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AIR QUALITY MONITORING IN COMMUNITIES OF THE CANADIAN ARCTIC DURING THE HIGH SHIPPING SEASON WITH A FOCUS ON LOCAL AND MARINE POLLUTION

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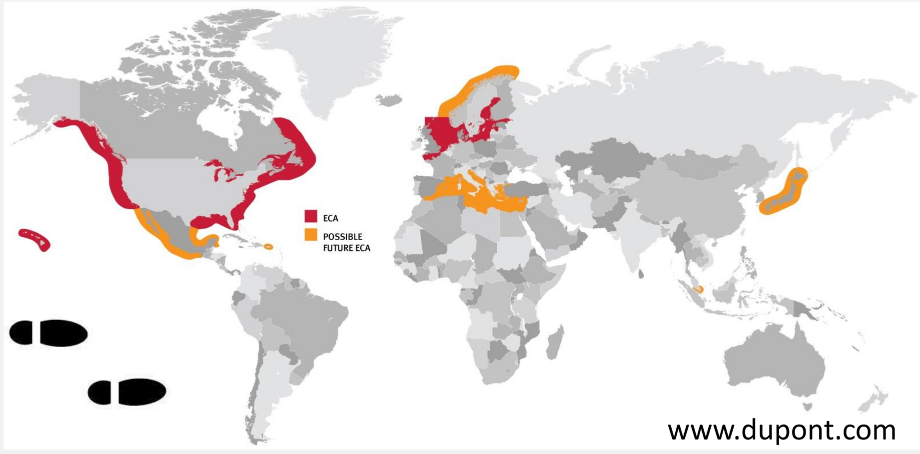
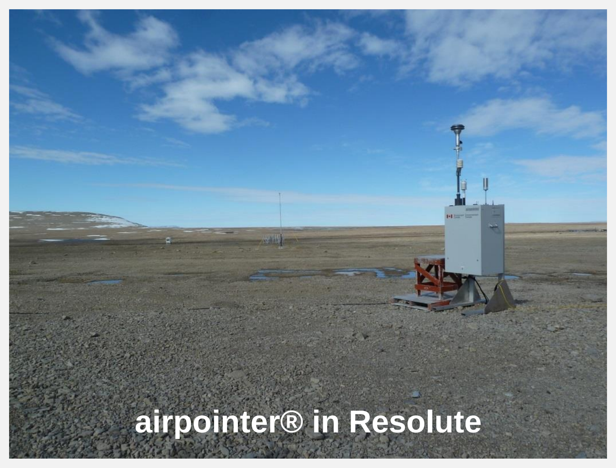


The Northern Routes:

The increasing shipping traffic in the Canadian Arctic, co-incident with the declining sea ice extent, is well documented. The monthly traffic increase was reported as high as 22 additional vessels per decade in July for all vessel classes since 1990 (Pizzolato, 2014). The Northwest Passage (NWP), the Arctic Bridge, and the Northern Sea Route (NSR) have the potential to divert global shipping traffic by mid century (Smith and Stephenson, 2013).

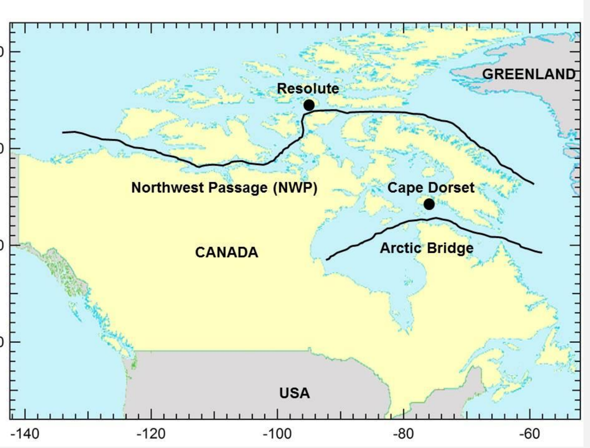


Monitoring Stations:

The monitoring stations are situated near the airports for both Cape Dorset and Resolute sites. Availability of power, ease of maintenance, and distance from local villages made this location practical for installation. In addition to shipping pollution, the stations measure local pollution that come from the aircrafts, waste burn, power generator, local traffic, road dust, etc… (NPRI, 2011). Resupply and other ships stay near anchoring position due to lack of harbor facility in remote Northern villages. The tank farms store the annual fuel for the village consumption. The generators are fueled by diesel. Figures below show the town facilities, monitoring stations, and the wind roses at each site during the shipping season.

Introduction:

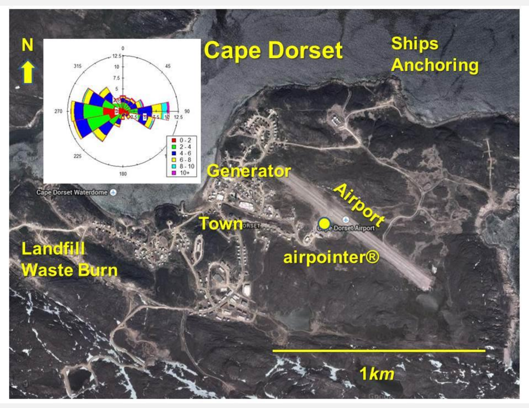
Shipping accounts for 3.3%, 5-8%, and 2% of global CO_2, SO_2, and BC emissions (Lack and Corbett, 2012). The existing emissions regulations are set by International Maritime Organization (IMO). Emissions Control Areas (ECAs) are defined and regulated by IMO to enforce more stringent measures in designated areas. For example the North American (NA) ECA limits sulphur content in ship fuels to 1.0% globally (effective 2011) but to 0.1% (effective 2015) within NA-ECA. To date, there are only a few ECAs in force globally, as shown in the figure above , under IMO Annex VI. Most recent additions were the North Sea (2007), Gulfs Area (2008), Mediterranean Sea (2009), and Caribbean Region (2011) (www.imo.org). The Canadian Arctic is not one of them.

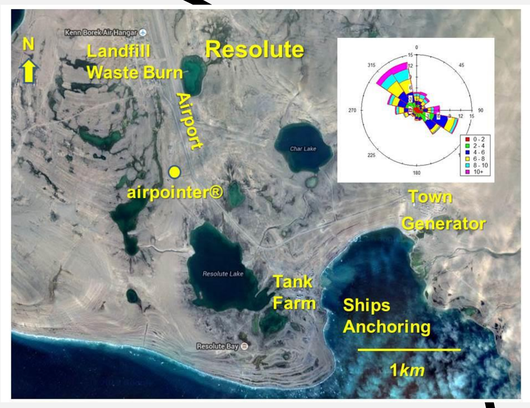


Research Objective:

In order to understand the impact of shipping on Arctic air quality during the 2013 shipping season, two monitoring stations have been set up in Cape Dorset and Resolute, Nunavut, and have been measuring air pollution since June 2013. These communities are located close to the NWP and the Arctic Bridge. The Arctic shipping season is from 1 June to 1 November every year.

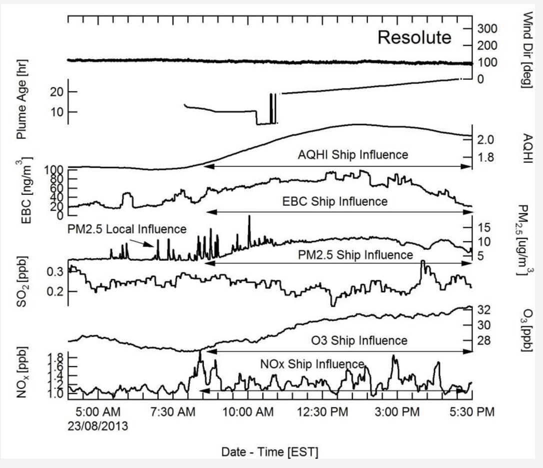
The monitoring stations, airpointer® (v. 2), are manufactured by Recordum in Austria and measure NO_x, O_3, SO_2, and $PM_{2.5}$, based on Chemiluminescence, UV photometry, UV Fluorescence, and nephelometry. Additionally, Resolute is equipped with particle size (TSI 3034 SMPS) and Elemental Black Carbon (EBC) measurements (CLAP).





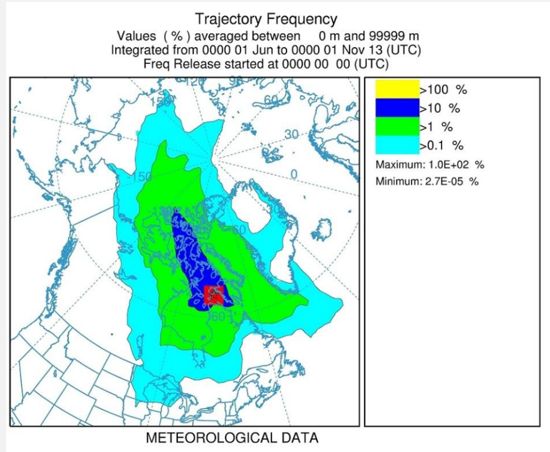
Effect of Local Pollution:

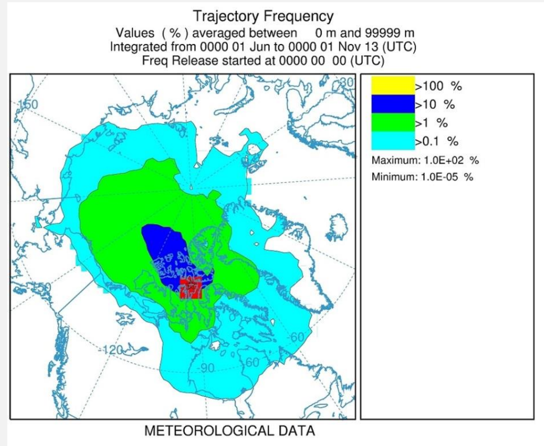
Local pollution affects both $PM_{2.5}$ and NO_x levels. These come from waste burn, power generators, local traffic, road dust, and more. On the other hand SO_2 levels are enhanced only by airport activity and ships at anchoring position. Due to declining sulphur content in ship fuels, only occasional and sporadic SO_2 spikes are detected in the dataset.



Air Quality Health Index Series:

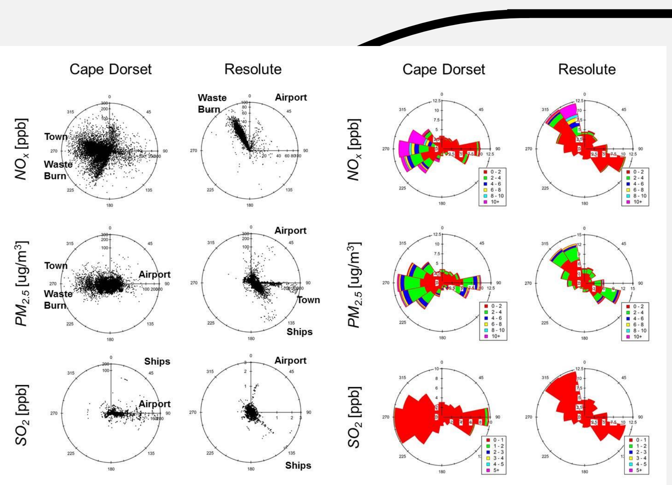
Air Quality Health Index (AQHI) is a numeric integer scale to quantify the acute effect of air pollution (NO_2, O_3, and $PM_{2.5}$) on human health. It can be any number greater than 0, but it is rounded to a range from 1 (no risk) to 10 (very high risk) (Stieb, 2008). The time series below indicates a seasonal increase in the high resolution AQHI from 0.5 to 3, mainly due to the seasonal O_3 trend. AQHI is higher for Cape Dorset than Resolute. The ship influence in AQHI is embedded in the time series.





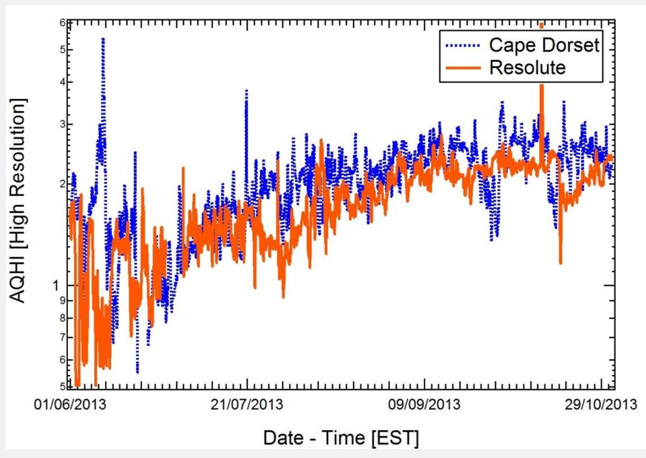
Ship Tracking Method:

The Canadian Coast Guard (CCG) database was used to track all ships within the Canadian Arctic jurisdiction (NORDREG) from 1 June to 1 November 2013 (www.innave.gc.ca). 109 major ships were observed to have had active traffic including merchant, passenger, cargo, fishing, cruise, and other vessels. Ships report their activity and location to CCG at least daily. 27, 921 activity reports were processed. Ship latitudes and longitudes were interpolated at 1-minute resolution using spatial and temporal filters in order to create homogeneous motion tracks. Interpolated ship tracks and traffic density are plotted below, clearly indicating traffic through the NWP and Arctic Bridge.



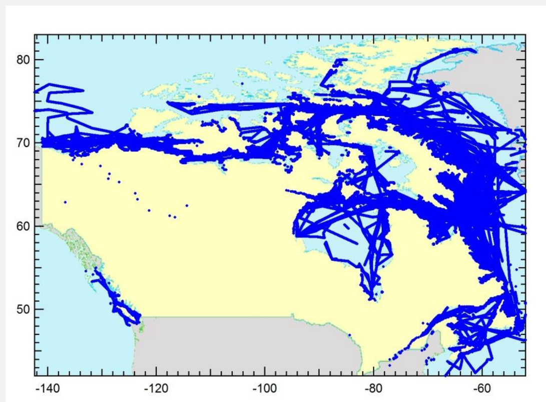
A Single Ship Pollution Episode:

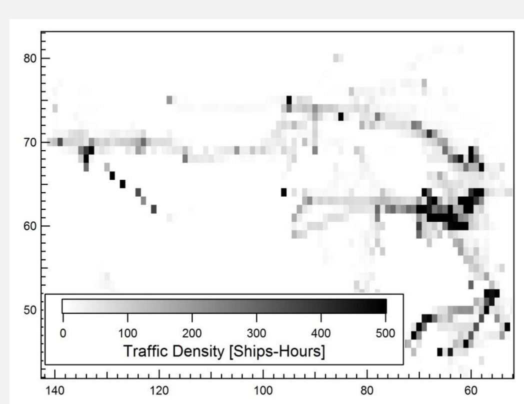
In Resolute, pollution in from single ship plume is illustrated in the figure above. The evolution of time series as a function of plume age indicate that EBC, $PM_{2.5}$, O_3, and AQHI exhibit wide and low peaks associated with the plume, while sharp and narrow peaks are characteristics of local pollution. Local pollution is occasionally superimposed on ship pollution.



Air Mass Back Trajectory Analysis:

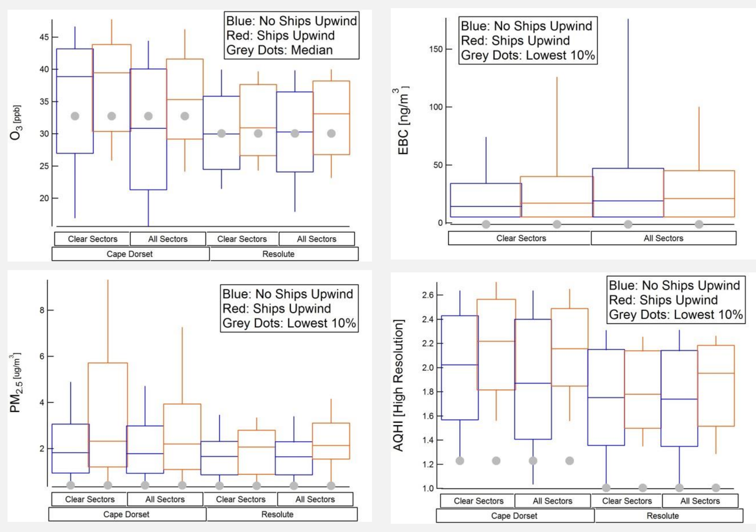
Source apportionment of surface pollutants in our study was partially accomplished using NOAA's HYSPLIT 4 air mass back trajectory model. The 1-degree spatial "gdas" meteorology files were used. For the entire 2013 shipping season, air masses that arrived at both Cape Dorset and Resolute sites were tracked hourly and further interpolated to provide a 1-minute time resolution. The trajectory clustering was performed in combination with ship traffic tracking. An air mass was considered to be "influenced" by ship emissions if it crossed a latitude/longitude at low elevation that contained a ship with a tolerance equal to 20% of the trajectory's length. 3696 trajectories were run for each site.





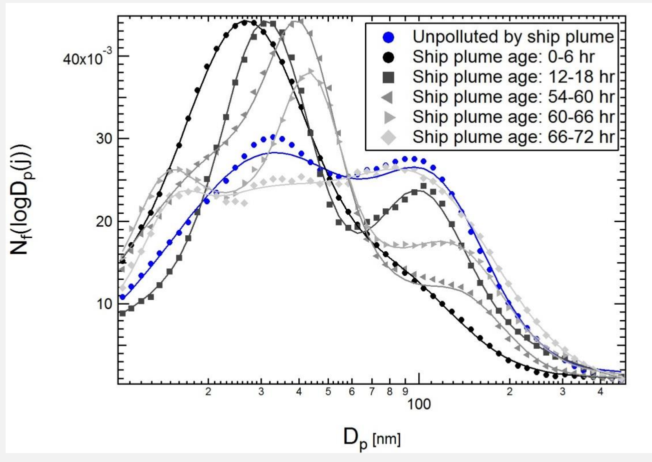
Trajectory Clustering Analysis:

Trajectories were divided into four groups (A-D), depending on the wind sector in which they arrived at the monitoring stations. Sectors A and C are associated with air masses weakly contaminated by local pollution (Clear Sectors), while sectors B and D contain air masses that are affected by local pollution. Trajectories are further sub-grouped based on whether or not they were influenced by ship emissions (No Ships Upwind or Ships Upwind).



Cumulative Contribution of Shipping:

Surface level concentrations are integrated over time to provide an estimate of shipping impact on air quality versus that of local pollution. Ship-influenced air masses from clear wind sectors (A+C) provide a lower bound for the shipping impact, while those from all wind sectors (A to D) provide an upper bound, due to contamination from local sources. In either case, the percent contribution is defined as:
F=(Ship-influenced int. conc.)/(All int. conc.)
The percent ship contribution to air pollution is in the range 5-30% for the 2013 shipping season. The contribution is higher in Cape Dorset than Resolute.



Conclusions and Future Work:

The impact of shipping in the Canadian Arctic on air quality during the 2013 shipping season was quantified. It was shown, statistically, that air quality degraded when ships influenced near-surface air masses, by an increase in $PM_{2.5}$, O_3, EBC, and AQHI levels. Air quality measurements in the North will assist air quality modeling capacities of Environment Canada in the North. In addition, continued air quality measurements in the North will reveal long-term trends and year-to-year variability in surface air quality due to shipping activity and local pollution.

Please view full article and comment online: Aliabadi et al., Atmos. Chem. Phys. Discuss. doi:10.5194/acpd-14-1-2014

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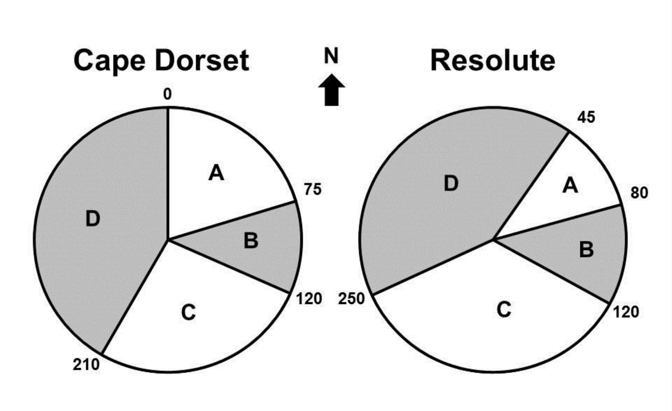
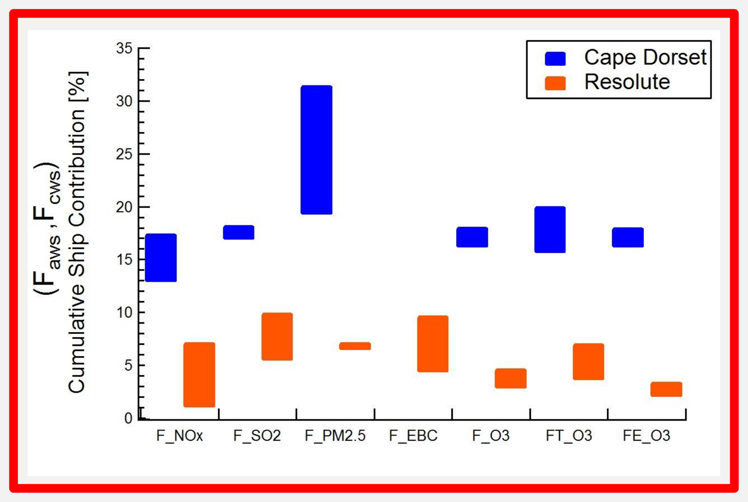


Statistical Analysis:

The mean difference between ship-influenced and no-ship-influenced concentrations or index in air masses are estimated using a two-sample t-test (Walpole et al., 2002). Trajectories up to 24hr and 72hr are considered. O3 (72hr), PM2.5 (24hr), EBC (24hr), and AQHI (72hr) consistently show an increase for ship-influenced air masses. The 90% confidence interval in mean difference for the above quantities are up to 4.6-4.7ppb, 1.8-1.9μgm^{-3}, 0.4-10.1 ngm^{-3}, and 0.2-0.3, respectively, depending on site location and wind sector.



Particle Size Dynamics in Ship Plumes:

The ship-influenced particle size distribution was further sub-grouped as a function of plume age from 0 to 72hr in 6-hr time intervals. The background size distribution is bi-modal in the Aitken (28-37nm) and accumulation (105-115nm) regimes. Fresh plumes (0-6hr) exhibit an accentuated combustion (Aitken) mode at 27nm, which shifts to larger sizes (44nm) due to agglomeration and growth as the plume ages (60-66hr). The distribution eventually approaches the background condition (>66hr), with an additional nucleation mode from Dimethyl Sulphide (DMS).

References: Lack and Corbett, Atmos. Chem. Phys., 2012 (doi:10.5194/acp-12-3985-2012), Pizzolato et al., Environ. Sci. Technol., 2012 (doi:10.1007/s10584-013-1038-3), Smith and Stephenson, P. Natl. Acad. Sci., 2013 (doi:10.1073/pnas.1214212110), National Pollutants Release Inventory, http://www.ec.gc.ca/inrp-npri/, 2011, Stieb et al. J. Air Waste Manage., 2008 (doi:10.3155/10473289.58.3.465), Walpole et al., Probability and Statistics for Engineers and Scientists, 7th Edn., 2002

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