Estimating Global Ocean Absolute Geostrophic Velocities with Satellite and Autonomous Float Observations

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Background: Subsurface Ocean Circulation

- Historically, there are sparse observations of the subsurface ocean, limiting the ability to understand and predict its circulation.
- Geostrophic velocities play an important role in the energetics of the ocean-climate system.
- The *mesoscale field (10s -100s of kilometers, weeks – months)* contains the majority of kinetic energy in the ocean. [1]

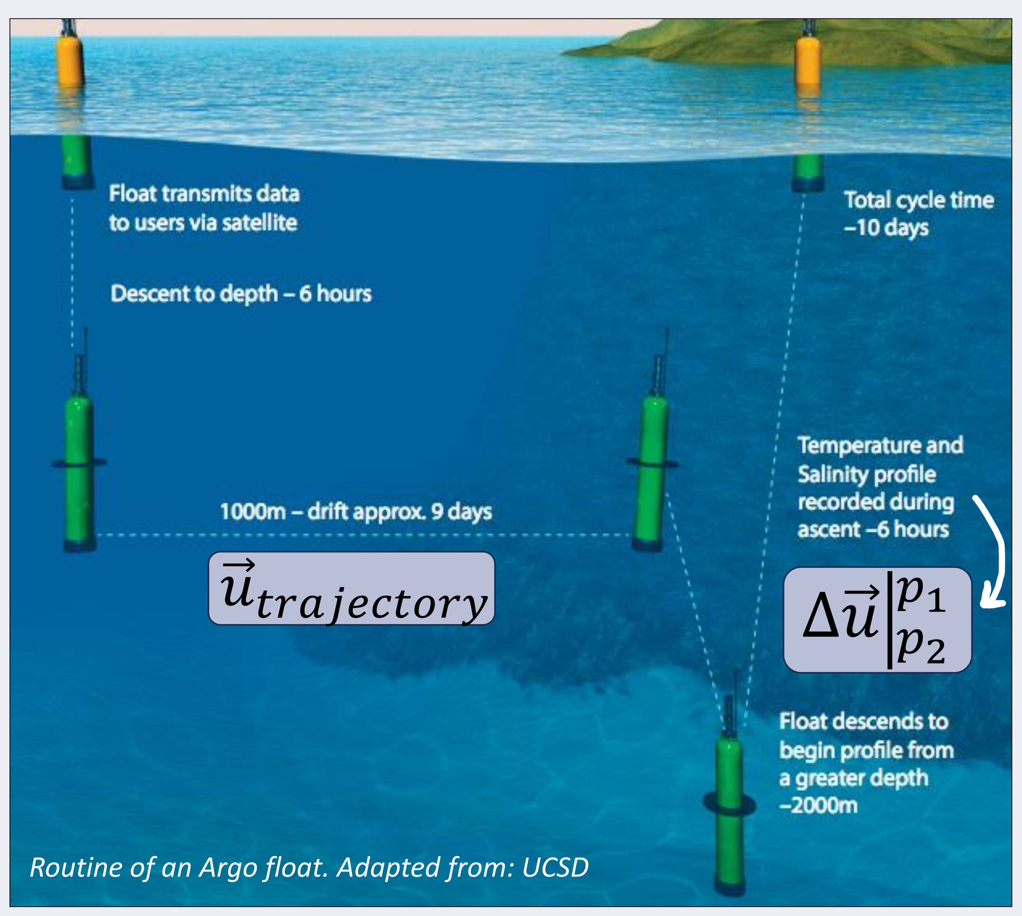
Data: Satellite Altimetry

For decades, satellite altimeters have measured global sea surface height, which is used to **derive the surface geostrophic velocities:** $\vec{u}_{surface}$ However, satellite data cannot observe the subsurface ocean, and therefore can't reveal the 3D structure of mesoscale geostrophic velocities. In this project, we use global gridded L4 altimetry fields from AVISO [2].

Data: Argo Floats

Nearly 4000 autonomous instruments that collect ocean data from the surface to 2000m, allowing the subsurface ocean to be studied over longer time scales and with unprecedented spatial coverage. Argo floats provide us with ~2M measurements from 01/2004 - 08/2022 of:

- **Velocity estimates at ~1000 m trajectory depth** [3], $\vec{u}_{trajectory}$
- Temperature, salinity, and pressure profiles that are used to compute **Dynamic Height (DH) and shear between pressure levels,** $\Delta\vec{u}\big|_{p_2}^{p_1}$



Routine of an Argo float. Adapted from: UCSD

Data & Methods Flow Chart

Argo Temperature & Salinity profiles → $DH = \int_{p_2}^{p_1} \frac{1}{\rho(T,S,p)} dP$ (Dynamic height between adjacent pressure levels) → ***DH* profiles** → Multi-scale Spatial-temporal mapping (Gridded large-scale & small-scale parameters) → $\Delta\vec{u}\big|_{p_2}^{p_1} = \frac{1}{f}\boldsymbol{k} \times \nabla DH$ (Geostrophic shear between adjacent pressure levels) → $\Delta\vec{u}\big|_{p_2}^{p_1}$

$\vec{u}_{surface}$, $\vec{u}_{trajectory}$, $\Delta\vec{u}\big|_{p_2}^{p_1}$ → Weighted least-squares data combination (Geostrophic modes used as basis) → $\vec{u}_{fit}$ **profiles at Argo trajectory locations** → Multi-scale Spatial-temporal mapping (Gridded large-scale & small-scale parameters) → **Global estimated geostrophic velocity profiles, $\vec{u}(x,y,p,t)$, on monthly $^1/_4{}^\circ \times {}^1/_4{}^\circ$ grid**

See the data!

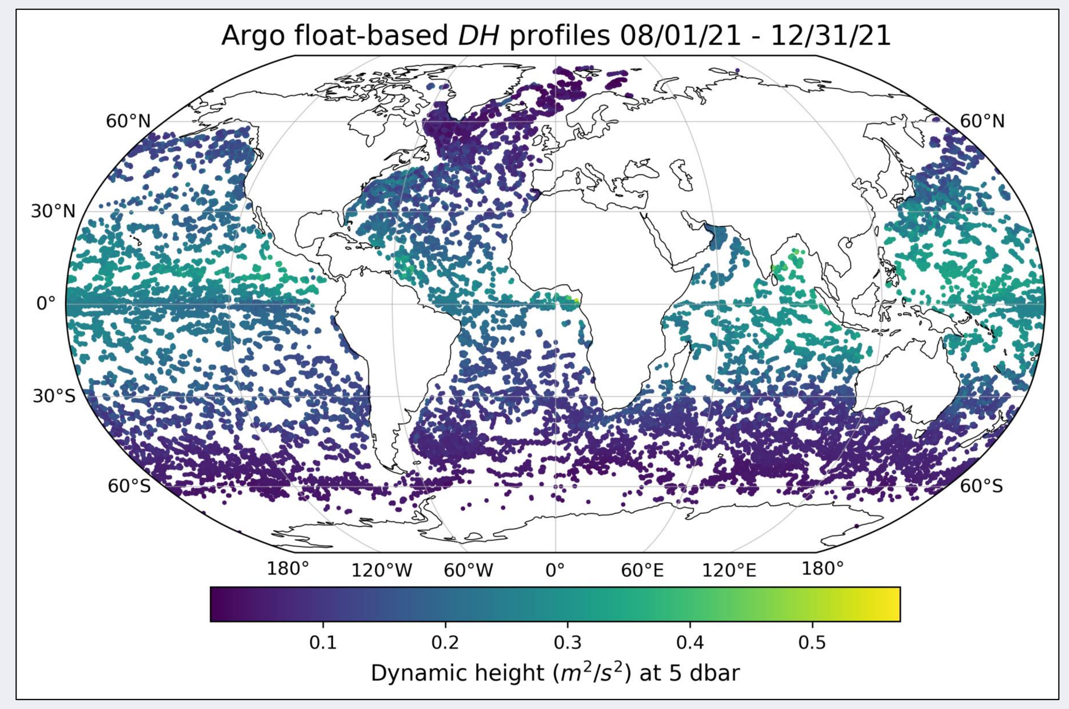
- Interactive plot tool to visualize data and mapping parameters (in development)

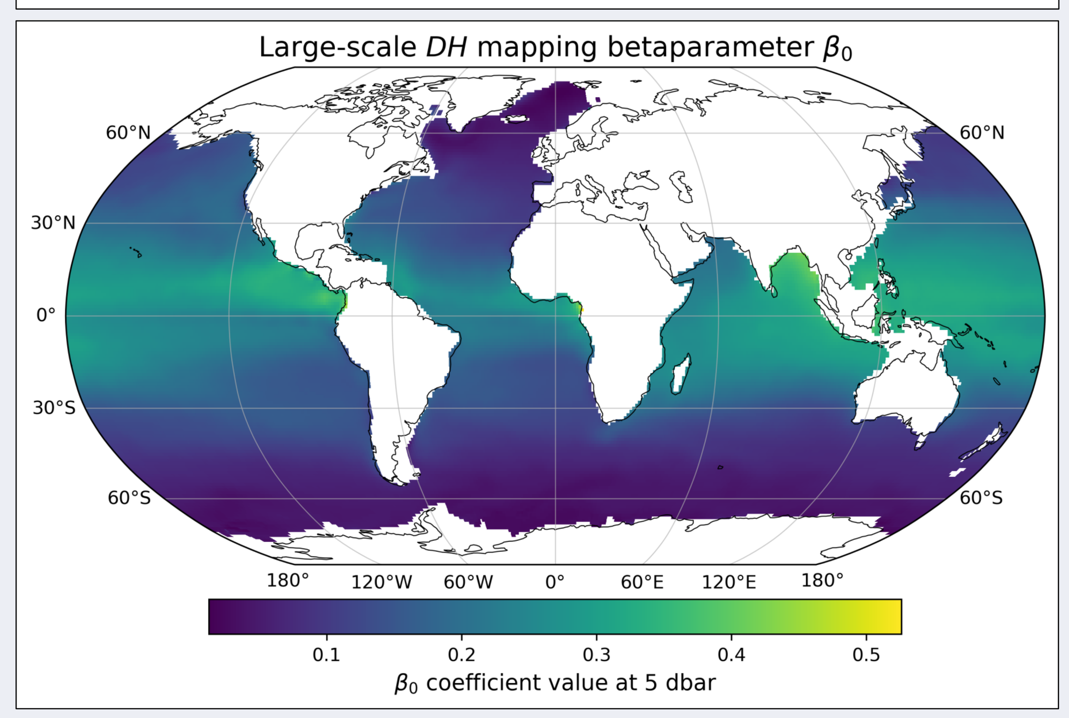
Spatial-temporal Mapping

Large-Scale Mapping

- Second-order polynomial regression within local window around each grid point to capture large-scale structure and seasonal cycle.

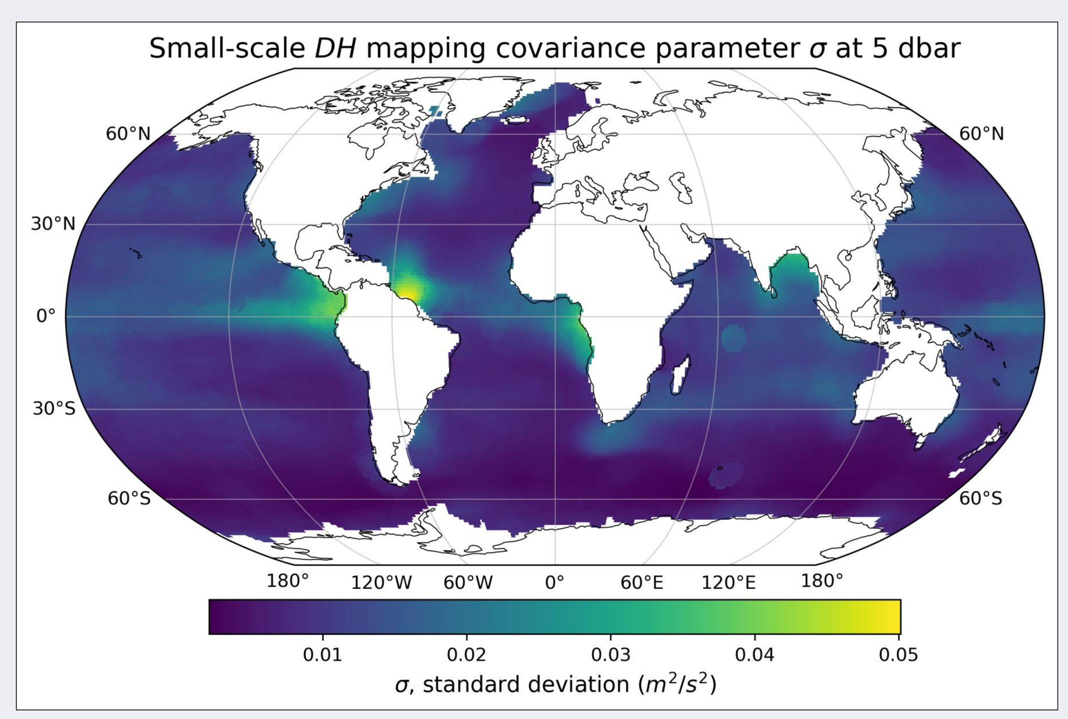
$$m(\vec{x},t) = \beta_0 + \beta_x x + \beta_y y + \beta_{xy} xy + \beta_{x^2} x^2 + \beta_{y^2} y^2 + \sum_{k=1}^{2}\left[\beta_{c_k}\cos\left(\frac{2\pi kt}{365}\right) + \beta_{s_k}\sin\left(2\frac{\pi kt}{365}\right)\right]$$

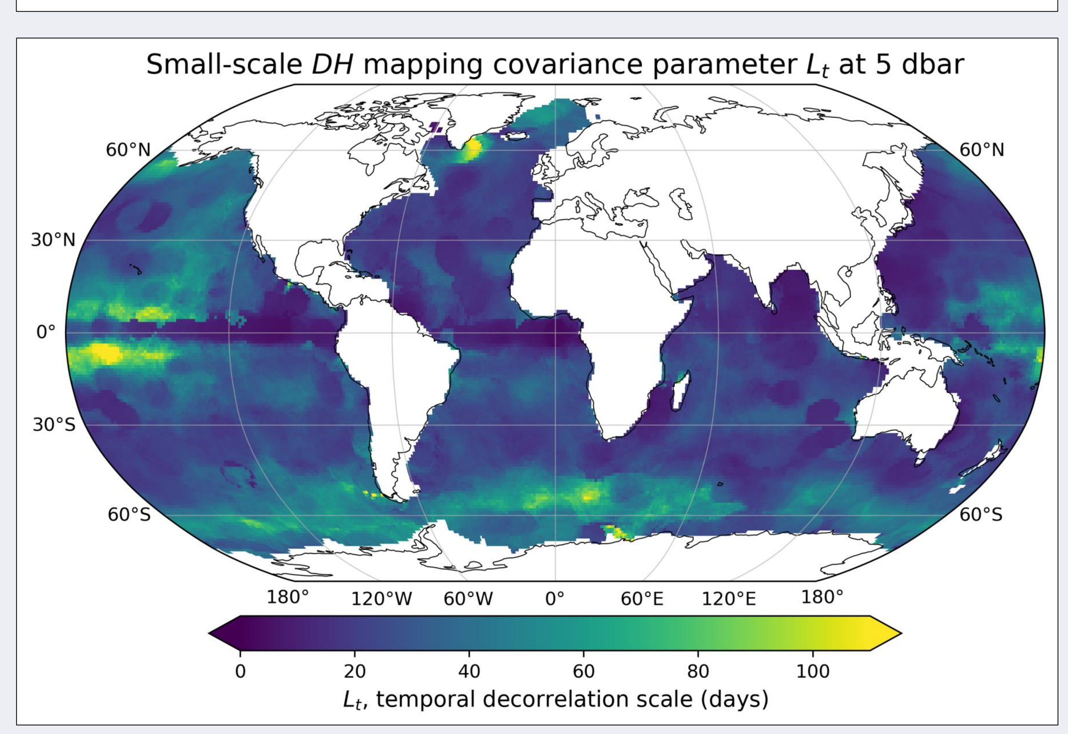




Small-scale mapping

- The Maximum Likelihood Estimate (MLE) is computed for covariance parameters $\xi = (\sigma^2, L_x, L_y, L_t)$ in a Matérn covariance function. Then, Gaussian Process Regression (GPR) is performed to map dynamic height (DH) profiles to dynamic height gradient (∇DH) at Argo trajectory locations.
- L-BFGS algorithm offers efficient maximization of the log likelihood.

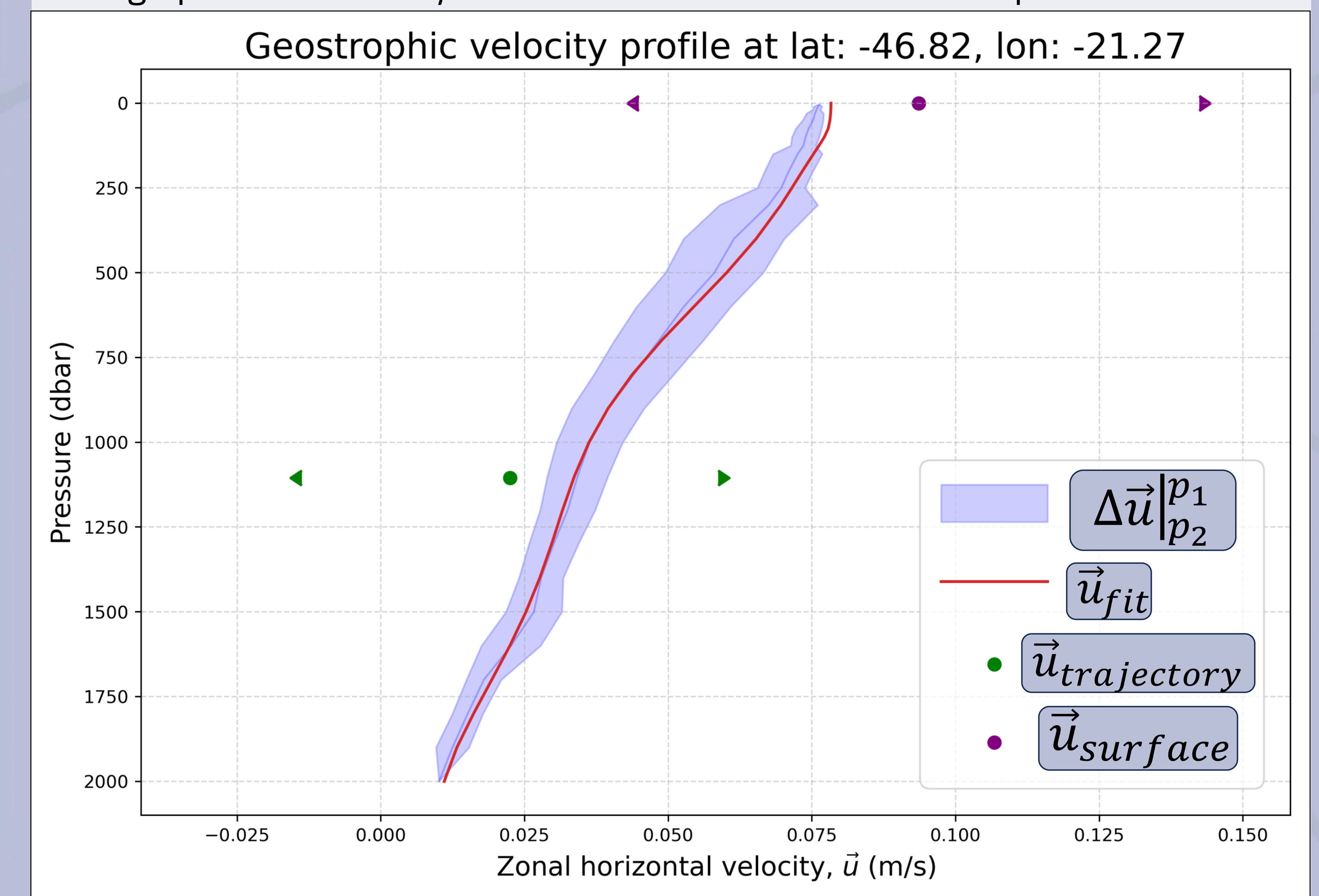




Combining Altimetry and Argo Data

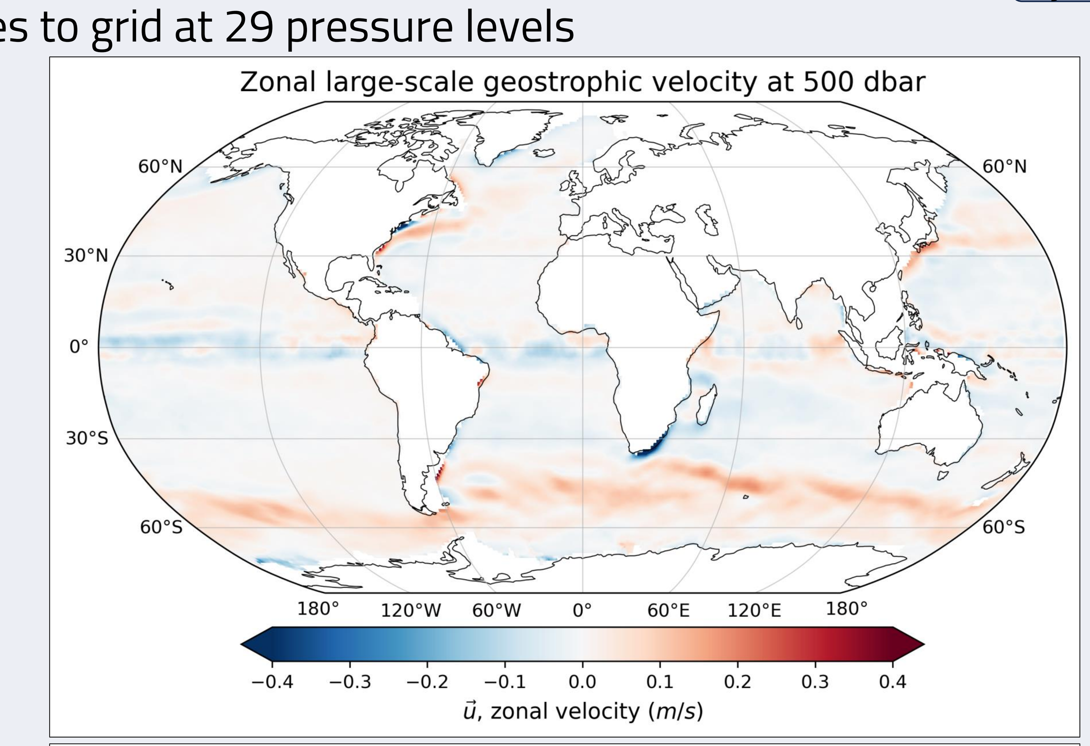
Absolute geostrophic velocity profiles 0-2000m $\vec{u}_{fit}$

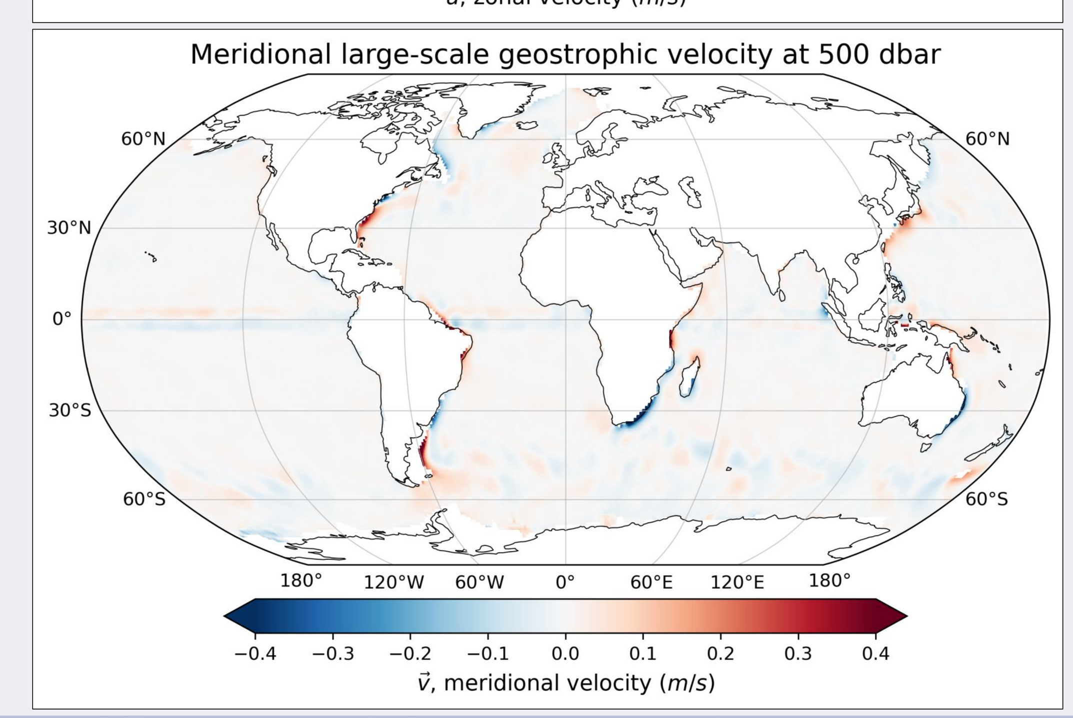
- Weighted least squares fit with basis of geostrophic modes [4]
- Altimetry and float trajectory measurements used as absolute velocities
- Argo profile-based dynamic shear used to estimate full profile



$\vec{u}(x,y,p,t)$, on monthly $^1/_4{}^\circ \times {}^1/_4{}^\circ$ grid

- Spatial-temporal mapping procedure is performed to map $\vec{u}_{fit}$ profiles to grid at 29 pressure levels





Key Takeaways

- Gaussian Process Regression and covariance parameter estimation are successful methods to map non-stationary data like autonomous float profiles to different space-time grids.
- High resolution altimetry and profiling float data can be combined to estimate subsurface, global geostrophic velocities.

This work was made possible thanks to: UNIVERSITY of WASHINGTON

Sources: [1] Wunsch, and Ferrari, 2004. *Annu. Rev. Fluid Mech.*, [2] Copernicus Marine Environment Monitoring Service, 2023. [3] Zilberman et al, 2023. *J. Atmos. Oceanic Technol.*, [4] Early et al, 2020. *J. Adv. Model. Earth Syst.*