Assessing predictions of the ocean eddy structure:

A case study in an eddy-rich region over a period of unprecedented data richness (Aug 2023 – Jul 2024)

OceanPredict Symposium 2024

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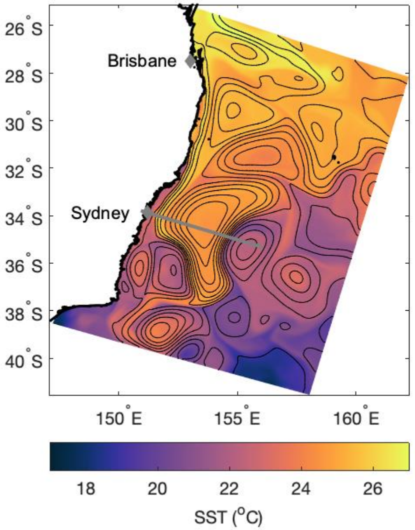

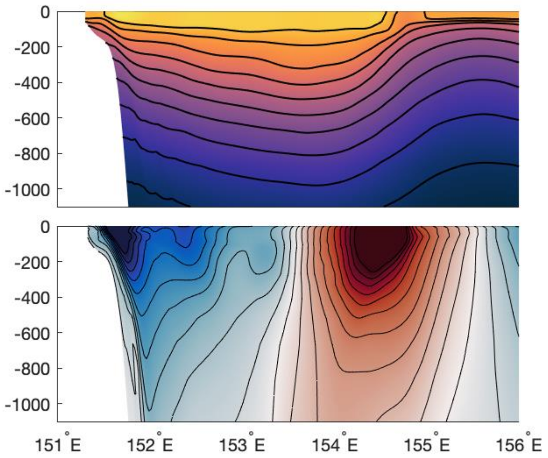

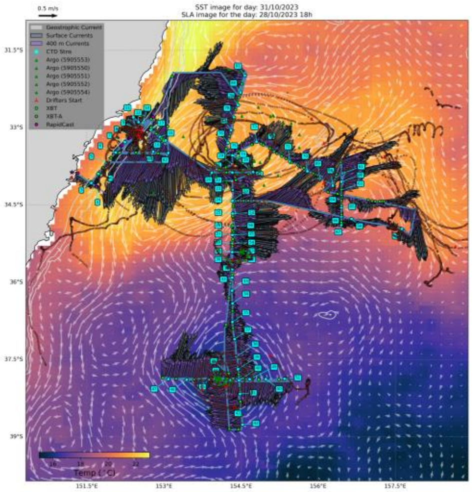

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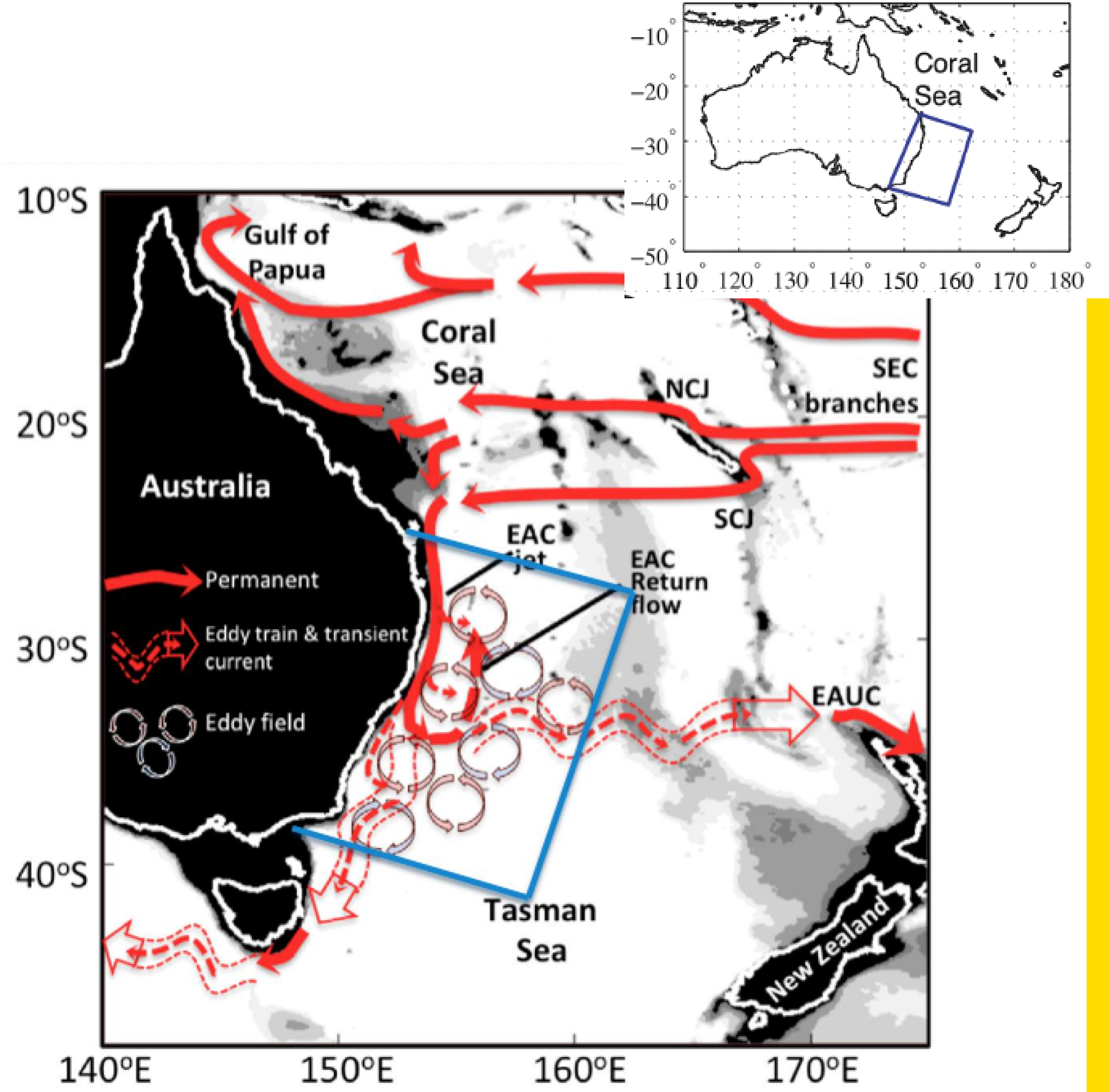
GOOS | CoastPredict with The Global Ocean Observing System

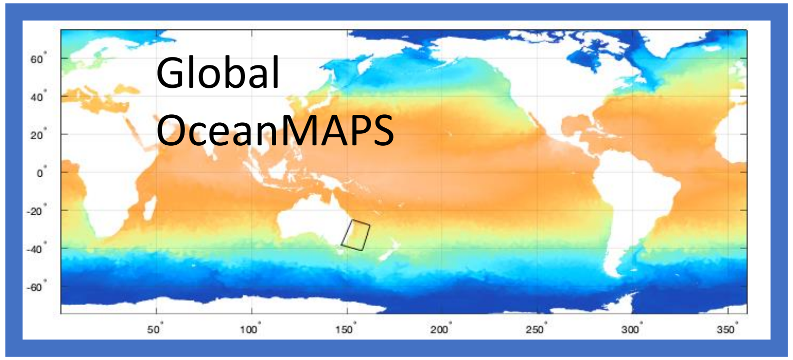
2021 2030 United Nations Decade of Ocean Science for Sustainable Development

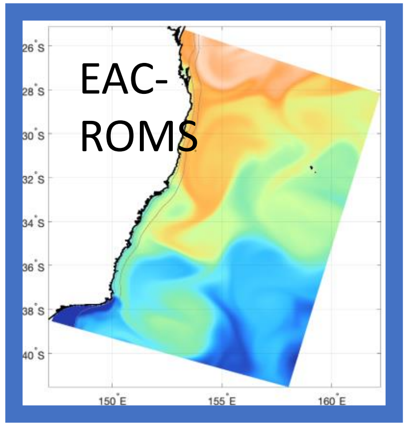
The East Australian Current System

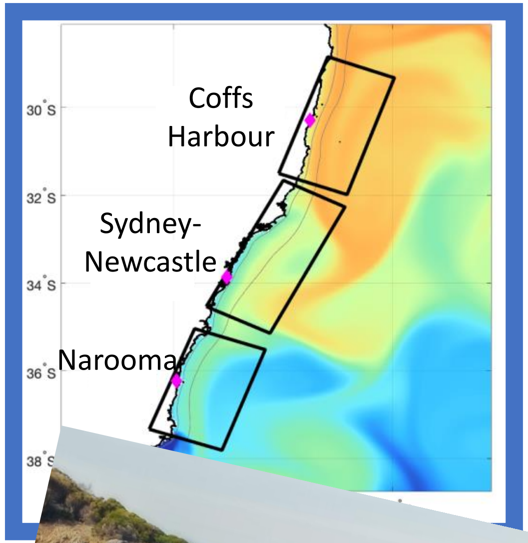
- EAC dominates the SE Australia coastal environment
- Interactions between the EAC (and its eddies) and coastal waters drive complex ocean currents and temperature gradients
- Accurate past estimates and future predictions of these features are crucial for
    - Understanding EAC dynamics and trends
    - Weather prediction (East Coast Lows)
    - Biological productivity and the distribution of nutrients and biota
    - Adaptive management of fisheries
    - Search and Rescue
    - Navigation, optimal ship routes
    - MHW prediction
    - Managing pollution spills and flood plumes



The south-eastern Australia coastal ocean forecast (SEA-COFS)





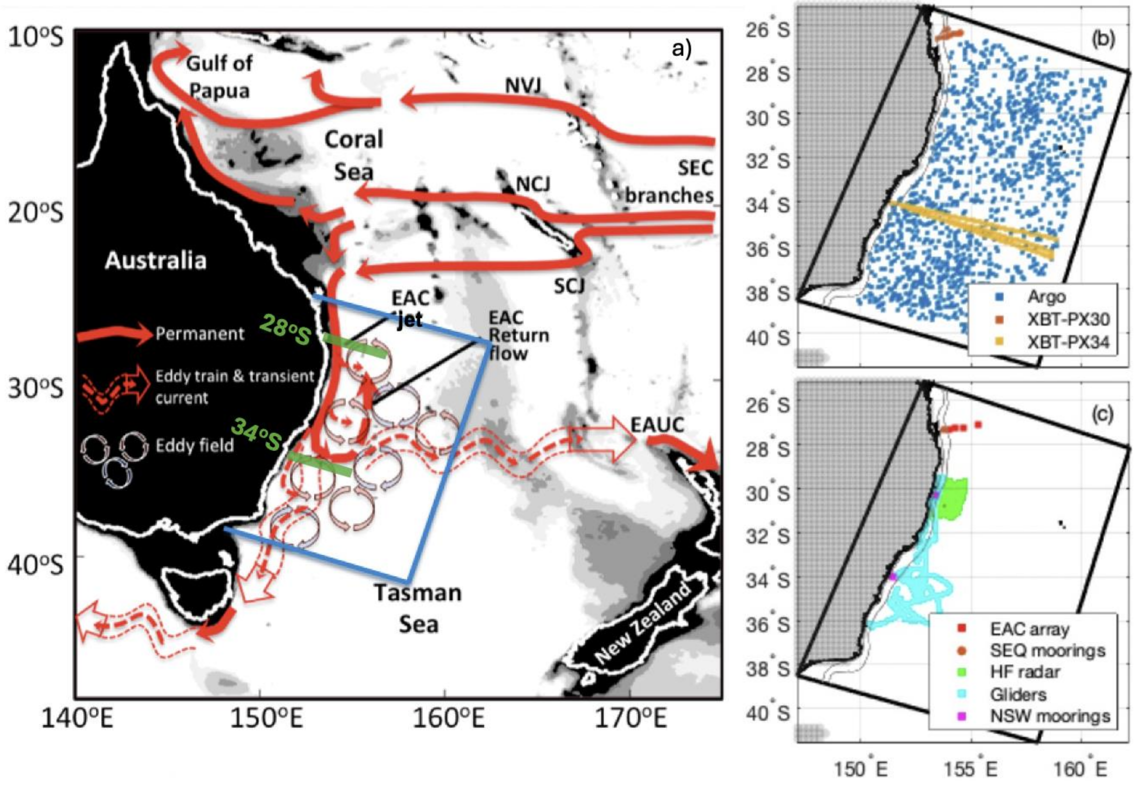


- Ocean model
  - OFAM3 – MOM5
  - 1/10° x 1/10° (10km)
  - 51 levels
- Data assimilation
  - Hybrid EnKF
  - 48 dynamic members
  - 144 low-mode stationary modes
- Atmospheric forcing
  - ACCESS-G3 (12km)
  - Bulk formulae
- Observations
  - RADS altimetry [Jason-3, Sentinnel-3A and 3B, Sentinnel-6A, Cryosat-2, SARAL]
  - Satellite SST [VIIRS/NPP, VIIRS/NOAA20, AVHRR/NAVO, AMSR2]
  - Argo, XBT, Mooring CTD, other CTDs

- Ocean model
  - ROMS
  - **2.5-5km** (increased on shelf/slope)
  - 30 levels
- Data assimilation
  - **4D-Var**
- Atmospheric forcing
  - ACCESS-G3 (12km)
  - Bulk formulae
- Observations
  - **SSH, SST, profiles**
  - HF radar Coffs and Newcastle
  - Gliders
  - Shelf moorings
  - FishSOOP
  - SWOT

The pilot studies: EAC-ROMS for 2012-2013 period

- Three types of Observation Impact Experiments revealed consistent results
  - Adjoint-based observation impacts, OSEs and OSSEs
  - Observations impact up- and down-stream
  - Observing the eddy field particularly impactful
  - Need subsurface observations that constrain the structure of the mixed layer and thermocline
  - Revealed challenges with submesoscale/frontal eddy predictability



THE OCEANOGRAPHY SOCIETY

Model-based Observing System Evaluation in a Western Boundary Current: Observation Impact from the Coherent Jet to the Eddy Field

Kerry, Roughan, Keating, Gwyther

UNSW SYDNEY

Assessing predictions of the ocean eddy structure:
Research Questions

The subsurface ⟷ The submesoscale

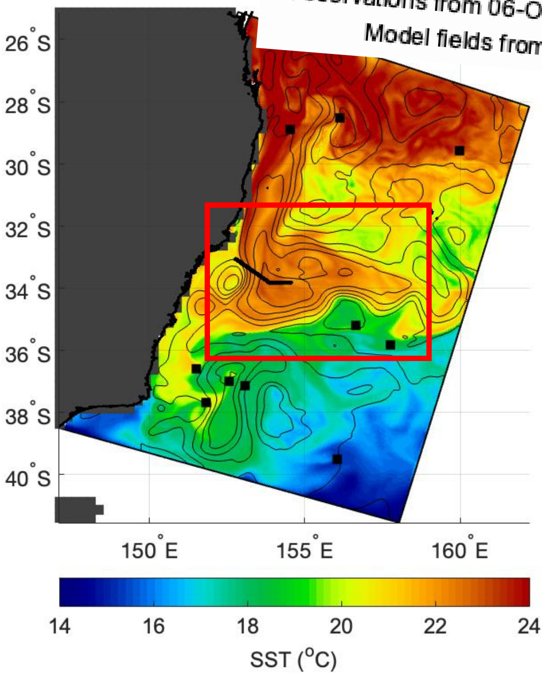
The subsurface

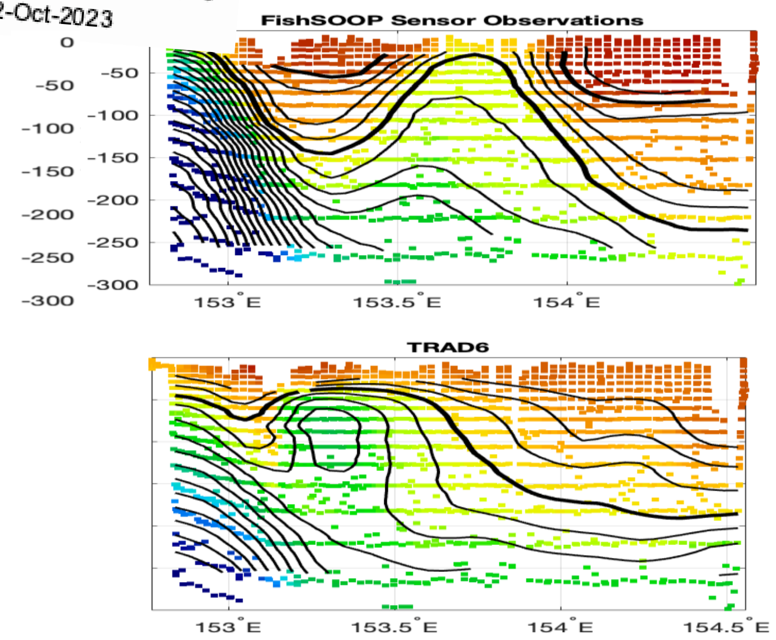
- Argo profiling floats are sparse (in regional context)
- Can we predict the complex subsurface structure of eddy-eddy, eddy-coast interactions?

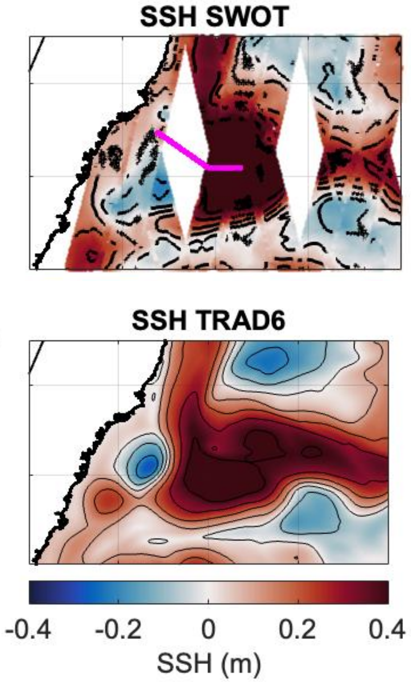
The submesoscale

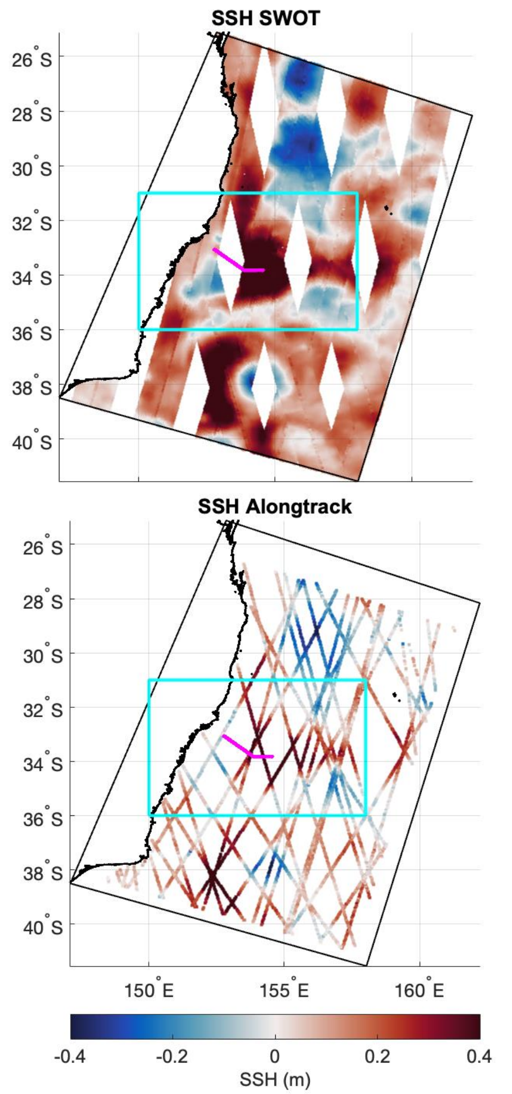
- SWOT is providing unprecedented detail of the ocean's surface, revealing complex eddy shapes and fine-scale variability
- But at low temporal frequency
- Are these fine-scales predictable?

Observations from 06-Oct-2023 to 12-Oct-2023
Model fields from 12-Oct-2023





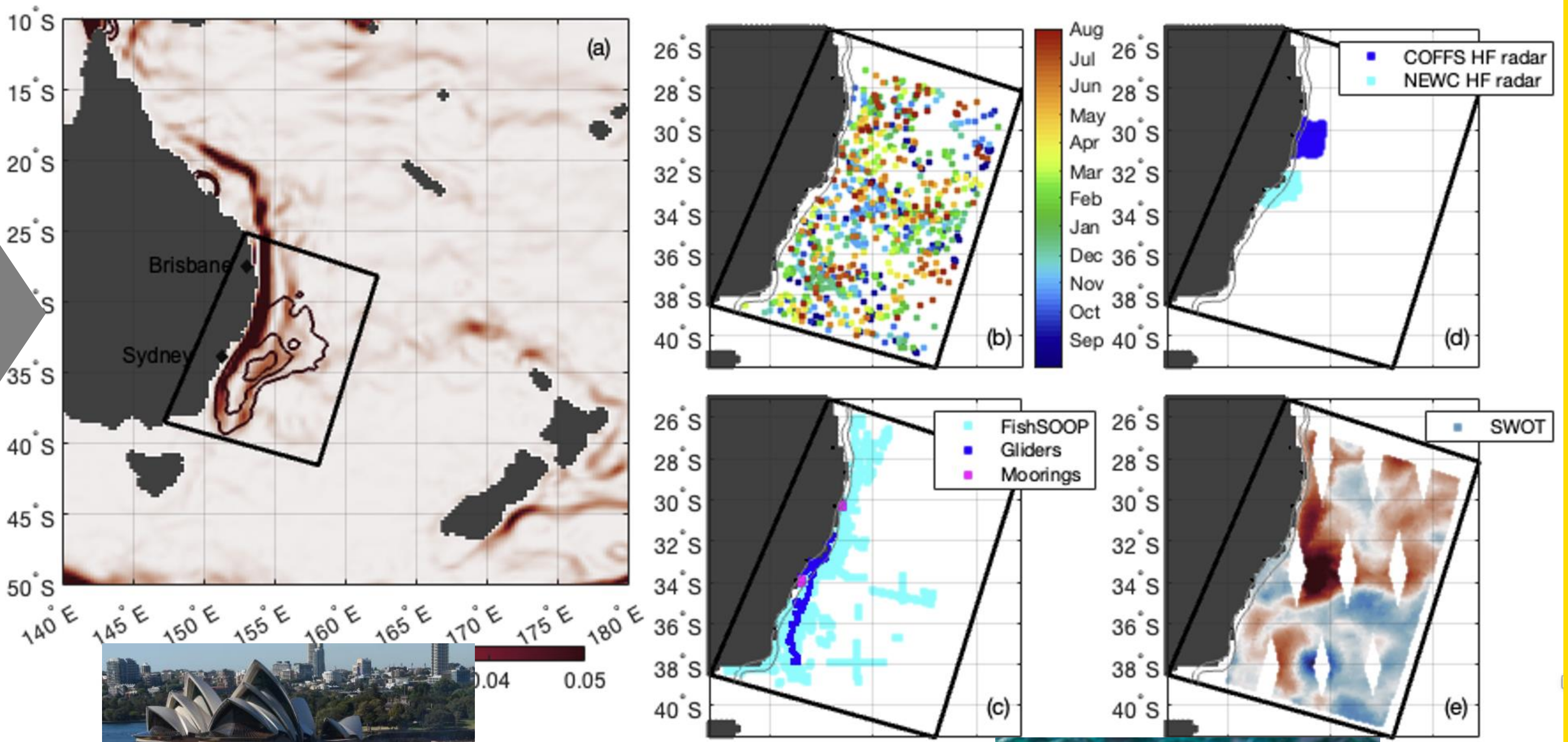


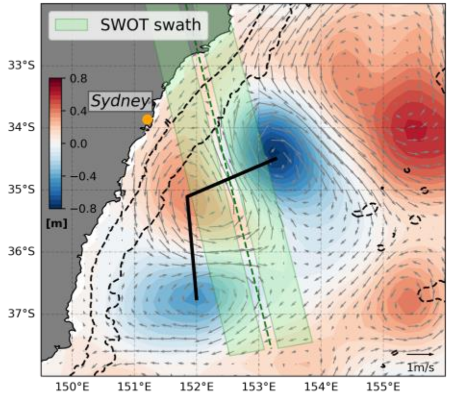


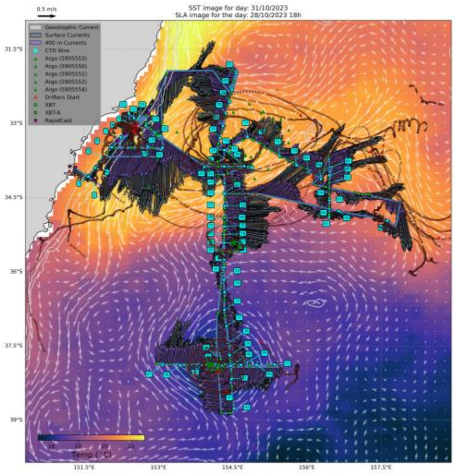
1-year pilot study, Aug 2023-Jul 2024

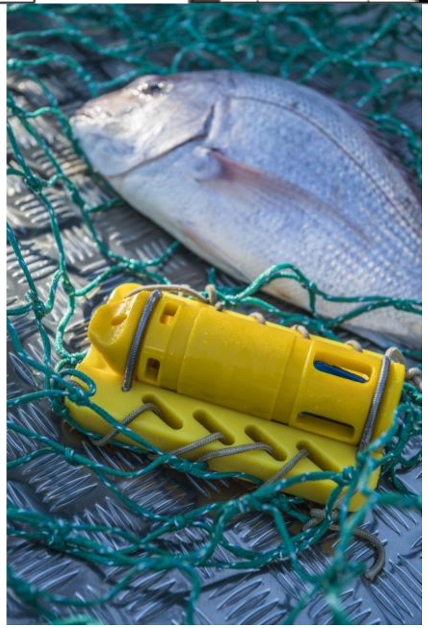
Period of unprecedented data richness and complex eddy dynamics

- AVISO SSH, SST, Argo profiles
- HF radar
- Gliders
- Shelf moorings
- SWOT
- Moana Sensors (FishSOOP)
- RV Investigator cruise (Oct 2023)









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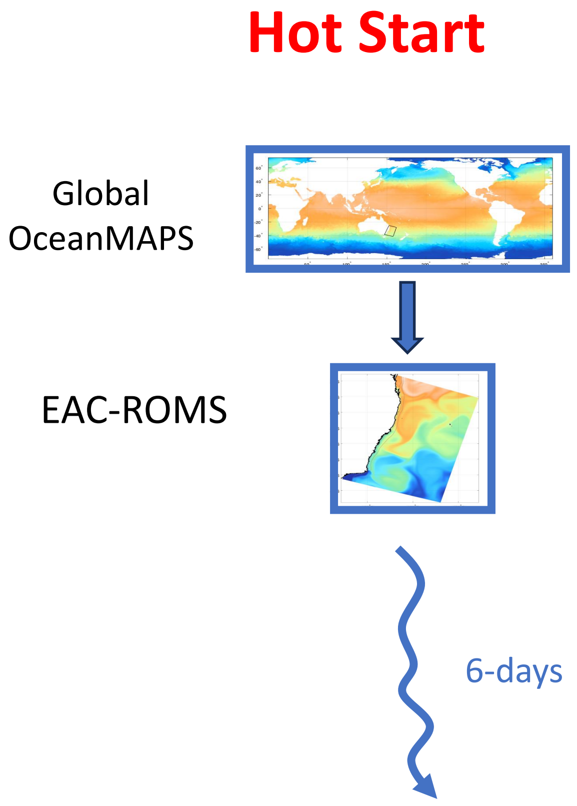
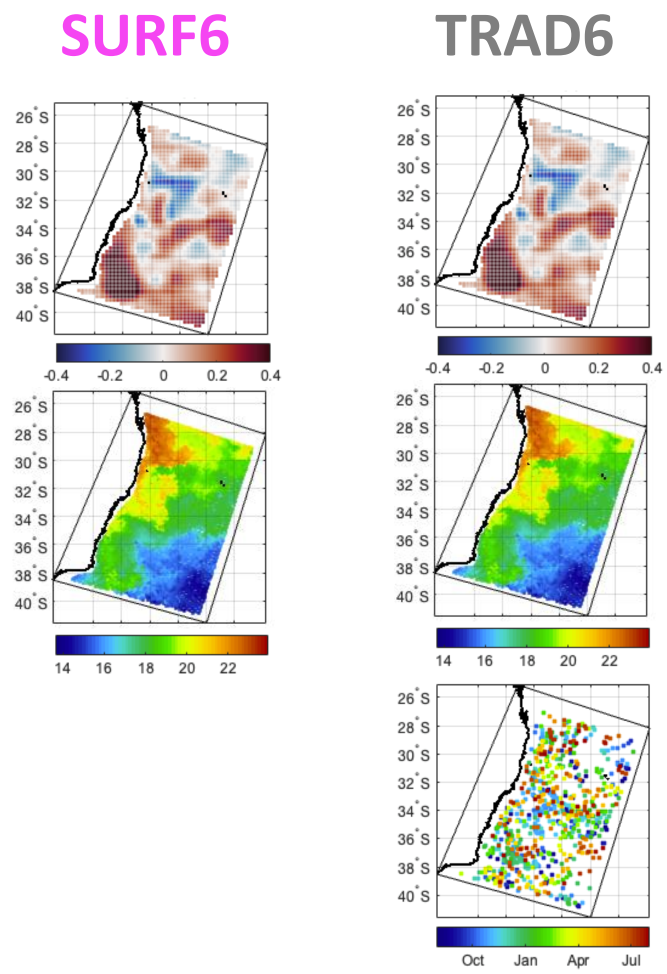
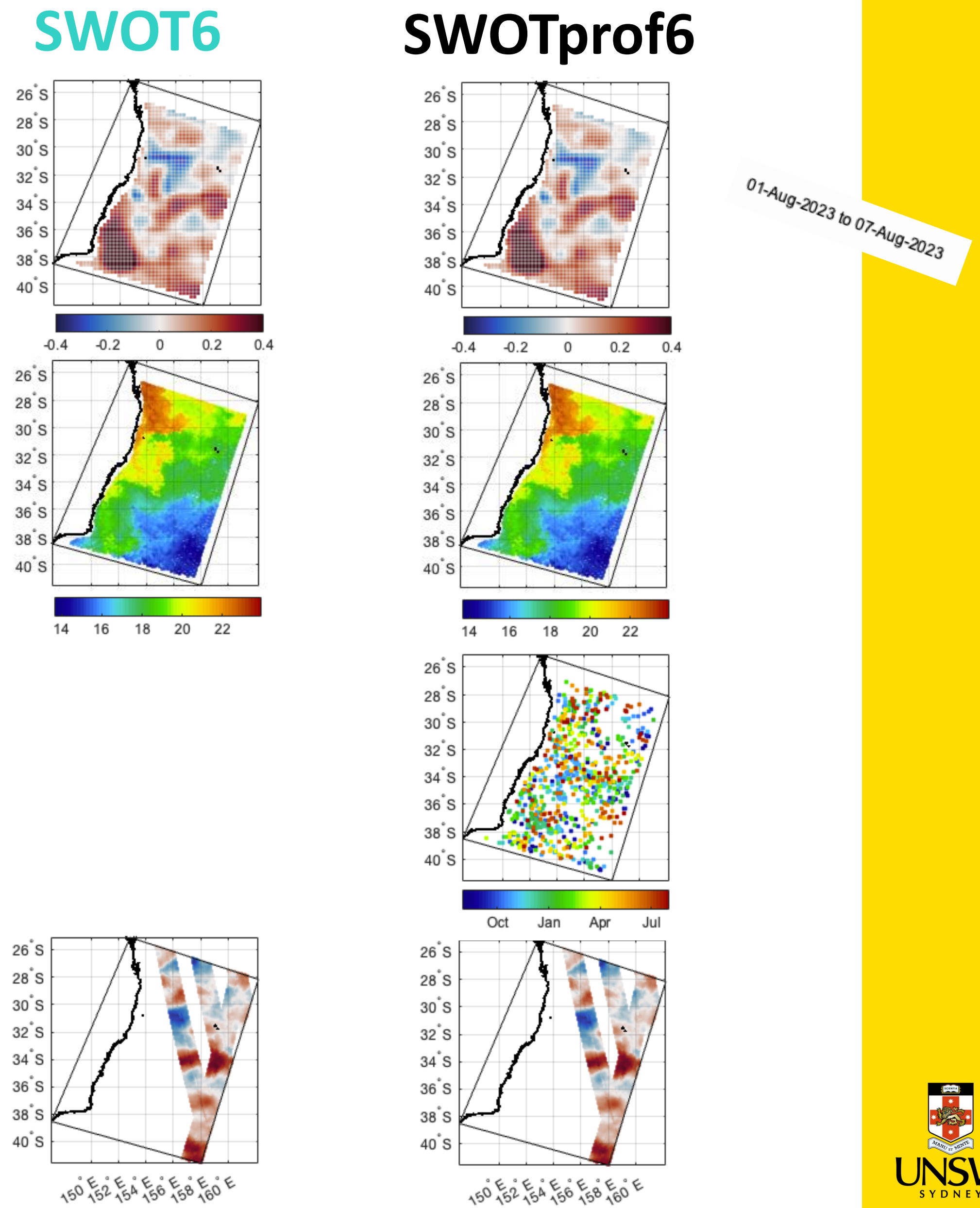
System Overview – Observations and DA Experiments

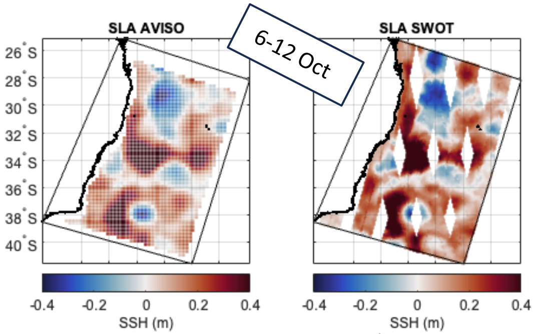


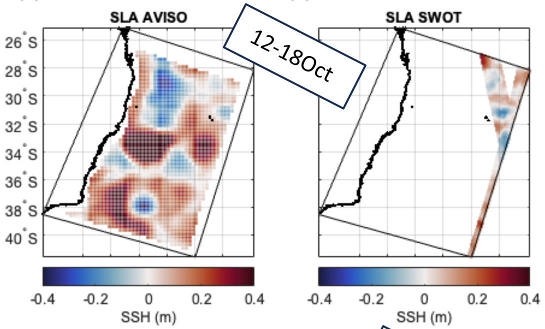


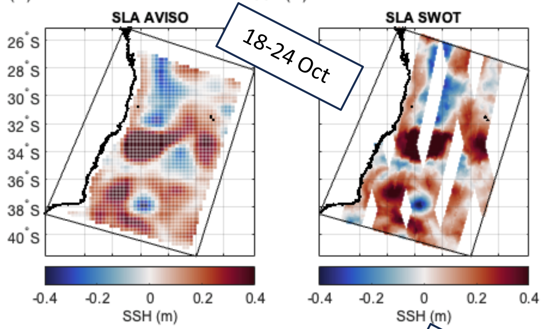


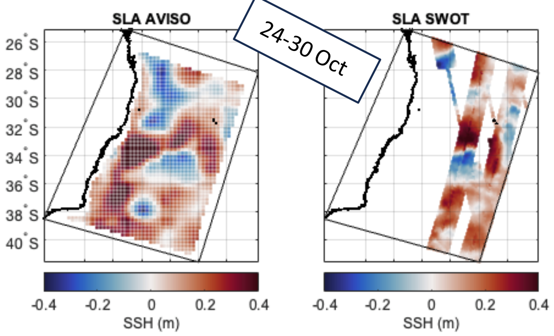
- Gridded SSH, operational NRT AVISO
- Midnight SST gridded (super-obbed) from NAVO, AMSA2, VIIRS and VIIRS2
- Profiles of temperature and salinity (Average of 5-6 profiles/day)
- SWOT L3 v1.0.2

Performance Summary









Mean Absolute Difference for assimilated and independent observations

Model experiment name:	Free run	Hot Start	SURF6	TRAD6	SWOT6	SWOTprof6
AVISO SSH (cm)	16.9 (×)	9.3 (×)	8.4 (✓)	9.1 (✓)	7.1 (✓)	7.2 (✓)
SWOT SSH (cm)	16.4 (×)	9.7 (×)	9.2 (×)	10.1 (×)	4.9 (✓)	5.0 (✓)
Midnight SST (^oC)	0.97 (×)	0.53 (×)	0.53 (✓)	0.54 (✓)	0.58 (✓)	0.59 (✓)
Argo temperature (upper 1000 m)	1.16 (×)	0.68 (×)	0.95 (×)	0.55 (✓)	0.98 (×)	0.55 (✓)
Argo salinity (upper 1000 m)	0.105 (×)	0.070 (×)	0.111 (×)	0.050 (✓)	0.140 (×)	0.059 (✓)
...ana temperature	1.54 (×)	1.07 (×)	1.06 (×)	1.06 (×)	1.07 (×)	1.06 (×)
...ider temperature	0.65 (×)	0.75 (×)	0.89 (×)	0.84 (×)	0.83 (×)	0.89 (×)
Glider salinity	0.082 (×)	0.084 (×)	0.079 (×)	0.080 (×)	0.095 (×)	0.096 (×)

- Assimilating SWOT improves fit to AVISO, which represents the daily large-scale SSH field
- ….and fit to SWOT!

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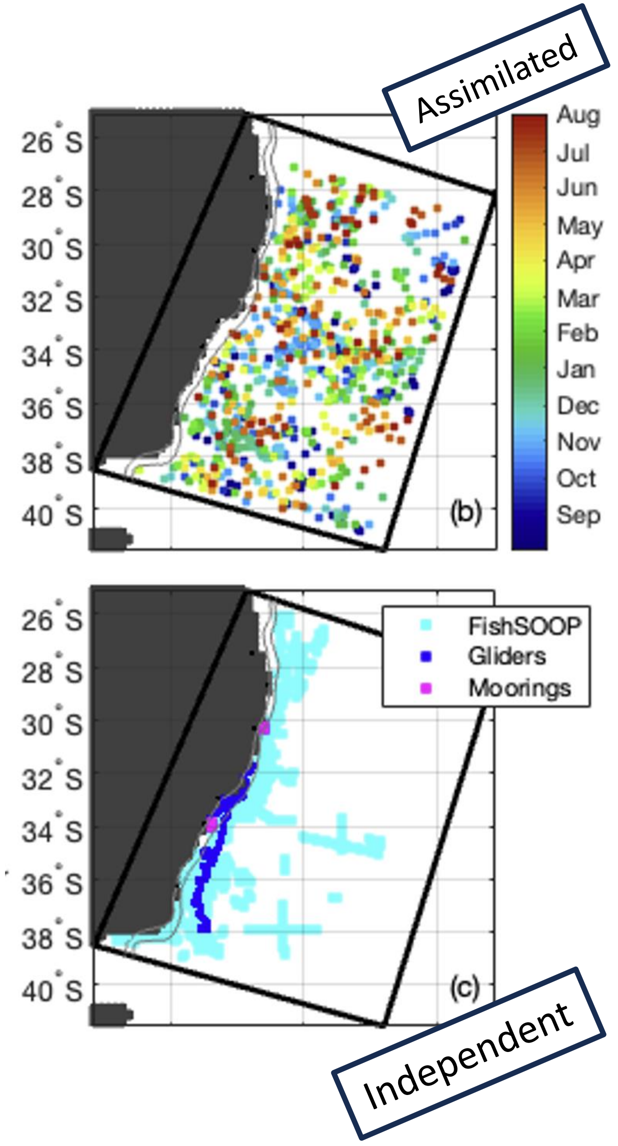
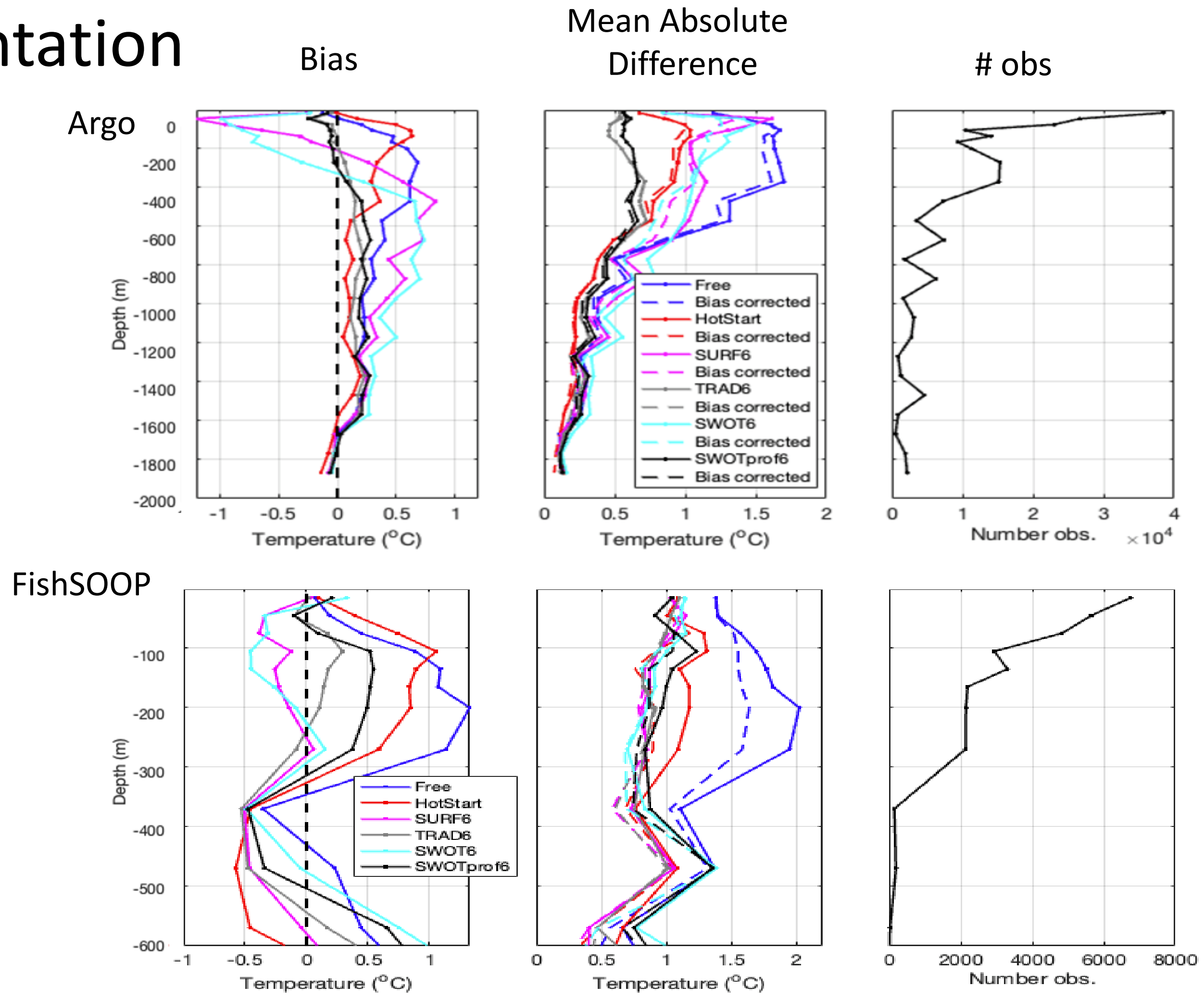
Sub-surface representation





Argo:

Free 1.16 °C
Hot Start 0.68 °C
SURF6 0.95 °C
TRAD6 0.55 °C
SWOT6 0.98 °C
SWOTprof6 0.55 °C

FishSOOP:

Free 1.54 °C
Hot Start 1.07 °C
SURF6 1.06 °C
TRAD6 1.06 °C
SWOT6 1.07 °C
SWOTprof6 1.06 °C

- Assimilating profiles from Argo gives significant improvement at profile locations
- Surface only observations degrades fit to Argo
- DA on the EAC-ROMS domain improves bias and MAD at independent temperature profile locations
- Independent subsurface observations are represented with similar accuracy across all experiments (on average)

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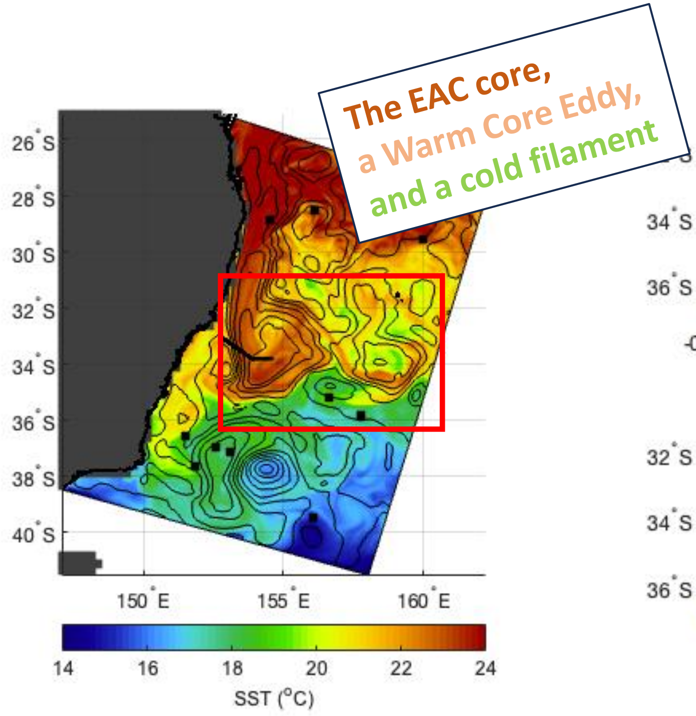
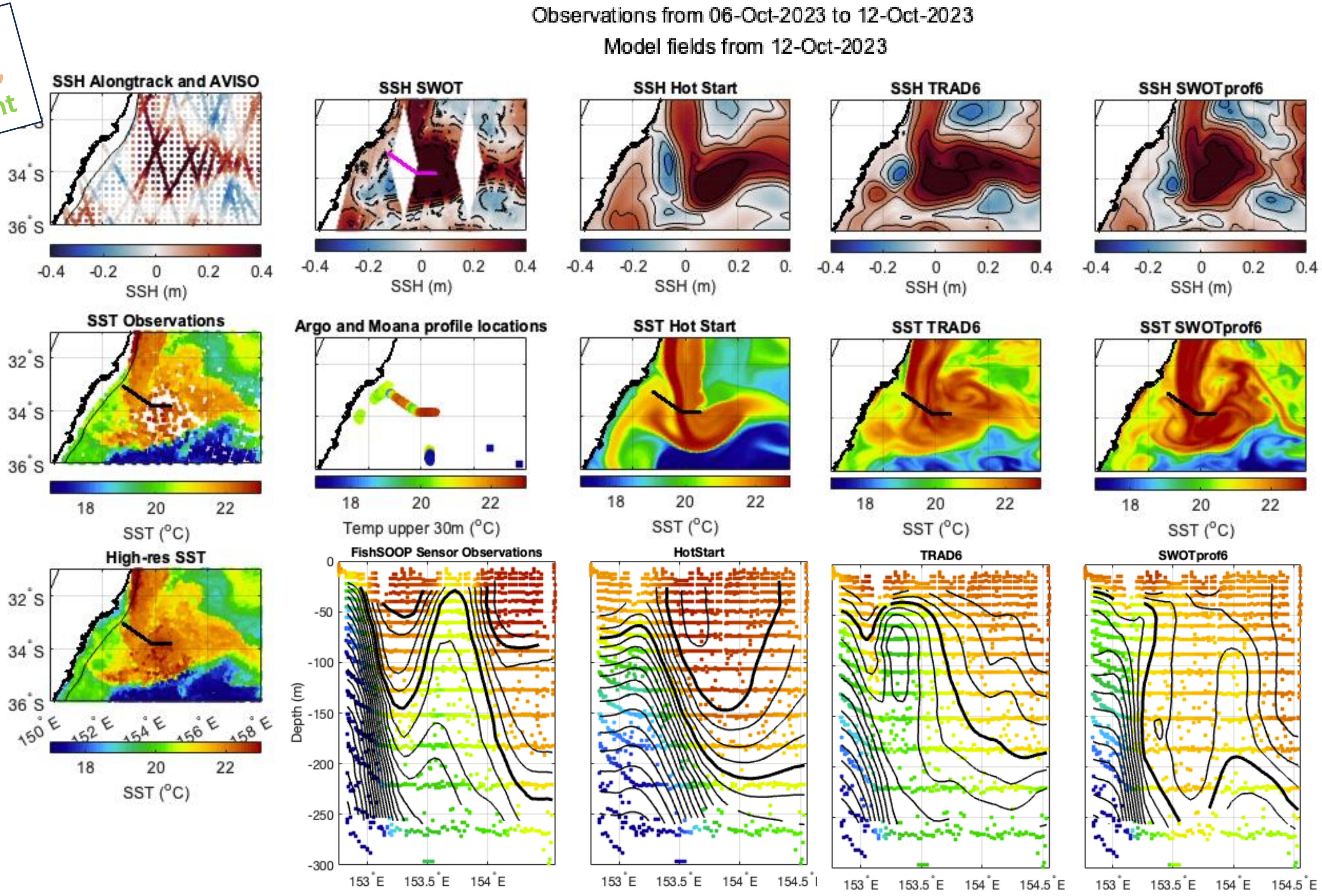
Case Study

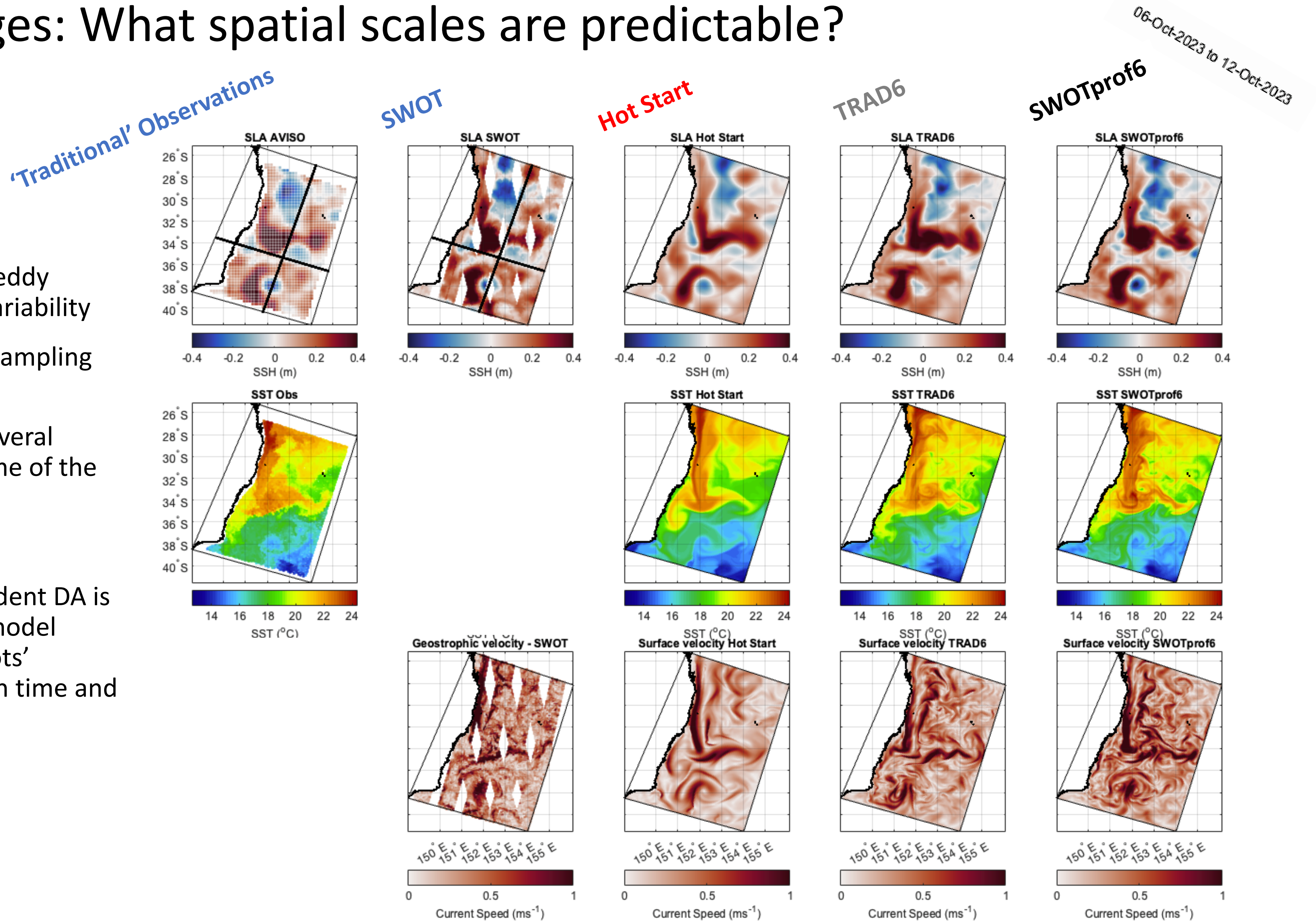




- Different experiments reveal very different subsurface structure
- Highlights the value of subsurface observations == FishSOOP

SWOT challenges: What spatial scales are predictable?

- SWOT reveals complex eddy shapes and fine-scale variability
- But with low temporal sampling frequency
- 6-day windows allow several passes per window (some of the time)
- The goal of time-dependent DA is to use the (linearised) model dynamics to 'join the dots' between observations in time and space



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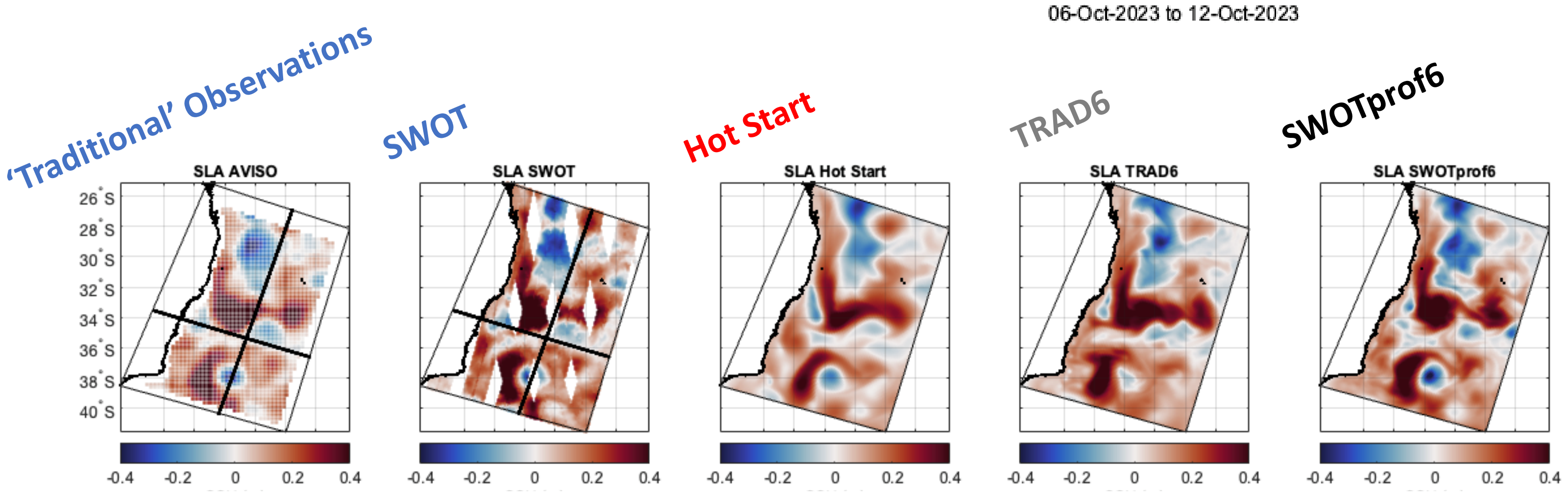
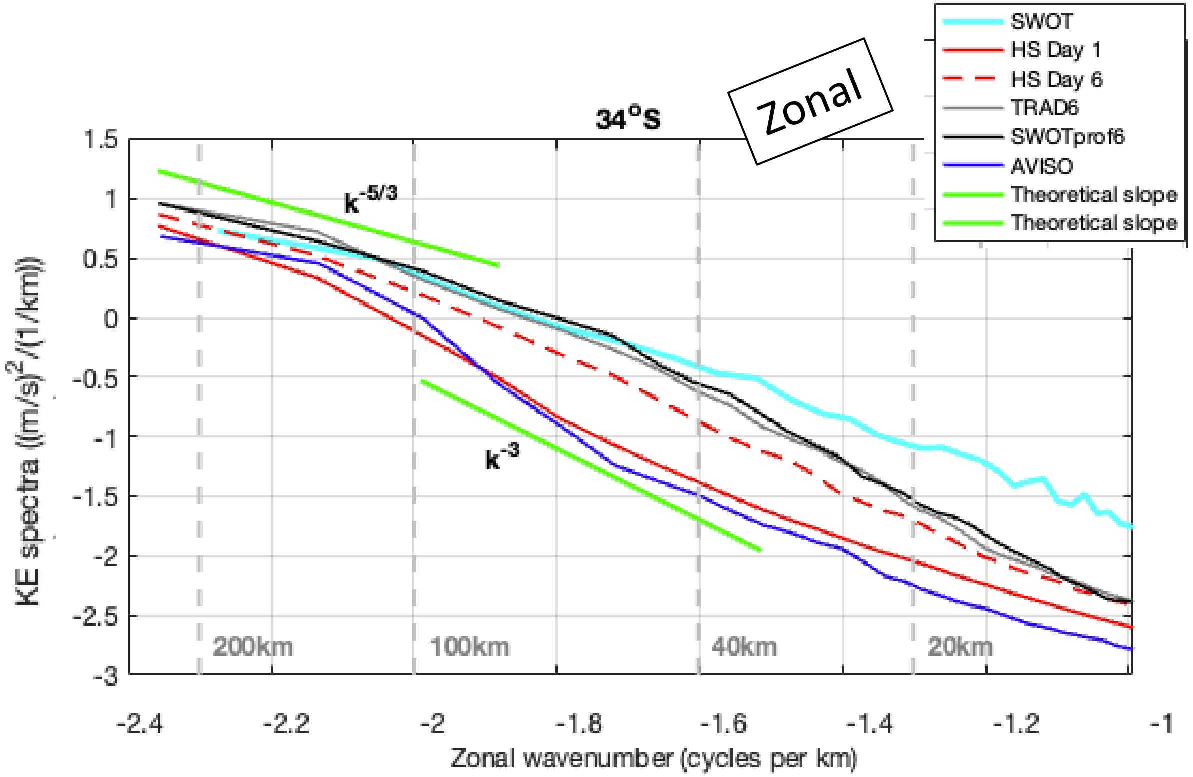
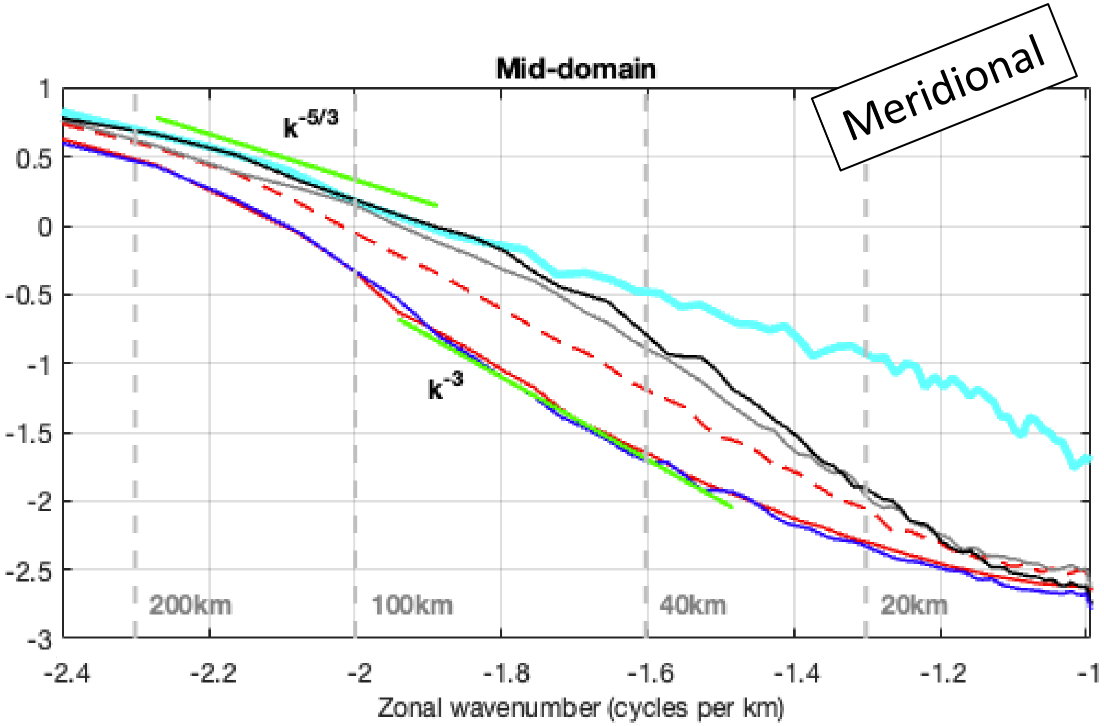
Spatial scales

- Surface wavenumber spectra shows considerably more energy at finer scales resolved by SWOT
- SWOTprof6 provides a very good match to the observed kinetic energy spectra for scales <~50km

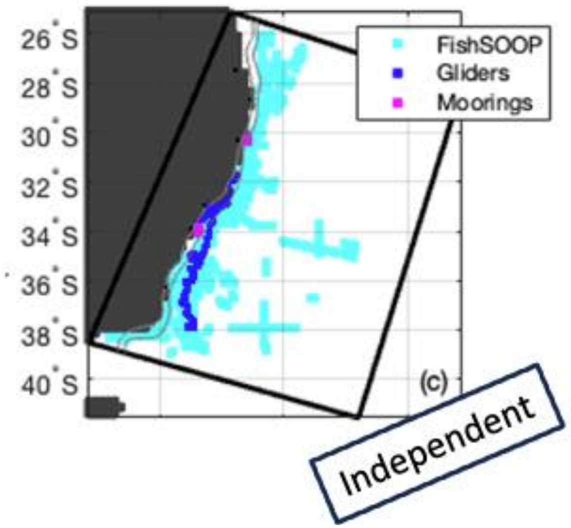




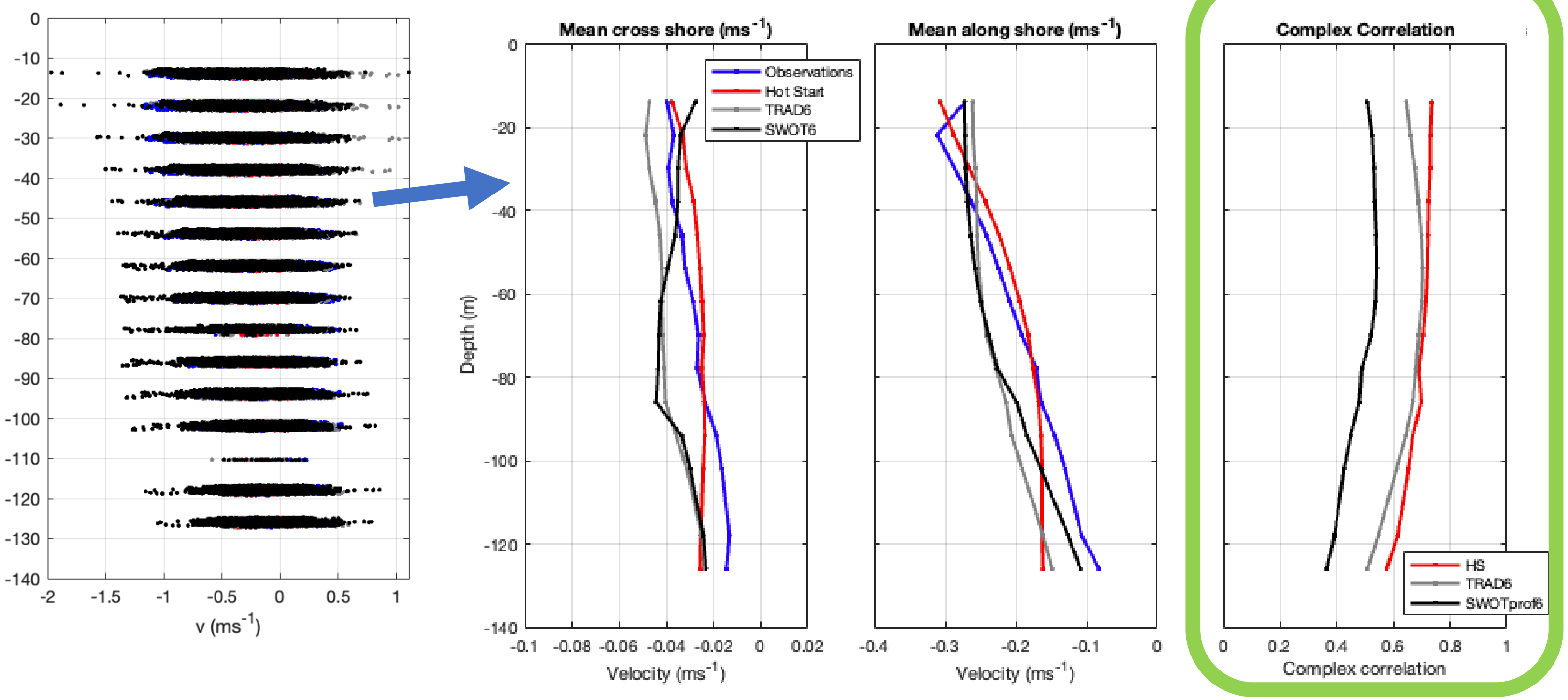


Time scales

- Hourly velocity observations at coastal/shelf moorings
- SWOTprof6 provides a better match to observations in frequency kinetic energy spectra
- … but a lower correlation (if all frequencies are considered)

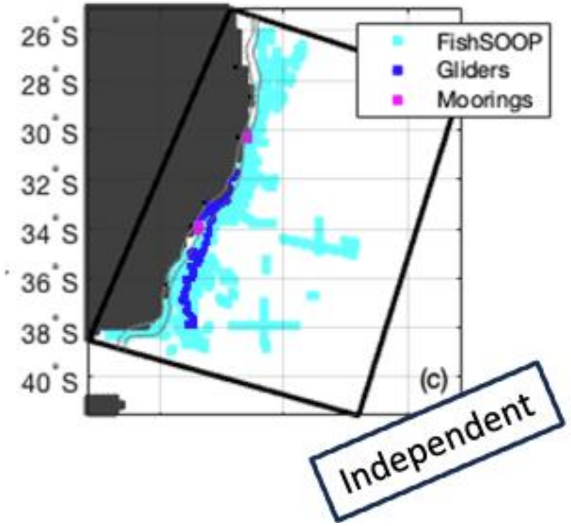


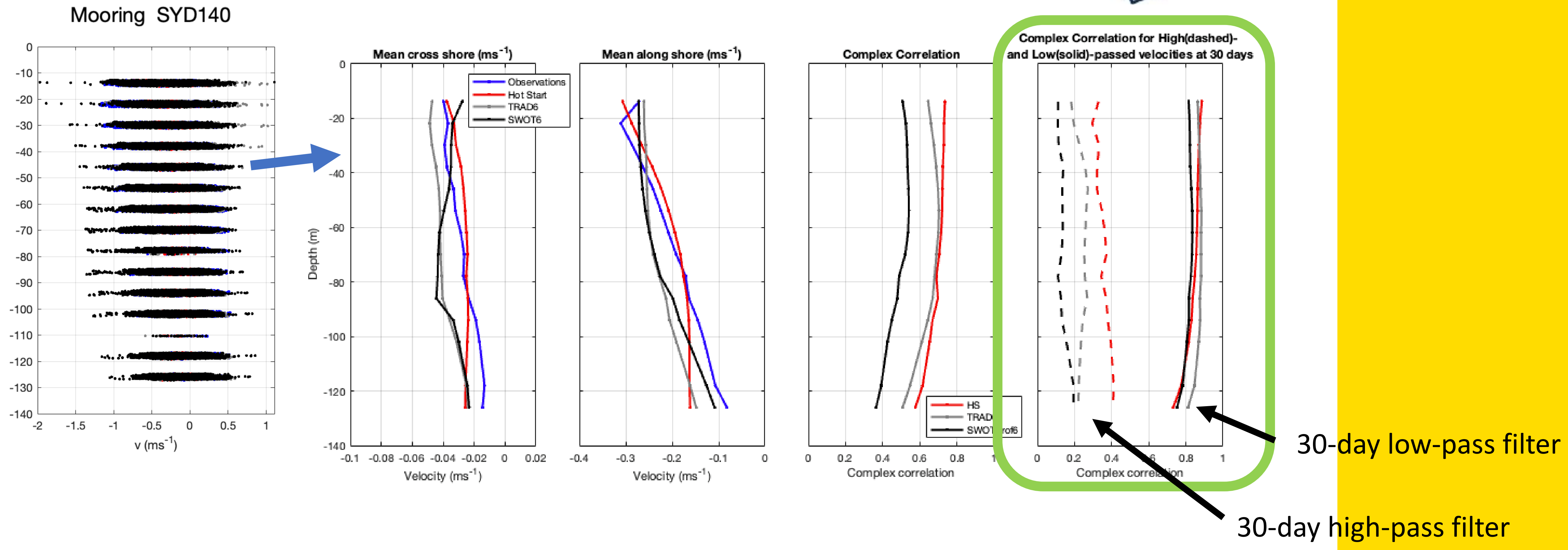
Mooring SYD140



Predictability at various time scales

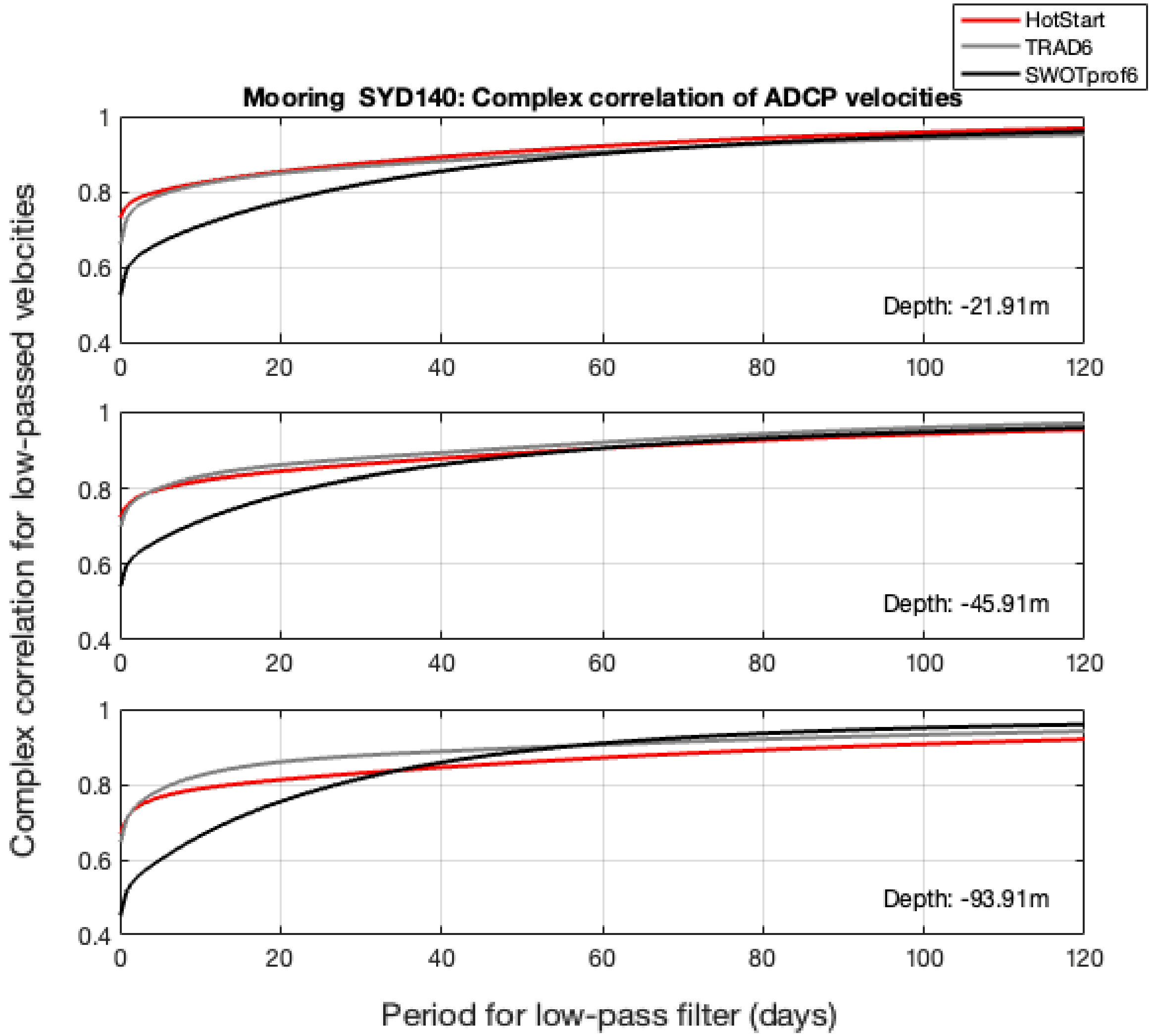
- Low frequency (>30 days) correlations are comparable
- High frequency variability in SWOTprof6 shows low correlation





Submesoscale (un)predictability

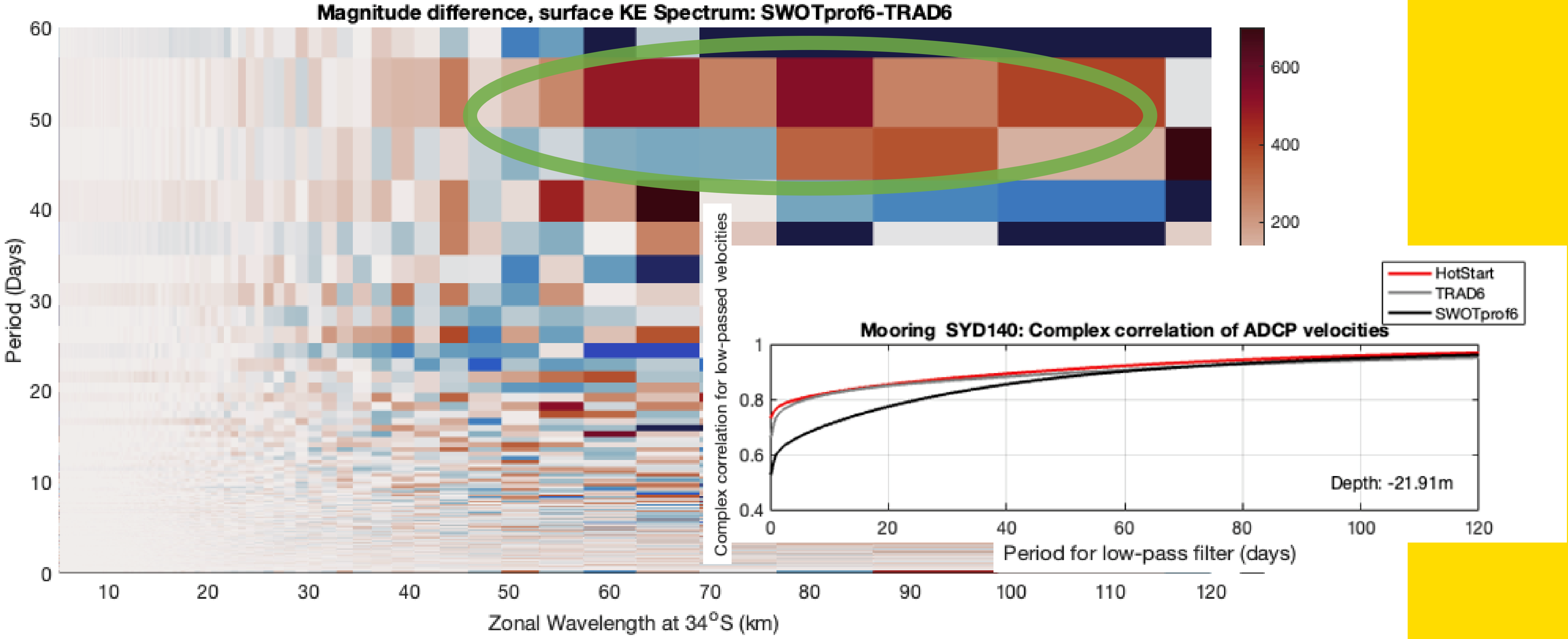
Mooring data



Wavenumber-frequency analysis
Difference plot

- Cross-shore section through 34°S
- All runs show dominant energy at the **mesoscale** (~100 days, ~200-350km)

- SWOTprof6 has elevated energy in the 40-50 days, 50-100km range: **submesocale**



Summary

- Successful assimilation of SWOT data with improved representation of the largescale SSH field

Subsurface
- Assimilation of Argo profile data improves overall subsurface representation
- However independent observations reveal that the complex subsurface eddy structure remains poorly represented
- Provides motivation for additional subsurface observations (FishSOOP)

Scales of variability
- Assimilation of SWOT introduces additional variability at fine spatial scales (50-100km) and short time scales (<50 days)
- However, these fine scales / high frequencies are NOT predictable (in this model configuration)

Future work
- Can we improve our model and DA system to better ‘join the dots’?
- Do we need higher-resolution models to draw benefit from SWOT (1km rather than 2.5-5km)?
- OSSEs for ‘Truth’ about the fine-scales.

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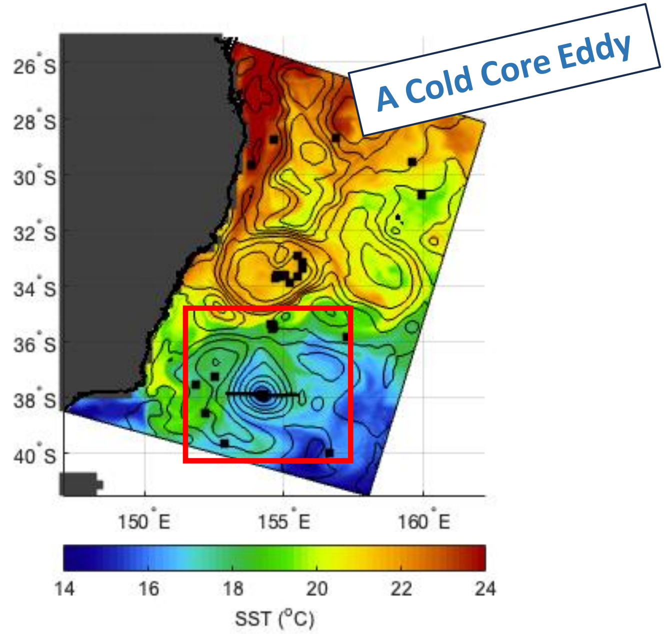
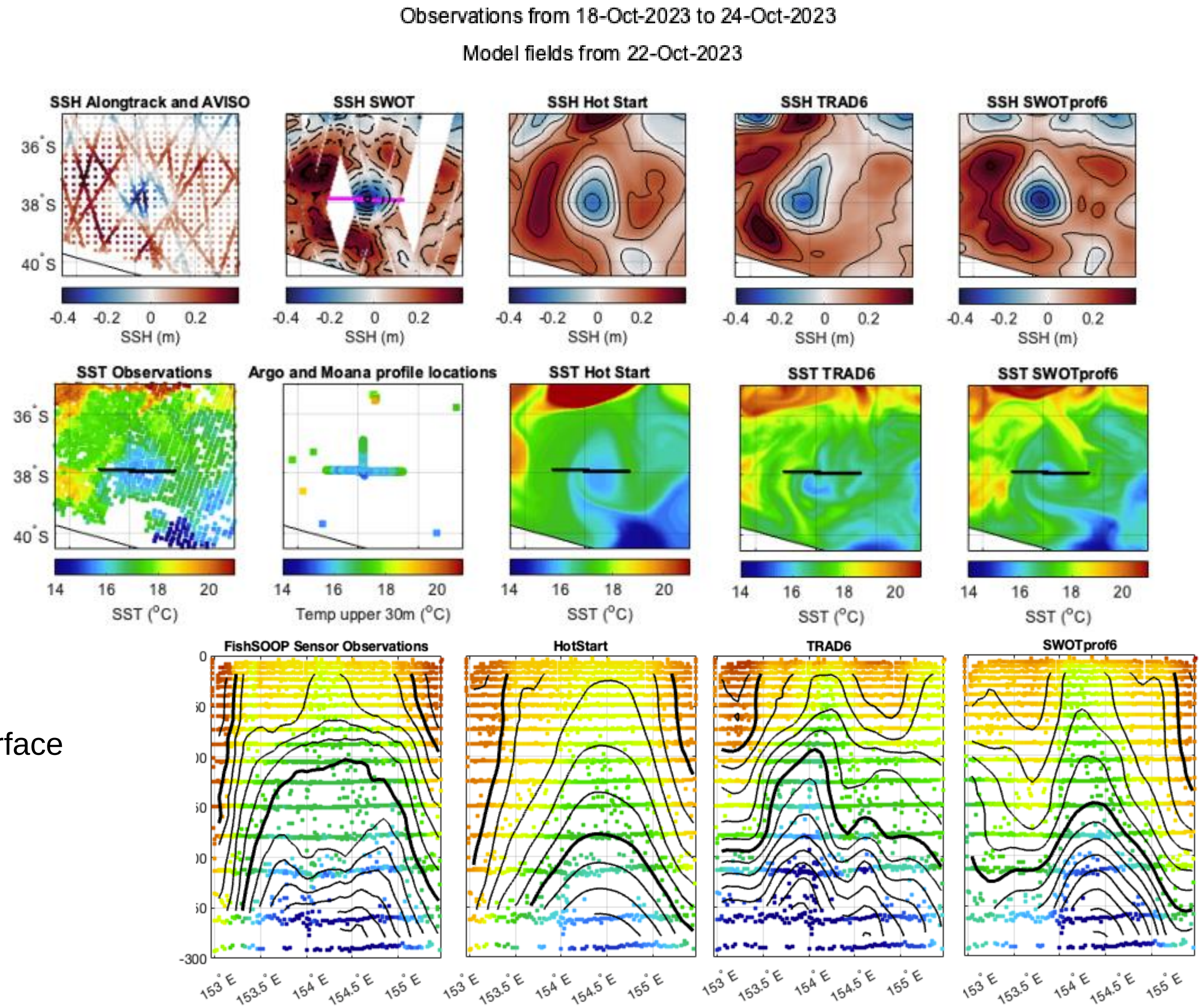
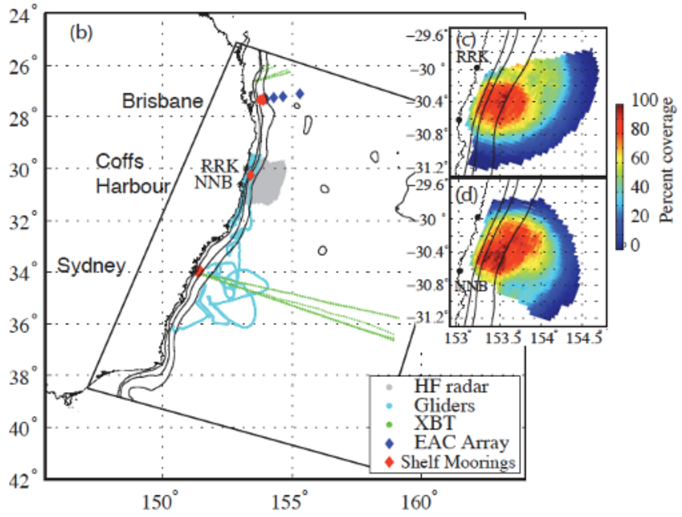
Case Study: Cold Core Eddy

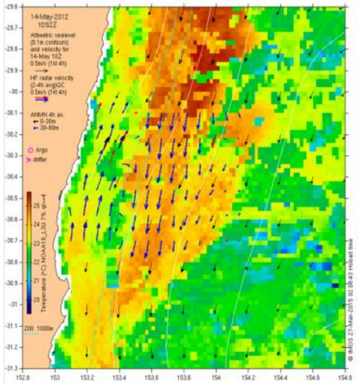




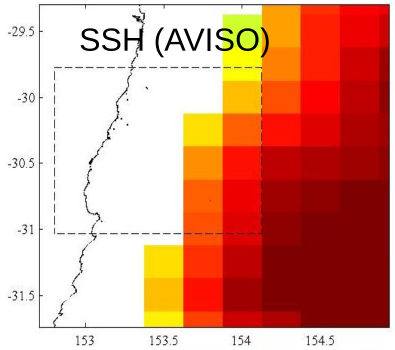
- Stable Cold Core Eddy
- Different experiments reveal quite different subsurface structures

Submesoscale (un)predictability – HF radar assimilation

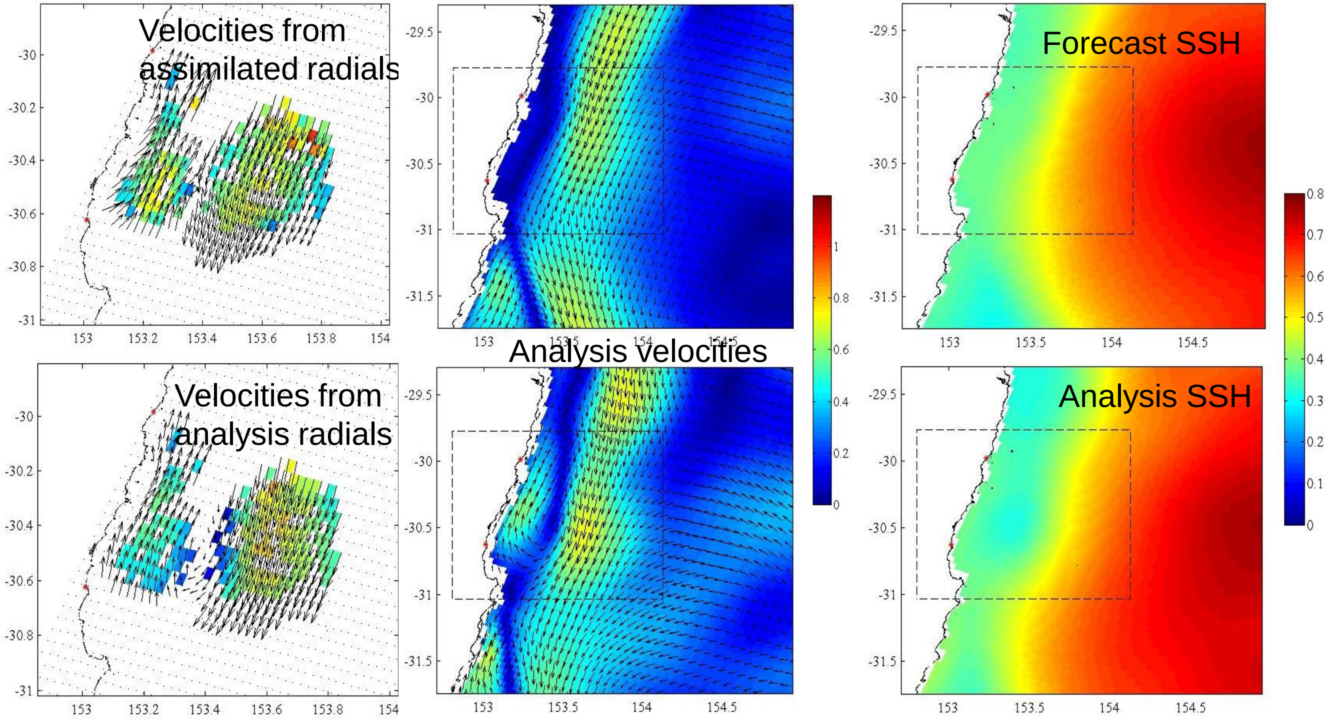




Assimilation of radial velocities from HF Radar array, specific example (May 14 2012)



Forecast velocities



- Assimilating radial velocities results in increased cyclonic vorticity inshore of the EAC and a sharper vorticity gradient along the EAC's inshore edge
- The impacts are seen both up- and down-stream

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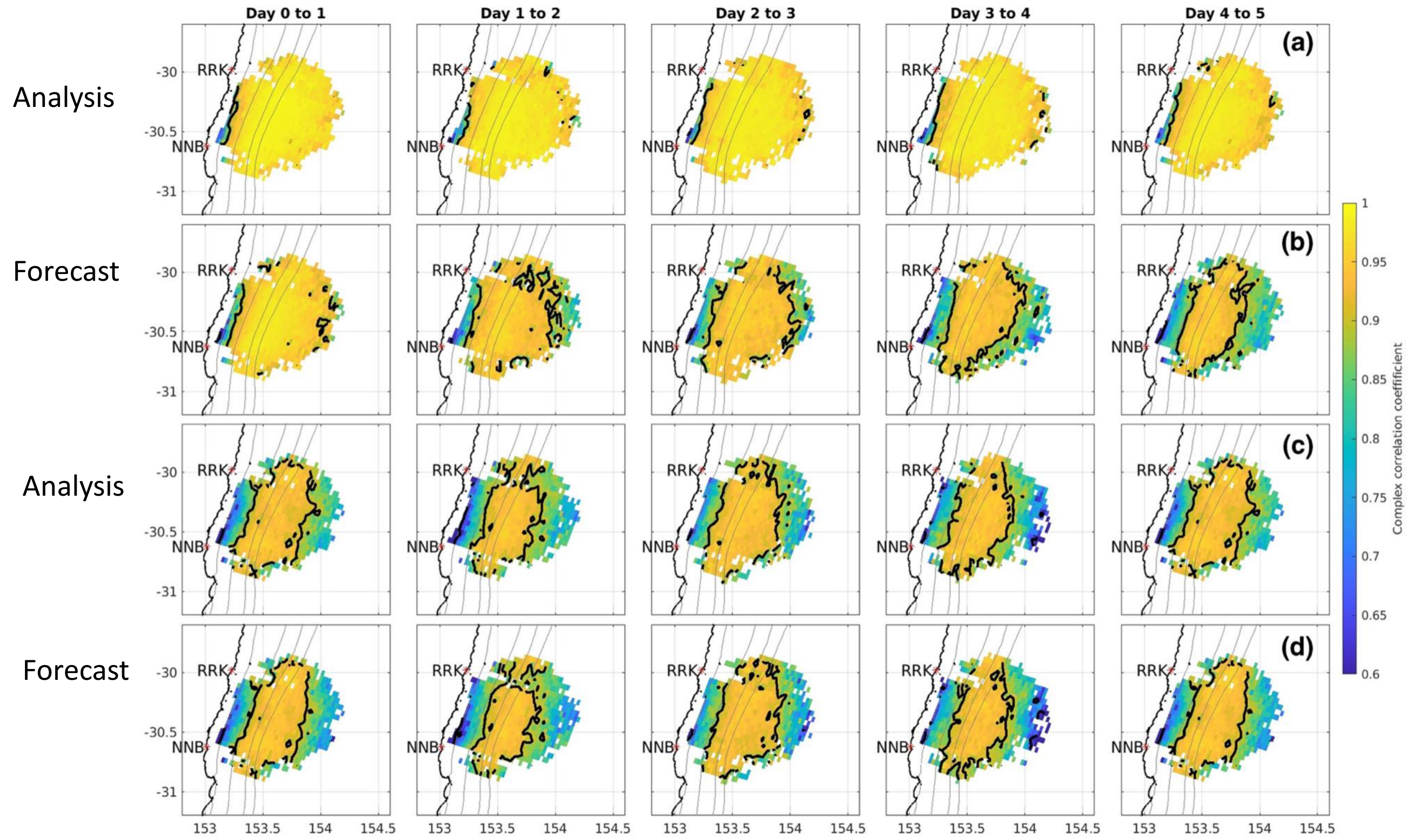
Submesoscale (un)predictability – HF radar assimilation

- However, after 5-day forecasts skill is lost

Velocity complex correlations with window day

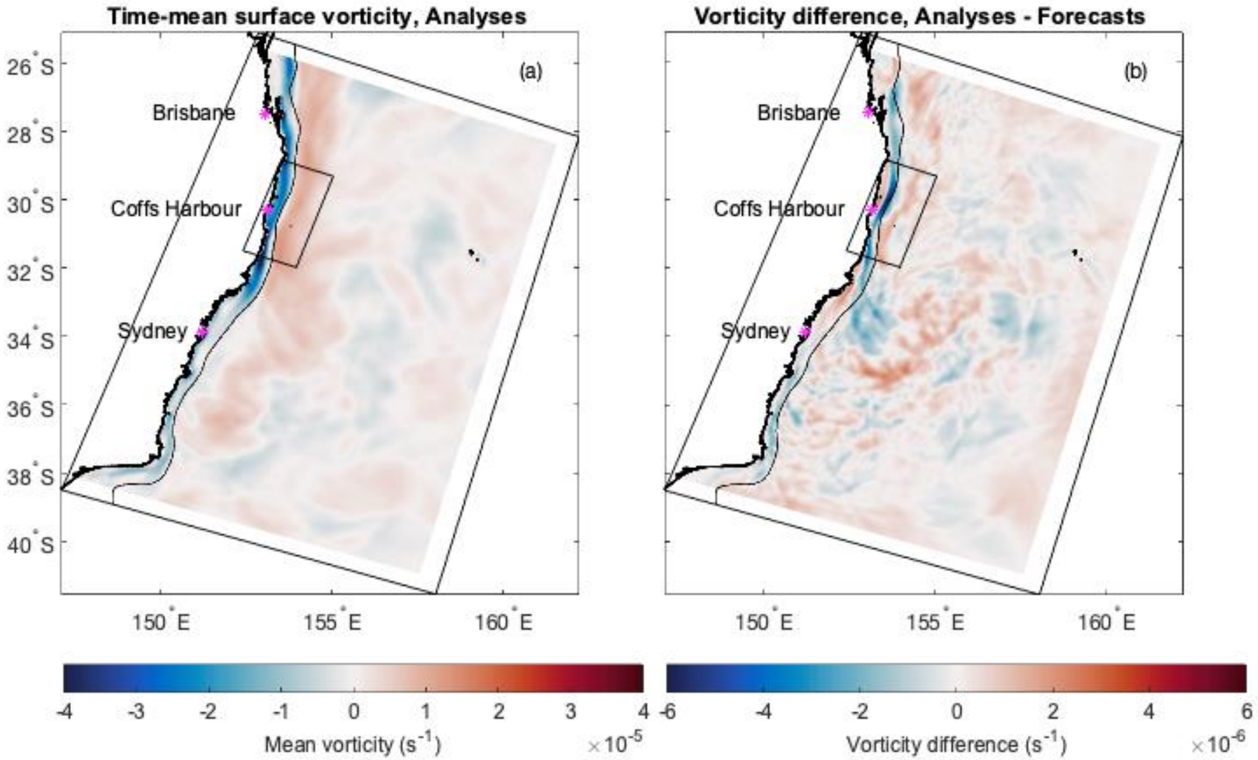
Assimilating HF Radar Data

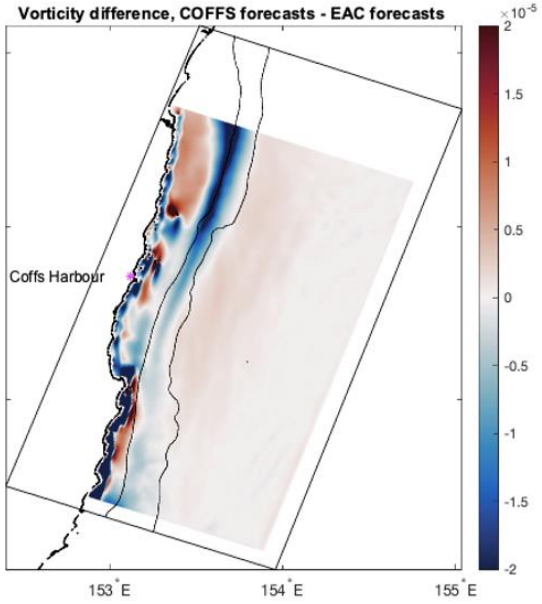
Withholding HF Radar Data



Submesoscale (un)predictability – HF radar assimilation

- A higher (1km) resolution model **maintains the vorticity gradient** in the forecasts
- But the **evolution of the specific submesoscale features is not well predicted**





Kerry, C., Roughan, M. and Powell, B., 2020. Predicting the submesoscale circulation inshore of the East Australian Current. *Journal of Marine Systems*, *204*, p.103286.

Assessing predictions of the ocean eddy structure:
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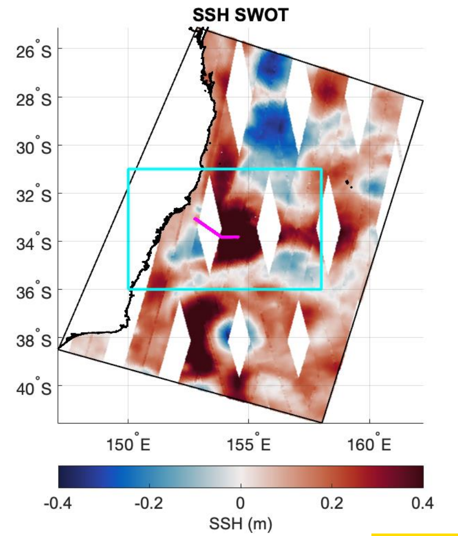

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- Can we predict the complex subsurface structure of eddy-eddy, eddy-coast interactions?

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- But at low temporal frequency
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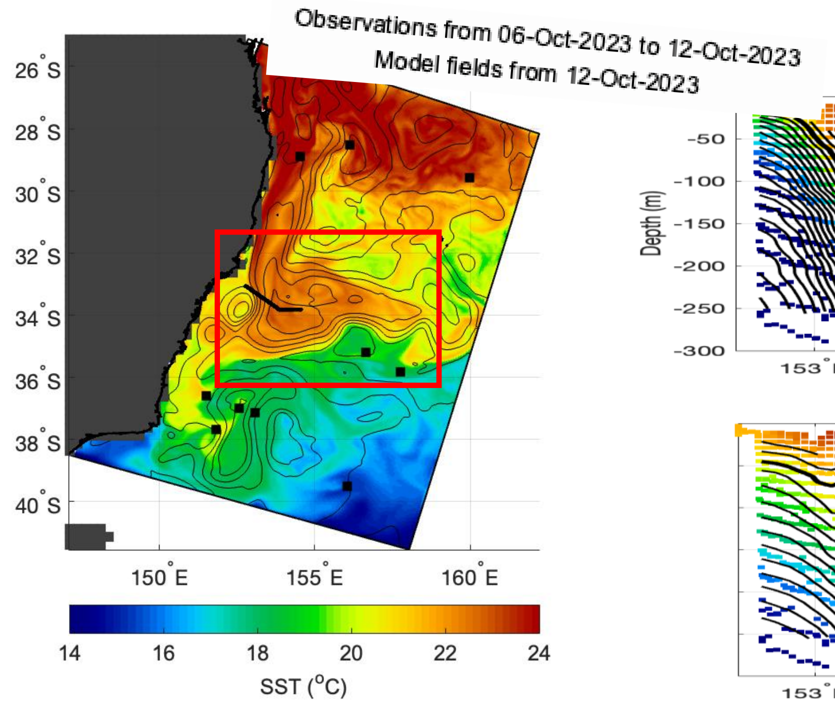

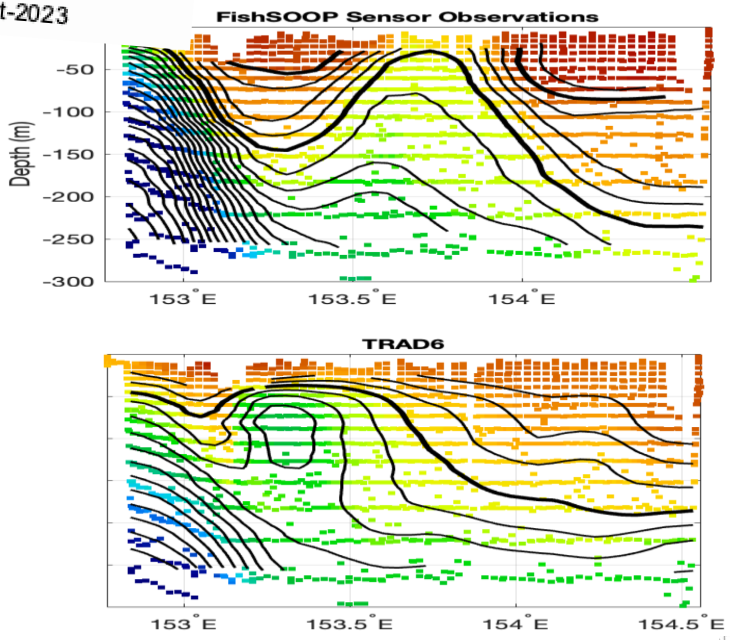

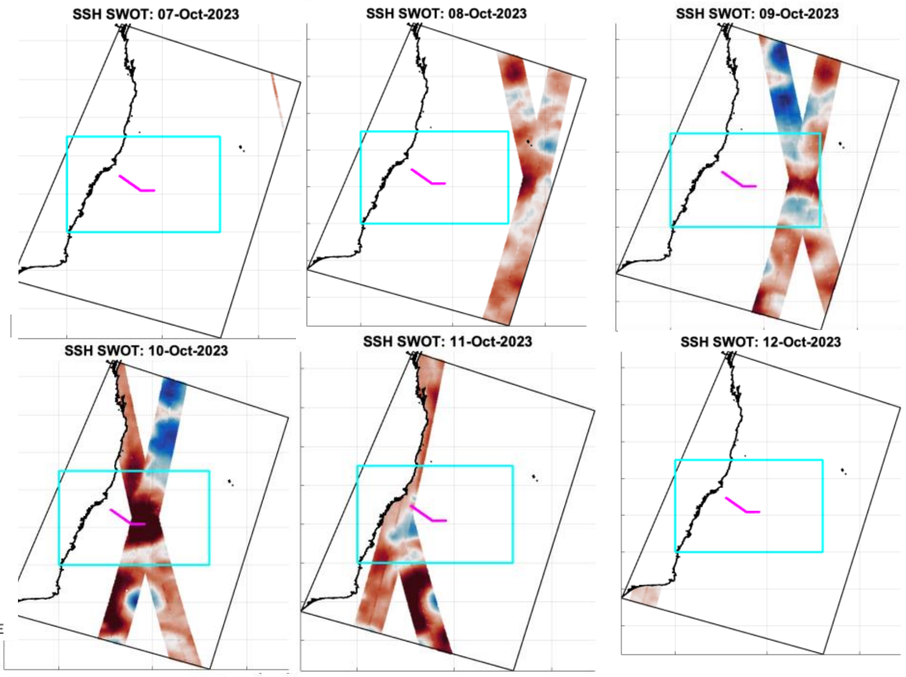

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