

# Satellite Oceanographic Data Assimilation in the US West Coast Operational Forecast System (WCOFS)

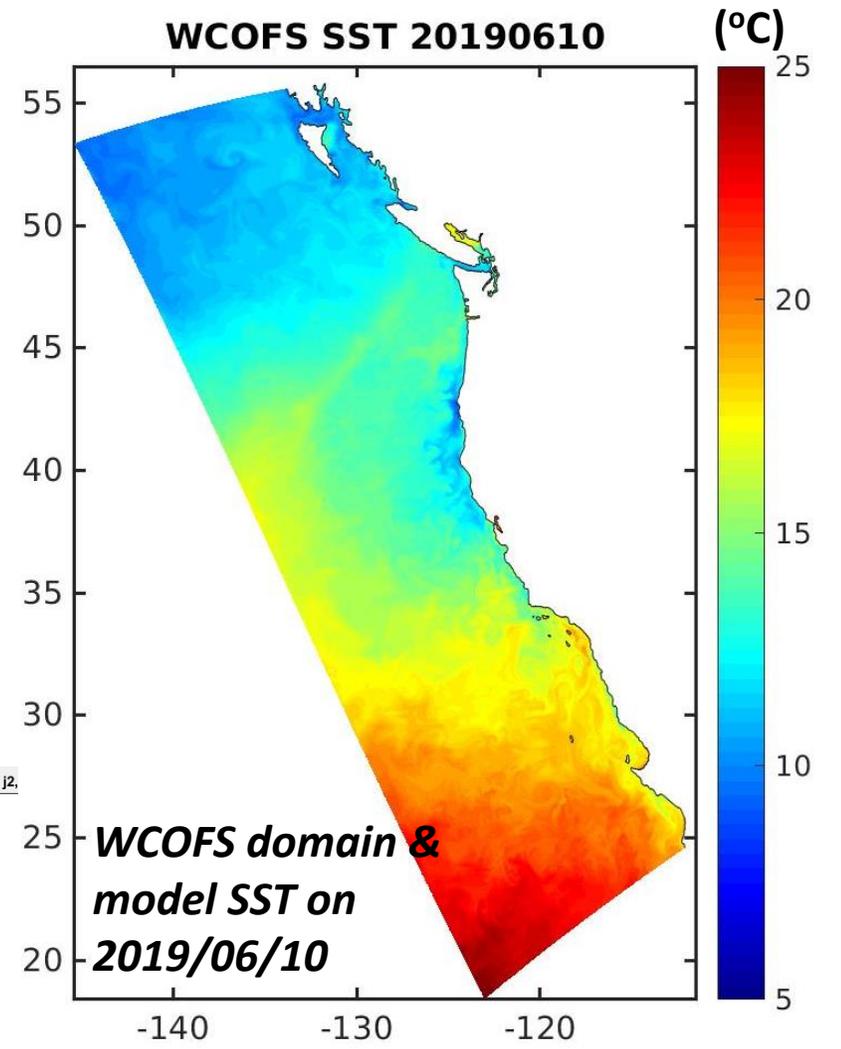
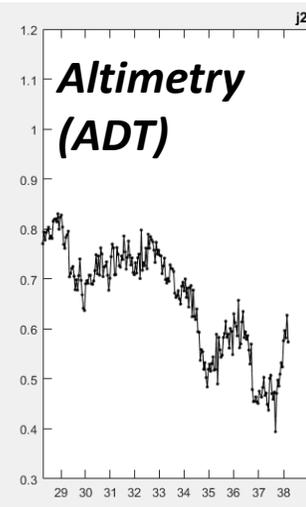
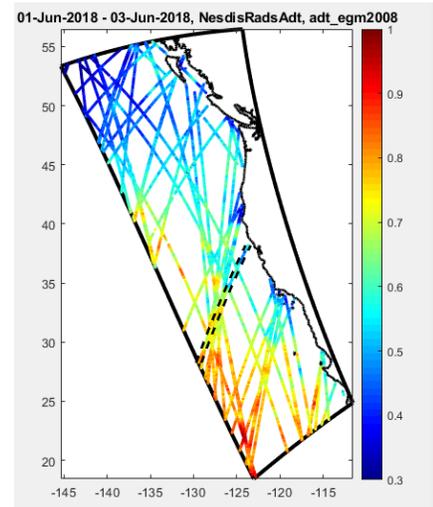
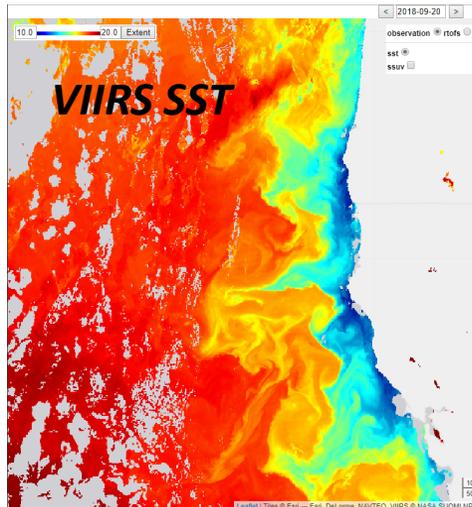
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## Motivation for operational prediction of coastal currents, temperature, salinity, and sea level:

- Precision navigation (incl. optimal ship routes)
- Navigation safety
- Search and rescue
- Environmental hazard response (oil spills, marine debris tracking, etc.)
- Fisheries (trip planning, fuel savings, safety)
- Beach erosion monitoring
- Public health (harmful algae blooms, pathogens)
- Coastal weather prediction



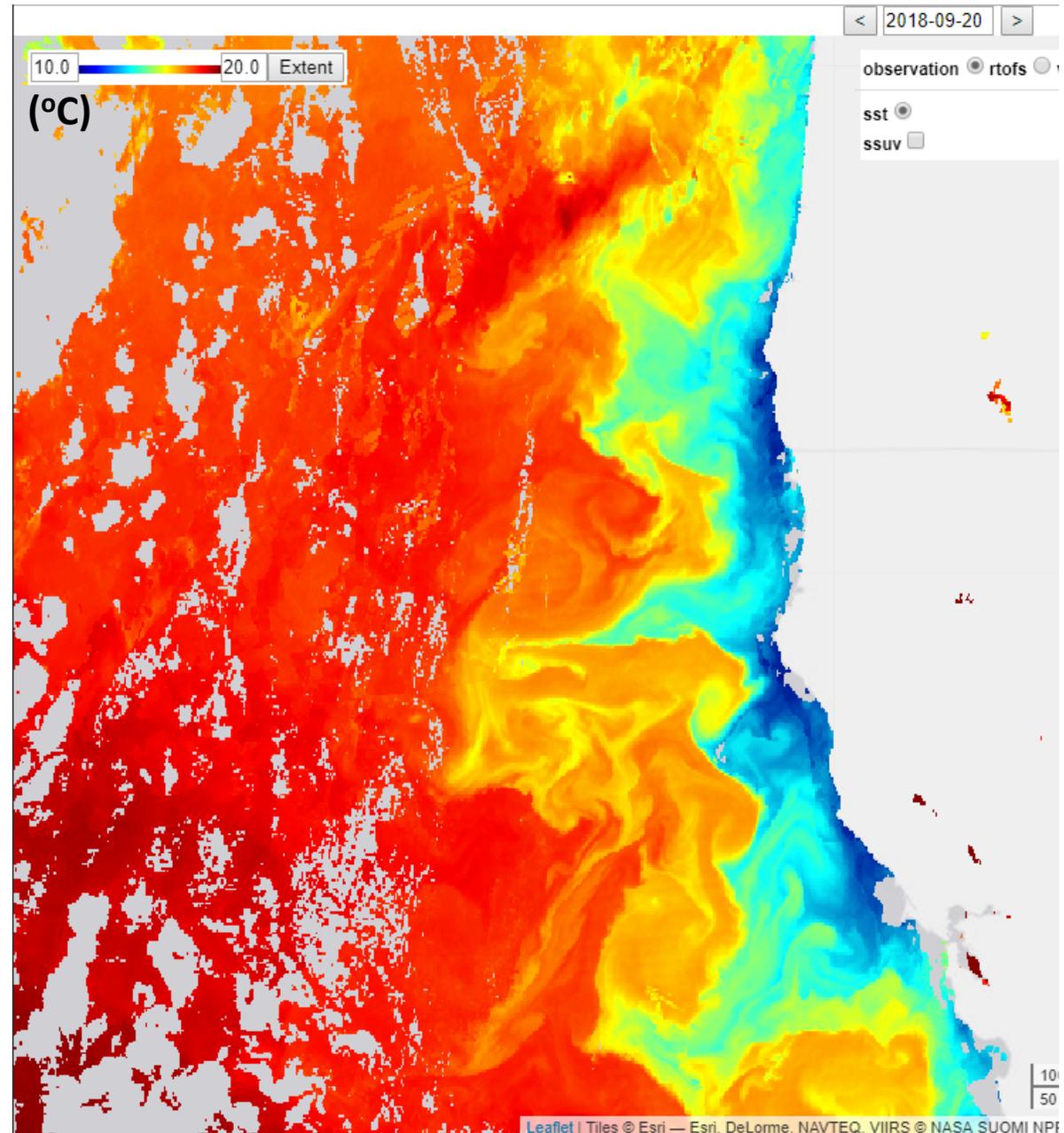
Credit : Eric Mortenson, Doug Beghtel /The Oregonian, [www.naturalbuy.com](http://www.naturalbuy.com), USCG, <http://i.livescience.com/>, Grantham et al. (2002)

## In particular, fishermen want to know SST front locations (more fish there):

### *Problems:*

- Clouds
- SST imagery is not available for tomorrow

We combine an ocean circulation model, forecasts of the atmospheric fields (winds, heat fluxes) and available recent data to forecast ocean currents and temperature fronts for 1-3 days ahead



## The ocean circulation model: Regional Ocean Modeling System (ROMS)

- 3-D
- Terrain following coordinates in the vertical (to resolve the surface and bottom boundary layers on the shelf)
- Fully nonlinear (hydrostatic, Boussinesq approximations)
- Free-surface (predicts both tidal and non-tidal variations)
- Prognostic variables: sea level, horizontal velocity, temperature, salinity

### **Horizontal resolution:**

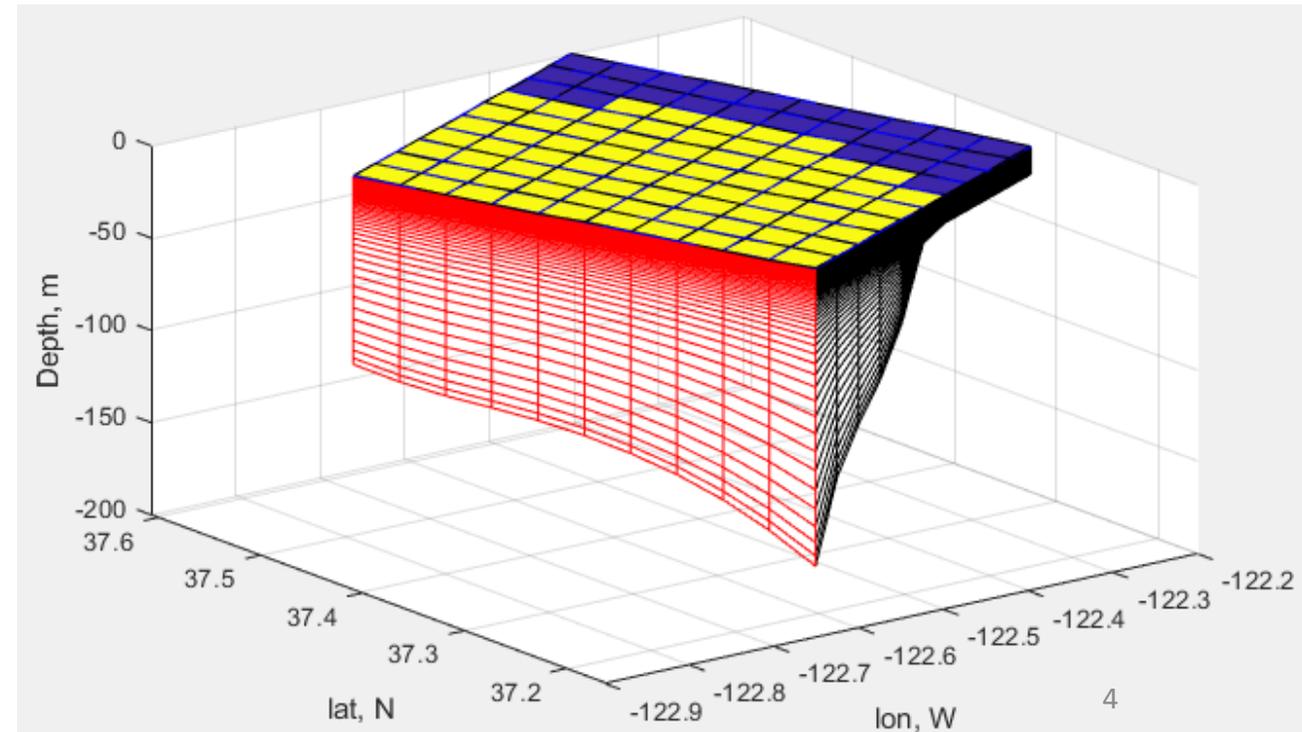
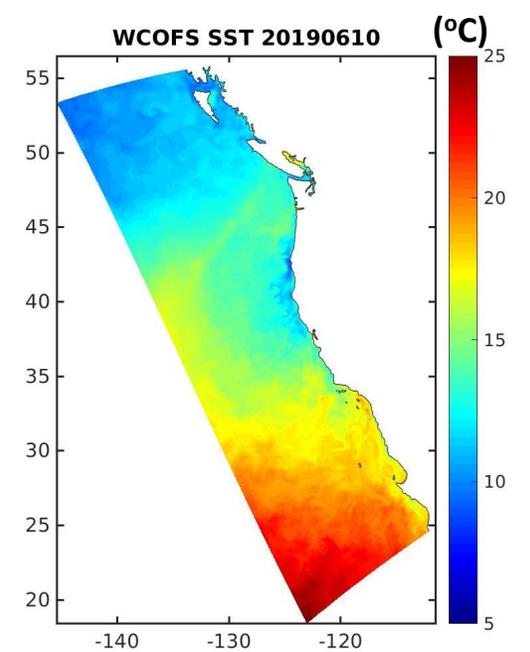
- Data Assimilative (DA) model: 4-km
- Non-DA runs (used for model skill assessment): 2-km

### **Vertical resolution:** 40 layers

### **Forcing:**

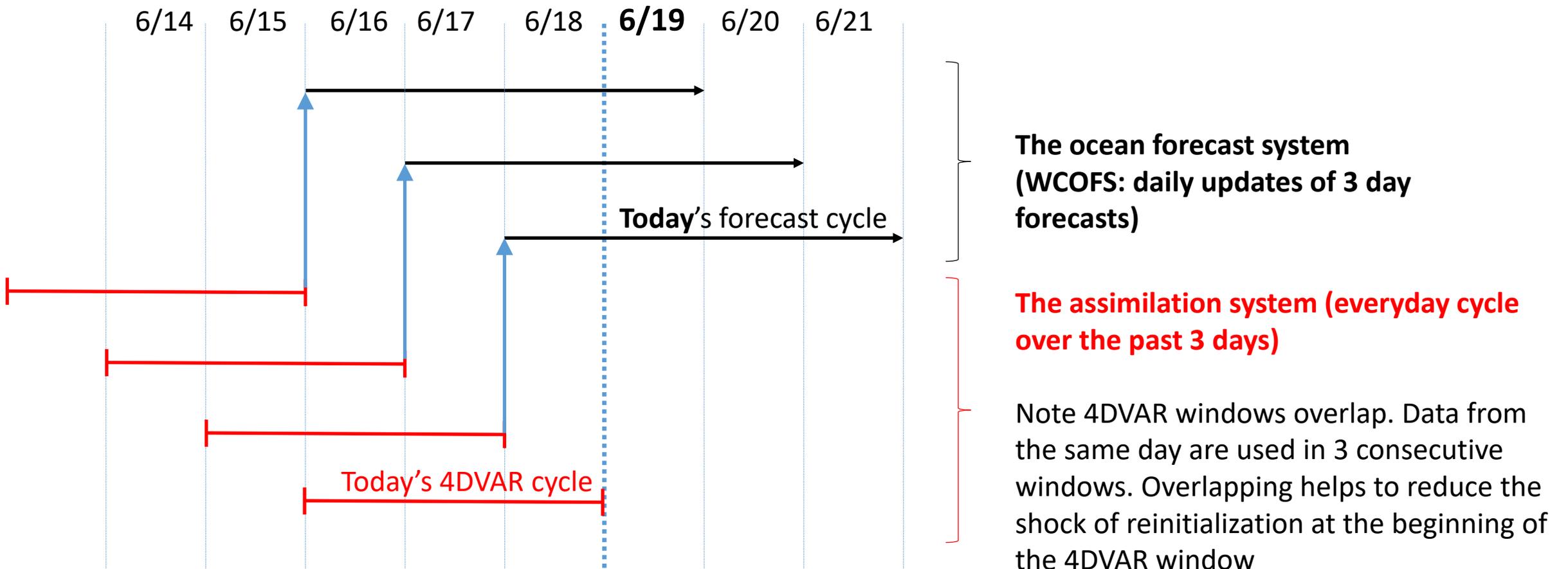
- Atmospheric fields from NOAA 12km-NAM (wind velocity, net shortwave radiation, downward longwave radiation,  $P_{air}$ ,  $T_{air}$ , relative humidity, rain)
- River discharge from USGS or climatology
- Non-tidal boundary conditions: global RTOFS
- Tides: TPXO\* (Egbert and Erofeeva, 2002)

\*Note: TPXO assimilates tidal data from altimetry

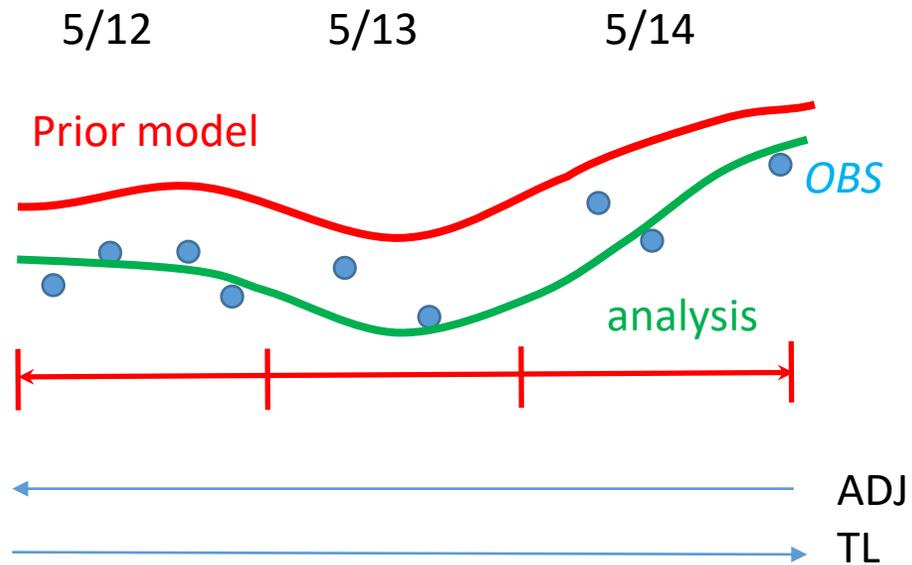


**Data assimilation:** Combine the model and available observations to obtain improved initial conditions for forecasts

Every day, the ROMS **4DVAR** is run to improve the ocean state estimate at the beginning of the 3-day window. Then the 3-day nonlinear analysis is run over the same period. **Initial conditions for the forecasts are sampled from the DA analysis**



## The 4DVAR cycle:



(VIIRS L3U: we assimilate data from individual granules, at their respective times)

(Altimetry: we assimilate alongtrack data at their respective times)

- Over a given time interval (in our case, 3 days) use available observations to correct initial conditions for the analysis
- Minimize the misfit between the model analysis and observations
- 4DVAR requires repeated forward-backward application of the tangent linear model and its adjoint counterpart
- We are using the 4DVAR system embedded in ROMS
- 4DVAR: provides dynamically consistent time- and space-interpolation of sparse data sets
- DA: synthesis of data from different observational platforms

## Observations:

- Satellite SST
- Satellite altimetry
- Surface currents from a network of land-based high frequency (HF) radars

Observation type	Real-time WCOFS	Hindcast tests	Future studies:
SST	NPP VIIRS L3U*	NPP VIIRS L3U	N20 VIIRS, AMSR2 (microwave), GOES-17 ABI, L3 collated IR products***
Altimetry	-----	RADS ADT** (Jason2, Jason3, Cryosat2, Centinel 3, SARAL/Altika)	SWOT (when avail. in near-real time)
HFR	Hourly, mapped	Hourly, mapped	Radial velocity components
In-situ	-----	-----	Argo, glider T&S, buoy

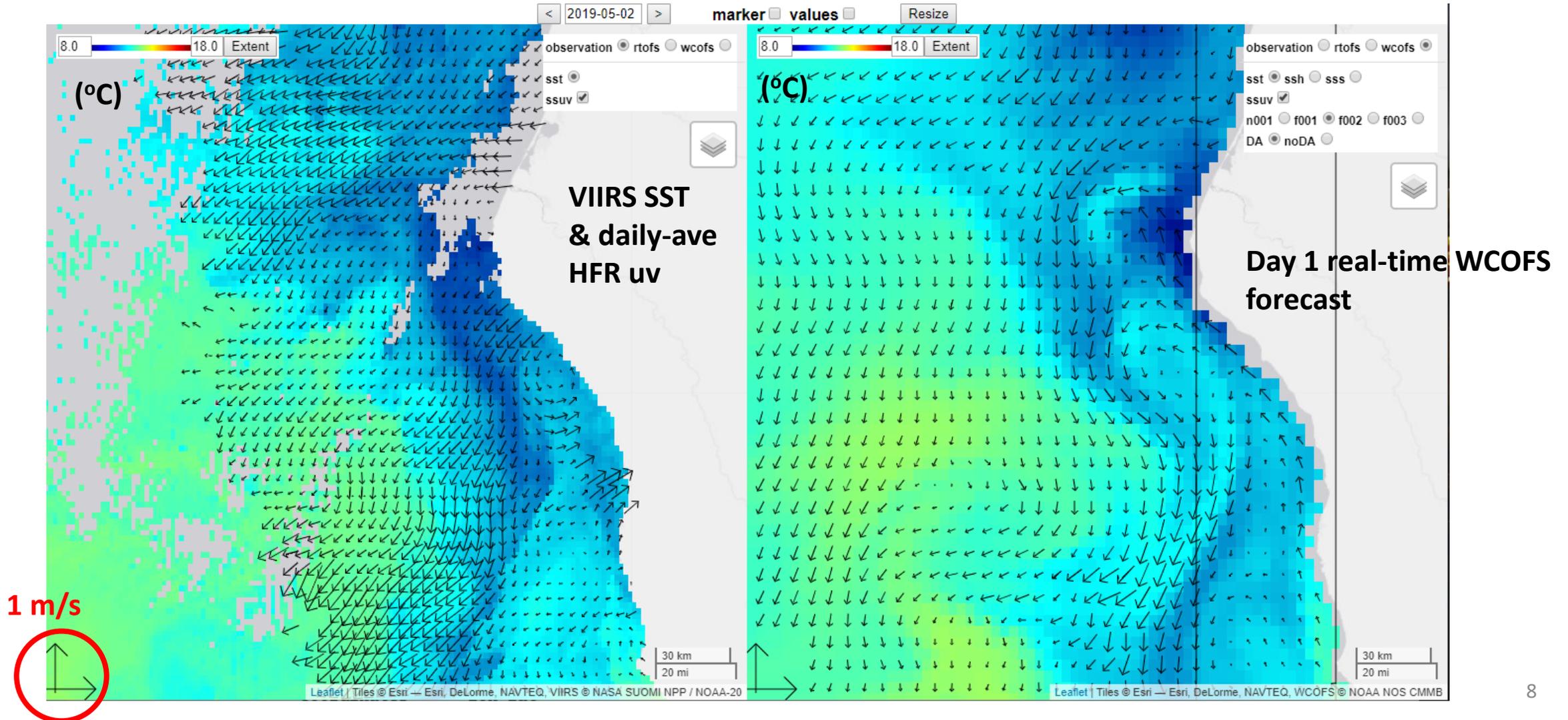
\*A. Ignatov et al., NESDIS

\*\*Homogenized 5-satellite Absolute Dynamic Topography set (RADS), provided by E. Leuliette et al (NESDIS)

\*\*\*The L3S product (Gladkova and Ignatov)

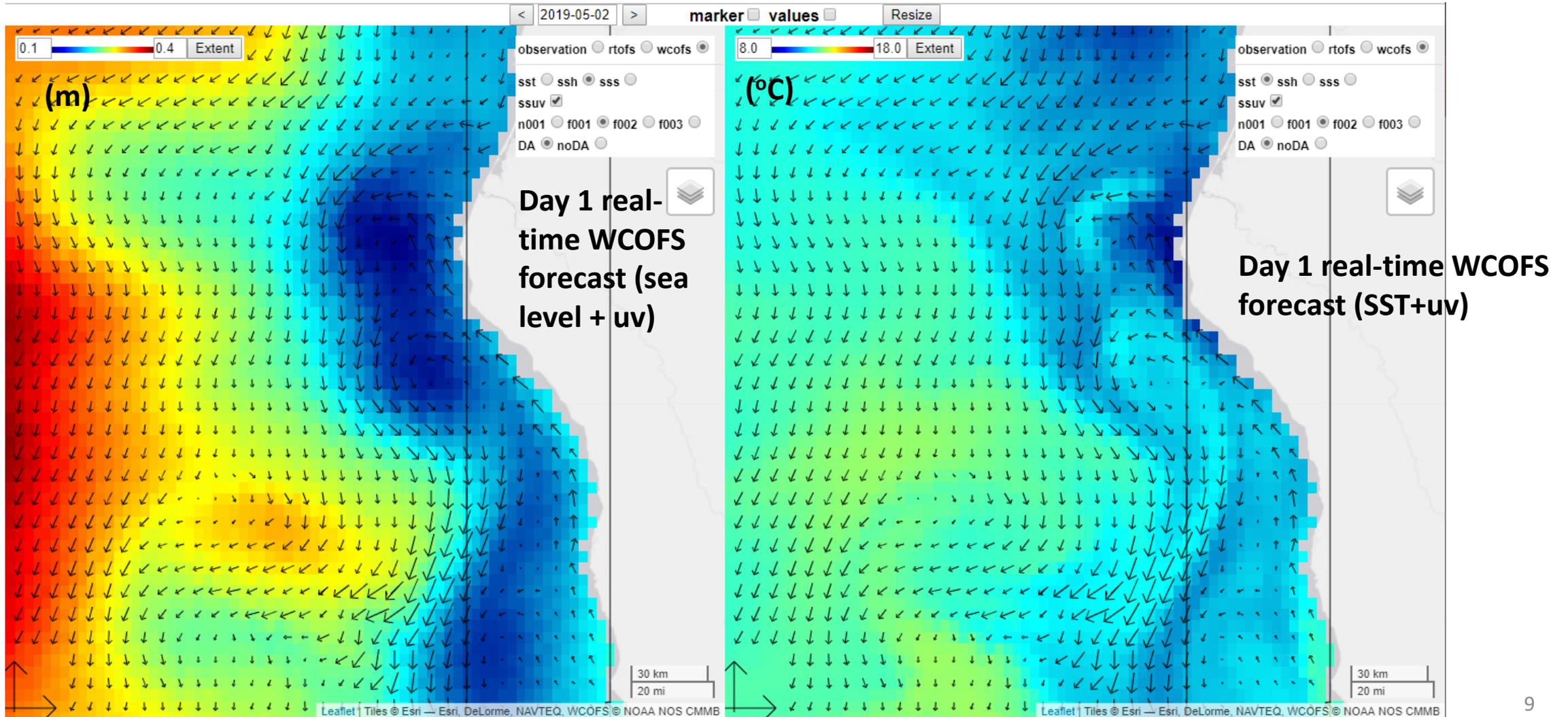
## SST assimilation: potential impact on currents

- Temperature is a dynamically active tracer
- Cold filaments
- Increased currents along the temperature fronts (as a result of 3D baroclinic dynamics)

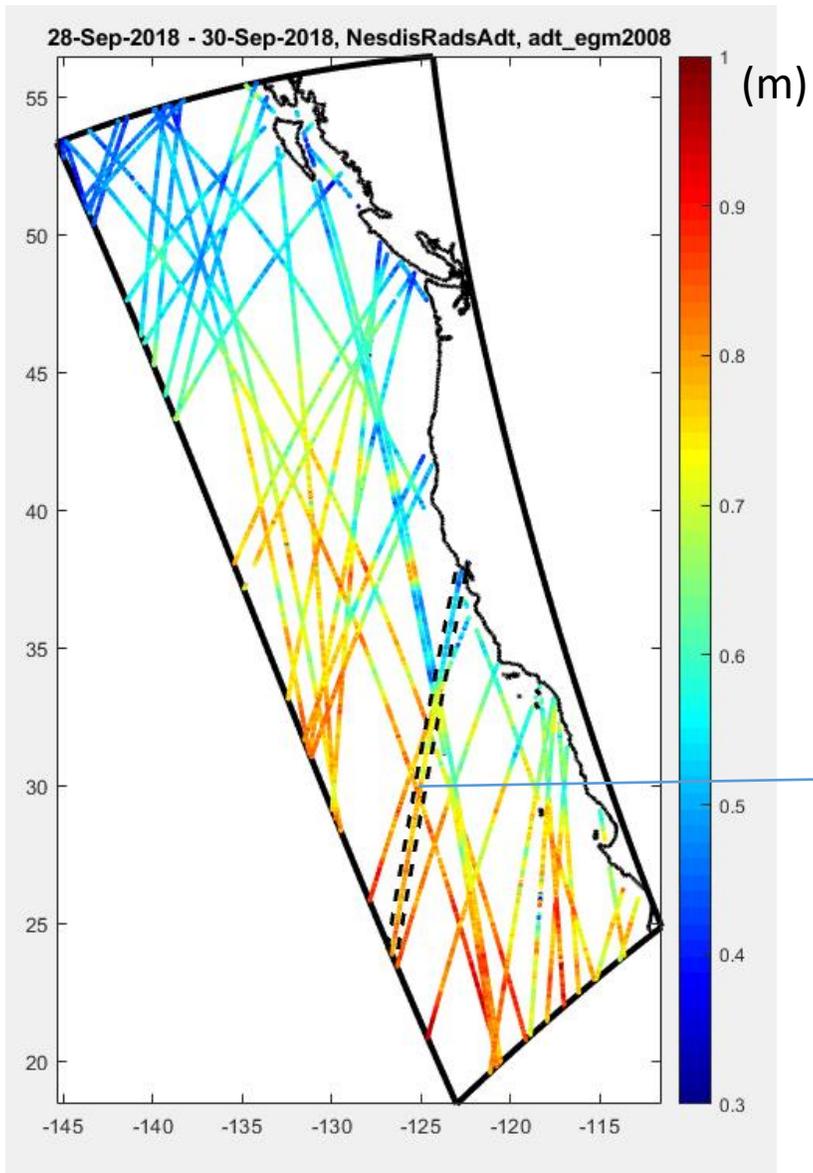


## SSH assimilation: potential impact on currents

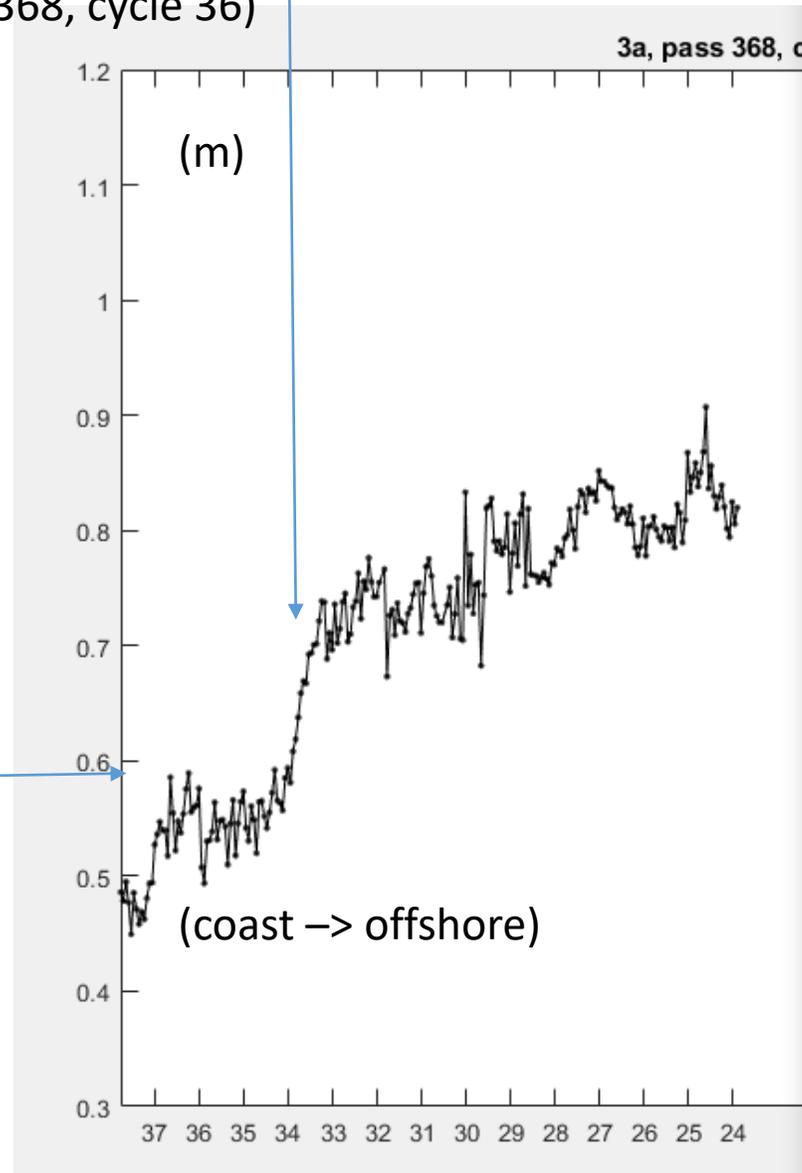
- Coastal jets and mesoscale offshore eddies: in geostrophic balance
- Depression in summer near coast (upwelling signal)...relatively small, but measurable signal (0.1-0.2 m)
- Assimilation of altimetry has the potential to improve accuracy of the coastal currents and eddies



Altimetry tracks in a 3-day DA window  
(28-Sep-2018)



**Evidence of the front location** (strong geostrophic current) in the satellite-derived Absolute Dynamic Topography (Sentinel 3, pass 368, cycle 36)



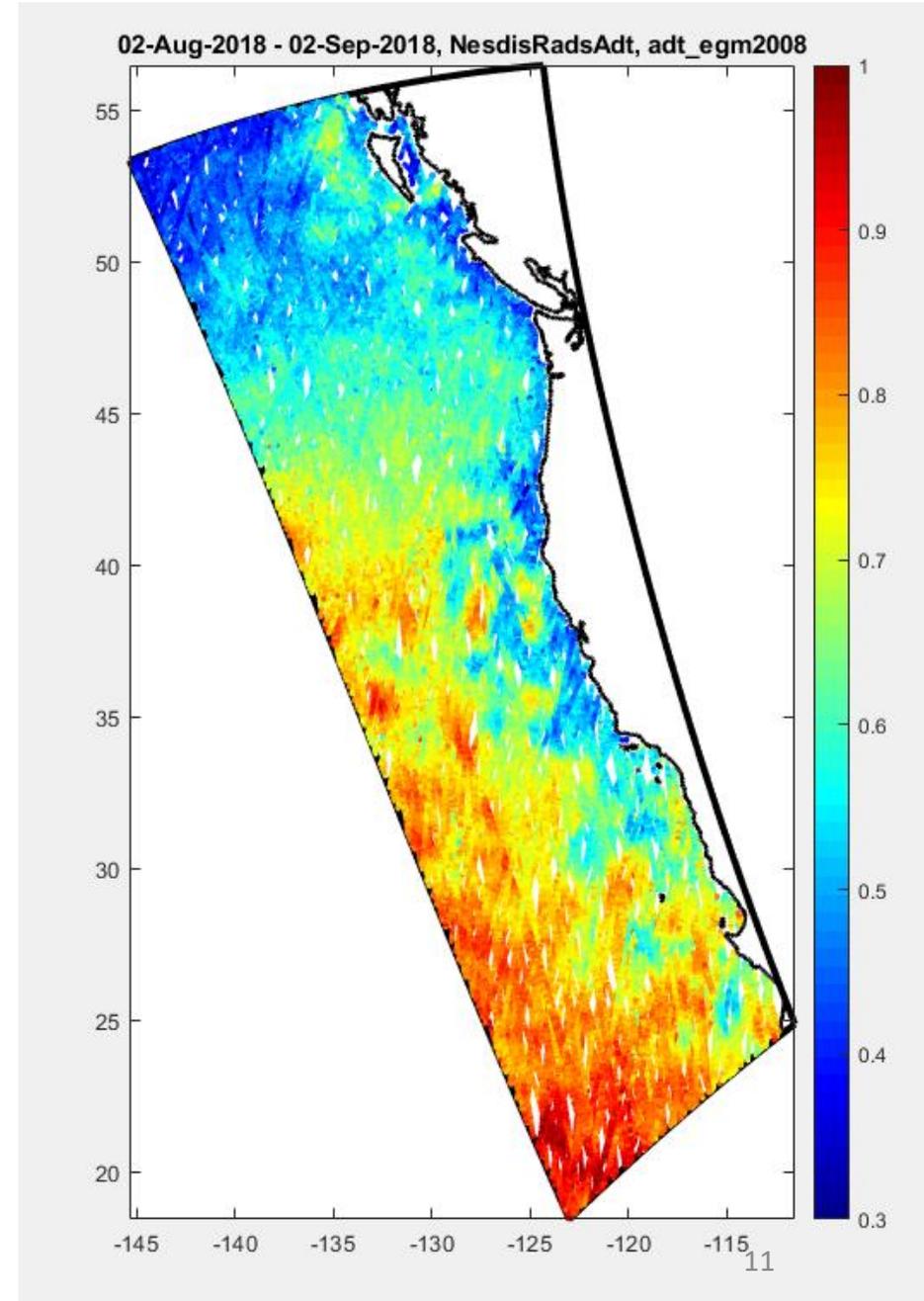
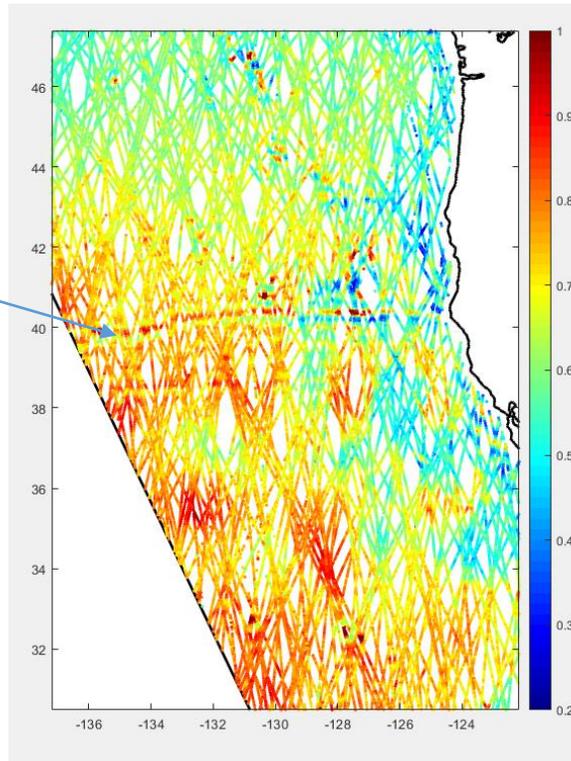
In the monthly ADT mosaic from 5 satellites: almost gap-free coverage, emerging picture of the eddies and fronts



**Assimilation considerations:**

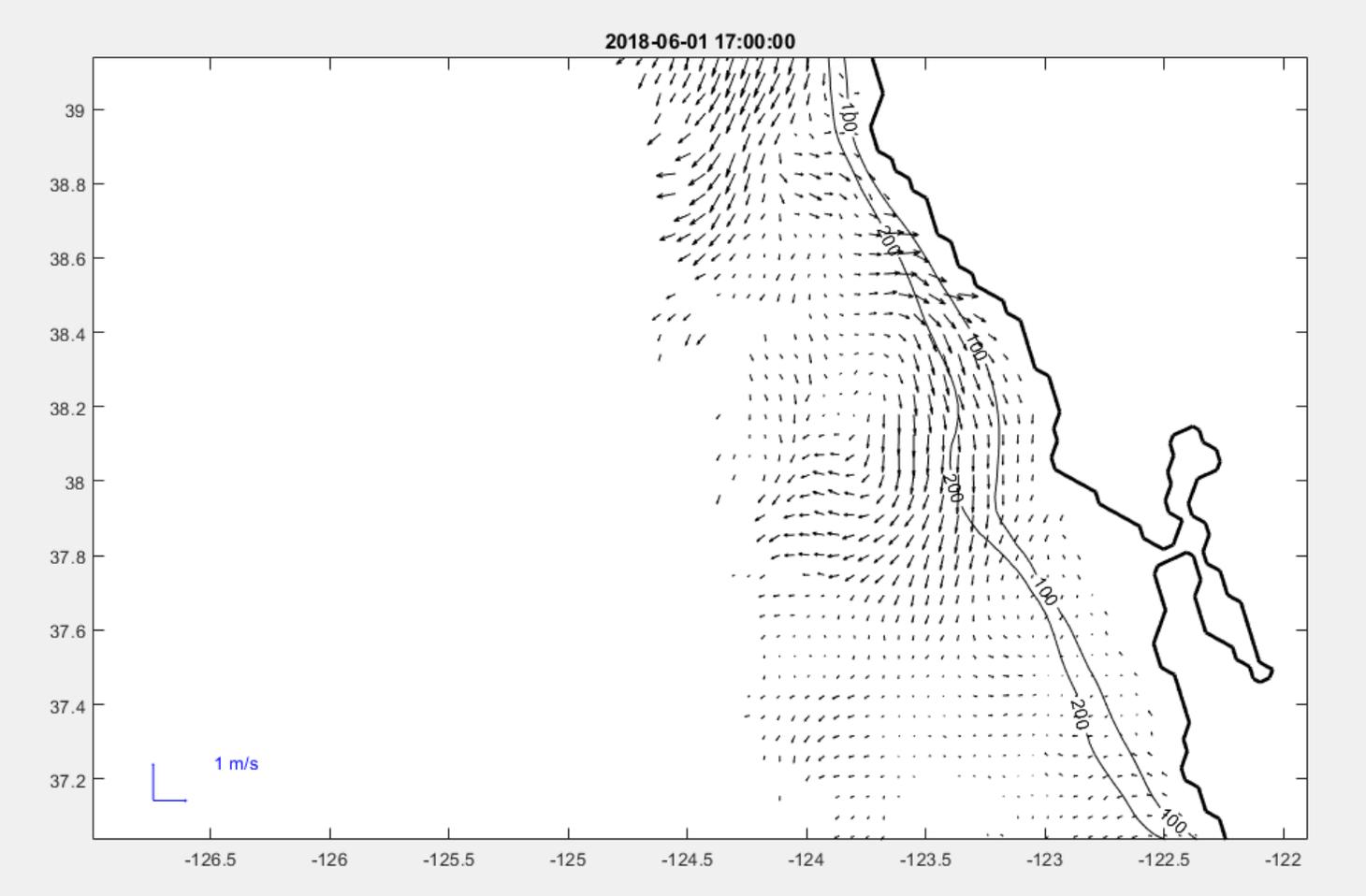
- Model has tides. Model tidal constituents are estimated from the long model run and added to ADT observations for assimilation
- Geoid model (adt\_egm2008: less noise than in adt\_xgm2016)

Erroneous signal along Mendocino Escarpment in adt\_xgm2016 (error in the geoid?)...  
...not apparent in adt\_egm2008



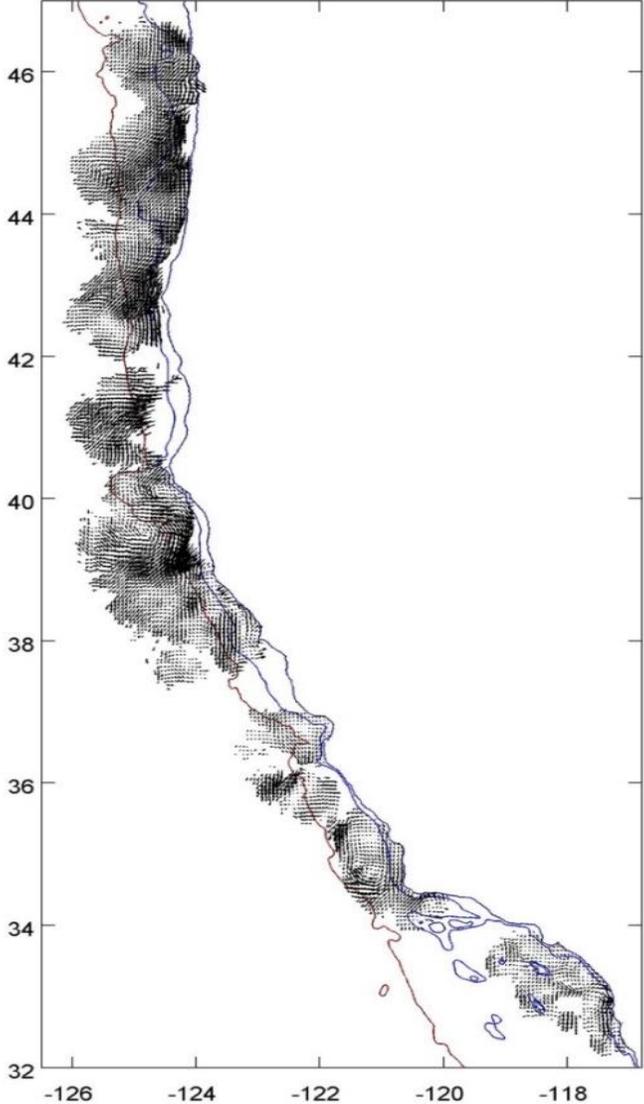
In addition to the satellite observations, surface currents from a network of land-based HF radars are assimilated

Instantaneous HFR current near San Francisco Bay (6-km resolution map)



US West Coast  
HF radar Network: 32-47N

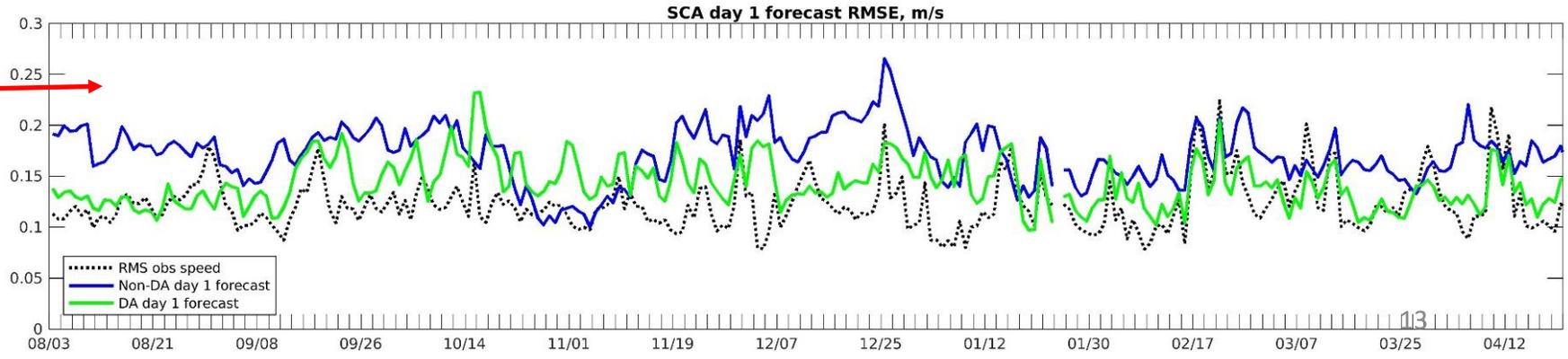
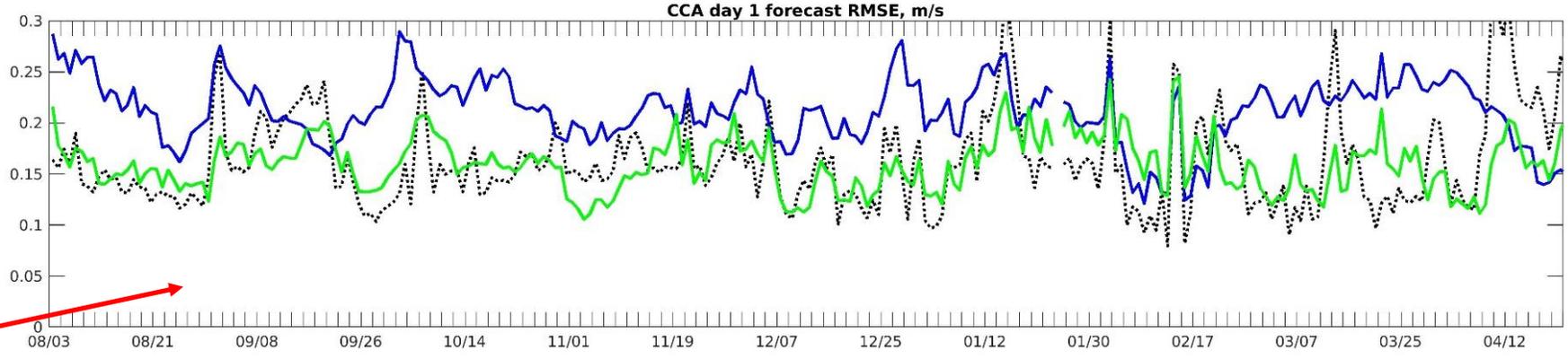
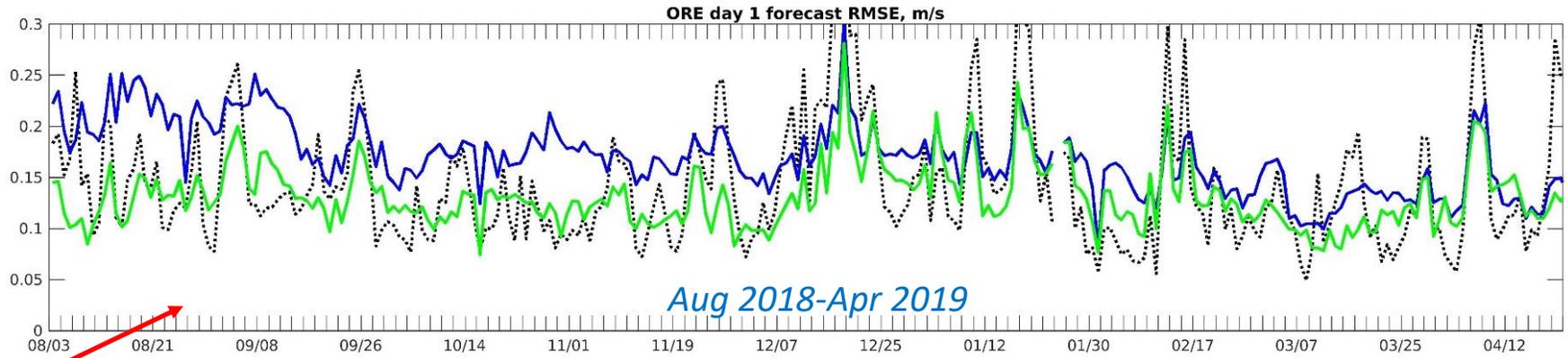
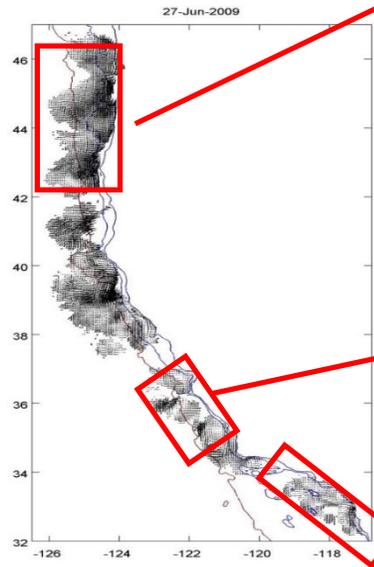
27-Jun-2009



# The real-time WCOFS with 4DVAR:

assimilates only NPP VIIRS SST and HFR uv

Assimilation improves forecast RMSE for area-averaged, daily averaged currents (when compared against future data)

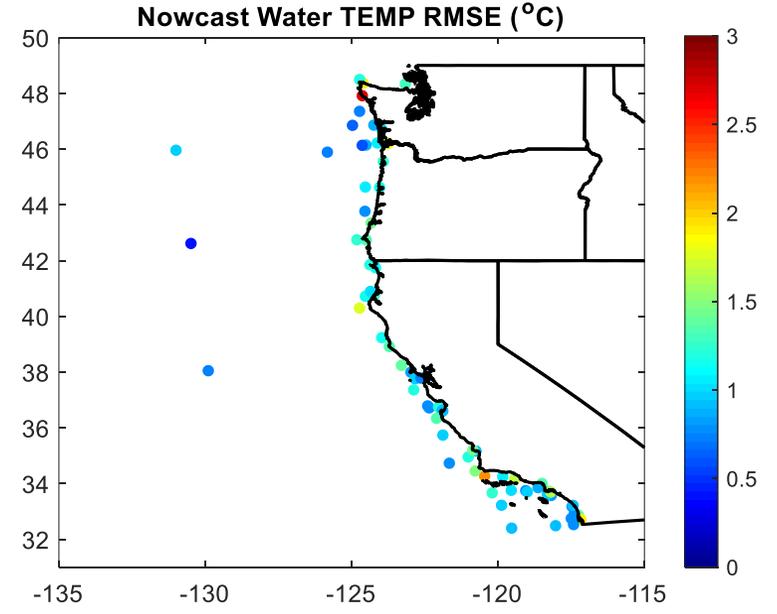
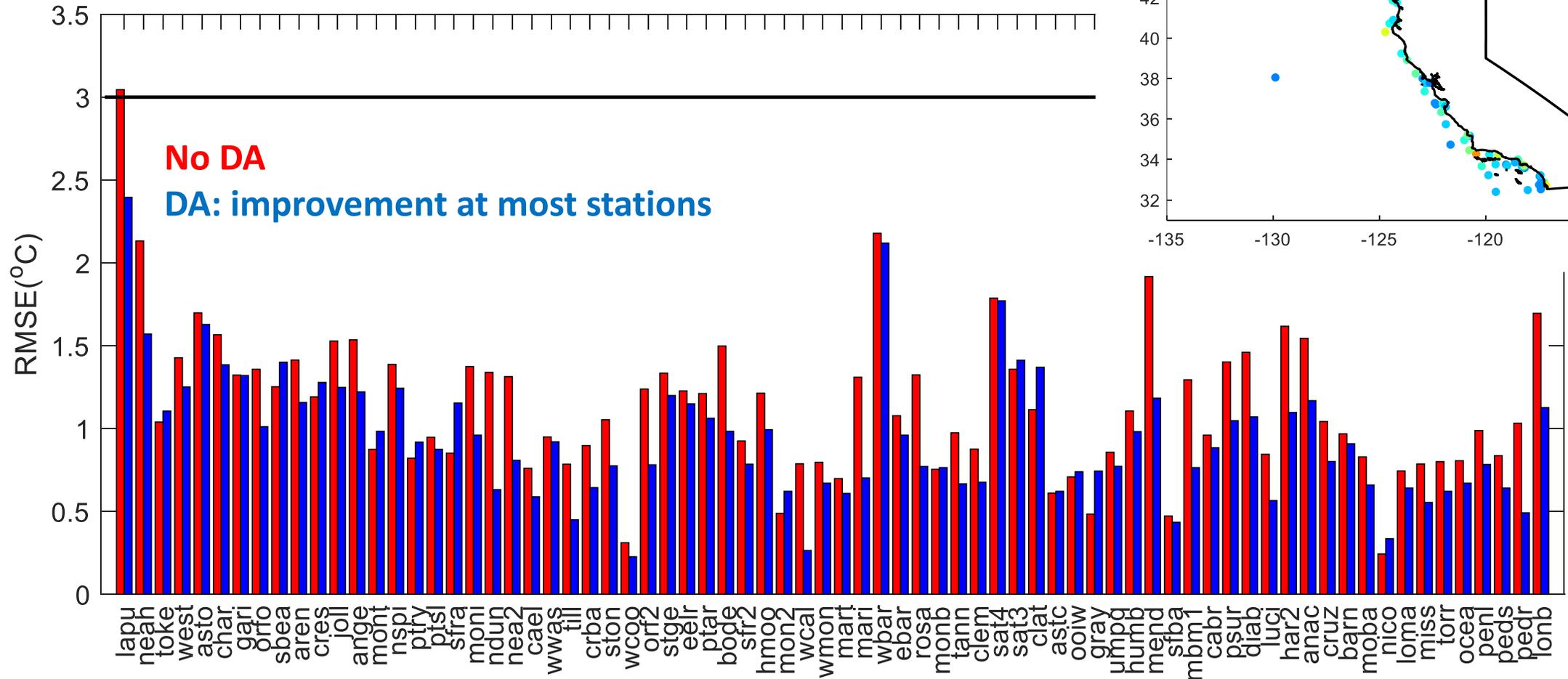


..... RMS obs speed  
— Non-DA day 1 forecast  
— DA day 1 forecast

..... RMS obs speed  
— Non-DA day 1 forecast  
— DA day 1 forecast

Assimilation improves model-observation RMSE for surface temperature, compared against the unassimilated NDBC buoy and CO-OPS tide gauges time series data

72-hr forecast model-data T RMSE (Aug 2018-Apr 2019)



## SUMMARY:

- Satellite observations contain important information about coastal ocean processes to improve the forecast skill of regional operational forecast systems such as WCOFS
- Assimilation of SST and HFR observations in WCOFS improves forecasts for the surface currents and temperature
- Adding SST from multiple satellites should help reduce gaps (esp. microwave). Concerns: cross-satellite biases, pre-assimilation data quality control
- In our ongoing study, we want to see if assimilation of alongtrack altimetry helps improve RMSE of the forecasts for the surface currents

## Challenges:

- Constraining unobserved fields (salinity... CMOS: coarse resolution, accuracy?...)
- Spurious and erroneous temperature corrections due to HFR data assimilation on cloudy days
- In-situ data: sparse compared to the horizontal scales of the ocean motions of interest... spurious eddy generation (Pasmans, Kurapov et al., JGR 2019)
- High-frequency variability in observations (esp. altimetry, HFR) vs. model... e.g. internal tides and inertial