SWOT Science Team Meeting
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Increasing the Resolution of Mapped Sea Surface Height in the California Current system

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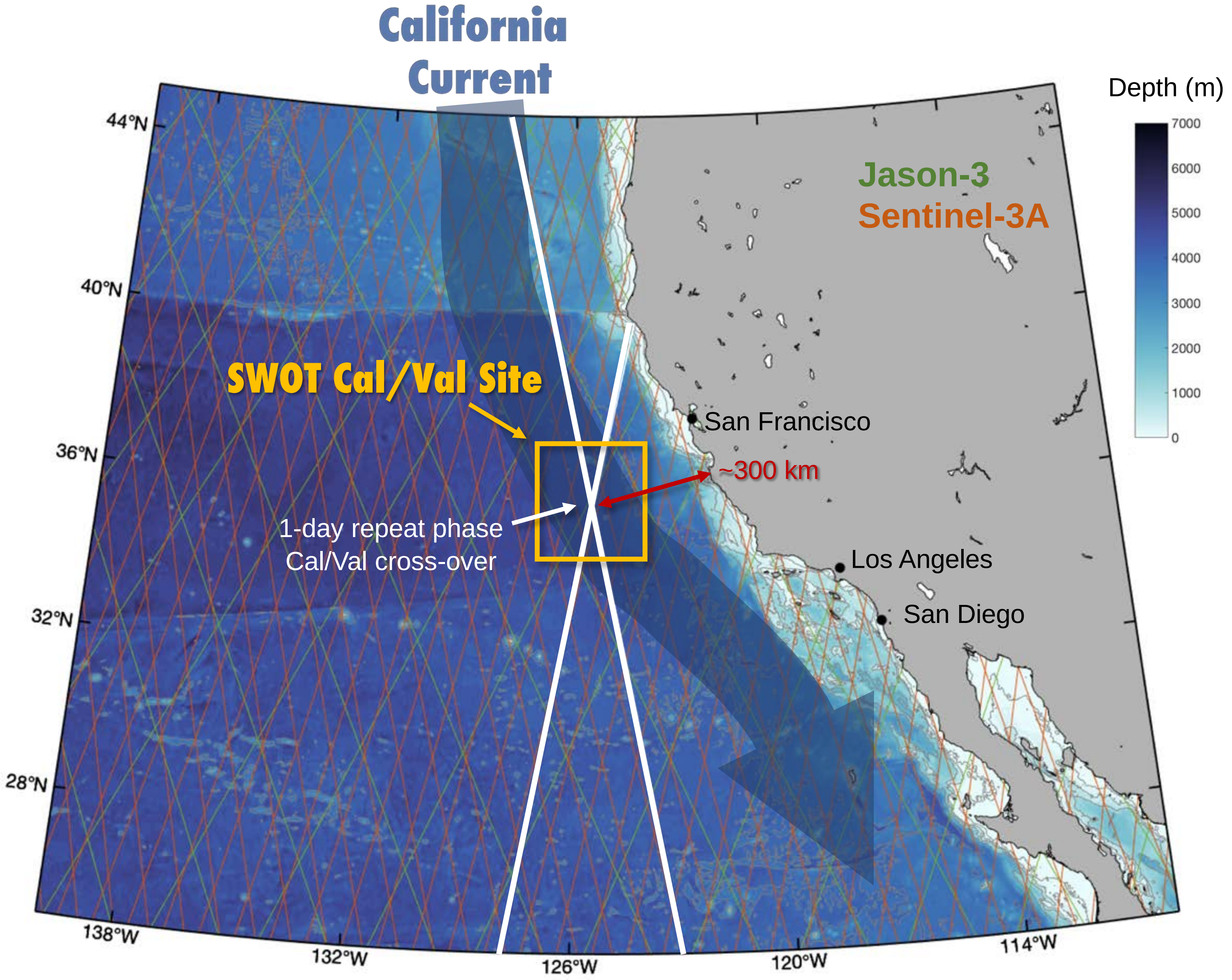
Motivation – SWOT Cal/Val

Pre- and post-launch field campaigns



Motivation – Research Question

- In the California Current system, the **best altimetry product** is SSALTO/DUACS sea surface height (SSH) distributed by **AVISO** (DUACS-DT2018)

  Le Traon et al. (1998); Pujol et al. (2016)

- However, this is **a global dataset** for a 25+ year period – *not tailored to California Current*

- While along-track SSH resolution is ~65 km, AVISO maps are ~200 km mid-latitude

  Chelton et al. (2011)

- We know that **regional** studies can provide **improved resolution SSH maps**

  Pascual et al. (2006); Dussurget et al. (2011); Escudier et al. (2013); Ubelmann et al. (2016)

- There are currently 6 available altimeters for 2019, and potentially 7 for 2021

  http://marine.copernicus.eu

Q: how far can we push the resolution of SSH maps in the California Current system, using the existing altimetry constellation?

Optimal Interpolation – AVISO

Bretherton et al. (1976), Le Traon et al. (98; 01; 03); Pujol et al. (2016)

Works by minimizing the mean squared error of the solution

$$x = x^b + Wd$$

Weight

Via Gauss-Markov theorem.
"BLUE" *Best Linear Unbiased Estimator*

$\boldsymbol{R}$ – observational error covariance

Based on:

- Instrument noise (*uncorrelated*)
- Long wavelength error (*correlated*)

$$W = \boldsymbol{B}\boldsymbol{H}^{\boldsymbol{T}}(\boldsymbol{H}\boldsymbol{B}\boldsymbol{H}^{\boldsymbol{T}} + \boldsymbol{R})^{-1}$$

Background error covariance **between grid point and observation point**

Background error covariance **between observation points**

$\boldsymbol{B}$ – background error covariance

Based on:

- Spatial and temporal correlation scales
- Propagation speeds

optimized for the global ocean and
25+ years with variable altimetry coverage

Our Methodology – 2-D Variational Analysis (2DVAR)

Chao et al. (2009); Li et al. (2016)

Solves for least squares solution via a different approach – by minimizing a cost function:

'Increment'   'Innovation'

$$J(x) = \underbrace{\frac{1}{2}\left(x - x^b\right)^T B^{-1} \overbrace{\left(x - x^b\right)}^{\text{'Increment'}}}_{\text{Background}} + \underbrace{\frac{1}{2}(y^o - Hx)^T (R + F)^{-1} \overbrace{(y^o - Hx)}^{\text{'Innovation'}}}_{\text{Observations}}$$

Background   Observations

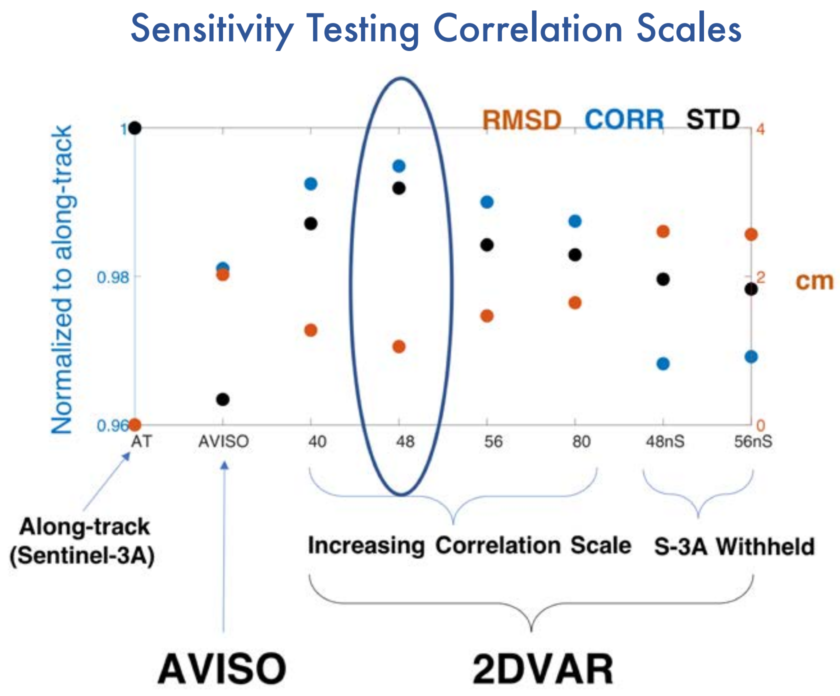
Advantages for implementation:

- Computationally faster – optimization method
- Uses all available data – no need to sub-sample, and additional data can be added without increased computation time
- More flexible to add additional constraints (future work), anisotropic error covariances

2-D Variational Analysis (2DVAR)

Key modifications in our approach compared with AVISO*

1. Smaller correlation scale
2. Background field – prior day's full-resolution field
3. No smoothing of along-track data
4. No time correlation function
5. Addition of a *representation* error in R, to penalize observations further away in time



Dataset

DUACS-DT2018 (L3) unfiltered along-track altimetry data

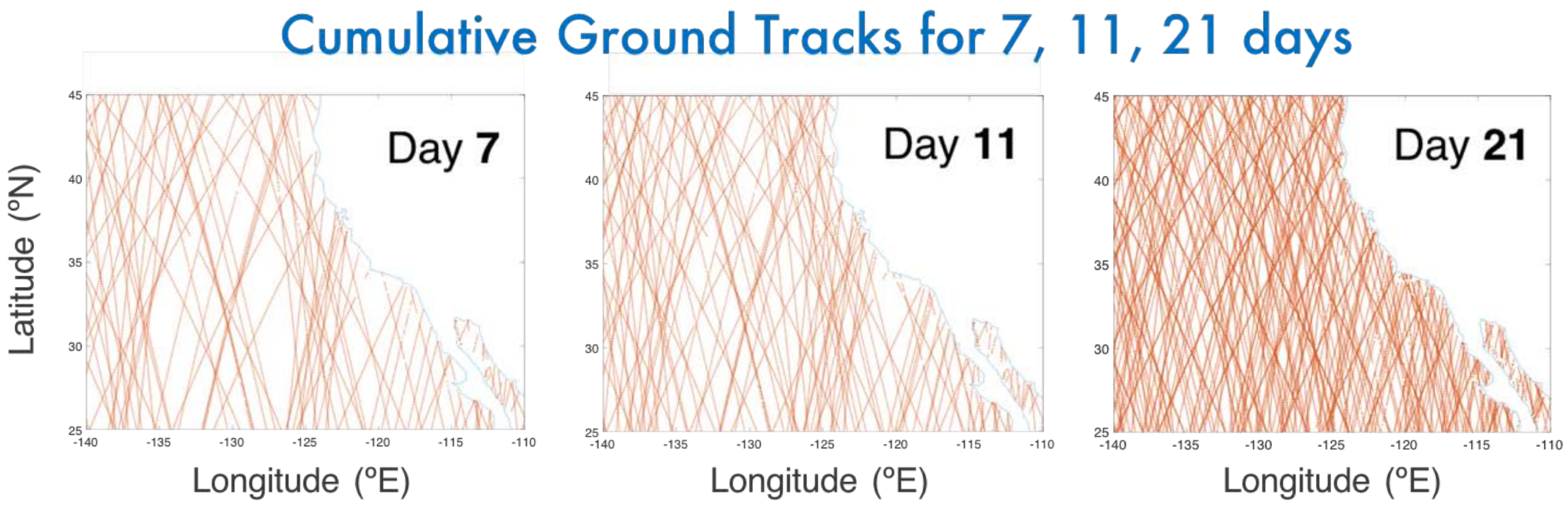
Publicly available through the Copernicus website
http://marine.copernicus.eu/

Between **Jan to June 2018** there were **5** altimeters in orbit:

1. Jason-3
2. Sentinel-3A
3. SARAL/AltiKa-DP
4. Cryosat-2
5. HaiYang-2A G

REPEAT (1–2)

GEODETIC (3–5)



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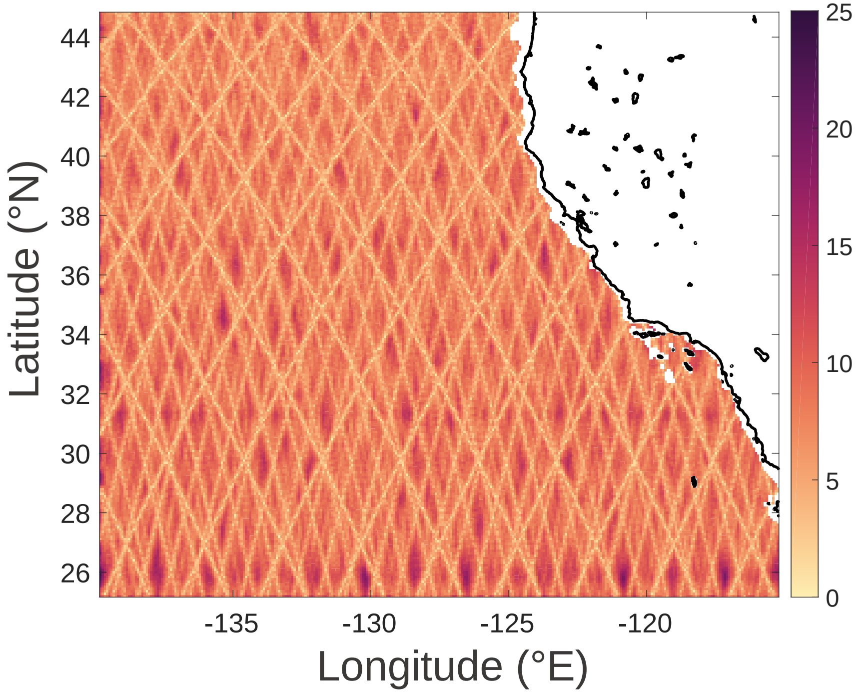
Jason-3 and Sentinel-3A: **REPEAT**

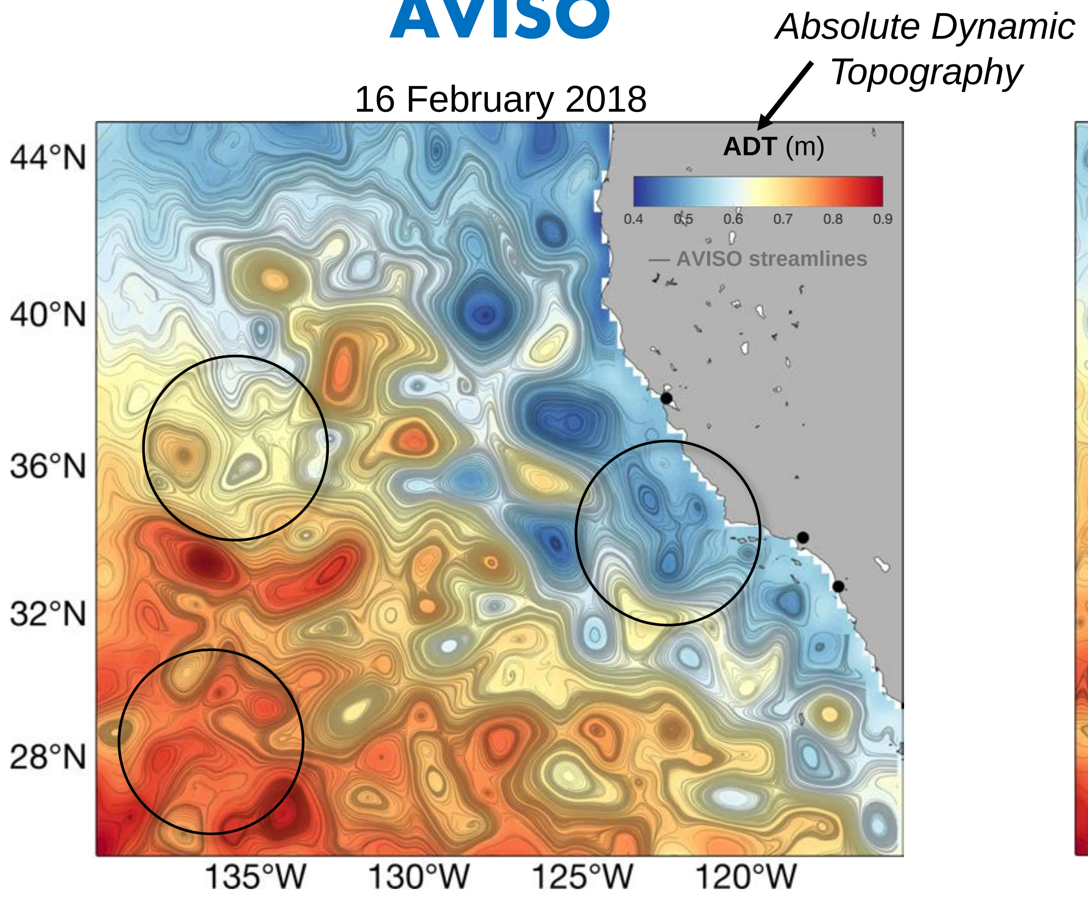
SARAL/AltiKa-DP, Cryosat-2 and HaiYang-2A G: **GEODETIC**

Average Distance (km)
to an observation (closest point)



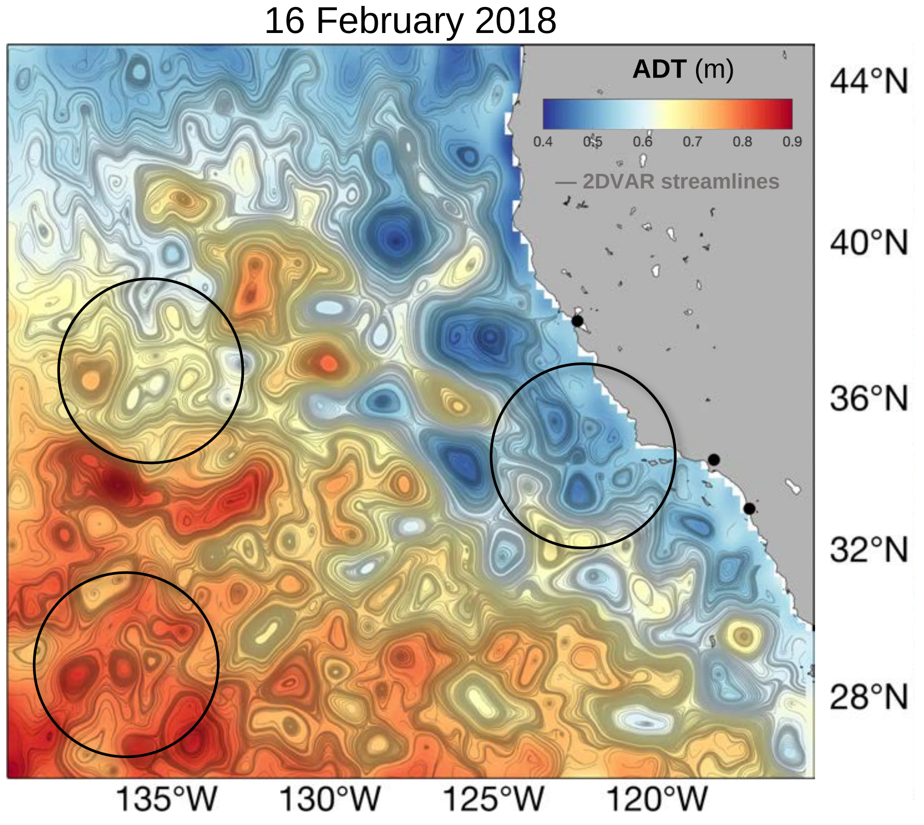
Results – A Snapshot View

AVISO



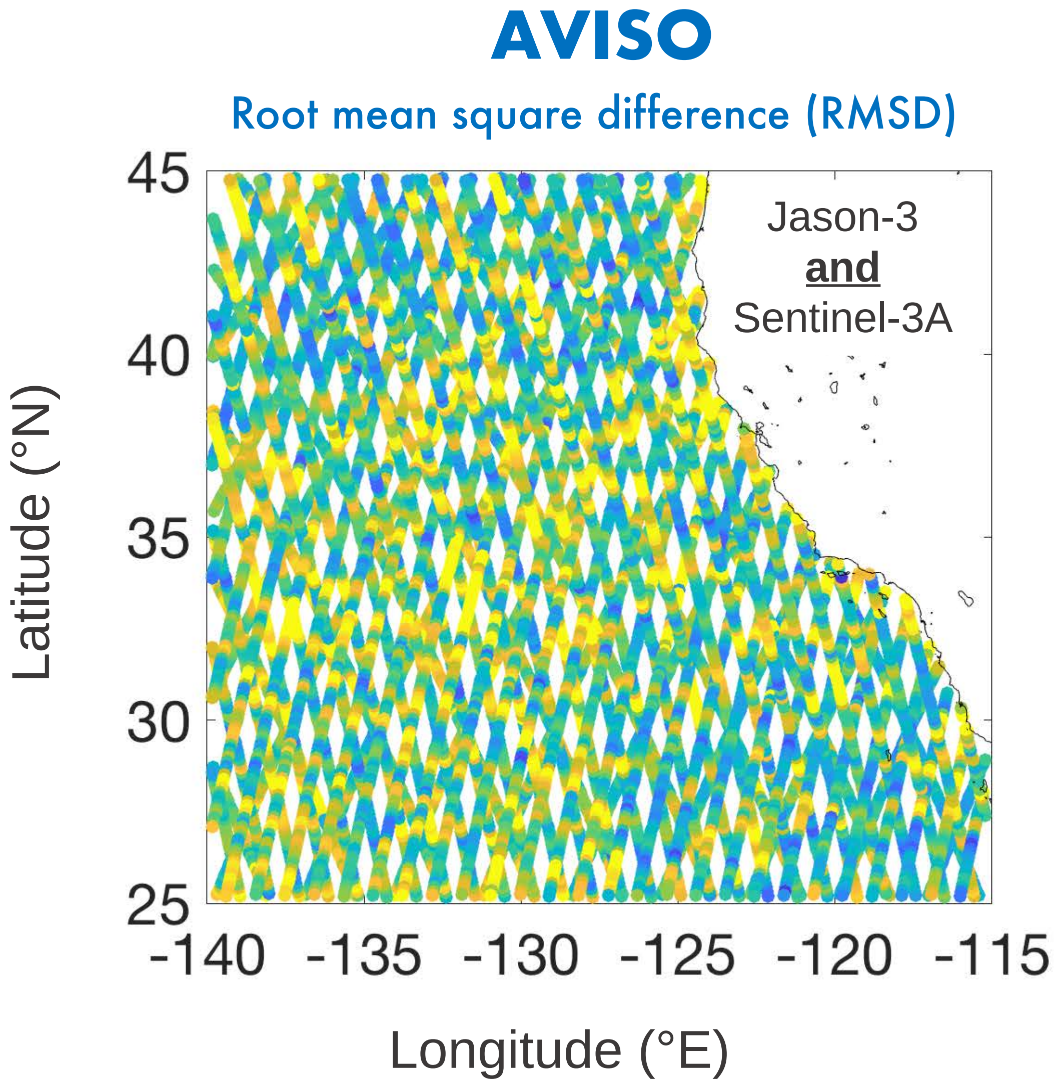
Smoother field

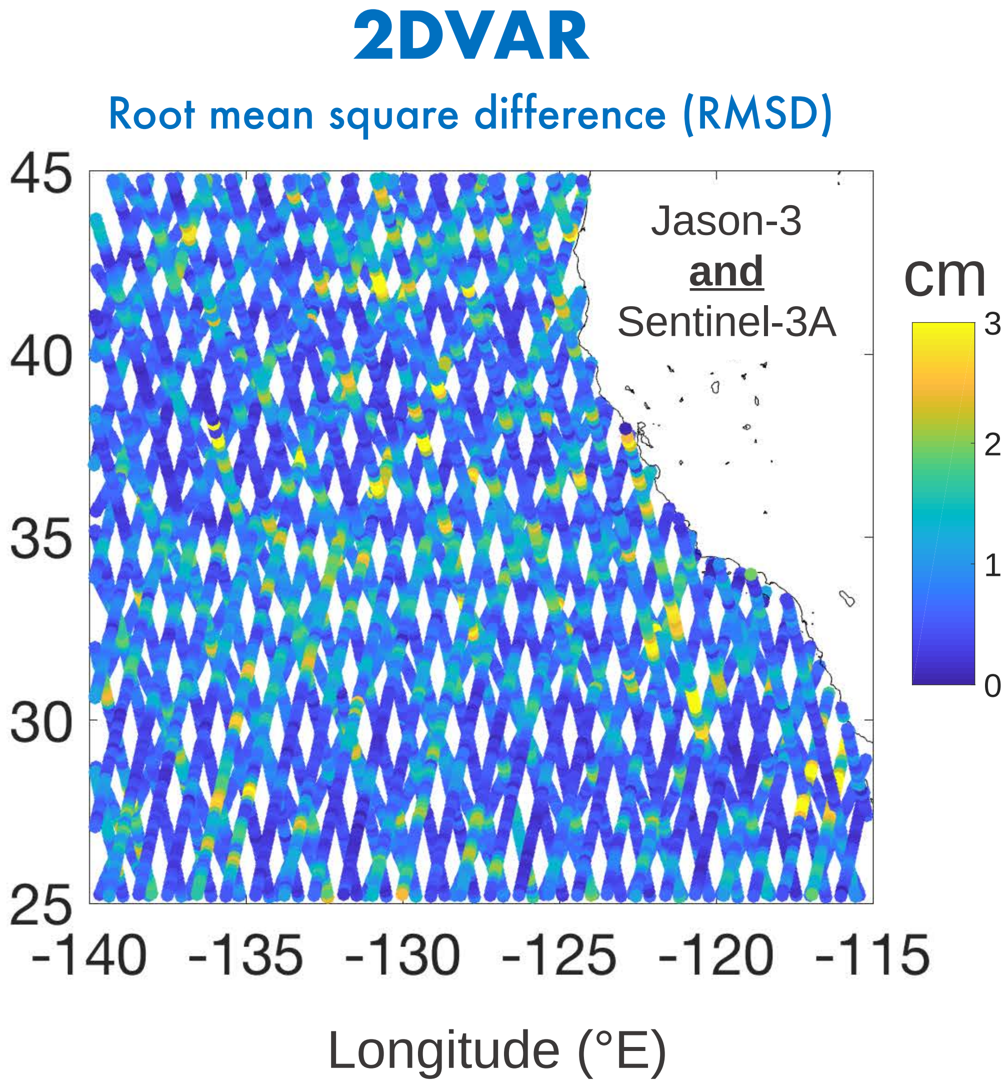
2DVAR



Smaller-scale features

Results – Mapping Performance vs. Along-Track (included)

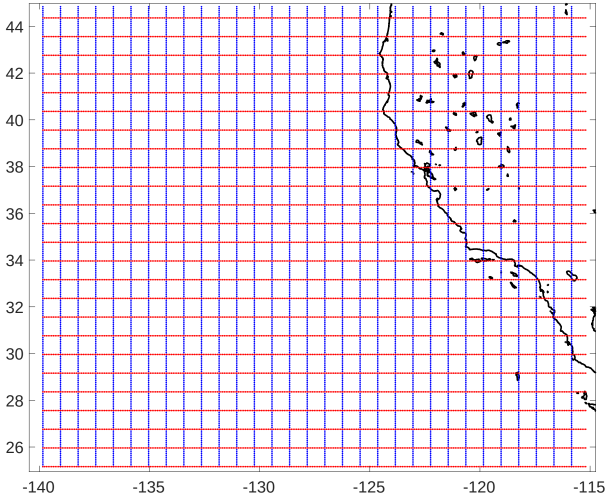




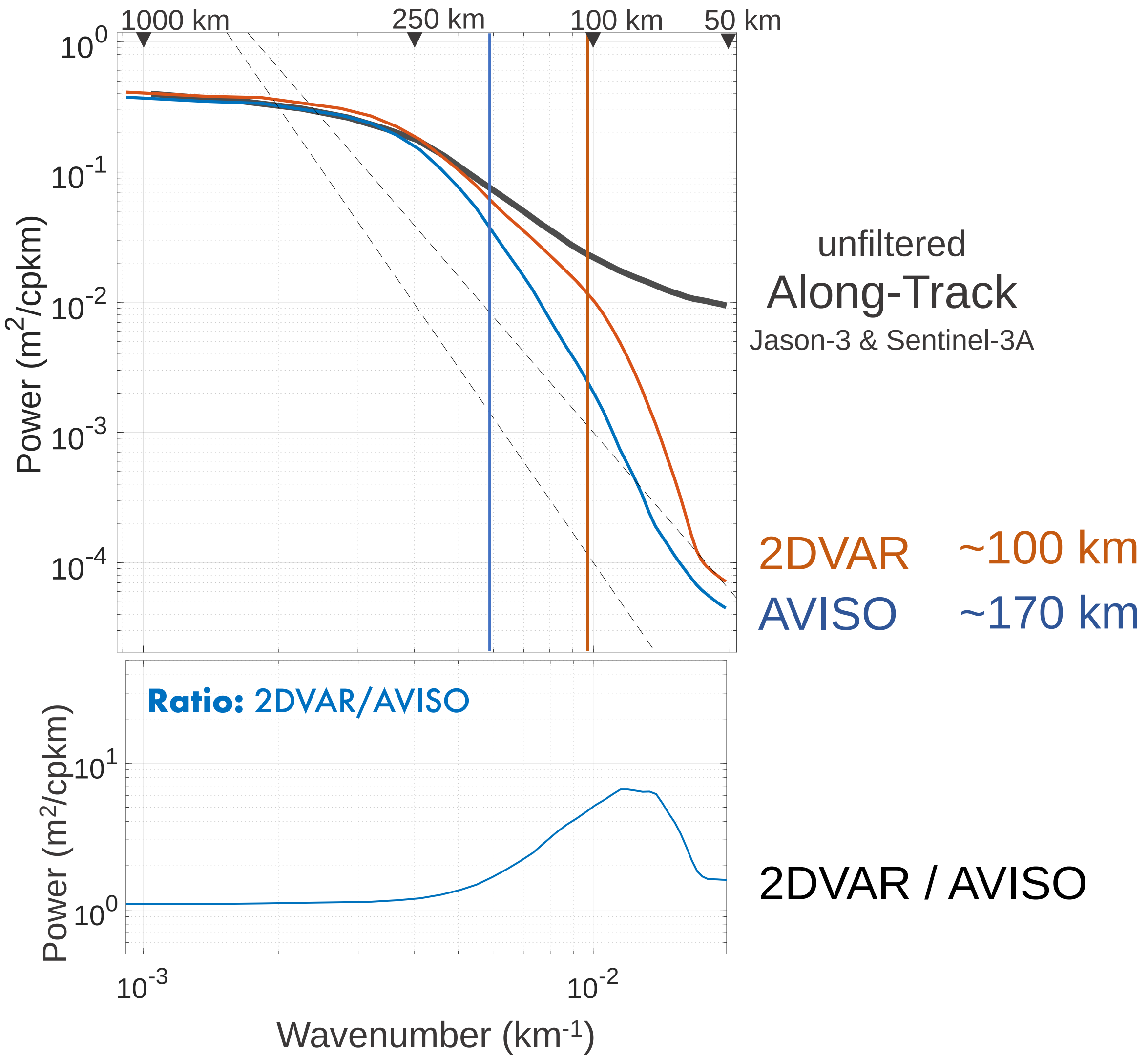
Results – SSH Wavenumber Spectra

How does the variability match up over different spatial scales?

Zonal and Meridional Transects



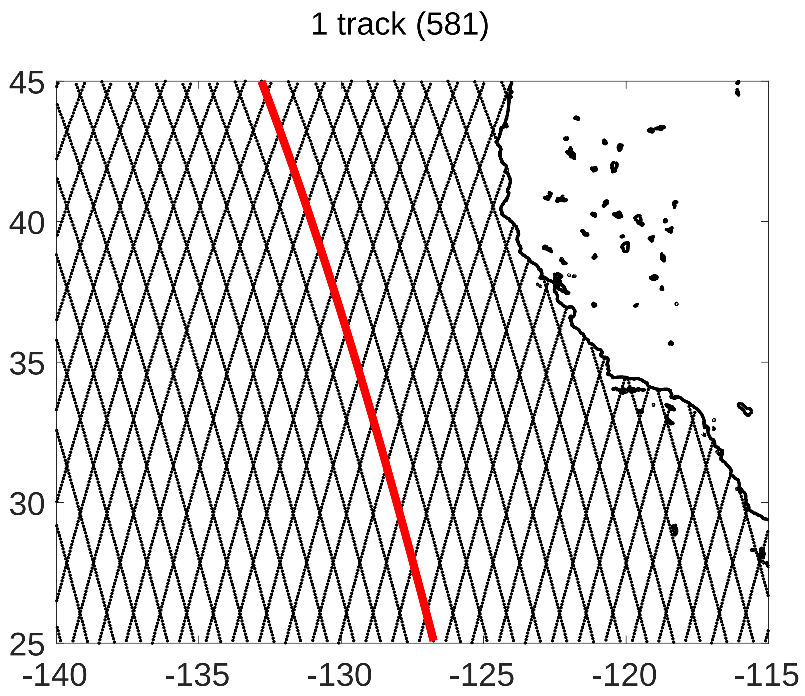
Mean 1-D Wavenumber Spectra

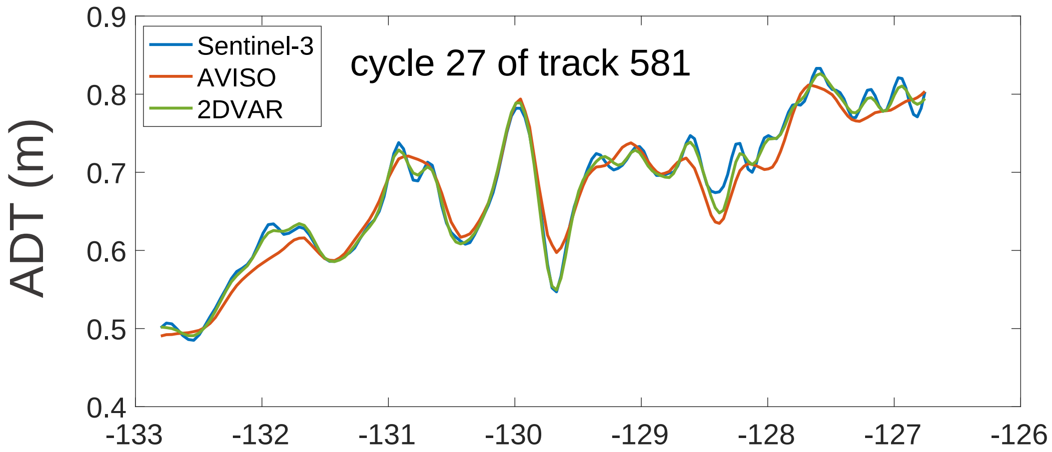


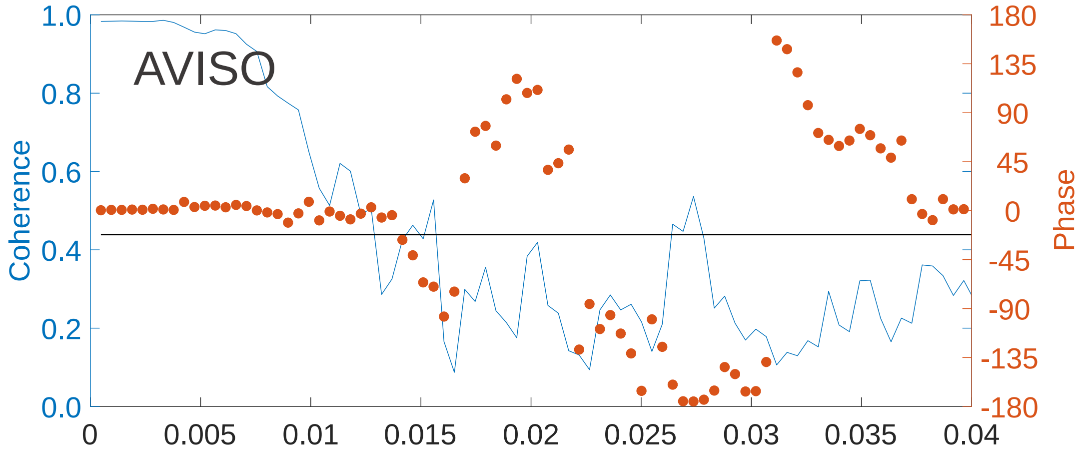
EFFECTIVE RESOLUTION
Defined as wavenumber where power spectral density of map is **half** of along-track Chelton and Schlax. (2003)

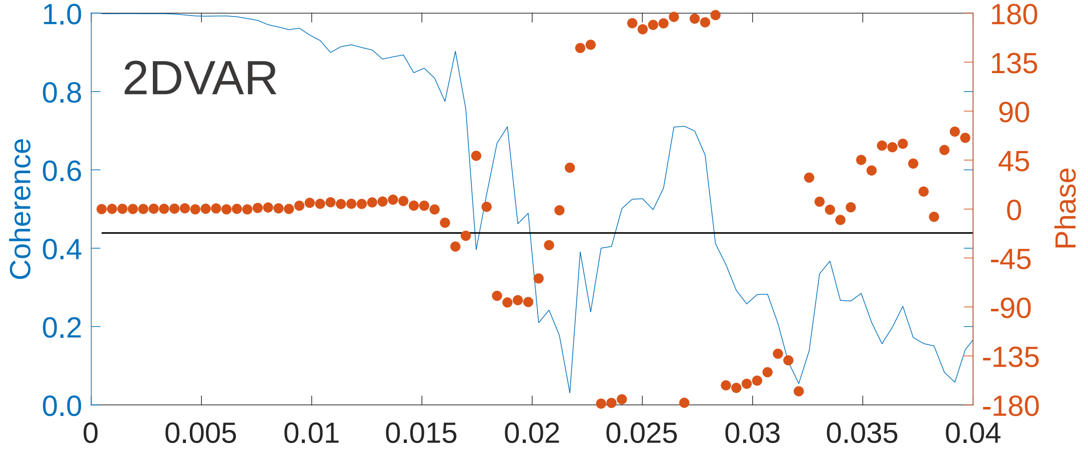
Results – Coherence

Spectral coherence between mapped and along-track data (Sentinel-3A here) for 1 track and cycle (as an example).









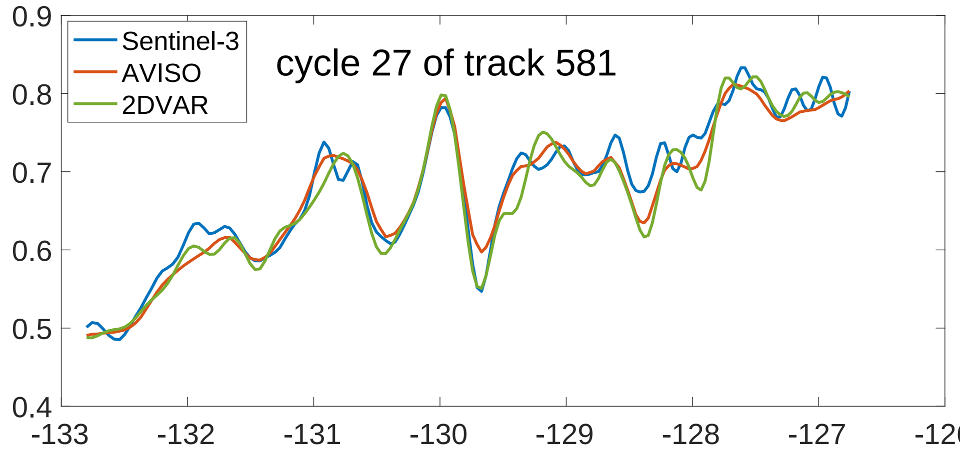
= 2DVAR is coherent with along-track data at smaller wavelengths

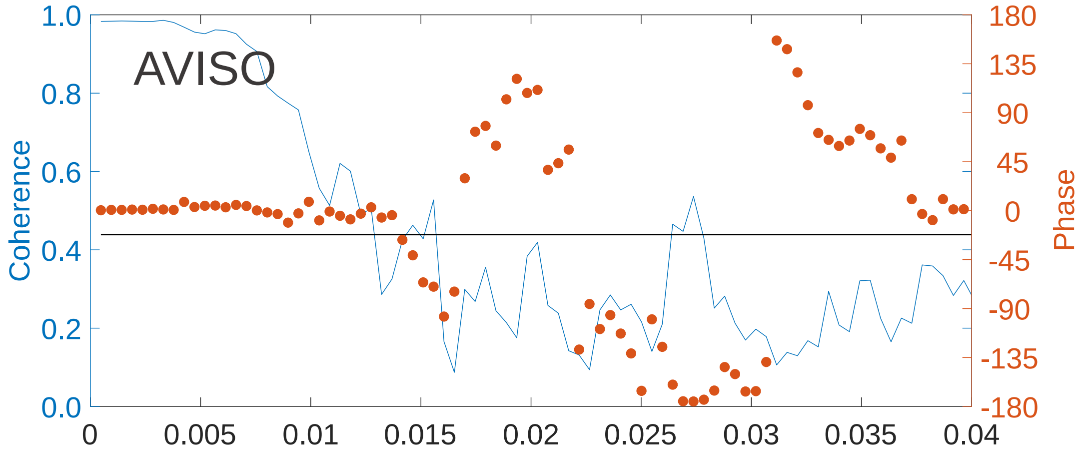
Results – Coherence (withheld)

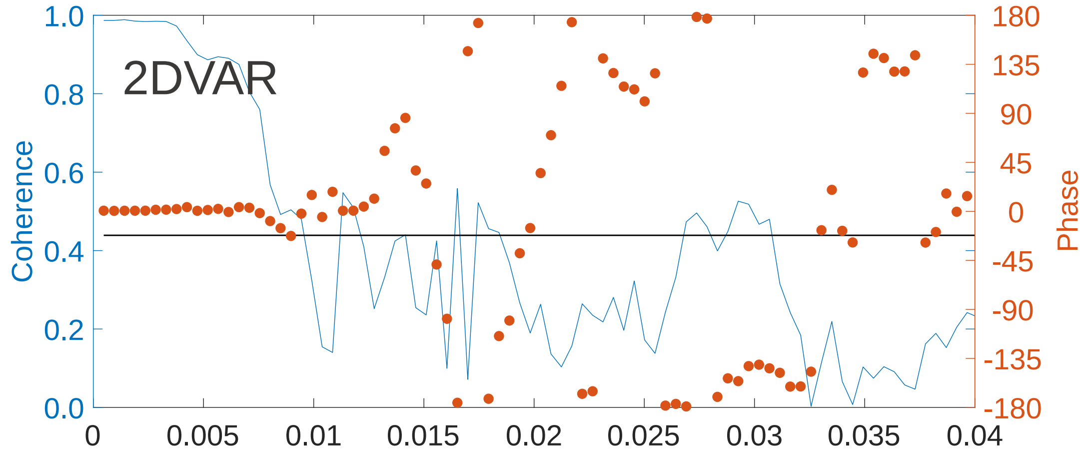
Spectral coherence between mapped and along-track data (Sentinel-3A here) for 1 track and cycle (as an example).

Note: Sentinel-3A data withheld only from 2DVAR, which is thus degraded in comparison

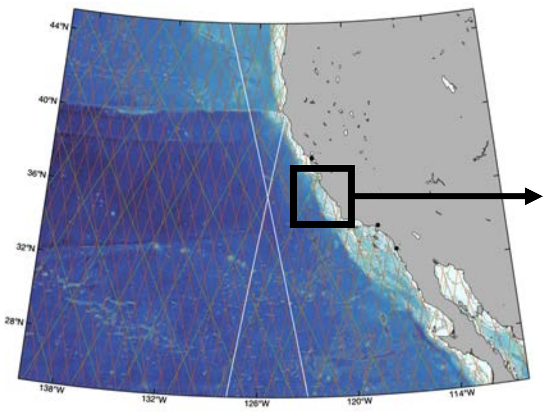
Note 2: Withholding Sentinel-3A does not affect comparison with Jason-3 (backup slides)





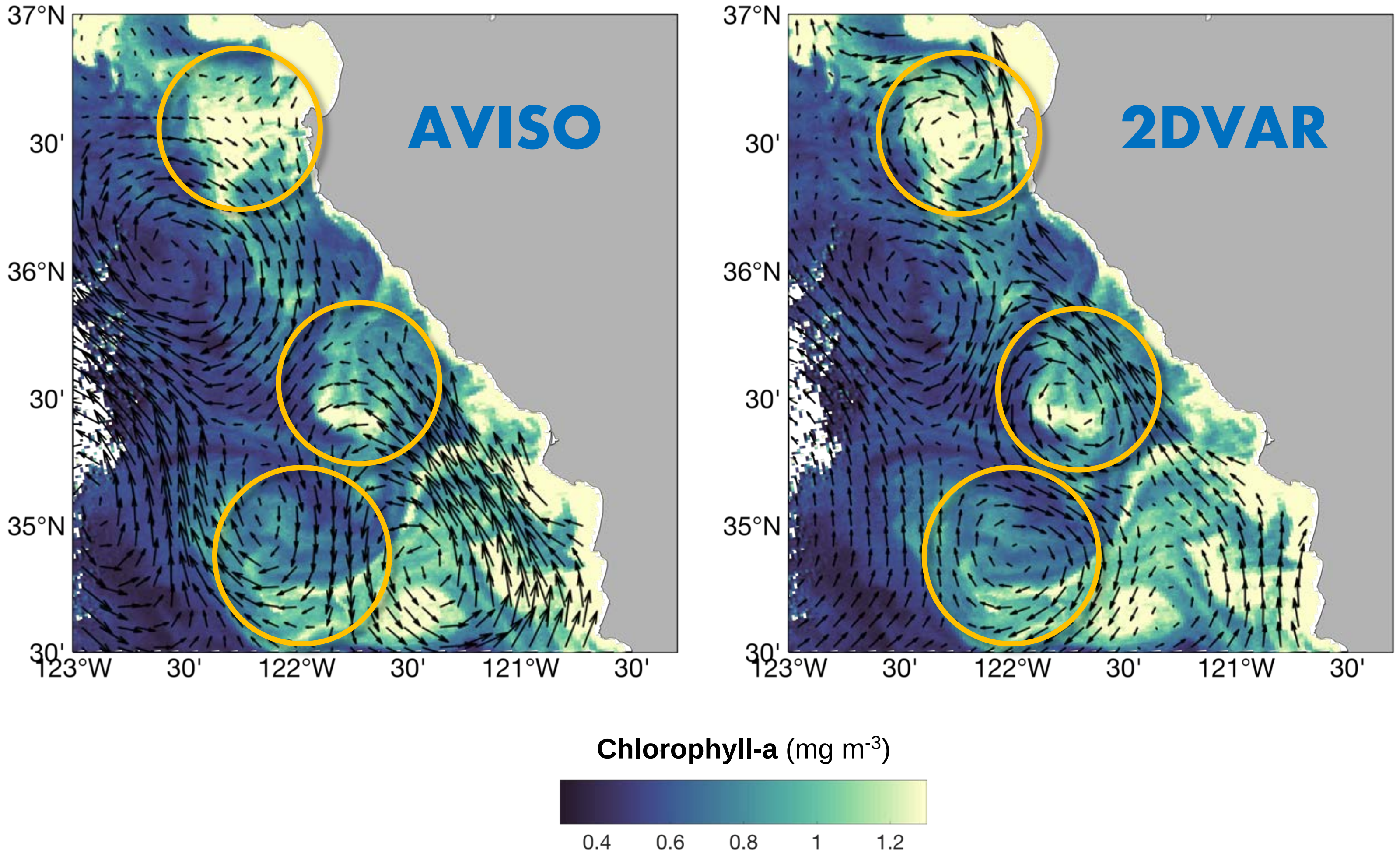


Independent Data – Satellite Imagery



AVISO misses coastal features

2DVAR picks up smaller-scale eddies



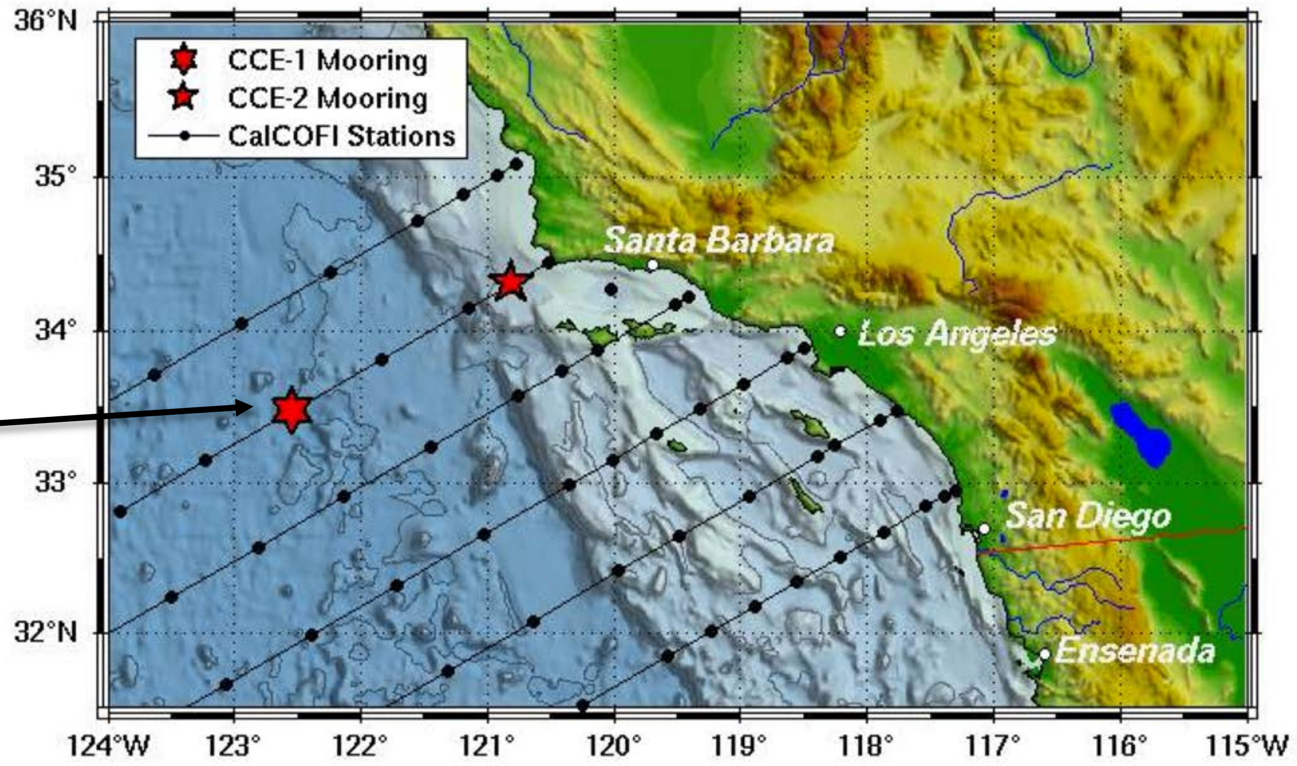
Independent Data – In situ ADCP velocity

“California Current Ecosystem” CCE Project,

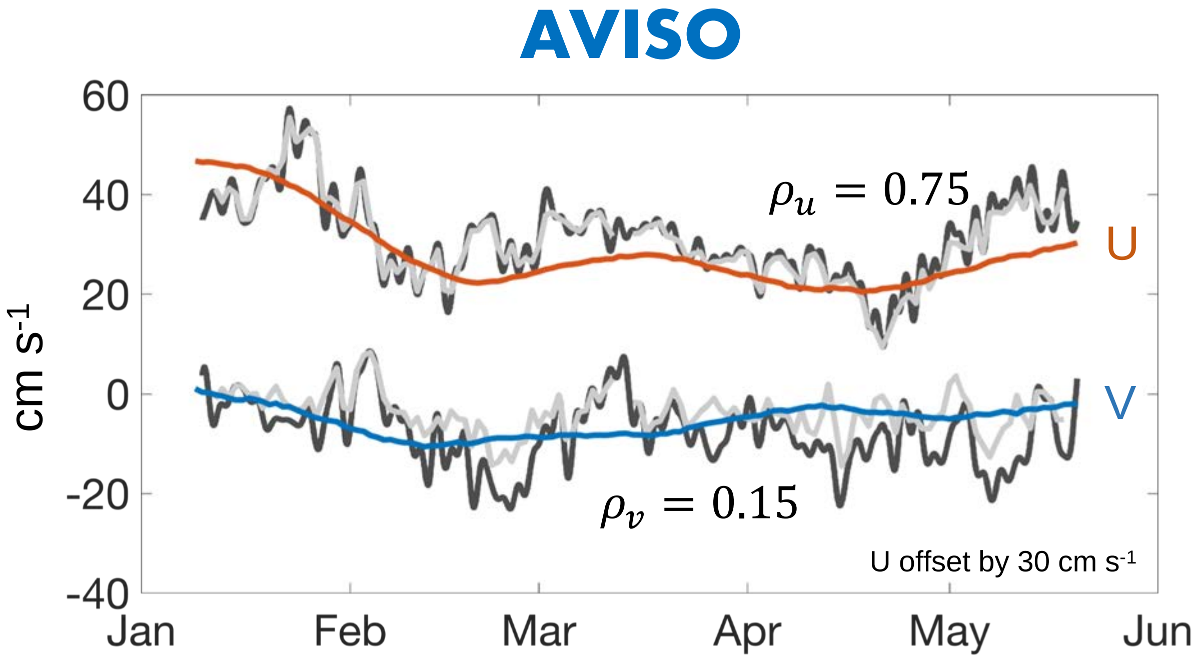
Interdisciplinary Biogeochemical Moorings

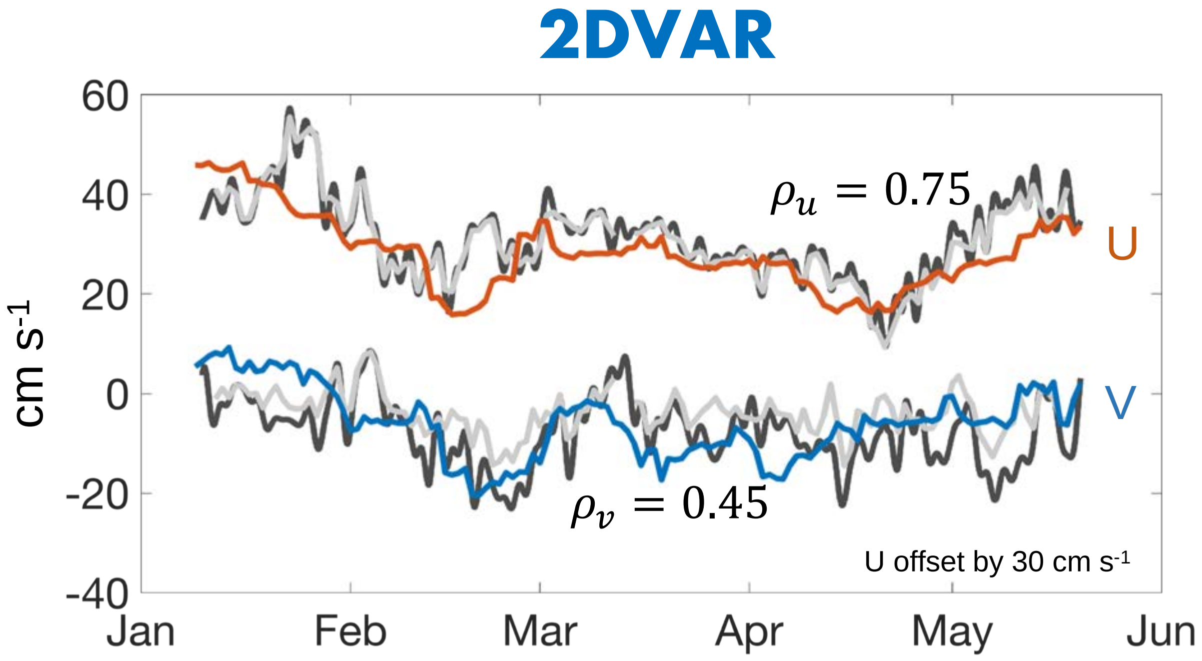
Investigators: U. Send, M. Ohman, D. Demer, T. Martz, C. Sabine, J. Hildebrand, A. Dickson

Mooring CCE-1
~250 km offshore



Independent Data – In situ ADCP velocity

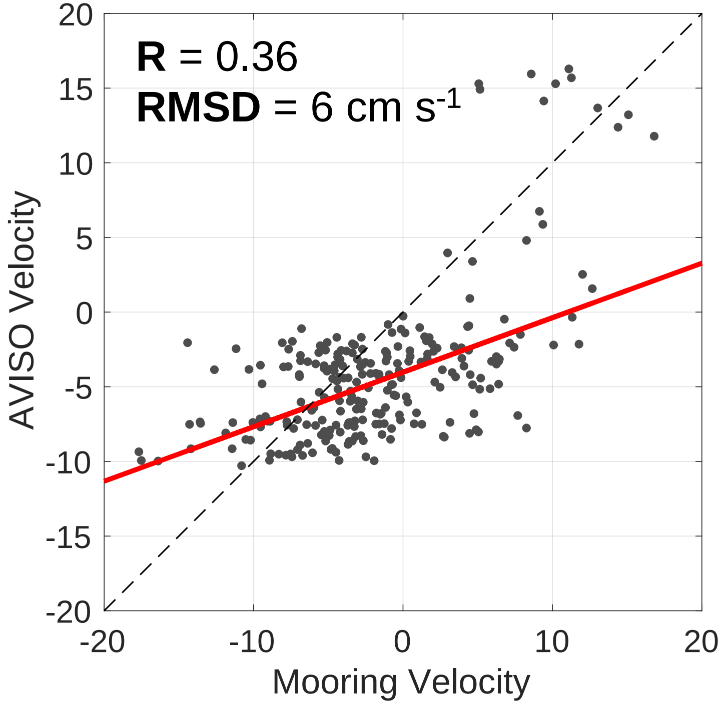




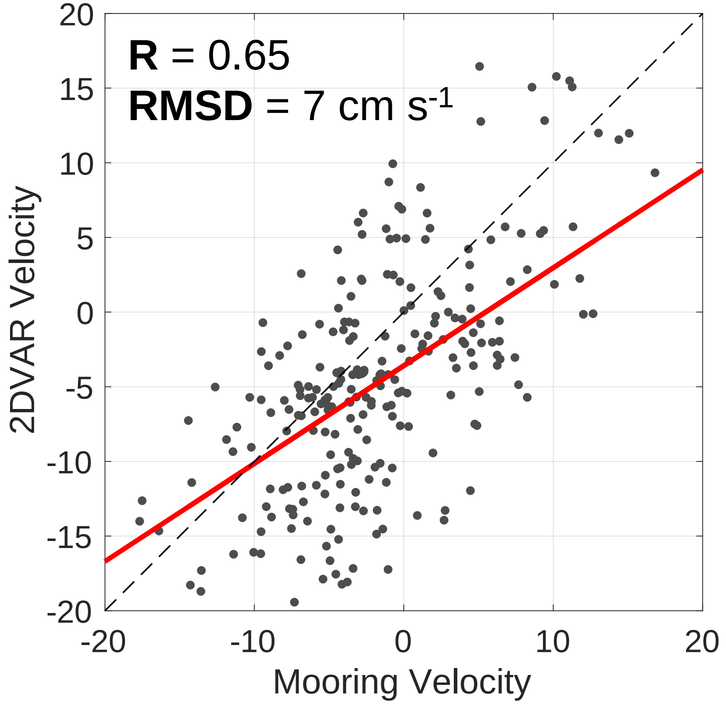
2DVAR has higher temporal variability, with
higher correlation to independent mooring data

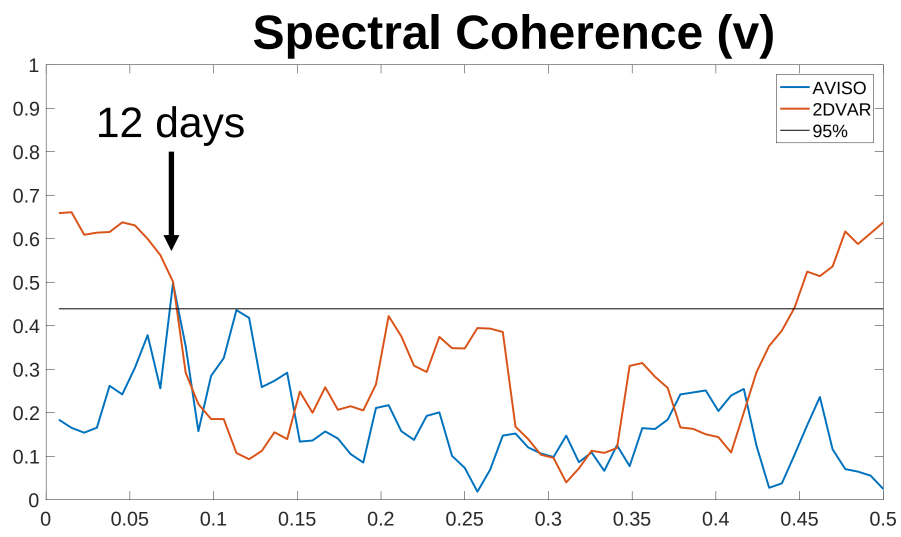
Independent Data – In situ ADCP velocity

AVISO



2DVAR





AVISO underestimates larger velocities,
2DVAR shows a better slope but reveals
more variability (noise).

Summary

- Jan-June 2018 there were **5** altimeters in orbit, in 2019 there are **6,** in 2021 – **7**?
- Goal: use this large number of altimeters to see how far we can push the resolution of SSH maps in space and time in the California Current system
- We apply a variational method to map along-track measurements
  – **equivalent solution** to optimal interpolation, but *different approach*
  – more computationally efficient and flexible to refine
- Preliminary focus: correlation scales, background field, and time representation (resolution > uniform error)
- Obtain finer scale maps than AVISO (100 km vs. 170 km)
  – Resolve smaller-scale features but also incorporate more noise

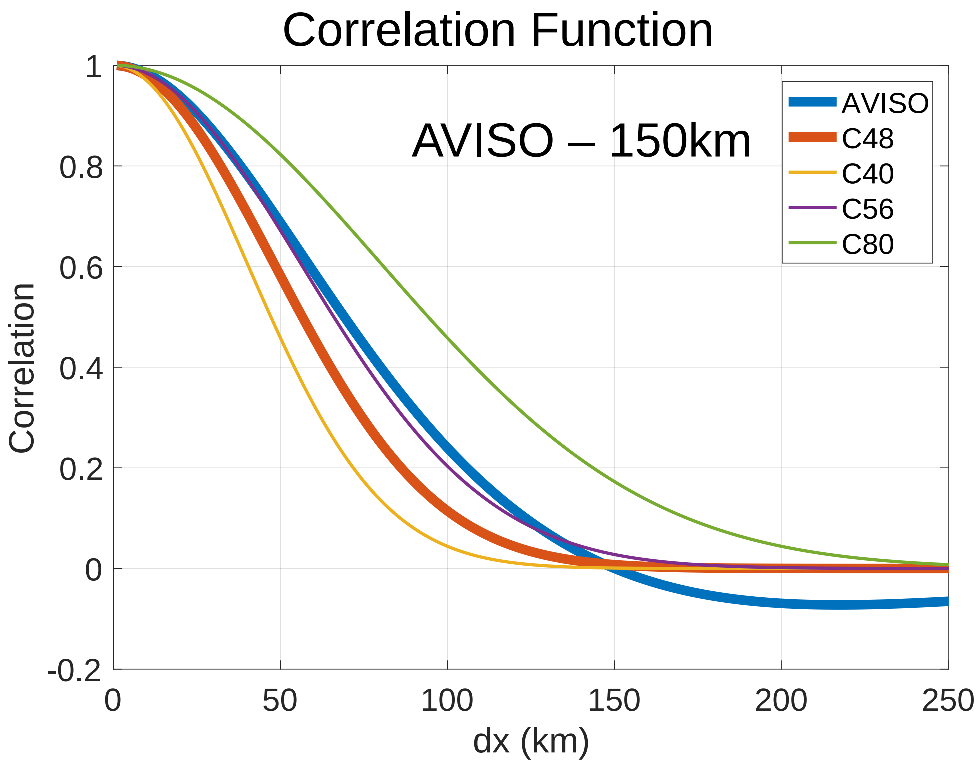
Ongoing Work

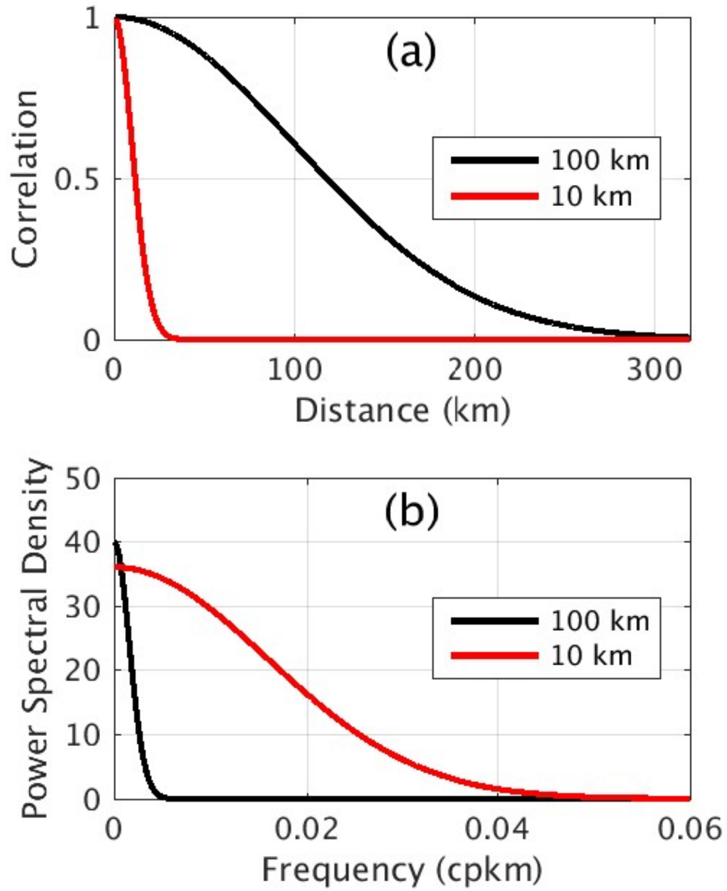
- **Further testing**:
  - More comprehensive withheld along-track comparison – longer time period
  - More independent dataset analysis – drifters, HF radar
  - Dynamical test – how well does each dataset follow quasi-geostrophy? (PV conservation)
  - Perhaps explore method and data using a data assimilating model

- **Improve and enhance the method**:
  - Improve the time representation error (*F*)
  - Incorporate long wavelength error, and refine the uncorrelated error budget
  - Consider constraints (dynamical (Ubelmann et al., 2016), topography (Escudier et al., 2013), etc.)

Thank You

Backup Slides

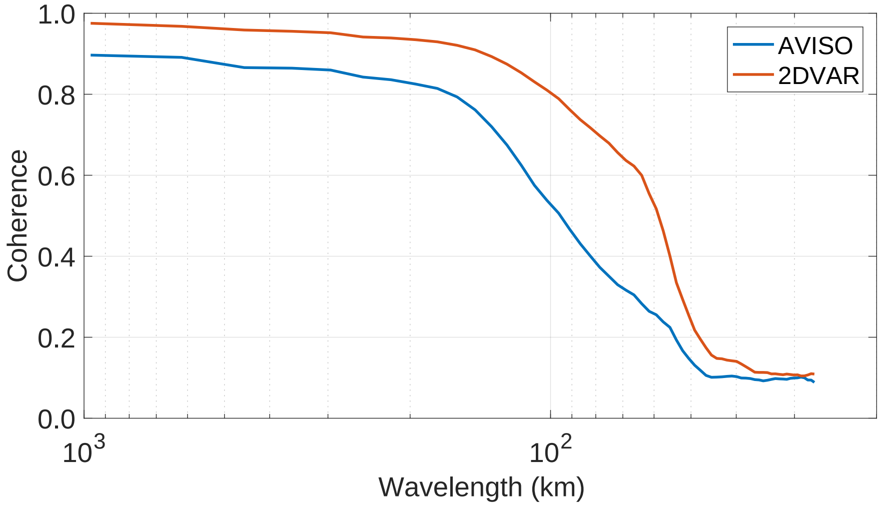


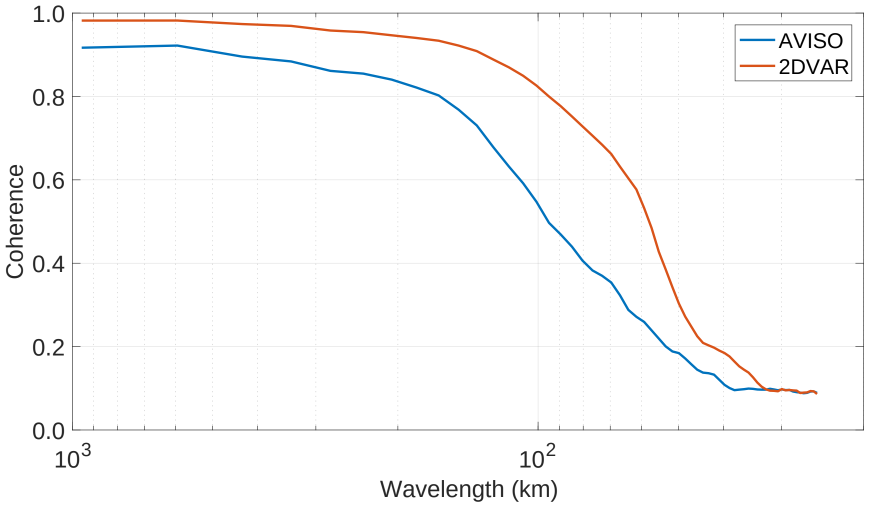


Results – Mean Coherence

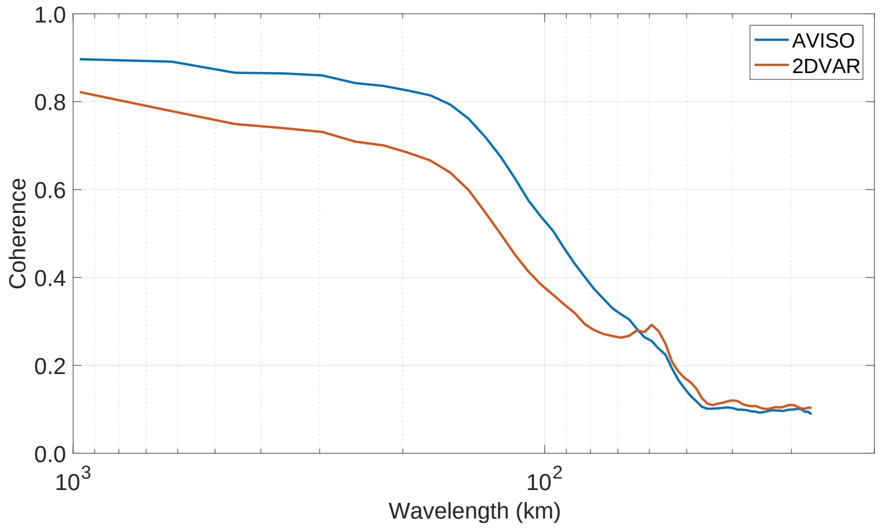
Vs. Sentinel-3A | **Vs. Jason-3**

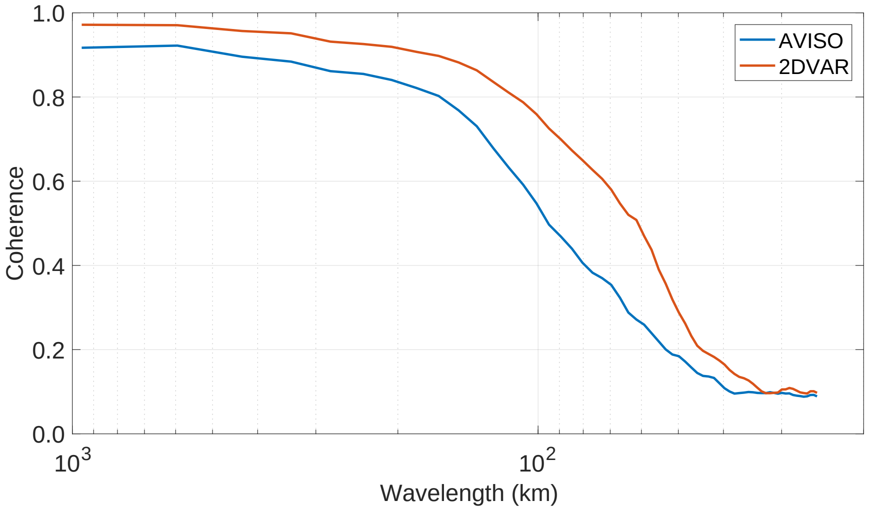
Sentinel-3A is
INCLUDED
(both AVISO & 2DVAR)





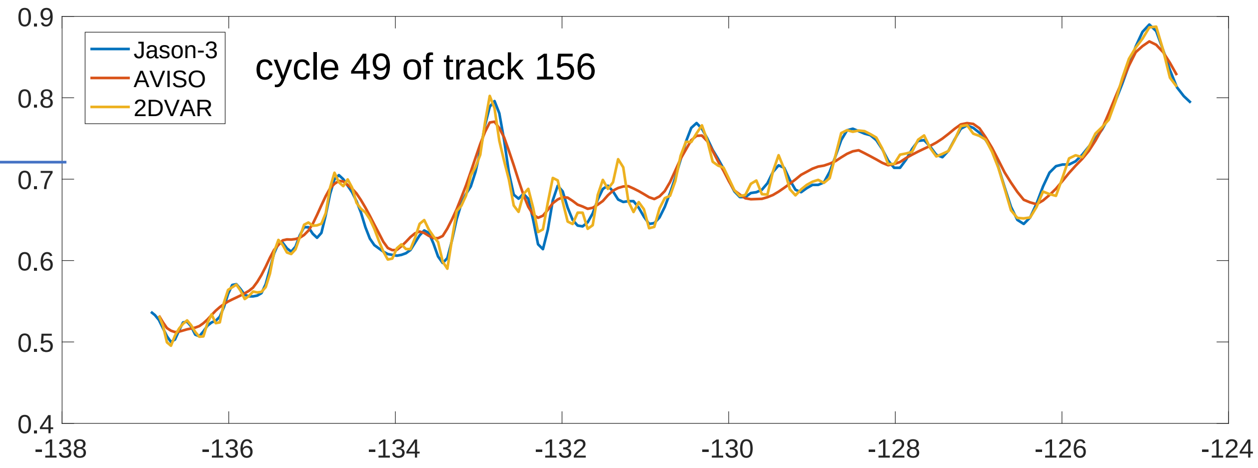
Sentinel-3A is
WITHHELD
(from 2DVAR *only*)

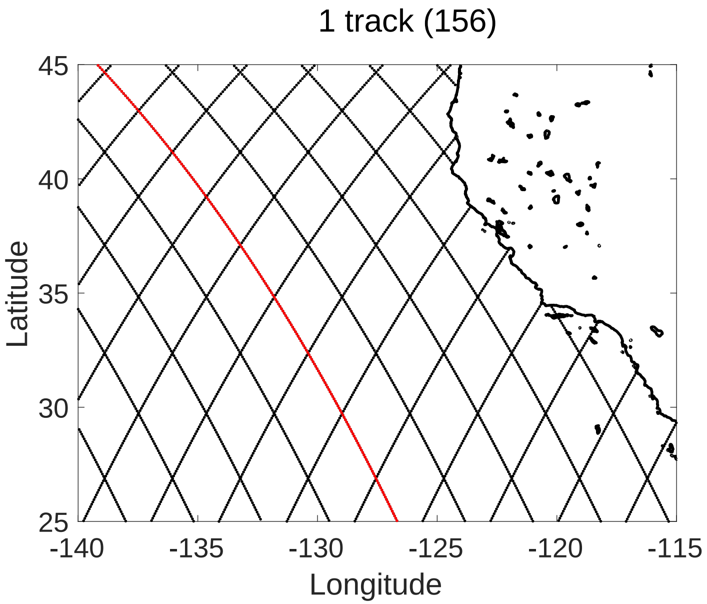




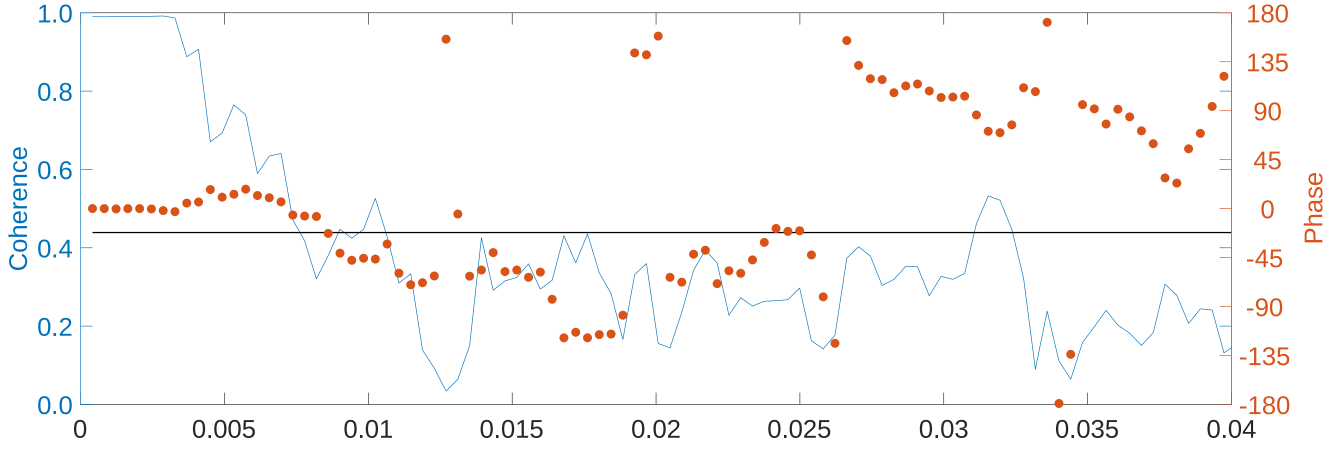
Results – Coherence

Spectral coherence between mapped and along-track data (Jason-3 here)

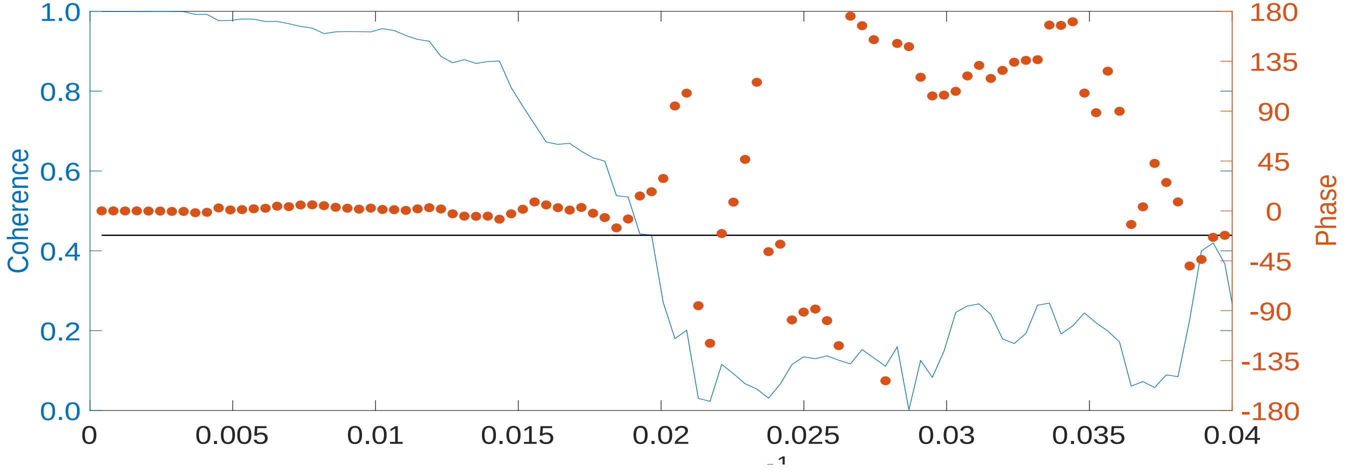




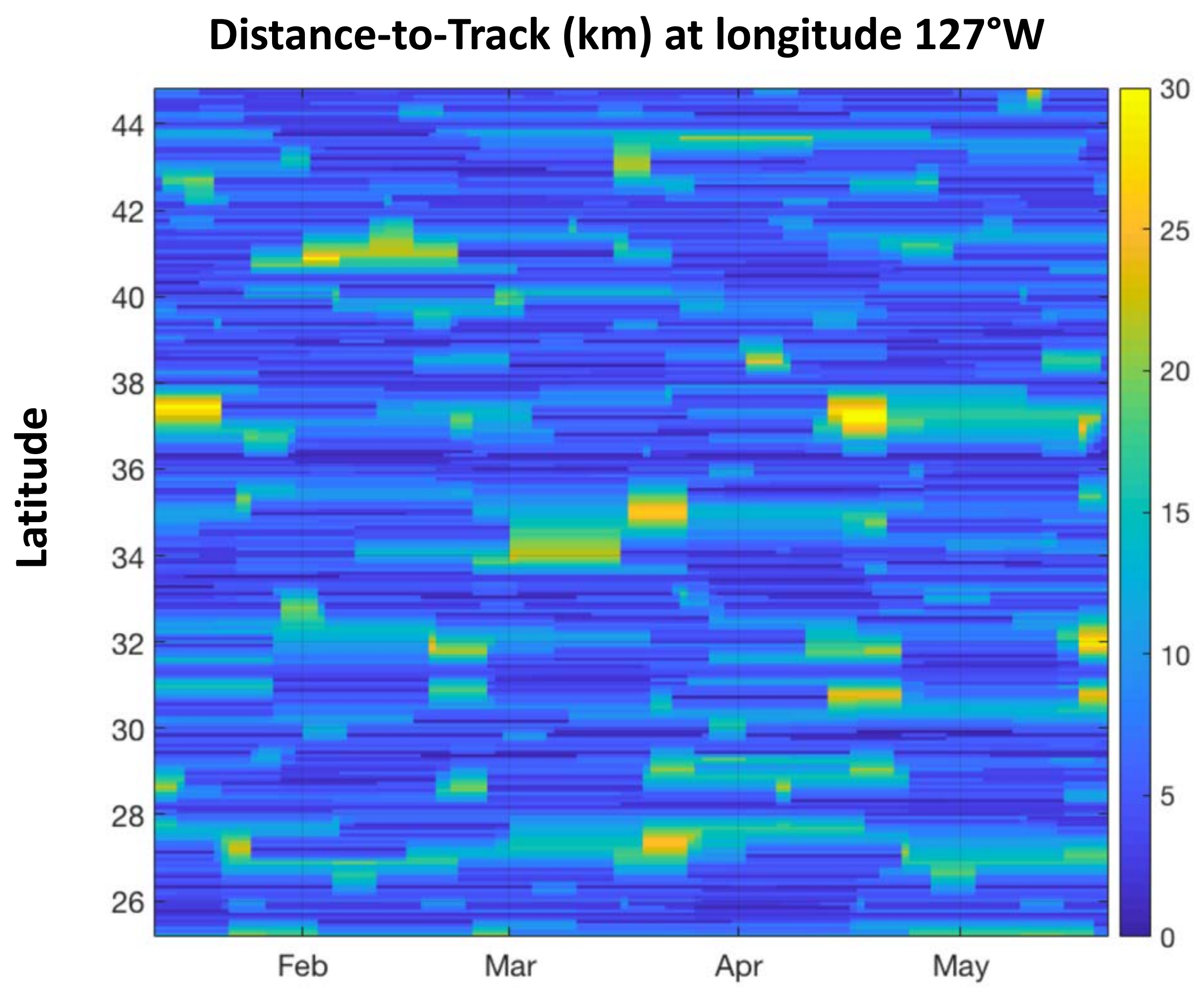
AVISO and Jason-3

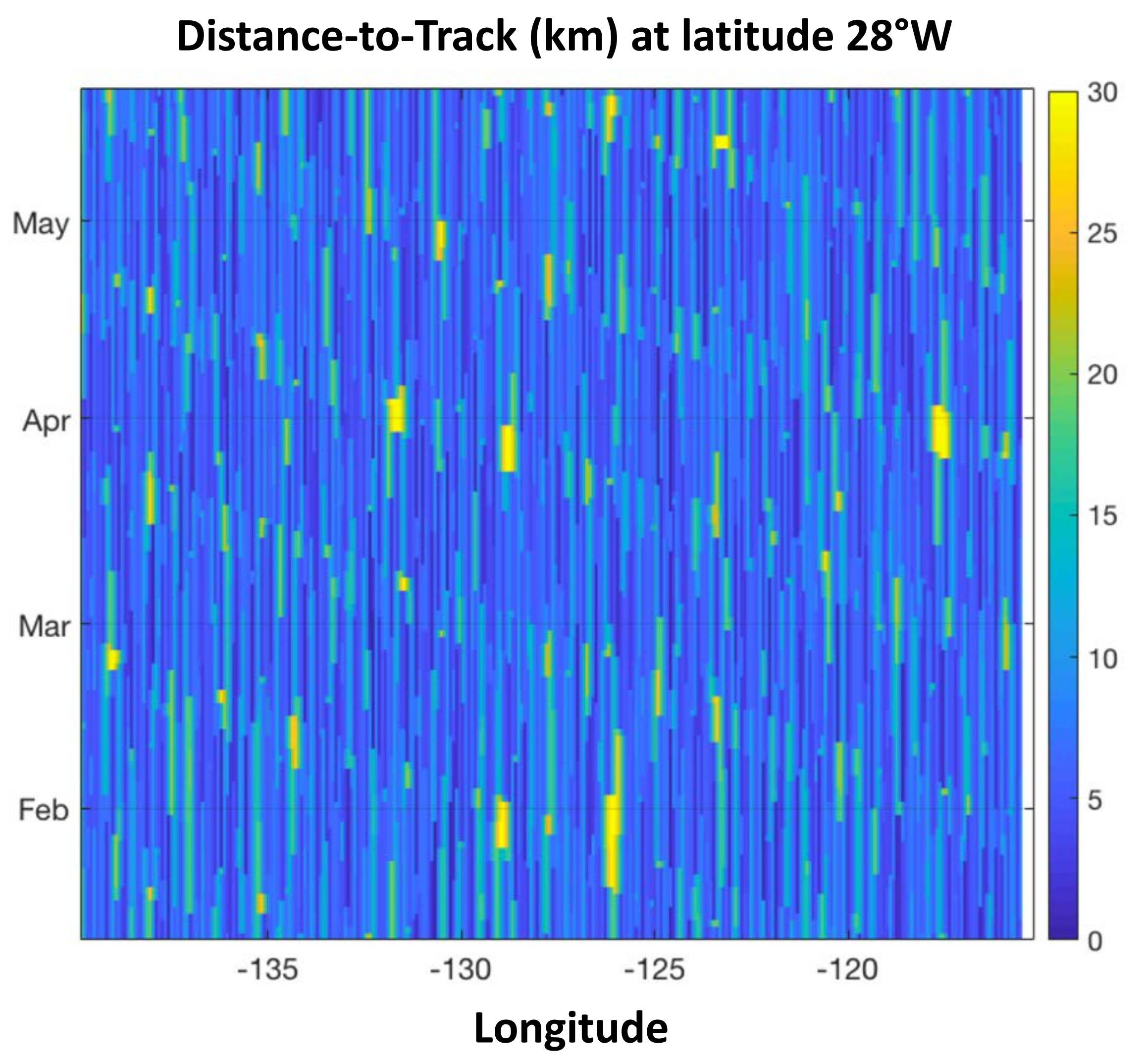


2DVAR and Jason-3



Distance-to-Track is the distance between each grid point and the closest along-track observation point (in km)

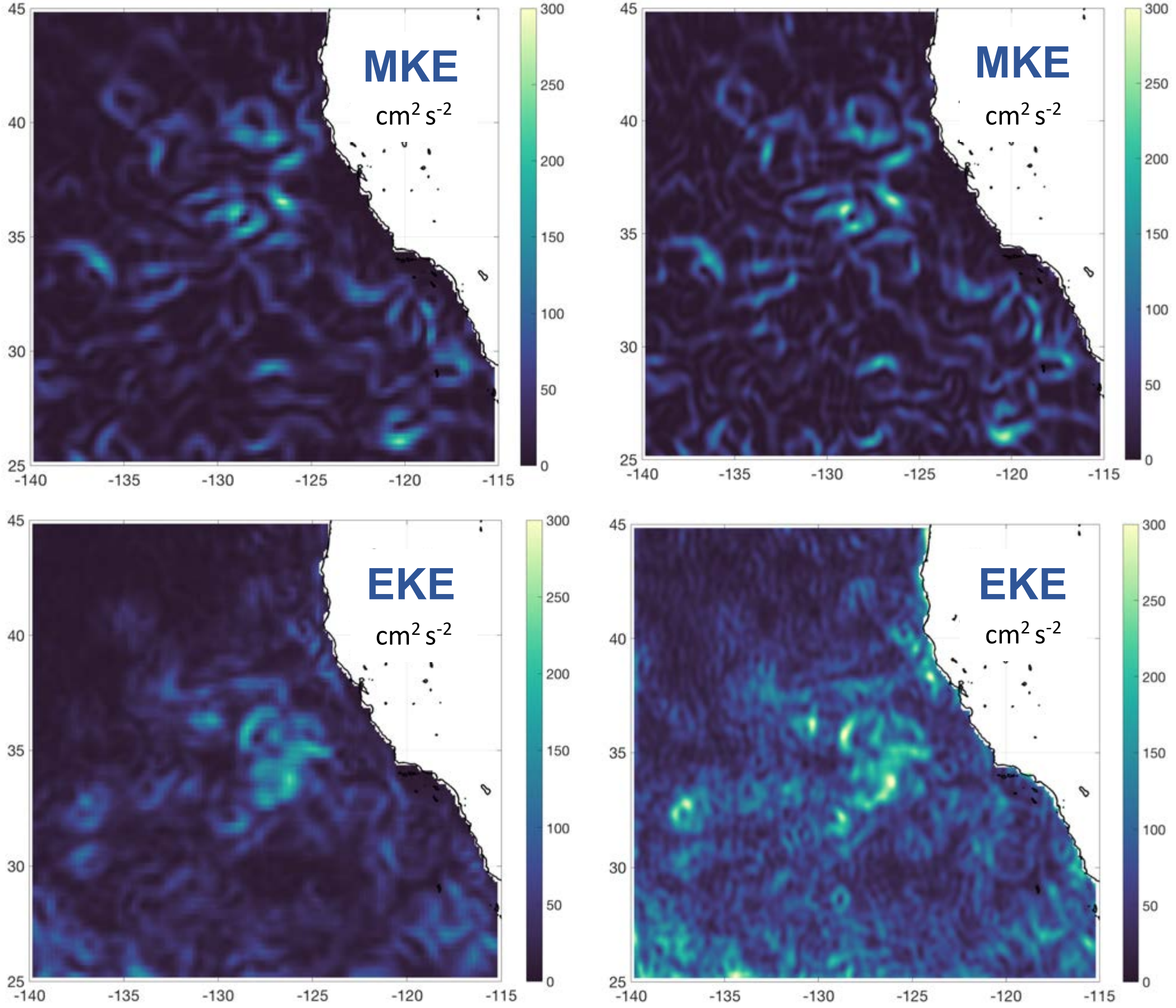




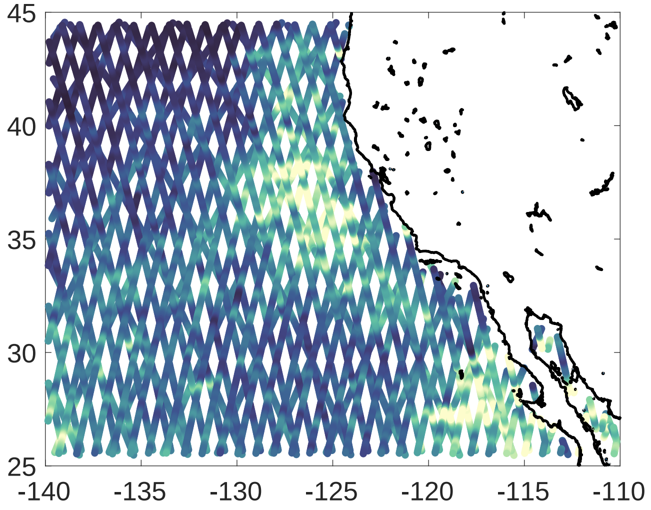
Results – Kinetic Energy

AVISO

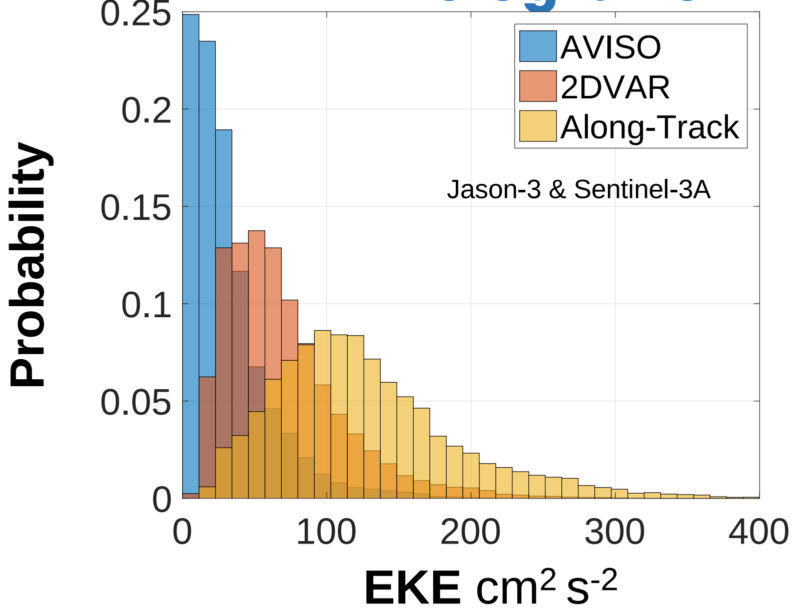
2DVAR



Along-Track EKE



EKE Histograms



Results – Mapping Performance vs. Along-Track