The Second Wadati Conference on Global Change and the Polar Climate

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1. *Introduction*

The First Wadati Conference on Global Change and the Polar Climate (Walsh et al., 1996) was organized in 1995 in order to identify, synthesize and report the most recent findings on climate change in the Arctic. Climate studies during the past 5 years have indicated a need for revised conceptual models of the Arctic atmosphere, cryosphere, ocean, and terrestrial environment, and a re-thinking of climate change theories and process parameterization. The major goal of the Second Wadati Conference (Tsukuba, Japan on 7-9 March 2001) was to summarize our understanding of the climate variability and climate change in the context of the evolution of global climate. The goal also included an analysis of new directions and perspectives of polar climate investigation building upon emerging information and pointing to additional data needs. To these purposes experts in a wide variety of relevant disciplines were invited to present papers and to hold panel and informal discussions. Different aspects of climate science were synthesized in five sessions. The first session, "Evidence of Climate Change" was devoted to observational evidence of the variability of oceanic, atmospheric and cryospheric parameters based on instrumental records and model reconstructions. Atmospheric circulation variability, sea ice thinning, contemporary trends in air temperature, sea level heights, and ice sheet mass balance for the last 50-100 years were discussed. The second session, "Paleoclimatic Reconstructions" provided important data and interpretations reflecting past climate variations based on analyses of ice cores, tree rings, lake and ocean sediments, and permafrost temperatures. Timescales of these studies range from a hundred to a hundred thousand years. Methods and results of the paleoclimate numerical simulations were also discussed.

The purpose of the third session, "Processes, Interactions and Feedback" was to identify major processes, interactions and types of feedback leading to climate variability in the polar regions. Studies of the terrestrial and hydrologic processes under a global warming scenario, investigations of seesaw and oscillation phenomena in sea-ice conditions and atmospheric pressure fields, and research of sea-ice and snow albedo feedback were discussed in detail.

Arctic climate simulation results were presented in the fourth session, "Climate Modeling." Presentations included analyses of the 20th century climate simulations, assessments of the 21st century climate scenarios, and investigations of the roles which different factors play in climate change.

The fifth session, "Consequences and Impacts of Change" was an overview summarizing the impacts of climate change in the Arctic, both on the environment and on human activities. Inclusion of this new session in the Wadati conference demonstrates that the fingerprints of global climate change in the Arctic are apparent, and that arctic climate variability is important in assessing economic and social impacts.

2. *Evidence of climate change*

The emphasis of this session was mainly on observational evidence of arctic climate change during 20th century. Konstantin Vinnikov with coauthors presented results showing that the observed contemporary trends in the arctic surface air temperature and snow cover closely match the Geophysical Fluid Dynamics Laboratory model predictions, when forced with anthropogenic greenhouse gases and tropospheric aerosols. This work continues earlier research (Vinnikov et al., 1999) where similar conclusion was made based on analysis of sea ice extent in the Northern Hemisphere.

Genrikh Alekseev et al. made a comparative analysis of the arctic warming during 1920s-1930s and 1980s-1990s and found significant difference between these two warming events in the Arctic. They noted that 1920-1930s were warmer in the North Atlantic and Eurasian Arctic (up to 1 degree C in November) but 1980-1990s were warmer in the Siberian and Canadian sectors of the Arctic. They also concluded that the changes in the atmospheric and oceanic circulation regimes are responsible for both arctic warmings, and they speculated that the changes in the oceanic conditions are more important for the arctic warming in 1920-1930 than in the 1980-1990s.

Speakers from different disciplines and sessions discussed oscillatory behavior of different environmental parameters and their relation to the indexes of the Arctic Oscillation (AO) (Thompson and Wallace, 1998), North Atlantic Oscillation (NAO), and Arctic Ocean Oscillation (AOO) (Proshutinsky and Johnson, 1997).

Michael Wallace et al. used sea ice motion datasets derived from a network of buoys drifting on the pack ice of the Arctic Ocean since 1979 (International Arctic Buoy Program, IABP). They showed that during the last decade (1989-1998) the Transpolar Drift pattern shifted towards Canada and ice drift velocities are smaller than during the previous decade (1979-1988). This change is related to wind-forcing effects of the decreasing atmospheric pressure (more cyclonic) in the central Arctic. They also support an idea that ice thinning in the central Arctic is a result of dynamical causes (less convergence in ice motion which leads to less ridging of the first-year ice). To show the corresponding changes in sea ice motion in response to changes in the AO index they regressed monthly sea ice motion fields on the AO index.

Peter Wadhams reported results of his research of ice thinning in the Nansen Basin of the Arctic Ocean based on September data from a British submarine cruise (HMS Trafalgar, 1996) and earlier cruise in September-October 1976 (HMS Sovereign). Comparison of the two data sets over a latitude range 81-90^{o}N in the longitude range 5^{o}E to 5^{o}W showed a loss of mean draft of 43.2\%, which is in close agreement with the results of Rothrock et al., [1999]. The most important conclusion of this work is that the thinning reveals itself through larger amounts of open water, a low mean draft of undeformed ice, and shortage of deep pressure ridges. Among the most interesting conclusions is that the largest part of the ice thinning during recent decades seems to have occurred prior to 1990, while the biggest changes in Arctic environmental conditions (ocean heat flux, air temperature, ocean circulation patterns) have occurred after 1990. This conclusion is in agreement with Prohutinsky's work related to investigation of the Arctic climate variability during 20^{th} century. Andrey Proshutinsky showed that there are at least two major regimes in the Arctic's ice, ocean, and atmospheric conditions with each regime persisting for 5-7 years. According to Proshutinsky, accumulation of ice (increase of ice thickness and ice extent) occurs during anticyclonic climate regimes and during the cyclonic climate regime the ice thickness and ice extent decrease. In 1976, the anticyclonic circulation regime dominated in the Arctic and in 1996, the cyclonic circulation regime prevailed. This is also in agreement with the simulation results of Ernst Augstein and Rudiger Gerdes who have analyzed 100 years of the coupled ice-ocean model run forced by NCAR SLP data (reconstructed for the first part of the century). They concluded that the decadal variability of ice volume in the arctic ocean is mainly forced by wind stresses, but the general decreasing trend of the sea ice volume decrease is a result of the positive trend in the surface air temperature in the Arctic.

Vladimir Pavlov showed the interdependence between sea level change and thermohaline circulation in the Arctic Ocean at seasonal, interannual, and decadal time scales using observational data and model results for the 1950s, 1960s, 1970s, and 1980s. The major conclusion is that the changes in the thermohaline circulation (T-S structures) are responsible for acceleration of sea level rise in the Arctic Ocean during 1970-1980.

To monitor trends in ice sheet mass balance Jay Zwally has used ERS-1 and ERS-2 satellite data. Expected consequences of climate warming in polar regions are an increase in precipitation and an increase in summer ice sheet melting. The observed height of the polar ice sheets increases at higher elevations in both Greenland and West Antarctica are consistent with the above expectation. Trends in elevation over the 7 years from ERS data are generally positive at higher elevations of Greenland and generally negative at lower elevations.

Atsumu Ohmura described a European proposal for the Summit Greenland environmental observatory which offers a unique platform for long-term observations in the Northern Hemisphere. The observatory location represents the middle troposphere with conditions (dry air, homogeneous snow surface, large distance from direct anthropogenic emissions) that are not possible at lower altitudes in the Arctic. The observations are grouped in six themes: ice-core interpretation and tropospheric chemistry, energy balance and boundary layer processes, stratospheric physics and chemistry, atmospheric electricity, polar aeronomy and space sciences, seismology and geodesy.

3. *Paleoclimatic reconstructions*

This session addressed the recent information deduced from tree rings, ice cores, lake and ocean sediments, and permafrost temperatures.

Philip Jones discussed sources of past data for the Arctic region, focusing on long instrumental records from Fennoscandia and longer tree-ring information for the circum-Arctic region of northern Eurasia and northern North America. Instrumental records from Europe show cooler temperatures in the late 17^{th} and early 19^{th} century, about 1^{o}C cooler than today. The 1730s, 1760s and 1820s were only marginaly cooler than 1930s and 1990s over western and northern Europe. A temperature reconstruction from tree-ring density data shows that most high-latitude regions experienced cooler conditions between 1550 and 1900 but that between 1400 and 1550 temperatures were milder.

Ice core records are available from selected high, low and mid-latitude ice caps. Several speakers in this session addressed recent results of ice cores studies in all latitudes. Lonnie Thompson demonstrated that tropical and subtropical ice core records have the potential to provide annual to millennial scale records of El Nino-Southern Oscillation events and monsoon variability, and can provide further insight to both regional and global scale events ranging from the Little Ice Age and Younger Dryas cold phase, to the Late Glacial Stage. However some, if not all, of these unique natural "archives" are in imminent danger of being lost by melting if the current warming persists.

Ellen Mosley-Thompson presented some results of the Greenland ice core contributions to the Program for Arctic Regional Climate Assessment (PARCA) with emphasis on reconstructing the annual accumulation history. Since 1995 PARCA investigators have collected 77 cores from 49 locations. The accumulation and climate histories emerging from these PARCA cores promise the best dated and most spatially extensive ice-core based data set for Greenland. These proxy data provide (1) an initial baseline against which future assessments will reveal accumulation trends, (2) input to mass balance estimates, (3) ground truth data for both satellite-based observations and model simulations, and (4) histories of accumulation and climate for widely distributed sites around Greenland. The PARCA collection includes a number of annual mass accumulation histories that cover the last 3-4 centuries. Comparisons among regional composites reveal that multi-decadal variability of accumulation differs significantly among the regions of Greenland. These results suggest that efforts to reconstruct NAO variability from single ice cores, as well as from other proxy records, should be pursued cautiously.

Kumiko Goto-Azuma with coauthors discussed temporal changes of sea-salt concentrations for the last two centuries. The data were derived from arctic ice cores. Annual mean chloride concentrations from five arctic sites were analyzed. Increase of the chloride concentration is interpreted as sea-ice retreat during arctic warming. Analysis showed that there is a significant disagreement among data from different sites and more research and ice cores are needed to explain these disagreements.

A description of physical properties of Dome Fuji (Antarctica) ice cores and paleoenvironmental reconstructions were presented by T. Hondon with coauthors (Dome-F Ice Core Research Group) and T. Nakazawa et al. A continuous 2503m long ice core was recovered at the summit of Dome Fuji during 1993-1997 and is expected to provide paleoclimate and paleoenvironmental records for over 300,000 years.

Two speakers (Takeshi Nakatsuka and the Okhotsk Sediment Core Analyses Group and T. Oba) reported results of paleoclimate reconstructions based on sediments cores. Nakatsuka with coauthors discussed possible variations in the oceanographic parameters during last 120,000 years in the Sea of Okhotsk. Three sediment cores have been collected by a joint Japan-Russia expedition in 1998. The major goal of this research is to reconstruct sea ice conditions and sea surface temperature. Preliminary results show that there are significant differences in the ice-rafted debris and reconstructed surface salinity for different cores and that more work is needed to explain these disagreement. Oba analyzed sea surface temperature off the east Coast of Japan at the last glacial maximum inferred from oxygen isotopes of foraminiferal tests. The sea surface temperature reconstructed from the paleodata at the northern core site is very close to the present temperature because the cold Oyashio Current has been very stable since the Last Glacial Maximum (LGM) The southern core site analysis shows that the sea surface temperature in this region was about 9^{o}C colder during LGM than at present because the Kuroshio Current was replaced by a colder water mass.

4. Processes, interactions and feedbacks

The presentations in this session addressed the processes underlying the interactions and feedbacks within the polar climate system. It included a report by Mark Serreze et al. on variability and trends in the hydro-climatology of the major Eurasian arctic drainages. Serreze noted that it is increasingly recognized that the hydro-climatology of the Arctic terrestrial drainages plays an important role in the climate system through controlling freshwater discharge to the Arctic Ocean. To date, however, information regarding basic hydrologic aspects such as seasonal cycles and variability of precipitation (P), evatranspiration (ET) and effective precipitation (P-ET) is quite limited. There is also a need to examine the hydrologic cycle in the context of recent changes in northern high latitude land areas. Linear trends in P, P-ET and ET have been calculated for each major Siberian river basin (Ob, Yenisei, Lena) by both month and season over the period 1960-1999. While a number of significant trends (both positive and negative) are found for each variable, no coherent patterns emerge. It was also shown that there is a significant link between high latitude summer precipitation and the location of the Arctic frontal zone. A group of researches from University of the Colorado, University of New Hampshire, the Ohio State University and the Jet Propulsion Laboratory are working together to develop a system for monitoring the major components of the pan-Arctic terrestrial water cycle. This system will make use of products from EOS-era satellites, numerical weather prediction models and other data sets in conjunction with an atmosphere-land surface water budgeting scheme. A major concern is the degradation of the already sparse high-latitude precipitation network and the difficulty in updating the time series.

Different aspects of the river runoff and the arctic climate variability were presented by Nina Savelieva and Igor Semiletov, who showed high correlation among Siberian river runoff, indexes of atmospheric circulation and ice conditions in the marginal seas. Results an investigation of the role of temperature-albedo feedback in the regulation of seasonal snowmelt processes in Northern Alaska were reported by Robert Stone. He concluded that, on average, the spring snowmelt in this region has advanced by about 8 days since the mid 1960s. The trend is attributed to changes or shifts in atmospheric circulation that have diminished winter snowfall and favored warmer spring conditions. Stone estimated that the annual net radiative forcing associated with an 8-day advance in snowmelt is about 2W/square meter, and that the most dramatic increase, more than 150 W/square meter on a daily basis, occurs immediately following snowmelt.

Hiroshi Tanaka and Hiroki Tokida investigated AO phenomena induced by a positive feedback between the polar vortex and baroclinic instability in high latitudes.They analyzed behavior of the monopole Charney mode M1, which is identified as the ordinary Charney mode excited by the baroclinicity of the polar vortex rather than the subtropical jet and is responsible for eddy momentum transfer from the low latitudes to the polar regions. As the polar vortex strengthens, the intensity of the M1 mode increases. Then the increased eddy momentum transfer further intensifies the polar vortex.Tanaka and Tokida speculate that the positive feedback between the polar vortex and the Charney mode M1 may result in the generation of the annual AO mode.Kaoru Sato et al. described the climatology and possible sources of stratospheric gravity waves in the polar stratosphere. Gravity wave energy is correlated with surface wind in the Arctic and with the stratospheric wind in the Antarctic. A powerful tool for studying small-scale disturbances in the upper atmosphere is the MST radar to be utilized by NIPR.

Larry Hinzman et al. investigated hydrologic response and feedbacks to a warmer climate in the Arctic. They suggested that soil moisture storage in the terrestrial active layer is the key variable in understanding most ecological process interactions and atmospheric/terrestrial linkages. They postulated, and some field experiments and model results, confirm that the primary control on local hydrological processes in northern regions is the presence or absence of permafrost, including the influences of the thickness of the active layer and the total thickness of the underlying permafrost. As permafrost becomes thinner or decreases in areal extent, the interaction of surface and sub-permafrost ground water processes becomes more important. The inability of soil moisture to infiltrate to deeper groundwater zones due to ice-rich permafrost maintains very wet soils in arctic regions. However, in the slightly warmer regions of the subarctic, the permafrost is thinner or discontinuous. In permafrost-free areas, surface soils can be quite dry as infiltration is not restricted, impacting ecosystem dynamics, fire frequency and latent and sensible heat fluxes. Hinzman et al. pointed out that with arctic warming and thawing of permafrost the surface soil moisture will decrease and existing tundra ponds may disappear. Analysis of meteorological data from Nome, Alaska indicates periods of both warming and cooling trends and increases and decreases in precipitation, Over the last fifty years, the long-term trends do not show marked differences likely to cause drying of the ponds. Nevertheless, it is interesting that the Siberian river runoff increase during the last two decades reported by Savelieva and Semiletov is attributable mainly to the increase of river discharge during winter, when only underground sources of water supply are the main sources of the runoff. This fact indirectly confirms Hinzman's hypothesis.

Peter Mikhalevsky and Alexander Gavrilov reported results of the Arctic climate observations using the Underwater Sound (ACOUS) project. Two acoustic sections of April 1994 and April 1999 detected basin-scale warming in the Atlantic water layer of the Arctic Ocean. These results have been confirmed by the US Navy Submarine Science Expeditions (SCICEX). A proposed network of cabled Arctic moorings (3 sources and 6 receivers) could provide real-time year-round synoptic measurement of the mean water temperature in the Atlantic Layer.

5. *Climate modeling*

An analysis of Arctic output from global simulations available through model intercomparison projects was reported by John Walsh The results pointed to several challenges facing modelers of Arctic climate and climate change. First, there is a wide range of sea ice extent simulated for the present climate by coupled global climate models. This wide range of simulated sea ice coverage leads to an across-model variance of temperature that is larger over the subpolar oceans than anywhere else in the Northern Hemisphere. The spatial distribution of the simulated sea ice thickness is also biased relative to observations, primarily because the simulated pattern of wind-forcing (sea level pressure) is significantly biased relative to observations. Consequently, the transport of sea ice (and hence freshwater) through Fram Strait and other key transects is problematic in the models. In addition, the models show tremendous ranges in their simulations of present-day Arctic precipitation and cloudiness. The large scatter in the present-day Arctic simulations extends to simulations of future climate, as the across-model variance of greenhouse-projected (21^{st}-century) temperatures is greater in the central Arctic than in any other region of the globe.

Thomas Delworth and Thomas Knutson described an ensemble of 20^{th}-century (1865-2000) simulations by the coupled global climate model of the Geophysical Fluid Dynamics Laboratory. The simulations were forced by prescribed (20^{th}-century) greenhouse gas and sulfate aerosol concentrations. In every ensemble member, global mean temperature showed a decadal-scale warming, attributable to internal variability, that resembled the observed warming of the early 20^{th} century, although the warming due to internal variability was generally not in phase with the observed warming. The timescale of the internal variations is compatible with those shown for the Arctic Ocean by Proshutinsky. However, internal variability alone is unable to explain the full magnitude observed 20^{th}-century waring. The results point to the fundamental need to perform ensembles of climate simulations in order to delineate the inherent uncertainties in climate change simulations.

Augstein and Gerdes analyzed 100 years of the coupled ice-ocean model run forced by NCAR SLP data reconstructed for the first part of the century. They concluded that the decadal variability of ice volume in the Arctic Ocean is mainly forced by wind stresses but the general trend of the sea ice volume decrease is a result of the positive trend in the surface air temperature in the Arctic.

Regional Arctic climate model simulations, using the German HIRHAM4 model, were described by Klaus Dethloff et al. The model's resolution is 0.5 degrees in latitude and longitude. When run for a full annual cycle (1990) forced by lateral and surface boundary conditions from ECMWF, the model reproduces quite well the seasonal variation of Arctic sea level pressure. A coupled version of the model simulates successfully the annual cycle of Arctic sea ice cover, while experiments with aerosol parameterizations show a sensitivity of about 2 C to the aerosol forcing of Arctic haze.

Glen Liston at al. reported on simulations of Alaskan climate using the climate version of the Regional Atmospheric Modeling System (ClimRAMS). In simulations of the 1994-1995 hydrologic year, the dates of initial snow accumulation and the spring snow melt differed from observations by approximately two weeks. However, the highly nonuniform character of the observed snow cover on scales of 100 m or less is not captured by this model (nor by any regional or global climate model), as the finest grid resolution used here was 3 km. Other snow-related deficiencies in regional and global climate models are their inadequate treatments of blowing snow and their inability to capture the interactions between snow and changing vegetation.

Uma Bhatt described a model study of the sensitivity of a global climate model to North Pacific sea ice. The experiments utilized the NCAR Climate System Model. The results showed that an east-west dipole in the Bering Sea appears as the second EOF. A comparison of coupled and uncoupled runs provided some suggestion of a feedback between sea ice and sea level pressure in the Bering sector. However, the atmospheric response in the Pacific appears to be rather shallow on the basis of an initial suite of simulations.

Akira Noda and Kazuki Yamaguchi reported on an intercomparison of AO-like modes in the simulations of climate change by a suite of approximately ten coupled global climate models. Most of the models were from the IPCC/DDC archive. The prescribed forcing was from either the IS92a scenario or the CMIP2's 1% per year increase of CO_2. Interestingly, every model simulates an AO-like mode as the first mode of sea level pressure. The global warming patterns in these models project onto the leading modes of large-scale natural variability in the models. However, none of the models predicts both ENSO-like changes and AO-like changes, i.e., the interactions between these modes. The results point to a need to improve models simulations of natural variability in the context of interactions among natural modes of variability having different origins such as the AO and ENSO.

6. Consequences and impacts of change

This session dealt with the likely impacts in the Arctic of future climate change. There were five papers in this session. Walter Oechel described the role of the tundra as a source or sink of trace gases, particularly carbon dioxide and methane. The amount of carbon in the soil of all northern ecosystems is 400-450 GtC (there are about 750 GtC in the atmosphere). So, an amount equal to about 2/3 of the atmospheric CO_2 is in soil organic layers (upper soil and bogs). This large reservoir could release large quantities of CO_2 and CH_4, which in turn could produce feedback effects on the climate. Oechel has observed increased rates of CO_2 release from the tundra in recent years, reversing earlier measurements on the North Slope of Alaska, which indicated the tundra to be a sink of CO_2. The latest data, however, show that the tundra has become a small summer sink again, after it has adjusted to the new climatic regime. Due to winter carbon loss, the arctic areas observed remain an annual source.

A detailed account of how a warmer climate affects the permafrost, and hence the possible release of trace gases, was given by Kazuki Yamaguchi et al, who described a numerical study, applying a multiple-layer ground model, of changes in permafrost induced by greenhouse warming. Including soil freezing processes in the model is important. Soil moisture plays a critical part in affecting the climate and the model results show that CO_2 warming will result in moister and cooler summers, and warmer winters.

The importance of coastal processes (river transport, coastal erosion etc.) was described by Semiletov. New data obtained by him and others along the Eurasian and North American Arctic Rim demonstrate that coastal erosion (up to a few tens of meters per summer, with a mean of 2-6 m per summer) and permafrost degradation is an important source of terrestrial material including organics. In the Laptev and East Siberian Seas net transport of terrestrial material induced by coastal erosion could be 8-10 times higher than riverine transport. In the coastal zone large quantities of terrestrial organics are oxidizing into CO2 and supply the shelf with new nutrients of a terrestrial signature. Because rates of coastal retreat might increase in the near future terrestrial transport of organic material to the shelf could also increase significantly. This, together with winter soil respiration, CO2 release due to the drying and warming of soils, expansion of thaw lakes releasing CH4, and increase in cyclonic frequency which increases coastal erosion, could produce a strong positive feedback loop on the climate.

The last two papers dealt with economic impacts of climate change in the Arctic. Gunter Weller's paper described present and future climate impacts in the Arctic. He showed that the warming in Siberia, Alaska and NW-Canada has already led to major impacts on the environment and on economic activities. If these trends continue as predicted by modeling the greenhouse effect, the impacts will be exacerbated and will affect the natural resource-dependent economy of many regions in the Arctic. He discussed the likely effects on economic activities, including oil, gas and mineral production and transportation, and on fisheries, agriculture and forestry, as well as the the subsistence lifestyles of Native communities.

Finally H. Kitagawa described renewed industrial interest in the Northern Sea Route across the top of Siberia. In shipping goods from the Far East or the West Coast of the United States to Europe and vice versa this route is considerably shorter than the ones now used, either through the Suez or the Panama canals. At present there is little shipping across the Northern Sea Route but if the present trends of reduced sea ice cover and thickness continue this route may indeed become economically feasible in the future.

7. *Concluding remarks*

During the concluding plenary session, participants discussed broad spectra of polar climate problems. The main points are summarized below.

7.1. Chasing a phantom

There is an increasing and dangerous tendency in many presentations and publications now to search for some "magic" and universal indices, which can explain climate variability. It is becoming increasingly apparent that, in the quest for numerical indices to explain climate variability, standard statistical tools (e.g., EOFs) sometimes lead to conclusions that do not have physical explanation. Usage of these tools for short time series, non-stationary or non-linear processes without appropriate statistical and physical background and deep knowledge of regional climatology may lead to wrong conclusions and decisions. Arctic climate anomalies can not be explained by NAO, AO, AOO or PDO etc. alone. All these diagnostic indexes reflect only some features of the Arctic climate variability and do not drive climate.

7.2 Arctic climate oscillations and trends

Robust multi-year trends and 10-15-year oscillations have been detected in several arctic environmental variables. For instance, surface air temperature in the Arctic shows positive trend of about 0.8 degree C per 100 years. The precipitation has been increasing during the 20^{th} century with a linear trend of 30mm per 100 years. The sea ice area has been reducing during the 20^{th} century with a rate of about 1 mln square km per 100 years. Sea level rise is observed in the Arctic during last 50 years. The linear trend is about 10 cm per 100 years based on results of numerical simulations and available observations. Wind-driven motion in the central Arctic alternates between anti-cyclonic and cyclonic circulation with each regime persisting for five to seven years. Anti-cyclonic wind-driven motion in the central Arctic appeared during 1946-1952, 1958-1963, 1972-1979, 1984-1988, and 1997-2001, and cyclonic motion appeared during 1953-1957, 1964-1971, 1980-1983, and 1989-1996, 2001-present. Shifts from one regime to another are forced by changes in the location and intensity of the Icelandic low and the Siberian high. These transformations from one regime to another occur quite rapidly and can be defined as climate shifts. Arctic Oscillation (AO) and North Atlantic Oscillation indecies are unusually high and also demonstrate oscillatory regime during last 30 years. All these phenomena are physically consistent with the global warming scenario.

7.3 Emerging needs

Regional variations need to be incorporated into our expectations of, and planning for, future Arctic climate changes. We should not expect a uniform warming in the Arctic. Observations and model results both indicate warming in some areas and cooling in others.

There is a significant degradation of the observational network everywhere in the Arctic since 1992. Long-term internationally (CLIC, WMO) coordinated monitoring of the atmosphere, ice and ocean is needed in the Arctic.

Sea ice thickness data is important for climate change studies. A huge archive of submarine data is available for analysis. Appropriate funding and specialists are needed to complete this work.

Dedicated reanalisys of the oceanic and ice conditions in the Arctic Ocean for the last 50-years is needed.

One of the major tasks for the future studies is a separation of natural climate variability from variability induced by anthropogenic effects.

It is important to continue developing and testing new technologies and techniques for remote investigations of the Arctic Ocean:

- Acoustic thermometry and acoustic tomography;
- satellite-based observations;
- automatic underwater vehicles.

7.4 Conference Report

A preprint volume of the papers presented at the conference is available from H. L. Tanaka, Institute of Geoscience, University of Tsukuba, Tsukuba 305-8571, Japan.

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