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Regular Airborne Surveys of Arctic Sea Ice and Atmosphere

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The Arctic is undergoing rapid environmental change, manifested most dramatically by reductions in sea ice extent and thickness. The changes are attributed to anthropogenic effects related to greenhouse warming, with secondary contributions from changing ocean and wind currents as well as from pollutants, especially "absorbing" black carbon. The warmer Arctic air temperatures and new patterns of wind and ocean circulation have also contributed to a younger ice cover [*Maslanik et al.,* 2011].

Specific factors that determine the temporal distribution of sea ice are poorly understood because few observations of key variables have been made in the central Arctic. For example, the planetary boundary layer (PBL), the lowest part of the atmosphere governed by interaction with Earth's surface, plays a critical role involving the exchange of momentum, heat, water vapor, trace gases, and aerosol particles. Satellites can provide limited observations of sea ice properties, but so far, accurate measurements of ice thickness or boundary layer properties have not been easily obtained. Although satellite retrievals of geophysical variables might be an essential source of information, their reliability remains questionable owing to inadequate spatial and/or temporal resolution and to a need for further validation.

To address these limitations, the Alfred Wegener Institute for Polar and Marine Research (AWI) and Environment Canada (EC) initiated a program to undertake airborne surveys of sea ice thickness and properties of the Arctic troposphere. Data collection began in 2009, and efforts are under way to make the surveys an annual occurrence.

Initial Surveys

The first campaigns, referred to as the Polar Airborne Measurements and Arctic Regional Climate Model Simulation Project (PAMARCMiP), took place during April 2009 and April 2011. Measurements were made from AWI's Polar 5 aircraft, a Basler BT-67 (see Figure 1), and the existing network of Arctic meteorological stations served logistical needs of the mission (providing fuel, facilities for overnight stays, office and Internet services, runway ground support, etc.) very well.

Instrumentation on board Polar 5 included a tethered electromagnetic sensor to measure ice thickness; analyzers for ozone, gaseous elementary mercury, bromine monoxide, and black carbon concentrations; in situ measurements of aerosol number concentration and size distribution; and spectral aerosol optical depth derived from photometric data. In addition, aerosol and ozone lidar (light detecting and ranging) were operated, and dropsondes were launched to characterize atmospheric state variables. Participants from Germany (AWI, Jade University of Applied

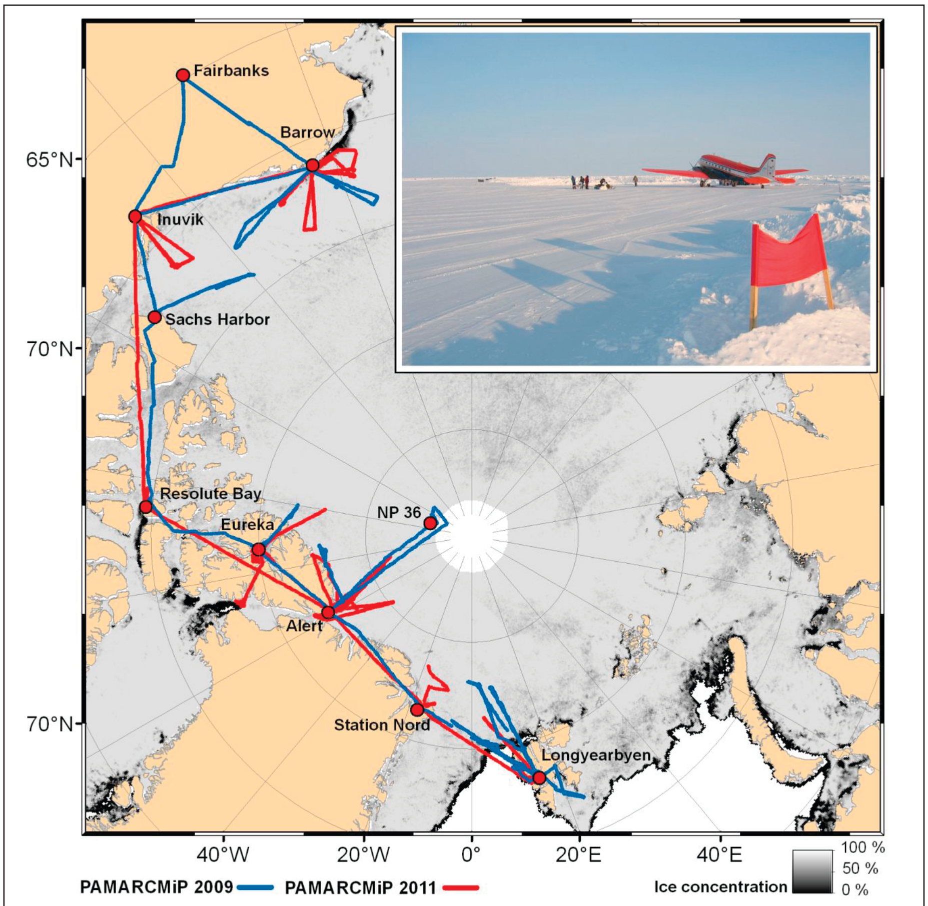

Fig. 1. The (blue) 2009 and (red) 2011 flight tracks of the Polar 5 aircraft, as part of the Polar Airborne Measurements and Arctic Regional Climate Model Simulation Project (PAMARCMiP). The image also shows sea ice concentration derived from the Earth Observing System satellite's Advanced Microwave Scanning Radiometer, based on data from 15 April 2011 (courtesy of G. Heygster). Along the transect are Longyearbyen (in Svalbard, Norway), Station Nord (in Greenland), Alert and Eureka (on Canada's Ellesmere Island), the Russian North Pole drifting station NP-36, Resolute Bay (Cornwallis Island, Alaska), and Sachs Harbor (Banks Island, Alaska), as well as the Alaskan cities of Fairbanks and Barrow. The northernmost position was reached on 10 April 2009 (88°40'N), made possible with support from the Arctic and Antarctic Research Institute, St. Petersburg, Russia, which had prepared an ice runway at NP-36 and supplied fuel for the return flight to Alert. Inset shows the Polar 5 aircraft at NP-36 (photo by R. Stone).

Sciences, and FIELAX), Canada (EC, University of Alberta, and York University), Italy (Italian National Research Council's Institute of Atmospheric Sciences and Climate), Russia (Arctic and Antarctic Research Institute), the United States (National Oceanic and Atmospheric Administration's Earth System Research Laboratory, NASA's Langley Research Center, University of Fairbanks, and National Science Foundation), and the European Space Agency (ESA) conducted the surveys between Svalbard, Norway, and Barrow, Alaska, as indicated in Figure 1. Both traverses were completed within a month, providing three-dimensional snapshots of sea ice and atmospheric conditions along the track.

Preliminary Results

The campaigns yielded comprehensive sea ice thickness surveys over key regions of the central Arctic Ocean. Comparisons with previous surveys showed that the modal thicknesses of old ice had changed little between 2007 and 2009 [*Haas et al.*, 2010] but were significantly less in 2011. A highlight of the 2011 campaign was a coordinated activity in the vicinity of Alert to validate the ESA's CryoSat-2 mission (http://www.esa.int/esaLP/LPcryosat.html), which included flyovers of several in situ sea ice validation sites established by an international team coordinated by ESA.

While previous coastal observations revealed that ozone and mercury are often depleted within the Arctic's PBL during spring, limited observations had been available over the more consolidated pack ice. During both campaigns, Polar 5 made several low-level traverses over the central Arctic, documenting similar ozone depletion events in spring within a very shallow PBL.

The 2009 aerosol data indicated that the lower troposphere was generally more turbid than middle and higher levels and included higher concentrations of black carbon. This gave rise to enhanced light extinction at low altitudes as derived from profiles of aerosol optical depth and retrieved from the airborne lidar system. During April 2009 the atmosphere over the European and North American Arctic was variably hazy, with transport mainly from Eurasia [*Stone et al.,* 2010]. Conditions were favorable for the transport of Arctic haze, as has been documented in the literature [e.g., *Shaw,* 1995]. During both campaigns, black carbon was observed at all altitudes sampled but at relatively low concentrations compared with historical values. Some aerosol measurements in 2011 were also coordinated with satellite flyovers of NASA's Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO; http://www.nasa.gov/mission_pages/calipso/main). This helped to validate aerosol retrievals.

Future Plans

On the basis of these two successful campaigns, the plan is to undertake annual April missions in successive years to monitor interannual changes of surface and atmospheric properties at the time of sea ice maximum extent. The goal is to gain a better understanding of how the surface energy budget varies and in turn affects the distribution of sea ice cover if the global climate continues to warm. Investigations of how the Arctic atmosphere, ocean, and cryosphere are coupled to the global atmospheric and oceanic circulations are also to be undertaken as part of PAMARCMiP. In addition, the further acquisition of aerosol and trace gas data from the suite of instruments on board Polar 5 will provide valuable validation data sets to improve satellite retrievals and develop better parameterizations for use in regional climate models.

Acknowledgments

PAMARCMiP was a success thanks to behind-the-scenes efforts by many individuals from the participating institutes and affiliates, In particular, the flight crews are due special thanks. We would also like to thank Thomas Krumpen (AWI) for help in preparing the flight map.

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