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Global Change in the Arctic : Recent Studies (Extended Abstract)

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There have recently been a large number of reports on climate change in the Arctic as well as on a global scale, indicating the latter 20th century is anomalous in terms of warming and that the 1990s are likely the warmest decade (Jacoby and D'Arrigo, 1989 ; Mann *et al.*, 1999 ; Ledley *et al.*, 1989 ; Levitus *et al.*, 2000 ; Karl *et al.*, 2000 ; and Delworth *et al.*, 2000). All computer modeling results indicate an enhanced warming in the future, due to increasing of atmospheric CO_2, particularly in late autumn and winter in the Arctic (IPCC Report, Chapter 5, 1990 ; Washington, 1992 ; IPCC Report, Chapter 6, 1996 ; Russell *et al.*, 2000).

Air temperature has shown a distinct warming at a rate of about 1°C per decade in winter and spring months, particularly in the continental areas during the last few decades (Chapman and Walsh, 1993). Martin *et al.* (1997) examined the 2-m, 6-hourly air temperatures from the Russian North Pole drifting ice station and showed a winter/spring warming of about 0.25°C per decade. Rigor *et al.* (2000) found that almost the entire Arctic shows significant warming trends during spring. These changes are significantly greater than the global average increase of about 1°C per century.

The reason for the amplification of warming in the Arctic is due to positive feedback processes, making the Arctic sensitive to climatic change. Because of this sensitivity, Overpeck *et al.* (1997) suggested that climatic change may become evident in the Arctic before it is discernible in other parts of the world. As an example of the feedback process, Kuang and Yung (2000) showed a 1.5 per cent decrease in the springtime UV reflectivity over the 13 years ; the authors point out that this is equivalent to a 5×10^6 km^2 decrease in the spring snow cover.

In the Arctic Ocean, there has been other evidence of significant climatic change. Belchansky *et al.* (1995) showed that the annual sea ice coverage over the Barents Sea and Western Kara Sea has decreased from 1965. Parkinson *et al.* (1999) and Vinnikov *et al.* (1999) found a decrease in northern hemisphere sea ice extent during the past 46 years. Comparing their results and others with the Geophysical Fluid Dynamics Laboratory and Hadley Center climate models, Vinnikov *et al.* (1999) concluded that the probability of the observed trends resulting from natural climate variability is less than 2% for the 1978-98 sea ice trends. Based on microwave satellite remote sensing data, Johannessen *et al.* (1999) showed a reduction of about 3% per decade in the areal extent of the Arctic Ocean ice cover. Further, Rothrock *et al.* (1995) showed that submarine data acquired between 1958 and 1976 indicates that the mean ice draft at the end of the melt season has decreased by about 1.3 m in most of the deep water portion of the Arctic Ocean.

These changes of the Arctic Ocean sea ice appear to be related, at least in part, to flow of the North Atlantic Ocean water into the Arctic Ocean (Aagaard, 1989; Rudels *et al.*, 1994). Smith (1998) simulated this phenomenon. Further, this inflow appears to show a decadal and interdecadal oscillatory change (Walsh *et al.*, 1996; Proshutinsky and M. Johnson, 1997; Mysak and Venegar, 1998; Zhang *et al.*, 1998; Johnson *et al.*, 1998; Polyakov and Johnson, 2000). The decadal oscillation is called the Arctic Oscillation (AO) (Thompson and Wallace, 1995); it is closely related to the North Atlantic Oscillation (NAO) (Dickson, 1999, Hilmer and Jung, 2000; Kwok, 2000; Deser, 2000).

Some modeling efforts on the major changes in the Arctic Ocean seem to suggest that the warming trend during the last few decades is enhanced by superposition of a few natural oscillatory changes and anthropogenic effects (Gillett *et al.*, 2000; 2000; Andronova and Schlesinger, 2000), while Johnson *et al.* (1998) and Proshutinsky *et al.* (1999) emphasize particularly the importance of the superposed natural change.

Many glaciers around the world have retreated on a global scale during the 20th century (Bradley, 2000), although individual glaciers respond to specific microclimate characteristics (Meier, 1965). For example, a large loss of ice mass of the West Gulkana Glacier in Central Alaska has been extensively been studied (Brazel *et al.*, 1992). The large Seward-Malaspina Glacier (2,830 km^2) on the coast of South Alaska has been losing ice thickness at an average rate of 1 m/year for the past several decades (Tangborn *et al.*, 2000). Thomas *et al.* (2000) reported a rapid thinning of the Kanyerdlungssuaq Glacier in East Greenland of several meters over a 5-year period, while Sohn *et al.* (1998) found a rapid retreat of the Jakobshaven Glacier of West Central Greenland between 1962 and 1992.

Rabus and Echelmeyer (1998) examined the mass-balance of the McCall Glacier and found that its thickness was reduced by 19 cm per year between 1969 and 1972 and 43 cm per year between 1993 and 1996. This glacier is particularly useful to study effects of climate change because of its low-exchange rate. Sapiono *et al.* (1998) examined changes of the thickness of nine glaciers in North America and found a decrease of the thickness of about 10 m between 1957-58 and 1993-96. Adalgeirstottir *et al.* (1998) examined also the thickness change of the Harding Ice Field located in South Central Alaska and found a decrease of about 21 m in a 43 year period.

Osterkamp (1994), Osterkamp and Romanovsky (1996, 1997, 1999) and Romanovsky and Osterkamp *et al.* (1995) have found that continuous permafrost in Alaska has warmed up to 3°C at the surface, discontinuous permafrost has warmed as much as 1.5°C and some of the discontinuous permafrost has been thawing during the last decade or so.

From the Arctic Ocean to the sub-arctic region, the distribution of flora and vegetation vary fairly systematically, dividing the Arctic into several circumpolar zones; polar desert, steppe, tundra, taiga, timberline forest, and boreal forests (Young, 1989). It is expected that climate change will have profound impacts on such natural ecosystems in the Arctic. Global warming is expected to cause the poleward migration of flora and vegetation as observed from the Holocene era to date. However, understanding of this process requires interdisciplinary research (Chapin *et al.*, 1995; Pitelka *et al.*, 1997). Boreal forests account for about one-third of the carbon sequestered in terrestrial ecosystems, so that changes of the distribution of boreal forest will modify important feedbacks to the climate system (Mitchel and Hinzman, 1999).

The respiration rate of CO_2 in tundra ecosystems is controlled by climatic change as respiration increases with increasing temperature and a deep water table causes more efficient aerobic processes which also lead to an increased release of CO_2. Further, there is a strong linkage between CO_2 exchange and CH_4 formation in some wet tundra (Christensen, 1999). Oechel *et al.* (1997) found an indication that arctic tundra ecosystems change from net CO_2 sink to a source.

In a recent general review of studies of climate change in the northern high latitude environment, Serreze *et al.* (2000), concluded "..Taken together, these results point a reasonably coherent picture of change, but their interpretation as signals of enhanced greenhouse warming is open to debate. ..Nevertheless, the general patterns of change broadly agree with model predictions."

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