atmosphere

Commentary

Arctic Climate Extremes

James E. Overland

NOAA/Pacific Marine Environmental Laboratory, Seattle, WA 98115, USA; james.e.overland@noaa.gov

Abstract: There are multiple extreme events underway in the Arctic that are beyond previous records: rain in Greenland, Alaska weather variability, and ecosystem reorganizations in the Barents and the northern Bering Sea associated with climate change and sea-ice loss. Such unique extreme events represent a philosophical challenge for interpretation, i.e., a lack of statistical basis, as well as important information for regional adaptation to climate change. These changes are affecting regional food security, human/wildlife health, cultural activities, and marine wildlife conservation. Twenty years ago, the Arctic was more resilient to climate change than now, as sea ice had a broader extent and was three times thicker than today. These new states cannot be assigned probabilities because one cannot a priori conceive of these states. They often have no historical analogues. A way forward for adaptation to future extremes is through scenario/narrative approaches; a recent development in climate change policy is through decision making under deep uncertainty (DMDU).

Keywords: Arctic; climate change; extreme events; community adaptation; Bering Sea; Atlantification

check for updates

Citation: Overland, J.E. Arctic Climate Extremes. *Atmosphere* **2022**, *13*, 1670. https://doi.org/10.3390/atmos13101670

Academic Editors: Brian Odhiambo Ayugi, Victor Ongoma and Kenny T.C. Lim Kam Sian

Received: 18 September 2022
Accepted: 10 October 2022
Published: 13 October 2022

1. Introduction

Arctic extremes are increasing and are often record-shattering [1–3]. Compared to twenty years ago, the Arctic is now less resilient to climate change, as sea ice is more mobile, has a reduced extent, and is a third of its former thickness. These three factors lead to increased atmosphere/sea ice/ocean interaction. It is difficult to interpret the importance of an extreme event that has not occurred before [4], and approaching such a difficulty is the purpose of this paper, both for the Arctic and beyond. It is far from obvious how to even pose the question since nearly every extreme event is unique compared with previous data. Climate change is by definition statistically non-stationary. Moon et al. [5] note the expanding footprint of rapid Arctic change. Landrum and Holland [6] conclude that the Arctic is already transitioning away from a cryosphere-dominated system. Taken together (consilience), the examples here of multiple types of extremes are a major indicator of current rapid Arctic change relative to trends in single variables such as increasing temperatures.

2. Discussion

2.1. Sample List of Unusual Events

Reports on the ground are an important source of information. The 2017–2022 records from the Local Environmental Observer (LEO) Network are provided by a solicited group of observations from local residents, news articles, and topic experts, who share knowledge about unusual animal, environment, and weather events in the Arctic. LEO maintains a database that is searchable based on the type of event and impact. In 2015 the LEO Network was selected as a model program of the Arctic Council to raise awareness and improve communication about climate change in the circumpolar region. From entries for 2017–2022, here are the distribution of unusual events north of 60° N (Figure 1). Temperature extremes, snow and sea-ice changes, and shifts in seasonality are the most frequently reported. Ecosystems are impacted by changes in species range and animal die-offs.

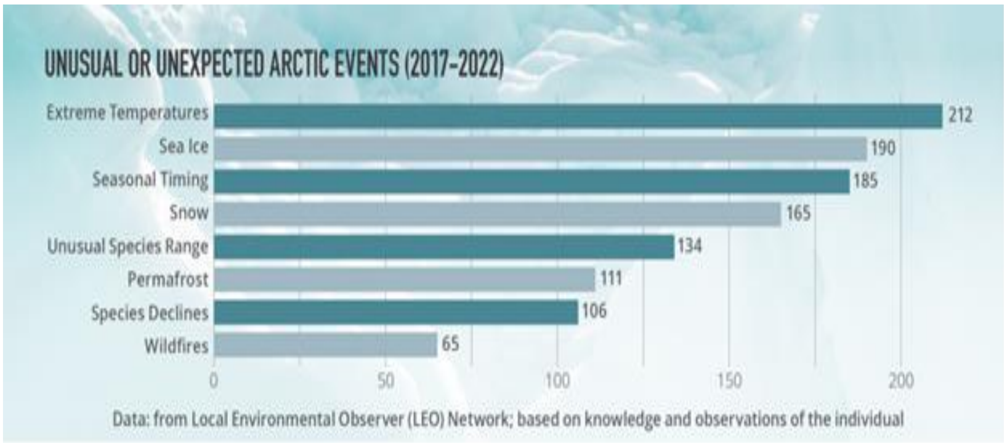

Figure 1. Unusual or unexpected Arctic events from the Local Environmental Observer (LEO) database.

2.2. Probabilistic Reasoning and Radical Uncertainty

The term extreme is understood in one of two ways. The first is as a statistical extreme that is defined in terms of known rareness. The second is in terms of previously unknown events.

One pole of uncertainty is resolvable based on stationary probability distributions. Formally, the distribution can be generated from historical data or model simulations. Such a figure for the impact of climate change is shown from the US National Academies Report, *Attribution of Extreme Weather Events in the Context of Climate Change* [7]. Climate change can have different effects on the probability of extreme values of the distribution. For example, in Figure 2a, a simple shift of the entire distribution toward a warmer climate leads to fewer extreme cold weather events and more hot weather and extreme hot weather events. Alternatively in Figure 2b, increased temperature variability without a shift in the mean could lead to more extreme cold and heat events, with lower probability of mid-range temperature events.

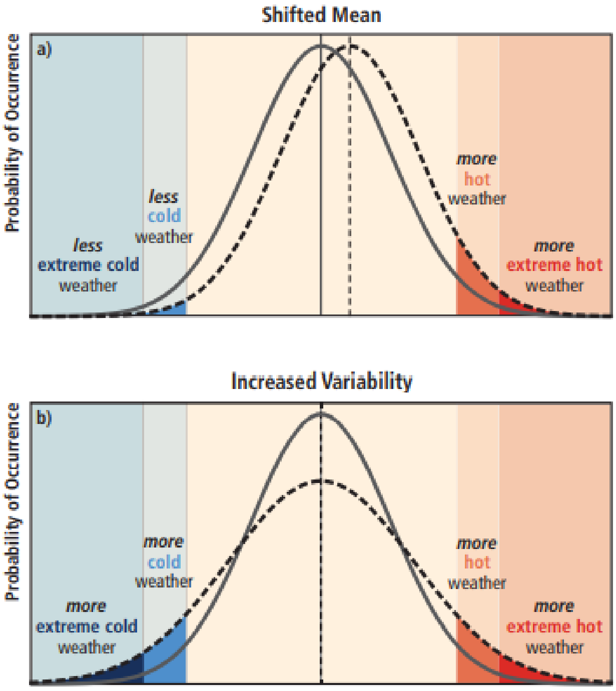

Figure 2. This probability density function captures the likelihood of specified events resulting from a given temperature distribution and its changes. As with any bell curve, those events that fall near the center are most likely, and events that occur in lower and upper temperature extremes have smaller probability. (**a**) a shift in the mean; (**b**) a shift in the varience [7].

Using this approach, marine heat waves were described for the Arctic during 1982–2020 using three criteria and three independently produced daily sea surface temperature (SST) products (Figure 3) [8]. The primary source was the NOAA DOISST v2.1 that is a global daily SST product with a resolution of 0.25° that blends in situ and bias-corrected advanced very high resolution radiometer (AVHRR) SST measurements. The criteria were (a) SST anomalies are higher than the 95th percentile threshold based on 1982–2011 period, and (b) the high anomalies are sustained for at least five consecutive days. Their analyses indicated that the intensity, duration, frequency, and areal coverage of Arctic marine heat waves increased during 1982–2020, and were greater in recent decades due to a warming climate. The maximum SST extremes are between 3 °C and 5 °C in the Barents Sea, Kara Sea, Laptev Sea, East Siberian Sea, Chukchi Sea, Beaufort Sea, and Baffin Bay, and between 3 °C and 4 °C in the Norwegian Sea and the Greenland Sea. These events were triggered in mid-July to early August from 1982 to 2020; they endured until mid-August during 1982–2000, until early September during 2000–2010, and until late September during 2010–2020.

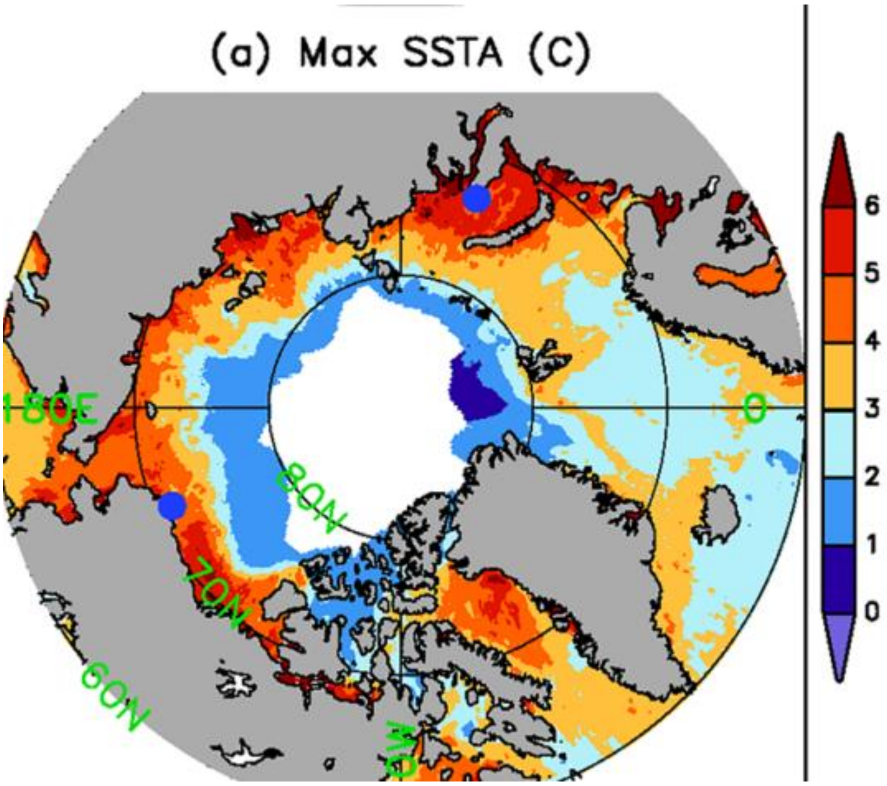

Figure 3. Maximum (1980–2020) sea surface temperature anomaly (SSTA in °C), derived using the 95th percentile threshold [8].

At the opposite pole from true randomness are genuinely unknown unknowns. These are states to which one cannot attach probabilities because one cannot a priori conceive of these states. These are not low probability events, but unimaginable given previous data. There are often no historical analogues. They are not likely to be the result of a long tail event arising from a very low probability outcome from a known frequency distribution, e.g., a black swan, but as a result that was not previously expected.

For more than a half century the distribution approach has dominated decision science. The example in Figure 3 certainly brings awareness that Arctic change is underway. In fact, the statistical approach often does not conceivably have the information required to specify the distribution of extreme events, and consequences are uncertain. An alternative is to suggest positive outcomes and avoid outcomes that are worse. Many aspects of climate science are based on the extent of prior knowledge, and being comparatively data-poor in terms of what one is actually trying to predict. The observed record provides a limited sample of what is possible, and is, moreover, affected by sources of non-stationarity. In such a situation, using statistical methods that eschew physical reasoning and prior knowledge, "letting the data speak for itself", is a recipe for disaster [9].

2.3. Conceptual Model: Natural Weather Variability Interacting with Arctic Changes

A goal for research is to tie biological/societal impacts of environmental events with extreme weather events into joint causal accounts. Are there thresholds and tipping points of concern? A hypothesis is that new extremes are often forced by the interaction of atmosphere, ocean, and other Arctic changes, affecting ecosystems and communities. Fluctuations outside existing ranges often lead to detrimental impacts.

A conceptual model is shown in Figure 4 where global warming from greenhouse gases increases as an ongoing thermodynamic response in Arctic Amplification, AA, leading to temperature increases, permafrost thaw, and sea-ice loss/open water, a push [10]. These factors can combine constructively with the natural range of atmospheric and oceanic dynamics, a pulse, e.g., jet stream meanders, atmospheric blocking, weather patterns, storms, and upper ocean heat content [3,11]. AA provides precursors to major impacts. Atmosphere/ocean/sea ice interdependence produces new extremes. That new extremes do not apparently require atmospheric circulation deviations to be much beyond their normal range is a reason for the large number of different types of recent impacts and inter-annual and location variability of extreme events. These weather and climate extremes selectively influence ecosystems based on species-specific life history, such as the timing of reproduction and migration. Societal impacts on livelihoods and culture follow from sea-ice and ecosystem shifts.

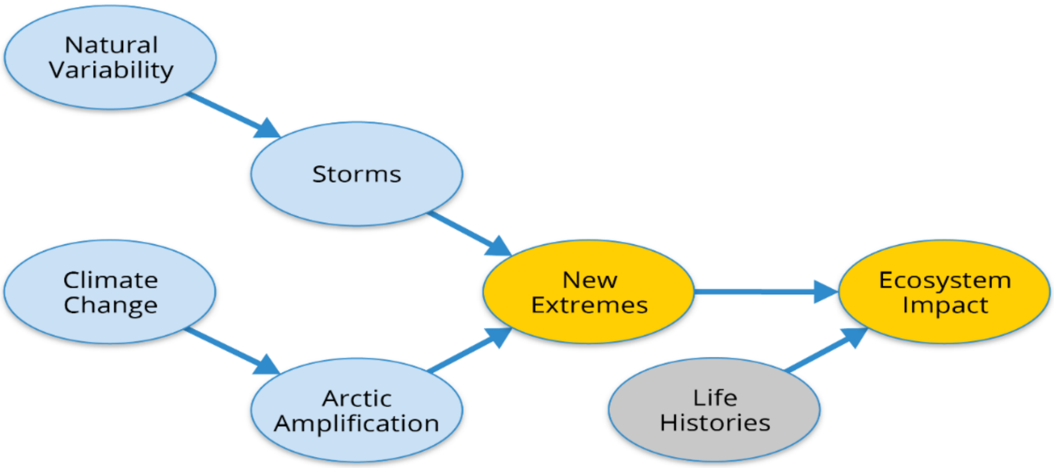

Figure 4. Conceptual model of extremes forced by atmosphere and ocean processes that interact with the ecosystem life histories.

3. Recent Arctic Examples of Extremes That go beyond Previous Records

A key point is that many of these examples show change that are well beyond previous records. Extrapolation of probabilities from previous obsevational distributions do not apply to the current and future climate change of the real world.

3.1. Greenland Rain

On 14 August 2021, rainfall was witnessed for the first time at Summit station near the highest point of the Greenland ice sheet [12,13] and was accompanied by high surface melt spatial extent. Satellite measurements reveal a rapid retreat of the snowline, exposing a large extent of relatively dark bare ice. Exceptional heating of the ice sheet occurred due to the heat transfer from condensation and the elevated air temperature during the August episode of warm air and rainfall arriving in what is termed an atmospheric river (AR). The frequency of moist ARs reaching Greenland is increasing [14], likely driven by high-amplitude wavy jet-stream patterns [15]. This Greenland extreme is an example of the application of Figure 4, AA combined with AR variability. August 2021 was followed by an unusually late, September 2022, heat wave that caused extensive melting across the ice sheet. This was the largest melt event ever to occur in September, according to data sets spanning nearly four decades.

3.2. *Alaskan Summer 2022 High Variability*

Total wildfire for Alaska reached 1 million acres as of 18 June 2022, the earliest date in the past 32 years of observation [16]. The two previous early dates, 1 July for 2004 and 2015, had the largest seasonal burn area suggesting that 2022 would continue to set records. However, drought conditions ended, with record rainfall. On 26 July Utqiaġvik had 1.42 inches rain, the highest 24-h precipitation on record (previous 1.32 inches 21–22 July 1987). Anchorage rainfall, at 7.24 inches from Mid-July to mid-August, was the highest on record, at three times the normal level [16]. The season ended with the strongest Bering Sea September storm of the last 70 years, a 940 mb low pressure with hurricane force winds.

3.3. *Arctic Snow Cover*

For the 5th year in a row, late spring (April–June) northern hemispheric snow cover extent in 2022 was smaller than the 1981–2020 average, in contrast to more than average amounts before 2005 (Figure 5) [17].

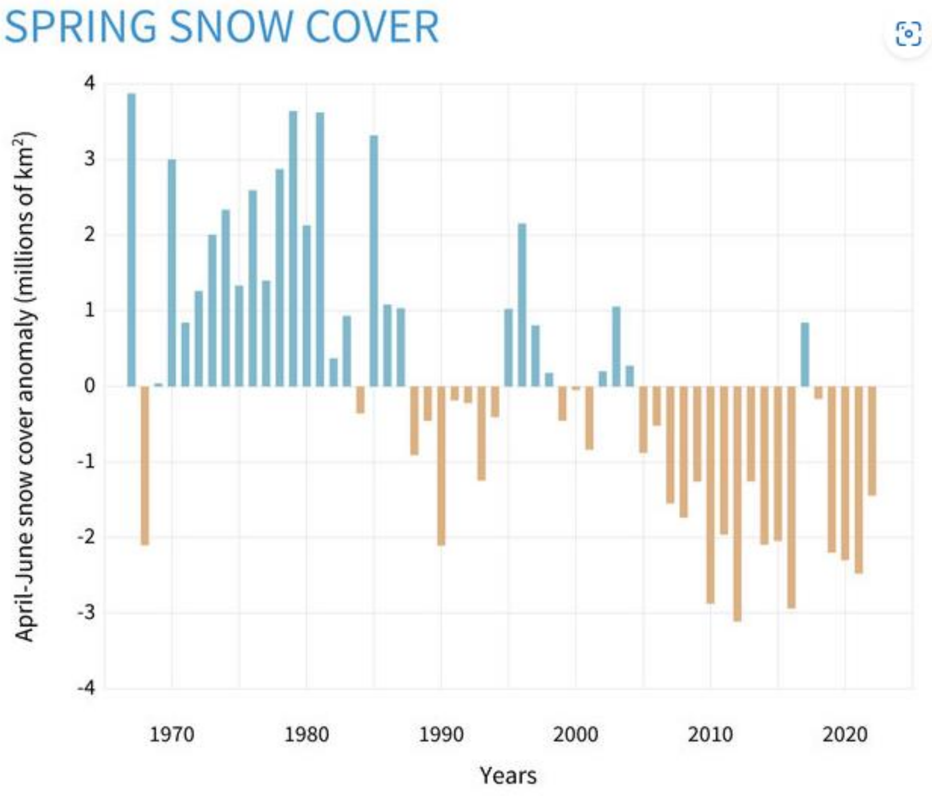

Figure 5. Spring (April–June) snow extent each year compared to the 1981–2010 average for the northern hemisphere. Years with above-average snow cover are blue-green, while years with below-average snow cover are brown. Graph by NOAA Climate.gov, based on Rutgers Snow Lab data provided by Thomas Estilow.

3.4. *Barents Sea Extreme Temperatures and Atlantification*

Isaksen et al. [18] find unprecedented increase in annually averaged 2001–2020 surface air temperature (SAT) over the northern Barents Sea of 5.4 °C at Karl XII-øya on northeastern Svalbard and 4.4 °C at Krenkel Observatory on Franz Josef Land. Both locations had even larger values in autumn (SON) and winter (DJF). The warming is greater than hitherto known in this region and is exceptional even for the warming Arctic. The average June 2022 temperature at Svalbard airport Longyearbyen was 6.0 °C, which is 2.4 °C above average and the warmest ever recorded. The warming is linked, in both space and time, to the reduction of sea ice and increased SST; there is a negative correlation between SAT and sea-ice at multiple stations of −0.94 in autumn and −0.97 in winter. The northern Barents Sea highlights high temperatures of the twenty-first century, with a warming rate that is greater and longer lasting than during the early 20th-century warming [19]. Figure 6 shows the spatial distribution of the annual rate of change for the Barents Sea over 2001–2020 for two reanalyses of SAT, sea-ice loss, and SST increase [18]. Changes in SAT and sea ice are largest over the marginal ice zone north of the ice edge contour in grey.

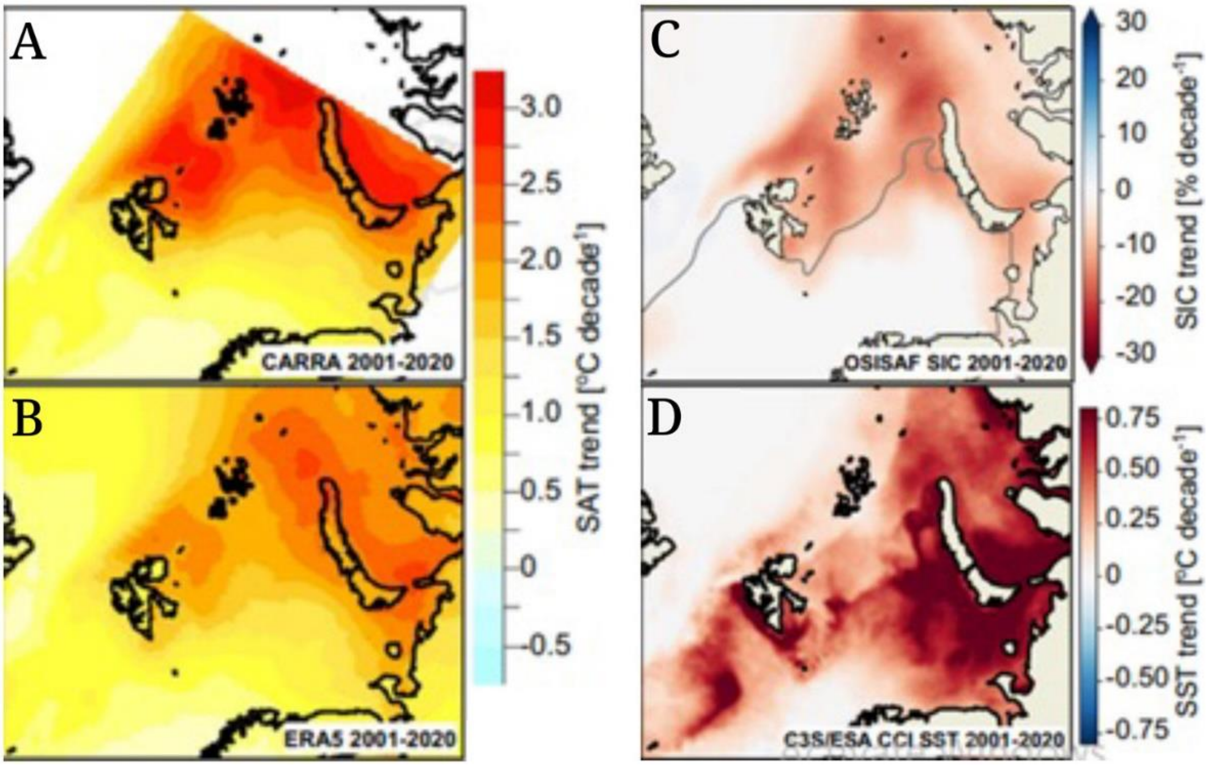

Figure 6. The spatial pattern of changes in surface air temperature, sea ice, and sea surface temperature (SST) trends in the Barents study area for 2001–2020. (**A**,**B**) Annual SAT trends (°C/decade) derived from CARRA and ERA5 reanalyses. (**C**) Annual trends in sea ice coverage (SIC) (%/decade) with mean 15% SIC (ice edge) contour line marked in grey. (**D**) presents the annual SST trends (°C/decade).

A factor for warm temperatures in northern Svalbard was the increased presence in these decades of low sea level pressure over the central Barents Sea that cause easterly warm winds to the north of the low pressure center. Extreme Svalbard temperatures from joint sea-ice loss and strong wind location is an example of applying the combination of AA and weather systems as in Figure 4. Northeastly atmospheric wind circulation contributes most to extreme warming [20]. Meteorological conditions lead to rain-on-snow events in Svalbard [21]. The cumulative sea-ice melting across Svalbard between 1 June and 31 July 2022 was 1.5 times larger than the previous record from 2018. For 1 May through 25 July 2022, parts of the archipelago saw air temperatures that averaged up to 1.8 °C higher than average. A significant pulse of warm air starting on 15 July produced Svalbard's highest recorded melt volume on 17 July. Temperature measurements taken at Svalbard Airport from June, July and August show that the Arctic archipelago went through a record hot summer during 2022.

The major increase in SST is in the eastern Barents Sea and the northward coastal current on the west coast of Svalbard, the two branches of the Norwegian Atlantic Current. This is an indication of the Atlantification of the Barents Sea, a transition from more Arctic Ocean properties to those of the inflowing Atlantic waters. A strong warming, up to 0.8 °C per decade, occurred in the southeastern region just outside of the mean sea-ice zone. Atlantification is the regional increasing influence of warmer and saltier Atlantic water [22]. The warming of the surface water causes a retreat in sea-ice in winter and an absence of sea-ice in summer. The loss of winter sea-ice means that the cold freshwater layer from melting sea ice in summer at the surface is not replenished. This causes a weaker difference between the upper layers in the ocean and stronger mixing of Atlantic water. Transition to Atlantification across the Barents Sea is almost complete [23], and there are ecosystem consequences. Barents Sea phytoplankton blooms have moved 5° latitude further north compared to 1989 [24]. Fish communities are moving northward with an influence on sea birds, seals, and whales that depend directly on the fish populations [25,26].

3.5. Community Observations of Continuing Extreme Events in the Northern Bering Sea

Unprecedented minimum winter sea-ice coverage occurred in the Bering Sea during 2017/2018 and 2018/2019, occupying 70% less area than the climatological mean since 1950, with major impacts on ecosystem dynamics, and human food security and human/wildlife health, lasting through 2022 [27]. Ecosystem impacts were immediately observed including multi-year changes in ecosystem energy flow and structure, harmful algal blooms, loss of sea-ice algae and large lipid-rich zooplankton, loss of commercially fished crab, northward expansion of commercially fished Pacific cod and Alaskan pollock, reductions of all species of northern salmon runs, an Unusual Mortality Event for three species of ice-associated seals [28], and five consecutive years of multi-species seabird mortality.

In the northern Bering Sea/Bering Strait region, the non-commercial acquisition and utilization of diverse marine wildlife are essential to the nutritional, cultural, and economic well-being of coastal communities (Figure 7) [29,30]. The recent regional reduction in the duration, extent, and quality of sea ice continues to cascade into an ecosystem transition based on newly arrived cod predation on lower trophic levels, resulting in widespread concern by coastal residents. Additional concerns beyond sea-ice loss impacts are geographical distributional shifts of marine species such as Stejneger's beaked whale, the establishment of invasive species such as Hanasaki crab, and toxic algae in pinniped and cetaceans at levels that indicate potential health concerns. Recent changes represent an ecological shock; no coastal community remains untouched by the suite of changes.

Figure 7. Examples of diverse non-commercial marine resources essential to the nutritional, cultural, and economic well-being of coastal communities in the northern Bering Sea/Bering Strait region. From left to right: sculpin, walrus, and clams from the walrus' stomach.

3.6. Arctic Acidification

Qi et al. [31] found that this sea-ice loss in the western Arctic Ocean is causing more uptake of atmospheric carbon dioxide by surface water and driving acidification at a rate three to four times higher than that of the other ocean basins. They attribute this finding to the increased open water area, ice-melt-driven addition of freshwater, and resulting changes in seawater chemistry.

4. Concluding Remarks

4.1. Impact-Based Projections

The increase in unknown future conditions due to a lack of robust extrapolation does not mean that planning is less important. A way forward for adaptation to future extremes is through scenario/narrative approaches; a recent approach in climate change policy is through decision making under deep uncertainty, DMDU. DMDU is an adaptive method, defining specific risks, policy objectives, and evaluation criteria [32]. For example, proposed impacts on the ecosystem are extrapolated backwards through species life histories to identify causal factors (e.g., temperature, storms, sea ice, permafrost). Such impacts could include wildfires, flooding, ecosystem shifts, biological pests, change in snow, storm intensity, fisheries and marine mammals. DMDU inverts conventional deterministic planning approaches to emphasize identification of major impacts and then their causes with strategies that are adaptable and robust. Human impacts include concern for exposure and vulnerability beyond specification of ecosystem events.

4.2. A changing Arctic

Implementing successful conservation for the climate-altered future Arctic requires proactive application of emerging adaptation approaches. Futures must be assumed different from what has been experienced [9,33–35]. Expectations are for social and ecological change, requiring monitoring and balancing risks and opportunities. A fundamental necessity is an understanding of ecosystem community turnover and goals based on stakeholders' values. Maintaining processes that generate heterogeneity in habitats, genes, and community structures should be prioritized [36]. Strategies that enable adaptation and change in species and ecosystems that minimize climate change impacts will happen at local to regional scales starting in the northern Bering Sea, Barents Sea, coastal Siberia, and parts of maritime Canada.

Multiple types of Arctic extreme events, which have not occurred before, are a major indicator of current rapid Arctic change, relative to trends in single variables such as increasing temperatures. I list several such extreme events that are underway, unique compared with previous data. They represent a philosophical challenge for interpretation, i.e., a lack of statistical basis, as well as being important information for regional adaptation to change. These examples of extremes beyond previous records result in ongoing changes that are impacting livelihoods and cultural activities in Arctic coastal communities, and weather for residents at lower latitudes [37].

Funding: This research was funded by NOAA/Arctic Research Program/GOMO.

Data Availability Statement: Not applicable, Figures are based on existing sources.

Acknowledgments: I appreciate discussions with B. Voss, G. Sheffield and E. Siddon of NOAA. This is PMEL contribution 5423.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Walsh, J.E.; Ballinger, T.J.; Euskirchen, E.S.; Hanna, E.; Mård, J.; Overland, J.E.; Tangen, H.; Vihma, T. Extreme weather and climate events in northern areas: A review. *Earth-Sci. Rev.* **2020**, *209*, 103324. [CrossRef]
2. Fischer, E.M.; Sippel, S.; Knutti, R. Increasing probability of record-shattering climate extremes. *Nat. Clim. Chang.* **2021**, *11*, 689–695. [CrossRef]
3. Overland, J.E. Rare events in the Arctic. *Clim. Chang.* **2021**, *168*, 27. [CrossRef]
4. Diffenbaugh, N.S.; Singh, D.; Mankin, J.S.; Horton, D.E.; Swain, D.L.; Touma, D.; Charland, A.; Liu, Y.; Haugen, M.; Tsiang, M.; et al. Quantifying the influence of global warming on unprecedented extreme climate events. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 4881–4886. [CrossRef]
5. Moon, T.A.; Overeem, I.; Druckenmiller, M.; Holland, M.; Huntington, H.; Kling, G.; Lovecraft, A.L.; Miller, G.; Scambos, T.; Schädel, C.; et al. The expanding footprint of rapid Arctic change. *Earth's Future* **2019**, *7*, 212–218. [CrossRef]
6. Landrum, L.; Holland, M.M. Extremes become routine in an emerging new Arctic. *Nat. Clim. Chang.* **2020**, *10*, 1108–1115. [CrossRef]

7. National Academies of Sciences, Engineering, and Medicine. *Attribution of Extreme Weather Events in the Context of Climate Change*; The National Academies Press: Washington, DC, USA, 2016. [CrossRef]
8. Huang, B.; Wang, Z.; Yin, X.; Arguez, A.; Graham, G.; Liu, C.; Smith, T.; Zhang, H. Prolonged Marine Heatwaves in the Arctic: 1982−2020. *Geophys. Res. Lett.* **2021**, *48*, e2021GL095590. [CrossRef]
9. Shepherd, T.G. Bringing physical reasoning into statistical practice in climate-change science. *Clim. Chang.* **2021**, *169*, 2. [CrossRef]
10. Harris, R.M.B.; Beaumont, L.J.; Vance, T.R.; Tozer, C.R.; Remenyi, T.A.; Perkins-Kirkpatrick, S.E.; Mitchell, P.; Nicotra, A.; McGregor, S.; Andrew, N.R.; et al. Biological responses to the press and pulse of climate trends and extreme events. *Nat. Clim. Chang.* **2018**, *8*, 579–587. [CrossRef]
11. Zhang, R. Mechanisms for low-frequency variability of summer Arctic sea ice extent. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 4570–4575. [CrossRef]
12. Ramirez, R. Rain Fell at the Normally Snowy Summit of Greenland for the First Time on Record. *CNN*, 19 August 2021. Available online: https://edition.cnn.com/2021/08/19/weather/greenland-summit-rain-climate-change/index.html (accessed on 20 September 2022).
13. Box, J.E.; Wehrlé, A.; van As, D.; Fausto, R.S.; Kjeldsen, K.K.; Dachauer, A.; Ahlstrøm, A.P.; Picard, G. Greenland ice sheet rainfall, heat and albedo feedback impacts from the mid-August 2021 atmospheric river. *Geophys. Res. Lett.* **2022**, *49*, e2021GL097356. [CrossRef]
14. Mattingly, K.S.; Ramseyer, C.A.; Rosen, J.J.; Mote, T.L.; Muthyala, R. Increasing water vapor transport to the Greenland Ice Sheet revealed using self-organizing maps: Increasing Greenland moisture transport. *Geophys. Res. Lett.* **2016**, *43*, 9250–9258. [CrossRef]
15. Francis, J.; Skific, N. Evidence linking rapid Arctic warming to mid-latitude weather patterns. *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.* **2015**, *373*, 20140170. [CrossRef] [PubMed]
16. Thoman, R.; University of Alaska Fairbanks, Fairbanks, AK, USA. Personal communication, 2022.
17. Robinson, D.A. Northern Hemisphere continental snow cover extent in "State of the Climate in 2020". *Bull. Am. Meteor. Soc.* **2021**, *102*, S46–S47. [CrossRef]
18. Isaksen, K.; Nordli, Ø.; Ivanov, B.; Køltzow, M.A..; Aaboe, S.; Gjelten, H.M.; Mezghani, A.; Eastwood, S.; Førland, E.; Benestad, R.E.; et al. Exceptional warming over the Barents area. *Sci. Rep.* **2022**, *12*, 9371. [CrossRef]
19. Førland, E.J.; Benestad, R.; Hanssen-Bauer, I.; Haugen, J.E.; Skaugen, T.E. Temperature and Precipitation Development at Svalbard 1900–2100. *Adv. Meteorol.* **2011**, *2011*, 893790. [CrossRef]
20. Wickström, S.; The University Centre in Svalbard, Longyearbyen, Norway. Personal communication, 2022.
21. Jonassen, M.; The University Centre in Svalbard, Longyearbyen, Norway. Personal communication, 2022.
22. Polyakov, I.V.; Pnyushkov, A.V.; Alkire, M.B.; Ashik, I.M.; Baumann, T.M.; Carmack, E.C.; Goszczko, I.; Guthrie, J.; Ivanov, V.V.; Kanzow, T.; et al. Greater role for Atlantic inflows on sea-ice loss in the Eurasian Basin of the Arctic Ocean. *Science* **2017**, *356*, 285–291. [CrossRef]
23. Lind, S.; Ingvaldsen, R.B.; Furevik, T. Arctic warming hotspot in the northern Barents Sea linked to declining sea-ice import. *Nat. Clim. Chang.* **2018**, *8*, 634–639. [CrossRef]
24. Neukermans, G.; Oziel, L.; Babin, M. Increased intrusion of warming Atlantic water leads to rapid expansion of temperate phytoplankton in the Arctic. *Glob. Chang. Biol.* **2018**, *24*, 2545–2553. [CrossRef]
25. Fossheim, M.; Primicerio, R.; Johannesen, E.; Ingvaldsen, R.B.; Aschan, M.M.; Dolgov, A. Recent warming leads to a rapid borealization of fish communities in the Arctic. *Nat. Clim. Chang.* **2015**, *5*, 673–677. [CrossRef]
26. Griffith, G.P.; Hop, H.; Vihtakari, M.; Wold, A.; Kalhagen, K.; Gabrielsen, G.W. Ecological resilience of Arctic marine food webs to climate change. *Nat. Clim. Chang.* **2019**, *9*, 868–872. [CrossRef]
27. Thoman, R.L.; Bhatt, U.S.; Bieniek, P.A.; Brettschneider, B.R.; Brubaker, M.; Danielson, S.L.; Labe, Z.; Lader, R.; Meier, W.N.; Sheffield, G.; et al. The Record Low Bering Sea Ice Extent in 2018: Context, Impacts, and an Assessment of the Role of Anthropogenic Climate Change. *Bull. Am. Meteorol. Soc.* **2020**, *101*, S53–S58. [CrossRef]
28. Boveng, P.L.; Ziel, H.L.; McClintock, B.T.; Cameron, M.F. Body condition of phocid seals during a period of rapid environmental change in the Bering Sea and Aleutian Islands, Alaska. *Deep. Sea Res. Part II Top. Stud. Oceanogr.* **2020**, *181–182*, 104904. [CrossRef]
29. Huntington, H.P.; Zagorsky, A.; Kaltenborn, B.P.; Shin, H.C.; Dawson, J.; Lukin, M.; Dahl, P.E.; Guo, P.; Thomas, D.N. Societal implications of a changing Arctic Ocean. *Ambio* **2022**, *51*, 298–306. [CrossRef] [PubMed]
30. Brinkman, T.; Charles, B.; Stevens, B.; Wright, B.; John, S.; Ervin, B.; Joe, J.; Ninguelook, G.; Heeringa, K.; Nu, J.; et al. Changes in Sharing and Participation are Important Predictors of the Health of Traditional Harvest Practices in Indigenous Communities in Alaska. *Hum. Ecol.* **2022**, 1–15. [CrossRef]
31. Qi, D.; Ouyang, Z.; Chen, L.; Wu, Y.; Lei, R.; Chen, B.; Feely, R.A.; Anderson, L.G.; Zhong, W.; Lin, H.; et al. Climate change drives rapid decadal acidification in the Arctic Ocean from 1994 to 2020. *Science* **2022**, *377*, 1544–1550. [CrossRef]
32. Shortridge, J.; Guikema, S.; Zaitchik, B. Robust decision making in data scarce contexts: Addressing data and model limitations for infrastructure planning under transient climate change. *Clim. Chang.* **2017**, *140*, 323–337. [CrossRef]
33. Lloyd, E.A.; Shepherd, T.G. Environmental catastrophes, climate change, and attribution. *Ann. N. Y. Acad. Sci.* **2020**, *1469*, 105–124. [CrossRef]
34. van Beest, F.M.; Barry, T.; Christensen, T.; Heiðmarsson, S.; McLennan, D.; Schmidt, N.M. Extreme event impacts on terrestrial and freshwater biota in the arctic: A synthesis of knowledge and opportunities. *Front. Environ. Sci.* **2022**, *10*, 983637. [CrossRef]

35. Aoki, L.R.; Brisbin, M.M.; Hounshell, A.G.; Kincaid, D.W.; Larson, E.I.; Sansom, B.J.; Shogren, A.J.; Smith, R.S.; Sullivan-Stack, J. Preparing Aquatic Research for an Extreme Future: Call for Improved Definitions and Responsive, Multidisciplinary Approaches. *BioScience* **2022**, *72*, 508–520. [CrossRef]
36. Moore, J.W.; Schindler, D.E. Getting ahead of climate change for ecological adaptation and resilience. *Science* **2022**, *376*, 1421–1426. [CrossRef]
37. Overland, J.E.; Kim, B.-M.; Tachibana, Y. Communicating Arctic-midlatitude weather and ecosystem connections: Direct observations and sources of intermittency. *Environ. Res. Lett.* **2021**, *16*, 105006. [CrossRef]