# INVESTIGATING SMALL-SCALE PROCESSES FROM AN ABUNDANCE OF AUTONOMOUS OBSERVATIONS

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## ABSTRACT

Small-scale processes, those with spatial and/or temporal scales less than a few hundred kilometers and a few weeks, can be investigated on global and decadal scales from autonomous observations collected through dedicated global-scale programs or the collective dataset of individual regional campaigns. The specific processes that can be investigated are determined by the minimum scale sampled by each autonomous platform. Recent examples are highlighted, and the future potential is discussed.

## INTRODUCTION

Autonomous platforms sample a range of horizontal and temporal scales regardless of whether they are utilized for short-term localized studies, regional studies, or decadal-scale global studies. Spatially, observations span from the submesoscale or mesoscale in the horizontal to the regional or global scale of interest. Temporally, observations span from hourly to weekly timescales at a minimum to several months or, increasingly, more than a decade at a maximum. Data collection is often motivated by larger-scale phenomena, whether regional or global in nature, and the smaller-scale phenomena that are also observed are frequently removed or smoothed. Increasingly, smaller spatial or temporal scale phenomena are being investigated, and the potential to investigate such processes on the regional to global scale or seasonal to decadal scale should not be overlooked in the future.

Investigating global / decadal scale variations in smaller-scale processes requires a large amount of data. Global-scale programs have collected enough data through operations over multiple years. Such datasets are appealing for this purpose as data coverage is somewhat uniform in space and time. Regional-scale programs will continue to build up sufficient data through the combined dataset of a particular platform (e.g., all glider data). While coverage is certainly not uniform in space or time, and is often biased towards dynamically interesting regions, investigating dependence on parameters of interest (e.g., latitude, background stratification) is feasible.

## MINING SMALL-SCALE PROCESSES

The specific small-scale processes that can be investigated are determined by the minimum scale at which platforms sample. This minimum scale varies by platform: for example, one hour for drifters (Lumpkin and Pazos, 2007), a few hours and a few kilometers for gliders (Rudnick et al., 2004; Rudnick 2016) and Ice-Tethered Profilers (Toole et al., 2011); 10 days and typically 10s of kilometers for Argo floats (for standard operation; Roemmich et al., 2009). With profiling platforms, the vertical resolution can also be a determining factor, with minimum vertical resolutions ranging from 0.25 m for Ice-Tethered Profilers to 10 m or more for the standard operation of Argo floats.

One example is illustrated here: Argo float data have been used to investigate mesoscale stirring and horizontal eddy diffusivity on a global scale (Cole et al., 2015; Figure 1). By combining the entire Argo database, a typical 3° grid box has more than 100 profiles collected over a range of seasons and years, which is sufficient to investigate mesoscale variability. The Argo program measures two key components needed to estimate eddy diffusivity: the fluctuations of temperature and salinity along a density surface and within a grid-box, and the large-scale horizontal temperature and salinity gradient; eddy kinetic energy estimated from ECCO-2 is also utilized. Eddy diffusivity was found to vary significantly with depth and geographic location with the largest values in strong current regions (Figure 1); diffusivity at depth in particular is not easily estimated on a global scale from other observations.

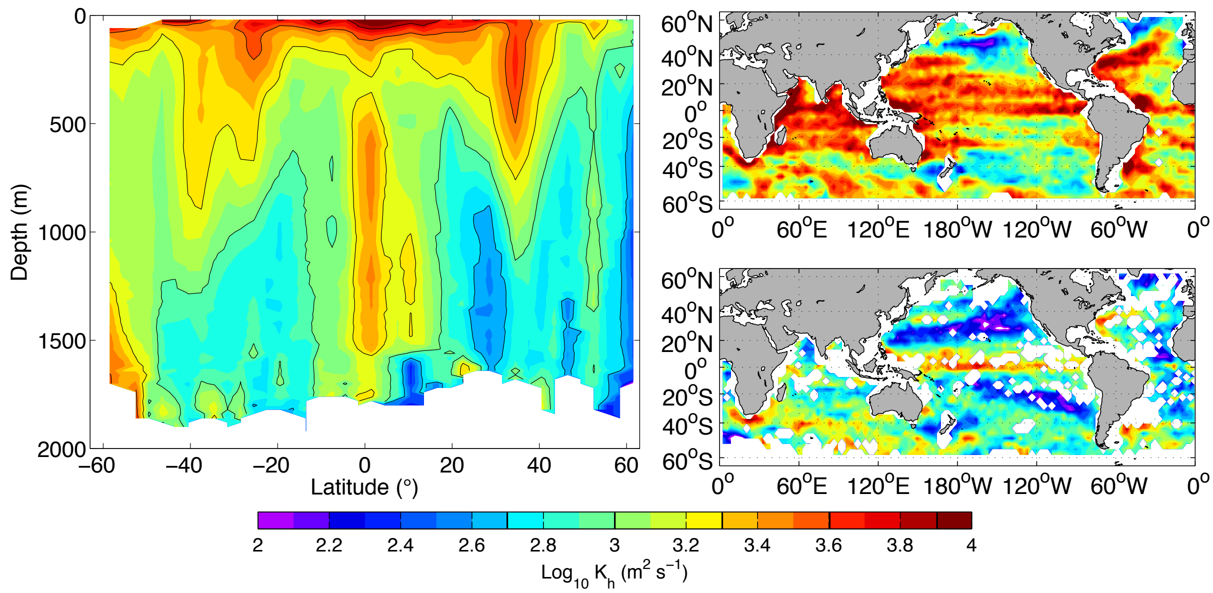


*Figure 1. Horizontal eddy diffusivity derived from Argo float temperature and salinity profiles and ECCO-2 eddy kinetic energy (Cole et al., 2015). LEFT: Zonally averaged with the 500, 1000, 2000 and 4000 $m^2$ $s^{-1}$ contours in black. RIGHT: At the base of the winter mixed layer (top) and 1000 m depth (bottom).*

Many different studies have addressed smaller-scale processes by combining multiple years of autonomous observations on the regional and global scale. On sub-daily temporal scales, the global drifter dataset has quantified near-inertial and tidal surface currents (Poulain and Centurioni, 2015; Elipot et al., 2016). Internal wave energy, also at the near-inertial and tidal frequencies, has been investigated on a regional scale from glider data (e.g., Johnston and Rudnick, 2015) and Ice-Tethered Profiler data (Dosser and Rainville, 2016), and on the global scale from Argo floats (Whalen et al., 2012). Mesoscale and submesoscale processes have also been studied individually in such regional datasets (e.g., Cole and Rudnick, 2012; Zhao et al., 2016) as well as in global datasets (e.g., Zhurbas et al., 2014; Cole et al., 2015). Spatial modulations in double-diffusive staircases, a small-scale process in the vertical, have been quantified in the Arctic Ocean from Ice-Tethered Profilers (Shibley et al., 2017). While investigations of such processes are not exclusive to autonomous platforms, they are growing increasingly common and feasible, and show larger-scale modulations in smaller-scale processes that are only possible from such large datasets.

## FUTURE POTENTIAL

Improvements in technology will allow for finer resolution and investigation of increasingly smaller-scale processes. Finer temporal, horizontal, or vertical resolution will result from cheaper platforms that increase the number of platforms deployed, increased battery life, and/or increased ease of data telemetry.

Increasing amounts and types of data collected will allow for more detailed investigations of many processes. As biogeochemical observations become more routine, they allow for studies of biogeochemical specific processes, as well as physical processes for which such observations serve as a maker (e.g., of eddy stirring). Turbulent scale processes can be directly observed from autonomous platforms, and the growing collection will lead to its study on larger scales. The range of temporal scales will also expand beyond decadal, providing a more detailed look at interannual variability of small-scale phenomena.

Access to autonomous observations is a key component for the feasibility of such future studies. This is especially true for those platforms that do not have routine global-scale coverage, but are instead composed of numerous regional studies throughout the global ocean.

**REFERENCES**


Cole, S. T., and D. L. Rudnick, 2012: The spatial distribution and annual cycle of upper ocean thermohaline structure, *J. Geophys. Res.*, 117, C02027, https://doi.org/10.1029/2011JC007033.

Cole, S. T., C. Wortham, E. Kunze, and W. B. Owens, 2015: Eddy stirring and horizontal diffusivity from Argo float observations: Geographic and depth variability, *Geophys. Res. Lett.*, 42, 3989-3997, https://doi.org/10.1002/2015GL063827.

Dosser, H. V., and L. Rainville, 2016: Dynamics of the changing near-inertial internal wave field in the Arctic Ocean, *J. Phys. Oceanogr.*, 46, 395-415, https://doi.org/10.1175/JPO-D-15-0056.1.

Elipot, S., R. Lumpkin, R. C. Perez, J. M. Lilly, J. J. Early, A. M. Sykulski, 2016: A global surface drifter data set at hourly resolution, *J. Geophys. Res.*, 121, 2937-2966, https://doi.org/10.1002/2016JC011716.

Johnston, T. M. S., and D. L. Rudnick, 2015: Trapped diurnal internal tides, propagating semidiurnal internal tides, and mixing estimates in the California Current System from sustained glider observations, 2006-2012, *Deep Sea Res. II*, 112, 61-78, https://doi.org/10.1016/j.dsr2.2014.03.009.

Lumpkin, R., and M. Pazos, 2007: Measuring surface currents with Surface Velocity Program drifters: the instrument, its data, and some recent results. Chapter 2 of 'Lagrangian analysis and prediction of coastal and ocean dynamics', ed. A Griffa, A. D. Kirwan, A. Mariano, T. Ozgokmen, and T. Rossby, Cambridge University press.

Poulain, P.-M., and L. Centurioni, 2015: Direct measurements of World Ocean tidal currents with surface drifters, *J. Geophys. Res.*, 120, 6986-7003, https://doi.org/10.1002/2015JC010818.

Roemmich, D., G. C. Johnson, S. Riser, R. Davis, J. Gilson, W. B. Owens, S. L. Garzoli, C. Schmid, and M. Ignaszewski, 2009: The Argo program: Observing the global ocean with profiling floats, *Oceanogr.*, 22, 34-43, https://doi.org/10.5670/oceanog.2009.36.

Rudnick, D. L., R. E. Davis, C. C. Eriksen, D. M. Fratantoni, and M. J. Perry, 2004: Underwater gliders for ocean research, *Marine Tech. Soc. J.*, 38, 73-84, https://doi.org/10.4031/002533204787522703.

Rudnick, D. L., 2016: Ocean research enabled by underwater gliders, *Ann. Rev. Marine Sci.*, 8, 519-541, https://doi.org/10.1146/annurev-marine-122414-033913.

Shibley, N., M.-L. Timmermans, J. R. Carpenter, and J. Toole, 2017: Spatial variability of the Arctic Ocean's double-diffusive staircase, *J. Geophys. Res., in press*.

Toole, J. M., R.A. Krishfield, M.-L. Timermans, and A. Proshutinsky, 2011: The Ice-Tethered Profiler: Argo of the Arctic, *Oceanogr.*, 24, 126-135, https://doi.org/10.5670/oceanog.2011.64.

Whalen, C. B., L. D. Talley, and J. A. MacKinnon, 2012: Spatial and temporal variability of global ocean mixing inferred from ARGO profiles, *Geophys. Res. Lett.*, 39, L18612, https://doi.org/10.1029/2012GL053196.

Zhao, M., M.-L. Timmermans, S. Cole, R. Krishfield, and J. Toole, 2016: Evolution of the eddy field in the Arctic Ocean's Canada Basin, 2005-2015, *Geophys. Res. Lett.*, 43, 8106-8114, https://doi.org/10.1002/2016FL069671.

Zhurbas, V., D. Lyzhkov, and N. Kuzmina, 2014: Drifter-derived estimates of lateral eddy diffusivity in the World Ocean with emphasis on the Indian Ocean and problems of parameterization, *Deep Sea Res. I*, 83, 1-11. https://doi.org/10.1016/j.dsr.2013.09.001.