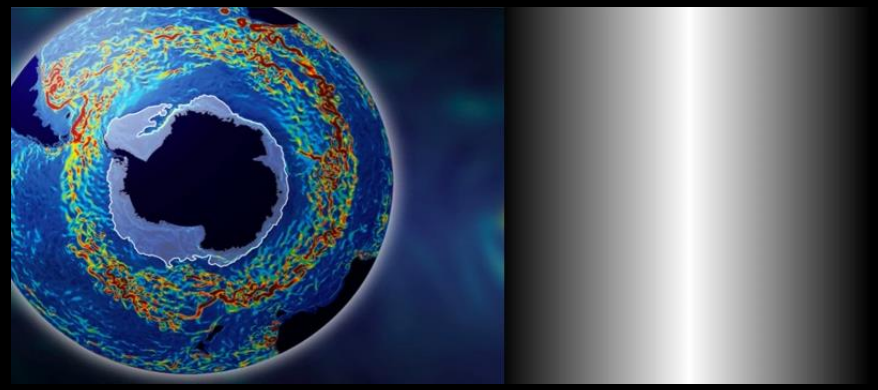


Regional state estimates

ECCO Summer School 2025

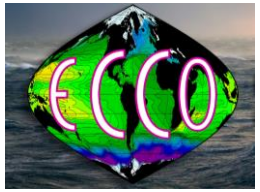
Matt Mazloff, Bruce Cornuelle, Ganesh Gopalakrishnan,
Ariane Verdy, ECCO, et al.

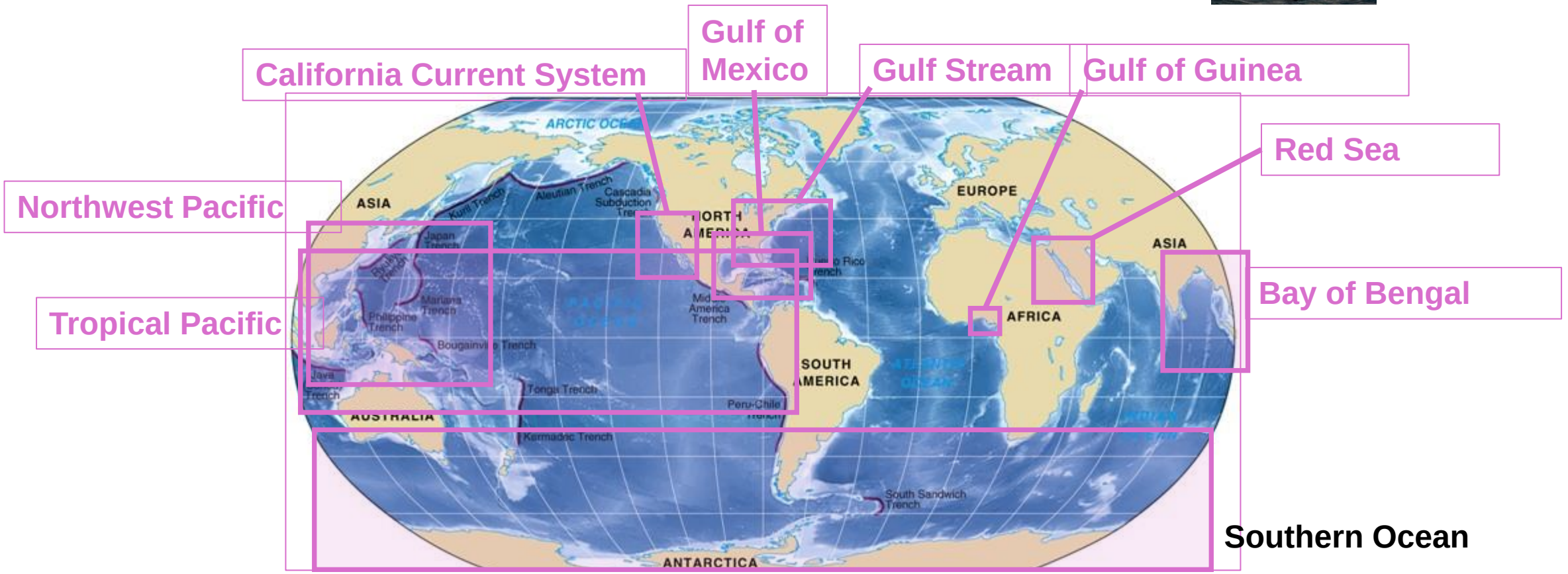
SCRIPPS INSTITUTION OF OCEANOGRAPHY

Regional state estimation activities at Scripps Institution of Oceanography

Matt Mazloff, Ariane Verdy, Angela Kuhn,
Ganesh Gopalakrishnan, Bruce Cornuelle

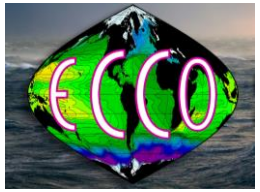
Software from the consortium for Estimating the Circulation and Climate of the Ocean (ECCO)

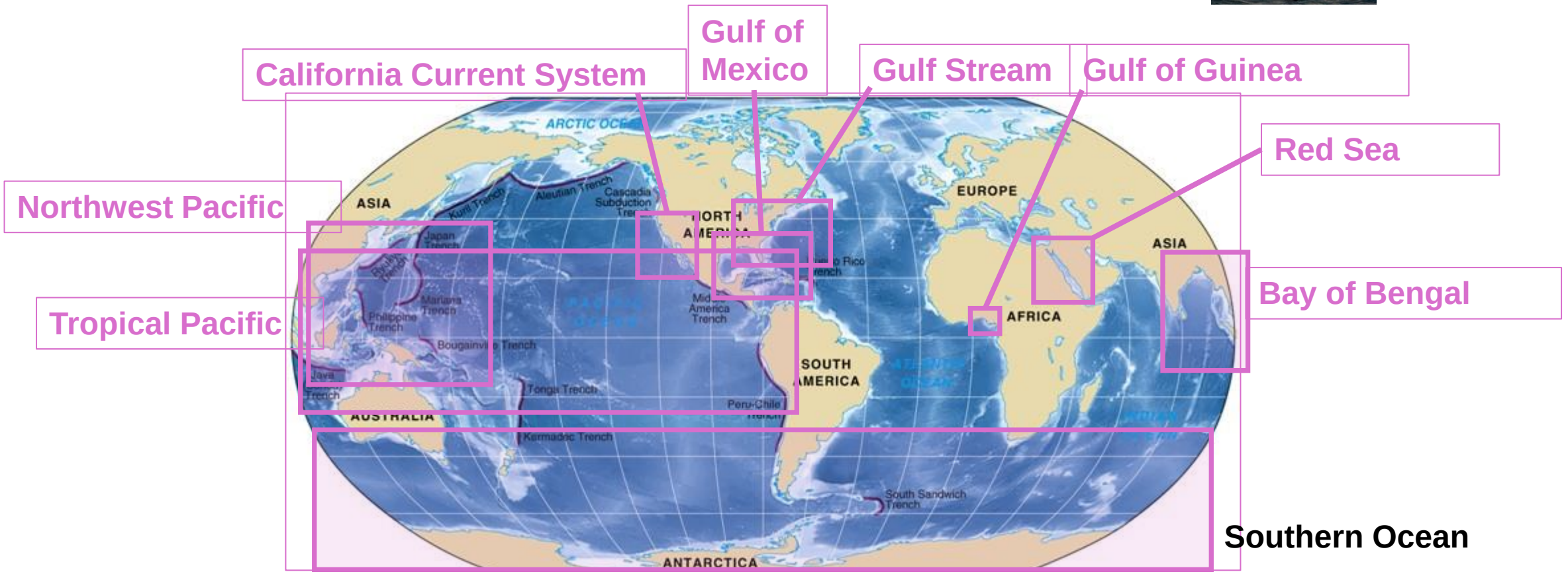




What is the utility of a regional state estimate?
Why produce regional ocean data assimilations?

oftware from the consortium for Estimating the Circulation and Climate of the Ocean (ECCO)





Who needs to know what the ocean is doing?

Pollutants, search and rescue, ship routing & navigation, acoustics, weather prediction, storm surge, wave state, ecosystem health, fish stock assessment, hydrological cycle, Etc.

What is the utility of a regional state estimate?
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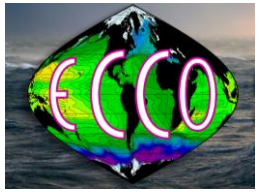
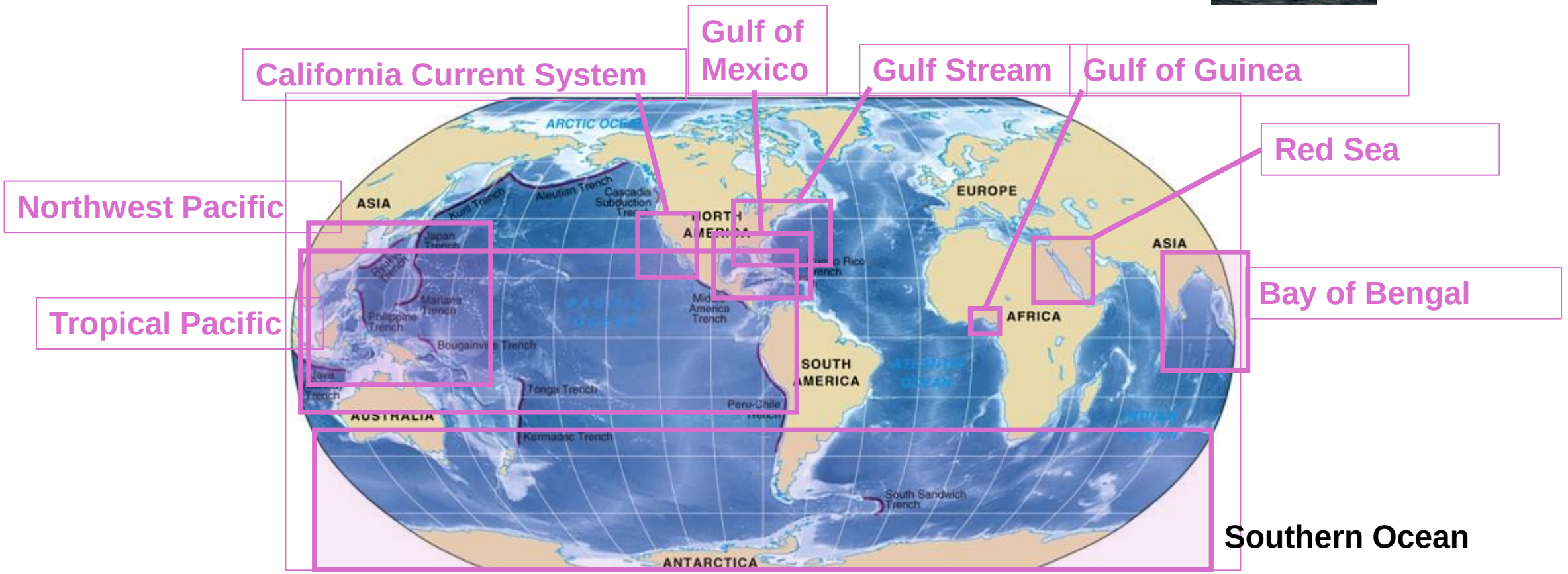
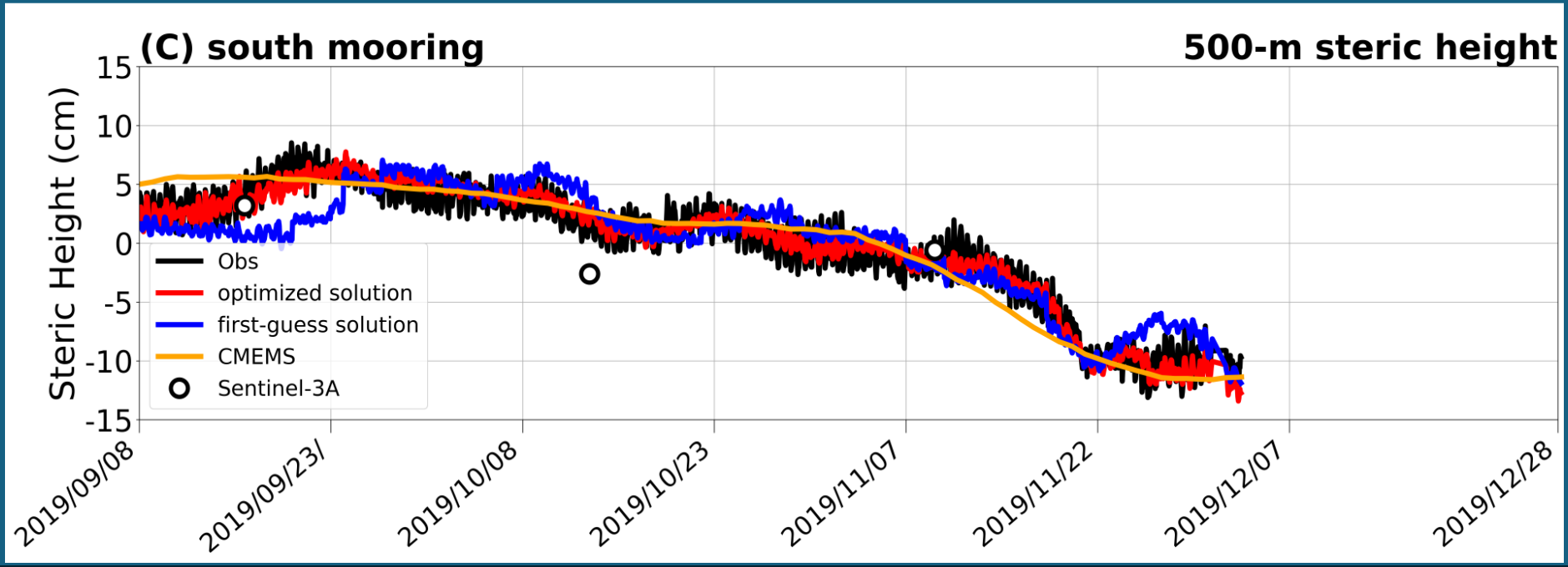


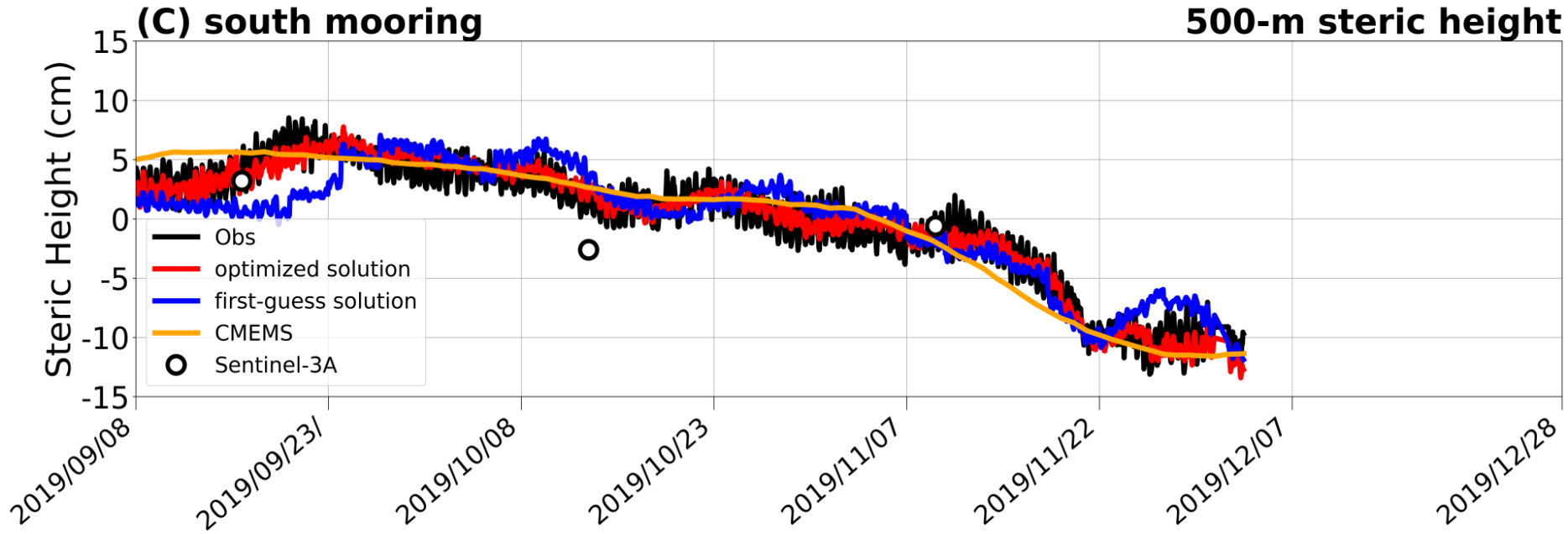


Why regional assimilations?

- Model setup and data assimilation machinery are tools.
- One often has a focused set of questions, and regional setups allows customized ‘tools’.
- Targeted regional efforts can enable consistency with specific dynamical or system components (e.g. eddies, biomass, coastal, new obs platforms).
- Targeted regional efforts can enable consistency in specific regions or times, or with specific observational platforms.



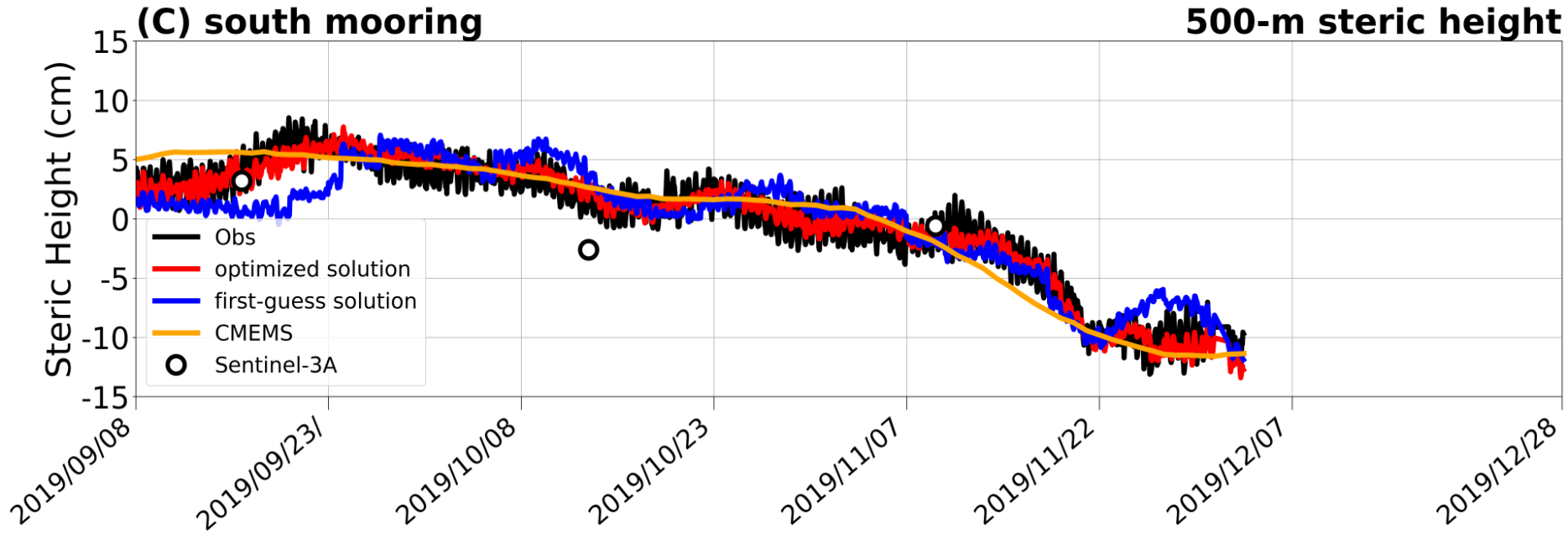
Tchonang et al 2024: Evaluation of a 4DVAR Assimilation System in the California Current at the SWOT Calibration/Validation Site. *JTECH*



Tchonang et al 2024: Evaluation of a 4DVAR Assimilation System in the California Current at the SWOT Calibration/Validation Site. *JTECH*

Targeted efforts can enable reproducing eddies

- Mapped products have formal mapping errors and representation error.
- **Formal mapping error** primarily from lack of info: sparse or noisy obs.
- **Representation error** comes from low resolution, missing physics, or errors in the model-data synthesis methodology.
- Mapping methods vary substantially, primarily with regards to how covariance estimates are determined and the level of physics included.
- **Representation error: must choose what scales are signal or noise.**



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- **Representation error: must choose what scales are signal or noise.**

The science:

The model is our hypothesis of how the world works.

We make assumptions for computational efficiency.

If we understand the ocean, those assumptions will give us the expected answers.

If we don't understand, we must go back & make a new hypothesis – a new model

How do we model ocean vertical transport?

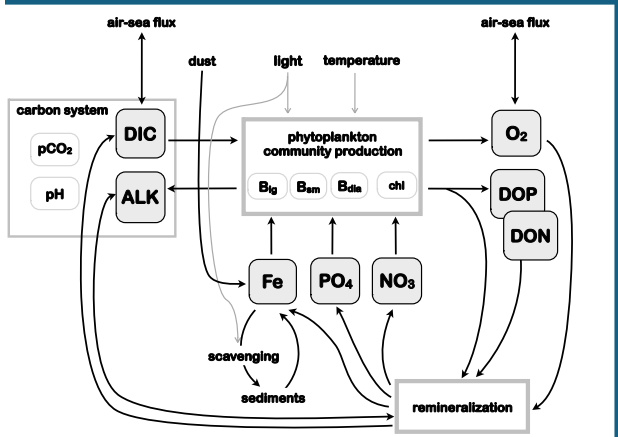
How do we forecast ocean sea level?

Once we have a good model (i.e. the forward problem), we can better use observations (i.e. the inverse problem)

Tropical Pacific State Estimate (TPOSE)

2010-2019

+ bgc

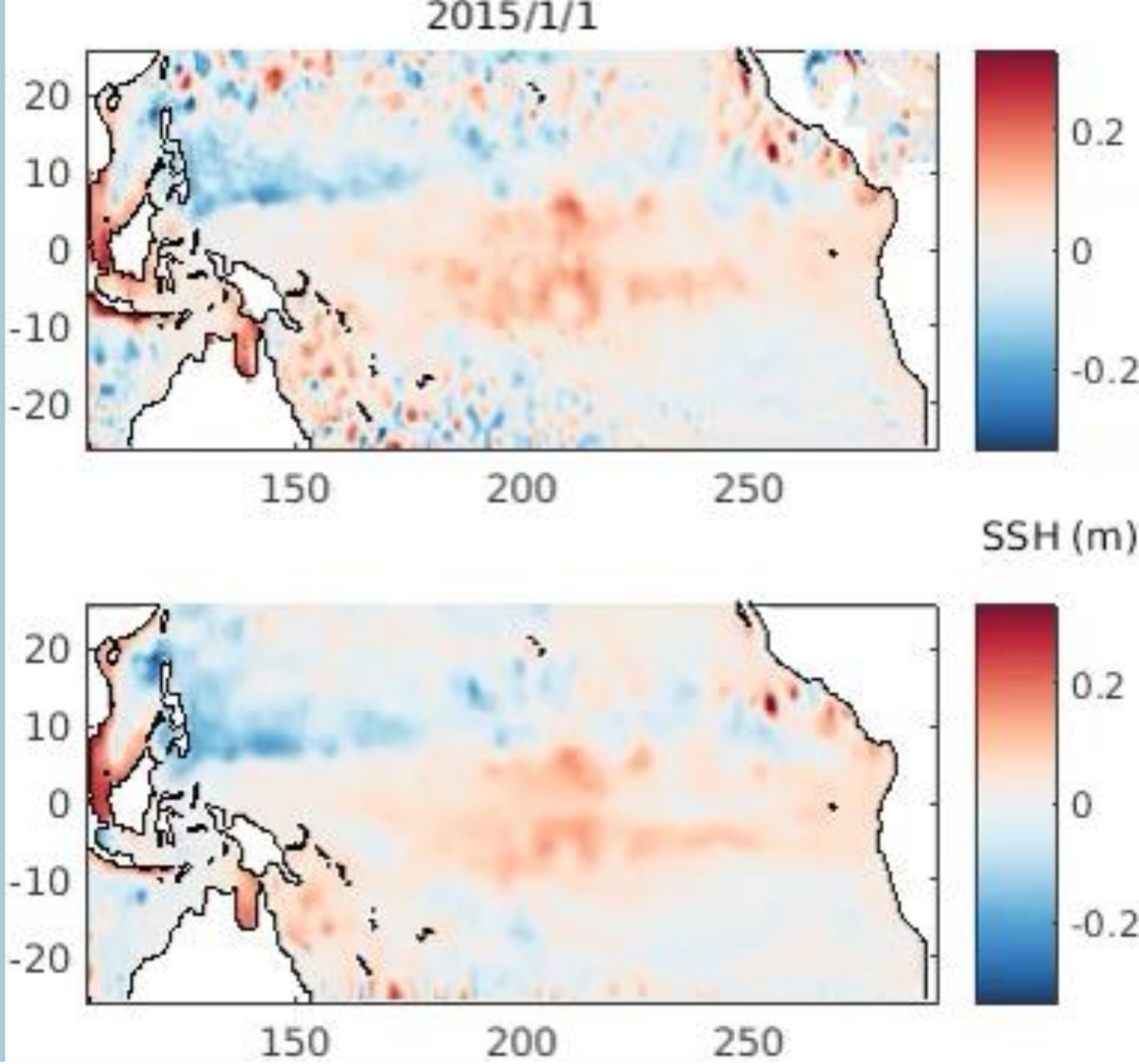


Exploring connections between surface forcing and interior dynamics through mixing

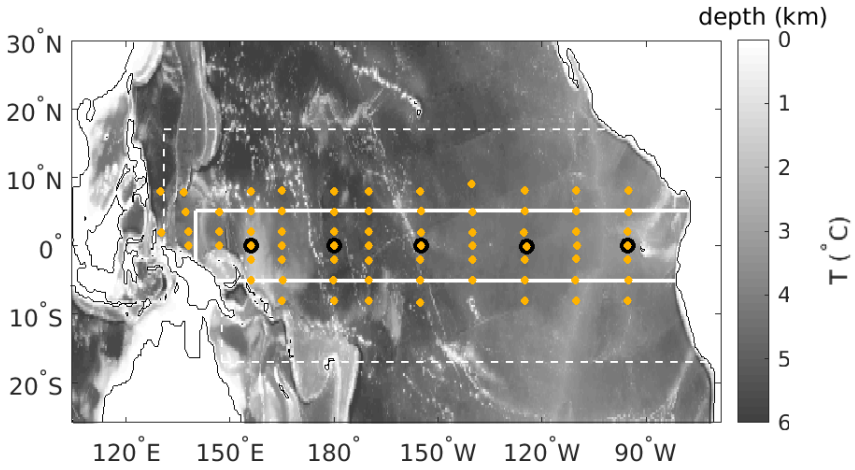
Sea Surface Height (SSH) anomaly

AVISO mapped

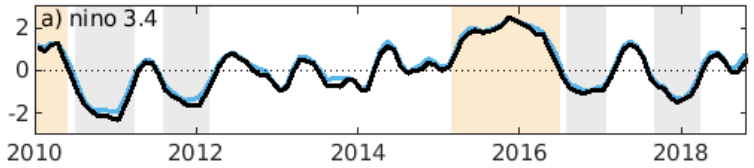
Tropical Pacific State Estimate (TPOSE)



Tropical Pacific State Estimate (TPOSE)



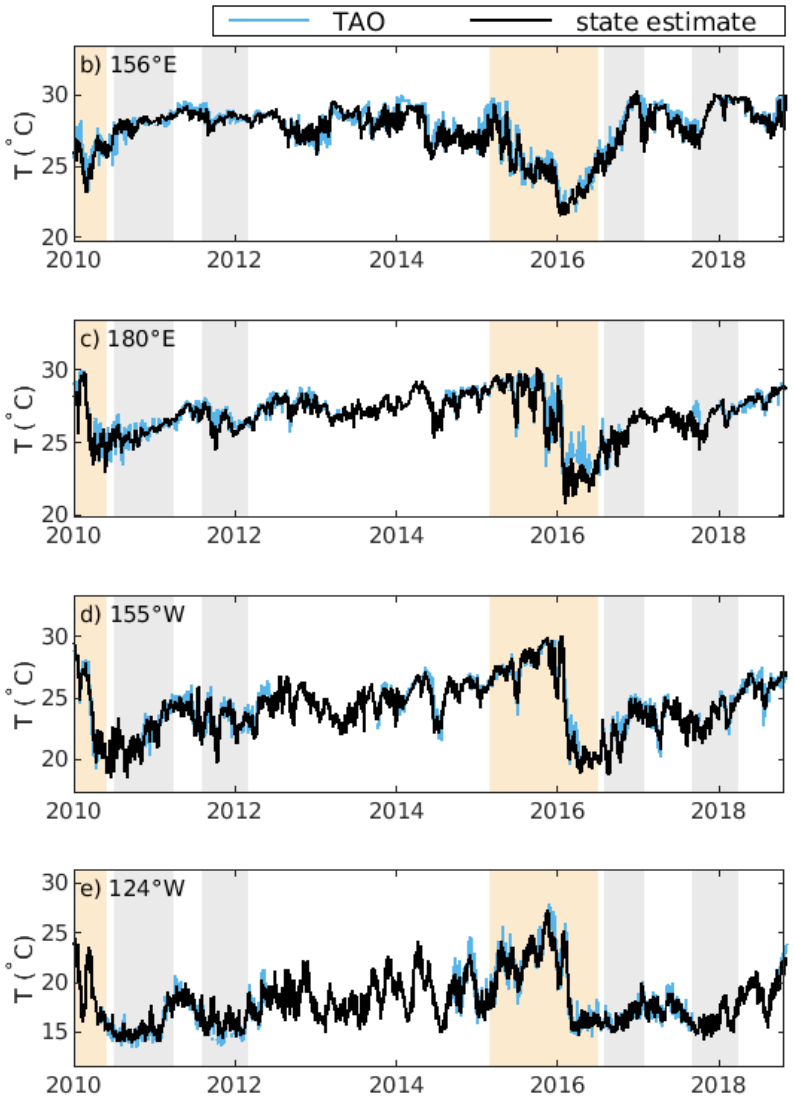
Nino3.4



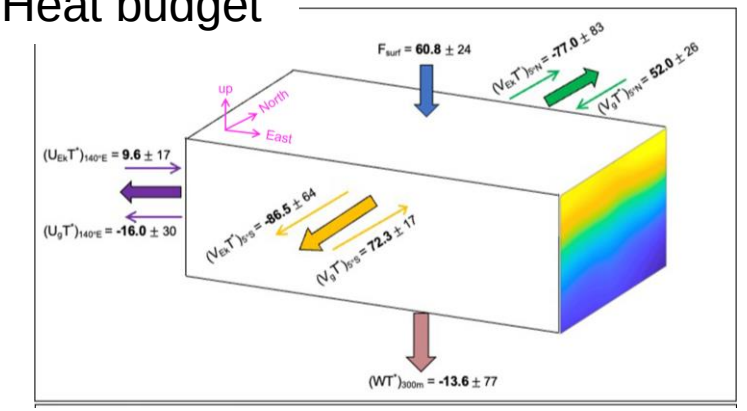
Good fit to observations

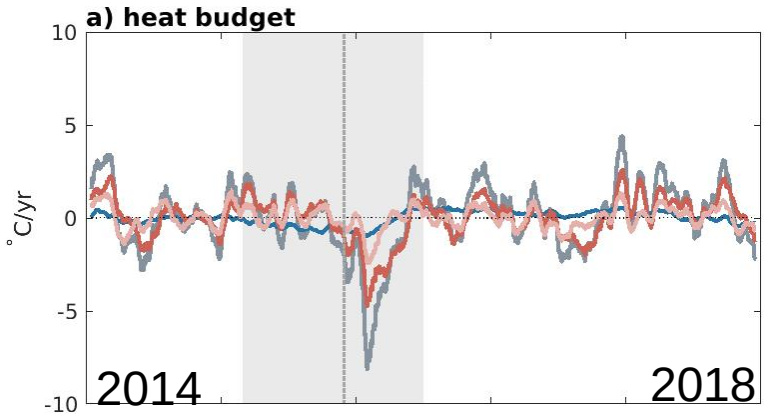
Tool for understanding T, S budgets variability during 2015/16 El Nino

100-m T from TAO moorings (independent data)



Heat budget



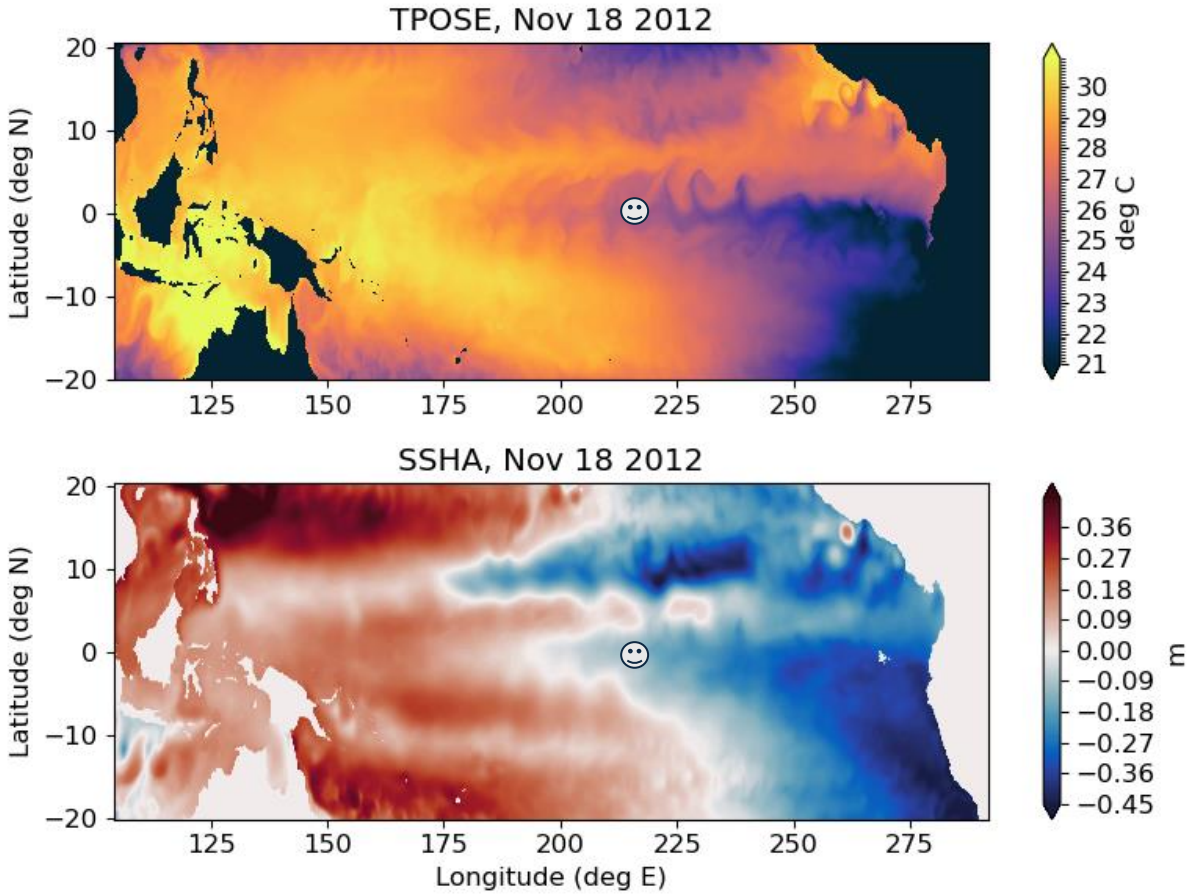


Verdy et al. (2023). **Balancing Volume, Temperature, and Salinity Budgets During 2014-2018 in the Tropical Pacific Ocean State Estimate**. JGR-Oceans

Mechanisms of Zonal Momentum Transport at 0N, 140W in an Ocean State Estimate

Ellen Davenport[1], Ariane Verdy[1], Matt Mazloff[1], Bruce Cornuelle[1], Amy Waterhouse[1], and Dan Whitt[2]

[1]*Scripps Institution of Oceanography*
[2]*NASA Ames*



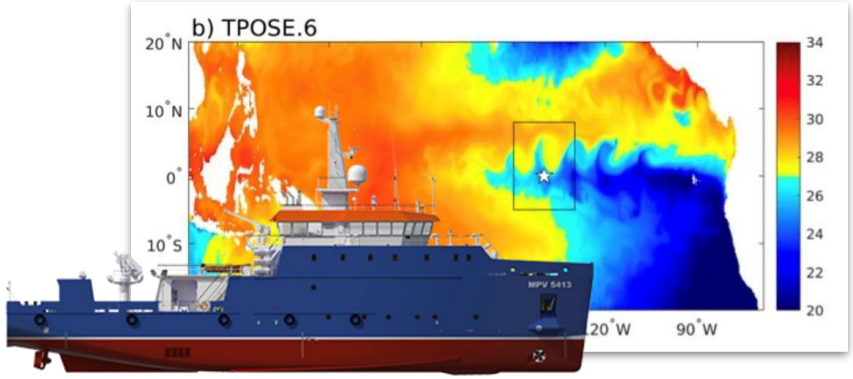
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE

UC San Diego

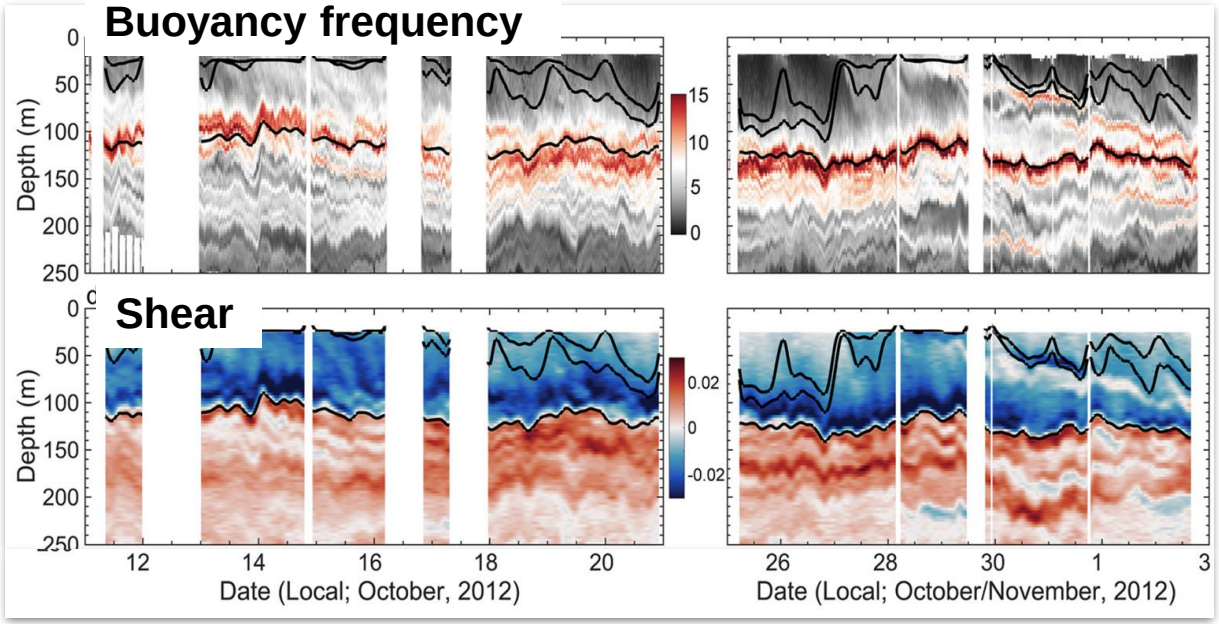
SCRIPPS INSTITUTION OF OCEANOGRAPHY

Tropical Pacific State Estimate (TPOSE)

Ellen Davenport, UCSD

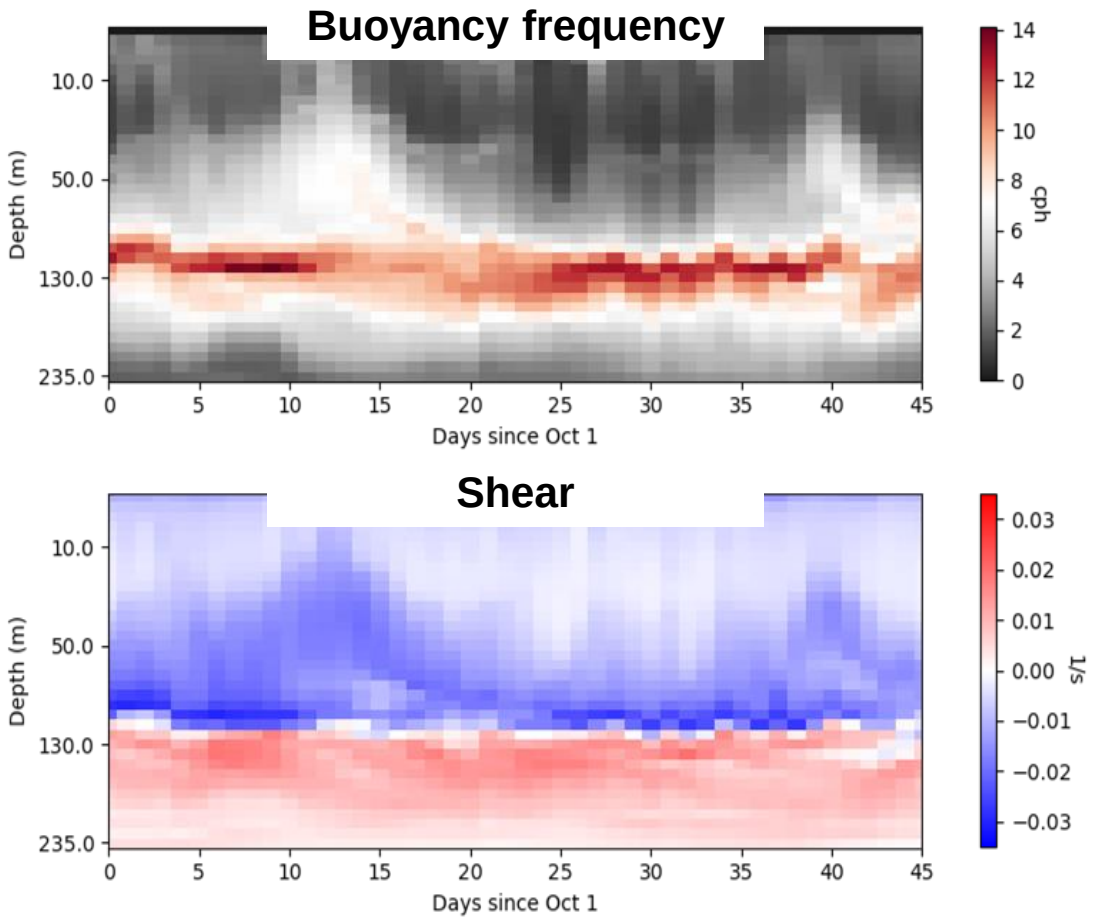


EquatorMix: 0°N,140°W, October 2012

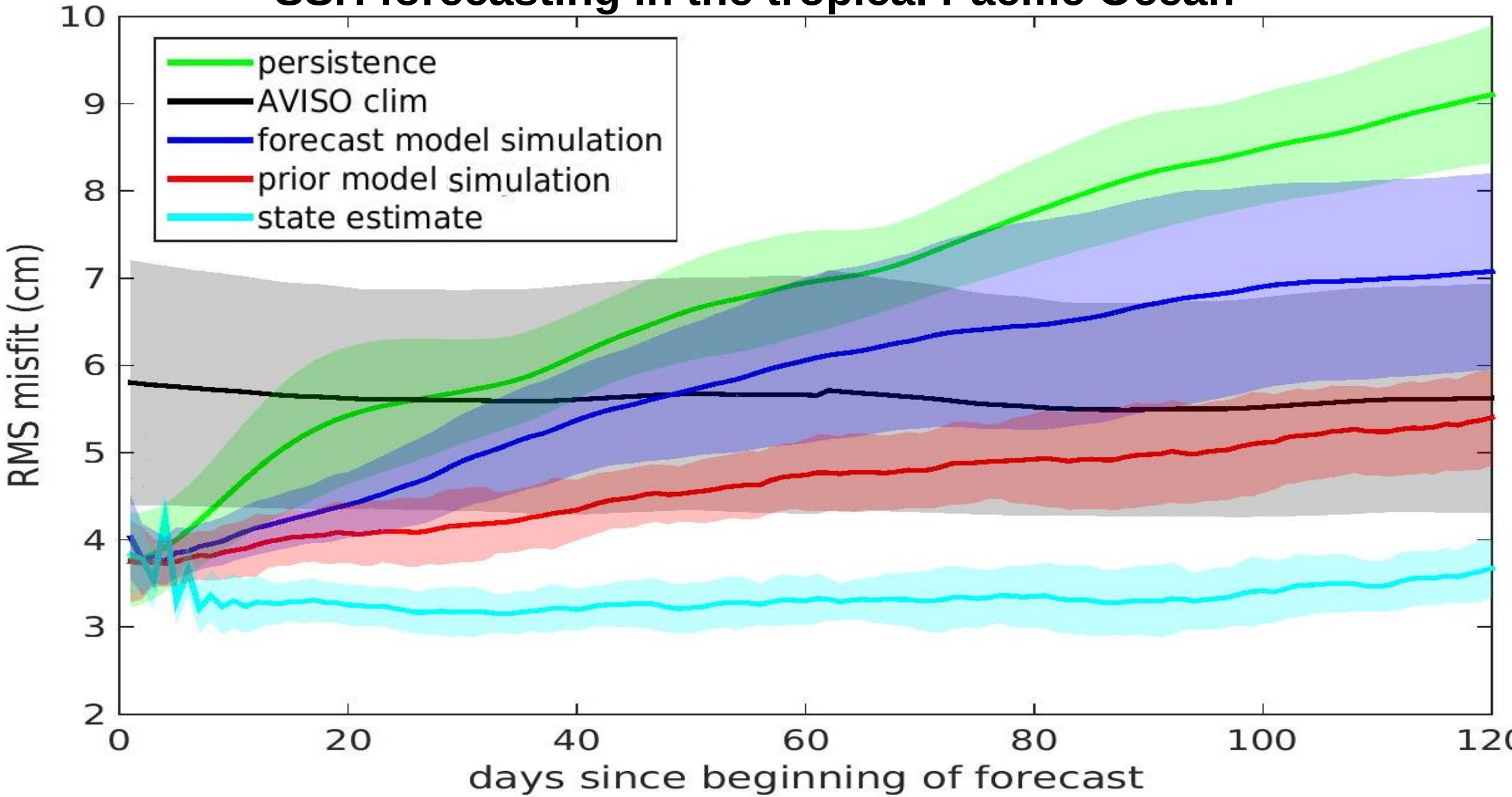


Pinkel et al. (2023) GRL

TPOSE: 0°N,140°W, October 2012



SSH forecasting in the tropical Pacific Ocean

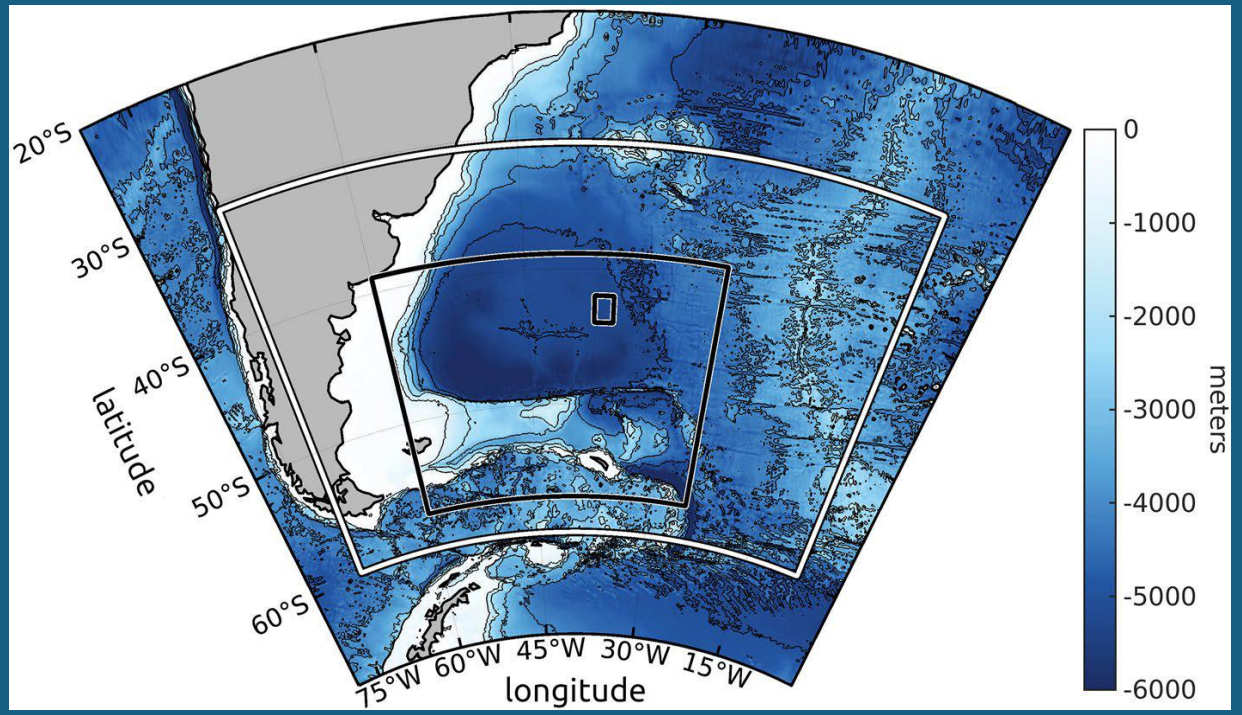


Sources of forecast error: model params, initial conditions, boundary conditions

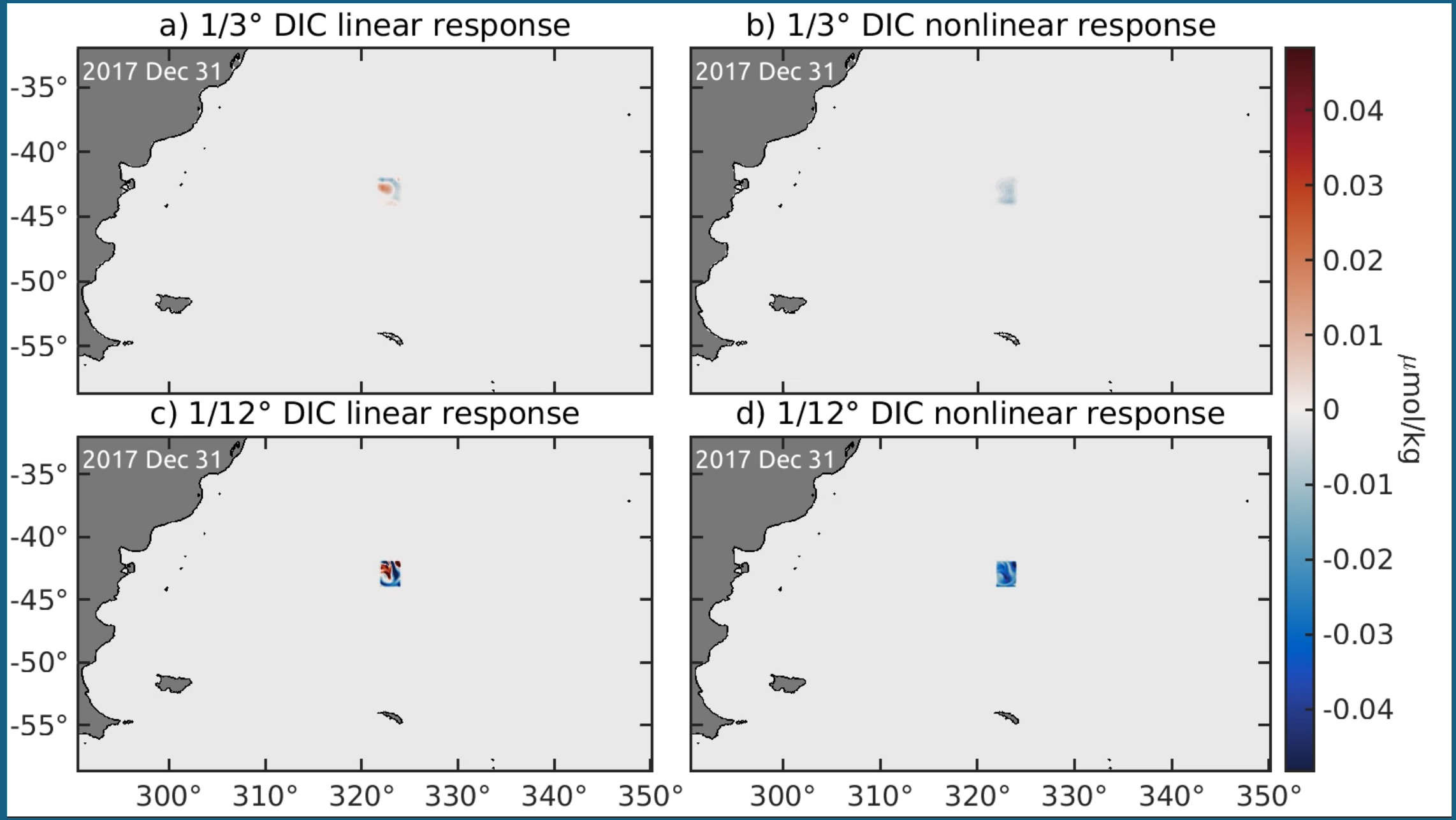
Forecast errors due to amplification of initial condition errors by flow instabilities.

- What skill can be achieved for what lead times?
- May be addressed by increasing or reallocating observations, which requires understanding their structure. What and where to observe to maximize predictability?
- Can we control/damp the chaotic behavior and then parameterize the impact?
- Can we derive a nudging in the form of a parameterization of the chaotic processes?

Investigating Predictability of DIC and SST in the Argentine Basin Through Wind Stress Perturbation Experiments
Swierczek et al, 2021



Sources of error: Forecast errors due to amplification of IC errors by flow instabilities.



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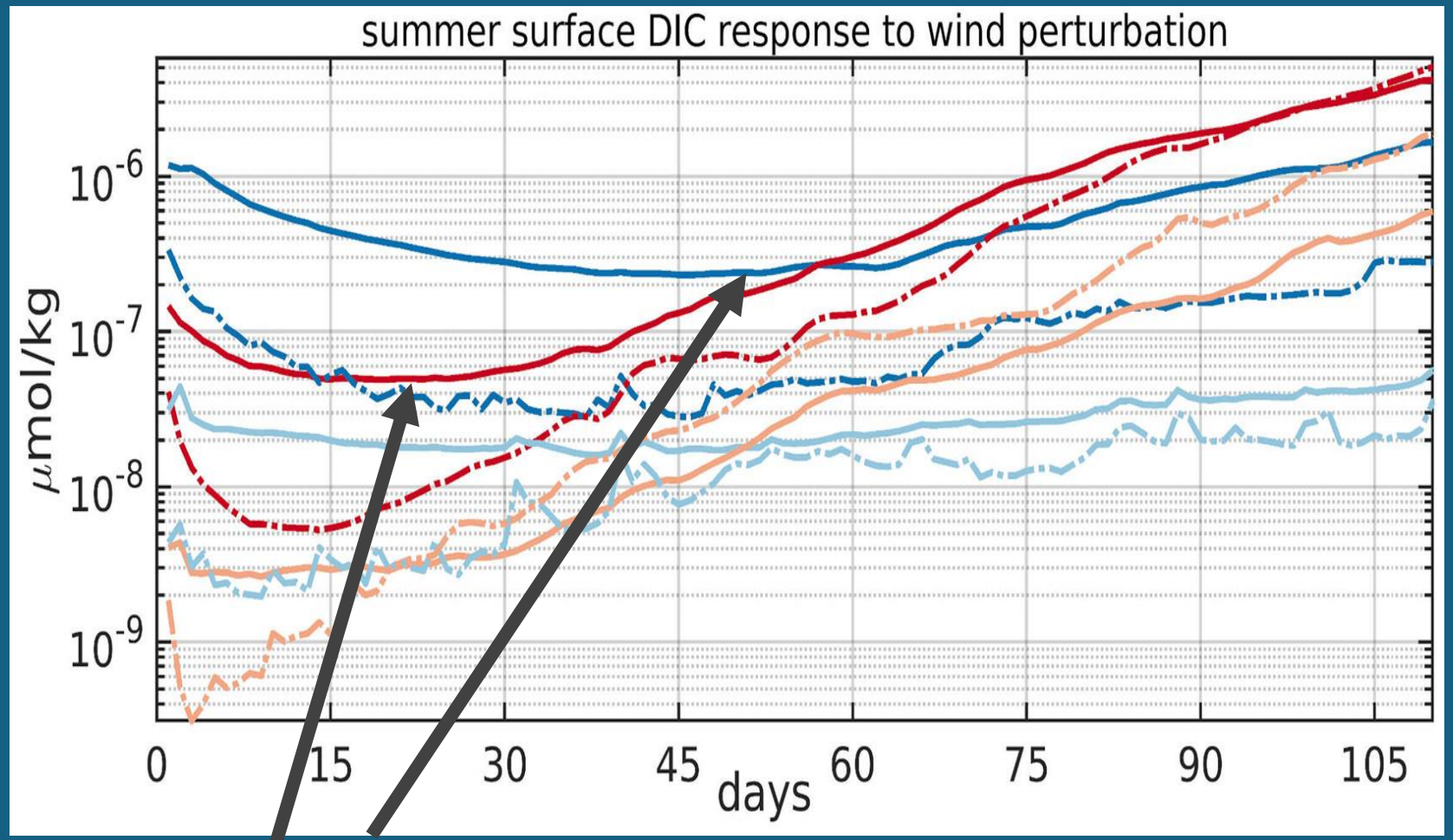
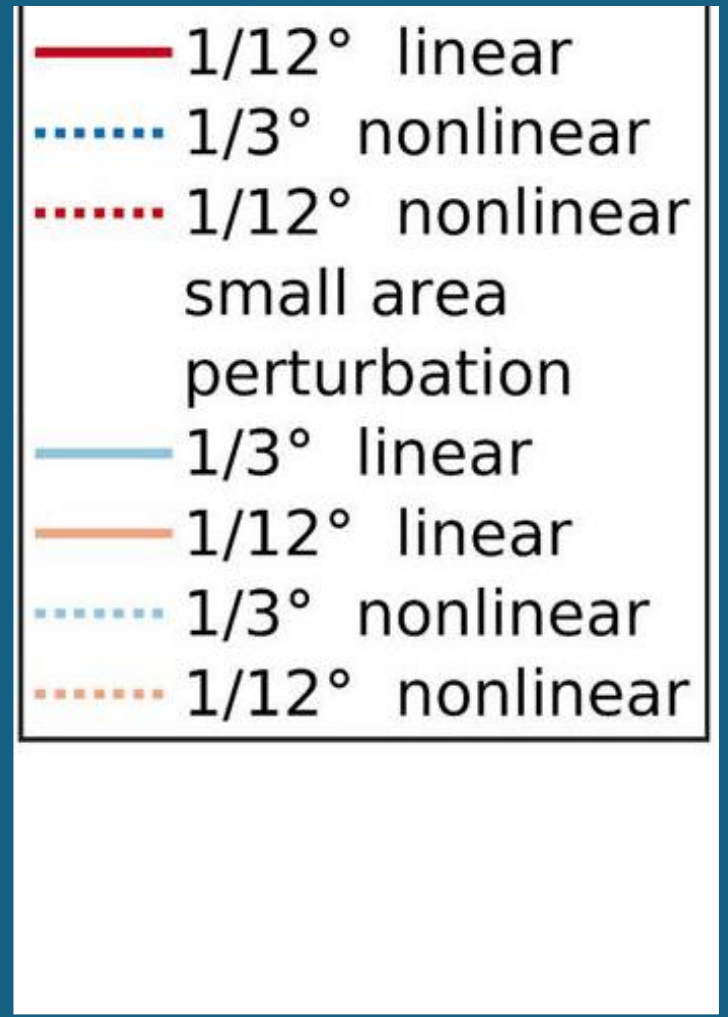


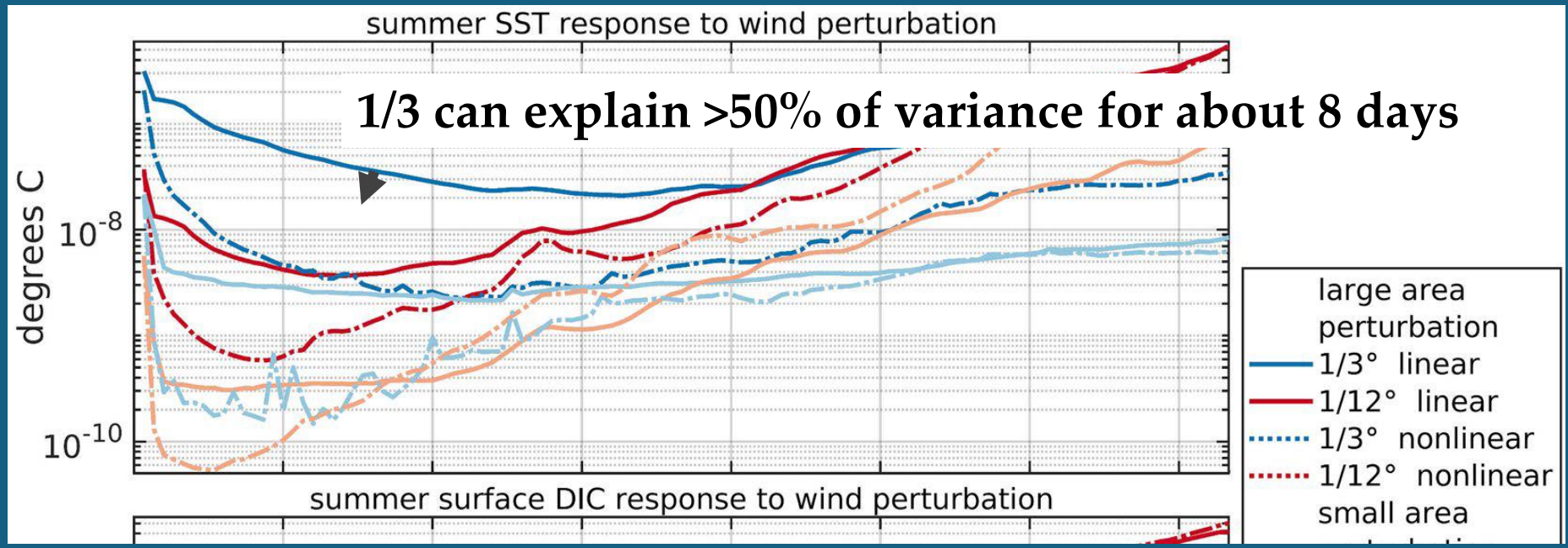


1/3 model loss of predictability about 7 weeks

1/12 model loss of predictability about 3 weeks

Sources of error: Forecast errors due to amplification of IC errors by flow instabilities.

Fraction of variance explained of 1/12 response by 1/3 model



- The 1/3 is more predictable.
- But the 1/3° model response is only consistent with the 1/12° model for about 8 days calling into question the potential predictive skill of the coarser model at longer lead times.

Can we derive a nudging in the form of a parameterization of the chaotic processes?

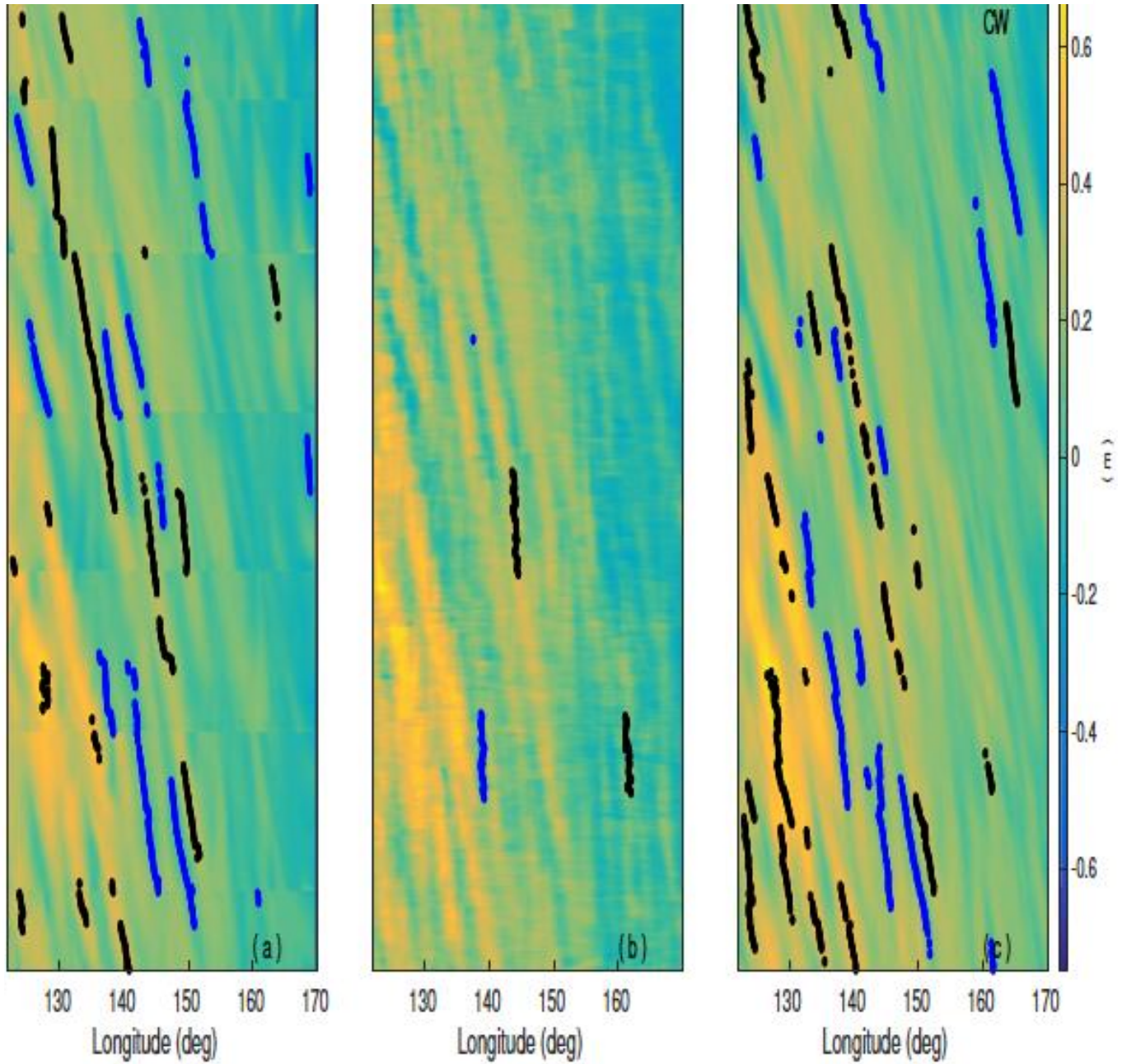
MIT state estimates

HYCOM/NCODA

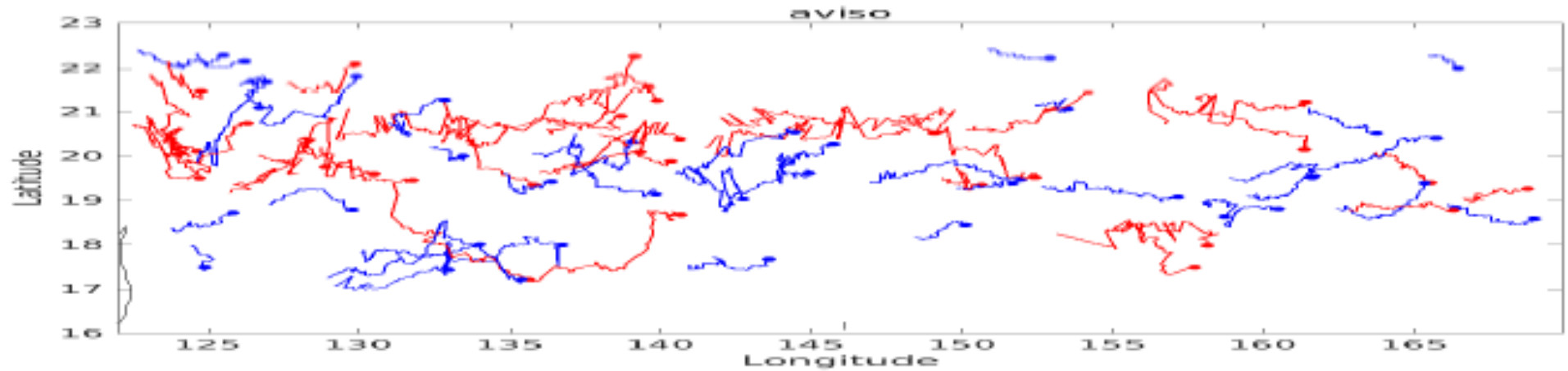
AVISO

April 2011

Sea surface height (m) along 20°N. Eddy detection applied with criteria that lifetime greater than 4 weeks. The eddy locations shown in blue (CCW) and black (CW)



April 2010


aviso
Latitude
Longitude
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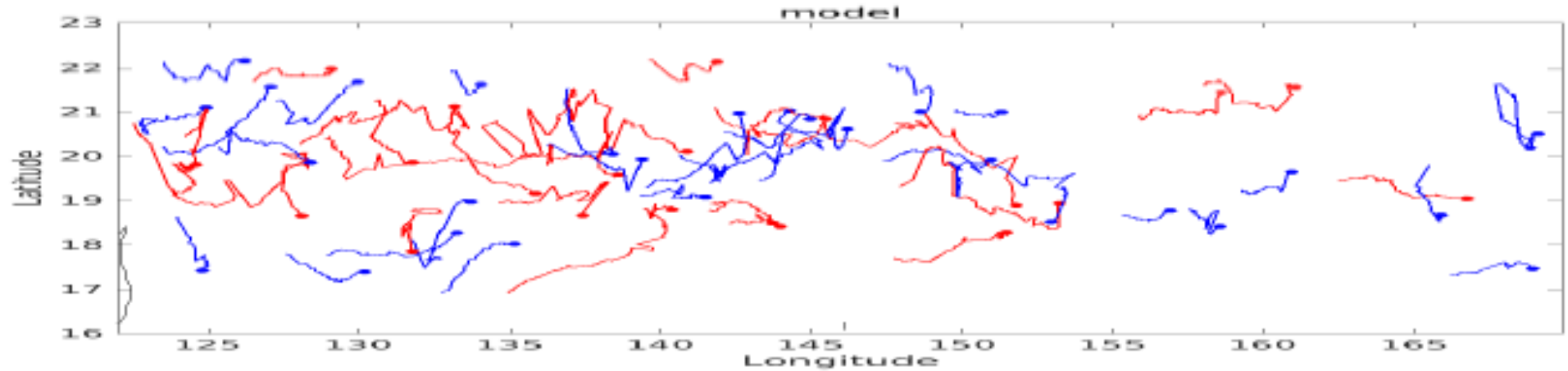
model
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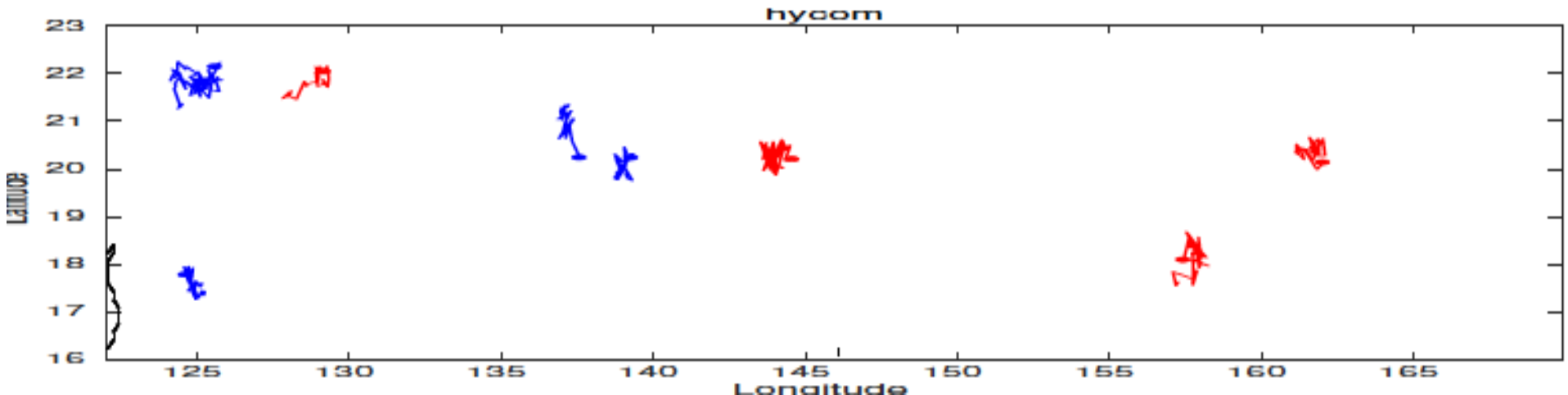
hycom
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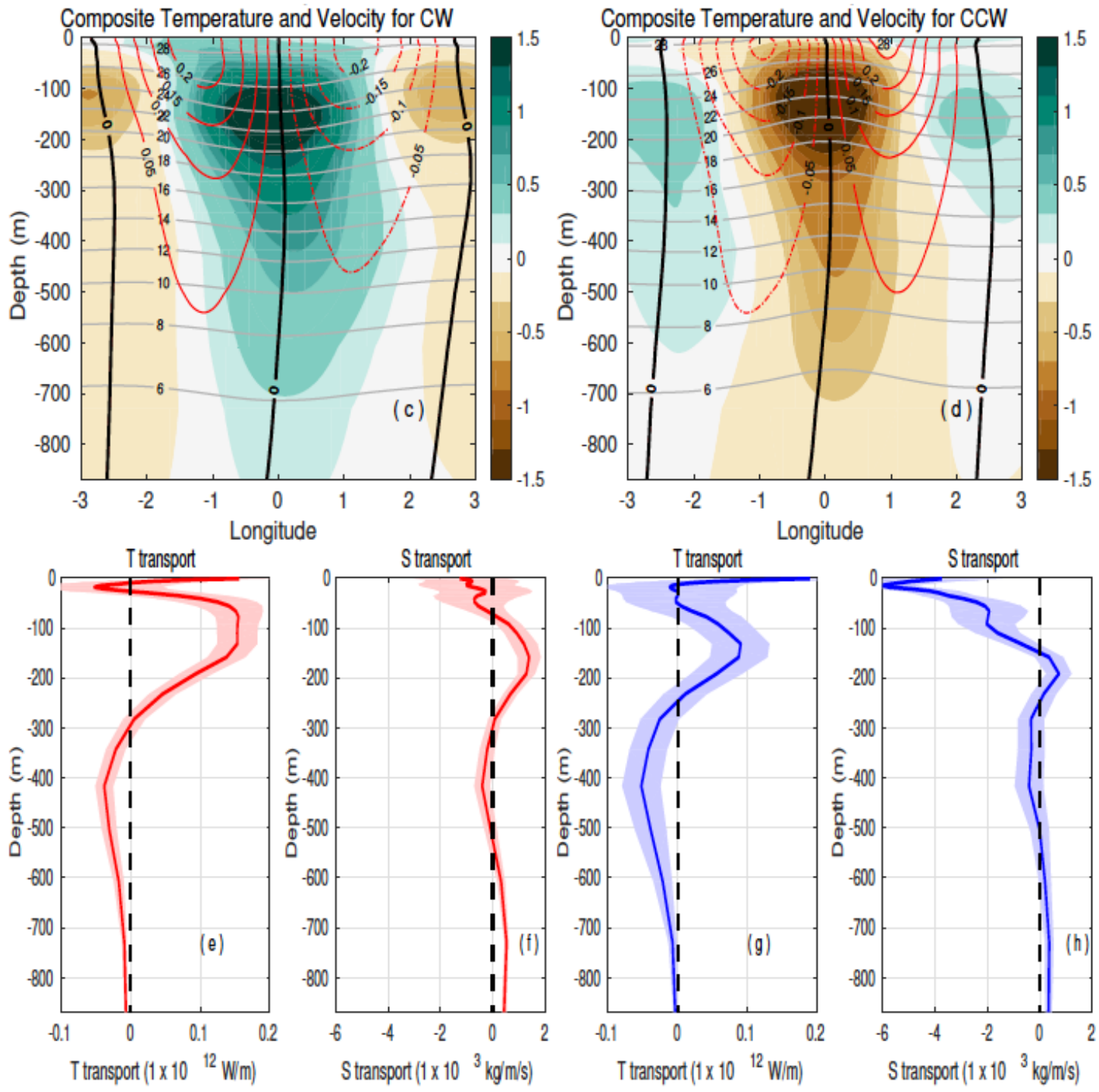
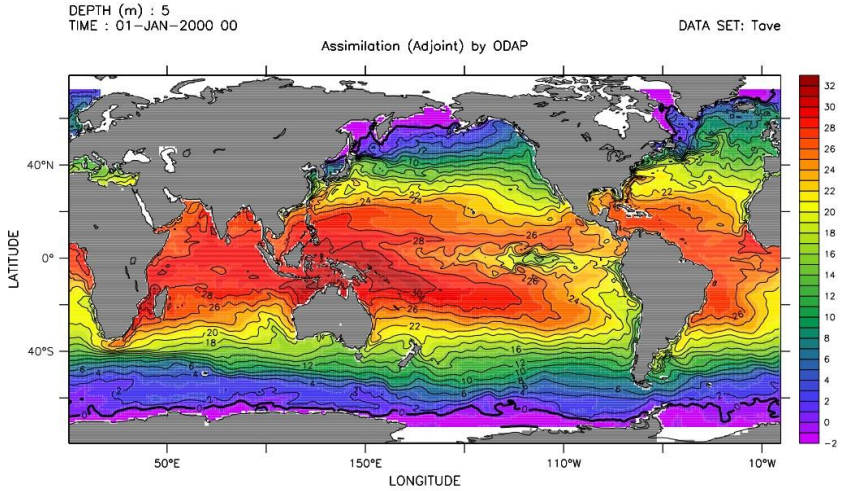
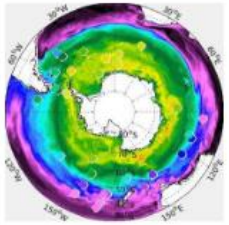

Composite Temperature and Velocity for CW
Composite Temperature and Velocity for CCW
Depth (m)
Longitude
(c)
(d)
T transport
S transport
(e)
(f)
(g)
(h)
T transport (1 x 10 12 W/m)
S transport (1 x 10 3 kg/m/s)

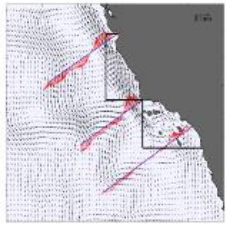
ECCO software enables numerous applications

Flagship: 1992 to present production run

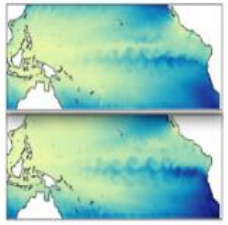




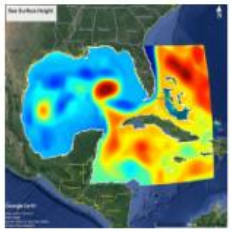
Southern Ocean State Estimate (SOSE)



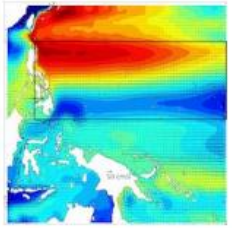
California Current System State Estimate (CASE)



Tropical Pacific Ocean State Estimate (TPOSE)



Gulf of Mexico State Estimate (GoM)



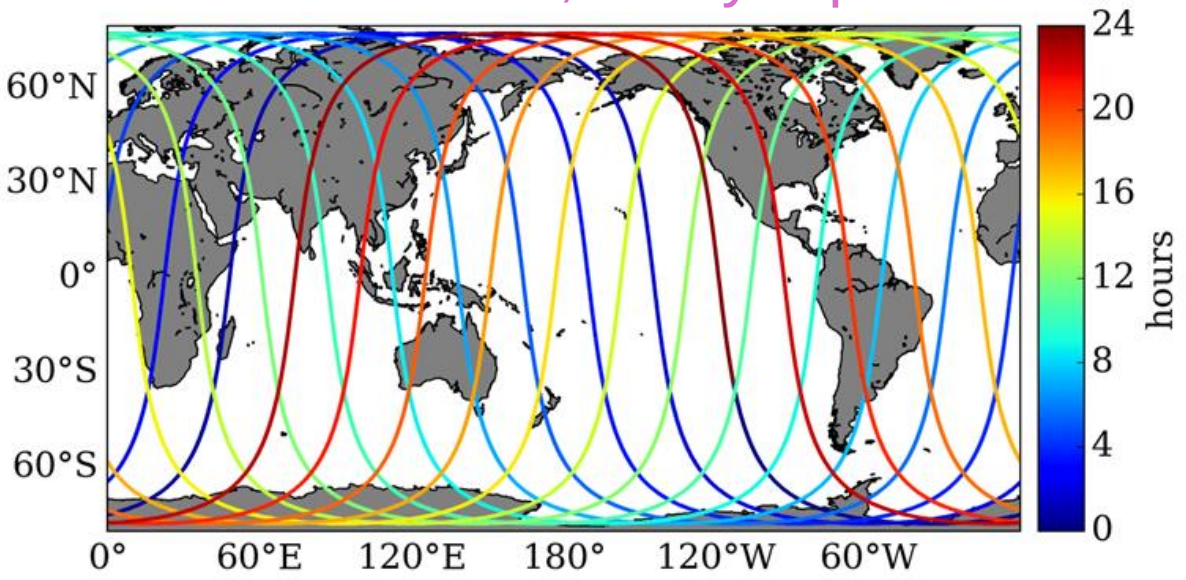
Northwest Pacific State Estimate (NWPac)

Targeted efforts can enable

- Reproducing eddies: currently intrinsic eddies only controllable with initial conditions.
- Consistency with specific system components (e.g. BGC, coast, internal waves)
- Consistency in specific regions or times, or with specific obs platforms. Here the optimization problem can be framed to prioritize consistency
- Observing system design
- Forecasting: goal of state estimate is to provide forecast initialization
- Development

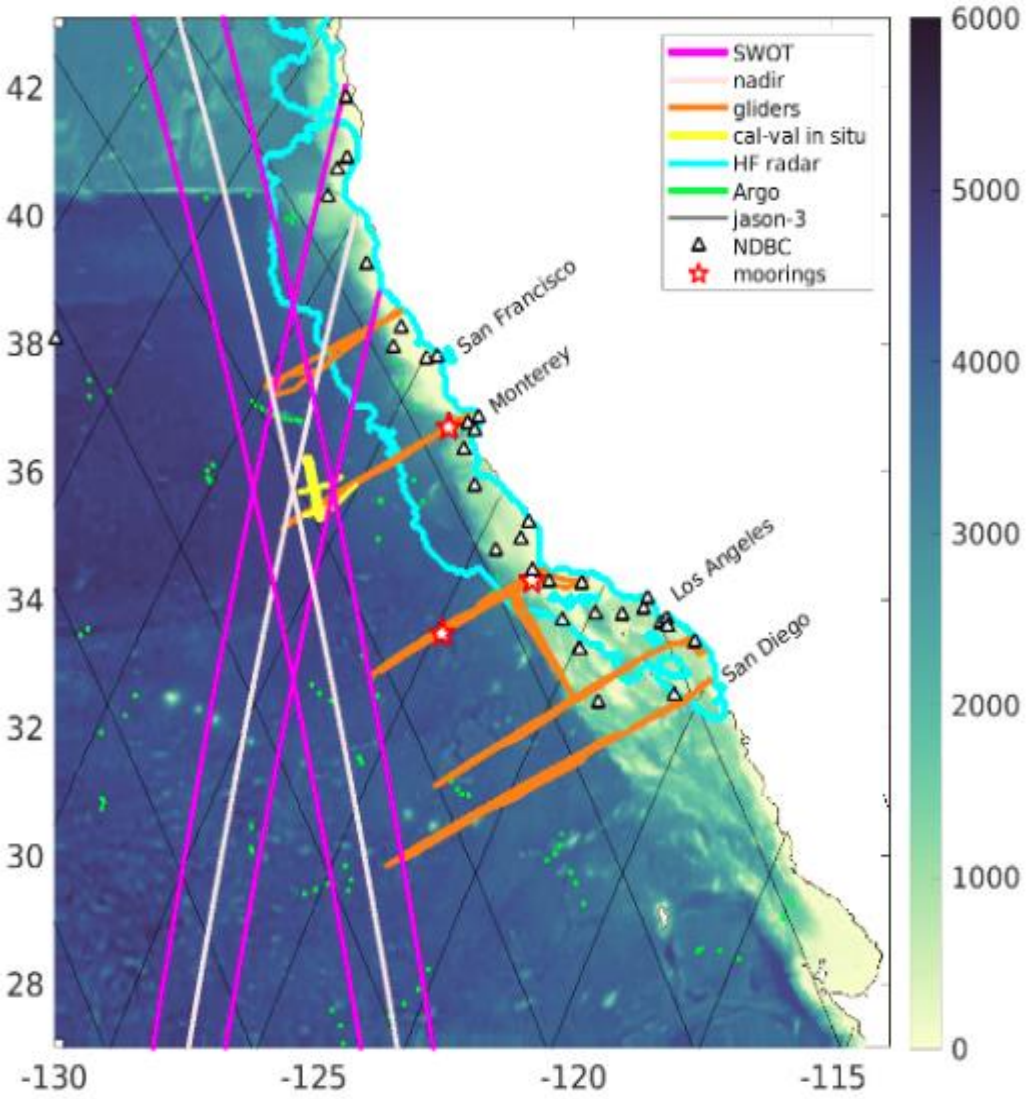
California Current System (CCS)

SWOT altimeter, 1-day repeat



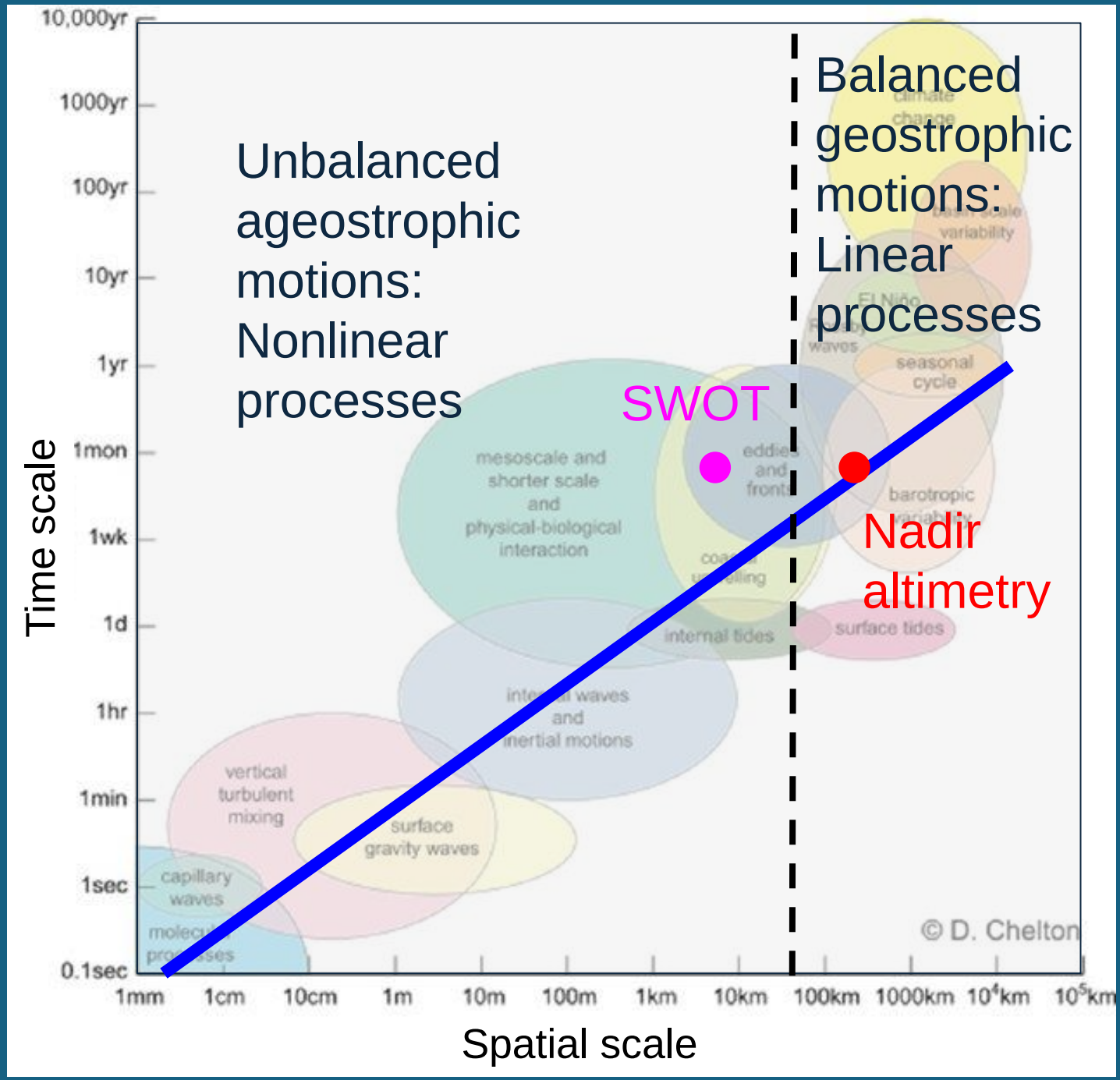
4D-Var assimilation for SWOT: from geostrophic balance to km-scale dynamics

Observing system

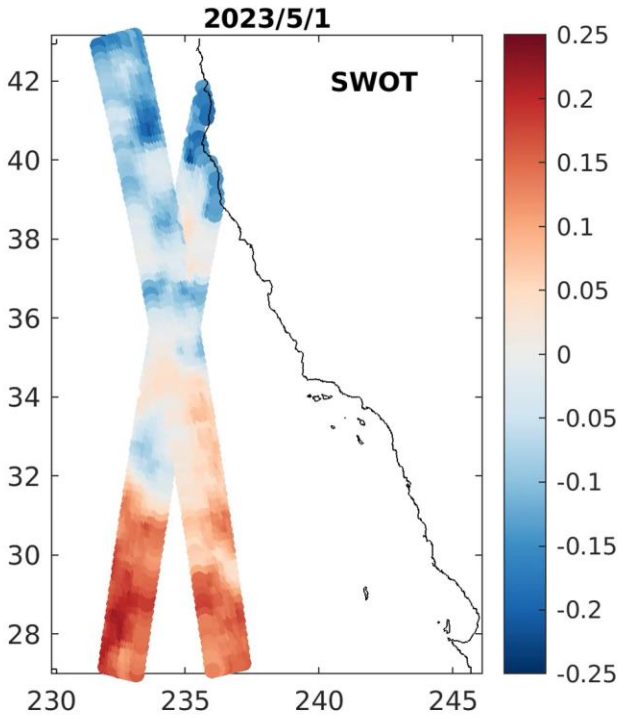


The SWOT Challenge

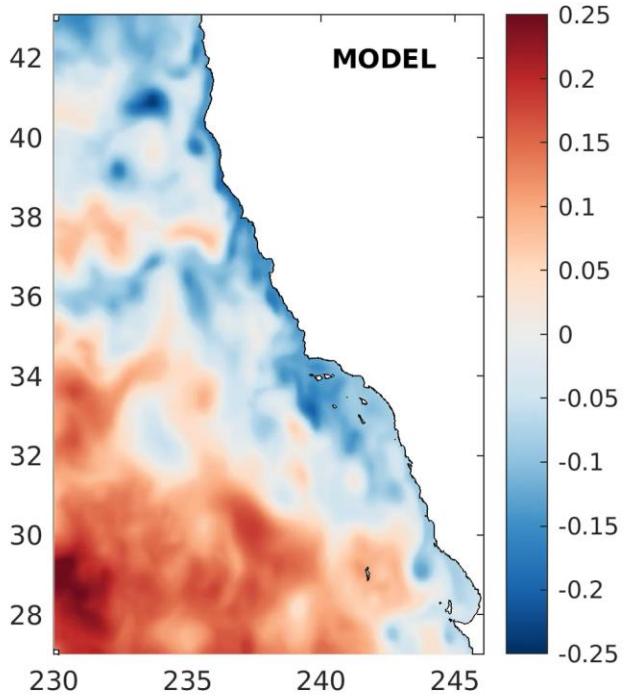
- How do we take advantage of SWOT's spatial resolution, without corresponding temporal resolution?
- Our goal: **with 4D-Var assimilation, use data to constrain dynamics**



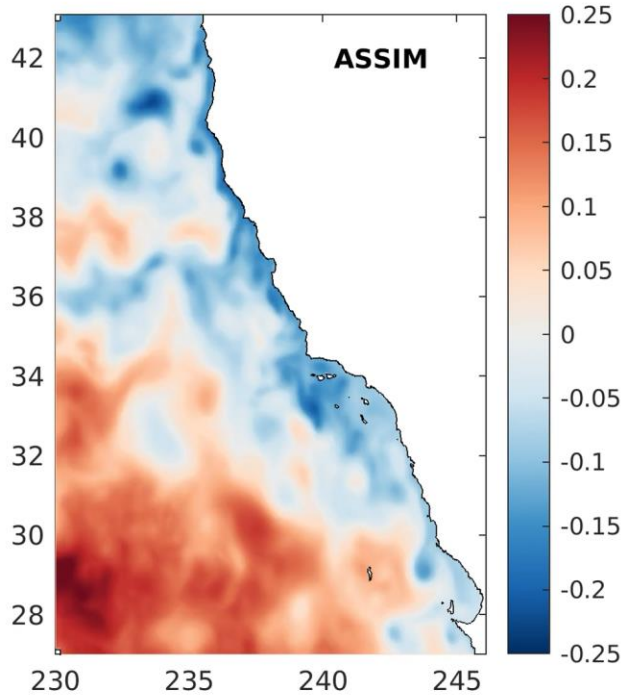
Observed and modeled SSH



Observations



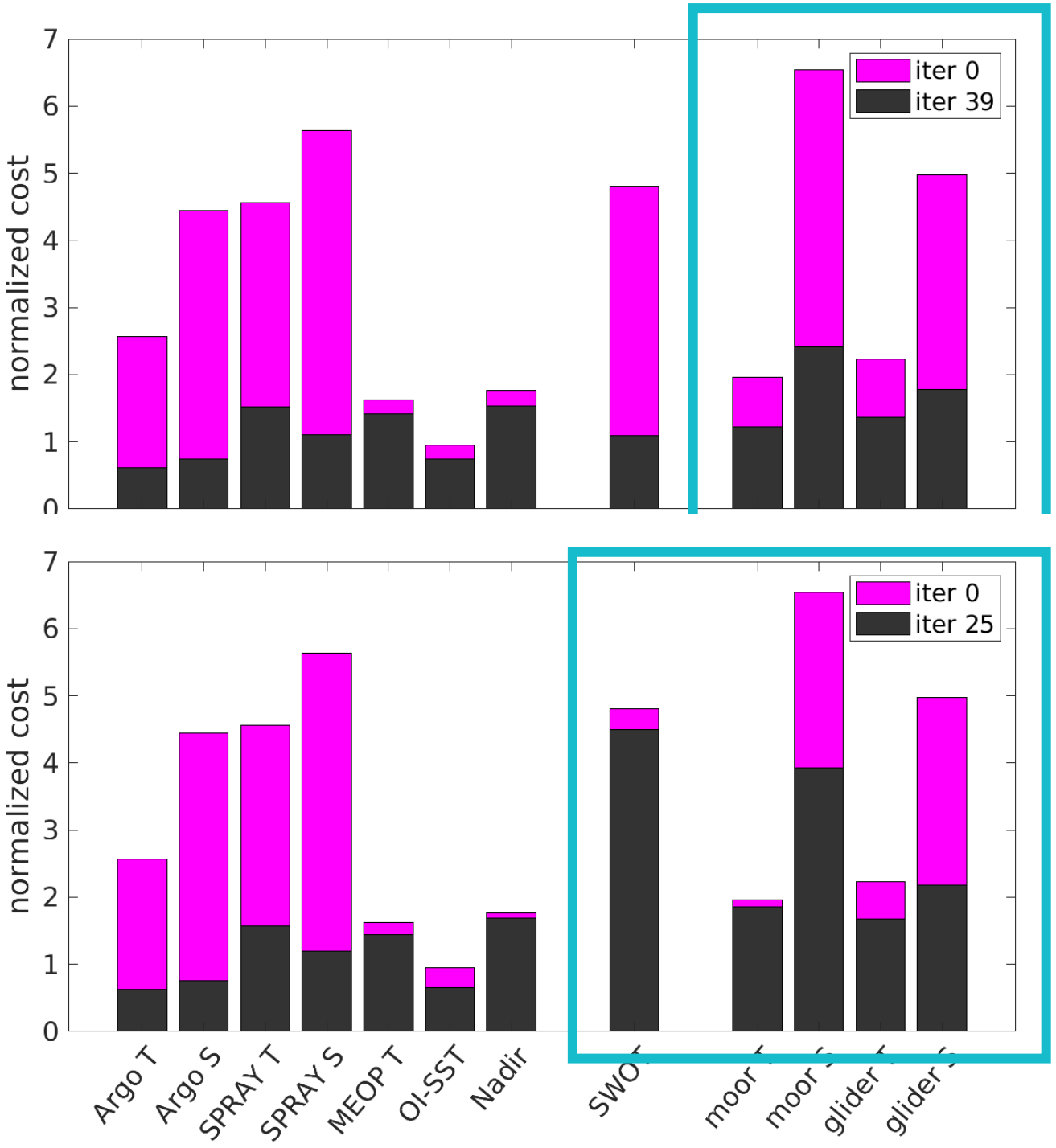
Forward model run (iteration 0)



State estimate (iteration 39)

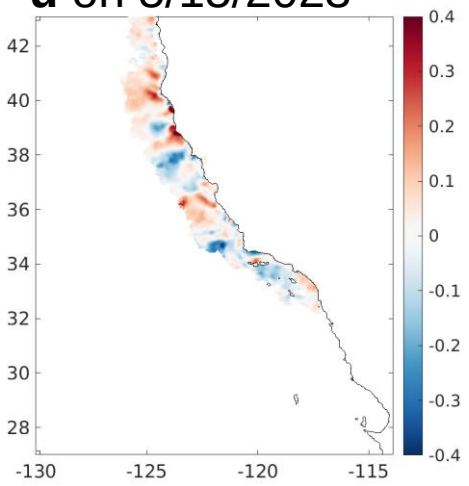
SWOT assimilated

SWOT withheld

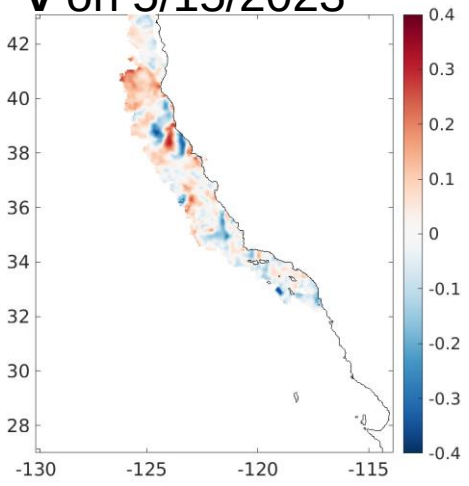


Independent data (not assimilated)

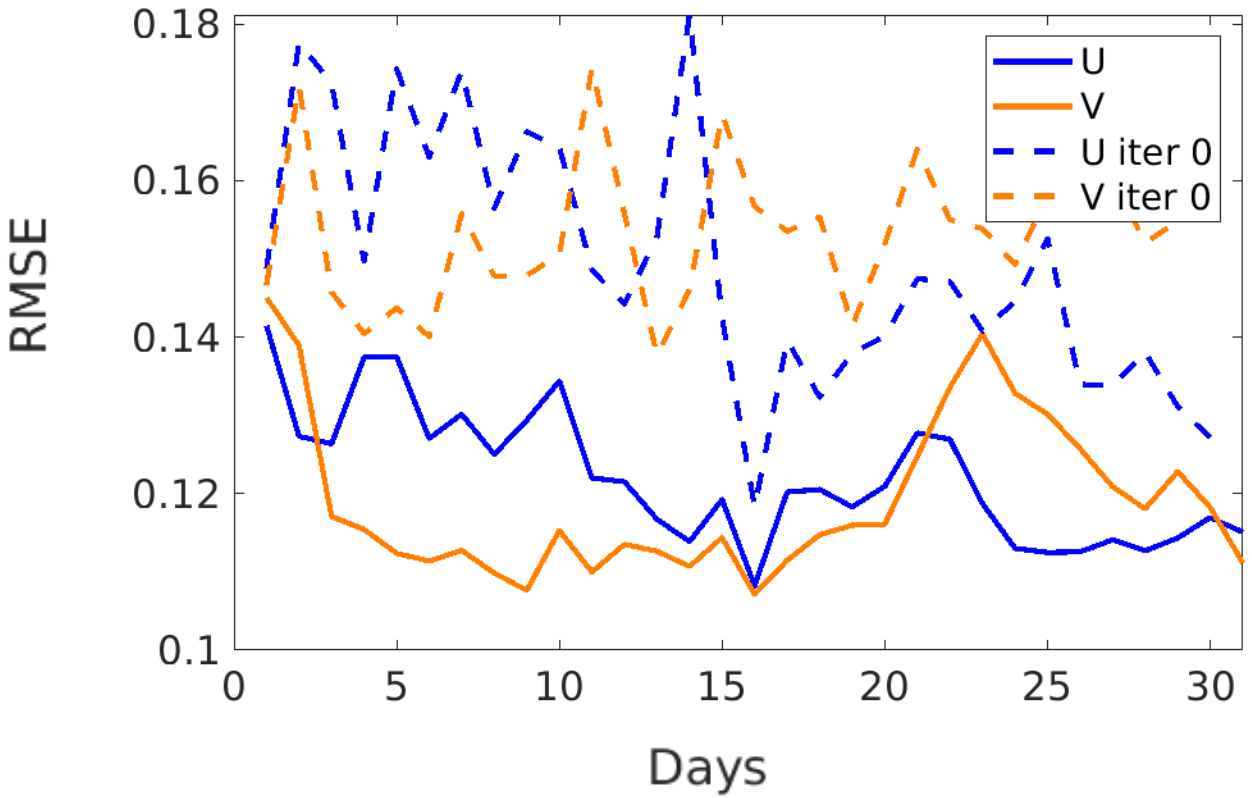
u on 5/15/2023



v on 5/15/2023

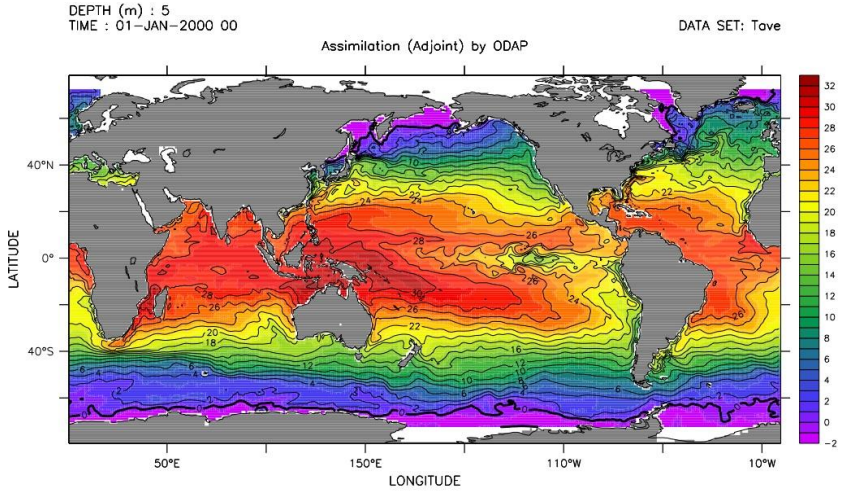


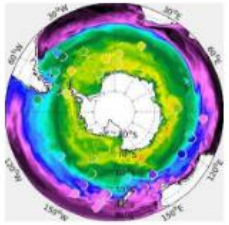
HF radar misfits vs time



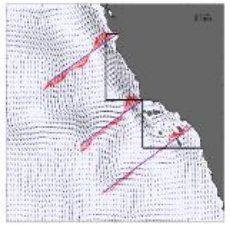
ECCO software enables numerous applications

Flagship: 1992 to present production run

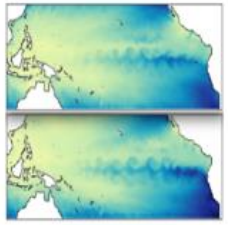




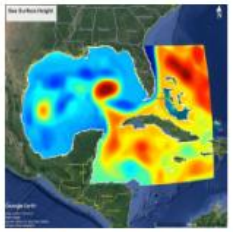
Southern Ocean State Estimate (SOSE)



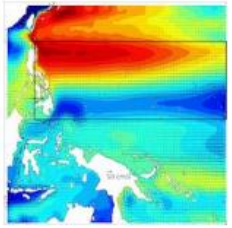
California Current System State Estimate (CASE)



Tropical Pacific Ocean State Estimate (TPOSE)



Gulf of Mexico State Estimate (GoM)



Northwest Pacific State Estimate (NWPac)

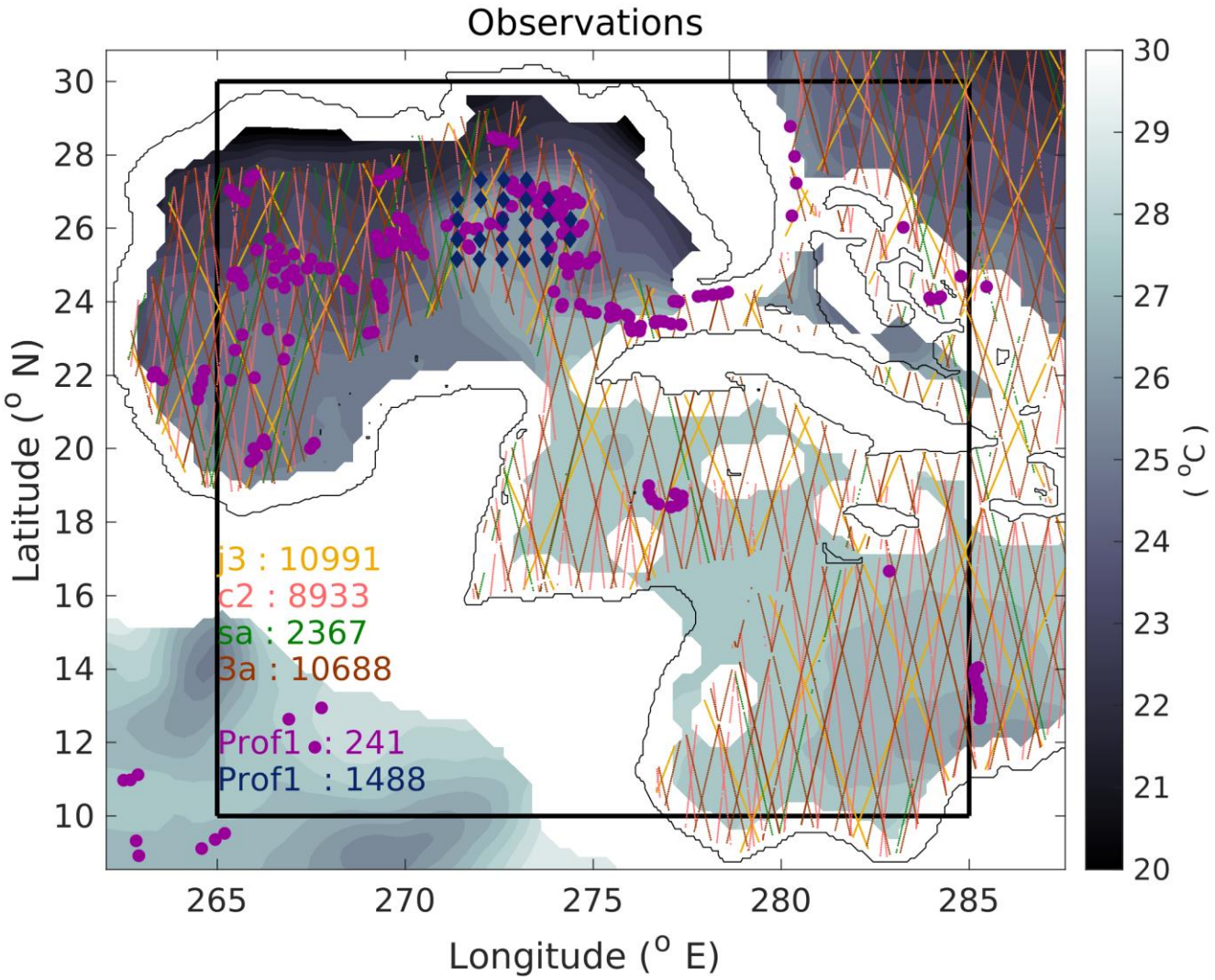
Targeted efforts can enable

- Reproducing eddies: currently intrinsic eddies only controllable with initial conditions.
- Consistency with specific system components (e.g. BGC, coast, internal waves)
- Consistency in specific regions or times, or with specific obs platforms. Here the optimization problem can be framed to prioritize consistency
- Observing system design
- Forecasting: goal of state estimate is to provide forecast initialization


Regional models are great for targeted efforts
• Reproducing small scales
• Consistency with specific system components, regions, times, obs platforms
• Observing system design
• Forecasting
• Development


But beware the open boundaries!!!

Gulf of Mexico State Estimation and Prediction



Observing system design for loop current and eddy shedding

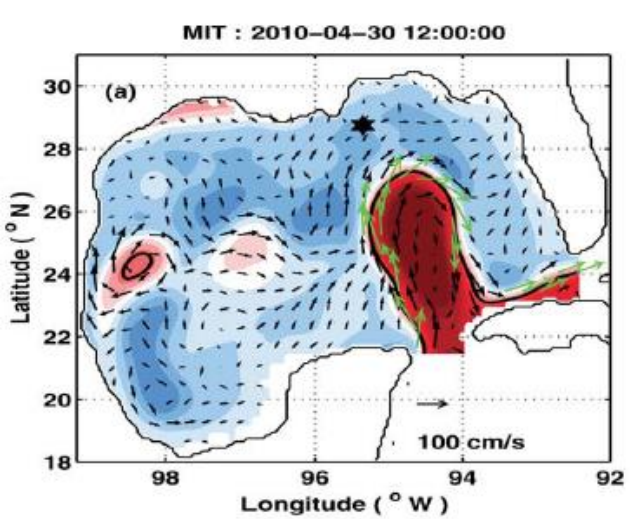
- SSH along-track anomalies
- Gridded OI-SST
- Argo program T/S profiles
- CPIES T/S profiles

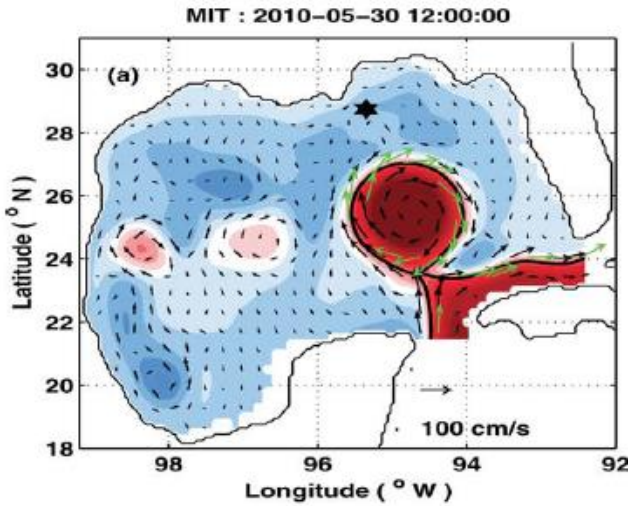
Forecasting the loop current
Gopalakrishnan et al 2013

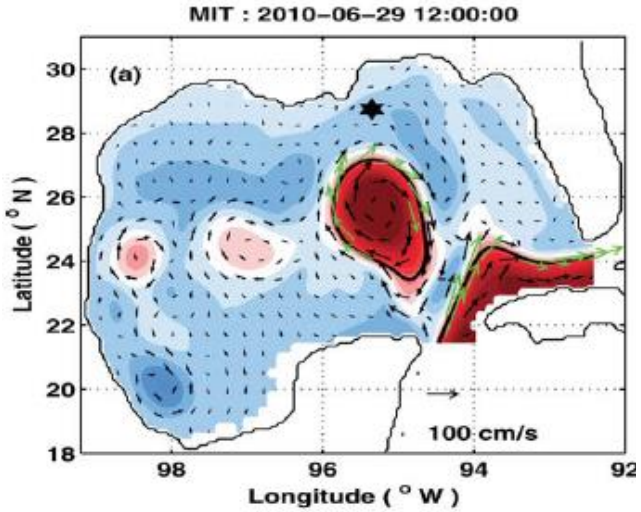
End of 2 month state estimate

Forecast at 1 month

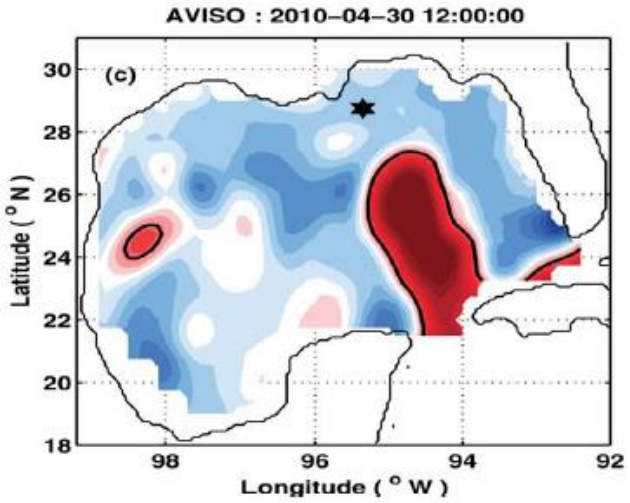
Forecast at 2 months

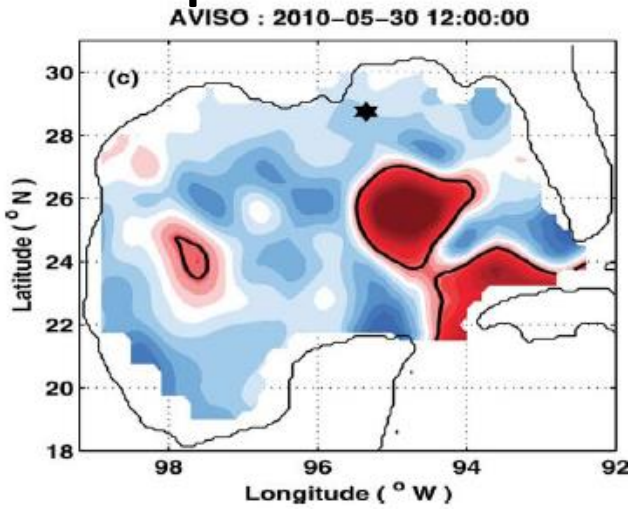


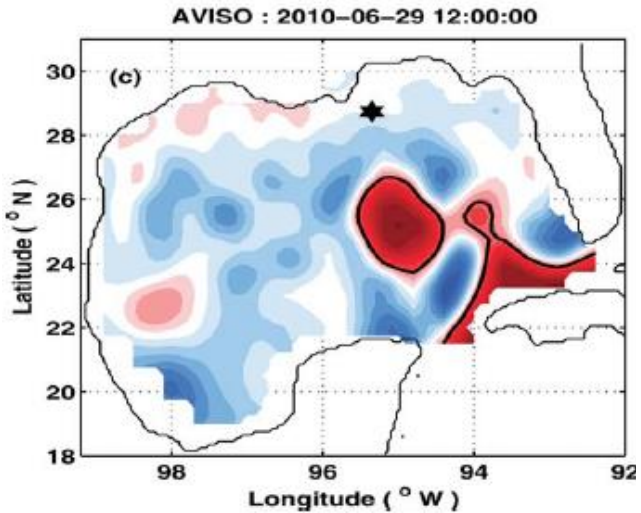


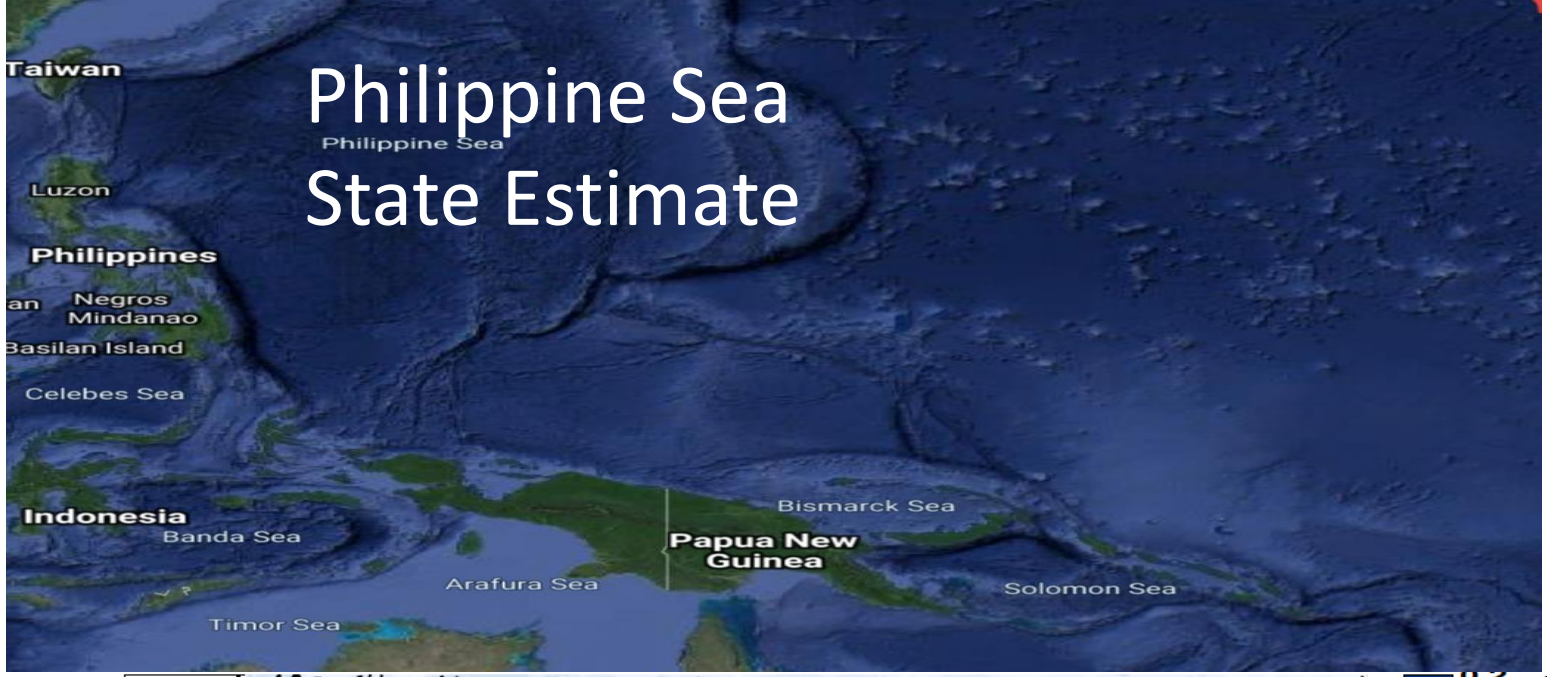


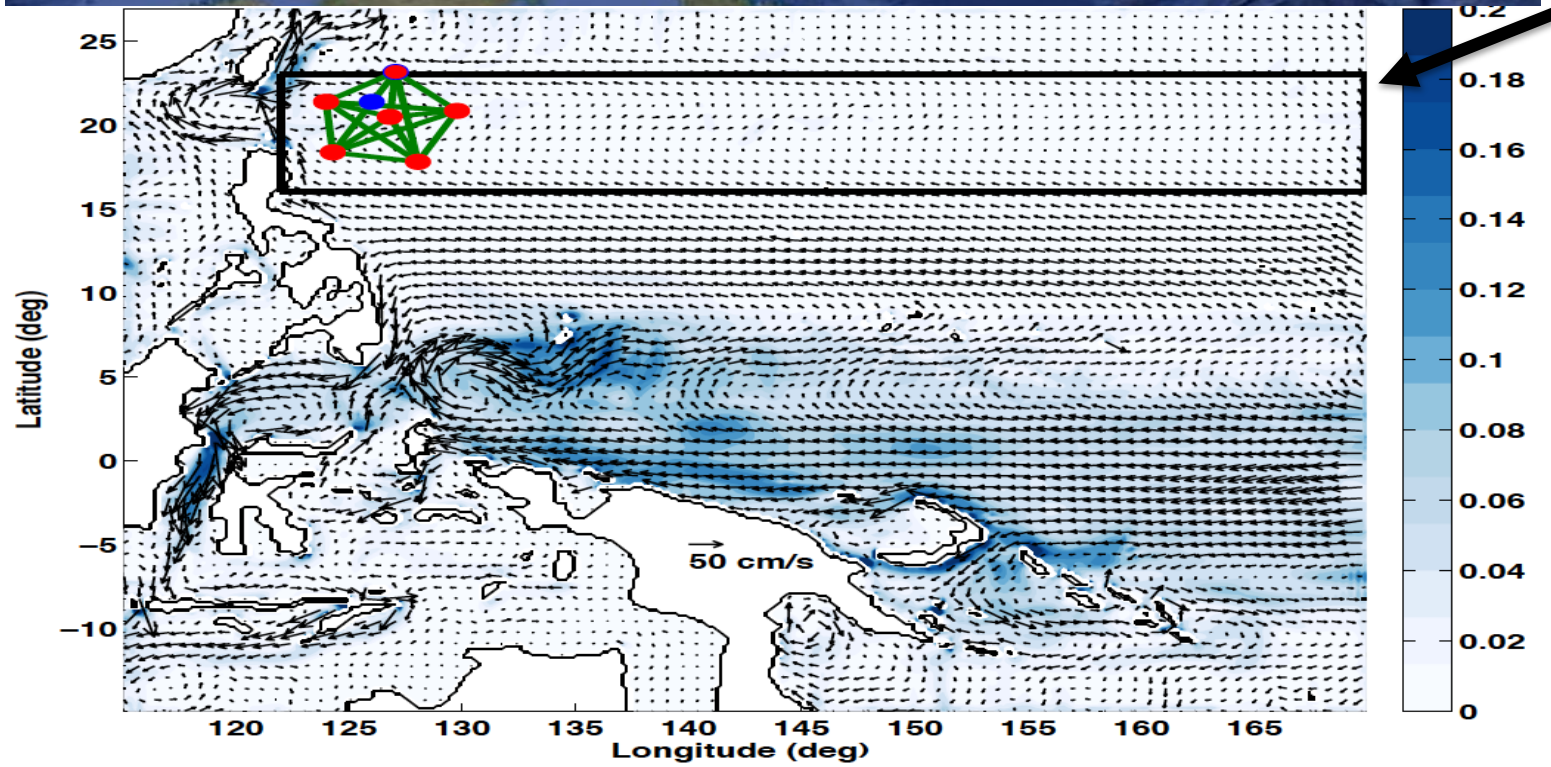
AVISO at particular time











Eddies drive transport across box. Nonlinear dynamics dominate, but eddies persist for many months. Can we estimate eddy fluxes?