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# Climate Change's Profound Disruption of the Arctic Proceedings of the 45th Canada-United States Law Institute Annual Conference - Climate Change and the Arctic: Profound Disruption, Uncertain Impact

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# CLIMATE CHANGE'S PROFOUND DISRUPTION OF THE ARCTIC

MR. STEPHEN PETRAS: Our first panel today is titled Climate Change's Profound Disruption of the Arctic. We are very pleased to have as our moderator of this panel, Michael Sfraga, a Doctor of Philosophy in Geography and Northern Studies, who is the founding director of the Polar Institute at the Woodrow Wilson Institute. A resident of Alaska, his work focuses on the changing geography of the Arctic, Arctic policy, and the impacts and implications of a changing climate in the Arctic. Dr. Sfraga is an affiliate professor at the International Arctic Research Center, University of Alaska Fairbanks, and serves as the Co-Director of the University of the Arctic's Institute for Arctic policy. You can see and hear Dr. Sfraga, on MSNBC National Public Radio, Bloomberg News, and C span. And he holds many fascinating and outstanding webinars on Arctic issues through the Wilson Center. Mike, over to you.

DR. MIKE SFRAGA: Steve, thank you very much for the kind introduction, and for the compliment of inviting the Wilson Center and the Polar Institute to this very important discussion. All of my colleagues at the Wilson Center appreciate this as well. And a special thank you to my friend Chris Sands, the director of the Canada Institute, for his support, as well. I have the honor of moderating this first panel, entitled Climate Change's Profound Disruption of the Arctic, and I'm joined by two distinguished experts. My friend and colleague Professor Hajo Eicken, the Director of the International Arctic Research Center, and professor of geophysics at the University of Alaska Fairbanks, and Professor Marcel Babin, professor and Canada Excellence Research Chair in remote sensing with Canada's new Arctic frontier at the University of Laval. Let me begin this panel with some context. As many of you know, the Arctic is not emerging, it's not an emerging issue, it has emerged. It's an interrelated, integrated component of the global, environmental, political, social, cultural, economic, and security landscape. We're living in a new, globalized Arctic; we have a new ocean opening, at least for part of the year, right before our eyes, with all of the implications of this new reality. Many of these issues will be explored by my friends and colleagues later on in different panels. And it's wonderful to see many of them participating today.

For context, once again, I'm often asked by members of the Congress, administration, local, national, regional, international policymakers, why is the Arctic important? Is it really changing? How can they better understand the issues at play in the Arctic? Why should they care? Why does the Arctic matter? It's hard for many of them, many policy makers, to grasp the scale and the scope of the Arctic, and the scale and scope of the challenges of the Arctic. So I came up with a framework that many of my colleagues have heard before. And in my opinion, when I tried to explain the Arctic, to me, there are seven key drivers, seven key themes at play in the Arctic, that are literally reshaping the contours of our Arctic.

And in my opinion, it's a way to bundle and explain the dynamics of the Arctic, it's a way for people to think about the Arctic. And in the end, it will be our ability to navigate these key drivers. I have found that each of these drivers in my opinion starts with the letter C, and how we navigate each of these Cs will determine really how the Arctic emerges later on into our future. So to me, navigating the Arctic seven Cs, is really important. The first C in my framework for legislators and others to think about the Arctic is climate. So how we navigate the seven Cs, to me is driven by the most significant C: climate change. And this panel is focused on that and the disruption that climate change brings to the region. Let me give you the other seven Cs for context, and then we'll go into the panel. But the first C in navigating the Arctic seven Cs, obviously is climate, where the Arctic is warming more than two times the global average. Commodities is the second C; those who think there's a rush for commodities in the Arctic will point to that: oil and gas, rare earth minerals, strategic minerals. Commerce is the third; the shipping of these commerce, the transportation of these commodities. Connectivity in all of its realms, whether its broadband ports, rail, highways, connectivity is a big driver in the Arctic communities. Communities don't just want to sustain themselves; they want to thrive. But they have many challenges in this new Arctic. Cooperation is my sixth C, there's a lot of cooperation in the Arctic; Arctic Council, Arctic coastguard forum research. And finally, the seven C is competition; there is competition in the Arctic. For now, we're able to manage this competition in all of its realms. But we have to keep our eye on that. That's why the cooperation C is important. But to me, the first C, climate, is the principal driver of almost everything else we see in the Arctic. And that's why today's panel, Climate's Profound Disruption of the Arctic, is so important. And we can only address the challenges of the Arctic or the seven C, through fact-based, science driven, policy formulation and implementation. So, to begin our exploration and discussion on this topic, it's a pleasure to offer the virtual floor to my colleague, Dr. Hajo Eicken. Hajo, the virtual floor is yours.

DR. HAJO EICKEN: Thank you, Mike. And good morning, everybody. I'm Hajo Eicken. I'm Director of the International Arctic Research Center at the University of Alaska Fairbanks. UAF, for short, is located on the Troth Yeddha' Campus on the homelands of the Lower Tanana Dine. And I'm pleased to be able to give you just a brief perspective on some of the physical and environmental aspects of disruptive Arctic change. So in order to give you a better perspective on that, I'll share some slides with you that I've prepared and then my colleague, Dr. Babin will take over after this and give you a bit more of a perspective in particular on the ecosystem changes and their implications in the Arctic. So, you should be seeing the slides. Is that correct, Mike? Yes. So, the topic of this conference today is disruptive Arctic change. And I just wanted to set the frame slightly differently and emphasize something that I'm sure all of you are aware of that the Arctic plays an important role both as a disrupter and a provider. And it's really only in recent years, that this aspect of disruption has come to the fore. If you look at the photo on the right here, that was taken outside Toksook Bay, in the Yukon-Kuskokwim Delta in southwestern Alaska, you see, a Yupiit scanning the horizon for mukluk, or bearded seal, the use of the sea ice cover that surrounds and lines the Arctic countries, and the Arctic Ocean, as a platform. And as a provider of services, both to the people of the Arctic, the Indigenous peoples of the Arctic, and its marine and coastal ecosystems, is an important aspect of the role of the Arctic as a service provider, but there's a range of other services. And these services ultimately are being disrupted and requiring both local and regional and global concerted action in the form of a response. You see some of this disruption here in the photo on the left; this is a much more common type of scene that you see now, this is taken here at Utqiagvik a community in northern Alaska, formerly known as Barrow. The summers used to be such that you had a lot of sea ice remaining on the oceans over the course of the summer months, and in recent years, the retreat of that sea ice is something that we'll talk a bit more about here in my presentation, has led to larger areas of open water, fall storms and summer storms that generate these large waves that you see come crashing into the shore here. And there's a great increase in the amount of flooding events and the coastal erosion that comes with it. That is one aspect of the disruption of the services that the Arctic provides.

So to put it more broadly-and these are some of the points that both Marcel Babin and I will touch on in our presentation- you can think of the Arctic providing key services and benefits to all of humanity, but in particular to the people of the Arctic, and it's the disruption of these services and benefits that is creating some of the challenges that we hope to talk a bit more about today. One aspect, for example, has already been pointed out by the first of the Cs that Dr. Sfraga got introduced, and that is that the Arctic serves as important global, globally important regulator of the climate system, through in particular the Greenland ice sheet and glaciers. The Arctic also serves as an important function as a regulator of sea level up but then also you see this here, illustrated by the photo on the right with a number of walrus hauled out in an ice flow, the Arctic supports marine food webs, it's an important supportive biodiversity. It provides food, serves as a transportation corridor, and the cultural services in particular for Arctic Indigenous peoples, but also for tourists that are visiting at intervals are important aspect of the services the Arctic provides as well. So, I'd like to have you keep those aspects of the Arctic services in mind as we start reviewing some of the changes that we've seen in recent times. And it's also important to understand in the type of context of this meeting and the great roster of distinguished participants that you have here represents that in the context of legal frameworks, a lot of these services are not regulated, such as the services that you would receive if you if you take your car into a shop and expect that whoever's working on your car is conforming with common business practices, is complying with local and federal laws, etc., etc. These types of services that you see here, even though they are arguably much more important than the types of services you might get, if you're if you're looking for an oil change in your car, are a much more complex set of services that are that are very difficult and challenging. To regulate and parse both on a local and a global scale. And that's part of the challenge of the Arctic: its global role, makes it- I guess that's another C here for your eight C's there, Mike-it is, it is a challenging, but also an important aspect of the global system.

So just a brief perspective on what I like to cover here. Today, I'm going to talk briefly about the Arctic in a global context, then I'll focus in particular on the cryosphere, that is all forms of snow and ice and permafrost, that define the Arctic, and also define its role in a global context, and also give a bit more perspective on why some of these changes we see are so disruptive. And I'll focus on one aspect of the cryosphere in particular: that is, the ice cover on the Arctic oceans, and its marginal seas, the sea ice, talk a bit about drivers of change and consequences, and then briefly come to some conclusions, again, looking at the Arctic through the lens of a provider and a disrupter. So if we look at the Arctic in a global context, on the right here, you see a graphic that was put together by the Intergovernmental Panel on Climate Change in a special report a couple of years ago, that looks at various aspects of the global system, the Earth system, in terms of their responses, and potentially disruptive impacts and risks as a result of global warming largely driven by increases in human caused greenhouse gas emissions. And you'll notice here, the Arctic called out. Apart from warm water called coral regions, the Arctic is a region that at a projected 1.5 centigrade degree global warming, which we know in the Arctic will take the form of an even greater warming through a process that I'll briefly mentioned here, the amplification or the increase of a global increase in temperature in the Arctic, by a factor of about two to three. This warming here, indicated on the scale here in the left-and apologies to my American colleagues, this is in Centigrade, and not in Fahrenheit-the warming for the Arctic region, based on both observations and models, is projected to come with severe and widespread impacts and risks. And in particular, a component of strong irreversibility such that many of the changes that we expect to see or are already seeing happening now in particular, those to the cryosphere, such as permafrost, are not reversible in the near term. And those are those are important points to keep in mind as well as we think about disruption. And of course, a lot of these changes also have global repercussions, as I've already pointed out. So this is this is one aspect of the of global impacts. The other is something that Mike Sfraga already briefly alluded to, and that is the rapid rate of warming of the Arctic. If you look at this figure, or the two panels here on the right, what you see is a comparison, the dash bar here on the left shown for different regions of the earth, North America over here, and then towards the right, you have the Arctic, you'll notice that for the time period 1851 to 1930, the rate of change of temperature for most of the globe is roughly located around zero degrees Centigrade per decade. So, you have both up swings and down swings of temperature, natural variations. But then, as global warming has started to impact us more significantly, for the time period 1971 to 2020, you notice that in recent years here, you see an increase in the rate of temperature change to roughly 0.4-05 degrees Centigrade per decade for the Arctic. And that is much larger than for any of the other areas which are also expected to warm, save with the exception of parts of Europe that are going to experience or have experienced significant warming rates as well. So, the other aspect to keep in mind here is that this temperature change and rate of change will continue to remain at very high levels throughout the course of much of the century, much larger than for any of the other regions of the globe. So, you can see here that we've already started to enter into this area of much, much greater temperature increase. And this is this is something that the Earth has not experienced in recent times these rapid rates of change. And so the rate of change in itself is a key aspect of disruptive change and something that may leave us not as well prepared in terms of understanding how the Earth and the Earth system respond to some of what we're seeing happening now. So, how does that change express itself regionally? In a study here, Timothy Lenten looked at so-called "tipping elements" of the Arctic, in the context of the Earth system. So changes in external forcing. So, this, this would be changes, for example, in our case of greatest interest right now, changes in the greenhouse gas concentrations in the atmosphere can induce changes in state. That is the state of, for example, the Arctic Ocean in terms of temperature, or salinity, the state of the sea ice cover in terms of its thickness, and its lateral extent. And some of these changes may then result in irreversible transitions into new states of these different components of the Arctic. And important elements that you see called out here include, for example, the boreal forest that covers much of the northern parts of the North American continent and Siberia, you'll see also changes in the marine realm here for different parts of the Arctic Ocean, that's something that Marcel Babin will talk about a bit more. I'll briefly cover this as well. And then you see, parts of the cryosphere called out here, such as Arctic Sea ice cover, different aspects of permafrost. And a lot of these elements here are in fact directly or indirectly linked to changes in the Arctic snow and ice cover. I'll cover some of the aspects of the work that researchers at the institute I'm leading, the International Arctic Research Center, are currently studying in terms of disruptive change. This here is another perspective on these elements, tipping elements of the Arctic System and their response and potentially disruptive response in terms of the global warming in terms of temperature and degrees Centigrade here and again, I'd just like to highlight that the Arctic summer sea ice, an important aspect of the Arctic System, is particularly susceptible to disruptive change, something I'll cover in a bit more detail here in a moment.

So, let's briefly talk about the cryosphere as a defining element of the Arctic. The figure you see here gives you a glimpse of the interrelatedness between a range of different processes and human activities that make the Arctic important as a so called social environmental system. But you'll notice that a lot of these, these activities and arrows here, in some form or another, are associated with different forms of snow and ice, whether it's floating sea ice, permafrost on land, the snow cover, play a disproportionately important role in the Arctic. I'd also like to point out that the Arctic Ocean is an important element of the global ocean system in terms of heat, and nutrient exchange, and again, this is something that we're Marcel Babin and we'll talk a bit more about with respect to implications for the biology of the region. Another important point to keep in mind, in particular, from a legal perspective is that one quarter of the Arctic Ocean, or sorry, the Arctic shelf seas, so the shallow water areas that are lining the landmass of surrounding the Arctic, these shallow shelf seas account for a quarter of the global shelf seas, and make the Arctic an interesting region also from the perspective of International Law of the Sea, because of the implications in terms of national jurisdictions. And that's something that some of the speakers later in this meeting here will probably cover in more detail. And then of course, another thing that we're intimately familiar with both in Canada and the US are midlatitude weather linkages to the Arctic itself, something that I'm not going to cover in, in more detail here. So, let's talk a bit about the components of the cryosphere here. This This map illustrates the regional distribution of key elements of the cryosphere; you see here shown, in different shades of brown, the distribution of permafrost in particular continuous or, discontinuous permafrost here so you see much of Alaska and Canada, being underlined by permafrost. On the marine side you have shown here for the year 2012. The summer minimum sea ice extent and wintertime, sea ice covers much more extensive. And then, of course, you have the seasonal snow cover. Seasonal snow and sea ice are much more dynamic in terms of responses to the change in climate, the permafrost and the ice sheets and glaciers in particular, the Greenland ice sheet here have a more sluggish response. But all of these responses to a warming climate have larger scale implications, both in terms of the albedo the ability of snow to reflect a vast proportion of the incoming sunlight. High albedo of snow and ice surfaces is a key element of its role as a climate regulator, and in particular, over the oceans loss of sea ice goes along with a lowering of the albedo, and an increase in the amount of solar heat absorbed by the earth system. But then also overland, the release of methane potent greenhouse gas from thawing permafrost and key aspects of ocean circulation here, and sea level are important aspects of the role of the cryosphere.

So, let's briefly talk about sea ice changes in terms of drivers and consequences in a bit more detail, because that helps illustrate the disruptive nature of some of these changes that we're observing. So shown here is a is a map of the of the Arctic Ocean for fall October of 2019. And what you see here is the so-called sea ice concentration anomaly for October 2019. That is a measure of the amount of sea ice that is present in this region, relative to the long term mean for the past 30 years. So what you might call the longer-term climate. And you'll notice here that for this month of October 2019, large areas, in particular of the Siberian and North American Arctic have experienced ice amounts or ice concentrations, well below those normally found. These areas are actually mostly open water still at this time of year in October 2019. And these, these larger openings, in fact, are one key aspect of the loss of the perennial ice cover the year-round ice cover of the central Arctic Ocean that we've seen play out over the past few decades. Reduce ice extent, has several implications. It has coastal impacts. If you recall, I showed you that photo of wood Kavik in northern Alaska here at the tip of the landmass. So these large amounts of open water here expose the coastlines, more implications for coastal erosion, but they also provide, of course, greater access. So it gets back to this question of commerce that Mike Sfraga already pointed out, but in general, what we're finding is that even the perennial ice here in the central Arctic Ocean is more mobile. And this greater ice mobility also, apart from greater access, is associated with significant ice hazards. It's important, again, to keep in mind the rapidity of this change. In Alaska, we've looked at this in more detail through a combination of collaborations with Indigenous Yupik, and Inukjuak ice experts in coastal communities, remote sensing data and modeling. And we've seen a reduction in the length of the sea ice season by about two to three weeks per decade, since the 1970s. So you now have several months, longer open water extent, and that has major implications. One point I wanted to make in the context of loss of summer sea ice is that we understand very well that this loss of summer sea ice is associated with increase in greenhouse gas concentration, specifically $CO_2$, carbon dioxide. The panel I'm going to write here is from a paper by Dr. Knotts, Julian Struga, and it chose the shown as plots here and as a line, based on observations from remote sensing data gives you perspective on the amount of sea ice area that remains at the end of summer melt in September, throughout the Arctic, in relation to the cumulative amount of total amount of $CO_2$ accumulated in the atmosphere over the same time period here and you can see that as the total amount of $CO_2$ increases, shown at the bottom axis here, there is an associated or a direct correlation here in terms of reduction of the sea ice area. This is a phenomenon that's well understood both in terms of observations the processes involved The lines here are Earth's system models that also provide projections through the end of the century, you see a significant scatter and in some of the models here, but overall, all of them are able to replicate this reduction very well, and the best models are actually able now to give us a quite accurate perspective on this loss of sea ice. The reason this figure may also be of interest in the context of this conference, the co-chairs alluded to this earlier, by holding the meeting virtually and not having people fly, including myself, to be present in Cleveland in-person, we're actually indirectly, helping preserve part of the Arctic Sea ice cover. Knots and Struga have presented an interesting way of thinking about sea ice loss in terms of every metric tonne of $CO_2$ emitted based on this relationship shown here, is responsible for the sustained loss of roughly three square meters of sea ice. And if you if you think about personal production of $CO_2$, I'm looking at my carbon footprint very carefully. We're trying to stay for our home here at a per capita level of about 25 to 30 tons. But that already, as you can see would be a corresponding significant reduction and sea ice extent. So that's an important aspect, is the fact that greenhouse gas emissions result in sea ice loss, that sea ice loss and turn though has larger scale climate regulation impacts. And it's these connections here, again, that are the underpinnings of some of the disruptive change we're seeing in the Arctic. The same type of thing is true for winter sea ice extent changes. Here's the corresponding image here from March, where you see large scale loss of sea ice, some in the Bering Sea. Just one aspect that may be relevant in the later parts of the conference here as well as that Bering Strait now is ice choked, so Bering Strait over here, for less than two months of the year. And that actually has significant national security and maritime transport implications that some of the other experts later on in the conference might like give you more perspectives on. I also want to make sure that I point out here that the observations at the local scale, and indigenous or Arctic coastal communities give us a much more detailed and nuanced picture of how these changes play out. For example, Inupiaq, in northern Alaska here, these are images and summaries for the same year 2019, from an observing program that's led out of the International Arctic Research Center with a number of Indigenous observers. I just want to highlight here, observations from

Guy Omnik from Point Hope, who compares his ability to fish from the ice in October of 2011 here was October 2019, where you see complete absence of sea ice, so these changes at the community level are quite significant. And you'll be hearing more later in the conference from Dr. Dalee Sambo Dorough the chair of the Inuit Circumpolar Council, who can provide a much better perspective of what this means in the context of Indigenous peoples impacts.

So then, just to conclude here with a brief aspect of one component of disruptive change that I see also as a transition to some of the things that Marcel Babin is going to talk about, I'd just like to highlight some recent findings from a large, now going on to 20 year long-term observing program of Arctic change in the marine sector of the Arctic here across the Siberian shelves led by Igor Polyakov, one of our research professors here at the International Arctic Research Center, looking at the role of ocean heat, both in ascending and shrinking of the ice cover, but also in other contexts. So what you see here on the left is a conceptual diagram of the Arctic Ocean that shows basically the surface layer of the Arctic, these blue arrows here that sea ice and ocean water moved around and circulation patterns of the Beaufort Gyre and the so-called Transpolar drift. The surface ocean, if you look at this cross section of the ocean here, in terms of temperature, typically is relatively cold, very close to the freezing point of the upper 50-100 meters. It's also much fresher in terms of its salinity than the underlying water layers at depth at depths of greater than 100-200 meters. You have the so called warm Atlantic water that comes in from the north Atlantic and spreads throughout the Arctic Ocean. And one important aspect that has only recently been appreciated in the implications and its magnitude is the fact that this Atlantic water layer, a great reservoir of heat, has been moving towards the surface here are data for the past decade from 2013 to 2015, 2018. For this part of the Arctic, these warmer Arctic waters moving up, is putting more heat into the surface ocean, and not just contributing to the warming of the upper ocean loss of sea ice, but also increase in the nutrient concentrations in the upper ocean, something that Marcel Babin will be talking about a bit more.

So then, in terms of conclusions, what does this all mean? I just like to think about this in a bit more of a temporal context, shown here are timescales at the bottom timescales relevant for the natural environment, ranging from the seasonal variations that we see to inter annual variations, longer term variations on the scale of 10-30 years, and then multi decadal variations, and superimposed on all of this now rapid change of climate both in the Arctic and outside, what we're grappling with, from my perspective is the challenge these changes now present in terms of impacts of infrastructure, much of the infrastructure is built and designed with a stable climate in mind, designed for lifetimes on the order of about 30 years or so some urban community infrastructure, longer lifetimes. And we're finding now that with these changes, that are repetitive the change and its magnitude and peculiar changes in the cryosphere in the Arctic, are challenging a lot of these infrastructure underpinnings that are important to a number of processes. And the same thing could be said, potentially-and that's something later parts of the meeting can speak to-about how this rapid change is changing, both challenging both legislative or business adaptation responses, as well as the longer-term responses to the Arctic. So to conclude, keep clients, the Arctic cryosphere, particular as an important component of the Arctic as a provider and disrupter, the rate of change of challenges are that we're seeing, challenges, responses, and those who need to respond to art to change and require attention. And I'd be happy to take more questions down the line. Thanks.

Dr. SFRAGA: Thank you very much. Hajo, outstanding presentation, especially, you know, somewhere around four or five o'clock in the morning in Alaska. That's sort of outstanding for noon. But I appreciate that presentation very much. And Hajo did welcome questions. And I would also welcome questions with both of our experts here today. So if you do have questions, please send those in, and we'll follow up as time allows. So now, Marcel, I will turn over the virtual floor to you and then we'll come back for hopefully some questions from the audience. I certainly do have some themes that I'd like to explore as well.

DR. MARCEL BABIN: Do you see my slides? Dr. SFRAGA: Yes, we can.

Dr. BABIN: Good, thank you very much. I will follow up on Hajo's presentation with some reports of the impacts of ongoing changes in the Arctic on ecosystems. I will put some emphasis on marine ecosystems, but not only. And I will also emphasize the fact that the Arctic is really a sentinel of global change with many respects. So, just to summarize, what we've heard from Hajo, the rate of increase in temperature in Arctic is high, is the highest on Earth. So that's one major change that takes place in the Arctic and has an impact on ecosystems. We've heard also that the extent of the ice pack on the Arctic Ocean is decreasing as we show here with the black line. And numerical models predict that during summer, we will, we will reach an ice-free Arctic Ocean within the coming decades and probably-

Dr. SFRAGA: -I'm sorry, may interrupt you. Are you going through your slides because I'm just seeing the cover slide.

Dr. BABIN: Yes, I am.

Dr. SFRAGA: Okay, apparently it's not advancing. At least I can't see it advance.

Dr. BABIN: And now you don't see me.

Dr. SFRAGA: I still just see the cover slide. Maybe we can ask our colleagues from the conference to help us a bit here.

Dr. EICKEN: Marcel, maybe you might want to just stop sharing and then try sharing again. Okay. Mike, while Marcel's working on that. Do you want to take one of the questions here?

Dr. SFRAGA: I do. You know the wonderful thing about the Arctic is we all know each other and both of my cell phones or I don't know what's happening on the on the chat, but I had my cell phone. So, I've been writing them down. Hajo, one of the things you mentioned is irreversible change. One of the questions that came in is, is this ever reversible? If we were to meet, you know, climate $CO_2$ goals that are discussed this week, if we were to do all the things that we've heard about from policymakers, will we ever return to the Arctic that we have known or something close to it? Are we simply just going to have to live with an Arctic that has changed, it's just a matter of degree of change?

Dr. EICKEN: So, I mentioned this also for the, for the permafrost, sluggish response. So, part of that change is reversible, but will require as we now know, several decades to play out. So, even if we were to stop emitting greenhouse gases, this moment, the way $CO_2$ and other greenhouse gases are redistributed through the system, and the way in particular, Arctic, elements of the cryosphere, respond is such that some changes will take time to play out. Sea ice, fortunately, is a very rapid responder. So, in that context, it responds quickly, you know, on timescales of a year to two to those changes. So that's the good news. But some other elements of the Arctic, in particular, permafrost degradation are clearly irreversible.

Dr. SFRAGA: Thank you very much for that. Marcel. We're starting to see your slides again. So, there we go. You're, you're now on target. Thank you.

Dr. BABIN: And can you hear me? Dr. SFRAGA: Yes, we can hear you.

Dr. BABIN: Okay, good. switched on my portable laptop computer. Okay. All right. So, yeah, I was just recalling that the Arctic is the most rapidly warming region of the world. And you see the next slide?

Dr. SFRAGA: Yes.

Dr. BABIN: Okay. And that the extent of the ice pack is decreasing very rapidly, it may disappear during summer, before the end of the century. And one other major change that is maybe a little bit more subtle, is the increase in the amount of freshwater that arise in the Arctic Ocean, either through precipitation or through the run ups. So, because of an increase of precipitation over the watershed, but also because of the glaciers melting. We see this this freshwater coming in the Arctic Ocean, it makes the ocean surface pressure, and this pressure water flows a little bit like oil on the on water and it kind of prevents the ocean from being readily mixed, which we will see may be a problem for ecosystems. The other impact of freshening also is that may make the Arctic Ocean more sensitive to acidification. So, what are the impacts on ecosystems? I will start with the ocean, because the ocean is where most of life is present in the Arctic, as you can see on this picture lands are very high latitude. There is not much life on it simply because it's very cold. Mostly because it's very cold. It's a little bit like on high mountains. If you imagine where at very high altitudes, you find that kind of landscape as well. And this is related to temperature, while in the ocean. The temperature is never much below zero degrees. It's most -1.8 or so it's never -40. And for that reason, the ocean is kind of is like an oasis. And it's really where you find life in the Arctic, and most living organisms in the end, depend on the ocean, even those that do not live in the ocean. This drawing shows is just is a very simple representation of marine ecosystems in the Arctic Ocean. It's a rather simple network, simpler network of organisms with general lower diversity and at lower latitudes. And so, you see the main components here with which a number of microbes and then you see fishes, especially the Arctic cod, which is a very important species in the Arctic. The small animals and fish, feed fish, larger fishes, as well as marine mammals. And also because a large fraction of the Arctic Ocean is rather shallow, much of the algae that are produced at surface and up on the bottom, where they feed a rich fauna of sea bottom organisms, and the marine mammals, some marine mammals feed on these organisms. So, you see, you see how it works. And it's pretty tightly coupled. One important component on this of this network is what you see in the within the red circles is really what we call the micro algae. The micro algae is really, most of the biomass in the ocean takes the form of micro algae and not a large algae, the large algae you see on the [inaudible] represents a small fraction only of the biomass of the plant biomass in the ocean globally. And plant biomass in the ocean represents, I mean, the amount of carbon fixed by plant biomass in the ocean is as important as the amount of carbon fixed by plant biomass on land. So it is small, but it is very significant. And in Arctic as anywhere in the ocean, those micro algae makes life possible in the ocean, they are the basis of the food chain. They use sunlight to produce organic matter that can get then be consumed by other organisms through the fruit, the food web. So, we'll see that the current changes taking place in the Arctic first affect this level of the food chain, the microbiology. So, what we know now, thanks to satellites, because we can see them from space simply by looking by measuring the changes in the color of sea water, we could we have figured out that the production of the amount of biomass adults, those micro algae produce within a year has increased since the end of the 90s. To now by more than 40%, as you can see on this plot. And this increase is due partly to the decrease in the extent of sea ice. The sea ice acts as a blanket on the ocean; when you remove it, there is more lights. And these are plants, they like light. So they grow more. That's one reason. The other reason is that it seems that the ocean may be more mixed as well, because when you remove sea ice, you expose the ocean to the wind and to some interactions with the atmosphere, which may promote some mixing, which is good for algae, because mixing brings nutrients at the surface. So that's one impact. It seems that the Arctic Ocean would become more productive in that sense. But there are other reports that that say the opposite. In some regions of the Arctic Ocean and as especially in well, in the high Arctic, in what we call the Beaufort Gyre of Alaska and Yukon in the center of the Arctic. There it seems that the increased amount of freshwater coming to the ocean accumulates and make this part of the Arctic Ocean less prone to mixing, which would transform the Arctic Ocean into a desert. So this is this is what these little graphics show. If you look at this curve, what you see here is the decrease in the salinity of seawater at surface from 2004 to 2010. So it's very short period. But we did observe a significant decrease in the salinity; water is getting fresher. In parallel, we have observed that that's the ocean, the surface of the ocean. During that same period, there is less now there is less nutrients available for those micro algae. And the effect of those changes is the following. First, we, what we observed is that the amount of large the larger microbiology, like the diatoms, which are really the ones that feeds the higher trophic levels of the food chain, the amount of those algae is decreasing, while the amount of the much smaller algae, much smaller few microbes, which are typical of desert oceans, the amount of those algae is increasing. So, you see we have some contradictory results about the productivity of the ocean and the impact of current changes on the productivity. Now, I just talked, I only talked about biomass and the amount of biomass. But, if we just have, for a brief moment, a closer look to species, to more specific group of algae or other organisms, it seems that there may be species living in the South that would be invading the Arctic Ocean, as it gets warmer, sea water gets warmer as well. The conditions in general get more favorable to species living in the South. And those species may either replace our typical Arctic species, or also we may see coming some species of microbiology, for instance, that are harmful. So one example of documented expansion of a southern species in the Arctic is this small micro algae that you see here that is just a few micron large, it's very small. But in the North Atlantic, for instance, when they grow, and they bloom during spring, mostly, they cover the ocean. And the nice thing is that because their cell wall is made of calcite, of chalk, and makes the water white, wider, and this can be observed from space. So you see here, for instance, on this picture below, you can see such a bloom of these coccolithophores of Brittany and Southcombe, UK, you can see that it's easy to see them. So the nice thing with this species, which is a kind of sentinel, is that you can follow it from space with satellites. And we could show recently that in the Bering Sea, north of Norway, we could see that the blooms of this species, the extent of the blooms, has progressed towards the north. So, you can see here the dashed red line, that's the Northern Limit of blooms of this species in 1998. And the full red line here shows the position of the Northern limits of blooms of the species and 2050. So, it's a nice example and it does demonstrate that some species are indeed invading the Arctic.

Okay, now, let's look at other levels of this, this traffic network of other organisms in these ecosystems that you can see on this drawing, I will one example for the region of the Bering Strait, which has been very well documented, thanks to the distributed biological observatory for many years now, and they did document the response of the ecosystems at several levels of the food chain. So we have kind of a complete story. It's a region that is very productive. As you know, the Bering Sea is very productive place, where the fisheries are quite successful. It's one of the most productive places in the in the Arctic Ocean And we've seen major modification in this region as well. So what you see on the right panel is the changes in sea ice. The red and yellow color show places where there is less sea ice than there used to be, and on the right, the yellow and red areas show places where the production of biomass has increased as a response to the decrease in sea ice, so there, also, we do see an increase in primary production, that it seems to be due to a decrease in sea ice. However, it may look surprising, but if you look at the fauna that lives on this ocean bottoms and especially at some bivalves, that are very important, because they, they, they those bivalves are food for sea dogs, seals, walrus and some whales. So you see the blue dots, and you see this trend over since the middle of the end of the 80s. to nearly now, you can see that the amount of some of the bivalves those bivlaves, especially, that are used by these birds, and marine mammals, their amount is decreasing, while what you see in red is an increase in the amount of another species, but that is not used as food by diving ducks, for instance. And this is due to the fact that while there is more biomass produced at the surface, all this biomass does not reach the bottom, it's just consumed by other organisms in the water column before it reaches the bottom. And what it indicates is simply that the whole structure of this food web is changing; there is more species from the south, species of fishes, species of plankton, at about every level of the food chain, we do see modifications and modifications of the species that are present. Now on land, just briefly on land, so the most spectacular modification of land ecosystem takes place in permafrost, the soil that is always frozen, and contains a huge amount of organic carbon, twice the amount that we find in the in the atmosphere. And this carbon is sequestered, however, because this permafrost, which is just frozen ground over 10s, and 100s of meters, is starting to thaw. And at surface, this thawing just elicits degradation by bacteria-some of them produce $CO_2$, and some of them produce methane. And so, you probably know that the amount of these green gasses released by permafrost, because it's thawing, is increasing. At the same time what we do observe is a northward expansion of the tree line, as you can see on those two pictures, one taken in 1988, in Nunavik, Northern Quebec, and another one in 2008. And as you can see, there is much more vegetation, which modifies also the response of permafrost to climate change. It has an impact, of course, also, on living organisms. And finally, those modifications in permafrost also have an impact on all kinds of infrastructures, including landing strips, and roads, for instance, and other impacts that Hajo has shown in his presentation.

Now, I've talked mostly about the impact of global warming on the Arctic. But there's many other things taking place in the Arctic, and some of them are not directly related to global warming, for instance, pollution. Pollution is one of the major issues, environmental issues and they are taking place in the Arctic. And that pollution is mostly produced elsewhere and transported by the atmosphere to the Arctic. So while one may think that the Arctic is a clean place, in fact, it does receive a number of long-range pollutants, like persistent organic pollutants and mercury and other ones. And those pollutants, they kind of precipitate in different ecosystems, marine land ecosystems, and then they are transported by freshwater for instance, and they get accumulated they get absorbed by living organisms and bio accumulated. That's one major problem that we do observe.

So, that will be it for my short review of some of the major changes taking place in the Arctic. I will conclude with these few slides. The first one, just asks the following question what's needed to scientifically address Arctic environmental issues? Well, first, I think we still need massive extensive process studies, scientific studies, multidisciplinary, with experts, and many different fields, very well organized around major projects. What we need also is more data. More data collected from multiple platforms, which include satellites, icebreakers, land-based research stations, are collected by scientist, I'm thinking also about community-based monitoring, we need much more data and some of those data could be collected using new observing technologies, such as some that you can see on this slide. Why new observing technologies? Well, first to collect more and better data, but also, to compensate for the fact that the Arctic is large, not many people live in the Arctic, it's hardly accessible, especially in winter, so that we really lack data to understand what's going on there and how the system works in general, so that it's hard to predict what will happen. And, for instance, we don't know so much about what's happening during the winter. And while winter is very important season, in fact, the Arctic ecosystems are not sleeping in winter. One of such technologies is one that you see here on this app, this picture, it's a bio Argo float, it's a float that is deployed at the moment, everywhere and the world ocean, you can see on the map here, the position of all the floats that are active at the moment, nearly 4000 subs everywhere in the world ocean, but there's not many in the Arctic Ocean, we have started only recently to deploy those flows that can collect and transmit data from the ocean. Over one, two or even three years, they can overwinter under sea ice. We did an experiment, this deployment of such floats in Baffin Bay, for instance, to study the dynamics of micro algae blooms. So just to conclude, most of the documented impacts that I've shown in this presentation are due to global change and are not produced locally in fact. And that therefore the solutions are to be found mostly globally, we can, of course, mitigate the impact locally, but we cannot prevent those changes to take place unless we address them globally. Thank you.

Dr. SFRAGA: Thank you, Marcel, very much for that presentation. I thank you both for explaining in a very straightforward and meaningful way very complex issues. Linking the oceans to land, and I think provides for everybody here a context for the rest of today's conference. I've noted a couple of questions. We have about 10 minutes or so, maybe less, for some questions. I've noted a number of questions in no particular order, but I noticed one and then it went away but it's to Hajo specifically, and then we'll get to the to the research components. But specifically, you captured someone someone's imagination, when you noted that you are tracking your own carbon footprint. And this individual is wondering how you are doing that and what tools and techniques you're using.

Dr. EICKEN: Thanks, Mike and I actually posted two links to this in the Q&A section. So if you for those Zoom participants if you click on Q&A And you'll find the links. One is by the US Environmental Protection Agency, the one I use is by the Nature Conservancy. And I mean, it's sort of an interesting aspect. Alaska Airlines, for example, which Mike and I support-you know, also so we definitely do our fair share, even though we're trying to minimize this-just recently announced a couple of days ago that they're planning to go carbon neutral, by 2030. So there's a lot happening in the airline industry in particular, this year is the first year that under ITA, the International Transportation Agreement, airlines have to provide offsets for carbon. So there's increasing recognition that keeping track of these aspects of human activities is important and has impacts on the Arctic. I would like to point out just briefly, since you bring this up that there's also another aspect to this, I mentioned that the Arctic performs important services on a global scale. There are some companies that have looked at certification of specific products through an Arctic sustainability lens. So one of the examples, I had some of my students, and one of the courses I taught look at a bit more detail is, in fact, a paper company that was using model output to demonstrate that their impacts on the Arctic environment are substantially less than then their major competitors. So there's an increasing recognition of these global connections that Marcel was talking about as well.

Dr. SFRAGA: Thank you. So, another question. I'll just read it, you can see it, but let me read it for everyone else, several world leaders, including President Biden and Prime Minister Trudeau met yesterday to discuss climate change. A number of states set more ambitious and emissions goals reduction targets. Are the goals established yesterday, sufficient to mitigate a climate crisis in the Arctic? Or is more Arctic specific action required? And either of you can take that one first.

Dr. BABIN: Well, as I concluded, I mean, if we cannot prevent what's happening at the moments unless we take action at the global level, because, I mean, what we observe in sea ice, for instance, is due to global warming, not to local warming. And it's the same with invading species coming from the south. It's the same for thawing permafrost. Of course, we can take local actions, just to kind of mitigate the impact on people, on infrastructure, we can deal with those changes to make them the least harmful possible. But I think we should really also look at the Arctic as one of the best sentinels of what's taking place at the global level. And we should always often put this forward to call for global actions.

Dr. SFRAGA: I have comments on that before I move on to the next.

Dr. EICKEN: No, I think that that's a great point, Marcel. I mean, the only other thing I would add is that keeping in mind also that if it whatever global temperature increase we're talking about, you have to double to potentially quadruple that for the Arctic, right. So we are now already committed to a warming of the Arctic region that's on the order of 3-5 degrees Centigrade. That's very important to point out. And that is, of course, a bigger issue in the context of environmental and climate justice. That has been an increasing topic of discussion. And again, I would point to Dr. Dalee, somebody who has a background in law, who I think will have a very, will have an important perspective on this topic.

Dr. SFRAGA: Thank you. A question, I know we only have a few minutes left. Thinking through from both of your perspectives, right. This is what the work you have provided for, the work you do and have communicated today is fundamentally important, fundamentally important to all of us globally, not just in the Arctic. My question to you is, thinking about the audience that we're standing before, virtually standing and sitting before, the question is, how do you each communicate to lawmakers, policymakers, those who influence both the policies for the Arctic, but also the research agenda for different countries, whether it's nationally or internationally? How do you communicate these complex systems and change to lawmakers and policymakers in a way that they get it and then can apply I wouldn't have shared with them in some meaningful manner?

Dr. EICKEN: If I may. I mean, these are these are complex issues, right. One of our faculty just defended her PhD in climate science, science communication from George Mason University on Monday, Dr. Kristen Tim, she's looked in great detail at how the US National Climate Assessment has been framed as a topic in the media very interesting findings. I think what climate or what science communication, cognitive psychology and other branches of social sciences are teaching us is that the classic communication models just do not work in the circumstances. Now, of course, in the US, congressional staffers, in Canada, parliamentarian staffers are very, very sophisticated people that work closely with the research community and others, to make sure that they have the best available science. But in many respects, I think we have to rethink some of the models of how the research community engages in the policymaking process, drawing on principles of what's commonly referred to as knowledge co-production, where you where you jointly define the problem, or at least, are involved. And be sure that the legislative process, if you will, in the broader public helps to define the problems that the research community addresses, I'd just like to point out that that the recognition that this is an important issue is, for example, the fact that, outside of the Arctic Council, outside of other agreements, you have a meeting of the science ministers of around 30 or so countries, the so-called third Arctic Science Ministerial, that's being hosted jointly by Iceland, as a former chair of the or still current chair of the Arctic Council in Japan, to be held in Tokyo in a couple of weeks' time. And that process, for example, the fact that you have the science ministers meet, because they want to do something about climate change in the Arctic specifically and respond to Arctic change is a great sign that there's recognition at the highest levels of the executive of these communities. But I think at the same time, I'm a member of the science advisory board for that current Arctic Science Ministerial. My sense is that, though those higher levels of government are also still grappling with what are the best processes that you can put in place to respond quickly enough? That's the big challenge. That's the gears of the Arctic Council, and some of these other bodies are grinding very, very slowly. No offense to those who are active in those venues. That's an important work, but you just have to consider that as well. Marcel, we have about a minute left, do you want to weigh in on that question?

Dr. BABIN: Well, it's always very challenging for us to connect with lawmakers and policymakers. I'm going to say as you can see, the kind of stuff we are presenting, you know, microalgae are not the most charismatic organisms, you know, compared with polar bears. And, and it's, again, we do all kinds of outreach activities, you know, to make this kind of make it interesting, but I mean, it's science. But fortunately, there are processes like the IPCC reports, which I think do a pretty good job. I mean, there was this special report on oceans and the cryosphere, which do distill, you know, all the information coming from the scientific community into the quite simple documents, a more detailed one, and one that is dedicated to policymakers and lawmakers. I think that those reports should be read, I think they contain the essential information. And it's really written for them. So I guess that's one successful approach. And it's a very solid approach.

Dr. SFRAGA: Thank you very much. And thanks to Marcel and Hajo for spending the morning here kicking off I think the conference in a in a most productive way, laying the foundation, I'm sure for the rest of these discussions. Thank you both for that. And thank you all for listening. I think if we were all in an auditorium, they'd be big round of applause. But Steve, I want to turn this back over to you and once again, thank my colleagues here for sharing their expertise and their insights. Steve, back to you.

Mr. PETRAS: Yeah, thank you, Mike, Hajo and Marcel, for providing us a deep look at the physical disruptions of climate change in the Arctic. outstanding presentation and you certainly set the stage with distinction for the rest of our conference. It's now time for a short break, about approximately four minutes I see. We will start again at 10am sharp, so please be back in four minutes. Thanks.