Symposium on Arctic Sea Ice and Climate

November 2008, Woods Hole, MA

This summary by: M.-L. Timmermans

Speakers: C. Ashjian, J. Cassano, J. Francis, J.C. Gascard, L. Hamilton, R. Kwok, S. Laxon, R. Lindsay, P. Matrai, H. Melling, M. Miles, J. Overland, D. Perovich, A. Proshutinsky, V. Smolyanitsky, T. Weingartner

Recent change to the Arctic climate system appears to have been forced by both anthropogenic change and natural variability, together with feedbacks between the sea ice, atmosphere and ocean. This was the consensus of discussions and presentations during a Symposium on Arctic Sea Ice and Climate in November 2008 at the Woods Hole Oceanographic Institution (Woods Hole, MA). Presentations by scientists from the United States, Canada, France, Russia and the UK dealt with the most up-to-date understanding of the physical and biological parameters and mechanisms in a changing Arctic climate. The timing for the symposium was notable -immediately following the September 2008 second-lowest minimum summer sea-ice extent on record, with the extreme minimum set only the previous year - in both 2007 and 2008, summer sea-ice extents were about four standard deviations lower than would have been expected by extrapolation from the 1980-2006 trend (NSIDC). A number of small Arctic communities find themselves on the front lines of Arctic climate change, experiencing impacts such as accelerating shoreline erosion. Decreasing or later-forming sea ice offers less protection from the waves of fall storms, affecting coastal communities such as Kivalina and Shishmaref. Around the Arctic, migration and other demographic indicators often respond quickly to external pressures, and bear watching through the coming environmental changes (Hamilton and Mitiguy, 2008). The changed climate state is not limited to ice-cover. Atmospheric indices based on gradients of sea-level in the central Arctic basin indicate extreme 60-year maxima in the intensity of the anticyclonic circulation regime of the wind-driven ice and water circulation of the Arctic Ocean (A. Proshutinsky). This report, in summarizing the discussion themes and general conclusions of scientists who participated in the symposium, highlights the immense complexity in the cause and effect relationships between the Arctic atmosphere, sea ice and ocean.

Recent studies have linked the rapid summer sea-ice decline to unusual natural atmospheric circulation patterns (e.g. L'Heureux et al., 2008). Arctic climate patterns of this decade seem to be distinctly different from any other time in the 20th century (Overland et al., 2008). The 20th century was dominated by the two main climate patterns for the Northern Hemisphere -the Arctic Oscillation (AO) and the Pacific-North American (PNA) pattern. Overland et al. (2008) show how surface air temperature and sea-level pressure patterns during 2000-2007 do not resemble the AO and PNA. The period 2000-2007 was characterized by unusual meridional flow toward the North Pole (Overland and Wang, 2005; Overland et al., 2008). These anomalous winds contributed to sea-ice loss via enhanced transport of warm air to the Arctic and enhanced advective ice transport from the Arctic. Note that a similar meridional pattern occurred in the late 1930s although it did not result in the massive ice losses seen in recent years. It may be that today's strong global warming signal (increased temperatures) prevents recovery of an ice pack affected by anomalous winds. In 2000-2007, Arctic surface air temperatures in winter and spring were more than one degree warmer (with some regions 3 degrees warmer) compared to the 20th century (consistent with model projections based on anthropogenic forcing), with ice retreat further enhancing warm autumn temperature anomalies (Overland et al., 2008). The 2007 and 2008 winter AO index was more positive than in previous years (a positive phase of the AO is typically associated with warmer temperatures and export of ice from the Arctic Ocean), although not as strongly positive as in the early 1990s. It remains to be seen whether a future return to a consistently strongly negative AO (typically associated with cooler temperatures and sequestered ice in the Arctic) will be sufficient to reverse the trend of warming and ice decline. While it would seem that warming temperatures and ice-ocean feedbacks leave the Arctic climate more susceptible to natural atmospheric variability, it is unclear to what extent changes in atmospheric circulation are influenced by global warming.

The increased vulnerability of the Arctic system to anomalous atmospheric forcing can be argued from an alternative perspective. Lindsay et al. (2009) use a coupled ice-ocean model to show that the record minima ice extents in 2007 and 2008 may be the result of a steady thinning of sea ice in a warming climate over the past decades. The mean ice thickness and compactness over the entire Arctic basin began to decline consistently beginning in the late 1980s (likely triggered by the high AO years of the early 1990s) leading to increased open water areas in the summer and subsequent ice-albedo feedback (Lindsay and Zhang, 2005). Lindsay et al. (2009) demonstrate that the recent anomalous wind patterns that blew the ice from the Pacific to the Atlantic side of the Arctic basin, where a significant fraction was pushed out of the Arctic Ocean through Fram Strait, would have been less influential without prior thinning of the ice pack -a less compact ice pack is more susceptible to advection by the winds and currents. In this sense, recent ice loss is deemed the result of a long-term preconditioning to thinner ice that is more easily pushed around the basin by moderately unusual winds.

Speculating on mechanisms controlling recent Arctic change is particularly challenging given that past variability is not well known. This includes the variability of the flow of Pacific Water through the Bering Strait, believed to be driven by steric forcing and modified by winds which drive seasonal variations in transport (Woodgate et al., 2005; Aagaard et al., 2006). Pacific Water is a key nutrient, freshwater and heat source, providing about 33% of the freshwater input to the Arctic (Woodgate and Aagaard, 2005). It maintains the Arctic Ocean stratification in the form of a cold halocline layer, which insulates the ice from the warm Atlantic water beneath. A 20% decrease in steric height difference between the Bering Sea and the Arctic Ocean between 1993 and 2000 occurred as a result of both Arctic Ocean warming and freshening (partly due to advection of warm water from the North Atlantic), and salinization in the Bering Sea. Since 2000, the steric height has increased due to a freshening and warming of the Bering Sea. This interannual variability demonstrates the strong impact of remote forcing -not only is an efficient long-term monitoring array necessary to improve estimates of mass, salt and heat fluxes in the Bering Strait, but additional measurements from the Bering Shelf and basin, the Gulf of Alaska, and the Arctic are also required to make broader connections.

A multidecadal perspective is needed for reliable assessments of natural variability of the Arctic system. Long-term observations of sea ice and numerical model results show 60 to 80 year variations in sea-ice extent in the Labrador, Greenland, Barents and Icelandic seas (M. Miles). These sea-ice variations are coherent with the Atlantic Multidecadal Oscillation [AMO, defined from sea-surface temperature variability in the North Atlantic] (Kerr, 2005). While temporal evolution of Arctic and sub-Arctic surface air temperatures suggests that 20th-century Arctic warming patterns can be linked to large-scale ocean variability (the AMO), it is still unclear to what degree the AMO is responsible for recent sea-ice decreases and surface air temperature increases. Furthermore, relationships to other modes of atmosphere-ocean-ice variability (e.g. the AO) are not well quantified.

Understanding long-term behavior does not necessarily mean that inferences about present dynamics or future predictions on the state of the Arctic are possible. Lindsay et al. (2008) point out that the rapid changes in statistical relationships between the ice, ocean and atmosphere make future predictions unfeasible. Sudden shifts in climate parameters need to be considered in investigating mechanisms of climate variability. For example, Arctic “seasonal catastrophes” have been shown to take place when several climate parameters suddenly change in magnitude, or significantly shift their climatologic cycle (A. Proshutinsky), as seems to have occurred in summer 2007. The sudden drop in summer sea ice in 2007, plus ice redistribution and associated changes in surface albedo, will no doubt play an important role in the Arctic system during the next several years or more.

Both short and long-term studies of Arctic sea ice require strong observational evidence. Ice extent data for the Eurasian sector of the Arctic have been developed by the Arctic and Antarctic Research Institute for the period 1900-2008 (Mahoney et al., 2008). Records show declining summer sea-ice extent over the Russian Arctic (although not over every sea) until the mid-1950s, after which summer sea ice generally increased or was stable until the 1980s. Since the mid-1980s, the record shows a decrease in sea-ice extent in all seas and in all seasons. Of interest is that the Hadley Centre’s global sea-ice coverage and sea surface temperature (HadISST) data show a more continuous decline in summer ice cover in the Russian Arctic in the last century. The HadISST data do not indicate the transition from increasing to decreasing summer sea ice in the 1980s. These discrepancies may be important in assimilation of ice-extent data in climate models.

Shorter-term ice drift records are based on passive microwave, synthetic-aperture radar and buoy drift. Between 1979-2007, there is no statistically significant trend in Fram Strait ice area export, although trends on shorter timescales are apparent (Kwok, 2008). Kwok (2008) examined sea-ice motion in summer derived from the Advanced Microwave Scanning Radiometer -EOS (AMSR-E) between 2003-2007 and showed that the flux of sea ice (area) from the Pacific sector of the Arctic Ocean to the Atlantic sector peaked in 2007 and accounted for more than 20% of the total sea-ice retreat in the Pacific sector. Kwok’s analysis indicates that the prevailing summer circulation in recent years has contributed to a distinct positive trend in the export of sea ice from the Arctic, contributing up to 30% of the sea-ice retreat during the past 3 to 4 years. Ice origin is important in assessing the volume flux of ice since sea ice is generally thicker closer to Greenland and thinner in the central Arctic. Source regions of sea ice can be determined by back propagation of daily ice drift from Fram Strait (R. Kwok calculates the trajectories of ice particles at Fram Strait between 1979-2007). Kwok finds a strong transpolar drift (when ice originates from the high central Arctic) is associated with relatively large annual ice drift. When annual ice drift is relatively low, most of the ice originates from east of the prime meridian closer to Greenland. These relationships are particularly important to assess the fraction of multi-year ice exiting the Arctic over time where direct observations of ice thickness in Fram Strait are limited.

Since 2003, progress has been made in determining sea-ice freeboard and thickness (after accounting for the hydrostatic load of the snow layer) from ICESat laser altimeter elevation profiles (Kwok and Cunningham, 2008) and satellite radar altimetry data from the European Space Agency (ESA) satellites ERS-1, ERS-2 and Envisat (e.g. Laxon et al., 2003; Giles et al., 2008). Giles et al. (2008) use measurements from Envisat to estimate Arctic sea-ice thickness change between 2002 and 2008 (before and after the September 2007 ice-extent minimum). They show during winter 2007-2008, the Arctic-wide average ice thickness was 0.26 m less than the average winter ice thickness for the five years preceding; their results indicate that the ice-extent minima in fall 2007 lead to a decrease in ice thickness the following winter, with the largest decrease (0.49 m) in the Western Arctic. These reductions in ice thickness are in general consistent with results using ICESat measurements (R. Kwok, NSIDC). Uncertainties remain in deriving ice thickness from satellite measurements, perhaps the biggest being inaccuracies in snow depth. It is clear that moorings to measure ice draft are needed for ongoing validation programs.

Canada has supported continuous measurements of ice draft by underwater sonar in the Beaufort Sea since 1990 with Ice-profiling and Doppler sonar instruments on moorings at eleven sites in first-year ice and one site in multi-year sea ice (e.g. Melling et al., 2005). In seasonal pack ice, measurements indicate no significant trend in draft over this time. This result is consistent with longer-term measurements (since the 1930s) in the seasonal land-fast ice. The domain of seasonal ice is expanding (there has been a 30% reduction in the area of the multi-year ice pack since 1989). As a result, volumetrically, there is more growth of sea ice now than in the past. In pack ice, the thickening of ice sheets by freezing is augmented substantially by mechanics. Mechanical ridging of drifting ice floes creates features up to 20 times thicker than would be possible via thermodynamics alone (H. Melling). The available measurements indicate that very thick multi-year floes, formed by accumulation of ice rubble at the interface between pack ice and fast ice along the western margin of the Canadian polar shelf, still remain in the Arctic. The continuing presence of these extremely thick multi-year floes is further evidence for the importance of realistic ice-deformation parameterizations in models.

Direct measurements of multi-year ice thickness are made by autonomous ice-mass balance buoys (IMB) [Richter-Menge et al., 2006]. Perovich et al.'s (2008) analysis of IMB thickness measurements showed that absorption of solar radiation in the Arctic Ocean surface layer in summer 2007 led to greatly enhanced melting of the bottom surface of multi-year ice in the Beaufort Sea. An increase in the area of open water that summer resulted in a large positive anomaly in solar heat input to the upper ocean setting off a strong ice-albedo feedback whereby more open water resulted in the absorption of more solar heat, which in turn resulted in more melting and more open water. The excess warming of the upper ocean contributed to delayed freezing in fall 2007 (Comiso et al., 2008) in effect lengthening the melt season.

Clouds play an important role in surface-atmosphere feedbacks as well. For example, the impact of clouds in albedo feedbacks depends on the surface (whether over high-albedo snow cover where they enhance net radiation, or over open-water leads where they impede solar absorption). At the same time, changes in sea ice affect the exchange of heat and moisture between the atmosphere, thereby impacting clouds. In fact summer sea-ice changes appear to have lasting effects. For example, in autumns following low-ice extent summers, the height of the atmospheric boundary layer increases (the cloud layer rises) because of higher near-surface temperatures, while lower boundary layer heights are observed in autumns following summers with more ice (Schweiger et al., 2008). Further, the substantial ice loss in summer 2007 led to net increases in the amount of clouds during the following autumn, likely due to increased evaporation. In autumn 2007, positive cloudiness anomalies, particularly in the eastern Arctic, were two standard deviations above the mean. Increased infrared fluxes to the surface generally inhibit ice formation and the lower atmosphere stays warm; this in turn impacts large scale atmospheric climate indices (e.g. after summers with low ice extent, the poleward thickness gradient between the Azores and Iceland is reduced by 20% relative to summers with extensive ice). Following the extreme ice loss of 2007, these complicated feedbacks ("memory mechanisms") between clouds and ice lead to subsequent changes to sea-level pressure and precipitation patterns throughout the Northern Hemisphere (J. Francis). These processes indicate the importance of weather in global climate models; in the high latitudes, synoptic weather patterns have been related to large-scale circulation indices (Schuenemann et al. [2009] found, for example, that an increase in precipitation over Greenland is related to the changing frequency of weather patterns.).

The physical characteristics of the Arctic system are closely linked with biology and more corroborative biological data are needed to better understand these connections. Primary productivity appears to have responded to recent Arctic change, although establishing decadal trends in Arctic Ocean primary productivity is not possible with limited primary productivity, chlorophyll and nutrient field data. Remote sensing and insitu measurements indicate that annual primary productivity in the Arctic Ocean has been increasing over the last decade. This increase appears to be a function of a longer growth season that arises under greater open water extent (P. Matrai). While first order productivity can be predicted from chlorophyll biomass, the vertical distribution of primary productivity presents a challenge for ocean color. For example, post bloom biomass maxima take place at depths deeper than observable by satellite. More year-round insitu biogeochemical measurements are necessary not only as ice-based measurements, but also from shelf regions where primary productivity is known to be very high. For biology, one of the key ice parameters is the timing of ice retreat. For example, some events in biology are not cued by their immediate environment but rather timing, hence in a rapidly changing Arctic a disparity between biology and the physical environment can arise.

The Arctic is a hugely complex system with a strong natural variability, intricate feedbacks and a multi-year memory for ocean-ice-atmosphere processes. Although continued Arctic change may be unstoppable under present anthropogenic warming, the rate and consequences of this change are less clear. It may be that the feedback mechanisms, steady warming and atmospheric circulation patterns will cause further dramatic reductions in summer ice, or that the Arctic will remain in a new, stable state of reduced seasonal ice cover for many years to come (one might begin to argue the latter given the nonappearance of a further precipitous drop in summer sea-ice extent in 2008, although evidence is still scarce). The coming decades will be of great significance to our understanding of Arctic climate.

References

Aagaard, K., T. J. Weingartner, S.L. Danielson, R.A. Woodgate, G.C. Johnson, and T.E. Whitledge, 2006: Some controls on flow and salinity in Bering Strait, Geophys. Res. Lett., 33, L19602, doi:10.1029/2006GL026612.

Comiso, J. C., C. L. Parkinson, R. Gersten, and L. Stock, 2008: Accelerated decline in the Arctic sea ice cover, Geophys. Res. Lett., 35, L01703, doi:10.1029/2007GL031972.

Giles, K. A., S. W. Laxon, and A. L. Ridout, 2008: Circumpolar thinning of Arctic sea ice following the 2007 record ice extent minimum, Geophys. Res. Lett., 35, L22502, doi:10.1029/2008GL035710.

Hamilton, L.C. and A. Mitiguy. 2008. Population Dynamics in Arctic Alaska: Graphical Views of Community Change. http://www.carseyinstitute.unh.edu/alaska-indicators.htm

Kerr, R. A., 2005: Atlantic climate pacemaker for millennia past, decades hence?: Science, v. 309, p. 4143.

Kwok, R., 2008: Summer sea ice motion from the 18 GHz channel of AMSR-E and the exchange of sea ice between the Pacific and Atlantic sectors, Geophys. Res. Lett., 35, L03504, doi:10.1029/2007GL032692.

Kwok, R., and G. F. Cunningham, 2008: ICESat over Arctic sea ice: Estimation of snow depth and ice thickness, J. Geophys. Res., 113, C08010, doi:10.1029/2008JC004753.

Laxon, S., N. Peacock, and D. Smith, 2003: High interannual variability of sea ice thickness in the Arctic region, Nature, 425, 947950.

L'Heureux, M.L., A. Kumar, G. D. Bell, M. S. Halpert, and R. W. Higgins, 2008: Role of the Pacific-North American (PNA) pattern in the 2007 Arctic sea ice decline, Geophys. Res. Lett., 35, L20701, doi:10.1029/2008GL035205.

Lindsay, R. W., J. Zhang, A. J. Schweiger, and M. A. Steele, 2008: Seasonal predictions of ice extent in the Arctic Ocean, J. Geophys. Res., 113, C02023, doi:10.1029/2007JC004259.

Lindsay, R.W., J. Zhang, A. Schweiger, M. Steele, and H. Stern, 2009: Arctic Sea Ice Retreat in 2007 Follows Thinning Trend, J. Climate, 22, 165176.

Mahoney, A. R., R. G. Barry, V. Smolyanitsky, and F. Fetterer, 2008: Observed sea ice extent in the Russian Arctic, 19332006, J. Geophys. Res., 113, C11005, doi:10.1029/2008JC004830.

Melling, H., D. A. Riedel, and Z. Gedalof, 2005: Trends in the draft and extent of seasonal pack ice, Canadian Beaufort Sea, Geophys. Res. Lett., 32, L24501, doi:10.1029/2005GL024483.

Overland, J. E. and M. Wang, 2005: The Arctic climate paradox: the recent decrease of the Arctic Oscillation, Geophys. Res. Lett. 32, L06701, doi:10.1029/2004GL021752.

Overland, J. E., M. Wang, and S. Salo, 2008: The recent Arctic warm period, Tellus, Ser. A, 60, 589 597, doi:10.1111/j.1600-0870.2008. 00327.

Perovich, D. K., J. A. Richter-Menge, K. F. Jones, and B. Light, 2008: Sunlight, water, and ice: Extreme Arctic sea ice melt during the summer of 2007, Geophys. Res. Lett., 35, L11501, doi:10.1029/2008GL034007.

Richter-Menge, J. A., D.K. Perovich, B.C. Elder, K. Claffey, I. Rigor, and M. Ortmeyer, 2006: Ice mass balance buoys: A tool for measuring and attributing changes in the thickness of the Arctic sea ice cover, Ann. Glaciol., 44, 205210.

Schuenemann, K., J.J. Cassano, and J. Finnis, 2009: Forcing of precipitation over Greenland: Synoptic climatology for 1961 to 1999, J. Hydrometeorology, In press?

Schweiger, A.J., R.W. Lindsay, S. Vavrus, and J.A. Francis, 2008: Relationships between Arctic sea ice and clouds during autumn, J. Climate, 21, 4799-4810.

Woodgate, R. A., K. Aagaard, and T. J. Weingartner, 2005: A year in the physical oceanography of the Chukchi Sea: Moored measurements from autumn 19901991, Deep Sea Res., Part II, 52(24 26), 3116 3149.