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Preliminary Report: Arctic Change Expedition

Expedition June – September 2020

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Introduction

Over the last decades, the atmospheric concentrations of greenhouse gases (GHGs) have increased dramatically, contributing to global warming. The increase of the Earth's average temperatures together with ice loss and sea-level change, followed by extreme weather events and natural disasters raise concerns among the scientists and policy-makers. GHGs that naturally occur in the environment can also be emitted by anthropogenic activities. Burning of fossil fuels for transportation or energy contributes to higher emissions of CO_2 and alters its natural budgets and rates of exchange. CO_2 and CH_4 are the two major carbon GHGs that deserve attention due to their warming potentials. Their concentrations in the atmosphere with regards to the pre-industrial times have grown substantially (from 280 ppm in the 19th century to 410 ppm in 2019 for CO_2 concentrations and from 722 ppb to 1866 ppb for CH_4). Although CH_4 concentrations are much lower than CO_2 in the atmosphere, the global warming potential is approximately 86 times greater (on the 20 year timescale) due to its higher energy absorption (IPCC 2013). Moreover, CH_4 is about 25 times less soluble in the water than CO_2 and therefore forms bubbles, which can be released and further exacerbate the local warming (McGinnis et al. 2006).

Polar regions are the most vulnerable ecosystems in the world when it comes to climate change. The temperature in the arctic regions has increased at twice the rate as much as anywhere else in the world; a phenomenon known as polar amplification (Sukyoung 2014). Since 1950s the Arctic has warmed by 2-3°C. The local cryosphere has been undergoing ice sheet melting and glaciers retreating, increase in permafrost temperature and thinning of snow cover (IPCC 2019). According to the last IPCC (2019) report on the ocean and cryosphere, between 2006 and 2015 the Greenland Ice Sheet lost ice mass at an average rate of 278 ± 11 Gt yr. In the past three decades, the Arctic sea ice has thinned substantially, and the proportion of old ice (> 5 years) had declined by 90% (IPCC 2019). The extent of ice measured at its minimum (in September) shows a clear negative trend falling from 7.5 million km in 1980 to 4.15 mln km in 2019 (NSIDC 2019). The phenomenon of polar amplification is a result of the existing positive feedbacks in the system. The most important one is that the albedo (surface reflectivity) decreases as the white, highly reflective area decreases. Consequently, more heat is absorbed and melting in the region intensifies.

Another important effect is that due to the vast melting of permafrost (permanently frozen soil, which stores ancient organic material) in the Arctic, stored CO_2 and CH_4 are emitted, which further amplifies the global warming. It is estimated that 350 Pg of carbon will be released from thawed permafrost by 2100 in the form of CO_2 (3.4 x 10^{11} tons). Currently, the Arctic ocean is an important sink of CO_2 (McGuire et al. 2009), however the ongoing warming of the Arctic is not indifferent for the exchange of gases between water and atmosphere. As the solubility of gases decrease with warmer temperatures, polar amplification will cause smaller fluxes (MacIntyre et al. 2010). Given the continuing warming, scientists have already identified areas that emit CO_2 to the atmosphere and will continue to do so on a larger scale (Parmentier et al. 2013). Due to the larger warming potential of CH_4 and its lower solubility, the Arctic Ocean is potentially a source of this gas. Unfortunately, the complexity of ongoing processes makes the gas fluxes in the Arctic difficult to quantify (McGuire et al. 2009) and a highly understudied issue. Climate change and continuous increase in greenhouse gases concentrations is expected to bring a potentially significant impact on the CO_2 and CH_4 fluxes, therefore it is an extremely current and relevant topic to investigate.

Data collection and processing

The sailing ship Mauritius followed the route presented on the Map 1 below, collecting data from June to September 2020.

Map 1. Route followed by Mauritius ship from June to September 2020.

Atmospheric GHG data were continuously collected by a portable greenhouse gas analyzer (CH_4 and CO_2, Los Gatos Research, Ultraportable Greenhouse Gas Analyzer) installed on the vessel. The measurements were taken every 10 minutes for 10 weeks along the ship route, and sampled via an intake installed on the aft mast. Unfortunately, the atmospheric CH_4 data were not collected properly due to the problems with device, therefore they cannot be analyzed. Longitude and latitude were simultaneously recorded via an onboard GPS. A water probe was installed through the hull of Mauritius (a YSI EXO2 Multiparameter Sonde) and collected surface water temperature, salinity, conductivity, depth, turbidity, and dissolved oxygen. Water samples, which were taken from the surface water were collected of dissolved gas analysis. The gas was extracted from the samples onboard Mauritius and the sample water discarded. Gas samples were stored in a 12mL evacuated Exetainer and shipped for analysis at University of Geneva. These samples were analyzed for CH_4, CO2 and their stable carbon isotopes. With these measurements, the water dissolved concentrations could be back calculated. The raw data together with the file explaining the variables are being sent as separate files attached to this report.

Since one of the main objectives of the project is to calculate the fluxes of CO_2 and CH_4 in the region, the following calculations will be performed in order to obtain the results.

The gases passively move between the surfaces by diffusion, following the Fick's First Law (Wanninkhof, 2014), which can be written as a following formula:

$$F_{gas} = k * (C_w - C_{eq}) ;$$

where F is the flux [mmol m^{-2} d^{-1}], k is a gas exchange coefficient [m d^{-1}], C_w is the concentrations at the surface water [mmol m^{-3}] and C_{eq} is the concentration at its equilibrium with atmosphere (MacIntyre et al. 2010). Fluxes are higher in turbulent conditions; therefore, rates of gas exchange are enhanced by wind or currents (Wanninkhof, 2014). In order to obtain a k per measurement, the following equation will be used, which includes the wind speed (U_{10}) in [m s^{-1}] (McIntyre et al. 2010):

$$k = 2.04 * U_{10} + 2.0$$

One of the assumptions used in the quantification of fluxes is Henry's Law, which states: "At a constant temperature, the amount of a given gas that dissolves in a given type and volume of liquid is directly proportional to the partial pressure of that gas in equilibrium with that liquid" (Speight 2019) and can be written as a formula:

$$C_{eq} = H_i * P_i$$

Where C_{eq} is the solubility that is being research, P_i is the partial pressure of the individual gas, and H_i is Henry's Law constant. The "H_i" is obtained from Sander (2015) and corrected for local temperature and salinity.

Data analysis

Data analysis is part of the Master's thesis project on "Carbon dioxide, methane emissions and climate change in the Arctic" performed by Ms. Iga Józefiak under the supervision of Prof. D. F. McGinnis at University of Geneve. The thesis will identify key sources and sinks of CO_2 and CH_4 in the region and investigate the fluxes of these gases between the ocean and the atmosphere, based on the collected data. The purpose of the thesis is to discuss the further impact of the gas fluxes on the local climate and permafrost stability. The results of the ongoing analysis will contribute to a better understanding of the complex physics that occurs at the boundary of ocean and air in this polar region. The preliminary findings show that in general there is an uptake of CO_2 in the region and the inverse pattern with regards to CH_4, which the Arctic ocean is mostly emitting. The complete results and conclusions are planned to be finalized by mid-2021.

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