6.28 **SATELLITE-DERIVED ARCTIC CLIMATE CHARACTERISTICS AND RECENT TRENDS**

Xuanji Wang[1] and Jeffrey R. Key[2]

[1]*Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison, Madison, Wisconsin*

[2]*Office of Research and Applications, National Environmental Satellite, Data, and Information Service, NOAA Madison, Wisconsin*

1. INTRODUCTION

Satellite sensors can provide data needed for the analysis of spatial and temporal patterns of climate parameters in data-sparse regions such as the Arctic and Antarctic. The newly available Advanced Very High Resolution Radiometer (AVHRR) Polar Pathfinder (APP) data has been extended to create a comprehensive data set, called APP-x, containing cloud fraction, cloud optical depth, cloud particle phase and size, cloud top pressure and temperature, surface temperature and broadband albedo, radiative fluxes and cloud forcing over the Arctic and Antarctic for the period 1982-2000.

Recent observations have shown that Northern Hemisphere sea ice extent and thickness have been decreasing beyond the expectation of natural climate variability (*Comiso 2002; Cavalieri et al. 2003; Johannessen et al. 2004).* Numerous climate modeling studies have pointed out that the Arctic is one of the most sensitive regions to global climate change as a result of the positive feedback between surface temperature, surface albedo, and ice extent, known as the ice-albedo feedback (*Manabe and Stouffer 1994; Manabe et al. 1992; Miller and Russell 2000; Meehl and Washington 1990; Curry et al. 1996*).

The purpose of this paper is to draw a more complete picture of Arctic climate by describing the temporal and spatial distributions of the climate components, and recent Arctic climate trends in surface, cloud, and radiation properties are also presented over the period of 1982 to 2000 based on the APP-x data set. Possible linkages with global climate change have been investigated. First and second order statistics will be given for surface, cloud, and radiation properties for the Arctic as a whole and for 18 sub-regions, by season and in the annual mean.

2. DATA SETS AND RETRIEVALS

Data from the Advanced Very High Resolution Radiometer (AVHRR), on-board NOAA polar-orbiting satellites, were used in this study. The specific data set is a product of the AVHRR Polar Pathfinder (APP) project (*Meier et al. 1997*). The APP data are twice-daily composites available at 5x5 km^2 pixel size from 1982 to 2000.

We have extended APP standard products to include the all sky surface temperature, broadband albedo, cloud properties (particle phase, effective radius, optical depth, temperature, and pressure.), and radiative fluxes using algorithms in the Cloud and Surface Parameter Retrieval (CASPR) system (*Key 2002*). Radiative fluxes were computed in CASPR using *FluxNet* (*Key and schweiger 2000*). The daily APP composite data used here are centered on local solar time 14:00 and 04:00. The area north of 60°N latitude is of primary interest. The extended products have been primarily validated with data collected during Surface Heat Balance of the Arctic Ocean (SHEBA) field experiment in the western Arctic and with data from two Antarctic meteorological stations (*Wang and Key 2003; Pavolonis et al. 2002*).

3. ARCTIC CLIMATE CHARACTERISTICS

3.1 Cloud Properties

Clouds are a very important component of the Arctic climate system. They affect Arctic climate by interacting with the atmosphere and highly reflective underlying sur-

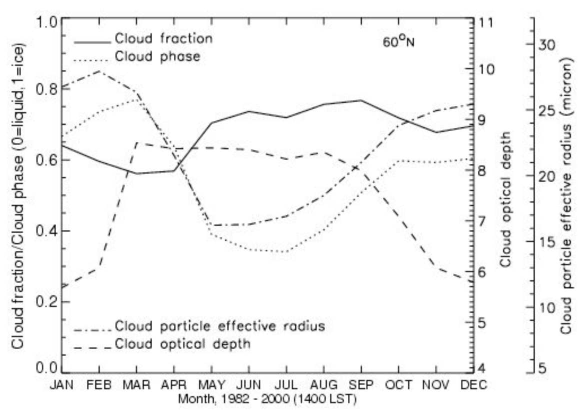

Fig. 1. The annual cycles of the total cloud fraction, cloud particle phase, effective radius, and visible optical depth for the Arctic region north of 60°N.

Corresponding author address: Xuanji Wang, CIMSS/SSEC, Univ. of Wisconsin-Madison, Madison, Wisconsin, 53706; email: xuanjiw@ssec.wisc.edu.

face through the absorption, emission and scattering of radiation. Figure 1 shows the annual cycles of the total cloud fraction, cloud particle phase, effective radius, and visible optical depth for the Arctic region north of 60°N. As expected, more ice clouds occur in cold seasons and with lower optical depths than in warm seasons.

Figure 2 shows the spatial distribution of annual mean cloud optical depth averaged over 1982-2000 over the Arctic. The larger cloud optical depths are always associated with the North Atlantic Ocean warm and moist air inflow in the Norwegian and Greenland Seas.

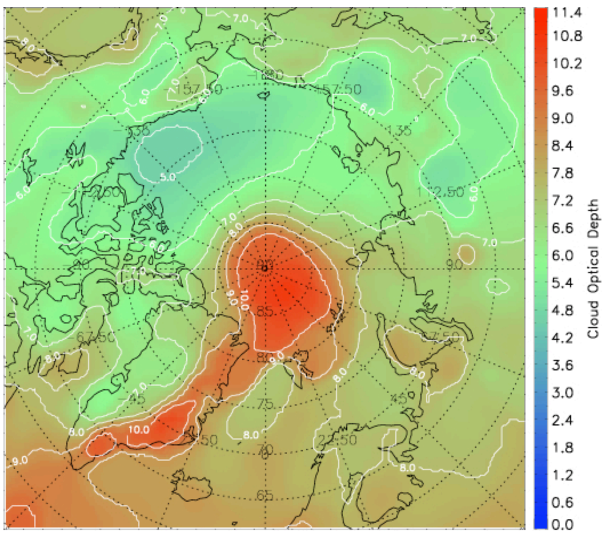

Fig. 2. The spatial distribution of annual mean cloud optical depth averaged over 1982-2000 at local solar time 14:00 over the Arctic.

3.2. Surface Properties

Figure 3 gives the annual cycles of the surface temperature, surface broadband albedo, cloud temperature and atmospheric total precipitable water averaged over 1982–2000 for the Arctic region north of 60°N. The surface temperature, cloud temperature and precipitable water show one peak only in a year, while the surface albedo shows a sinusoidal variation associated with melting and freezing seasons.

3.3. Surface Radiation

Figure 4 shows the annual cycles of all components of the surface radiation field averaged over 1982–2000 at a local solar time 14:00 for the Arctic region north of 60°N. It clearly indicates that there is time lag of about one month between maximum downwelling shortwave radiative flux and maximum net all radiative flux at surface because of the special underlying surface characteristics and cloudiness over the Arctic.

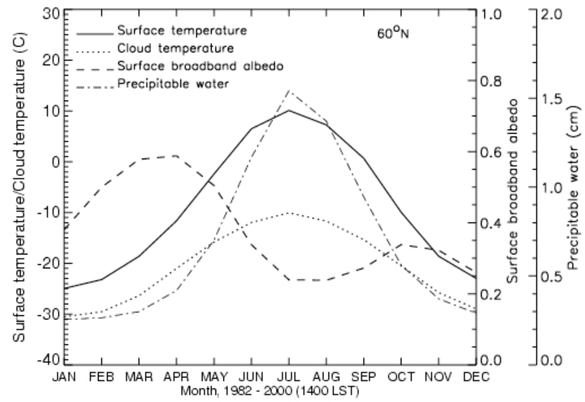

Fig. 3. The annual cycles of the surface skin temperature, surface broadband albedo, cloud top temperature, and atmospheric precipitable water for the Arctic region north of 60°N.

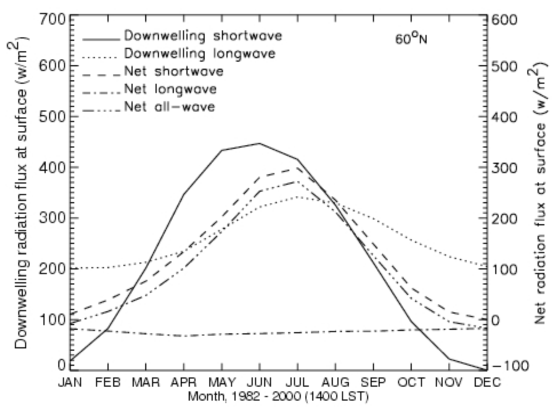

Fig. 4. The annual cycles of the surface downwelling shortwave and longwave radiative fluxes, and the net surface shortwave, longwave and all-wave radiative fluxes for the Arctic region north of 60°N.

4. RECENT TRENDS

Recent observations have clearly shown that the Northern Hemisphere sea ice extent and thickness have been decreasing beyond the expectation of natural climate variability (*Vinnikov et al. 1999*), and that Arctic climate changes are also evident in other climate factors such as surface temperature, cyclonic activity, precipitation, snowfall, and biogeochemical cycling. The significant turning point occurred in the late 1980s and early

1990s as revealed by the Arctic Oscillation (AO) and the North Atlantic Oscillation (NAO) (*Thompson and Wallace 1998*).

Trends for yearly cloud properties, surface properties and radiation components were calculated using linear regression with the 19 full years of retrieved products, 1982 through 2000. For each trend line a standard F test was performed at the confidence level of 95% to determine if the trend is statistically significant, and the trend uncertainties were also estimated. Figure 5 shows the trends in surface temperature and cloud fraction, for the Arctic region north of 60ºN extracted from the APP-x 14:00 data set. Except for winter, surface temperatures have increased at the decadal rates of 1.16ºC, 0.60 ºC, and 0.64 ºC in spring, summer and autumn, respectively. Overall, the annual mean surface temperatures have increased significantly at the decadal rate of 0.57ºC with uncertainty of 0.2ºC. The APP-x 04:00 data set also shows an increase in surface temperature in spring, summer, and autumn at the decadal rates of 0.90ºC, 0.86ºC, and 0.52ºC, respectively, and a similar increasing decadal rate of 0.53ºC in the 14:00 data set. Cloud cover over the Arctic has increased in spring, summer, and autumn for 14:00 data set, but decreased in spring, autumn, and annual mean for 04:00 data set. Winter cloud amount has decreased for both times. In terms of the cloud radiative effect, i.e. cloud forcing, clouds have played a damping role in the Arctic warming trend in the twice-daily APP-x data sets. Surface broadband albedo also shows strong decreasing trend in autumn, indicating late freeze-up in the Arctic. Regarding the net radiative fluxes at the surface, no significant trends were found, implying that the Arctic warming must be related to interactions with the low latitude atmosphere and oceans.

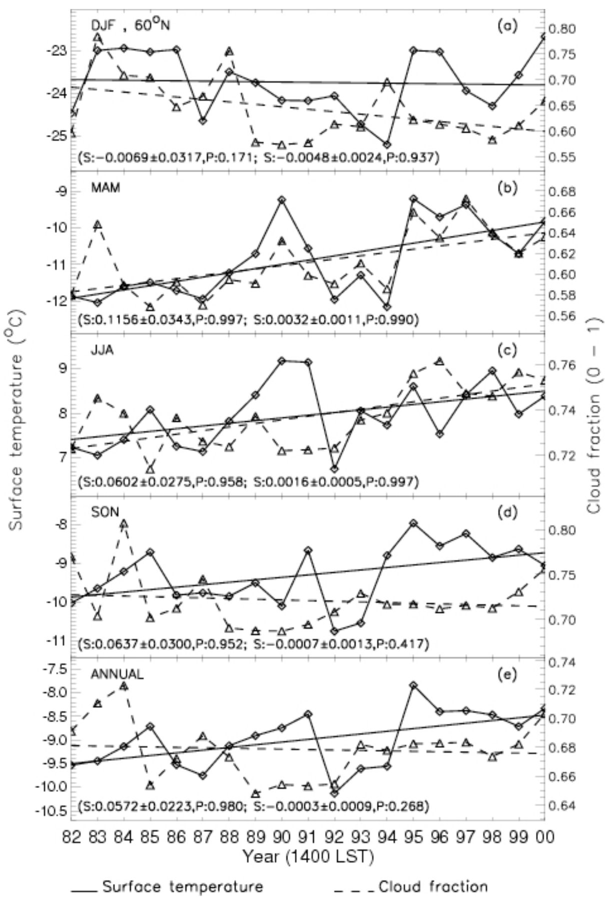

Fig. 5. The time series and trend in surface skin temperature and cloud coverage for the Arctic region north of 60ºN from APP-x 14:00 data sets.

Figure 6 shows the annual cross correlation coefficient image between AO indices and surface temperature anomalies for the Arctic. Here the simultaneous correlation calculation, i.e. the time lag is zero, was adopted to calculate the coefficients. The contours on the image represent statistical significance (1 = most confident, 0 = lowest confident). It clearly shows that the AO can explain as much as 50% of the Arctic warming for some of the areas, which are climatically sensitive areas in the Arctic. The correlation patterns are similar and persistent for all seasons from both local solar times, verifying that the relationship is real.

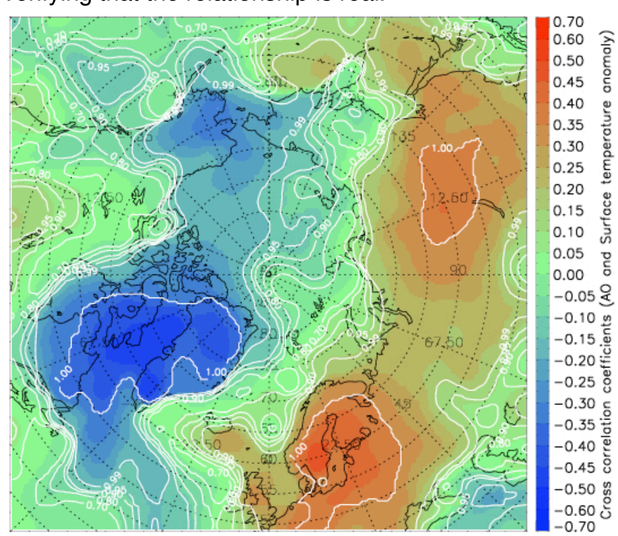

Fig. 6. The cross correlation coefficients between AO indices and surface temperature anomalies with time lag equal to zero from APP-x 04:00 data set. The contours on the image represent statistical significance (1 = most confident, 0 = lowest confident).

5. CONCLUSIONS

Satellite retrievals of surface, cloud, and radiation parameters over the Arctic region were used to investigate Arctic climate characteristics and recent trends. The present study indicates that the Arctic climate has been warming in spring, summer, and autumn. However, overall in winter the Arctic surface temperature has no statistically significant trend, though strong cooling was found in the most of central Arctic Ocean. The surface temperature has been increasing at a decadal rate of about 0.57°C and the surface broadband albedo has been decreasing at a rate of -1.2% per decade on the annual average. Cloud cover has been increasing during the sunlit period and decreasing during the dark period over the Arctic, acting to dampen the Arctic warming trend. The correlation analysis indicates that Arctic climate change must be closely related to large-scale circulation.

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