CLOUD MASKING AND SURFACE TEMPERATURE DISTRIBUTIONS IN THE POLAR REGIONS USING AVHRR AND OTHER SATELLITE DATA

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1. Introduction

Surface temperature is one of the key variables associated with weather and climate. Accurate measurements of surface air temperatures are routinely made in meteorological stations around the world. Also, satellite data have been used to produce synoptic global temperature distributions. However, not much attention has been paid on temperature distributions in the polar regions. In the polar regions, the number of stations is very sparse. Because of adverse weather conditions and general inaccessibility, surface field measurements are also limited. Furthermore, accurate retrievals from satellite data in the region have been difficult to make because of persistent cloudiness and ambiguities in the discrimination of clouds from snow or ice.

Surface temperature observations are required in the polar regions for air-sea-ice interaction studies, especially in the calculation of heat, salinity, and humidity fluxes. They are also useful in identifying areas of melt or meltponding within the sea ice pack and the ice sheets and in the calculation of emissivities of these surfaces. Moreover, the polar regions are unique in that they are the sites of temperature extremes, the location of which is difficult to identify without a global monitoring system. Furthermore, the regions may provide an early signal to a potential climate change because such signal is expected to be amplified in the region due to feedback effects (Budyko, 1966).

In cloud free areas, the thermal channels from infrared systems provide surface temperatures at relatively good accuracies. Previous capabilities include the use of the Temperature Humidity Infrared Radiometer (THIR) onboard the Nimbus-7 satellite which was launched in 1978. Current capabilities include the use of the Advance Very High Resolution Radiometer (AVHRR) aboard NOAA satellites. Together, these two systems cover a span of 16 years of thermal infrared data. Techniques for retrieving surface temperatures with these sensors in the polar regions have been developed (Key and Haefliger, 1992; Steffen et al., 1993; Comiso, 1994; Massom and Comiso, 1994). Errors have been estimated to range from 1K to 5K mainly due to cloud masking problems. With many additional channels available, it is expected that the EOS-Moderate Resolution Imaging Spectroradiometer (MODIS) will provide an improved characterization of clouds and a good discrimination of clouds from snow or ice surfaces.

2. Cloud Masking

Microwave systems have been used to monitor the polar regions primarily because of almost all weather capability. Unfortunately, they cannot be used for surface temperature measurements because the snow surface is transparent to microwave radiation. Thermal infrared systems may be the only way to obtain spatially and temporally coherent surface temperatures. Accurate retrievals, however, may not be possible until an effective cloud masking technique is developed.

The techniques that have so far been used for masking clouds in the polar regions are: (a) spectral thresholding; (b) statistical and clustering; (c) textural; and (d) a combination of spectral, statistical and textural. The merit of each technique has been evaluated by Welch et al., (1992). The most popular option has been to use a combination of the first and the second because of ease in implementation. Textural techniques have been used for the difficult cases, but despite the introduction of sophisticated methods, (i.e., neural network, fuzzy logic, etc.), ability to masked out clouds consistently has not been achieved. Such techniques are also computationally very demanding.

This work utilizes primarily the first two techniques. The areas of emphasis are sea ice surfaces and continental ice sheets, but the technique is expected to be effective in the adjacent open water and land areas as well. Thresholding is usually done using the radiances of either channel 1 or channel 2, or the differences of the radiances between channels 3 and 4, and/or between channels 4 and 5. To gain insight into the effectiveness of this technique, a scatter plot of channel 1 radiances versus the differences between channels 3 and 4 is presented in Figure 1a while a scatter plot of the differences between channels 4 and 5 versus the differences between channels 3 and 4 is shown in Figure 1b. The data points are from an AVHRR image in the Central Arctic region (western side) on July 17, 1992. The plots show distinct clusters, labeled A, B, and C. The data points in cluster A are usually from sea ice covered regions, while those from cluster B are from ice free open water. The data points in cluster C and those distributed almost at random in non-cluster areas, represents cloud covered areas. Setting up a threshold (of say 10 and above) along the abscissa for (channel 3-4) would basically eliminate much of the cloud covered areas. Also, channel 1 (or channel 2) can be utilized to further remove cloud cover effects not removed by the channel 3-4 threshold. The channel 4-5 difference (see Figure 1b) can be similarly utilized to remove remaining cloud cover that has not been masked. The clusters A and B are distinct when channel 1 is utilized but are indistinguishable when the difference between channels 4 and 5 is used. With channel 1, the thresholds can thus be optimized separately for the ocean and ice surfaces.

In general, the utilization of a combination of channels as outlined above do not mask out all the clouds. Further masking is done by taking advantage of the fact that the cloud cover moves. By taking the difference between two orbits, further cleaning up of cloud covered areas is possible as was done in Comiso (1994). Additional procedure for open ocean areas was also utilized using co-registered SSM/I data. Weather effects are easily identified with the latter over the open ocean and was therefore used as additional mask when necessary.

Cloud masking is generally most effective for AVHRR data when done in a supervised manner. The thresholds must be set such that clear sky scenes are not inadvertently masked out for otherwise the data set will be full of gaps.

3. Polar Surface Temperatures

Historical orbital AVHRR data have been preserved in the GAC format but only a limited fraction is readily available in the full resolution LAC format. The resolution of the GAC data is about 4 km while that of the LAC data is about 1 km at nadir. For a global surface temperature data set, the difference in resolution is not critical in most scientific applications. However, it is important to know whether the LAC data provide significantly different results from the GAC data. Scatter plots similar to that of Figure 1 were generated for both GAC and LAC data and the results indicate very similar clusters for both of them. Also, it was found that there was no need to readjust the thresholds. The resulting surface temperatures were also found to be almost identical.

To minimize gaps due to the masking of persistent clouds, weekly surface temperatures are usually the final product. Cloud masking is done on an orbit to orbit basis. Only the data from the middle 351 are chosen from the 409 AVHRR measurements that goes from -55^{o} to $+55^{o}$ from nadir. Daily maps are created from all available orbital data during the day. Difference maps between days are then created to further mask out clouds which were not successfully masked out previously. Surface temperatures are generated from each daily map using a regression technique similar to that used for open ocean (McClain et al., 1985).

Examples of AVHRR polar maps during winter in the northern and southern hemispheres are shown in Figure 2. The maps show details that are not available from climatological maps which are usually generated from sparsely spaced historical data. Figure 2a shows that on July 19-25, 1988, the coldest area in the southern hemisphere is located, as expected, in the Antarctic plateau, but not at the Vostoc station where the coldest temperature on earth was previously observed. The coldest temperature in the northern hemisphere on January 17-23, 1988 is seen to have occured in the Greenland ice sheet. However, as shown by Comiso (1994), the coldest area could be over the Central Arctic or the Siberian region during other times of the year.

4. Summary

Thermal infrared satellite data could provide a useful climate data set of surface temperatures in the polar regions. Current capability provides data at average uncertainties between 1 to 5 K. However, the precision provided by the satellite sensor is much better (i.e., < 1K). The main cause of uncertainty is the inability of mask out clouds effectively because of ambiguities in the discrimination of clouds from snow or ice. Masking techniques have been developed and can only improve with time as more sophisticated methods becomes more mature. Also, the new AVHRR systems are expected to carry a 1.6 micron channel which can better discriminate clouds from snow and ice than the 3.7 micron (channel 3). With systems, like MODIS, the potential for effective cloud removal and for better discrimination of different types of clouds would even be greater.

5. References

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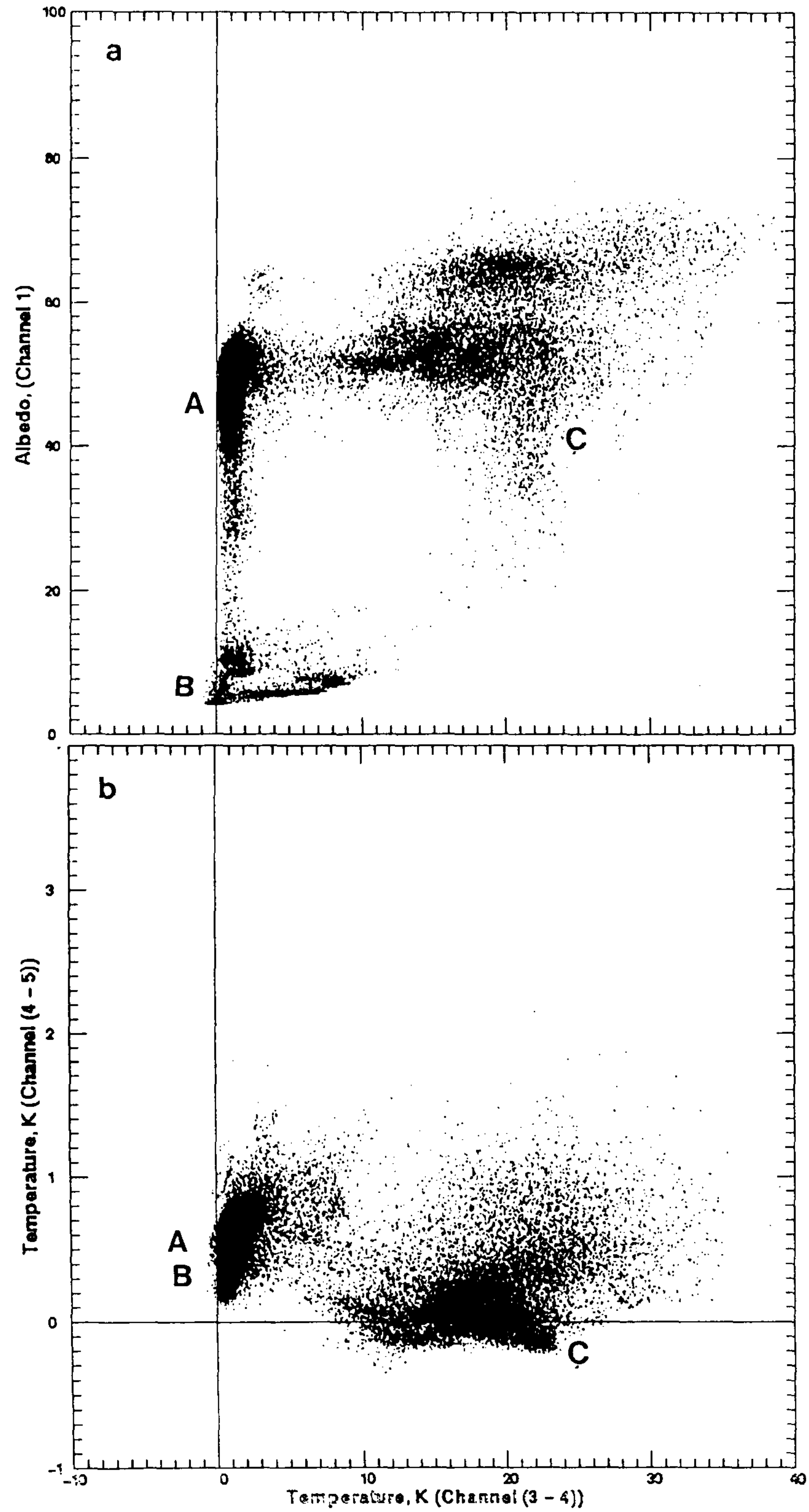

Figure 1. (a) Scatter plot of albedo from channel 1 versus the differences of the temperatures from channel 3 and 4 for data in the western Arctic region on July 17, 1992; (b) Scatter plot of the differences of the temperatures from channels 4 and 5 versus those from channels 3 and 4 for the same area and day.

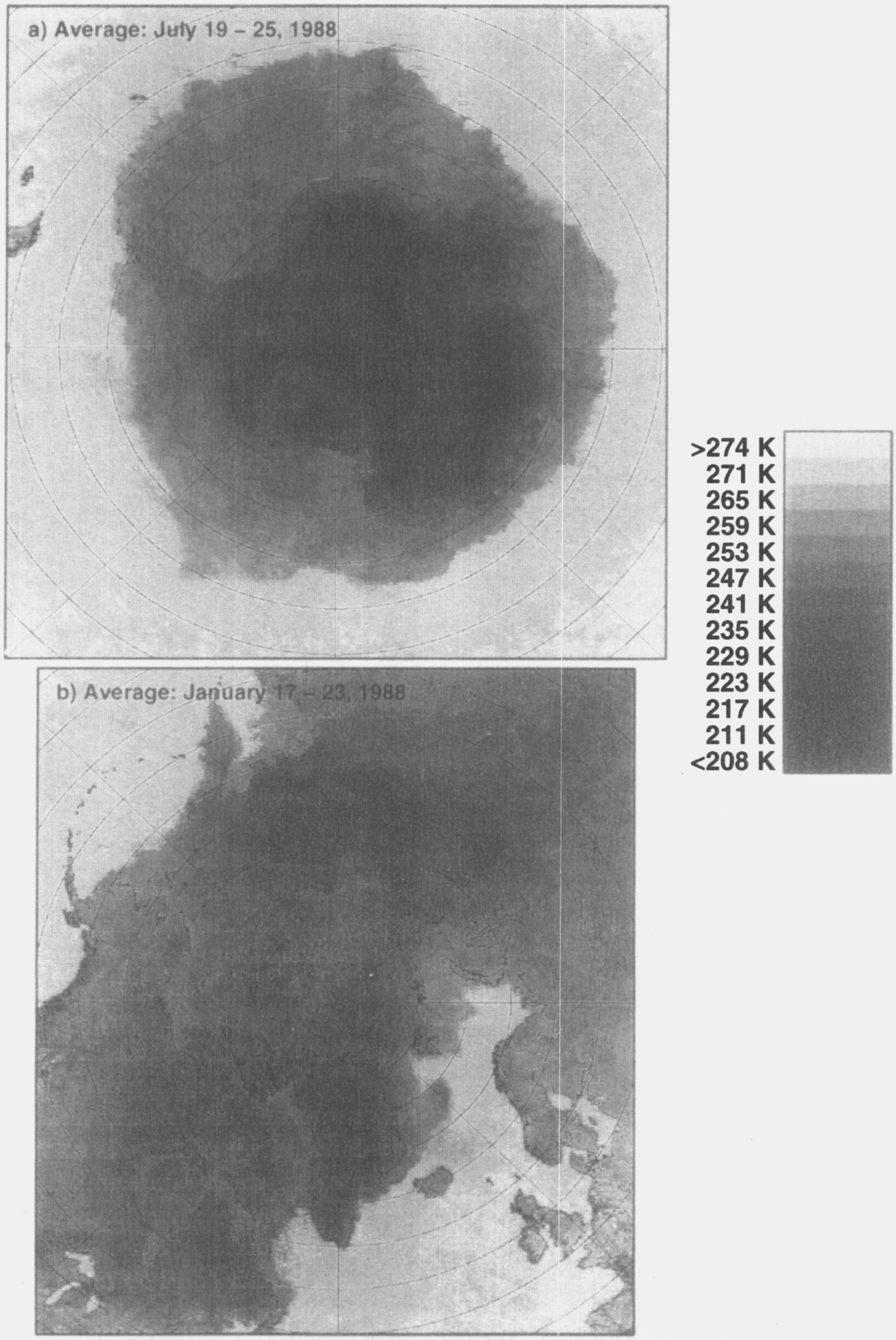

Figure 2. Surface ice temperatures retrieved from AVHRR GAC data in (a) the Southern Hemisphere on July 19 to 25, 1988; and (b) the Northern Hemisphere on January 17-23, 1988.