Doing science with the operational model outputs:

West Coast Ocean Forecast System (WCOFS) experience

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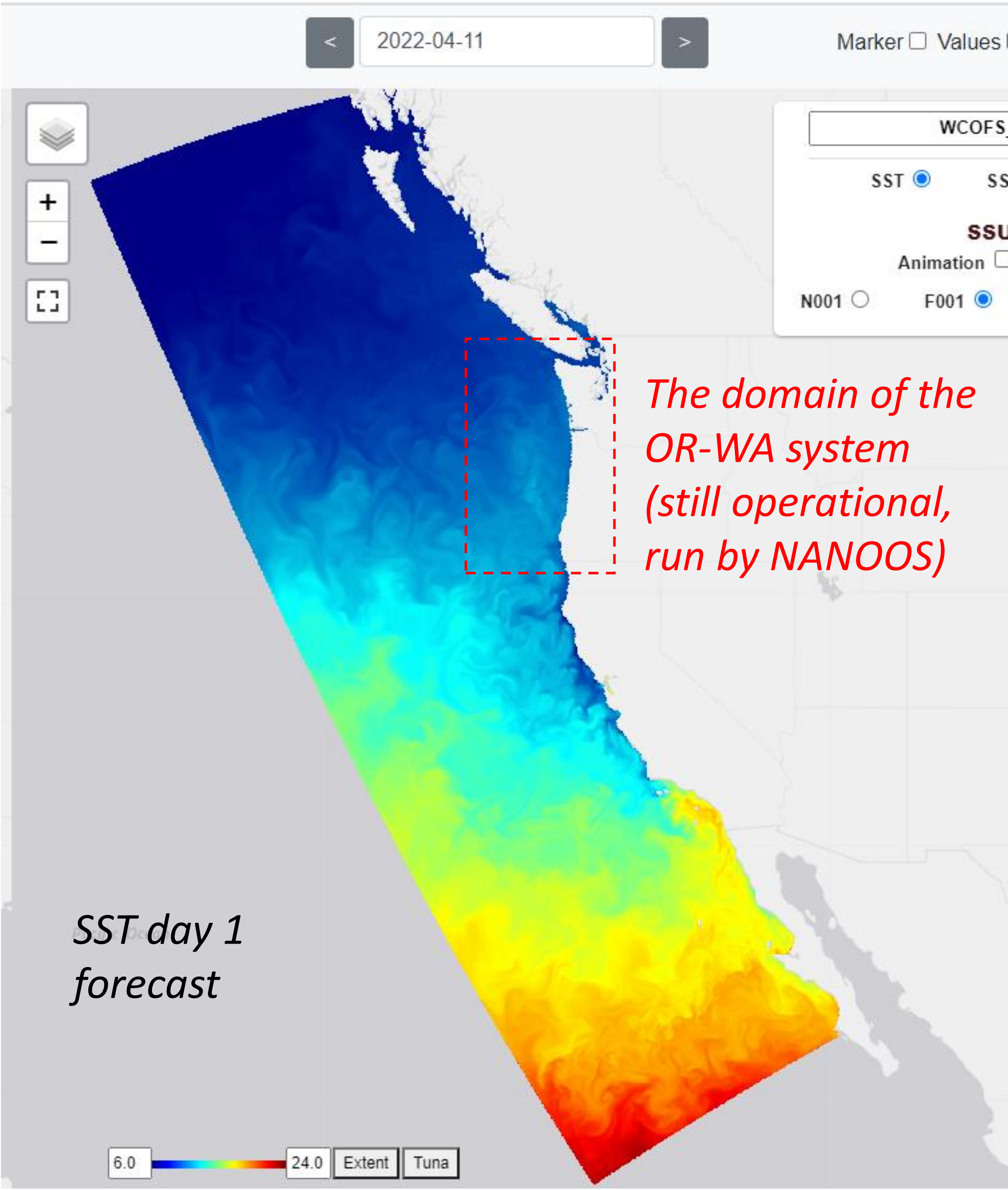
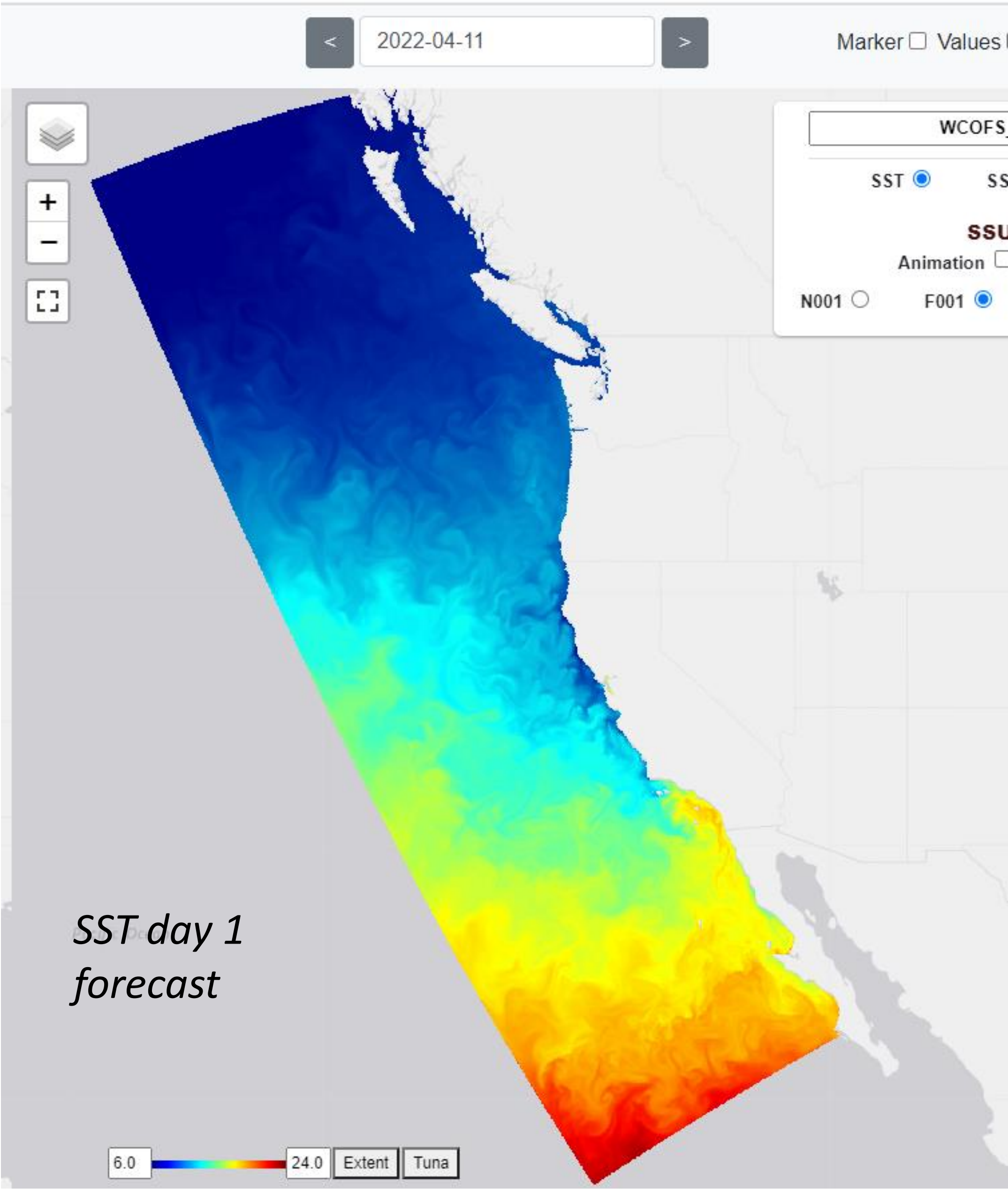
- WCOFS: status, future updates & ideas
    - RT 4-km WCOFS DA (2021-present)
    - RT 4-km WCOFS no-DA
    - OR-WA coastal ocean forecast system
- Using pre-operational models beyond skill assessments
    - 2-km WCOFS no-DA, 2008-2018



WCOFS: West Coast Ocean Forecast System

- ROMS (*Arango, Moore, Wilkin, Edwards, Levine*, etc.)
- Operational since Mar 2021
- Daily updates of 3-day forecasts (SSH, u, v, T, S)
- Forcing: Atmospheric, terrestrial discharges (Columbia, Fraser, Puget Sound rivers), boundary conditions (non-tidal, tidal)
- Data assimilation: altimetry, SST, HF radar surface u,v
- 4DVAR, 3-day windows, daily updates
- 4-km resolution / 40 vertical layers

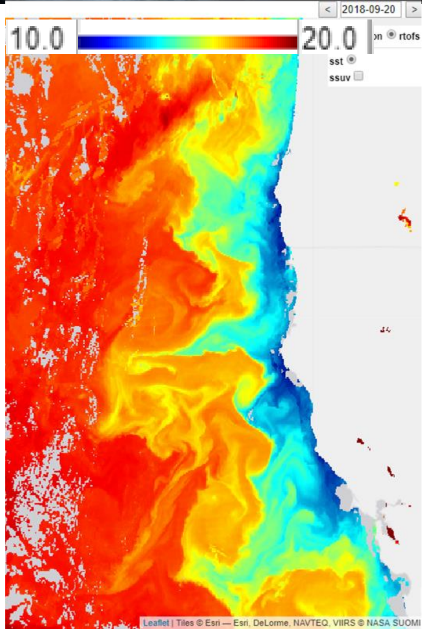


Assimilated observations

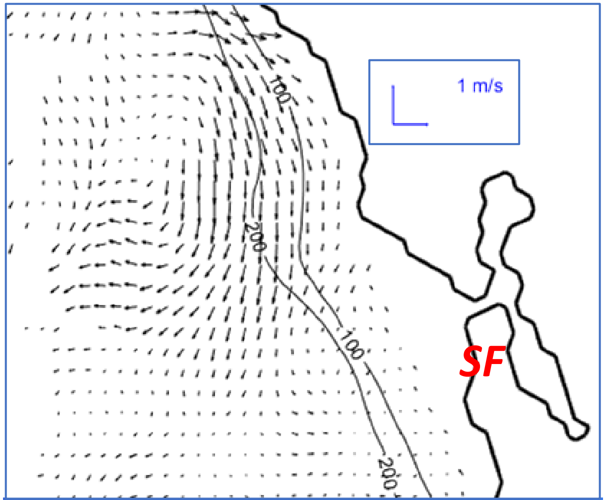
(direct obs of model variables, local in space and time)

Type	Data Sources
Sea Surface Temp (SST)	NPP VIIRS L3U NOAA20 VIIRS L3U GOES17 ABI L3C
Sea Surface Height (SSH)	RADS Absolute Dynamic Topography (Jason3, Cryosat2, Sentinel 3a/b, SARAL/Altika)
Surface Currents	Land-based High Frequency (HF) Radar: hourly, mapped

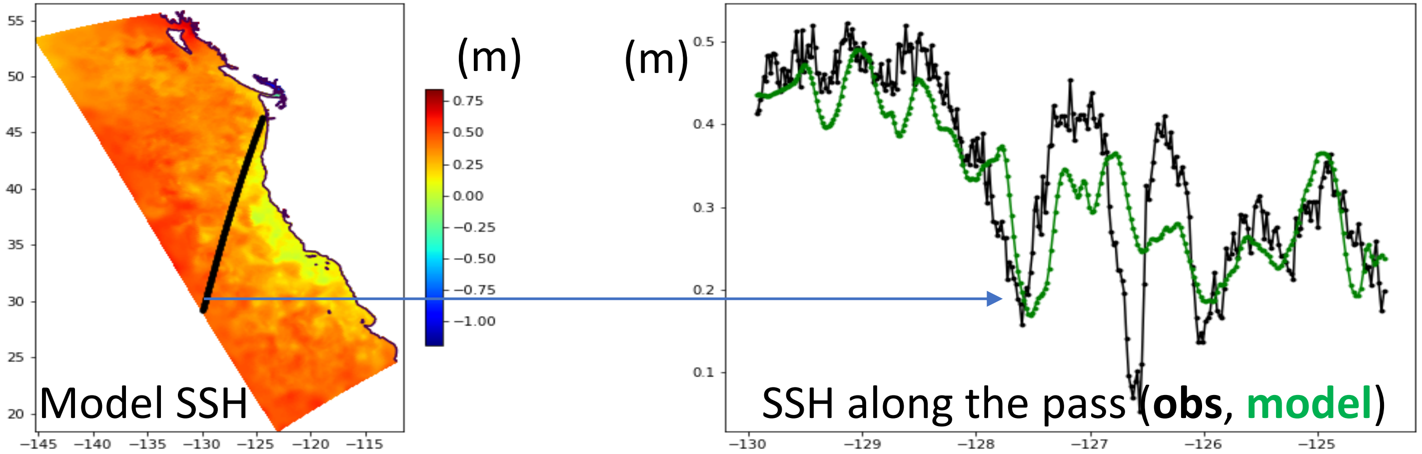

Picture credit:
nesdis.noaa.gov



NPP VIIRS




Picture credit:
tidesandcurrents.noaa.gov



WCOFS: planned upgrades

- Improve time efficiency, resolution:
  - test the newest ROMS code (mixed precision arithmetic)
  - *try implicit vertical advection* (?)

- Model error covariance:
  - balanced operator (Weaver et al., 2005, Kurapov et al., JGR 2011)
  - longer term goal: ensemble-4DVAR (Pasmans et al., MWR 2017, OM 2019, 2020)

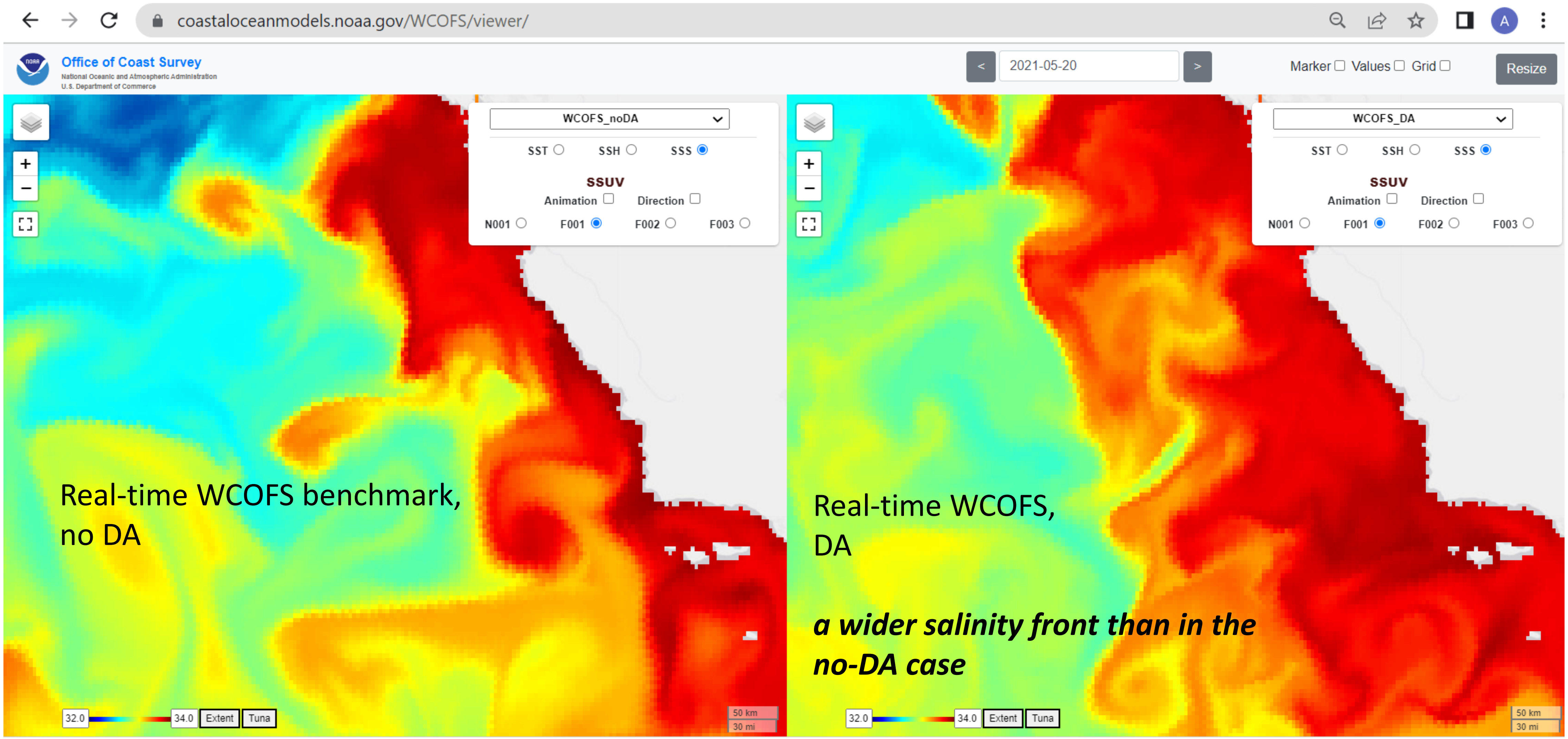
- Altimetry:
  - assimilate the geostrophic slope (e.g., Kurapov et al., 2011) *au lieu de la TDA* => better fit the eddies
  - *3D projection of the surface altimetry signal?*

- HF radar surface currents:
  - radial component data (improve coverage and utilization)… this option is available in ROMS now
  - daily-averaged data (Yu et al. OM 2012, Pasmans et al., OM 2019, 2020): match to daily-averaged model (avoid fitting the model to the poorly predictable and intermittent inertial and internal tide motions)

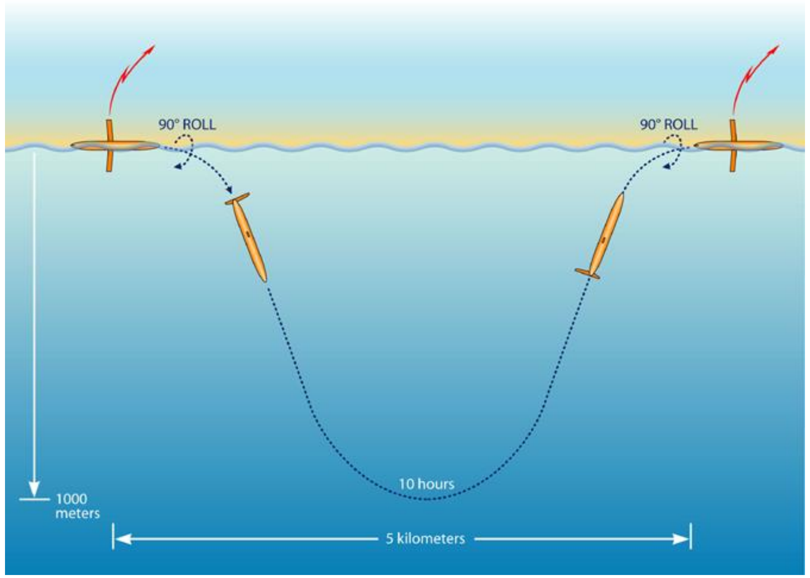
- SST: transition to ACSPO 0.02^o L3 “Super-collated” (including Metop-A, B, C, VIIRS NPP and N20)

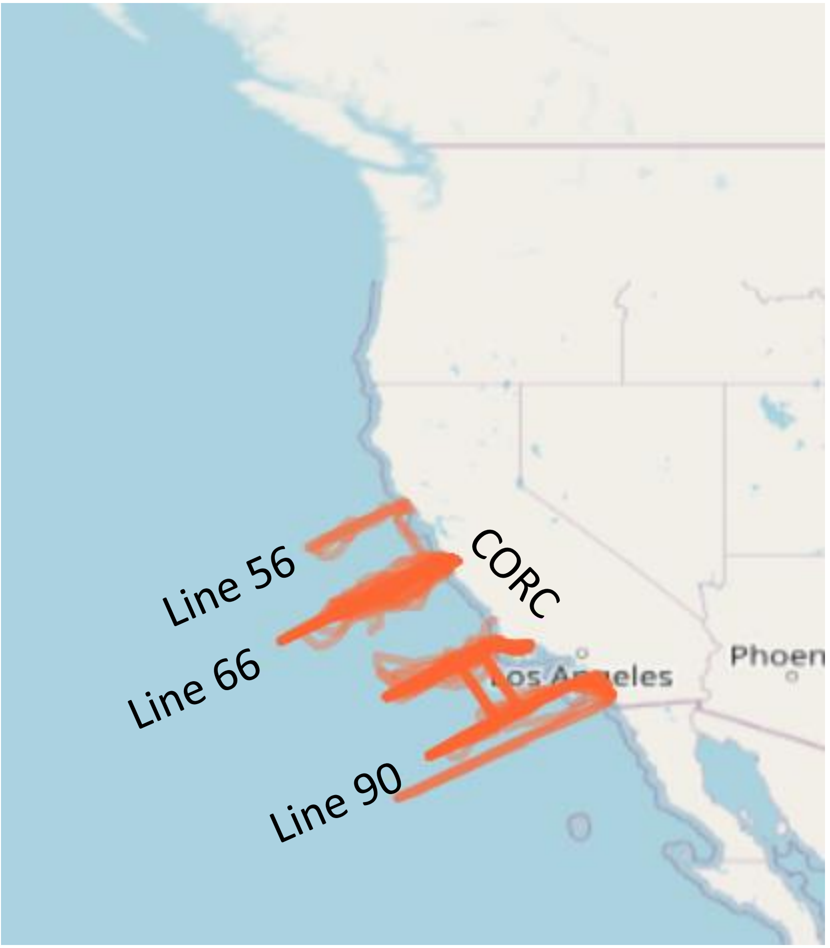
- Add in-situ (caution: local correction of the density profile => spurious eddy variability … Pasmans et al., JGR 2019)

Positive salinity bias as a result of data assimilation (of everything that is not salinity)

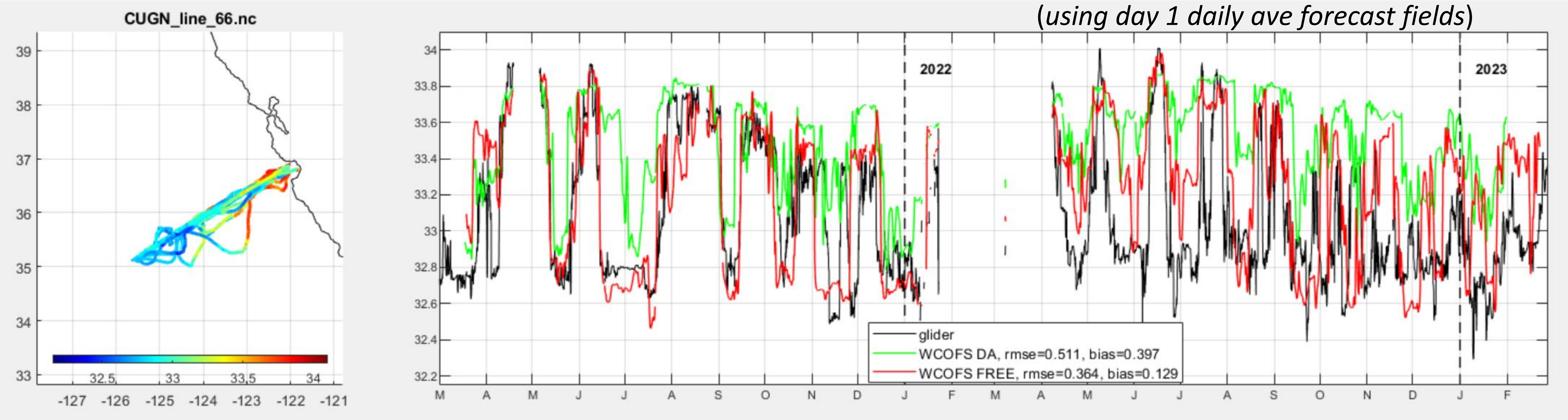


California Underwater Glider Network (CUGN, Rudnick et al., https://spraydata.ucsd.edu/projects/CUGN/)





DA of SST, SSH, and HF uv worsen RMSE for SSS:

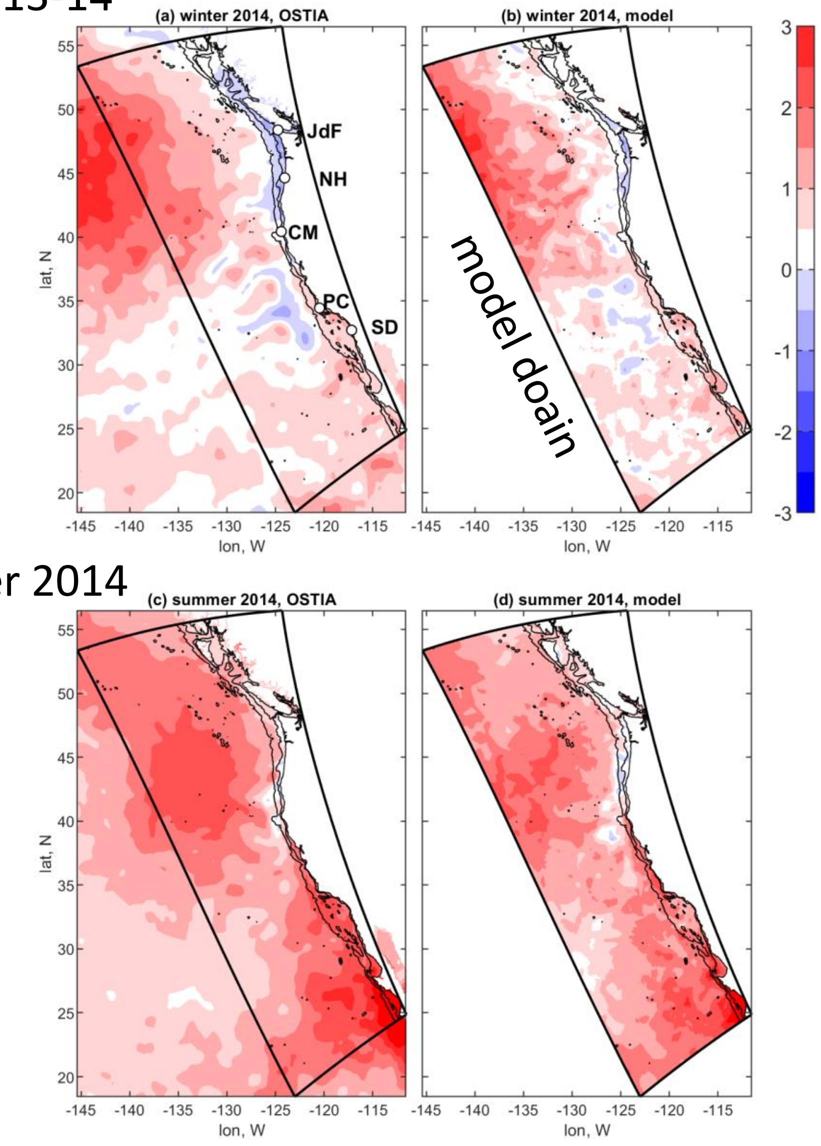


- Hypothesis: DA increases eddy variability => increased offshore transport of upwelled salinity

- Mitigation:
  - improve assimilation of SSH and HF radar uv
  - Assimilate in-situ salinity (too sparse?)
  - Satellite altimetry: RMSE (L2 SMAP – glider) = 1 psu (BAD)
  - Seasonal cycle from the non-DA 2-km res model: RMSE = 0.2 psu (away from Columbia R.)
  - *SSS proxy (based on L3 monthly SMAP SSS, SST, color, local in situ data)* ?

Pre-operational model assessments: go beyond skill assessments, look at the processes

- Use the 2-km ROMS model simulation, 2008-2018
- No data assimilation (a dynamically and thermodynamically balanced solution)
- Including 2014-2016 heat wave events (Warm Blob, El Niño)

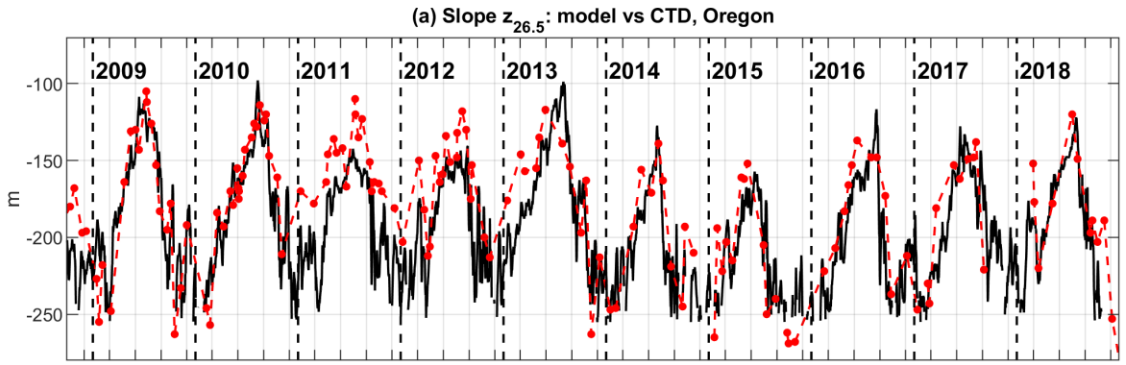


Shown:
SST anomaly (using 2009-13 as clim.)

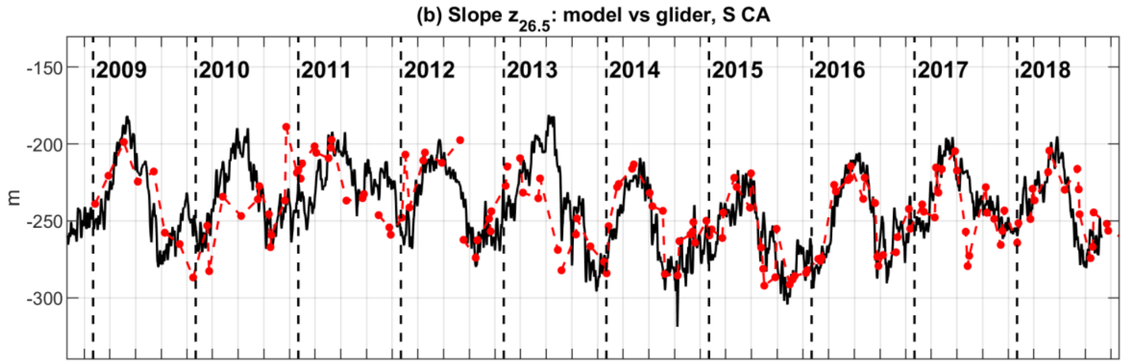
Kurapov et al. JGR 2022:

- model-data comparisons (2008-2018)
    - Coastal sea level
    - HF radar surface currents
    - Surface temperature moorings
    - Near-bottom shelf current in Oregon – ADCP (positive anomalies in summer 2014 and 2015)
    - Depth of σ_θ = 26.5 kg/m^3 (against glider and CTD observations): negative (deeper) anomalies over the slope off CA and OR

Oregon:
model vs
ship CTD (Fisher et al.)



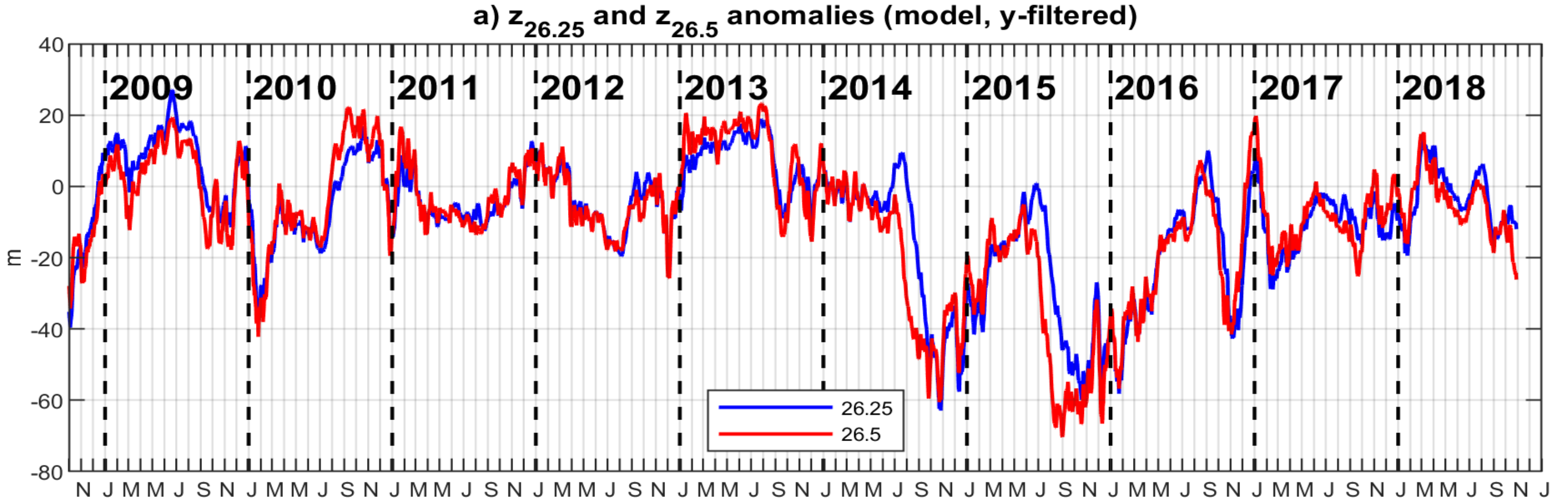
S CA
model vs
glider (Rudnick)



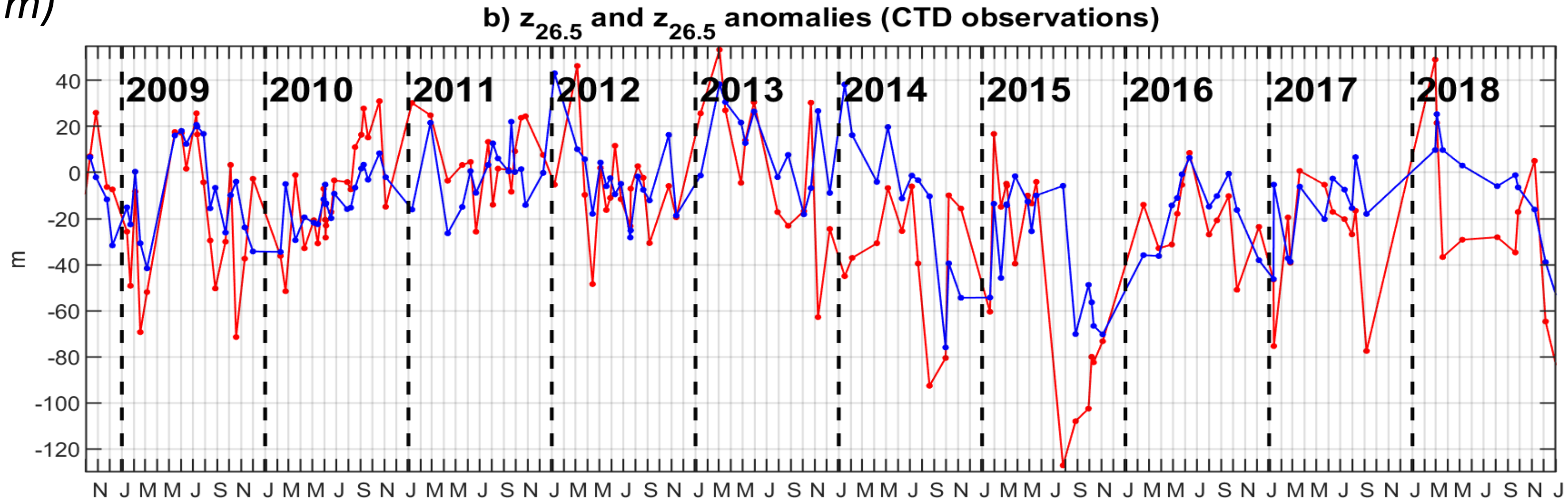
z_ρ anomalies over the slope off Oregon (Kurapov, JGR, 2023 in review):

- $z_{26.5}$ and $z_{26.25}$ are anomalously deep in summer 2014 and 2015
- The vertical distance between these layers is anomalously high only in these two summers

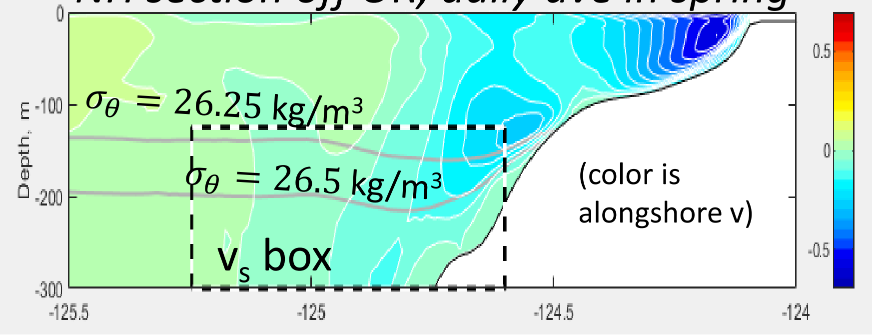
Model anomaly (cross-slope averaged)



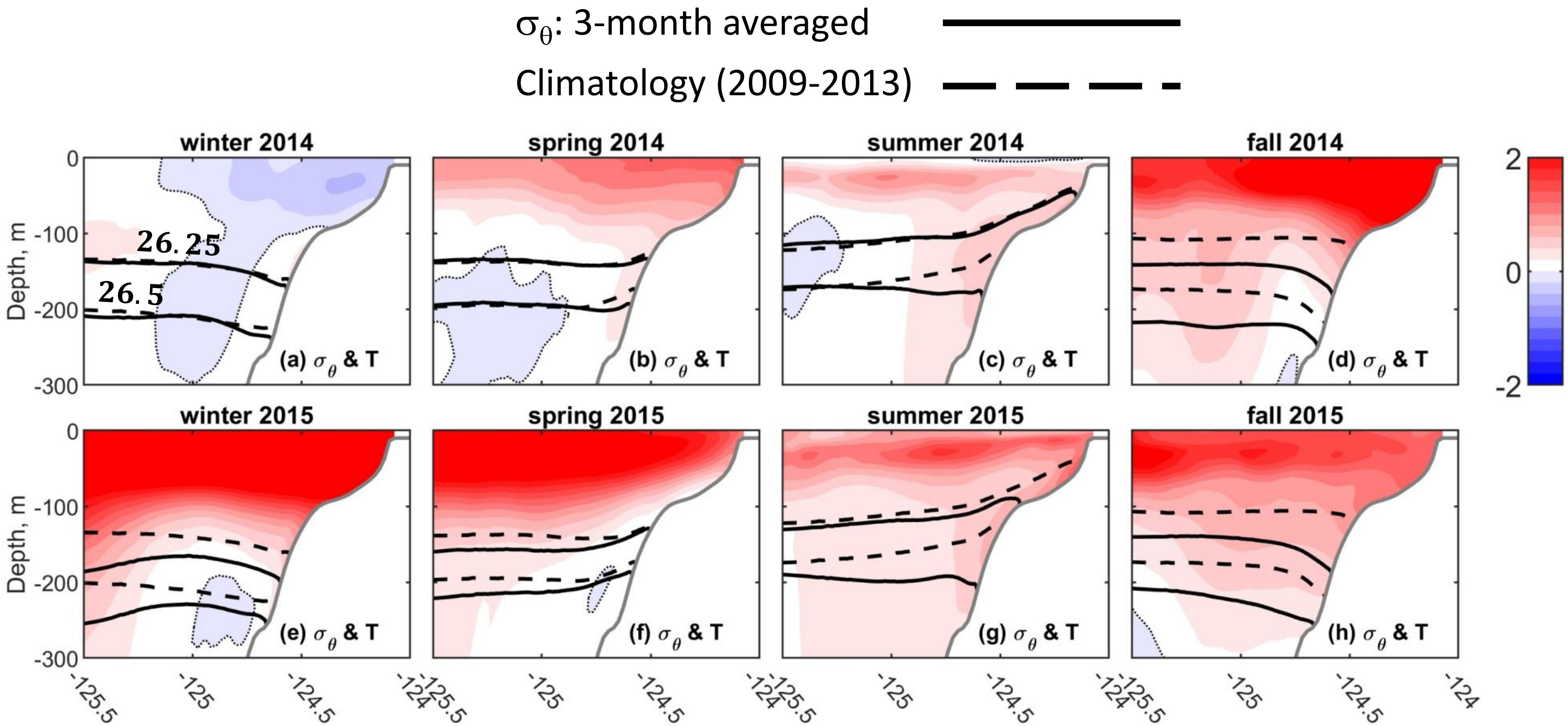
Ship CTD (Fisher), NH25 (275 m)



NH section off OR, daily ave in spring



Cross-shore sections off Oregon (44.65N): T anomalies (color), σ_θ = 26.25, 25.5 kg/m^3 (black lines)



- Negative $N^2 = -\left(\frac{g}{\rho_0}\right)\frac{\partial \sigma_\theta}{\partial z}$ anomalies in summers 2014 and 2015
- Can be explained as the effect of advection of the seasonal gradient of the potential vorticity ($\mathrm{PV} \approx (f + \nabla \times u)N^2$) by the anomalously positive (poleward) alongslope current

The negative N^2 anomalies in summers 2014 and 2015 can be explained as the effect of advection of the seasonal gradient of the PV by the anomalously positive (poleward) alongslope current

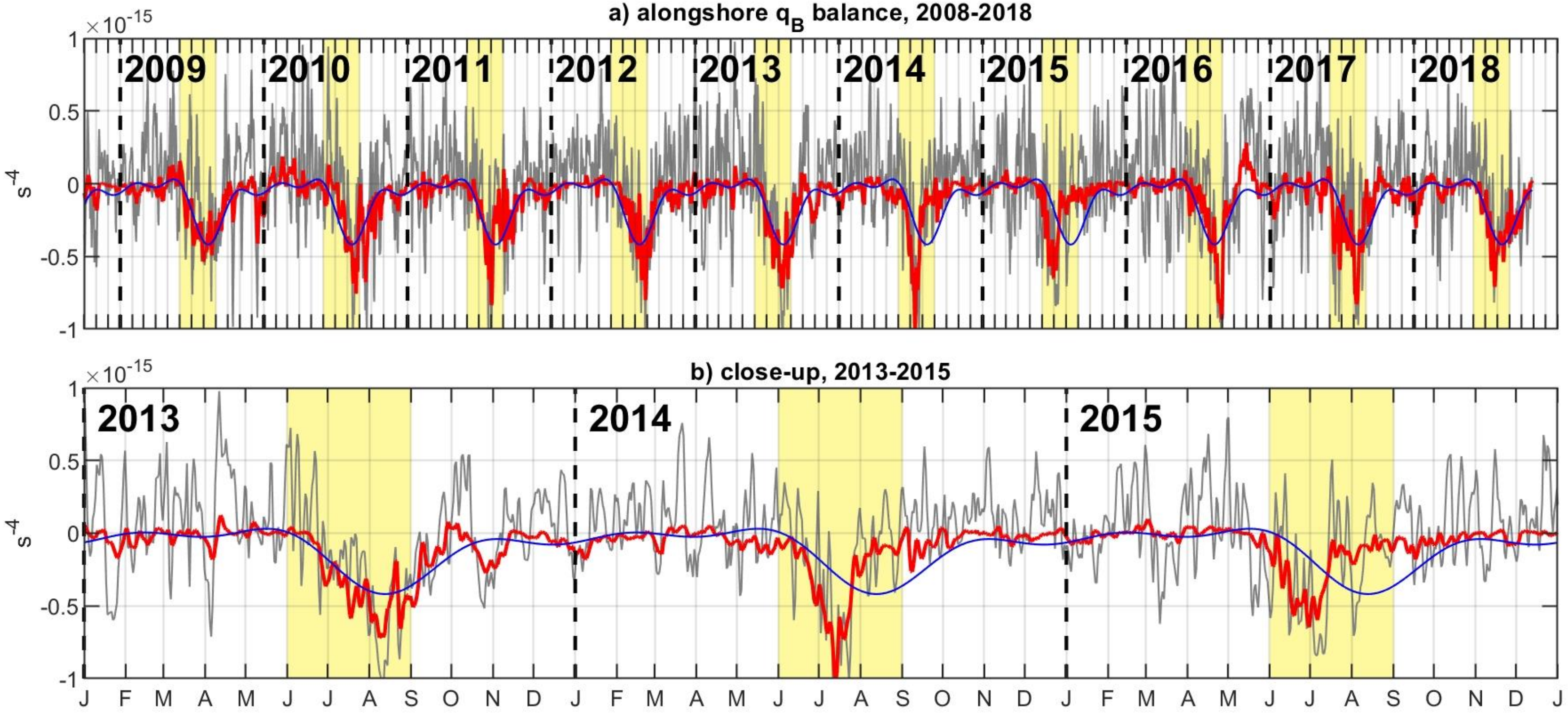
$PV \approx (f + \nabla \times u)N^2, \qquad q_B = f N^2$

$d\, q_B / d\, t \approx - v\, d\, q_B / d\, y$

(y = alongshore coordinate)

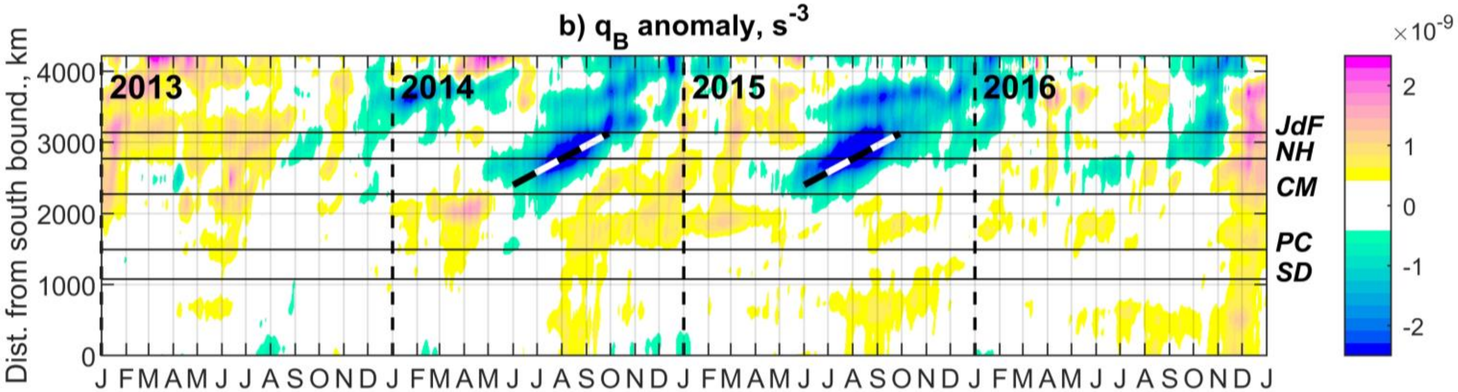
(using slope averaged q_B and “undercurrent” v)

Blue line:
annual cycle in **$- v\, d\, q_B / d\, y$**



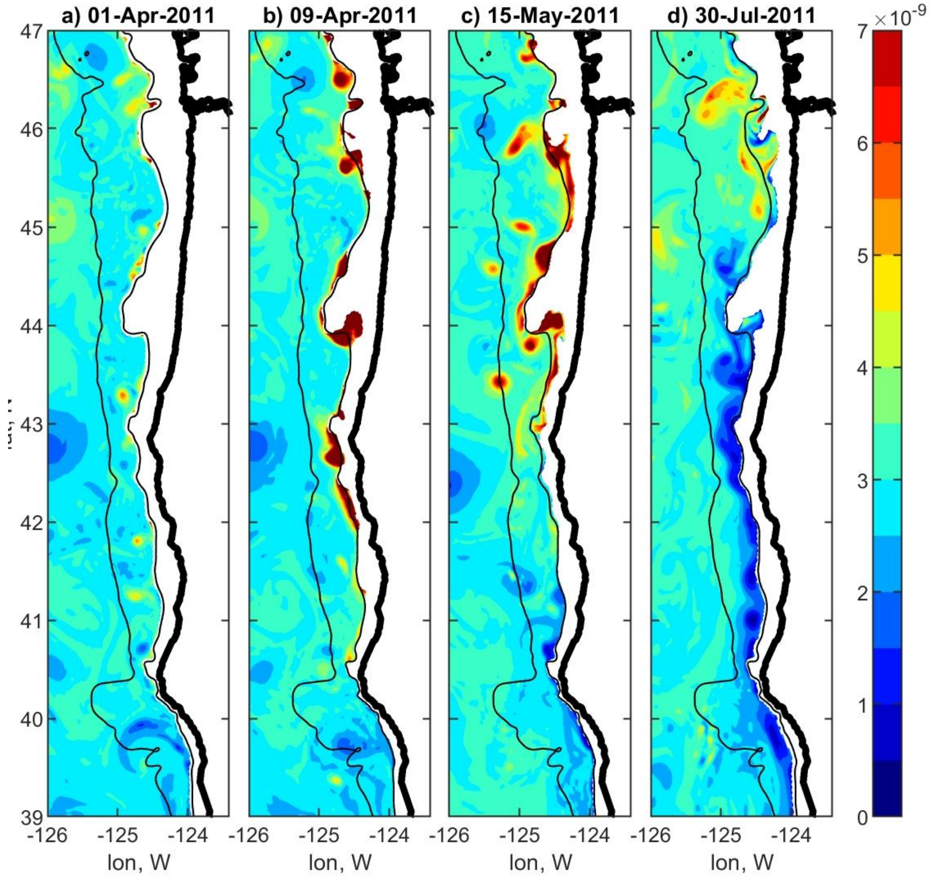
In summer 2014, 2015:
- positive v anomaly transports the seasonal gradient of PV earlier in the season than on average

Time vs alongshore coordinate PV (s^{-3}) anomaly over the slope:



- strong negative anomaly found only in 2014 and 2015 and only north of (N CA – OR – WA): the strong seasonal gradient of PV is supported by local upwelling and PV transport off the shelf)

- this anomaly is advected to the north (0.07 m/s)



PV at σ_θ = 25.5 kg/m^3:

- PV injection in the BBL over the shelf with upwelling (Benthuysen & Thomas, 2012)
- Eddy transport in the slope area
- Lower PV is associated with the undercurrent

SUMMARY:

- The WCOFS was transitioned to operations as the first NOAA regional OFS with data assimilation

- A long list of tasks to make it better (DA efficiency, model resolution, background covariance, ways to treat the data, constrain the salinity bias)

- Models provide not only the opportunity to predict the flows with some accuracy, but also an opportunity to dive into the basic research

- Episodes of the anomalously low stratification over the slope off Oregon in summers 2014 and 2015 can be explained as the effect of the PV advection by the anomalously strong slope current
  - the v anomaly: part of the CTW El Nino response
  - strong seasonal gradient in PV over the slope at the level of σ_θ = 26.25, 25.5 kg/m^3 : supported by upwelling