Testimony of

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before

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on

Update on the Role of the Oceans in Climate Extremes and Rising Sea Level

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Chairman Boxer, Ranking Member Inhofe, and Members of the Committee, thank you for this opportunity to provide an update on the role of the oceans in climate extremes and rising sea level. Ocean processes are linked to many of the extreme weather events on land. Recent observed changes in the ocean, many of which only a few decades ago were thought unimaginable in our lifetimes are now occurring as result of human-caused climate change.

My hope today is to show clearly what some recent studies of the ocean are now telling us about how climate is changing and contributing to the growing intensity of extreme weather events on land.

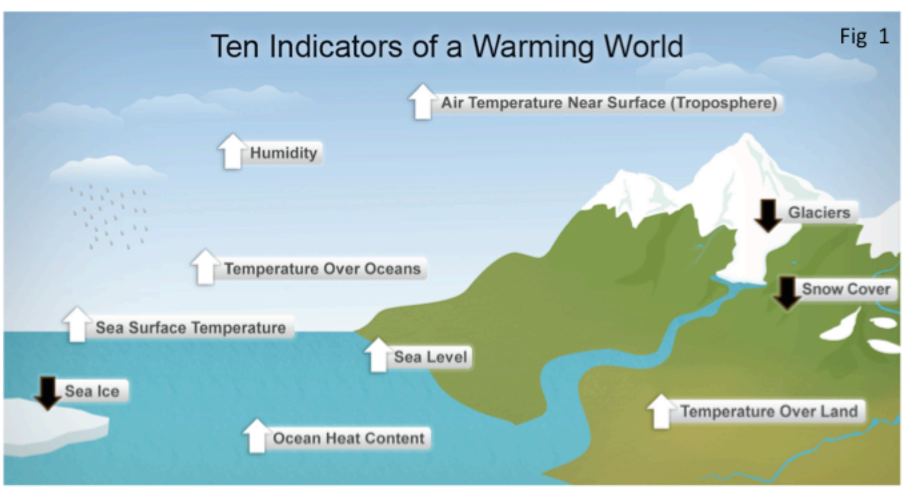
I am the Alexander Agassiz Professor of Biological Oceanography, at Harvard University, where I teach courses on ocean and climate science. For the past four decades my research has delved into many aspects of climate science. I have been also involved in the planning and implementation of several climate science research programs and assessments of climate science. From 1997 to 2001, I was the leader of Working Group II of the Intergovernmental Panel on Climate Change (IPCC), which had responsibilities for assessing impacts of and vulnerabilities to global climate change in the Third IPCC Assessment. I was also an author on the 2005 Arctic Climate Impact Assessment, the 2007 Northeast Climate Impact

Assessment, and the 2009 U.S. government report on Global Climate Change Impacts in the United States. I am Past-President of the American Association for the Advancement of Science, and currently the Chair of the Board of the Union of Concerned Scientists.

My own research has taken me to all the oceans – the high North Atlantic, the South Atlantic near Antarctica, the Artic, the Indian, the upwelling regions off the coasts of North and South America, the equatorial region in the central Pacific, the Sargasso Sea, the Caribbean Sea, as well as several coastal and estuarine systems.

I. How We know that Earth is Warming Globally

Half a century ago many distinguished scientists pointed to new data that demonstrated changes in the carbon dioxide concentration of the atmosphere, and argued that if this trend continued over time it would have a global effect on Earth's climate. One can imagine the check-list that would have been developed at the time – what you would want to be watching for to test the warming hypothesis – and the list would have looked something like the indictors in Fig. 1.



Consistent Trends in All these Indicators Over the Last Several Decades Provide Robust Evidence that Earth is Warming

NOAA/BAMS 2009

Many of these indicators could not, however, be measured well enough to discern trends before the 1980s, which is when Earth sensing satellites were first deployed. With variation from year to year, in Arctic sea ice, for example, it took time to know with confidence whether change was actually occurring. And initially some of the satellite data seemed to contradict land surface measurements, in surface temperature, for example. But with experience the new methods became reliable. For some indicators, such as sea level rise, satellite systems improved substantially the accuracy of the data.

Today there is widespread agreement among specialists who devote their careers to perfecting and deploying the myriad systems that monitor the state of these indicators that trends for all of them point as would be expected if the Earth is warming. This clear global signal becomes stronger with every passing year.

II. Observed Changes in Ocean Temperature

As an oceanographer, I have a particular interest in one of the last pieces of evidence to fall in place among these indicators – the heat content of the ocean. In the early 1980s land surface data were beginning to indicate unusual warming, but a trend in warming or cooling of even the surface ocean would be much harder to detect - vast areas of the ocean were not regularly sampled.

And, just how much change in the ocean would a scientist expect to see over the course of a career in ocean science? Until a few decades ago, the guess would have been – not very much. The oceans have an average depth of more than 12,000 feet. It takes about a thousand years for ocean currents to fully mix the oceans, and most of the deep ocean is influenced only very slowly by what happens at the surface or in the atmosphere. But more significantly, we had decades, and in some cases more than a century, of data indicating relative constancy in deep ocean conditions.

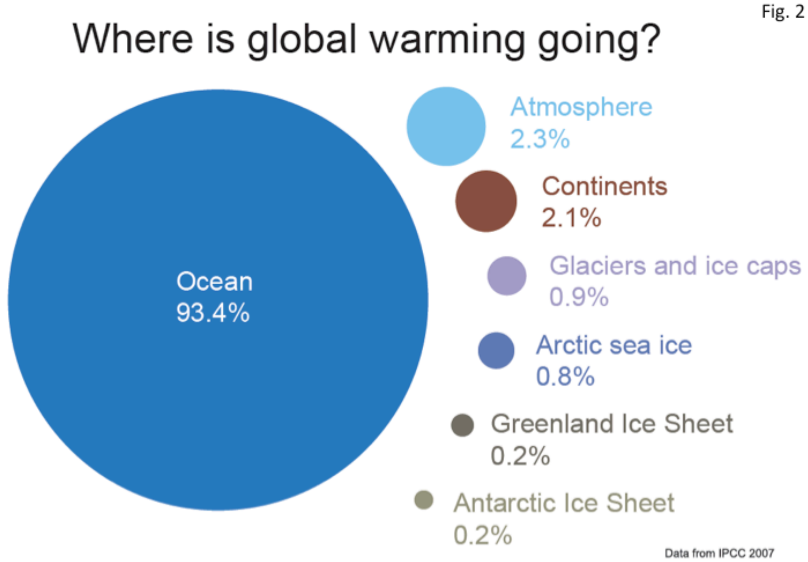
The oceans are an integral part of Earth's climate system and function as a grand flywheel. Their enormous mass and the high specific heat of water provide a steadying characteristic that helps to dampen rates of climate change. In a running engine, a spinning flywheel helps the engine running run steadily, as individual cylinders fire in sequence. If the engine stops running the inertia of the flywheel will keep it rotating albeit more slowly as energy is lost to friction. Similarly, the ocean helps to keep climate within bounds by absorbing and releasing heat slowly, and the range of these bounds guides us, as it did our ancestors, as we make decisions as to where to plant our important crops, were to develop our cities, where and how to position our key infrastructures, etc. Ocean conditions far from land influence swings within these bounds. It's obvious that oceans influence climate in coastal regions, but changes in surface temperature in the central Pacific Ocean are linked to weather patterns thousands of miles away in the Great Plains of the United States.

We now know that the ocean is changing more rapidly than was imagined likely just a few decades ago. The additional heat in the climate system caused by the greenhouse gases that we release with our burning of fossil fuels and land use practices is now penetrating deep within the oceans.

This means that the flywheel that has helped to keep climate extremes within bounds, bounds that we have assumed would remain steady, is now is behaving differently. If these changes continue unabated we put at risk what many of us as individuals and societies hold dear – our investments in properties, commodities, and services.

With the findings of Levitus et al. (2000) and others who have confirmed these results, it is now clear that the ocean has absorbed more than 90% of the heat trapped over the past century by greenhouse gasses that have accumulated in Earth's atmosphere due to human activity (Fig. 2)

Fig. 2



NOAA/BAMS 2009

Confidence in these findings has been greatly strengthened with data from instrumented ocean buoys, known as Argo floats, that drift about the oceans at 3000 feet and every ten days descend to 6000 feet (Fig. 3). They then come to the surface and report via satellite their location, their trajectory over the prior nine days, and data for ocean temperature and salt content all along the way.

Fig. 3

Argo Drifting Floats Monitor Changes in
The Oceans' Heat Content – Initiated in the 2000s

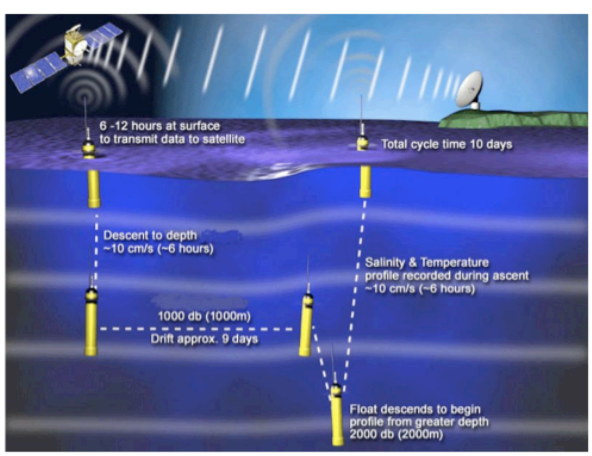
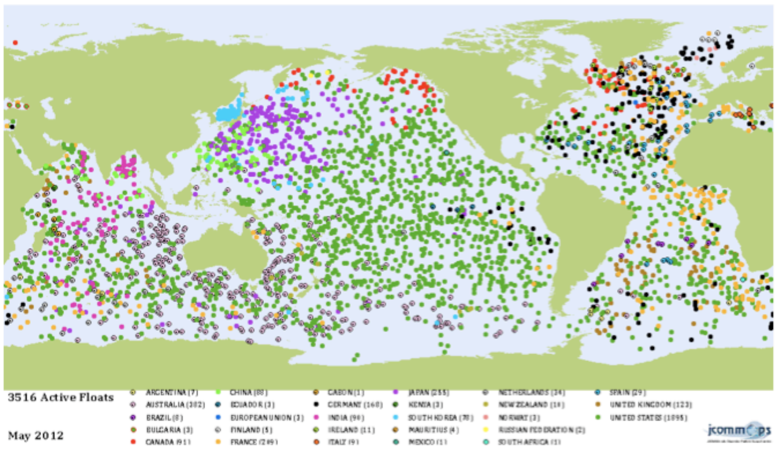


Fig. 4

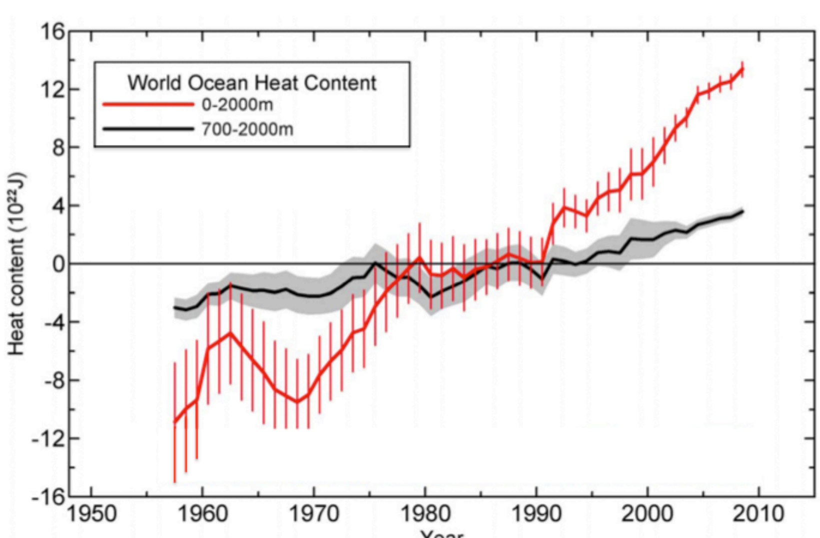
More than 3500 Drifting Argo Floats in Regular Operation
Profiling Ocean Temperature & Salinity to 2000 meters every 10 Days



This program ramped up rapidly during the 2000s, with about two-dozen nations sharing in the costs (Fig. 4). Now there are about 3500 of these floats providing data for large areas of the ocean that are rarely transited by ships. These new data have greatly improved precision in measurements of the oceans' heat content, and as can be seen in Fig. 5, the oceans have warmed steadily over recent decades.

The Deep Oceans are Warming at Great Depths

Fig. 5



Levitus et al. 2012

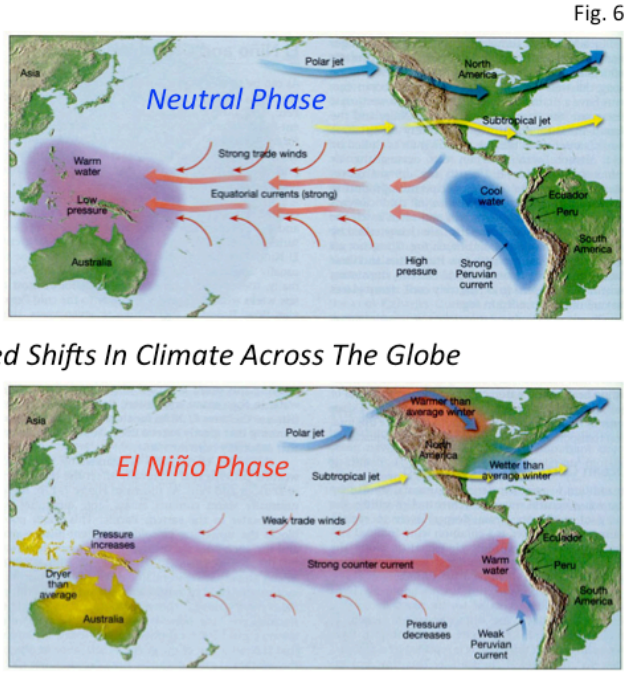
III. Atmosphere – Ocean Climate Cycles

There are many natural climate cycles. The Pacific Decadal Oscillation, the North Atlantic Oscillation, the Arctic Oscillation, the Atlantic Multidecadal Oscillation, etc., but because of their long periods we have had little opportunity to see some of these cycles repeat in the modern era of ocean science.

One, very strong and well-studied climate cycle, is the El Niño Southern Oscillation, or more commonly, simply, El Niño. Every few years (nominally 2 – 7) the trade winds that blow from east to west across the tropical Pacific Ocean relax. When this occurs the warm water that has piled up in the western Pacific flows east and elevates surface temperatures all along the Equator and along adjacent coasts of South and Central America, creating the condition known as El Niño (Fig. 6). The lens of warm water also elevates local sea-level, and during an El Niño this effect can be seen as far north as the coast of California.

Fig. 6

Cool Ocean Water in the East and Warm in the West



With Associated Shifts In Climate Across The Globe

Every 2 – 7 yr the Trade Winds Relax, and Warm Water Flows East

When the cycle tips from El Niño back to the neutral phase, it can overshoot and create a brief exceptionally cool period, and this phase is called "La Niña".

During the strong El Niño in 1982 unusual patterns in precipitation across the American continents, Africa, southern Asia, and Australia sparked new efforts to understand the relationship between this cycle in Pacific Ocean climate and weather patterns across the globe. NOAA helped to put in place a suite of ocean surface buoys across the Pacific to detect early stages of El Niño and to provide warnings of likely effects on weather all around the tropical and temperate latitudes. At the time, the 1982 El Niño was referred to as the "El Niño of the century", but then in 1998 there was an even stronger El Niño. The ocean buoy observing system allowed forecasts well in advance of this El Niño, and in some areas the adoption of adaptive measures were highly successful.

Over the last three decades these new networks of sensing systems (deployed and maintained by NOAA in the United States), have provided the opportunity to study carefully the phases of the ENSO cycle. Fig. 6 shows the general pattern of weather that develops across the United States during an El Niño. There are also well-established patterns associated with La Niña. For example on September 8, 2011, NOAA's Climate Prediction Center issued the following forecast:

> La Niña, which contributed to extreme weather around the globe during the first half of 2011, has re-emerged in the tropical Pacific Ocean and is forecast to gradually strengthen and continue into winter…. La Niña winters often see drier than normal conditions across the southern tier of the United States and wetter than normal conditions in the Pacific Northwest and Ohio Valley…."This means drought is likely to continue in the drought-stricken states of Texas, Oklahoma and New Mexico," said Mike Halpert, deputy director of the Climate Prediction Center. La Niña also often brings colder winters to the Pacific Northwest and the northern Plains, and warmer temperatures to the southern states.

As Earth's average surface temperature continues to rise, an obvious question is how the El Niño Southern Oscillation will behave. Will El Niño's become more likely, more intense, or more persistent if the background temperature during the neutral phase increases? There is no clear answer from model simulations and this remains an active area of research. The 1982 and 1998 El Niño's were both exceptionally strong, and it was surprising to see the second one appear so soon after the first. But recent proxy data now reveal that there was a strong El Niño in the late 1880s.

On balance the El Niño has a much broader influence than the La Niña on global climate, and even if El Niños continue with the same frequency and intensity their effects will become more damaging as they occur in a climate that is warmed by increasing concentrations of greenhouse gases.

The concurrence of three independent analyses of global surface temperature data since 1840 is shown in Fig. 7. There is notable interannual variability, and this has led some people to question the upward trend in recent years or to even suggest that warming has abated. Close scrutiny suggests otherwise when the role of the El Niño is taken into consideration.

Fig. 7

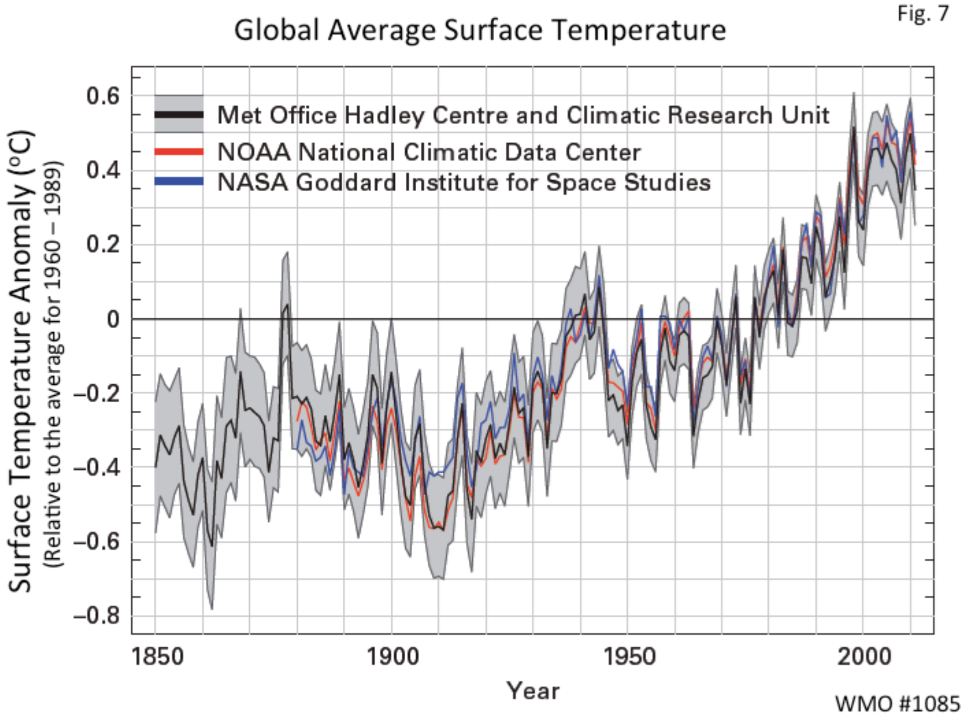
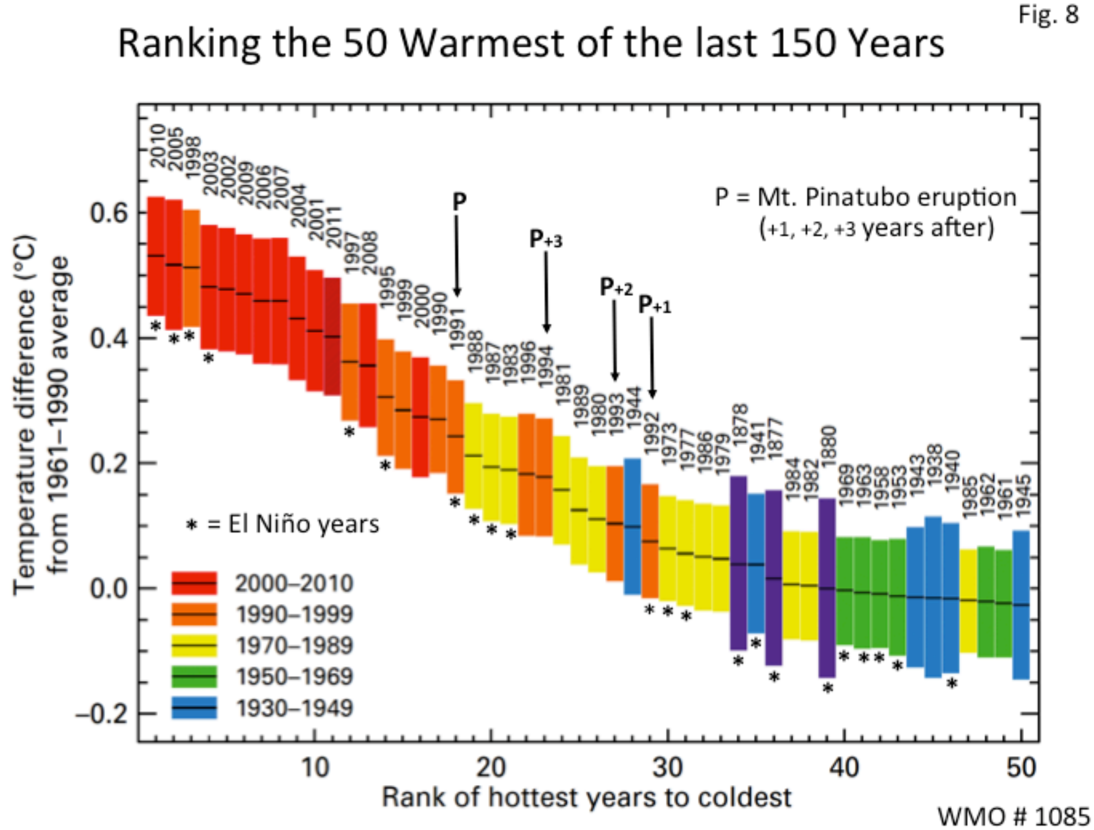


Fig. 8 is an abbreviated version of a World Meteorological Organization (WMO) figure that shows the ranking of the 50 warmest years for Earth's surface temperature since 1840. Either a single (2000s; 1990s) decade or pairs of decades (1970s + 1980s; 1950s + 1960s; 1930s + 1940s) are binned and assigned a color. Note that two colors are not in the legend: the singular deep red for 2011 (the 11th warmest year) and the three darkest blue for 1877, 1878, and 1880.

Fig. 8



An * symbol marks El Niño years, and as expected the warmest years for each of the colors are typically El Niño years. There are just two El Niño years (1973 and 1977) that do not rise to the head of their decadal cohort.

Another natural phenomenon that can influence global climate is significant volcanic eruption. The last major volcano to be large enough to affect global climate significantly was Mt. Pinatubo in the Philippines during June 1991. Satellite systems allowed for the estimation of tiny particles – aerosols – released to the upper atmosphere by this eruption, and climate modelers at that time predicted that the following few years would be cooled by the aerosol reflection of solar energy. Note in Fig. 8 that 1992 was the coolest in its decadal bin, 1993 was the second coolest, 1994 was the third coolest. The prior large volcanic eruption was El Chicon in Mexico in 1982. Since 1982 was a major El Niño year, this one is a little more complicated, but the same pattern of response to an aerosol injection plays out in the years following the eruption of El Chicon. Looking ahead, we can't predict volcanic eruptions, but some will surely occur.

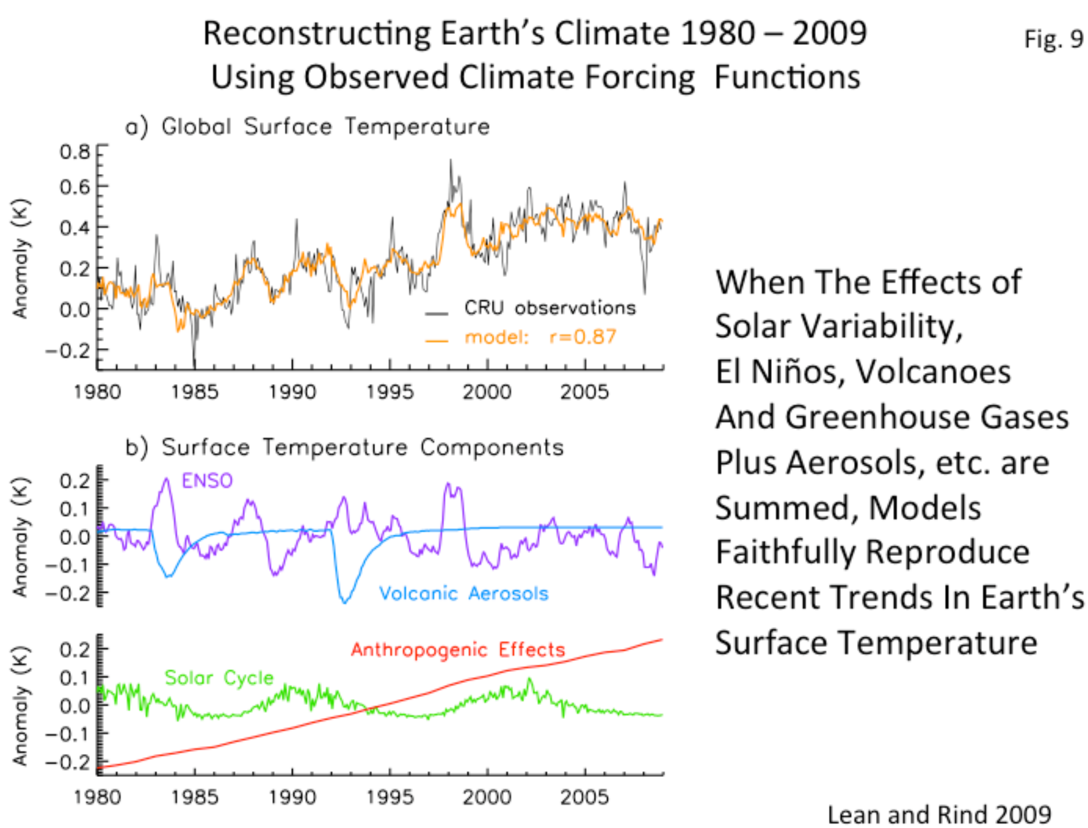
Another natural source of variability is in the luminosity of the sun. An eleven-year cycle in sunspot activity was first documented in the mid 1800s, but it wasn't until satellites began orbiting Earth in 1980 that the actual variation in solar activity over a sunspot cycle could be measured precisely.

The Sun's energy recently reached a minimum in the eleven-year cycle, so over the next few years Earth will receive more intense solar irradiance. In fact:

> "This week researchers announced that a storm is coming--the most intense solar maximum in fifty years. The prediction comes from a team led by Mausumi Dikpati of the National Center for Atmospheric Research (NCAR). 'The next sunspot cycle will be 30% to 50% stronger than the previous one,' she says. If correct, the years ahead could produce a burst of solar activity second only to the historic Solar Max of 1958."
> (http://www.auroraborealispage.net/solarmax.html: 23 July 2012)

Interestingly, 1958, also an El Niño year, was the warmest year between 1950 and 1970 (Fig. 8).

Thus, over the past three decades, the known drivers of climate variation can now be measured directly and put into common units of energy. Many climate research groups have done this, and a good example is the work of Judith Lean (a solar physicist at the Naval Research Laboratory) and David Rind (a climate modeler at NASS). When greenhouse gases, aerosols, (including volcanic), solar variability and El Niño events are assembled over time to forecast Earth's surface temperature a remarkably realistic simulation emerges (Fig. 9). This is not curve fitting. It is rather a test to see if there are any significant missing components and a way of assessing the relative contribution of each of the components.



There are many published examples of these sorts of analyses by climate modeling groups in the US and abroad. The consistent conclusions are that most of the observed warming over the past half century results from increasing greenhouse gasses, that the variation from year to year is strongly influenced by El Niño events and volcanoes, and that solar variability is playing a relatively small role in climate change.

The final component, that of the human generated greenhouse gases that remain in the atmosphere shows little or no evidence of cycles. Rather its trend is that of a steady secular increase with small wiggles reflecting economic shifts and politics.

Thus, in the future, as in the past, global average temperatures will be unusually warm during El Niño years and during peak years for solar activity. In the future, however, if greenhouse gases continue to increase, strong El Niños will wreak even more havoc as they break old records for warm and wet conditions across much of the globe, because they will be occurring upon a higher baseline of warming.

The answer to the question of just how intense new extremes in heat and precipitation will be, in part will be answered with the choices that we make about our practices and policies that release greenhouse gases to the atmosphere.

IV. Observed Changes in Arctic Climate

A. The Arctic Ocean

A dozen years ago the news that Arctic sea ice was thinning and that during late summer there were large areas of open water in the central Arctic was surprising. Models had long projected that the Arctic would warm faster than other regions as atmospheric concentrations of greenhouse gases increased, but summer sea ice was being lost faster than the models projected. Part of the explanation may lie with the role of small soot particles from diesel combustion and fires that is blown north from lower latitudes. Though tiny, these dark particles increase the rate of snow and ice melt across the Arctic.

As is evident in Fig. 10, the summer extent of Arctic sea ice has declined since the satellite measurements for sea ice began in 1979, and it has thinned even more rapidly. Annually Arctic sea ice reaches its winter maximum in March and its minimum in September. As can be seen in Fig. 11, recent data indicate that new record lows for sea ice extent have been set during June and July 2012. The sea ice melt season began earlier this year, and the extent of open water now in the Kara and Barents Seas (north of Norway and western Russia) would typically not be seen until September.

Fig. 10

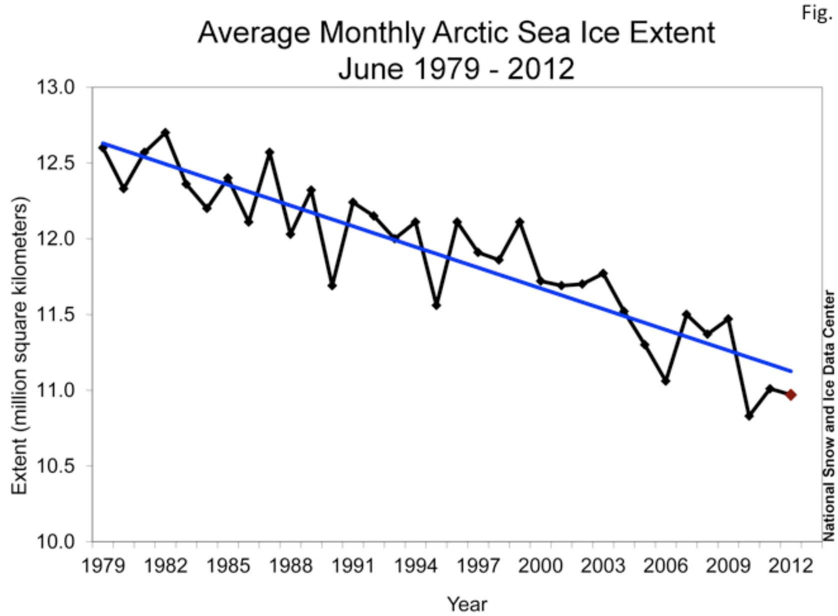
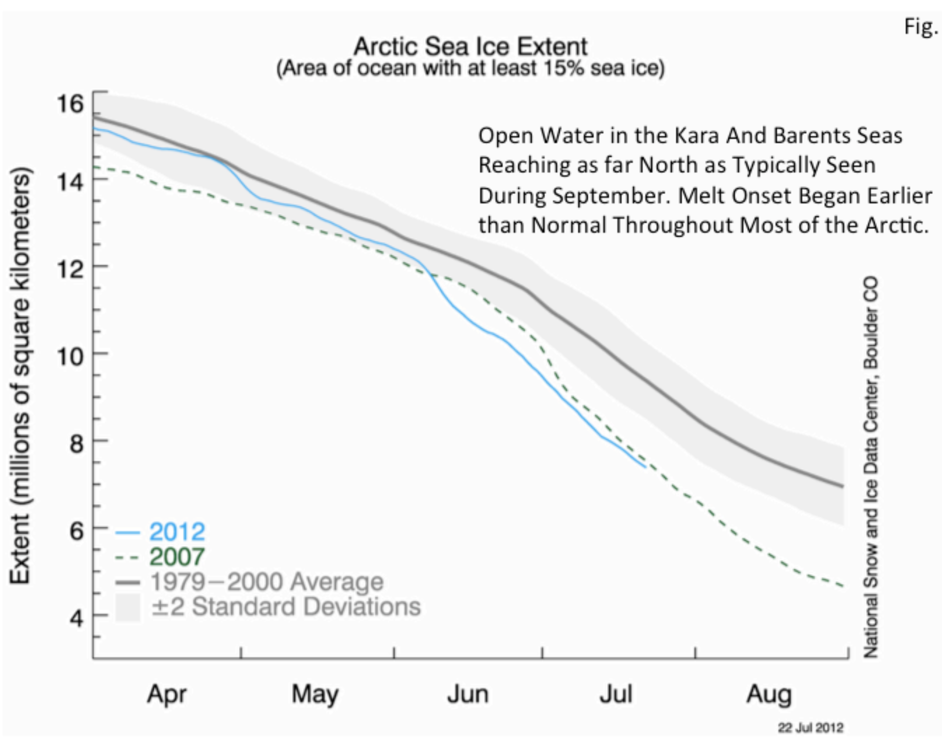


Fig. 11



Will someone who doesn't live in the Arctic be affected if the Arctic continues to warm and the area of sea ice continues to decrease during summer? New research shows links between the summer loss of Arctic sea ice and unusual extreme weather conditions across the temperate regions of North America and Eurasia (Overland et al. 2010). Ice atop water acts an insulator. Without an ice cover the surface ocean releases heat and water to the atmosphere. What most limits winter snowfall across much of North America is not temperature in winter, but rather availability of water vapor. It is often cold enough to snow but doesn't. More open water in the Arctic and in lakes increases the potential for snow across large continental regions.

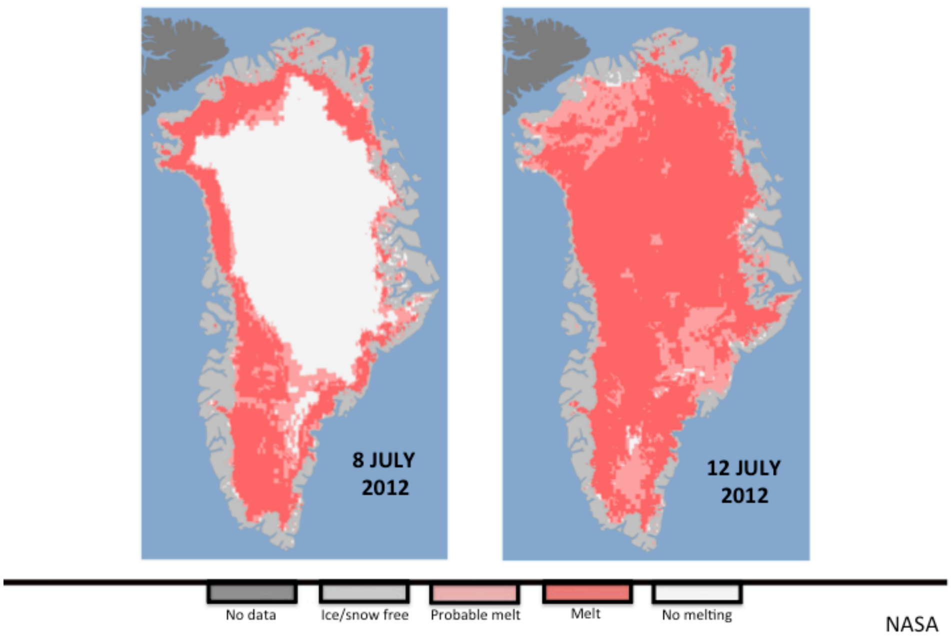
New studies (Francis and Vavrus, in press) show how warming in the Arctic can also influence the path of the upper atmospheric Jet Stream, creating higher amplitude waves, and in effect slow the propagation of weather patterns across the central North America. The result is that both warm periods and cold periods persist longer, potentially creating weather extremes on both ends of the scale. The authors suggest that this was in play during winter 2010-11, when record snow and cold occurred across parts of the central and eastern US just as record high temperatures were occurring across central Canada. During winter 2011-12 the La Niña also had a strong influence on the path of the Jet Stream – it was relatively flat rather than undulating – thus keeping cold air masses further north than usual.

It is also now well established that these changing ice conditions in the Arctic are affecting the exchanges of water between the Arctic Ocean and the north Atlantic Ocean in unusual ways (Speilhagen et al. 2012), and with unknown implications for future climate across regions bordering the North Atlantic.

B. Glacial ice melt

There was a lot of press coverage recently about an unusual Greenland melt event (Fig. 12). Greenland is covered by the most substantial mass of glacial ice in the northern hemisphere. It accounts for 10% of the surface fresh water on the planet. This ice cap is a broad flat dome that rises to about 10,500 feet, and were it all to melt global sea level would rise 22 feet. About a decade ago satellite images began to show that summer surface melting was occurring at increasing elevations and blue melt pools were beginning to appear above 6000 feet. These pools eventually drain through fissures in the ice, and probably speed the flow of glacial ice as it move along the solid bedrock. It is not terribly surprising that something like the recent July warm condition occurred. The white area of "no melting" in this image doesn't indicate just how much below freezing any of this area actually is.

Rapid Melt on Greenland Surface during July 2012 Fig. 12



NASA

According to NASA reports there is evidence in the ice core records of a strong warming event over Greenland in the 1880s. Data in Fig. 8 for global temperature show that the 1880s were unusually warm. As the Arctic continues to warm summer melting snow and ice at all elevations on Greenland will become more common.

This past July Greenland was also in the news for the release of an iceberg roughly twice the size of Manhattan from the Petermann Glacier in NW Greenland. Satellite data now allow for very precise estimates of the mass of Greenland ice and changes in its outlet glaciers, which drain ice from the ice cap to lower elevations. Fig. 13

shows terminations of the major outlet glaciers, with black for those with land terminations and green for those with marine terminations, also known as tidewater glaciers.

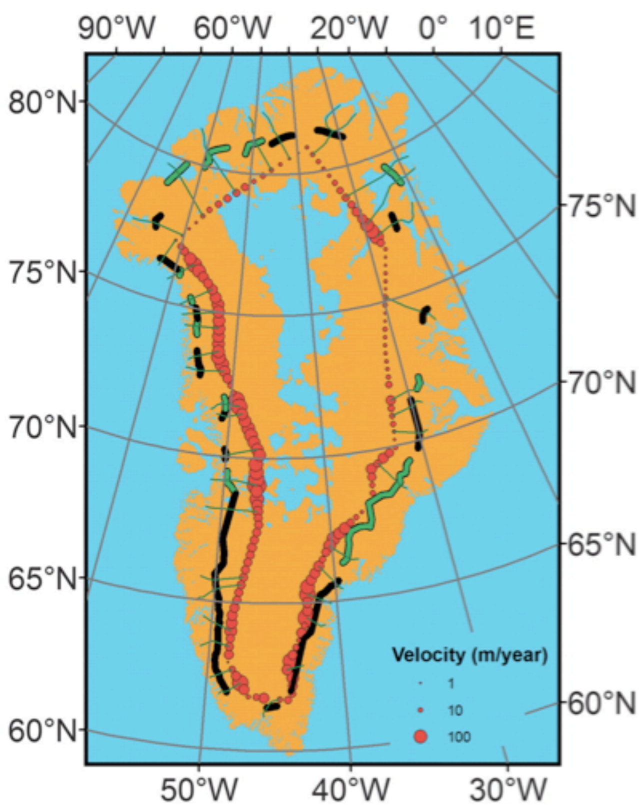


Fig. 13

Rates of Glacial Motion and Locations of Greenland Outlet Glaciers with Terrestrial (black) and Marine (green) Terminations

"On the basis of calculations presented here, we suggest that an improved estimate of the range of sea level rise to 2100 including increased ice dynamics lies between 0.8 and 2.0 meters [31 – 78 inches]."

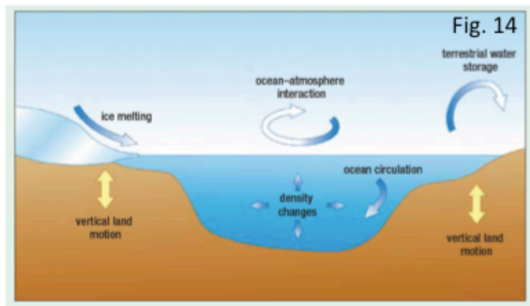
Pfeffer et al. 2008

The greatest changes in Greenland glaciers over the past decades have been the rapid retreats of tidewater glaciers like Petermann. While conditions at higher elevation certainly affect glacial flow, the factor most likely responsible for the retreat and shedding of large icebergs by Greenland's tidewater glaciers is the warming of waters surrounding Greenland and their melting influence on the snouts of these glaciers. The string of red dots of varying sizes on Fig. 13 circumscribe the edges of the high ice cap and indicate, from satellite data, the best estimates for rates of glacial discharge (largest of the three sizes of red dot is 100 times faster than the smallest red dot). Note that the weight of this mass of ice depresses the center of Greenland below the sea level surrounding Greenland.

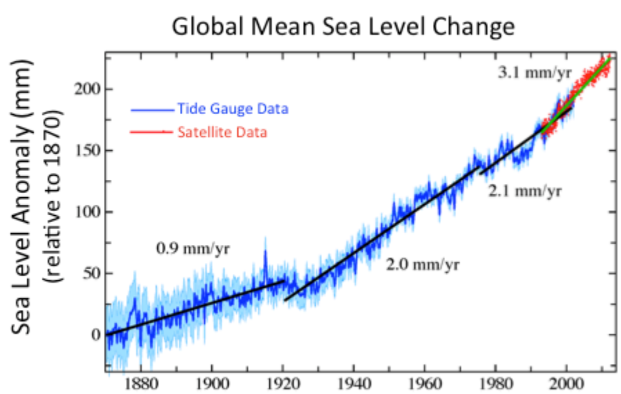
V. Sea Level Rise

Sea level is influenced by several factors (Fig. 14). Globally the ocean's heat content and the amount of land ice are dominant factors. As the ocean warms, its volume increases and sea level rises. A warming atmosphere and ocean cause land ice to melt, and if this water reaches the ocean, it too contributes to sea level rise. Other factors, such as coastal uplifting or subsidence of the land will strongly affect local manifestations of sea level. Importantly, the rise of an ocean that is warming and receiving more water from ice melt on land isn't distributed uniformly across the world's oceans. I will return to this point shortly.

Contributing Components to Local and Global Sea Level



Tide Gauge and Satellite Data for Sea Level 1870 - 2012



The rate of sea level rise has increased in recent decades, and is today greater than the conservative projections made by the IPCC one or two decades ago, and it is now clear that changes in sea level are speeding up.

In 2001, the IPCC reported that "[w]ithin present uncertainties, observations and models are both consistent with a lack of significant acceleration of sea level rise during the 20th century" (IPCC 2001). But it is now evident (Rahmstorf *et al.* 2007) that sea-level rise has accelerated since 1990 (Fig. 14).

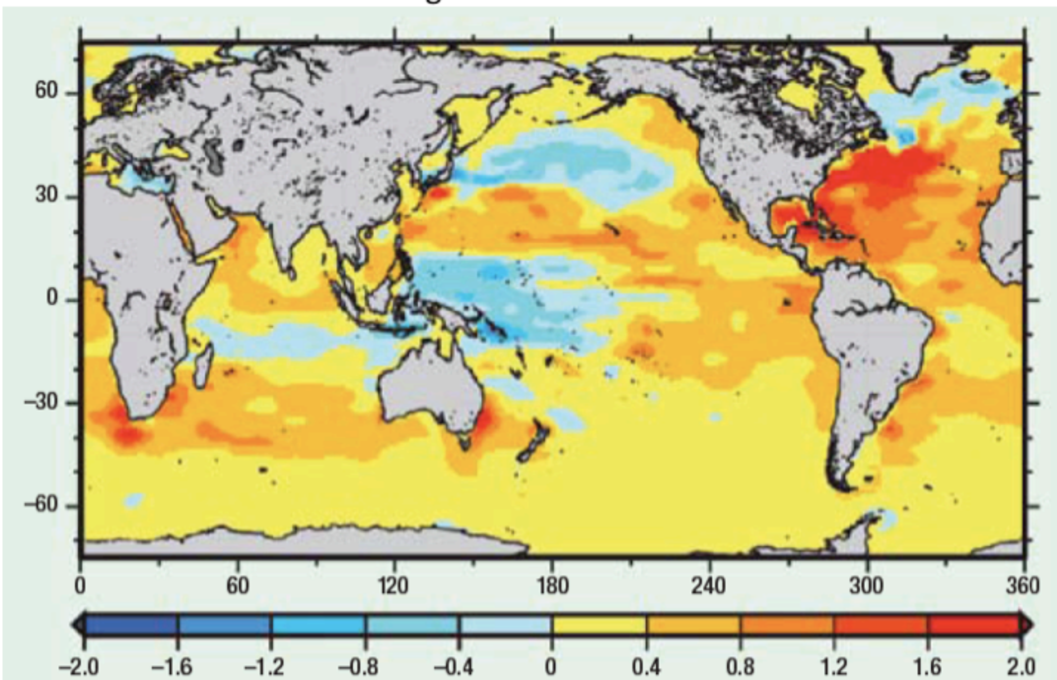
The 2007 IPCC report projected 12 – 24 inches of sea-level rise by 2100. These estimates did not preclude higher rates of rise due to increased rates of ice loss on Greenland and Antarctica. Although the IPCC authors were aware of publications relating to recent changes in Greenland and Antarctic ice, they lacked confidence that they could extrapolate meaningfully from these data to future sea-level rise. Rahmstorf (2007) used a semi-empirical relationship from 20th-century temperature and sea-level changes to project future sea-level rise from the IPCC scenarios for warming and derived an estimate of sea-level rise of about 2 – 4.5 feet for 2100 relative to the 1990 level. Using current outlet glacier discharge rates for Greenland to improve on the IPCC 2007 projections, Pfeffer *et al.* (2008) estimated a sea level rise between 2.5 and 6.5 feet by 2100 (Fig. 13).

An average sea-level rise of even 2.5 feet during this century would be of enormous consequence for lives, livelihoods, and property in coastal regions across the globe. Major cities, large portions of nations, indeed entire island nations will be affected. But for any specific locality future sea level will also be influenced by changes in currents and winds, proximity to the mass of melting ice sheets, and on the vertical movements of the land due to geological processes.

For example, a 2-foot rise in global sea level by the end of this century would result in a relative sea-level rise of 2.3 feet at New York City, 2.9 feet at Hampton Roads, Virginia, 3.5 feet at Galveston, Texas, and 1 foot at Neah Bay in Washington State (Karl et al. 2009). The southeastern and eastern coasts of the US have already experienced greater than average rates of increase over the last half-century (Fig. 15).

Trends in Sea- Level Change (mm/yr) due to Warming from 1955 to 2003

Fig. 15



Milne 2008

In the Gulf Coast area alone, an estimated 2,400 miles of major roadway and 246 miles of freight rail lines are at risk of permanent flooding within 50 to 100 years as global warming and land subsidence (sinking). Seven of the 10 largest ports (by tons of traffic) are located on the Gulf Coast.(Karl et al. 2009)   The US Navy estimates that $100 billion of Navy installations would be at risk with a sea level rise of about 3 ft. (NRC 2011)

VI. Personal Reflections on a Scientist's Journey

Scientific knowledge is always evolving. Science progresses because scientists constantly question every aspect of scientific understanding. New findings, seemingly credible, and perspectives that prevailed for decades are sometimes proven to be wrong. The process of science is one of always questioning and challenging both the new and the well-established findings.

A scientist is always asking: Does evidence adequately support the prevailing view as to how a particular process works? Is there an alternative explanation that is also, or perhaps even more, consistent with the highest quality evidence?

All good scientists ask these questions about everything they have either been taught or have discovered themselves. We train our students to go beyond what we can teach them – to use newer methods for gathering evidence, to subject their data to ever more sophisticated analyses, to always keep their mind open to other views in order to advance, in the most genuine sense of the word, the science. The very best students will discover errors and inadequacies in what their mentors thought to be the best understanding of the natural world.

For many of us in ocean science the compelling evidence for human-caused climate change came with the observations of deep ocean warming, the ice core data that demonstrate linkages between Earth's past temperature and atmospheric greenhouse gas content, the acceleration in sea level rise, the abrupt melting of land ice and ice shelves that had been in place for many thousands of years, and global changes in ocean chemistry. Such changes in these phenomena can only be consistently explained by an unusual rate of greenhouse gas release to the atmosphere.

The idea that greenhouse gases from fossil fuel combustion affect climate, which was studied by Arrhenius more than a century ago and developed further by Calendar a half century later, is correct. Interestingly, Arrhenius did not anticipate the rapid growth in human population during the 20th century and our increasing demands for energy - he thought that it would take millennia rather than a just a century to double the pre-industrial atmospheric CO_2 concentration.

State of the art fully coupled climate models can now simulate the natural processes that affect climate (solar cycles, volcanoes, and internal cycles such as the El Niño – Southern Oscillation) and the human-caused processes that affect climate (greenhouse gases and aerosols) to show the relative importance of each of these components in the climate of the past and present. Using assumptions about trends in population, type of energy used, etc. these same models can make projections about future climate. One very clear finding from these studies is that one of the largest uncertainties about future climate relates to the choices that we and our children will make regarding energy use. The more dependent we are on CO_2-emitting sources of energy, the more Earth's climate will change.

In the public media there is a lot of confusion about climate science. Most National Academies and professional societies have issued statements about climate science. The American Meteorological Society, for example, in a 2007 two-page statement says:

> "Despite the uncertainties noted above, there is adequate evidence from observations and interpretations of climate simulations to conclude that the atmosphere, ocean, and land surface are warming; that humans have significantly contributed to this change; and that further climate change will continue to have important impacts on human societies, on economies, on ecosystems, and on wildlife through the 21st century and beyond."

Other professional organizations of ocean and atmospheric scientists and National Academies have issued similar statements.

It can be tempting to think that any of us know better than the experts, or that the risks don't apply to us. Early in my life I had many friends and family who smoked cigarettes. But most of them stopped when organizations such as the American Medical Association, the American Cancer Society, the American Lung Association, the American Association for Thoracic Surgery, etc. issued statements saying that smoking contributes to lung and heart disease. Some continued smoking because habits are hard to break, and others continued because they thought that it couldn't be said with certainty that they would get cancer.

This same sense of self-preservation and responsibility for our actions that will affect future generations should motivate us to wisely use knowledge from climate science to reduce risks of harm from unnecessarily disruptive climate.

Thank you for inviting me to contribute to this discussion.

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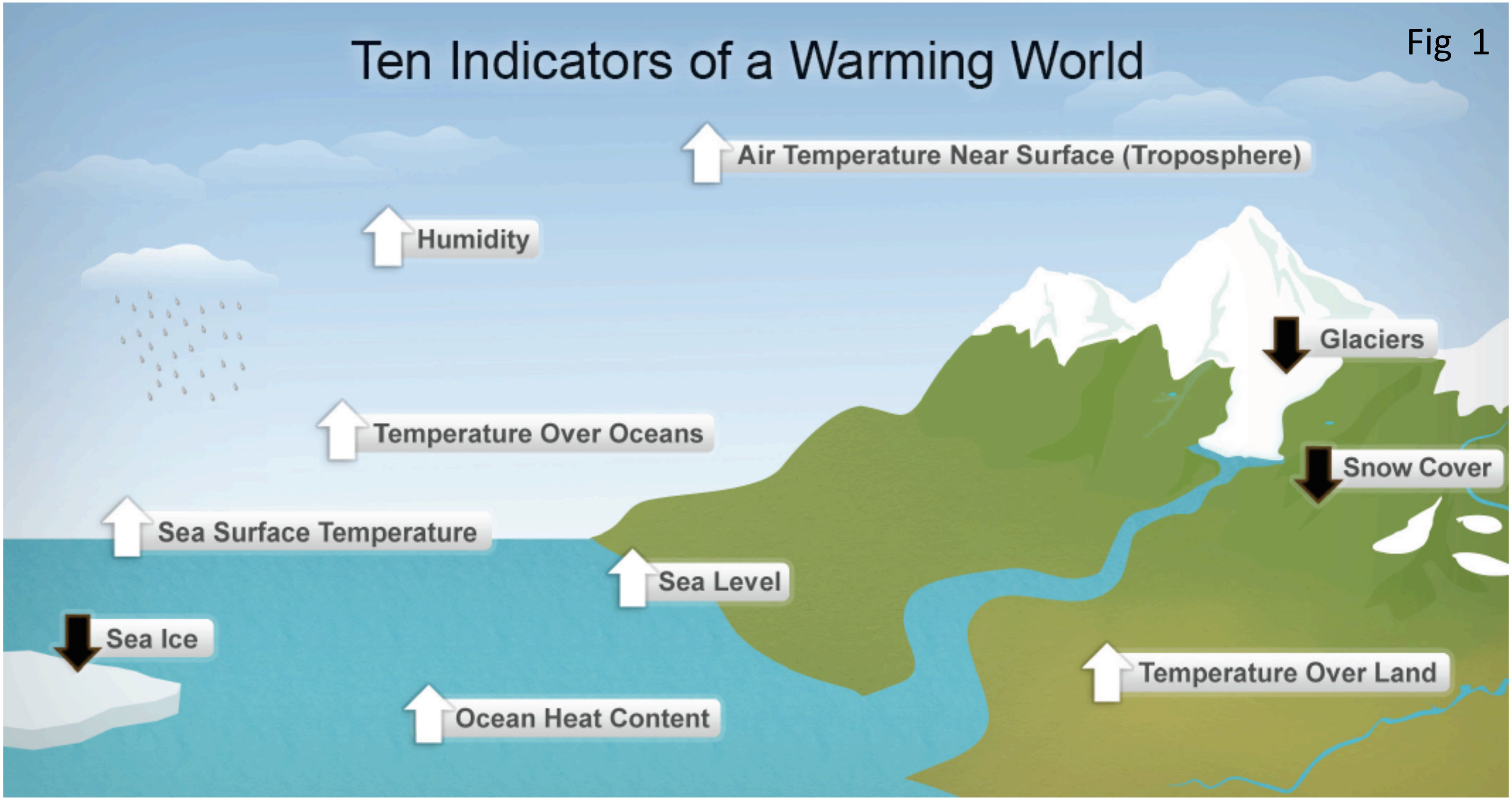
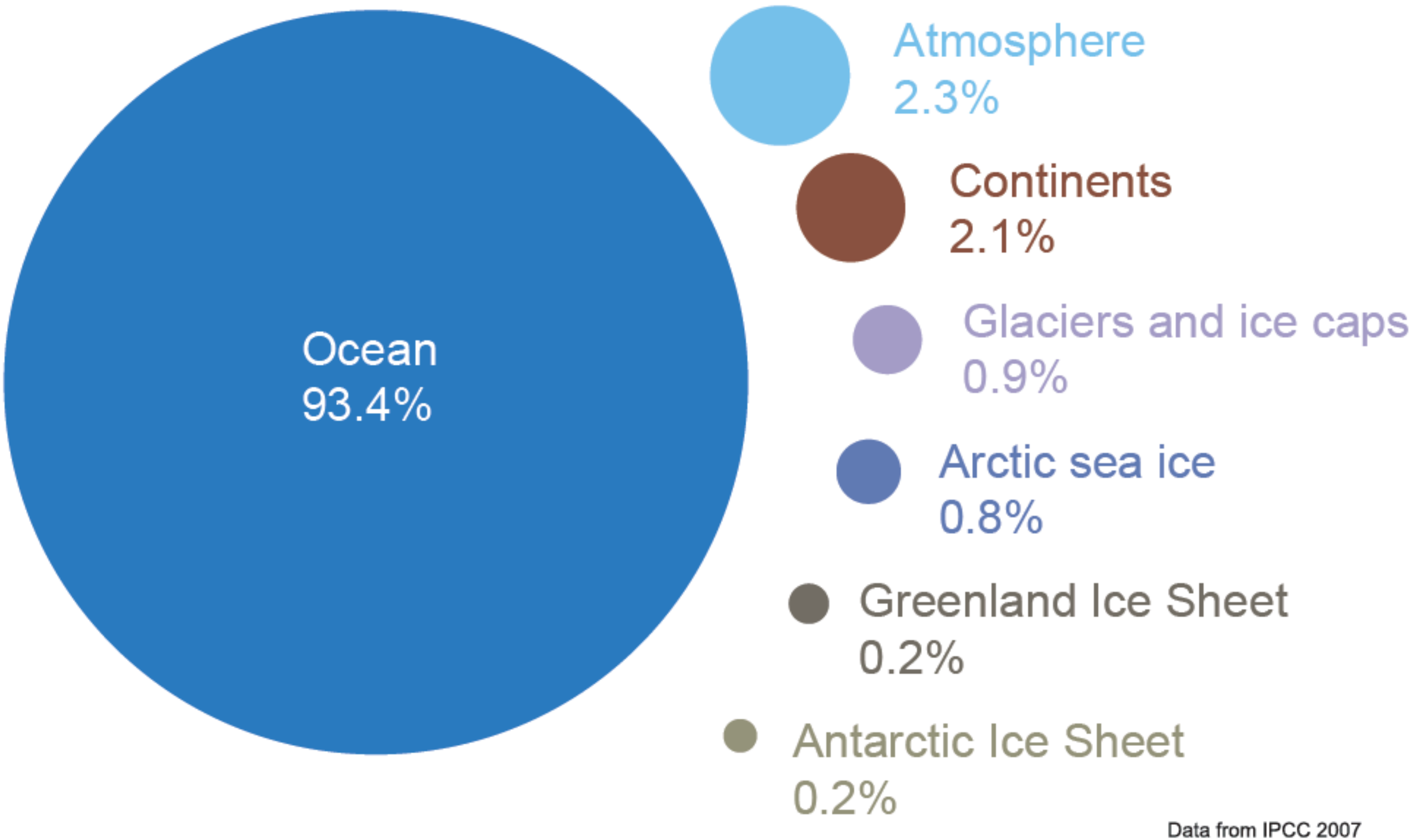


Consistent Trends in All these Indicators Over the Last Several Decades Provide Robust Evidence that Earth is Warming

NOAA/BAMS 2009

Fig. 2

Where is global warming going?



NOAA/BAMS 2009

Fig. 3

Argo Drifting Floats Monitor Changes in The Oceans' Heat Content – Initiated in the 2000s

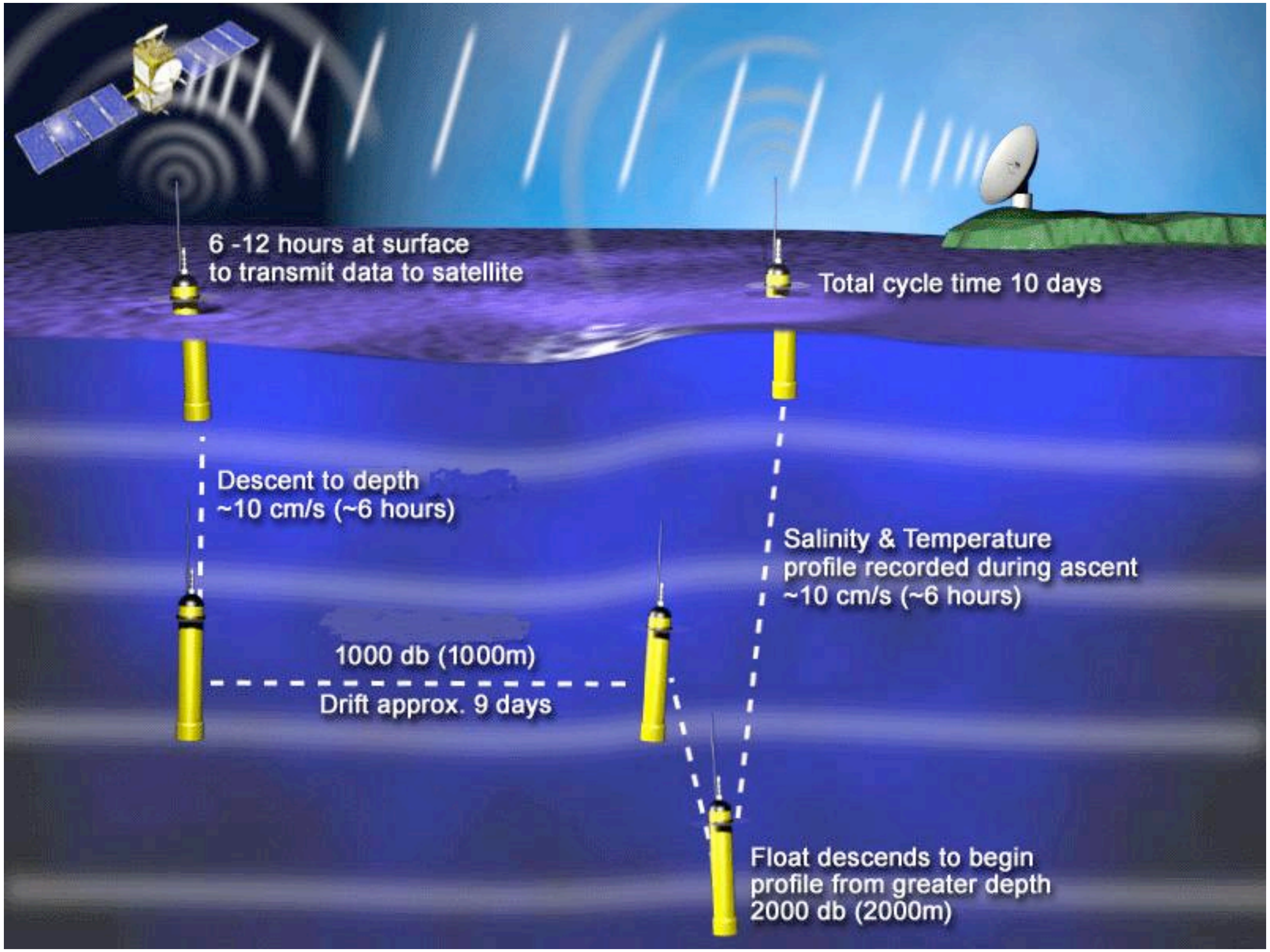


Fig. 4

More than 3500 Drifting Argo Floats in Regular Operation Profiling Ocean Temperature & Salinity to 2000 meters every 10 Days

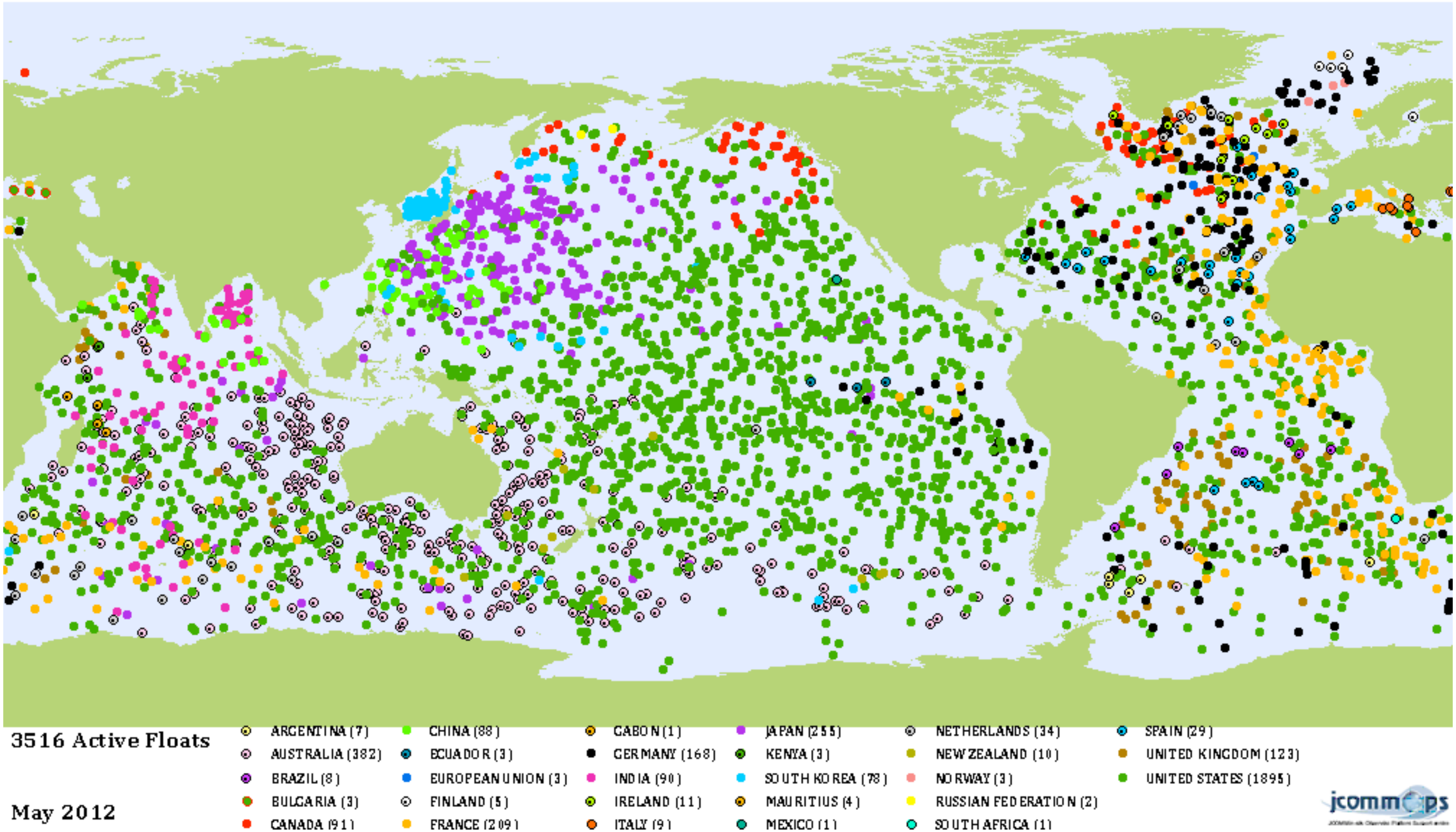
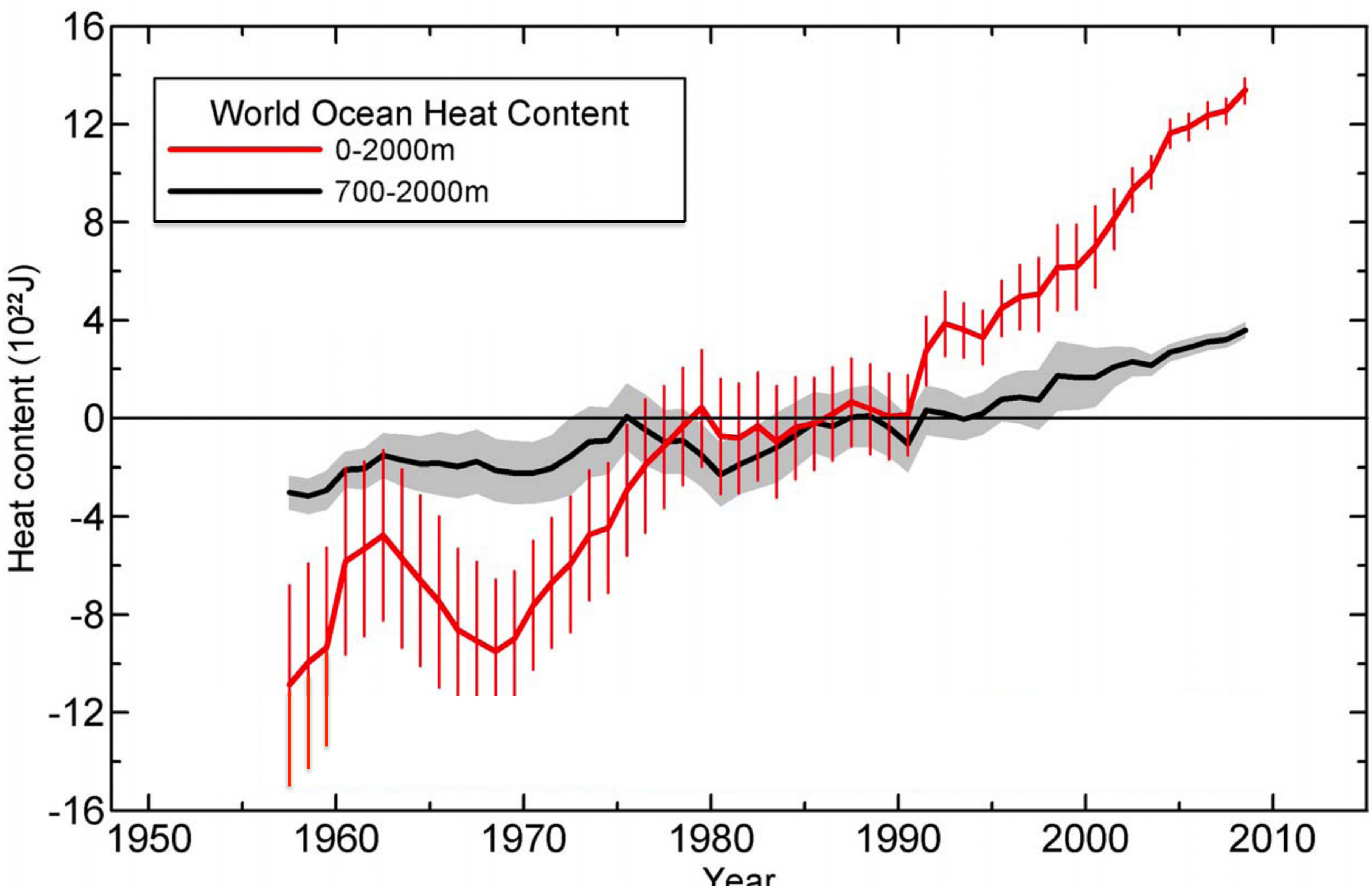


Fig. 5

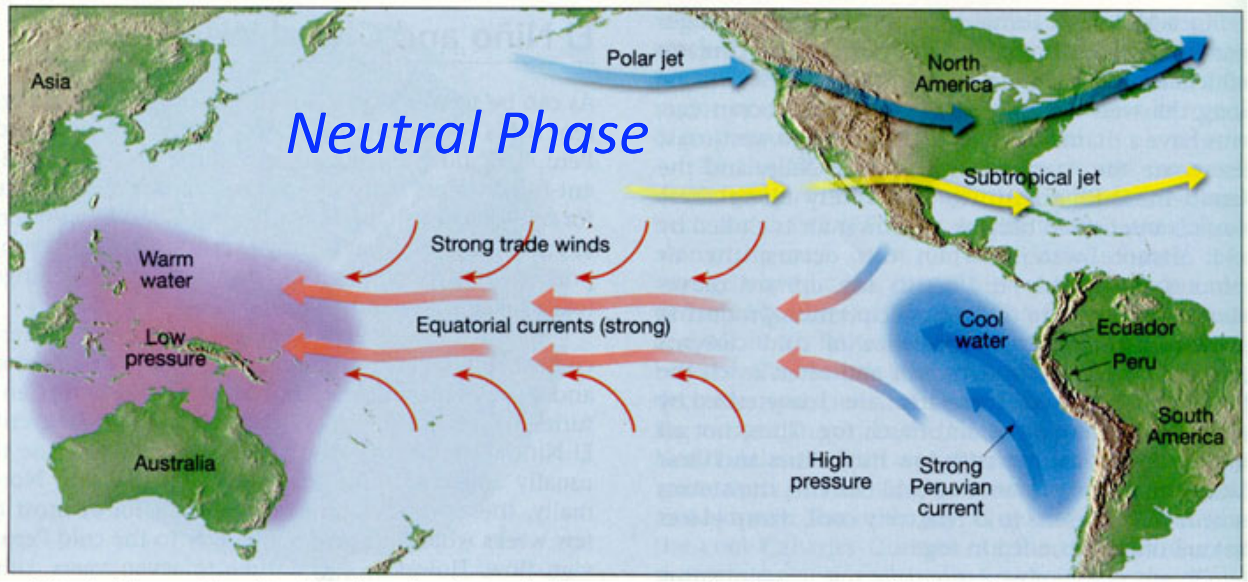
The Deep Oceans are Warming at Great Depths



Levitus et al. 2012

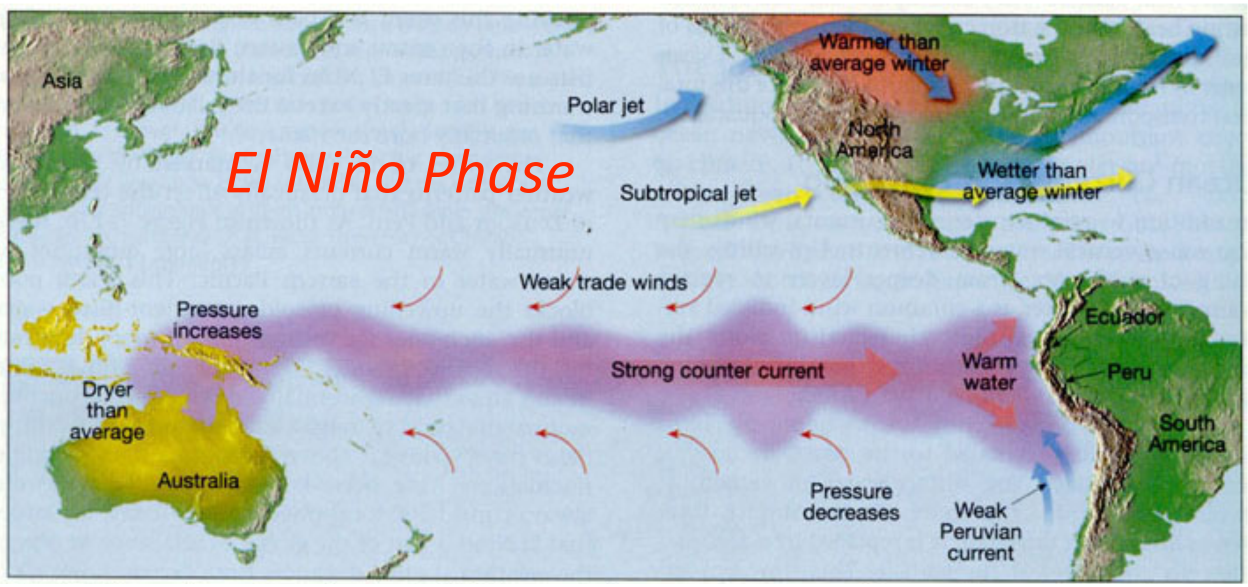
Fig. 6

Cool Ocean Water in the East and Warm in the West

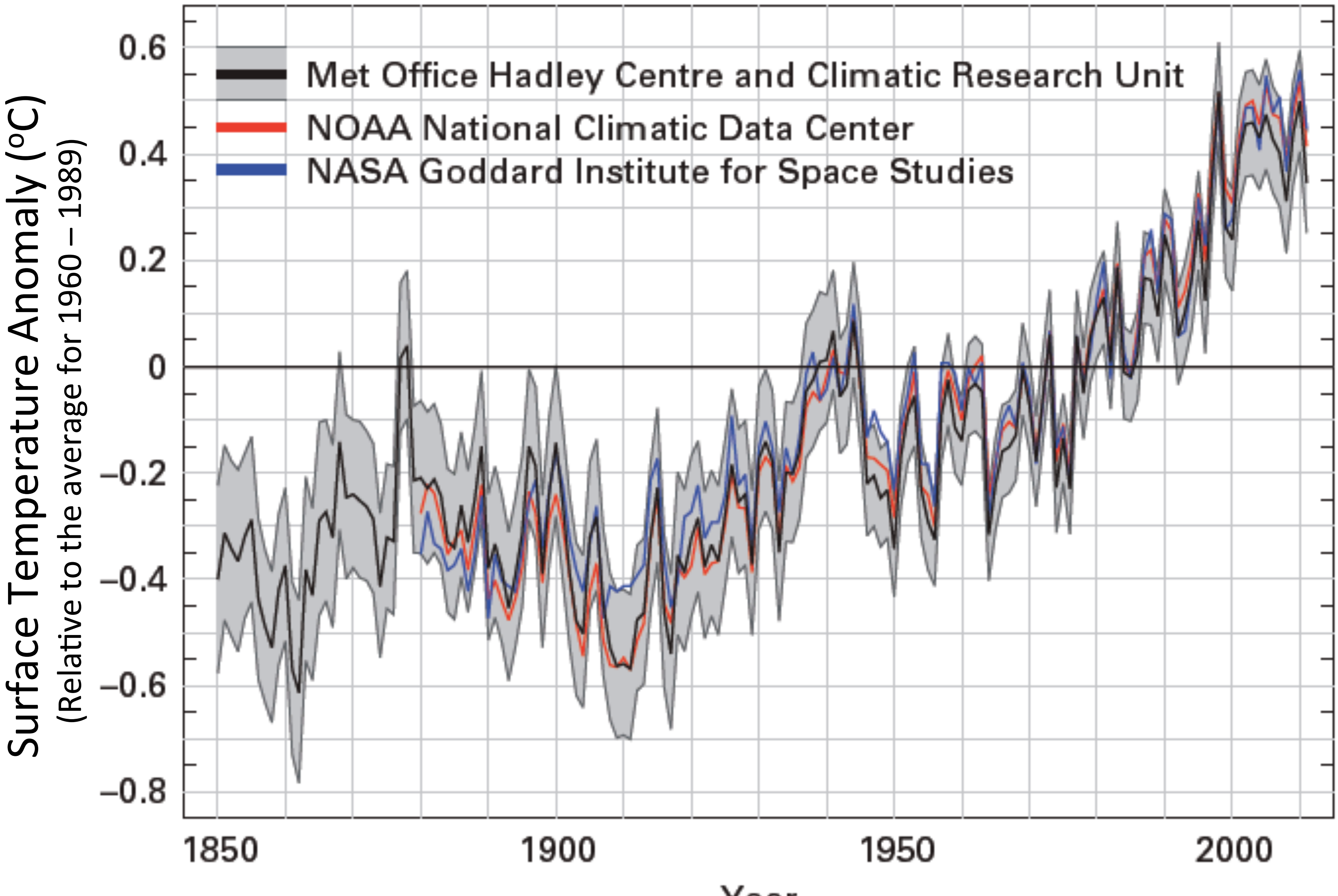


With Associated Shifts In Climate Across The Globe

Every 2 – 7 yr the Trade Winds Relax, and Warm Water Flows East



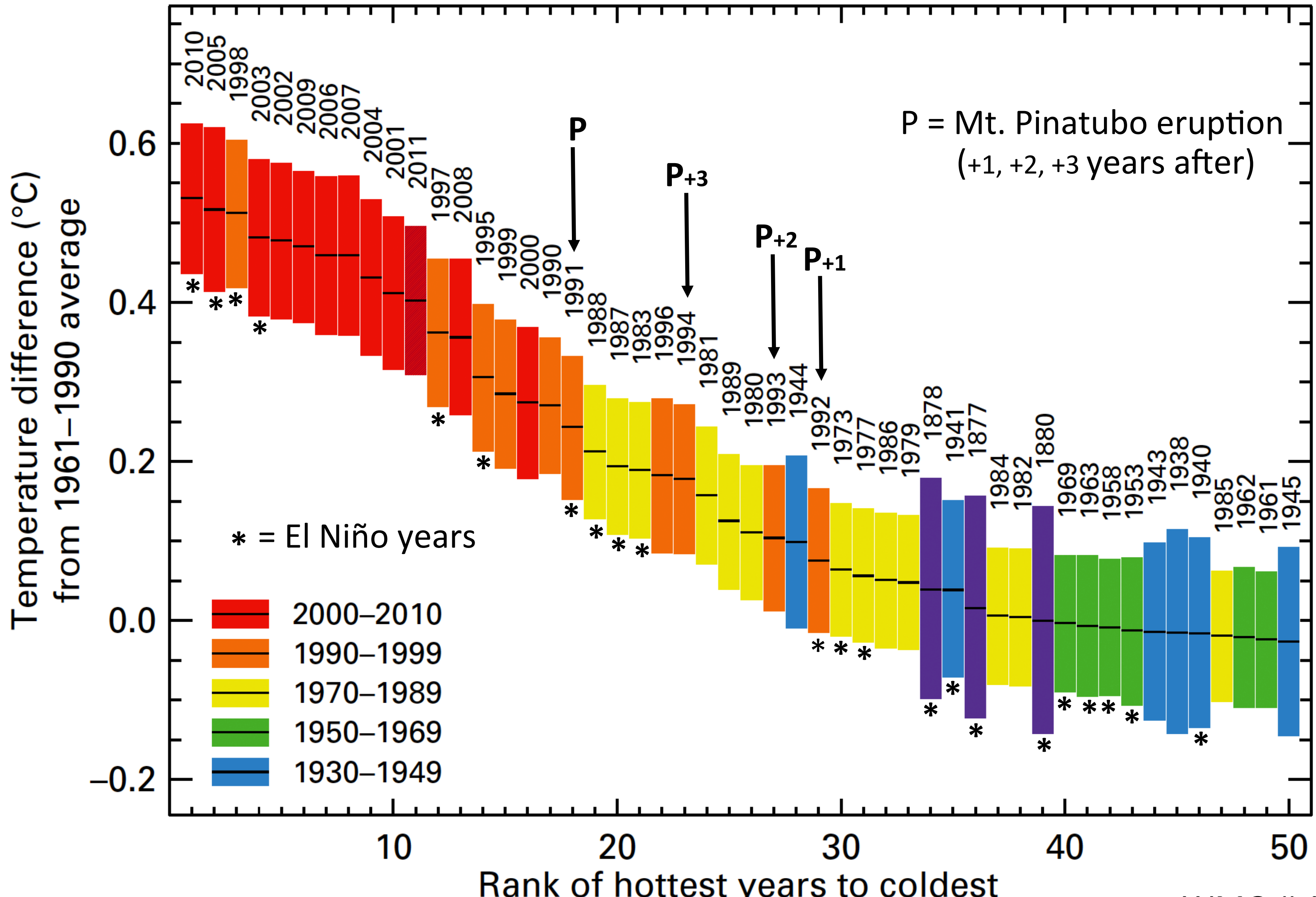
Global Average Surface Temperature



WMO #1085

Fig. 8

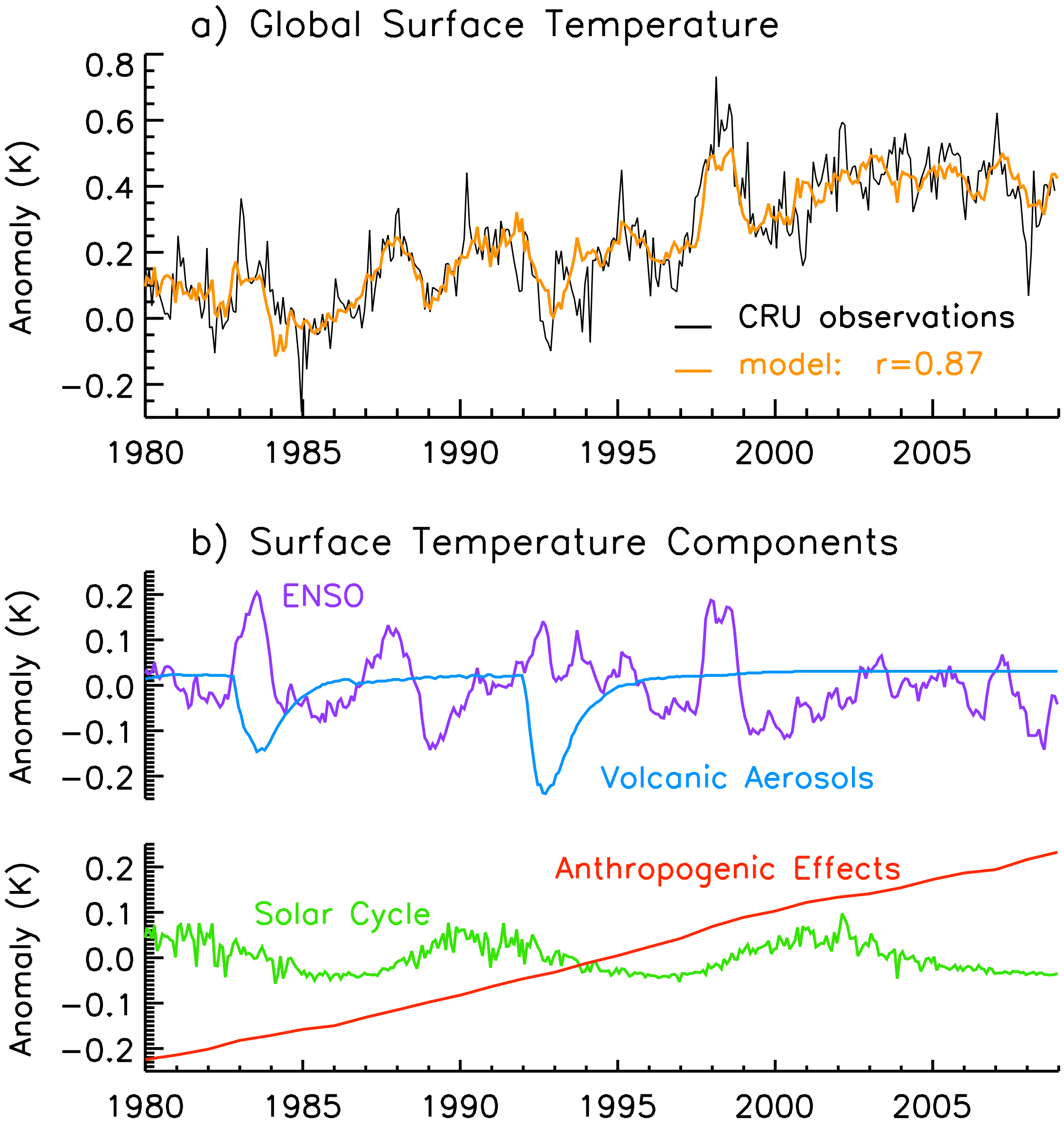
Ranking the 50 Warmest of the last 150 Years



WMO # 1085

Reconstructing Earth's Climate 1980 – 2009 Using Observed Climate Forcing Functions

Fig. 9



When The Effects of Solar Variability, El Niños, Volcanoes And Greenhouse Gases Plus Aerosols, etc. are Summed, Models Faithfully Reproduce Recent Trends In Earth's Surface Temperature

Lean and Rind 2009

Fig. 10

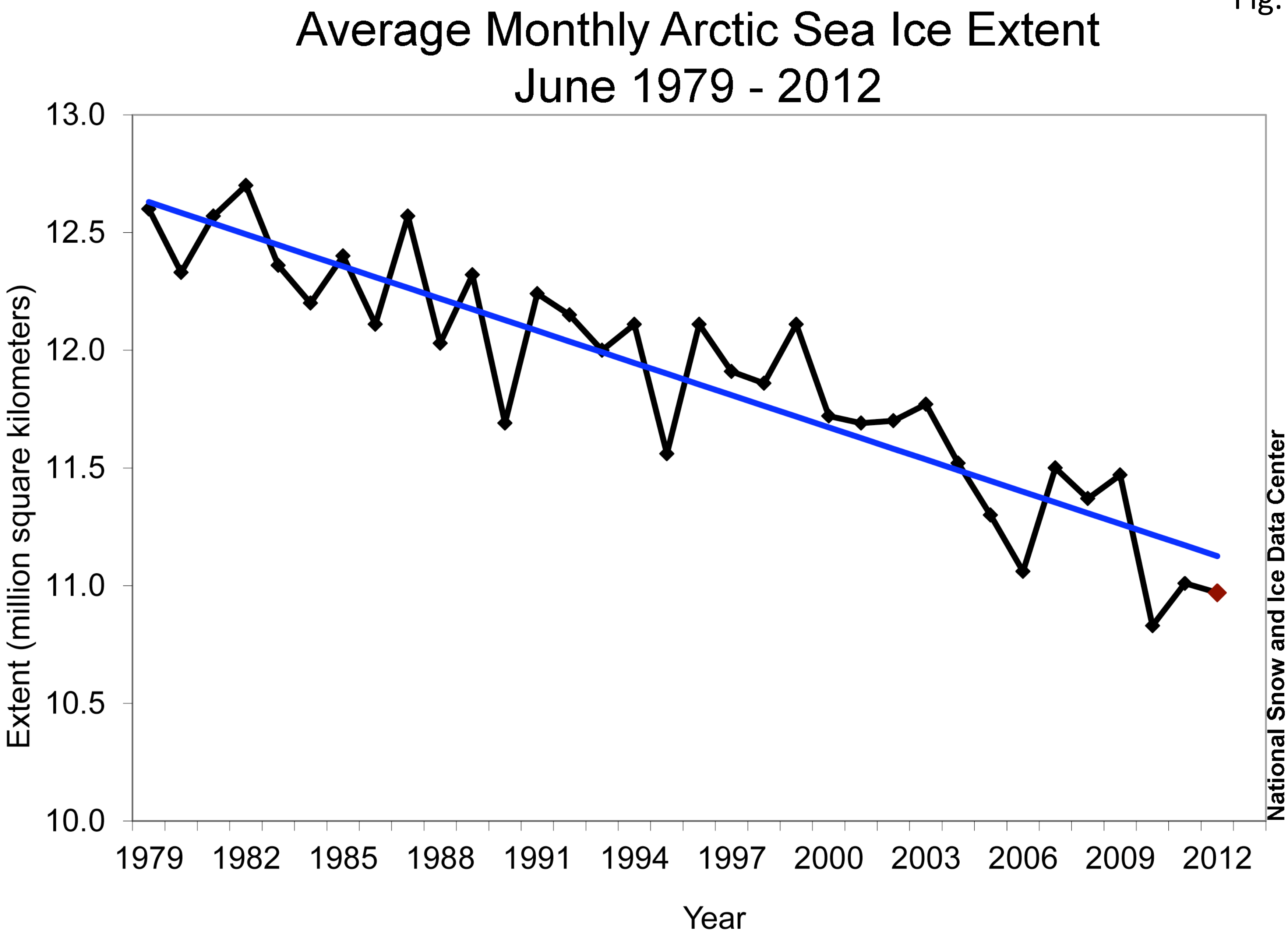
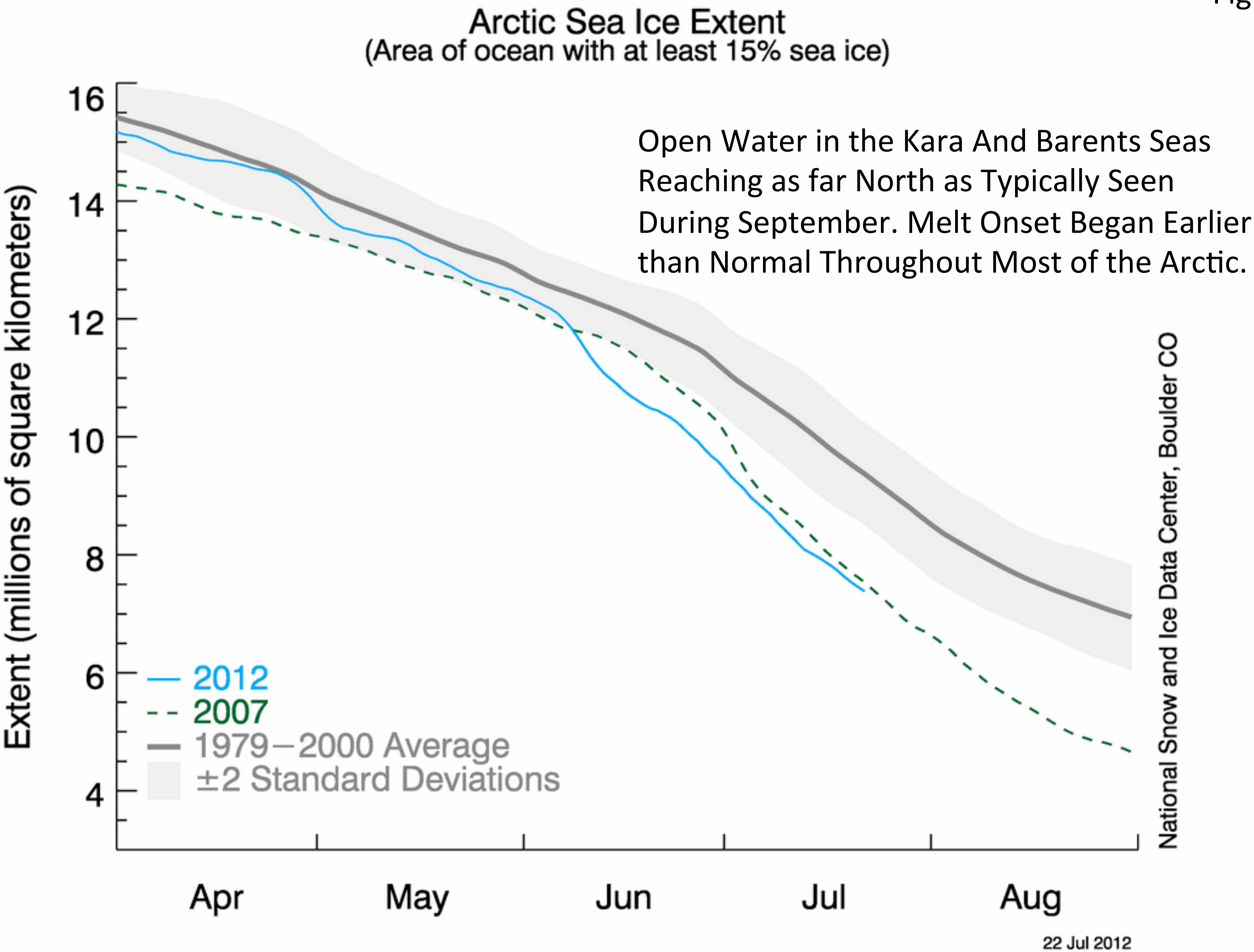
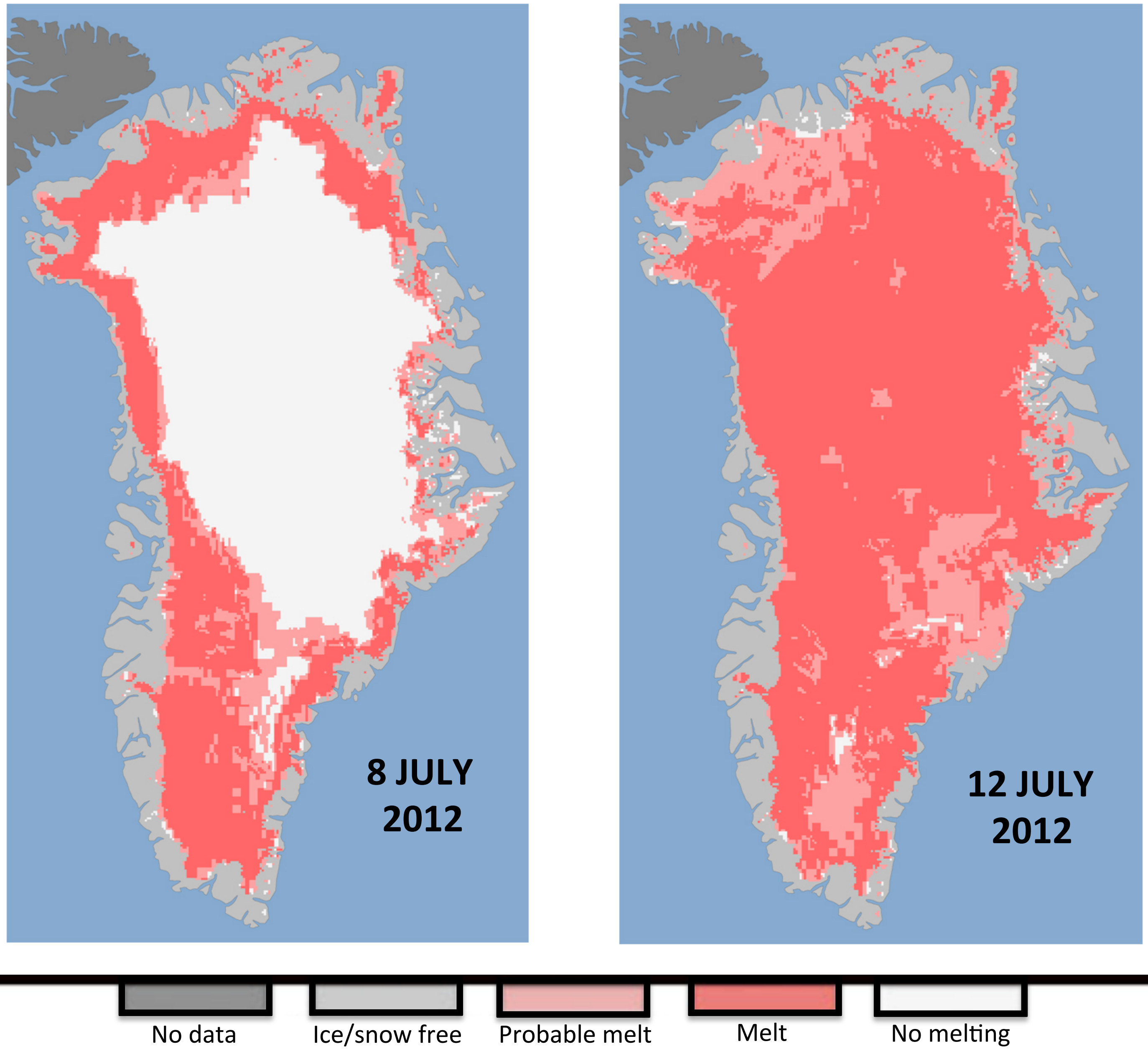

Average Monthly Arctic Sea Ice Extent
June 1979 - 2012
13.0
12.5
12.0
11.5
11.0
10.5
10.0
Extent (million square kilometers)
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
Year
National Snow and Ice Data Center

Fig. 11


Arctic Sea Ice Extent
(Area of ocean with at least 15% sea ice)
Open Water in the Kara And Barents Seas Reaching as far North as Typically Seen During September. Melt Onset Began Earlier than Normal Throughout Most of the Arctic.
Extent (millions of square kilometers)
16
14
12
10
8
6
4
Apr
May
Jun
Jul
Aug
2012
2007
1979–2000 Average
±2 Standard Deviations
National Snow and Ice Data Center, Boulder CO
22 Jul 2012

Rapid Melt on Greenland Surface during July 2012

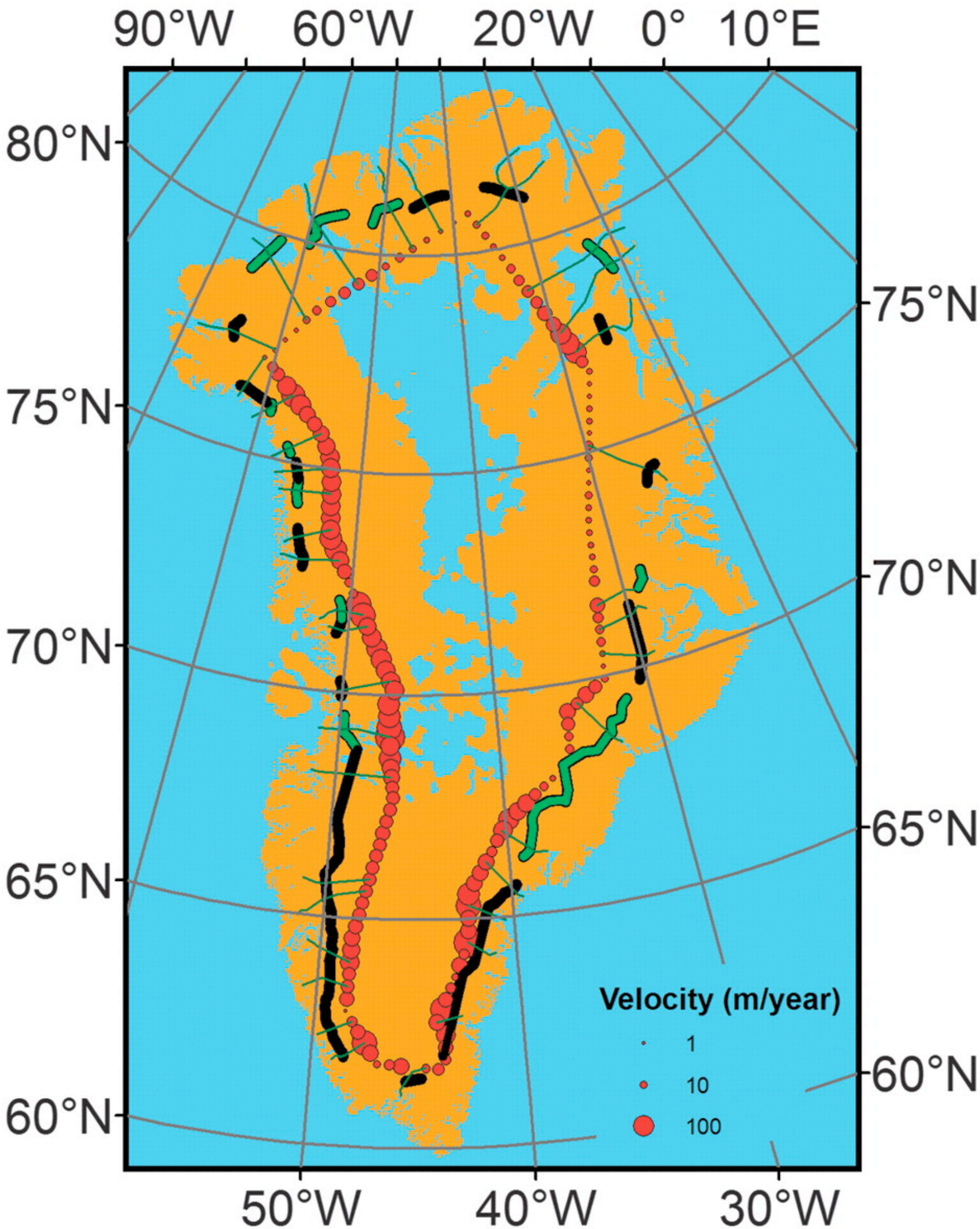
Fig. 12



NASA

Fig. 13

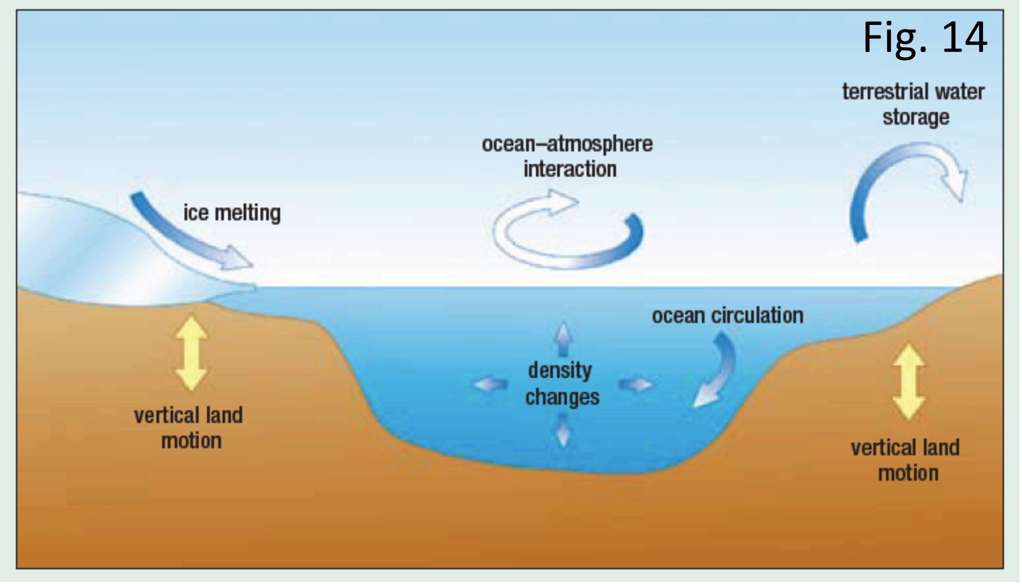
Rates of Glacial Motion and Locations of Greenland Outlet Glaciers with Terrestrial (black) and Marine (green) Terminations



"On the basis of calculations presented here, we suggest that an improved estimate of the range of sea level rise to 2100 including increased ice dynamics lies between 0.8 and 2.0 meters [31 – 78 inches]."

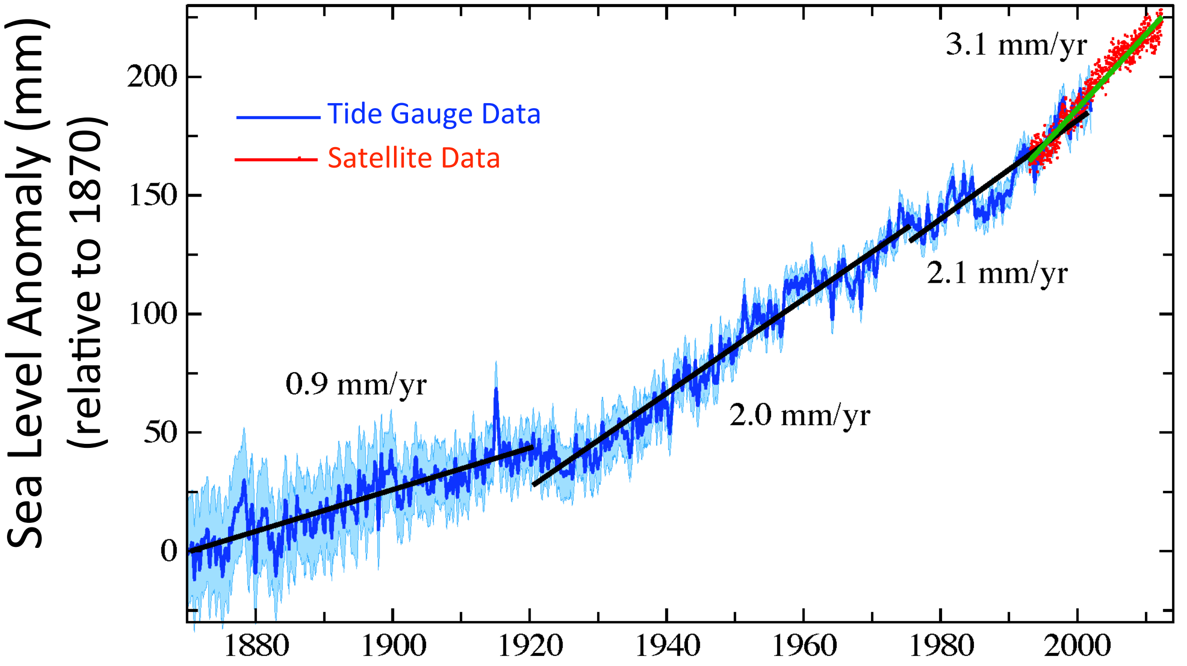
Pfeffer et al. 2008

Contributing Components to Local and Global Sea Level

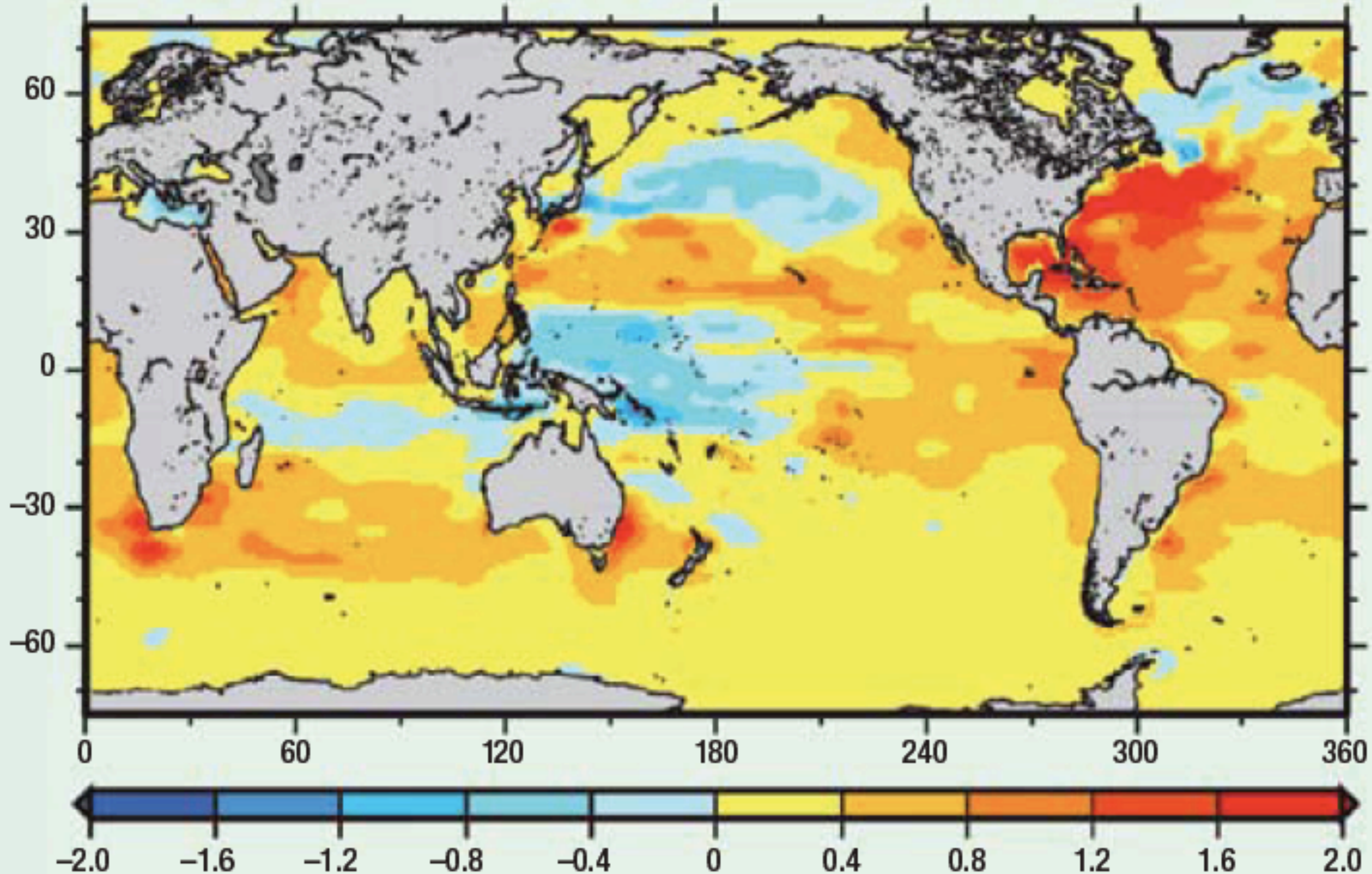


Tide Gauge and Satellite Data for Sea Level 1870 - 2012

Global Mean Sea Level Change



Trends in Sea- Level Change (mm/yr) due to Warming from 1955 to 2003



Milne 2008