Cloud Radiative Forcing at the Surface of Arctic Polynyas

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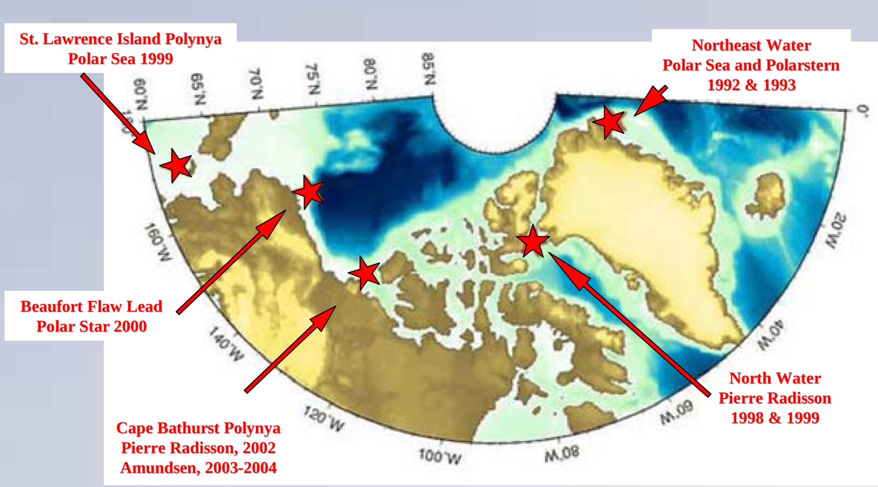
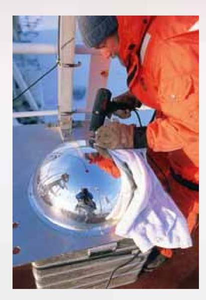
Introduction

The Arctic Shelf Seas are a critical component not only of the Arctic Ocean, but of the Earth's climate system as a whole. The varying interactions between the ocean and the overlying atmosphere that result from the seasonal changes in the sea-ice cover influence the surface heat budget, including the radiative fluxes at the surface. In general the radiative terms of the surface heat budget predominate over the turbulent exchanges. A series of possible feedbacks arise between the surface and the clouds above; these can serve to increase or diminish the heat at the surface available for ice melt or refreeze, and amplify or reduce perturbations to the ice cover.

Here we present analyses of measurements of clouds and surface radiative fluxes taken from a series of cruises on research icebreakers to Arctic Polynyas during the sunlit months of several years in the past decade and more.





Arctic Polynyas studied in IAPP. Measurements have been taken with a (largely) self-consistent set of instruments.

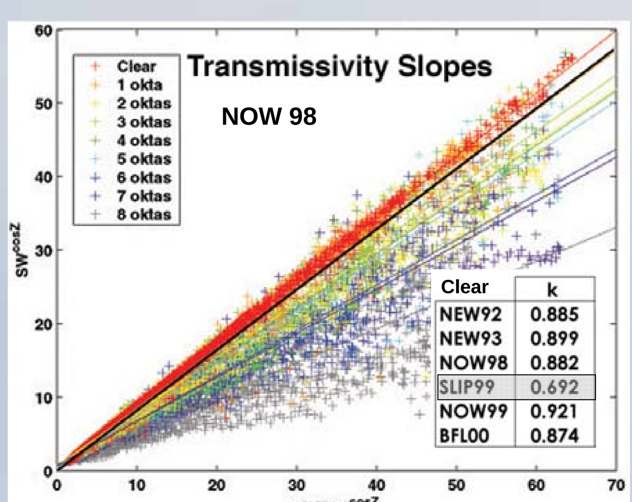
The effects of of clouds

•Clouds reduce the incoming solar radiation (SW↓).
•Clouds increase the incident thermal infrared radiation at the surface (LW↓).
•Clouds modulate the thermal infrared radiation leaving the top of the atmosphere.

$$C_{SW} = SW\downarrow_{Ac} - SW\downarrow_{(Ac=0)}$$

$$C_{LW} = LW\downarrow_{Ac} - LW\downarrow_{(Ac=0)}$$

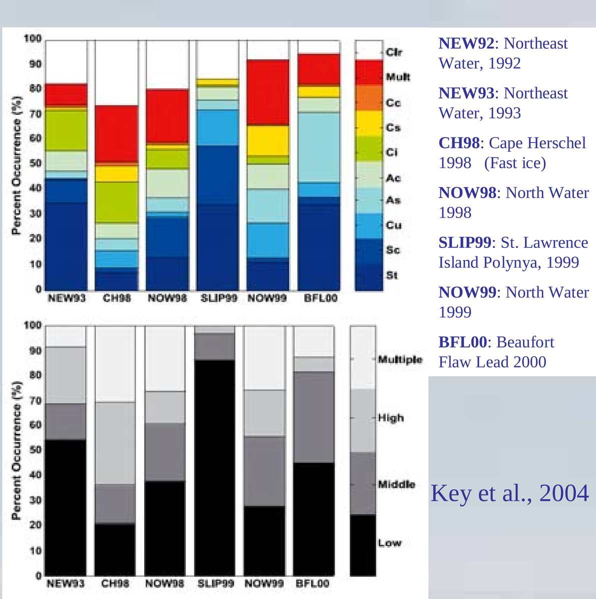
Cloud radiative forcing (CRF; Ramanathan et al, 1989) is defines here in terms of incident radiation.



Atmospheric transmissivity (k) :

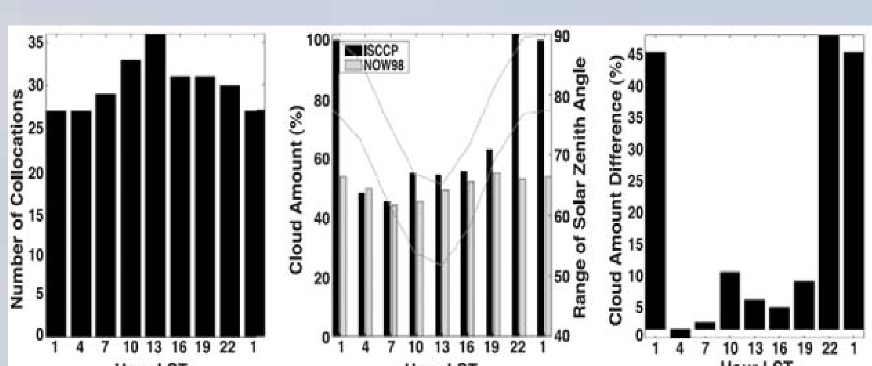
$$SW\downarrow = SW_o\downarrow\, k^{(1/\cos(\theta))}$$

where θ is the solar zenith angle. (Minnett, 1999). k shows little variability for different polynyas, SLIP being an exception (Key, 2004).



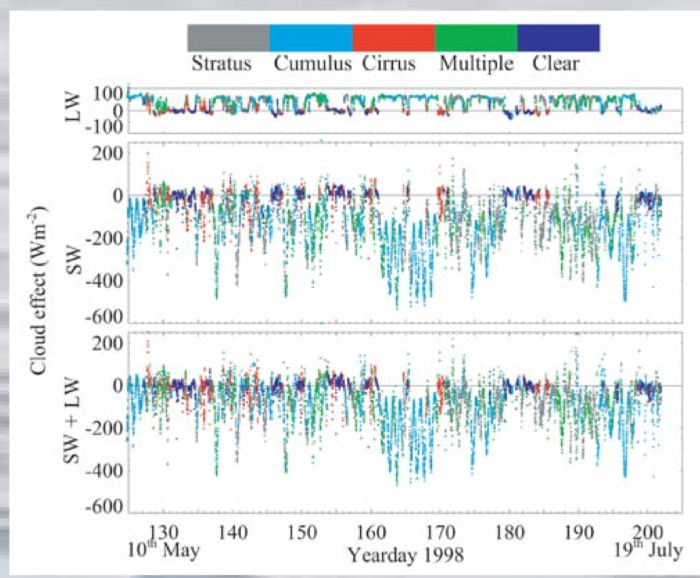
Key et al., 2004

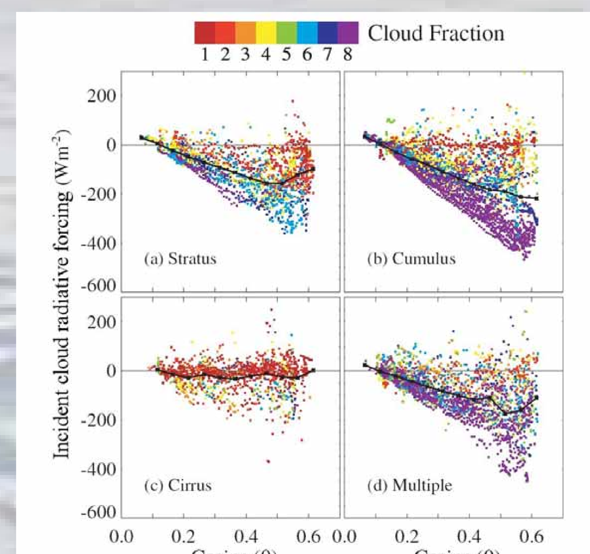
Cloud characteristics over Arctic polynyas.



ISCCP (International Satellite Cloud Climatology Project; Rossow et al 1996) retrievals from AVHRR [280km, 3hr] over the North Water. Cloud amount retrieved over the polynya is good, but diurnal representation is poor. This is the case over all of the regions studied (Key et al., 2004)

North Water 1998.





Left: Time series of longwave, shortwave and net cloud forcing, where the colors represent the cloud type present. Right: Cloud forcing as a function of solar zenith angle (θ) . The black lines represent the average value of net cloud forcing as a function of cosine solar zenith angle (θ) calculated in bins of 0.05. From Hanafin and Minnett, 2001.

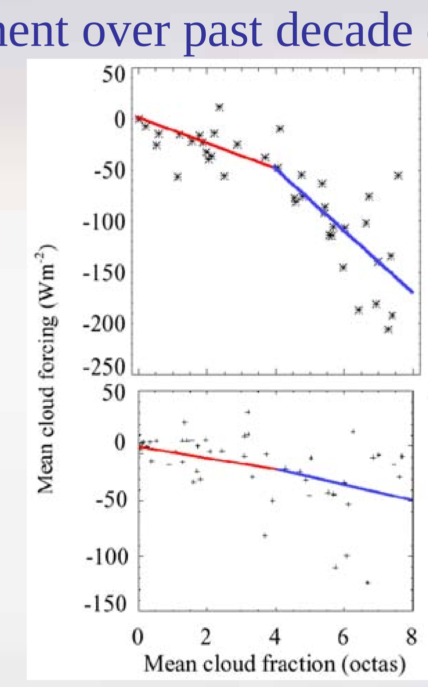
Background

The cryosphere and underlying ocean are largely controlled by atmospheric drivers, from local convective processes to large-scale climatic indices, such as the Arctic Oscillation.

• The interaction between the atmosphere and Arctic components – frozen, liquid, and gaseous – is complex and difficult to measure, and so still remains uncertain, both in magnitude and sign.
• The Arctic is changing: evidence from satellite and in situ measurements that Arctic ice is becoming thinner, and less extensive in the summer (Serreze et al, 2003). 2005 experienced a new minimum in ice cover.
• Polynyas and leads are a natural subject for research in possessing broad range of characteristics on relatively small scales.
• The Arctic is considered to be particularly sensitive to climate change (Arrhenius, 1896).
• The complex interactions between the surface and the overlying atmosphere are important aspects of the surface heat budget both locally and, through the atmospheric and oceanic general circulations, at global scales.
•Coupled and global climate modeling efforts show significant divergence in Arctic predictions; little improvement over past decade or so.

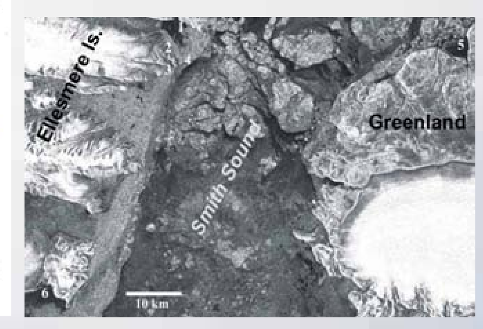
The effects of ice

The presence or absence of ice on the ocean influences the radiative fluxes and surface heating by replacing bright, reflective surface with a dark, absorbing one. Transitions can be on short time and spatial scales. CRF is bilinear over open water, more linear over fast ice.



NOW 98 – polynya

Cape Herschel – fast ice at north of NOW



Summary of Results

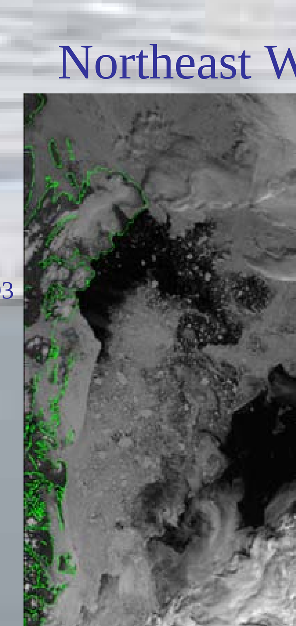
•Polynyas and leads modify, and are modified by, the atmosphere above (radiatively and dynamically – Marsden *et al*, 2004) and the water beneath
•Effects occur on scales that are not resolved by climate models and GCMs
•Effects occur on scales that are not easily resolved in many satellite products.
•Some aspects of the atmosphere above polynyas are common (k = 0.89), but most are not. For example, wind directions are influenced by coastal orography.
•Data from coastal weather stations should be put into context, and are not necessarily applicable to the conditions off-shore.
•For the summer season, turbulent fluxes are secondary to radiative fluxes, in terms of heat budget., but are important to injecting humidity and CCNs into the boundary layer.
•Cloud radiative forcing is generally negative during the summer months and positive otherwise. Positive for large solar zenith angles.

Conclusions

•Scales of polynyas allow for in-depth sampling of fairly complete, complex Arctic conditions. Studying leads and polynyas provides a test-bed for the more open water areas anticipated in future decades.
•Feedbacks in Arctic leads and polynyas can accelerate or decelerate the changes; interactions between radiation, clouds, aerosols and surface albedo are critical.
  -Timing is important: earlier polynya opening has +ve CRF; becomes –ve as season progresses.
•Feedbacks between clouds and aerosols and the surface are complex and poorly understood.
  - Need for advanced and accurate parameterization schemes which include the complex atmospheric interactions.
  - Unsatisfactory cloud record and lack of understanding of many feedbacks.
  - Second order effects, such as cloud-aerosol interactions, may change the sign of cloud radiative forcing, supporting further melt or bringing stability to the system and encouraging ice re-freeze.
•The circum-Arctic flaw lead system links many coastal polynyas and will become more extensive as ice retreats.

Northeast Water: then and now

NOAA-11 AVHRR July 31, 1993



NASA Aqua MODIS Sept 5, 2004

Future developments

The IAPP Studies have revealed much about the behavior of Arctic polynyas and the interaction with the atmosphere above. But the Arctic is changing and our current understanding may not be applicable as the amount of open water in the Arctic increases . "**Polynyas in the Arctic's Changing Environment**" **(PACE)** is designed to provide the framework for future endeavors, building on IAPP results and extending research into the changing Arctic system.

Acknowledgements

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• Captains, crews and colleagues of the *Polar Sea*, *Polar Star*, *Pierre Radisson* and *Amundsen*
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Background Photograph – taken from the bridge of the NGCC *Amundsen* in the Beaufort Sea, July 2004, during the year-long expedition of the Canadian Arctic Shelf Exchange Study.