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About five years ago I started a project where we decided that the best way of illustrating to the nonscientist what was happened to glaciers in Alaska would be by occupying locations where historical photographs have been made in the past and then duplicating the photographs. So we had a pair of photos, side by side, the before and the after, to look at changes. Once we started looking in archives, we discovered a number of photos that went back as early as the middle of the 1880s. And in the five years since we began this activity, we've collected over 200 pairs of photos documenting the location that the historical photo was made and we've begun to do quantitative and qualitative analysis. And what we see in about 95% of the cases are glaciers retreating, vegetative succession rapidly occurring, sedimentation filling fjords, changes in the hydrology and a number of other significant examples of rapid landscape evolution. To date, we're doing this in four national parks in Alaska: Glacier Bay National Park, Kenai Fjords National Park, Denali National Park and Wrangell St. Elias National Park. And we're also working with colleagues who are doing this in Glacier National Park in Montana, in Sequoia Kings Canyon in California and in the North Cascades in Washington. In each of these locations we're seeing significant response of glaciers and the landscape as a whole to changing climate.

I recently completed a study that will be published in 2005 that examined glaciers in every area of Alaska that currently supports glacier ice, 14 different geographic regions. And I looked at about 2,000 of the larger glaciers, almost all of which were glaciers that descended from the mountains down to the lowest elevations, several hundred feet down to, in some cases, sea level. And of the 2,000 large glaciers, more than 95%, in fact, closer to 99% of these glaciers are currently retreating, thinning or stagnating. By stagnating I mean that they are kind of debris covered. They're covered by sediment so they're insulated from melting but they're not moving. They're just sort of wasting away in place. And that's typical of what we see at the lower elevations.

On the other hand, once you get above about a mile and a half in elevation in Alaska-- and you have to remember that Alaska has glaciers that go as high as 20,000 feet-- once you get about 8,000 feet or more in elevation, you stop seeing rapid melting. Actually in some cases you see just the opposite. You see thickening of accumulation areas and a buildup of snow. So what we're seeing is a change in Alaska today that can easily be explained as lower elevations where there's definitely been a warming trend, melting of glacier ice in most locations; higher elevations where a slight warming trend may actually have triggered an increase in precipitation, accumulation of snow and ice.

What does it mean is an interesting question? What we're seeing is the response of one part of the Earth's surface environment-- the glaciers-- to changes in climate. If you look at the last thousand years, we had a natural warming event called the Medieval Warm, which is a very interesting event in its own right. In the Medieval Warm, Greenland was able to support an agricultural based European economy and settlers came from Iceland

and Norway. Following about 250 years of successful agriculture, climate began to deteriorate. It got colder and we went into a period of time that's known as the Little Ice Age when glaciers on all six continents that support temperate glaciers expanded. And beginning about 250 years ago, we started a warming event. This is the post Little Ice Age climatic event that we're currently in. And in this climatic event we're seeing a significant melting of temperate glacier ice on all continents on Earth. It has impacts in the Polar Regions as well but the greatest manifestation of it is the disappearance of lower elevation temperate glaciers.

A number of reports have suggested that the temperate glaciers are melting more rapidly now in the last 50 years, than they have in any of the past 250 years. And in many locations, this appears to be the case. We have some slightly contradictory information for parts of Alaska. For instance, in Glacier Bay, once the ice retreat began about 1750, during the first hundred years we lost perhaps 25% of the total volume of ice that filled Glacier Bay. We don't have good temperature information for that period 200 plus years ago. But for, for the period of time where we have records, we're certainly seeing an increase in rates of melting in the last 50 years.

From the information that we have been able to collect, it appears the temperate glaciers are melting now, and in the last 20 or so years, at a rate that has been greater than any reported in the last 250 years. One of the problems we have, though, is that we did not have good quantitative measurements at the end of the Little Ice Age and it's only been in the last 50 years that the technology has evolved so that we can accurately measure small temperature changes and actually measure using remote sensing global changes in temperate glaciers. There are some areas, like southern Alaska, where from 1750 to 1850 there was an extremely rapid retreat of the glacier that filled Glacier Bay. And this has produced some speculation that that might have been comparable in the rates that we're seeing today in most of the temperate world. But without question, temperate glaciers on all continents are rapidly disappearing and at rates now that exceed any of the rates that we had previous information for.

Fifty years from now we'll see a continuation of this trend of melting lower elevation glaciers. Again, I'm speaking for Alaska. Alaska has over 100,000 glaciers; 80,000 or more of these are at higher elevations. Those will experience minimal change in the temperature environment that we're experiencing today and what we anticipate over the next few decades. At lower elevations, however, we'll continue to see a shrinkage of large ice tongues in most parts of Alaska and I would think if you use the present statistics as a basis for making future predictions, we're going to see again more than 95% of these larger glaciers that come to lower elevations shrink and in some cases completely disappear. On the other continents and in the lower 48 where the glacier cover is smaller, we may see an even more rapid disappearance of lower elevation glaciers, especially those that have south facing orientations.

This is evidence of global climate change and regional warming. Global warming is an interesting phrase. It implies a uniform warming of the globe and the data that we have is far more complicated than that. It shows many areas where we can clearly document

warming trends, a number of areas where we see very little change and a few areas on the Earth's surface that are actually cooling. I'd prefer to talk about the specifics in the areas where the glaciers are located and in those regions we're definitely seeing significant warming trends. In Alaska, for instance, where we have temperature records and climatic evidence that spans more than a hundred years, we see between two and three degree Fahrenheit increase in temperature in the last century. In other parts of the world we're seeing similar warming. The higher the latitude the greater the amounts of temperature change.

In many places the summer melt of glaciers is the primary source of both potable water and irrigation water. This is the case in the Canadian Plains where a lot of Rocky Mountain glacier ice provides nourishment for farms in Alberta and British Columbia. In many locations, glaciers, as they melt, have a high probability of an increased flooding and this has produced significant impacts on communities down valley. For instance, in Italy and Switzerland, there are numerous well-populated communities that sit in valleys where there are glaciers at the heads of the valleys. Two years ago there was major news coverage of an event in Italy where a glacier marginal lake, an ice marginal lake was artificially drained in order to minimize the risk of flooding and damage to the villages below. In Peru there have been a number of instances where these huge outburst floods have killed tens of thousands of people. And so this is something that we have to be very cognizant of.

Melting glacier ice means more liquid water. More liquid water means a greater potential for flooding. Also, this melt water makes its way into the oceans and as temperate glaciers melt, they have a small impact on rising global sea level. If you were to melt all the temperate glacier ice on Earth, we'd see sea level rise by two-thirds of a foot. That may seem to be an insignificant number, but if you live in Bangladesh or southern Florida, if you add another two-thirds of a foot onto the height of storm waves such as the ones that we experienced in the last few hurricanes, it can have a devastating impact on coastal infrastructure. The big question is what will happen in the Polar Regions. If you were to melt the Greenland ice cap, sea level would go up more than 20 feet. And if you were to melt Antarctica it would go up something on the order of 250 feet. Neither of these are high probability situations but there are some things that we need to keep in mind because there are evidences in the geologic record of both Greenland and Antarctica having lost their ice covers at various times in the geologic past.

What you can do to prevent glacier melting is an interesting concept --very, very little because climate is naturally changing. Humans are probably augmenting the rate of climate change. But, even if humans were not burning fossil fuels or were doing other things to impact greenhouse gases and our environment, we would still see glaciers fluctuating. The geologic record shows more than a hundred major periods of glacier advance and retreat over the last billion and a half years. And as recently as about 18,000 years ago, global sea level was more than 300 feet lower than it is today because of the huge ice cover that covered the northern part of North America, covered Europe, covered parts of South America and covered Asia. Those glaciers melted between 18,000 years ago and about 7,000 years ago when sea level rose more than 300 feet. At that time

population was flexible and as the coastline changed people moved. Today, because we have so much infrastructure in the coastal zones, we're forced to look at ways of protecting what we've built. And, with rising sea level becoming a reality, that's extremely expensive and very difficult to do. We can't stop the rate of glacier melting. We may be able to reduce greenhouse gases and other factors that are accelerating the rate but, with natural climate variability, we need to learn to live with melting glaciers.

Sea level fluctuates naturally. As glaciers grow, sea level changes by being lowered. You have what's called a eustatic change. You're taking water out of the oceans and putting it into land based ice. As the ice melts, sea level rises. That's one aspect. That's the total volume of water in the oceans. We also have temperature related changes, steric changes where as you warm ocean water it expands. And a couple of degree warming of surface ocean water will result in almost the same volume of sea level increase, as does the melting of the temperate glaciers on Earth. So, as we go through natural warming and natural cooling cycles, the elevation of the surface of the sea changes naturally. And as human activity augments that, we have to contend with even more complicated changes to our natural environment.

Glacier National Park is a good example of how the Earth's surface is responding to climate change. Today there are about 20 glaciers left in the Park. A hundred and fifty years ago it was probably two and a half times that number. And the 20 glaciers that are left have been shrinking significantly over the last 150 or more years in response to a warming that's definitely been documented in the Montana, North Dakota, Wyoming, Colorado, Oregon, Idaho area, the Northwestern United States area. And what we're seeing there is a significant melting and in some cases even caving into iceberg marginal lakes that is reducing the size of the glaciers. Many of them will probably disappear in the next 50 to a hundred years. Some, which have northern exposures and have good snow accumulations, may survive but this is true of what happens in many temperate areas, including parts of Alaska. As temperature changes, as precipitation changes, the glaciers, which are extremely sensitive indicators, also change and they change very rapidly. And we're losing many, many small glaciers in Alaska, glaciers on the size of the ones that we're seeing in Montana in Glacier National Park as well.

One of the things that our studies have shown is that glaciers have fluctuated not only hundreds of millions of years ago but have certainly gone through a number of fluctuations even in the last few thousand years. For instance, in the Wrangell Mountains, some of the work that we're just reviewing suggests that at least three times in the post-Christian era, since about 1800 years ago, the glaciers have advanced and retreated with the last significant advance being the Little Ice Age advance beginning about 450 to 500 years ago. In other parts of Alaska, glaciers are currently advancing, which is an interesting phenomenon. Hubbard Glacier, for instance, has been advancing for over a hundred years and has moved forward by a mile and a half during that time period. In several other locations such as Lituya Bay, there are two glaciers that have been advancing for more than 200 years, have thickening and are pushing their way towards the Pacific Ocean. So, local climate variability is an extremely important aspect of what happens to individual glaciers. We've got the regional impacts of warming but in some

cases this warming is resulting in increased precipitation and this increased precipitation is nourishing glaciers such as the Hubbard, such as Lituya and North Crillon Glaciers in Lituya Bay and those glaciers are the exceptions that make it very interesting to try to speculate in terms of regional and even global changes.

Island nations are one of the most dramatically impacted locations on the surface of the Earth due to changes in sea level. We have evidence that sea level rise over the last century has been on the order of three to five inches. With this continued rate over the next hundred to 200 years, many low elevation coastal locations, such as the Marshall Islands, Bangladesh, even south Florida, can be impacted significantly.

The fact that some glaciers in Alaska are advancing, is that good or bad? That's an interesting concept and interesting question. From the glacier's perspective, if it had one, it would probably be quite good. From an arm-waving perspective it shows how complex natural climate variability can be. It shows how dynamic the Earth's surface is and it also shows that we don't have a simple answer for most of the processes that we're observing that are taking place today.