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The fearful symmetry of Arctic climate change: accumulation by degradation

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Abstract. The rapid decline of Arctic sea ice has triggered new rounds of territorial claims making, investment, and development in northern states. This article argues that the physical processes of climate change require a rethinking of the typical mechanics of environmental degradation to account for the renewed possibilities for accumulation emerging in the Arctic, where the effects of historic, large-scale fossil fuel combustion are being organized into new regional production strategies that sharpen and deflect environmental degradation—a process I call 'accumulation by degradation'. The region's hyperamplified thermodynamic response to radiative forcing by anthropogenic greenhouse gases allows for strategic maneuvering by nation-states and firms eager to secure various forms of rent and make climate change literally perform physical work for capital. These opportunities for new Arctic energy extraction and shipping are both heightened and complicated by contemporary geopolitics and commodity prices. Nevertheless, the much-heralded possibilities for capital accumulation in the Arctic may be overestimated. The entire conjuncture depends on a precarious coordination of markets, turnover times of capital, regulatory regimes, and fundamentally uncontrollable physical processes across many operational scales. Because the climate is a nonlinear system, emergent physical properties may materialize rapidly and unpredictably, drastically changing the regional operating environment for capital. Such emergence might well be both a result of and an obstruction to Arctic accumulation by degradation.

1 Introduction

Over the summer of 2007 sea ice in the Arctic Ocean dwindled to by far the smallest area ever recorded. Meanwhile, circumpolar nations busily launched scientific expeditions to their continental shelves, extended territorial claims to exclusive economic zones on the seafloor,[1] and initiated a military build-up in the region. In the press there followed much handwringing about potential international conflict over newly accessible maritime passageways and hydrocarbon reserves.[2] The Arctic became one of the preeminent causes célèbres of foreign policy and defense apparatchiks warning of the national security risks wrought by climate change. As Dodds (2008) has recently pointed out, northern states and firms have begun attempting to take material and strategic advantage of the physical results of climate change in the Arctic, turning this particularly impacted region into a site of geopolitical rivalry and anticipatory rent-seeking.

Here I suggest that these contemporary opportunistic movements should be situated within global historical trajectories of resource extraction and environmental degradation. I present a theoretical framework to demonstrate the relationship between the second-order rent-seeking and accumulation strategies of the present and the fossil fuel-based industrial development of the past century and a half. Merging historical and 'green' Marxian analysis with physical geography, I suggest that contemporary climate change is the result of industrial capitalism's largest negative environmental

[1] Through the UN's Commission on the Limits of the Continental Shelf (UNCLCS), established by the UN Convention on the Law of the Sea (see footnote 20).

[2] Arctic scholar Oran Young has cautioned that concerns raised in the press were actually "more alarmist than alarming" (2009a, page 81).

externalities—greenhouse gas emissions. As in many places around the globe, the effects of climate change are physically transforming the conditions of production. But, in an unusual configuration of cause and effect, in the Arctic[3] it is these increasingly fragile conditions themselves that are relinquishing sea access to hydrocarbons whose extraction costs have kept them 'frozen' and locked away from commodification since the emergence of modern capitalism. These geophysical changes are in fact altering the natural properties of the territory, thus raising new opportunities for rent-seeking and production strategies that sharpen and deflect the general ecological contradiction—a process I call 'accumulation by degradation'. The creation and exploitation of this new frontier for the "extensive expansion of capital into nature" (Smith, 2007, page 18) depend on disjunctures between the radically diverse spatiotemporal scales that characterize climate change processes *globally*, versus *locally* and *regionally* in the Arctic.

To lay the groundwork for this argument, the following section presents a brief primer on some of the physical processes that pertain to this reworking of nature and discusses the physical conditions that made 2007 a watershed year. The next section demonstrates how multiscalar physical properties of greenhouse gases and processes specific to anthropogenic climate change demand a rethinking of the typical mechanics of environmental externalities and factors of production in order to account for the rather unique renewed accumulation possibilities emerging in the Arctic. I review the resurgence of territorial claims, national scientific expeditions, and militarization in the Arctic as nation-states attempt to secure new sources of rent (and expand avenues for accumulation more generally). Finally, I argue that this second-order cycle of accumulation may be short lived, given both the potential political and economic barriers that may soon derail the regional cycling of capital and the dynamical emergent properties that are likely to materialize in the physical climate system. These properties may well be both results of and obstructions to further Arctic accumulation by degradation.

2 The Arctic crucible

Due to physical peculiarities of the polar region, the Arctic climate has proven hypersensitive to increased radiative forcing from greenhouse gas (GHG) emissions. In 2004 an international effort to quantify and collect all contemporary climate data on the region found that Arctic average temperatures were rising at almost twice the rate of the rest of the Earth (see figure 1).[4] While the whole globe has warmed an average of 0.6°C over the last century, vast regions of the Arctic have warmed 2–3°C in the last fifty years alone. Climatologists predict an additional average temperature increase of 5–7°C by 2100, with regions closest to the North Pole reaching 10–12°C above their current temperatures in the winter months (ACIA, 2004). This phenomenon of polar amplification—in which the rate of regional temperature change far outpaces global

[3] For ease of reference I define this as the region lying above the 65th parallel. This includes parts of Canada, Finland, Greenland (Denmark), Iceland, Norway, Russia, Sweden, and the US. Though this is a more expansive geographical limit than that demarcated by the Arctic Circle, which lies at 66°30′ N latitude, it is also more geographically limited than many recent attempts to define the region using provincial boundaries. Yet another method defines the Arctic climatologically as the northern region within which the average temperature for the warmest month does not exceed 10° C, yielding a wildly curving boundary that does not conform to any single latitude.

[4] Though there is variation among regional sites, and even some isolated examples of cooling, the general surface air temperature trend is overwhelmingly upwards. During the winter months of December through February these changes have been even more dramatic: Siberia and northwestern Canada have both seen warming of 4°C (ACIA, 2004).

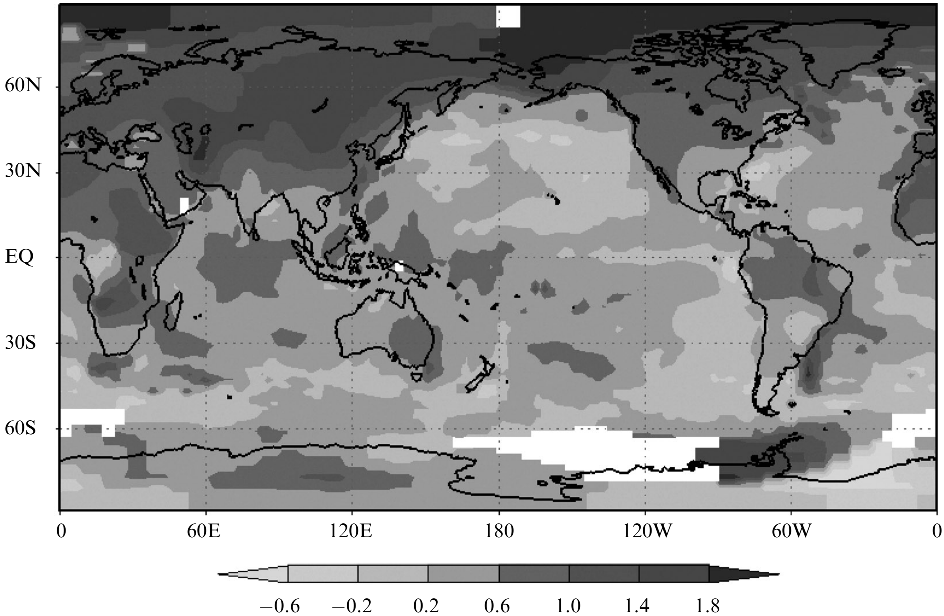

Figure 1. Mean annual surface temperature anomalies for 2001 – 07 compared with the base period 1951 – 80. White depicts areas where data are not available for the entire time period [source: data from Hansen (2008) and figure by Miren Vizaíno].

changes in the same value—is an example of what Sayre (2005; 2009) calls the ontological or operational moment of scale—where "scale is an actual, material property of processes" (2009, page 98).

A powerful set of thermodynamic and dynamic factors combine to make the Arctic a crucible. The most prominent is the ice-albedo feedback mechanism, a thermodynamic process in which melting ice and snow allow the earth to absorb more heat, thus accelerating melt. As the Sun's energy hits the surface of the Earth, it is absorbed or reflected in varying degrees depending on the reflectivity (albedo) of specific surfaces and the angle at which it hits. Fully frozen ice and snow can act as excellent reflectors, sending 70 – 90% of the Sun's energy back out into space as short-wave radiation. When sea ice melts, however, it exposes dark open water or creates melt ponds on top of ice. Both of these scenarios drastically decrease reflectivity to between 5 and 30%, meaning that 70 – 90% of solar radiation is absorbed (Perovich, 1996).[5] The mechanism is a positive feedback, since the absorbed energy raises sea and air temperatures, thereby melting even more ice and slowing down the winter refreeze. Seasonal ice also has a lower albedo and greater conductivity than multiyear ice, so even if winter refreezing restores the extent of ice area, the net effect will still be higher heat absorption (Perovich et al, 2002).[6]

The quantitative measures of sea ice melt are dramatic. Stroeve et al (2008) estimate that the extent of sea ice in September 2007 was half the typical ice extent in the same month from the 1950s to 1970s. Compared with the previous ice extent minimum,

[5] Loss of perennial snow and ice cover on land also lowers reflectivity and accelerates the melting of frozen ground.

[6] Not all of the Arctic ice melt in recent decades is attributable to the ice-albedo feedback, however; natural variability in ocean atmosphere dynamics has also played an important part in amplifying conditions. Natural atmospheric variability results in oscillations of pressure in the Arctic and North Atlantic, which in turn modify the dominant directions of ice transport in the Arctic Ocean (Nghiem et al, 2007).

reached in 2005, the 2007 area was 23% smaller, the equivalent of losing the area of California and Texas combined. There has also been a dramatic shift toward younger, weaker ice; ice five years or older has now virtually disappeared in the central Arctic Basin, whereas in 1987 it composed 57% of all cover in the area (Maslanik et al, 2007). Ice thickness—which has declined by 25% over the last two decades—appears to be a critical variable in determining ice extent. New research has indicated that there may be a threshold ice thickness beyond which summer melt potential is greatly increased, leading to a rapid acceleration in the rate of open water formation (Holland et al, 2006). The rapid and unparalleled melt of Arctic sea ice in the summer of 2007 caused some experts to hypothesize that this 'tipping point' had been crossed. Recent modeling studies have suggested a seasonally ice-free Arctic will be a reality well before 2100. Holland et al (2006) found a high probability of rapid (five-year) decays in Arctic sea ice cover that could be triggered as soon as 2040 by increases in the ocean heat transport to the region.(7) After the unanticipated scale of the summer 2007 melt, the same team of scientists revised their projection to conclude that "a seasonally ice-free Arctic Ocean might be realized as early as 2030" (Stroeve et al, 2008, page 14).

This physical transformation brings with it a host of economic and geostrategic implications, to say nothing of its impact on the region's human populations and ecosystems. A report by the United Nations Environment Programme dryly noted: "the wilderness of the Arctic has not remained intact this long due to strong legislation and good spatial planning practices, but rather because of the remoteness from industrial centers, inaccessibility, and harsh climatic conditions of this region, protected vastly by the pack ice during winter. These conditions are now changing" (Ahlenius et al, 2005, page 27). As industrial and finance capital speculate on these changes, attempting to locate profitable returns for themselves amid disasters, their activities recall Foster's warning that we "should not underestimate capitalism's capacity to accumulate in the midst of the most blatant ecological destruction, to profit from environmental degradation ... and to continue to destroy to earth ..." (2002, pages 10–11).(8) In an environmental reworking of neoliberal privatization and disaster capitalism's (Harvey, 2003; Klein, 2007) tendency to find renewed market opportunities at the doorstep of every crisis, firms and nations are attempting to turn the Arctic *environmental* crisis into an *economic* solution. However, contra Foster, the success of this anticipatory reconfiguration is far from assured.

3 Externalities and scalar disjunctures

The remainder of this paper theorizes how constellations of states and financial and industrial actors are operating not just *on* but also *through* the environment. Tracing the mechanics of this operation requires a temporal refiguring in order to place historical processes within the contemporary moment. What processes physically produced the present conjuncture? How do they continue to amplify the magnitude of its impact? What is their relation to space and scale?

Here I am concerned with considering the historical and contemporary practices of large-scale fossil fuel combustion alongside the unfolding present conditions in the

(7) In addition to sea ice, Arctic glacial melt has accelerated dramatically. The majority of land ice in the region is contained in the Greenland Ice Sheet, whose entire volume would raise global sea levels by 7 meters. In the past twenty-five years the surface melt on the ice sheet has increased by 16%, and shrinking of Alaskan glaciers has been even greater (ACIA, 2004).

(8) Foster concludes this sentence with "destroy the earth to the point of no return". It seems doubtful, however, that such unconstrained accumulation and destruction can continue without bringing about significant reorganization, dictated either by economic or ecological crises or political struggles (cf O'Connor, 1998).

Arctic, both in environmental and political economic terms. For our purposes, the first major impact of economic development on atmospheric chemistry began with widespread coal-burning accompanying the first industrial revolution and was quantitatively transformed by the second industrial revolution's reliance on electricity and oil.[9] Carbon emissions alone have totaled approximately 600 gigatons since 1700 (Houghton, 2004, page 31).[10] Prior to the industrial revolution, global concentrations of carbon dioxide (CO_2) in the atmosphere had fluctuated closely around 280 parts per million (ppm) for several thousand years and had not exceeded 300 ppm for at least the past 650 000 years (Siegenthaler et al, 2005). In 2009 atmospheric concentrations were 387 ppm and were increasing annually at a rate of roughly 1.5 – 2 ppm by volume (Tans, 2010). Of course, apart from energy and CO_2, the combustion reaction also yields carbon aerosols and nitrogen oxides. Notwithstanding some recent efforts to constrain their release, generally speaking, these byproducts have been allowed to escape into the atmosphere, where they also trap longwave radiation.

The energetic efficiency, mobility, and physical forms of fossil fuels enabled the development of modern industry,[11] and to this extent it might be said that capitalism has always demanded a 'cross-scale subsidy' of ancient solar energy from nature. Carpenter et al (2001, page 767) use 'cross-scale subsidy' to refer to the transfer of resources across temporal and spatial scales to sustain socioecological systems. They suggest fossil fuels as an example of such subsidies, transferred from their origins on geologic timescales to consumption on human timescales.[12] In the past 250 years the carbon that humans have used in the form of fossil fuels amounts to more than 13 300 years worth of the entire quantity of global net primary productivity (Dukes, 2003). Certainly this temporal scale jumping operated as a massive 'ecological fix' for capital (Bakker, 2004), whereby "the labour time embodied in any given commodity [could] be shortened through practices that degrade[d] the quality of the conditions of production, and thus greater profit [could] be extracted" (page 35). This deflection of degradation onto the environment for the maximization of profit is surely a type of externality—but of what sort?

In neoclassical economic terms originating with Alfred Marshall, 'externalities' are the physical, social, or economic impacts whose costs are not reflected in market transactions. Although neoclassical proponents attempt to explain negative externalities as irregular 'market failures' that can be corrected by the proper operation of free markets, others—epitomized first by K William Kapp in *The Social Costs of Private Enterprise* (1975)—conclude that such 'social costs' are endemic to an economic system organized for the maximization of private enterprises' earnings. According to Kapp, "A system of decision-making operating in accordance with the principle of investment for profit cannot be expected to proceed in any way other than by trying to reduce its costs whenever possible and by ignoring those losses that can be shifted to third persons or to society at large" (1975, page xii). Typically, negative environmental

[9] Leaving aside earlier variations in emissions stemming from agriculture, livestock, and land clearance.

[10] A gigaton of carbon is equivalent to 3.7 gigatons of CO_2. Here I focus exclusively on the relationship between CO_2 concentrations and fossil fuel combustion since combustion has contributed roughly three quarters of the current radiative forcing of CO_2, while land-use changes account for the remaining quarter (Forster et al, 2007).

[11] Echoing Marx, Altvater (2007) argues that fossil fuels were a necessary, though not alone sufficient, condition for capitalism's growth. He particularly points to "the congruence of [fossil energy's] physical properties with the socioeconomic and political logics of capitalist development" requiring flexibility of application, spatial mobility, and temporally constant intensity (page 41; also see Huber, 2009).

[12] I am indebted to Nathan Sayre for pointing this out.

externalities are conceptualized as waste byproducts or ecosystemic degradation, resulting from a production process in which individual firms or industries have profited while deflecting certain costs onto society. For example, an entire community may bear the environmental and bodily costs of groundwater pollution from toxic industrial waste long after production facilities have closed; a river system may become so sediment laden following clear-cut logging or pit mining that it no longer supports native fish populations.

How then should we evaluate the externalities created by the use of fossil fuels? Certainly the extraction of coal, oil, and gas may have immediate negative environmental consequences on ecosystemic integrity, and the combustion of coal and petroleum releases gases and particulate matter that contribute to local and regional air pollution.[13] These, however, are relatively localized and point-sourced impacts that resemble other classic examples of environmental externalities. By comparison, the effects of the long-lived GHGs emitted in the process of combustion are far more complex given their geographical and temporal dispersion. Following the "further adventures" (Benton, 1989, page 73) of these byproducts raises theoretical questions about causality and the spatial and temporal scales at which environmental waste generates problems or opportunities for the conditions of production.

Depending on their concentrations and lifetime in the atmosphere, long-lived GHGs can alter the radiative balance, and thus the temperature, of the Earth. The Earth's temperature is dictated by its reradiation of the Sun's energy into space, and by the extent to which the surrounding atmosphere traps Earth's heat. The ability of the atmosphere to trap outgoing long-wave radiation emitted by the Earth is determined by the absorptive properties of GHGs such as water vapor, carbon dioxide, methane, and nitrous oxide. The molecular structure of these gases enables them to absorb the energy that is reradiated by the Earth in long wavelengths (not in the visible spectrum). The 'radiative forcing' of a gas, measured in watts per meter squared (W/m^2), is "the change in average net radiation at the top of the troposphere ... which occurs because of a change in the concentration" of the gas (Houghton, 2004, page 338). Anthropogenic emissions of these gases into the atmosphere thus increase the heating of the Earth at a measurable and predictable rate.[14]

Nevertheless, unraveling the spatially and temporally multiscalar ramifications of CO_2 emissions is complicated by their chemical properties as well as the long timescales on which the earth system responds to them. Because CO_2 is uniformly mixed in the atmosphere, all molecules of the gas are equally effective at trapping longwave radiation, and all will circulate through global carbon reservoirs, rubbing elbows with molecules of radically different geographic and temporal origins.[15] Their effects can be both instantaneous and cumulative; if atmospheric concentrations of GHGs were frozen at their current levels, we would continue seeing upward climatic adjustments around the globe for at least the next fifty years due in large part to the

[13] One need only visualize the sky of London at the height of the industrial revolution or that of today's Los Angeles or Mexico City for examples.

[14] The estimated radiative forcing of carbon dioxide is the greatest magnitude of all the long-lived GHGs, at 1.66 W/m^2. Other significant radiative forcings come from methane (0.48 W/m^2), chlorofluorocarbon (CFC)-12 (0.17 W/m^2), nitrous oxide (0.16 W/m^2), and CFC-11 (0.06 W/m^2) (Forster et al, 2007, page 141).

[15] Clark and York (2005) suggest a biospheric rift in the carbon cycle driven by the cycle of expanded reproduction. They detail the carbon cycle's natural 'sinks' and argue that capitalism has systematically exhausted these reservoirs of the global commons through deforestation and excess emissions. My treatment of carbon and externalities focuses on radiative forcing because this seems the most productive way to theorize the thermodynamic processes at work in the Arctic; however, the two analytics (carbon cycle and radiative balance) are complementary.

thermal inertia of the oceans (Hansen et al, 2005). CO_2 is a long-lived gas whose lifetime is more difficult to quantify than other long-lived GHGs like nitrous oxide (114 years), methane (12 years), or CFC-12 (100 years).[16] Excess atmospheric CO_2 is unique because it has no single lifetime (Joos et al, 2001). Although it takes only three to four years to be initially removed from the atmosphere, it is taken up by a multitude of different sinks—the terrestrial biosphere and the ocean's mixed layer, for example—which subsequently cycle or *rerelease* CO_2 back to the atmosphere on radically divergent timescales, from months to decades to hundreds of years. This tangle of effects and feedbacks makes any strict quantification or 'tracing' of the impact of point-specific CO_2 emissions virtually impossible in both physical and economic terms.

The new political and economic activities emerging in the Arctic attempt to exploit two scalar disjunctures. The first is a spatial and temporal disjunture between the local scales at which individual fossil fuel combustion events have taken place over the last 150 years and the global scales at which the resultant GHGs mix in the atmosphere to affect the energy balance of the Earth today. An additional scalar disjuncture is manifest in the geophysical phenomenon of polar amplification, detailed above, as the rate and magnitude of Arctic regional warming radically outpace average warming globally (see figure 1). Prospects for accumulation in the region are thus highly dependent on specific physical properties (of GHGs) and geophysical processes (radiative transfer and the ice-albedo feedback).

Through a remarkable intersection of capitalism's historical development, biogeochemical processes, and the climate system's physical dynamics, the original externalities of GHG emissions themselves literally do *physical work*. This work, calculable in Joules through the first law of thermodynamics, drives the physical feedback of ice melt that is giving segments of capital and certain nation-states access to new factors of production and sources of rent—hydrocarbons and shipping lanes among them. Thus, we can trace a fearful symmetry emerging as the previous combustion of fossil fuels by industry generates geophysical changes that are exploited in order to identify, extract, and combust additional hydrocarbons that will fuel development and, of course, future CO_2 emissions. So, though ice melt may grant access to new factors of production and more efficient transportation routes, the *use* of these newly accessible energy sources will sharpen the problem of radiative forcing and make the conditions of production less stable in the long term (figure 2). This process might be glossed as 'accumulation by degradation', a concatenation of ecological fixes that are contingent on the self-amplifying feedbacks of the geophysical world.

The Arctic conjuncture complicates the typical temporal and causal architecture of externalities, making them *iterative* and compounding. Standard conceptual models assume the relation as such: factors of production $\rightarrow$ production $\rightarrow$ goods/surplus + external cost. Recent treatments of 'neoliberal natures' expand this model to highlight the creation of an additional market, or accumulation cycle, using a commodified external cost such as waste management, pollution trading, or carbon sequestration (cf Castree 2008a; 2008b; McCarthy and Prudham, 2004; Smith, 2007). If I may be permitted a simplification, these markets in externalities usually conform to one of two typologies: (1) disposing, repackaging, or trading waste, as in the garbage and recycling businesses (Rogers, 2007) or the carbon trading market, or (2) recuperating and selling

[16] The quantification of net forcing effects—indirect as well as direct—has been attempted through several different metrics such as 'Global Warming Potential' (GWP), Global Temperature Potential (GNP) (cf Forster et al, 2007, pages 211–216), and half-life (Moore and Braswell, 1994). The Intergovernmental Panel on Climate Change standard GWP accounts for the radiative forcing effect of each gas, as well as its lifetime in the atmosphere.

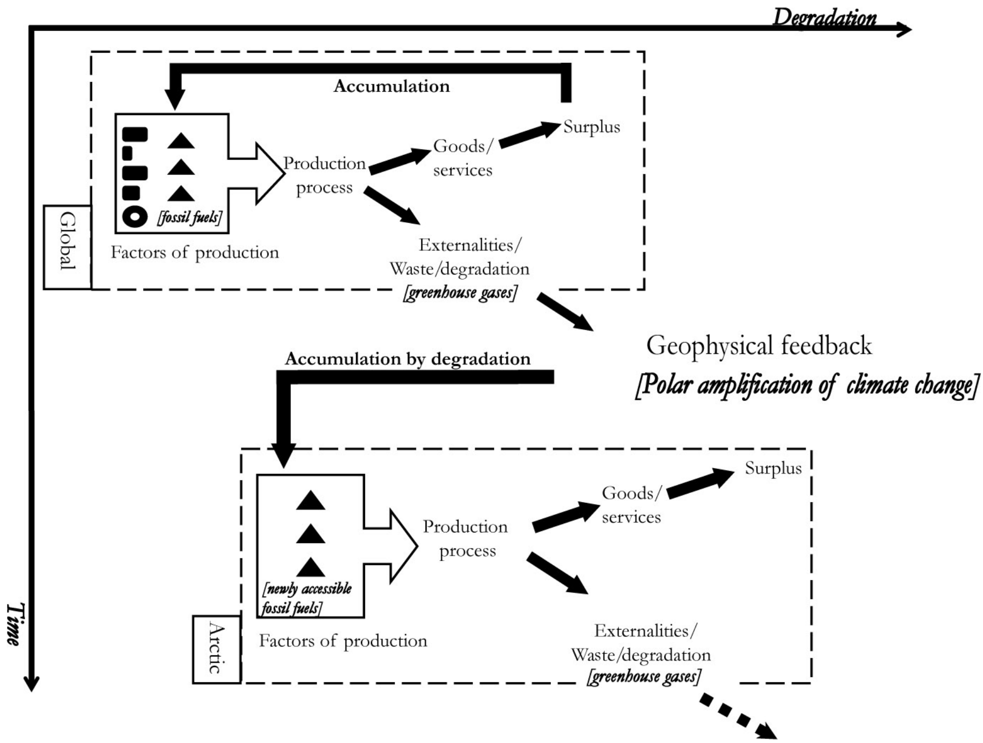

Figure 2. Conceptual model of production and environmental degradation under expanded reproduction, in which externalities act as tools for accumulation by degradation via geophysical processes.

a resource that has become degraded, as in the sale of water (Bakker, 2004), stream restoration (Lave et al, forthcoming), or wetland ecosystem services credits (Robertson, 2004; 2006). The present case cannot be easily matched to any of these models. The external costs of radiative forcing on the Earth's temperature are not themselves commodified (as they are in carbon trading or sequestration); rather, the radiative forcing from excess GHGs sets in motion a natural thermodynamic feedback mechanism that grants access to new factors of production. Within this iterative cycle of accumulation by degradation, fossil energy and its waste may *both* operate as subsidies for capital.

4 Anticipatory strategies

How might these new paths to accumulation by degradation be opened up, and how will they be secured? The popular press has made much of the 'new territorial scramble' for the Arctic and continues to herald the energy and investment opportunities that abound in the region. But as Young (2009b) points out, "[p]rojections of recoverable reserves of oil and gas ... are largely speculative [and]... there are a number of obstacles to greatly increased commercial shipping in the region" (page 425). And, as I argue below, geophysical properties should make us skeptical of popular projections of unfettered, climate-driven opportunity over the medium to long term. Nevertheless, in the present moment the logic of geopolitical expansion is in full swing, as demonstrated by the remilitarization of the region and a spate of new territorial claims-making projects and scientific expeditions (Dodds, 2008). Private firms are also investing in coastal infrastructure and in some cases making claims on the seafloor themselves (see Powell, 2008).

Taken together, these activities illustrate a number of *anticipatory* strategies that landowner states and segments of capital are taking to secure authority over potential rents and profits in a rapidly changing Arctic environment. They represent an array of attempts to make environmental changes do 'work' for future accumulation. This section does not attempt an exhaustive enumeration of recent geopolitical or policy activity; rather, it references a number of contemporary examples that reflect different anticipatory strategies for securing present and future rents in the energy and shipping sectors.[17] Table 1 roughly lays out these strategies with respect to the Marxian categories of rent (Harvey, 1982). Without delving into the definitional debates over the fundamental identities of rent (see Sheppard and Barnes, 1990, chapter 6), broadly speaking, the total quantity of rent that can be commanded for a parcel of land is a function of three interacting criteria. First, the social relations of ownership—that is, the ability or inability of the landowning class or state to demand a share of surplus value from production—determine absolute and monopoly rents. Second, the particular characteristics of the land (its fertility, mineral resources, climate, etc) in combination with the amount of land in production determine differential rent, DR I. Third, the capital invested in improvements to the land (land clearing, wells, roads, etc) in comparison with nonimproved land determines another differential return, DR II. These characteristics of rent can be loosely applied to any parcels of the Earth's surface that are 'owned', although they are morphologically distinct in the cases of subsurface property rights, seafloors, and sea surfaces. In many parts of the Arctic the geophysical processes outlined in section 3 are reshaping the contours of all these categories of rent.[18]

Table 1. Schematic of rent-seeking activities and the effects of Arctic environmental change.

Type of rent	Actions to secure rents	Potential modulation by arctic environmental change
Absolute	Petitioning for extension of nations' exclusive economic zones, attempting to establish control over shipping lanes.	Makes new areas accessible, raising total size of recoverable reserves.
Monopoly	Strategic political appeals to symbolic energy security and free-market principles, warnings against outside intervention.	Newly accessible areas further shift balance of power from OPEC; within Arctic, shift balance between state-run and private models.
Differential I	Assessment and exploration to identify hydrocarbon reserves with greatest potential and accessibility.	Makes new areas accessible, raising total size of recoverable reserves; makes other areas less accessible.
Differential II	Investment in infrastructure and technology: pipelines, processing facilities, ice breakers, new extraction/refining techniques.	Lowers costs of drilling and transport in some parts of ocean. Raises maintenance costs of coastal infrastructure.

(17) Reports also suggest that timber harvesting and agricultural production may be feasible farther north than ever before, and the location of fisheries may change (ACIA, 2004). I have not considered these examples here because the timescale on which these biological changes occur is slower and, as of yet, there is little evidence of explicit maneuverings or speculative investments in these arenas.

(18) I am grateful to an anonymous reviewer for framing the problem in these terms.

4.1 Absolute rents and jurisdiction

If states are to benefit from any of the opportunities raised by ice melt, they must assert their power—both individually and as a block—to demand rents by virtue of their ownership status. Reaffirming and securing that ownership status becomes crucial in order to command an absolute rent on any particular parcel. It is not surprising, then, that coastal Arctic nations are either expanding their own claims or contesting the claims of others. In the summer of 2007 two Russian submersibles descended 2.5 miles underwater to plant a Russian flag on the North Pole in the course of gathering seafloor samples (Borgerson, 2008). Canada's Foreign Affairs Minister ridiculed the move, quipping "this isn't the 15th century" (Boswell, 2007). Nevertheless, in that same month Canada announced it would spend $7 billion for six to eight new Navy patrol vessels to guard the Northwest Passage and build a new Canadian Army training base and deep-sea port along the passage (Gillies, 2007).[19]

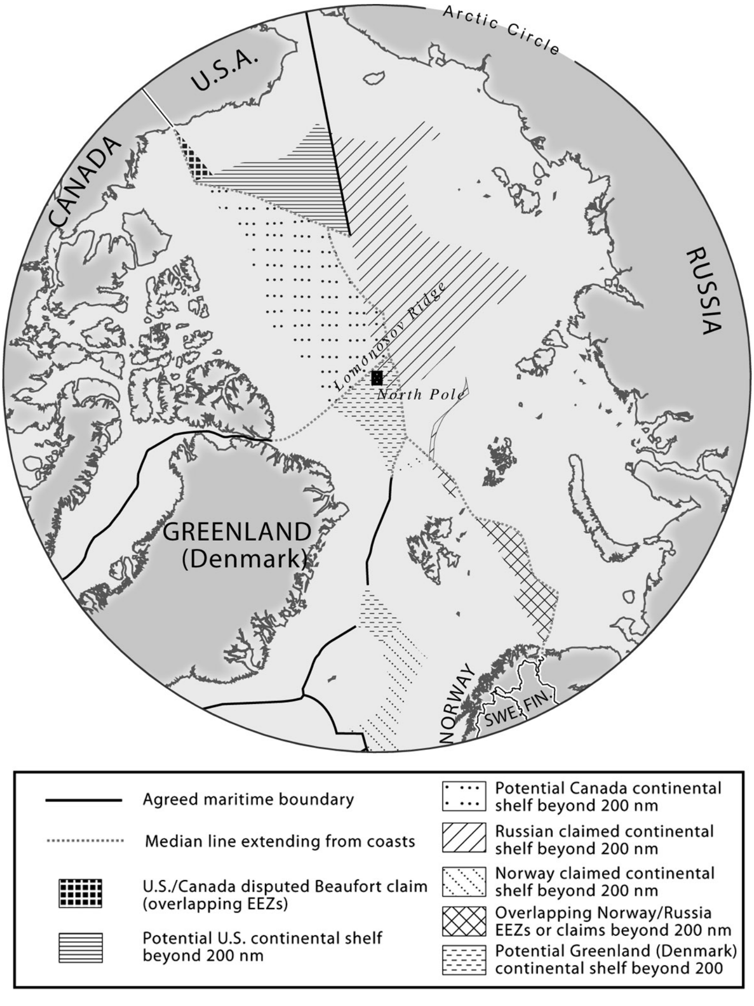

Figure 3. Existing and potential territorial claims for exclusive economic zones (EEZs) beyond 200 nautical miles (nm), per Article 76 of the UN Convention on the Law of the Sea [source: adapted from IBRU (2008) and Ahlenius and UNEP/GRID-Arendal (2003)].

[19] In this instance Canada's activities are both asserting ownership and attempting improvement of the land through infrastructure investment—both absolute and DR II are in play.

Hand in hand with developing military capabilities, national scientific expeditions are being launched to extend territorial boundaries. The particulars of international law have led to an explosion of bathymetric and seafloor coring projects around the Pole. Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS) allows nations to petition for the extension of their exclusive economic zone (traditionally limited to 230 miles from the shoreline) based on evidence of 'natural prolongation' of the territory's continental shelf.[20] Mapping expeditions have generated conflicting claims extending far beyond traditional limits of continental shelves; the Russian petition to the UNCLCS (see footnote 1) claimed another million square kilometers reaching to the North Pole (see figure 3). Some geologists project that the area contains roughly five billion tons of standard fuel, the exploration and development rights to which would lie with Russia if its geological continuity were established (Itar-Tass, 2001). Renewed scientific expeditions to the North Pole in 2004 and 2007 were intended to gather further evidence supporting the country's claim. The Russian excursion in 2007 was quickly followed by a Danish expedition to prove that the Lomonosov Ridge—an 1800 kilometer-long ridge bisecting the North Pole—is geologically attached to its territory, Greenland. Canada announced the initiation of its own mapping project to demonstrate that part of the ridge is connected to the Canadian Archipelago. The same year, American scientists embarked on a seafloor mapping project off Alaska but claimed that the project was in no way related to the other nations' activities (Gillies, 2007; Powell, 2008).

Despite the appearance of infighting between the five coastal Arctic states, they have collectively signaled their determination to govern the region and manage its resources without intervention from the international community. This signal came in the form of the Ilulissat Declaration of the Arctic Ocean Conference, issued in May 2008, in which the group endorsed UNCLOS as the legal framework under which it would continue to operate to adjudicate conflicting territorial claims, protect marine environments, and regulate shipping (in cooperation with the International Maritime Organization).[21] If there are barriers to the exercise of coastal states' power to command absolute rents, these may exist in the form of potential resistance from indigenous peoples' groups rather than opposition from noncoastal states. Although it is beyond the scope of this paper to discuss the tremen-dous and growing literature on indigenous peoples' particular vulnerabilities and their changing relations with Northern states (for example, see AHDR, 2004), we should note that, if coastal Arctic states are to continue commanding absolute rent, it will be politically and symbolically important to secure the cooperation of these groups. Many of them are organized into highly visible councils and associations (see footnote 21), and if they were to collectively oppose the operational decisions of the Arctic nations, it could seriously destabilize the legitimacy of Arctic governance in the eyes of the global community.

[20] With the exception of the US, all Arctic littoral nations—Canada, Denmark (Greenland), Norway, and Russia—are signatories to the Convention, which went into effect in 1994. Norway and Russia submitted petitions regarding the extension of their EEZs in 2001 and 2006, respectively, and Denmark and Canada are expected to do so (Young, 2009a).

[21] The eight-nation Arctic Council has been widely lauded for its work to assess social and environmental risks and establish safety guidelines and standards for scientific cooperation. The organization—which also includes six indigenous peoples' councils and associations as permanent participants—was formally established as a 'high-level intergovernmental forum' in 1996. It has been responsible for a number of influential scientific and policy documents, including the Arctic Climate Impact Assessment report (ACIA, 2004) and the Arctic Oil and Gas Assessment report (AMAP, 2007).

4.2 Shifting qualities

In the long term, ice melt could reduce the extraordinarily intensive capital outlays for deep water exploration and transport of cargo, drilling equipment, and petroleum and extend the seasonal periods in which such operations are feasible.[22] This environmental opening would presumably bring down some of the most uncompromising regional barriers to entry. But if these quickly changing qualities are to be exploited for their rent-generating possibilities, states and firms must know how best to begin. Emel and Huber (2008, page 1398) point out that attracting energy investment increasingly depends on states providing free exploration data or financing private firms' exploratory activities to compensate for the geological uncertainties. To this end, the scientific expeditions to the Arctic seafloor may offer some initial clues as to the geological potential of particular regions. In a more explicit case, the US Geological Survey recently completed its first *probabilistic* assessment of all *undiscovered* oil and gas deposits north of the Arctic Circle. It estimated that the region holds the following amounts of the world's undiscovered resources: 30% of natural gas (1669 trillion cubic feet), 20% of natural gas liquids (44 billion barrels), and 13% of oil (90 billion barrels) (USGS CARA Assessment Team, 2008).[23] Framing these quantities in probabilistic terms appears to be a targeted attempt to provide firms with quantifiable justification for pursuing new exploration.

The long-sought possibility of large-scale shipping through Arctic passages (see figure 4) also brings with it new sources of DR I. Here, it is physical processes that are changing the areas' qualities and rent potentials. Today's shipping seasons through the Northern Sea Route and Northwest Passage last between six weeks and two months for ships outfitted with ice armor or accompanied by icebreakers.[24] Earlier onset dates for spring melt and later fall freeze may add weeks or months to this window.[25] Routes through Arctic waters can cut thousands of miles off of traditional transoceanic shipping voyages in the Northern Hemisphere, increasing delivery throughput and decreasing fuel expenditures. States like Russia and Canada thus have an interest in controlling routes in their territorial waters for the purposes of regulation, taxation, or both. The Northern Sea Route, which reduces the shipping distance from Europe to Asia by up to 40% (Krauss et al, 2005), will be the first to benefit from decreasing ice cover. But similar climatic conditions may have diverging consequences contingent upon geography.[26] For example, due to decreasing stability of multiyear ice and the resultant *increase* in iceberg production, the Northwest Passage and the Canadian Archipelago may remain effectively locked up for much of the year in the near term. However, a Russian floating dry dock was successfully

[22] For the time being, however, energy exploration in the Arctic has primarily been carried out by the oil majors with access to the necessary capital and equipment. See Verma et al (2008, page 4) for a startling example of how Arctic climate conditions elevate the operating costs for a (shallow) offshore field by billions of dollars. Several Arctic deepwater drilling operations have existed in the Barents Sea for some time, such as the Norwegian Statoil complex. These operations are feasible—and exceptional—because the basin remains ice free for most, if not all, of the year thanks to warm and salty surface water pumped from the west by the North Atlantic current (Loeng, 1991; Pritchard, 2006).

[23] The estimate includes only oil and gas that are 'technically recoverable' with current technology. This excludes tar sand, gas hydrate, oil shale, etc. The estimate ignores the technical challenges posed by deep ocean drilling and sea ice.

[24] Russia has regulated the Northern Sea Route through centralized state management since the 1930s and provides state icebreaker services throughout the route (Itar-Tass, 2000; McCannon, 1998). Indeed, establishing the route as an operational sea-lane was a key part of Soviet strategy to exploit the Arctic.

[25] However, natural interannual and regional variability of the melt season due to the Arctic Oscillation is likely to endure (Belchansky et al, 2004).

[26] Estimates of increasing summer sea ice melt and open water production depend on variables such as the locations of gyres, currents, freshwater versus saltwater inputs, and land distribution.

Figure 4. Marine navigation routes, hydrocarbon sites in production, and areas of exploratory drilling [source: adapted from Ahlenius and UNEP/GRID-Arendal (2003; 2006) and Rekacewicz and Ahlenius (2007)].

towed through the Northwest Passage to the Bahamas in 1999, demonstrating the navigability of the passage for large vessels and precarious cargo, and in the summer of 2006 seven ships—including cruise ships carrying tourists—successfully traversed the entire Passage (Huebert, 2003; Struck, 2006).

Just as the rents on agricultural lands depend on the quantity and quality of land under cultivation, the attractiveness of new opportunities for both oil and shipping are modulated by the global political economy of oil—that is to say, the relative cost of oil from other sources. Price spikes in 2007 made cost-cutting measures indispensable in the transport sector while increasing the potential return on new, capital-intensive exploration and drilling in the petroleum sector. Amidst complaints of stagnating capacity and political risks in the petro-states of the Middle East, Africa, and South America (cf McNulty, 2007) and financial speculation in the midst of the global economic downturn that drove oil prices to nearly \$150 per barrel, the Arctic once again became an attractive site for exploration and development of both oil and gas fields. In 2009, however, the price of oil sharply declined to below \$40 per barrel. Although the price has been steadily rising since then, it is not a foregone conclusion that the Arctic will remain an attractive location if global demand stagnates. The degree to which the oil industry finds the region attractive also depends on its political and technological access to other, potentially cheaper sources such as tar sands, oil shale, and new discoveries in temperate climates. Likewise, in the shipping industry, it is unclear how high the savings in fuel costs would need to be to offset the considerable costs and risks associated with shipping through Arctic waters (where icebreakers will still be required despite the melt, and where marine insurance premiums are high)

(Young, 2009a). Further complicating issues, a future global climate regulatory regime could dramatically increase costs and regulations in both industries. Ironically, a tax on emissions might encourage fuel-saving voyages through the Arctic while making Arctic energy extraction economically unrewarding. Regulations or economic incentives for low-carbon 'green tech' energy development could also divert capital that otherwise would have been invested in developing Arctic drilling technology or financing exploration. Finally, the hypervisibility of Arctic ecological change in the global media could pose a reputational risk for energy companies operating in the region, particularly for those attempting to establish themselves as leaders in renewable energy alternatives.(27) The global media currency of the region also raises the stakes involved in managing fallout from accidents such as oil spills, which are more likely to occur in icy waters.

4.3 Monopoly rents on 'security'

While images of a desperately vulnerable Arctic propagate through global environmental circles, political leaders in the region are attempting a different reconfiguration of image politics. Regardless of whether the US Geological Survey predictions of recoverable reserves are accurate,(28) the Arctic supply is of critical symbolic and strategic importance. As when Arctic hydrocarbons in Prudhoe Bay first captivated the ambitions of the Western energy industry in the late 1960s, the current global supply picture is haunted by the specters of political instability and overzealous landlord states prone to nationalizing hydrocarbon reserves. Countries able to offer politically stable access to reserves with the backing of the state are specially positioned to garner a sort of monopoly rent. The government of neoconservative Canadian Prime Minister Stephen Harper, for one, has grasped the political potential for growth.(29) It has adopted a new strategy for branding Canada—the world's fifth largest energy exporter—as a uniquely 'safe', reliable, and democratic energy source that operates according to free-market principles, "not self-serving monopolistic political strategies" (Harper, 2006). The strategy plays up the country's energy-rich North, while differentiating it from state-interventionist Russia, Middle Eastern OPEC-controlled sources, and notoriously 'unstable' African countries increasingly courted by the Chinese.

4.4 Capital, technology, and fixed investments

Classically, a second kind of differential rent arises from the increased productivity resulting from the application of capital. In short, investments that improve the qualities of the 'land' demand their own return, a fact that has not eluded entrepreneurs in the Arctic. Thanks to neoliberal reforms and climatic changes, investors are engaged in a wave of anticipatory development on both sides of a third trans-Arctic route, dubbed the Arctic Bridge. The route connects the ports of Murmansk, Russia, and Churchill, Manitoba, where rail lines begin and stretch as far south as Monterrey, Mexico. The voyage from Murmansk to Churchill takes roughly half the time of the typical route from Murmansk through the St Lawrence to Thunder Bay, Ontario (eight versus seventeen days) (Krauss et al, 2005). Recent rounds of denationalization and infrastructural privatization in Russia and Canada have left both the Murmansk Shipping Company (as of yet, the only operation outfitted for trans-Arctic shipping

(27) Thanks are due to an anonymous reviewer for pointing this out.

(28) Estimates of the world's remaining 'undiscovered' energy are particularly uncertain given increasing deepwater offshore finds in ice-free areas. Nevertheless, analyst Michael Klare, a champion of the idea that oil scarcity will provoke resource wars, has dramatically suggested that new "extreme methods" of energy extraction in the Arctic are indicative of "desperate efforts to set aside adequate stocks of energy for the years of scarcity [ahead]" (2008, page 41).

(29) Denmark's and Norway's energy projects offer other examples of the appeal to symbolic energy security.

from Murmansk) and the port of Churchill and its associated railways in the hands of entrepreneurs. American investor Pat Broe's railroad company OmniTrax purchased the port of Churchill from Canada in 1997, paying only 10 Canadian dollars at auction; earlier it bought 810 miles of denationalized rail track in Manitoba for $11 million (Krauss et al, 2005). Again, much like the territorial claims of states, these investments are conjectural; although they may put their owners in ideal positions to extract rents and profit from an Arctic boom, this is far from assured. Although wheat producers ship many hundreds of thousands of tons of grain annually from Churchill to Murmansk and other buyers in Europe, the port had not received any Russian shipments until October 2007, when a Russian vessel delivered fertilizer purchased by a group of Saskatchewan farmers (Friesen, 2007). Churchill's port is open only from July through November, but boosters say it could have a longer season if insurers would recognize that ice conditions have changed and reconfigure their maritime policies accordingly.(30) They also project a bright future for the port as an importer of Eurasian oil and gas, though current shipments are limited to bulk dry commodities and agricultural machinery.

Increased energy exploration and extraction bring with them a demand for more infrastructure in the form of ports, ships, storage facilities, and pipelines. The ocean's iceberg-filled waters also pose unique demands and opportunities for the ship construction industry to produce double-hulled tankers and icebreakers, which can cost millions more than ordinary seafaring ships (Madslien, 2005). Deep-water drilling rigs destined for the Arctic must be specially equipped with ice-breaking capabilities, high wave stabilization, and insulation from polar temperatures. One such ship was recently ordered for $942 million, roughly $500 million more than the going rate for temperate deep-water rigs (Mouawad and Fackler, 2008). The financial apparatuses of export/import banks, credit, and insurance must also be extended to facilitate these developments. Arctic pursuits require greater outlays of financial capital to fund long-term infrastructure and exploration projects, and the costs to insure these ventures are especially high given the high risk of environmental disaster and damage to equipment.

5 Conclusion: precarious coincidence and emergent properties

> "[E]very participator knows that the thunderstorm will come sooner or later, but every one expects that the lightning will fall on the head of his neighbour, after he himself shall have had time to collect the golden rain and store it up safely. *Après moi le déluge!* is the battle-cry of every capitalist and of every capitalist nation."
>
> Karl Marx (1967 [1867], page 269)

Whether these investments will succeed in terms of accumulation remains to be seen. At this juncture it is difficult to determine whether the contracts to develop the region will generate productive capacity or are overly optimistic speculation. Since rent is paid to landowners from the surplus value accruing from production, if any rents are to be realized, production must *actually* occur. A tremendous number of factors must coalesce, including physical environments, successful energy exploration and extraction, supportive governments, and permissive climate and/or carbon regimes.

Even if impressive economic returns result from the current investments being made in the Arctic, a theoretical accounting of accumulation by degradation would be incomplete if it stopped with the observation that the externalities put 'to work' for capital in the Arctic may combat a profit squeeze on the supply side by lowering costs and decreasing turnover times. Although this may well be true in the short term,

(30) Murmansk's port is ice free year-round thanks to the Gulf Stream.

its simplicity is economistic. The entire Arctic conjuncture depends on a rather precarious coincidence of commodity prices, international regulatory regimes, entrepreneurialism, territorial sovereignty, and fundamentally uncontrollable physical processes across many operational scales. This final factor is, in my view, the most likely to derail the recursive cycling of factors of production, accumulation, and external costs diagramed in figure 2 above. For myriad reasons, there is no 'just doing business' in the Arctic, be it construction or energy or banking. The turnover times of capital must be somehow reconciled with the materiality of the Earth's turnover times—annual cycles of temperature, melt and freeze, light and dark—that reach their extremes at the poles. Here, more so than in many other places, biophysical nature must be a party to the process of expanded reproduction, and it is not always an agreeable or predictable ally—particularly as it becomes more environmentally degraded through the cycles of accumulation by degradation.

These possibilities and perils for capital in the Arctic require an engagement with the argument that capitalism will always manage to accumulate its way through crisis, barring human extinction (cf Clark and York, 2005; Foster, 2002). The Arctic case demonstrates that, for the time being, segments of capital may be able to instrumentalize these externalities to hold down production costs, all the while reorganizing themselves as multistrategy energy companies with corporate visions 'Beyond Petroleum'. The question of how *long* this pattern can go on is, of course, the crucial one, which I think depends largely on properties of climate and biogeochemical systems that are as of yet unknown.[31] Much of the debate regarding the inevitability (or not) of an environmentally sourced economic crisis for capitalism turns on divergent spatial and temporal scales at which crisis is defined: the tensions between short-term versus long-term profitability, sectors versus capital as a whole, regional versus global ecological debts, and so on. I find the infinite regress of this argument to be unrewarding, particularly given the pressing need to grapple with the possibility of nonlinear, emergent behaviors of socionatural systems.

I find it untenable to simply assume that capital will continue to be logistically able to exploit uneven development, and that nature will keep behaving in essentially predictable and manageable ways—for example, that carbon sinks will continue to uptake excess atmospheric CO_2 and that the terrestrial biosphere will not transition from a carbon sink to *source* (cf Joos et al, 2001). Over the medium term to long term, it seems foolhardy to conjecture that emergent properties in nonlinear systems like the climate will not pose a problem for capital accumulation. Climate data from the mid-Pliocene (3.3 to 3.0 million years ago), in which global atmospheric CO_2 concentrations approximated current levels, suggest the end potential of warming and point to the existence of some rather dramatic feedback mechanisms. In this period, surface air temperatures in high northern latitudes may have been 10 to 20°C higher than today, ice sheets were far smaller, and sea level was at least 15 to 25 meters higher (Jansen et al, 2007). These records suggest that our current global climate models may not fully account for all the positive feedbacks that will affect the climate beyond the 21st century. Emergent properties in the climate system could be triggered by the magnified radiative forcing that results from accumulation by degradation.

Contemporary configurations of capital in the Arctic are organized around short-term to medium-term strategies to exploit temporal and spatial disjunctures in the scales at which climate change is progressing. But investment in the 'new Arctic' is plagued by tensions. Chief among the contradictions is that the profits and rents to be had in the extraction, transport, and sale of newly accessible hydrocarbons are large,

[31] See Pittock (2006), who argues we may be drastically underestimating the possible extent of climate change due to positive feedbacks and tipping points that climate models do not or cannot resolve.

potentially rapid,[32] and dominated by a relatively short time horizon. The ultimate environmental effects of the continued combustion of hydrocarbons are, on the other hand, long-term, global, and likely detrimental to the global economy as a whole: rising sea levels, increasing droughts, heat waves, and decreasing water supplies, to name only a few (McCarthy et al, 2001).[33] Although socially organized scarcity may indeed permit the market to function with great prosperity under these conditions (Harvey, 1973), there is only so far the system can endure without coming face-to-face with what O'Connor has called the second contradiction of capital: the underproduction of environmental conditions (O'Connor, 1998).

Ultimately, the success of accumulation by degradation is an open question. The process rests on a fragile concatenation of political and financial commitments that depend on an uncontrollable natural process. Just as the operation of physical dynamics set the economic process in motion, so also does the continuation of accumulation depend on 'cooperation' from nature and the continuing supply of correct environmental conditions—in this case, increased iceberg production must be minimal, newly ice-free Arctic coastlines must remain stable against increased wave action, permafrost must not melt,[34] and sea level must not rise too dramatically. If these conditions do not hold, the new fixed capital in the Arctic built environment may find itself drastically devalued before ever having got off the ground. In the meantime, we have every reason to believe that firms operating within the Arctic will continue with the short-term and profit-maximizing behavior that Marx parodies as "Après moi, le déluge!", which Foster (2002) has argued applies equally well to environmental and human degradation. It remains unclear whether nature or society will oblige, and it is precisely this uncertainty that demands further attention from critical geography.

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References

ACIA, 2004 *Arctic Climate Impact Assessment: Impacts of a Warming Arctic* (Cambridge University Press, Cambridge)

AHDR, 2004, "Arctic Human Development Report", Stefansson Arctic Institute, Akureyri

Ahlenius H, UNEP/GRID-Arendal, 2003, "Arctic, AMAP and CAFF area", UNEP/GRID-Arendal Maps and Graphics Library, http://maps.grida.no/go/graphic/arctic-amap-and-caff-area

[32] However, the return time on capital invested depends to a great degree on the success of exploratory drilling and the continued development of new technologies capable of operating in deep icy waters.

[33] There are numerous estimates of the economic impact of climate change on particular industries and nations, many of which project disastrous consequences. See the *Stern Review* (HM Treasury, 2006), a report commissioned by the British Treasury that estimated the future economic cost of climate change to be at least 5% of global GDP annually, 'now and forever', and as much as 20% if the full range of impacts and risks are taken into account. Comparison across projections is difficult, since each varies with regards to the future economic scenarios and political responses input to models, and also with respect to the scale of processes modeled.

[34] New research by Lawrence et al (2008) suggests that rapid Arctic sea ice loss events—like those Holland et al (2006) predict—might trigger land air warming in the Arctic of the order of 1.6° C/decade (as opposed to 0.46° C/decade without rapid ice loss). While the most dramatic land air temperature warming would be along coastlines, simulations indicate it could penetrate 1500 kilometers inland. Models of permafrost depth and soil heat content indicate that rapid air warming would cause drastic melting of 'warm' (−0.3° C) permafrost, potentially creating thermokarst and transforming surface hydrology. This could have disastrous destabilizing effects on infrastructure such as ports, roads, and processing facilities.

Ahlenius H, UNEP/GRID-Arendal, 2006, "Arctic, topography and bathymetry", UNEP/GRID-Arendal Maps and Graphics Library, http://maps.grida.no/go/graphic/arctic-topography-and-bathymetry2

Ahlenius H, Johnsen K, Nellemann C, 2005, "Vital Arctic graphics: people and global heritage on our last wild shores", United Nations Environment Programme, New York

Altvater E, 2007, "The social and natural environment of fossil capitalism", in *Socialist Register 2007: Coming to Terms with Nature* Eds L Panitch, C Leys (Monthly Review Press, New York) pp 37 – 59

AMAP, 2007, "Arctic oil and gas 2007", Arctic Monitoring and Assessment Programme, Arctic Council, Oslo

Bakker K, 2004 *An Uncooperative Commodity: Privatizing Water in England and Wales* (Oxford University Press, Oxford)

Belchansky G, Douglas D, Platonov N, 2004, "Duration of the Arctic Sea ice melt season: regional and interannual variability, 1979 – 2001" *Journal of Climate* **17** 67 – 80

Benton T, 1989, "Marxism and natural limits: an ecological critique and reconstruction" *New Left Review* number 178, 51 – 86

Borgerson S, 2008, "Arctic meltdown" *Foreign Affairs* **87** 63 – 77

Boswell R, 2007, "MacKay mocks Russia's '15th century' *Arctic Claim*", Reuters, 2 August

Carpenter S, Walker B, Anderies M, Abel N, 2001, "From metaphor to measurement: resilience of what to what?" *Ecosystems* **4** 765 – 781

Castree N, 2008a, "Neoliberalising nature: the logics of deregulation and reregulation" *Environment and Planning A* **40** 131 – 152

Castree N, 2008b, "Neoliberalising nature: processes, effects, and evaluations" *Environment and Planning A* **40** 153 – 173

Clark B, York R, 2005, "Carbon metabolism: global capitalism, climate change, and the biospheric rift" *Theory and Society* **34** 391 – 428

Dodds K, 2008, "Icy geopolitics" *Environment and Planning D: Society and Space* **26** 1 – 6

Dukes J, 2003, "Burning buried sunshine: human consumption of ancient solar energy" *Climatic Change* **61** 33 – 34

Emel J, Huber M, 2008, "A risky business: mining, rent and the neoliberalization of 'risk' " *Geoforum* **39** 1393 – 1407

Forster P, et al, 2007, "Changes in atmospheric constituents and in radiative forcing", in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Eds S Solomon, D Qin, M Manning, Z Chen, M Marquis, K B Averyt, M Tignor, H L Miller (Cambridge University Press, New York) pp 129 – 234

Foster J, 2002, "Capitalism and ecology: the nature of the contradiction" *Monthly Review* **54** 6 – 16

Friesen J, 2007, "Russian ship crosses 'Arctic Bridge' to Manitoba" *Globe and Mail* 18 October

Gillies R, 2007, "Canada announces Arctic base, port" *Associated Press* 10 August

Hansen J, et al, 2005, "Earth's energy imbalance: confirmation and implications" *Science* **308** 1431 – 1435

Hansen J, 2008, "GISS surface temperature analysis", Goddard Institute for Space Studies, NASA, http://data.giss.nasa.gov/gistemp/

Harper S, 2006, Speech to the Canada – UK Chamber of Commerce, London

Harvey D, 1973 *Social Justice and the City* (Johns Hopkins University Press, Baltimore, MD)

Harvey D, 1982 *The Limits to Capital* (Blackwell, Oxford)

Harvey D, 2003 *The New Imperialism* (Oxford University Press, New York)

HM Treasury, 2006, "Stern Review on the economics of climate change", HM Treasury, London

Holland M, Bitz C, Tremblay B, 2006, "Future abrupt reductions in the summer Arctic sea ice" *Geophysical Research Letters* **33** L23503, 1 – 5

Houghton J, 2004 *Global Warming: The Complete Briefing* (Cambridge University Press, Cambridge)

Huber M, 2009, "Energizing historical materialism: fossil fuels, space and the capitalist mode of production" *Geoforum* **40** 105 – 115

Huebert R, 2003, "The shipping news part II—how Canada's Arctic sovereignty is on thinning ice" *International Journal* **58** 295 – 308

IBRU, 2008, "Maritime jurisdiction and boundaries in the Arctic region", map produced by the International Boundaries Research Unit, Durham University, http://www.dur.ac.uk/resources/ibru/arctic.pdf

Itar-Tass, 2000, "Russia vows to guard its interests in Southern, Northern Seas", Itar-Tass News Agency/BBC Monitoring Former Soviet Union, 23 June

Itar-Tass, 2001, "Russia claims larger economic zone in Arctic Ocean", Itar-Tass News Agency/BBC Monitoring Former Soviet Union, 6 November

Jansen E, et al, 2007, "Palaeoclimate", in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Eds S Solomon, D Qin, M Manning, Z Chen, M Marquis, K B Averyt, M Tignor, H L Miller (Cambridge University Press, New York) pp 433 – 498

Joos F, Prentice I C, Sitch S, Meyer R, Hooss G, Plattner G-K, Gerber S, Hasselmann K, 2001, "Global warming feedbacks on terrestrial carbon uptake under the Intergovernmental Panel on Climate Change (IPCC) emission scenarios" *Global Biogeochemical Cycles* **15** 891 – 907

Kapp W, 1975 [1950] *The Social Costs of Private Enterprise* (Harvard University Press, Cambridge, MA)

Klare M, 2008 *Rising Powers, Shrinking Planet: The New Geopolitics of Energy* (Henry Holt, New York)

Klein N, 2007 *The Shock Doctrine: The Rise of Disaster Capitalism* (Metropolitan Books, New York)

Krauss C, Myers S L, Revkin A, Romero S, 2005, "As polar ice turns to water, dreams of treasure abound" *The New York Times* 10 October

Lave R, Doyle M, Robertson M, forthcoming, "Privatizing stream restoration in the US" *Social Studies of Science* **40**

Lawrence D, Slater A, Tomas R, Holland M, Deser C, 2008, "Accelerated Arctic land warming and permafrost degradation during rapid sea ice loss" *Geophysical Research Letters* **35** L11506

Loeng H, 1991, "Features of the physical oceanographic conditions of the Barents Sea" *Polar Research* **10** 5 – 18

McCannon J, 1998 *Red Arctic: Polar Exploration and the Myth of the North in the Soviet Union* (Oxford University Press, Oxford)

McCarthy J, Prudham S, 2004, "Neoliberal nature and the nature of neoliberalism" *Geoforum* **35** 275 – 283

McCarthy J, Canziani O, Leary N, Dokken D, White K (Eds), 2001 *Climate Change 2001: Impacts, Adaptation, and Vulnerability: Third Assessment Report of IPCC* (Cambridge University Press, New York)

McNulty S, 2007, "Easy profits herald global oil crunch" *The Financial Times* 10 May

Madslien J, 2005, "Global warming: help or hindrance?" *BBC News Online* 27 October

Madslien J, 2006, "Big-dollar deals tempt Arctic firms" *BBC News Online* 9 November

Marx K, 1967 [1867] *Capital* volume I (International Publishers, New York)

Maslanik J, Fowler C, Stroeve J, Drobot S, Zwally J, Yi D, Emery W, 2007, "A younger, thinner Arctic ice cover: increased potential for rapid, extensive sea-ice loss" *Geophysical Research Letters* **34** L24501

Moore B, Braswell B, 1994, "The lifetime of excess atmospheric carbon dioxide" *Global Biogeochemical Cycles* **8** 23 – 38

Mouawad J, Fackler M, 2008, "Dearth of ships delays drilling of offshore oil" *The New York Times* 19 June

Nghiem S, Rigor I G, Perovich D K, Clemente-Colón P, Weatherly J W, Neumann G, 2007, "Rapid reduction of Arctic perennial sea ice" *Geophysical Research Letters* **34** L19504, 1 – 6

O'Connor J, 1998 *Natural Causes: Essays in Ecological Marxism* (Guilford Press, New York)

Perovich D, 1996, "The optical properties of sea ice", Monograph 96-1, Cold Regions Research and Engineering Laboratory, Hanover, NH

Perovich D, Grenfell T, Light B, Hobbs P, 2002, "Seasonal evolution of the albedo of multiyear Arctic sea ice" *Journal of Geophysical Research-Oceans* **107** SHE 20 – 21

Pittock A B, 2006, "Are scientists underestimating climate change?" *EOS: Transactions of the American Geophysical Union* **87** 340 – 341

Powell R, 2008, "Configuring an 'Arctic Commons'?" *Political Geography* **27** 827 – 832

Pritchard L, 2006, "The Norwegian Barents Sea: historical overview and future perspectives", *Monthly Newsletter of the Petroleum Exploration Society of Great Britain* December

Rekacewicz P, Ahlenius H, 2007, "Fossil fuel resources and oil and gas production in the Arctic", UNEP/GRID-Arendal Maps and Graphics Library, http://maps.grida.no/go/graphic/fossil-fuel-resources-and-oil-and-gas-production-in-the-arctic

Robertson M, 2004, "The neoliberalization of ecosystem services" *Geoforum* **35** 361 – 374

Robertson M, 2006, "The nature that capital can see: science, state, and market in the commodification of ecosystem services" *Environment and Planning D: Society and Space* **24** 367 – 387

Rogers H, 2007, "Garbage capitalism's green commerce", in *Socialist Register 2007: Coming to Terms with Nature* Eds L Panitch, C Leys (Monthly Review Press, New York) pp 231 – 253
Sayre N, 2005, "Ecological and geographical scale: parallels and potential for integration" *Progress in Human Geography* **29** 276 – 290
Sayre N, 2009, "Scale", in *A Companion to Environmental Geography* Eds N Castree, D Demeritt, B Rhoads, D Liverman (Blackwell, London) pp 95 – 108
Sheppard E, Barnes T, 1990 *The Capitalist Space Economy: Geographical Analysis after Ricardo, Marx and Sraffa* (Unwin Hyman, London)
Siegenthaler U, et al, 2005, "Stable carbon cycle – climate relationship during the late pleistocene" *Science* **310** 1313 – 1317
Smith N, 2007, "Nature as accumulation strategy", in *Socialist Register 2007: Coming to Terms with Nature* Eds L Panitch, C Leys (Monthly Review Press, New York) pp 16 – 36
Stroeve J, Serreze M, Drobot S, Gearheard S, Holland M, Maslanik J, Meier W, Scambos T, 2008, "Arctic sea ice extent plummets in 2007" *EOS, Transactions of the American Geophysical Union* **89** 13 – 14
Struck D, 2006, "Melting Arctic makes way for man" *The Washington Post* 5 November
Symons T, Alsford S, Kitzan C, 1999 *Meta Incognita: A Discourse of Discovery: Martin Frobisher's Arctic Expeditions, 1576 – 1578* (Canadian Museum of Civilization, Hull, Quebec)
Tans P, 2010, "Mauna Loa CO_2 annual mean data", National Oceanic and Atmospheric Administration/Earth System Research Laboratory (NOAA/ESRL), http://www.esrl.noaa.gov/gmd/ccgg/trends/
USGS CARA Assessment Team, 2008, "Circum-Artic resource appraisal: estimates of undiscovered oil and gas north of the Arctic Circle", USGS Fact Sheet 2008-3049 (United States Geological Survey, Menlo Park, CA)
Verma M, White L, Gautier D, 2008, "Engineering and economics of the USGS Circum-Arctic oil and gas resource appraisal (CARA) project", US Geological Survey Open-File Report 2008-1193, USGS, Reston, VA
Wallace H, 1980 *The Navy, the Company, and Richard King: British Exploration in the Canadian Arctic, 1829 – 1860* (McGill – Queen's University Press, Montreal)
Young O, 2009a, "Whither the Arctic? Conflict or cooperation in the circumpolar north" *Polar Record* **45** 73 – 82
Young O, 2009b, "The Arctic in play: governance in a time of rapid change" *The International Journal of Marine and Coastal Law* **24** 423 – 442