Trajectories in the Ocean: What We Learn from Argo

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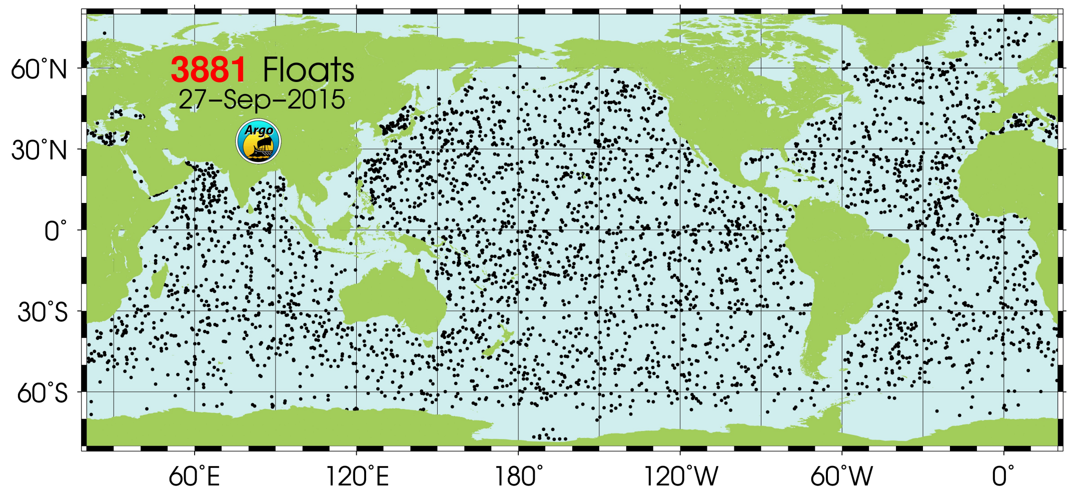
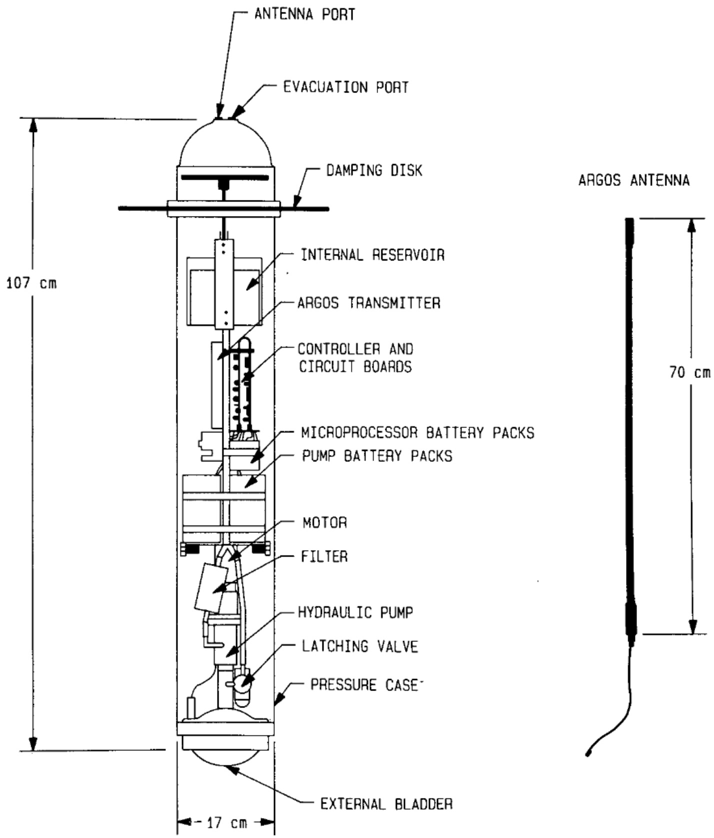


http://www.argo.ucsd.edu/

Scripps Institution of Oceanography, San Diego

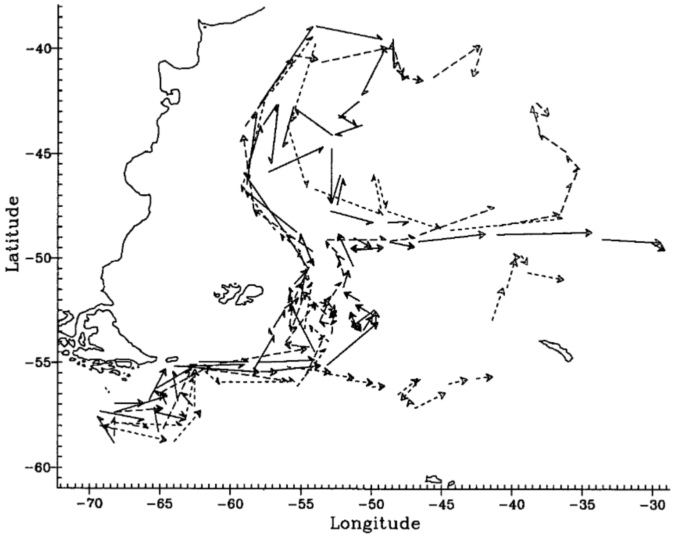
Origins of Argo: Autonomous Lagrangian Circulation Explorer (ALACE)



Davis et al, JTech, 1992

- Developed as part of World Ocean Circulation Experiment
- Profiling float, tracked via satellite at ocean surface but designed to follow current at 800 or 1000 m depth

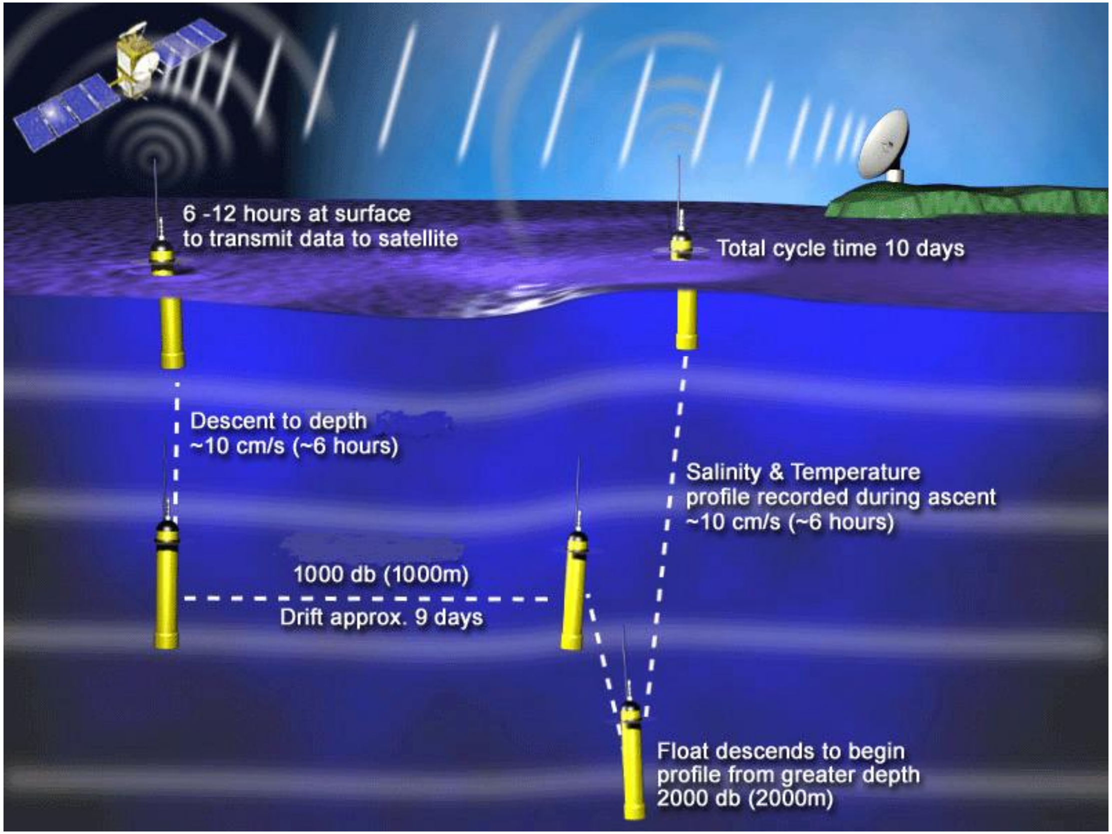
Origins of Argo: Year 1 ALACE Trajectories



Davis et al, JTech, 1992

- 7 floats
- 14-day trajectories at 800-m depth
- Temperature measured at parking depth
- Goal: map large-scale, low-frequency velocity over global ocean to address the geostrophic reference velocity problem.
- Subsequent improvements added CTD to measure temperature and conductivity (salinity) while profiling: Profiling ALACE (PALACE)
- No acoustic tracking

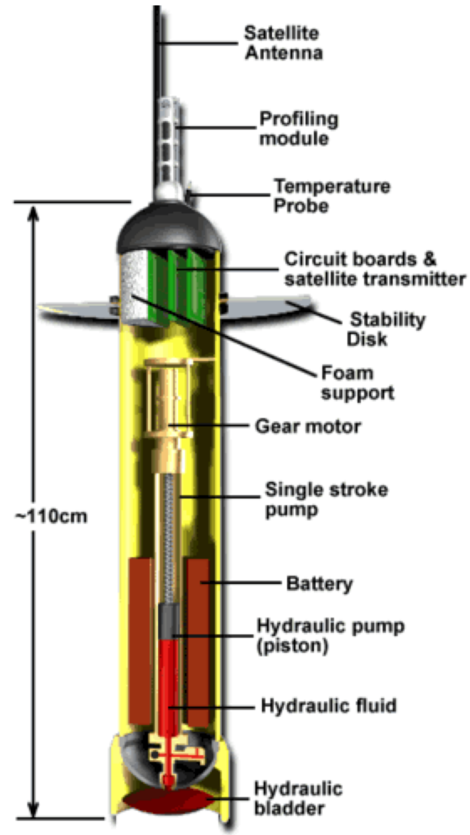
Transitioning to Argo



- Early 2000s: ALACE/PALACE became global Argo program
- Emphasis on profile data; trajectories not initially quality controlled

Outline: What Argo Lets Us Learn

- What Argo measures
- Defining the mean and time varying properties of the ocean from Argo.
- Using trajectories as a reference velocity
- Pushing the limits. Can we evaluate eddy variability?
- Prospects for the future. How well do we know where an Argo float will go?



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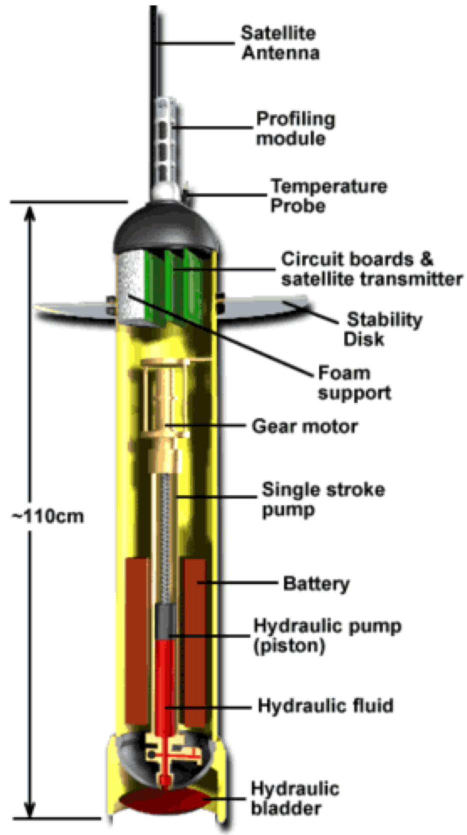
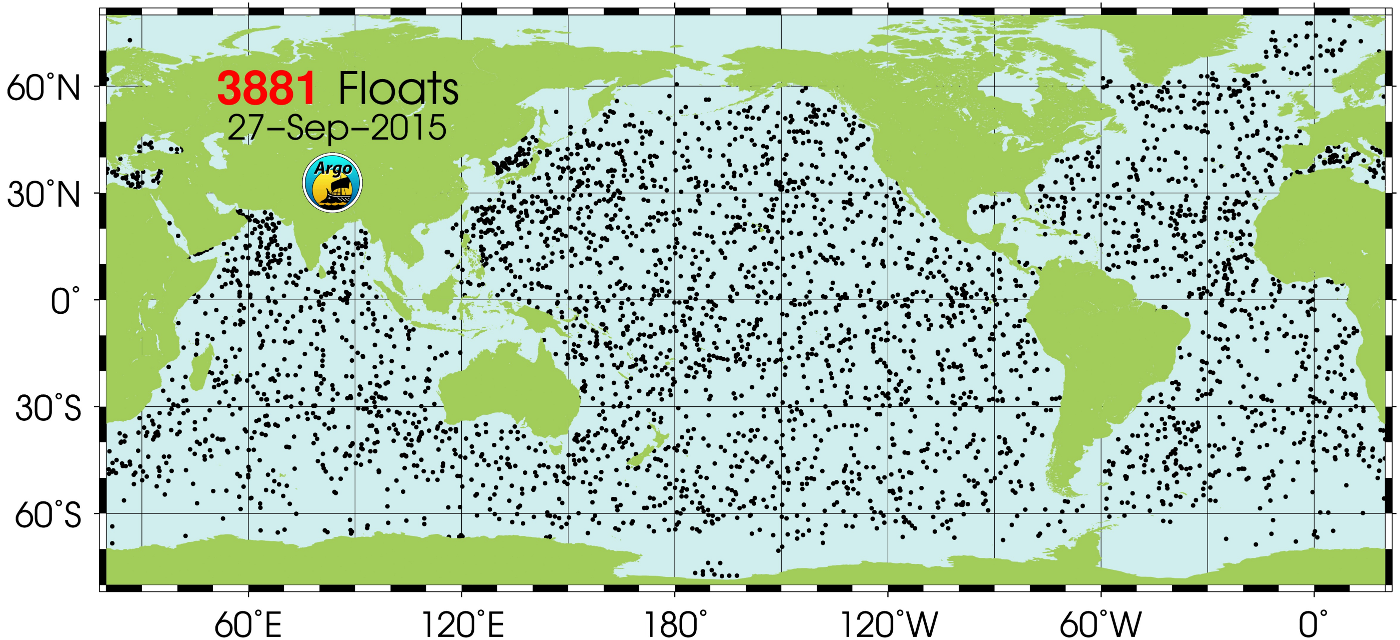


Argo measurements

http://soccom.princeton.edu/

- Temperature, salinity
- pH, O_2, nitrate, fluorescence, backscatter (SOCCOM)
- EM-APEX: small-scale velocities
- χ (turbulence): Prototype
- Acoustic tracking: Tested but not highly successful
- Trajectory information: Collected but not in initial quality control requirements

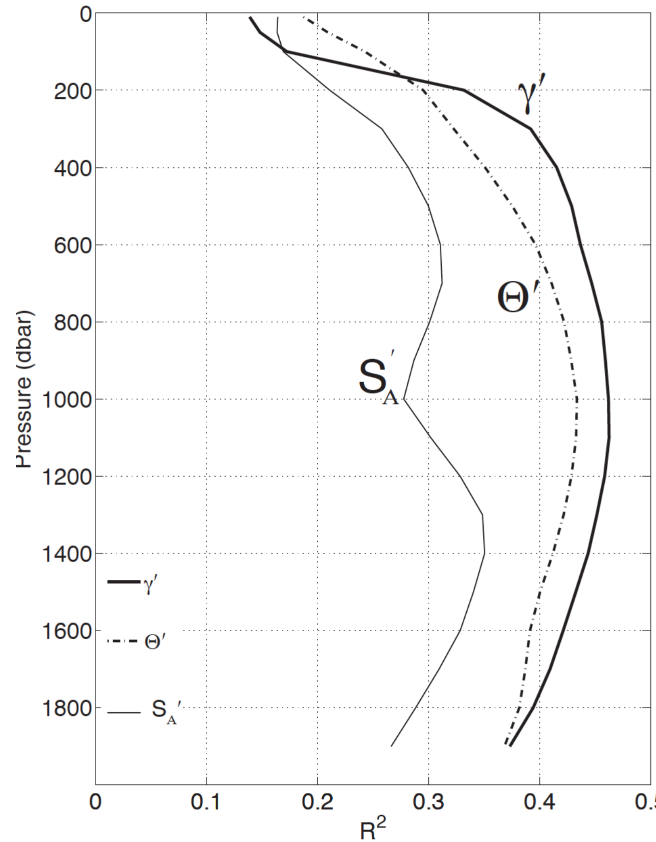
Mapping Argo data: How well do we sample an ed-dying ocean?



http://www.argo.ucsd.edu/

Mapping Argo data: Using altimetry to remove eddies

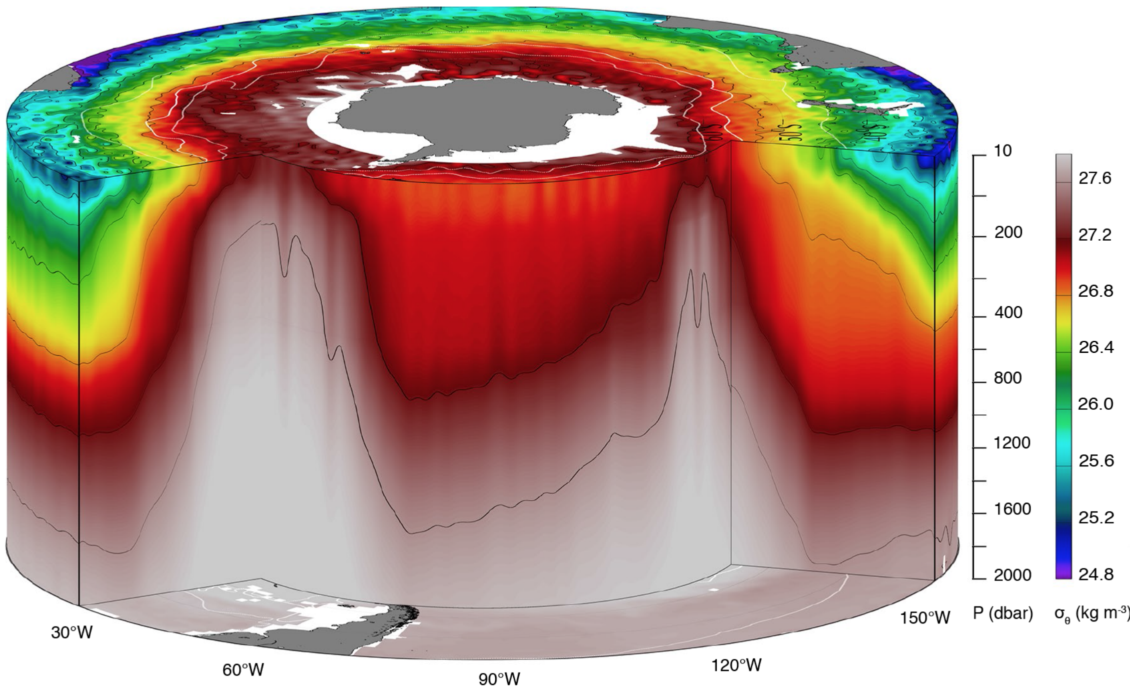
- Eddies are the biggest non-seasonal process.
- Satellite altimeter correlated with Argo measurements, particularly in mid-depth ocean, below mixed-layer



Correlation coefficients: sea surface height and Argo

Zajaczkovski and Gille, submitted, 2015

Mapping the ocean from Argo: Time-mean potential density



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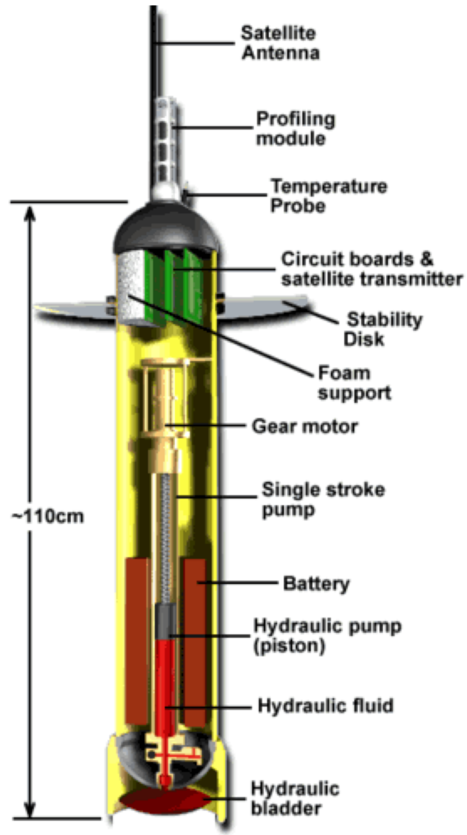
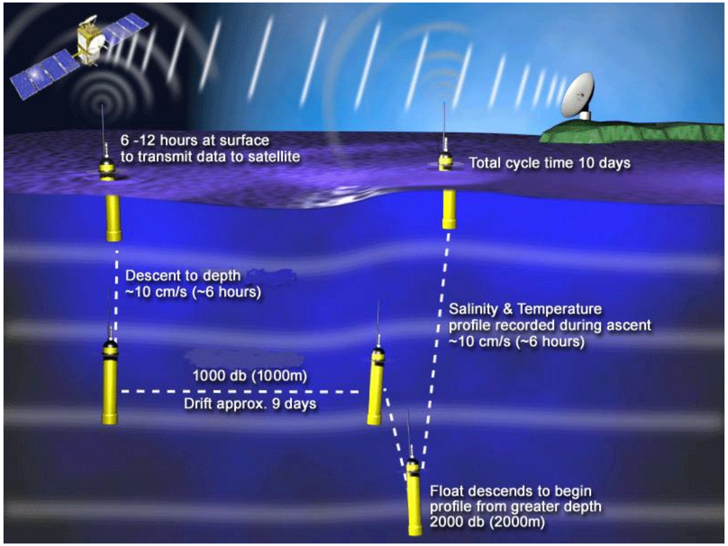
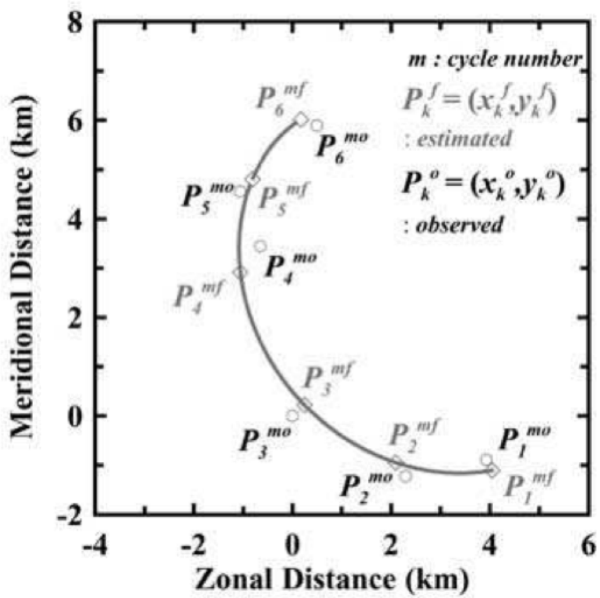


How to get a good trajectory



- When did the float arrive at the surface?
- How did the float move at the surface before making transmitting its position to satellite? (With ARGOS transmitters, floats spent ~24 hours at the surface to transmit data.)

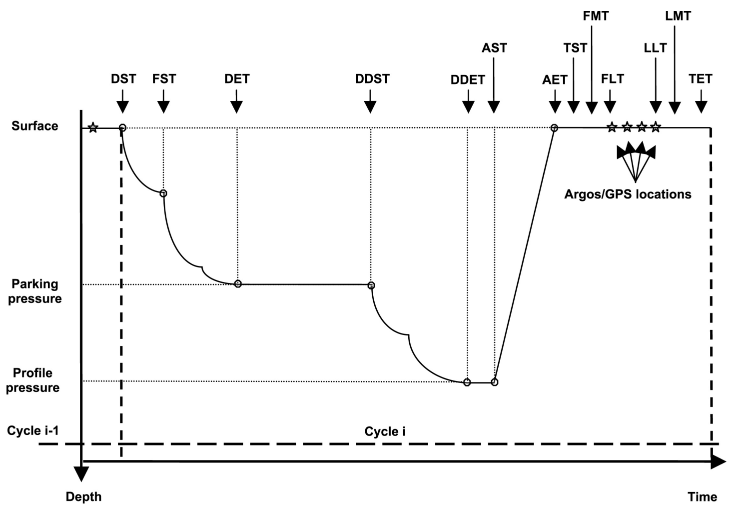
How to get a good trajectory: Inertial motion at the surface



Park et al, GRL, 2004

- Assume inertial motion
- Least-squares fit multiple position fixes to derive best estimate of surface trajectory
- Extrapolate forward and back in time for surface position and dive position.

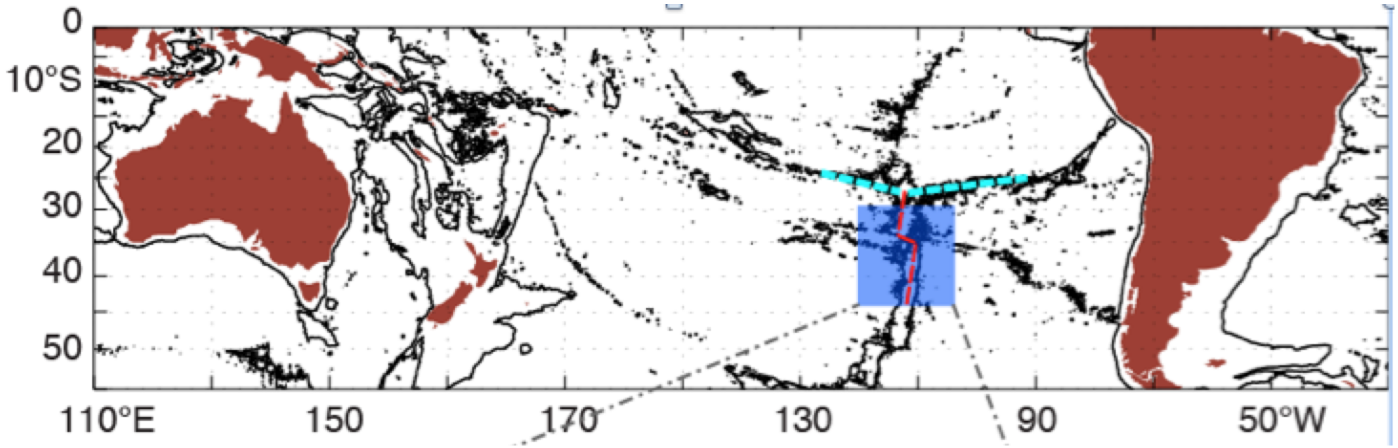
How to get a good trajectory: When do the floats surface?



Ollitrault and Rannou, JTech, 2013

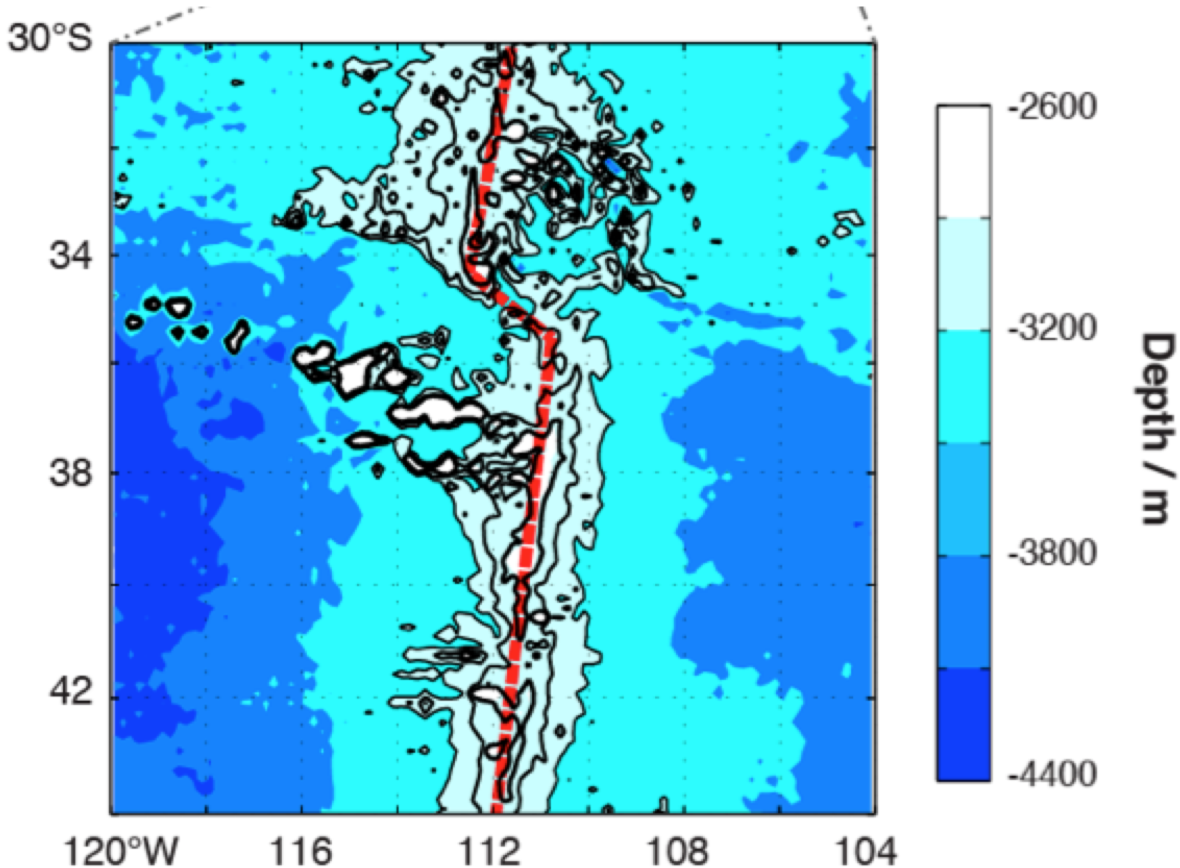
- Retrieve surfacing times from raw data by counting number of attempts to transmit.
- Neglect inertial motion.
- Released data base of trajectories, BUT weren't funded to extend to present, and didn't implement inertial motion correction.
- Megan Scanderbeg and Nathalie Zilberman (SIO) working on complete trajectory quality control.

What do we learn from trajectories?



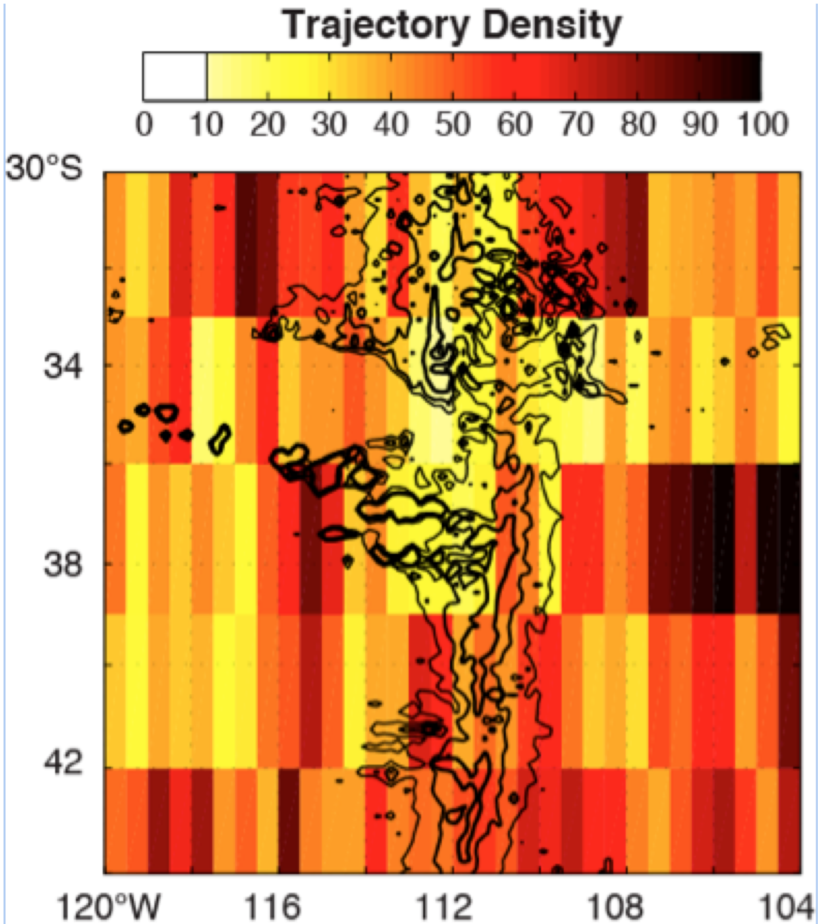
Zilberman, Roemmich, Gille, in prep, 2015

East Pacific Rise



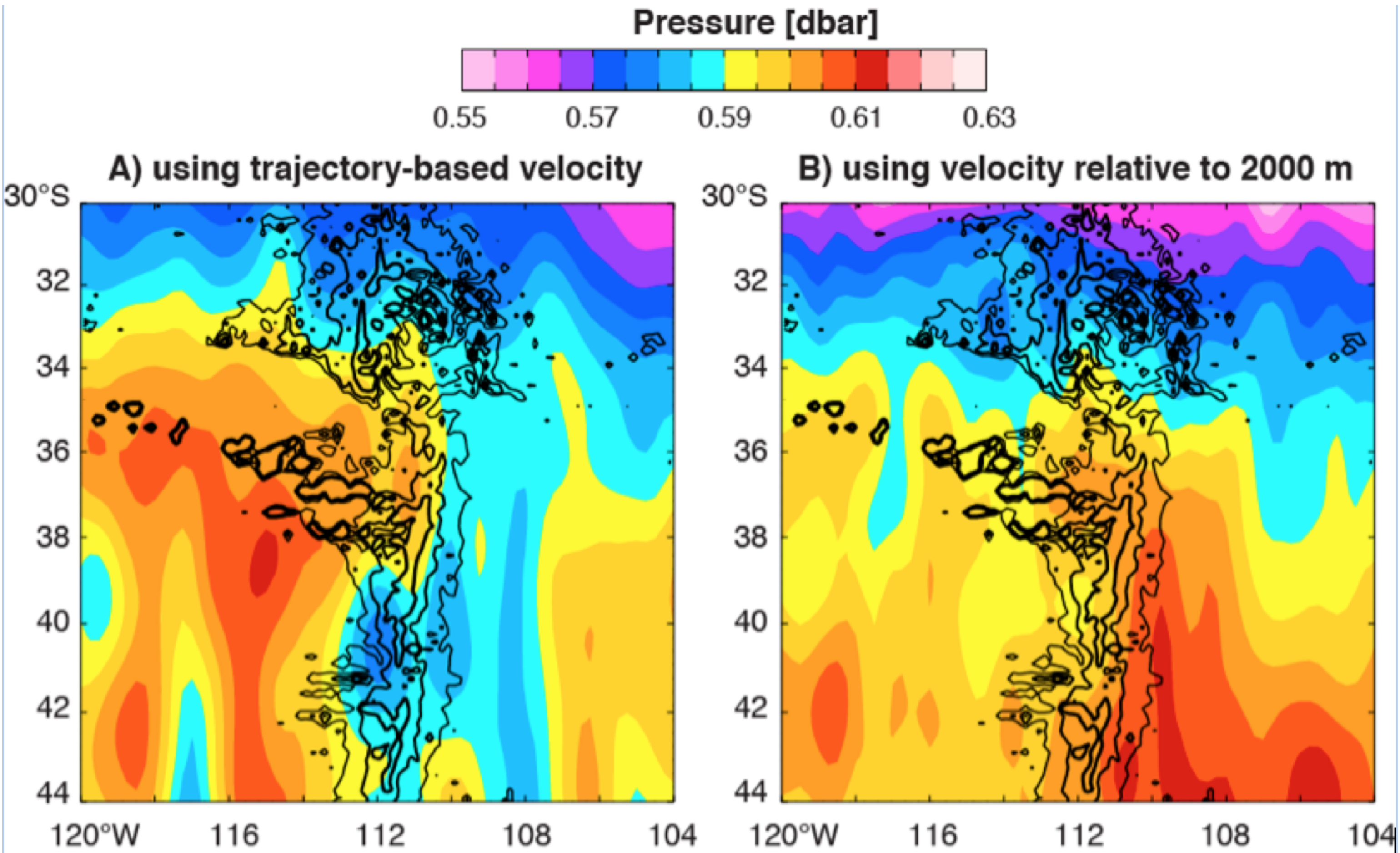
Zilberman, Roemmich, Gille, in prep, 2015

Trajectory coverage



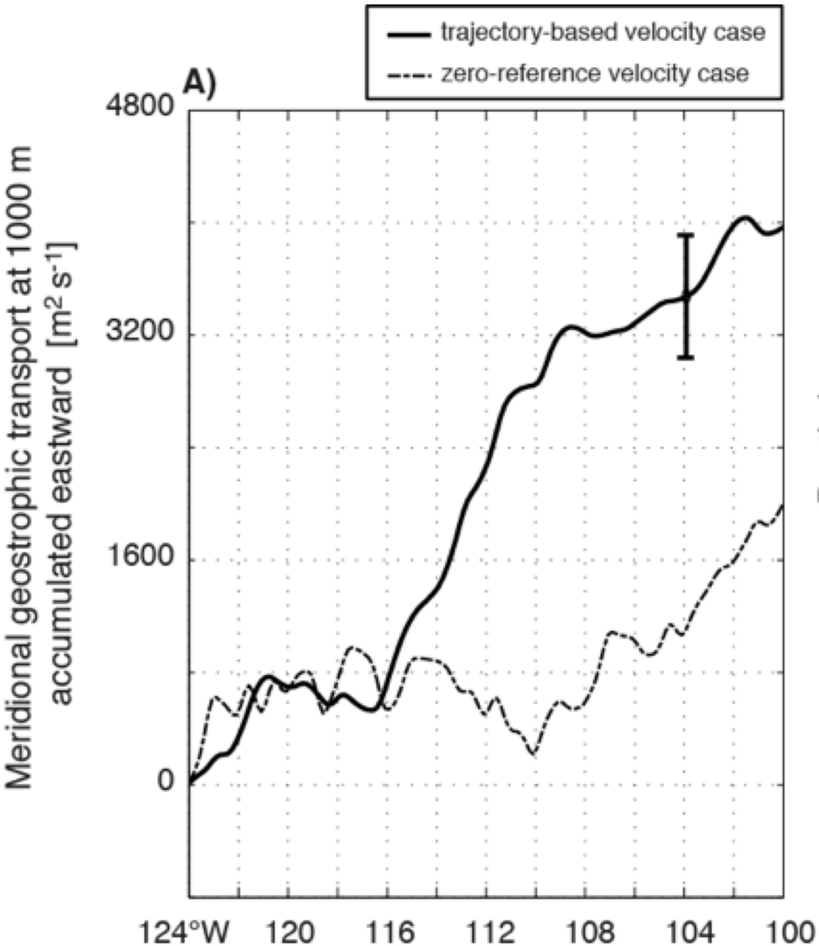
Zilberman, Roemmich, Gille, in prep, 2015

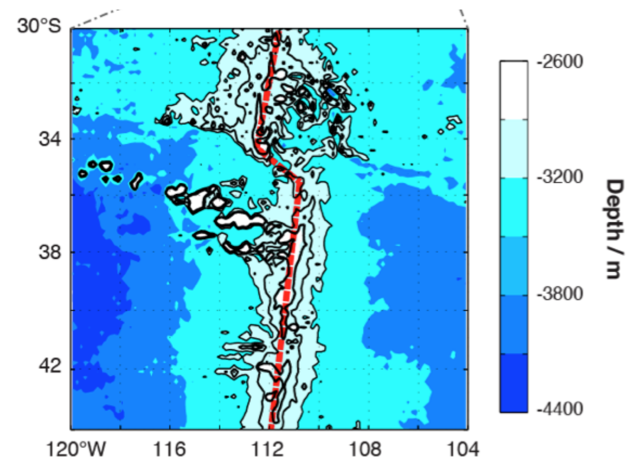
Pressure maps (with trajectories and hydrography only)



Zilberman, Roemmich, Gille, in prep, 2015

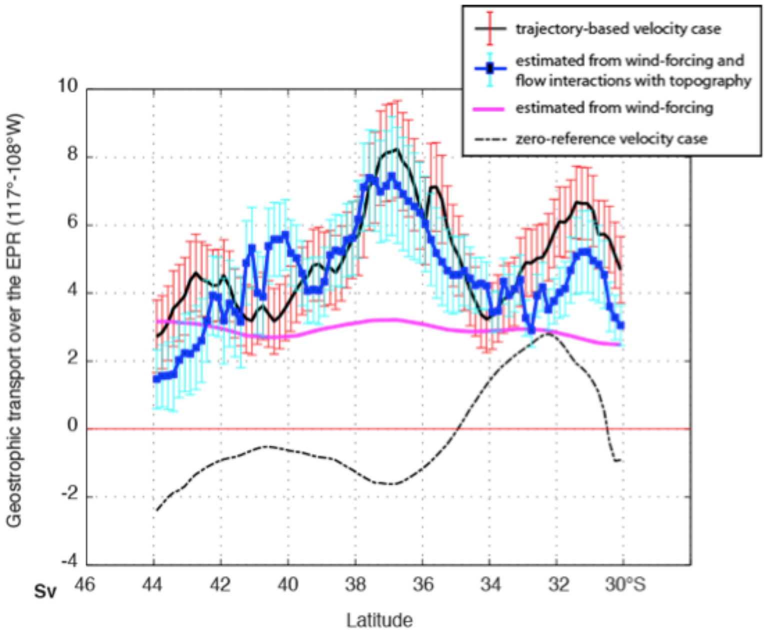
Transport at 1000 m differs when trajectories are used





Zilberman, Roemmich, Gille, in prep, 2015

Classic wind-driven Sverdrup balance augmented with bottom torque



Zilberman, Roemmich, Gille, in prep, 2015

- Transport from temperature/salinity profiles alone (black) nothing like transport referenced with trajectories (red).
- Classic Sverdrup balance (magenta) matches neither.
- Adding bottom torque (blue) implies agreement within error bars.
- East Pacific Rise Current new, not previously identified. Robust impact on global meridional transport.
- Expect other mid-ocean ridges to support similar current structures.

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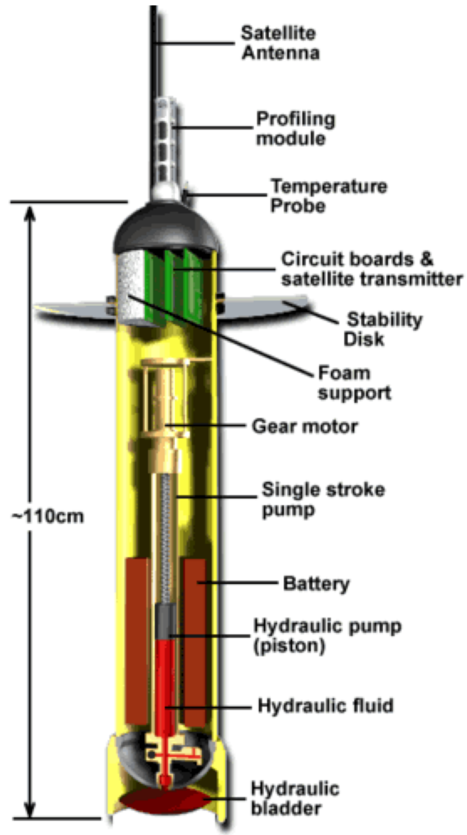
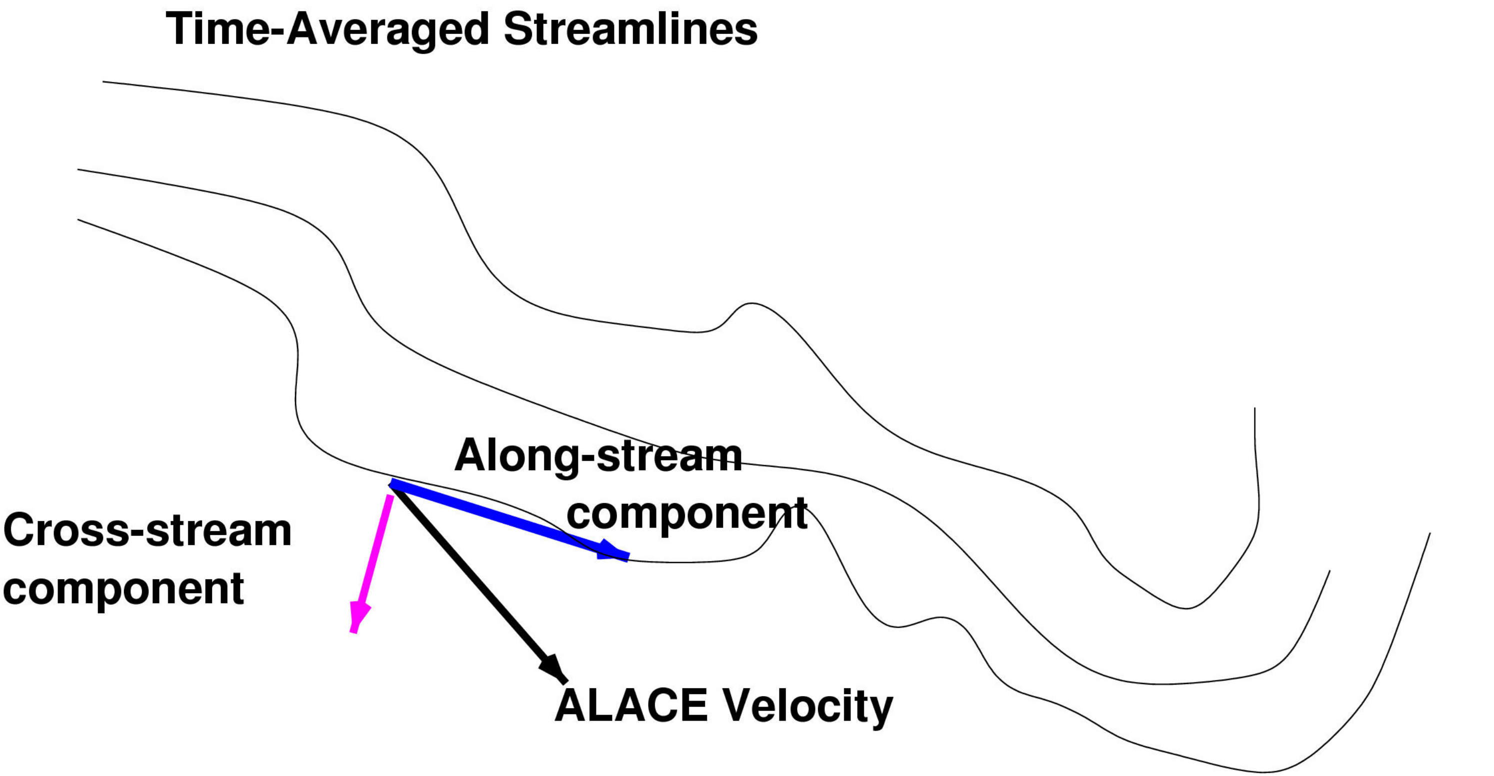


Can we evaluate eddy variability?

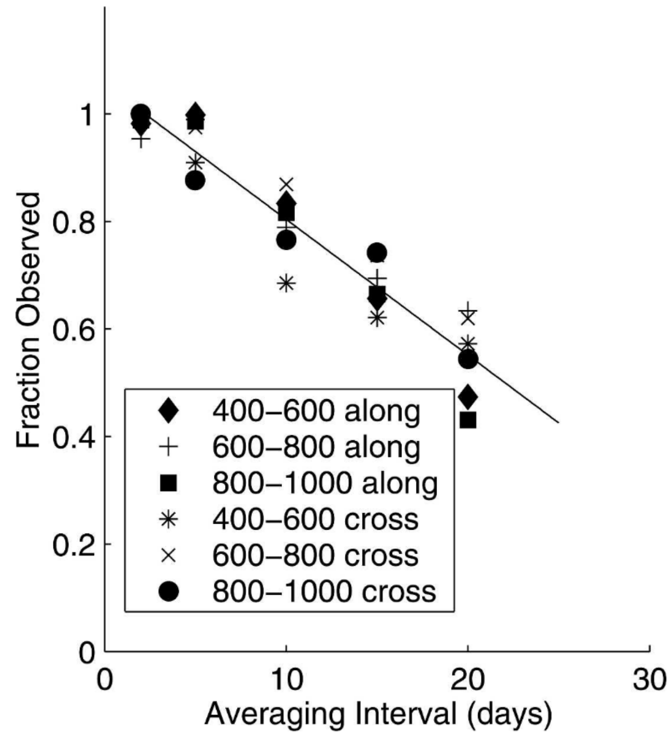
$$\overline{\frac{\partial T}{\partial t}} + \nabla \cdot (\overline{\mathbf{u}}\overline{T}) + \nabla \cdot (\overline{\mathbf{u}'T'}) = \text{forcing}$$

Estimate: $\overline{v'T'}$ from float data



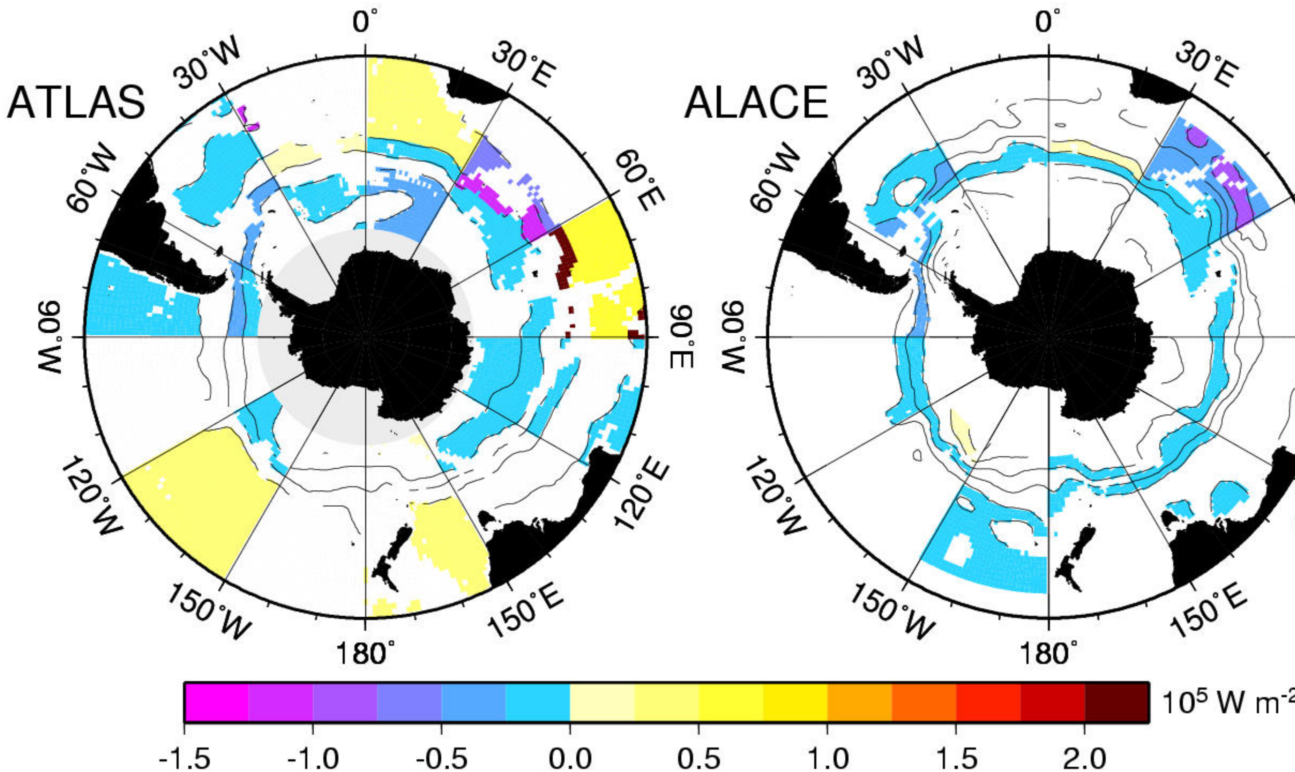
Missing high-frequency component

- Floats measure $\overline{v'}_{\text{10 days}}$ and $\overline{T'}_{\text{10 days}}$.
- We want $\overline{v'T'}_{\text{10 days}}$. What have we lost?



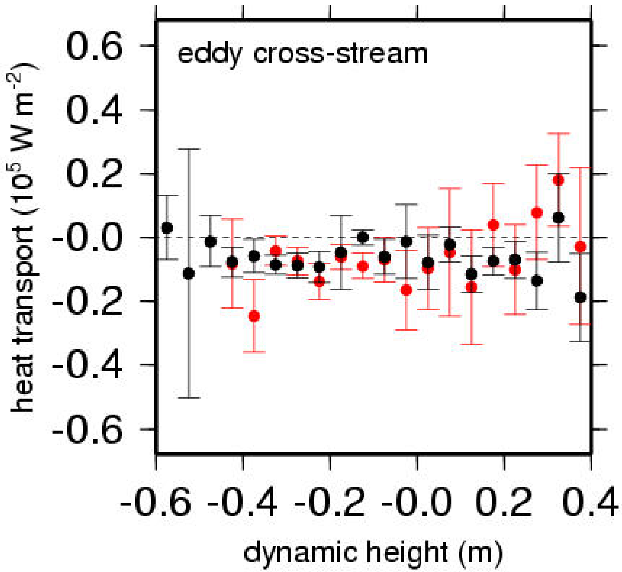
Chinn and Gille, JTech, 2007

Geographic distributions: Meridional heat flux



Gille, JPO, 2003

Along-stream averages: Net meridional heat flux



Total heat flux at 900 m: 4.7 to 7.5 kW/m^2.

Implies 0.3 PW heat loss to atmosphere south of ACC.

Temperature change at 900 m in 50 years: $> 2^\circ$ C.

Gille, JPO, 2003; see also Gray and Riser, in prep

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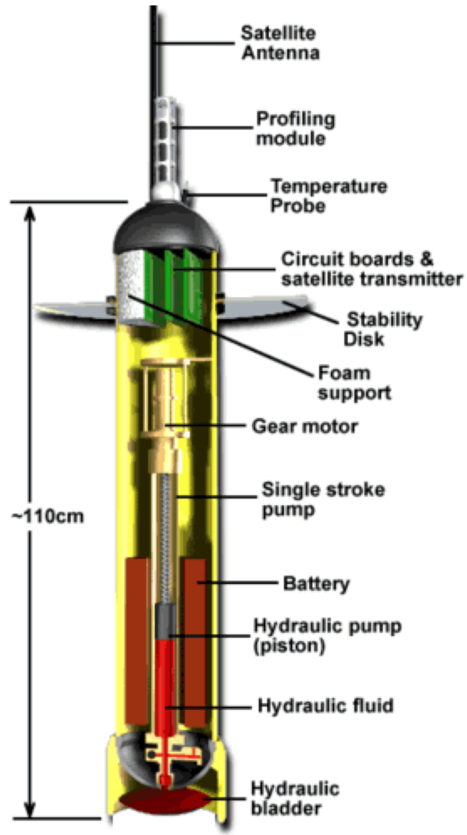
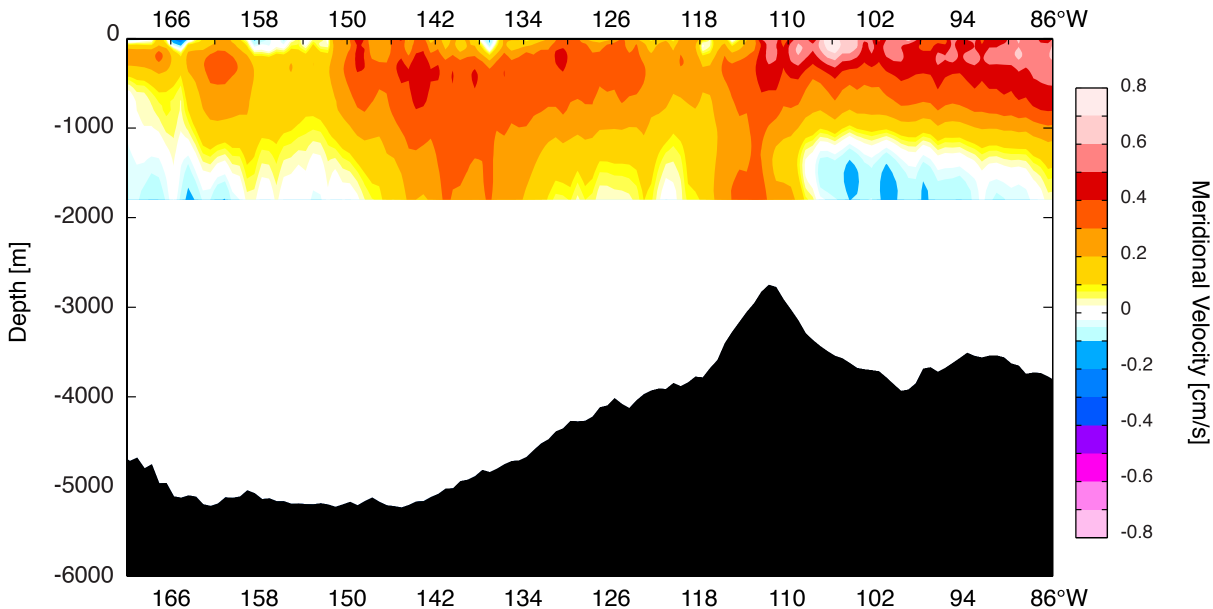
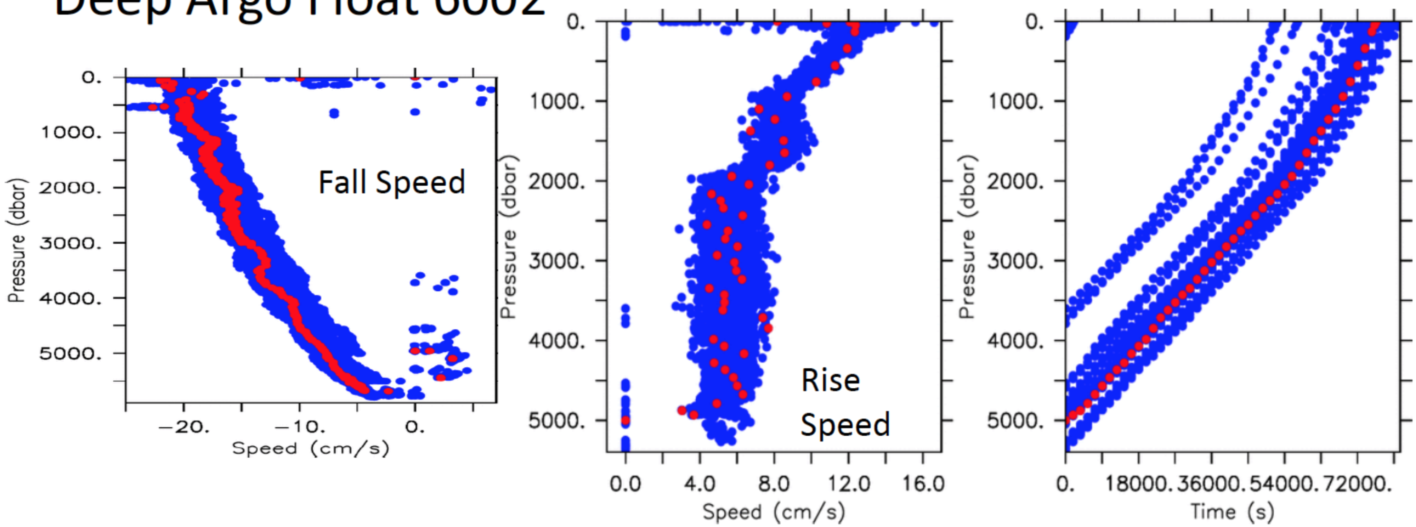


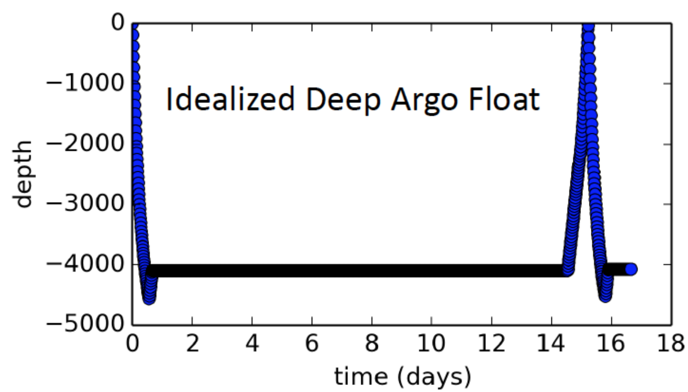
Planning for future deployments



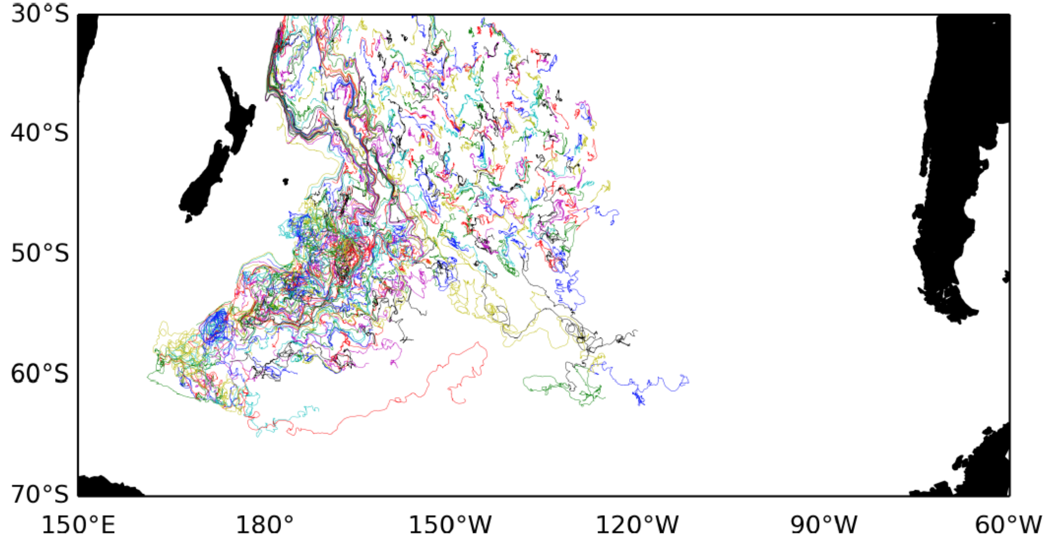
- Upper 2000 m of ocean well sampled by Argo, but deep ocean is a data void.
- Deep Argo will help to fill gaps, albeit at higher cost.
- Sampling strategy will require planning.

Deep Argo Float 6002

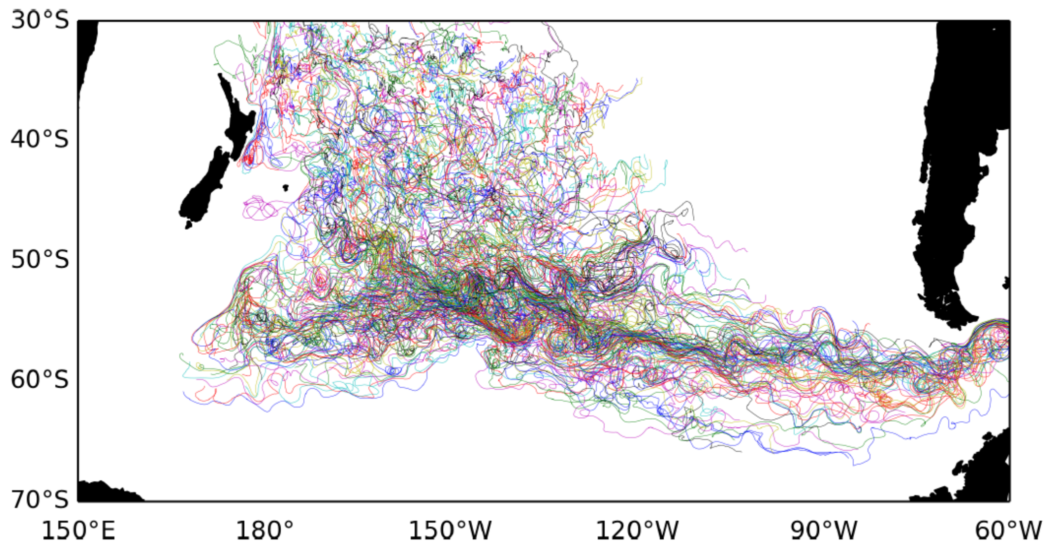




Parking depth
500 m above
seafloor



Parking depth
1000 m below
surface



Summary

- Argo has transformed physical oceanography mostly because of T/S measurements.
- Argo trajectories are latecomers to the Argo data stream but good constraints on reference velocities.
- However, Argo trajectories are difficult to interpret as Lagrangian measurements.
- Lagrangian methods will be useful in planning future Argo deployments, for Deep Argo, Core Argo, and other Argo-related programs.

Deep SOLO Float deployment, R/V Tangaroa, June 2014, south-west Pacific