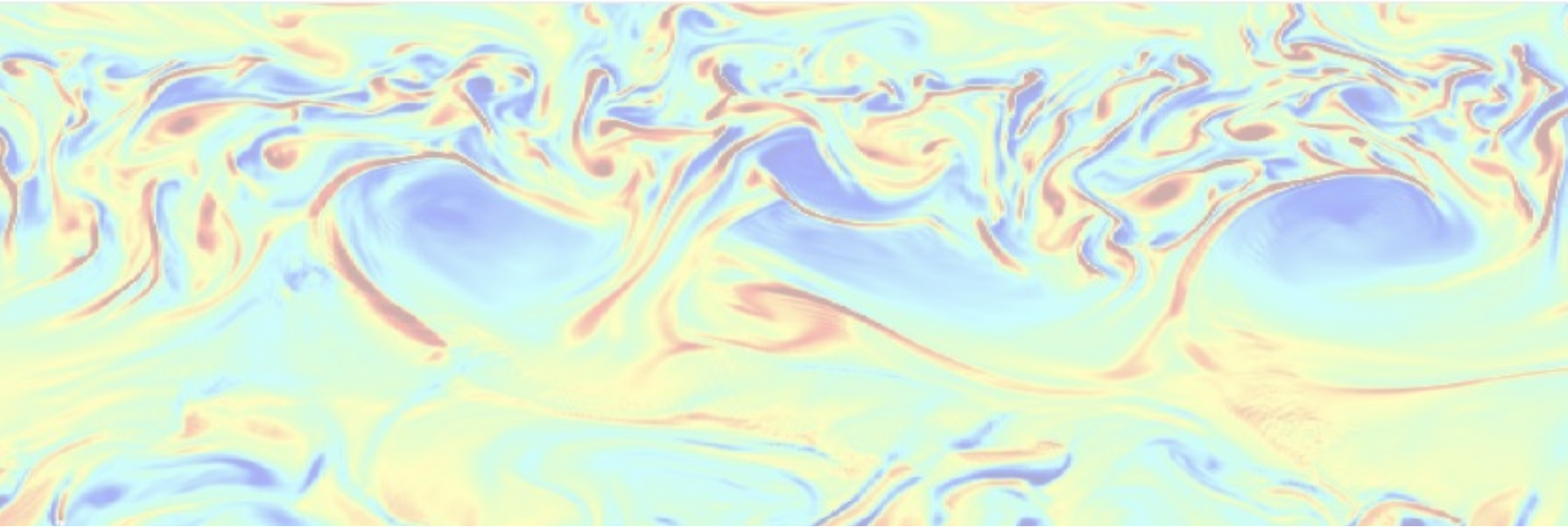
(Sub)mesoscale currents around the Pacific cold tongue

Dan Whitt
NASA / Ames

OASIS Meeting
September 17 2024

(Sub)mesoscale currents around the Pacific cold tongue



Dan Whitt (NASA/Ames)
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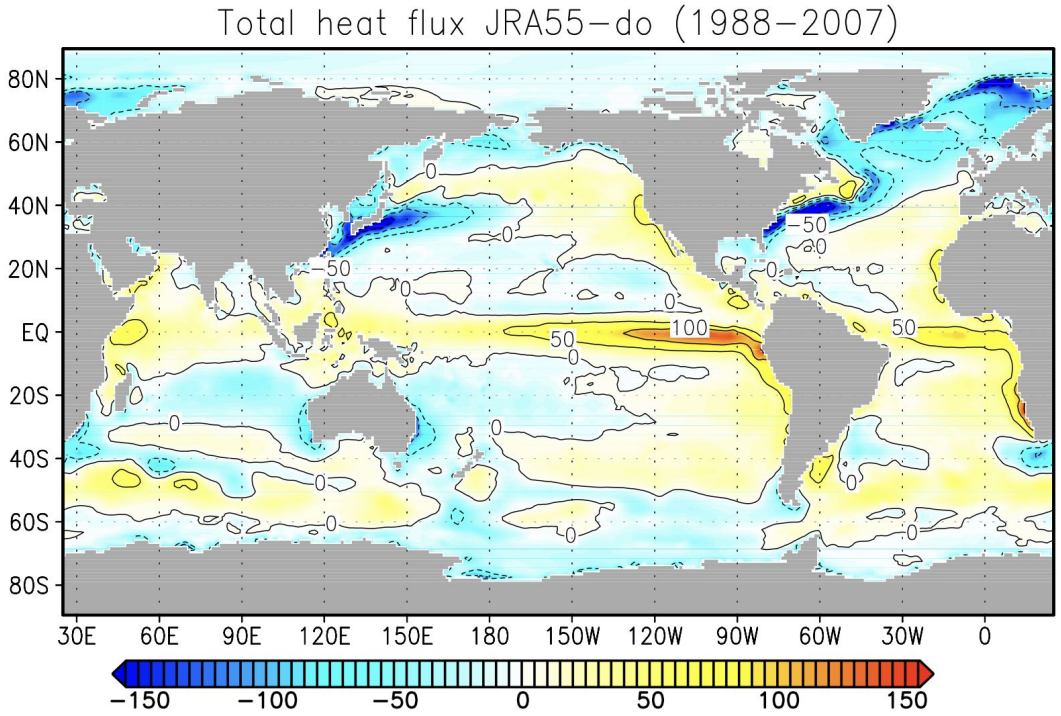
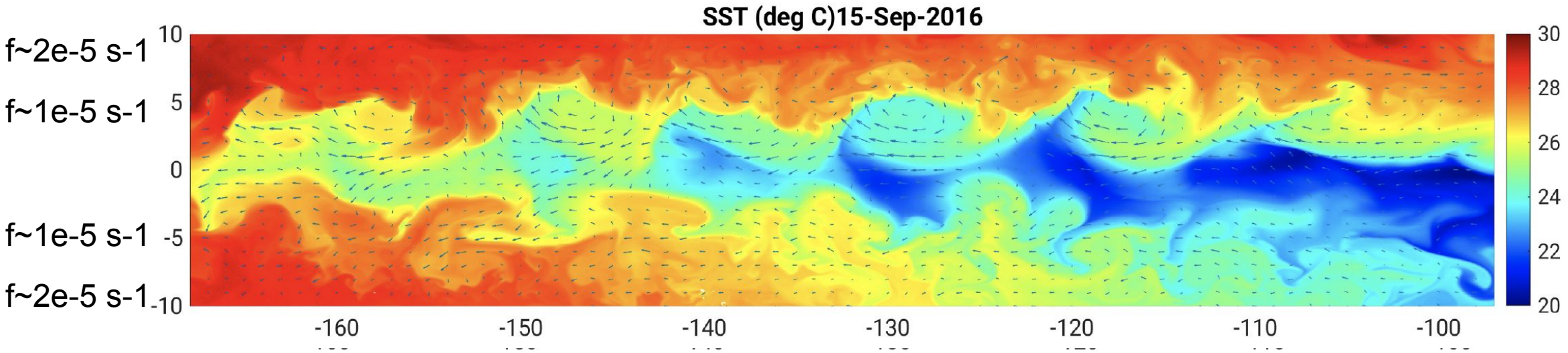
Equatorial Pacific Cold Tongue – a region of leading significance for global climate dynamics and prediction



Tsujino et al. 2018

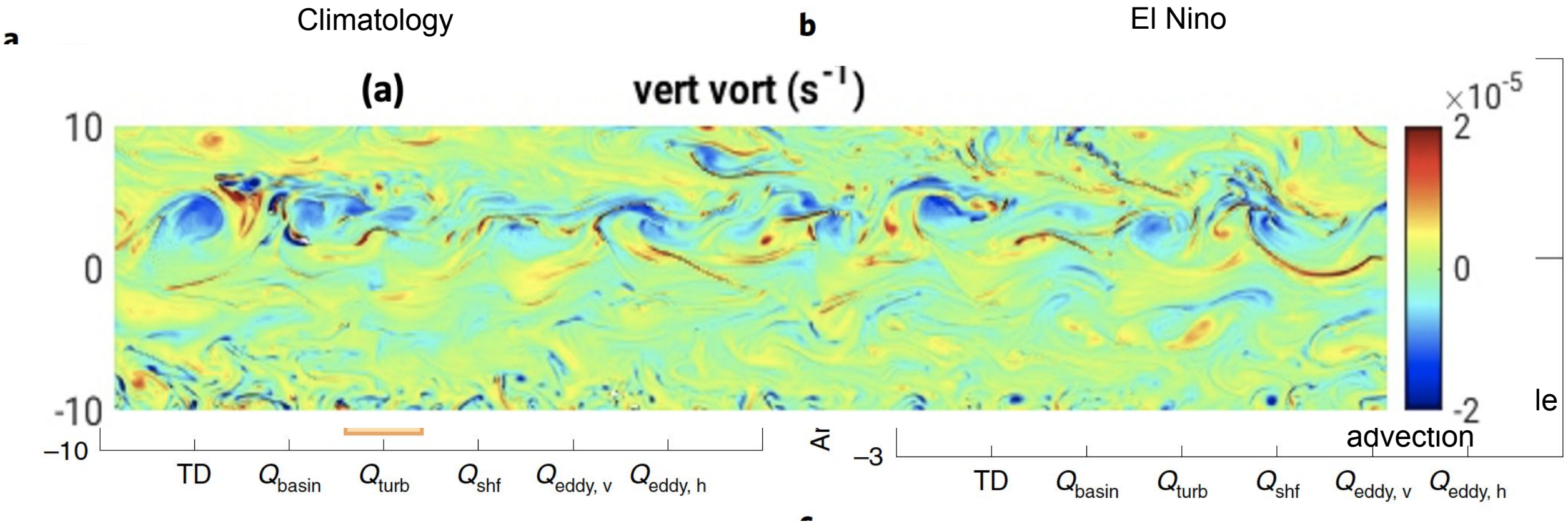
- Important participant in global circulation of heat and carbon
- Center of action of ENSO; key to S2I prediction
- Cold tongue biases persist in many climate models,
  - e.g. CESM2, Danabasoglu et al. 2020, Wei et al. 2021

Models of tropical-to-global dynamics minimize uncertain role of vigorous small-scale variability



“Realistic” regional model – 5km resolution -- Whitt et al. 2022 JPO -- Cherian et al. 2021 JPO

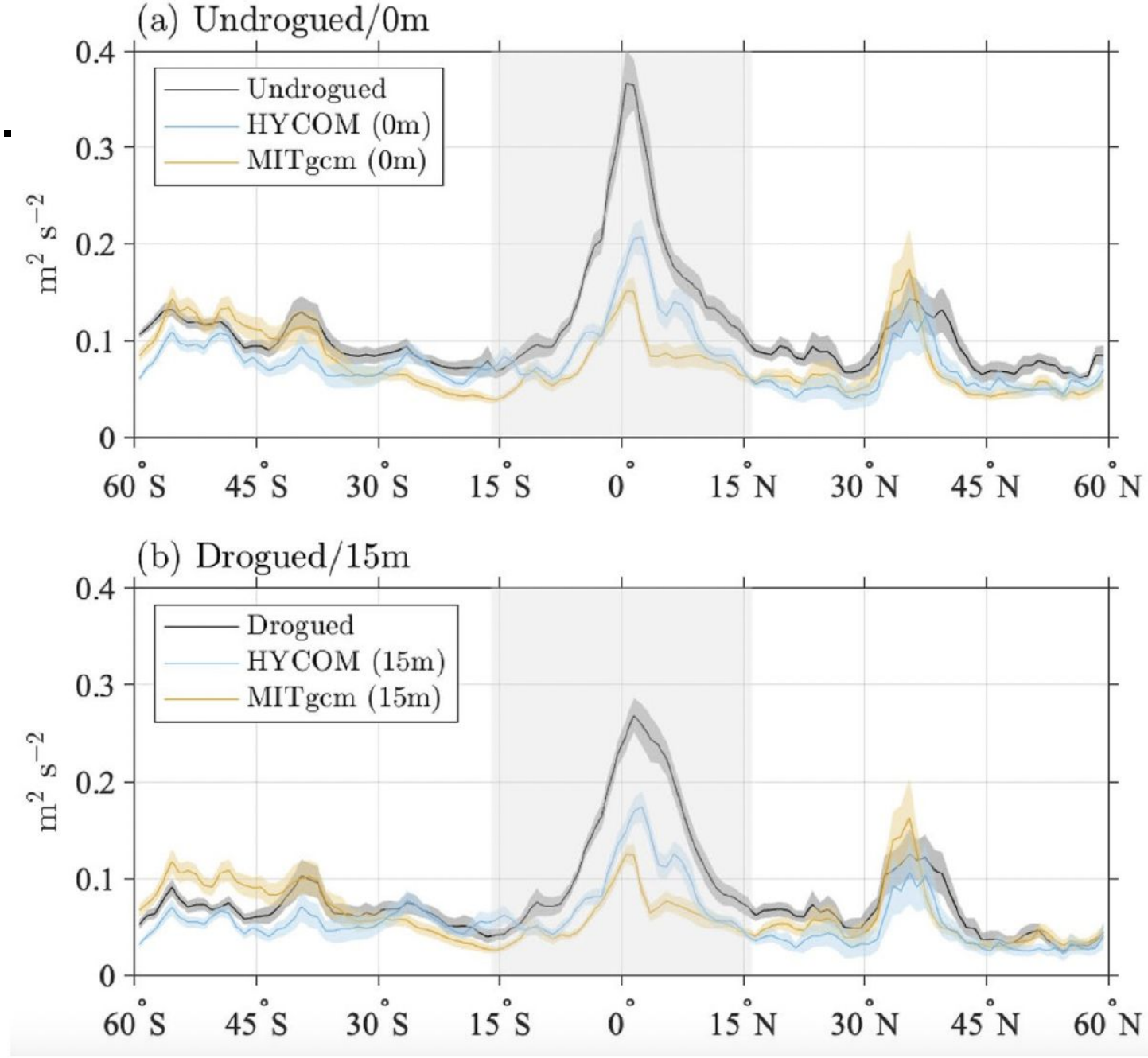
High-resolution models show small-scale ocean physics is significant in regional SST dynamics with global significance



Wang *et al. (2022). Nat. Geosci.*

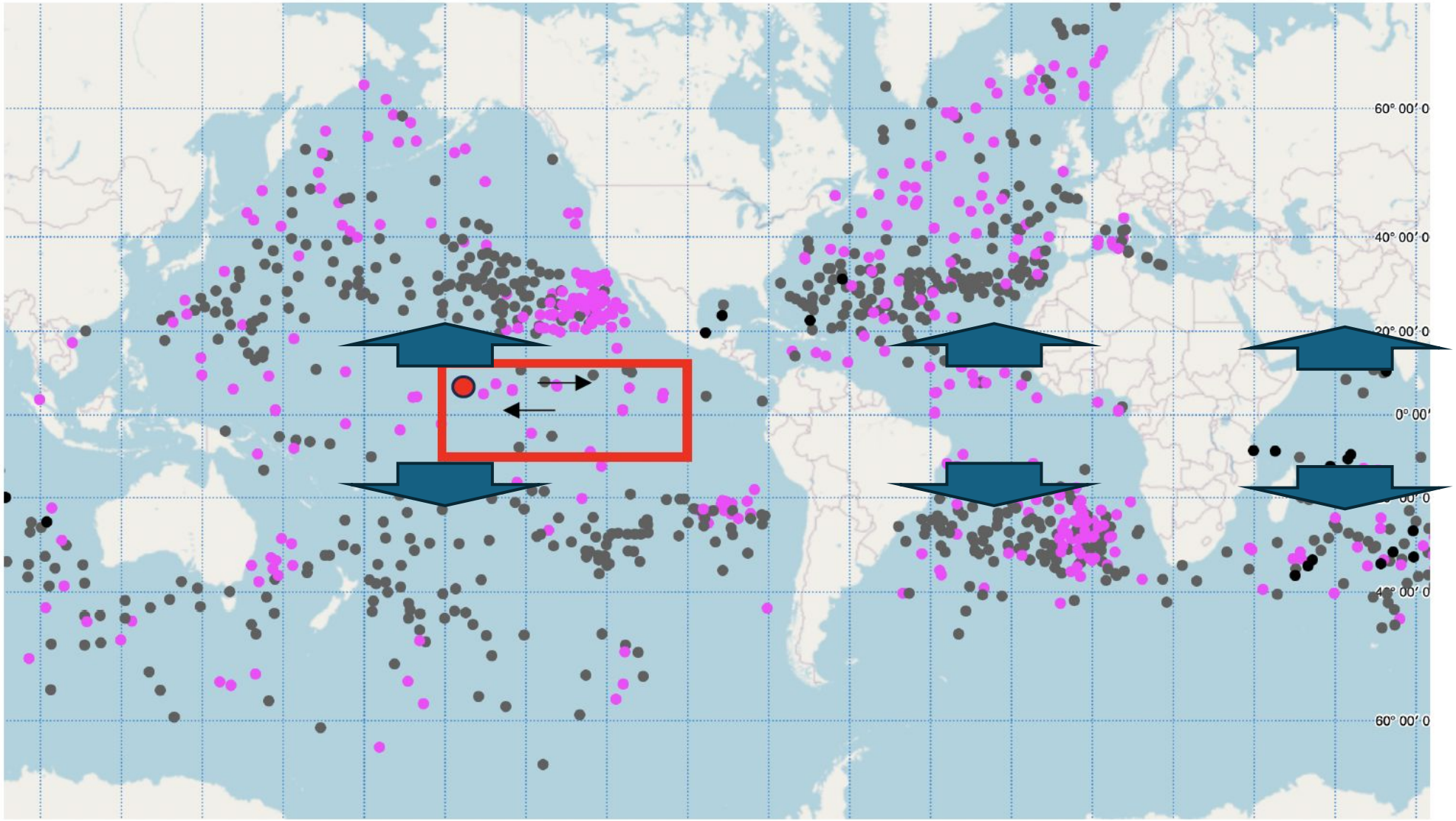
Yet, typical climate models don’t resolve (sub)mesoscales.

Even ultra-high-resolution ocean models have difficulties with tropical surface currents



Arbic et al. 2022

Because equatorial surface Ekman divergence,
few sustained surface current observations available in Equatorial Pacific



Improved observations & models of (sub)mesoscale surface currents in cold tongue may yield better models and predictions of global climate

Submesoscale currents: extensively studied in last 20 years

but tropics

Rossby number

U/(fL) ~ 1

Froude number

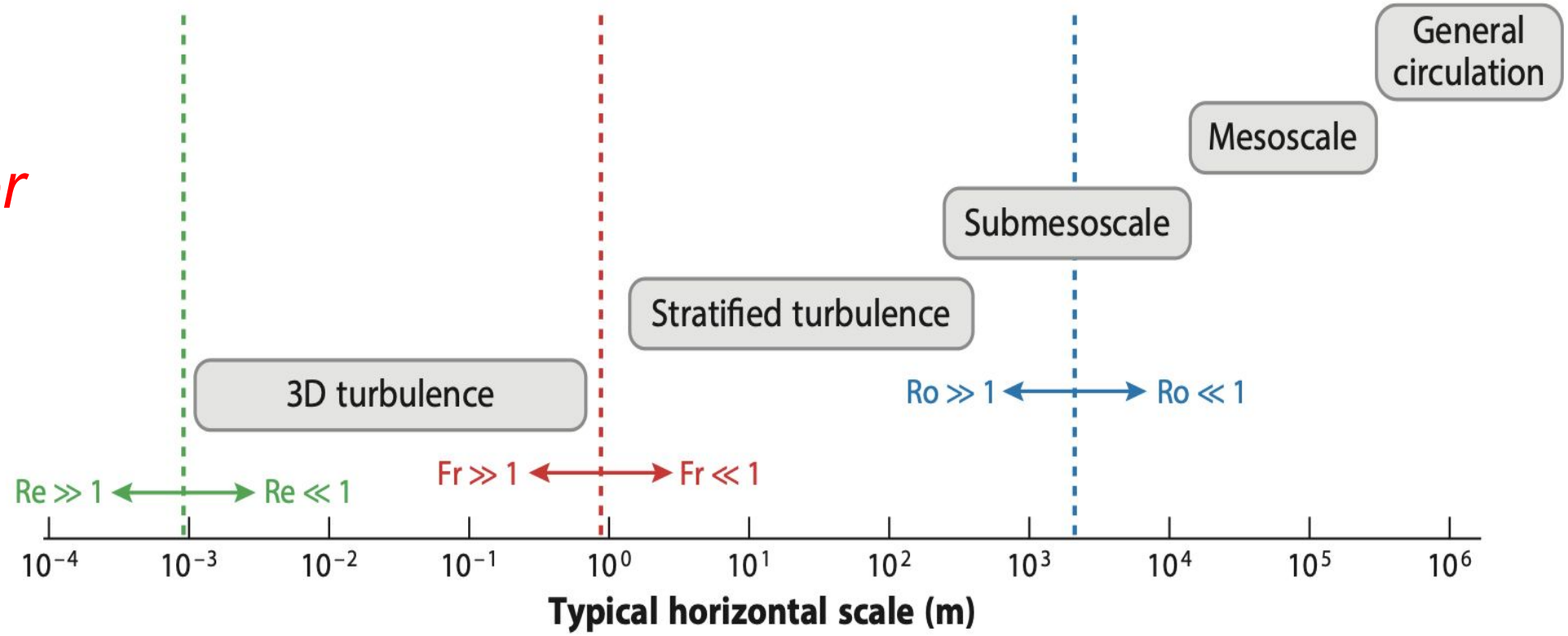
U/(NH) ~ 1

Length scale

L~ 0.1-10 km

Aspect ratio

H / L ~ 0.01



Reviews: Thomas et al. 2008 -- McWilliams 2016 -- **Taylor and Thompson 2023**

Submesoscale currents: extensively studied in last 20 years,

but tropics have received less attention than midlatitudes

Rossby number

U/(fL) ~ 1

Froude number

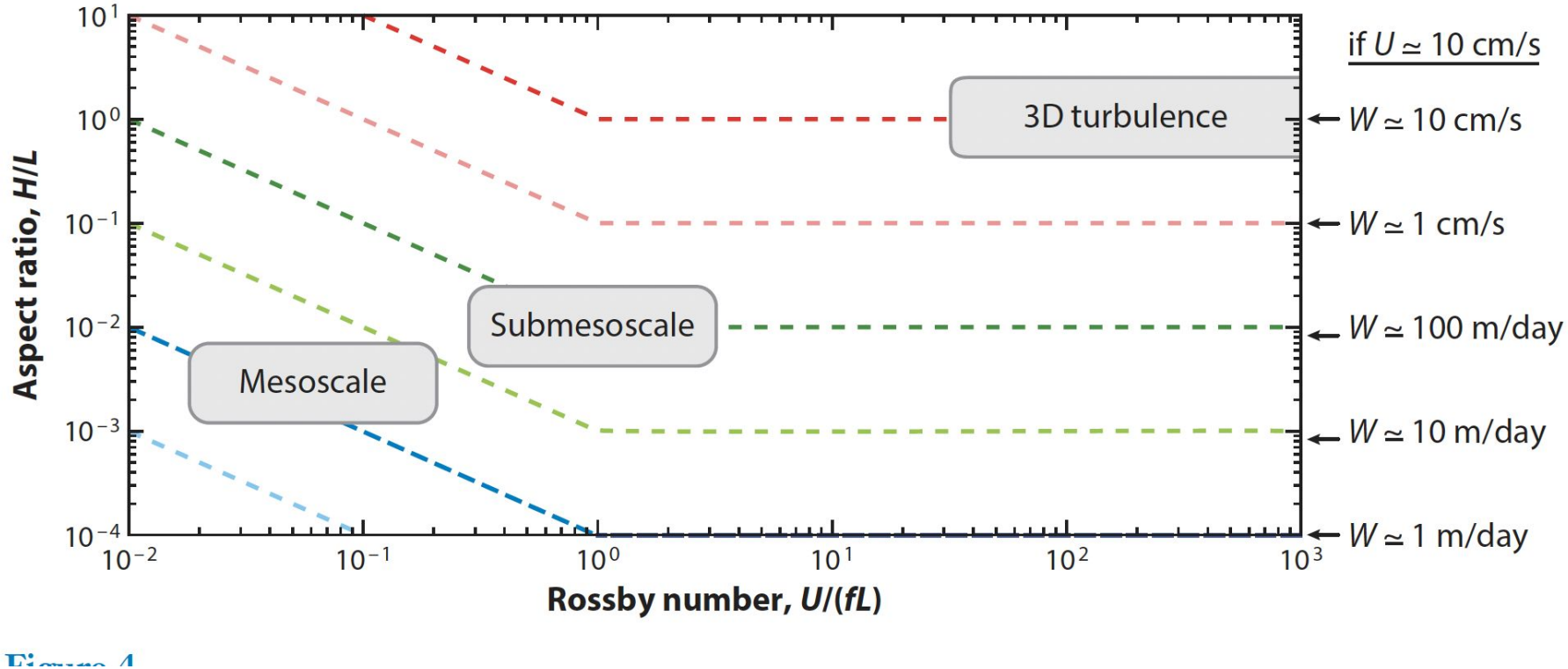
U/(NH) ~ 1

Length scale

L~ 0.1-10 km

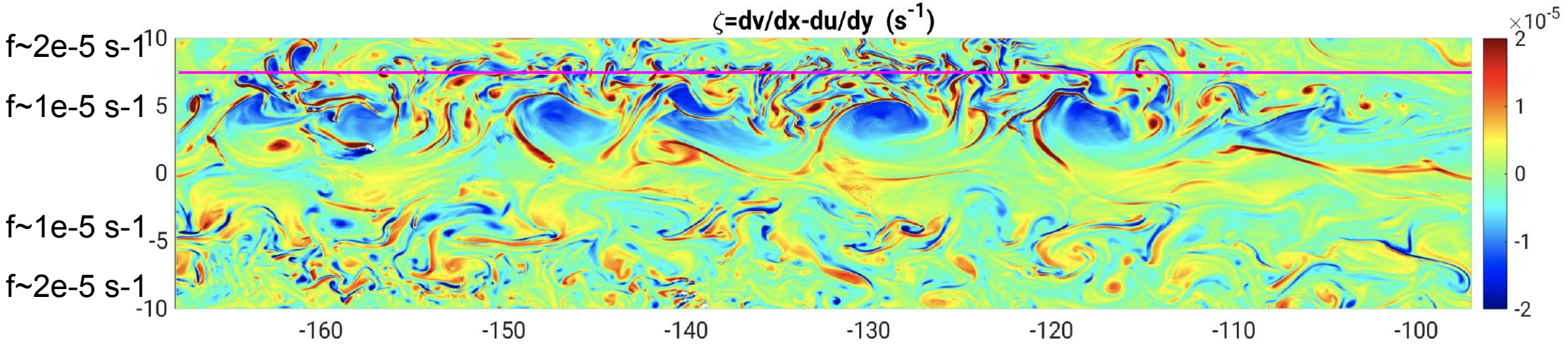
Aspect ratio

H / L ~ 0.01



Reviews: Thomas et al. 2008 -- McWilliams 2016 -- **Taylor and Thompson 2023**

Models reveal submesoscale currents around the equatorial Pacific cold tongue



“Realistic” regional model – 5km resolution -- Whitt et al. 2022 JPO -- Cherian et al. 2021 JPO

U ~ 0.2 m/s

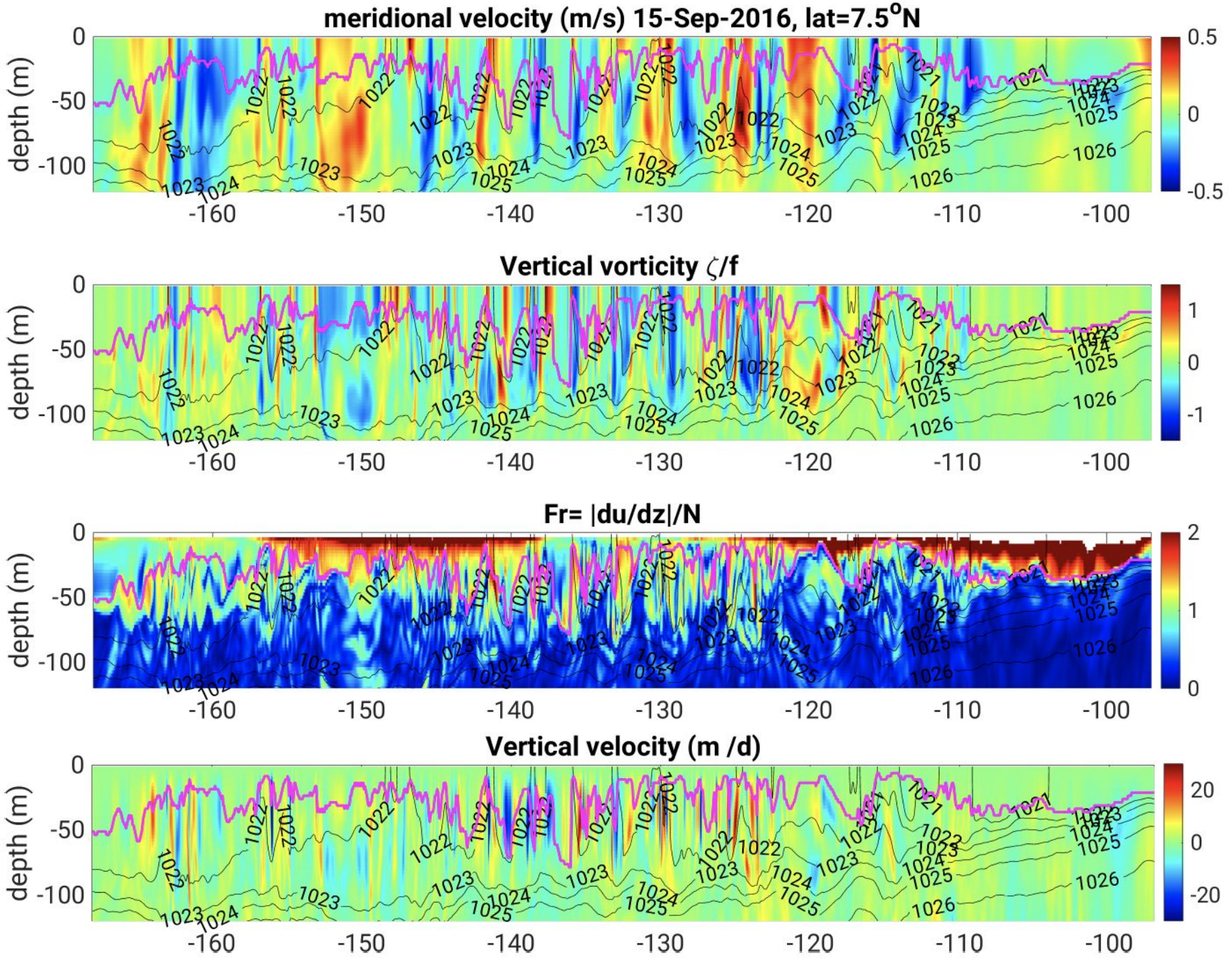
H~100 m
L~ 100 km
H/L ~ 0.001

Ro ~ 1

Fr ~ 1

W ~ 10 m/d

W/U ~ 0.001



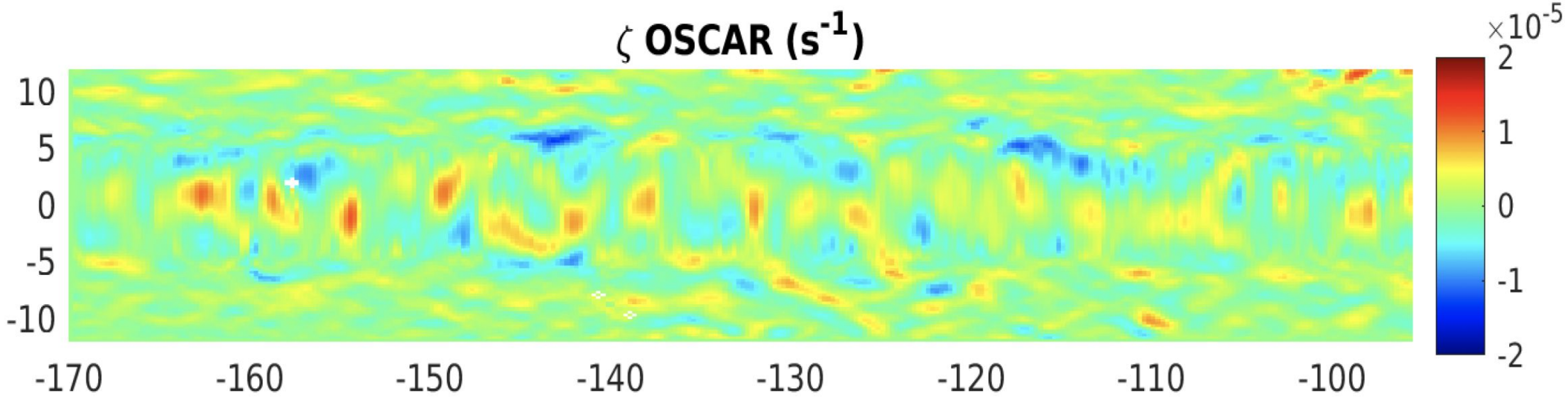
Observational support is limited

f~2e-5 s^{-1}

f~1e-5 s^{-1}

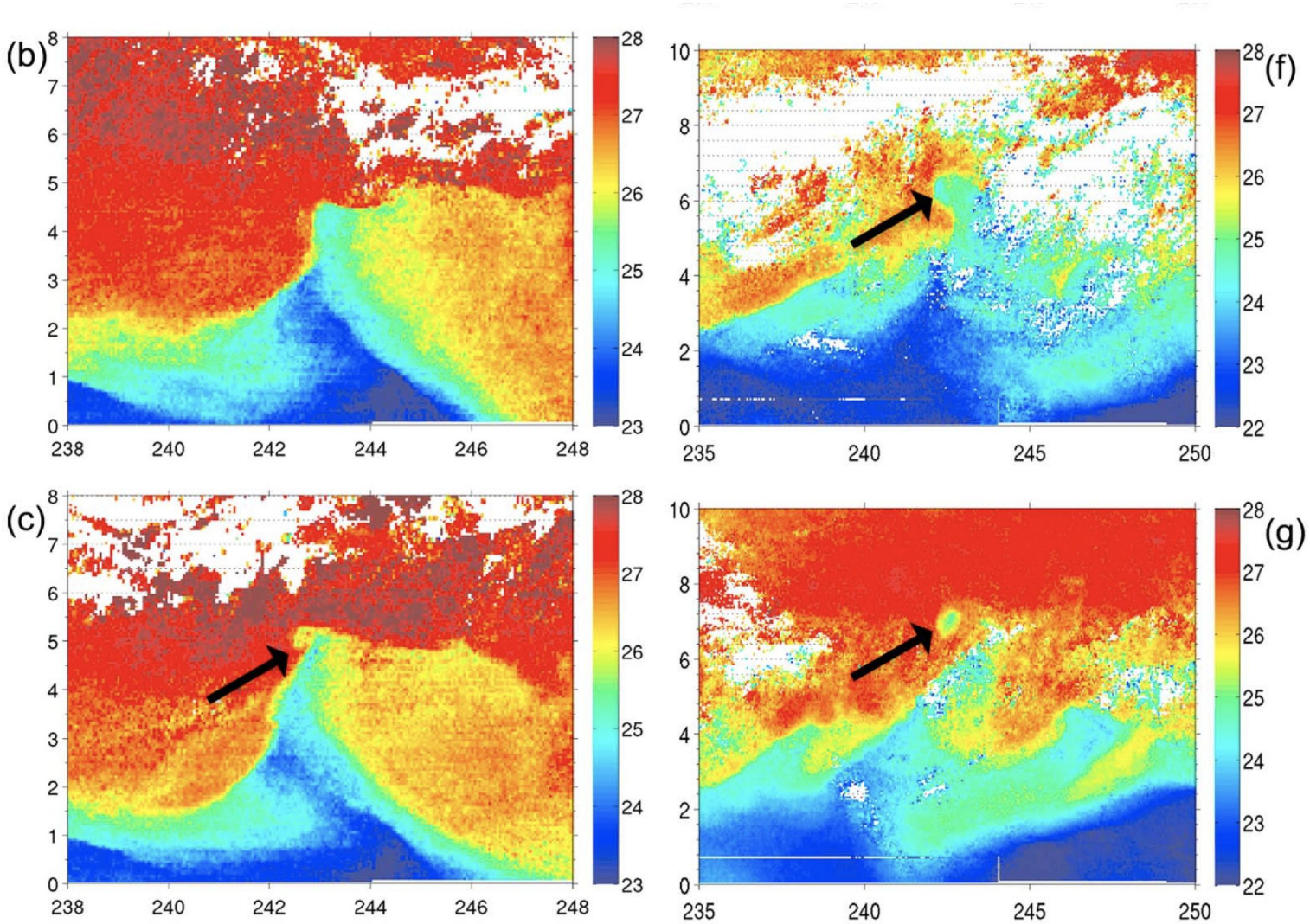
f~1e-5 s^{-1}

f~2e-5 s^{-1}



“Realistic” regional model – 5km resolution -- Whitt et al. 2022 JPO -- Cherian et al. 2021 JPO

But not zero.



Ubelmann and Fu (2011) JGR

TROPIC-SWOT:
equatorial Pacific submesoscale current study for SWOTST

Goals:

- Characterize (sub)mesoscale SSH and currents and their relation in the tropical Pacific
- Understand the local dynamics and how they scales up to participate in regional and global dynamics
  - Participation in strong 2023-2024 El Nino and its decay.

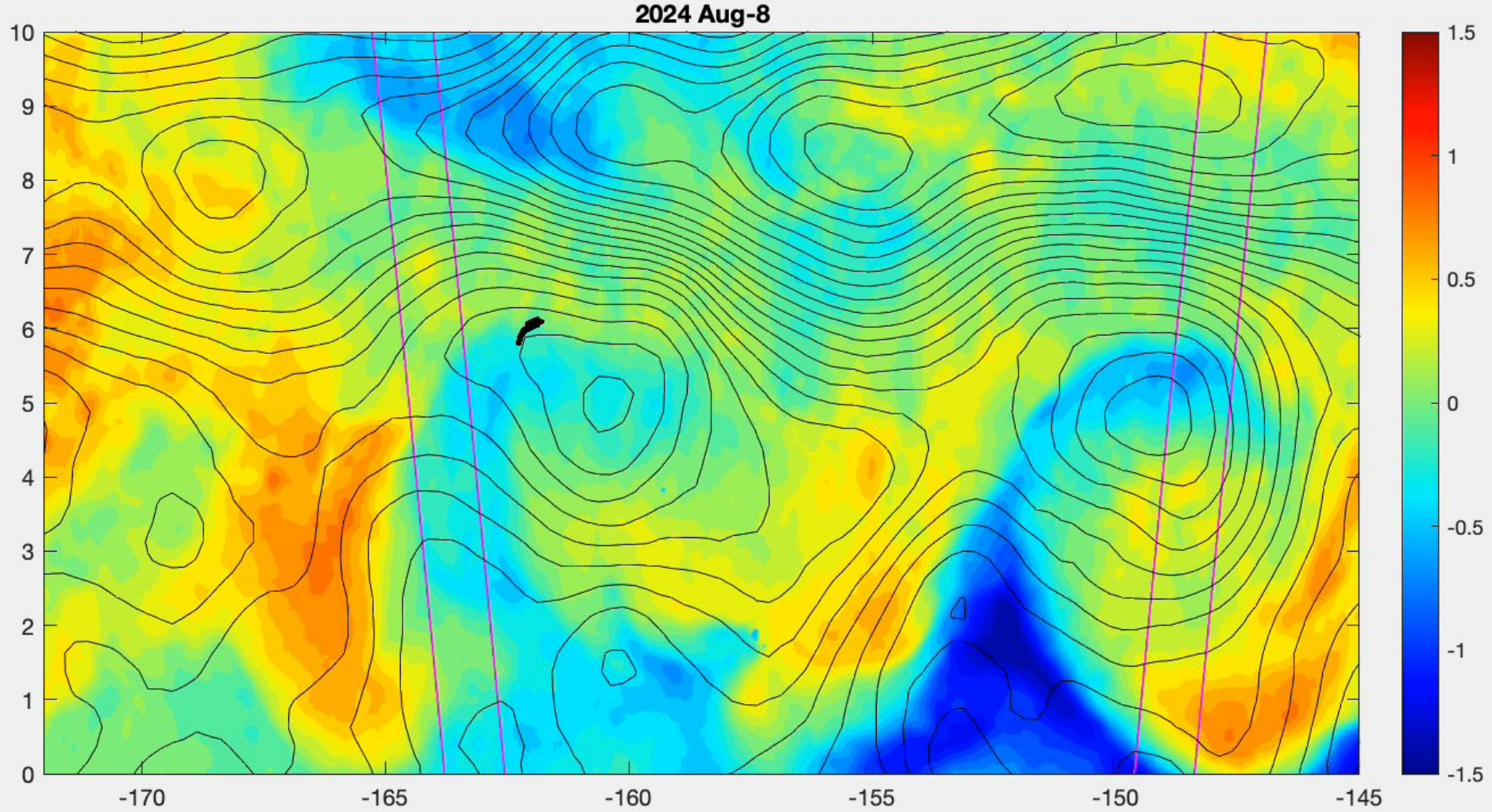
Key Data:

- Submesoscale surface currents from Lagrangian drifter releases
- Submesoscale SSH observations from SWOT
- High-res numerical models

Lagrangian drifter releases will yield enhanced in-situ measurements of submesoscale currents

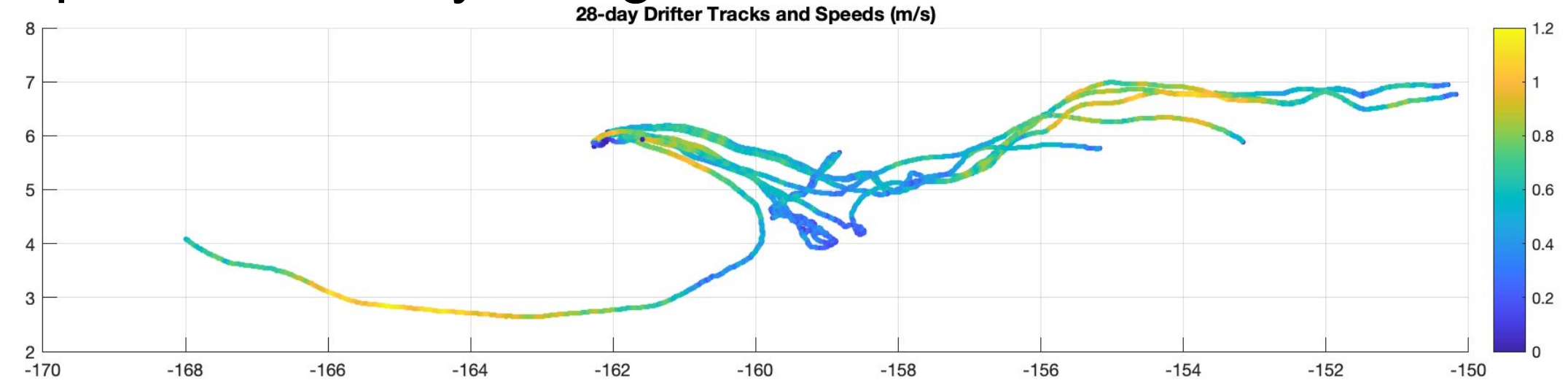
- Monthly deployments
- 5 GDP/SVP drifters per deployment
- 2 year duration
- Aligned with SWOT overpasses
- Consistent release spacing & location
  Palmyra Atoll@6N,162W

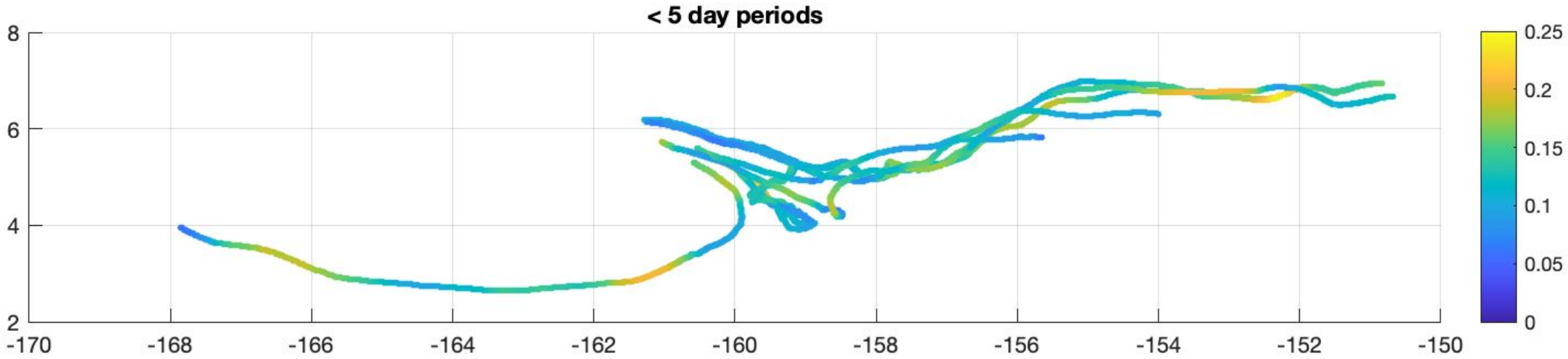
Example from August 2024
Drifter tracks modulated by tropical instability vortices



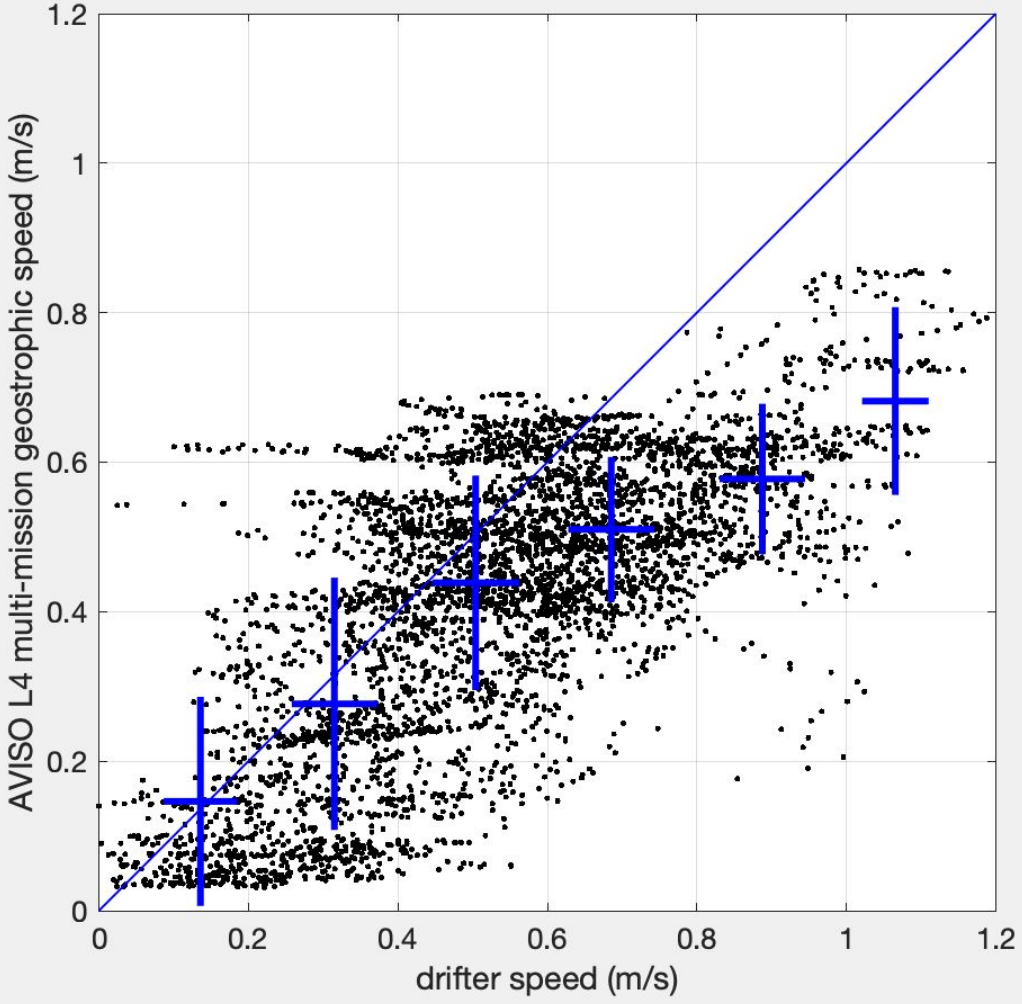
SSTa (color) + ADT (black) + SWOT swaths (magenta)

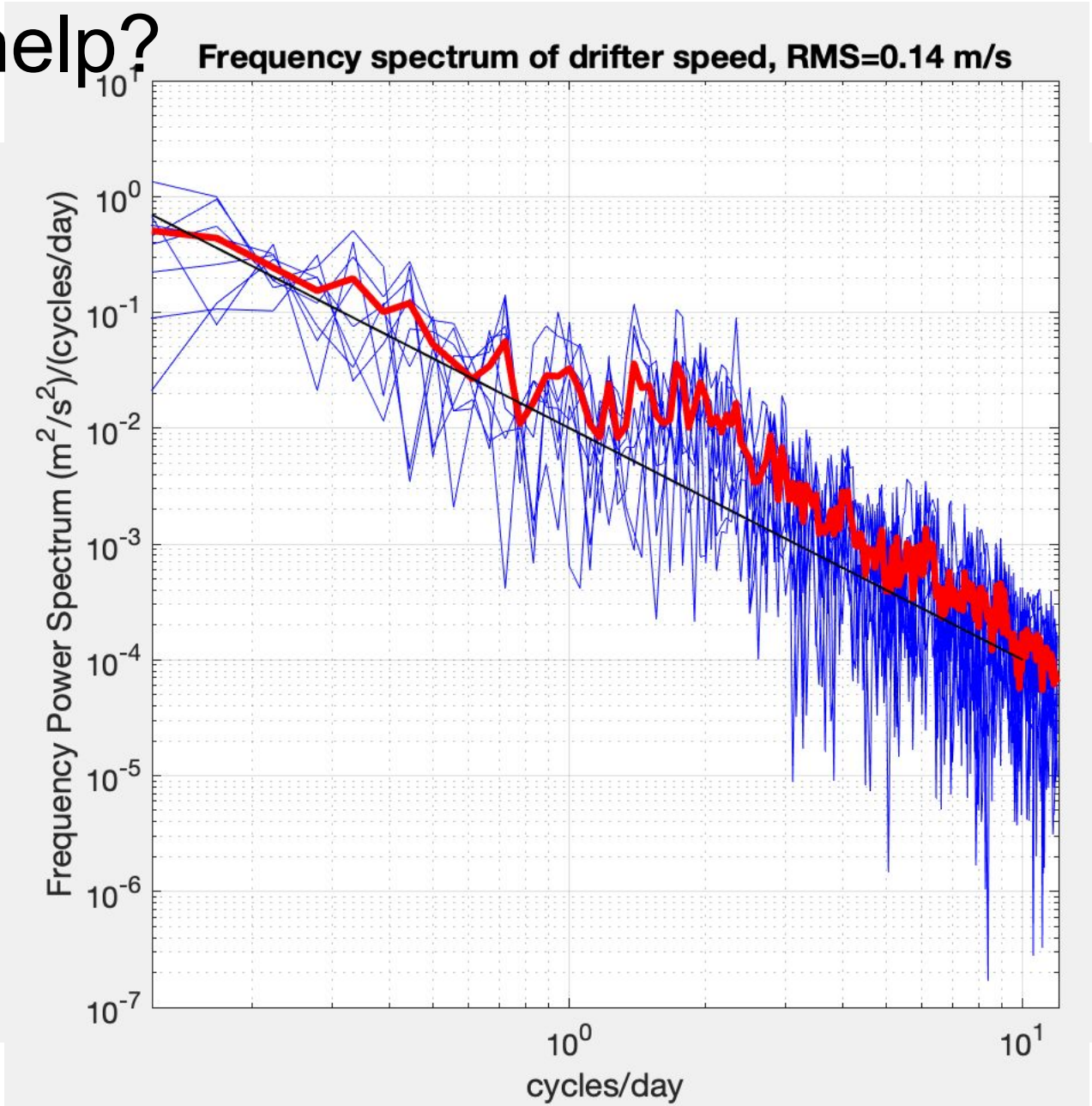
Speed ranges to 1.2 m/s
Short-periods < 5 days range to ~0.2 m/s





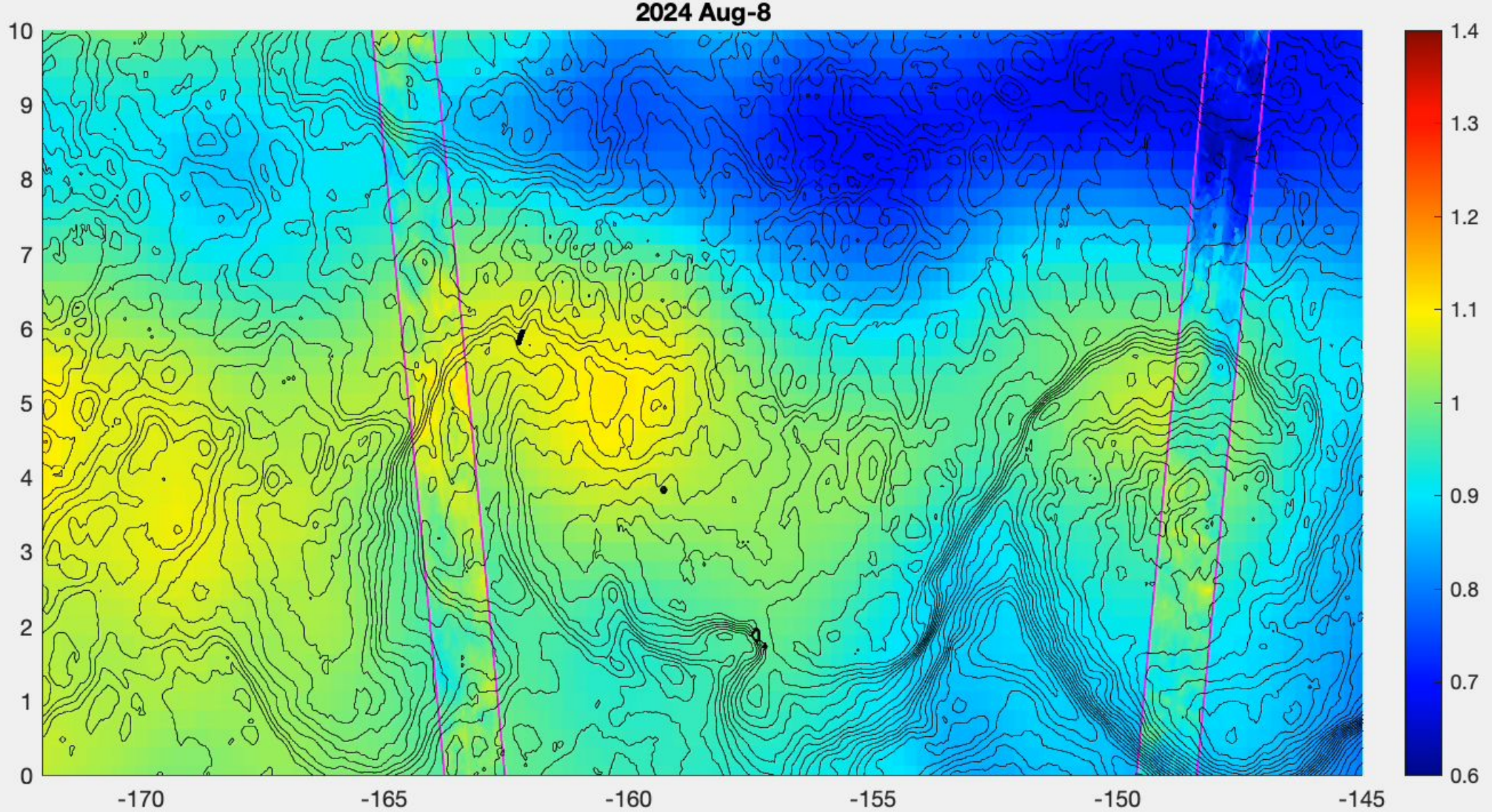
Geostrophy+prior altimeters can explain some variance
Much is missing. Can SWOT help?





Submesoscale SSH from SWOT to advance understanding of relationship: SSH and currents

- Hundreds of matchups anticipated.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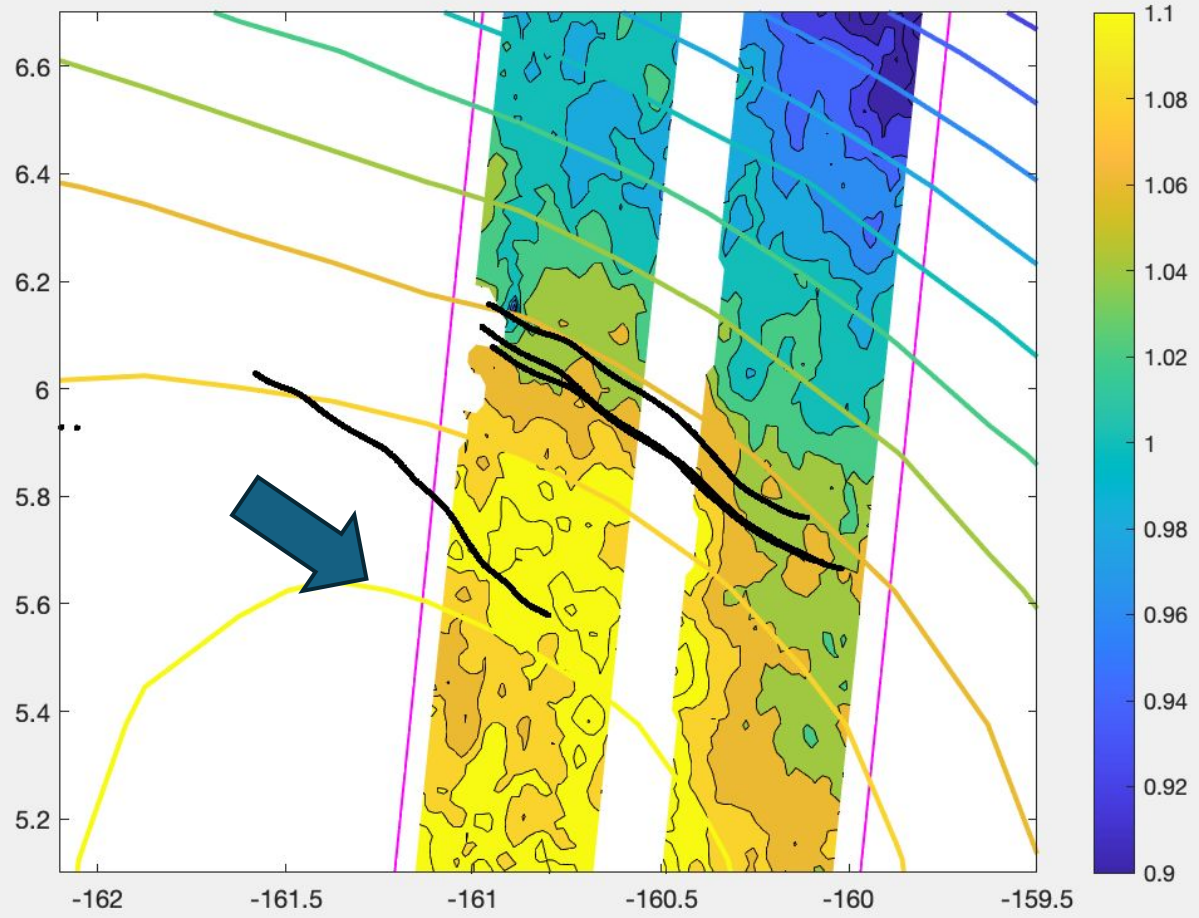
Aug 13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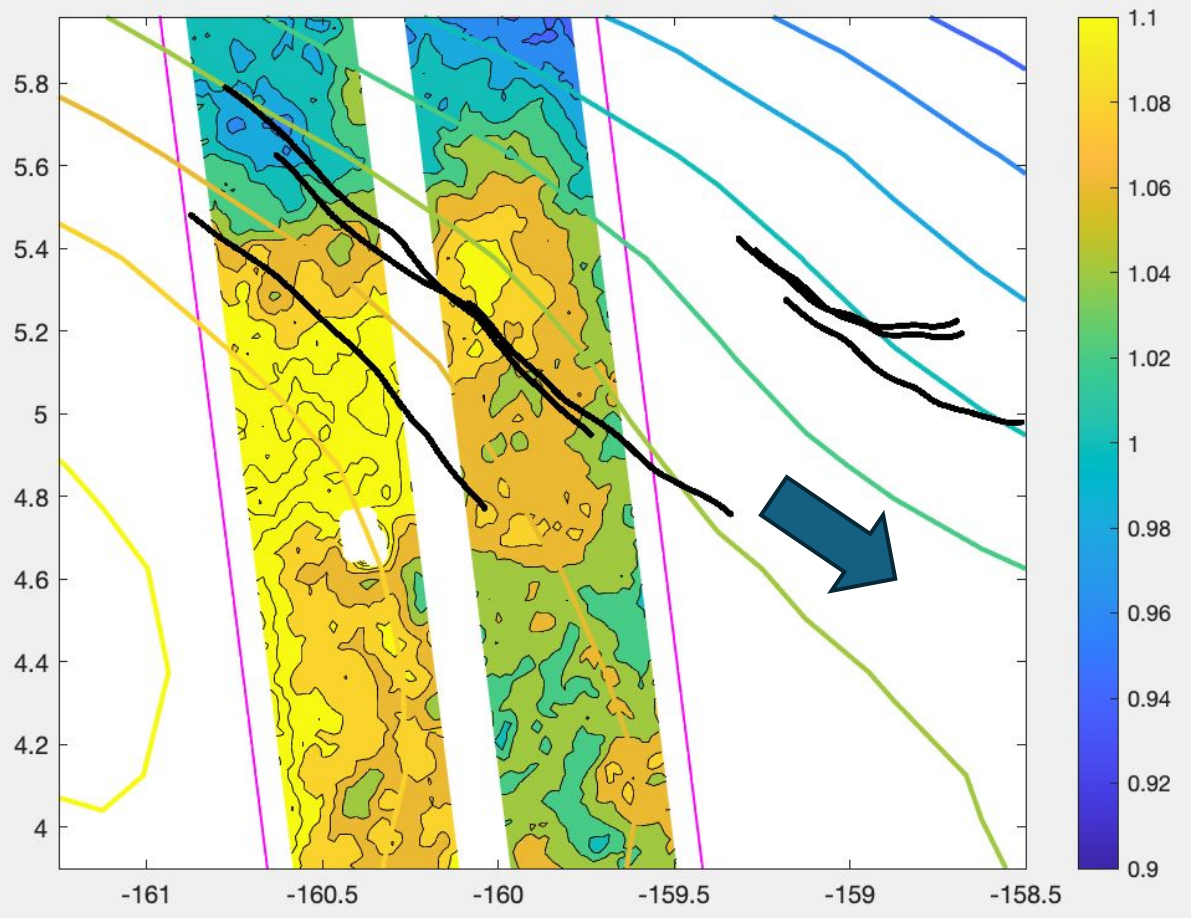
Aug 17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-160
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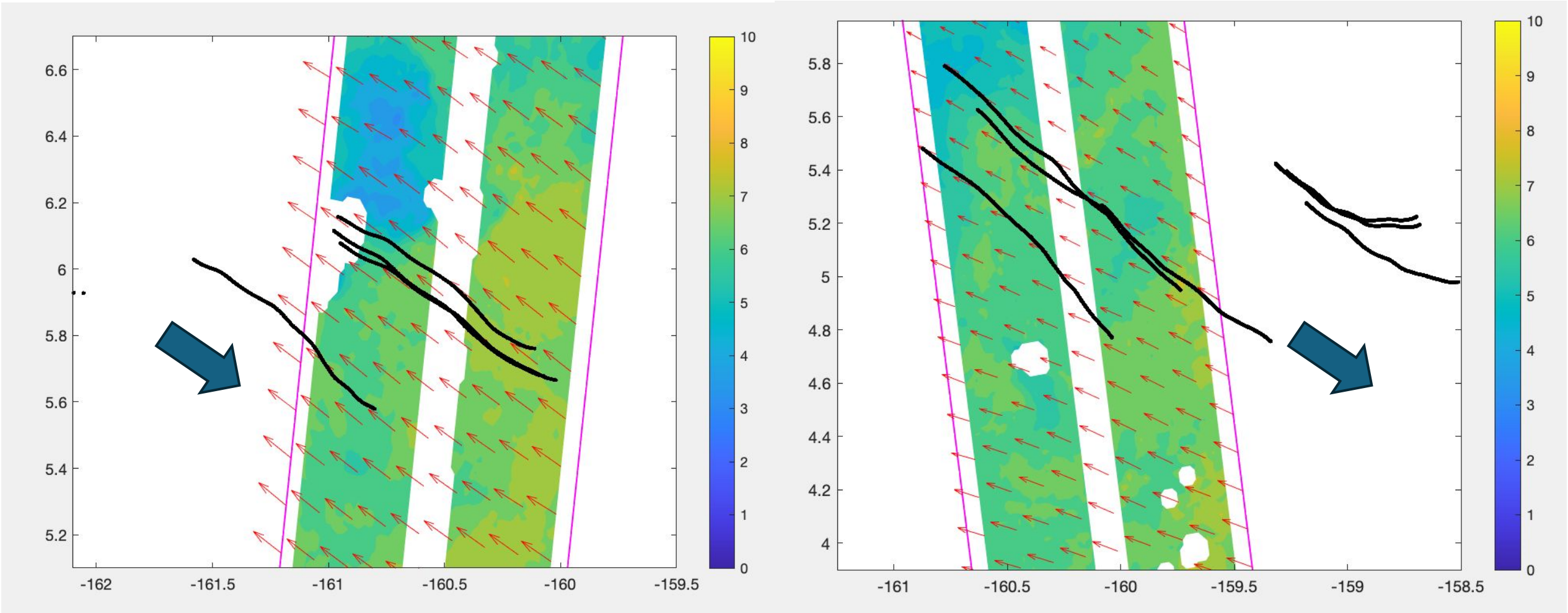
-159
-158.5
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9

Smoothing to ~40 km

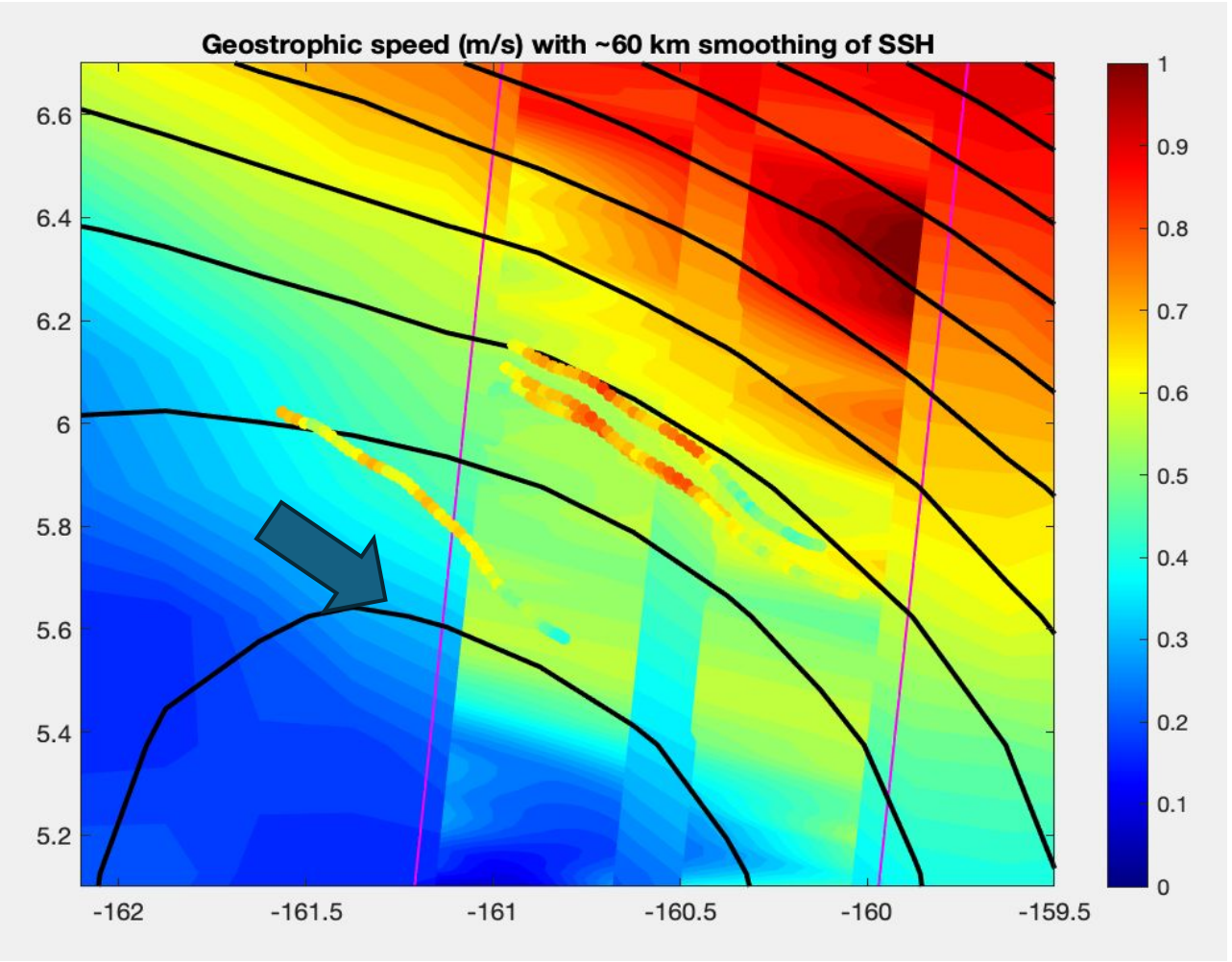
Aug 13

Aug 17



SWOT observes the general magnitude of SSH gradients and geostrophic speed.
Small scale structure is sometimes correlated with other variables, e.g. SSTa
But remains to fully understand

Aug 13



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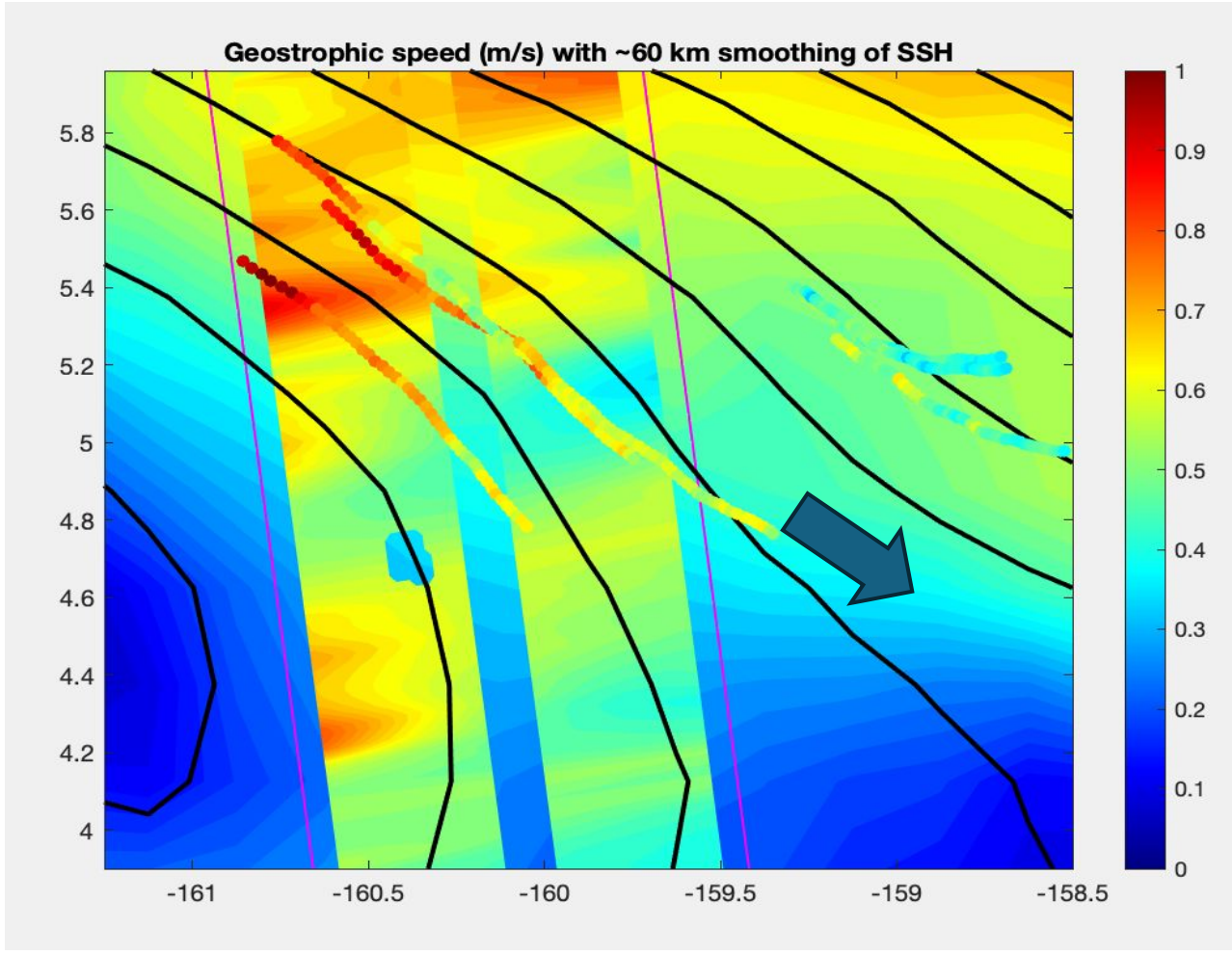
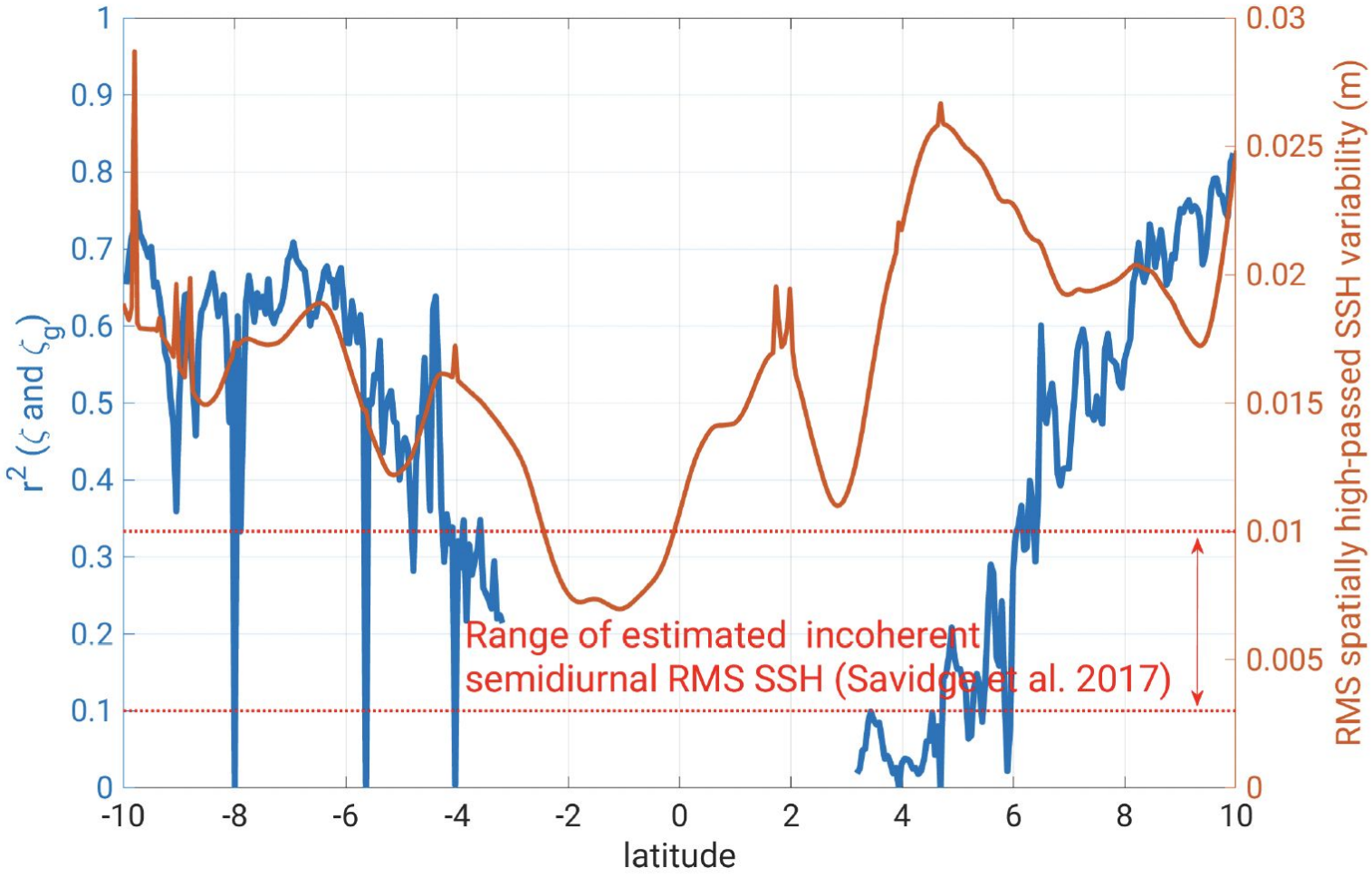


Anecdotally:
More expansive smoothing required to yield consistency with drifters
What smoothing is optimal? What scales are resolvable?

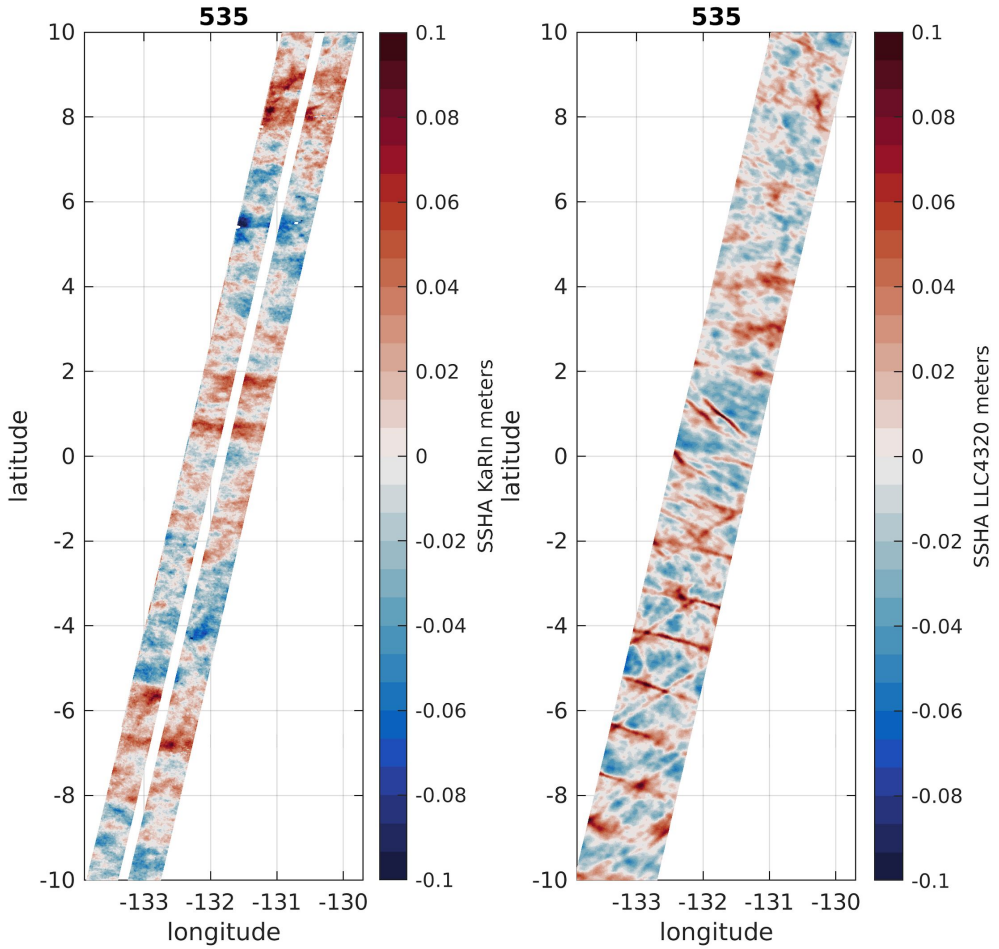
Complicating factor #1: Geostrophy is expected to be relevant to tropical submesoscale dynamics but not the whole story

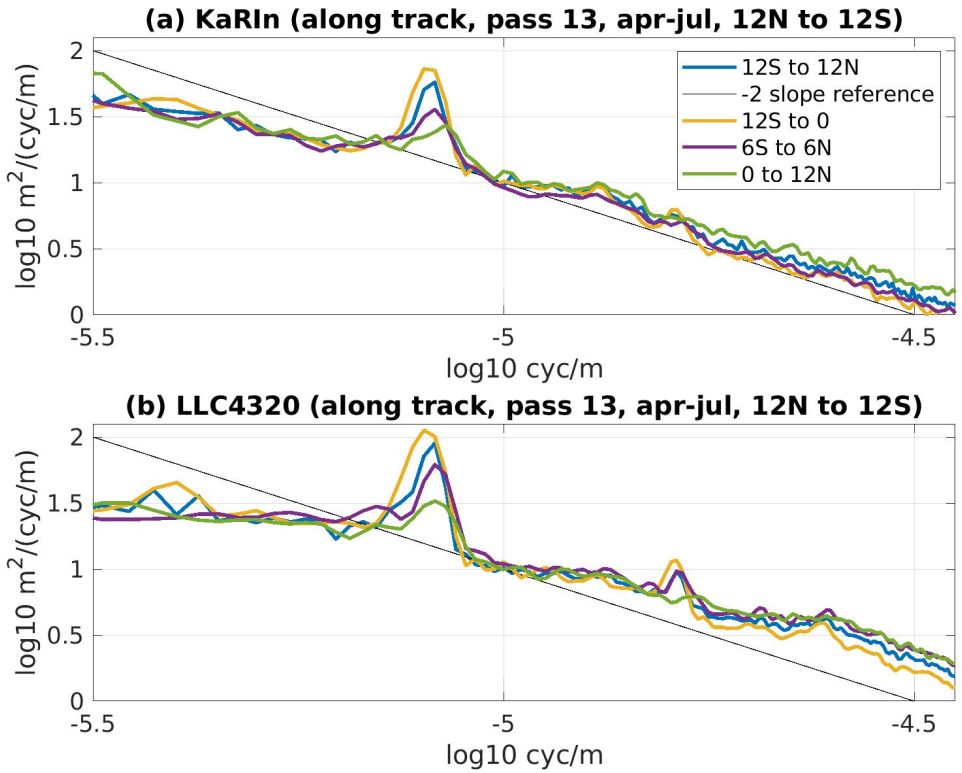
Model results



Daily Mean, 5 km resolution, no tides

Complicating factor #2: Unbalanced motions contribute to SSH at similar scales: semi-diurnal internal tides in SWOT and model SSH





More complete models of SSH <-> current relationships are needed

High-resolution simulations

- Evaluating and maybe improving models
- Expanding understanding

Why studying submesoscales around the cold tongue is important?

A new large-scale perspective…

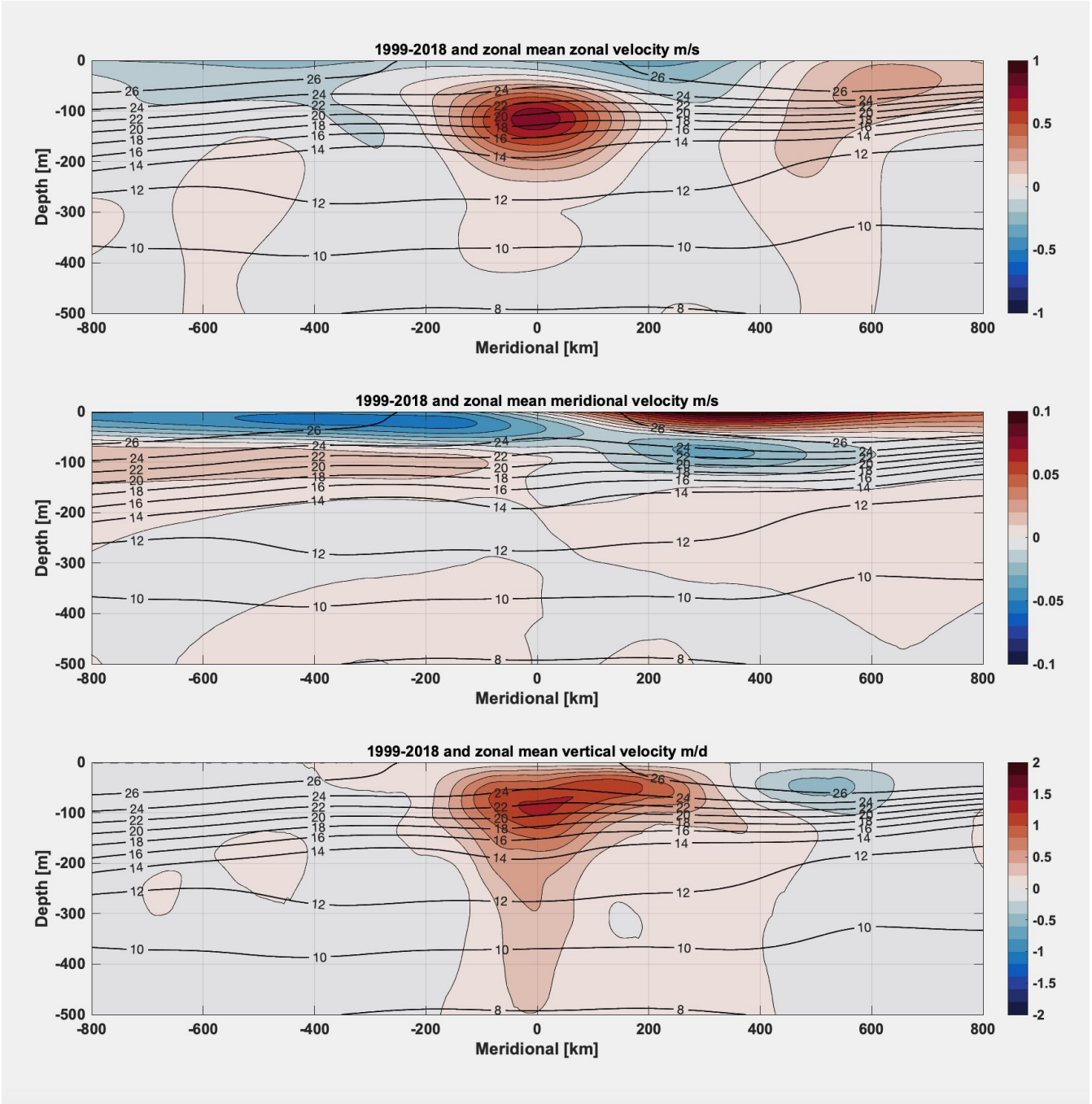
Time and zonal mean

Zonal Velocity

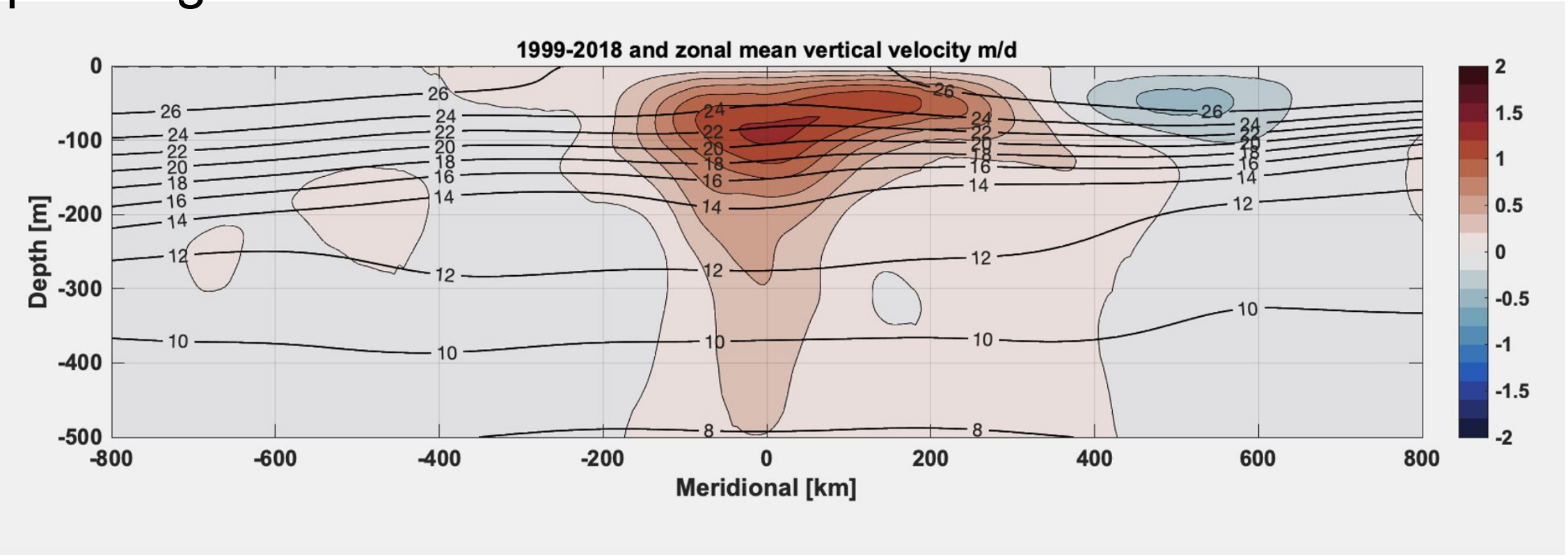
Meridional Velocity
negative at equator,
10-100 m depth

Vertical Velocity
With tongue of strong upwelling
extending north past 2 N

Black temperature contours overlaid

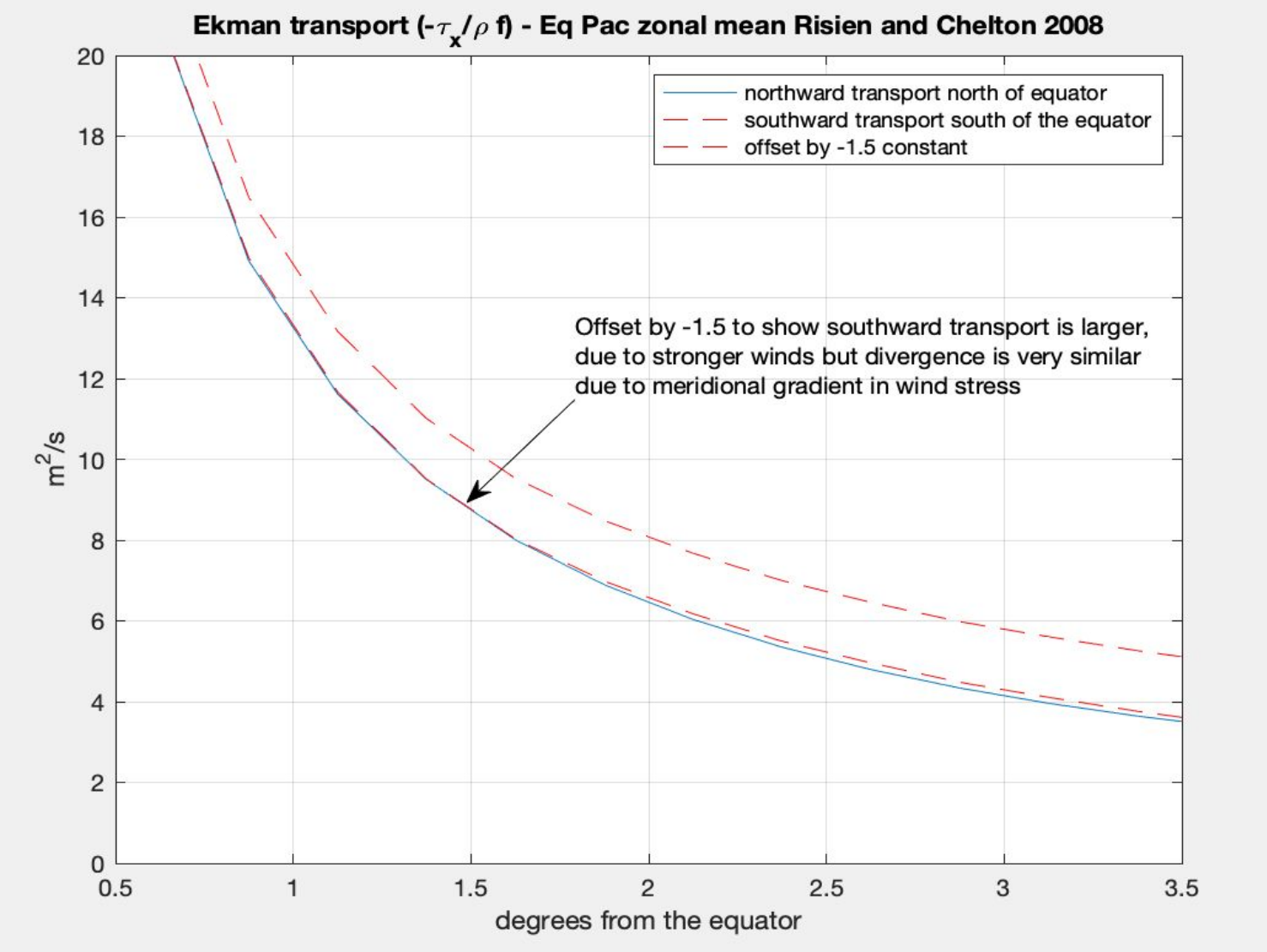


(Sub)mesoscales participate in meridionally asymmetric upwelling

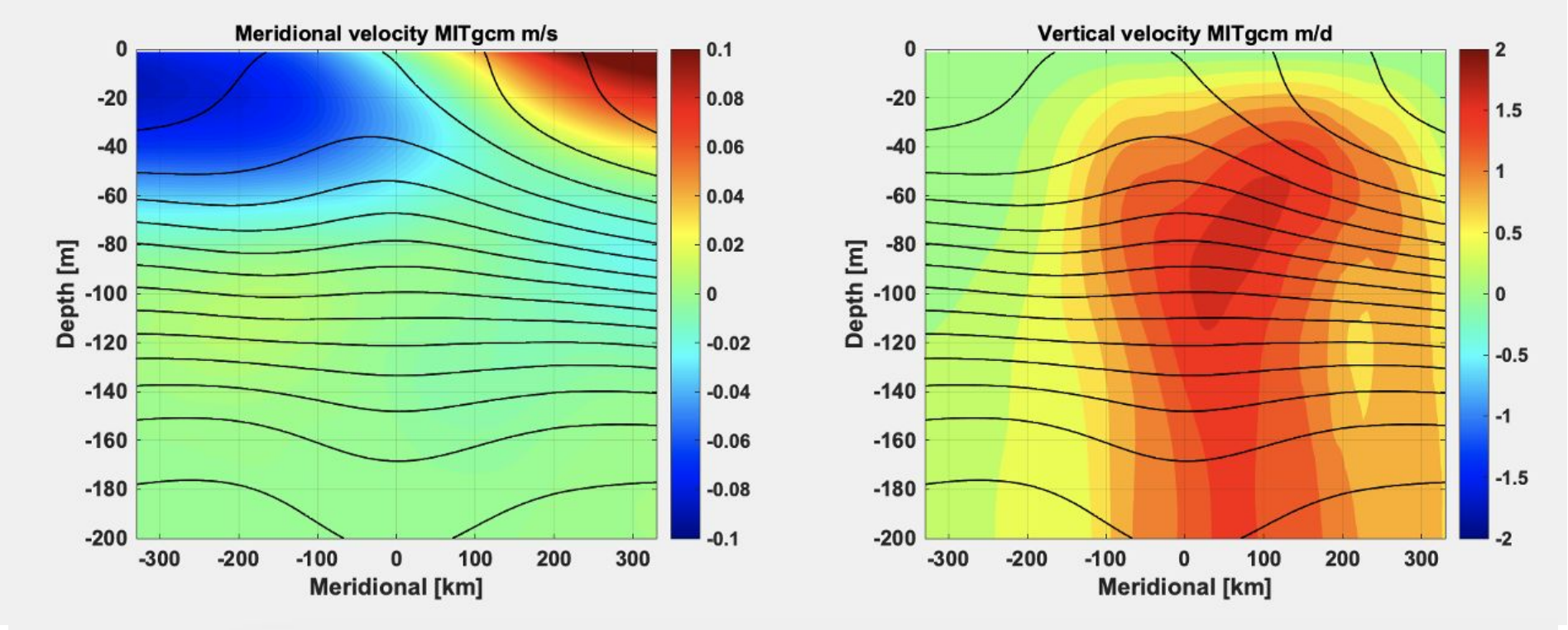


Mostly due to dv/dy

Climatological meridional Ekman transport divergence is nearly symmetric on both sides of the equator



Eliassen-Sawyer equation gives you approximately symmetric upwelling response to friction



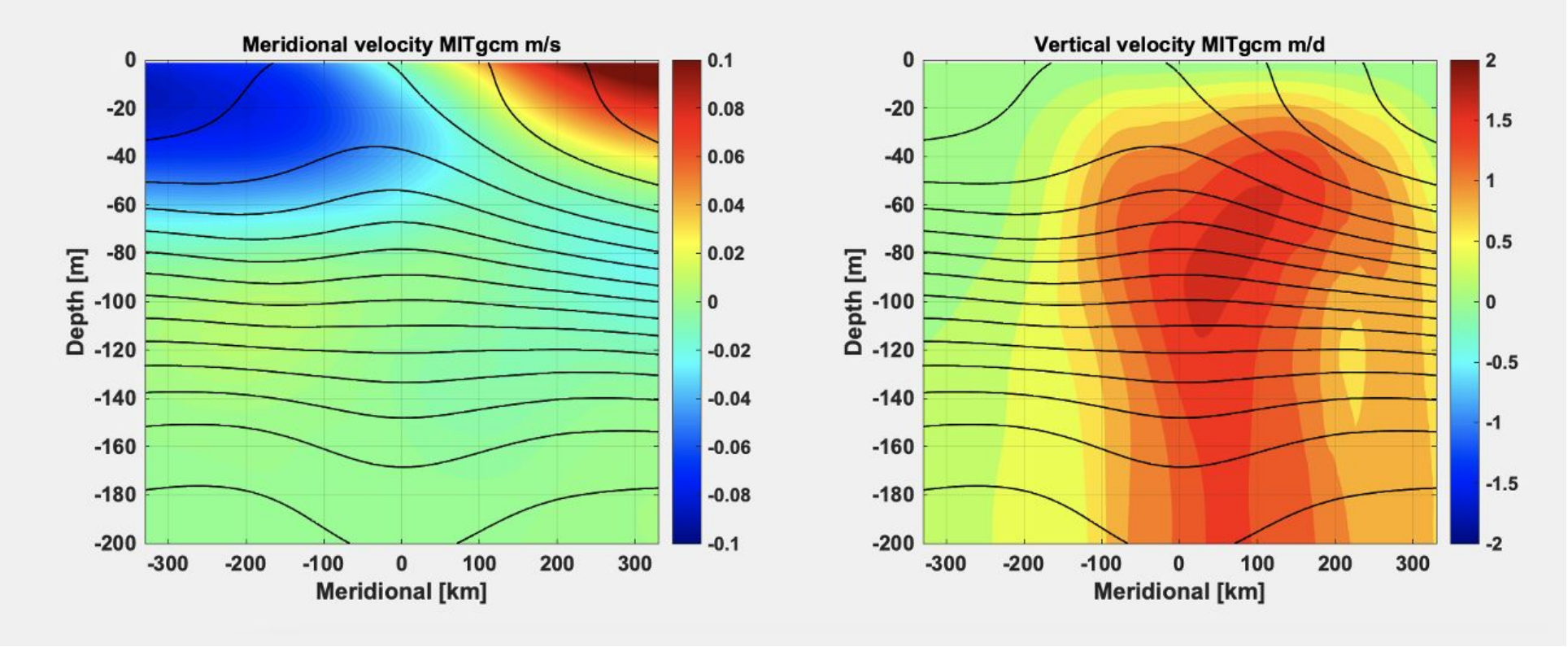
$$F^2\psi_{zz} + 2S^2\psi_{zy} + N^2\psi_{yy}$$

Eulerian mean secondary circulation response

$$= -fX_z - B_y$$

Destruction of mean thermal wind balance by friction, diabatic, and nonlinear eddy fluxes

Including eddy-fluxes of momentum and buoyancy drive off-equatorial upwelling response



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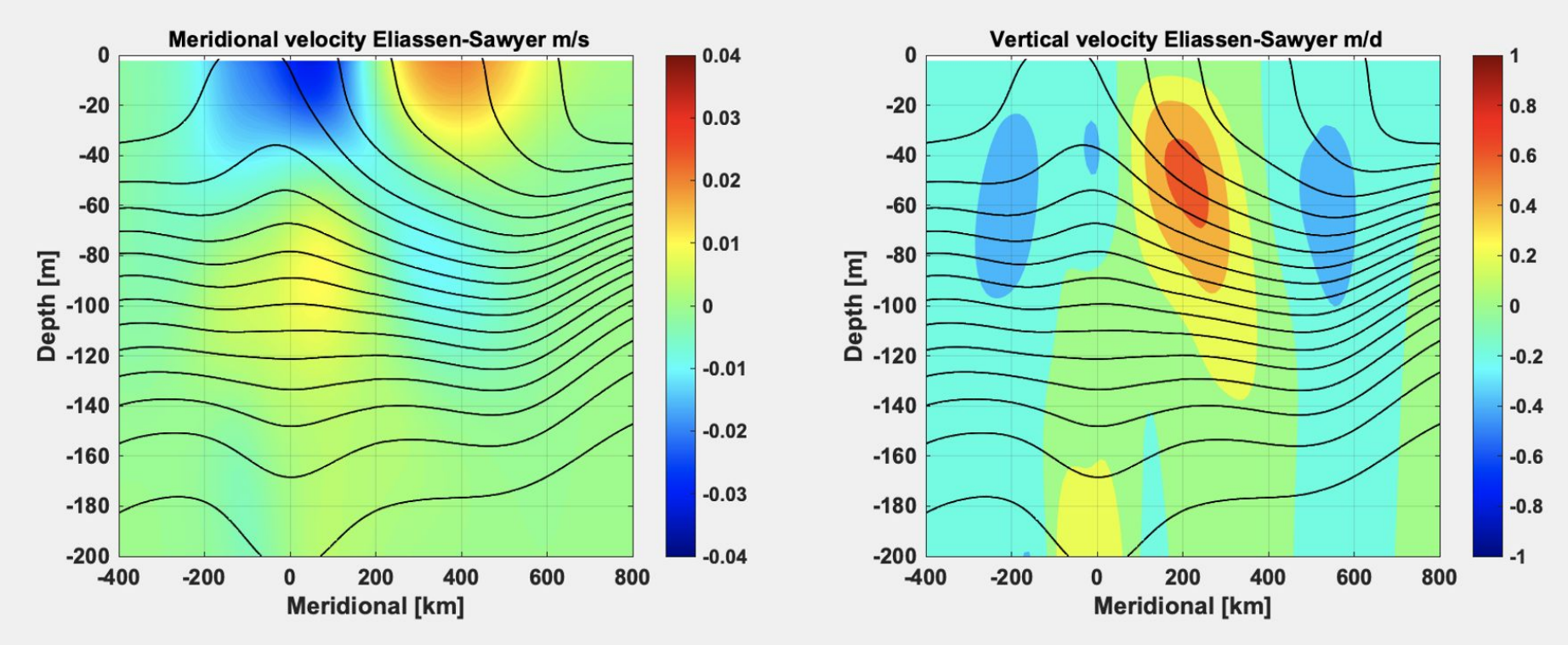
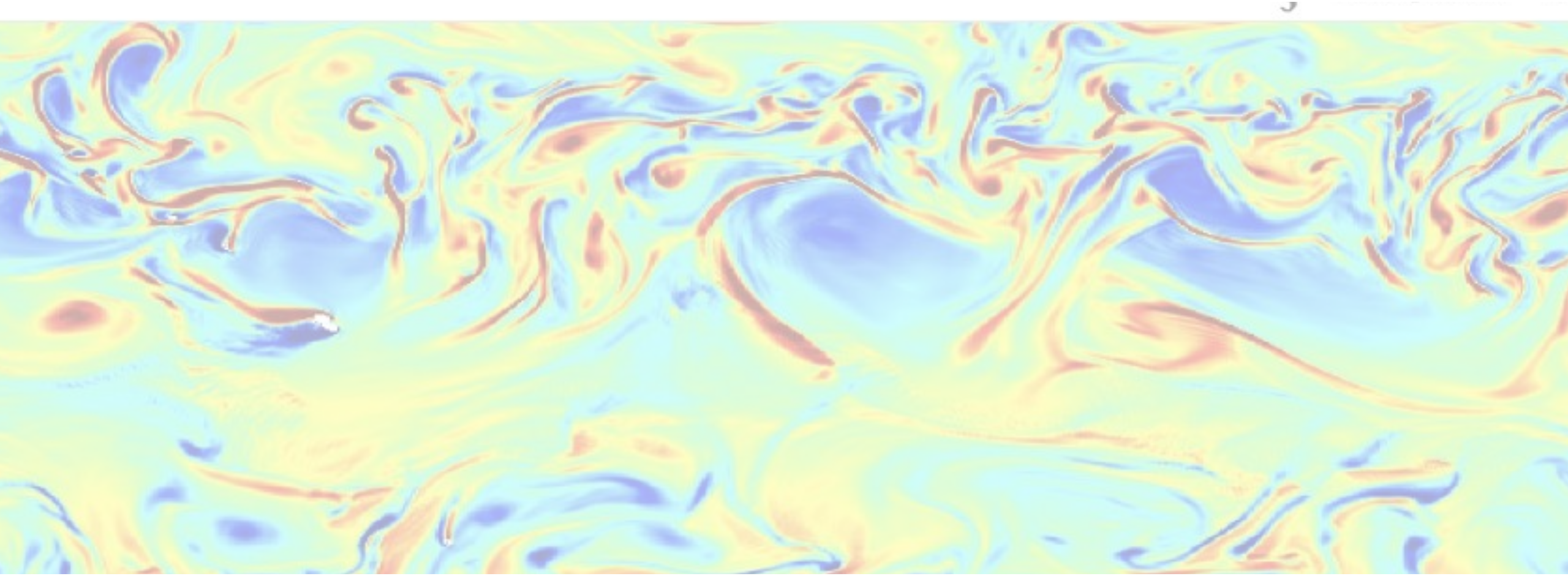


Bigger picture – lots to do!
Looking for collaborators, grad interns, post-docs…



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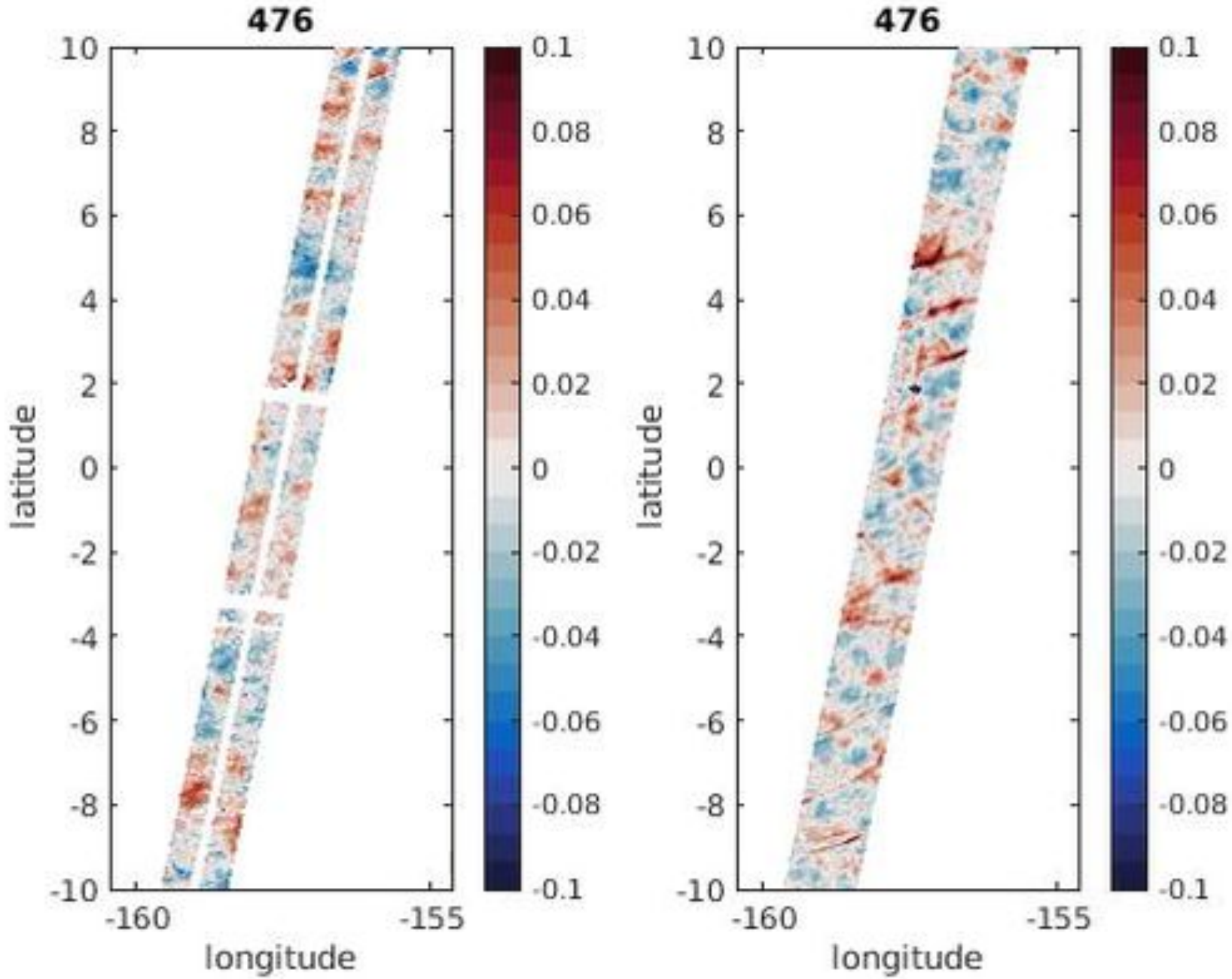
Daily SWOT observations from April – July 2023



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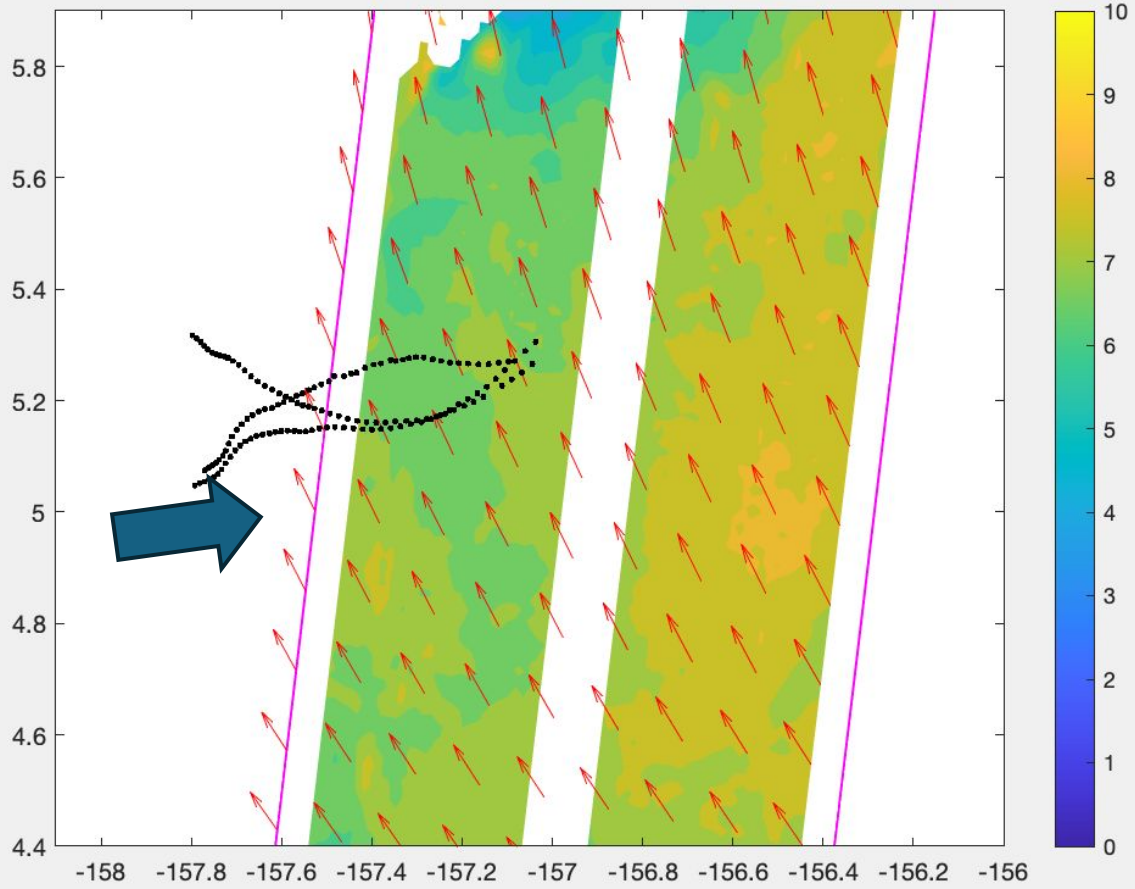
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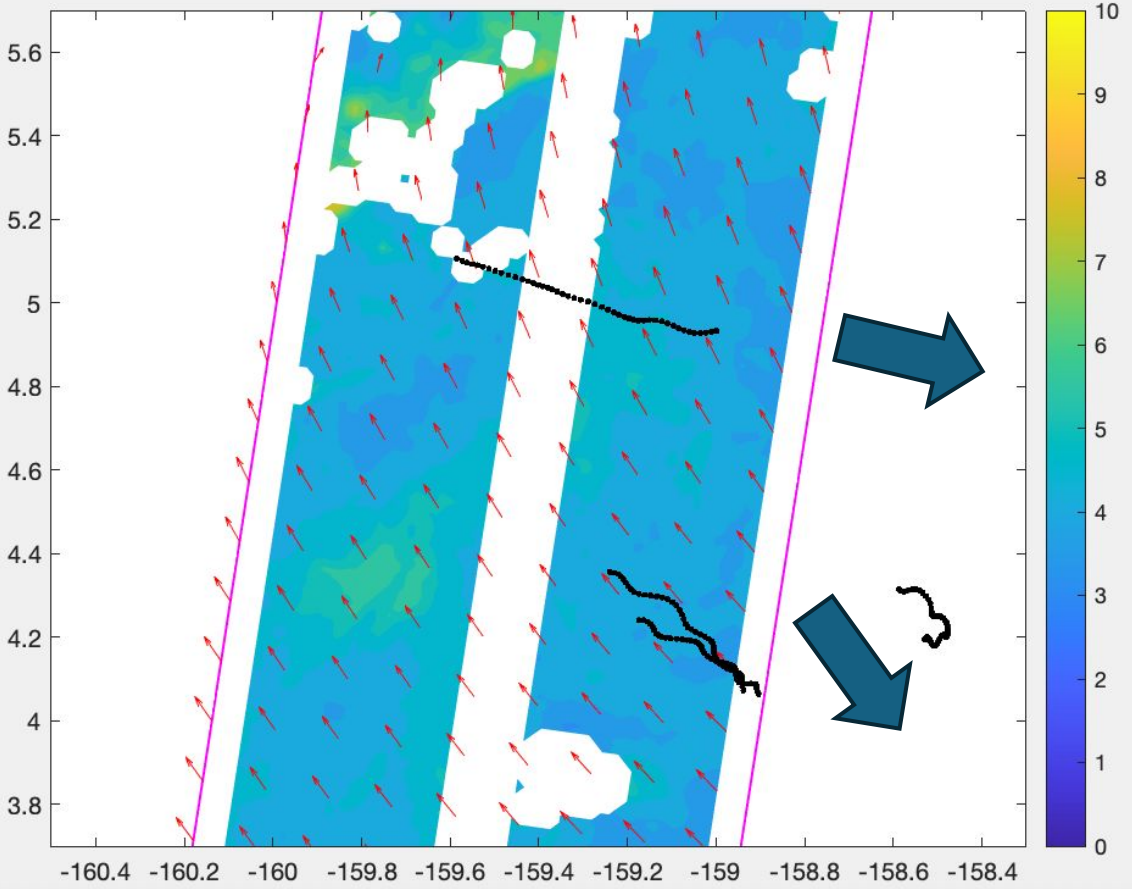
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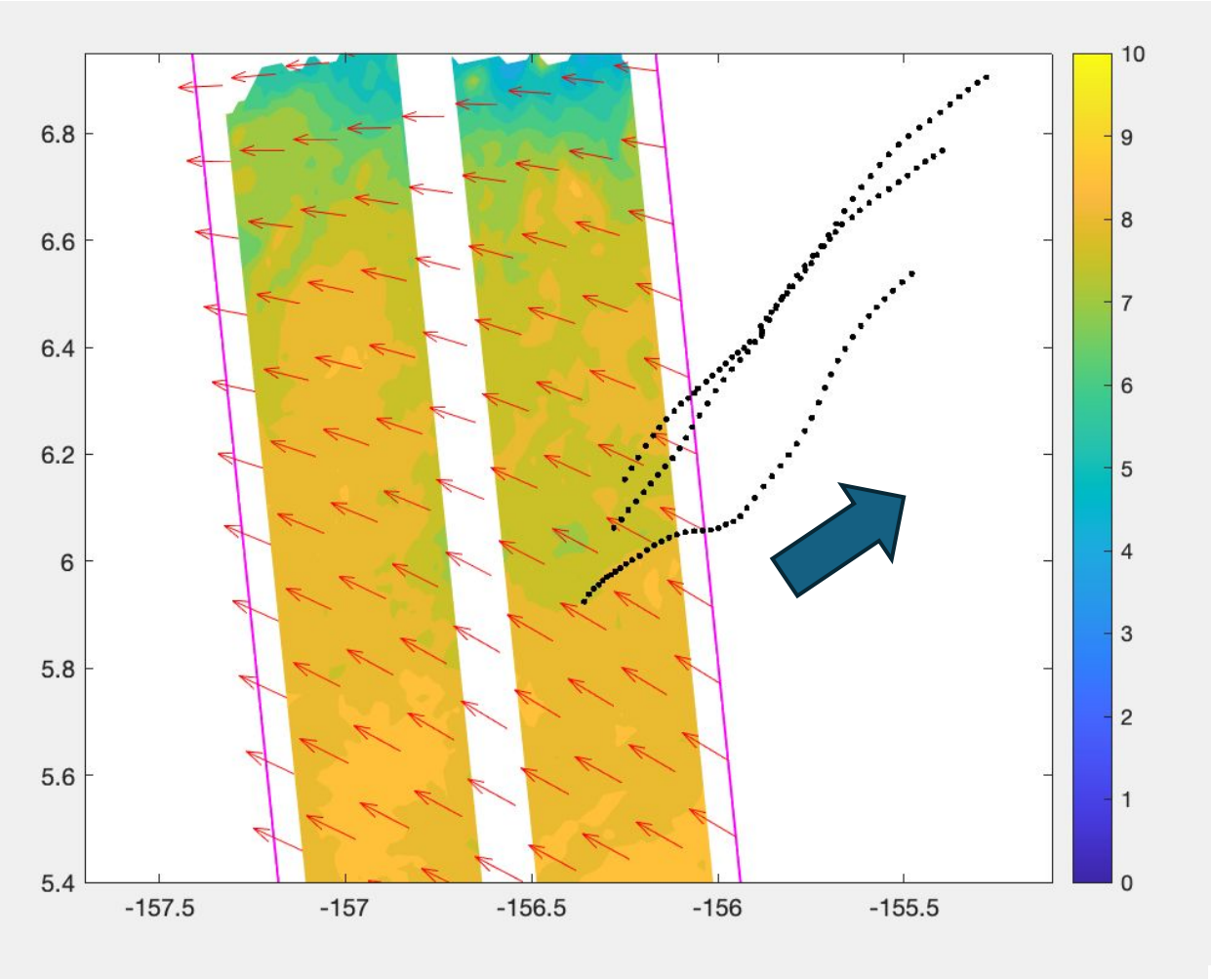
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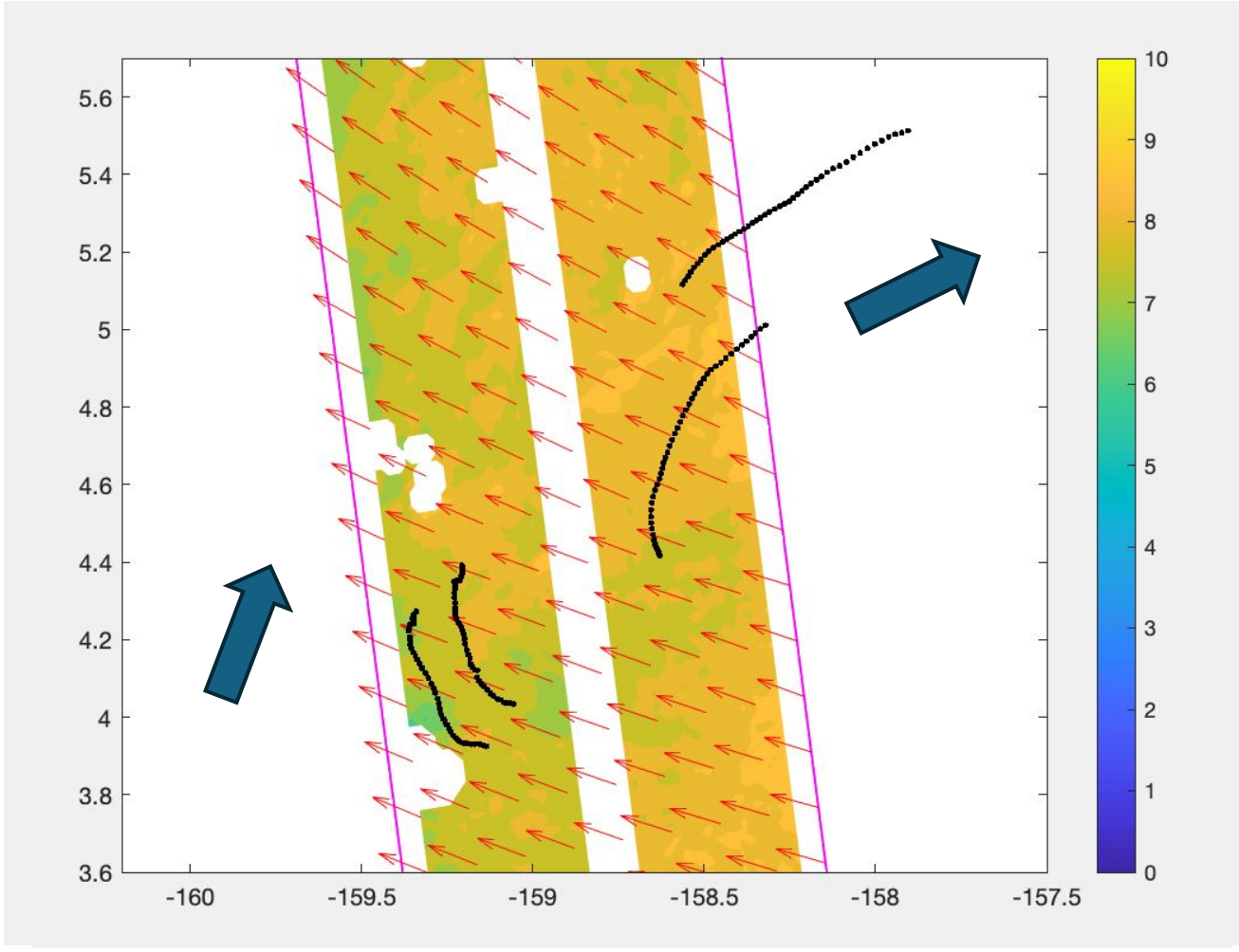
Aug 27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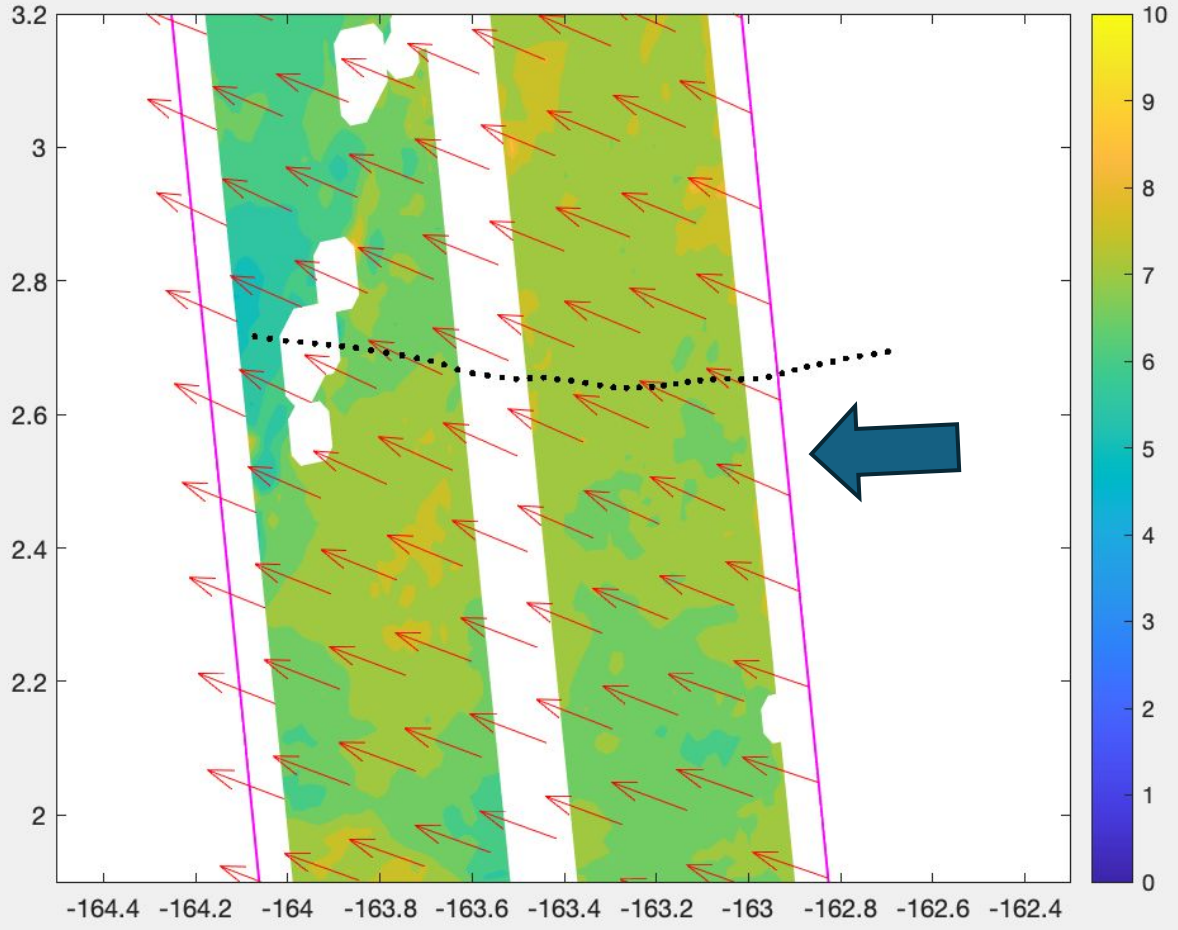
Aug 29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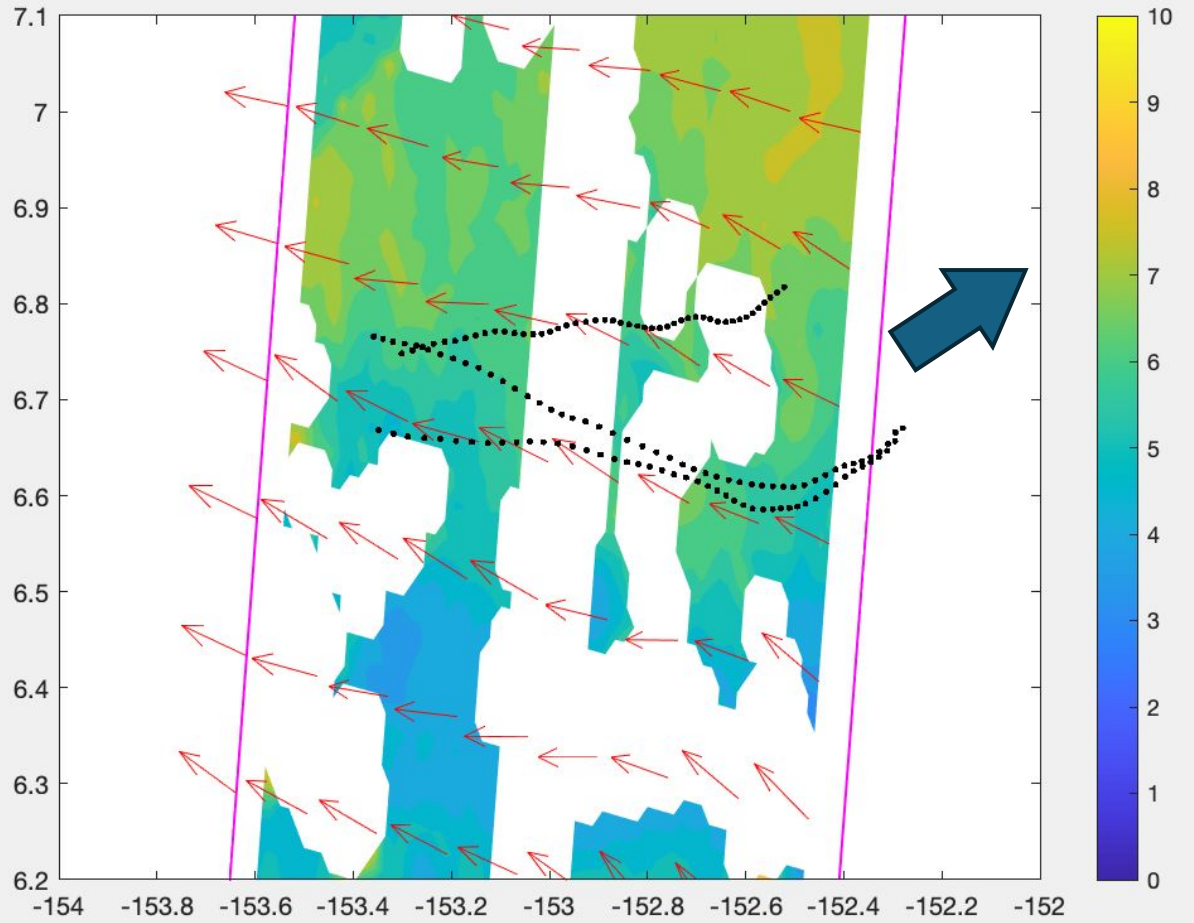
Aug 31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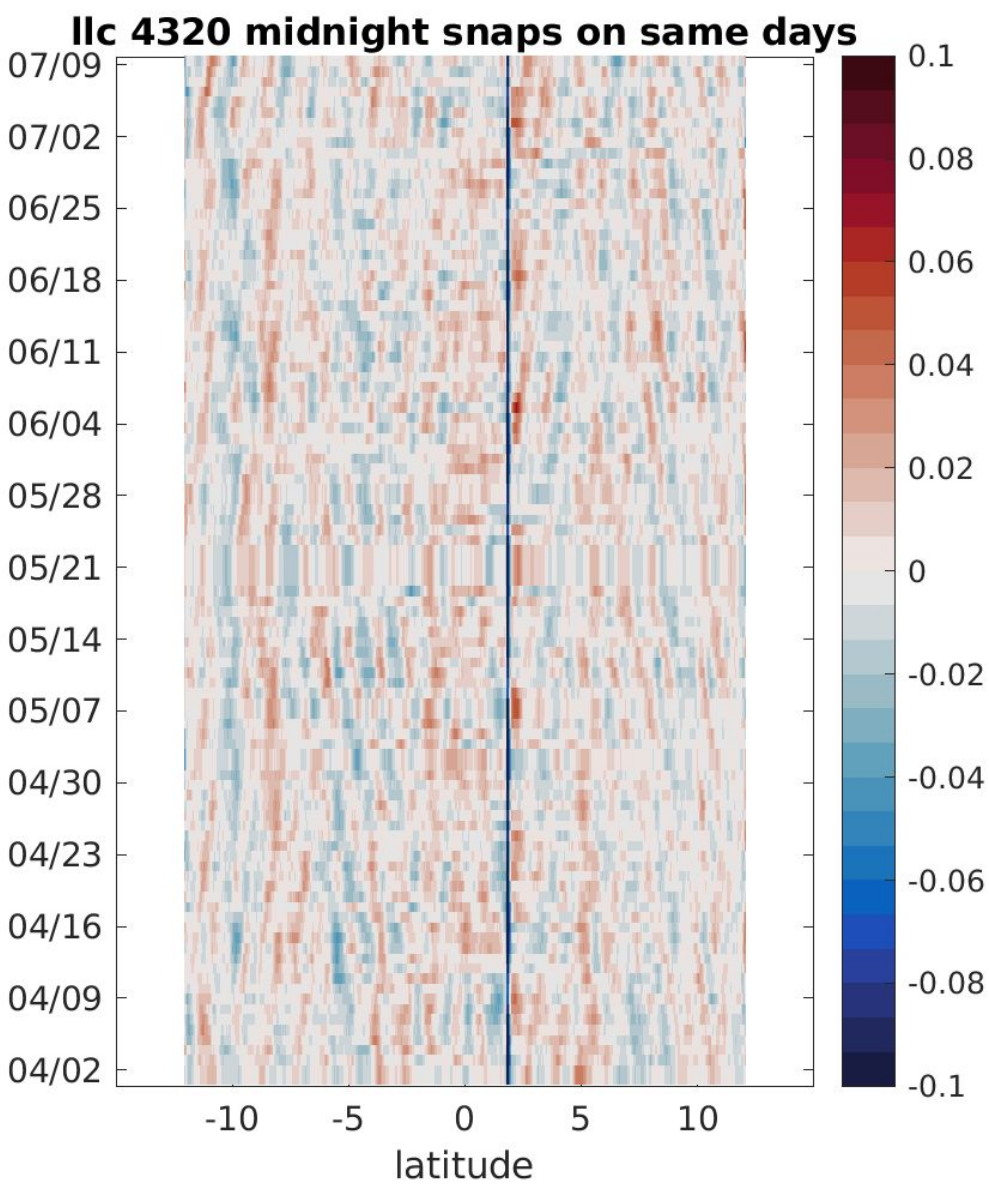
llc 4320 midnight snaps on same days
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06/25
06/18
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04/30
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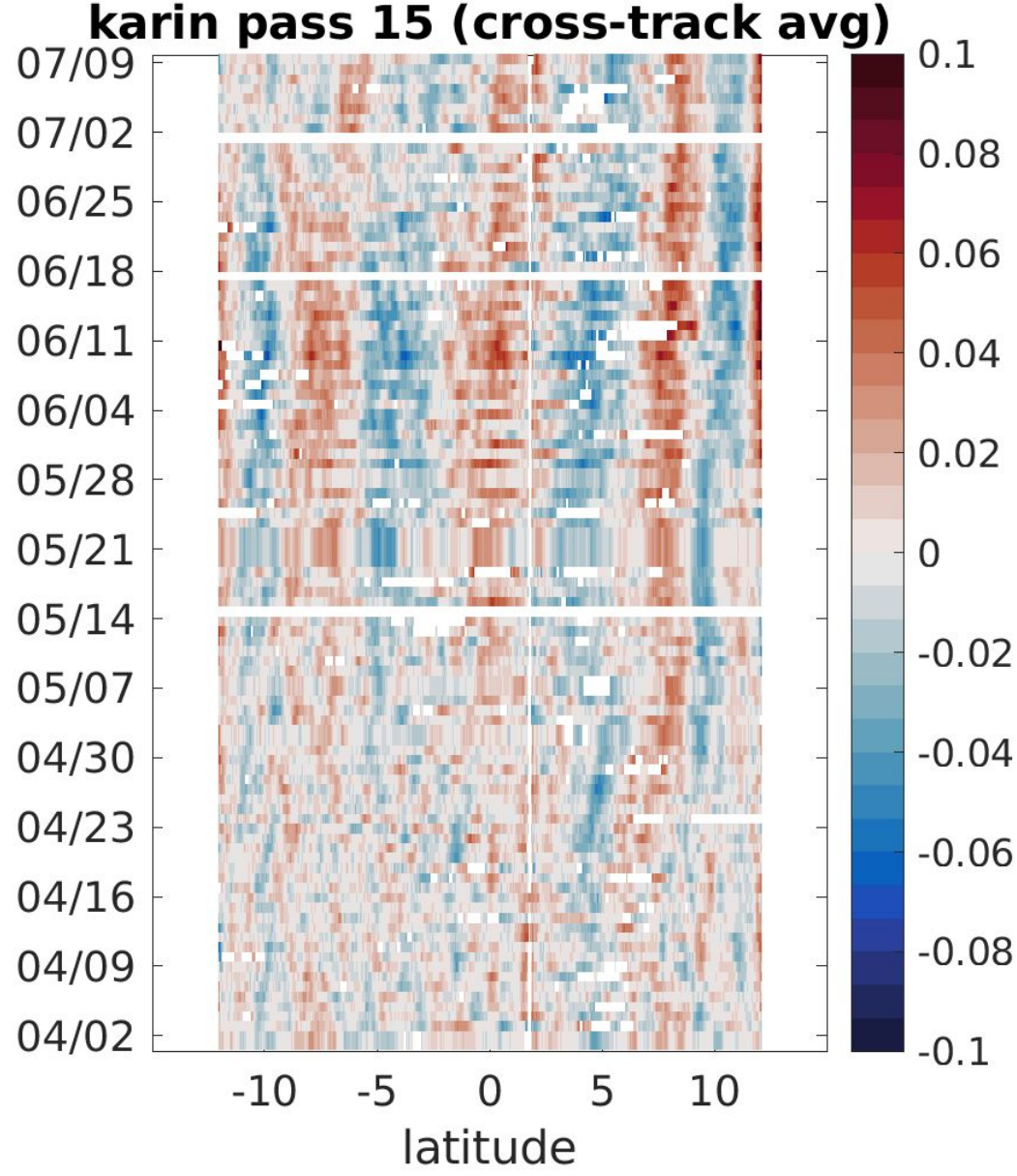
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1


karin pass 15 (cross-track avg)
07/09
07/02
06/25
06/18
06/11
06/04
05/28
05/21
05/14
05/07
04/30
04/23
04/16
04/09
04/02
-10
-5
0
5
10
latitude
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1