IGSD Institute for Governance & Sustainable Development

**Additional Background on**
**Accelerating Rates of Global and Arctic Warming**

The rate of climate change is accelerating. Earth has warmed 1 ºC since pre-industrial times,[1] and if warming continues at the present rate, global average temperature could add 50% more warming and reach 1.5 ºC as soon as 2030, according to the IPCC's Special Report on 1.5 ºC.[2] The Arctic is warming at twice the global average.[3]

The rate of global annual temperature increase has more than doubled in recent decades to a rate of 0.17 ºC per decade.[4] The rate of $CO_2$ concentration in the atmosphere also is accelerating, growing to 2.82 ppm/year in 2018[5]; for comparison, the average increase of $CO_2$ in the 1980s was about 1.6 ppm/year and 2.2 ppm/year during the last decade (2008–2017).[6] On 22 March 2019 the Keeling Curve at Scripps Institution of Oceanography reported 410.13 ppm of $CO_2$ at Mauna Loa.[7] Global $CO_2$ emissions rose 1.6% in 2017 and are projected to rise 2.7% (range of 1.8 to 3.7%) in 2018, following three years of stable emissions between 2014 and 2016.[8]

The accelerating warming is being driven not only by continuing emissions, but also by self-reinforcing feedbacks, including the loss of the reflective shield provided by Arctic sea ice.[9] From 1979 through 2011, Arctic summer sea ice declined by 40%, which added radiative forcing in the Arctic of 6.4 $W/m^2$; if averaged globally this would be equivalent to 25% of the forcing from $CO_2$ during the same timeframe.[10]

Arctic sea ice volume has decreased 75% since 1979.[11] In 2018, strong, multi-year ice was down to just 1% of the Arctic sea ice, a 95% reduction over the last 33 years.[12] Loss of remaining Arctic summer sea ice could occur within 15 years (±10 years).[13] Increased Arctic warming is expected to allow greater ocean swells,[14] while also being conducive to more cyclones with greater winds,[15] both of which can break up sea ice, especially the younger, thinner, and more fragile ice. The continuing loss of sea ice will add significantly more warming to the Arctic.

Accelerating Arctic warming is triggering permafrost thaw[16], another self-reinforcing feedback loop that further amplifies warming through release of both $CO_2$ and methane.[17] Already, 3.4 million square kilometers of permafrost have thawed; and with warming of 1.5 ºC approaching, an additional 4.8 million square kilometers could thaw.[18] The carbon stored in permafrost is nearly twice what is already in the atmosphere—1,700 Gt carbon in permafrost versus 850 Gt carbon in the atmosphere.[19]

In the past two decades, the melt rate across Greenland has increased 250–575%,[20] with some areas melting at four times the previous rate,[21] approaching a tipping point that threatens to contribute even more sea-level rise. The threshold for irreversible melting of the Greenland ice sheet—which could contribute up to 7 meters of sea-level rise—may be as low as 1.6 ºC.[22]

Ocean heat waves—discrete periods of extreme regional ocean warming—are increasing in frequency and further threatening biodiversity, including corals, seagrasses, and kelps, and these events are expected to increase in intensity with continuing climate emissions.[23] In the Arctic, warmer ocean waters can accelerate ice melt.[24]

The accelerating rate of warming is leading to a climate emergency, where the increasing emissions and the self-reinforcing feedbacks are pushing the world toward "Hothouse Earth" with catastrophic and potentially existential impacts.[25] If past climates are any indication of what the future may bring, unabated emissions could lead to 4 to 5 ºC of global warming; when temperatures were this high in the mid-Miocene, sea levels were 10 to 60 meters higher.[26]

Protecting the Arctic must start with cuts to short-lived climate pollutants, which can reduce the rate of Arctic warming by two-thirds,[27] along with cuts to $CO_2$ emissions and removal of existing $CO_2$.[28]

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[1] World Meteorological Organization (2018) WMO STATEMENT ON THE STATE OF THE GLOBAL CLIMATE IN 2017, 4.

[2] Allen M., *et al.* (2018) SUMMARY FOR POLICYMAKERS, *in* IPCC (2018) GLOBAL WARMING OF 1.5 ºC, 6 ("Human activities are estimated to have caused approximately 1.0 ºC of global warming above pre-industrial levels, with a *likely* range of 0.8 ºC to 1.2 ºC. Global warming is *likely* to reach 1.5 ºC between 2030 and 2052 if it continues to increase at the current rate. (*high confidence*)").

[3] Arctic Monitoring and Assessment Programme (AMAP) (2017) SNOW, WATER, ICE AND PERMAFROST IN THE ARCTIC, EXECUTIVE SUMMARY AND KEY MESSAGE.

[4] National Oceanic and Atmospheric Administration (NOAA), *Global Climate Report - Annual 2018* (*last accessed* 24 March 2019) ("During the 21st century, the global land and ocean temperature departure from average has reached new record highs five times (2005, 2010, 2014, 2015, and 2016), with three of those being set back-to-back. From 1880 to 1980, a new temperature record was set on average every 13 years; however, for the period 1981–2018, the frequency of a new record has increased on average to once every three years. Nine of the 10 warmest years (listed below) have occurred since 2005, with the last five years (2014–2018) ranking as the five warmest years on record. The year 1998 is the only year from the 20th century among the ten warmest years on record, currently tying with 2009 as the ninth warmest year on record. The yearly global land and ocean temperature has increased at an average rate of 0.07°C (0.13°F) per decade since 1880; however, the average rate of increase since 1981 (0.17°C / 0.31°F) is more than twice as great.").

[5] National Oceanic and Atmospheric Administration (NOAA), Earth System Research Laboratory Global Monitoring Division, "Trends in Atmospheric Carbon Dioxide" (*last accessed* 24 March 2019).

[6] National Oceanic and Atmospheric Administration (NOAA), Earth System Research Laboratory Global Monitoring Division, "The NOAA Annual Greenhouse gas index (AGGI)" (*last accessed* 24 March 2019).

[7] Scripps Institution of Oceanography, "The Keeling Curve" (*last accessed* 23 March 2019).

[8] Jackson R. B., *et al.* (2018) *Global energy growth is outpacing decarbonization*, ENVTL. RESEARCH LETTERS 13(120401):1–7, 1.

[9] Steffen W., *et al.* (2018) *Trajectories of the Earth System in the Anthropocene*, PROC. NAT'L. ACAD. SCI. 115(33):8252–8259.

[10] Pistone K., *et al.* (2014) *Observational Determination of Albedo Decrease Caused by Vanishing Arctic Sea Ice*, PROC. NAT'L. ACAD. SCI. 111(9):3322–3326, 3325.

[11] Overland J., *et al.* (2018) *The urgency of Arctic change*, POLAR SCIENCE, Accepted Manuscript, 1–28, 5 ("Major sea ice shifts have occurred; the lateral extent of multiyear old, thick sea ice extent is currently 60% below that of the 1980s (AMAP, 2017a; Kwok, 2018) and September Arctic sea ice volume has reduced by 75% since 1979 (Schweiger et al., 2011, updated A. Schweiger). In addition, the Greenland ice sheet exhibited surface melt significantly earlier and stronger in some recent years (Kintisch, 2017).").

[12] Osborne E., *et al.* (2018) *Executive Summary*, *in* ARCTIC REPORT CARD 2018. ("When scientists began measuring Arctic ice thickness in 1985, 16% of the ice pack was very old (i.e., multiyear) ice. In 2018, old ice constituted less than 1% of the ice pack, meaning that very old Arctic ice has declined by 95% in the last 33 years.")

[13] Overland J. E. & Wang M. (2013) *When will the summer Arctic be nearly sea ice free?*, GEOPHYSICAL RESEARCH LETTERS 40:2097–2101, 2097. ("Time horizons for a nearly sea ice-free summer for these three approaches are roughly 2020 or earlier, 2030 ± 10 years, and 2040 or later.")

[14] Thomson J. & Rogers W. E. (2014) *Swell and sea in the emerging Arctic Ocean*, GEOPHYSICAL RESEARCH LETTERS 41:3136–3140, 3136.

[15] Day J. J. & Hodges K. I. (2018) *Growing Land-Sea Temperature Contrast and the Intensification of Arctic Cyclones*, GEOPHYSICAL RESEARCH LETTERS 45:3673–3681, 3680.

[16] Lawrence D. M., *et al.* (2008) *Accelerated Arctic land warming and permafrost degradation during rapid sea ice loss*, GEOPHYSICAL RESEARCH LETTERS 35(L11506):1–6.

[17] Schaefer K., *et al.* (2014) *The Impact of the Permafrost Carbon Feedback on Global Climate*, ENVTL. RESEARCH LETTERS 9:1–9, 2.

[18] Chadburn S. E., *et al.* (2017) *An observation-based constraint on permafrost loss as a function of global warming*, NATURE CLIMATE CHANGE 7:340–344, 342.

[19] Schuur E. A. G., *et al.* (2015) *Climate Change and the Permafrost Carbon Feedback*, NATURE 520:171–179, 171.

[20] Trusel L. D., *et al.* (2018) *Nonlinear rise in Greenland runoff in response to post-industrial Arctic warming*, NATURE 564:104–108, 104.

[21] Bevis M., *et al.* (2019) *Accelerating changes in ice mass within Greenland, and the ice sheet's sensitivity to atmospheric forcing*, PROC. NAT'L. ACAD. SCI. 116(6):1934–1939, 1934.

[22] Robinson A., *et al.* (2012) *Multistability and critical thresholds of the Greenland ice sheet*, NATURE CLIMATE CHANGE 2:429–432, 431.

[23] Smale D. A., *et al.* (2019) *Marine heatwaves threaten global biodiversity and the provision of ecosystem services*, NATURE CLIMATE CHANGE, Online Publication, 1–7, 1 ("The global ocean has warmed substantially over the past century, with far-reaching implications for marine ecosystems. Concurrent with long-term persistent warming, discrete periods of extreme regional ocean warming (marine heatwaves, MHWs) have increased in frequency. Here we quantify trends and attributes of MHWs across all ocean basins and examine their biological impacts from species to ecosystems. Multiple regions in the Pacific, Atlantic and Indian Oceans are particularly vulnerable to MHW intensification, due to the co-existence of high levels of biodiversity, a prevalence of species found at their warm range edges or concurrent non-climatic human impacts. The physical attributes of prominent MHWs varied considerably, but all had deleterious impacts across a range of biological processes and taxa, including critical foundation species (corals, seagrasses and kelps). MHWs, which will probably intensify with anthropogenic climate change, are rapidly emerging as forceful agents of disturbance with the capacity to restructure entire ecosystems and disrupt the provision of ecological goods and services in coming decades.").

[24] Zhang J., *et al.* (2013) *The impact of an intense summer cyclone on 2012 Arctic sea ice retreat*, GEOPHYSICAL RESEARCH LETTERS 40:720–726, 720 ("This model study examines the impact of an intense early August cyclone on the 2012 record low Arctic sea ice extent. The cyclone passed when Arctic sea ice was thin and the simulated Arctic ice volume had already declined ~40% from the 2007–2011 mean. The thin sea ice pack and the presence of ocean heat in the near surface temperature maximum layer created conditions that made the ice particularly vulnerable to storms. During the storm, ice volume decreased about twice as fast as usual, owing largely to a quadrupling in bottom melt caused by increased upward ocean heat transport. This increased ocean heat flux was due to enhanced mixing in the oceanic boundary layer, driven by strong winds and rapid ice movement. A comparison with a sensitivity simulation driven by reduced wind speeds during the cyclone indicates that cyclone-enhanced bottom melt strongly reduces ice extent for about 2 weeks, with a declining effect afterward. The simulated Arctic sea ice extent minimum in 2012 is reduced by the cyclone but only by $0.15 \times 10^6$ $km^2$ (4.4%). Thus, without the storm, 2012 would still have produced a record minimum.").

[25] Steffen W., *et al.* (2018) *Trajectories of the Earth System in the Anthropocene*, PROC. NAT'L. ACAD. SCI. 115(33):8252–8259.

[26] Steffen W., *et al.* (2018) *Trajectories of the Earth System in the Anthropocene*, PROC. NAT'L. ACAD. SCI. 115(33):8252–8259 (*see* Supporting Information, Table S1).

[27] Schoolmeester, T., *et al.* (2019) Global Linkages – A graphic look at the changing Arctic (concluding that "instant measures to reduce SLCPs…across the world could cut the rate of warming in the Arctic by up to two-thirds by mid-century."). *See also* Arctic Monitoring and Assessment Programme (AMAP) (2017) SNOW, WATER, ICE AND PERMAFROST IN THE ARCTIC (SWIPA) 2017, xiii–xiv ("Stabilizing Arctic warming and its associated impacts will require substantial near-term cuts in net global greenhouse gas emissions. Full implementation of the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) will cause Arctic temperatures to stabilize—at a higher level than today—in the latter half of this century. This will require much larger cuts in global greenhouse gas emissions than those planned under current nationally determined contributions to the fulfillment of

the UNFCCC. The Arctic states, permanent participants, and observers to the Arctic Council should individually and collectively lead global efforts for an early, ambitious, and full implementation of the Paris COP21 Agreement, including efforts to reduce emissions of short-lived climate forcers."); and Allen M., *et al.* (2018) SUMMARY FOR POLICYMAKERS, *in* IPCC (2018) GLOBAL WARMING OF 1.5 °C.

[28] Allen M., *et al.* (2018) SUMMARY FOR POLICYMAKERS, *in* IPCC (2018) GLOBAL WARMING OF 1.5 °C.