The expanding footprint of rapid Arctic change

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Key Points:

- Rapid changes in the Arctic physical environment have substantial impacts in low and mid latitudes.
- Loss of sea ice, land ice, and permafrost is accelerating and these losses are further exacerbating climate change.
- Effects of Arctic change include rising sea level, increased coastal erosion, greater storm impacts, and ocean and atmospheric warming.

Abstract

Arctic land ice is melting, sea ice is decreasing, and permafrost is thawing. Changes in these Arctic elements are interconnected, and most interactions accelerate the rate of change. The changes affect infrastructure, economics, and cultures of people inside and outside of the Arctic, including in temperate and tropical regions, through sea level rise, worsening storm and hurricane impacts, and enhanced warming. Coastal communities worldwide are already experiencing more regular flooding, drinking water contamination, and coastal erosion. We describe and summarize the nature of change for Arctic permafrost, land ice, and sea ice, and its influences on lower latitudes, particularly the United States. We emphasize that impacts will worsen in the future unless individuals, businesses, communities, and policy makers proactively engage in mitigation and adaptation activities to reduce the effects of Arctic changes and safeguard people and society.

1 Introduction

Popular media articles commonly refer to the Arctic as a disappearing physical environment, using words like shrinking, melting, dissolving, thawing, and collapsing. These descriptors give the impression that the Arctic, which already feels distant to most people, is fading away and becoming a relic. It is easy then to consider these far-off events as only a scientific curiosity, with negligible influence on global environments and economies. But in fact, as permafrost, land ice, and sea ice in the Arctic (Figure 1) rapidly thaw, melt, and shrink, the Arctic has an increasing impact on societies and infrastructure across the globe. The effects show up as amplified climate change, rising sea level, coastal flooding and erosion, and more devastating storms (Figure 2) [e.g., AMAP, 2017]. As we will discuss here, the global footprint of influence from Arctic change is growing, not shrinking. Reducing future risk requires reducing greenhouse gas emissions and mitigating the drivers of global climate change.

2 Rapid Arctic cryosphere change

2.1 Thawing permafrost

Permafrost is a defining environmental characteristic of the far north. Approximately 20-25% percent of the Northern Hemisphere land surface is underlain by permafrost, ground that remains frozen for two years or more [Brown et al., 1998; Gruber, 2012]. Arctic warming is causing widespread thawing of permafrost areas [Romanovsky, 2018] leading to infrastructure damage to buildings, roads, and utilities in northern communities as ice subsides and the ground becomes waterlogged. Alaska infrastructure damage over 2015-2099 is estimated at $5.5 billion under the Intergovernmental Panel on Climate Change RCP8.5 ‘business as usual’ emission scenario, with almost half of that cost due directly to permafrost thaw [Melvin et al., 2017]. The impact of permafrost thaw goes beyond the Arctic because the large amount of biomass carbon contained in permafrost is beginning to decompose and release carbon dioxide and methane to the atmosphere [Schuur et al., 2008]. These added greenhouse gases further heat the atmosphere, setting up a self-reinforcing cycle, or feedback, of thawing and heating. Data analyses of permafrost soils up to 3m depth estimate the potential carbon pool to be as much as 1,035 ± 150 Pg (1 Pg = 1 Gt) [Hugelius et al., 2014; Schuur et al., 2015], with another 425-565 Pg C contained in permafrost deeper than 3m [Strauss et al., 2017]**.** This pool is climate sensitive and large; soils in all other biomes combined are thought to comprise ~2,050 Pg carbon in the top 3 m. The total permafrost carbon pool (1460-1600 Pg C) contains about twice as much carbon as the Earth's current atmosphere [Schuur et al., 2018]. A release of 10% of the permafrost carbon pool as carbon dioxide and methane would be of similar magnitude as emissions from land use change (currently 1.3 ±0.7 Pg carbon per year) thereby providing a substantial contribution to future greenhouse gas release [Le Quéré et al., 2018].

Earth system models mainly represent top-down thaw of permafrost as a result of a warming climate, which is only one process that influences permafrost and carbon emissions. Global dynamic models generally show potential release of permafrost carbon ranging from tens to hundreds of Pg C into the atmosphere by 2100 under the RCP 8.5 warming trajectory. The newest model simulations show similar permafrost carbon losses, but also the potential for stimulated plant growth to offset some or all of these losses [McGuire et al. 2018]. Even so, these new model results suggest that plant offsets will be overwhelmed by soil carbon losses, leading eventually to the same permafrost carbon – climate warming feedback. Other recent research also indicates that permafrost feedbacks respond quickly even with a relatively small magnitude of global warming, meaning that large impacts occur even if we limit global warming to 1.5°C [Burke et al., 2018: Comyn-Platt et al., 2018; IPCC, 2018].

2.2 Melting land ice

Land ice forms when winter snowfall exceeds summer snowmelt over decades to millennia. Arctic land ice includes the Greenland Ice Sheet and smaller ice caps and glaciers across the Greenland perimeter, Alaska, Canada, Russia, Svalbard, Iceland, and other Nordic countries. Roughly 8% of the world's freshwater is contained in Northern Hemisphere glaciers and ice sheets, and Arctic land ice comprise over 2 million square kilometers [RGI Consortium, 2017]. This area is diminishing rapidly due to warming air and ocean temperatures. Widespread retreat of glaciers and ice caps is well documented across the Arctic [e.g., Howat and Eddy, 2011; Carr et al., 2017], and long-term records of glaciers across the globe confirm that retreat has accelerated in the 21st century as a result of human-caused climate change [Roe et al., 2016]. The speed and magnitude of change is unprecedented. For example, dating of tundra plants exposed at the edges of shrinking glaciers in the Eastern Canadian Arctic suggests that summer warmth of the past century now exceeds any century in at least 40,000 years, and likely any century since the end of the last interglaciation, ~115,000 years ago [Pendleton et al. 2019]. The effects of this warming are apparent in current rapid rates of Arctic ice loss [e.g., Fisher et al., 2012].

Ice retreat is not the only change. Most areas of land ice are also thinning, primarily due to surface melt [Kjeldsen et al., 2015]. Loss of ice volume has tripled over the satellite observational era (since the early 1990s) [Shepherd et al., 2012]. Annual ice loss from Greenland and the Arctic glaciers and ice caps contributed ~1.2 mm of sea level rise to the world ocean each year from 2003 to 2015 and land ice overall has contributed ~60% of total sea level rise since 1972 (with the Arctic alone contributing 31% since 1992), exceeding the contribution from thermal expansion [AMAP, 2017; Box et al., 2018]. Computer simulations show that the rapid loss of land ice observed over the most recent decades will continue if current warming trajectories are maintained. Arctic land ice loss will be the major contributor to the projected average sea level rise of roughly one-half to one meter by 2100 [IPCC, 2013] (note that some estimates of global totals include much higher values based on potential ice loss mechanisms particularly applicable in Antarctica [DeConto and Pollard, 2016]).

2.3 Diminishing sea ice

Sea ice, formed from and sitting atop ocean water, covers roughly 3.5 to 16 million km^2 of the Arctic ocean, depending on the season [Fetterer et al., 2017]. Persistent declines in Arctic sea ice extent began in the mid-1990s, with the lowest sea ice minimum to date in September 2012, and the reduction in September ice cover currently exceeding 13% per decade [Stroeve et al., 2012]. Perhaps of even higher consequence is the substantial decline in sea ice thickness. More than 60% of sea ice volume was lost in only 30 years [Lindsay and Schweiger, 2015]. In comparison to thicker multi-year sea ice, thinner sea ice is more susceptible to complete melt each summer and is more easily moved and fractured by winds and currents. Sea ice shelters the Arctic coast and its loss has caused intense acceleration of coastal erosion in Siberia and Alaska [Overeem et al., 2011; Barnhart et al., 2014; Fritz et al., 2017]. Sea ice loss has global consequences because sea ice helps to regulate the Earth’s climate. The bright surface of sea ice reflects much of the incoming solar radiation back into space, preventing that energy from warming the planet [Euskirchen et al., 2013]. As sea ice coverage declines, the exposed darker ocean water absorbs upwards of 9 times more solar radiation in summer. That additional energy raises Arctic air temperatures as it is released in fall and winter. The decrease in surface reflectivity is one of the primary reasons that global warming is amplified in the Arctic [Manabe and Stouffer, 1980; Pithan and Mauritsen, 2014].

The character and behavior of Arctic sea ice is now fundamentally different than it was in the 20th century, and there is no expectation of return to previous conditions. Instead, if fossil fuel use and greenhouse gas emissions are not considerably reduced (i.e., if we continue to follow a trajectory like RCP8.5), climate models predict that sea ice will cover Arctic coastal regions for only half of the year by 2070 and frequent ice-free conditions will prevail throughout the entire Arctic Ocean by 2100 [Barnhart et al., 2015; Jahn, 2018].

3 Connections across the Arctic system

Permafrost, land ice, and sea ice are commonly discussed as separate features of the Arctic environment, although in fact they are closely interconnected. First, they are responding to common climate forcing across the Arctic and, second, each component is influencing changes in the other components. For example, sea ice loss is projected to continue, including periods of especially rapid change [e.g. Holland et al., 2006] (rapid declines already occurred in 2007 and 2012 [Stroeve et al., 2012]). Rapid sea ice loss not only heightens atmospheric warming, but early loss of sea ice locally near the Greenland Ice Sheet may increase heat transfer from the ocean to the atmosphere above the ice sheet and result in increased ice sheet melt [Stroeve et al., 2017]. Rapid sea ice loss also has a significant effect on temperatures over land with implications for permafrost thaw [Lawrence et al., 2008], and increased wave activity due to sea ice loss can also lead to stronger permafrost coastal erosion, further exacerbated by sea level rise from land ice loss [Fritz et al., 2017]. Changes in permafrost, land ice, and sea ice also affect all other elements of the Arctic system. For example, permafrost thaw contributes to an intensification of the Arctic terrestrial hydrological cycle, and Arctic river runoff has significantly increased over the last decades [Overeem and Syvitski, 2010]. The Arctic marine ecosystem is also influenced by land ice, sea ice, and permafrost reductions via changes in nutrient cycles, the marine light environment, stratification, benthic-pelagic connections, and changing wind and ocean current patterns.

4 Impacts of Arctic change on low and mid-latitudes

Rapid changes across the Arctic are increasingly influencing people and economies across the low and mid-latitudes. The permafrost carbon feedback is a direct-effect example, where thawing permafrost releases additional greenhouse gases to the global atmosphere with consequential warming impacting the entire world population. Other effects are particularly apparent for coastal regions and communities where rapid Arctic change is contributing to rising ocean levels [AMAP, 2017; Box et al., 2018] and heightening the damage caused by storms and hurricanes [Lin et al. 2012; UNISDR, 2017]. Even sheltered inland regions are connected to coastal areas economically and socially, and will be vulnerable to the knock-on effects of Arctic-induced coastal change.

Worldwide 625 million people lived in the low-elevation coastal zone (<10 m elevation) in 2000, and future migration tends to be directed toward the coast, with an expected coastal zone population of 939 million by 2030 [Neumann et al., 2015]. Fourteen of the world's seventeen largest cities are located on coasts, including Tokyo, Shanghai, Jakarta, and New York City. Arctic changes contribute to coastal impacts like flooding, freshwater contamination by salty ocean water, coastal erosion, and higher storm surges. Looking at the U.S., wetland and coastal erosion are already displacing rural communities in Louisiana, drinking water problems are affecting Monterrey, Ventura, and Los Angeles counties in California [Barlow et al., 2010], sea cliff retreat is dramatic and impacting infrastructure along the West Coast [Limber et al., 2018], and Miami and many other areas of the Gulf Coast and Eastern Seaboard now have increased regular flooding [Wdowinski et al., 2016]. Similar impacts are occurring worldwide [e.g., Nurse et al., 2014; Wong et al., 2014]; all examples of ways in which Arctic change affects economics and security globally.

Sea level rise across the globe is also worsening the impacts of all coastal storm and flood events by raising the baseline. Hurricane Sandy along the U.S. Eastern Seaboard and Hurricane Harvey along the Texas coast both were more damaging due to sea level rise. And sea level rise between 1950 and 2012 increased the likelihood of Hurricane Sandy-level events by one- to two-thirds depending on East Coast location [Sweet and Park, 2013]. Because glacial ice mass loss changes the Earth's gravitational potential, sea level rise from Arctic ice melt is also disproportionally higher at faraway low latitude coasts, such as the U.S. Gulf Coast and Asian coasts (Larour et al., 2017). More rapid sea level rise also reduces the engineered design safety margins of protective sea walls and levees, putting them at risk during storm surges now riding on top of a higher base sea level [e.g., Sebastiaan et al., 2013].

Arctic changes may also be transforming the character of storms and extreme weather events – including snow storms and droughts - experienced in mid-latitudes across the Northern Hemisphere. An area of active research, one leading hypothesis is that an Arctic-induced change in the jet stream is intensifying extreme weather events that are now more frequent in the U.S., Canada, Europe, and Asia [Screen and Simmonds, 2014; Rahmstorf and Coumou, 2011; Mann et al., 2018]. As the Arctic warms more quickly than lower latitudes, the temperature gradient from the North Pole to the Equator is declining, weakening west-to-east jet stream winds, and contributing to a wavier jet stream [Francis and Vavrus, 2012]. This derives in part from diminishing Arctic sea ice. Diminished sea ice allows the ocean north of Alaska to take up more summer heat. In autumn, the heat is released into the atmosphere causing stronger northward swings, or ridges, in the jet stream. This type of Arctic warming may have strengthened the atmospheric ridge that was largely responsible for California's recent extreme drought [Swain et al., 2016]. The downstream effect of this northern ridge is also an intensified south-dipping trough, which brought extreme cold to eastern U.S. states during the 2013/14 and 2014/15 winters. These large jet stream waves are more likely to remain in one place, bringing locally persistent warm and dry or cold and stormy weather [e.g., Mann et al., 2018].

As the flattest, most low-lying U.S. state, Florida is a stark example of the negative influence Arctic change is having and will have in lower latitudes. Key West has already experienced a threefold increase in coastal flooding since 1990, and St. Petersburg has seen a 40% increase. Future increases in sea level and storm damage will negatively affect major infrastructure. Across the state, ~5,500 square kilometers of land lie less than 1 meter above the high tide line. This includes 300,000 homes, 35 public schools, 4,112 kilometers of road, and 978 EPA-listed hazardous waste dumps or sewage plants [Strauss et al., 2014]. Within 2 meters above high tide, the land area affected almost doubles and overall property value rises from $145 billion (at 1 meter) to $544 billion, including 14 power plants and 1.4 million homes. Within just the next 30 years, floods that rise up to 60 cm above the high tide line could occur every 1 to 5 years depending on location. Around the world, other low-lying regions are experiencing similarly severe effects. Assuming global mean sea level rises of 0.5-2.0 m by 2100, 72 to 187 million people will be displaced if no protections are put into place [Wong et al., 2014]. Some communities, for example on the Torres Islands, Vanuatu, have already been displaced [Nurse et al., 2014].

5 Conclusions and a call to action

Unprecedented changes underway in Arctic permafrost, land ice, and sea ice have direct and indirect effects on the Continental U.S. and other temperate and tropical countries. The recent Intergovernmental Panel on Climate Change 2018 report on “Global Warming of 1.5˚C” underscores that every additional level of warming has far reaching consequences. With a global mean surface temperature change of 1.5˚C or more above preindustrial levels, relative to the 1.0˚C rise that we have already seen, the change in the Arctic, the occurrence of extreme events, and the interconnectedness of global impacts increase substantially [IPCC, 2018]. Businesses, municipalities, state and national decision makers must weigh the choice of reducing greenhouse gas emissions against spiraling upward costs of reactive adaptation and mitigation. At the same time, concerted planning efforts are needed to prepare for the impacts that are already inevitable due to current greenhouse gas emissions [Solomon et al., 2009]. Developing resilience to upcoming and known coastal changes is key to protecting people, economies, infrastructure, and biodiversity. We emphasize that many actions are available. Essentially anything and everything that reduces greenhouse gases [e.g., Hawken, 2017] helps to curb rapid Arctic change and reduce impacts in the U.S. and globally. Since the Arctic cryosphere is highly interconnected and changes there have far-reaching consequences in other geographies, thoughtful actions are needed, including constructive social activism, informed legislation, business practice reform, and supporting multi-level action addressing climate change.

Acknowledgments

This paper is a contribution of the Study of Environmental Arctic Change (SEARCH) under award 1331100 from the National Science Foundation. We acknowledge James Balog and the Earth Vision Institute for the Figure 2 images.

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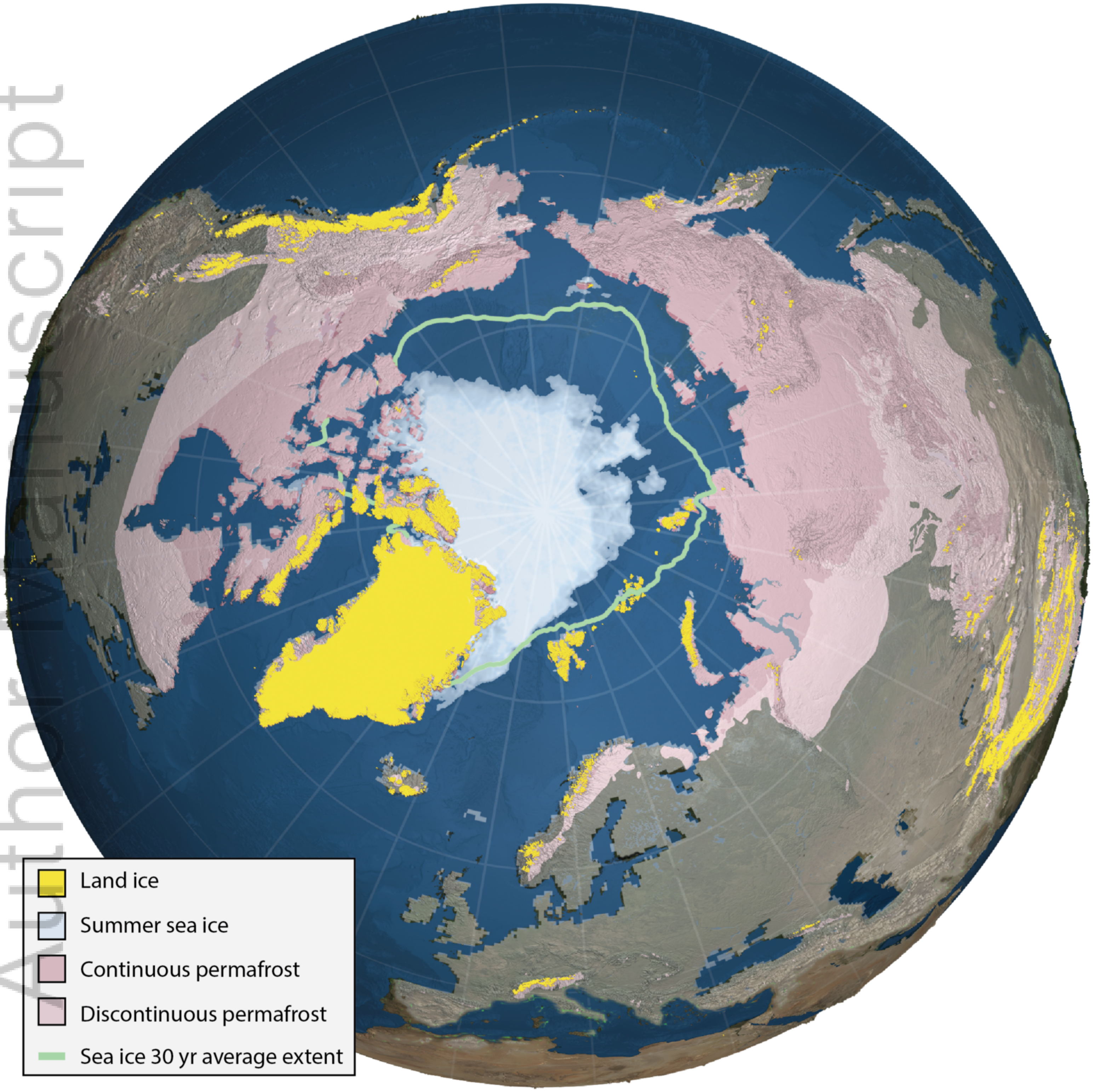
Figure 1. Land ice, summer sea ice, and permafrost in the Northern Hemisphere. Image modified from NASA/Goddard Space Flight Center Scientific Visualization Studio [https://svs.gsfc.nasa.gov/3885].

Figure 2. Flooding and storm damage in the US are connected to rapid Arctic change. a) South Ponte Vedra Beach, Florida, b) Black Creek area near Jacksonville, Florida, c) Charleston, South Carolina, and d) Lumberton, North Carolina. Images: James Balog/Earth Vision Institute.



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