Arctic Climate Change Studies at the international Arctic Research Center (Extended Abstract)

Tôhoku Geophys. Journ. (Sci. Rep. Tôhoku Univ., Ser. 5), Vol. 36, No. 2, pp. 181-187, 2001

Arctic Climate Change Studied at the International Arctic Research Center (Extended Abstract)

MOTOYOSHI IKEDA

Graduate School of Environmental Earth Science, Hokkaido University,
North-10, West-5, Kita-ku, Sapporo, 060-0810
The International Arctic Research Center/Frontier Research System for Global Change,
University of Alaska, Fairbanks, Alaska, USA

(Received September 6, 2000)

The International Arctic Research Center has been established within the University of Alaska at Fairbanks under the cooperative agreement between the Science and Technology Agency of Japan and the University of Alaska. A main focus of the program funded by Japanese agencies and operated by the Frontier Research System for Global Change is on the atmosphere-ice-ocean system and its interactions with global climate system. The program is actively proceeded by a few tens of scientists. One of the most exciting outcome is reported in this paper.

The ice cover in the Arctic Ocean is reducing along with decadal variability in the last 40 years. The trend is attributable to atmospheric conditions, among which the summer cloud reduction is the most critical. This cloud trend permits more solar heating and consequent ice reduction, and is possibly caused by a weakening in transport of the humid air mass from the East Asia-Pacific region. An additional contribution is made by increasing winter cloudiness, which reduces outgoing longwave radiation. The increased winter clouds can be the result of a regional phenomenon of moisture associated with synoptic cyclones. The positive ice-albedo feedback associated with more open water, which absorbs more solar radiation, also contributes to further ice reduction. A minor contributor is atmospheric circulation associated with the intensifying polar vortex, which can dynamically and thermodynamically reduce the ice cover. These characters should be compared with model simulations of global warming, and will give a hint to whether the ice reduction is related to anthropogenic change or natural climate variability.

Sea Ice Decrease

Most of the Arctic Basin is covered by sea ice for a whole year. A reduction in the ice cover was found in satellite images taken during the last two decades (Parkinson *et al.*, 1999). An analysis extended to the pre-satellite era suggested a qualitatively similar trend for the last four decades (Vinnikov *et al.*, 1999). Also, a decadal variability was found to be superimposed upon the trend (Mysak and Venegas, 1998 ; Deser *et al.*, 2000 ; Wang and Ikeda, 2000). In the present study, a particular focus is given to the Arctic Basin. The ice area is analyzed over three regions shown : region 1-the Beaufort and Chukchi seas, region 2-the East Siberian and Laptev seas, and region 3-the Kara and Barents seas. The monthly ice extent data, which were updated by the University of Illinois sea ice group (Chapman and Walsh, 1993), are separated into four seasons (Dec. to Feb., Mar. to May, Jun. to Aug. and Sep. to Nov.). The time series in Fig. 1 shows drastic decreasing trends over all three regions, while the short data period prevents us from determining whether they are trends or part of a long-period (>50 yrs) oscillation.

Since the sea ice in the summer hardly contains newly formed thin ice, the reduction of an ice area in the summer should be reflected as ice thinning. The Arctic has been documented to experience ice thickness reduction by about 1 m in last 30 years (Wadhams, 1992 ; Rothrock *et al.*, 1999). Under the estimation of the ice thickness distributed uniformly between 0 m and 4 m, a 1-m thickness reduction corresponds to an area reduction of 1.2×10^6 km^2, which is 25% of 5×10^6 km^2, the average ice-covered area in the Arctic Basin. This estimated area decrease is comparable with the observed decrease. Thus, the decreasing trends exist in the area, thickness and volume of the Arctic sea ice.

As predicted by a coupled atmosphere-ocean model, the ice cover might be reduced by global warming due to increased carbon dioxide (Manabe *et al.*, 1992). A positive feedback exists between air temperature and the surface albedo related to sea ice in the summer : *i.e.*, once sea ice melts more, the area-averaged albedo is reduced, and more heat is absorbed by sea water. Sea ice continues to be thinner in the fall and winter, allowing larger heat flux to the atmosphere, and causing air temperature to be higher. Ice growth in the winter is reduced, and the ice area in the subsequent summer is smaller. Since little analysis has been made on the relationship between these thermal processes and atmospheric general circulation plus clouds in global warming simulations, we must look into various atmospheric parameters.

The effects of the positive ice-albedo feedback are estimated and used as a reference for estimates of the atmospheric effects. The ice cover decreases by more than 10^6 km^2 in 30 years. The summer shortwave radiation is about 250 W m^{-2} (Serreze *et al.*, 1998), and a difference in albedo between sea ice and open water is 0.4. Thus, absorption of shortwave radiation increases by 100 W m^{-2}. The ice-free area has a ratio of 1/6 to the total Arctic Ocean with an area of 6×10^6 km^2, and hence, the annual average gives 4 W m^{-2} at the end of the 30-year period.

Atmospheric Circulation Effects

Atmospheric conditions are examined first. The AO has a gentle trend toward a positive phase (Thompson and Wallace, 1998). This trend is consistent with a pressure decrease in the central Arctic (Walsh *et al.*, 1996). The wind effects are examined on the ice cover in the Arctic Basin. Sea ice is directly advected by wind stresses, which show decadal and interdecadal variabilities and modify the ice area (Deser *et al.*, 2000). However, the wind effects do not change the total ice volume directly, but require thermodynamic mechanisms to reduce ice volume : *e.g.*, the positive ice-albedo feedback associated with a reduction in the ice cover.

The atmospheric circulation can induce thermodynamic effects by varying an export of sea ice and an exchange of sea water through Fram Strait. Since ocean circulation is mainly controlled by curl of wind stress, the sea level pressure difference is taken from the NCEP reanalysis data (Fig. 2) between the Central Arctic (85°N) and the coastline around the Basin (70°N) as the index of polar vortex over the Basin. Both summer and winter time series have decadal oscillations similar to the AO (Thompson and Wallace, 1998 ; Slonosky *et al.*, 1997). The trends of the polar vortex indices are less robust than the decadal signals : *i.e.*, the winter index trend is opposite to the summer index trend and the winter AO trend. Consequently, the annual average of the circulation pattern has a minor trend toward the intensifying polar vortex over the Basin.

The intensifying polar vortex is examined by referring to the ice-ocean model experiments (Ikeda, 1987; Ikeda, 1990; Polyakov *et al.*, 1999). The polar vortex has its central pressure decreased by 1 hPa in 30 years and is responsible for increasing a wind stress curl of 10^{-8} Pa m^{-1} on the Arctic Ocean (Ikeda, 1990). The wind stress curl increases the water exchange through Fram Strait by $0.5\times10^{6}m^{3}s^{-1}$ (Ikeda, 1987), which is equivalent to a velocity increase of 0.025 m s^{-1}, provided that the current width is 200 km, and the depth is 100 m. The exchange increase accumulates to 2.5×10^{14} m^{3} in 30 years and increases the thickness of the Atlantic Water layer by 40 m beneath the Arctic Water in the Arctic Ocean. This increase is comparable with the observed increase found in 1990s in the Atlantic Water layer (Morison *et al.*, 1998; Steele and Boyd, 1998), although it is still difficult to separate the trend from decadal oscillations in the oceanographic data. The increase in the Atlantic Water layer contributes an extra heat flux to sea ice. Once half of the extra Atlantic Water, which is warmer than the Arctic Water by 4°K, is mixed with the Arctic Water, the extra heat is 0.7 W m^{-2} at the end of the 30 year period. This extra heat is equivalent with sea ice melting by 1 m in 30 years.

Sea ice flows out through Fram Strait along with ocean currents. The extra ice outflow is $5\times10^{3}m^{3}s^{-1}$ under the condition that the velocity increase is 0.025 m s^{-1} in a sea ice band with a width of 200 km and a thickness of 1 m. Once this ice outflow is replaced with sea water at the freezing point, the extra heat is 0.3 W m^{-2} at the end of the 30 year period.

Cloud and Radiation Effects

Clouds may be the candidates to clarify the long-term variabilities in the ice cover (Curry *et al.*, 1996). Clouds are mostly low stratus clouds over the colder sea surface and have roles to suppress shortwave radiation in the summer, when the Arctic receives shortwave radiation comparable to the mid-latitude region (Serreze *et al.*, 1998). In the winter, clouds are more associated with synoptic scale weather patterns and reduce outgoing longwave radiation. A longwave radiation balance is a major component in the surface heat budget in the winter. Therefore, clouds may play significant roles in Arctic climates.

Arctic clouds show clear trends as observed at the North Pole stations (Makshtas *et al.*, 1999). In their study, the data were counted only when the buoys were located in the region north of 85°N or in the fan-shape region between 140°E and 120°W north of 80°N. The shortwave radiation in July and the percentage of clear sky (0 to 2 tenths) in February are shown in Fig. 3 (Makshtas *et al.*, 1999). The summer trend is an increase in shortwave radiation, which is supported by decreasing low stratus clouds, through replacement of overcast (8 to 10 tenths) with less cloud conditions (0 to 7 tenths). The decadal variability in the summer radiation is indicated by the deviation from the trend and corresponds to the ice area in the manner opposite to the trends in regions 1 and 2 (Fig. 1); *e.g.*, the higher radiation occurs with the larger ice area around 1965, 1975 and 1985. In the winter, the trend is a decrease in clear sky replaced with more cloud conditions (3 to 10 tenths), and hence, the outgoing longwave radiation is reduced. Both trends contribute warming to the Arctic.

The shortwave radiation increases by 40 W m^{-2} in the summer. The area-averaged albedo is about 0.4 in the 80% ice-covered ocean, giving an increase of 24 W m^{-2} for the ocean. A difference in outgoing longwave radiation between clear sky and overcast reaches 100 W m^{-2} in high latitudes (Smith and Dobson, 1984). Overcast is replaced with the average of 4-tenths cloud

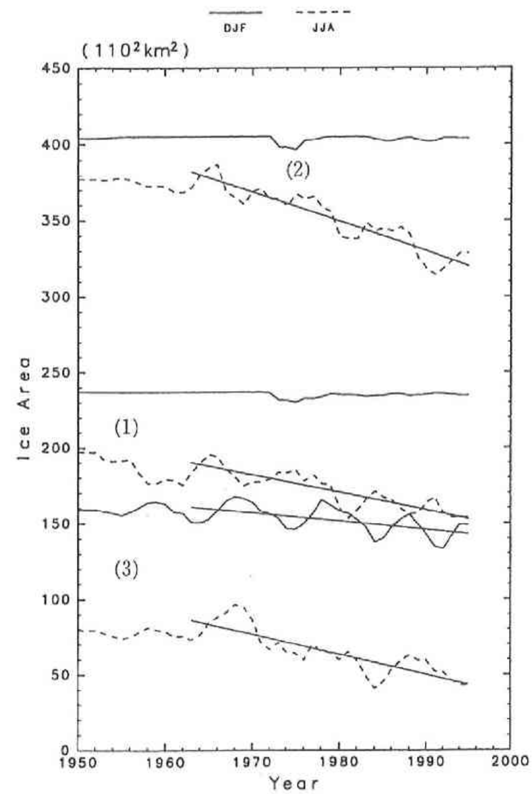

Fig. 1 The time series of the ice-covered areas over region 1-the Beaufort and Chukchi seas, region 2-the East Siberian and Laptev seas and region 3-the Kara and Barents seas. The summer ice covers in regions 1 and 2 are increased after 1978 by 10×110^2 km² and 20×110^2 km², respectively. A 3-year running mean is applied. The linear trends are drawn after 1962.

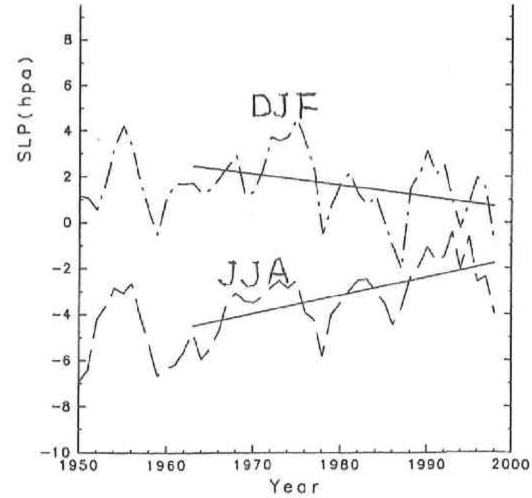

Fig. 2 The time series of the sea level pressure difference, which is the coastline of the Arctic Basin (70°N) minus the Central Arctic (85°N), in the winter and summer.

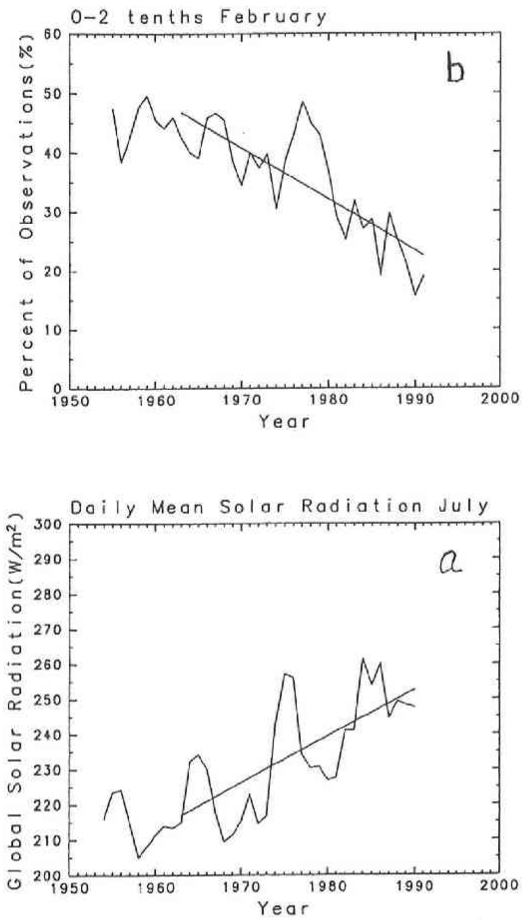

Fig. 3 The time series of (a) the daily-averaged global shortwave radiation in July and (b) the percentage of clear sky (0 to 2 tenths) in February collected at North Pole Stations.

cover by 15% in the summer, increasing the outgoing longwave radiation by 8 W m^{-2}. In the winter, clear sky is replaced equivalently with 6-tenths clouds by 25%, reducing the outgoing longwave radiation by 12 W m^{-2}. The area represented by North Pole stations is assumed to be one half of the Arctic Ocean, and hence, the annual average is an increase in the heat flux of 3.5 W m^{-2}.

The increase in winter clouds may be easily related to increased open water, from which vapor is emitted, and clouds are provided. This regional mechanism is consistent with the decadal variability in the summer, but contrary to the summer trend: *i.e.*, more open water was expected to increase clouds, whereas cloud density is actually reduced. We should then search for causes outside of the Arctic, such as mid-latitude atmospheric circulation. In the summer, a persistent low pressure is located over Asia, while a high pressure is situated over the northern North Pacific. Here, an index to represent the poleward air flow is taken to be the pressure difference between 120°E and 180°E in the latitudes 55 to 45°N. The reducing trend of this index reflects a weakening in the land-ocean contrast and consequent poleward flow (figure not shown).

Discussion

The total atmospheric effects are comparable with those of the positive ice-albedo feedback. The total extra heat flux, including the positive feedback, is 9 W m^{-2} at the end of 30-year period and equivalent to melting of sea ice of about 10 m in 30 years. The implication of the present study is that the ice cover trend is first triggered by the summer cloud decrease, which is caused by the atmospheric circulation in the mid-latitude Asia-Pacific region. Sea ice is further decreased by the positive ice-albedo feedback in the summer and the ice-cloud feedback in the winter. The heat stored in the ocean is mostly lost to the atmosphere in the fall and winter through open water and sea ice thinner than in the previous period, with a small portion used to create the ice cover trend. Therefore, the winter becomes warmer, and the ice area does not recover by the end of winter. We have made the following remarks: the positive ice-albedo feedback has been active on the Arctic sea ice trend in last 40 years, whereas its trigger is not an increase in air temperature in contrast to the previous suggestion (Vinnikov *et al.*, 1999). The candidates of the triggers include ice advection within the Arctic Basin (Deser *et al.*, 2000), the export of sea ice and the Arctic Water through Fram Strait, and cloudiness over the Arctic. The last candidate induces thermodynamic effects comparable with the ice-albedo feedback and much larger than the effects of the other two candidates. It is an open question whether the mid-latitude change, which has been identified as the cause of the Arctic cloud trend, is related to global warming. Since Arctic clouds are not simulated in doubled carbon dioxide experiments convincingly (Curry *et al.*, 1996), the further cloud parameterization and subsequent analysis of model output should be attemped in the experiments.

Acknowledgment: The work was supported by the Japanese Science and Technology Agency and Ministry of Education, Sports, Science and Culture. The authors appreciated fruitful discussions with J. Walsh, A. Makshtas, K. Yamazaki, H. Eicken, R. Colony and S. Xie, as well as proof-reading by K. Ikeda and N. Rozell, and data processing by A. Yamada.

References

Chapman, W.L. and J.E. Walsh, 1993: Recent variations of sea ice and air temperature in high latitudes, *Bull. Amer. Meteorol. Soc.*, **74**, 33-47.

Curry, J.A., W.B. Rossow, D. Randall and J.L. Schramm, 1996: Overview of Arctic cloud and radiation characteristics, *J. Climate*, **9**, 1731-1764.

Deser, C., J.E. Walsh and M.S. Timlin, 2000: Arctic sea ice variability in the context of recent atmospheric circulation trends, *J. Climate*, **13**, 617-633.

Ikeda, M., 1987: Wind effects on the buoyancy-driven general circulation in a closed basin using a two-level model, *J. Phys. Oceanogr.*, **17**, 1707-1723.

Ikeda, M., 1990: Decadal oscillations of the air-ice-ocean system in the northern hemisphere, *Atmos. Ocean*, **28**, 106-139.

Makshtas, A.P., E.L. Andreas, P.N. Svyashchennikov and V.F. Timachev, 1999: Accounting for clouds in sea ice models, *Atmos. Res.*, **52**, 77-113.

Manabe, S., M.J. Spelman and R.J. Stouffer, 1992: Transient responses of a coupled ocean-atmosphere model to gradual changes to atmopsheric CO_2. Part II: seasonal response, *J. Climate*, **5**, 105-126.

Morison, J.H., M. Steele, and R. Andersen, 1998: Hydrography of the upper Arctic Ocean measured from the nuclear submarine USS Pargo, *Deep-Sea Res.*, **45**, 15-38.

Mysak, L.A. and S.A. Venegas, 1998: Decadal climate oscillations in the Arctic: A new feedback loop for atmosphere-ice-ocean interactions, *Geophys. Res. Lett.*, **25**, 3607-3610.

Parkinson, C.L., D.J. Cavalieri, P. Gloersen, H.J. Zwally and J.C. Comiso, 1999 : Arctic sea ice extents, areas, and trends, 1978-1996, *J. Geophys. Res.*, **104**, 20837-20856.

Polyakov, I.V., A.Y. Proshutinsky and M.A. Johnson, 1999 : Seasonal cycles in two regimes of Arctic climate, *J. Geophys. Res.*, **104**, 25716-25788.

Rothrock, D.A., Y. Yu and G.A. Maykut, 1999 : Thinning of the Arctic sea-ice cover, *Geophys. Res. Lett.*, **26**, 3469-3472.

Serreze, M.C., J.R. Key, J.E. Box, J.A. Maslanik and K. Steffen, 1998 : A new monthly climatology of global radiation for the Arctic and comparisons with NCEP-NCAR reanalysis and ISCCP-C2 fields, *J. Clim.*, **11**, 121-136.

Slonosky, V.C., L.A. Mysak and J. Derome, 1997 : Linking Arctic sea-ice and atmospheric circulation anomalies on interannual and decadal timescales, *Atmos. Ocean*, **35**, 333-366.

Smith, S.D. and F.W. Dobson, 1984 : The heat budget at Ocean Weather Station Bravo, *Atmos. Ocean*, **22**, 1-22.

Steele, M. and T. Boyd, 1998 : Retreat of the cold halocline layer in the Arctic Ocean, *J. Geophys. Res.*, **103**, 10419-10435.

Thompson, D.W.J. and J.M. Wallace, 1998 : The Arctic oscillation signature in the wintertime geopotential height and temperature fields, *Geophys. Res. Lett.*, **25**, 1297-1300.

Vinnikov, K.Y., A. Robock, R.J. Stouffer, J.E. Walsh, C.L. Parkinson, D.J. Cavalieri, J.F.B. Mitchell, D. Garett and V.F. Zakharov, 1999: Detection and attribution of global warming using northern hemisphere sea ice, *Science*, **286**, 1934-1937.

Wadhams, P., 1992 : Sea ice thickness distribution in the Greenland Sea and Eurasian Basin, *J. Geophys. Res.*, **97**, 5331-5348.

Walsh, J.E., W.L. Chapman and T.L. Shy, 1996 : Recent decrease of sea level pressure in the Central Arctic, *J. Clim.*, **9**, 480-486.

Wang, J. and M. Ikeda, 2000 : Arctic oscillation and Arctic sea ice oscillation, *Geophys. Res. Lett.*, **27**, 1287-1290.