Studying Bromine, Ozone, and Mercury Chemistry in the Arctic

PAGES 289–291

Accentuated by a new record low in 2012, the springtime extent of Arctic perennial sea ice continues its precipitous decline. Consequently, the Arctic sea ice cover is increasingly dominated by seasonal sea ice, consisting of thinner and saltier ice with more leads (fractures), polynyas (areas of open water), nilas (sea ice crust less than about 10 centimeters thick), frost flowers (clusters of salty ice crystals on sea ice surface), and saline snow. The increase in the salinity of the sea ice cover is potentially conducive to ice-mediated photochemical and meteorological processes leading to ozone (O_3) and gaseous elemental mercury depletion from the atmosphere.

As the saltier season sea ice becomes more extensive, bromine explosions from sea salt sources may change the level of tropospheric ozone (a pollutant in the troposphere) and affect the surface deposition of atmospheric mercury originating from long-range pollution transport. As deposited mercury becomes toxic through subsequent biochemical processes, understanding the overall process may lend scientific support to international efforts to address adverse impacts of Arctic sea ice reduction.

Field Campaign Setting

To investigate implications of the perennial sea ice reduction on tropospheric bromine, ozone, and mercury chemical processes, transport, and distribution, the Bromine, Ozone, and Mercury Experiment (BROMEX) was conducted in March and April 2012 around Barrow, Alaska. BROMEX involved multiple satellite instruments, three aircraft, various field sites on sea ice and tundra, and meteorological buoys and stations (Figure 1). The field area extended from inland terrestrial sites to a large region of the sea ice offshore in the Beaufort Sea and Chukchi Sea, where energetic dynamics created large leads, providing a variety of sea, ice, and atmospheric conditions. BROMEX was carried out with international participation and contributions of 20 agencies and institutions from the United States, Canada, Germany, and the United Kingdom.

Satellite and Aircraft Observations

Data acquisitions from 14 different satellites were coordinated during BROMEX (for a listing of the satellites, see the supporting information in the online version of this brief report). These satellites provided observations of snow and sea ice changes, lead formations, and plumes emanating from open water areas. In addition, the Airborne Laboratory for Atmospheric Research was flown in 11 long-range excursions to obtain unprecedented views of the vertical profiles of bromine monoxide (BrO), aerosols, and ozone over the tundra snowpack and various types of sea ice surfaces. To measure thickness of snow and sea ice with radar and laser altimeters, the IceBridge NASA P3 aircraft was flown from the Beaufort Sea, across the Elson Lagoon, above the tundra, and offshore over the Chukchi Sea.

Ocean and Land Surface Measurements

Two instrument packages were deployed on sea ice with a helicopter: IceLander IL1 in the Beaufort Sea and IL2 in the Chukchi Sea. A primary strategy of BROMEX was to capture measurements by the IceLanders to characterize O_3 and BrO processes both upwind and downwind of areas where lead formation was active to investigate effects of both open water and freshly refrozen leads on bromine chemistry. IL1 was primarily stationary during BROMEX. IL2 drifted with the sea ice under changing conditions, including pack ice, lead formations and closures, and unconsolidated ice floes from March to June 2012, when it was toppled by a polar bear. Another similar instrument was installed at a fixed site near Barrow. O_3 data from IL1, IL2, and Barrow revealed that ozone depletion events occurred quite frequently. Moreover, Barrow data suggest a relationship between the seasonal end date of BrO activities and snow properties.

Data on gaseous elemental mercury, reactive gaseous mercury, and fine-particulate mercury were obtained simultaneously with Environment Canada's Out On The Ice (OOTI) system for mercury measurements over the Chukchi Sea ice site and over the snow-covered Arctic tundra (Tundra field site). From initial analyses, mercury cycling showed clear differences between the sites: higher mercury levels deposited in the surface snow at the Chukchi Sea site were associated with higher ion concentrations over the Arctic Ocean, while higher levels of mercury reemitted into the atmosphere were observed above the tundra land. Mercury and halogen chemical processes are found to be influenced by vapor plumes emanating from leads in sea ice. A high-definition video showing vapor plumes from leads in the Chukchi Sea is included in the supporting information in the online version of this brief report.

Halogen, ozone, and mercury measurements were also made at a tundra site about 5 kilometers inland, southeast of the town of Barrow. Near-continuous measurements of diatomic bromine (Br_2), bromine monoxide (BrO), hypobromous acid (HOBr), diatomic chlorine (Cl_2), and chlorine monoxide (ClO) were made with 1-minute time resolution using chemical ionization mass spectrometry. Br_2 production was examined from various saline snow and sea ice samples exposed to sunlight and ozone within an outdoor snow chamber. Surface snow collected above tundra and first-year sea ice was found to be an efficient substrate for bromine activation that was dependent on acidity and bromide/chloride ratios [*Pratt et al.*, 2013].

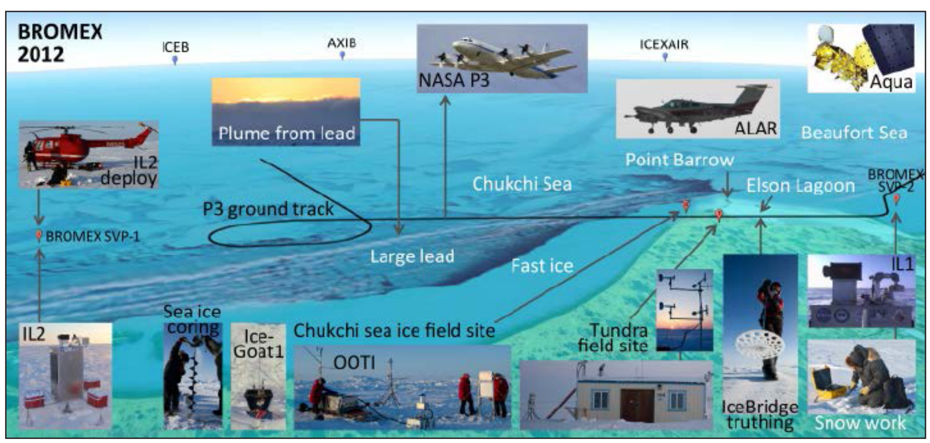

Fig. 1. Description of the Bromine, Ozone, and Mercury Experiment (BROMEX) field campaign. The background image is a composite from Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua bands 1, 2, and 7 on 25 March 2012: sea ice appears as blue, open water as dark blue, plumes from leads as long blue streaks, lagoon as light blue, and land as green. For satellites, Aqua is shown as an example among many other satellites used. Aircraft include Airborne Laboratory for Atmospheric Research (ALAR), NASA P3, and BO-105 helicopter. Balloons mark buoys (Surface Velocity Program buoy 1 (SVP-1); SVP-2; IceGoat1 buoy; Ice Beacon (ICEB) buoy; Airborne Expendable Ice Buoy (AXIB); and ICEXAIR, an air-droppable meteorological buoy built by Christian Michelsen Research). The IceLander1 (IL1) and IL2 instruments, as well as Environment Canada's Out-On-The-Ice (OOTI) system for mercury measurements are also shown. Several other field sites, instruments, networks, and activities are depicted. Photo and image credits: NASA and the BROMEX Team. A version of this figure with larger versions of the inset photos can be found in the supporting information in the online version of this brief report.

In addition, portable weather stations were installed to measure wind and temperature. Buoys from the International Arctic Buoy Programme (IABP) deployed offshore from the field camp and beyond provided measurements vital for large-scale analyses. The IceGoat1 meteorological buoy, acoustic instrumentation systems, and thermochrons were also deployed. Analyses of temperature data revealed complexities that emphasize the need for a rigorous protocol to be developed for accurate and consistent temperature measurements across the Arctic. Field excursions were also launched to collect extensive in situ data for sea ice and snow measurements for remote sensing validations.

Need for Future Monitoring of Arctic Chemistry

BROMEX successfully acquired a vast array of coordinated measurements beyond the initial intention of the research scope. While analyses are ongoing, the results from BROMEX are already beginning to further advance scientific understanding of bromine processes (activation, distribution, and termination), together with ozone depletion in the troposphere and mercury deposition into sea ice. In view of the Minamata Convention, a landmark agreement reached in January 2013 for a global treaty to curb mercury pollution, interdisciplinary research such as that conducted as part of the BROMEX project needs to be sustained in establishing the scientific foundation to assess the efficacy of the treaty. As climate change profoundly alters the Arctic, monitoring chemical and environmental changes in the new Arctic is crucial to account for their potential impacts.

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Reference

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