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Super Climate Events

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Abstract: New environmental extremes are currently underway and are much greater than those in previous records. These are mostly regional, singular events that are caused by global change/local weather combinations and are larger than the impact of linear temperature increases projected using climate models. These new states cannot easily be assigned probabilities because they often have no historical analogs. Thus, the term super climate extremes is used. Examples are the loss of sea ice and ecosystem reorganization in northern marine Alaska, heatwave extreme in western Canada, and the loss of snow in Greenland. New combined extreme occurrences, which are reported almost daily, lead to a new, higher level of climate change urgency. The loss of sea ice in 2018–2019 was a result of warmer Arctic temperatures and changes in the jet stream. They resulted in a chain of impacts from southerly winds, the northward movement of predatory fish, and the reduction of food security for coastal communities. Record temperatures were measured in southwestern British Columbia following previous drought conditions, a confluence of two storm tracks, and warming through atmospheric subsidence. Greenland's losses had clear skies and jet stream events. Such new extremes are present indicators of climate change. Their impacts result from the interaction between physical and ecological processes, and they justify the creation of a new climate change category based on super climate extremes.

Keywords: climate change; extreme events; environmental impacts

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1. Introduction

New environmental extremes are currently underway and are greater than previous records. In analyzing these events, it is important to distinguish risk and radical uncertainty. For risks, one can assign probabilities, which are primarily calculated using historical data. For events that are greater than previous records, there is no firm scientific basis to form probabilities. They are not likely to be the result of a long-tail statistical event arising from a very low probability outcome from a known frequency distribution, e.g., a black swan. These new states cannot easily be assigned probabilities because they often have no historical analogs. Thus, the term super climate extremes is used. The definition of Super Climate events are those that appear beyond statistical extrapolation from previous data and may include new physical and/or biological processes.

Further, the combination of multiple super events leads to a new level of urgency. The examples here, and new cases that occur almost daily (e.g., Canadian wildfires and Antarctic sea-ice loss), taken together, lead to a unification of ideas in support of a global climate change. These super events are extreme, episodic, regional, have a limited duration, and comprise different types and mechanisms; yet, they can be represented by a single background causation. With additional external information, such as increasing greenhouse gases, one can predict the occurrence of future extreme events, but they are uncertain in their frequency, timing, location, and intensity. This is a world of uncertain futures and unpredictable consequences, which represents radical uncertainty. Projections are important speculations based upon "what if" scenarios.

Climate change is often reported as temperature increases of several degrees by the mid-century, which are calculated using climate models. These models can miss the complicated interaction of physical and ecological processes due to a lack of spatial resolution. A specific issue is modeling a regional wavy jet stream that can initiate an extreme event. Current extreme events combine thermodynamic changes caused by global warming, such as modest temperature increases, sea-ice loss resulting in increased open water areas, the loss of soil moisture and permafrost thaw, and regional atmospheric dynamics, such as natural storm tracks, and intensities [1]. A conceptual model is shown in Figure 1. One hypothesis is that new extremes are forced by the interaction of the atmosphere, ocean, and biological changes. Fluctuations outside existing ranges can lead to detrimental impacts, as ecosystems and human systems are not designed to respond to them. Global warming due to greenhouse gases promotes ongoing thermodynamic changes. Thermodynamic factors constructively combine with the natural range of atmospheric and oceanic dynamics, e.g., jet stream meanders, atmospheric blocking, and storm tracks. That new extremes do not apparently require atmospheric circulation deviations to be much beyond their normal range is the reason for the large number of different types of recent events and the inter-annual and location variability of extreme impacts. These weather and climate extremes selectively influence ecosystems based on species-specific life histories, such as the timing of reproduction and migration. Societal impacts on livelihoods and cultures follow from physical and ecosystem shifts.

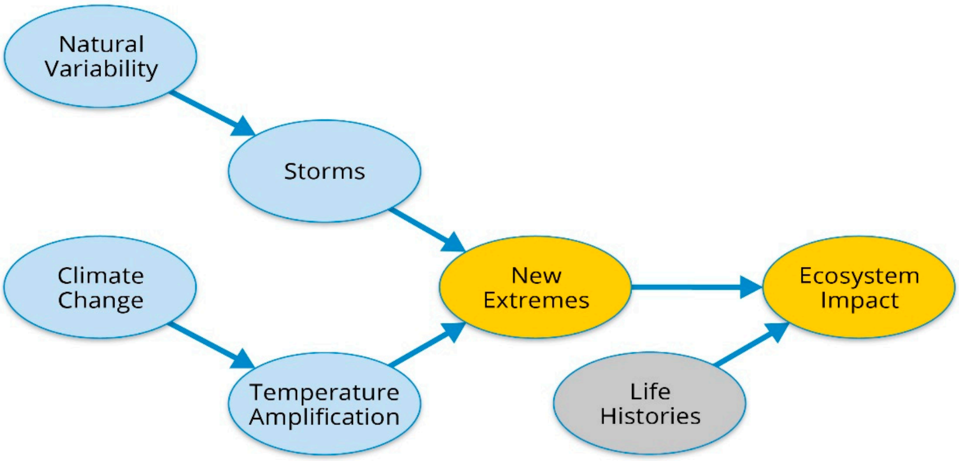

Figure 1. Conceptual model of extremes caused by atmosphere and ocean processes that interact with ecosystem life histories.

2. Examples

2.1. Northwestern Alaska

There were record minimum sea-ice cover during the winters of 2018 and 2019 in the northern Bering/Chukchi Seas (Figure 2), with continuing, multi-year impacts on the marine ecosystem and human activities. Back-to-back sea-ice minimum values recorded during 2018 and 2019 were certainly unexpected, given the normal large year-to-year variability of storms in the northern Bering Sea. The sea-ice minimum values relate to southerly winds and warmer temperatures that, in turn, depended on the weakening of the atmospheric Arctic Front and a change in storm tracks. Ecological shifts indicate the reorganization of the northern marine food web, which included the loss of sea-ice algae and young crabs, predatory Pacific cod and pollock moving north thereby impacting lower trophic levels, and the lengthening of the food chain through changes in plankton species. The direct human impacts include increased seabird and ice-associated seal emaciation and mortality and increased harmful algal blooms. These changes affect regional food security, human/wildlife health, cultural activities, and marine wildlife conservation. Global warming initiates these events through a weakened atmospheric Arctic Front that promotes the self-reinforcing interaction of sea-ice loss, warmer temperatures, southerly winds, and a wavy jet stream.

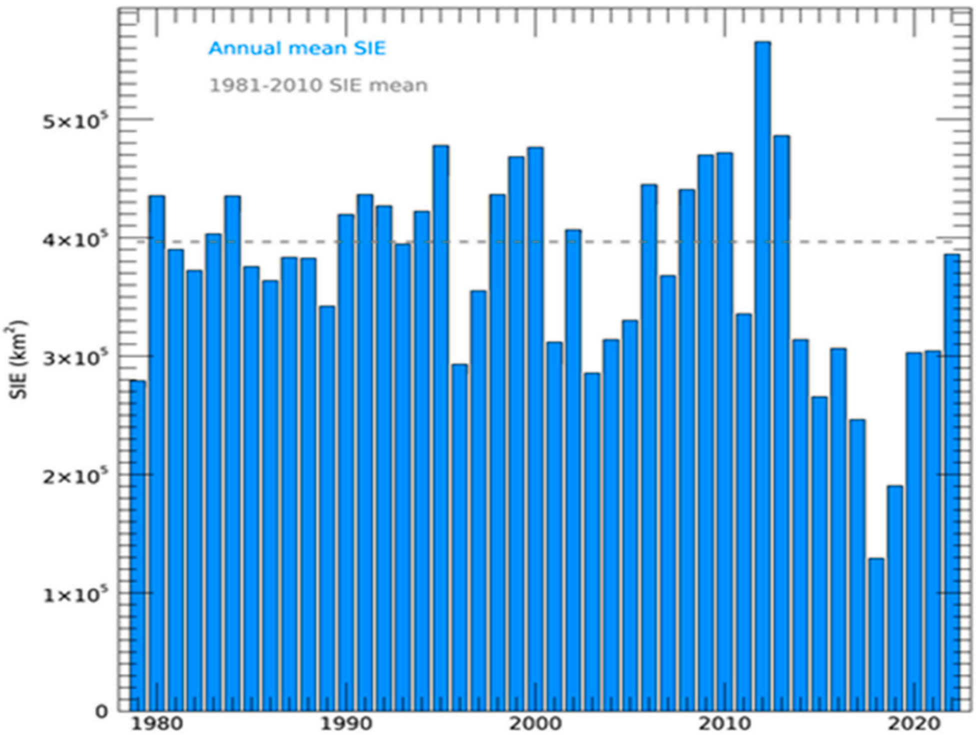

Figure 2. Bering Sea annual cycle (November to the following July mean) sea-ice extent (SIE in km^2) from 1978–1979 to 2021–2022. Provided by Thomas Ballinger.

2.2. Western Canadian Wildfires

The extreme heat event that hit the Pacific Northwest (Oregon, Washington, and southern British Columbia) [2,3] at the end of June 2021 was 6 °C warmer than the previous record (Figure 3). There were hundreds of deaths over the region and a loss of marine life and forests. A polar vortex instability center formed over the Bering Sea, which then extended southward along the west coast of North America. A tropospheric trough (low geopotential heights) established a multi-day synoptic-scale block (west–east oriented low/high/low geopotential heights) centered over the Pacific Northwest. Warming was sustained in the region due to prior drought conditions, subsidence/adiabatic heating, and solar radiation, which were the main reasons for such temperature extremes.

Both the Pacific Northwest event in 2021 and the Siberian heatwave climax in June 2020 are examples of the world crossing a critical state in terms of large-scale atmospheric circulation variability. Southwestern Alaska had impactful fires in 2022. A total of 1.61 million acres were burned in 2022, which was larger than the previous record of 0.81 in 2015 (R. Thoman, personal communication 2023).

2.3. Greenland Ice Melt

In September 2021 and 2022, Greenland experienced exceptional heat and rainfall as a result of a series of atmospheric wind/temperature transport events [4,5]. In 2022, the temperatures in September were the highest on record; up to 8 °C higher than the average. The ice sheet melted as a record rate, with at least 23% of its area impacted during the peak of the first heatwave (Figure 4). The level of rainfall was much higher than the average across southern and western areas of the ice sheet.

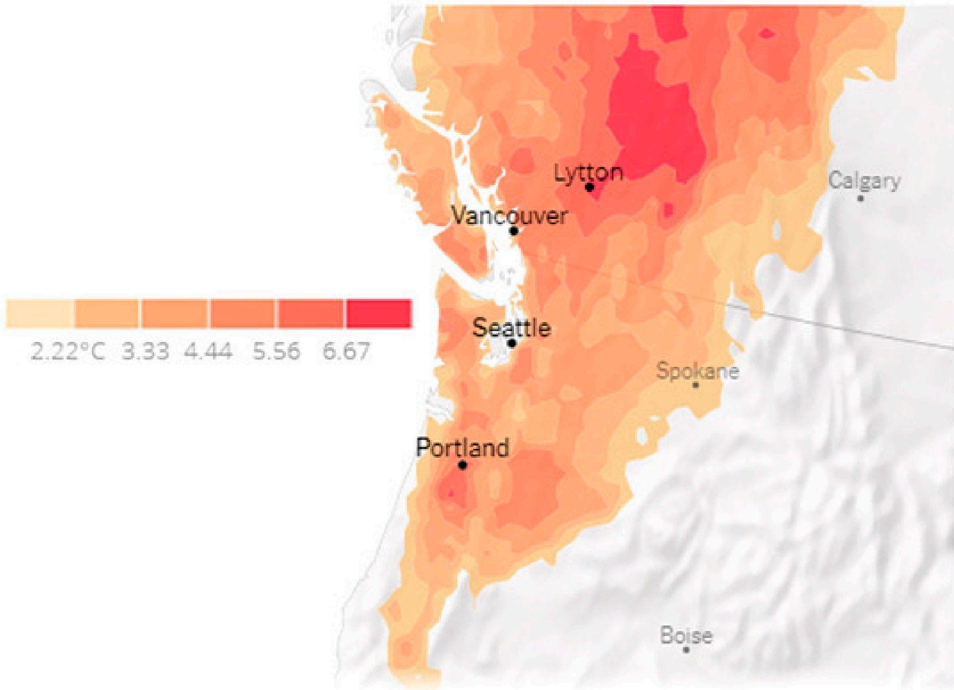

Figure 3. How much warm temperature records were exceeded in June 2021 compared to the highest temperatures from 1950–2020. Source: Geert Jan van Oldenborgh based on ERA5 reanalysis from Copernicus/ECMWF.

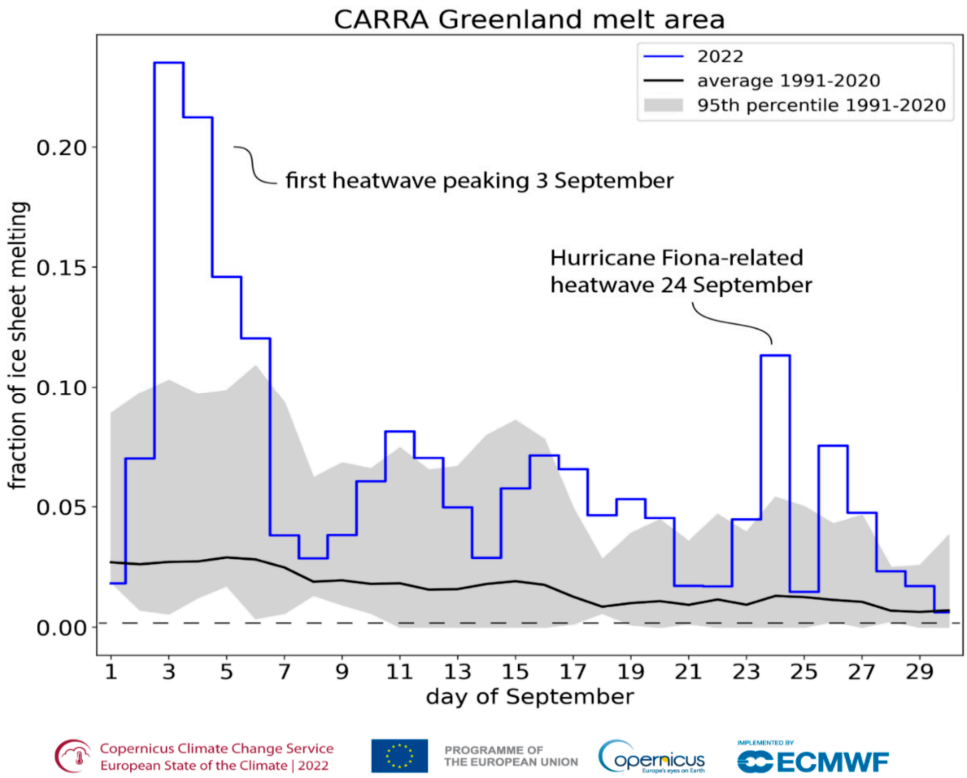

Figure 4. Melt area (daily fraction of the ice sheet melted) of the Greenland ice sheet and peripheral glaciers during 2022 (blue) compared to the average for the 1991–2020 reference period (black), and the range of values seen over the reference period (5th to 95th percentile, blue–grey shading). Data source: CARRA. Credit: GEUS/C3S/ECMWF; provided by Jason Box.

During these heatwaves, the temperatures were above freezing in several locations on the Greenland ice sheet. For example, a high-altitude (2883 m elevation), automated weather station on the southern dome of the ice sheet recorded there having been 39 h with temperatures above 0 °C. Previously, the only periods with temperatures above 0 °C at this station were much shorter: four hours in 2003 and one hour in 2016. Another location, in western Greenland, there were 325 h with temperatures above 0 °C during September. Here, melting had occurred during 18 previous years out of a 28-year record, with an average of 57 h of melting. The exceptional heat further impacted the ice sheet by reducing the snow albedo by up to 15%. Ice crystals vary in shape, and the heat rounds the otherwise sharp ice crystal edges, reducing their albedo and accelerating melting. These heat extremes resulted from a combination of an atmospheric storm track and local processes.

3. Summary

Historically, the attribution of the causes for large environmental changes, including those related to temperatures, sea and land ice, and biological impacts, is a formidable task because it is difficult to separate the signal caused by anthropogenic greenhouse gases from the background of large natural climate variability. Observational evidence now shows multiple extreme examples, super climate events, that are greater than those in previous records. They are not likely to be the result of a long-term event arising from a very low probability outcome from a known frequency distribution, e.g., a black swan [6]. These new states cannot easily be assigned probabilities because they often have no historical analogs. They suggest that other climate surprises are in store.

Such super events are short-lived, occur in multiple regions, and are multi-variate. A conceptual model is shown in Figure 1, where global warming caused by greenhouse gases increases as an ongoing thermodynamic response, leading to temperature increases, land surface changes, such as droughts, and sea-ice loss/open water increase, providing precursors to major impacts. These factors constructively combine with the natural range of short-term atmospheric and oceanic dynamics, e.g., jet stream meanders, atmospheric blocking, storms, and upper ocean heat content [7]. Such an interdependence produces the characteristics of these new super climate extremes. Weather and climate extremes selectively influence ecosystems based on species-specific life histories. Societal impacts on livelihoods and culture follow [8]. Such super events can be considered as new indicators of global climate change.

This is a world of uncertain futures and unpredictable consequences that represent radical uncertainty, with implications for adaptation and mitigation strategies. As suggested in [6], these projections are important speculations based upon "what if" calculations. Rather than treating model projections as the future truth, multiple scenarios can be developed. Management involves the avoidance of worse cases.

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References

1. Overland, J. Arctic climate extremes. *Atmosphere* **2022**, *13*, 1670. [CrossRef]
2. Overland, J.E. Causes of the record-breaking Pacific Northwest heatwave, late June 2021. *Atmosphere* **2021**, *12*, 1434. [CrossRef]
3. Wang, C.Z.; Zheng, J.Y.; Lin, W.; Wang, Y.Q. Unprecedented heatwave in western North America during late June of 2021: Roles of atmospheric circulation and global warming. *Adv. Atmos. Sci.* **2022**, *40*, 14–28. [CrossRef]
4. Climate Change Service (C3S). Arctic, Greenland heatwaves. In *European State of the Climate (ESOTC) 2022*; Copernicus, 2023. Available online: https://climate.copernicus.eu/esotc/2022/greenland-heatwaves (accessed on 11 May 2023).
5. 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]

6. Shepherd, T.G. Bringing physical reasoning into statistical practice in climate change science. *Clim. Chang.* **2021**, *169*, 2. [CrossRef]
7. White, R.H.; Kornhuber, K.; Martius, O.; Wirth, V. From atmospheric waves to heatwaves: A waveguide perspective for understanding and predicting concurrent, persistent and extreme extratropical weather. *Bull. Am. Meteorol. Soc.* **2021**, *103*, E923–E935. [CrossRef]
8. 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]

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