Aircraft Measurements of Heat Fluxes Over Wind-Driven Coastal Polynyas in the Bering Sea

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***Abstract*—The first estimates of the average bulk heat transfer coefficient for Arctic sea ice are presented as a function of mean ice thickness. Turbulent heat flux measurements made by the NASA P-3 over the St. Lawrence Island polynya (SLIP) and Kuskokwim Bay in the Bering Sea during AMSR-Ice03 were used to estimate the values of the heat transfer coefficient $C_{\rm H}$. Estimates of ice thickness were made from the algorithm of Perovich *et al.* using broadband albedos obtained from Moderate Resolution Imaging Spectroradiometer data. Plots of $C_{\rm H}$ as a function of ice thickness showed a nearly linear relationship for ice thicknesses in the range of 0–14 cm in the polynyas. Previous estimates of $C_{\rm H}$ for different cases over the SLIP were 1.2×10^{-3}, but no estimates of ice thickness were available. These results will allow more accurate estimates of heat fluxes from the thin-ice areas of polynyas using satellite retrievals.**

***Index Terms*—Atmospheric measurements, covariance analysis, meteorology, remote sensing, sea ice.**

I. Introduction

POLYNYAS are irregular regions of open water in sea ice that range from a few hundred meters to hundreds of kilometers [1]. They occur at certain predictable locations throughout polar regions and under climatological conditions where ice-covered waters would be expected [2]. They appear in winter when air temperatures are well below the freezing point of seawater and are surrounded by water that is ice covered.

Wind-driven coastal polynyas, which are the subject of this investigation, are called latent heat polynyas [2] and are major sources of nonuniformity in the surface forcing of the atmospheric boundary layer (ABL) in the Arctic. A wind-driven coastal polynya is formed when offshore winds push the ice away from the coastline and expose open water to the cold air. Frazil ice is initially formed and organized into linear streaks by Langmuir circulations in the water. As the frazil is blown downwind in the polynya, it increases in concentration, forming "pancakes" that pile up at the downwind side of the polynya.

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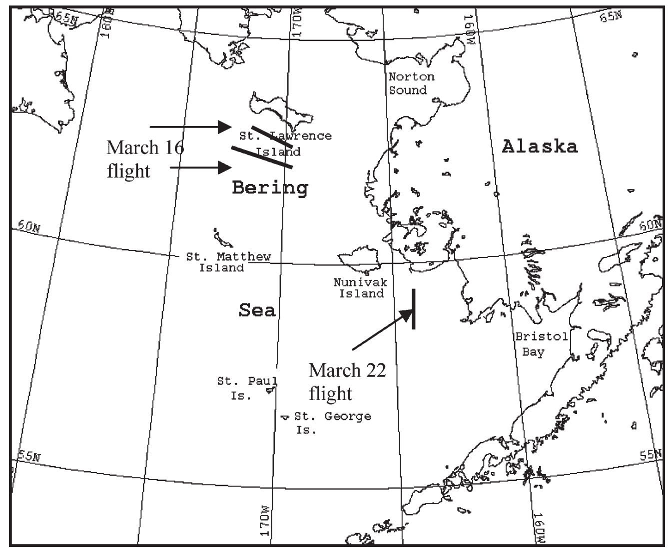

Fig. 1. Map of the Bering Sea showing the locations of the two flights.

Polynyas play a critical role in the Arctic climate in a number of ways [3]. An important way that we focus on here is through the transfer of large sensible heat fluxes to the atmosphere from the open-water and thin-ice areas of polynyas. This results in the formation of sea ice and the production of dense water, which plays a major role in the maintenance of the Arctic halocline. Although polynyas cover only 3%–4% of the area of the Arctic, they control up to 50% of the ocean-to-atmosphere heat transfer in winter [4].

Recurrent polynyas in the western Arctic form on the Canadian and Alaskan coasts, from Banks Island to the Bering Strait, and on the Siberian coast, from the Bering Strait to the New Siberian Islands, and have been the subject of both modeling [5], [6] and satellite observational studies [7], [8]. A major polynya in the Bering Sea occurs in the lee of St. Lawrence Island under northerly wind conditions.

The amount of dense shelf water that formed in these coastal polynyas depends on the ice production, which in turn depends on the ocean-to-atmosphere heat flux. Estimates of these heat fluxes over open-water areas of coastal polynyas are typically made by using a combination of satellite-observed open-water/thin-ice areas and data from either weather stations or surface weather analyses. The sensible heat flux varies by three orders of magnitude as the polynya opens and closes. During winter and early spring, large air–sea temperature differences can result in heat fluxes of 500–1000 W/m^2 [9].

Estimates of the contribution of polynyas to ice production and deep-water formation have been made through

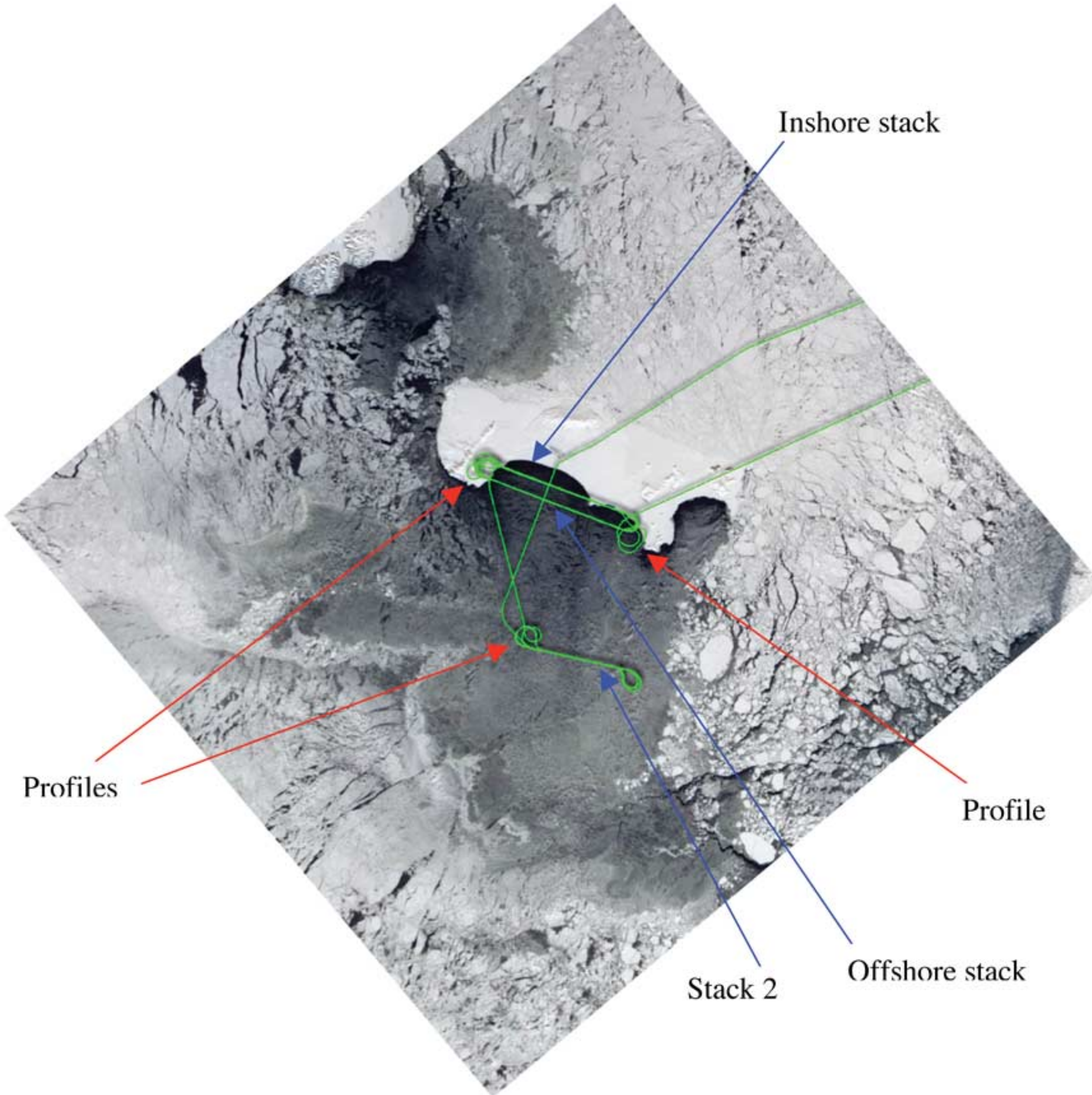

Fig. 2. Entire flight track (green line) for the March 16 flight over the SLIP, which was overlayed on a MODIS image.

the use of satellite data, in particular, passive microwave measurements using instruments such as the Special Sensor Microwave/Imager and recently, the Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E) [10]. There are a number of weak links in the satellite-based measurements of polynya areas, which may constitute a major source of error in computing ice and dense-water production [6], [11].

The principal sources of error result from inaccuracies in measuring the open-water area (i.e., polynya size), in estimating the meteorological parameters (near-surface air temperature, humidity, and wind speed), and in using bulk flux parameterizations to calculate the heat and moisture fluxes. Another source of error results from neglecting the heat loss over thin-ice areas. Furthermore, modeling studies have shown that correct parameterization of both the polynya forcing areas (open-water area) and the polynya forcing fall-off region (thin-ice area) is important to understanding the production of dense water and its transport across the continental shelf [12].

VII. Summary

We presented the first estimates of the average bulk heat transfer coefficient for Arctic sea ice as a function of mean ice thickness. Turbulent heat flux measurements made by the NASA P-3 over the SLIP and Kuskokwim Bay in the Bering Sea during AMSR-Ice03 were used to estimate the values of the heat transfer coefficient C_{H}. The estimates of ice thickness were made based on the algorithm of Perovich *et al.* [28] using broadband albedos obtained from MODIS data. The plots of C_{H} as a function of thickness showed a nearly linear relationship for ice thicknesses in the range of 0–14 cm in the polynyas here. Previous estimates of C_{H} for different cases over the SLIP were 1.2×10^{-3}, but no estimates of ice thickness were available. These results will allow more accurate estimates of heat fluxes from the thin-ice areas of polynyas using satellite retrievals.

For different ice conditions, the estimates of C_{H} for multiyear ice with open leads in the central Beaufort Sea were 1.2×10^{-3} [32], whereas the value of C_{H} was 0.73×10^{-3} for solid first-year ice in the northern Bering Sea [22]. These latter two cases show the large effect that areas of open water in sea ice can have on the transfer of heat from the ocean to the atmosphere in the Arctic.