Agents of Change in the New North

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Abstract: A geographer with extensive experience in the high latitudes of the Northern Hemisphere outlines 12 major agents of change currently active in that hemisphere's Northern Rim (lands and seas poleward of 45° N Lat.). These include population trajectories, aboriginal populations, rising air temperatures and precipitation, thawing of permafrost and winter roads, hydrocarbon and agricultural development, sea ice and shipping, ecosystem shifts, and issues of territorial sovereignty. In addition to exploring the current and potential impacts of each agent across the region as a whole, the paper also highlights key differences among the Northern Rim countries (Canada, Greenland/Denmark, Finland, Iceland, Norway, Russia, Sweden, United States) in terms of their responses and/or susceptibilities to these various elements of change. *Journal of Economic Literature*, Classification Numbers: F500, L900, Q300, O180, Q540. 5 figures, 2 tables, 108 references. Key words: Northern Rim, Russia, Canada, climate change, hydrocarbon development, UNCLOS, Fennoscandia, Iceland, Greenland, ANCSA, land claims agreements, permafrost, winter roads, ecosystem range shifts, sea ice, Northern Sea Route, Northwest Passage, aboriginal rights.

INTRODUCTION

Climate change, resource exploitation, and migration are three of the more powerful forces affecting northern environments and populations, from the high Arctic to southern cities like Moscow and Calgary. This paper presents a broadly geographic perspective on these and associated geophysical and societal factors that will be important to northern regions over the next four decades. While some emphasis is placed on the Russian Federation, its themes engage other countries of the Circumpolar North as well, collectively coined the Northern Rim countries or NORCs (Smith, 2010). Adoption of this broader geographic context allows consideration of national trends as well as the Arctic, and of North America as well as Eurasia. Where suitable numerical models exist, long-term projections to 2050 are used to add temporal, as well as geographical, perspective to the analysis.

THE NORTHERN RIM AND NORCS

As defined by Smith (2010), the Northern Rim refers to territories and seas northward of 45° N Lat. controlled by eight nations with significant access to the Arctic, the so-called Northern Rim countries or NORCs (Russia, Finland, Sweden, Norway, Iceland, Greenland/

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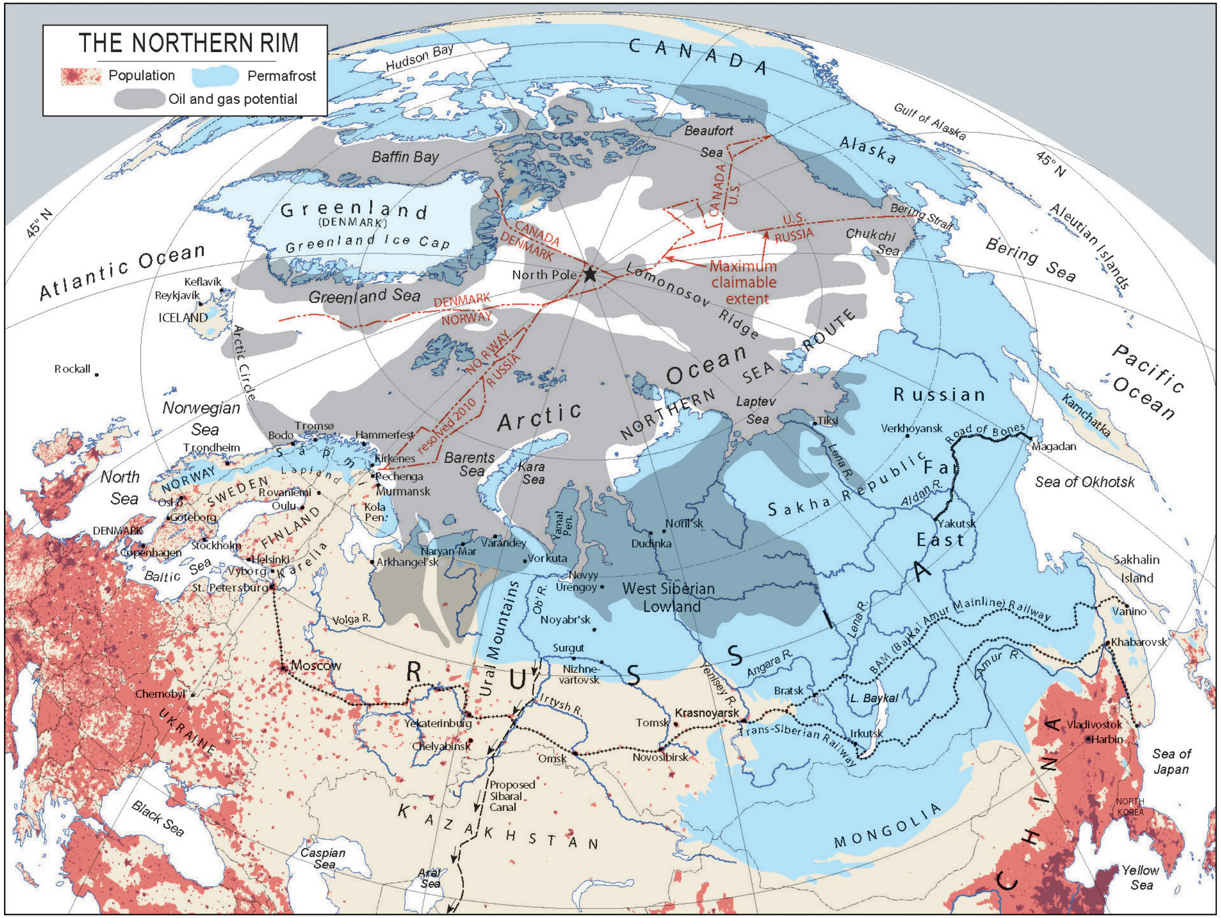

Fig. 1. The Northern Rim viewed from Eurasia, with population density in red and permafrost influence in blue. Grey tones delineate hydrocarbon provinces with potential for undiscovered natural gas and oil, as recently assessed by the U.S. Geological Survey.

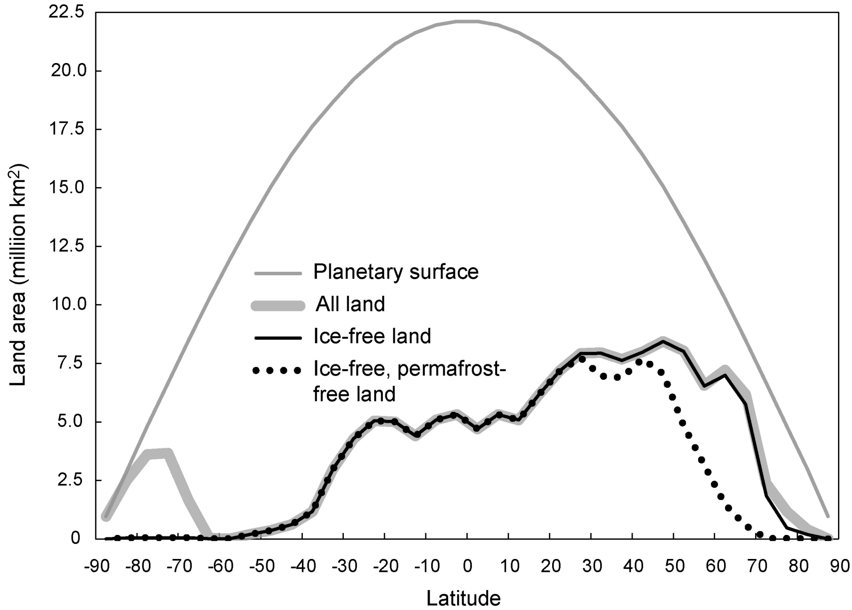

Fig. 2. Distribution of the world's total land area (thick line), minus glaciers (thin line), minus glaciers and permafrost (stipple), all as a function of latitude (5° bins). Total land area decreases sharply north of the Arctic Circle (66°33' N) and is mostly frozen in permafrost. Land area north of 45° N is much more extensive, with thawed as well as frozen terrain. Total ocean area is represented by the gap between total land area and total planetary surface area (grey line).

Denmark, Canada, and the United States; Fig. 1). As such, the Northern Rim includes but is substantially larger[2] than the Arctic, a contrast further emphasized if the spatial distributions of land and thaw state are considered in addition to planetary surface area (Fig. 2). Assessed in this way, the Northern Rim contains about one-fifth of the world's terrestrial land, including its most expansive latitudinal concentration (centered around ~50° N).

In terms of human population totals and economic clout, of course, the contrast between the Arctic and the Northern Rim is also very large. Under a generous geographic definition (~12 million km^2) employed by the Arctic Human Development Report (2004),[3] the Arctic contains ~4 million people and an economy of ~USD $230 billion per year (AHDR, 2004). The Northern Rim, in contrast, spans some 32 million km^2, with over 250 million people and a $7.1 trillion economy, even after restricting U.S. membership to its northernmost states only

[2]From GIS analysis of global map data, I calculate the following in square kilometers for the world's planetary surface area, land extent, glacier-free land extent, and glacier-free/permafrost-free land extent, respectively. World: 508,779,504 km^2, 147,263,072 km^2, 132,801,596 km^2, and 109,508,640 km^2, respectively. North of 45°N: 74,697,936 km^2, 40,364,452 km^2, 38,212,960 km^2, and 17,100,072 km^2. North of Arctic Circle: 21,239,512 km^2, 7,930,424 km^2, 6,159,648 km^2, and 271,632 km^2.

[3]The AHDR definition of "Arctic" encompasses all of Alaska; Canada north of 60° N together with northern Quebec and Labrador; Greenland and the Faroe Islands; Iceland; the northern counties of Norway, Sweden, and Finland; and in Russia Murmansk Oblast, the Nenets, Yamal-Nenets, Taymyr, and Chukotka autonomous okrugs, Vorkuta City in the Komi Republic, Noril'sk and Igarka in Krasnoyarsk Kray, and parts of the Sakha Republic lying closest to the Arctic Circle (AHDR, 2004, pp. 17–18).

Table 1. NORC GDP, Land Area, and Population vs. Selected Other World Economies

Economy	GDP (PPP, bill. $US)	GDP (world rank)	Land area (km^2)	Population
USA North	2,693	[6][a]	1,471,053	55,039,000
Russia	2,116	8	17,098,242	139,390,000
Canada	1,277	15	9,984,670	33,760,000
Nordic countries	1,006	[16]	3,424,422	26,000,000
"Arctic"	230	[213]	12,575,000	4,058,000
Total NORCs	**7,092**	**[4]**	**31,978,387**	**254,189,000**
BRICs	16,624	[1]	38,441,883	2,843,742,000
EU	14,430	1	4,324,782	492,387,000
USA (all)	14,120	2	9,826,675	310,233,000
China	8,818	3	9,596,961	1,330,141,000
Japan	4,149	4	377,915	126,804,000
India	3,680	5	3,287,263	1,173,108,000
Germany	2,815	6	357,022	82,283,000
UK	2,123	7	243,610	62,348,000
Brazil	2,010	10	8,459,417	201,103,000

[a]Entries within brackets [ ] indicate relative world GDP rank for economic blocs not included in the 2010 CIA World Factbook rankings.
Sources: Compiled by the author from AHDR, 2004; USDC, 2008; CIA, 2010; and *Nordic*, 2010.

(Table 1).[4] Measured in this way, the Northern Rim would rank as the world's fourth largest economy behind the BRICs ($16.6 trillion),[5] the European Union ($14.4 trillion), and the United States in its entirety ($14.1 trillion). Approximately $3 trillion (44 percent) and 165 million people (65 percent) of these totals are in Eurasia.

AGENTS OF CHANGE

Population Trajectories

According to medium-variant projections of the United Nations World Population Division, human populations are stable or growing in most NORC countries (Table 2). By 2050 Canada's population, in particular, is projected to increase by nearly a third (+31 percent), a rate of growth similar to India (+33 percent) and substantially faster than China (+5 percent) or Brazil (+12 percent). Double-digit population growth is also projected for Sweden, Norway, Iceland, and the United States. A glaring exception is Russia, with a projected

[4]Alaska, Idaho, Maine, Michigan, Minnesota, Montana, New Hampshire, New York, North Dakota, South Dakota, Vermont, Washington, and Wisconsin all graze the 45th parallel and fall within a NORC country as per the Northern Rim definition of Smith (2010). Excluding New York state would lower the NORC totals to $5.947 trillion GDP, 31,837,087 km^2 land area, and 234,648,000 population.

[5]Brazil, Russia, India, and China.

Table 2. NORC Population Trajectories 2010–2050

Country	Net migration rate (per 1000)	Total population, 2010	Total population, 2050	Population change (%)
Canada	6.0	33,890,000	44,414,000	31
USA	3.3	317,641,000	403,932,000	27
Iceland	5.9	329,000	407,000	24
Norway	4.0	4,855,000	5,947,000	22
Sweden	2.7	9,293,000	10,571,000	14
Finland	1.7	5,346,000	5,445,000	2
Denmark	1.1	5,481,000	5,551,000	1
Russian Federation	0.4	140,367,000	116,097,000	–17

Source: Compiled by author from data in UNPD, 2009. For different projections of these countries' 2050 populations, see PRB (2010).

population decline of ~24 million people (–17 percent) by 2050. This trend is driven by numerous unfavorable demographic factors, including low total fertility rate, low median life expectancy, an aging population, and low net migration.

Like most developed countries, the NORCs are greying and fertility rates dropping, so immigration rates are a critical determinant of future population stability and/or growth. By 2003, the return of some three million ethnic Russians from former Soviet republics to Russia had largely ended. In 2006, the Putin Administration launched a program to recruit 20 million expatriates to "return home," but it was unlikely to attract more than two and half million people, even if migrants from the Baltic States are counted (Saveliev, 2007; see also Ioffe and Zayonchkovskaya, 2010). With 16 people dying for every 10 babies born, Russia's population is now dropping by nearly 800,000 people annually. National leaders have long realized the need to raise legal foreign immigration into the country, but policies to do so are deeply unpopular. Xenophobia is widespread despite Russia's heavy reliance on migrant workers from Kazakhstan, Ukraine, Uzbekistan, Kyrgyzstan, Moldova, Tajikistan and, increasingly, China in the Far East (Ryzhova and Ioffe, 2009). In 2008, at least 525 migrants suffered hate-crime attacks and 97 of them were killed (Kozhevnikova, 2009).

Canada, in contrast, now has higher net migration (on a per capita basis) than any other NORC (Table 2). Furthermore, its immigration policies are specifically designed to recruit educated, multi-lingual, skilled workers above all else, greatly benefiting the Canadian labor force. Since 1967, an intricate scoring system has been used to rank applicants, with points awarded for education, language skills, optimal working age, etc. (Newbold, 2007; pp. 121–128). Nearly one in five Canadians today (19.3 percent) are foreign born, and of the quarter-million immigrants admitted annually into the country, skilled workers outnumber family members by nearly three to one.[6] This emphasis on work skills differs importantly from U.S.

[6]As of 2005, the share of foreign born in Canada was 19.3 percent (Dumont and Lemaître, 2005, Table 1). Canada admitted 247,243 legal permanent residents in 2008, of which 149,072 were in the "Economic Class" (skilled workers), 65,567 in the "Family Class" (reunification), and 32,602 were in the "Refugees" or "Other" classes (CIC, 2009).

immigration policy, which also considers work skills but prioritizes family reunification first. Upon legal entry both countries offer prescribed paths to citizenship and both countries also admit much smaller numbers of political refugees.

The Nordic countries, in principle, admit migrant workers from anywhere in the European Union.[7] Gaining citizenship, however, remains difficult, often requiring a language test. Immigrants from outside the EU are largely unwelcomed and confined to a small pool of refugees.

Subtle differences do exist among the Nordic countries' receptivity to immigration. About 12 percent of Sweden's population is now foreign born, comparable to the United States and Germany. Iceland has also ramped up its migrant workforce, with a foreign-born population rising to 10 percent prior to the country's 2008 banking crisis. Foreign-born populations are lower in Norway (7.3 percent), Denmark (6.8 percent), and Finland (2.5 percent) (Dumont and Lemaître, 2005, Table 1). Finland, despite membership in the EU and thus technically open to migrants from EU members, is probably the least-welcoming Nordic NORC, in part due to difficulty of the language but also a general lack of recruitment programs. In general Finns, like many Russians, tend to prefer less immigration versus more, despite economic and demographic costs. Medium-variant population growth in this country is projected at just +2 percent by 2050 (Table 2), among the lowest of the NORCs.

Aboriginal Groups

The Northern Rim's aboriginal population may be estimated as either 6 or 26 million, depending on how Russia is counted. Unofficially, it contains perhaps ~20 million (~14 percent of the country's total population) but only ~250,000 are legally recognized (Donahoe et al., 2008). In the other NORCs, aboriginal minorities are smaller, with Canada's the largest (3.8 percent), followed by the U.S.A. (1.6 percent), Denmark (0.9 percent), Norway (0.9 percent), Sweden (0.2 percent), and Finland (0.1 percent).[8] However, the seemingly small size of these numbers masks the keen importance of aboriginal populations to many NORC Arctic and sub-Arctic hinterlands. The State of Alaska, for example, is 16 percent aboriginal. Canadian aboriginals constitute substantial minorities of the populations of Saskatchewan (15 percent), Manitoba (15 percent), and Yukon Territory (25 percent), half the total population of the Northwest Territories, and 85 percent of Nunavut. Greenland is 88 percent aboriginal. Certain northern counties of Sweden, Norway and Finland are 11, 34, and 40 percent aboriginal (Sámi), respectively. In northern Russia, even the officially recognized population share is 2 percent, ten times the official national average. While not officially recognized as indigenous, some 400,000 Yakuts comprise about a third of the population of Sakha Republic.[9]

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[7]Norway and Iceland are not members of EU, but have liberalized their labor markets through the European Free Trade Association and the Schengen Agreement.

[8]Iceland has no indigenous population.

[9]The Russian Federation recognizes almost 200 "nationalities," of which 130 (~20 million people) are likely aboriginal. However, only 45 groups (~250,000 people) are officially recognized as "indigenous numerically small peoples of the north," just 0.2 percent of Russia's total population (Government of Russian Federation, 2000). The United States has 4.9 million aboriginals, Canada 1.2 million, Denmark 50,000, Norway 40,000, Sweden perhaps 20,000, and Finland 7,500. Iceland was unoccupied when discovered by Vikings in the 9th century A.D. North American aboriginal population data from the U.S. Census Bureau and Statistics Canada. For the Nordic countries, which do not collect ethnicity data during census, estimates are from U.N. World Directory of Minorities and Indigenous Peoples. As of the 2000 U.S. Census, the aboriginal population of Alaska was 85,698 out of 550,043 (15.6 percent; U.S. Census Bureau, 2002). The Sámi population of Sweden averages about 11 percent (5900 of 53,772) across Kiruna, Gällivare, Jokkmokk, and Arvidsjaur municipalities (Minority Rights Group, 2008c); in Finland

In Canada and the United States, aboriginal populations are growing. American Indians and Alaska Natives, currently numbering 4.9 million, are projected to increase to 8.6 million by 2050 (U.S. Census Bureau, 2008). Between 1996 and 2006 Canada's aboriginal population ballooned by nearly 400,000 (45 percent), a phenomenal growth rate nearly six times faster than the national average. This rapid population growth is not echoed in the Russian Federation or Nordic countries.[10]

One reason for this is a stark contrast in aboriginal political and economic fortunes between North America and Eurasia. The 1971 Alaska Native Claims Settlement Act (ANCSA) deeded fee simple property title and mineral rights to ~40 million acres of land (about one-ninth of the State of Alaska's land area), nearly $1 billion in cash, and a Regional Corporation business model to Alaskan aboriginals. ANCSA then inspired a four-decades-long wave of modern comprehensive land claims agreements (LCAs) across Canada, and Greenland's Home Rule Act in 1979. By 2009 the Canadian government had ceded over one billion acres to aboriginal groups under the auspices of these modern treaties. Dozens of smaller claims are still being finalized, especially in British Columbia (Penikett, 2006).

Through these new legal agreements, many Canadian aboriginals have secured not only property rights but political, social, and cultural ones as well, and in some cases self-governance. Like ANCSA, the modern agreements entitle aboriginal constituencies to rents from natural resource extraction, but from public as well as deeded lands.[11] Outside business interests must hire prescribed numbers of aboriginal workers and local services from aboriginal-owned companies. The federal government must allow aboriginal input regarding development, wildlife management, and environmental protections, and so on.

The powerful, rapidly-evolving aboriginal societies of North America are not echoed in Eurasia. In northern Fennoscandia, some 70 thousand Sámi have little hope of forming a collective political governance unit. Their ancestral homeland is divided among four different countries (Norway, Sweden, Finland and Russia), with little legal recourse for the kind of litigation that prompted settlement of the North American claims. Russia's northern aboriginals live in gritty, impoverished, multiethnic villages rife with unemployment, alcoholism, and suicide (Balzer, 2006). Life expectancies are low, the ability of aboriginal groups to halt or moderate outside exploitation of natural resources is virtually nil, as are rents when said resources are developed. Greatly outnumbered by ethnic Russians, there is little opportunity for aboriginals to form political majorities except within small *okruga* (regions) and *rayony* (districts). Exceptions, like the Yukagir group in the Sakha Republic (who won self-governance in the Nelemnoye and Andrushkino townships; AHDR, 2004, p. 97) are rare. Even essential food sources are vulnerable to commercial harvesting: Kamchatka aboriginals recently beseeched President Medvedev and Prime Minister Putin to halt auction lease sales of their salmon rivers to protect them from starvation (Kharyuchi, 2009).

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about 40 percent (7,500 of 18,990) across Utsjoki, Inari, Enontekiö, and Sodankylä (Minority Rights Group, 2008a); in Norway's Finnmark County, about 34 percent (25,000 of 73,000; Minority Rights Group, 2008b). Denmark/Greenland and Sakha Yakut data from AHDP (2004).

[10]Canada's 2006 census recorded 1,172,790 people as North American Indian (First Nations), Inuit, or Métis (mixed race), versus 976,305 in 2001 and 799,010 in 1996 (Statistics Canada, 2008).

[11]The amount and details of resource royalty returns varies greatly among land-claims settlements. In general, ANCSA granted full mineral and subsurface rights to deeded land, but not surrounding public land. Canadian LCAs may receive only a portion of subsurface royalties from their deeded holdings, but also receive revenues for extraction from surrounding public lands, which are also under shared management. Thus, the geographic reach of the Canadian agreements commonly extends across public as well as aboriginal-owned lands.

Warmer Air Temperatures

Anthropogenic emissions have raised the atmospheric concentration of carbon dioxide from ~280 parts per million by volume (ppm) in preindustrial times to ~390 ppm by 2010.[12] Concentrations of methane and nitrous oxide, two other important greenhouse gases released by human activity, have similarly increased. Approximately two-thirds of the measured CO_2 increase has occurred since 1958, when the first continuous air sampling program began at Hawaii's Mauna Loa Observatory as part of the International Geophysical Year. From historical weather station records, the Earth's global mean annual air temperature (MAAT) increased +0.74° C between 1906 and 2005 (IPCC, 2007).

The Northern Rim temperature increases, however, have been larger and occasionally asynchronous with the globally averaged MAAT trend. In the Arctic, air temperatures rose throughout most of the 20th century except for a notable cooling phase from ~1946 to 1965 (ACIA, 2005; see also Kelmelis, 2011, this issue). During this time, some areas of southern Eurasia and southern Canada continued to warm. From about 1966 onward, MAATs again commenced rising throughout the Northern Rim, especially in the continental interiors of northern Eurasia and northwestern North America where average temperatures rose 1–2° C per decade, roughly 10 times the global average (ACIA, 2005; Anisimov et al., 2007; Dery and Brown, 2007). While these numbers are calculated over all 12 months of the year, the northern MAAT increases have been driven especially by warmer temperatures in winter and spring.

Climate model projections of future MAAT depend greatly on assumptions regarding technological advance, carbon regulation, and the world economy. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) considered CO_2 concentrations ranging from 450 to 1550 ppm by the end of the 21st century, corresponding to a +0.6 to +4.0° C increase in global MAAT in addition to the +0.7° C increase already experienced thus far (IPCC, 2007). Many policy pragmatists now feel a +2° C global MAAT increase is all but assured following the failures of the 2009 and 2010 United Nations Climate Change conferences at Copenhagen and Cancun to produce a binding international carbon regulatory agreement. In truth, limiting the global MAAT increase even to +2° C poses enormous challenges: To avoid exceeding this threshold will require a sustained 90 percent reduction in global carbon emissions, as well as a successful technology to capture and permanently sequester CO_2 underground by the year 2050 (Weaver et al., 2007).

The globally and temporally averaged MAATs described thus far mask geographic and temporal contrasts that are of keen importance to the Northern Rim. Paramount among these is a localized amplification of the global mean trend, owing to uniquely northern positive feedbacks to climate. One of these is lowered albedo (darkening) of the Arctic Ocean as sea ice retreats, exposing ocean water beneath, thus causing more sunlight to be absorbed by the ocean rather than reflected back to space.[13] This feedback may be non-linear, causing temperatures to increase sharply once sea ice thins to a vulnerable state (Serreze et al., 2007). Other reasons for the northern amplification of the global trend include lower albedo on land (owing to reduced snow cover during the spring, when solar insolation is high), low evaporation into cold air, and a thinner atmosphere. Not all temperature feedbacks are positive; for

[12]Measurements of carbon dioxide and other atmospheric constituents have been collected since 1958 at the Mauna Loa Observatory, Hawaii, by the Scripps CO_2 program. (For updated data see http://scrippsco2.ucsd.edu).

[13]This ice-albedo feedback also operates in the reverse direction, amplifying global cooling trends.

example, increased wildfire abundance in boreal forest may lower a landscape's albedo over the long term (Lyons et al., 2008).

The physics of this northern temperature amplification is now well captured by atmospheric general circulation models (AGCMs). Figure 3 presents worldwide temperature changes for 2011–2030, 2046–2065, and 2080–2099 (IPCC, 2007), assuming three different carbon emission scenarios—B1, A1B, and A2, as defined by the IPCC Special Report on Emissions Scenarios (IPCC, 2000). The B1 scenario (labeled "optimistic" on Fig. 3) describes a convergent, globalized world, with widespread adoption and sharing of new energy technologies and a rapid transition toward a global service and information economy. The A1B scenario (labeled "moderate") assumes rapid economic growth, a global population peak around 2050, and rapidly advancing energy technology with a balance between fossil and non-fossil energy. The A2 scenario (labeled "pessimistic") describes a non-globalized, neo-feudalistic world, with high population growth, slower economic growth, and slow adoption of new energy technology.

Two important conclusions may be drawn from the figure. The first is that the Northern Rim will experience some of the most extreme temperature rises on Earth, especially in the Arctic. While the magnitude of increase varies, this general geographic pattern holds true across all time slices and carbon emissions scenarios. The second conclusion is that social choices do matter deeply for the planet's climatic future, especially by century's end. In an A2 world, MAATs in China, Europe, and the conterminous United States are projected to rise +3.5–5° C by 2080–2099, versus 2–2.5° C in a B1 world. In the Northern Rim, of course, the increases are even larger owing to the temperature amplification effect: under B1 conditions, northern MAATs rise +1.5–2.5° C by 2046–2065 and +3.5–6° C by century's end. In an A2 world, the extremes rise to +8° C or more (Fig. 3).

Rising Precipitation and River Runoff

A second climatic trend with robust consensus agreement among AGCMs is one of rising precipitation throughout most of the Northern Rim, especially in winter and in its northernmost regions (Wang, 2005; IPCC, 2007). Two clear outcomes of this will be snowier winters and higher river flows. One respected modeling study suggests that by mid-century, many rivers across southern Europe, western North America, the Middle East, and southern Africa will have flows averaging 10–30 percent below today's, while in Russia, Scandinavia, Alaska, and northern Canada river flows will increase by a similar amount (Milly et al., 2005). Evidence of this is already apparent in statistical analyses of historical hydrologic data records, with river flow increases observed first in Russia (Peterson et al., 2003), then northern Canada (Déry et al., 2009; Rennermalm et al., 2010). The observed increases are greatest in winter, suggesting that shallower frost depth, rising groundwater inputs, and/or increasing winter thaw events may be direct causal mechanisms (Smith et al., 2007). There is no evidence of increasing severity of the spring flood (Shiklomanov et al., 2007).

In a world with stable or rising river runoff in northern countries but rising water stress in southern neighboring countries, the revival of 20th century mega-engineering proposals for north-to-south bulk water diversions is not inconceivable (Smith, 2010). In North America, the so-called Great Recycling and Northern Development (GRAND) Canal, a 1960s-era scheme to construct a coffer dam across James Bay and to return north-flowing rivers south toward the Great Lakes (Fig. 4), continues to have advocates even today. Another, scaled-down proposal (Gingras, 2009) is to capture part of this water in seasonal impoundments in several

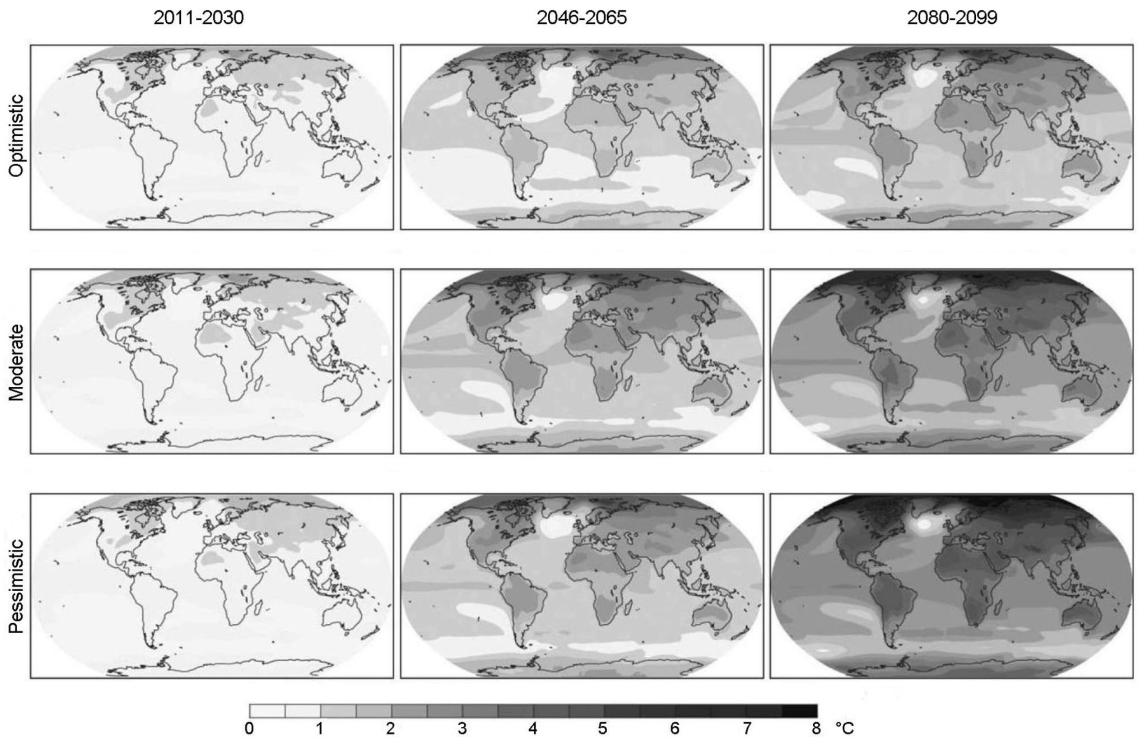

Fig. 3. Projected changes to mean annual air temperature (MAAT) climatology by the early, mid-, and late 21st century as modeled for "optimistic" (B2), "moderate" (A1B), and "pessimistic" (A2) IPCC carbon-emission scenarios. These maps are ensemble products averaged from many simulations and climate models, and are thus more robust than any one model or simulation alone. Social choices wield enormous influence on MAAT outcomes, especially by century's end. Under all scenarios and time frames, the manifestation of climate warming is geographically uneven, with the Northern Rim experiencing temperature increases of at least twice the global average (adapted from IPCC, 2007).

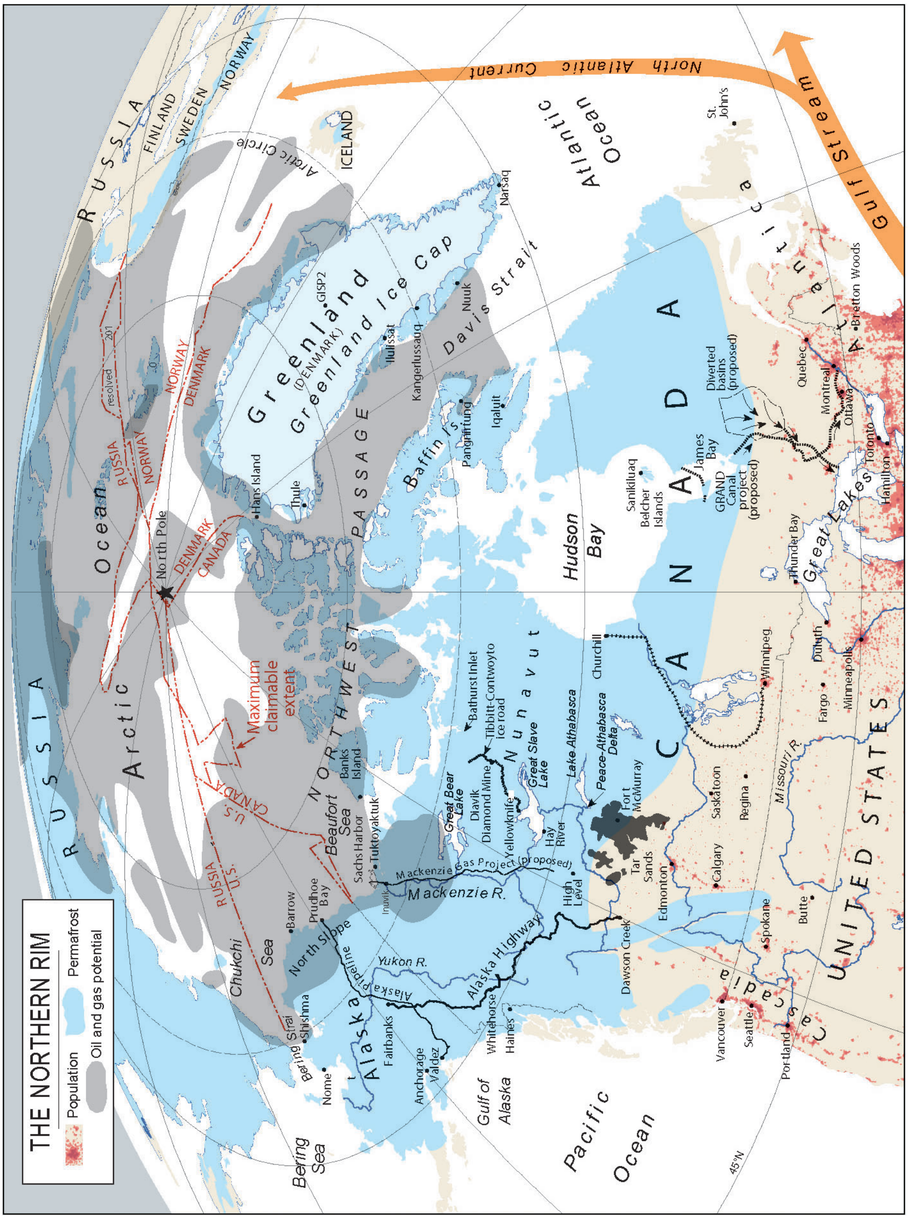

Fig 4. The Northern Rim, viewed from North America.

basins southeast of James Bay (Fig. 4). At the present time, however, river mega-engineering projects are deeply unpopular in North America.

A more plausible revival of a 20th century north-to-south water diversion scheme may be the Soviet-era Sibaral project in Eurasia. Even in the 1870s, tsarist engineers had contemplated the possibility of diverting water from the north-flowing Ob', Irtysh, and Yenisey drainages south toward Central Asia, in what is today Kazakhstan and Uzbekistan, via a long, low-relief topographic corridor connecting West Siberia to the Aral-Caspian lowland (Micklin, 2006, 2011). From the late 1960s to the early 1980s, the USSR studied, surveyed, and finalized construction plans for a 2,544-kilometer-long canal called "Sibaral" (short for Siberia to Aral Sea; Fig. 1) to bring Siberian river water south to the Aral Sea region, until Mikhail Gorbachev abruptly halted the project in 1986 citing environmental and economic concerns.

Today, Sibaral continues to enjoy favor among relevant former Soviet republics (Kazakhstan, Turkmenistan, Uzbekistan, Kyrgyzstan, and Tajikistan), with mixed support in Russia amid occasional calls for Sibaral's resuscitation. In 2002, Moscow's then-mayor Yuriy Luzhkov wrote a letter to President Putin urging that the project be revived, citing potential unrest in Central Asia over future water shortages and the specter of refugees pouring across the Russian border. A deputy minister of Natural Resources also wrote in support for the plan. In 2004, the director of Soyuzvodproyekt said that the water agency was gathering archived materials from more than 300 institutes in order to revisit and revise the old plans (Pearce, 2004). However, many Russian scientists still disapprove of the project on environmental grounds.

Ecosystem Range Shifts

One of the more bizarre biological oddities of recent years was discovered in the Canadian Arctic in 2006, when an American big-game hunter killed the first grizzly–polar bear offspring ever seen in the wild. In 2010, a second specimen was shot, this time the offspring of a hybrid, indicating successful reproduction. While impossible to confidently attribute these two unusual events to climate change, they required abnormal courtship behavior and a grizzly to range far north into polar bear territory, something wildlife biologists are now beginning to see more often (Doupé et al., 2007).

More definitive is a decades-long global migration of plant and animal species toward the poles, averaging about 6.1 kilometers per decade, based on meta-statistical analyses (Parmesan and Yohe, 2003). In Eurasia, north-moving land species include geometrid moths in Fennoscandia (Jepson, 2008), the greater white-fronted goose *Anser albifrons* in Japan (Shimada et al., 2005), and the brown hare *Lepus europaeus* in Sweden (Jansson and Pehrson 2007). In Russia, the common buzzard *Buteo buteo* has begun wintering near Moscow, nearly one thousand kilometers north of its normal range (Morozov, 2007). Elsewhere around the Arctic, shrub and tree habitats are expanding (CAFF, 2010), and the red fox *Vulpes vulpes* is displacing the Arctic fox *Alopex lagopus* (Post et al., 2009). In Canada, insect pests like the mountain pine beetle *Dendroctonus ponderosae* and also *Ixodes scapularis*—the Lyme-disease carrying tick—are surviving winterkill and pressing northward (Ogden, 2006).

Milder winters, the hallmark driver of the observed and projected Northern Rim mean annual temperature increases of Figure 3, are the key enabler of such expansions owing to increased survival of southern species through the winter (e.g. Pitt et al., 2008). Large range shifts have also occurred in the ocean; for example, warm-water copepod crustaceans that have expanded 10° of latitude northward (~700 km) in the European shelf seas and eastern North Atlantic, displacing cold-water species that are in turn retreating poleward (Beaugrand et al, 2002). Two-thirds of all fish species in the North Sea, one of the world's most productive fisheries, have either shifted north or sunk down to cooler depths (Perry et al., 2005). One study poses the spectre of an "Arctic invasion" of North Pacific molluscs penetrating north through the Bering Strait, expanding through a warmer Arctic Ocean and eventually reaching the North Atlantic (Vermeij and Roopnarine, 2008).

The Northern Rim's polar species thus face new competition, food-web disturbances, parasites, and abnormal species interactions from southern invaders, alongside a plethora of other climate-change threats like shrinking sea ice, winter rain-on-snow events, deeper snowpack, altered hydrology, and rising severity of droughts and wildfires. Also problematic are phenological "mismatches" that develop, for example, when insects or plant budburst arrive earlier in spring, but the bird migrations or reindeer that feed upon them do not (Post et al., 2009). While occurring globally, phenological shifts are again most evident in the Northern Rim, averaging 4.2 days earlier per decade between 32° N and 49° N Lat., rising to 5.5 days between 50° N and 72° N (Root et al., 2003).

Cold-adapted species cannot relocate if their climatic comfort zone shifts to a place incompatible for other reasons, or vanishes altogether. Modeling suggests that under the A2 carbon emissions scenario, current climates will disappear for some 10–48 percent of the Earth's terrestrial surface, mostly in high-latitude and high-altitude areas (Williams et al., 2007). In the tropics and subtropics, some 12–39 percent of the Earth's surface will develop hot new climates that exist nowhere on Earth today. Already, the western United States has lost 73 percent of its "alpine tundra" climatic zone (Diaz et al., 2007). Especially vulnerable are species with specialized dependence on ice for foraging, reproduction, or predator avoidance, including the ivory gull (*Pagophila eburnean*), Pacific walrus (*Odobenus rosmarus divergens*), ringed seal, hooded seal (*Cystophora cristata*), narwhal (*Monodon monoceros*), and polar bear (*Ursus maritimus*) (Post et al., 2009). Polar bears, in particular, are displaying declining birth rates and aberrant behavior, including cannibalism (Amstrup et al, 2006; Regehr et al., 2007). Based on climate model projections of shrinking sea ice, forecasts for future polar bear populations are bleak, with up to two-thirds of the global population vanishing by mid-century. The steepest losses are expected in Russia's Southern Beaufort Sea, Chukchi Sea, Laptev Sea, Kara Sea, and the Barents Sea, which may see complete extirpation of polar bears within the next 75 years (Amstrup et al., 2007).

Agriculture

The impacts of climate warming upon agriculture in the Northern Rim, while still not fully understood, are likely to be somewhat more favorable than for many other parts of the world. On average, longer, warmer growing seasons should increase crop yields of traditional northern staples such as wheat, barley, rye, rapeseed, and potatoes, and perhaps allow introduction of new varieties as well. Climate model projections suggest a general pattern of modest gains in crop yields for Fennoscandia, Russia, the United Kingdom, Canada, and certain northern U.S. states such as Michigan, Wisconsin, and Minnesota (Adams et al., 1990; Sirotenko et al., 1991, 1997; Lal et al., 2001; Olesen and Bindi, 2002; Maracchi et al., 2005). This general consensus among published modeling studies is unusual when compared to other regions like China, where agricultural projections are often inconclusive owing to divergent climate model predictions of precipitation and assumptions about carbon fertilization (Chavas et al., 2009; Piao et al., 2010).[14]

A major geographic expansion of farming is unlikely, owing to poor soils, short growing seasons, inappropriate terrain, and the presence of permafrost. Also, even if today's northernmost fringes of agriculture benefit from rising temperatures, this could be countered by drought losses in water-limited areas including southern Russia and Canada's prairies. Some modeling studies suggest crop yield declines in such areas, offsetting any yield gains further north. For example, Russia's West Siberian, East Siberian, Northwestern, North, and Far East regions are all forecast to experience higher cereal and potato productivity by the 2020s but its Central, Central Chernozem, North Caucasus, Volga-Vyatka, and Volga regions are projected to decline (Kirilenko et al., 2004). Also, most previous analyses consider only the effects of mean temperature. Newer studies factoring in an increased frequency of extreme events (i.e., droughts) reveal key vulnerabilities, especially in southern Russia (Alcamo et al., 2007) and Canada's southern prairies (Sushama et al., 2010). Alcamo et al. (2007) suggest that production shortfalls may double in many important growing regions of Russia by the 2020s and triple by the 2070s, with the number of people living in vulnerable regions rising from ~50 million to roughly 82–139 million. For the Russian Federation, at least, it appears that the northern crop yield increases will not compensate for yield declines in its currently most productive southern regions (Dronin and Kirilenko, 2008). Russia's water availability and crop productivity may increase at the national level, but new vulnerabilities in its populous, water-stressed southern growing regions pose a significant threat to Russian food security (Alcamo et al., 2007). A harbinger could prove to be the summer of 2010, one of the worst droughts in decades, which destroyed over twenty percent of Russia's wheat crop (Wegren, 2011) and triggered extensive boreal wildfires across the western part of the country.

Thawing Permafrost

Permafrost is frozen ground that maintains subzero temperatures throughout the year except for a thin upper "active layer," a few centimeters to decimeters deep, that thaws at the surface each summer. About one-fourth of the world's land is currently frozen in some state of permafrost, mostly in the Northern Hemisphere and northward of 50° N Lat. (see Figs. 1, 2, and 4). Permafrost is ubiquitous throughout the Arctic, but extends furthest south in eastern Eurasia (Fig. 1). Buildings, roads, pipelines, and other physical structures may be built over permafrost if they are designed to prevent thawing the ground.[15] Heating or otherwise disturbing the ground, however, can cause localized thawing, causing the substrate to settle, thus damaging or destroying the overlying structure.

While proper engineering can protect against local thawing and settling, impacts due to climate change cannot be avoided. Warmer temperatures and/or deeper snow cover (which insulates the ground) cause permafrost temperatures to rise. Depending on soil geological

[14]There is more to such projections than simply temperature and rain. A key issue is the so-called CO_2 fertilization effect. Plants benefit from CO_2, so more of it in the air tends to raise crop yields. Most agro-climate models build in a hefty benefit for this, based on early greenhouse experiments using enclosed chambers. This enables the models to offset a large share of the damages of summer heat and drought, owing to the fertilization benefit from elevated CO_2 levels. However, more realistic experiments staged outdoors, using blowers over actual farm fields, suggest a much lower fertilization benefit. This implies that the models may be seriously underestimating the negative impacts of climate change on world food production (Long, 2006).

[15]A major recent feat in permafrost engineering, for example, is China's recently completed Qinghai–Tibet Railroad, from Golmud to Lhasa.

properties, this can trigger regional ground settling and the appearance of large depressions, damaging roads, buildings, rail lines, and other infrastructure. In continuous permafrost, the depressions often fill with water, creating ponds and lakes, while in thin or discontinuous permafrost, existing lakes may disappear (Smith et al., 2005). Settling is most common in ice-rich, unconsolidated silt and clay soils. In rocky, ice-poor ground, thawing has less impact on the ground surface (Jorgenson et al., 2010).

Deep permafrost can extend hundreds of meters underground, requiring centuries or millennia to disappear completely. However, significant reductions in shallow permafrost are projected by the mid-21st century, with a 13–29 percent reduction in permafrost globally and seasonal thaw-depths increasing by about 50 percent (ACIA, 2005).

By combining climate model projections with geographic information on current permafrost distribution, ice content, and soil settling susceptibility, it is possible to identify areas at greatest risk in the future. Nelson et al. (2001, 2002) mapped potential permafrost hazards into low-, moderate-, and or high-risk categories around the Northern Rim. A high-risk zone encircles much of the Arctic Ocean, including the population centers of Salekhard, Igarka, Dudinka, and Tiksi in Russia, Inuvik in Canada, and Barrow in Alaska. Other high-risk areas include natural gas facilities in the Nadym–Pur–Taz area of West Siberia, and the Bilibino nuclear power station. The large population and industrial centers of Yakutsk, Noril'sk, and Vorkuta were deemed at moderate risk, along with much of the Trans-Siberian Railroad, the Baikal–Amur Mainline, and numerous roads (Nelson et al., 2001). Already, thawing permafrost has closed one runway at the Yakutsk airport and triggered a fourteen-fold increase in water-filled depressions on the surrounding landscape (Nelson et al., 2002).

The Russian Federation contains more permafrost than any other country (covering ~60 percent of its land area) and also the highest proportion of major human settlements and infrastructure built over permafrost. Russia's northern oil and gas industry is particularly exposed to potential damages to pipelines, pump stations, and extraction facilities, as well as environmental damages from oil spills (Anisimov and Reneva, 2008). By the late 1990s, deformation of the Baikal-Amur Mainline subgrade had increased sharply, and 10–80 percent of all buildings in Noril'sk, Vorkuta, Magadan, Chita, Dudinka, Pevek, Amderma, and Dikson were deemed unsafe (ACIA, 2005, pp. 935–936). It is important to note, however, that at least many of these damages are likely caused by failures of design and management (Anisimov et al., 2010). A broad-scale inventory to distinguish the effects of faulty design from regional climate change has yet to be attempted.

A truly global threat from thawing permafrost is the possible mobilization of large stocks of carbon currently frozen in organic-rich soils (Zimov et al., 2006; Schurr et al., 2008). Permafrost thawing enables microbial decomposition of this material, thus releasing large quantities of carbon dioxide (a byproduct of aerobic microbial decomposition) and/or methane (a byproduct of anaerobic decomposition) greenhouse gases to the atmosphere. A recent global inventory of this carbon reservoir suggests ~1,672 gigatons (Gt C) may be stored in permafrost (Tarnocai, 2009), an enormous number representing roughly half of the world's total soil carbon.[16] While it is not plausible that all of it could thaw in this century, the return of even a small fraction of this carbon to the atmosphere would represent an important positive feedback to global climate warming. Decomposition of even 5 percent of it by mid-century,

[16]To put this large number in perspective, the world's living plants hold about 650 Gt, and its atmosphere currently contains about 730 Gt of carbon, up from 360 Gt during the last ice age and 560 Gt before industrialization. Remaining proved reserves of conventional oil contain about 145 Gt and coal about 632 Gt. Each year humans release around 6.5 Gt of carbon from burning fossil fuels and making cement. The total target reduction for "Annex 1" (developed world) signatory countries to the Kyoto Protocol was 0.2 Gt per year.

for example, would release ~2 Gt C per year, canceling out the Kyoto Protocol Annex 1 target emissions reductions ten times over.

A more conservative study, focused on deeper seasonal thawing of upper permafrost layers in Russia, estimates that the annual net flux of methane from Russian permafrost may increase by ~0.6–0.8 Gt/year by 2050 (20–30 percent higher than present-day levels). This would elevate the overall concentration of atmospheric methane by +0.04 ppm, thus contributing +0.012° C of global MAAT increase from Russian wetlands alone (Anisimov et al., 2007). The West Siberian Lowland, in particular (Fig. 1) is already a major source of methane today and has accumulated at least 70 Gt of peat carbon over the last 12,000 years, nearly half of it now interred in permafrost (Sheng et al., 2004; Smith et al., 2004).

Winter Roads

A second way in which milder winters and/or deeper snowpack affect human activity in the Northern Rim is through their detrimental impact on winter roads. For many remote northern landscapes, cost-effective ground transportation is available only in winter, when wet and/or environmentally sensitive landscapes freeze sufficiently hard so to allow a firm driving surface for wheeled vehicles. "Winter roads" and ice roads are temporary features built across frozen rivers, lakes, and boggy ground, using simple grading, compacted snow, water pumped from adjacent lakes, or ice aggregates. They are used extensively in Alaska, Canada, Russia, and Sweden, as well as Norway, Finland, Estonia, and several northern U.S. states. Because winter roads are much cheaper to build than permanent roads, they are often the only realistic way to transport heavy equipment and cargo for resource extraction, construction projects, and community resupply. This is especially true for remote, boggy areas and for industries operating on tight profit margins.

Like permafrost, subzero ground temperatures are critical to maintaining adequate strength and ice thickness for winter roads, so milder winters and/or increased snow depths shorten their seasonal life. On Alaska's North Slope, winter road seasons have declined from over 200 days to just over 100 days since the 1970s (Hinzman et al., 2005). Road operations can also be disrupted in the middle of winter by unusual rainfall or thaw events. In Canada, a vital winter road used to support diamond mining operations in the Northwest Territories, the Tibbitt-Contwoyto ice road (Fig. 4), may lose nearly one-fifth of its operating season by 2020 (Hayley and Proskin, 2008).

In an ongoing research project that will likely prove to be the first study of its kind, Stephenson (2010) is now modeling likely losses in winter road potential (i.e., the areas of suitably cold climate over appropriate landscapes) around the Northern Rim by the middle of this century. This approach requires adapting a traditional GIS-based transportation accessibility framework to include climate model variables (air temperature and snow depth), together with static datasets on land cover, topography, hydrography, and built infrastructure. Preliminary results suggest that by the mid-21st century many NORCs will experience sizable losses in total land area with potential suitability for winter roads, with Russia and Canada accounting for the vast majority of lost winter road potential in absolute terms.

Hydrocarbon Development

Throughout history the Northern Rim has supplied raw commodities to world markets including furs, cetaceans, timber, precious metals, minerals, and fish. More recently, oil and gas development has assumed an especially dominant role in the economies of Russia, Alaska, and western Canada. The decision of the Soviet Union to develop the stunningly remote West Siberian Lowland (WSL), after discovery of four supergiant oil fields there between 1962 and 1965, presaged a long rise to global eminence of the Russian hydrocarbon economy. After nearly five decades of development, West Siberia is now populated with over three million people and a number of small cities, some founded only since the 1980s. Hydrocarbon facilities have also expanded in Alaska, and in northern Alberta where oils sands development has fueled rapid economic and population growth of Fort McMurray and Calgary (Fig. 4).

After nearly five decades of operations in West Siberia, Russia is now the world's largest producer of natural gas and second-largest producer of oil. New operations have begun in the eastern Barents Sea (the Shtokman gas field) and Sakhalin Island as well as the WSL. However, two out of every three barrels of Russian oil and 85 percent of Russian gas still derive from West Siberia. Like all petroleum provinces, the size distributions of this region's oil and gas fields are log-normal, so production has entered asymptotic decline. The Samotlor oil field, one of the world's largest, peaked at 3.4 million barrels per day in 1980 and has since dropped over 90 percent, producing just 300,000 barrels per day from its approximately five thousand wells (Grace, 2005; see also Sagers, 2006). The region's giant gas fields (Urengoy, Yamburg, and Medvezh'ye) have also entered decline, with production expected to fall 75 percent, to just 130 billion cubic meters per year, by 2030 (Andreyeva and Kryukov, 2008). West Siberian hydrocarbon development is therefore shifting away from the middle reaches of the Ob' River, where most of the basin's oil is found, to immense concentrations of natural gas and condensate found further north in approximately 60 to 100 fields (Grace, 2005; see also Sagers, 2007). The Yamal Peninsula, in particular, will doubtless be developed. While it is unclear if a port facility can be built on its shallow western coast, at least two pipelines to the Yamal are planned, and construction of the first, linking the Bovanenkovo gas field to Europe, began in 2009.[17]

A more speculative possibility, decades ahead, is offshore development in the Arctic Ocean itself. Recent assessments by the U.S. Geological Survey suggest the Arctic may potentially hold ~13 percent of the world's undiscovered oil, and ~30 percent of its undiscovered gas (USGS, 2008; Gautier et al., 2009; see also Figs. 1 and 4 and Kelmelis, 2011, this issue). The Alaska Platform, extending offshore from the North Slope, may hold 28 billion barrels of oil; this is comparable to the proved reserves of Nigeria and about one-fourth those of Iraq. Russia's South Kara Sea alone may hold 607 trillion cubic feet of natural gas, more than twice the proved reserves of the U.S. and Canada combined. Other promising geological provinces include Canada's Mackenzie Delta, the Barents Sea, remaining areas of West Siberia, and three provinces off the eastern and western coasts of northern Greenland. However, a "full-scale assault" on offshore Arctic oil and gas has yet to materialize, as new developments in the Caspian Sea, offshore Sakhalin Island, and in deep waters have generally met global energy demand (Brigham, 2007).

Offshore Sovereignty under UNCLOS Article 76

In terms of both physical and political geography, the planet's two poles could hardly be more opposite. At one lies a continent encircled by oceans, buried deeply in ancient glacier ice. At the other lies an ocean encircled by continents, ephemerally covered with a thin skin of floating sea ice. In terms of governance, the Antarctic continent is controlled unlike any

[17]Gazprom commenced laying pipeline across the floor of Baydaratskaya Bay in 2009, hoping to open the Bovanenkovo gas field for European markets sometime in 2011 (Barents Observer, 2009).

other, under shared jurisdiction of nearly 50 countries. The Arctic Ocean is controlled like any other ocean, in accordance with UNCLOS, the United Nations Convention on the Law of the Sea.[18] Much of it already falls within 200-nautical-mile exclusive economic zones (EEZs) off the coastlines of the United States, Canada, Norway, Greenland, and Russia. Outside of these EEZs are high seas, controlled by no one. However, Article 76 of the UNCLOS treaty allows signatory nations to petition for extended sovereignty claims, called an "Extended Continental Shelf" (ECS), of up to 350 nautical miles provided it can be shown scientifically that the ECS seafloor is a natural geological extension of a country's continental shelf. Unlike the EEZ, these extended zones does not include control over pelagic resources like fishing, but do include the seafloor and thus mineral and hydrocarbon resources that may lie beneath.

Because the Arctic Ocean is small, and encircled by continents with unusually broad continental shelves, nearly all of it might potentially be carved up into these extended ECS zones (IBRU, 2008; also see the "maximum theoretical limits"on Figs. 1 and 4). A second factor affecting territorial claims is the Lomonosov Ridge, an undersea mountain chain rising some three thousand meters above the sea floor, that bisects the Arctic Ocean. The physical characteristics of this undersea feature will be especially important to ECS claims between Greenland and Canada, and could produce a Russian claim extending as far as the North Pole in the central Arctic basin (Fig. 1). Russia, in particular, stands to gain greatly from Article 76. In 2009, Norway was the first NORC to have an ECS claim approved . The United States, Canada, Denmark, and Russia are still conducting necessary hydrographic surveys, geological sampling, and other scientific measurements, with Russia closest to completion.

Sea Ice and Shipping

The presence of sea ice is the single greatest obstacle to ships entering the Arctic Ocean, as plainly reflected in contemporary shipping patterns that seek to avoid it by hugging closely the NORC countries' northern coastlines (AMSA, 2009, p. 85; Smith, 2010, pp. 158–159). The annual minimum extent of Arctic sea ice has been generally declining since NASA passive microwave satellites first began mapping it in 1979 (Fig. 5). By 2010, four consecutive record lows in the September ice minimum had spurred new interest in the Northwest Passage and Northern Sea Route, with the latter successfully traversed by two escorted voyages in 2010 and ten more pending for 2011 (Barents Observer, 2010). This overall trend of declining summer sea ice is expected to continue, with the Arctic Ocean perhaps becoming briefly ice-free in summer, within the next 20–30 years (Wang and Overland, 2009; NSIDC, 2010). A new ice pack will always reform in winter. However, the proportion of multi-year ice surviving one or more summers will fall relative to first-year ice that does not survive its first summer. This too will greatly facilitate shipping and other maritime activities in the Arctic, because multi-year ice is generally harder, thicker, and more dangerous than first-year ice.

Often overlooked in discussions of future shipping regimes (which tend to focus on transnational shipping routes; Brigham, 2010) is the importance of destinational (local) shipping in the Arctic. Destinational shipping goals include hydrocarbon exploration, community resupply, mineral resource extraction, transport of heavy equipment, and the like. Tourism is growing quickly, especially in Greenland. In 2004 some 1.2 million passengers visited Greenland in cruise ships; three years later, that number had more than doubled (AMSA, 2009, p. 79).

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[18]The United States is the sole NORC that has not yet ratified UNCLOS, but is obeying its rules and is expected to eventually ratify the treaty.

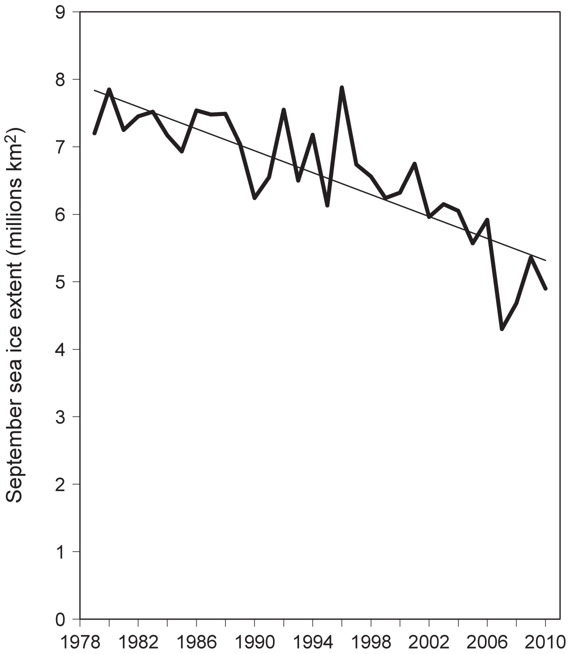

Fig. 5. Over three decades of passive microwave satellite measurements document a general trend of shrinking Arctic Ocean sea ice in the Arctic Ocean. Shown here are monthly averages for September, when ice extent falls to its annual minimum. 2007–2010 are the four lowest years on record. Compiled by author from NSIDC (2010).

Fishing is also expected to increase in the Arctic as the sea ice retreats (Smetacek and Nicol, 2005; Post et al., 2009).

In the same ongoing study used to model potential areas of future winter road declines, Stephenson (2010) is now exploring potential changes in future Arctic Ocean shipping viability based on climate-model projections of sea ice concentration and thickness. This ongoing work, based on an A1B carbon emissions scenario, suggests that deteriorating sea ice conditions could substantially improve maritime access to NORC offshore exclusive economic zones, especially Greenland, Canada, Russia, and the United States. Owing to a long coastline as well as an increasingly ice-free Northern Sea Route, Russia stands to benefit most in absolute terms. However, it is important to note that improved technical accessibility alone does not presage the materialization of a busy shipping route along Russia's northern coast. Substantial investments in physical infrastructure, provision of marine services, and environmental safeguards will be required before any Arctic route can reliably be used on a large scale (Ho, 2010).

CONCLUDING REMARKS

From all current indications, the next four decades promise rising average temperatures, the global reach of commerce, and a world population of nine billion people, with at least one billion new urban consumers in China alone. Such pressures portend substantial changes for the Northern Rim, making it a "New North," a place of higher human activity and perceived strategic value than today (Smith, 2010). The foundations for this run far south of the Arctic—to major immigration hubs like Toronto and Moscow; to global markets for hydrocarbons, fish, and minerals; and the rising economies of China and India. This review has examined 12 key agents of change—immigration and population trends, aboriginal land-claims treaties, hydrocarbon development, UNCLOS Article 76 claims, projected temperature, precipitation, agriculture, ecosystem, permafrost, sea ice, winter road, and shipping regimes—that will continue to shape this increasingly noticed region in the 21st century.

These agents operate in different ways, and to varying degrees, for different NORCs. Canada, for example, possesses some unique demographic advantages, owing especially to immigration policy, not shared by the Russian Federation. As a result, Canada is the fastest-growing NORC while Russia faces overall population decline, with the United States and Nordic countries arrayed to varying levels in between. North America's modern land claims agreements, together with Greenland's still-evolving Home Rule, portend a pivotal shift of political power from southern capitals to northern aboriginal governments. While still imperfect, this ongoing devolution is a giant step forward relative to abuses of the past, signaling a return of autonomy and dignity to many northern peoples. Economically, these new agreements herald abolition of a culture of paternalism and welfare in favor of engagement with the modern global economy.

The Eurasian NORCs, in contrast, tend to focus on protecting aboriginal subsistence cultures and traditional ways of life above all else. In Russia, for example, proof of such activity is a key requirement for winning certain protections and privileges (Fondahl and Poelzer, 2003). The Nordic countries have created aboriginal parliaments that are useful forums but politically weak, serving mainly in an advisory capacity to central governments. More generally, the Eurasian policies for aboriginal minorities tend to promote preservation of historical practice into living folklore. As such, they may be well intended, but, as put by the Arctic Council's *Arctic Human Development Report*, "one must question the tendency to consider change as a threat to some immemorial 'tradition' in discussing indigenous societies, when it is called progress in western societies" (AHDR, 2004, p. 50).

Russia possesses some unique geographic advantages, including a long coastline and broad continental shelf, suggesting sizable extensions, under UNCLOS Article 76, to already extensive exclusive economic zones in the Arctic Ocean. Unlike Canada, Russia also has a long history of logistical and scientific achievements in the Arctic, as does the United States. With an opening Northern Sea Route, enormous endowments of natural gas, and a northward expansion of the West siberian energy sector, Russia will continue to project strong presence in this region while its polar bears face long-term extirpation. Substantial reductions in the extent and physical hardness of sea ice will substantially improve shipping access to current and extended offshore exclusive economic zones, not only for Russia but also Greenland, Canada, and the U.S.A. All NORCs will enjoy relative abundance of water supply, compared with many more populous southern countries of the world.

However, potential agricultural gains in northern Russia and Canada could be countered by serious drought losses in important southern growing regions. All NORC polar ecosystems face new stresses from expanding southern competitors and pests, as well as more direct detrimental impacts of climate change. Declining viability of winter ice road networks promises reduced access to remote inland areas. This poses a direct threat to the economic sustainability of isolated settlements and low-profit industries located far from coasts or rivers, with Russia and Canada standing to suffer the most in absolute terms. Farther north, thawing permafrost will trigger centuries of ground subsidence and hydrologic changes, damaging infrastructure while releasing additional greenhouse gases to the atmosphere. Other disparities abound in the availability and quality of physical infrastructure, human capital, services, and environmental protection, as do current attitudes toward foreign investment and trade. Only to varying degrees, therefore, do the NORCs appear well-positioned for the coming century, even as their unique polar ecosystems are menaced by the linked threats of expanding hydrocarbon development and the most extreme climate changes on Earth.

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