The Oregon coastal ocean data assimilation system: performance assessment

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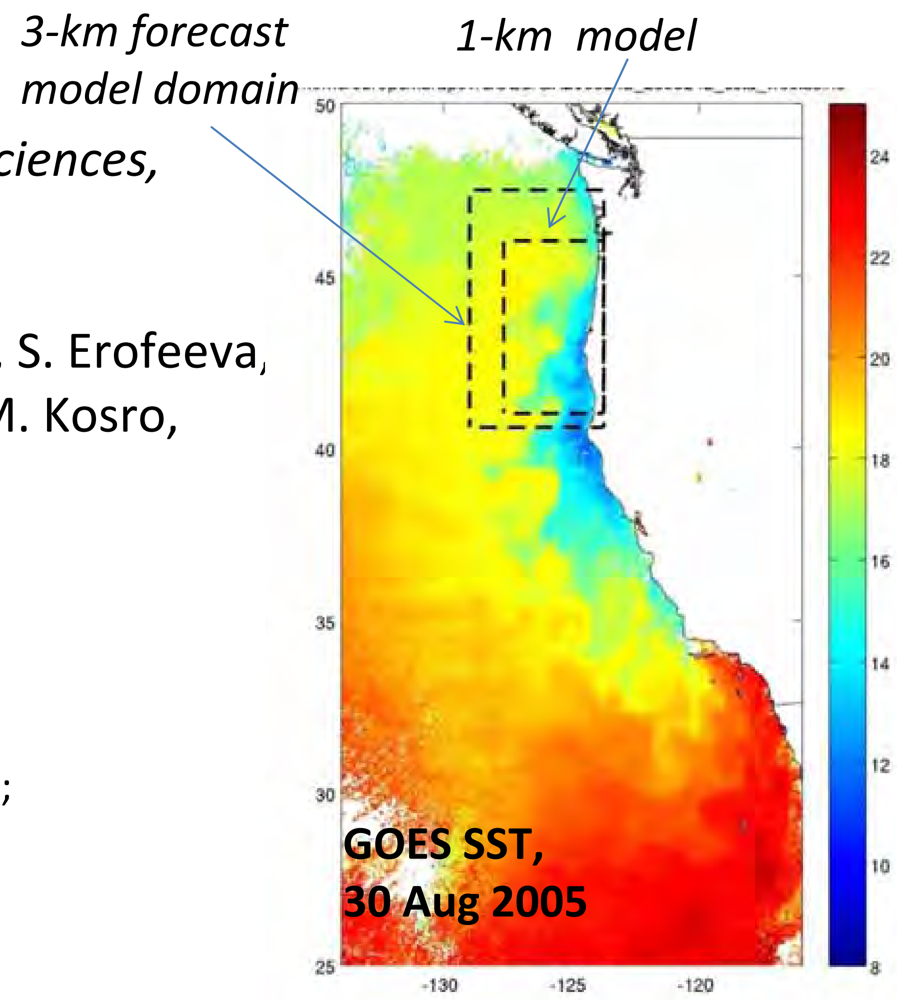


Support by:

ONR (DA methods in the coastal ocean)

NOAA (IOOS-NANOOS: real-time forecast model; CIOSS: utility of RADS SSH, GOES SST)

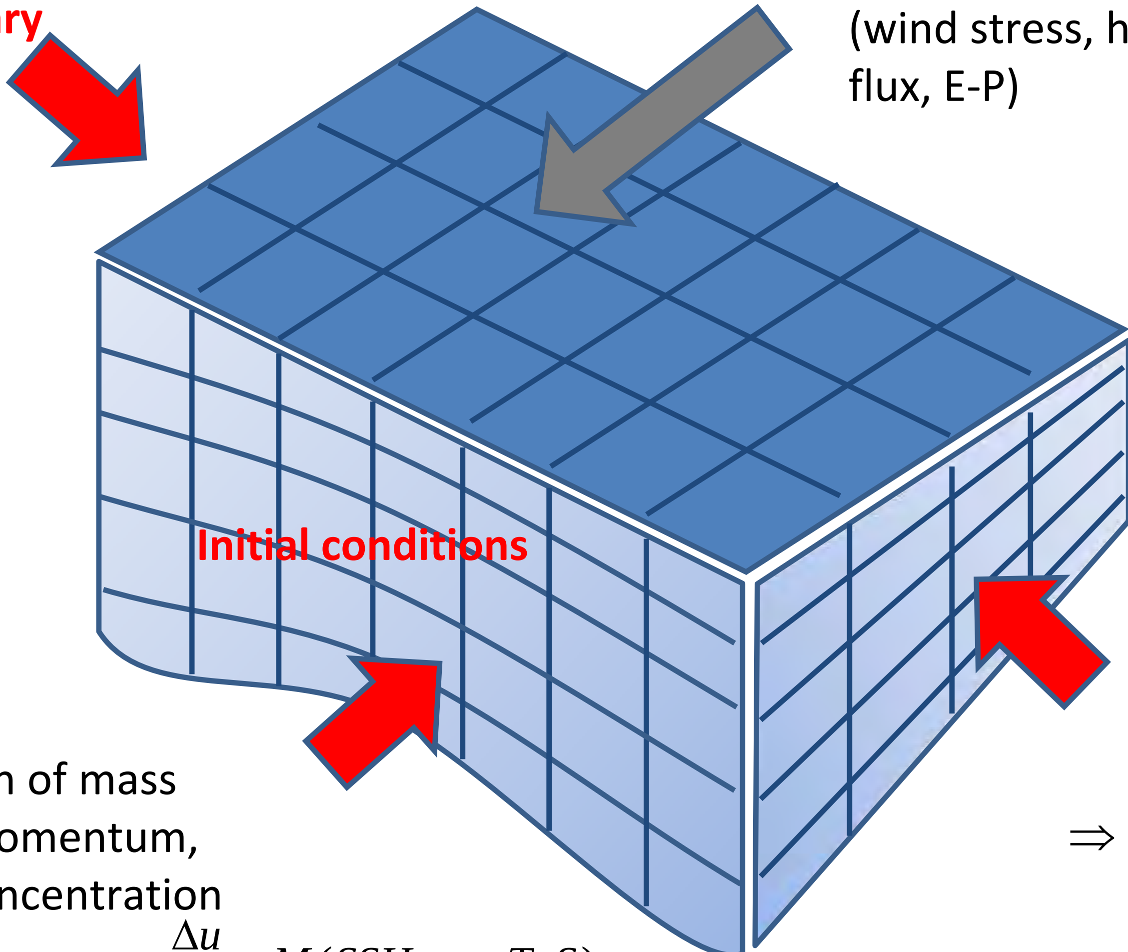
NSF (influences of tide- and wind-driven flows, interior - coastal ocean interactions)

A coastal/regional ocean model (such as Regional Ocean Modeling System – ROMS):

- Discretized equations of fluid mechanics and thermodynamics

Open boundary conditions:

Atmospheric forcing (wind stress, heat flux, E-P)



Conservation of mass (volume), momentum, heat, salt concentration

$$\frac{\Delta u}{\Delta t} = M(SSH, u, v, T, S)$$

$\Rightarrow$ SSH(t), u(t), v(t), T(t), S(t)

Models can be used for:

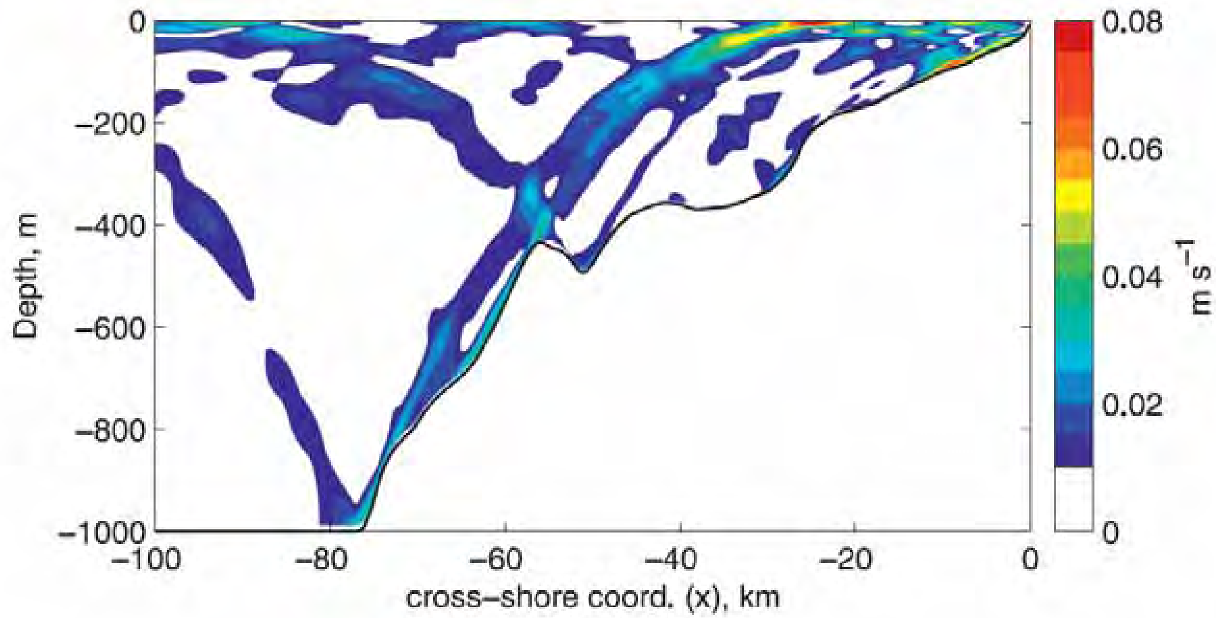
-Studies of ocean dynamics
-Prediction and forecasting of ocean conditions (esp., when combined with data – the task of data assimilation)

Studies of combined effects of tidally and wind-driven coastal ocean circulation:

Internal tide = superinertial baroclinic motions near the tidal (e.g., dominant M_2) frequency, forced by the barotropic tidal flow over topography

Shown: the average speed associated with the M_2 internal tide, increased along the beams of the internal tide propagation

[based on the idealized model, *Kurapov et al.*, JPO, 2010]



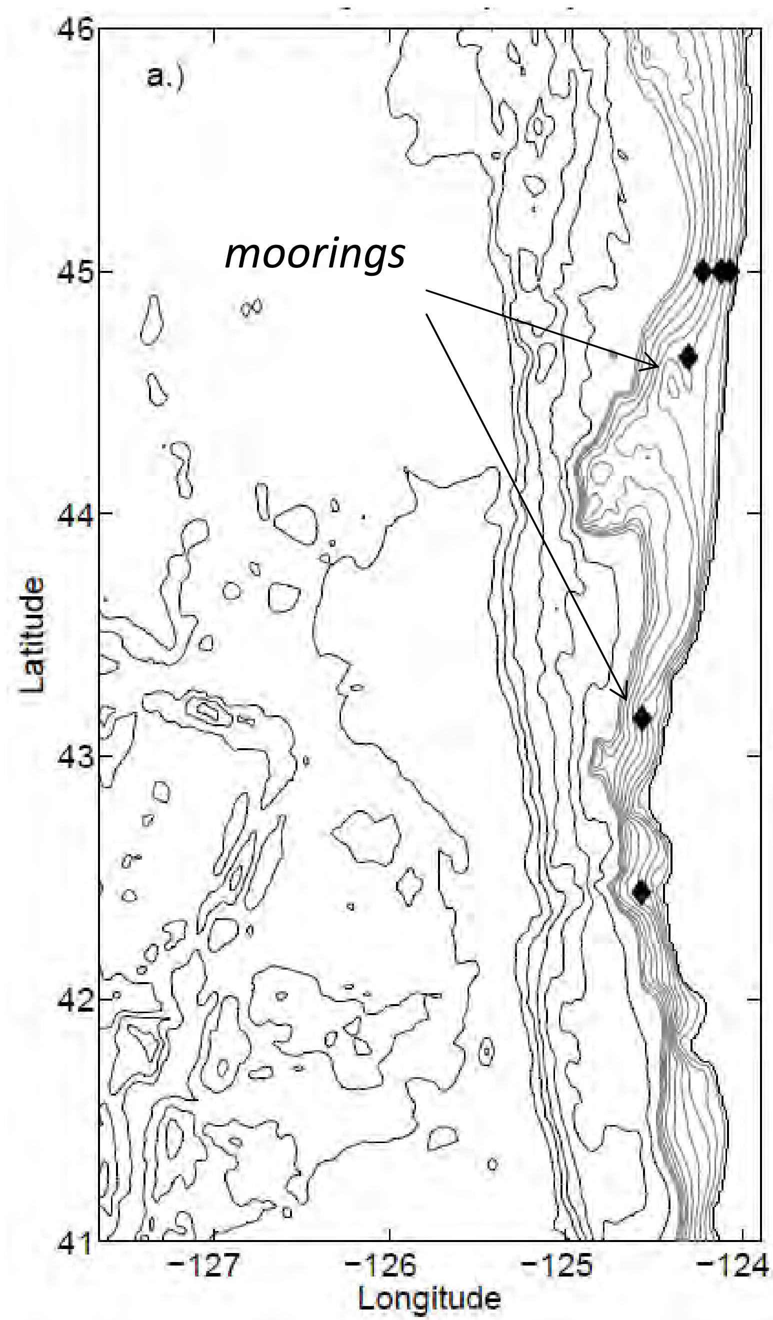
Internal tide:
- has small scales (*O*(10 km)) over the shelf
- is intermittent (amplitude and phase are sensitive to background stratification and currents)
- potentially affects circulation on subtidal time scales

A 3D model with realistic bathymetry, atmospheric, and tidal forcing
(Osborne et al., JPO, 2011**)**

ROMS, 1-km horizontal resolution, 40 vertical layers; boundary conditions from a 3-km regional ROMS model (*Koch, Kurapov, and Allen*, JGR, 2010); atm. forcing – COAMPS.

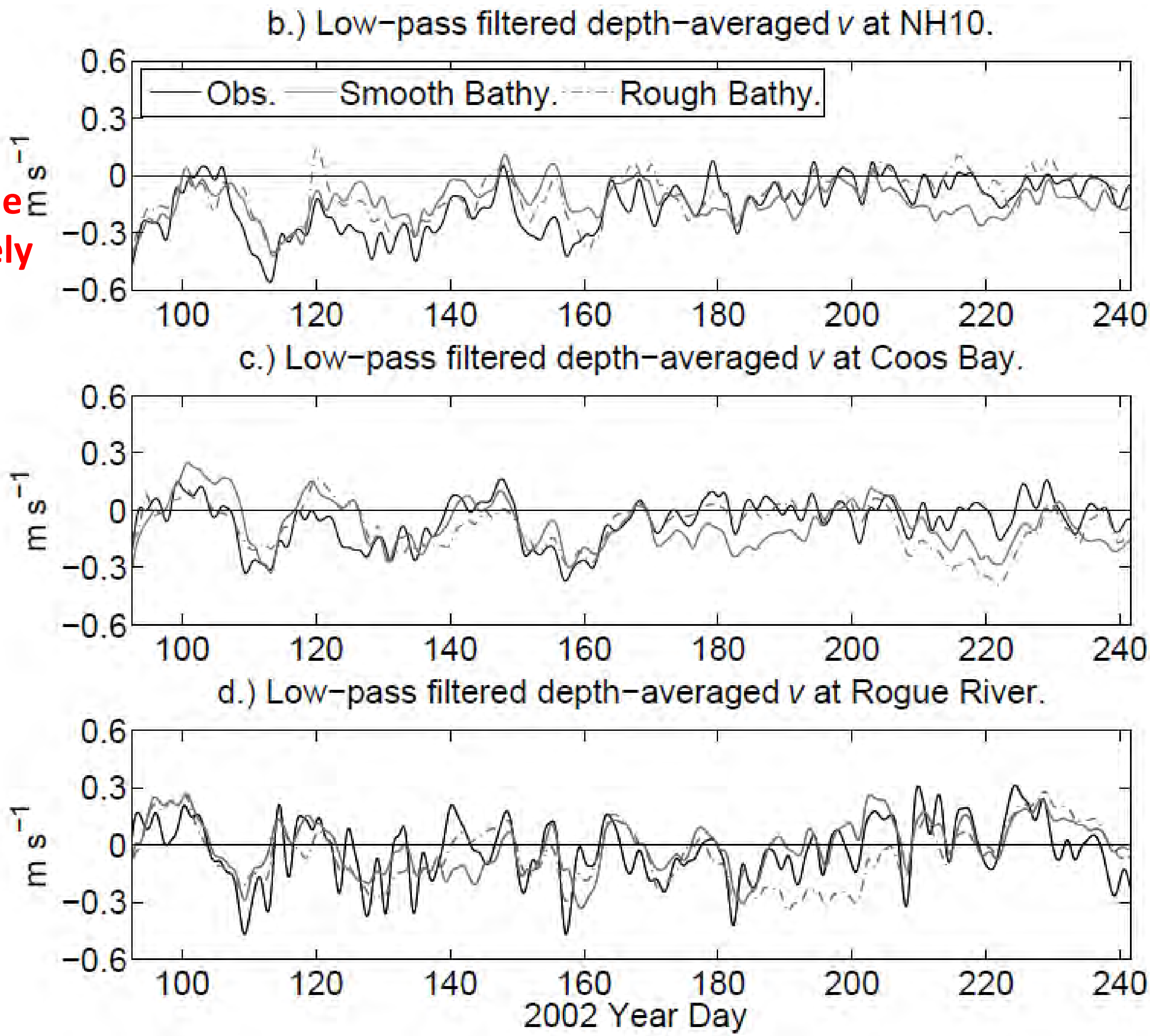
Study period April-Aug 2002
Cases:
-WO ("winds only")
-W+M2 (atm. forcing + dominant M_2 component) [*Osborne et al*., JPO, 2011]
-TW ("tide+wind", atm. forcing + 8 tidal components along the open boundary)

Shown: model domain (300x500 km). Half-tone contours are every 20 m, from the coast to 200 m depth; black contours are at every 500 m.



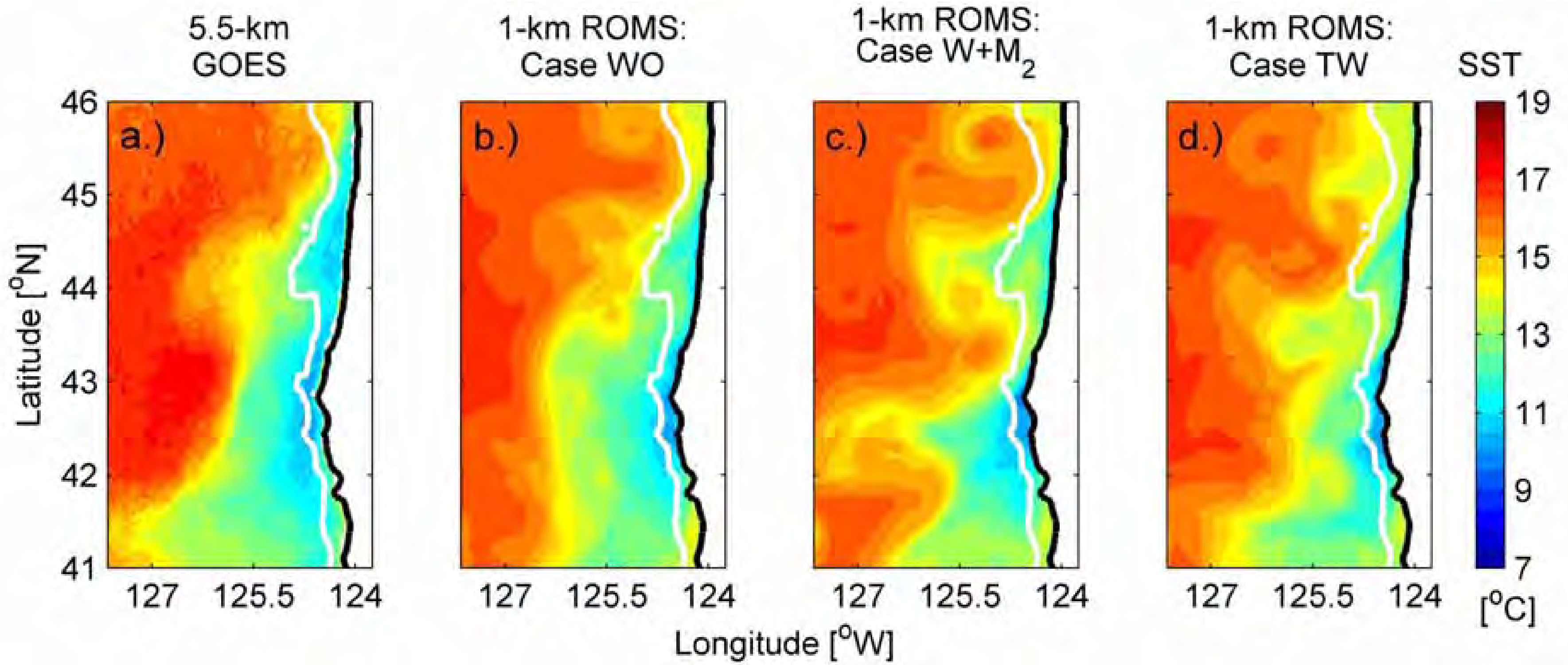
Alongshore velocity sub-tidal variability is strongly wind-driven

The model reproduces currents over the shelf qualitatively well



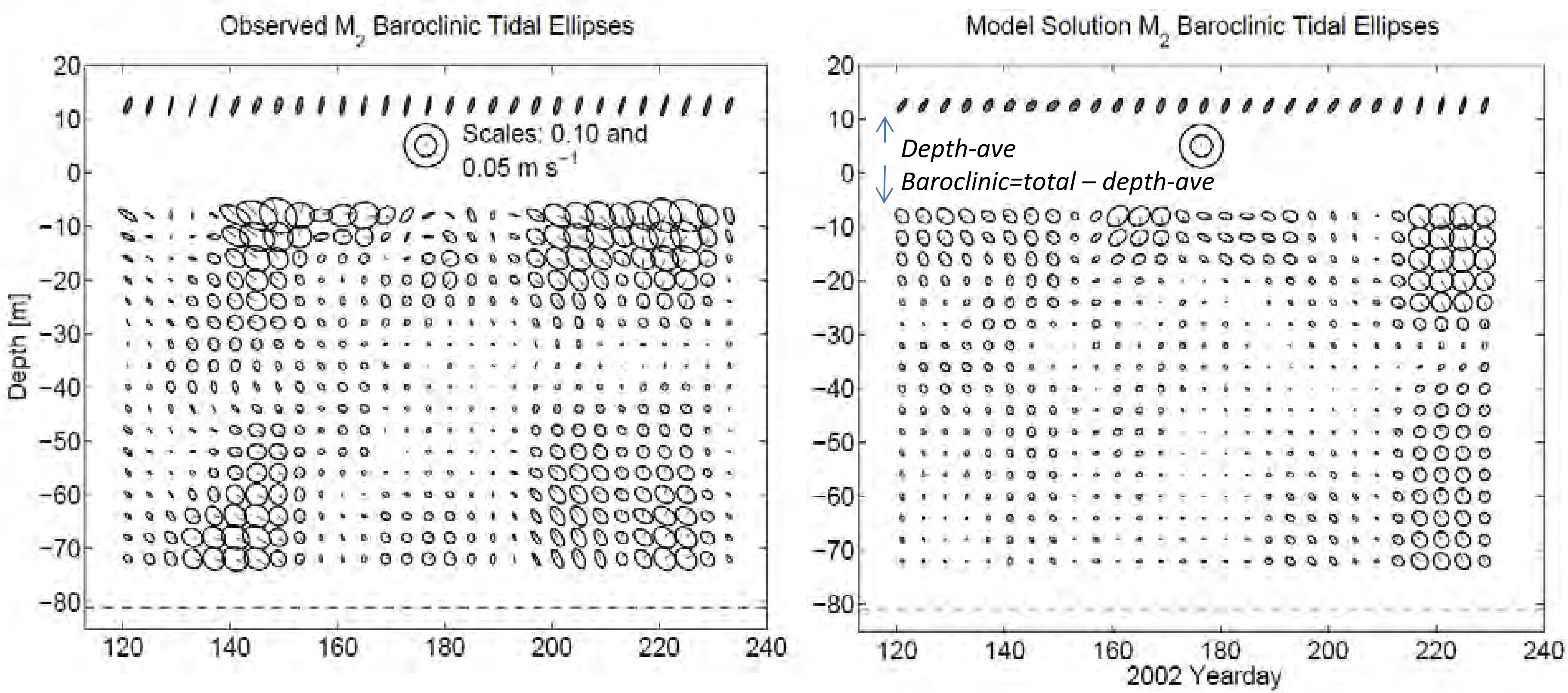
Coastal transition zone (CTZ): coastal currents separate, the SST front moves westward as summer upwelling progresses

Shown is monthly averaged SST, August 2002: (a) satellite, (b)-(d) model



The extent of the SST front in August is qualitatively correct
Dynamics in CTZ are less predictable than dynamics on the shelf
Modeled geometry of the SST front is sensitive to the tidal boundary conditions

Baroclinic tidal ellipses of horizontal currents (NH10 mooring location):



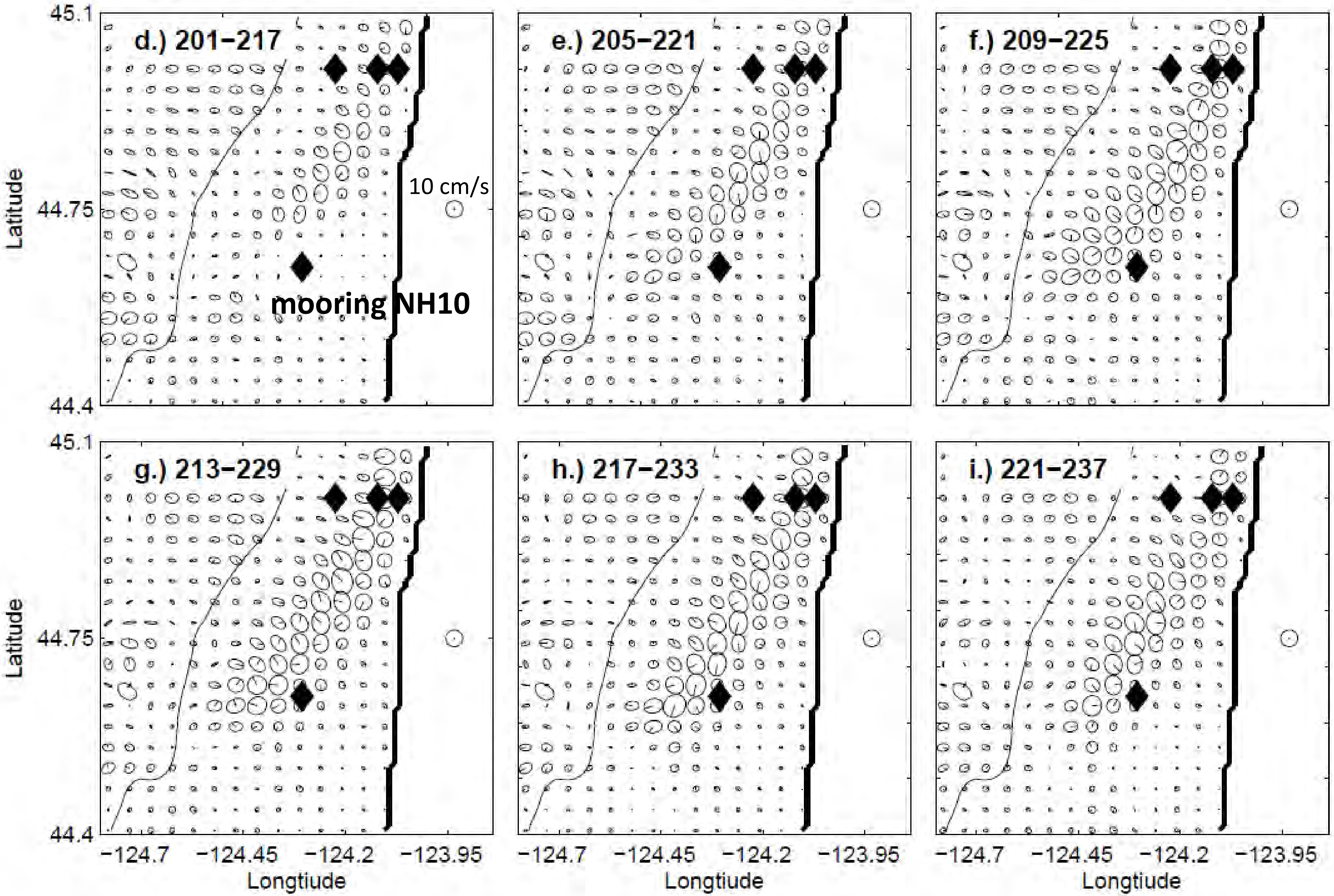
Each ellipse shows how large the horizontal M_2 internal tidal currents are at each vertical level

The ellipses are obtained using harmonic velocity constants obtained in a series of (overlapping) 16-day time windows.

Internal tides are intermittent;

instances of large internal tide at a given location may be hard to predict

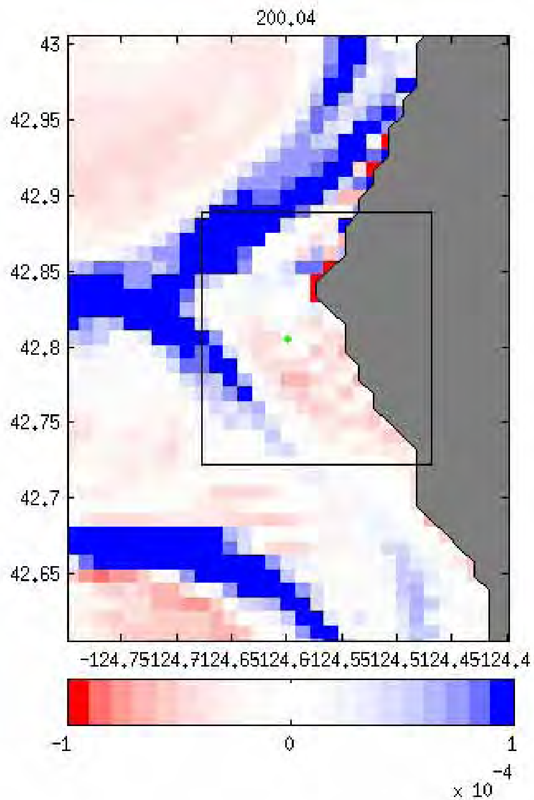
Surface baroclinic M_2 tidal ellipses: the area of the larger internal tide north of the NH10 mooring location



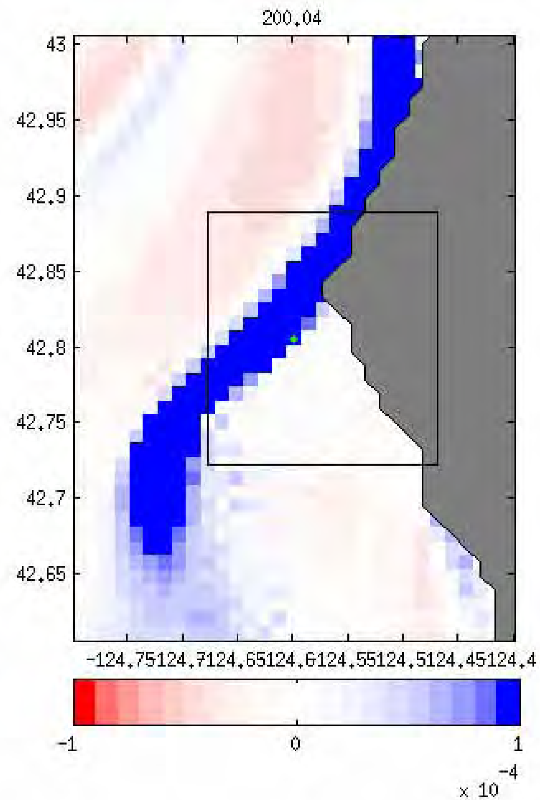
Tidal variability affects separation of the coastal current at Cape Blanco

(movie: vorticity of the surface horizontal currents) $$\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

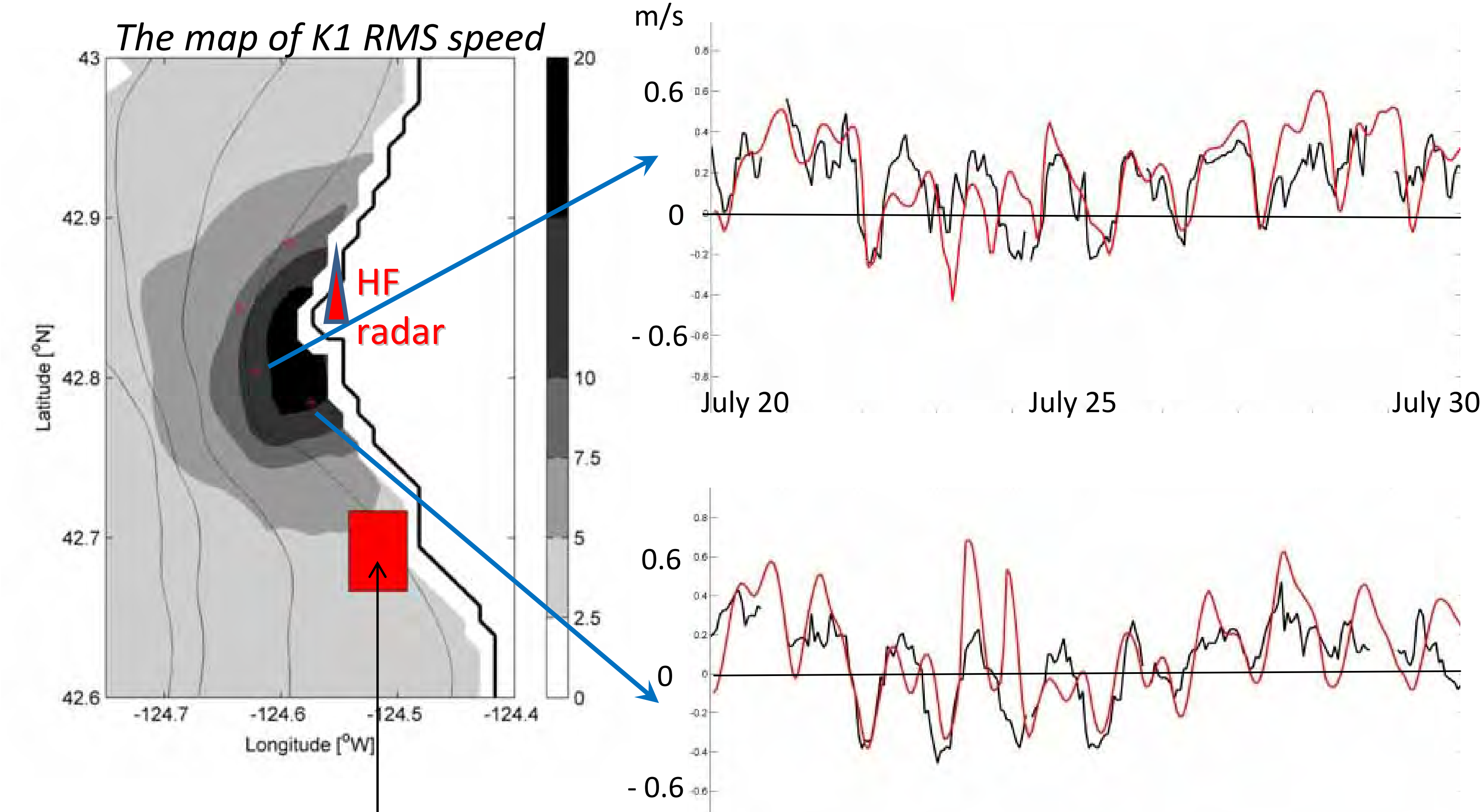
Tide+Wind



Wind only



Both semi-diurnal (M_2+S_2) and diurnal (K_1+O_1) tides contribute to eddy variability near Cape Blanco



Proposed location of the marine reserve area

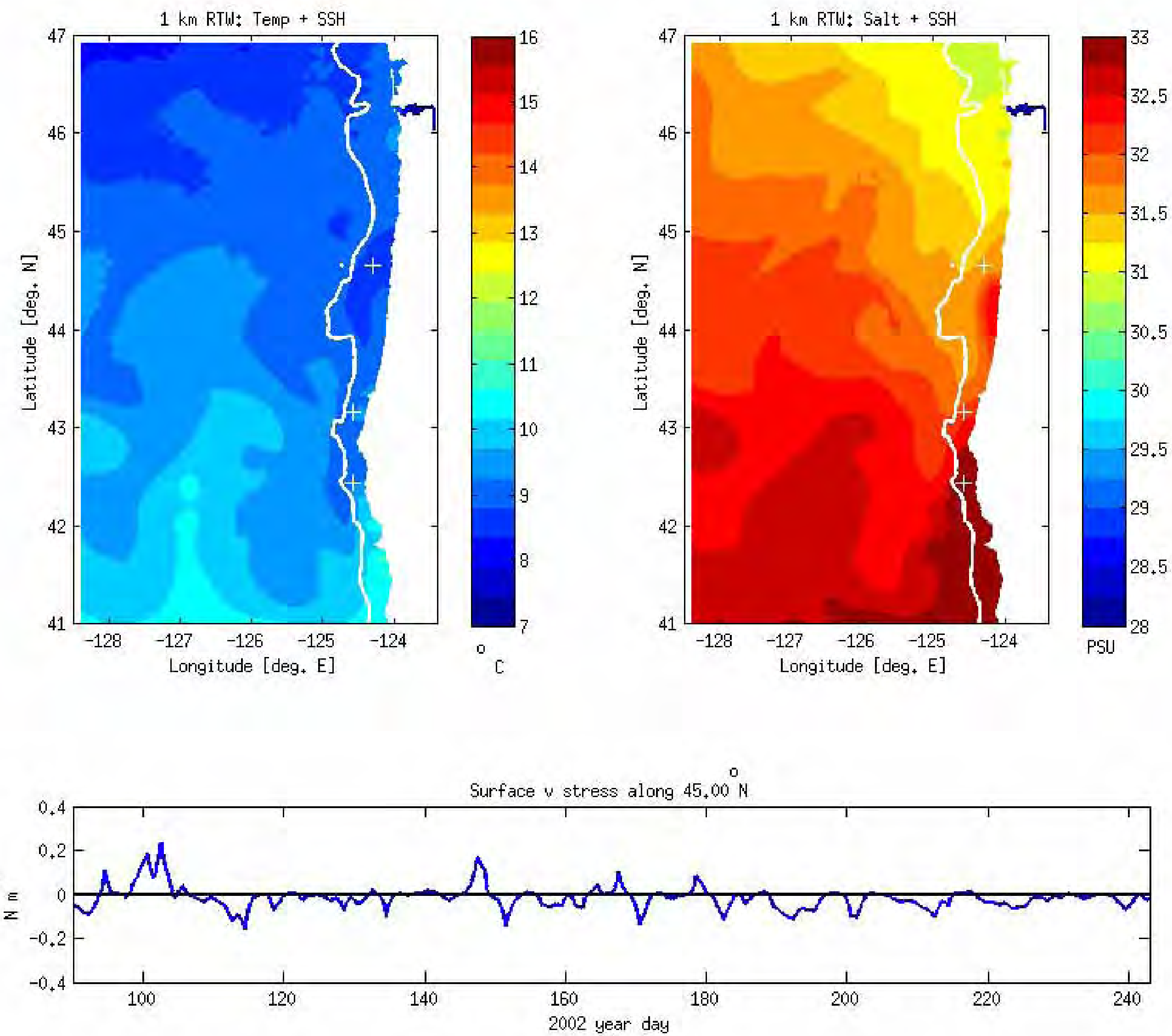
Surface velocity component toward the HF radar: **obs (**P. M. Kosro), **model**

Future directions : Effect of the Columbia R. on tidal and subtidal variability

(left) SST

(right) SSS

(simulation and animation courtesy J. Osrborne)

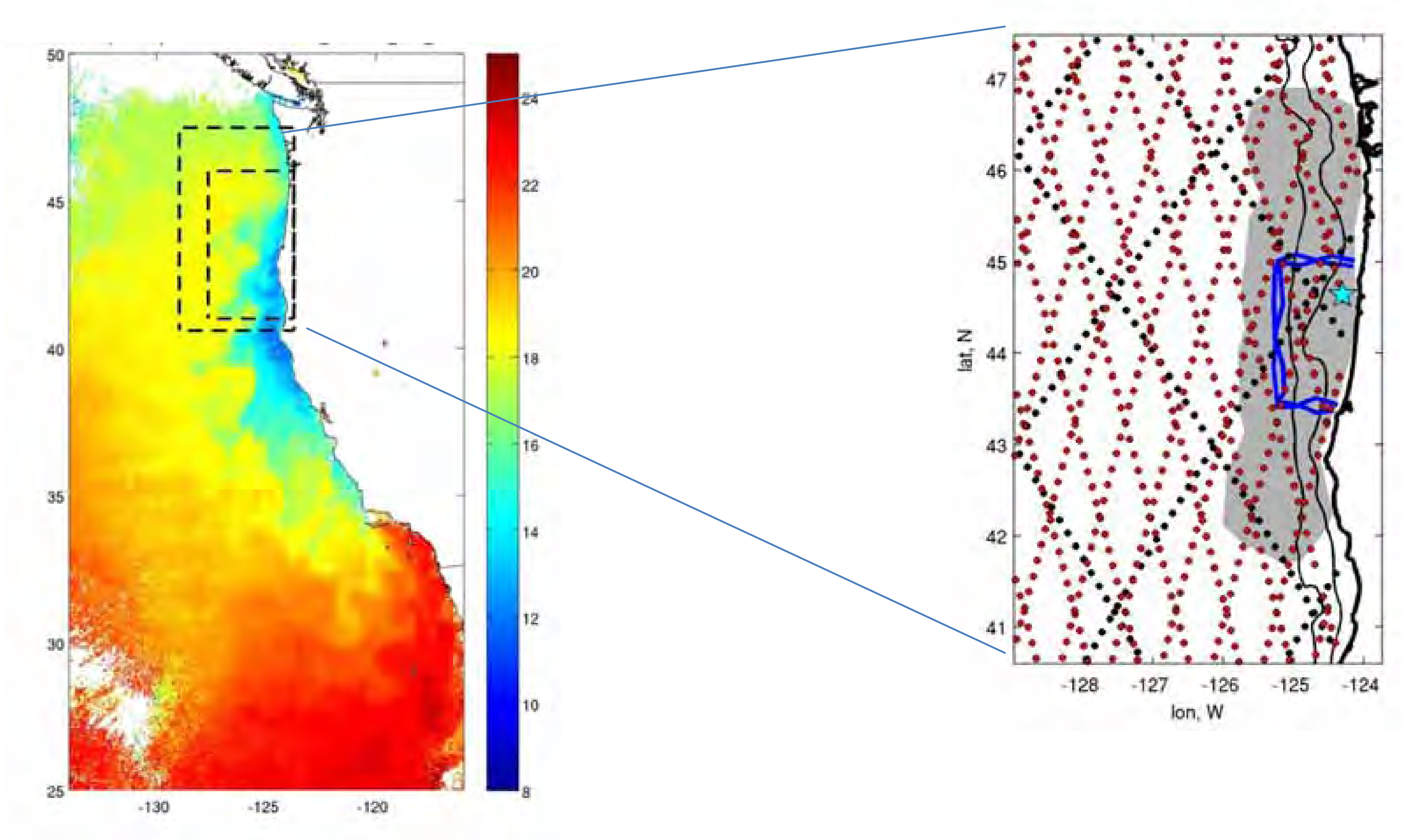


Data assimilation (DA): Model + Data = Improved Ocean State Estimate

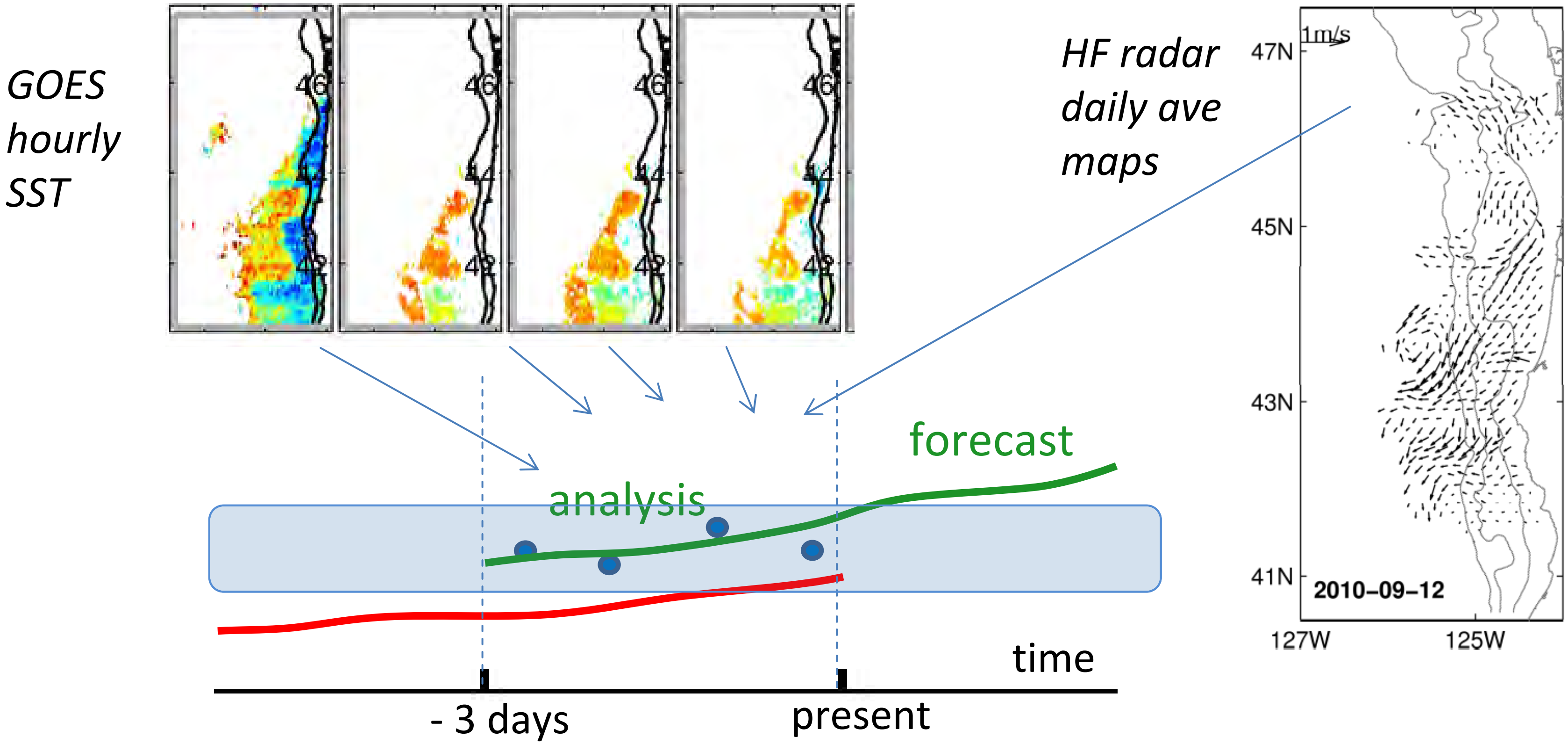
-A nonlinear optimization problem with many degrees of freedom

-Data are used to optimize model inputs (in particular, initial conditions for forecasts)

Data that we have assimilated: satellite SST, **HF radar**, alongtrack altimetry (also avail.: glider sections (Barth, Shearman), moorings)



4DVAR = dynamically based time- and space- interpolation of data



$$J(u) = (u(0) - u_0^B)^T C_0^{-1} (u(0) - u_0^B) + (d - Lu)^T C_d^{-1} (d - Lu) \rightarrow \min$$

- In each 3-day window, find the improved initial conditions (minimize the cost function)
- The nonlinear model, started from the improved initial conditions, yields the solution that is closer to the data (in a least squares sense), provides the forecast into future
- Correction is 3D and multivariate (due to model dynamics and model error covar. C_0)

To implement the 4DVAR algorithm, a tangent linear model and its adjoint counterpart are required

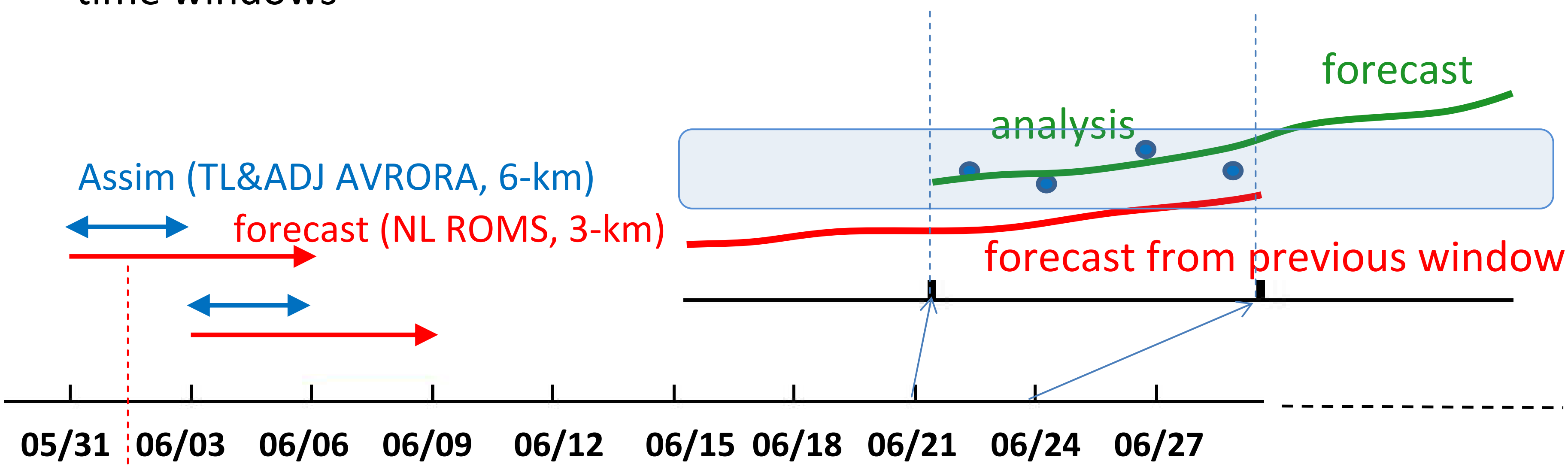
AVRORA (**Advanced Variational Regional Ocean Representer Analyzer**)

- AVRORA is our own set of tangent linear (TL) and adjoint (ADJ) model codes, numerically and algorithmically consistent with ROMS
- Flexibility designing data functionals, model error covariances
- Preconditioning to speed-up convergence of the minimization algorithm

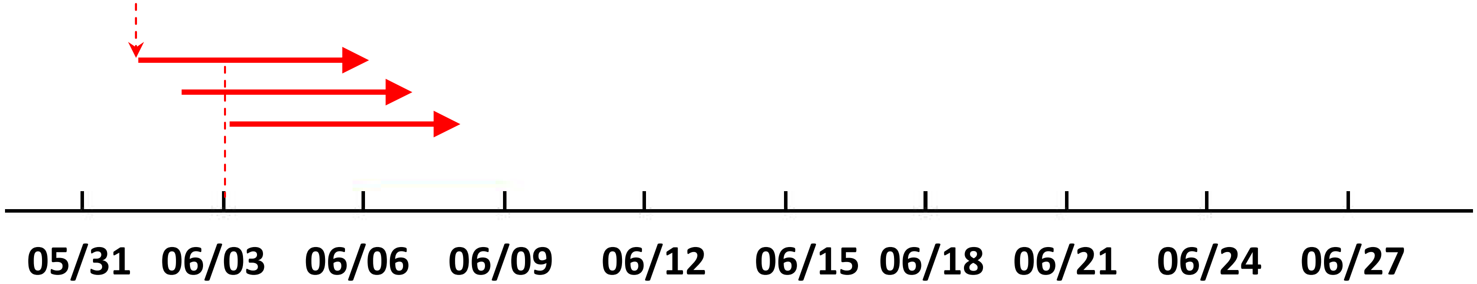
The algorithm is fast enough to do assimilation in near-real time

[Kurapov et al., *Dyn. Atm. Oc.*, 2009; *JGR*, 2011;
Yu et al., *Oc. Mod.*, 2011 - submitted]

Real-time coastal ocean forecast model: variational DA in a series of sliding time windows



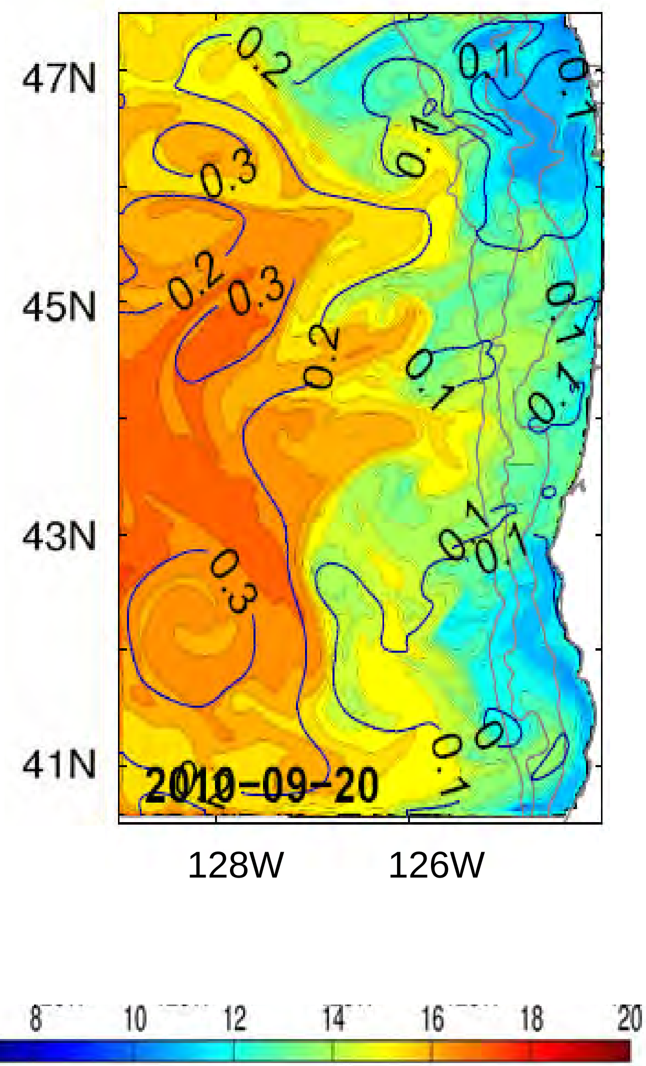
Forecast component (everyday update of 3-day forecasts)



Model details:

(shown: forecast SST & SSH, Sept. 20, 2010)

Regional Ocean Modeling System (ROMS)
3-km horizontal resolution,
30 vertical layers
(assimilate at 6-km resolution, correction then interpolated to the 3-km grid)



Atmospheric fluxes: NOAA –NAM forecasts

Boundary conditions: NCOM-CCS climatology

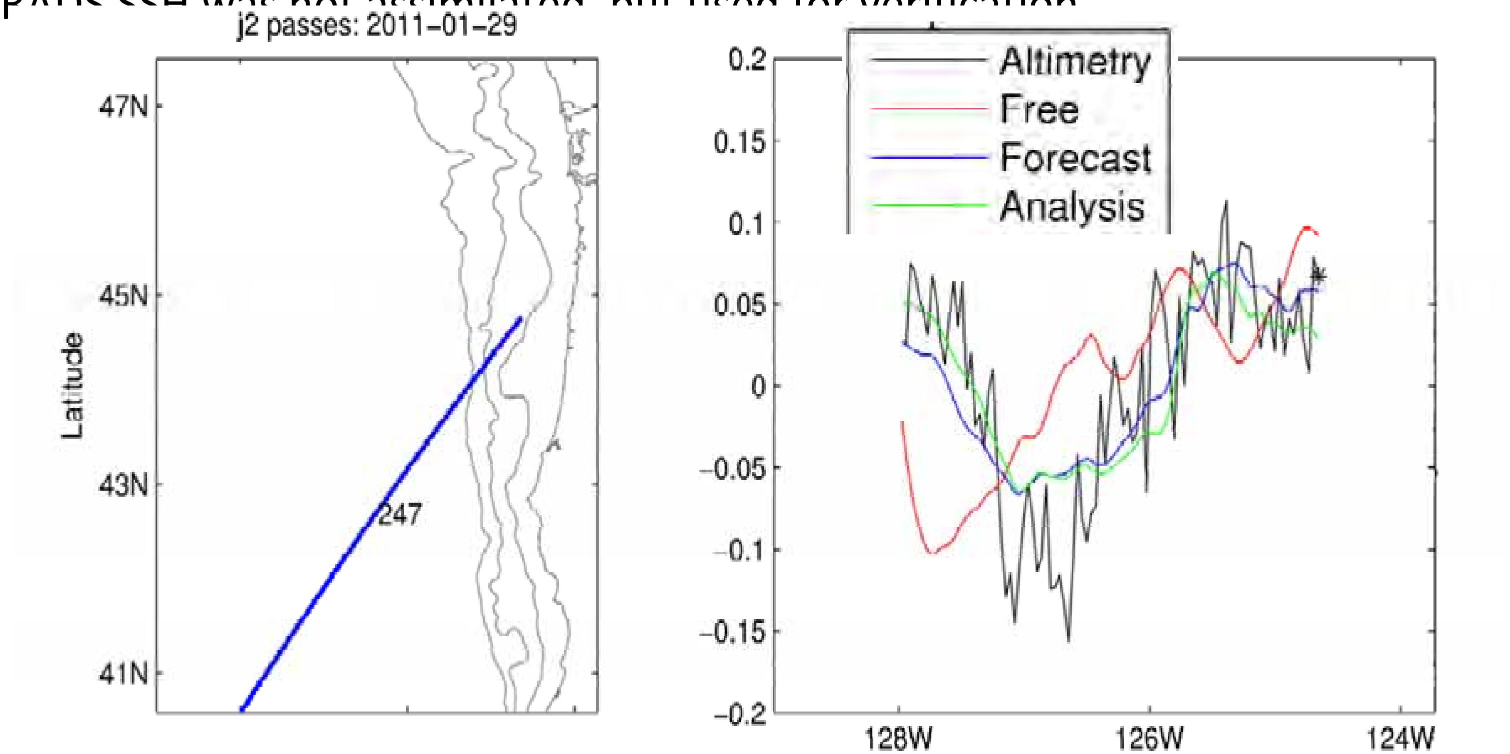
- Since 8/2010:
assimilation of HF radar surface currents
+ hourly GOES SST

- Since July 2011:
assimilation of HFR currents
+GOES SS
+RADS alongtrack SSH

Effect of DA on the coastal ocean surface topography

Initially, our real-time system assimilated only GOES SST and HFR surface currents

RADS SSH was not assimilated, but used for verification

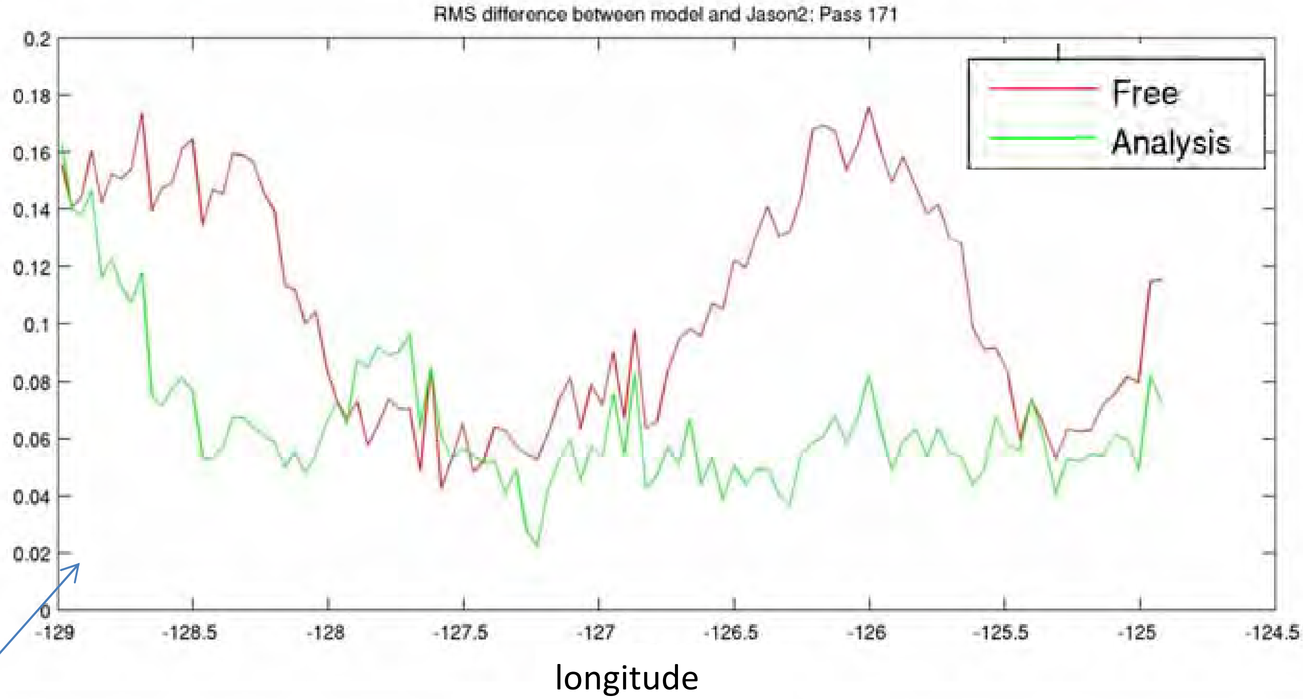


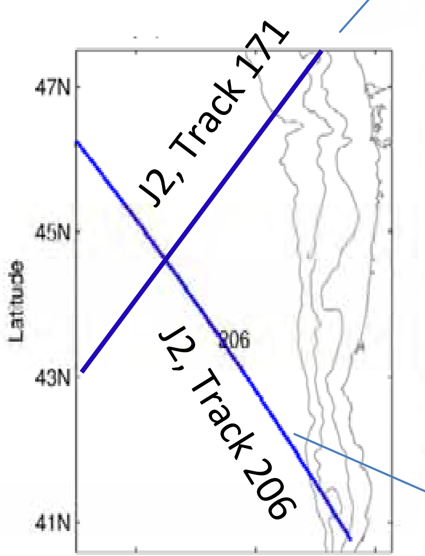
Combined assimilation of SST and HF radar surface currents helps improve the slope of SSH

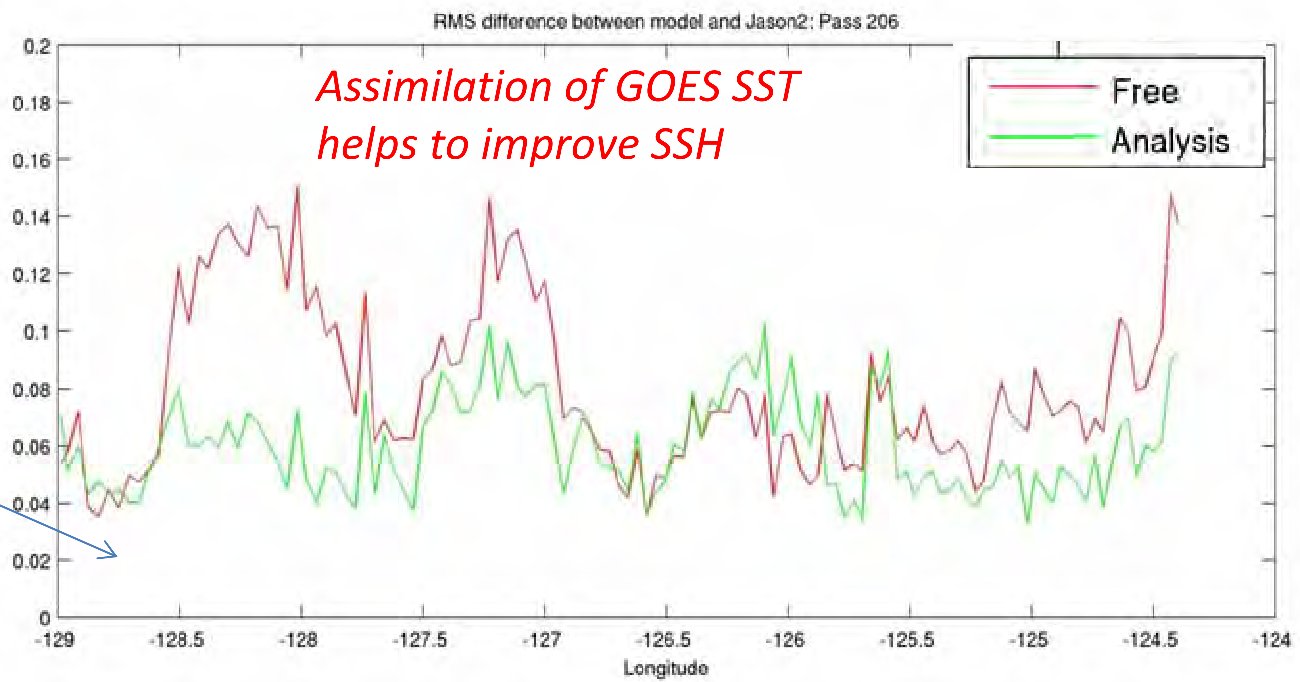
Improved statistics: Time-averaged model-data RMS difference for alongtrack SSH (m)

(alongtrack means taken out)

Aug 2010 – Jan 2011







Assimilation of GOES SST helps to improve SSH

Improved statistics:

Time-averaged model-data RMS difference for alongtrack SSH (m)

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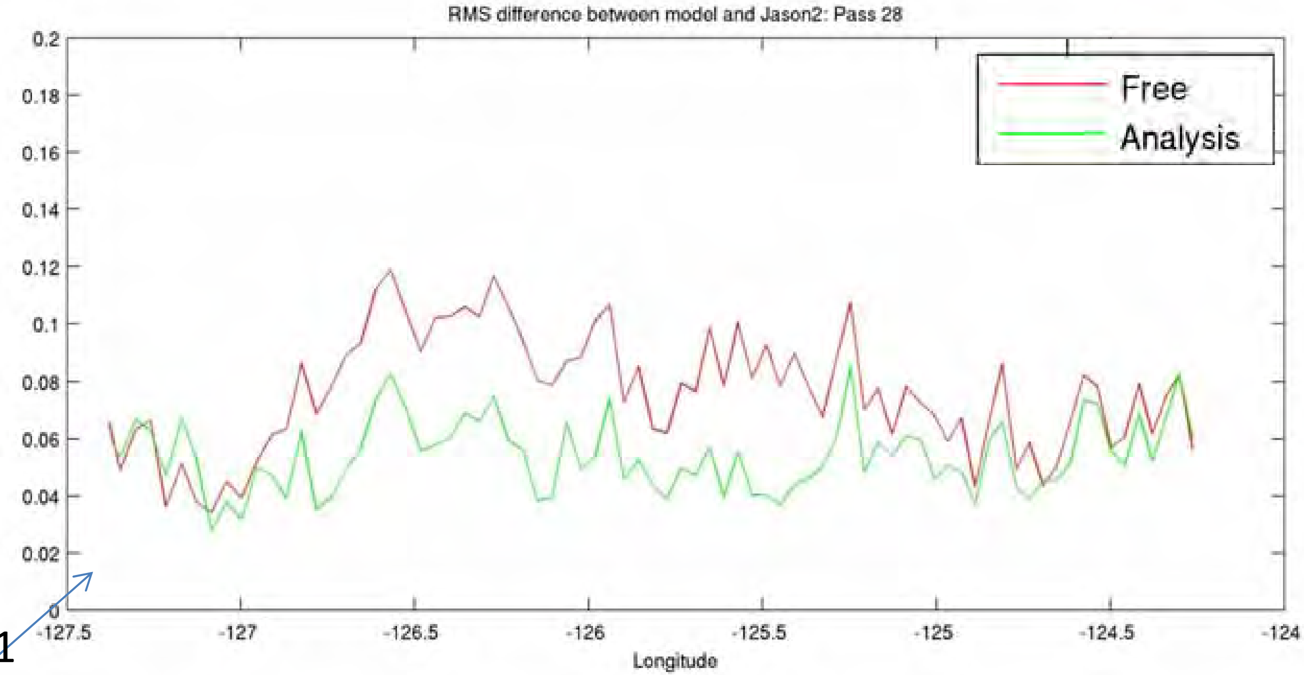
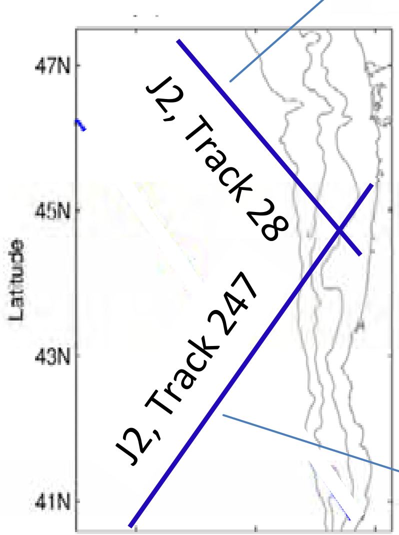
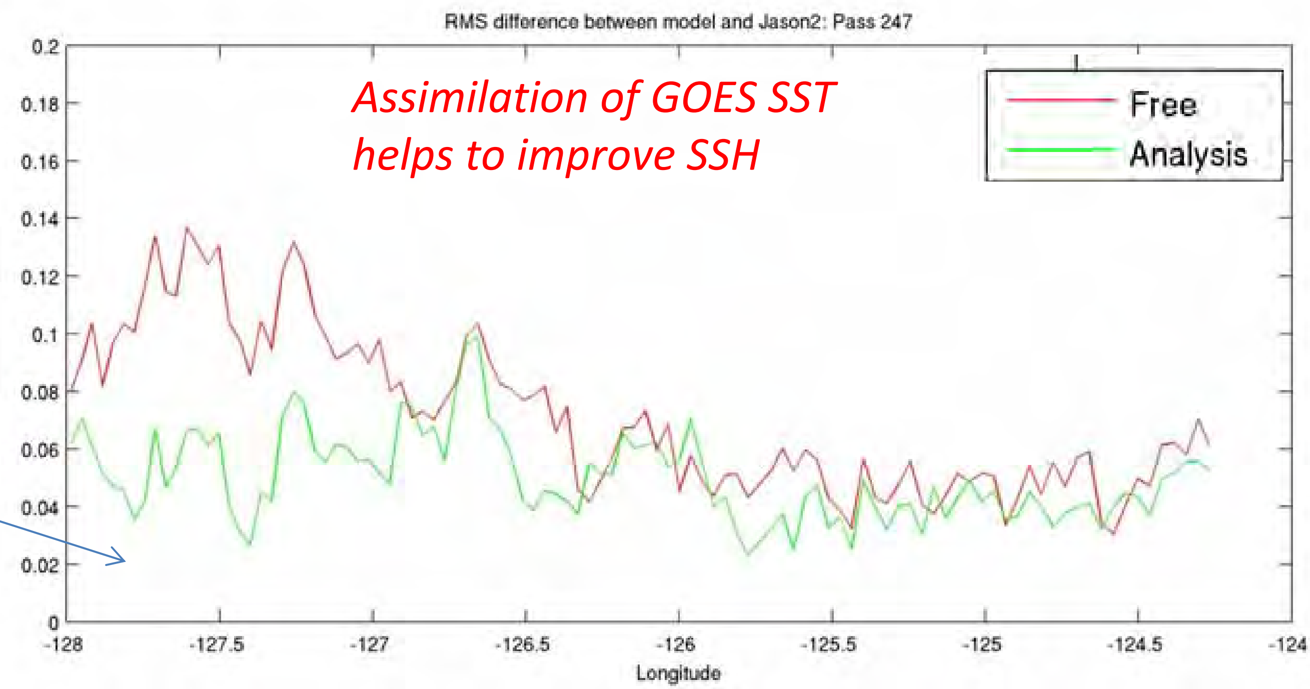




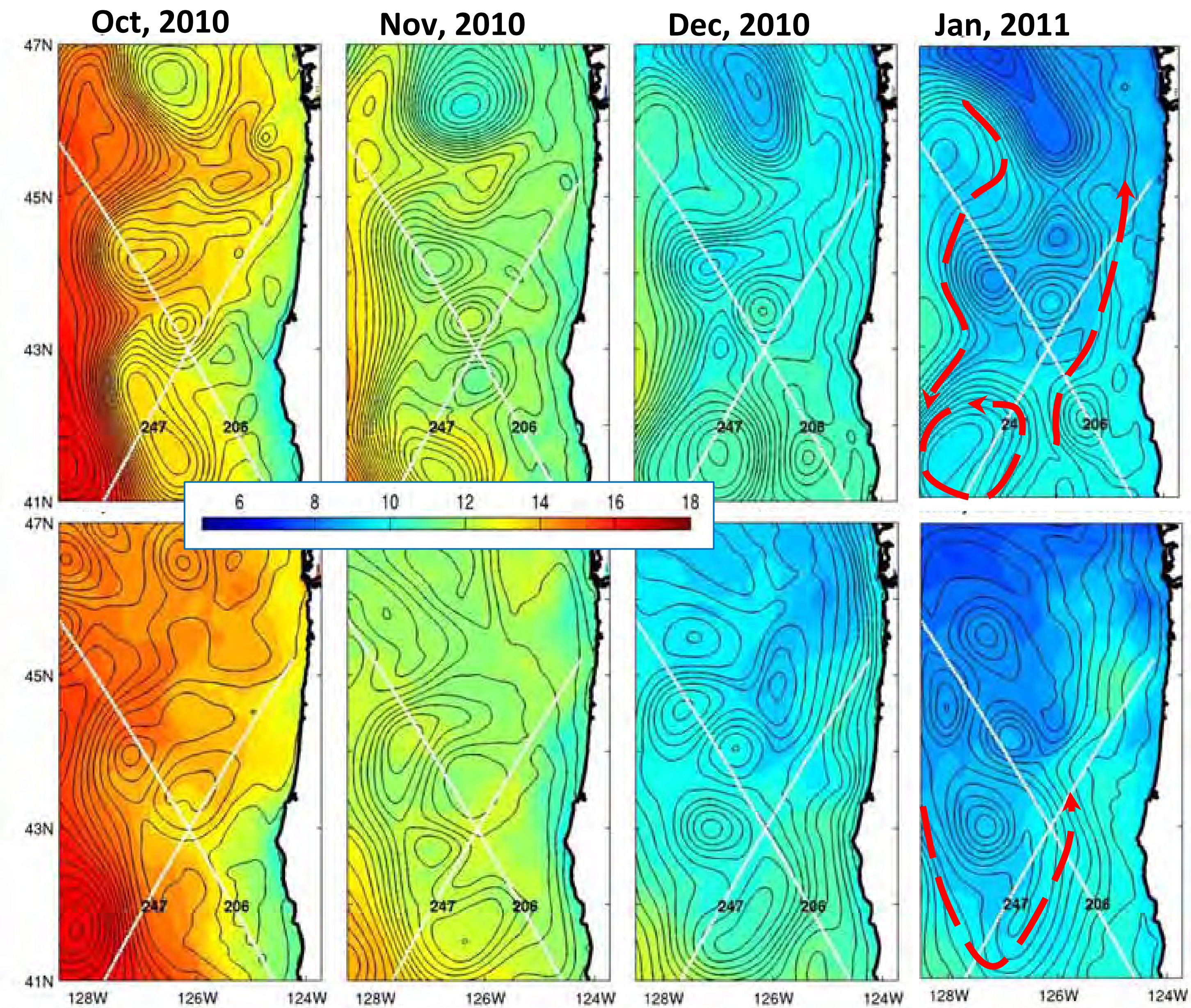


DA constrains connectivity of interior and coastal ocean in winter

Monthly Mean SST (color) and SSH (contours):

No assimilation

Assimilation: HF radar surface (u,v) and hourly GOES SST



Area-averaged RMS model-data differences (SSH, SST, HFR surface currents)

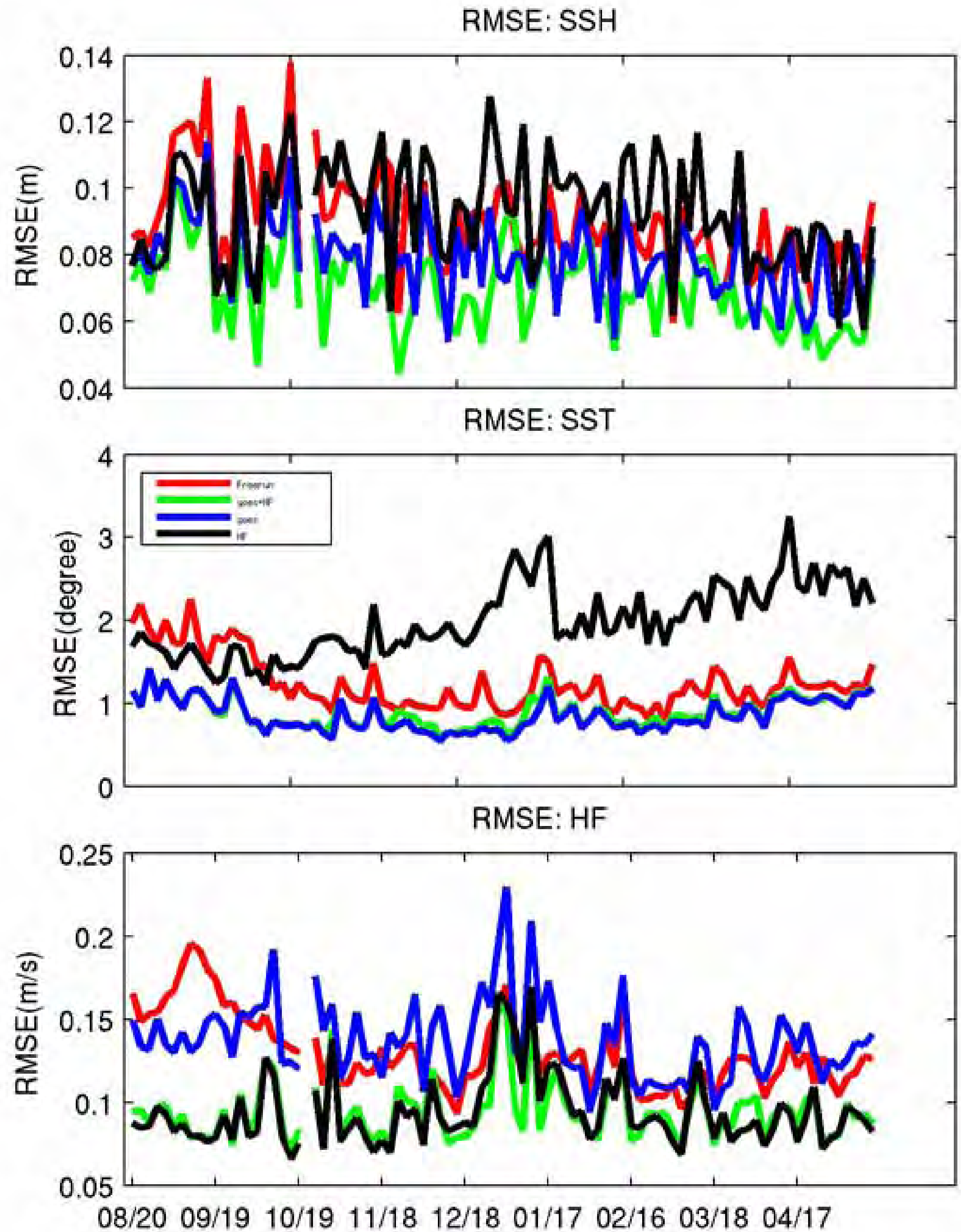
Cases: **no DA, DA SST+HF, DA SST, DA HF**

Notes:

-**Assimilation of surface currents alone:** no positive effect on SSH RMSE, inaccurate SST in winter

-**Assimilation of GOES SST alone:** some improvement of SSH RMS, compared to the no DA case (velocities not so good)

-**Combined assimilation of SST and HFR:** the strongest impact on SSH



Impact of assimilation of RADS SSH in addition to SST and HFR currents

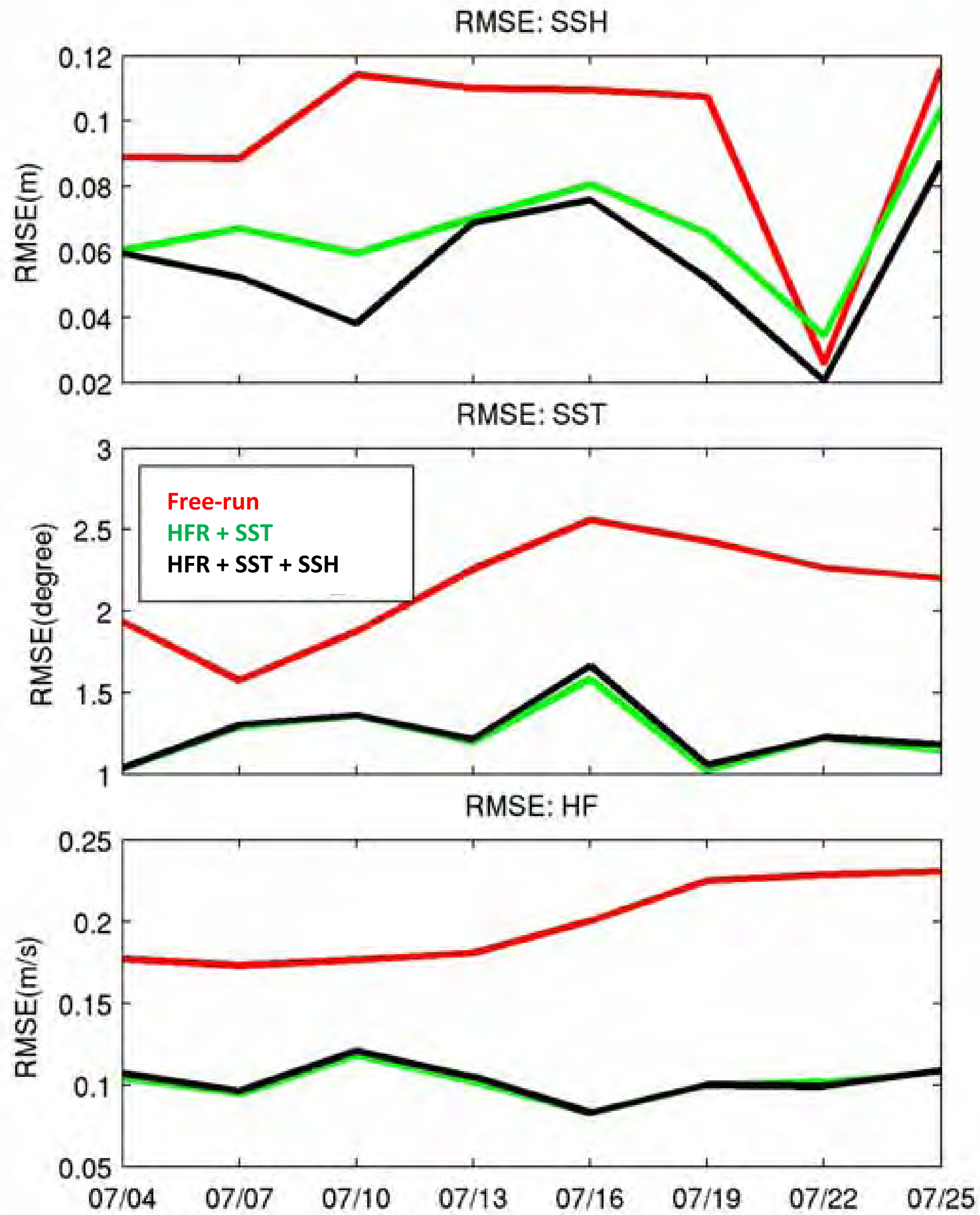
Shown are area-averaged, 3-day time-averaged model-data RMS differences (“data fit”):

Free-run ROMS
DA: HFR + GOES SST
DA: HFR + GOES SST + RADS SSH

Notes:

1) SSH assimilation additionally improves the fit to SSH

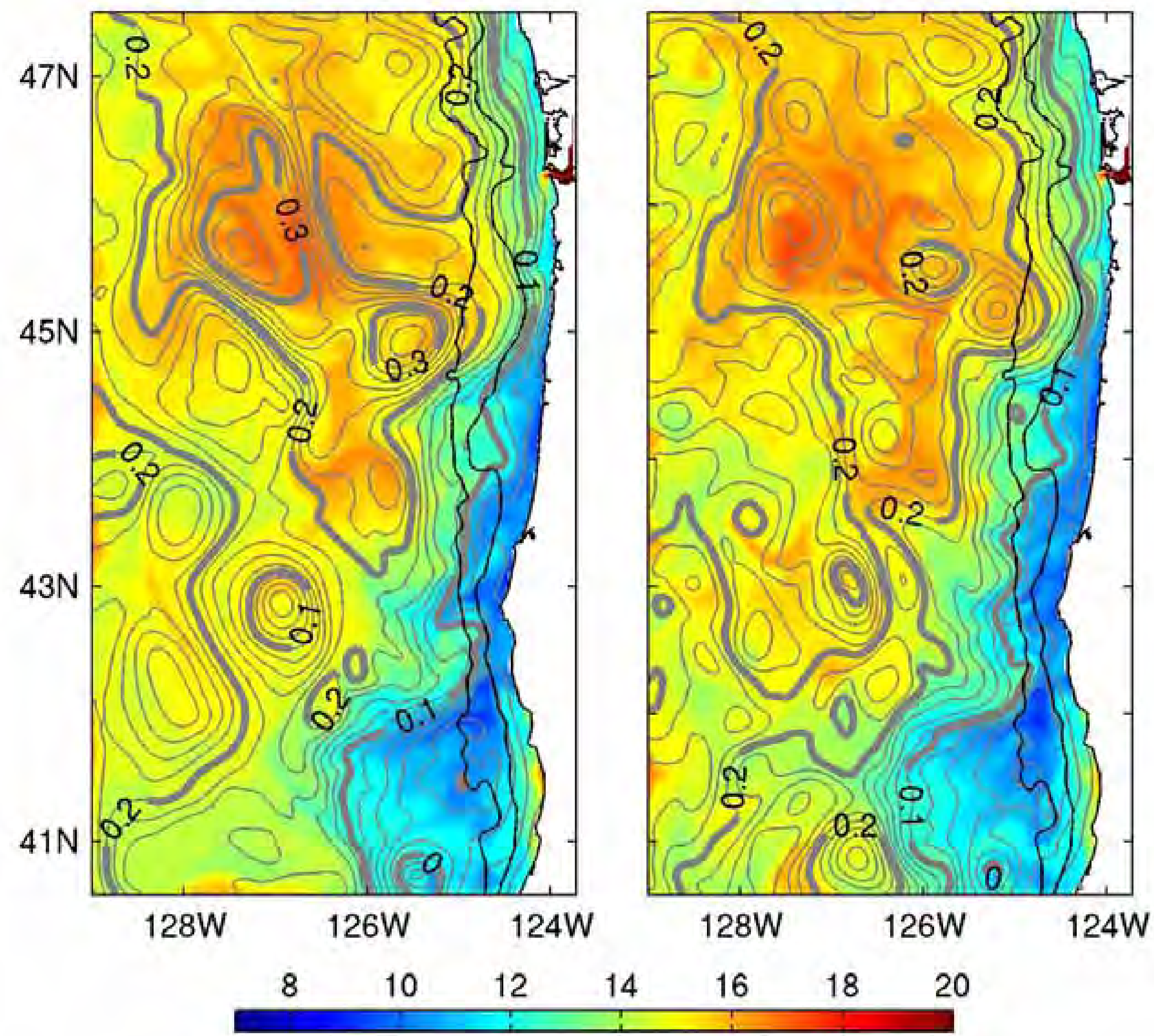
3) SSH assim.: no impact on surface velocity or SST RMSE (which are already constrained by assimilation)



Adding RADS alongtrack SSH to the set of assimilated data impacts details of the near-surface geostrophic transport

Shown: SST (color) and SSH (contours), 1 August, 2011

(left) DA SST+HFR
(right) DA SSH+SST+HFR



Future directions (ongoing):

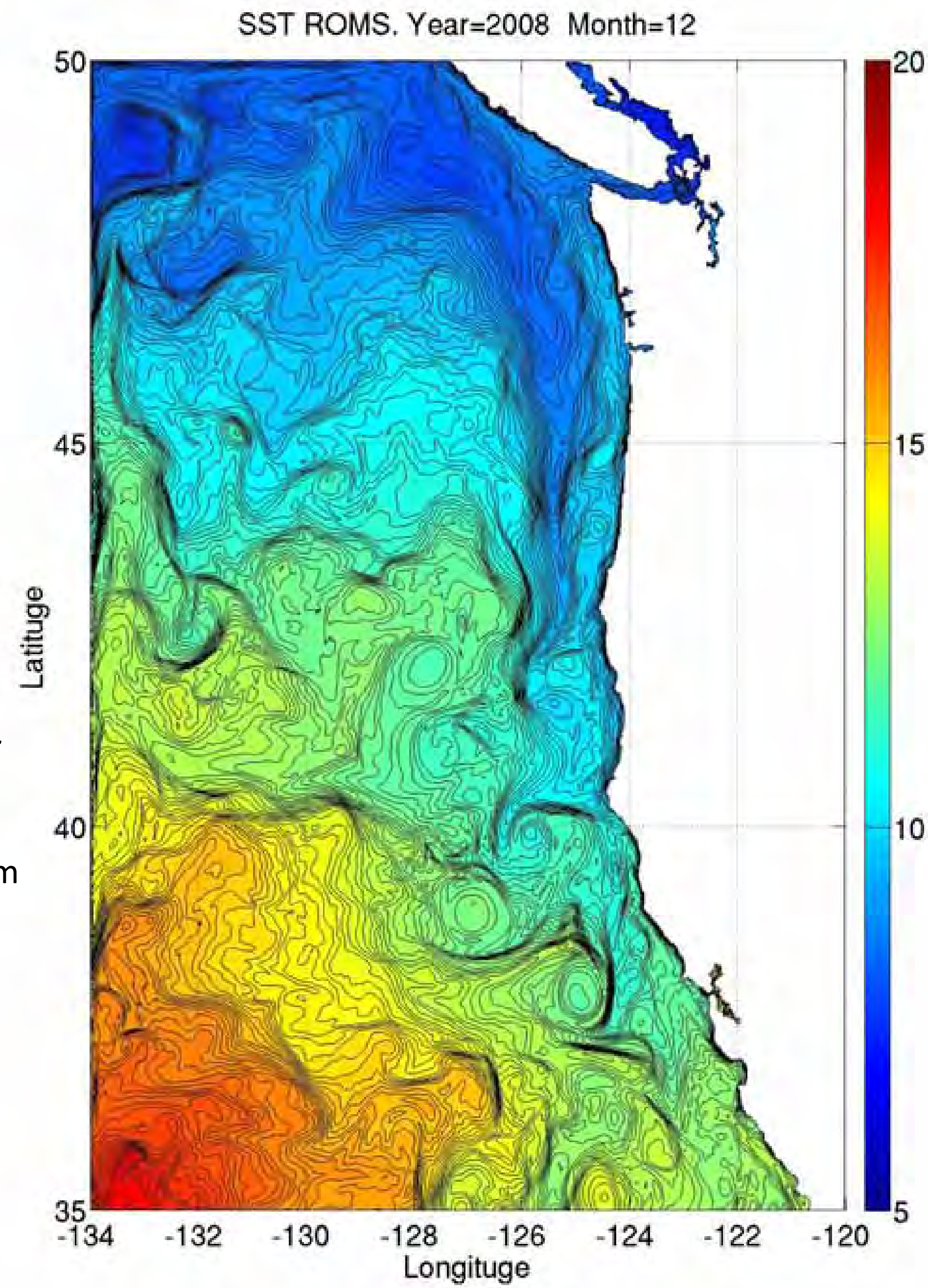
High-resolution modeling and assimilation in a larger domain

Multi-year simulations

Studies of larger scale (climate) variability on coastal ocean dynamics

Shown (right): Monthly averaged SST (December 2008) from a 2-km ROMS model. Boundary conditions are provided from global 1/12th degree resolution HYCOM. Atmospheric forcing: 12 km resolution NOAA NAM

[Preliminary results and graphics: P. Fayman (OSU)]



Summary:

-The 1-km model based on ROMS yields an accurate solution, facilitating studies of wind-, tidally-, and river-plume-driven coastal ocean circulation off Oregon

-Semi-diurnal internal tides are sensitive to background conditions

-Near capes, diurnal tides are amplified and contribute to eddy variability

-Combined assimilation of hourly GOES SST and HF radar surface currents provides improvement of the model SSH in the coastal area off Oregon (both summer upwelling and winter downwelling seasons)

-Assimilation of SST alone or HFR currents alone does not have a comparable, positive impact on SSH

-Variational data assimilation provides is a dynamically based time- and space interpolation of data. Assimilation can positively affect fields that are not directly observed