Introduction

Atmospheric transport and deposition of aerosols is an important delivery mechanism of natural and contaminant trace elements to the Arctic. Existing data show that atmospheric deposition of contaminant elements like Hg, Pb, and Se may be a major input of these elements to the Arctic, with likely sources being anthropogenic – industrial or power plant emissions associated with fossil fuel combustion in Europe, Russia, and Asia. The atmospheric input of trace elements plays a key role in controlling biogeochemical processes in the ocean, and recent work suggests this might be true in the Arctic as well. These inputs have strong implications for the ecosystem, and even human health. Assessment of this input is difficult however because measurements of deposition rates in remote ocean regions are rare, and particularly daunting in the Arctic because harsh conditions and limited research platforms make it difficult to obtain quality-controlled precipitation and aerosol chemistry measurements on a routine basis. Furthermore the Arctic is complicated by the existence of different catchments (water/ice/snow) that partition the atmospheric input such that elements will have circuitous paths to the oceanic ecosystem. The seasonality of this partitioning between compartments (as a function of melt and sea ice extent) likely affects ocean chemistry and the ecosystem. Understanding the seasonality of aerosol trace element (TE) partitioning will provide insight into how the distribution of TEs will change as the Arctic ice-cover continues to evolve over the coming years. In addition, aerosol concentrations in the Arctic exhibit strong seasonality, with the highest concentrations found in winter and early spring (December-April), due to the southward migration of the Polar Front. This is manifested as the well-known 'Arctic haze'. The Boreal summers however, are characterized by low aerosol concentrations, which are inferred to yield low rates of deposition. ***However, it is emphasized that while aerosol samples can be collected from ship board or land-based aerosol samplers, the chemical concentration data derived from these collections in of themselves cannot yield the deposition rate of trace elements. To transform these concentrations into rates, a method of determining flux is required***. Such determinations in the Arctic, particularly in the winter months, are exceedingly rare. Like many processes in the Arctic, understanding of atmospheric deposition is limited by lack of observations. Given the dearth of direct measurements, the ocean community has relied on atmospheric transport and deposition models to assess aerosol fluxes. However these models are themselves poorly constrained as to the amounts of precipitation delivered to the ocean and the parameterization of aerosol removal processes.

Another approach involves the use of natural radionuclides which are delivered to the ocean from the atmosphere. These provide useful tracers for the input of atmospherically derived chemical species, as the source terms are definable and measurements are not readily contaminated within normal environmental conditions. The information obtained from the use of such tracers can be used to characterize the deposition of trace metals. For example, the global distribution of ^{7}Be (half-life = 53.3 d) in the atmosphere and its deposition to the ocean has been modeled and parameters developed in such models can be extended to the modeling of other species including those from anthropogenic sources. Be-7 can be applied to evaluate deposition of chemical species into the ocean as the ocean inventory of ^{7}Be is a direct measure of its rate of atmospheric input. The ability to readily derive ^{7}Be flux from its deposited inventory provides the means to link the chemical concentration data of aerosols to flux.

^{7}Be is particularly well suited for studying the deposition of chemical species into the Arctic as the inventory of ^{7}Be, partitioned between the ice/ocean, is a direct measure of its rate of atmospheric input to these catchments. We will use the inventory and distribution of ^{7}Be within the water column, ice, snow, and melt ponds to trace the seasonal partitioning and pathways of atmospherically-deposited elements within the Arctic system. Significantly, by coupling the ^{7}Be inventories, ^{7}Be aerosol activity, and trace

element aerosol concentrations, estimates of the yearly atmospheric deposition flux of aerosol trace elements will be derived. These include those of biogeochemical importance as well as pollutant species.

This work will be part of the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) initiative. MOSAiC will entail **year-round**, coordinated and comprehensive measurements extending across the central Arctic atmosphere-sea-ice-ocean system to advance process-level understanding of the changing Arctic physical and biogeochemical systems. The significance for this work is that for the first time a study of the seasonal changes in Arctic aerosol and associated chemical flux will be possible.

The MOSAiC Project

The Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) is an international initiative motivated by the rapidly evolving Arctic climate system, with thinning sea ice, warming ocean and atmosphere temperatures, strong climate feedbacks, and dramatic implications for society. To model and predict this "New Arctic" system will require an understanding of its emergent properties and coupled system processes. To achieve this goal, MOSAiC will entail year-round, coordinated and comprehensive measurements, extending across the central Arctic atmosphere-sea-ice-ocean system. Analyses and syntheses built on this foundation will contribute to improved understanding and modeling of Arctic climate and weather, assessment of ecosystem change, and prediction of Arctic sea ice. To develop the requisite representative understanding of this evolving system, MOSAiC will examine the system in great detail over model grid-box scales and continuously over a full annual cycle.

Numerous workshops over five years have helped identify high priority modeling needs and deficiencies that can uniquely be addressed through MOSAiC. These form a basis for research questions around which MOSAiC observational and modeling activities are organized. Two such questions are highly relevant to the work to be performed here:

1) *How do interfacial exchange rates, biology, and chemistry couple to regulate ecosystems and the major elemental cycles in the high Arctic sea ice?*

2) How do ongoing changes in the Arctic ice-ocean-atmosphere system impact heat and mass transfers of importance to climate and ecosystems?

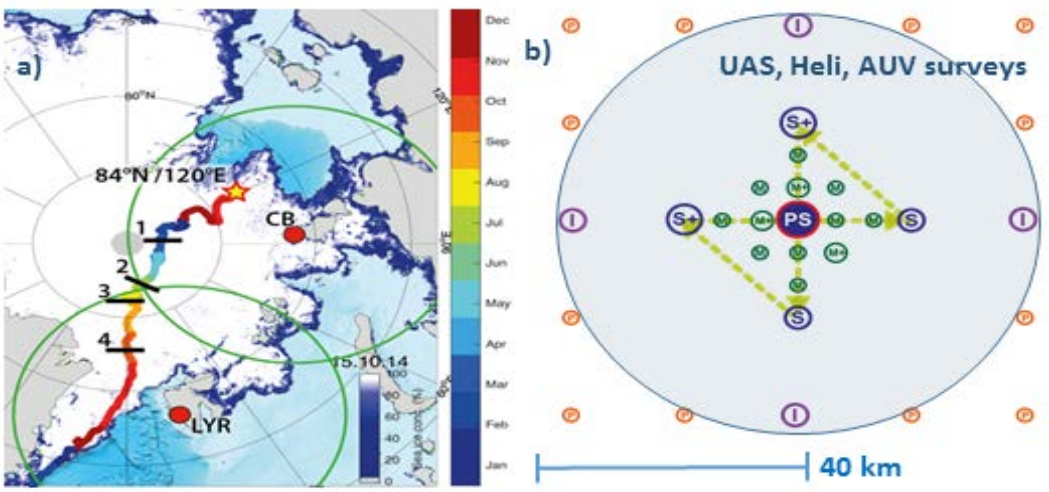

Figure 1: a) Drift trajectories for the selected starting position at 120°E and 84°N. Colors represent the month of the drift. Green circles show helicopter ranges from Cape Baranov (CB) and Longyearbyen (LYR). Numbers and black ticks indicate where the resupply would happen based on this trajectory. b) Conceptual diagram of distributed network around Polarstern (PS) with numerous node types.

To address these and other questions, a central observatory based on and around the German icebreaker Polarstern will passively drift along the Transpolar Drift for a full year (Fig. 1a), starting in the newly forming sea ice of the northern Laptev Sea in late fall (October) 2019. Observations made on the ship and at an adjacent ice camp will provide a detailed and comprehensive characterization of coupled-system processes associated with all stages of the sea ice life cycle. Surrounding the central observatory will be a distributed network of autonomous stations, unmanned observing systems, and episodic measurements for characterizing spatial variability and heterogeneity on model grid-box scales (Fig. 1b).

The goal of this work is to provide estimates of the yearly atmospheric deposition flux of aerosol trace elements. These include those of biogeochemical importance as well as pollutant species. The seasonal evolution of ^{7}Be partitioning within the various catchments will also provide insight into the seasonal distribution of atmospherically-derived species among these reservoirs. The work will involve measurements of ^{7}Be inventories, ^{7}Be aerosol activities, and aerosol concentrations of trace elements. Figure 2 illustrates how the flux of ^{7}Be is distributed among the various Arctic catchments.

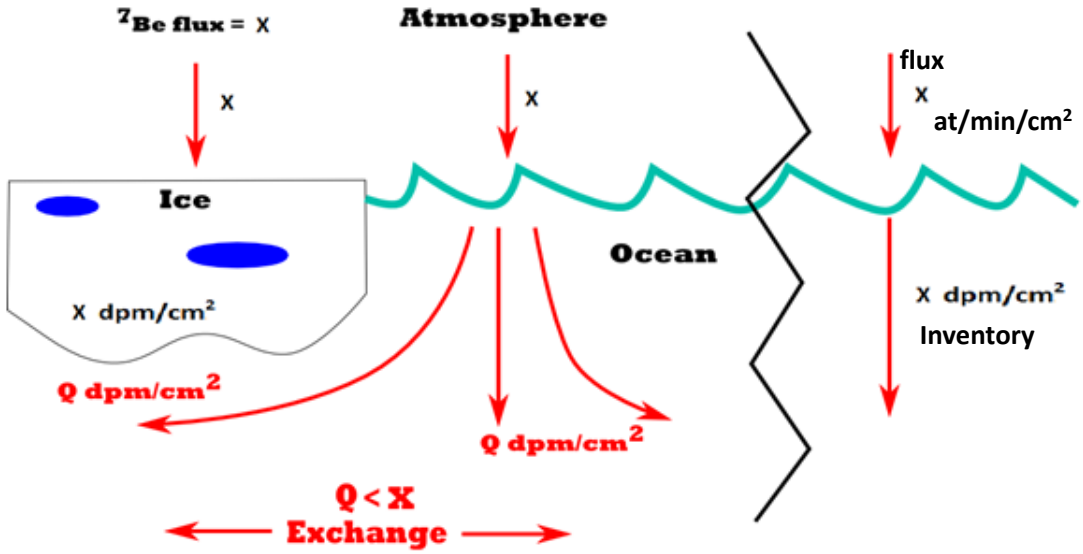

Figure 2. Schematic representation of the distribution of ^{7}Be input within the Arctic system.

The use of the ^{7}Be method in the context of a year-long platform allows the seasonal variability of aerosol depositional parameters such as depositional velocity and washout ratios to be assessed. To our knowledge, an opportunity for such a comprehensive study of the yearly depositional flux of trace elements into the Arctic ocean/ice ecosystem has never before been available.

^{7}Be: Be-7 is a cosmic ray produced isotope (half-life = 53.3 d) that is deposited upon the ocean surface primarily by precipitation and subsequently homogenized within the surface mixed layer. The ^{7}Be flux and water column inventory vary as a function of rainfall, and over broad oceanic regions are relatively constant. This is manifested by the observation that water column inventories are inversely related to surface salinity. In the low particle environment of the open ocean, numerous studies have shown that ^{7}Be is quite soluble thus allowing particle scavenging losses to be ignored. Therefore, in the absence of physical removal processes other than radioactive decay, the water column inventory of the isotope

represents an integration of the atmospheric input flux over approximately the previous mean-life (77 d) of the isotope, making it relevant to studies encompassing seasonal timescales. Given this, then the flux of a trace element (Fi) can be expressed by

$$Fi = \Sigma^{7}Be \bullet \frac{[Cpi]}{[Cp_{7Be}}$$

Where ($\Sigma^{7}Be$) is the integrated ^{7}Be inventory and [Cpi]/[Cp_{7Be}] is the ratio of trace element concentration to ^{7}Be activity in aerosols.