1.21 REGIONAL AND TEMPORAL VARIATIONS IN ARCTIC CLOUDINESS

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1. INTRODUCTION

The polar cap north of 60 degrees represents only 13% of the Northern Hemisphere, yet hosts a wide variety of regional climates ranging from marine environments of the North Pacific and North Atlantic Ocean to continental areas within Siberia and North America to the perennially ice covered Arctic Ocean. Many of these regions have large fluctuations from season to season and year to year. It is believed that this area may be very sensitive to climatic forcing and that it may respond dramatically to global warming. Clouds strongly influence the arctic atmosphere and surface energy budget through their interactions with infrared and solar radiation, yet the factors that control arctic cloudiness are not well known. For example, Tao et al. (1996) found that most general circulation models (GCMs) are unable to reproduce even the most basic features of the annual cycle of cloudiness and surface air temperature over the Arctic Ocean.

The present study examines interregional, interseasonal, and interannual variations in cloud amount, cloud type and temperature. The goal is to identify the most robust features of arctic clouds that numerical models should reproduce. Some will be easy to explain and other will demand more detailed observational analyses and modeling studies. Understanding the physical processes behind these features is essential for improving cloud parameterizations in GCMs and predicting their role in arctic climate change.

2. DATA AND ANALYSIS PROCEDURE

This analysis employs Hahn and Warren's (1999) Extended Edited Cloud Report Archive (ECRA), a compilation of cloud and meteorological variables extracted from WMO weather reports from ships (1952-1996) and land stations (1971-1996) over the globe. Hahn and Warren developed rigorous quality control procedures that rejected about 25% of the original reports, and provided advice on avoiding biases when analyzing the data. In the Arctic the most important of these biases is the underestimation of cloudiness due to insufficient illumination during the winter when there is no solar illumination. Hahn et al. (1995) determined the amount of lunar illumination needed to make accurate estimates of cloudiness at nighttime. They computed the poor-illumination bias by comparing cloud reports observed under "good illumination" (i.e., sufficient moonlight) with all nighttime observations. Table 1 shows the mean cloud amounts for all observations and for those with good illumination at drifting sea-ice stations in the Arctic Ocean during 1955-1988 during December and January, when the magnitude of the bias is largest. Poor illumination causes total cloud amount to be underestimated by about 5%, which is similar to what Hahn et al. (1995) found for the 1982-1991 period. In poor illumination the main problem is the ability to see high (i.e. cirrus) clouds, which are underestimated on average by about a third. Low and middle clouds that tend to be more opaque than high clouds are not underestimated by surface observers. Low-level cloud amount is actually overestimated in the dark, possibly because surface observers are classifying ice crystal precipitation as low cloud in some cases.

The main emphasis of this study is on low clouds, defined as having cloud base heights of less than 2 km. Since low clouds are observed accurately under low illumination, all observations are used. Low cloud types include sky-obscuring fog, stratus, stratocumulus, cumulus, and cumulonimbus [see Houze (1993) for detailed descriptions]. The strength of the vertical motions in these cloud types increases in the order they are listed, with cumulonimbus having the strongest vertical motions. The static stability of the boundary layer is greater for clouds at the beginning of the list. In this analysis, the cloud type "stratus" includes stratus and sky-obscuring fog, which is essentially stratus in contact with the surface.

3. THE ANNUAL MARCH OF ARCTIC CLOUDINESS

The annual cycle of cloudiness was analyzed at locations representing three distinct surface types found in the Arctic: Jan Mayen at 71 N in the Greenland Sea (marine), a cluster of stations in central Siberia near 62N, 125E (continental), and the North Pole region (perennial sea ice pack). The "North Pole" observations are from drifting sea-ice stations over the central Arctic Ocean. We examine long-term monthly means of

TABLE 1: The impact of poor illumination on mean cloud fraction during December and January over the Arctic Ocean, as estimated by subtracting the mean cloud fraction observed under "good" illumination (see text) from the mean of all observations. Observations of total, low, middle and high cloudiness are from the North Pole region during 1955-1988. Mean cloud fraction is given in percent.

	Total	*Low*	*Middle*	*High*
All observations	51	20	30	19
Good illumination	55	18	30	30
Bias	-5	+2	0	-11

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surface air temperature, total cloud fraction, and low cloud fraction; and the frequency-of-occurrence of the four main types of low cloud: stratus (St), stratocumulus (Sc), cumulus (Cu), and cumulonimbus (Cb). The results illustrate that the North Pole climate has marine traits in the summer and continental traits in winter.

3.1 MARINE – JAN MAYEN

Most years, Jan Mayen is surrounded by open water year round. As a result the annual cycle in surface air temperature is small in amplitude, ranging from about -5 C to 5 C with a peak in July/August. The sky is very cloudy all year: total cloud fraction and low-cloud fraction are within several percent of 83% and 57%, respectively, for all months. Stratiform clouds (St and Sc) are more common than cumuliform clouds (Cu and Cb), but there is still considerable variation in the frequency of individual types over the year. In the summer the frequency of stratus clouds reaches a peak of about 50% and that of cumulonimbus drops to less than 5%. These seasonal changes are closely associated with changes in the static stability of the atmospheric boundary layer. Stratus clouds, which favor higher static stability, are most frequent in summer when the ocean is cooler than the atmosphere, and cumulonimbus clouds reach their peak during winter when the ocean is warmer than the atmosphere.

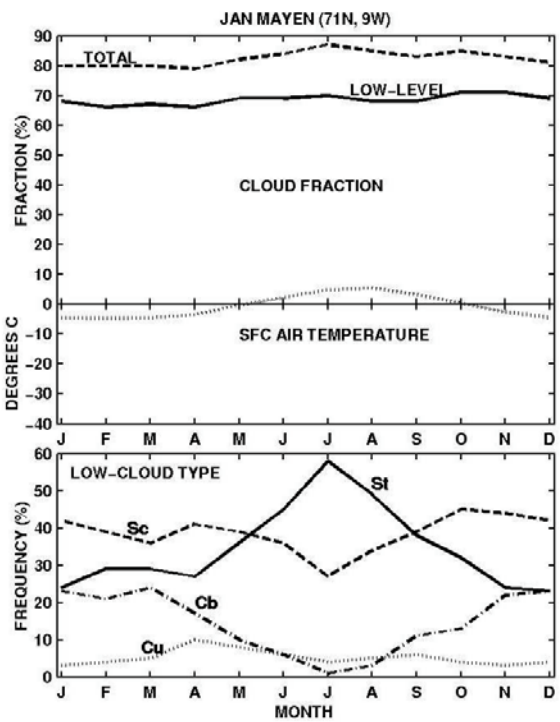

Figure 1: Mean annual cycle of cloud properties and surface air temperature at Jan Mayen, an island in the Greenland Sea at 71 N. The upper panel shows total and low-level cloud amount and temperature; the lower panel shows the frequency of occurrence of low-level cloud types: stratus and sky obscuring fog (St), stratocumulus (Sc), cumulus (Cu), and cumulonimbus (Cb).

3.2 CONTINENTAL – CENTRAL SIBERIA

Ranging from –37 to 18 C, the amplitude of the mean annual cycle of temperature is one of the largest on the globe. The total cloud fraction is fairly steady, with minor peaks in May and October. During summer, when the solar heating of the surface is large, cumuliform types are the most common low clouds. During the winter there are virtually no low clouds. It appears that the dome of cold air that forms over Siberia in the winter effectively isolates the surface from the free atmosphere. The weather systems that bring upper-level clouds to the area seem to pass over the cold dome rather than advecting heat and moisture at lower levels. At these temperatures, any moisture entering the lower atmosphere probably would convert directly to ice particles that fall out of the atmosphere rather than forming low clouds. Beesley and Moritz (1999) have suggested that this ice-fallout mechanism could explain the small amount of low cloud observed in areas where the temperature is consistently below about –15 C. Transitions in low-cloud amount occur mainly in April and October when the mean surface air temperature is about -10 C to –15 C.

3.3 PERENNIAL SEA ICE – NORTH POLE

The monthly average temperature over the Arctic Ocean ranges from about -32 C in January to 0 C during the summer melt. The dominant feature of the annual cycle is the variation of low-cloud fraction from 20% in winter to 65% in summer. During summer, the total and low cloud fractions in the North Pole region are similar

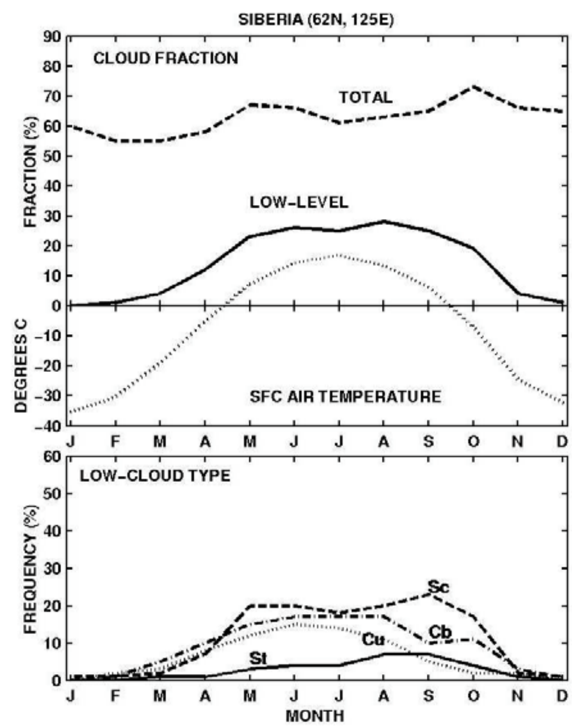

Figure 2: As in Figure 1, but for a region near 62 N, 125 E in central Siberia.

to those in Jan Mayen. Also like Jan Mayen, stratus is the most common type of summertime low cloud, stratocumulus is close behind, and cumulus and cumulonimbus are fairly rare. In both cases, the surface is cooler than the atmosphere, owing to the relatively cool ocean near Jan Mayen and ice melting at the North Pole.

Winter conditions are much more similar to those in SIberia. Average temperature is below –30 C and most of the cloudiness is above 2 km. The low-cloud fraction, however, is greater than in Siberia. This difference may be related to the fact that weather systems from the northern Atlantic and Pacific enter this area more frequently than Siberia. Transitions in low-cloud fraction in spring and fall occur when the mean temperature is about –10 to –15 C, as in Siberia.

4. MERIDIONAL CLOUD VARIATION

The previous figures illustrate how the mean annual cycle of cloudiness, especially at lower atmospheric levels, is closely related to the surface type. This section examines the regional contrasts in low-level cloud properties and temperature for a given season.

Figure 4 shows variations in temperature and low clouds locations near the prime meridian from the North Pole to the Faeroe Islands during January. The North Pole region and Viktoriya Island are both north of the ice edge and have temperatures below –20 C. Jan Mayen and the Faeroe Islands, both surrounded by open ocean, are both warmer than –5 C. Again, an association is seen between low-cloud fraction and temperature: the mean fraction is less than 25% at the colder locations and more than 60% at the warmer stations. Stratocumulus is the only low-cloud type seen more than 15% at the colder locations during January. Cumulus and cumulonimbus frequencies increase with temperature at the open-water stations. The most salient feature of this figure is the general yet striking contrast in wintertime cloudiness between the ice pack and open ocean.

Figure 5 shows changes along the 125 E meridian from the Arctic Ocean into Siberia during July. Heading southward from the NP, temperature increases from 0 C to almost 20 C, low-cloud base height increases from about 330 m to over 1000 m, and low-cloud fraction decreases from 65% to about 28%. Notable changes in cloud type include a decrease in stratus frequency from over 45% in the central Arctic to less than 5% at 63 N, and increases in cumulus and cumulonimbus from less than 5% to about 20%. The decrease in stratus frequency in favor of the more convective cloud types probably explains the increase in cloud base height. Solar surface warming, increasing to the south, appears to be the main driver of these transitions. Presumably, the static stability is lower toward the south, which would favor convective clouds over stratiform layer clouds.

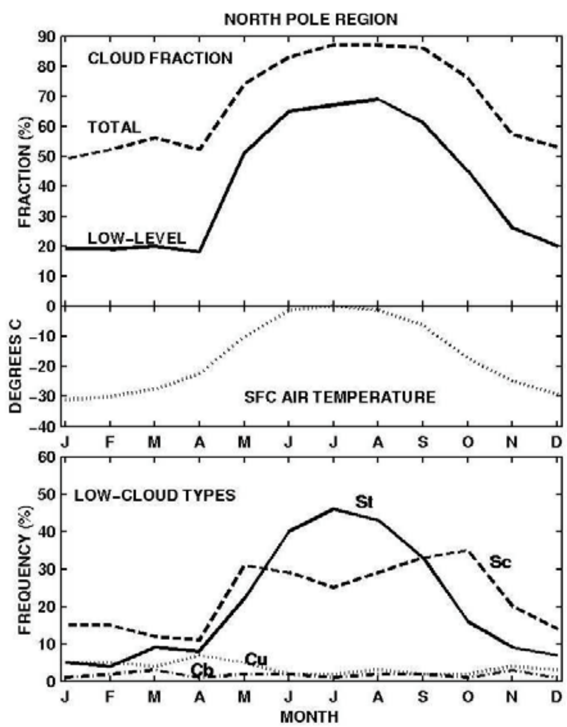

Figure 3: As in Figure 1, but for drifting sea-ice stations in the central Arctic Ocean.

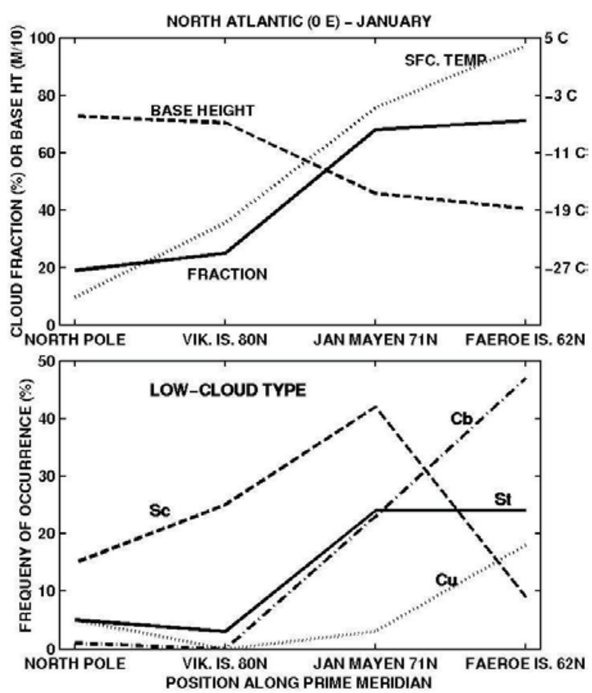

Figure 4: Transitions in cloud properties during January from the North Pole into the North Atlantic Ocean. From North to South, the locations are North Pole, Viktoriya Island (80N,34E), Jan Mayen (71N,9W), and Faeroe Islands (62N,7E). The upper panel shows low-cloud fraction (solid line), low-cloud base height (dashed line), and surface air temperature (dotted line, scale on right). Changes in low-cloud type are in the lower panel.

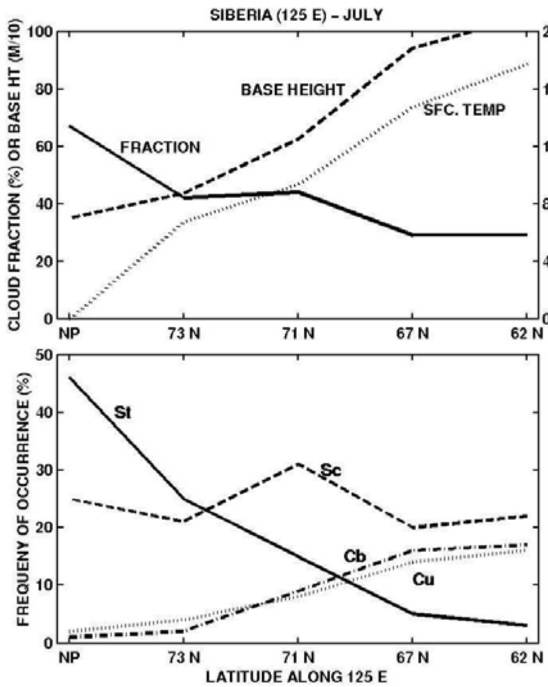

Figure 5: As in Figure 4, but during July along the 125 E meridian, from the North Pole into central Siberia.

This relationship between temperature and cloud fraction and cloud type is consistent with the findings of Norris (1998) for low clouds over oceans.

5. INTERANNUAL VARIATION

The above analysis of seasonal (Figs. 2 and 3) and regional (Fig. 4) variations in arctic cloudiness indicates that the mean low-level cloud fraction is significantly smaller when the average surface air temperature is below –10 to –15 C. The reason behind this relationship is not clear: clouds may be warming the surface or warmer surfaces may allow clouds to persist longer or the same process that brings warmer air also brings more low clouds. Nonetheless, in areas with mean temperatures hovering around –10 to –15 C, one might expect to find a correlation between surface temperature and low-cloud fraction from year to year. Figure 6 is a scatterplot of winter-averaged surface air temperature versus low-cloud cloud fraction for a region northeast of St. Petersburg, Russia. The positive correlation is clearly evident. Isaac and Stuart (1996) found that higher winter temperatures were associated overcast conditions in northwest Canada. More analysis is needed to gain a better understanding of this relationship.

6. SUMMARY

This analysis describes some of the most prominent features of low-level cloudiness in the polar cap north of 60 degrees, such as

- The dramatic reduction in mean low-level cloud fraction at temperatures below –15 C.

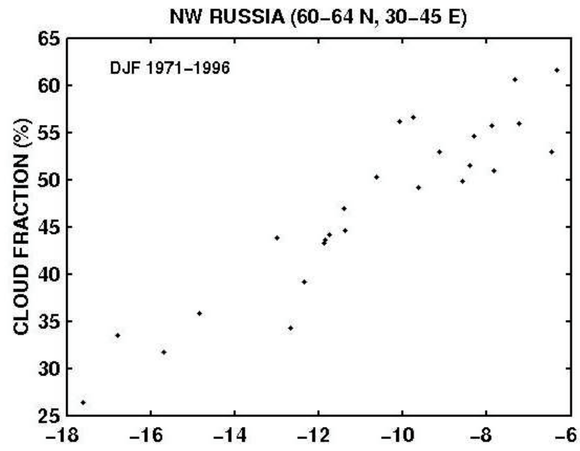

Figure 6: Scatterplot of low-level cloud fraction and surface air temperature in northwestern Russia (60-64N, 30-45E). Each point is December-February average over approximately 20 stations. The correlation is 0.93.

- The striking contrast in low-level clouds between oceanic and continental regions throughout the year,
- The pronounced annual cycles of low-cloud fraction in Siberia and the North Pole region,
- The "dual nature" of the cloud climatology of the central Arctic Ocean, which is similar to continental areas in the winter and similar to oceanic regions in the summer,

Any model relied upon to understand the past or predict the climatic conditions if the Arctic should be able to reproduce these features. Detailed modeling studies and analyses are needed to understand their causes and improve model physics.

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