A role for surfactant composition in the air-sea exchange of climate-active gases (Ref IAP2-18-130)

Newcastle University, School of Natural and Environmental Sciences

In partnership with Heriot Watt University, School of Energy, Geoscience and Society

Supervisory Team

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Key Words

Air-sea gas exchange; Gas transfer velocity; Surfactants; Atlantic Ocean; FluxEngine

Overview

Predicting future ocean-atmosphere exchange of climate-active trace gases and hence their global effects on climate, relies on quantifying: (i) their sea-to-air concentration gradients (ΔC); and (ii) the gas transfer velocity (kw), a kinetic rate term driven by turbulence and related to diffusivity. ΔC can be directly measured but kw cannot, and its strong spatio-temporal variability makes it the greatest source of uncertainty in estimating air-sea trace gas fluxes [1,2]. Routinely scaling kw with wind speed (a major instigator of sea surface turbulence) gives divergent, non-linear relations for which only ~50% of data scatter is method-related [3]. More inclusive parameterisations are compromised by insufficiently characterised controlling variables [4]. Using field data and a custom-built experimental gas exchange tank [5] we recently showed how variability in the amount and chemical nature of dissolved organic matter (DOM) accumulating at the sea surface must exert strong kw control [6]. This DOM is largely composed of plankton- and bacteri-derived soluble and insoluble surfactants [7], including transparent exopolymer particles (TEP) [8], polysaccharides [9], lipid-like material [10,11], chromophoric dissolved organic matter (CDOM) [12] and amino acids [13]. Soluble surfactants are most important to air-sea trace gas exchange [14-16], suppressing kw through capillary-gravity wave damping and by modifying surface hydrodynamics [17-19]. Laboratory and field experiments show up to 50% kw suppression by surfactants [15,20]. Perhaps unsurprisingly, total surfactant activity (SA) correlates broadly with primary productivity indices, showing large spatio-temporal gradients [21]. Lower kw in the open ocean than in coastal waters reflects higher nearshore surfactant due to higher productivity [4] and/or large terrestrial surfactant sources [6]). Unique relationships between kw and SA, or between kw and either wind speed or capillary-gravity wave slope for surfactant covered waters however, remain elusive. This must reflect strong spatio-temporal gradients in total surfactant amount and the overall composition of the surfactant pool driving such seasonality.

This PhD studentship will advance our recent work that (i) mapped ocean basin scale surfactant distributions [6]; (ii) derived simple measures of surfactant pool composition from DOM properties (absorbance; fluorescence) [6]; and (iii) evaluated their effects on kw directly, using a custom-built gas exchange tank [22]. The proposed project builds on a previous NERC PhD and is entirely appropriate to this level. Our external collaborator (Dr J. Shutler, Associate Professor, University of Exeter) will train the student to use configurable software [FluxEngine; 23], see Methodology) to scale the data to estimate ocean basin wide suppression of kw by surfactant, and thereby derive surfactant modified trace gas fluxes at the regional-to-global scale.

Based in Newcastle, the student will undertake scheduled research visits to Heriot-Watt and Exeter. Under supervision, he/she will lead experimental design and execution, be responsible for relevant analyses, and participate in planned Atlantic Ocean research cruises negotiated through our existing links with the Atlantic Meridional Transect programme (AMT) and through the NERC CLASS initiative, which is a component of NERC National Capability. The student will benefit by working closely with a range of...
Studentship Objectives (see Methodology)

1. Measure SA, dissolved organic carbon (DOC), chlorophyll-a, CDOM absorbance, absorption ratio ($E_{250}/E_{365}$) and spectral slope ratio ($S_{275-295}/S_{350-400}$) in the Atlantic Ocean, to derive broad surfactant “compositional indices”.
2. Optimise size exclusion chromatography (SEC) to derive compound group specific “surfactant fingerprints” using samples selected under 1.
3. Carry out gas exchange tank experiments [5,22] at preselected levels of turbulence, along natural gradients in SA and surfactant composition determined according to 1 and 2.
4. Carry out further gas exchange experiments using artificial seawater augmented with (i) single surfactant compound “models” of the “fingerprints” identified in 2 above, to isolate their individual effects on $k_w$; and (ii) surfactants derived from single and mixed phytoplankton cultures, to isolate the effects of different surfactant producing species on $k_w$.
5. Use FluxEngine [23] to derive regional trace gas fluxes and “adjust” $k_w$ derived from 1-4, to identify how spatio-temporal variations in SA and surfactant composition impact $k_w$.

Methodology

Newcastle will provide the gas exchange tank [5,21] and existing facilities for routine SA, chlorophyll and CDOM related measurements (objectives 1 & 3). Heriot-watt will provide SEC “compound fingerprint” analyses, phytoplankton cultures and culture facilities (objectives 2 & 4). Our external collaborator (Dr J. Shutler, Associate Professor in Earth Observation, University of Exeter) will train the student to use FluxEngine. This is a fully configurable software package designed by Dr Shutler and colleagues, that allows user-selected inputs and parameterisations, e.g. of model derived gas transfer rates from wind speed and/or sea state, or from other user-defined data. Using these, FluxEngine derives $k_w$ and gas fluxes along cruise tracks from in situ data, or from synoptic scale estimates based on combinations of in situ data, satellite observations and model outputs. The student will derive local, regional and global reference $k_w$ data and trace gas fluxes by applying a widely used global $k_w$ algorithm (e.g. [24]) that lacks explicit surfactant control, covering the same periods as the data. The local and regional mean surfactant effect on $k_w$ derived from field/experimental data will be relative to this reference. Using FluxEngine to calculate regional fluxes with modified $k_w$ will allow estimates of bias in regional flux estimates derived without accounting for the effect of surfactants. Incorporating regional ranges of surfactant effects will allow estimates of scatter due to regional variations in SA and surfactant composition and enable direct comparison of the effect of $k_w$ suppression with the synoptic situation regionally and globally.

Timeline

This is a 3.5 year PhD studentship with an annual stipend at the RCUK rate. The anticipated start date is 01.10.2019. The student will be expected and encouraged to participate in appropriate training courses (see below) and contribute to IAPETUS led events such as the annual science conference organised by the student cohort.

Year 1:
- Carry out a literature review of the role of surfactants in air-sea gas exchange (effects on $k_w$) for a range of marine conditions.
- Meet with both supervisors to finalise PhD objectives and to identify potential cruise participation from year 2.
- Identify training needs beyond those offered by IAPETUS and the partners.
- Receive training in use of the gas exchange tank and the analysis of SA, CDOM and associated variables.
- Carry out initial coastal transect, “training” surveys off Newcastle, collecting surfactants for gas exchange experiments and for SA, CDOM, SEC analysis etc.
- Visit Heriot-Watt for familiarisation with the SEC technique and for analysing samples collected on coastal transects.
- Set up and run preliminary phytoplankton cultures, deriving samples for use in gas exchange tank experiments to isolate the effects of different surfactant producing phytoplankton species.
- Visit Exeter for FluxEngine discussions.

Year 2:
- Analyse the results collected during the coastal transect “training”.
- Participate in selected research cruises via AMT, the NERC CLASS programme and consider others opportunities if they arise.
- Continue culture/surfactant/gas exchange tank experiments.
- Meet with all supervisors to assess progress and plan for year 3.

Year 3/3.5:
Training & Skills

The supervisors and collaborator will provide full training in their individual expertise areas, enabling the student to combine current best practice and develop the skills necessary to advance this science. Supervision of gas transfer activities will be provided jointly by Newcastle (RUG) and Heriot-Watt (RP) universities. JS (Exeter) will advise on FluxEngine. Technical and other directly relevant training will be provided by all three to equip the student with the skills necessary for all aspects of the project. IAPETUS fosters a strong sense of “community” that encourages students to organise a range of activities (e.g. annual conference) and identify additional training needs to be addressed via tailored opportunities. The student will have opportunities for additional training at the partner institutions. Through these opportunities and by participation in multi-disciplinary cruises, the student should develop strong collaborations that will potentially result in further opportunities.

References & Further Reading


Further Information

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