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The Evolving Arctic Operating Environment: Implications for Defence Planning

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Introduction

Effective planning for DND/CF activities in the arctic operating environment requires as reliable an understanding as may reasonably be achieved of what that environment is likely to be, and how it is likely to evolve, throughout the planning period in question. This is complicated by the inherently unpredictable nature of climate; as the United Nations' Intergovernmental Panel on Climate Change (IPCC) has acknowledged, "in climate research and modelling, we should recognize that we are dealing with a coupled non-linear chaotic system, and therefore that the long-term prediction of future climate states is not possible."[2]

Authorities from NASA's own climate modellers to Edward Lorenz, the father of 'chaos theory' himself, have inveighed against the feasibility of modelling chaotic systems. Lorenz evolved the theory of non-periodic systems while attempting to develop the first mathematical models of weather systems in the 1960s. He described the scope of the problem in the following terms:

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[1] The reported results, their interpretation, and any opinions expressed herein, remain those of the author and do not represent, or otherwise reflect, any official position of the Department of National Defence or the Government of Canada.
[2] United Nations Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University press, 2001), p. 774.

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> The average person, seeing that we can predict tides pretty well a few months ahead, would say, why can't we do the same thing with the atmosphere, it's just a different fluid system, the laws are about as complicated. But I realized that any physical system that behaved nonperiodically would be unpredictable.[3]

Half a century later, reliable climate models remain elusive. Gavin Schmidt, a climate scientist at the NASA Goddard Institute of Space Studies (GISS), recently acknowledged that

> The problem with climate prediction and projections going out to 2030 and 2050 is that we don't anticipate that they can be tested in the way you can test a weather forecast. It takes about 20 years to evaluate because there is so much unforced variability in the system which we can't predict — the chaotic component of the climate system — which is not predictable beyond two weeks, even theoretically.

"That," Schmidt noted, "is something that we can't really get a handle on."[4] This point – Lorenz's point – was echoed recently by two German physicists engaged in climate modelling, who stated that "The real world [is simply] too complex to be represented properly by a feasable [*sic*] system of equations ready for processing."[5]

In view of the inherent unpredictability of chaotic systems like climate, a thorough understanding of historical climate trends is the least unreliable means of achieving, with reasonable confidence, an idea of how future climate states are likely to evolve.[6] Trend analysis must of course be accompanied by innumerable caveats, not

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[3] Edward Lorenz, cited in James Gleick, *Chaos: Making a New Science* (New York: Viking Penguin, Inc., 1987), p. 18.

[4] [http://www.climatedepot.com/a/1813/US-Government-Scientists-Shock-Admission-Climate-Model-Software-Doesnt-Meet-the-Best-Standards-Available]. Accessed 26 March 2010.

[5] G. Gerlich and R.D. Tscheuschner, "Falsification of the Atmospheric CO_2 Effects Within the Frame of Physics", *Institut fur Mathematische Physik Technische Universitat Carolo-Wilhelmina*, 9 September 2007 [http://arxiv.org/PS_cache/arxiv/pdf/0707/0707.1161v3.pdf]. Accessed 26 March 2010.

[6] This is the approach advocated by the late Professor Hubert Lamb, founder of the Climate Research Unit (CRU) at the University of East Anglia in the UK. In support of his approach, Professor Lamb assembled a massive database of historical and proxy temperature records - a database which, according to the "Climategate" emails recently released by what appears to have been an insider, no longer exists. The CRU apparently retains only "quality-controlled and homogenized [i.e., altered] data". [http://www.cru.uea.ac.uk/cru/data/availability/]. Accessed 26 March 2010.

least of which is the inadvisability of attempting long-term projection of nonlinear trends. Furthermore, it is necessary to separate out from the process of trend projection assumptions that appear to conflict with observations, a complicating factor given the broad and highly variable array of assumptions that have been published in international, federal and departmental documents about possible future climate states in the arctic in general, and in the Canadian Arctic in particular. Projections that are not corroborated by subsequent observations are an inadequate foundation for strategic planning. This is particularly true in a difficult operating environment, where the gulf between past climate states, present climate states, and what is assumed and/or predicted to be the future state of the arctic climate, is very wide. Finally, projections about the evolution of non-linear trends require frequent and comprehensive reappraisals. Climate and environmental change are dynamic processes, and as time goes on, even those assumptions that may once have been – or at least seemed to be – valid, must be revisited periodically.

Because published assumptions about the evolving climate in the Arctic form the basis for force structure and procurement decisions at the departmental and federal levels, it is vital that they be re-examined on a regular basis in order to ensure that what we know – or what we think we know – about the operating environment in the arctic is both up to date and supported by evidence. This paper will review the published assumptions about how the arctic operating environment is changing, that are currently being used to guide DND/CF strategic planning; assess them in light of observed evidence and peer-reviewed scientific analysis; and reach conclusions about their validity over the extent of the outermost Defence planning horizon (i.e., Horizon 3, 10 to 30 years into the future).

The Assumptions

The assumptions discussed in this paper are derived from key federal and departmental documents that look at the near-term future shape and characteristics of the arctic operating environment. The documents that will be examined in this section are:

- *Canada's Northern Strategy: Our North, Our Heritage, Our Future*, Ministry of Indian Affairs and Northern Development, 2009 (federal strategy paper for the arctic)

- *From Impacts to Adaptation: Canada in a Changing Climate 2007*, Natural Resources Canada, 2008 (federal strategy paper assessing the likely impacts of climate change, especially Chapter 3, "Northern Canada")

- *Canada First Defence Strategy*, Department of National Defence, 2007 (federal defence policy); and

- *The Future Security Environment 2008-2030 Part One: Current and Emerging Trends*, Chief of Force Development, Department of National Defence, 27 January 2009.[7]

The reports of the UN Intergovernmental Panel on Climate Change (IPCC) will serve as the scientific reference point for projections of the impact on the arctic of climate change deriving from computer model projections based on the anthropogenic global warming hypothesis.

It should be noted that the vast majority of the predicted impacts of climate change deriving from international studies (especially the lengthy and detailed projections published quinquennially by the IPCC), are not relevant either to Canada's national security interests or to the Defence mission in the north. According to the recently published *Northern Strategy*, those interests and that mission begin with maintaining, exercising and if necessary defending Canadian sovereignty – "firmly asserting [Canada's] presence in the North, [and] ensuring we have the capability and capacity to protect and patrol the land, sea and sky in our sovereign Arctic territory."[8] While some current or proposed military activities (e.g., naval patrols of the Northwest Passage, putting "more boots on the ground", and the construction of a "deep-water berthing and fuelling facility" at Nanisivik and an Army Training Centre at Resolute

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[7] These documents may be found online at the following locations: *Canada's Northern Strategy* [http://www.northernstrategy.ca/index-eng.asp]; *From Impacts to Adaptation* [http://adaptation.rncan.gc.ca/assess/2007/index_e.php]; *Canada First Defence Strategy* [http://www.forces.gc.ca/site/pri/first-premier/June18_0910_CFDS_english_low-res.pdf]; and *Future Security Environment* [http://www.cfd-cdf.forces.gc.ca/documents/publications/Signed_ Eng_FSE_10Jul09_eng.pdf]. All documents accessed 30 March 2010.

[8] *Canada's Northern Strategy: Our North, Our Heritage, Our Future* (Ottawa: Ministry of Northern Affairs and Northern Development, 2009), p. 9.

Bay[9]) may potentially be impacted by changing climate states, others – such as enhanced monitoring of Arctic Ocean activities via RADARSAT II – will not.[10] Similarly, while it is perhaps possible that increased travel, trade, resource exploitation and other activities may result in pollution or harm to local ecosystems, flora or fauna, such results, while obviously regrettable, are unlikely to adversely affect Defence activities.

This paper focuses only on the assumptions about the effects of climate change that are likely to impact military operations in the north. Accordingly, the assumptions contained in the above-mentioned documents will be collated under three headings: the sea, including sea ice and its impact on arctic accessibility, and the rising sea levels expected as a result of the increase in average global temperature projected by the IPCC; the land, including glaciers and ice sheets, permafrost, and storms; and the extent to which the impact of climate change on human communities in the Canadian Arctic may lead to changing missions for Defence, thereby impacting DND/CF strategic planning. In all cases, the analytical horizon will not exceed the Defence planning horizon (Horizon 3, 10 to 30 years).

The Sea

Sea Ice

According to data maintained by the University of Illinois Cryosphere site,[11] average arctic sea ice coverage has declined slightly in recent years, a development balanced globally by a larger increase in Antarctic sea ice.[12] However, the long-term trend is small and may not be instructive, as the baseline is only 30 years. According to Canada's Northern Strategy, in 2007, satellite imagery "verified that the Northwest Passage [NWP] had less than 10 percent ice coverage, making it, by definition, 'fully

[9] *Canada's Northern Strategy*, 10.
[10] *Canada's Northern Strategy*, 10.
[11] [http://arctic.atmos.uiuc.edu/cryosphere/]. Accessed 26 March 2010.
[12] Antarctic sea ice, at time of writing, was at a record high. [http://www.iup.uni-bremen.de:8084/amsr/ice_ext_s.png]. Accessed 17 August 2010. As of 31 May 2011, it was average for 2003-2011.

navigable' for several weeks."[13] The Strategy argues that while the NWP is not expected to become a safe or reliable transportation route in the near future, "reduced ice coverage and longer periods of navigability may result in an increased number of ships undertaking destination travel for tourism, natural resource exploration or development."[14] Natural Resources Canada notes that while climate models disagree on when an ice-free arctic may be anticipated, "they agree in projecting that such conditions will eventually develop."[15]

Predictions of when the Arctic Ocean will become ice-free (or navigable, which is not exactly the same thing) range from a decade or so to the end of the 21st century. The IPCC 4th Assessment Report argued that, according to some climate model projections, "Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century."[16] The CFDS states that this is already occurring; "changing weather patterns are altering the environment, making it more accessible to sea traffic and economic activity. Retreating ice cover has opened the way for increased shipping, tourism and resource exploration, and new transportation routes are being considered, including through the Northwest Passage."[17] The *Future Security Environment* agrees, stating that "continued melting of polar ice is leading to increased human activity and easier access to the planet's poles."[18]

[13] *Canada's Northern Strategy*, 5.
[14] *Canada's Northern Strategy*, 5.
[15] *From Impacts to Adaptation*, Chapter 3, 74.
[16] AR4 SPM, 8.
[17] *Canada First Defence Strategy*, 6.
[18] *The Future Security Environment*, 37.

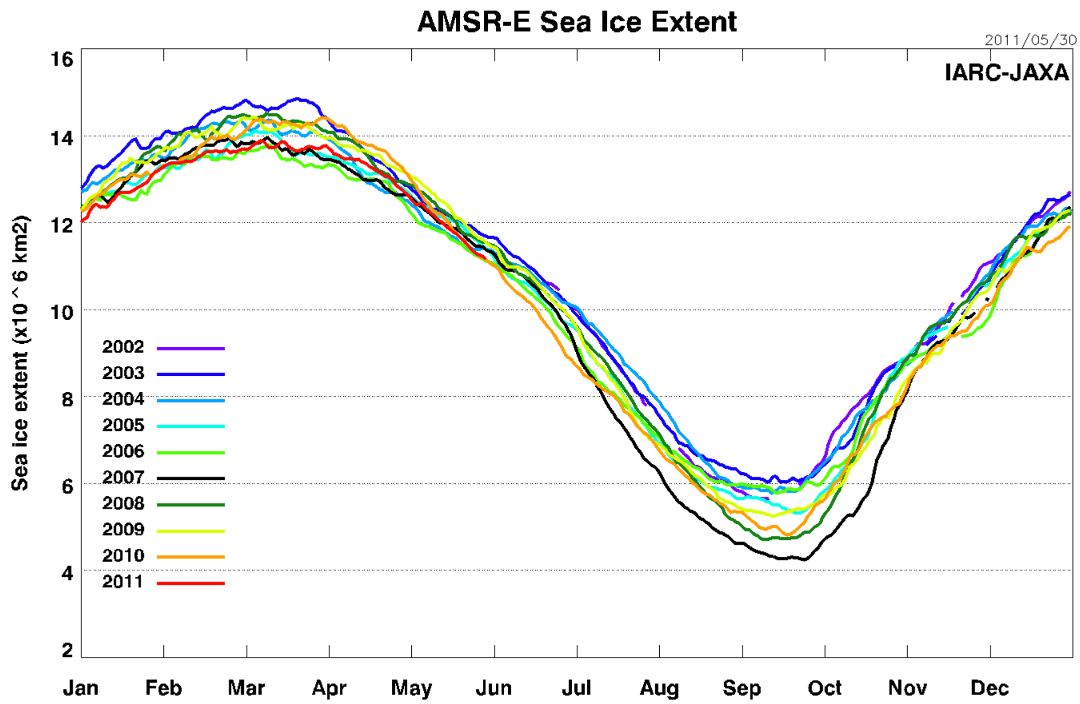


Figure 1 – Arctic Sea Ice Extent, 2002-2011 (30 May 2011, IARC/JAXA[19])

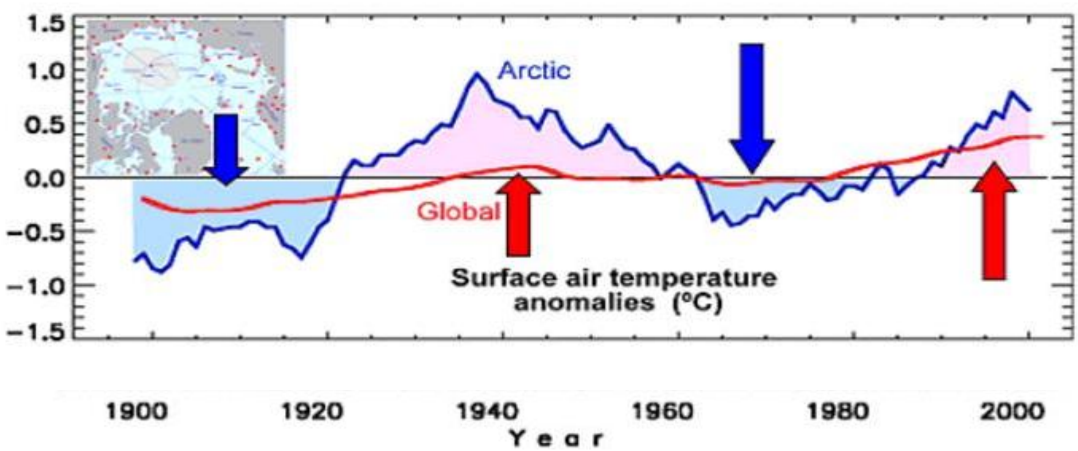
There is some empirical evidence to support these contentions. The satellite record of arctic sea ice coverage goes back only 30 years, and in September 2007, arctic sea ice reached a low point of slightly more than four million square kilometres for the first decade of the 21st Century (see Figure 1). While NASA attributed this development not to global warming but rather to "unusual wind patterns"[20] (the same phenomenon that caused relatively low extents of ice area during the 2010-11 winter), it nonetheless demonstrates variability in arctic sea ice coverage. Natural Resources Canada reinforces the NASA verdict, noting that "the primary cause of reductions in ice thickness and in late summer ice extent has been an increased export of multi-year ice from the Arctic via Fram Strait during 1989 –2003, not atmospheric warming;" and

[19] [http://www.ijis.iarc.uaf.edu/en/home/seaice_extent.htm], accessed 30 May 2011.

[20] NASA Jet Propulsion Laboratory, "NASA Examines Arctic Sea Ice Changes Leading to Record Low in 2007", 1 October 2007 [http://www.nasa.gov/vision/earth/lookingatearth/quikscat-20071001.html]. Accessed 26 March 2010.

adding that data from Siberia and Northern Canada show no significant change in the thickness of first-year ice over the second half of the 20th Century.[21]

Over the subsequent three years, arctic sea ice has recovered considerably. The minimum extent for 2008 was some 400,000 square kilometres higher than in 2007, and in 2009, the minimum extent was approximately 1,000,000 square kilometres – or roughly 25% – greater than the 2007 minimum. In 2010, arctic sea ice extent peaked in March; was higher in April, and lower in June, than at any other point in the 9-year record; and in August, ice extent was at the same level as 2008-09, and reached a very average minimum extent.[22] Moreover, the median thickness of arctic sea ice has increased every year since 2007 – from less than 1.5m in 2008, to 2m in 2009, and 2.75m in 2010,[23] and remains "within the bounds of natural variability."[24]



[21] *From Impacts to Adaptation*, Chapter 3, 74.

[22] See the University of Illinois Cryosphere website, [http://arctic.atmos.uiuc.edu/cryosphere/]; Johannesen et al., "Recent Ice-Sheet Growth in the Interior of Greenland ", *Science,* 11 November 2005: Vol. 310. no. 5750, pp. 1013 – 1016; Willie Soon, "Is the Arctic Melting?", *TCS*, 9 November 2004; and Tim Ball, "Wide Fluctuations in Arctic Temperatures Common", Frontier Center for Public Policy, 20 November 2004 [http://www.fcpp.org/main/publication_detail.php?PubID=872]. Accessed 26 March 2010.

[23] Steve Goddard, "The Undead Spiral", 2 June 2010 [http://wattsupwiththat.com/2010/06/02/the-undeath-spiral/#more-20128]. Accessed 3 June 2010.

[24] See Christian Haas, Stefan Hendricks, Hajo Eicken and Andreas Herber, "Synoptic airborne thickness surveys reveal state of Arctic sea ice cover", Geophysical Research Letters, 47, L09501 (2010).

Figure 2 – Atlantic Multidecadal Oscillation (AMO, Blue) vs. Global Average Temperature (Red)[25]

The 2010 arctic sea ice melt season began on 31 March 2010 – the latest that the melt season has begun since measurements began in 1979.[26] The 2010 melt season was the coldest on record, with temperatures north of 80°N Latitude below normal for the whole of the summer season.[27] As a result, for much of the year to date, ice extent has exceeded the 1979-2006 average (again, see Figure 1).[28]

According to the US National Snow and Ice Data Centre, the lowest ice extent of the 2010 melt season was more than four hundred thousand square kilometres above the 2007 minimum, higher than the 2008 minimum.[29] The correlation of the 2007 low point for arctic sea ice extent with the Atlantic Multidecadal Oscillation (AMO), which appears to operate on a 60-70 cycle, and which peaked in 2007, is unmistakeable (see Figure 2).

Comparing the AMO cycle from Figure 2 to the Northern Hemisphere Sea Ice Anomaly charts compiled by Cryosphere Today (Figure 3), one notes a correlation between the mid-1990s transition in the AMO from a cooling to a warming regime, and the mid-1990s transition in North Hemisphere Sea Ice anomaly from positive (pre-1995) to negative (post-1995).

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[25] International Arctic Research Centre, University of Fairbanks, Alaska.
[26] National Snow and Ice Data Centre, 6 April 2010 [http://nsidc.org/news/press/20100406_maximum.html]. Accessed 6 April 2010.
[27] See [http://climateinsiders.files.wordpress.com/2010/08/meant_2010-71.png]. Accessed 17 August 2010.
[28] [http://arctic-roos.org/observations/satellite-data/sea-ice/observation_images/ssmi1_ice_ext.png]. Accessed 10 May 2010.
[29] According to NSIDC scientist Julienne Strove, the fact that sea surface temperatures were colder in the 2010 melt season than in previous melt seasons “suggests that other factors played a more dominant role.” The most important “other factor”, according to NASA’s report on the 2007 melt season, is wind patterns.

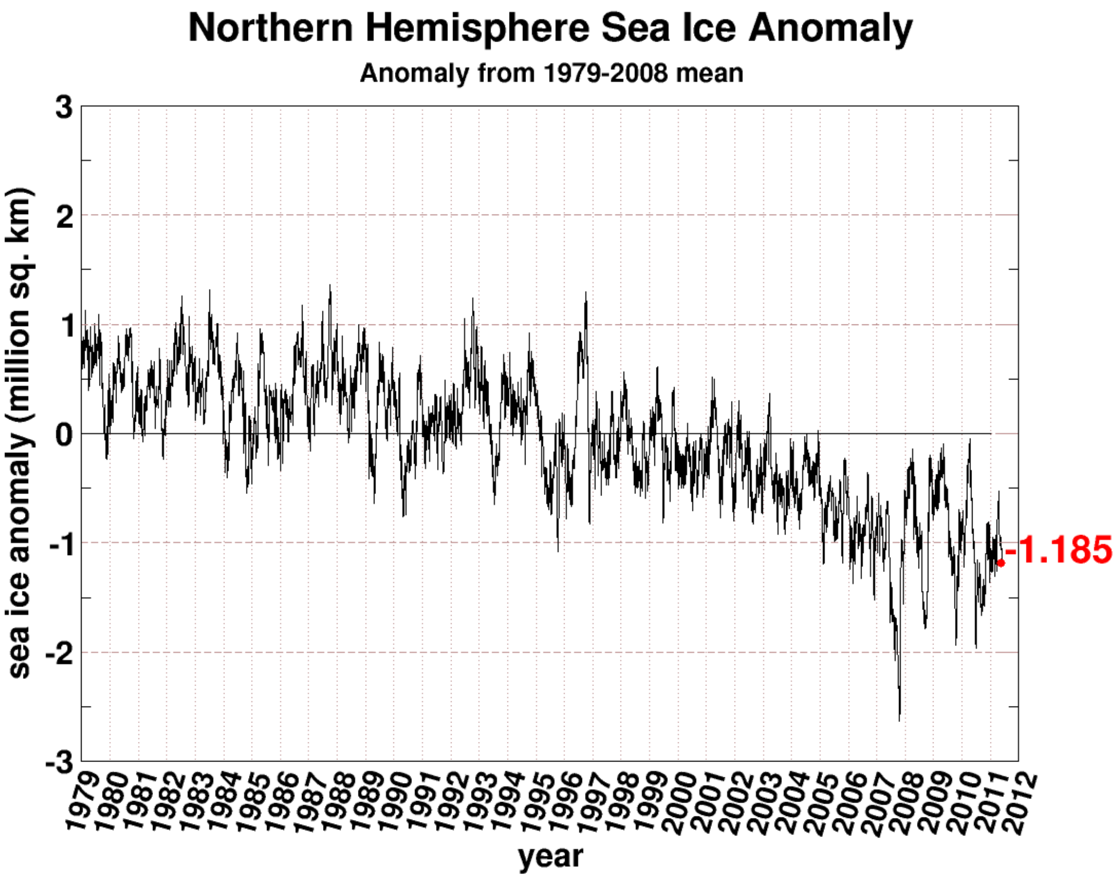

Figure 3 – Northern Hemisphere Sea Ice Anomaly, 1979-2010[30]

The correlation between a warming AMO and a negative arctic sea ice anomaly is too obvious to miss. As Polyakov et al. note,

> [Atlantic water] variability is dominated by multidecadal fluctuations with a time scale of 50–80 yr (LFO). The resemblance between variability of the AW and other key climatic parameters such as air temperature and pressure (Polyakov et al. 2003a), ice extent and thickness (Polyakov et al. 2003b), sea level (Dvorkin et al. 2000), and Barents Sea salinity (Polyakov and Johnson 2000) is striking, suggesting a close connection between large-scale atmospheric circulation and Arctic ice and oceanic conditions.[31]

[30] University of Illinois at Urbana-Champaign, The Cryosphere Today. [http://arctic.atmos.uiuc.edu/cryosphere/IMAGES/seaice.anomaly.arctic.png]. Accessed 31 May 2011.
[31] I.V. Polyakov et al., "Variability of the Intermediate Atlantic Water of the Arctic Ocean over the Last 100 Years", in Journal of Climate, Vol. 17, No. 23 (1 December 2004), 4494.

All empirical evidence, in short, suggests that arctic sea ice thickness and extent are cyclical, a product of many climatic factors of which air temperature is only one. More to the point, however, is the fact that the AMO has been in a warming trend since the early 1970s, peaking in about 2007, after which it appears to have entered a cooling trend. If, as history suggests, the AMO operates on a 60-70 year cycle, then the next 30-35 year period is likely to be characterized by a cooling AMO and, consequently, a return to a positive sea ice anomaly in the Northern Hemisphere. This means that, contrary to the assumptions contained in the FSE and elsewhere, sea ice in the arctic is likely to increase rather than decrease.[32]

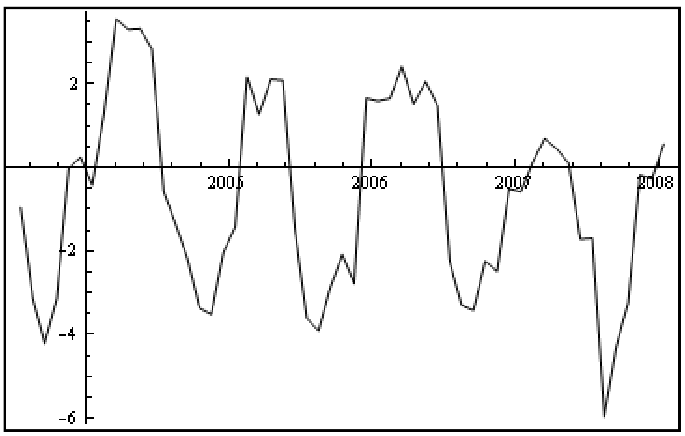

Figure 4 - Ocean Heat Content Trend 2004-2008 [x10²²J][33]

This projection is supported by oceanic temperature measurements over the past few years. Data from the ARGO floating buoy array demonstrates that the global trend in oceanic heat content for the past five years has been negative, equivalent to 0.35 x 10^{22} J/year (see Figure 4), and that the ongoing rate of change of aggregate oceanic heat content is "preponderantly negative."[34] Observations recorded by the Danish Meteorological Institute show that the average daily temperature above 80°N latitude

[32] Leading some analysts to predict a rebound in Arctic ice, likely peaking in 2030-35, DND's 'Horizon 3'. [http://wattsupwiththat.com/2010/10/16/arctic-ice-rebound%c2%a0predicted/]. Accessed 31 May 2011.

[33] Dr. Craig Loehle, "Broken Hockey Sticks, 1500 Year Cycles, and Ocean Cooling", Presentation to the International Conference on Climate Change, 9 March 2009 [http://www.heartland.org/events/NewYork09/proceedings.html]. Accessed 26 March 2010.

[34] Robert S. Knox and David H. Douglass, "Recent Energy Balance of Earth", *International Journal of Geosciences*, Vol. 1 (2010), p. 101.

during the arctic melt season has been declining for half a century.[35] If – as observed data suggest – ice thickness is indeed relatively stable,[36] and air temperatures (especially during the melt period) and ocean temperatures are both falling,[37] the likelihood of accelerating loss of arctic sea ice, a navigable Northwest Passage, or an ice-free Arctic Ocean is rather less than has been predicted on the basis of climate models.[38] It is more likely that arctic sea ice extent will remain relatively stable, or perhaps even increase, over the coming decades.

A return to declining temperatures and increasing sea ice in the arctic should not surprise us. History records periods when there was both more and less sea ice in the arctic. US nuclear submarines surfaced to find open water at the geographic North Pole in the 1950s, 1960s, and 1980s;[39] the Northwest Passage was open in 1945; according to a Soviet author writing in the 1940s, arctic ice in the Greenland Sea, ice quantity in the Barents Sea was "exceptionally low" in 1930, 1931 and 1932, with "catastrophic" receding of the Spitzbergen glaciers in 1934, and that ice cover "for the period 1921 to 1938 [was] 15 to 20 per cent less than for the period 1898 to 1920";[40] a Norwegian

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[35] Daily average temperature data, 80°-90° North Latitude, 1958-2010 [http://ocean.dmi.dk/arctic/meant80n.uk.php]. Accessed 21 October 2010.

[36] C. Haas, S. Hendricks, H. Eicken, and A. Herber (2010), "Synoptic airborne thickness surveys reveal state of Arctic sea ice cover", *Geophys. Res. Lett.*, 37 (2010), L09501, doi:10.1029/2010GL042652.

[37] All four global temperature databases show declining average global temperatures for the past seven years or more. See the NASA GISS website [http://data.giss.nasa.gov/gistemp/tabledata/GLB.Ts+dSST.txt]; Accessed 26 March 2010; and the Remote Sensing System website [http://www.remss.com/data/msu/monthly_time_series/ RSS_Monthly_MSU_AMSU_Channel_TTS_Anomalies_Land_and_Ocean_v03_2.txt]. Accessed 26 March 2010. The Hadley (land-based) and UAH MSU (satellite) data show similar cooling trends.

[38] Between March and April 2010, upper ocean equatorial heat content dropped by 1ºC, the largest amount since records began in 1979. [http://pielkeclimatesci.wordpress.com/2010/05/07/recent-variations-in-upper-ocean-heat-content-information-from-phil-klotzbach/]. Accessed 10 May 2010.

[39] Official U.S. Navy Photographs: photo # DN-ST-87-09888, and photo # DN-ST-87-09889, available from [dodmedia.osd.mil].

[40] N.N. Zubov, *Arctic Ice* (1943), trans. By the U.S. Navy Oceanographic Office (Washington, D.C.: US Navy Electronics Laboratory, 1963), 457 and 472. Zubov writes that "the period from 1869 to 1898 was a warm one for the Kara Sea"; "the period from 1899 through 1929 was a cold one"; "a warm period began again in 1929";and that according to Burke, "the warming of the Kara Sea will attain its maximum temperature around 1943 and 1944 while cooling will not commence until 1959." Zubov, 458. In other words, the Kara Sea ice fluctuated according to a cycle approximately 30 years in length. Concerning the Burke prediction cited by Zubov, it is worth noting that even the IPCC acknowledges that global average temperatures troughed from roughly 1940-1980. See Figure 3.1 in "Annual anomalies of global land-surface air temperature (°C), 1850 to 2005", Fourth Assessment Report, Report of Working Group I, *The*

research vessel was able to sail within 90 nautical miles of the Pole in 1921 (a feat that would have been impossible in 2007);[41] Commander Robert E. Peary, during the first trek to the North Pole, reported having to "cross and re-cross…open leads", i.e. clear water gaps in the arctic sea ice, during his approach march in the depths of the winter of 1907;[42] Amundsen traversed the Northwest Passage in a sailing ship in 1903; and the Royal Society urged the Admiralty to send a naval expedition to investigate a "change of climate" that was causing a reduction of arctic sea ice in 1817.[43] Natural Resources Canada notes that "even in the much cooler mid–nineteenth century, the extent of summer sea ice in the Canadian Archipelago, insofar as it is shown from ship tracks and the logbooks of explorers, was similar to the present."[44]

In short, arctic sea ice extent, like many individual manifestations of climate, appears to be cyclical, and appears to respond to many forcing agents beyond air and water temperature.[45] Even during periods when sea ice extent is minimal, the Arctic

Physical Science Basis [http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch3s3-2-2.html]. Accessed 10 May 2010.

Interestingly, Zubov also notes that "The Norwegian Vikings in the 10th and 11th centuries evidently experience no difficulties due to ice when sailing to Greenland," but that "Starting with the year 1261 the first written indications appear of an ice blockade of Iceland." Zubov, p. 461. The colonization voyages of Erik the Red, which took place in 984 and 987, occurred during the Medieval Warm Period, while the cited "ice blockade" coincides with the onset of the Little Ice Age.

[41] Sea ice data from the IARC-JAXA website [http://www.ijis.iarc.uaf.edu/en/home/seaice_extent.htm].

[42] Henry Collins Walsh, "The Pole At Last", *The New York Times*, 1 October 1910, p. 533.

[43] "It will without doubt have come to your Lordship's knowledge that a considerable change of climate, inexplicable at present to us, must have taken place in the Circumpolar Regions, by which the severity of the cold that has for centuries past enclosed the seas in the high northern latitudes in an impenetrable barrier of ice has been during the last two years, greatly abated." President of the Royal Society, London, to the Admiralty, 20th November, 1817, *Minutes of Council*, Volume 8. pp.149-153, Royal Society, London. 20th November, 1817 [via http://www.john-daly.com/polar/arctic.htm]. Incidentally, this letter urged the Admiralty to engage in exploration of the Arctic. It is probably not an accident that increased naval exploration was being considered just as the Royal Navy was paying off the better part of the world's largest naval establishment in the wake of the Napoleonic Wars.

[44] *From Impacts to Adaptation*, p. 74.

[45] For a comprehensive discussion of the complexity of the factors affecting Arctic climate, and especially Arctic sea ice, see Ian Plimer, *Heaven and Earth: Global Warming – The Missing Science* (New York: Lanham, 2009), pp. 257-267. For more recent research demonstrating the cyclical nature of polar temperatures, see B. Stenni et al., "The deuterium excess records of EPICA Dome C and Dronning Maud Land ice cores (East Antarctica)", Quaternary Science Reviews 29 (2010), pp. 146–159. [http://epic.awi.de/Publications/Ste2009a.pdf]. Accessed 15 June 2010.

Ocean is not an easy or hospitable region for maritime traffic. According to one report, despite arctic ice having retreated further in the 1940s than in 2007, there were only 11 foreign ship transits of the Northwest Passage between 1904 and 1984.[46] Unless summer ice-melt is substantially greater in the future than it was in the 20th Century, an assumption that is not supported either by historical or current trends, there is little prospect of the Northwest Passage becoming a practical or frequent choice for maritime transit, or of the Arctic Ocean being routinely used for transit or resource exploitation purposes.

The predictions of an ice-free arctic, whether in ten years or one hundred, that have been cited in the above-mentioned documents are based not on projection of actual climatic trends, but rather on the outputs of climate models. These projections have not been confirmed by observed data, which, as noted above, show that the Earth, for at least the last decade, has been cooling rather than warming. Natural Resources Canada notes that the scientific understanding of sea-ice dynamics is "incomplete"; that "the representation of the Arctic atmosphere-ice-ocean system in global climate models is relatively primitive"; and that accordingly, "the observational record of sea-ice extent in Canadian Arctic waters, and an understanding of the physical processes involved, become particularly important in projecting future changes in sea-ice regime".[47] The last time the arctic appears to have been even sporadically ice-free was during the early Holocene Climate Optimum (roughly 10,000 years ago),[48] even though the arctic was 2

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[46] "Battle for the Arctic Heats Up", CBC News, 17 August 2009 [http://www.cbc.ca/canada/story/2009/02/27/f-arctic-sovereignty.html]. Accessed 26 March 2010.

[47] *From Impacts to Adaptation*, p. 74.

[48] "The combined sea ice data suggest that the seasonal Arctic sea ice cover was strongly reduced during most of the early Holocene and there appear to have been periods of ice free summers in the central Arctic Ocean." Martin Jakobbsen et al., "New insights on Arctic Quaternary climate variability from palaeo-records and numerical modeling", in Quaternary Science Reviews (Online Edition, 2 October 2010). [http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VBC-51509K7-1&_user=10&_coverDate=10%2F02%2F2010&_alid=1521994296&_rdoc=6&_fmt=high&_orig=search&_origin=search&_zone=rslt_list_item&_cdi=5923&_sort=r&_st=13&_docanchor=&view=c&_ct=13&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=3b40a261dc92ec2327ece3eaf07061be&searchtype=a]. Accessed 1 November 2010. It is worth noting that these higher temperatures and the ice-free Arctic antedate human industrialization and consumption of fossil fuels by about eight thousand years.

to 3 degrees warmer 1,000 years ago, during the Medieval Warm Period, than it is at present.[49]

The uncertainties inherent in modelling future climate states and the fact that model projections have not been confirmed by observation has led the UK Meteorological Office to assess as "unlikely" the possibility that the Arctic Ocean will be ice-free before 2020, and to project that if the arctic does become ice-free, this will probably will not occur before 2060 at the earliest.[50] Even if this prediction should prove to be accurate, it lies well beyond the outermost planning limits of Horizon 3. It is therefore unlikely that changes to arctic sea ice will significantly impact the operating environment in the Canadian North over the Department's planning horizon.

Sea Level

Natural Resources Canada argues that climate change will lead to rising sea levels in the Arctic Ocean both through thermal expansion and through the addition of water to the world ocean from melting glaciers and ice sheets.[51] This is based on the IPCC 4th Assessment Report, which noted a rise in average global sea levels of about 175 mm from 1870-2000, and argued that the rate of sea level increase is accelerating. The IPCC assesses that sea levels are likely to increase by 18 to 59 centimetres by 2100.[52] "Rising sea levels," according to DND's *Future Security Environment*, "will bring severe flooding to low-lying countries" leading to "mass migration as people flee their homes."[53]

Observed data do not support the contention that sea level rise is likely to impact the arctic operating environment. There is nothing unusual about the rate of sea level

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49 W.J. D'Andrea and R.S. Bradley, "A 5,000 year alkenone-based temperature record from Lower Murray Lake reveals a distinct Medieval Warm Period in the Canadian High Arctic", Abstract #PP43C-10, Fall Meeting of the American Geophysical Union, December 2010 [http://adsabs.harvard.edu/abs/2010AGUFMPP43C..10D]. Accessed 21 December 2010.

50 Met Office, "The Decline in Arctic Summer Sea Ice", 15 October 2009 [http://www.metoffice.gov.uk/corporate/pressoffice/2009/pr20091015b.html]. Accessed 26 March 2010.

51 *From Impacts to Adaptation*, Chapter 3, p. 77.

52 IPCC Climate Change 2007 Synthesis Report, pp. 30-31.

53 *Future Security Environment,* p. 36.

rise during the 20th Century.[54] Despite rising at a rate of four feet per century for the past 10,000 years (i.e., since the end of the last glaciation), the rate of rise has been steadily declining, and sea levels rose only eight inches during the 20th century.[55] Since the University of Colorado began recording precise sea level measurements in 1993, the rate of sea level rise has been 3.2 mm per year. If this trend were to continue, it would amount to an increase in sea levels of 32 cm over the next century, which is in the lower half of the IPCC's predicted range of 18-59 cm (see Figure 5). However, the trend has not continued. No regular trend in sea level is evident over the past three centuries, and satellite telemetry shows virtually no change in the average global sea level over the past decade.[56] At present the rate of sea level rise is decelerating; there has been no statistically significant increase in sea level since 2006, either in the arctic, or worldwide.[57,58]

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[54] See J.A. Church et al., "Estimates of the regional distribution of sea-level rise over the 1950-2000 period", *Journal of Climate 17* (2004) p. 2609-2625; and S.J. Holgate, "On the decadal rates of sea level change during the twentieth century", *Geophysical Research Letters* **34**: 10.1029/2006GL028492.

[55] Plimer, 298-318.

[56] N.A. Morner, "Estimating future sea level changes from past records", *Global and Planetary Change* **40** (2004), pp. 49-54.

[57] See the data charts at the University of Colorado sea level change website [http://sealevel.colorado.edu/results.php].

[58] See Manfred Wenzel and Jens Schröter, "Reconstruction of mean sea-level anomalies from tide gauges using neural networks", Journal of Geophysical Research, Vol. 115, C08013, 2010 (doi:10.1029/2009JC005630). Abstract available at [http://www.agu.org/pubs/crossref/2010/2009JC005630.shtml]. Accessed 17 August 2010.

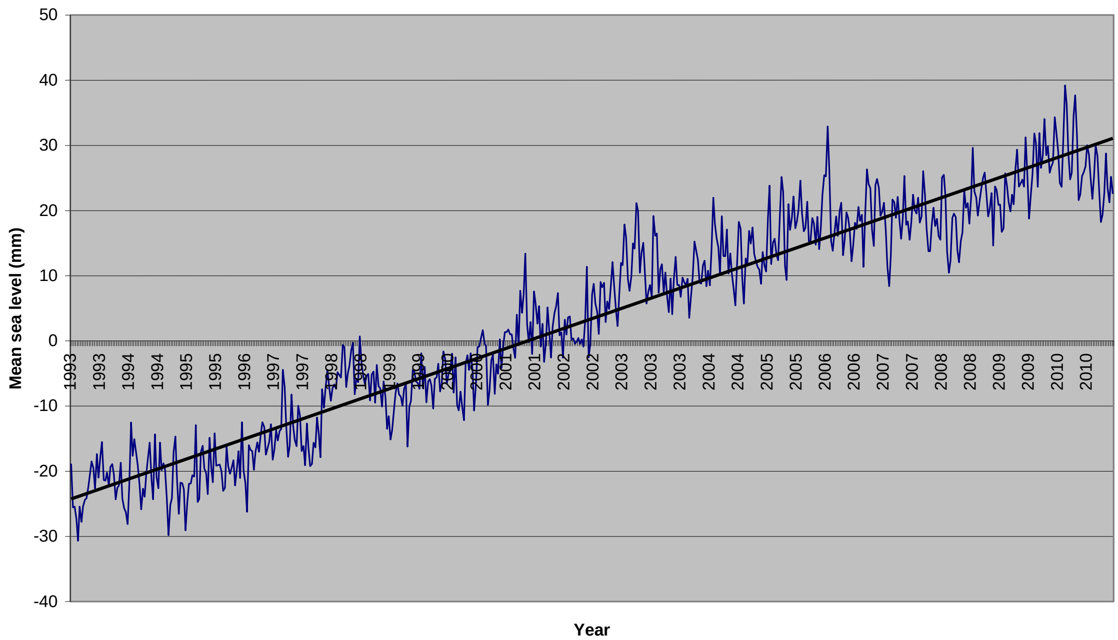

Figure 5 – Average Sea Level, 1993-2010[59]

For the past five years, the rate of sea level rise has been only a little over 2 mm per year (see Figure 6, below) – which is in fact was the average annual rate of sea level increase for the past century.

[59] Data source: University of Colorado sea level data page [http://sealevel.colorado.edu/results.php], inverted barometer not applied, seasonal signal removed. Accessed 17 January 2011.

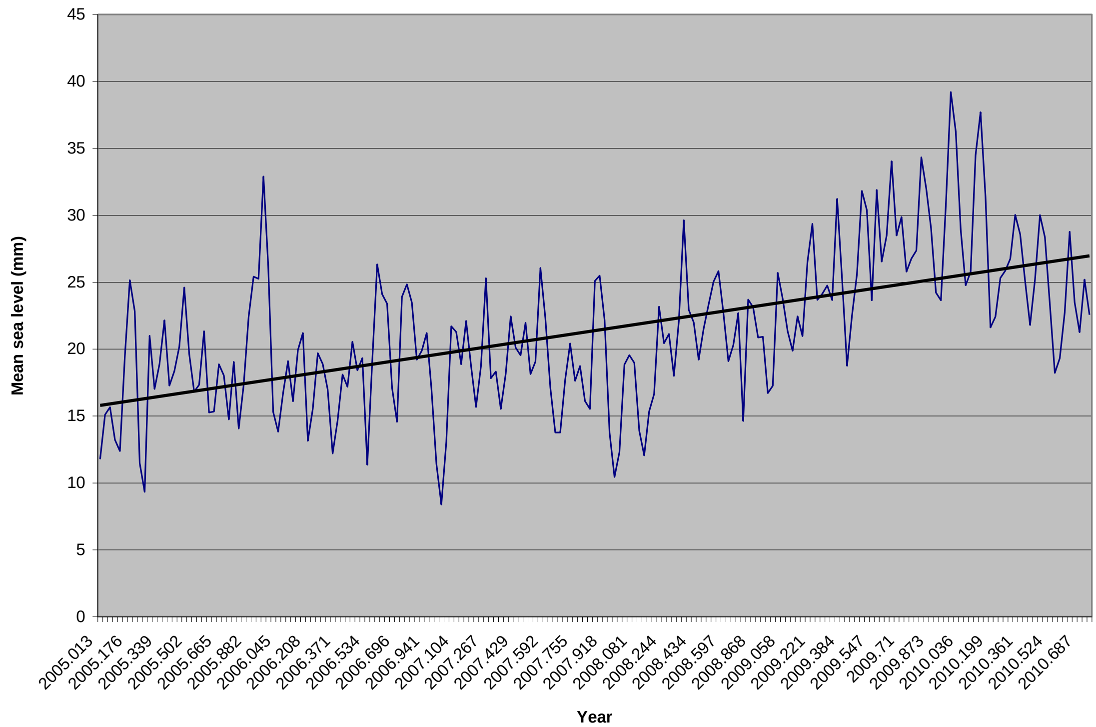

Figure 6 – Decelerating sea level increase, 2005-2010[60]

This has been confirmed by recent peer-reviewed analysis which has found that rather than accelerating, the "global sea level has possibly decelerated for at least the last 80 years."[61]

For the IPCC projection of a 59 cm increase in sea level by the year 2100 to be achieved, the average sea level would have to rise by 6.63 mm every year from 2011 to 2100, an annual rate that has not been achieved even once in the last 20 years. The current rate of increase is less than one-third of what would be required to achieve the

[60] Data source: University of Colorado sea level data page [http://sealevel.colorado.edu/results.php], inverted barometer not applied, seasonal signal removed. Accessed 17 January 2011. It is also worth noting that the r^2 value for Figure 5 is 0.92, demonstrating a fairly close correlation between increasing sea level and time; while the r^2 value for Figure 6 is only 0.33, demonstrating only a very loose correlation between increasing sea level and time. This is because two years out of the last five have shown decreases in average sea level.

[61] J.R. Houston and R.G. Dean, "Sea-level acceleration based on U.S. tide gauges and extensions of previous global-gauge analyses", Journal of Coastal Research, 2011, p. 7 (in press) [http://www.jcronline.org/doi/pdf/10.2112/JCOASTRES-D-10-00157.1]..Accessed 28 March 2011.

IPCC prediction. That there has been no net warming of the upper oceans,[62] and that the oceans are at present cooling,[63] limits the possibility of sea level rise through thermal expansion; while cooling of the atmosphere over the past decade suggests that melt-water is unlikely to make a greater contribution to sea level rise over the near term. Empirical evidence therefore does not support predictions of sea level rise in the Arctic Ocean (or elsewhere) greater than the very modest increase observed over the past hundred years (i.e., approximately 20 cm per century).

The impact on the arctic of any change in sea level is in any case likely to be uneven. A 2006 European Space Agency study of satellite measurements found, for example, that arctic sea levels are in fact falling by 2 mm per year, at precisely the same rate at which the remainder of the world's oceans have risen over the past century.[64] This contradicts IPCC predictions of net sea level rise in the arctic. These results may be due in part to the fact that much of the arctic coastline is rising due to post-glacial isostatic rebound; in some places, the land is rising by as much as 1 metre per century, roughly five times as fast as the average centennial increase in sea levels, and roughly twice as fast as the IPCC's maximum projected sea level rise.[65] Other areas appear to be subsiding.[66]

These measurements, and assessments of possible impacts of changing sea levels, are complicated by coastal erosion. While the *Future Security Environment* agues that a warming climate will lead to increased erosion and coastal retreat,[67] no significant trend in coastal erosion in the arctic has been detected over the 1972 to 2000 time-frame.[68] Indeed, reports of storm-related coastal erosion in Alaska in the 1960s suggest that

[62] Roger Pielke Sr., "A broader view of the role of humans in the climate system", *Physics Today* **61**, Vol. 11, pp. 54-55.
[63] Craig Loehle, "Cooling of the global ocean since 2003", *Energy & Environment* 20 (1&2), pp. 99-102. See also J. Lyman, J. Willis and G. Johnson, "Recent cooling of the upper ocean", *Geophysical Research Letters* **33** (2006).
[64] Jonathan Amos, "Arctic Dips as Global Waters Rise", BBC News, 15 June 2006 [http://news.bbc.co.uk/2/hi/5076322.stm?ls]. Accessed 26 March 2010.
[65] Plimer notes that a similar dynamic is at work around the Arctic littoral, for example, in Finno-Scandia, which is likewise rising at a rate of 1m per century. Plimer, p. 302.
[66] *From Impacts to Adaptation*, p. 77.
[67] *The Future Security Environment*, p. 36.
[68] *From Impacts to Adaptation*, p. 78.

erosion is a long-term feature not associated with recent warming, and demonstrates that, to the extent that erosion is a problem for northern communities, it is the result not of climate change but rather of decisions taken over time to build infrastructure uncomfortably close to an inherently unstable coastline.[69] This is a problem, incidentally, that plagues coastal communities worldwide; it is not peculiar to the arctic.

Tidal variation, moreover, is likely to overwhelm any change in sea levels. The daily tidal variation in the arctic during the third week of January 2010, for example, ranged from 30 cm in Tuktoyaktuk and Kugluktuk, to 70 cm at Alert; 100 cm at Hall Beach; and 860 cm at Iqaluit.[70] Against such figures, neither the increase projected by the IPCC (1.9 to 5.6 mm per year) nor the decrease noted by the European Space Agency (2 mm per year) would have a significant impact either on coastal communities or on CF operations in the arctic over the course of the planning horizon. Over the near term, tidal surges associated with storms are of far greater importance than projected long-term sea level change; Natural Resources Canada notes that storm surges of up to 2 metres have been recorded at low-lying coastal communities such as Tuktoyaktuk.[71] However, this problem is associated with weather patterns rather than sea level change.

In short, there is no empirical support for projections of a significant divergence from the sea level trend observed during the 20th Century, to wit, a modest rise of somewhat less than 2 mm per annum. This is likely to be lower than changes due to rising and falling land, and vastly lower than variations due to weather. It is therefore unlikely that changes to sea level will significantly impact the operating environment in the north over the Department's planning horizon.

The Land

Glaciers and Ice Sheets

[69] Patrick J. Michaels and Robert C. Balling, Jr., *Climate of Extremes* (Washington, D.C.: Cato Institute, 2009), pp. 129-30.
[70] Data from Fisheries and Oceans Canada [http://www.waterlevels.gc.ca/cgi-bin/tide-shc.cgi?queryType=showRegion&language=english&region=2]. Accessed 13 January 2010.
[71] *From Impacts to Adaptation*, Chapter 3, pp. 77-78.

According to the IPCC, the melting of glaciers and other land-based ice sheets is one of the principal observed indicators of 'climate change.'[72] "Mountain glaciers," it is argued, "have declined in both hemispheres."[73] This is echoed in *Canada's Northern Strategy*, which cites "melting glaciers" as evidence of "the effects of environmental change";[74] and in the *Future Security Environment*, which states (oddly) that "melting glaciers are expected to increase the possibility of land loss" and, more plausibly, "reduce access to fresh water resources."[75]

The estimated volume of land ice in the circumpolar arctic is approximately 3.1 million cubic kilometres. This is about eight percent of the ice on Earth, and is roughly one-tenth the volume of the Antarctic ice sheet. The majority of arctic land ice – about 2.6 million cubic kilometres – is contained in the Greenland ice sheet (GIS).[76, 77] It has been estimated that if all of the ice in the arctic were to melt, the result would be a rise in average global sea level of approximately 8 metres.[78] Actual melting has been much more modest; over the last 5 years of the 20th Century, roughly 25 cubic kilometres of land ice in the Canadian Arctic archipelago melted per year, contributing 0.064 mm of sea level rise per annum (an annual increase in oceanic depth approximately equivalent to half the thickness of a human hair).[79]

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[72] Pursuant to the anthropogenic global warming thesis posited by the IPCC et al., this is deemed to be one of the key indicators of *human-caused* climate change. Whether there is or is not a detectable anthropogenic signal in climate change is not relevant for purposes of this paper, which considers only what is happening, not why it is happening.

[73] *Climate Change 2007: Synthesis Report*, p. 30.

[74] *Canada's Northern Strategy*, p. 8.

[75] *The Future Security Environment,* 36. The document does not make clear how melting glaciers might lead to land loss (perhaps through rising sea levels). However, it does cite the IPCC contention that the Himalayan glaciers "will probably disappear by 2035" – a claim from the IPCC 4th Assessment Report that was not based on any scientific evidence, but that was adapted from a World Wildlife Federation website. [http://www.theaustralian.com.au/news/opinion/glaciergate-threatens-a-climate-change/story-e6frg6zo-1225822681922]. The claim of Himalayan glacier melt has since been retracted. Accessed 30 March 2010.

[76] *From Impacts to Adaptation*, Chapter 3, p. 75.

[77] "Greenland", in the *World Book Encyclopedia* (Chicago: World Book, 1999), p. 325.

[78] Richard S. Williams, Jr., and Jane G. Ferrigno, "Estimated present-day area and volume of glaciers and maximum sea level rise potential", Satellite Image Atlas of Glaciers of the World, US Geological Survey.

[79] *From Impacts to Adaptation*, Chapter 3, p. 75. Human hair ranges in diameter from 50 to 100 μm.

Most of the concern about the fate of arctic land ice logically centres upon the GIS, as this is where more than 80% of the arctic's land ice is found. The IPCC states that future changes in the GIS are a source of "uncertainty" in the response of models to warming scenarios.[80] Some of the more extreme climate change scenarios posit extensive melting or "collapse" of the GIS, although even the IPCC acknowledges that this is a process that would require significantly elevated temperatures lasting for thousands of years.[81]

Some researchers have argued that accelerated melting of the GIS is already underway.[82] These arguments have not been borne out by observed evidence. More recent research based on a wide-ranging survey of glacier conditions across Greenland suggests that the brief acceleration in ice movement in the early 21st Century began slowing in 2005 and has since ended; and that while a warmer climate might indeed lead to some melting, it is not appropriate, according to one researcher, to attempt to project the recent "wild behaviour" of the GIS in the first few years of the 21st Century into the distant future.[83] Indeed, more recent research suggests that the rate of melting of the GIS (and the Western Antarctic Ice Sheet as well) is about half what had originally been expected;[84] the amount of fresh water from melting glaciers moving into the East Greenland Current has not changed significantly for the past twenty years.[85] It is not clear whether the decreasing activity of the GIS is a consequence of the lack of statistically significant warming since 1995, and/or the actual decline in average global temperatures since 2002. According to recent research conducted at the Woods Hole Oceanographic Institution, oceanic currents have a greater impact on Greenland's

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[80] *Climate Change 2007: Synthesis Report*, p. 73.

[81] *Climate Change 2007: Synthesis Report*, p. 47. The IPCC further opines that "singularities" could lead to extensive melting of the GIS in only "centuries" (*ibid*., p. 65).

[82] See, for example, E. Rignot and P. Kanagaratnam, "Changes in the Velocity Structure of the Greenland Ice Sheet", in *Science* **311** (2006), pp. 986-990; and I. Velicogna and J. Wahr, "Acceleration of Greenland Ice Mass Loss in Spring 2004", in *Nature* **443** (2006), pp. 329-331.

[83] [http://www.sciencemag.org/cgi/content/full/323/5913/458a]. Accessed 26 March 2010.

[84] See the research results reported by L.L.A. Vermeersen at [http://www.tudelft.nl/live/pagina.jsp?id=7a6c3d15-1c1e-4869-b378-840a000c6803&lang=en]. Accessed 8 October 2010.

[85] American Geophysical Union Journal Highlights for 27 April 2011. [http://www.eurekalert.org/pub_releases/2011-04/agu-ajh042711.php]. Accessed 31 May 2011. See also [http://wattsupwiththat.com/2011/04/27/study-of-the-east-greenland-current-finds-no-trend/]. Accessed 31 May 2011.

glaciers than air temperatures, a dynamic that is poorly understood and not accounted for in climate models.[86]

History offers a deeper appreciation of the linkages between temperature and behaviour of the GIS. One quartet of researchers recently noted that Greenland warmed 33% faster during a 13-year period, three-quarters of a century ago (i.e., 1919-1932), than it did over the last 13 years.[87] This is an unsurprising conclusion, as the arctic was warmer during this period than it is at present[88] (as noted above, there was less polar sea ice during this period than there was at the 2007 low point). Alaska's glaciers were being "dismembered" by warmer temperatures in the 1940s,[89] a phenomenon that was apparently widespread; Alpine glaciers similarly melted at a faster rate in the 1940s than at present.[90] There is nothing new or unprecedented about receding glaciers, and the current rate of melt is less than that observed 70 years ago.

Studies of surface mass balance of the GIS show "total annual precipitation in the Greenland ice sheet for 1958-2007 to be up to 24% and surface mass balance up to 63% higher than previously thought." The same study observed that "considerably more mass accumulates on the Greenland Ice Sheet than previously thought, adjusting upwards earlier estimates by as much as 63%."[91] Another study concurred, concluding

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[86] Woods Hole Oceanographic Institution, "Team finds subtropical waters flushing through Greenland fjord", 16 February 2010 [http://www.whoi.edu/page.do?pid=7545&tid=282&cid=69134&ct=162]. Accessed 10 June 2010.

[87] Jason E. Box, Lei Yang, David H. Bromwich and Le-Sheng Bai, "Greenland ice sheet surface air temperature variability: 1840-2007", Journal of Climate (Early On-Line Release) 2009, 2, doi: 10.1175/2009JCLI2816.1, [http://ams.allenpress.com/perlserv/?request=get-abstract&doi=10.1175/2009JCLI2816.1&ct=1]. Accessed 26 March 2010.

[88] Plimer, p. 237.

[89] William O. Field, Jr., "Glacier recession in Muir Inlet, Glacier Bay, Alaska", in *Geographical Review*, Vol. 37, No. 3 (1947), p. 369.

[90] Huss M, Funk M & Ohmura A., "Strong Alpine glacier melt in the 1940s due to enhanced solar radiation", in *Geophysical Research Letters* (2009), 36, L23501, doi:10.1029/2009GL040789.

[91] Ettema, J., van den Broeke, M.R., van Meijgaard, E., van de Berg, W.J., Bamber, J.L., Box, J.E. and Bales, R.C. 2009. Higher surface mass balance of the Greenland ice sheet revealed by high-resolution climate modeling. *Geophysical Research Letters* **36**: 10.1029/2009GL038110.

that rather than a negative mass balance (i.e., melting), ice thickness is increasing in the Greenland highlands.[92]

Boundary events such as melting at the perimeter and the formation ("calving") of icebergs are often incorrectly taken as evidence of warming and/or significant change in the mass and stability of ice sheets. In fact, these phenomena are usually the result of internal dynamics related to pressure and ice re-crystallization. Ice sheet movement (plastic flow, or "creep") is usually slow, but "surges" are possible, usually as the result of increasing rather than decreasing mass at the centre of the sheet. Ice can also change quickly; movement rates may or may not respond to the presence of melt-water; and alpine valley glaciers can even flow uphill, driven by increasing ice mass in central depressions. Ice sheet movement relates less to recent changes in air or sea temperature, and more to changes that took place long ago; and shedding of ice at the margins of ice sheets is more prevalent during periods of global cooling than global warming, as thickening ice mass pushes the edge of sheets into the sea, where icebergs are calved.[93] Indeed, the discovery of ice-rafted debris on the Atlantic seabed (in some cases as far south as Africa) is one of the key geological fingerprints of past glaciations.[94]

Researchers engaged in the study of ice dynamics have argued that "variations in melting around the edge of ice sheets are no indication that they are collapsing. Indeed 'collapse' is impossible."[95] This argument is borne out by the existence of ice cores from the GIS showing 100,000-year cycles of warming and cooling over the past 800,000 years, the whole of the Pleistocene period of cyclical glaciations. The very existence of ice cores containing ice that survived four previous interglaciations demonstrates that even during past interglacial periods, when temperatures were up to 5°C higher than they are at present, the Greenland ice sheet did not "collapse."[96]

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[92] H.J. Zwally, et al., "ICESA's laser measurements of polar ice, atmosphere, ocean and land", *Journal of Geodynamics* **34** (2005), pp. 405-445.
[93] The list of references detailing the nature of ice movement is too long to list here. See Plimer, pp. 236-290.
[94] Henrik Svensmark and Nigel Calder, *The Chilling Stars: A Cosmic View of Climate Change* (Cambridge, UK: Icon Books, 2007), p. 25.
[95] [http://icecap.us/images/uploads/OllierPaine-NoIceSheetCollapse-AIGNewsAug.2009.pdf]. Accessed 26 March 2010.
[96] Plimer, pp. 266-67.

The Greenland ice sheet (and indeed much of the Canadian Arctic archipelago) is not at present being adversely affected by "global warming" because temperature measurements show that the region is not only cooling; it is cooler than it was seven decades ago. Figure 7 shows temperature measurements from the NASA Goddard Institute of Space Studies (GISS) ground station network. With the exception of the El Nino spike in 1998, Greenland was warmer in the 1940s than during the recent, late-20th Century warming. Recent changes to the Greenland ice sheet are smaller than those observed during the period 1920-1940,[97] and observed data show that Greenland is, at present, getting colder.[98] Projections of significant changes to northern ecosystems resulting from melting of glaciers and ice sheets are not corroborated by empirical evidence. It is therefore unlikely that changes to glaciers and ice sheets will significantly impact the operating environment in the north over the Department's planning horizon.

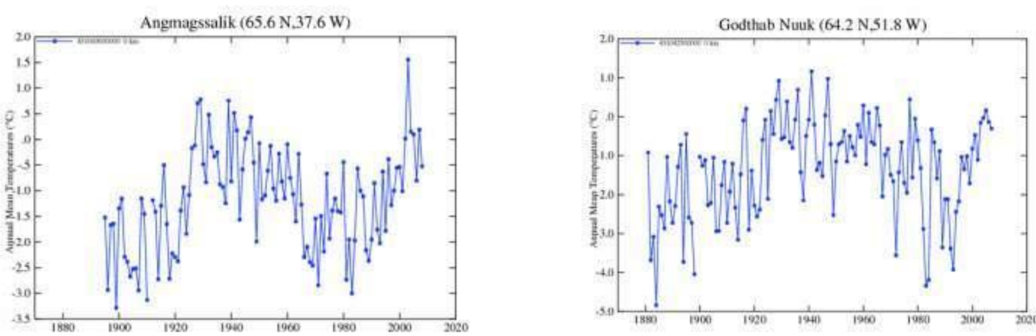

Figure 7 - Greenland was warmer in 1930-40 than it is today (NASA GISS)[99]

Permafrost

[97] P. Chylek, M.K. Dubey, and G. Lesins, "Greenland Warming of 1920-30 and 1995-2000", *Geophysical Research Letters* **13** (2006), L11707, doi:10.1029/2006GL26510.
[98] E. Hannah and J. Capellan, "Recent cooling in southern coastal Greenland and relation with the North Atlantic Oscillation", *Geophysical Research Letters* **30** (2003), 10.1029/2002GL015797.
[99] These charts are NASA's own data, and may be found at [http://data.giss.nasa.gov/cgi-bin/gistemp/findstation.py?datatype=gistemp&data_set=1&name=&world_map.x=279&world_map.y=49]. Accessed 26 March 2010. It should be noted that these are adjusted measured temperatures, not interpolated temperature representations, as is often published by NASA-GISS.

The IPCC states that, in the arctic, temperatures at the top of the permafrost layer have increased by up to 3°C and that these temperature increases are leading to "ground instability."[100] According to the 2007 Summary for Policymakers, "changes in snow, ice and frozen ground have with *high confidence* increased…ground instability in mountain and other permafrost regions and led to changes in some Arctic and Antarctic ecosystems."[101] The IPCC projects that the 21st Century will see "widespread increases in thaw depths" due to global warming, and notes that this will likely require investments in transportation technologies for affected areas.[102] *Canada's Northern Strategy* echoes these projections, anticipating that climate change will result in "shifting and melting permafrost" and "a shorter season for ice roads."[103]

Permafrost is a major feature of the Canadian landscape. It is common in the northern reaches of British Columbia, the Prairie Provinces, Ontario and Quebec; predominant in the Territories and Nunavut; and dominates the Arctic Archipelago (see Figure 8). According to Natural Resources Canada, recent warming of permafrost has occurred in many places in Canada, with increasing penetration of summer thaw prevalent throughout the 1990s. Warming has been greater in the western arctic, with increased depth of the active layer, and the largest increases are projected for the Yukon. The replacement of continuous permafrost by discontinuous permafrost is expected along the southern boundary of the permafrost zone (see Figure 9). Significant changes to permafrost may alter the hydrological conditions of affected areas.[104]

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[100] *Climate Change 2007: Synthesis Report*, pp. 30-31.
[101] AR4 SPM, p. 2.
[102] *ibid*., p. 46 and p. 57.
[103] *Canada's Northern Strategy*, p. 8. *The Future Security Environment* does not mention permafrost.
[104] *From Impacts to Adaptation*, pp. 75-76.

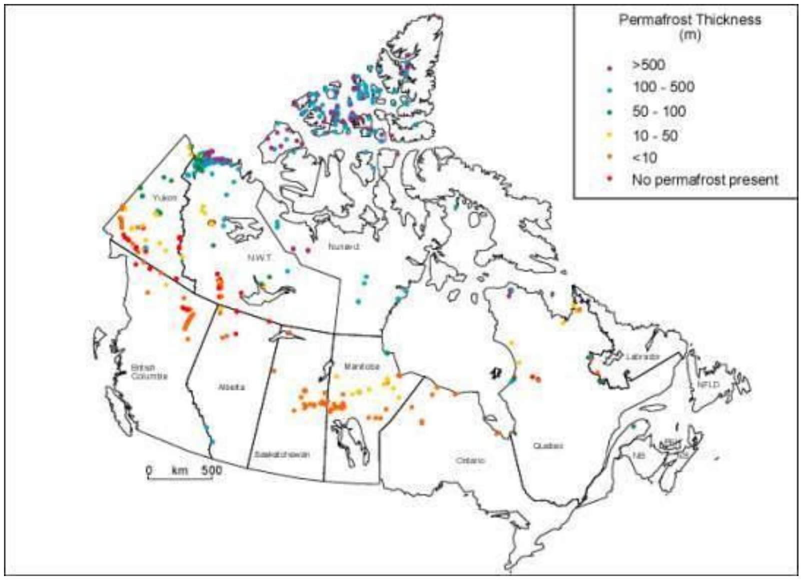

Figure 8 - Permafrost Thickness in Canada[105]

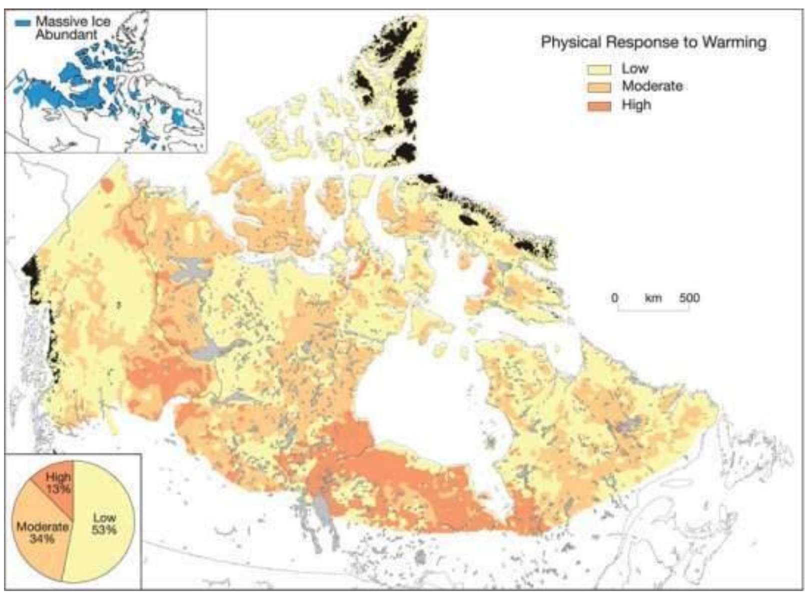

Figure 9 - Permafrost areas: Likelihood of physical response to warming[106]

105 Geological Survey of Canada [http://gsc.nrcan.gc.ca/permafrost/images/wheredoes4.jpg]. Accessed 26 March 2010.

106 Natural Resources Canada [http://adaptation.nrcan.gc.ca/assess/2007/ch3/images/fig13_e.jpg]. Accessed 26 March 2010.

Permafrost is affected by a wide variety of factors, most notably air temperature and snow cover, which both insulates the ground and affects its albedo, absorbing less energy than tundra and muskeg. While arctic snow cover decreased slightly over the period 1972-2003, changes in annual snow cover are not expected to be very large over the coming century, even assuming the arrival of the temperature regimes projected by climate models.[107] During the early 20th Century, which as noted above was warmer than the late 20th Century, the permafrost boundary in Siberia shifted by only 40 km.[108] Recent research suggests that even if the IPCC predictions of significant increases in global temperature over the next century are correct, the impact on arctic permafrost will not be as extensive as some have suggested. One scientist argues that "all areas north of 60°N will maintain permafrost at least at depth. North of 70°N, surface temperature values are in general below -11°C. These areas should maintain their active layer."[109]

It must be noted that projections of significant melting of permafrost are predicated on significant global warming as projected by the IPCC. The fact that air temperatures have been falling for nearly a decade augurs against adverse impacts on permafrost. If this analysis is correct, then changes to permafrost should not significantly affect the arctic operating environment over the Department's planning horizon.

Storms

Many discussions of climate change predict that increasing temperatures will give rise to increasing frequency and intensity of incidences of "extreme weather."[110] The *Canada First Defence Strategy* notes that "changing weather patterns" in the arctic are impacting the region,[111] while Natural Resources Canada argues that the "impacts of recent extreme weather events highlight the vulnerability of Canadian communities and critical infrastructure to climate change."[112] The *Future Security Environment* anticipates,

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[107] *From Impacts to Adaptation*, pp. 74-75.

[108] Plimer, p. 259.

[109] G. Delisle, "Near-Surface Permafrost Degradation: How Severe During the 21st Century?", *Geophysical Research Letters* **34, 9** (2007), doi:10.1029/2007GL029323.

[110] *Climate Change 2007: Synthesis Report*, p. 52.

[111] *Canada First Defence Strategy*, p. 6.

[112] *From Impacts to Adaptation*, p. 3.

as a result of climate change, "more frequent and more severe extreme weather events and related natural disasters, including storms, flooding, heat waves", and projects that extreme weather will intensify "seasonal rains, tropical cyclones and storm surges."[113]

Manifestations of changing weather anticipated due to climate change range from warm spells and heat waves (rated by the IPCC as "very likely") to more frequent heavy precipitation events ("very likely"), cyclonic activity ("likely") and extreme high sea levels ("likely").[114] Most of these are unlikely to affect the arctic region. Cyclonic activity and hurricanes rarely to never reach arctic latitudes, and while discrete weather events routinely overwhelm what are understood to be 'average' climatic conditions, the current declining temperature regime augurs against rather than in favour of an increase in "warm spells and heat waves".

Snow cover in the arctic decreased slightly during the late 20th Century warming, declining by roughly 10% between 1972 and 2003. By the winter of 2007-08 this trend had reversed, and snow cover over North America had reached a level not seen since 1966.[115] By the winter of 2009-10, North America was recording record cold temperatures and snowfalls; December 2009 was the second-snowiest for the continent as a whole since record-keeping began in 1966.[116] These recent figures provide useful context for climate model projections arguing that arctic snowfall is likely to decrease over the coming decades.[117]

There is little empirical evidence to support the contention that climate change is likely to lead to increases in the frequency and intensity of weather events. The accumulated cyclone energy index, for example, a measure of aggregate global

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113 *The Future Security Environment*, p. 36.

114 *Climate Change 2007: Synthesis Report*, p. 53.

115 L. Gunter, "Forget Global Warming: Welcome to the New Ice Age", National Post, 25 February 2008 [http://www.nationalpost.com/opinion/columnists/story.html?id=332289]. Accessed 26 March 2010. US NCDC [https://www.ncdc.noaa.gov/sotc/?report=snow&year=2009&month=12&submitted=Get+Report]. Accessed 30 March 2010.

116 The snowiest on record was December 1985. Rutgers University Global Snow Lab, [http://climate.rutgers.edu/snowcover/table_rankings.php?ui_set=1#namgnld]. Accessed 26 March 2010.

117 *From Impacts to Adaptation*, p. 75.

hurricane activity, reached a 30-year low in October 2008[118] and a 33-year low in October 2010.[119] This general observation extends even to the arctic, where there has been no clear trend in storm frequency over the past 50 years.[120] In view of these analyses based on observed data, it is inadvisable to attempt to draw conclusions about future weather patterns in the arctic. It does not appear likely that changing weather conditions attributable to climate change will significantly transform the arctic operating environment over the Department's planning horizon.

Impacts on Human Communities

The CF is required, amongst other things, to be able to exert and enforce sovereignty over the Canadian Arctic, and defend it if necessary; to conduct surveillance, both for national purposes and as a contributor through NORAD to the overall North American security picture; and to respond to requests for assistance. Much of the Defence interest in the arctic stems from the latter requirement, which is due primarily to the presence of human communities in the Yukon Territory, the Northwest Territory, and Nunavut.

The IPCC has expressed "medium confidence" that climate change is affecting human activities in the north, specifically mentioning "hunting and travel over snow and ice."[121] It is anticipated that indigenous communities in the arctic will become increasingly vulnerable to the deleterious impacts of "climate change,"[122] although the IPCC acknowledges that impacts, "particularly those resulting from changing snow and

[118] See, for example, Robert Balling Jr. and Randall Cerveny, "Compilation and discussion of trends in severe storms in the United States: Popular perception vs. climate reality", *Natural Hazards* **29** (2003), pp. 103-112; Keith Hage, "On destructive Canadian Prairie windstorms and severe winters: A climatological assessment in the context of global warming", *Natural Hazards* **29** (2003) pp. 207-228; and M.L. Khandekar, "Extreme weather trends vs. dangerous climate change: A need for a critical reassessment", *Energy & Environment* **16** (2005) pp. 327-331.

[119] See analysis by Dr. Ryan Maue at [www.coaps.fsu.edu/~maue/tropical/]. Accessed 8 October 2010.

[120] D.E. Atkinson, "Observed storminess patterns and trends in the circum-Arctic coastal regime", *Geomarine Letters* **25** (2005), pp. 98-109.

[121] AR4 SPM, p. 3.

[122] AR4 SPM, p. 19.

ice conditions, are projected to be mixed."[123] Suggested adaptation strategies include "integrating climate change considerations into national transport policy" and the provision by government of increased "investment in R&D for special situations, e.g. permafrost areas."[124]

Canada's Northern Strategy echoes the IPCC's assessment of the potential effects of climate change on arctic communities, applying a Canadian lens both to anticipated impacts and possible solutions. The federal government anticipates that increased accessibility will lead to greater human activity in the north, necessitating, amongst other things, an expansion of the Canadian Rangers. It also calls upon Defence to continue sovereignty patrols, surveillance of arctic terrain via NORAD and through the continued use of space assets, and expansion of arctic surveillance capabilities through the DRDC "Northern Watch" technology demonstration project.[125] The CFDS concurs, noting that ongoing changes in the arctic environment could "spark an increase in illegal activity", and that this could have "important implications for Canadian sovereignty and security" that could result in "a potential requirement for additional military support."[126]

Expanding on these and other themes identified in Canadian and international studies and assessments, the *Future Security Environment* offers a lengthy catalogue of potential adverse impacts of climate change upon arctic communities. These include, but are not limited to, rising sea levels, habitat shifts, species extinction, land loss, reduced access to fresh water resources, more frequent and more severe extreme weather, heat waves and coastal erosion.[127] The document suggests that these effects will be "more pronounced in coastal regions" (the vast majority of the population in the Canadian Arctic reside in coastal communities) and may lead to "mass migration" as "floods of environmental refugees seeking new resources and a more stable environment" look for less inhospitable places to live.[128]

[123] AR4 SPM, p. 12.
[124] AR4 SPM, p. 15.
[125] *Canada's Northern Strategy*, pp. 9-11.
[126] *Canada First Defence Strategy*, p. 6.
[127] *The Future Security Environment*, p. 36.
[128] *The Future Security Environment*, pp. 36-37.

The *Future Security Environment* argues that enhanced access to the arctic resulting from "the continued melting of polar ice" will result in "increased competition for decreasing global resources", and a heightened "potential for illegal trafficking of goods and people in the Arctic." These trends will also pose security challenges by "the increased transit of air, surface and sub-surface vessels", with important implications not only for "surveillance and monitoring, border control, law enforcement, search and rescue and disaster response", but also for the environment of "one of the most fragile ecosystems on the planet."[129]

The introduction of considerations of human interests, needs and behaviour into an already complex discussion of a chaotic system like climate makes it extremely difficult to foresee how the arctic security environment may evolve in the future. If, as a result of climate change, the full catalogue of woes predicted by the FSE does play out in the Canadian Arctic, the consequences for northern communities could be significant, and the CF, as one of the sole federal entities with the capacity to operate in the arctic, would in all probability be called upon to play a significant role in alleviating them.

That said, the ongoing decline in global temperatures, the continuing recovery of arctic sea ice, and the lack of any apparent causal correlation between climate change and (decelerating) sea level change, coastal erosion or weather, calls into question the logic underlying many if not most of these prognostications. The recovery of sea ice, for example, precludes the near-term "opening" of the North-West Passage to maritime traffic; reduces the probability of increased resource exploitation, over-fishing, illegal movement of people and goods, environmental damage from shipping, and the consequences (both the bad, and the potentially good) of an increase in commercial activity and regional development; and renders unlikely any form of hostile military activity, ranging from terrorist attacks to foreign military action to assert sovereignty or resource claims. Decreasing air temperatures, meanwhile, make northward movement of the permafrost line unlikely, and reduce concerns about accessibility via ice-roads and the stability and durability of permafrost, and the infrastructure built atop it.

As noted above, over the course of the Department's planning horizon, incremental changes to the arctic operating environment (whether due to climate

[129] *The Future Security Environment*, p. 37.

change or to some other driving factor or factors) are likely to be overwhelmed by natural periodic variability in weather systems. As problems with coastal erosion along the arctic littoral demonstrate, the vulnerability of human communities in the arctic to local phenomena, including weather conditions, is more likely to be affected by decisions taken – individually and collectively, both in those communities and at the federal level – than by incremental climatic change. As noted above, over the past century, the global average sea level rose less than 20 cm; but even a rise on the order of three times that figure (the upper range of the 18-59 cm predicted by the IPCC over the course of the next century, for example) would be irrelevant from a standpoint of military operations when community and infrastructure planning at, for example, Iqaluit, must be designed to cope with *daily* tidal variations of more than ten times that figure. Similarly, the IPCC's predicted increase in annual global temperatures of approximately 4°C over the next century has little operational relevance when planning, construction, and equipment design and procurement must take into account daily variations in temperature – at, again for example, Iqaluit - of twice that, and annual variations in average daily temperature of more than ten times the IPCC's projected increase.[130]

Community organization, infrastructure construction, equipment design and procurement, and operational planning should therefore continue to be based on a careful analysis of observed historical climatic and weather trends, rather than on projections of what sorts of conditions may exist a century hence, well beyond the Department's outermost planning horizon.

Conclusion

Many if not most of the challenges associated with the conduct of military operations in the far north are difficult to cope with in and of themselves, independent of any potential minor, incremental changes to the regional environment. As noted

[130] Historical temperature statistics for Iqaluit obtained from The Weather Network [http://www.theweathernetwork.com/statistics/C02106/canu0014?ref=topnav_fourteenday_statistics]. Accessed 24 March 2010.

above, for example, coastal erosion, despite the lack of any apparent link to climate change, may still threaten low-lying coastal communities, necessitating adaptive strategies and investments, and potentially requiring the CF to provide assistance in an emergency. Similarly, the lack of any evidentiary link between climate change and the severity or frequency of storms in the arctic or elsewhere does not in any way mitigate the challenge of coping with the arctic climate, which is already one of the most severe and forbidding in the world.

According to observed data and current climatic trends, it does not appear likely that climate change will significantly alter the operating environment in the arctic within the outermost limits of the DND/CF planning horizon (10-30 years). Average temperatures are declining, and the present cooling trend could last decades.[131] From a point of view of force development, the implications of such a trend point to conclusions rather different than those that have been reached on the basis of climate model projections. All other things being equal, "access to the arctic" appears unlikely to increase over the Defence planning horizon. The weather, the state of permafrost, and sea levels are unlikely to change in any way that will significantly alter the operating environment in the north; while continuing (or expanding) sea ice coverage will significantly reduce the likelihood of threats to Canadian security emanating from the region. While slight, gradual environmental changes may have implications for other government departments (e.g., in the form of changing needs for services in northern communities), this is unlikely to impact Defence. A significant increase in arctic maritime traffic is unlikely given observed temperature and sea ice trends, and the likelihood of increases in human trafficking, drug smuggling, environmental disasters, unconstrained resource exploitation and terrorism is therefore lower than has been elsewhere postulated. Accordingly, the need for additional DND resources to monitor and respond to such activities will be less than has been suggested.

[131] C. de Jaeger and S. Dunham, "Forecasting the parameters of sunspot cycle 24 and beyond", *Journal of Atmospheric and Solar-Terrestrial Physics* **71** (2009), pp. 239-245 [http://www.cdejager.com/wp-content/uploads/2009/02/2009-forecasting-jastp-71-239.pdf]. Accessed 26 March 2010. Some authors examining cyclical temperature trends expect the current decline in temperatures to persist to the end of the 2020s or longer. See L.B. Klyashtorin and A.A. Lyubushin, "On the Coherence between Dynamics of the World Fuel Consumption and Global Temperature Anomaly", Energy and Environment, Vol. 14, No. 6 (2003), pp. 773-782.

Consequently, it is questionable whether there is a requirement to build new facilities or increase the number of CF personnel permanently deployed in the north.

Force development, infrastructure, and procurement decisions predicated on model projections of a warmer, more clement and more accessible arctic should be reviewed in light of observed climatic trends. That said, regardless of how the natural environment may evolve, the core activities of DND in the far north are unlikely to change significantly. Maintaining situational awareness throughout the region, cooperating with allies in monitoring (and as necessary responding to) the military activities of other nations in the arctic, and conducting joint operations throughout the whole of Canadian territory are all essential military functions crucial to the defence of national security, national identity, and Canadian sovereignty. These tasks will continue to be necessary regardless of how climate changes; and they will be driven, as they have always been driven, not by environmental factors but rather by the intentions and capabilities of adversaries. A colder, more unforgiving northern climate will render the execution of these tasks more difficult and expensive. Harsher environmental conditions would complicate, perhaps even threaten, the sustainability of northern communities and northern industry; would place a higher premium on the use of space assets rather than air-breathing aircraft for surveillance purposes; would make routine military tasks, such as aerial surveillance and sovereignty patrolling, significantly more costly and demanding; and would exacerbate already difficult tasks like search-and-rescue, the practical exercise of sovereignty, maritime surveillance activities (including monitoring of under-ice submarine traffic), and the provision of aid to civil authorities in Canada's North.

The Canadian Arctic is already one of the most challenging military operational environments on Earth. Uncertainties about how the northern climate is likely change over the course of the Department's 10-30 year planning horizon, or about how evolving climatic trends may affect the nature of the arctic operating environment and the communities likely to be affected by them, suggest a conservative approach to policy and force development and decision-making. The prudent course is to explore infrastructure and procurement options that will enable the CF to continue to operate in the forbidding conditions of Canada's far north regardless of how the arctic operating environment may incrementally evolve.