Impacts of Climate Change and Melting Glaciers on the Gulf of Alaska

Webinar Transcript

Speakers:
John Crusius, USGS Coastal and Marine Geology Program

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Ashley Fortune: Good afternoon or good morning from the U.S. Fish and Wildlife Service's National Conservation Training Center in Shepherdstown, West Virginia. My name is Ashley Fortune, and I would like to welcome you to today's broadcast of the NCCWSC's Climate Change Science and Management Webinar Series. This series is held in partnership with the U.S. Geological Survey's National Climate Change and Wildlife Science Center. Today's webinar will focus on the impacts of melting glaciers on nutrient supply in coastal ecosystems of the northern Gulf of Alaska. Our speaker today is Dr. John Crusius.

John received a BA in Chemistry from Carleton College and a PhD in Geochemistry from Columbia University and the Lamont-Doherty Earth Observatory. John did postdoctoral work at the University of British Columbia in Vancouver and worked for a while as a research scientist at the International Atomic Energy Agency Marine Environment Lab in Monaco.

From 2003 to 2011, John was a research scientist in Woods Hole at the USGS Coastal and Marine Geology Center. Since 2011, John has remained a USGS research scientist with the Coastal and Marine Geology Program, but he is based in Seattle at the University of Washington, where he has an affiliate faculty position in the School of Oceanography. John is married and has one son in high school.

John, that's quite the experience. Everyone, please welcome John, and you may begin. Thank you.

John Crusius: Thanks a lot, Ashley, and thanks for your help setting up. Good afternoon, everyone, or good morning, depending on which time zone you're in. Today, I'd like to speak on "Impacts of Melting Glaciers on Nutrient Supplyand Coastal Ecosystems of the Northern Gulf of Alaska." I want to acknowledge a lot of collaborators who did a lot of this work. I'm going to give a broad overview. I've listed a lot of people here. I don't have time to acknowledge them all individually. In particular, I want to acknowledge funding from the USGS National Climate Change and Wildlife Science Center, from the Coastal Marine Geology Program, and from the Mendenhall Postdoctoral Fellowship Program. I'm going to speak briefly on some NASA-funded work of ours that is relevant to the overall project.

Here's an outline of what I want to present today. This is a challenging talk because this is a large, multi-investigator study, and I'm trying to summarize what a lot of people did in 45 minutes. Pretty much every slide I present could be expanded into a 45 minute talk, so I'm going to try to cover a lot of ground. I'm also going to try to keep it accessible to a fairly general audience while maintaining the scientific integrity, so please bear with me. I'll try to keep you with me as I go.

Just to give you an outline, I'm going to speak briefly on the evidence for glacier mass loss, from the northern Gulf of Alaska in particular. I'm going to examine the marine food web foundations, including nutrients nitrate and iron, which limit phytoplankton growth. I hope I will convince you that glaciers are a source of iron, which is a nutrient that limits phytoplankton growth and that rivers and sediment resuspension and dust are all important sources of the micronutrient iron.

I'm going to discuss some seasonal variability in the nutrient sources and allude to the fact that there's hyperactivity in the spring along the continental shelf transect that we studied in response to this high nutrient supply. By late summer, nitrate is the limiting nutrient.

Zooplankton and fish abundance tend to be high in the river plume that we studied, the Copper River plume, for reasons of predator evasion. Then I'm going to end with some model simulations of Copper River discharge into the Gulf of Alaska, including some simulations of two times present discharge and discuss some impacts of that.

Here are some results from a recent paper from the journal "Nature" showing evidence for glacier mass loss worldwide, although I'm focusing strictly on the northern Gulf of Alaska area glaciers. Here's a map of North America that you'll all recognize, and here's Alaska. You see this southern Alaska region at the northern end of what we refer to as the Gulf of Alaska, this being the Gulf of Alaska right where the number 12 is.

This area is lined by many mountain glaciers, and there's a paper, this paper that I mentioned in "Nature," which documented mass loss of these glaciers over the time period 2003 to 2011 using the GRACE Satellite. What you see here from 2003 to 2011 is mass increasing in the winter, decreasing in the summer and that cycle repeating over and over again, but there's a general downward trend that's pretty much indisputable over that time frame.

There have been a lot of high profile papers on this general topic in recent years, and I could have picked any number of them. I picked this one mainly because it's quite recent, it was in the journal "Nature," and it actually shows data from this southern Alaska region.

Some work that is relevant that was done by one of our USGS team members, I'm presenting here. This is work done on the Bering Glacier from 2002 to 2012. Our project really included fieldwork only from 2010 and 2011, so this represents a whole lot of extra effort by the lead author, Ed Josberger. This is work from the Bering Glacier at the northern end of the Gulf of Alaska. It's just a little bit east of the Copper River, for those of you who know where that is, and I'll show you that in a minute.

This is a little bit different from the last paper I alluded to. This is documenting summer melt as a function of time from 2002 to 2012, and it teases apart the contributions to that melt of ice melt, snow melt, and precipitation. What's striking, to me anyway, is that there's surprisingly little variability during this 10-year time frame, fairly steady melt of 40 plus or minus 3 cubic kilometers per year. A little bit of up and down as time goes on but not a really noticeable temporal trend showing an increase over time.

This line with the diamonds connecting it shows melting degree days, a measure of the warmth, essentially, during the summer melt period. Sure enough, during warmer periods, as you might expect, there's more melt and less melt during colder days, but there is not an overall trend.

I want to emphasize that this is not really in conflict with the previous slide because this is only showing the summer melt. This is not looking at the annual mass balance, but interestingly, over this 10-year time period, there's not an increase in melt over time. I'm going to come back to this analysis of what might happen in the future a little bit later.

This is a map, obviously, of North America, primarily, and here is the Gulf of Alaska area. Here is this coastal Gulf of Alaska area. What I want to point out simply is that this area, which is not that well known to most people living in the lower 48 states, despite being fairly far removed from large population centers, it's actually an area that receives a tremendous amount of river discharge. Just to give you a number, these coastal Gulf of Alaska rivers discharge about 870 cubic kilometers per year.

Contrast that with the Mississippi River, a much better known river, which discharges 530 cubic kilometers per year, and the Columbia and the Yukon, around 200 cubic kilometers per year. Despite the fact that these Gulf of Alaska rivers are relatively obscure to most people, they discharge a heck of a lot of water, and that's because there's a lot of precipitation in this region. That's the main reason, primarily there's a lot of precipitation and then much of that drains off into the Gulf of Alaska.

Another reason this area is of interest, scientifically, is that the Gulf of Alaska, again that's this region to the south of Alaska, is referred to as an iron-limited ecosystem. That means that iron is a nutrient that limits the growth of phytoplankton, essentially the base of the marine food web because of its relative scarcity.

What I'm showing here in this plot is a global map of nitrate concentrations. What you see is that the nitrate concentrations in this Gulf of Alaska region are fairly high. That's for a couple of reasons, really. It's partly because that's at the end of what's casually referred to as the Global Conveyor Belt, the meridional overturning circulation that leads to upwelling of deepwater in this north Pacific region.

So, it's the end of the line in terms of oceanographic circulation, but, in addition, phytoplankton growth is iron-limited because of distance from iron sources in this region. That is another thing that makes it somewhat unusual relative to the rest of the ocean, where nitrate is more typically the limiting nutrient.

We know that iron is a limiting nutrient, but we don't know very much about the processes that transport iron to the iron-limited regions of the Gulf of Alaska. Some of this work is going to shed some light on some of those processes.

This is just a two-dimensional schematic that doesn't really do justice to everything, and I just want to point out this does not show eddies, which are a phenomenon that can transport iron from the coast into the open ocean. I'm going to focus on riverine inputs, on dust inputs, on some iron inputs from this continental shelf region, and all of these end up being sources of iron that fuel high plankton productivity in this shelf region.

Another thing that makes this part of the world interesting, this is again showing the southern Alaska region and the coastal area just south of that glacier-dominated area I referred to. This is a plot of chlorophyll concentration, and you see this high chlorophyll concentration in this coastal area. Some work by Ware and Thomson in "Science" in 2005 showed a relationship between mean chlorophyll concentration and the mean resident fish yield, which they interpreted to mean this ecosystem was controlled from the bottom up, in other words, from the base of the food web up, and phytoplankton being the base of the food web.

One of the questions we posed was whether this ecosystem of the Copper River plume region, and that, just for your reference, is right around here on this plot, is also controlled in similar bottom-up ecosystem fashion.

Why the Copper River? We're going to focus on the Copper River, which is one of these rivers that drains into the Gulf of Alaska. First of all, it's the site of important fisheries. It's the single largest freshwater source for the Gulf of Alaska. A significant portion of the Copper River watershed is glacier-covered, and that has implications for the nutrient cycling and nutrient inputs into the ocean.

Also, prior to this work there were little or no iron data and few oceanographic observations from the vicinity. Finally, a more general justification is that river plumes, in other words, the plume of water that extends out into the ocean from the river, can serve as protection for various organisms from predators.

This is a plot of Copper River discharge from the Million Dollar Bridge Station, not too far from where it discharges into the ocean. A bit of an unusual representation of time, but the main point to make here is that...I guess there are a couple of main points. First of all, discharge increases dramatically in this April-May time frame. Discharge reaches a peak in July-August, and it's still fairly high in the fall in response to various floods.

This pattern of discharge is typical. This is an average discharge from the Copper River. It's typical for this region. It's quite atypical for probably most of the rivers that most of you who are listening are familiar with. The reason the discharge peaks in the summer is not that that's when all the precipitation happens. It's because that's when all the snow and ice melt happens, so you get this massive discharge peak in July and August.

In the winter, from roughly November to March or so, there's very little discharge. Again, there's plenty of precipitation. This is not evidence of lack of precipitation at that time. It's just that the precipitation is freezing and not going out the river. This timing is quite different from rivers that many of you might be familiar with, but it has implications for the timing of the nutrient inputs into the ocean in this part of the world.

One of the first questions we posed was, "How will the flux and distribution of riverine iron delivered to the Gulf of Alaska change due to warming climates and retreating glaciers"? First of all, let's just get oriented here. We're going to show some data from a series of tributaries from the Copper River watershed.

Here's Alaska. Here, outlined in orange, is the Copper River watershed, and I'm going to show data from the set of tributaries. This is work that was carried out virtually entirely by Andrew Schroth as part of his Mendenhall Postdoctoral Program when he was at Woods Hole.

This is the Copper River watershed. I'm going to show data from a few different river types, but the two main points I want to make are that there are these glacier-dominated rivers. Those of you who have seen glacier-dominated rivers have probably seen this type of murky water before, this murky gray water. It's murky and gray because there's a lot of fine particulate matter in it that results from weathering from these glaciers. That's one river type. Whenever the river drains what we call a "glacierized river valley," this is typically what you see, very murky water.

The other river type is this boreal lowland “blackwater” river type. This is a river that drains water that's much lower elevation, no glaciers, but very peaty. It's a region that's full of peatlands, wetlands, and, as a consequence, the water gets very brown because it has high concentrations of organic acids, high dissolved organic matter concentrations.

This is actually a photo that shows these two river types mixing together when they flow into each other, just to show those two river types in one photo. I'm going to show how each of these manifests itself in terms of impacts on iron in just a minute.

Here is a picture of the, again, the Copper River watershed. These dots represent different tributaries of the Copper River. Here's Andrew showing off his trace metal clean river sampling strategy. We always get a lot of laughs when we show this image of him in the truck. We need to get a different image for that, but that shows the trace metal clean river sampling.

We're going to mention some different size fractions of iron. Particulate iron is larger than 0.45 micron. Colloidal iron is smaller than 0.45 micron but larger than 0.02 micron, and dissolved is less than 0.02 micron. This has implications for the fate of that iron as it goes into the ocean, which we'll get to in a minute.

So these different tributary types have different characteristics, the glacierized tributaries...Let me back up, I'm plotting colloidal iron. You can think of it as small particles, concentration of small particles of iron versus dissolved iron. This is stuff that passes through a very fine filter and it's truly in solution, truly dissolved.

These two different river types have very different iron types. There's the largely particulate iron that's common in these glacierized watersheds and a largely dissolved iron in these wetland dominated rivers. You can see that in a different way when you plot colloidal iron versus colloidal silica.

Essentially, the glacier-dominated rivers have both fine particulate iron and fine particulate silica because it's essentially ground-up rock. There's ground-up rock that is giving it that milky gray color. That's a source of iron, that's also a source of dissolved silica, versus the boreal forested rivers which show much lower dissolved silica concentration and, typically, smaller concentrations of iron as well.

Andrew did some time series river sampling that I don't have time to show, but I just want to acknowledge that that work is a big part of this project as well.

I'm going to jump ahead to some work that Andrew and I did at the mouth of the Copper River. Here is a satellite image of the Copper River and you see this muddy river plume extending into the ocean. On the right is actually a close up of that taken with a camera.

On the left is this muddy river plume, freshwater, on the right is seawater, and this front occurs over a space of centimeters really, it's really dramatic. What is known from the iron literature is that dissolved iron tends to be removed in estuaries. Now, the estuary of the Copper River is quite different from what most of you might be familiar with when you think of an estuary.

The Copper River is more this abrupt front from fresh to salt rather than a gradual mixing of the two. We did our best to try to sample across this front and I'm going to focus first on this plot on the lower right where I'm plotting dissolved iron versus salinity.

The dissolved iron concentrations that have low salinity are quite high. That's because of this fresh water input into the ocean. At high salinity they're low, because that iron is getting diluted with iron poor sea water.

If you had mixing of freshwater with sea water with no iron removal, the data points would fall on a line, looking something like this for my -- pretty much a straight line. Instead what you see is this pronounced curve where the iron concentration has dropped dramatically as you go into the salt water and then they stay fairly low.

That shape is characteristic of dissolved iron removal. What happens is the organic iron complex readily flocculates and is removed. What that means is iron from these lowland, wetland dominated rivers is largely removed when it hits the ocean. By contrast, this total dissolvable iron is a measure of the particulate iron.

This iron concentration, also quite high, shows different characteristics, it's largely a linear behavior between freshwater and saline water. What that means is a lot of the particulate iron -- in other words, a lot of the particulate iron is coming out from the glacier, this muddy, gray stuff is actually getting mixed out into the ocean without a lot of removal. So that has some big implications, the fact that that fine particulate stuff largely persists in the ocean.

That's a very quick summary of the terrestrial sampling, I'm going to show you a summary of the marine sampling that we did on this transect from the Copper River mouth. Here is the Copper River. Again, here is Alaska, here's the mouth of the Copper River. This is the continental shelf break, our transect extended from the mouth of the Copper River out beyond the continental shelf break.

We sampled on this ship, the RB Montague, based out of Cordova, Alaska. I'm just going to quickly show you some trace metal clean sampling equipment. We used this Teflon vein that was put in the water, it houses Teflon line tubing. This thing here is submerged below the water.

There's a pump on the ship that runs all the time and sucks up water from this intake through the tubing, up through here, it comes into this lab. Here's an inside shot of the lab and you see this tubing coming to the lab. This is Andrew Schroth's sampling.

Essentially, while the ship is moving, we can sample trace metal clean water just by turning a tap. It's pretty cool. The time from sample intake to sample collection is about one minute. It's quite a quick process. I'm going to show you some data from that sample collection system, which is necessary, that I should point out, to collect uncontaminated samples for iron.

One thing about iron is it's easy to contaminate when you're sampling from a big, rusty ship, because their concentrations are pretty low in the ocean typically.

This is some of the motivation for this marine work. This is an image of chlorophyll. Here is Prince William Sound, to orient you, here is the Copper River. Red is high chlorophyll. This is from May of 2009, which is actually a year before our sampling started.

But the main point here is there are these high plumes of chlorophyll in this coastal region that respond, we think, to high concentrations of nutrients. Our sampling was designed to examine some of those nutrient sources and try to understand what's causing this phytoplankton biomass and, I should say, high productivity as well.

One thing that the oceanographers in the crowd will already know, but I'll mention it to those people who don't, who aren't oceanographers, this process of upwelling is a process by which deep water from the ocean is driven to the surface where the nutrients contained therein can be used by surface dwelling organisms like phytoplankton.

The northern Gulf of Alaska, which I will refer to, periodically, as the GoA, is a downwelling area. In other words, it's predominantly downwelling. The water from the depth is not being raised to the surface. There's actually water from the surface going down.

This is a NOAA daily upwelling index which is a function of wind largely. But the point here is that there's downwelling, so we go into this process by which deep water gets raised to the surface, except on fairly rare occasion.

What's interesting is despite the fact that this area is a downwelling area, you still get high concentrations of nutrients sufficient to drive high productivity in this coastal area. Those processes are not that well understood and that was part of the motivation for this work.

Here are some basic oceanographic observations from this coastal Gulf of Alaska area. This is just salinity in the top 40 meters of water. A lot of information on this slide. This is collected using this device called the mini bat by Rob Campbell of the Prince William Sound Science Center as part of our coastal cruises.

This thing flies through the water going up and down to depths of up to 30 or 40 meters. It can essentially map out a 2D map of parameters that can be measured, in this case, salinity.

Salinity of zero is freshwater. Salinity of 35 is truly sea water. There's a series of time slices here. What I want to point out is that in March the salinity is pretty boring, it's all fairly uniform at salinity of about 32 or so. That's because the water comes well mixed. You've got deep winter storms, there's not really any significant river discharge at that time of year.

But starting in May you begin to see this yellow and blue region at the very surface. It's a very thin layer, only a few meters deep and extending some tens of kilometers off shore. But that is the river plume manifesting itself as freshwater discharge.

Remember, there's not much river discharge in the winter, hence you don't see it in the winter. But starting in May and June you start to see this freshwater plume. That has big implications for all sorts of things.

OK. One of those things is iron. In April, which is early in the season, again, the water column is well mixed. You get these deep storms and deep storms lead to churning up of the bottom of sediments. That's visible in this satellite image from up above where you can actually see this murky gray iron rich water in this whole coastal region.

This blue line represents the 500 meter contour getting into deep water. But up until that point pretty much everything is this murky gray and that shows up in our iron data. This is what we refer to as dissolvable iron. It's the iron that dissolves from an unfiltered sample at pH 2.

I think of it as a measure of the particle concentration of the water. Essentially, it crosses the entire continental shelf region. There are very high concentrations of particulate iron and then it drops off beyond that.

This continental shelf break shown with this arrow is a real break point. It's a real point beyond which the things really change and you see that the iron concentrations drop off dramatically beyond that.

Green is a measure of the dissolved iron, that which goes through a filter. That's more what the phytoplankton actually use. But you see that also drops off once you get beyond that continental shelf break.

In response to all that iron, the nitrate gets consumed. These are actual depth profiles of nitrate from the same time frame. In green I'm showing nitrate in April. Nitrate concentrations are pretty boring in April, they're pretty uniform, consistent with that initial slide that I showed you.

The nitrate profiles are roughly 18 micromolars, which is a high concentration. But by July that nitrate is largely gone in the surface water. So high nitrate in spring, by the summertime that nitrate is gone, that's because there's abundant iron and the iron is sufficient to allow complete draw down of this nitrate.

Now, I want to draw your attention to a couple things, which I'm going to help make sense of something in a minute. Note that the nitrate concentration is depleted in the surface waters in these more offshore stations, but there are still plenty of nitrates below a depth of a few tens of meters in this July timeframe. That's going to help make some sense of something in a minute.

Here is a plot of chlorophyll as a function of both time and distance. This is distance from the coast, from 0 to 25 kilometers, over time, from March through August.

The thing to remember is that blue is low chlorophyll. Red is high chlorophyll. Chlorophyll is an indication of phytoplankton concentration, again, phytoplankton being the base of the marine food chain. In blue, early in the season in March, it's quite boring. There's essentially no chlorophyll. There's no fresh water discharge. There's very little light, at least not enough light to initiate a bloom.

Starting in May, remember we got that river discharge, you get riverine input that is causing a freshwater lens at the surface in response to the freshwater input as well as the increased light levels at that time of year. You see this chlorophyll layer, this high chlorophyll layer. In other words, the phytoplankton are responding to the nutrients and the light in the surface water. By May 28th, note that the phytoplankton are largely...The concentrations are much lower in this nearshore region on May 28th.

But, by the middle of May, the phytoplankton in this midshore region, at a distance about 10 to 20 kilometers or so, they've moved deeper in the water column. They're about 20 meters. Remember, the nitrate was largely consumed by this time, so what the phytoplankton are doing, they're actually moving down in the water column in response to the presence of the essential nutrient, nitrate, down there.

By June, July, August, the phytoplankton concentrations across this whole transect are noticeably lower. Again, these are data by Rob Campbell from the Prince William Sound Science Center and collected as part of our joint cruises in this region.

I want to acknowledge as well the extensive work by Laurel McFadden, who was a Master's student of Rob Campbell at the University of Alaska, Anchorage. She did some extensive work on the distribution and ecology of zooplankton and juvenile pelagic fishes in the Copper River plume. I don't have time to give this work justice, so I'm just going to acknowledge her extensive work and move on from there.

I'm going to jump back very quickly to iron. Now remember, the freshwater discharge maxes out in July and August in the Copper River. This is this transect from shore, from the mouth of the Copper River offshore again. What you see is this low salinity water. I'm plotting both iron and salinity on the same plot as a function of distance from shore in July. You see this low salinity water with extremely high concentrations of iron. That's this particulate iron coming in from this massive river discharge that's happening.

In fact, if you look closely at this plot, you see that iron and salinity, they covary at this time of year. Whenever the salinity is low, the iron is high. Whenever the salinity is high, the iron is low. What that's telling us is that the iron at this time of year is coming from this glacial melt water, and it's a pretty dramatic effect.

Just a quick mention of interesting phenomena of nitrate. Remember nitrate is the limiting nutrient for phytoplankton in much of this transect. At this low salinity time of year when the river discharge is at its maximum, we see these low salinity surface waters and these nearshore stations offshore the Copper River. We also see a slight enrichment in nitrate in those surface waters.

Remember this is a time of year when, by and large, the ocean-derived nitrate is consumed, but what we see is that there's nitrate enrichment in this river plume water. It's suggestive, although not entirely convincing, that the river is becoming a source of nitrate at that time of year. There are a couple of possible explanations for that. One of which is that there could be nitrogen-fixing plants that are invading the landscape that are causing this nitrate delivery. There are some other possibilities as well.

Very briefly, I'm going to quickly mention another mechanism by which iron gets into the Gulf of Alaska and gets transported a long distance. Again, this is the Copper River region. What we're looking at in this instance is a satellite image of dust. This gray plume that you see...Here's the scale for reference, 0 to 100 kilometers or so. This gray plume is actually atmospherically transported dust that originates in the Copper River but also at some other sites along the coastline.

This image was created using the MODIS sensor on satellites. It's a snapshot in time from November 6, 2006. I just want to highlight the location of Middleton Island because, in response to this observation that there are these dust events blowing iron and glacier-derived dust out into the ocean, we set up a measurement station out on Middleton Island.

Why dust in the autumn? The river levels are low, as I mentioned earlier. There's little or no snow. There are these abundant exposed sediments. They're essentially leftover glacial flour from the weathering that the glacier has achieved all summer long. This is fine sediment just sitting there. What happens is you get strong winds blowing out of these mountains that re-suspend a lot of this material and transport it far offshore.

I alluded to Middleton Island. Here's a satellite image from November 2011. It's not nearly as dramatic an event as the other event I showed you. Nonetheless, we have aerosol measurements from this time interval, and, in fact, you see dust being transported and being captured by our sampling system out on Middleton Island at exactly the same time that you see this dust in the air.

This actually was a fairly modest event by the scale of other events that we've seen in the past. This past year, the fall of 2012, we had a much more dramatic event. I don't have the chemistry data to share with you, but we have the samples, and there's a lot of dust on those samples. This is just showing you the sampling equipment. Here's an aerial view of Middleton Island. This is our aerosol sampler system. I'm going to move forward just because I want to get to the end here.

That's a very, very, very quick overview of some of the sampling. Now I want to give you a sense of some of the modeling that's been done by a group based at the University of Maine. I'm going to show you work for which Yuan Wang is the first author. He was a graduate student of Fei Chai and Huijie Xue at the University of Maine, and they took an existing Gulf of Alaska physical model and added Copper River discharge to that model. What I'm going to show you is the results of that work.

Again, here's Alaska. Here's the Copper River watershed. Here's a brief model description. This is what's referred to as a ROMS model. ROMS is short for Regional Ocean Modeling System. It's what's referred to as a three-level nested model. In other words, there are different regions of the ocean that get sampled at higher and higher resolution within the model. There's this coarser resolution region up here, smaller region at finer resolution, and finest resolution at this Copper River mouth region.

There's horizontal resolution of 3.6 kilometers and 40 vertical layers. I'm going to show you results from 2010 and 2011, our sampling period. Essentially what these guys have done is created a modeling tool that can be used to simulate the entire Gulf of Alaska and, in particular, simulate how it's influenced by discharge from the Copper River.

They used realistic model forcing, including North American Mesoscale Model meteorology. They use river discharge from the USGS office in Anchorage, including real-time freshwater observations and nutrient concentrations, specifically nitrate concentrations based on the river sampling that we did.

They used three model cases. I'm going to show you two of those. I'm going to show you their model results with typical river discharge and also double discharge. The double discharge is an example of what would happen in an extreme case of warming where the discharge coming out of the Copper River is greatly increased. That is a substantial increase, but they did that largely to demonstrate what such a substantial increase would cause. When you use smaller perturbations, the changes are not quite so obvious.

I should say right up front, this is definitely their work. I am not a modeler, and so I'm doing my best to describe what I can of their model. I might have had them present this, but the two lead scientists from this modeling effort are both in China right now, so we made a decision that I would present it for them, and I'll do my best.

This is the model topography. Again, this is the Copper River. What you see, this blocky land, that is what really gets simulated in the model. This is Prince William Sound. This is the Copper River. These are our sampling stations over here, just off the Copper River. I'm going to show you also data from this mooring in the coastal region off Seward, this GAK1 location. GAK, is short for Gulf of Alaska, 1, just to orient you here.

For those of you who are not oceanographers, it's well known and has been known for quite a long time there's a pattern of circulation that's well documented for the Gulf of Alaska. You have these coastal currents that come along the coastline from the south, and they bend along this northern Gulf of Alaska area to the west, and then they turn back south again. That's well known.

You're going to see that show up in the model simulation in just a minute. Right now, I'm walking you through some still slides, and I'm going to do a model simulation at the very end just in case there are any hang-ups, so we won't be delayed by that hang-up in the model.

These are comparisons of the model results with this GAK1 mooring, this coastal site. The blue data are actual observations, actual measurements of salinity at 20 meters. The red is a model. It's not a perfect match. You'll see that in the winter, typically the model salinity is a little bit low, and the timing of these changes is not spot on.

But in general, it captures the overall flavor of this variability in salinity in response to oceanographic processes. The model does a pretty good job although obviously not perfect. This is a simulation of temperature. The model does a pretty good job of simulating temperature. Temperatures are a little bit cooler in the model much of the time, but they're pretty close.

What I'm going to show you is the results of a tracer experiment where they initiated this model-only tracer. There's essentially discharge happening from the Copper River and coming out of the Copper River. This is just to show where this water from the Copper River goes and what happens to it and what the impacts are of some of that water.

This is not really salinity. You can think of it as freshwater, but it's not really. It's something that you can do in a model that's a lot harder to do in the real world. They essentially created this fake parameter that they could trace, essentially just to show where the Copper River discharge goes. That was the whole point of it.

Just to give some background, this two times discharge is not completely arbitrary. It's quite a big perturbation. Ed Josberger's work from the Bering Glacier suggests that if we had substantial warming to the tune of about four or five degrees, you would get double the melt discharge, double the summer discharge from the Bering Glacier, just to give you a rough idea.

Again, I'm going to show you still shots, which are not as instructive as the video, but I'm going to do it just because there's potential that the video's going to have problems. In a nutshell, these are simulations from July 10th, from both 2010 and 2011.

This upper left panel is just the normal discharge with the normal river discharge. You see this Copper River plume extending out into the ocean. With two times the river discharge, you see a much larger area impacted by that Copper River plume.

2011, it's a little bit different because the conditions were a little bit different, but the contrast is the same pretty much. The region affected by this discharge being doubled is quite a bit larger than in the normal river discharge example.

Just to give a sense of where this water's going in terms of a mass balance, if you have a hundred units of water coming out of the Copper River, a lot of it is going to be transported, as I mentioned before, to the west. Some of it's going to go into Prince William Sound. Some of it's going to come back out of Prince William Sound. Almost none of it is going to travel to the east because the prevailing currents are towards the west.

What I want to draw your attention to at the moment is this contrast in what is transported offshore. The red line is the normal river discharge transport. It's only 3.8 percent of the total, but contrast that with the two times river discharge. If you double the river discharge, you have a 300 percent increase in offshore transport. In other words, it's three times as much transport offshore of this river-influenced water. That's one important difference of this double discharge scenario on the physical circulation.

As a part outreach and part science effort, Rob Campbell conducted an experiment in collaboration with the native village of Eyak. This is a native group in Cordova, Alaska. Again, this is Prince William Sound. This is the Copper River. They released these drifters. These are devices that essentially float with the water. They did it three times in 2011, in March, May, and July. These devices have GPS on them, so they can be tracked and see where they go over time and see where they end up.

What you see is, at all times, these drifters were transported along the coast and to the west as the theory would predict and as the model would predict. Some of them went into Prince William Sound. Some of them came back out.

The drifter experiment, while limited in scope with only three drifters, essentially confirms the predictions of the model. It's a nice validation. I mentioned it's part outreach, part science experiment, but it's a neat confirmation of what we think we know about circulation in the area.

I'm just going to conclude, and then I'm going to come back and show that video. Just to conclude, I hope I convinced you that glaciers are losing mass in the Gulf of Alaska region, as in other regions worldwide. Glacier melt is a source of iron to the coastal Gulf of Alaska region. There's summertime river discharge, when much of the fine particulate mass in that river actually gets out of the ocean and escapes the estuary. Hence that glacier-driven discharge is important.

In the wintertime, there's sediment resuspension from the continental shelf region. That still is this fine particulate matter from the glacier. It's just that it's settled out into the sediments, but it gets resuspended every year in the winter. In the autumn, there's dust derived from these winds that race down those mountain valleys and transport this fine sediment out from these river valleys hundreds of kilometers out into the ocean.

I want to paint a picture of very seasonally variable sources of iron to this coastal Gulf of Alaska region. In the winter, there's deep, deep mixing as you get strong storms and limited river discharge. That leads to the water column being very well mixed and churned up and leads to high concentrations of iron and nitrate in surface waters, which together fuel high spring phytoplankton biomass on the shelf. Nitrate is actually the limiting nutrient on our shelf transect.

I didn't actually show you, but Laurel's work suggests that zooplankton and fish she sampled tend to be more abundant within the river plume than outside the river plume. That's in response to evasion of predators in these turbid river waters.

I want to emphasize that melting of glaciers is perturbing these nutrient cycles in ways that we do not fully understand, although there is a suggestion that the rivers are now becoming a summertime source of nitrate. In the winter, the ocean is that source of nitrate, but that nitrate gets used up by massive phytoplankton blooms in the spring and by the summertime, these glacier-dominated rivers are becoming a source of nitrate, with a few different possibilities for sources.

Impacts of the increased river discharge in response to the increased melt include...There's a larger area of Copper River plume. There's increased offshore transport of this river water, which includes particulate iron and other species as well. There's most likely increased stratification. In other words, that freshwater layer is less dense. It resides in its surface, and it reduces vertical mixing. The deep water can't mix up to the surface, and that probably translates to reduced nitrate flux to the surface.

Some ecosystem responses in response to such a perturbation of increased Copper River discharge...These are fairly speculative, and I have to take ownership for this part. This is my speculation.

These ecosystem responses might include increased productivity beyond the shelf in response to that increased offshore transport of iron and reduced productivity over the shelf in response to that increased stratification that limits nitrate flux to the surface. I just want to mention that impacts on eddies are beyond the scope of this project.

I'm going to try to show a video quickly. Should I make this full screen?

Ashley: Yes.

John: What I'm going to show you is a video. This is a simulation of that discharge from the Copper River to give you a sense of the power of this. This is actually a really nice tool. Again, the people from the Gulf of Maine added the Copper River discharge to this Gulf of Alaska model, and with that, we can now understand impacts of Copper River discharge on this entire northern Gulf of Alaska region. Just to orient you, this is discharge from the Copper River, a tracer, if you will. It's just Copper River water, not really salinity. I want to point out the date at the top. It's May 1st, 2010. You'll see the date click along, and you'll see this river water discharge come out through this Copper River mouth in just a second. Bear with me.

Now you see the dates moving along. You see increased discharge in response to increased melt in the summer and this phenomenon of this water being transported along shore.

Now it's July. We're getting close to the period of peak discharge, and you'll begin to see this Copper River water going into Prince William Sound. There you go. Some of it makes its way into Prince William Sound, and it's harder to see it coming out again.

Now the discharge is diminishing as summer winds down. It just gives you a feeling for the power of this modeling approach. Now we're into the autumn when there's much less discharge. I think I can stop it there.

I'd be happy to take any questions. Phew. Got through it.

Ashley: [laughs] Thanks John. If you guys would like to ask a question...We do have one question from Gwenn, and it says, "How bioavailable is the particulate iron from the glacier melt waters"?

John: That's a good question. I perhaps should have gone into that, but I had to gloss over a lot of details. It's a very good question. Most of that is not bioavailable, but the thing to keep in mind is that it's a massive, massive quantity. It just takes a small amount of dissolution of that massive quantity of particulate iron to translate to a lot of iron in parts of the dissolved phase. This is a complicated thing to quantify, and there are various ways of doing it. Numbers that people throw out there as ballpark estimates of how much of that is available would be something in the range of maybe 2 to 20 percent.

The literature on this is pretty confusing because there are estimates that range from well under 2 to well over 20 percent. In a nutshell, if you have a small amount of particulate matter in a large amount of water, you tend to dissolve a higher proportion of that particulate matter. Anyway, that's a quick answer to that. Does that answer your question?

Ashley: Gwenn says, "Yes, thank you."

John: OK.

Ashley: I know that we're running a little bit late, but if there are any last minute questions...We do have one from Benjamin, and it says, "At the beginning of your presentation, I think that you said that the GoA was not a nitrogen-limited system but, on the conclusion slide, that you said there was a transect that was nitrogen-limited. Did I see that right, and, if so, why the difference?"

John: Perhaps I glossed over that too quickly. The broader Gulf of Alaska is iron-limited, but the coastal region tends to be nitrate-limited. It depends on the time of year and where exactly you're talking about. Early in the growing season, it's not limited at all because there's abundant nitrate and abundant iron. One or the other tends to the limiting nutrient. By the time mid-summer rolls along, in the coastal region, what I tried to emphasize is that nitrate tends to be fully consumed, and so nitrate tends to be limiting in that coastal area. Iron is more limiting farther offshore. That's not always the case.

There are some coastal areas where they're iron-limited, but, at least from our data, it would appear that nitrate is actually the limiting nutrient in the summer, in the nearshore region. Somewhere out beyond the continental shelf break is where iron limitation kicks in.

Ashley: Thank you. We have a question from Tom, and it says, "What is the relationship between the Copper River outflow nutrients and the downwelling-upwelling nutrient input"?

John: Good question. Again, something I really glossed over. I have to preface this by saying that the people who could best answer that question would be the modelers, and that's not me. The Copper River discharge into the ocean induces a process by which, at least it can induce a process by which you get upward mixing of nutrients from below in an estuarine circulation where you get outflow at the surface of this freshwater, and that induces entrainment of water below that that causes a return flow and an upwelling. The presence of the river itself can induce this upward, sort of an upwelling in the vicinity of the river plume. That's one reason that river plumes can be fairly productive, because you have all this mixing going on of deeper water being raised to the surface. That's a process that's somewhat independent of this downwelling-upwelling phenomenon.

The upwelling index that I showed, which tended to show primarily downwelling, that's more relevant to regions outside of the influence of the river, where the prevailing winds are largely what drive that. The winds are such that you tend to get downwelling, except in fairly rare occasions, in that part of the world. I'm not sure if I answered your question, but that's one attempt.

Ashley: Tom, if you just want to chat "yes" or "no," that would be great. He said, "Yes, it does. Thank you."

John: OK.

Ashley: We have one more question from Patricia, and it says, "Have you looked at how productivity varies with PDO or other climate variation? Put another way, do the local factors you discussed dominate productivity shifts, or do other factors like PDO dominate productivity at certain times or phases?"

John: Very good question. Let's see, it's hard for me to give a short answer to that question. Different people define productivity in different ways. Often people use the satellite image of Chlorophyll to say something about productivity. Chlorophyll was pretty much the only thing I showed in this presentation but that really is a measure of phytoplankton biomass whereas productivity is a rate that isn't really measured by that Chlorophyll concentration.

To get at productivity requires, well, there's a whole bunch of different methods that people use. The classical way is to incubate samples in a bottle, radiocarbon labeling.

Paul Clay, here at the University of Washington, is one of the people who has come up with a very elegant way, using dissolved gas measurements to get at this rate of carbon uptake or option production.

In a nutshell, you get different answers depending on how you measure it. The bottle method I mentioned is an instantaneous snapshot plus there is sometimes bottle effects.

I'm not trying to waffle. I'm trying just to say, there really aren't sufficient observations with enough different techniques to answer that question. Because you get variation, the different methods disagree by many times, by two to eight times when you intercompare them.

There really needs to be more intercomparison of these various methods of inferring biological productivity. There hasn’t been a lot of that. Until there is a rigorous intercomparison, I don't feel like I can answer that question.

No doubt broad scale oceanographic processes, such as the PDO, which by the way, stands for Pacific Decadal Oscillation, for those who don't know that term. They are going to have a big influence on biological processes in the broad Gulf of Alaska.

Our work was focused more on the coastal region off shore of the Copper River, which is heavily influenced by the processes in the Gulf of Alaska. It is its own beast in a way too, because of the tremendous amount of fresh water discharge coming out there which influences nutrients and stratification.

Ashley: All right, I'm just scanning for any additional questions. Patricia said, "Thank you very much." We do have another one from Kay and it says, "How might ocean acidification affect the iron concentration in the model, if at all? (Fe)."

John: Another very good question. The first primary thing I have to say is that I don't think we know, and not because of insufficient observations. Your first instinct is that ocean acidification would lead to greater iron concentrations. The solubility of iron is a function of pH. Now, ocean acidification is a pretty small perturbation of pH. But, when the ocean gets more acidic, there's going to tend to be a little more solubility of iron. If anything, acidification, in and of itself, is probably going to cause slight increase in iron concentration.

Having said that, it's probably likely that ocean acidification is going to have so many other impacts, that that pH effect, by itself, is going - well and this is my own gut feeling - it's going to be dominated by other things that are also going to effect the iron concentration. Just pH alone is going to affect the iron solubility and iron concentration.

Ashley: Thank you John. I'm not seeing any more questions. Kay says, "Thank you very much, John." All right, I'd like to thank John for an excellent presentation and that was very informative.

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