STATMOS-SIO Workshop on Argo Data Statistics
At Scripps Institution of Oceanography, La Jolla, CA
April 25-27 (Tuesday-Thursday), 2017: 9:30am-6pm

Open problems for discussion and possible approaches to solutions

Problem 1: Map flow data with pressure information under geostrophic flow conditions or full OCGM conditions (Oceanographers: Sarah Gille *[lead]*, Donata Giglio, Megan Scanderbeg, Matt Mazloff, Nathalie Zilberman, Breck Owens)

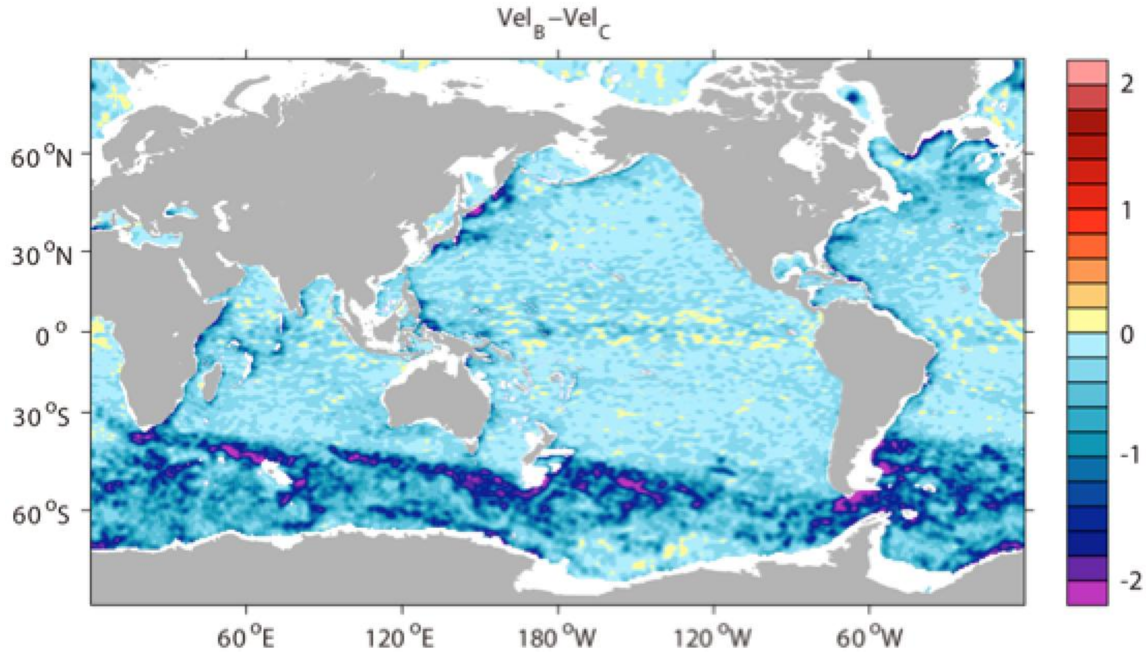
One of the challenges in working with Argo trajectory data comes in figuring out how best to map the data. Argo trajectories are computed from the 10-day displacements, so they represent time-averaged velocities. Oceanographers often use trajectory information to map pressure fields by assuming non-divergent or geostrophic flow (i.e. pressure gradient is balanced by the Coriolis force, with zero total derivative of velocity respect to time), mathematically described below

fv = 1/rho dp/dx
fu = -1/rho dp/dy

Here u and v are velocities, f is the Coriolis parameter, rho is density, and p is pressure at a fixed depth. In the kriging algorithm, the fu and fv terms are linked together to map pressure. This mapping approach requires that we address a number of details, and, if possible, explicitly account for them in the mapping algorithm. The issues are:

a) Uncertainty in the prescribed decorrelation structure for pressure;
b) Argo position uncertainty is variable, the biggest difference and being far less accurate in the pre-Iridium satellite communication years of the Argo program;
c) Trajectories may be biased due to Argo floats displacing horizontally as they rise and fall;
d) Acceleration over the 10-day trajectory may introduce a bias. New model results suggest that eddies tend to drive floats into faster currents. The figure below is produced using numerical floats deployed in the ECCO model and shows that on average floats are in slower moving water at the start of their 10-day displacements than at the end of 10-day displacements. (This effect implies a possible sampling bias, that might be small compared with other effects such as tides or turbulent motions not captured in the model but might nonetheless be worth considering in accounting for mapping bias.)
e) In the long-term floats may under-sample strong flows. Over long time periods, Davis (1991) suggests that the mean flow advects floats out of regions of strong currents, potentially resulting in an under-sampling of strong currents (or a gradient in the concentration of floats.)

Figure: Average difference between float speed at the start of 10-day trajectory and float speed at the end of 10-day trajectory, computed for a large ensemble of numerical floats advected by velocity fields from the ECCO (Estimating the Circulation & Climate of the Ocean) assimilating global ocean model. Color bar indicates speed difference in units in cm/s. From Tianyu Wang et al, in prep.



References:

Bretherton, F. P., R. E. Davis, and C. B. Fandry, 1976: A technique for objective analysis and design of oceanographic experiments applied to MODE-73. *Deep-Sea Res.*, 23, 559–582.

Davis, RE. 1991. Observing the General-Circulation with Floats. *Deep-Sea Research Part a-Oceanographic Research Papers*. 38:S531-S571. 10.1016/S0198-0149(12)80023-9

Gille, S. T., 2003. Float observations of the Southern Ocean: Part 1, Estimating mean fields, bottom velocities, and topographic steering, *J. Phys. Oceanogr*, **33**, 1167-1181.

Gray, A. R., and S. C. Riser (2014), A global analysis of Sverdrup balance using absolute geostrophic velocities from Argo, *J. Phys. Oceanogr.*, 44, 1213-1229.

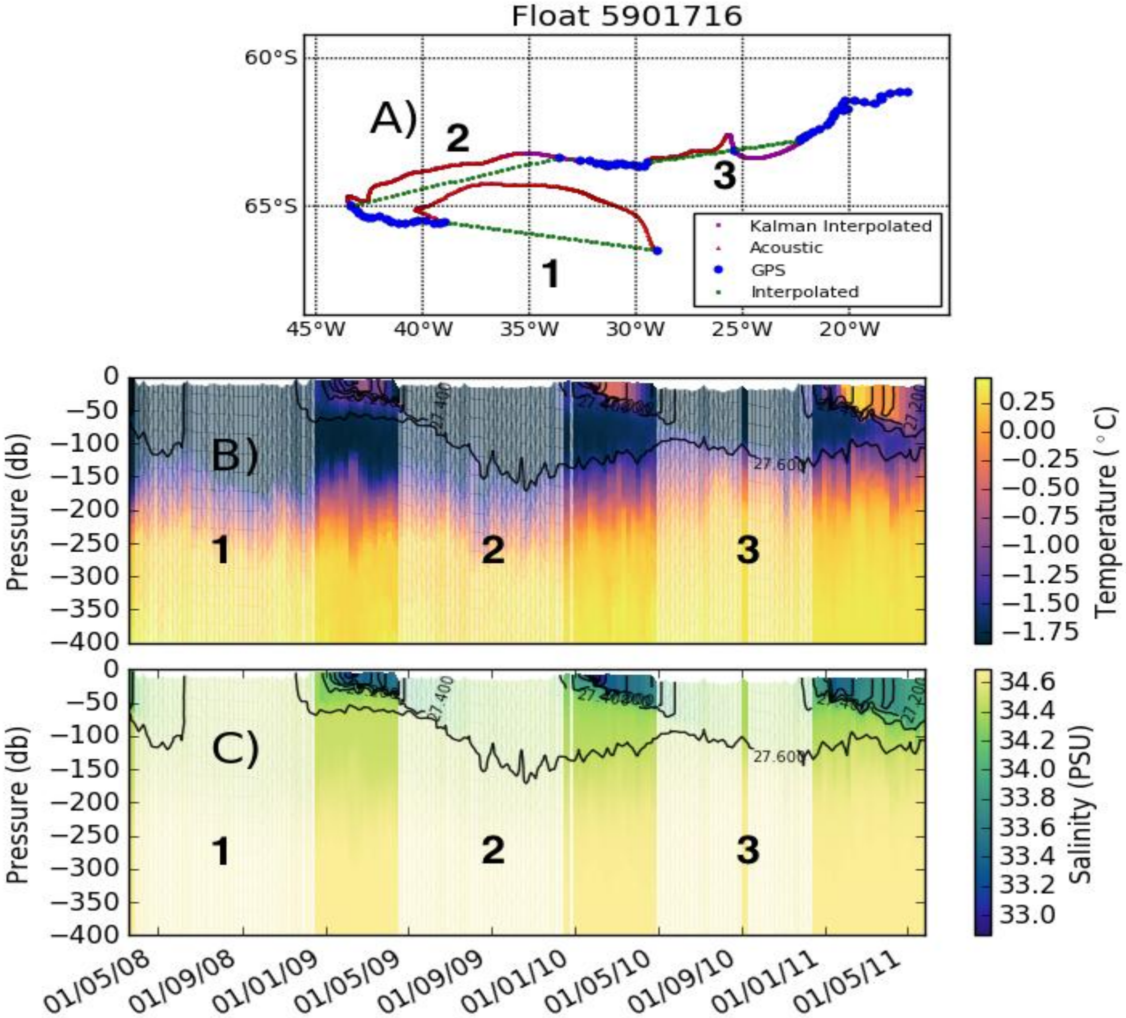
Zilberman, N., D. Roemmich, S. T. Gille, 2017. The East Pacific Rise Current: Topographic enhancement of the interior flow in the South Pacific Ocean, *Geophys. Res. Lett.*, **44**, 277-285, doi:10.1002/2016GL069039.

Possible statistical methods:

kriging/mapping algorithms, and estimation of spatio-temporal decorrelation

Problem 2: Path determination of the under-ice Argo motion (Oceanographers: Paul Chamberlain *[lead]*, Matthew Mazloff, Sarah Gille, Lynne Talley)

Increasingly, scientists who wish to understand under-ice dynamics are deploying Argo type profiling floats in the marginal sea ice zone. When floats profile under sea ice, the float antenna does not emerge from the surface of the ocean and they are not able to receive a GPS position fix. In the Southern Ocean, there are 10591 temperature-salinity profiles without position information from almost 218 Argo floats over 10 years. The Figure below shows Argo history and Argo interpolation. These data represent 9 % of the total Argo Southern Ocean dataset south of 55 S. What should we do with these data? Current practice is to linearly interpolate between known positions. Floats do not follow along these straight paths. Then what is the induced measurement uncertainty in assigning position in this way?



References:

Ninove et al. (2016): Spatial scales of temperature and salinity variability estimated from Argo observations

Wong and Riser (2011): Profiling float observations of the upper ocean under sea ice off the Wilkes Land Coast of Antarctica

Klatt et al. (2007) A profiling float's sense of ice

Possible methods:

a. Correlation analysis

b. Stochastic analysis

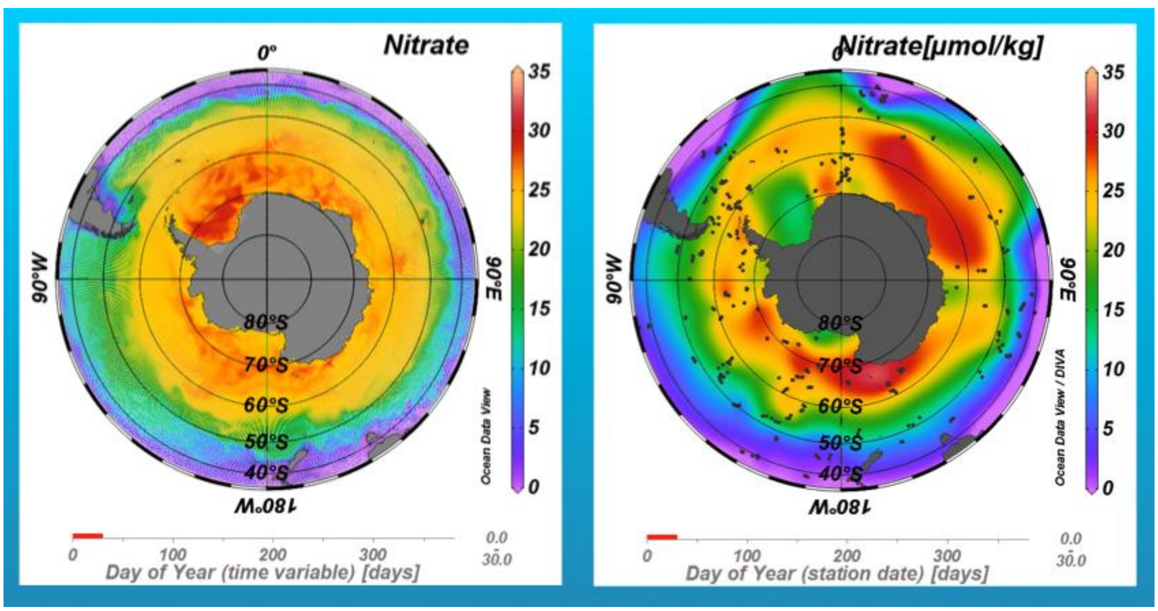
Problem 3: Develop reliable nitrate maps from sparse SOCCOM data using less computationally intensive statistical method (Oceanographers: Matt Mazloff *[lead]*, Sarah Gille, Ken Johnson, Bob Key)

The Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM, https://soccom.princeton.edu/) project is a multi-year NSF-supported initiative to deploy approximately 200 biogeochemical Argo floats in the Southern Ocean. In addition to standard Argo variables (temperature and salinity) the floats also measure nitrate, pH, dissolved oxygen, and fluorescence/backscatter. Since SOCCOM floats are sparsely distributed compared with core Argo floats, they pose additional mapping challenges. One strategy for working with sparse data is to assimilate them into a biogeochemical version of the Southern Ocean State Estimate (e.g. using 4-dimensional variational assimilation). However, there is value in developing less computationally intensive strategies for mapping data.

As an example, initial maps of nitrate have been developed using Data-Interpolating Variational Analysis (DIVA), which is readily accessible within the oceanographic data visualization package Ocean Data View (ODV). A better strategy might build from a prior and take advantage of correlations of nitrate with temperature and salinity, perhaps using multivariate empirical orthogonal functions. Our goal is to obtain a data-based strategy for mapping nitrate, pH, and surface oxygen concentration for the Southern Ocean, and to ensure that the methodology can be extended to other biogeochemical variables and to other geographic regions once biogeochemical floats are deployed globally.

The figure below is a snapshot of an animation to visualize the nitrate evolution in SOSE vs mapped SOCCOM-Argo data.

Figure: Screenshot from the animated gifs of surface nitrate from (Left) the B-SOSE 4D-Var assimilation (umol/L) and from (Right) the Ocean Data View DIVA gridding process (umol/kg).



References

Ocean Data View Reference Guide, Version 4.7.7, 2016.
https://odv.awi.de/fileadmin/user_upload/odv/misc/odv4Guide.pdf

Troupin, C., Barth, A., Sirjacobs, D., Ouberdous, M., Brankart, J. M., Brasseur, P., Rixen, M., Alvera-Azcárate, A., Belounis, M., Capet, A., Lenartz, F., Toussaint, M. E., and Beckers, J. M.: Generation of analysis and consistent error fields using the Data Interpolating Variational Analysis (DIVA), Ocean Model., 52–53, 90–101, doi:10.1016/j.ocemod.2012.05.002, 2012.

Possible methods:

a. Kriging
b. Multivariate regression
c. Multivariate empirical orthogonal functions

Problem 4: Map flow fields with proper constraints (Oceanographers: Breck Owens *[lead]*, Bruce Cornuelle)

[A brief outline is below and more details will be provided soon]

a) Development of possible forms for the a priori statistics that can be used to map various properties of the flow field.
b) Expanded version of OI that includes adding soft constraints in the mapping procedure. For example, Owens et al. investigated the best way to impose the no-flow boundary conditions when mapping the velocity field. They also developed the procedure to carry out the mapping including Argo, SSH, drifters and the wind field. This means that one does not have to prescribe a relationship with the wind field beforehand, but one can use OI to combine different fields.

References

McWilliams, J. C., W. B. Owens, and B.-L. Hua, 1986. An objective analysis of the POLYMODE Local Dynamics Experiment, I. General formalism and statistical model selection. *Journal of Physical Oceanography*, **16**(3), 483–504.