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Less climatic resilience in the Arctic

James E. Overland

NOAA/Pacific Marine Environmental Laboratory, 7600 Sand Point Way NE, Seattle, WA, 98115, USA

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ABSTRACT

Twenty years ago the Arctic system was more resilient than now as sea ice was three times thicker than today. Heavier and more persistent sea ice provided a buffer against the influence of short-term climate fluctuations. Such recent increases in sea ice/atmospheric interactions lead to revisiting the concept of abrupt change. The Arctic climate is stabilized by a negative radiative feedback, as increased temperatures of the surface and atmospheric lose more long wave energy. However, through new shifts in albedo feedback, open ocean areas are absorbing more of the incoming solar heat. Recent multi-year environmental extremes, potential albedo instabilities, and increased sensitivity of sea ice to storms in marginal seas, are overcoming negative radiative feedback, which point to passing impending climatic and ecosystem thresholds. Unless CO_2 emissions are reduced, further Arctic extremes are expected in the next decades with environmental and societal impacts spreading through the Arctic and beyond.

1. Introduction

The sequence of exceptionally low sea ice during winter 2018 and 2019 in the Bering Sea, and the recent occurrence of other large Arctic events such as the 38 °C Siberian heat wave in June 2020, lead to revisiting the concept of abrupt changes. Further transitions are suggested by chaos theory: evidence that a threshold event is nearing is based on all-season decline of sea ice and its transition to predominantly thin first-year ice, consistently warmer ocean and record air temperatures, increased variability, and increased sensitivity of the ocean-ice environment to weather in the marginal seas (Wagner and Eisenman, 2015; Graham et al., 2017). In 2018 such events caught the public's attention with reports of wintertime temperatures warming to near the freezing point at the North Pole. Wind-driven northward advection of atmospheric heat and moisture, which increase downward long wave radiation, delayed sea ice freeze-up. Southerly winds led to unprecedented absence of sea ice in the Bering Sea, the Barents Sea, near Svalbard, and a large loss event north of Greenland, thus providing a positive feedback to warming by dynamic and thermodynamic Arctic process. Many of these physical mechanisms that amplify extremes are recognized as unique to the Arctic. Atmosphere/sea ice interactions provide a mechanism for accelerating Arctic change.

It is difficult to predict abrupt transitions from empirical data (Moore, 2018; Lenton and Rockstrom, 2019). In these situations, when data are almost by definition insufficient, scientists generally err on the conservative side (Oppenheimier et al., 2019). As Oreskes et al. (2019) wrote “Many scientists consider underestimates to be “conservative,” because they are conservative with respect to the question of when to sound an alarm or how loudly to sound it. The logic of this can be questioned, because underestimation is not conservative when viewed in terms of giving people time to prepare.” Now, in the Arctic for more than two decades, we have been reporting negative tendencies in multiple climate indicators, not only regarding sea ice but across northern ecosystems (AMAP, 2017; Post and Alley, 2019; Arctic Reportcard, 2019). During this period several ‘surprising’ extremes were observed, like record Arctic sea-ice minima, Greenland melt, and ecosystem shifts.

A case can be made for a warning based on current sea ice and air temperatures beyond previous bounds and a cascade of impacts that follow through the ecosystem, given a continuing CO_2 increase (Hansen, 2020). No one should be surprised any longer when extreme events occur in the Arctic. They will continue with greater frequency than any time on record (Schweiger et al., 2019). Livelihoods and lifeways, and billion-dollar industries, will certainly be disrupted – as they already are in many communities across the north. One is not sure how to interpret new climate and ecosystem extreme events beyond previous experience (Overland et al., 2012; Thoman et al. 2019). Is it part of a previous climatology or a newly evolving one? These events have long been anticipated and have occurred faster than projected by models (Wang et al., 2018; Overland et al., 2019; Notz and coauthors, 2020). Sea-ice melt shows a wide range in model results. Models do not have all important feedbacks such as permafrost, and the jet stream in models do not resolve atmospheric regional blocking that is critical to heat

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E-mail addresses: james.e.overland@noaa.gov, james.e.overland@noaa.gov.

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transports. Such guidance puts one on alert for possible abrupt changes that further impact Arctic systems. A hypothesis is that Arctic change will occur sooner than projected by models, e.g. future summer sea ice loss by 2050 (Notz and coauthors, 2020). Although there is no proof for the timing of abrupt Arctic changes, there is a consilience of evidence for reduced resilience to change: multiple new Arctic extremes-heat waves, sea ice loss, unique Arctic processes such as sea ice/storm interactions, permafrost melt, albedo shifts, and ecosystem reorganizations.

2. Results: current state of the arctic

2.1. Sea ice

The varying condition of the Arctic sea ice over time is a measurable integration of factors that influence its growth, extent, and diminishment. For this reason, it is accepted as a bellwether of climate change. Fig. 1 shows the decadal shift to loss of multi-year sea ice, shown in red, in the Arctic based on satellite observations (Kwok, 2018). The shift from old to young, thin sea ice is dramatic over a relatively short period, a decade and a half (Perovich et al., 2018). Sea ice loss has occurred in both winter and summer and is unique in scale since 1901 (Schweiger et al., 2019). Arctic winter sea ice maxima for four recent years were all less than all previous years (Overland et al., 2019); although there was a rebound in 2019. Arctic warming has interrupted sea ice formation and the transpolar sea ice drift (Krumpen and coauthors, 2019). While the extent of summer sea ice is decreasing over the last two decades, a startling development is lower sea ice concentrations within the summer ice pack itself in recent years. Lower sea ice concentration implies greater area for solar absorption of heat and increased sea ice mobility, as noted by the drift of the 2020 MOSAiC Arctic drift experiment. If such decreased concentrations and thinning of sea ice continues, might summer sea ice wink out all at once in a near future late summer (Pistone et al., 2019)?

2.2. Air temperatures

Multi-year persistence can indicate an exceedance of a threshold of change. The previous five years of annual Arctic land temperatures north of 60° N each exceeded previous records (Overland et al., 2018). Rates of annual temperature increase in the Arctic are more than twice the global average. Both winter 2016 and 2018 had extensive Arctic areas with near-surface air temperature anomalies of >6.0 °C, almost twice as large as previous anomalies (1981–2010 climatology). Fig. 2 shows 2017–2018 annual near surface air temperature anomalies. Note the warm temperatures near Bering Strait and in northern Barents Sea; regions of seasonal sea ice loss.

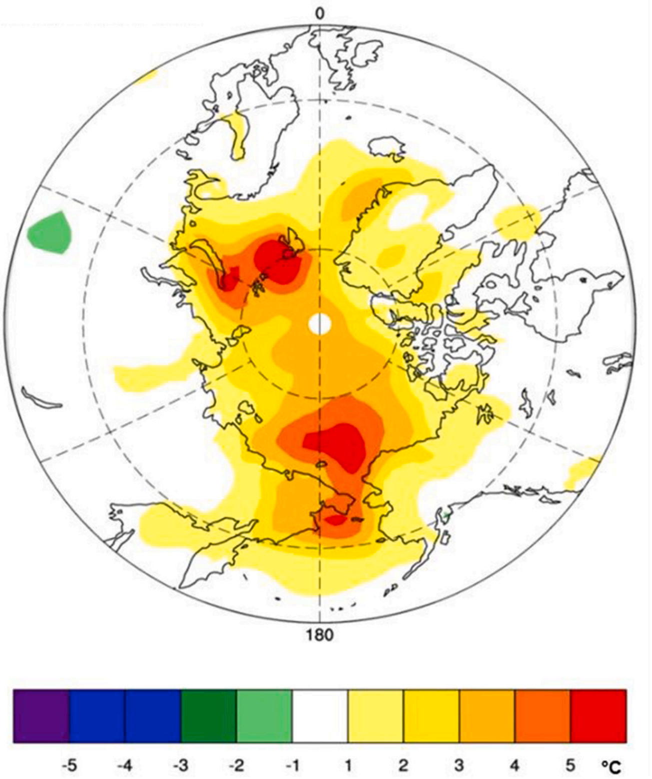

Fig. 2. Annual air temperature anomalies (1981–2010 baseline) for the Arctic October 2017 through September 2018. Values peak over 5 °C. Note the extremes over the marginal seas of the Barents and Kara Seas and north and south of Bering Strait. The pattern signature is primarily from winter. Data from NCEP/NCAR Reanalysis.

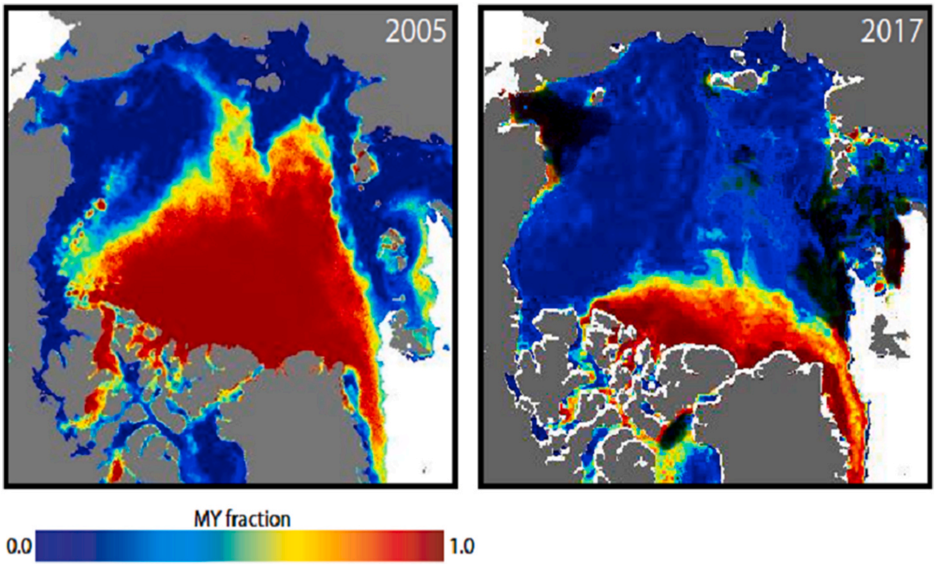

Fig. 1. Decadal decline in January multiyear Arctic sea ice coverage from the QuikSCAT (1999–2009) and ASCAT (2009–2018) satellite-based scatterometers. Old multi-year sea ice (red) is tracked by lower salinity. Multi-year sea ice now covers less than one-third of the Arctic Ocean. Seasonally formed sea ice (blue) is now the dominant ice type. After Kwok (2018). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

2.3. Winter and spring 2018 and 2019 Bering Sea

The Bering Sea historically grows sea ice from November through March through freezing and advection of ice southward by northerly winds. Such a pattern was broken during 2018 and 2019 (Fig. 3) with a decrease in ice area into February and March. The year 2019 was the first time in the 53-year record of hydrographic profiles (beginning 1966) on the Bering Sea shelf that show six years in a row of higher-than-average temperatures on the shelf (Danielson, personal communication, 2020). The Bering Sea has seen extremes in both directions; 2012 had maximum extents. These positive and negative extremes occurred in the last decade during the period of Arctic change.

The proximate cause of the 2018 and 2019 events was the movement of the stratospheric polar vortex and the tropospheric jet stream off of its more normal center over the North Pole to a location over Greenland (Fig. 4). In this figure the jet stream, at about 1/3 up in the atmosphere (700 hPa level) with strong winds that follow the purple/blue colors in a wavy pattern, bring warm air from the south over the Bering Sea and cold air into eastern North America. Winter 2018 showed a similar wavy jet stream pattern. More typical years such as 2017 and before, and 2020, show a more west-to-east zonal jet stream pattern located to the south of Alaska, allowing a more climatological winter sea ice growth in the Bering Sea (Fig. 3). The movement of the jet stream is considered chaotic and random, despite Arctic changes (Woollings and coauthors, 2018). The combined thinning of sea ice and chaotic weather extremes provide a new overall sea ice loss mechanism in the Bering Sea.

The year-to-year (2012) and within season (January 2018 versus 2019 and the large drop in April 2020) Bering Sea sea ice variability suggest a strong and new weather impact on thin, mobile sea ice. Winter 2012 Bering Sea sea ice maximum contrasts with the 2012 record low summer minimum in Arctic-wide averaged sea-ice extent, further noting regional and temporal differences related to weather/sea ice interaction in marginal seas. Increases in variability in sea ice and ecosystem responses to atmospheric circulation can be an indicator of regime change, as discussed further in section 3.

The risk of ecosystem reorganization is high for the Bering Sea (Britt et al., 2019; Duffy-Anderson et al., 2019). In previous "normal" years the southward advance of sea ice established a bottom layer ocean "cold pool," because of increased upper ocean stratification due to sea ice melt. The cold pool favored preferred prey for the large pollock fishery, and was lacking in 2018 and 2019 (Stabeno and Bell, 2019). Lack of sea ice changes the environment for the entire food chain. Large zooplankton (euphasids), the preferred food for pollock, are associated with relatively cold and ice-covered conditions (Duffy-Anderson et al., 2019). In 2019 walleye pollock and Pacific cod together comprised 36% of the fishery biomass in the northern Bering Sea (Britt et al., 2019); these fish together accounted for only 2% of the northern biomass in 2010.

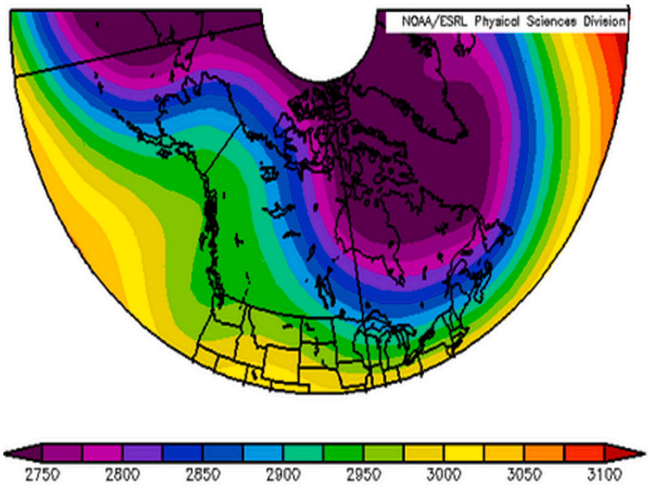

Fig. 4. 700 mb geopotential height for February–March 2019 showing a wavy jet stream (purple/blue) that supported southerly winds and no sea ice growth in the Bering Sea. NCEP/NCAR Reanalysis data plotted from NOAA ESRL/PSD website. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

The subsistence harvest of many native communities across Alaska and 40% of the commercial catch of fish and shellfish in the United States (currently valued more than $1 billion annually) are potentially hardest impacted (https://www.alaskaseafood.org/industry/seafood-market-info/economic-value-reports). Ice-dependent seals and walrus have lost their platform for resting and breeding. There have been warm-water driven toxic algae blooms, and seabird die-offs (Graham et al., 2017; personal communication). While the future is uncertain, the occurrence of sea ice loss in 2018 and 2019 is earlier than projected by models (Wang et al., 2018), and societal anticipation is necessary to respond to potential impacts of a repeat of 2018 and 2019. One should not be surprised to see a sequence of shocks on the time-scales of ecosystem response in less than a decade (Thoman et al. 2019; Stabeno and Bell, 2019). Subarctic fisheries are vulnerable to ecosystem

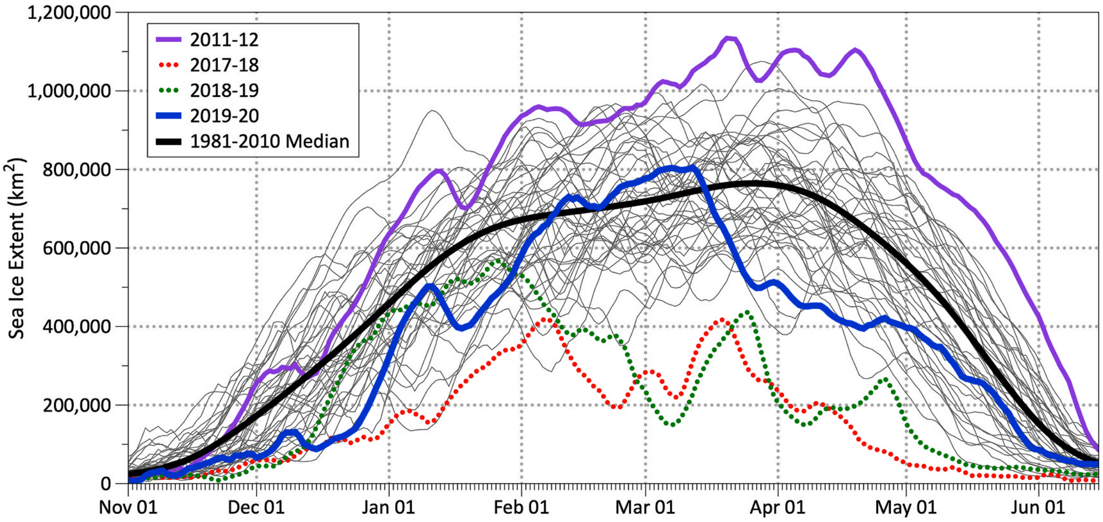

Fig. 3. Winter sea ice evolution in the Bering Sea. Low sea ice in winter 2018 and 2019. From R. Thoman and Bhatt, 2019, personal communication, data from National Snow and Ice Data Center (NSIDC).

reorganization in the Bering Sea (Graham et al., 2017), and harbinger of what is to come in the wider Arctic if the planet stays on the current CO_2 emissions path (Lewis et al., 2020).

2.4. North atlantic events

In 2018 unusual meteorological events caught the public's attention with reports of wintertime temperatures warming to near the freezing point at the North Pole. Several recent Arctic warm events such as 25 February 2018 (Fig. 5) were caused by advection of heat and moisture into the Arctic across the marginal sea ice zone on an Atlantic atmospheric pathway. Northward temperature advection increases downward long wave radiation, delayed sea ice freeze-up along the trajectory, and thus provides a positive feedback that maintained record high temperature events (Binder et al., 2017; Cullather et al., 2016; Kim et al., 2017; Rinke et al., 2017). Winter 2016, 2018 are examples where year-to-year and intra-seasonal variability in jet stream meanders (dynamics) combines with persistent Arctic thermodynamic changes to result in new extreme Arctic weather events. The Barents Sea has reached a "tipping point" (Lind et al., 2018). Loss of sea ice has shifted the Barents Sea from acting as a buffer between the Atlantic and Arctic oceans to something closer to an arm of the Atlantic. As in the Bering Sea, the Barents Sea shows the connection between sea ice loss, atmospheric circulation, warming temperatures, and ecosystem impacts (Isaksen et al., 2016; Lone et al., 2019).

3. Discussion: mechanisms

An abrupt change is simply defined as faster than expected changes in the Arctic over the next decades *relative to continued increasing CO_2 forcing* (Bathiany et al., 2018). Previously, heavier and more persistent classes of sea ice provided a buffer against the influence of short-term climate fluctuations. Of importance for the future of Arctic climate relative to other global areas is the destabilizing influence of sea ice feedback due to the large sea ice/open water albedo discontinuity adding more heat to the ocean (Zhang et al., 2019; Pistone et al., 2019), and more susceptibility to wind events (Overland et al., 2014; Screen and Deser, 2019).

Recent observations and existing theory for rapid environmental transitions overlap (Corti et al., 1999; *Chekroun* et al. *2011;* Moore, 2018; Bathiany et al. 2016; Livina and Lenton, 2013). Observed increases in extremes of both positive and negative values could be a precursor for change as suggested by theory, such as sea ice free regions in summer, large first year sea ice coverage during winter, and positive and negative sea ice extremes in the Bering and Barents Sea, as well as ecosystem responses (Onarheim et al., 2018). Increased variability in Arctic atmospheric circulation has also been noted (Overland and Wang, 2015). Rather than projecting a smooth trajectory for the state of climate change of the Arctic over the next 30 years, as often simulated in climate models (Barnes and Polvani, 2015; Bathiany et al., 2016a; Cai et al., 2018), current conditions of thin sea ice and atmospheric variability do not rule out a more rapid transition within the next two decades (Screen and Deser, 2019; Pistone et al., 2019). Impacts on the marine environment are seen in the collapse of fisheries, seabird and mammal populations, and subsequent restructuring of ecosystems (Hutchings, 2000; Rice, 2006; Britt et al., 2019). Current multiple environmental signs (consilience) imply that an Arctic abrupt change is more approachable compared to 30 years ago when thick sea ice provided a multi-year climate buffer to large excursions of the atmosphere and ocean (Box et al., 2019).

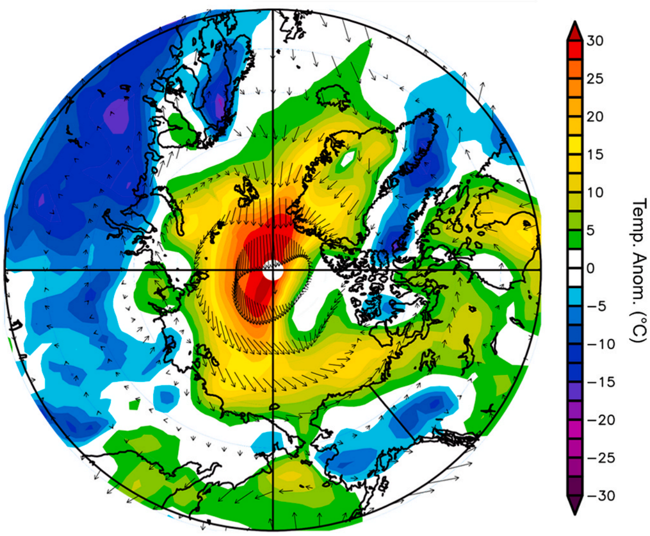

Fig. 5. Composite 2 m air temperature anomaly (1981–2010 baseline) and 1 000 hPa vector winds on 25 February 2018. Winds favorable to warm advection are associated with warm temperature anomalies of 15–30 °C. Temperatures at Cape Jessup, northern Greenland were +6 °C. Data from the NCEP/NCAR Reanalysis.

Of importance for the future of Arctic climate relative to other global areas is the destabilizing influence of sea ice feedback due to the large sea ice/open water albedo discontinuity. Thorndike (1992) illustrates the overcoming of the negative longwave radiative feedback due to warming temperatures by sea ice loss albedo-related radiative changes. Summer Arctic surface will absorb enough downward long wave radiation increases due to global warming and Arctic amplification, to eventually balance winter long wave radiation loss. Moon and Wettlaufer (2017) conclude that an abrupt threshold exists when increasing global warming destabilize sea ice loss. Such an albedo instability threshold is further noted by recent climate models, that it is unlikely that September Arctic sea ice vanishes for a limited global warming of 1.5 °C (Niederdrenk and Notz, 2018; Screen, 2018); the probability of an ice-free Arctic is greater at a global warming of >2 °C (Jahn, 2018; Sigmond et al., 2018). Such a transition requires continued increase in forcing; relaxation of CO_2 forcing suggests that sea ice loss is reversible (Armour et al., 2011; Tietsche et al., 2011).

Crossing a threshold in the physical system will have extended ecological and societal impacts. Abrupt changes in Arctic ecosystems are potentially irreversible on human time scales (Lewis et al., 2020). Ecological systems often pass through a series of difficult to reverse changes, e.g. niche replacements, food web reorganizations, extinctions, which prevent a return to prior state. This is further augmented by converging anthropogenic pressures such as industrial fishing. Whether a food web would recover if sea ice recovers, depends on whether there was a prior shift in biogeography or population collapse. The collapse and non-return of the eastern North American cod stocks are a warning (Hutchings and Reynolds, 2004; Rice, 2006; Meng et al., 2016). Although this loss included overfishing, a key lesson was that the ecosystem transitioned to another state. Subarctic fisheries, including the Bering Sea, are vulnerable to ecosystem reorganizations (Overland and Alheit, 2010; Duffy-Anderson et al., 2019; Britt et al., 2019; Hollowed and coauthors, 2020).

The foregoing section shows examples of new extreme observational sea ice and ecosystem conditions associated with extreme, but chaotic weather events. Thinning sea ice is ongoing, while the weather forcing is random (Overland et al., 2012; Thoman et al. 2019; Stabeno and Bell, 2019). That these events are newly evolving is reinforced when the change is accompanied by supporting information: sea ice/wind feedbacks, ecosystem shifts, and other major concomitant Arctic changes (AMAP, 2017). The sign of change is toward warming; the future rate will likely be unprecedented. Such guidance puts one on alert for possible abrupt change that further impacts Arctic systems. An appropriate response is vigilant surveillance.

4. Conclusion

The two marginal seas of the Bering and Barents are harbingers of what is to come in the wider Arctic if society stays on the current emissions path. Risks are associated with expensive losses in the fisheries along with concerns over food-supply and food security for coastal communities.

Traditional life-ways are already threatened. Where environmental prediction is not precise, potential economic costs are high, and impacts range across global economic and security interests.

Given the current rate of global CO_2 increases and the new climate trajectory away from the previous glacial–interglacial limit cycle (Steffen et al., 2018), sea ice albedo instability will eventually overcome the long wave radiation negative feedback within the next decades, suggesting abrupt change. Such a conclusion is supported by current year-to-year persistence in monthly extreme Arctic air temperatures, heat waves and wild fires, decreases in winter sea ice, summer low sea ice concentration (Kwok, 2018; Krompen et al. 2019), occurrence of sea ice/storm interactions, and fisheries and ecosystem shifts in Arctic marginal seas.

The Arctic holds unique internal feedbacks. The difficulties in specifying the conditions leading to multi-process environmental extremes provide uncertainty in timing (Overland and Alheit, 2010; Bathiany et al., 2016b). Multiple observed shifts of the Arctic cryosphere and chaos theory suggest a loss of resilience to major changes–more mobile, thin sea ice compared to previous, old thick sea ice, and impacts cascading through ecosystems. Results from recent climate models show major sea ice loss for approaching global temperature increases of >2.0 °C. It is better to plan for the Arctic to cross a threshold rather than base adaptation on model projections of steady change over three decades. Such a concern supports enhanced climate/ecosystem surveillance using advanced methods, autonomous systems, and real-time data. Manage the unavoidable to avoid the unimaginable.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.wace.2020.100275.

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