13.6 DETECTING ARCTIC CLIMATE CHANGE USING KÖPPEN CLIMATE CLASSIFICATION

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1. Introduction

The recent surface warming observed in the arctic is not a stand-alone phenomenon. Evidences have shown from various sources that the Arctic is changing, and changing fast. To name a few: the annual mean sea level pressure in the polar basin is decreasing since 1988 (Walsh et al. 1996), the general circulation patterns have been changed which are represented by the positive phase in the Arctic Oscillation (AO) index since 1989, (Thompson and Wallace, 1998), sea-ice extent has shown a downward trend (Champman and Walsh, 1993), and changes in the land cover, as a decrease in snow cover, an increase in permafrost temperatures in some areas, and a decrease in tundra area with replacement by shrubs and changes in tree line (Sturm, 2001). A nice summary of all these changes is presented by Morison et al. in the SEARCH Science plan (Morison et al., 2001).

The potential impact of vegetation changes to feedbacks on the atmospheric climate system is enormous because of their large land surface area and the multiyear memory of the vegetation cover. These changes have considerable impacts on the ecosystems in the Arctic and may also have global impacts through a variety of climate feedback mechanisms. By comparing the photographs taken in northern Alaska during 1948-50 and 1999 and 2000, Sturm (2001) found distinctive increases in the height and diameter of individual shrubs, and marked increase in the extent and density of the spruce forest. Because his study area is in a location where human disturbances are minimal, he attributes much of the increase in the abundance of shrubs to recent change in climate. In this study we are trying to quantify the changes in vegetation cover in the Arctic based on Köppen climate classification and the satellite NDVI (Normalized Difference Vegetation Index).

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2. Data Sets and Approach

A widely accepted system of climate classification is that developed by Köppen (1931). In this system, monthly mean surface temperatures and precipitation amounts are used as criteria for subdividing climates of the earth into five major groups (designated letters from A to E) and a number of subtypes. A modified version of this classification proposed by Trewartha and Horn (1980) recognizes temperature and precipitation as the two elements of paramount importance. The primary groupings are thermic, while rainfall differences create the subdivisions within the great temperature zones. The modified version of the classification separates the land of the globe into six great climatic groups (letters A to F). Five are based on the thermic zones, and the sixth is the dry group, which cuts across four of the thermic zones. For current study, only tundra and boreal, the two climate groups are important to the Arctic region. Near the southern boundary of our study region (50^{o}N), a small area may belong to the temperate climate zone. In the modified Köppen climate classification, the tundra area is defined as the monthly mean temperature of the warmest month is less than 10^{o}C, while the boreal area has at least 1 month of the temperature above 10^{o}C. When there are 4 or more months of the mean temperature above 10^{o}C, the area is classified as temperate climate zone. We use the NCEP/NCAR reanalysis monthly air temperature at sigma level of 0.995 for our study. A comparison of the 2-meter air temperature and temperature at sigma level 0.995 from NCEP/NCAR reanalysis with selected stations over the Arctic region shows that the later agrees better with the station observations than the former.

The satellite NDVI is calculated from the visible and near-infrared light reflected by vegetation. Written mathematically, the formula is

$$NDVI = \frac{NIR - VIS}{NIR + VIS}.$$

The NDVI provides a measure of the amount and vigor of vegetation at the land surface. The magnitude of NDVI is related to the level of photosynthetic activity in the observed vegetation.

In general, higher values of NDVI indicate greater vigor and amounts of vegetation. Values of NDVI for vegetated land generally range from 0.1 to 0.7, with values greater than 0.5 indicating dense vegetation, and ranges between –0.2 to 0.1 for snow, inland water bodies, desert, and exposed soils.

Our NDVI data set is from NASA, a product as part of the NOAA/NASA Pathfinder AVHRR Land program (PAL). The NASA data set is derived from the Advanced Very High Resolution Radiometers (AVHRR) on the "afternoon" NOAA operational meteorological satellites (NOAA-7, 9, 11, and 14), cover the period from July 1981 to September 2001. It is on global 1-degree resolution.

3. Results

Fig. 1 displays the area coverage of tundra (dashed red line in Fig. 1a), boreal (solid blue line), and temperate zone (dashed line in Fig 1b) in the last 5 decades for regions polarward of 50°N. Each vegetation zone is calculated from the modified Köppen climate classification based on NCEP/NCAR reanalysis data set. A 5-year running mean has been applied to the curve. The tundra area (Fig. 1a) has a minimum in the 1955, and started to increase until it reaches the maximum in the middle of 1970s. Since then, the tundra area has decreased continuously and reached its second minimum at year 1999/2000. At the same period, the boreal area shows the opposite trend, and the correlation of the two is –0.69 (-0.58 if the interannual variability is considered). The decrease in tundra area in the early 1950s, and the increase in the boreal area at the same period is in consistence with the warming in the late 1930 and 1940s, over Siberia and North America region found by Overland et al. (2003). The decreasing slope in the 1990s of tundra area is smoother than that of the early 1950s. The plateaus of the boreal area in the period of 1954 to 1962 and from 1990 to 2000 show that the regime shift changes the temperature anomaly from one phase to another, while the vegetation stays in its status for much longer period. The temperate zone coverage also shows negative correlations with boreal area (Fig. 1b), but this is true only for the early period. After mid-1970s, the increase of boreal area is not accompanied by a decrease in the temperate zone area. Instead the temperate zone stays nearly the same for the last 2 decades. This indicates that the southern boarder of the boreal area almost stays the same.

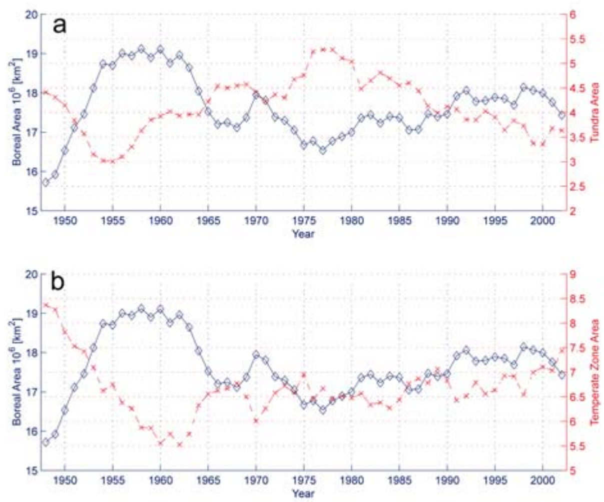

Figure 1 The time series of the area of tundra (dashed red line in Fig.1a) , boreal (solid blue line) and temperate zone (dashed red in Fig. 1b) based on surface air temperature from NCEP/NCAR reanalysis.

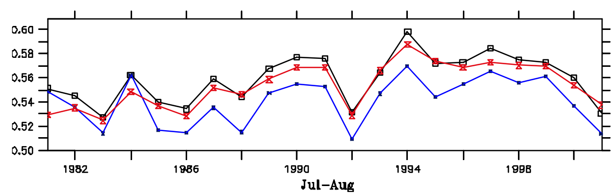

Figure 2 The areal average of NDVI for 50-90°N (black), North American (blue) and Eurasia (red) continent for summer season (July and August).

The NDVI analysis confirms what we have seen based on the Köppen climate classification. Fig. 2 shows the summer season (July and August) domain averaged NDVI index for 50-90°N region (solid line). The NDVI has increased from 0.55 in 1981 to its maximum of 0.60 at 1994. But it decreases since, and reached its minimum value of 0.53 at year 2001. At the same period the boreal area (solid line in Fig 1) coverage also show decreasing sign since 1998. Even though the values are decreasing in the 90s, the averaged value for the 90s is still higher than the means for 80s. This proves that the arctic are becoming greener than before.

The red and blue line in Fig. 2 show the NDVI values averaged over Eurasia and North American continents, respectively. The interannual variability over the Eurasia continent is less than the North American continent, but the averaged values are higher.

The spatial pattern of the mean NDVI for the past 20 years is shown in Fig. 3a. The tundra region is indicated by dark blue color. And this distribution agrees well with the Köppen classification (Figure not shown). Fig. 3b show the changes of the NDVI between 90s and 80s. We see that the maximum changes happened near the coastlines along the Arctic Ocean, i.e. region of tundra.

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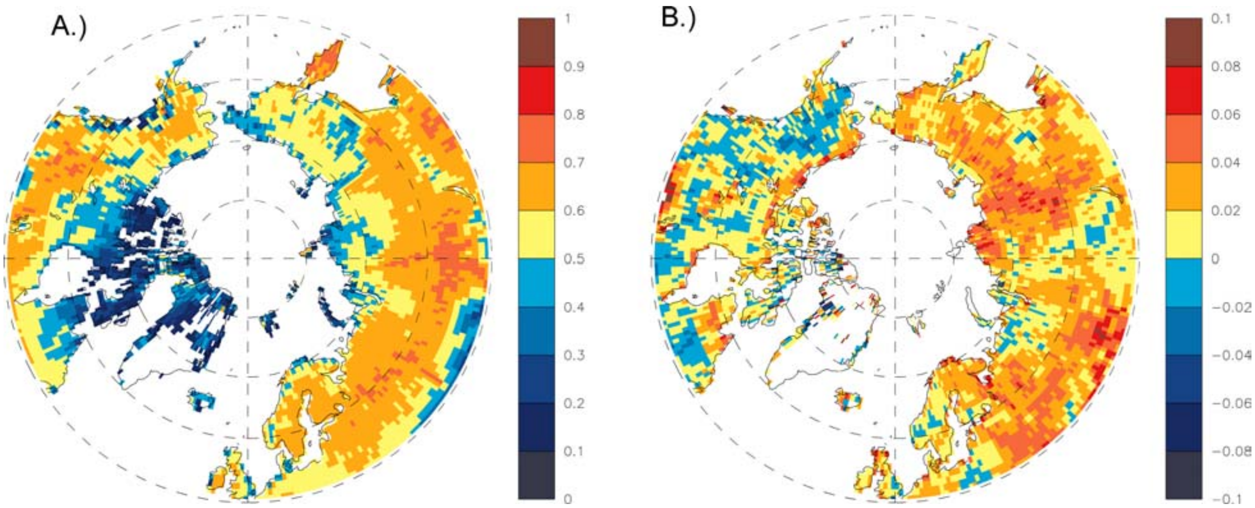

Figure 3 (a) 20 year average of the NDVI for teh summer month (July and August), and (B) the change from 1980s to 1990s in the NDVI.