Title: How to protect polar regions: Fate and accumulation of persistent organic pollutants in the warming Arctic

Introduction

Setting: Protecting Arctic ecosystems is of a global concern as threats originate from human activities from around the world. So far, global emissions of greenhouse gas macropollutants (esp. CO2, CH4, N2O) have received most attention, with impact of global warming being most pronounced in cold regions. Potential threats due to micropollutants such as Persistent Organic Pollutants (POPs) and mercury (Hg) have been investigated far less intensively. However, recent studies have shown that micropollutants can also affect animals and humans adversely. Even more, levels of some micropollutants in the Arctic are increasing and new substances are flooding the market, outpacing assessment of their environmental risks.

To address this scientific challenge and societal endeavour, we aim to link local and global micropollutant emissions to concentrations and effects in (esp. freshwater and terrestrial) food chains of the Arctic, under current and future climate conditions, improving models used in regulatory frameworks.

Objectives: we aim to

1) estimate local emissions due to intensified activities following temperature rise in the Arctic relative to import of global emissions.

2) model concentrations in air, water and soil following temperature rise and compare these to measured levels, esp. in terrestrial and freshwater systems.

3) determine accumulation of chemicals in warm-blooded species of the food chain under different climate conditions.

An extensive description is available on request. You can select one of these topics.

Methods

1) Estimate local emissions of chemicals due to intensified activities following temperature rise in the Arctic, relative to import of global emissions.

Derive developments in activities and climate change in the Arctic. To underpin expected development, we will first review trends indicated by monitoring programs and model scenarios for relevant climate conditions, such as (seasonal) temperatures and ice cover in the Arctic [Aksenov et al. 2017, Sporyshev et al. 2018]. Increases of some activities, esp. shipping (cargo, fishing, passenger) have already been linked to present [e.g., Eguíluz et al. 2016] and future [e.g., Aksenov et al. 2017] conditions. For others, such information might not be available. In these cases, we will derive relationships between activity and climate change ourselves. For mining, for instance, we will investigate whether current exploitation in sub-arctic areas may serve as an indication of investments to be expected when similar temperature conditions emerge in the Artic, keeping in mind technological progress [Boyd et al. 2016]. Increase in the number of people living in the Arctic may be covered by anticipated expansion of residential areas.

Convert activities to emissions in the Arctic using emission factors. To convert activities to emissions, we will collect so-called emission factors from literature. Emission factors indicate, e.g., the amount of a given micropollutant emitted per litre of fuel or per km of sailing, covering different ship and fuel types. If data allow, we will account for reductions of emission-factors due to technological improvements yielding lower emissions per unit of activity. While we focus on substances with increasing concentrations, such as Hg and PAHs, we will also use values on other substances reported in the same sources. Global emission factors obtained from specific studies will be underpinned by a comparison to default values in databases used for formal assessments such as ECOIVENT and TRI (e.g., https://www.ecoinvent.org/, https://www.epa.gov/toxics-release-inventory-tri-program]. In addition to emission factors, we will also use data from global emission inventories, like our own on Hg and extensions thereof to other micropollutants [Steenhuisen and Wilson 2019].

Compare emissions in the Arctic to import from temperate and tropical zones. To discern the importance of local and distant sources, we will compare the total of emission of each compound in the Arctic to the global influx of the same compound from the temperate zone, as calculated by the fate models of 2.

2) Model concentrations of chemicals in air, water and soil following temperature rise and compare to levels measured, esp. in terrestrial and freshwater systems. To understand the large discrepancies noted across predictions as described in the knowledge gaps above, we will review model studies on the impact of climate change on fate of micropollutants in the Artic. For further analysis, a selected set of advanced models used in these studies will be run during a stay of the PhD student at Toronto University (Prof. Wania). Based on these simulations, we will improve SIMPLEBOX, including new chemicals and processes related to ice and snow.

Calculate concentrations of different mercury species in abiotic compartments. Following our focus on mercury in freshwater and terrestrial systems, we will also apply advanced modelling for metal speciation. Mercury occurs in various inorganic and organic forms (also called species) such as Hg0, Hg+, Hg2+, CH3Hg+ and (CH3)2Hg. Each metal species is taken up by plants and animals at different rates. Hence, to model exposure correctly, concentrations of different species need to be determined. Extending our previous efforts on non-mercury metals, we will calculate mercury concentrations with both an advanced model (ORCHESTRA) and with transfer functions [Le and Hendriks 2014]. The estimations will be compared to joint measurements with WP4.

Improve and apply SIMPLEBOX for fate of micropollutants in the Arctic. To allow policy-making frameworks to rapidly calculate the implications of both local and global emissions for concentrations in the Arctic, we will adapt SIMPLEBOX to include appropriate equations for fate in polar regions. New data generated by ourselves or recent data published in literature will be used to further validate the model. The improved version will then be applied to calculate the concentrations resulting from both local and global emissions under present and future climate conditions. This will be presented to stakeholders involved in policy making on chemical emissions (10b.B).

3) Calculate trophic magnification factors for warm-blooded species in Arctic food chains, similar to earlier done for cold-blooded species [Hoondert et al. 2019].