THE OFFICIAL MAGAZINE OF THE OCEANOGRAPHY SOCIETY

Oceanography

CITATION

ten Doeschate, A., G. Sutherland, L. Esters, D. Wain, K. Walesby, and B. Ward. 2017. ASIP: Profiling the upper ocean. Oceanography 30(2):33–35, https://doi.org/10.5670/oceanog.2017.216.

DOI

https://doi.org/10.5670/oceanog.2017.216

ASIP: Profiling the Upper Ocean

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INTRODUCTION

To quote pioneering quantum physicist Wolfgang Ernst Pauli: "God made the bulk, surfaces were invented by the Devil" (Schroeder, 1991). Although it is not known whether this Austrian-Swiss professor was referring to the sea surface, many ocean scientists studying the air-sea interface would agree with him.

Fluxes of heat, energy, and trace gases between the atmosphere and the ocean are controlled by the dynamics of the air-sea interface and the layer below it. This layer, which responds to atmospheric forcing, is often referred to as the ocean surface boundary layer (OSBL). Roughly covering the upper 100 m of the ocean, the OSBL has a near-uniform density as a result of turbulent mixing through convective and wind-driven shear instabilities, Langmuir circulations, breaking waves, and the convergence of advected fronts. Below the depth of this well-mixed layer, the OSBL is capped by a sharp pycnocline, which separates it from the deep ocean. The depth of the mixed layer is variable and does not always correspond to the depth of active mixing, making the definition of the OSBL somewhat ambiguous. Day-night differences in atmospheric forcing, as well as weather events, cause density variability and an intermittency between stratification and active mixing at diurnal frequencies within the remnant mixed layer.

To quantify the air-sea fluxes of mass and energy, it is essential to understand the evolution of the OSBL. Simultaneous observations are needed of microstructure, rapid fluctuations in turbulence and scalars near the ocean surface, and the overall structure and depth of the mixed layer. Although advances in satellite remote sensing provide global coverage of many oceanic variables, these observations penetrate only a few centimeters into the OSBL, are lateral averages of O(1 km), and cannot capture variability at higher frequencies than the satellite crossings. High-frequency scalar variability in the near surface of the OSBL also remains relatively undersampled by in situ measurements from ships, as data collected in the upper 10 m may be contaminated by the ship's propulsion and wake. Most Argo profiling floats cease sampling at a few meters below the surface to prevent air entering their pumped conductivity sensor. In addition, few measurements of turbulence in the near-surface layer exist. Measuring turbulence requires sensors capable of measuring microstructure that can be mounted on a steadily moving, autonomous platform. Sea gliders equipped with such sensors have proven useful for this in the ocean interior, but few reliable measurements of near-surface turbulence have been published.

Here, we describe the Air-Sea Interaction Profiler (ASIP), an oceanographic instrument designed to contribute to filling this gap in the observational record. Developed by author Brian Ward and based at the Air-Sea Laboratory of the National University of Ireland Galway (https:airsea.nuigalway.ie), ASIP has been deployed in many oceanographic campaigns over the past decade.

ASIP

ASIP is a vertical, free-rising, autonomous, microstructure profiler. On its upward-facing side, the profiler is equipped with a suite of microstructure sensors. Two airfoil shear probes (SPM38) measure the velocity microstructure of two orthogonal components of the horizontal velocity. The turbulent kinetic energy (TKE) dissipation rate ε is derived through spectral analysis of the velocity microstructure measurements. This rate is expected to be equal to the production rate of TKE in a natural flow. A dual pin microconductivity sensor (SBE7) is mounted next to an FP07 thermistor whose shaft is tilted such that the tip of the sensor is positioned close to the microconductivity probe. This combination of sensors is used to measure salinity. A second microstructure temperature sensor is added for redundancy. A slow-response CT instrument with long-term sensor stability is attached to the side of the profiler to provide calibration of the scalar microstructure sensors in situ. A fast responding pressure transducer (Keller) is used to obtain accurate depth readings, and ASIP's orientation is tracked both with accelerometers and with a full motion package. A photosynthetically active radiation (PAR) sensor (LI-COR) and an oxygen sensor (Aanderaa) are usually also mounted on ASIP.

With its 2.8 m length and approximately 90 kg of weight in air, ASIP is "a bit of a beast." The fragile parts are exposed on the top of the profiler, and, though surrounded by a guard, deployment and recovery of the instrument remain somewhat risky. It has become practice to deploy ASIP from a small boat (see Figure 1) some distance away from the ship, which places some limitation to the sea states in which the profiler can be deployed and recovered.

To produce a profile, ASIP first descends by means of three thrusters to a programmed depth (maximum depth rating: 100 m). When the thrusters switch off, the instrument rises under its own buoyancy at a constant rise velocity of ~0.5 m s^{-1}. This choice of profiling speed is a compromise between the frequency response limitations of the thermistor and the output signal of the shear probe, which increases linearly with profiling speed. Data are logged during both the downward and upward profile; however, to avoid contamination from the wake and vibration caused by the thrusters, only turbulence measurements of the upward profile are used. The uncertainty in the sea surface level is of O(10^{-2} m), corresponding to the spatial response of the microconductivity sensor used for surface determination.

ASIP has battery capacity for a total of 6,000 m of profiles per deployment. Depending on the focus of the experiment, ASIP can be programmed to profile a few times per hour from the surface to below the mixed layer, or to shallower depths at a higher frequency, to improve the statistical robustness of turbulence measurements. It can be in a low-power standby mode for several days.

After each profile, ASIP extends its antenna to get a GPS fix and send a message containing its position and battery status to the research vessel via Iridium satellite communication. Simple mission commands, to change the target depth or number of profiles, or to pause or abort profiling, can be communicated from the ship to ASIP. For more details about the technology and data processing, see Ward et al. (2014).

OBSERVATIONS

Temperature and conductivity profiles collected by ASIP at 1 cm resolution, with ε resolved over 25 cm depth bins, offer extensive operational capability for observing the vertical structure of the full OSBL up to subskin level. In combination with good quality measurements of local meteorological conditions, near-surface currents, and waves, the ASIP profiles are of great value to the investigation of the upper ocean's response to atmospheric forcing conditions.

Most recently, ASIP has been used in a study of the effects of mixing processes on cod eggs in a Norwegian fjord and the damping of waves by oil spills. In previous international campaigns (see Figure 1), data from ASIP have been used to study:

- The relationship between gas exchange (CO_2, dimethyl sulfide) and ocean turbulence (Esters et al., 2017)
- The scaling of waves and turbulence in the OSBL (Sutherland et al., 2013, 2014)
- Internal wave breaking in the Labrador Sea (Wain et al., 2015)
- Double diffusion at the base of a rain-induced fresh lens (Walesby et al., 2015)
- The effect of diurnal warming on near-surface turbulence in (sub)tropical ocean regions (Callaghan et al., 2014; Sutherland et al., 2016)
- Rain effects in the North Atlantic

To briefly expand on the last two projects, deployment of ASIP in (sub)tropical open ocean regions resulted in observations of complete diurnal cycles of temperature-driven near-surface stratification while also resolving the evolution of ε both in and below the mixed layer. Figure 2 shows the warming of the upper 20 m in the subtropical North Atlantic. A strong stabilizing buoyancy flux during moderate wind speeds (panel a) results in the formation of a shallow thermal stratification (b,c). The momentum flux from the wind is focused into this layer, causing an intensification of surface currents, referred to as the diurnal jet, as well as enhanced values of ε.

A similar response was observed during a rain event in the mid-latitude North Atlantic (panel 2e–h). The salinity anomaly (f) caused by the rain was observed to form a shallow stratification (g) with enhanced ε near the surface and reduced turbulence below the shallow pycnocline (h). An earlier rain event of higher intensity that coincided with increasing wind speeds did not produce the same level of stratification, illustrating the strong dependence of the ocean response on ambient meteorological conditions.

OUTLOOK

ASIP deployment has resulted in a substantial data set of upper ocean turbulence measurements. Efforts are ongoing to use these data for a comprehensive analysis that compares the observed ε under various forcing conditions to different scaling approaches.

Several modifications and add-ons have been made to ASIP in the 10 years of its operation, ranging from testing smaller and faster microstructure sensors, to get closer to the interfacial values of temperature and salinity, to installing a full holographic system for stereo imaging of suspended organic and inorganic particles in the water. A quantitative understanding of biophysical interactions in the OSBL is a field of research in which ASIP could play a role. The future may see a redesign of the profiler with the addition of bio-optical sensors and improved performance (for longer time series) and user friendliness.

FIGURE 1. World map showing the locations of Air-Sea Interaction Profiler (ASIP) deployments, their years, and the research vessels. Insert from left to right: ASIP on the deck of R/V *Thalassa*, a close-up of the top section of the profiler with the sensors surrounded by a guard, and the deployment of ASIP from a small workboat in Plymouth Sound in May 2014.

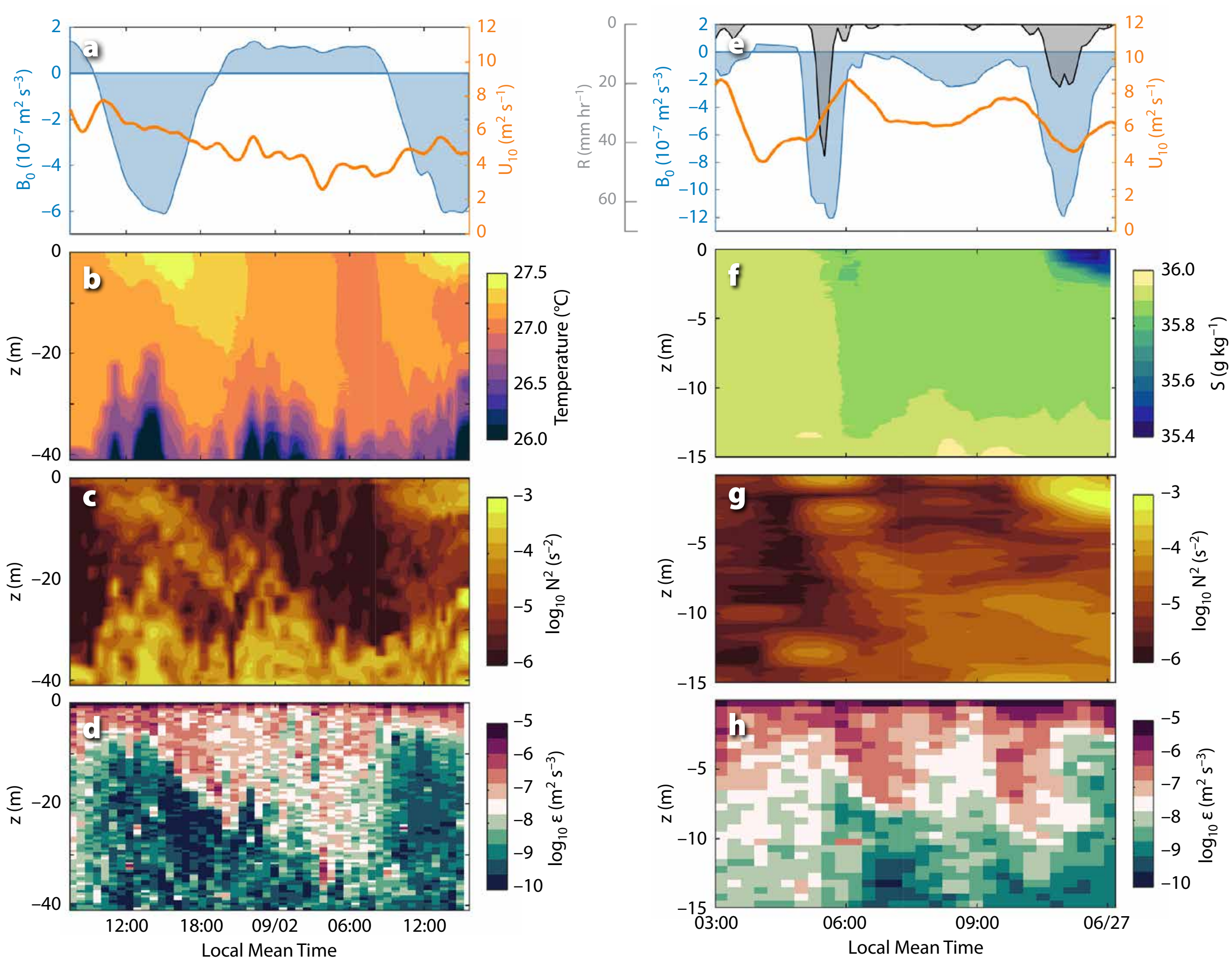

FIGURE 2. Time-depth composition of ASIP measurements from two separate cruises. The left column illustrates how diurnal warming of the upper ocean (b) creates a shallow stratification (c) in which turbulence gets trapped (d). The right column shows a similar reduction of the depth of mixing and increased turbulence (h) within a shallow, stratified layer of reduced salinity (f, g) following precipitation. Panels a and e show the surface buoyancy flux B_0, 10 m wind speed U_{10}, and rain rate R from observations made in the North Atlantic near 24.5°N, 38°W in 2012 (see also Sutherland et al., 2016) and 40.3°N, 59°W in 2011, respectively.

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ACKNOWLEDGMENTS

We thank everyone who has contributed to the development of the Air-Sea Interaction Profiler, as well as all funding bodies that contributed and/or continue to support research projects involving the profiler: Irish Research Council, US National Science Foundation, Norwegian Research Council, US Office of Naval Research-Global, NUIG College of Science, NUIG Ryan Institute.

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ARTICLE CITATION

ten Doeschate, A., G. Sutherland, L. Esters, D. Wain, K. Walesby, and B. Ward. 2017. ASIP: Profiling the upper ocean. *Oceanography* 30(2):33–35, https://doi.org/10.5670/oceanog.2017.216.