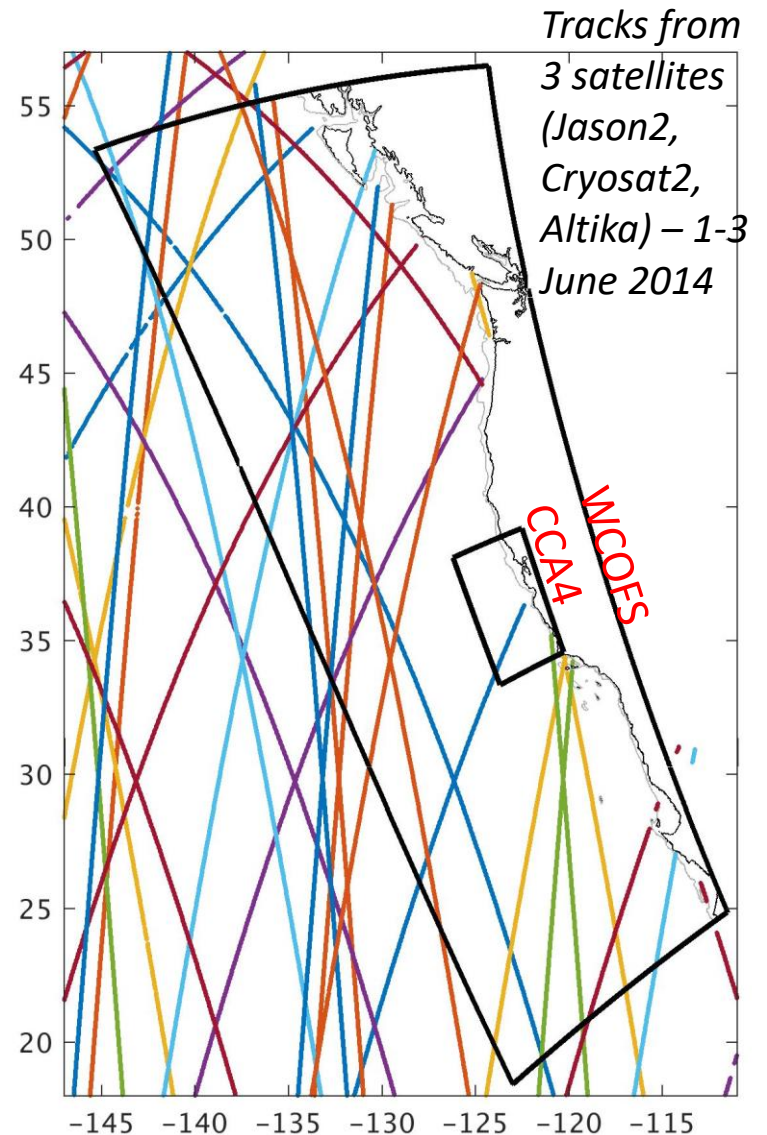
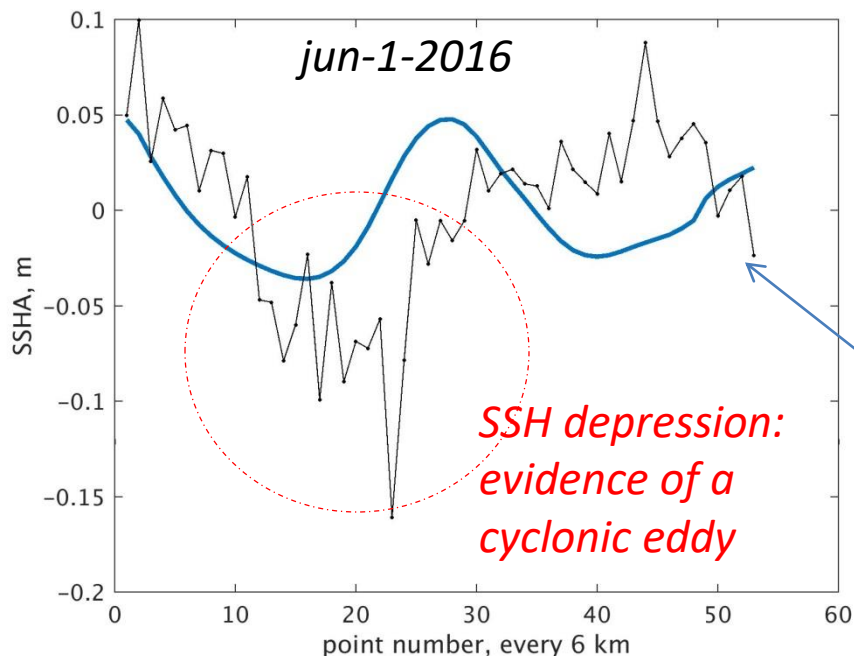


Next step: tests assimilating SST in combination with alongtrack altimetry

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

Year 4 plans:

- Forecasts provided by our model systems will be compared to available in-situ and satellite observations (*Kurapov, Edwards, Chao, MacCready*)
- Carbon variables (Alkalinity and DIC) will be added to the 6-component NPZDO-Banas model, and compared with observations (*MacCready*)
- The OR-WA 4DVAR system will be tested with a new (ensemble-based) model error covariance suitable for anisotropic ocean conditions in the presence of the Columbia River (*Kurapov*)
- The impact of glider and mooring data on coastal ocean prediction will be tested (*Kurapov, Chao*)
- The data assimilation methods (e.g., 3DVAR, 4DVAR and ensemble Kalman Filter) will be compared and evaluated (*Chao, Cornuelle, Moore*)
- Observing system simulation experiments (OSSE) will be performed for the regional UCSC model using observation sensitivity and observation impact tools developed for ROMS (*Moore*)
- In conjunction with NOAA CSDL, key metrics for physical forecast evaluation and will be tested (*all participants*)
- Metrics for skill assessment of biogeochemical fields, including Hypoxia and OA, will be developed (*Edwards, Chai, MacCready*)
- Available solutions will be contributed to COMT CI (*all participants*)

Transition to NOAA operations:

- One or more biogeochemical components will be tested in the WCOFS configuration (*all participants, year 4-5*)
- Feasibility of using ROMS 4DVAR in WCOFS will be tested (*Moore, Kurapov*)