Measurements of the Summertime Surface Radiation Budget in the Arctic

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Abstract

Measurements of the long- and short-wave incident radiation taken from the *USCGC Polar Sea* during a research cruise to the Northeast Water Polynya during the summer of 1993 are analyzed, together with observations of cloud type and amount, to determine the effects of summertime Arctic clouds on the surface radiation budget. The solar zenith angle is found to be critical in determining whether clouds heat or cool the surface. For large solar zenith angles, the infrared heating effect of clouds is greater than the reduction in insolation caused by clouds, and the surface is heated by the presence of clouds. For smaller zenith angles, the surface is cooled by the presence of clouds; at intermediate zenith angles, the surface radiation budget is insensitive to changes in cloud cover.

Introduction

The Arctic is generally believed to be one of the regions to first reveal the effects of global climate change. The response of the Arctic system, in terms of changing cloud and ice cover, is rendered difficult to predict because of various competing feedback factors and the dearth of available data. Measurements taken during a recent Arctic research cruise are used to explore the dependence of the surface radiation fields on cloud cover and differing cloud types in summertime conditions.

Data

The data were taken during a research cruise of the *USCGC Polar Sea* to the area of the North Water Polynya off northeast Greenland in the western part of the Fram Strait (Figure 1). The cruise took place in the summer of 1993; measurements were taken from July 22 to August 17. The incident short-wave (~0.3 to ~3.0 µm) and long-wave (~5 to ~50 µm) radiation was measured by an Eppley Pyranometer and an Eppley Pyrgeometer mounted on gimbals on top of the instrument mast at the bow of the ship. This arrangement minimized the influence of the ship and its motion on the measurements. The sensors were sampled at 1 Hz; averaged to 1 minute; and, for this study, averaged to ± 10 minutes centered on the hour. The data set used here is completed by meteorological observations made every hour on the hour by trained observers at the level of the bridge of the ship. These observations include cloud amount and cloud type. The data were taken over a range of surface types from open water to total ice cover. The statistics of the observations are given in Table 1. For the purposes of this study, the cloud types have been grouped into stratiform (stratus and altostratus), cirriform (cirrus and cirrostatus), cumuliform (cumulus, stratocumulus and altocumulus), and multi-layered clouds. In addition, the cases where the sky is classified as "obscured" have been grouped together, as these are almost always characterized by the presence of fog. The distribution of observations is biased by the conditions encountered; e.g., more than half of all observations are for stratiform clouds and fog, and cirriform clouds cover <0.5 of the sky.

Discussion

Figure 2 shows calculated insolation (SW) at the top of the atmosphere, measured insolation, cloud amount, and the energy removed from the insolation (difference between calculated top-of-atmosphere insolation and measured surface insolation). The straight line segments in the first, second, and fourth panels indicate missing data and do not contribute to the subsequent analysis. Effects of changing solar zenith angle dominate the SW effects. The solar zenith angle effects divide the observations into two populations, with stratus and fog cases showing the largest difference with respect to the top-of-atmosphere insolation, while cirrus cloud effects are generally indistinguishable from clear skies (but this may result from the small amounts of cirrus clouds).

Figure 1. The track of the *USCGC Polar Sea* during the cruise to the Northeast Water Polynya in July and August 1993 superimposed on an image of the ice cover derived from the measurements of the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA-11 polar-orbiting spacecraft. The image was taken on July 11, 1993. Although the ice conditions were not stationary, the general distribution of ice is characteristic of the conditions for most of the cruise period.

Using the measurements from the clear-sky cases, the SW atmospheric transmission, normalized by solar zenith angle, can be calculated and is found to be 0.90 ± 0.02.

Table 1. Summary of hourly cloud observations.

Cloud Type	N	%
Stratus	151	23.3
Altostratus	13	2.0
Cirrostratus	4	0.6
Cirrus	78	12.0
Cumulus	2	0.3
Stratocumulus	41	6.3
Altocumulus	35	5.4
Multi-layered	36	5.8
Obscured (fog)	199	30.7
Clear sky	89	13.7
Total	648	100.0

Considering only the cases where the sky was totally cloud-covered, the SW transmission for different cloud types can be derived (Table 2). The clear-sky transmission value can be used to calculate the amount of energy removed from the insolation by clear-sky effects, and this is shown as the smooth line in the lowest panel of Figure 2. The erratic line is the difference between the calculated top-of-atmosphere insolation and the measured insolation at the surface. The difference between the two lines in this panel is the reduction in insolation due to the presence of clouds.

The measured LW↓ shows a strong dependence on cloud type and cloud amount, with highest values occurring under stratus and obscured skies. The mean, clear-sky, incident

Table 2. Observed SW transmission (for normal incidence).

Clear sky	0.90 ± 0.02
Stratiform	0.70 ± 0.11
Obscured (fog)	0.69 ± 0.12
Cumuliform	0.85 ± 0.08

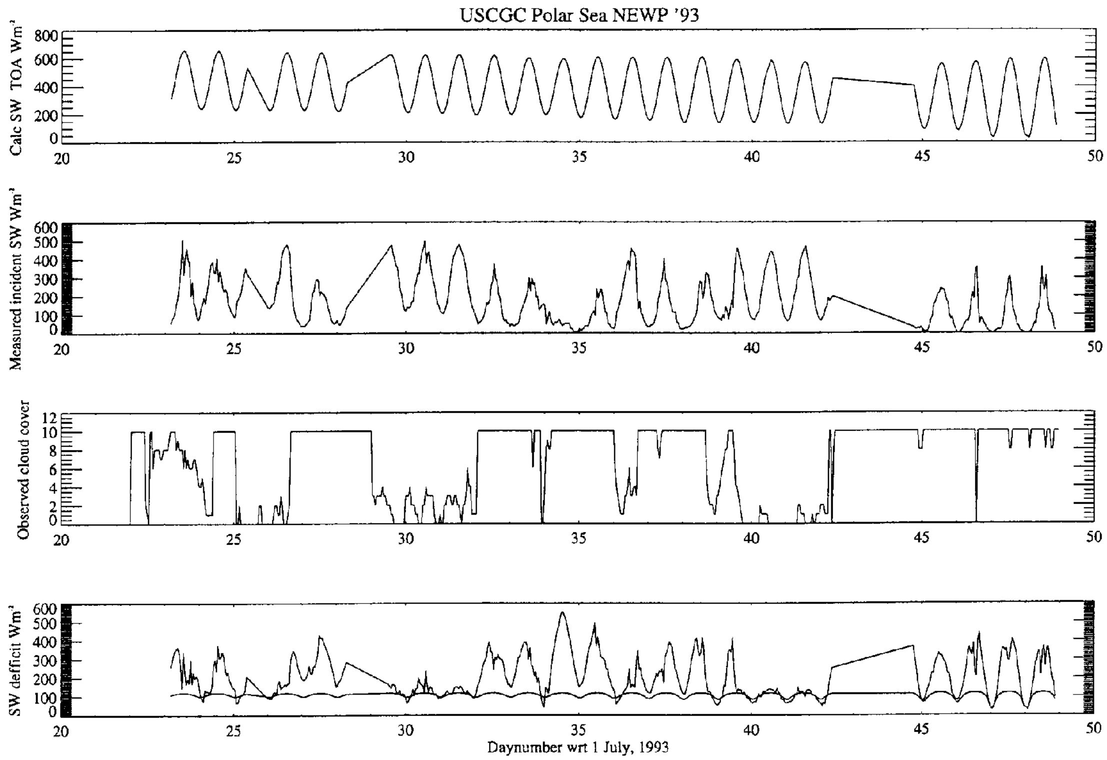

Figure 2. Time series of calculated top-of-atmosphere insolation, SW, (top panel), measured surface insolation, observed cloud cover, and SW deficit (bottom panel). The smooth line in the bottom panel represents the calculated surface insolation for clear-sky conditions with an atmospheric transmission of 0.90, which is the average value for the observed clear-sky cases; the erratic line is the difference between the top of atmosphere and surface insolation. Straight line segments in the first, second, and fourth panels indicate missing data.

long-wave radiation was 227.4 ± 13.7 Wm^{-2}, with stratus and obscured skies resulting in an increase of ~80 Wm^{-2} in the mean.

The effects of clouds in the SW and LW can be combined to give the net cloud effect. In Figure 3, the solid lines in the second and third panels are the appropriate clear-sky values, and the differences between these lines and the values indicated by the gray-tone blocks are the effects of clouds. When these are added, the net effect of clouds on the surface incident radiation is revealed (lowest panel). This shows a strong dependence on solar zenith angle and a weaker dependence on cloud type.

Plotting the net cloud effect as a function of solar zenith angle and cloud type reveals the effect for all types of clouds. For solar zenith angles >~80° (which make up 22% of these observations), the presence of clouds heats the surface (Figure 4). The distinction between the heating rates of different cloud types is not well defined, probably a consequence of the rather limited data set and the small number of samples for many of the cloud categories. For smaller solar zenith angles, clouds cool the surface, and there is a clearer distinction between different cloud types. The similarity between the cirriform and clear-sky cases reflects the small range of cloud cover experienced for cirriform clouds, i.e., the measurements are dominated by that part of the sky that is not cloud-covered. The scatter towards the zero-line for each cloud type is a result of decreasing cloud cover, and the scatter about the zero-line for clear skies indicates the consequences of variability in the clear-sky conditions (e.g., humidity, temperature, aerosol loading, etc.).

Conclusions

Using relatively simple instrumentation and manual observations, it is possible to determine some aspects of the dependence on clouds of the surface radiation fields in

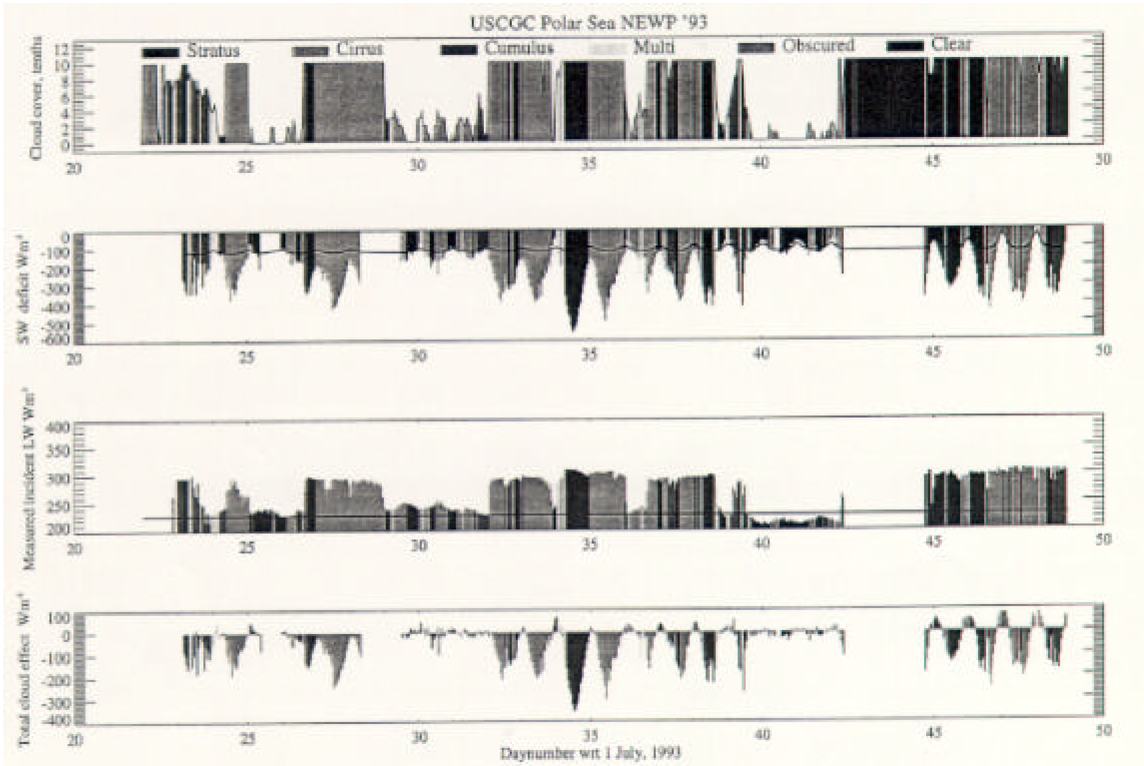

Figure 3. Time series of cloud cover, with gray tones indicating cloud type (top panel), SW deficit (made negative to indicate the surface is deprived of energy), measured surface incident longwave radiation, and net effect at the surface of the clouds (bottom panel). The solid lines in the second and third panels are the appropriate clear sky values.

the Arctic. If the Arctic cloud fields are modified as a result of global climate change, there will be regimes defined by the solar zenith angle where increasing cloud cover has opposite effects, and an intermediate regime in which the surface incident radiation is quite insensitive to cloud amounts and cloud types. Although the measurements are quite localized in time and space, they encompass a wide range of surface types, a typical range of solar zenith angles and a reasonable range of cloud cover and types. Thus, the conclusions are believed to be applicable for similar ranges of conditions elsewhere in the Arctic. Nevertheless, the data set is quite short and thereby limited, and the interpretation of the results should be made with this limitation in mind.

Acknowledgments

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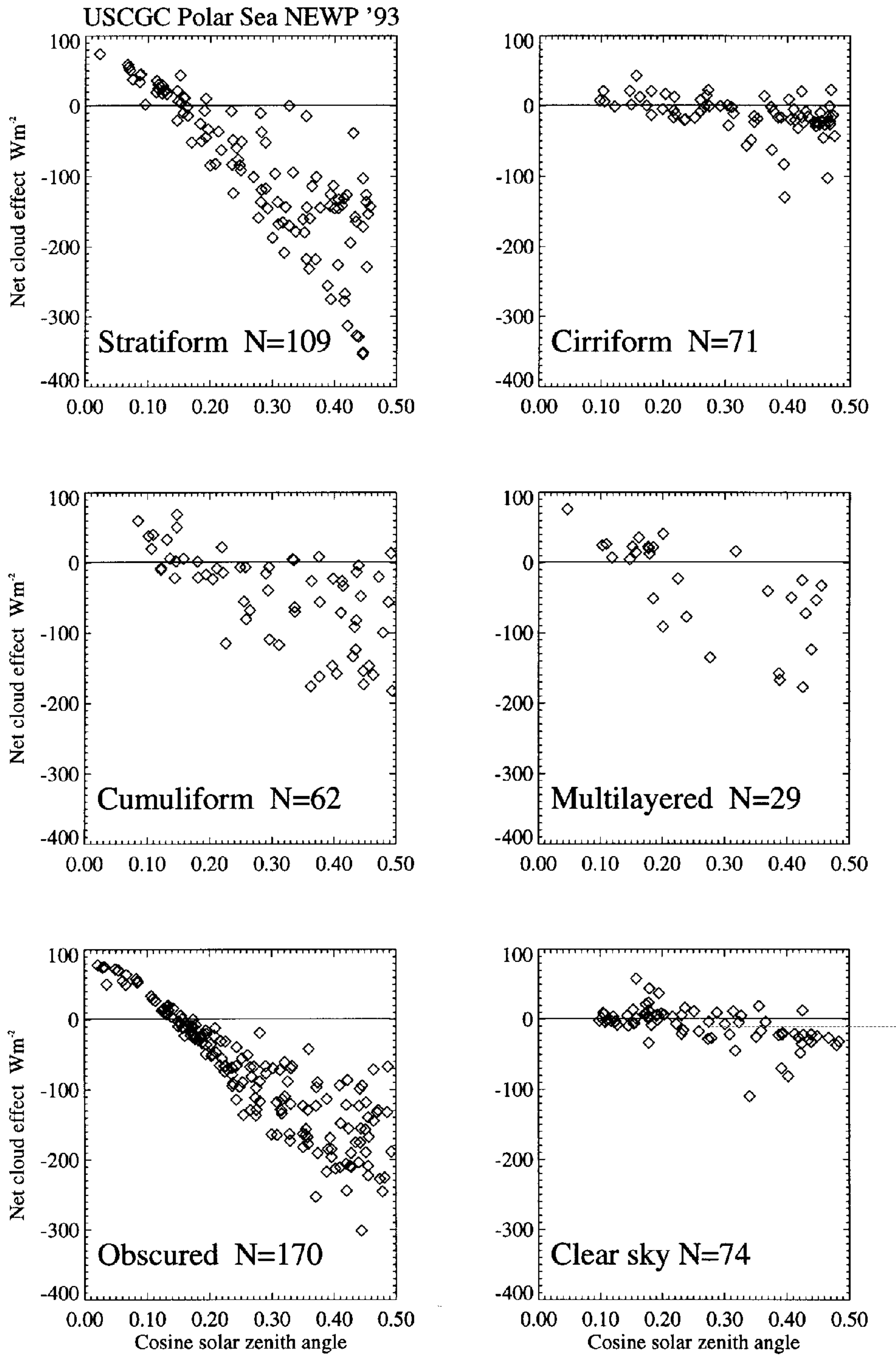

Figure 4. Scatter plots, by cloud categories, of the net cloud effects on the surface incident radiation as a function of solar zenith angle.