Chapter Three:
Consequences of Global Warming

Below is the list of topics this chapter will address. The list of concerns over consequences of global warming continues to grow.

- Sea-level rise
- Melting of mountain glaciers
- Melting of the polar ice caps: Antarctica and Greenland
- Arctic Warming & Disappearing sea ice
- Slowing of the oceanic circulation that keeps Western Europe warm
- Increased occurrence and increased intensity of hurricanes
- Increased El Ninos
- Increased drought
    - A surprise effect: dust from Africa and rain forests in the Amazon
- Increased wildfires
- Increased floods
- Increased storminess
- Increased frequency and intensity of tornadoes
- Declining coral populations
- Migrating species
- Species extinction
- Polar-bear endangerment
- Blocking high-pressure systems
- Ocean Acidification
- Unintended Consequences of "Solutions"
    - Carbon trading
    - Hydrogen-powered vehicles

The discussion of sea level in terms of polar ice and mountain glacial ice is long and tedious, but for good reason. Illustrated by this discussion is the way science is "done" and "delivered". These are the "stories behind the stories". The discussion of sea-ice disappearance is similarly in-depth. Discussion of hurricanes falls next in level of detail. Other projected consequences are easier and faster to get through; although they are enhanced with stories behind the story too. This may be slow reading. I hope it is worth it…

Sea level:

"Complete melting of the ice caps will result in a sea-level rise of 80 meters and will inundate coastal cities worldwide…"

True, sea level *will* rise 80 meters, inundating coastal cities worldwide *if* the icecaps *completely* disappear. But is there evidence to support disappearance of the ice caps? What justifies suggesting such an extreme scenario? Is it rooted in probability or sensationalism?

"Startling amounts of ice slipping into the sea have taken glaciologists by surprise; now they fear that this century's greenhouse emissions could be committing the world to a catastrophic sea-level rise"…

Icebergs calving into the sea…

Species endangerment: Polar bears stranded due to disappearing sea ice….

Impending doom portrayed in the movie "The Day After Tomorrow"…

Coastal cities flooded

"Greenland glaciers dumping ice into Atlantic at faster pace"

"A Worrying Trend of Less Ice, Higher Seas"

These are headlines reported in prestigious science journals…

What, other than disaster, can the informed person expect???

The current total annual sea-level rise is ~ 2mm/year. Less than half of this amount comes from ice-mass loss from the Greenland and Antarctic ice caps. More contribution to sea-level rise appears to be coming from Greenland than from Antarctica. Greenland is increasing mass in its center, but losing it along the coast. The net change, as calculated by some, is a loss of ice mass that translates to ~0.2 mm/year of sea-level rise. Then there are others who say there is no mass loss from Greenland.

Antarctica's net contribution is at most 0.02mm/year; sometimes its contribution is actually negative, meaning that during some years, Antarctica contributes to a declining sea level, albeit minute. Melting of mountain glaciers contributes ~ 0.41 mm/year. This is a highly variable value.

The remainder of sea-level rise can be attributed to a few other processes. One is climate related; the others are not. These processes include: thermal expansion of warmer waters, due to both global warming of surface ocean water and to decadally oscillating oceanic redistribution of water masses; displacement of water due to volcanic activity along spreading centers on the ocean floor; and to non-tectonic vertical "adjustments" of landmasses – compaction of sediment, sinking land due to extraction of water, oil, or natural gas, and the like.

Two hundred millimeters of sea-level rise in a hundred years seems relatively benign. This seemingly small amount might surprise the reader. So why the hand-waving and frenzied concern?

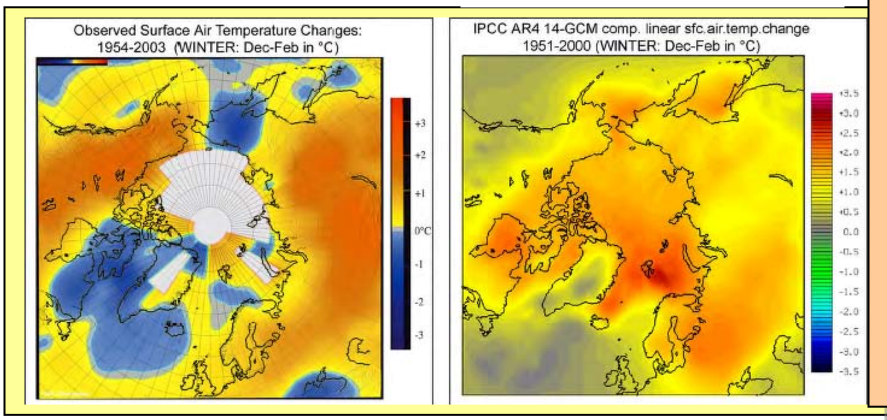
Few see unmanageable disruption resulting from less than a foot of sea-level rise in a hundred years. Concern is more rooted in issues that are not yet realized, but feared. These issues surround the movement of glaciers on the ice caps at either pole. Recent observations and calculations hint at changing behavior of these glaciers, which would lead to accelerated loss of ice. The fact that scientists are at a loss to explain what is going on, leads many to fear this is the consequence sentinels have long presaged. There are justifiable reasons to project greater sea-level increases, not due so much to simple melting, but to possible changes in ice dynamics.

A scientist can argue for panic or for calm about future conditions, and have foundation for the claims. The topic is complex (surprise), and as you've learned by now, "complex" is messy. The bottom line, there may be reason to be concerned. Equally likely, there may not be.

First, it might be of interest to the reader to hear this again: in contradiction to model predictions, the polar latitudes have mostly cooled when they were expected to be dominated by accelerated rates of warming. Ninety-nine percent of Antarctica is cooling and large sections of the Arctic have cooled when compared to the 1950s. What then, explains the disappearing ice?

Observed temperature changes since 1954

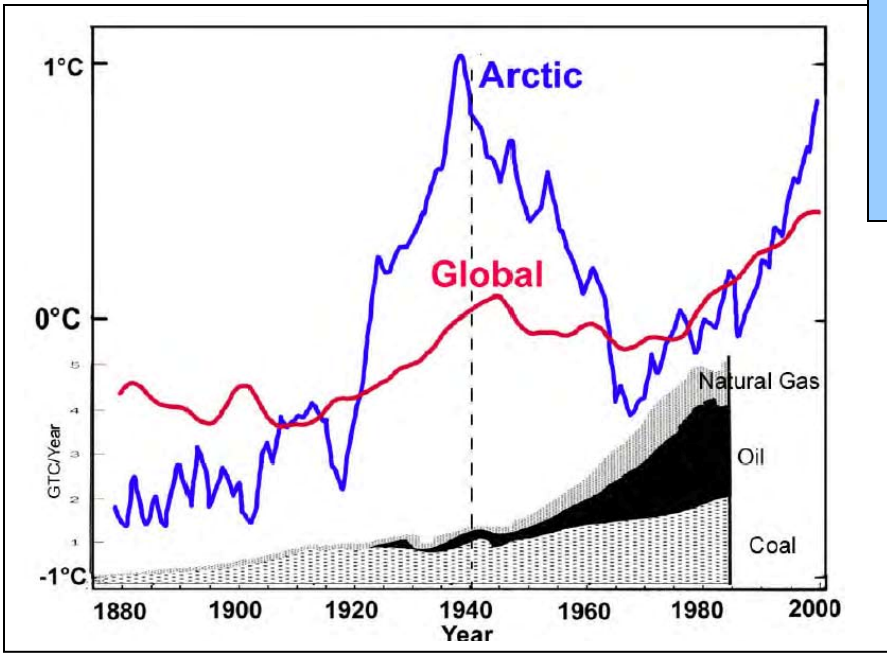
Model-generated predicted temperature changes since 1951



On the left is a depiction of observed temperature changes in the Arctic (blue = cooling; orange/red = warming; white = no data available) between 1954 and 2003. Most of Greenland has cooled over this time.

On the right is a modeled view of expected temperature changes in the same region over the same general time frame, between 1951 and 2000.

Because the pictures differ dramatically, it becomes all the more confusing as to why more ice is disappearing in the Arctic.



And recall this graph of the observed temperature changes over the last 120 years…

Warmth in the 1920s to 1940s was significant in both magnitude and rate of warming.

The list of studies on Arctic temperatures is lengthy – Darby et al. 2001, Kasper and Allard 2001, Muhs et al. 2001, Naurzbaev and Vaganov 2000, Moore et al. 2001, Areseneault and Payette '97, Gedalof and Smith 2001, Vaganov et al. 2000, Jorgneson et al. 2001, Zeeberg and Forman 2001, Comiso et al. 2001, Chylek et al. 2004, Polyakov et al. 2002, Benner et al. 2004, Przybylak 2000 and 2002, and more.

The general theme of them all is that Greenland has been warm before – in the last interglacial, in the middle of this interglacial (up to 5°C a few thousand years ago), and earlier in recent human history. Warming existed before the Little Ice Age (LIA). After ~ 1750, well into the second round of the LIA, temperatures dropped sharply. Around 1880, gradual emergence from the LIA was evident globally, as well as in the Arctic. From 1920 into the late 1930s, warming was stunningly rapid. Peak warmth occurred in Greenland in 1937, as one can see on the graph above. Annually averaged temperatures along coastal regions increased by 2 to 4°C in less than ten years (by as much as 6°C during the winter months). This warming phenomenon is so pronounced in the record that it is known as the "**great Greenland warming of the 1920s**". This warming coincided with a CO_2 increase of only 3 to 4 ppm; thus, warming in the Arctic need not be correlated to greenhouse-gas levels. Furthermore, if one reviews the broader historical perspective, fluctuations in temperature regimes follow a variety of oscillatory patterns – millennial and decadal. One familiar with climate history cannot help but be reminded of the abrupt warmings of the glacials (discussed in the last chapter), the Dansgaard-Oeschger events. **The pattern observed in the current interglacial resembles the pattern of the glacial; only the amplitude during the interglacial is much smaller**.

Interpreting study results can be confusing. One must take note of the details.

- ***Is the study based on observation or models, or both?***
- ***Are measurements direct, calculated, or interpolated?***
- ***Are the results representing temperatures or temperature changes?***
  - ***Often it is the latter.***
  - ***If so, what are the years against which these changes are compared?***

A recently published report on Arctic conditions is heralded as the last word on climate-change in the Arctic. I have offered a few highlights and a few tips on how to read a report like this, so that you can become *truly* informed.

A few salient quotes taken from the ACIA report…

http://www.acia.uaf.edu/

The observational database for the Arctic is quite limited, with few long-term stations and a paucity of observations in general, making it difficult to distinguish with confidence between the signals of climate variability and change. Based on the analysis of the climate of the 20th century, it is very probable that the Arctic has warmed over the past century, although the warming has not been uniform. Land stations north of 60° N indicate that the average surface temperature increased by approximately 0.09 °C/decade during the past century, which is greater than the 0.06 °C/decade increase averaged over the Northern Hemisphere. It is not possible to be certain of the variation in mean land-station temperature over the first half of the 20th century because of a scarcity of observations across the Arctic before about 1950. However, it is probable that the past decade was warmer than any other in the period of the instrumental record.

Evidence of polar amplification depends on the timescale of examination. Over the past 100 years, it is possible that there has been polar amplification, however, over the past 50 years it is probable th... cation has occurred.

The observational database for the Arctic is quite limited, with few long-term stations and a paucity of observations in general. The combination of a sparse observational dataset and high variability makes it difficult to distinguish with confidence between the signals of climate variability and change.

Within the text of the ACIA report, this point is re-stated, with slightly different wordina.

since the late 19th century. While the impact of urbanization on large-scale temperature trends in the Arctic has not been assessed, the results of Jones et al. (1990), Easterling et al. (1997), Peterson et al. (1999), and Peterson (2003) indicate that urbanization effects at the global, hemispheric, and even regional scale are small (<0.05 °C over the period 1900 to 1990).

It is clear that trends in temperature records, as evidence of polar amplification, depend on the timescale chosen.

scarcity of data prior to 1945, it is very difficult to say whether the Arctic as a whole was as warm in the 1930s and 1940s as it was during the 1990s. In the Polyakov et al. (2003b) analysis, only coastal stations were chosen and most of the stations contributing to the high average temperatures in the 1930s were in Scandinavia. Interior stations, especially those between 60° N (the southern limit for the analysis in this section) and 62° N (the southern limit for the Polyakov et al. (2003b) study), have warmed more than coastal stations over the past few decades. As discussed in section 2.6.3, arctic sea-ice extent contracted from 1918 to 1938 and then expanded between 1938 and 1968 (Zakharov, 2003).

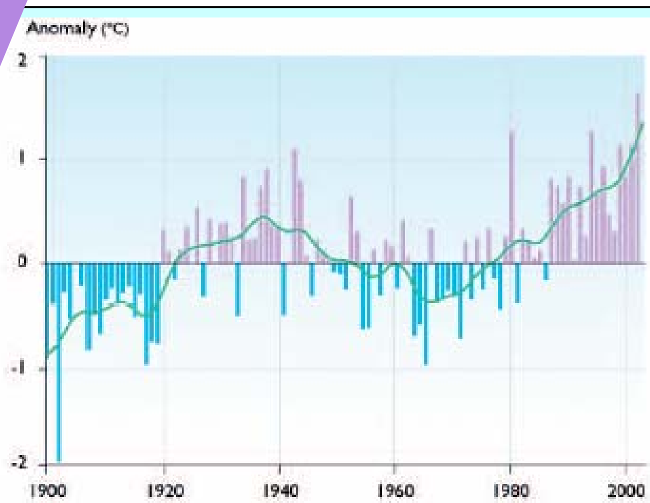


Fig. 2.6. Annual anomalies of land-surface air temperature in the Arctic (60° to 90° N) for the period 1900 to 2003 using the GHCN dataset (updated from Peterson and Vose, 1997). Anomalies are calculated relative to the 1961–1990 average. The smoothed curve was created using a 21-point binomial filter, which approximates a 10-year running mean.

Economic issues led to a significant reduction in the existing meteorological network in northern Russia and Canada in the 1990s. Thus, during the past decade, the number of arctic meteorological stations has noticeably decreased, and the number of the stations conducting atmospheric measurements using balloons has decreased sharply.

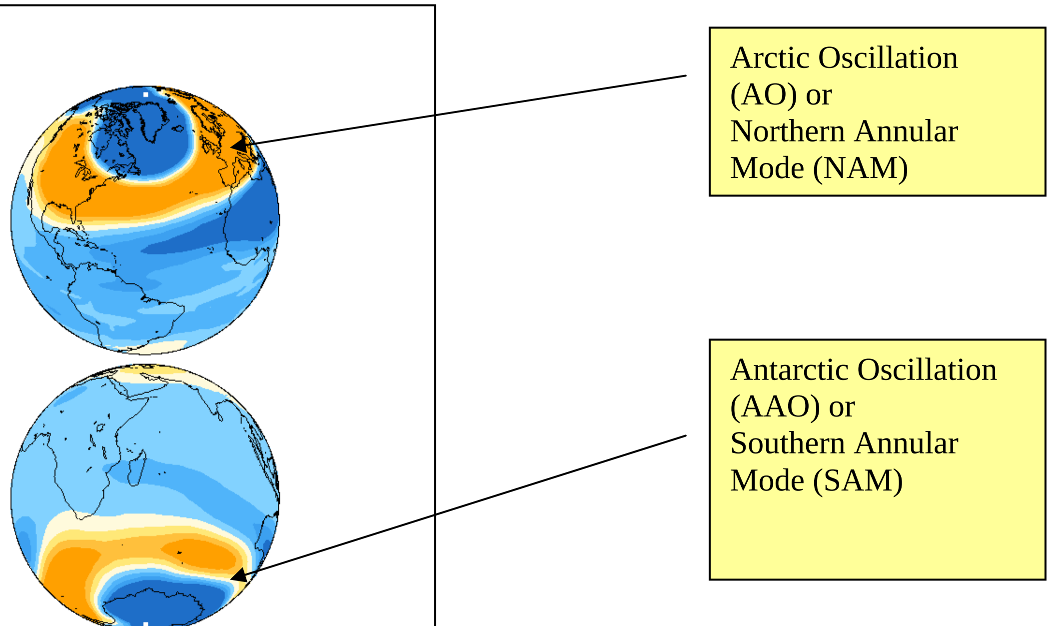
When one reads the often-cited ACIA report directly, one can start to pick out the nuances. Note the following aspects: Time frame of comparison, changing methods and distribution (many stations closed in 1990!) of measuring temperature, the lack of adjustment for urban-island heat effect, and the asserted assumption that this phenomenon has no effect on temperature (the studies cited as dismissing the urban-island heat effect are enormously controversial and the results contradict the numerous previous studies on the topic). It may be noted that the authors are liberal with admission of deficiencies (so pay attention to those), but the deficiencies are quickly minimized and dismissed, followed by comments such as "it is *probable* that the past decade was warmer than any other period in the instrumental record". When reading the study, consider: What the report failed to mention, how they word their conclusions, how graphic information is presented (always note error bars, how the "trend line" would look if measurements continued into the future or if a different time frame had been chosen), and what assumptions were made and then asserted with no mention of conflicting conclusions.

To conclude on the topic of temperatures in Greenland, while they are only now approaching levels reached in 1937, and not at as rapid a rate, when examining trends in temperature change over this time frame, one can see that the current trend has been one of mostly cooling. Of course, if one's frame of reference is restricted to the decades since the 1970s, then temperatures have warmed. Choose your point of reference, quote the statistic, and preach any agenda.

Antarctica, is mostly cooling, 99% of it, and at a very notable rate. In some areas the seasonally averaged surface air temperature has increased as much as 0.7°C per decade between 1986 and 1999. The West Antarctic Peninsula, on the other hand, is warming, and warming at an extremely fast rate. The far southwestern area of the West Antarctic Peninsula has warmed as much as any place on Earth over the last 50 years – as much as 2.5°C. This is a startling number, but confined to a very small area.

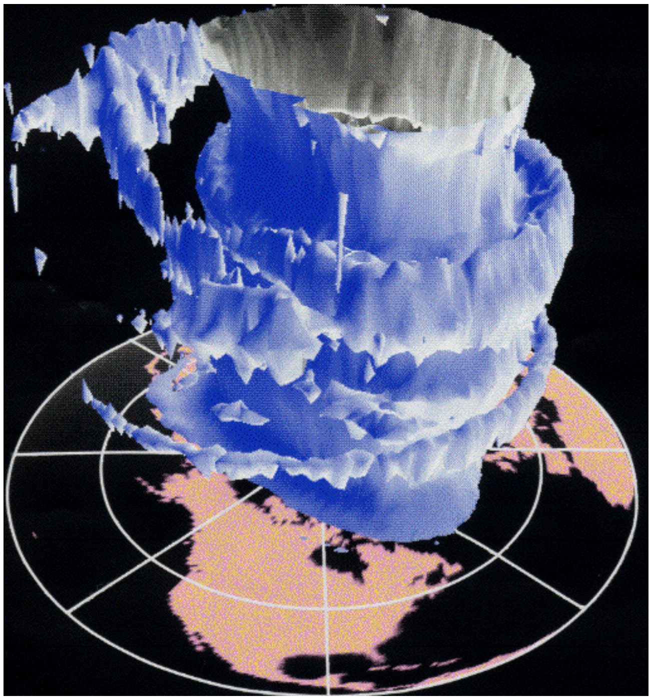
Two questions might be brewing in your mind right now: Why is ice loss accelerating (even if net loss remains unchanged) if current temperatures and the rate of temperature increase are not unprecedented? And what would explain the oscillatory pattern of temperature fluctuation detected in the record? Clearly, the interaction between ice dynamics and climate is not a simple matter of warming leading to melting. While ice loss behavior remains an enigma, the oscillatory pattern of temperature fluctuation is more forthcoming. It follows.

Mentioned briefly in the last chapter under the section of alternative climate forcings, mention was made of two globally dominant oscillatory patterns – the polar oscillations and El Nino. The polar oscillations, of importance to us here, are known to scientists as annular modes (annular referring to a ring-like structure) – the **Northern Annular Mode (NAM) and the Southern Annular Mode (SAM)**. In vernacular most often seen in the lay journals, one might see the terms: **Arctic Oscillation and Antarctic Oscillation – AO and AAO**.

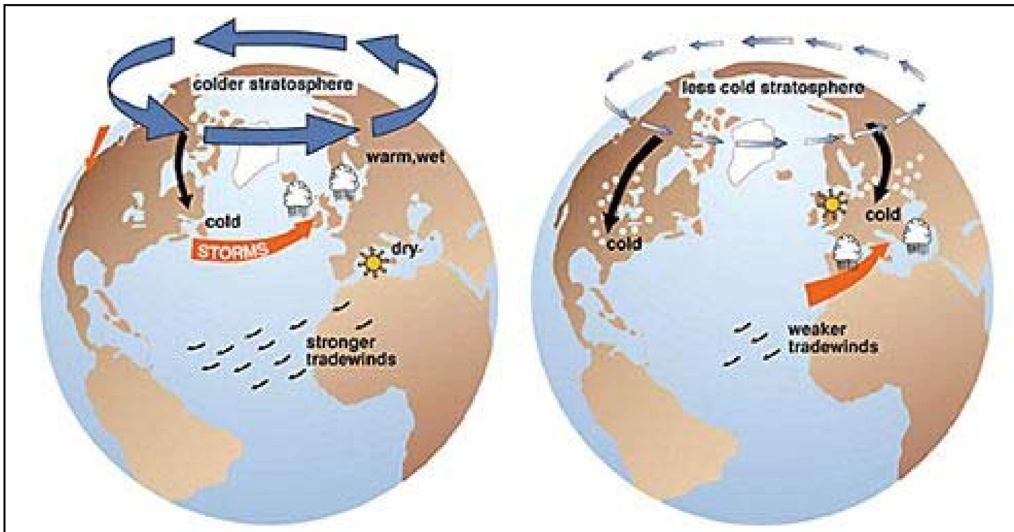


MSU2LT data regressed on the JFM NAM index (top) and the SAM index (bottom). Contour interval 0.1 K/std.

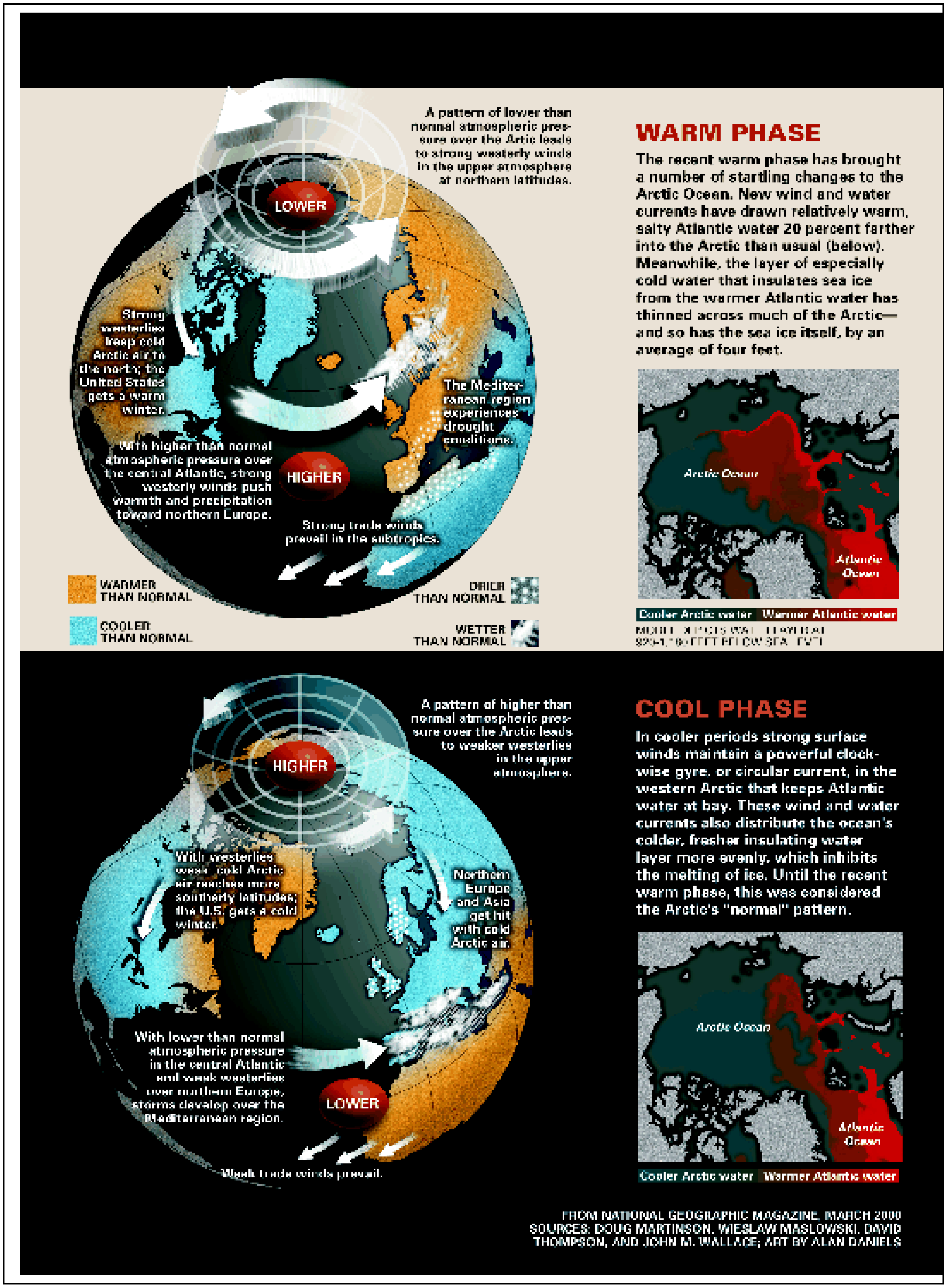
The annular modes are characterized by low pressure at the poles with a ring-like pattern of high pressure encircling it. As the polar winter ushers in perpetual night, temperatures cool dramatically. The pressure drops further. A ring of strong westerly winds high in the atmosphere begins to descend. This is known as the **polar vortex**. During warmer months, the vortex is a stratospheric phenomenon. During the late fall into early spring, it couples with the lower atmosphere, thus allowing this ring of strong westerly winds to persist.



The stronger the winds are, the more the cold air at the poles is locked in place. Warmth is brought from the tropical latitudes up to higher latitudes by these westerly winds. In essence, with a strong phase of this annular mode, mid latitude winter temperatures are warmer; polar temperatures are colder. If the ring of westerly winds is in a weaker phase, and the pressure difference between the polar region and the lower latitudes is not as great, cold polar air is likely to spill out, cooling the mid latitudes during the winter months. The air in the poles is not contained, and thus is less cold than it is during the strong phase. These modes, or oscillations, are naturally occurring. They oscillate between stronger and weaker on a daily basis; yet, they have a tendency to be more often in one "phase" than another for years at a time, even decades at a time. During much of the 1970s through most of the 1990s, the phase of the NAM (AO) was positive, or strong. This allowed for temperatures within the vortex to be cool and temperatures equatorward of the vortex to be warmer. This appears to align with temperature observations – a warm Northern Europe, a cold Greenland.

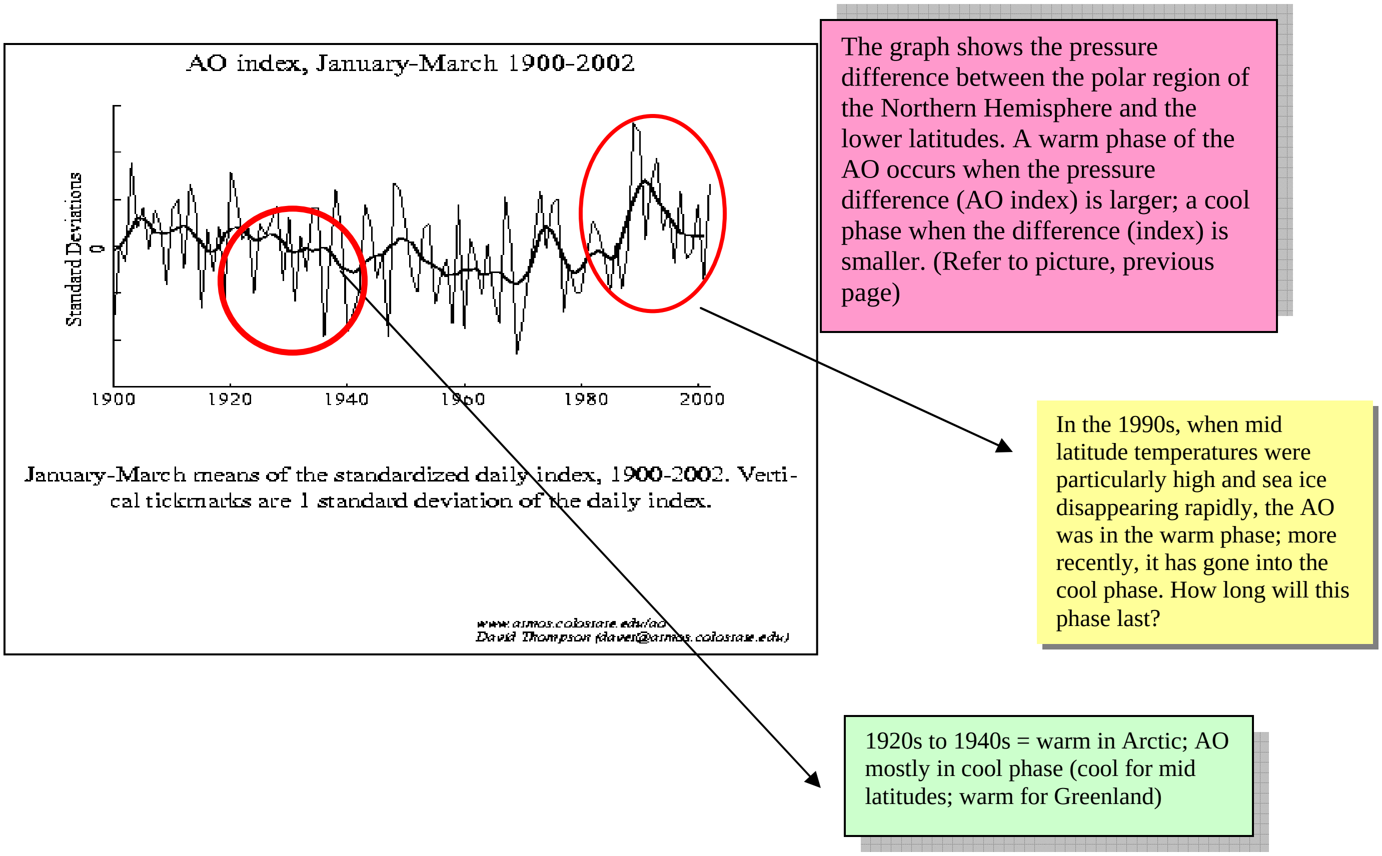


Globe on left shows the positive phase of the AO (NAM); note warmth in Northern Europe and a cold polar region.
Globe on right shows the negative, or weak phase, of the AO (NAM); Europe is cool during the winter and the pole is less cold.



The natural oscillatory nature of this phenomenon governing climate sent scientists back to the drawing board. Because it was naturally occurring, and, when in the warm, or positive phase, could well explain warm temperatures where they were being seen (mostly Northern Europe and Siberia), and could explain disappearing sea ice in the

Arctic due to the wind patterns (to be touched on later), it soon became a new focus of study.



January-March means of the standardized daily index, 1900-2002. Vertical tickmarks are 1 standard deviation of the daily index.

Not only did observation support the AO's oscillatory nature, but numerous influences can affect vortex strength, and thus strength of the annular phase. Solar output is one.

In 1999, Shindell et al. came out with a model-based study that showed how solar variability could influence the AO, pushing it into the warm phase when solar output was higher and into the cool phase when solar output was lower. Furthermore, the records of solar variability seem to correlate well. Others before him had suspected a link between solar output and the AO/AAO's variability, but models could not simulate the behavior. Shindell et al. did something different. They added another layer of the atmosphere to the model. When they added the upper stratosphere to the program, they found the dynamics matched those seen in nature. The reason involved the changes that accompany increased solar output. When the sun's luminosity increases, it does not do so uniformly across its entire spectrum of radiative output. The wavelengths that increase the most are those in the ultraviolet part of the spectrum. It is the ultraviolet that interacts with ozone in the stratosphere, and through a complex interplay that involves both heat production and photolysis (light-catalyzed reactions), the end result is a strengthened vortex with increased solar output. This was an amazing finding, and helped to explain many of the regional temperature variations of the last several centuries.

It came to be understood that numerous factors can influence the strength of this oscillatory pattern – ozone inventory (due to solar influence or other), volcanic eruptions, sea-surface temperatures, oscillatory patterns related to storm activity along the tropical Pacific, including El Nino events, and other patterns that boggle the mind of even the most informed climate scientist. But could human activity influence the pattern?

Shindell et al. performed another study in the same year as the solar study, 1999. This time, he modeled greenhouse gases, including the various levels of the stratosphere. Sure enough, it was determined that greenhouse gases could also influence the phase of the oscillation; an increased atmospheric inventory correlated with a positive phase in the model. Observations in the late 1990s seemed to support this finding.

If one looks at the Arctic Climate Impact Assessment, one will note there is no mention of Shindell et al.'s finding on solar, only his study on greenhouse gases.

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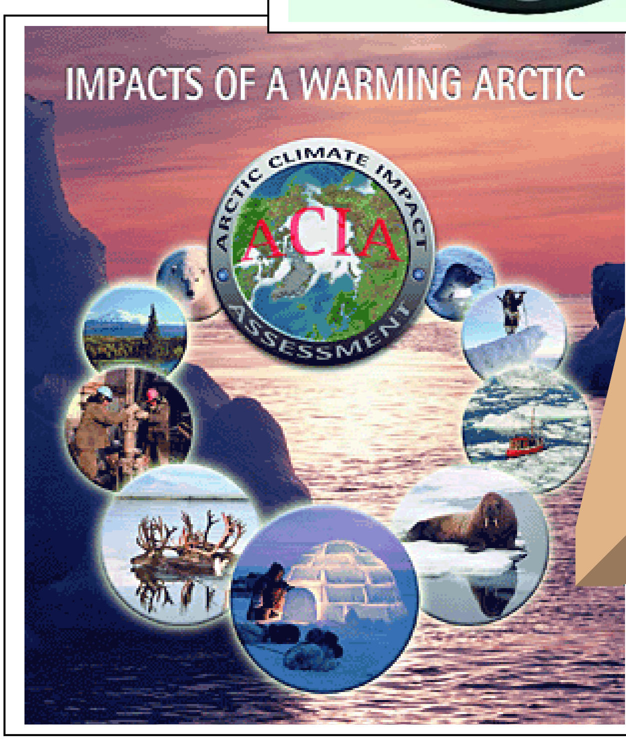
In the report, there is much discussion on the AO, but interestingly, there is mention only of greenhouse gases as being a factor in influencing the phase of the pattern.

A speaker from NOAA presented on the topic of AO recently (2006). She had been a colleague of David Shindell, the scientist whose studies on solar and greenhouse gases as influences on the AO I discussed above. She worked at Goddard Institute of Space Studies (GISS). So did Shindell. They were both there in 1999 when his studies on AO were published. During her presentation, she brought up the Shindell study, but she brought up only one, the one involving greenhouse gases. I asked her about the solar one published the same year. She knew nothing of it! I later sent her the article. She thanked me. No further discussion ensued.

Solar is very politically incorrect…



Greenland is under the influence of the annular pattern. It follows that if the AO dominates climate variability in that region, when the AO is in the warm phase, Greenland will be cooler-than-normal. When the AO is in the cool phase, Greenland will be less cold. Temperature trends in the mid-latitudes will be inversely related to those in Greenland.

The effect of AO on sea ice is another issue. When the AO is warm, the westerly winds are strong. Strong westerlies do two things. They hasten the flow of warm water brought poleward from lower latitudes, allowing the warm waters to help melt coastal ice from below, and they guide sea ice out of the Arctic region by ushering it out through a region known as the Fram Strait. Thus, during a warm phase, it can be seen that while Greenland temperature may be cooler-than-normal, melt can hasten along the coastlines and the sea-ice inventory can shrink.

Typically, with a reversal of phase, the temperature and sea-ice trends reverse. Recently, with the current reversal (which may or may not be short-lived), while temperature trends seem to have reversed, the sea-ice trend has not rebounded as much as would otherwise be expected. Some suggest that perhaps the ice thinned and re-distributed to such an extent that the reduced albedo (reflectivity) has contributed to a chain reaction of ice reduction, reaching a threshold minimum level, from which recovery is now impossible. Only time will tell.

But sea ice thinning or disappearance does not contribute to sea-level rise, as it floats on the ocean surface and is not added to the ocean reservoir as is land-based ice. So, I will delay further discussion of sea ice until after the discussion on sea-level.

So now the question comes about why melting rates and glacial acceleration – processes that lead to sea-level rise - have become features of a regional climate that shows warming that, when viewed in a context of a century or more, is not unprecedented or unusually spectacular.

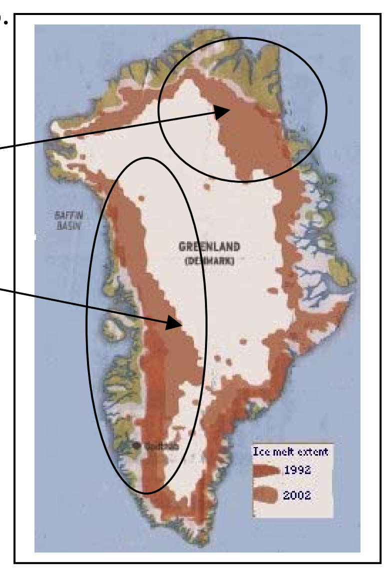
First, conclusions on ice-mass balance – the amount of net loss or net gain of ice – vary, partly because of techniques used to determine the conclusion, partly because of the area studied, and partly because of the time over which the study was conducted. Ice mass varies widely from year to year; thus conclusions can likewise vary widely.

A ping-pong match of conflicting studies regarding Greenland's ice-mass balance stirred the global-warming debate to new levels of passion beginning in 2005.

The concern voiced in the Alley et al. '05 study pointed to the dramatic increase of melting along the margins of the landmass.

"The Greenland Ice Sheet may melt entirely from future global warming", declared Alley et al. in 2005.

Ice-sheet loss equivalency, according to Alley et al., was ~ 0.21 mm/year from 1997 to 2003.



Alley et al. used estimates of ice loss based on what is termed "repeat altimetry", using laser altimetry satellite measurements for a certain area in repeat fashion. They combined these values with modeled values from simulating atmospheric and runoff processes. Spotty aerial and temporal sampling, combined with modeled, not observed values, has been fingered by some as being the foundation for the finding.

At exactly the same time, a study by Johannessen et al. '05 was published. The authors of this study mentioned sampling problems as hampering accuracy of previous studies. They worked to obtain uniform sampling across time and space for the years between 1992 and 2003. Assuming they were successful accomplishing this feat, their results suggest that Greenland's total ice mass is actually increasing. In that case, Greenland would not be contributing to sea-level rise. They agree that the marginal regions below an elevation of 1500 meters are losing ice; their figures are similar to Alley et al.'s. Yet they note that the interior ice sheet, which is at elevations higher than 1500 meters, is accumulating mass, more mass than the margins are losing.

This speaks to the sea-level issue. I must caution here that losing snow and ice along the margins changes the albedo, lowering the reflectivity, which is a warming feedback – a potential concern, but not a direct concern for sea-level rise.

But the ping-pong game does not end there. Then a paper came out by Rignot and Kanagaratnam '05 declaring "widespread glacier acceleration", warning that this had led to a doubling of the loss of mass balance of the Greenland ice sheet over the preceding decade. They cautioned this would increase the contribution of Greenland to sea-level rise. The study conclusions were based partly on observations and partly on model studies. While they used satellite data to determine the trend of ice cover, they used model results from another study to *calculate the <u>assumed</u> annual accumulation* of snow cover. The reasoning was sound; the difference between accumulation and loss would equal the net balance of ice. But were the model results sound? Assumptions correct?

It turns out that another study, again at the same time – 2005 – by Zwalley et al. used satellite radar altimetry combined with airborne laser altimeters to measure the snow inventory of the entire landmass. They found results similar to those of Johannessen et al. (mentioned above), that the regions inland and above 1500 meters were experiencing a large net gain of snow, while coastal regions below 1500 meters were experiencing a large net loss. The balance was determined to have been slightly positive over the last decade, meaning that it was contributing to a slight decrease in sea levels.

According to Zwalley et al., "We have strong evidence the ice sheet was near balance [during] the last decade of the 20th century. Our measures show a slight positive gain of 11 [cubic kilometers] per year [between 1992 and 2002]." But, worth note, and I must confess I am confused by it, Zwalley adds, "I would say that right now the current loss is 30 to 40 [cubic kilometers] per year." This comment is reported as being based on his "*gut feeling*" about the most recent observations. It might also be noted that Zwalley's results were "picked up" by the "skeptics" as being evidence for no concern. While this approach is no better than the misuse of "science" in the opposite manner, it does show the academically political necessity to frame conclusions that appear to contradict the "accepted paradigm" in a way that does not support any professed contradiction of the prevailing paradigm.

Politics of science aside, while Rignot and Kanagaratnam's observation that many glaciers appear to be accelerating is sound, the mass balance is not dropping accordingly, only the aerial extent of snow cover is.

Then came another study – Chen et al. '06. This time, instead of satellites measuring height of the ice surface, they measured gravity variations. Regions of different densities reflect different gravitational force values. This is a great technique for determining general rock type and distribution. The study was called the GRACE study, for Gravity Recovery and Climate Experiment. Conclusions of the study supported that of Rignot and Kanagaratnam – that the Greenland Ice Sheet was disappearing at a large rate.

One must evaluate the method in order to evaluate the conclusion.

Numerous problems were admitted by the authors. In addition, more problems were cited by other researchers. The list of method deficiencies includes: removing effects from the gravity signal that were irrelevant, such as atmospheric and oceanic components; corrections for vertical land movements, which is not only complex when employing this technique, but is likely contaminated by movements of land far outside the region being considered; limited spatial resolution, use of numerical models in attempt to correct for some of the deficiencies; and, as stated by the authors, "uncertainties in background geophysical model used and unquantified other leakage effects".

Other researchers pointed to a large scatter in the results (data points "all over the place"). A reader should always note the placement of the data points with respect to the trend line drawn through them. A trend line can always be computer generated, regardless of how scattered the points are, but when noting the scatter of points, the trend line may not always seem to tell the "real story".

Others have tried to analyze the GRACE data in a way that differs from Chen et al. One such approach was used by Luthcke et al. '06. Their results show only half the mass loss as shown by Chen et al., but the authors readily admit that the conclusion means little, as the measuring period is only over the frame from 2003 to 2005. One cannot base a trend on so short a time. Variability within the Arctic is dramatic on a year-to-year basis.

And finally, in the meeting of the American Geophysical Union in December 2006, James Overland of the National Oceanic and Atmospheric Administration (NOAA) noted the influence of natural oscillatory patterns governing much of the climatic variability in the Arctic. He cautioned that the public would likely lose faith in the veracity of the global warming problem when the natural cycle reverses, pointing to the likelihood that "it's very likely we'll see a slowing of the warming rate in the Arctic for a while." It was reported that this may "bolster climate contrarians who say it's all just Mother Nature fiddling with climate". Overland and colleagues had selected climate models that simulated the Arctic Oscillation fairly well. They then added parameterizations of the effect of slowly increasing levels of greenhouse gases. All the models produced strong warming in the late 20th century. He suggests that greenhouse-gas warming acts against the backdrop of natural variability. This makes sense, except, of course, for what could be interpreted as a contradiction. It has also been asserted that the greenhouse gases override the natural variability, pushing the Arctic Oscillation into a more persistent warm phase. So, the bottom line appears to be that whether it continues to warm or whether it cools, it can be explained…

One interesting aside, something rarely discussed, is the issue of sulfates masking the warming. You might recall earlier mention (chapter two) of a type of anthropogenic aerosol that increases Earth's reflectivity both directly and indirectly. Increased reflectivity cools. Other aerosols may also increase reflectivity, directly or indirectly, or they may decrease it. It's all very complex. But, climate models consider sulfates to be radiative cooling agents. Also mentioned earlier was the marked uncertainty surrounding the behavior of aerosols. Underscoring the uncertainty was a finding concerning the influence of anthropogenic aerosols on clouds contained within the polar vortex over the Arctic. A study in 2005 showed that these aerosols were interacting with clouds in such a way as to convert the sign of radiative forcing of the clouds. Cooling clouds were converted by these interactions to strongly warming clouds. Could this play a role in what is being observed? Food for thought….

All of these studies highlight the complexity of figuring out what is going on.

If we move away from the minutia of detail, one can see a picture that *may* warrant concern. While the mass balance of the high-latitude ice is remaining fairly close to zero, with increased snowfall on interior areas compensating for coastal losses, some scientists are concerned about what some assert is a **change in ice dynamics** – movement of ice versus melting of it. Accelerating glaciers may lead to the demise of the ice sheets, or so some fear. Some point to surface melting exacerbating the situation. They posit that meltwater could plummet into crevasses, lubricate the bottom of the ice, and thereby accelerate its flow. Others suggest exposure of the toe of the ice extent to warm ocean water causes that ice buttress to melt and/or fall into the sea, thereby removing the barricade that "holds" the glacier on land.

It is true that water can lubricate the base of an ice sheet and cause a surge in movement. This water may come from surface meltwater entering crevasses, but such a mechanism is not necessary for basal lubrication. An ice sheet is not static. As alluded to previously, to maintain balance, the ice accumulation has to be building somewhere and thinning somewhere else. Snow falls year after year. With weight, the snow is transformed into ice. Pressure from the accumulation of ice builds and results in melting at the base of the ice layer, prompting ice to flow. Flowing ice – glaciers - eventually works its way to the continental edge, as long as it is not impeded by topography. Here, at the continent's edge, the relative warmth of the surrounding ocean melts the edges. It has been reported that glaciers are accelerating on Greenland. This would make sense. Increased snowfall on the interior portion of ice sheet must be lost at the lower elevations of the ice sheet. If mass balance is in equilibrium, glacial movement would accelerate. But it appears to be more complex than this.

If temperatures along the coast are warm, the toe of the glacier melts. If the temperatures along the coast are too cold for melting to occur, the glaciers will calve into the ocean.

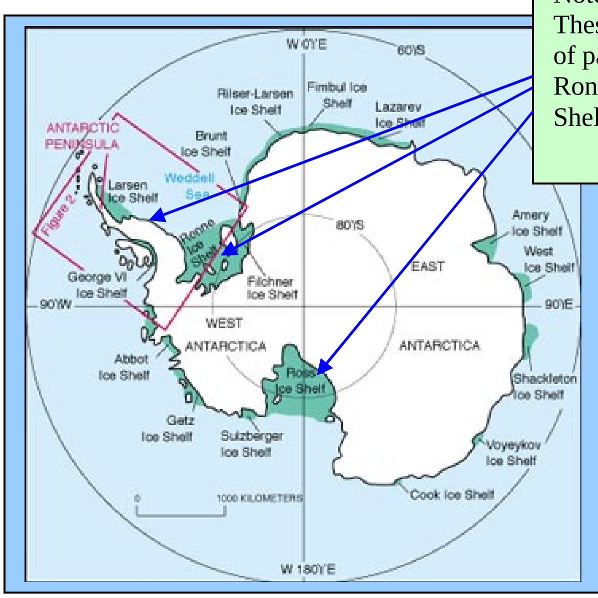
The calving process, although dramatic, is a normal process, with or without global warming.

Most glacial acceleration observed on Greenland involves glaciers whose "toes" are both grounded and free-floating. The upper portion of the toe floats on the ocean surface, while the lower portion of the "toe" is grounded to bedrock below sea level.

This observation may be the clue to the measured acceleration. Details in text.

A look at Antarctica may provide some insight into the ice dynamics seen on Greenland. Melting of Antarctic ice does not contribute to sea-level rise. As stated earlier, Antarctica's mass balance is essentially zero. Concern is that it will not remain at zero, and that, due to ice dynamics on Antarctica, dramatic increases in sea level could result.

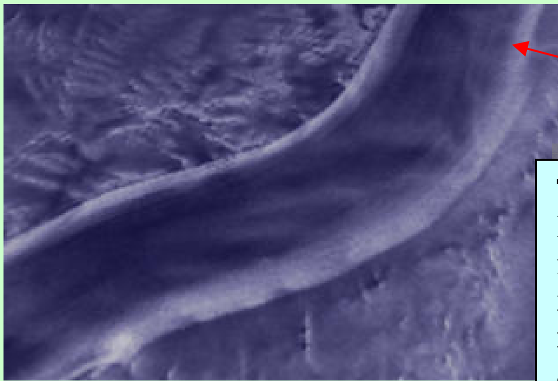
The situation involves the Antarctic ice shelves, particularly on the West Antarctic Peninsula. The ice shelves on Antarctica are broad areas of ice whose expanse covers both regions of ocean and regions of land.



Note the areas in green. These are ice shelves. Three of particular concern are the Ronne Ice Shelf, Larsen Ice Shelf, and the Ross Ice Shelf.

Ice shelves are fed by ice streams.

The ice shelves act as a barrier for the moving ice streams, in essence impeding the movement of the ice flow to the ocean. The ice shelf becomes larger with increased ice stream flow, but ice flow is prevented from flushing directly into the sea. Because the ice shelves provide such an impediment to movement of continental ice into the open sea, which would raise sea level, their continued existence is considered to be crucial.



These rivers of ice move between relatively stationary banks of ice. Streams of ice move much faster than does a large expanse

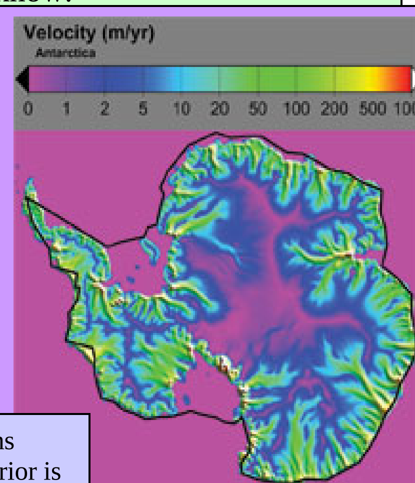
The ice shelves are "fed" by ice streams. Ice streams are channels of ice that flow from the continent's interior, where snow is accumulating, to the coastlines. In this manner, ice streams re-distribute the accumulation of snow.

The ice shelves act as a barrier for the moving ice streams, in essence impeding the movement of the ice flow to the ocean. The ice shelf becomes larger with increased ice stream flow, but ice flow is prevented from flushing directly into the sea.

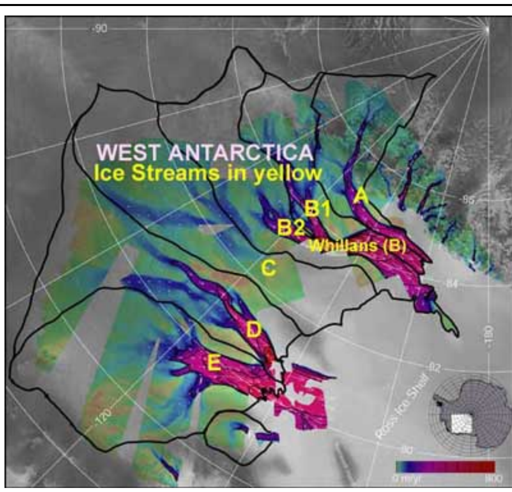
Because the ice shelves provide such an impediment to movement of continental ice into the open sea, which would raise sea level, their continued existence is considered to be crucial.

Unlike the ice *sheets* in Greenland and much of Antarctica, which move mostly like one large glacier, ice sheets in western Antarctica move in ice streams.

Currently, the Antarctic ice streams are gaining mass. This may slow them, or even stop them, which could stabilize them. But we really don't know.



The velocity of ice streams draining Antarctica's interior is shown at right.



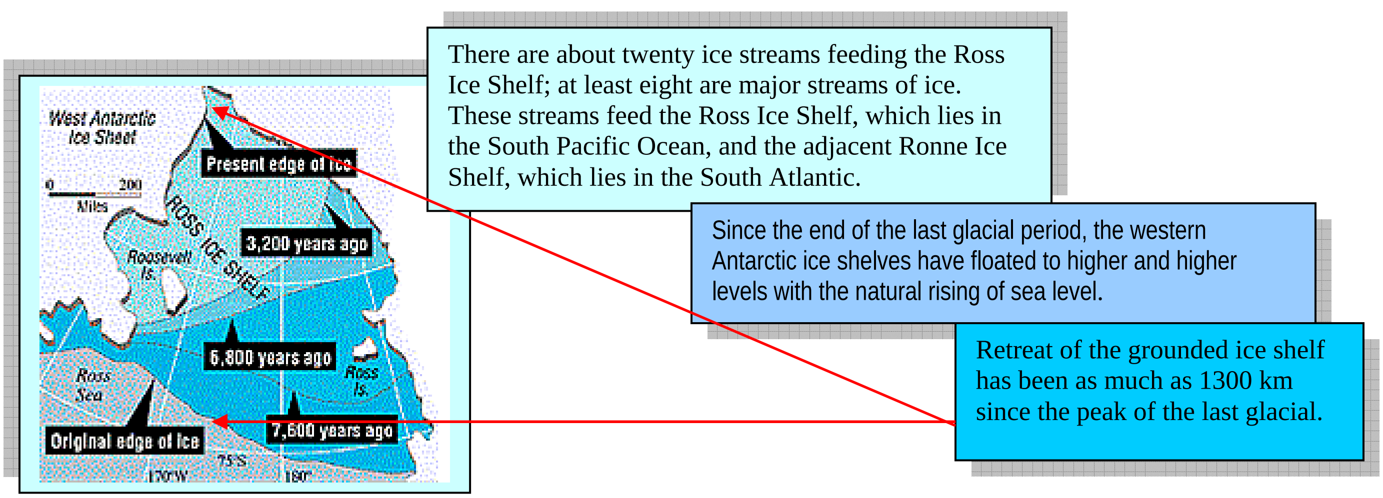
It appears that either increased sea level *or* decreased sea level could threaten the integrity of the ice shelf. It also appears that collapse of ice shelves is nothing new. It has been a cycle throughout the interglacial, and possibly before.

Evidence suggests that since the end of the last glacial interval about 10,000 to 11,000 years ago, Antarctic ice shelves have come and gone. It is hypothesized that this inferred instability of the Antarctic Peninsula's ice shelves is part of a natural cycle. Sediments also hint that the area was at least seasonally open 30,000 years ago, a time that was part of the last *glacial* interval. More scientific research is leading to the opinion that the Prince Gustav ice shelf and others in the region are short-lived, regardless of activities of mankind. Several ice shelves have met their demise along the Antarctic Peninsula in the last few decades. At first, blame went to industrial activities. Now, the answer does not appear so clear.

But, the loss of ice of western Antarctica, home of the Ross Ice Shelf, poses more of a problem. This area of western Antarctica is highly vulnerable to destabilization. The Western Antarctic Ice Sheet is bounded by the Ross Ice Shelf and the Ronne Ice Shelf. The integrity of the Ross Ice Shelf is currently of most concern to scientists.

Part of the ice shelf is anchored to the landmass of Antarctica, but that landmass is below sea level. Part of the ice shelf is free-floating. The free-floating ice will buoy upward or downward according to the trend of sea level.

Depth of the Ross Ice Shelf is thickest where it connects to the Antarctic bedrock, about 1200 meters (~4000 feet) in thickness. At the edge of the ice shelf, where it interfaces with the ocean water, the thickness is about 180 meters (~600 feet). The ice shelf is enormous; it covers about 644 kilometers (~400 miles) in length and about 966 kilometers (600 miles) in width. The concern with the Ross Ice Shelf is not that it will melt due to the projected increase in global temperature. *Melting* of the ice sheet is not what scientists are concerned about. Temperatures are far too cold to allow for melting. Potential collapse of the ice sheet is what worries scientists.



Since the end of the last glacial period about 10,000 years ago, the western Antarctic ice shelves have floated to higher and higher levels with the natural rising of sea level. It has been determined that along the western side of the Ross Ice Shelf, the grounding line, where the ice is anchored to the submerged bedrock, has retreated inland by 1300 km since the peak of the last glacial interval. Averaged out, the mean rate of retreat has been about 120 meters per year.

Concerns for an accelerated migration of the grounding line were magnified by research results that indicated that the discharge of ice from ice streams feeding the Ross Ice Shelf had resulted in a significant loss of continental ice. This loss exceeded by ~25% the accumulation rate of snow. It was feared that this accelerated movement of ice flowing in the streams was causing the continental ice sheet to thin. It was feared that this would cause the inland migration of the grounding line to retreat more quickly. Many studying the problem predicted that as a result of this grounding line migration, the Ross Ice Shelf would become more destabilized and would collapse in a matter of a century or so. Collapse of the Ross Ice Shelf would jeopardize the integrity of the entire Western Antarctic Ice Sheet. If the Western Antarctic Ice Sheet were to deteriorate as a consequence, sea level could rise by as much as five to six meters within 250 to 400 years.

"**To evaluate the conclusions, one must evaluate the methods**." These conclusions were based on minimal in-situ measurements of stream velocity (done in late 1980s). In some cases, only one or two in-situ measurements of flow were taken on an ice sheet. More recent research has relied on an expanded measuring system. Denser coverage of measurements via enhanced technology (Interferometric Synthetic Aperture Radar – InSAR) has changed the outlook. Instead of a dramatic thinning of continental ice, correlating with faster stream velocities, ice accumulation is actually exceeding ice loss by ~25%. Now the flow of the streams is decelerating. Some of the ice streams have stagnated altogether. This information has forced scientists to rethink the probable lifetime of the Western Antarctic Ice Sheet, which actually is believed to have survived at least one previous interglacial.

The real importance of this information is not what it says about our climate, and global warming or global cooling, but what it says about cycles and feedback systems and the incompleteness of our understanding of natural systems.

The natural process can easily be explained: When ice accumulates, it reaches a thickness where it becomes a very effective insulator. In the case of continental ice, this insulator is holding in geothermal heat emanating from Earth's surface. Enough heat from this geothermal heat accumulates, along with any frictional heat from the flowing icesheet, or in this case, ice streams, and basal melting occurs. If enough basal melting occurs, a significant layer of water develops at the base of the ice, providing a lubricant along the surface of slippage. The icesheet or ice streams flow. With more basal melting, the ice streams flow more quickly, carrying thick accumulations of ice away from the continental interior. The continental accumulation of ice thins as a consequence of this enhanced flow. A feedback response kicks in. The ice then becomes so thin because the streams are flowing so quickly, that the insulating capacity of the ice cover decreases. With less insulating effectiveness, the base of the icesheet or ice streams re-freezes to the base. Loss or discharge of ice minimizes. Continental snow and ice accumulation once again trends positively.

Sedimentary records indicate that the flow of ice streams feeding Western Antarctic ice shelves has waxed and waned numerous times throughout the history of such icesheets on Antarctica. The cycles occur on a periodicity of several thousand years. Researchers Joughin and Tulaczyk have nicknamed the cycles "binge and purge" cycles. According to these scientists, the Western Antarctic ice streams are currently transitioning from a "purge" to a "binge" stage.

What the consequences of this ice thickening will be are unknown. Could this be a reversal of the long-term Holocene natural warming? Has the retreat of the last several thousand years reversed? Complexities abound. On one hand, when it was thought that ice stream flow was rapid and ice accumulation inland was on a negative trend, it was feared that the Ross Ice Shelf would collapse as a result of inland migration of the grounding line. But now, there is a concern that if ice stream flow stagnates, the Ross Ice Shelf will thin and be vulnerable to retreat or breakage.

It should be painfully clear that there are no easy answers forthcoming about ice balance of the polar ice sheets and their potential contribution to future sea level. We can attempt to gain a better understanding of the matter by looking at evidence of conditions during the last interglacial. The last interglacial, about 125,000 years ago, was warmer than this one, by about 3°C. Earth's axis was more tilted then than it is now; thus, more direct radiation reached the higher latitudes. The knowledge that Earth was warmer, especially at the poles, and that sea level was higher by three to five meters, concerns scientists. Some wonder if increasing global temperatures, albeit due to greenhouse gases and not orbital parameters, will lead to similar sea-level elevations. Furthermore, since there is evidence that the Western Antarctic Peninsula survived the last interglacial, perhaps the extra contribution to sea level came from Greenland instead. And, finally, these scientists worry that the acceleration of glaciers and changing ice dynamics on Greenland might portend a similar fate as is suspected to have happened 125,000 years ago.

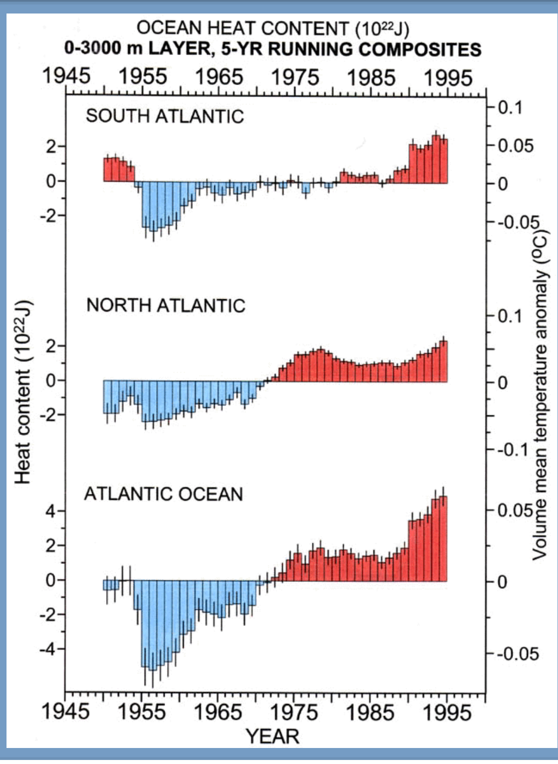
Traditional consensus of ice-sheet behavior rests on the long-held view that response of glacial ice to external forcing is not rapid, that it is delayed on time scales of centuries to millennia. Until recently, few would have suggested that response of ice sheets could be on the order of years. The change in ice dynamics recently detected by instrumentation has prompted many scientists to dismiss this traditional paradigm, assigning the new behavior to current forcing – i.e. to global warming. Considering the temperatures in the Greenland region were cooling for decades until ~ 1995, it would turn thinking upside down if indeed such large accumulations of ice could respond to a reversal of trend in so short a time. Could it be that this behavior is in response to changes in the 1920s through the 1940s, when temperatures in the Arctic were at peak warmth? Or could it be that there is an aspect of glacial behavior heretofore unrecognized?

Robert Bindschadler, in a perspective presented in *Science*, March 24 2006, explained that acceleration of glacial draining of the Greenland ice sheet could be responding to warming temperatures of the ocean subsurface.

Recall a conundrum that was presented in the last chapter – that only about half of the "expected" warming due to greenhouse gases has been realized. Reflectivity of anthropogenic sulfates may account for a cancellation of the remainder of the expected warming, or perhaps some of the warming has been absorbed by the oceans. If this latter hypothesis is correct, it may account for acceleration of outlet glaciers on the Greenland ice sheet.

Warmer oceans can melt the toe of a tidewater glacier. If this reduces the buttressing effect of a floating ice shelf, basal friction of the glacier is lowered and the glacier can accelerate. But this doesn't seem to be the case. Measurements fail to reveal the required warming in the surface of polar oceans.

But measurements of ocean temperature between the surface and three kilometers down do show a small increase of temperature.

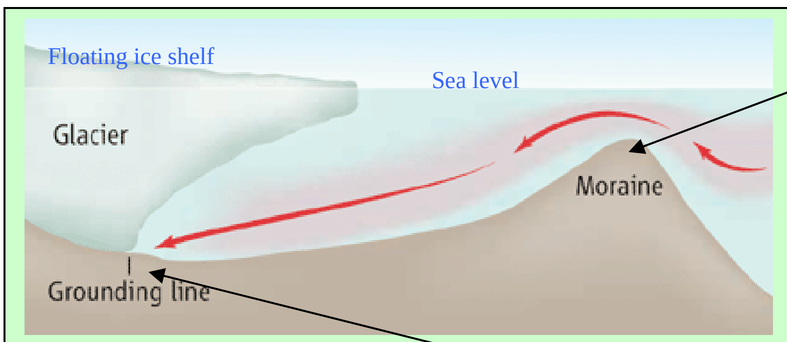


- The Atlantic, as indicated in the graph to the left, has warmed over the last fifty years.
- Measurements between the ocean surface and 3000 meters were taken in the Pacific, Indian, and Atlantic oceans.
- Levitus et al. found an approximate 0.06°C increase averaged over the three oceans between 1955 and 1995.
    - Most of this change was measured within the upper 300 meters.
- Because of the vastness of the ocean, this seemingly small increase in temperature represents an enormous change in heat content.
- Ocean temperatures vary on multi-decadal time scales. This is a long- recognized natural oscillatory component.
    - Note the selection of data points within this oscillatory behavior chosen for the study's conclusion. Note especially the South Atlantic component.
- Levitus et al. attribute a portion to natural variability; the remainder is assumed to be due to anthropogenic heating.
- No mention is given to the possibility of forcing effects by decreases in cloud cover and increases in solar variability, both of which exhibit oscillatory behavior.

The original significance taken from Levitus et al.'s work was that it seemed to explain the failure of the surface air temperature to be as high as models had predicted. Concluded from the work was the projection that eventually this heat would raise sea surface temperatures, and then air temperatures would follow. This line of thought can be wrapped up in the concept of climate sensitivity, discussed in the last chapter. Conclusion on that matter is highly controversial, but is not the topic here. Concerning sea-level rise, the observation that the subsurface has warmed, regardless of significance or cause, gives possible insight into accelerating glaciers on Greenland.

The reasoning goes back to the discussion of Antarctica's ice shelves and the concern over their collapse. The grounding line of the shelves is below sea level. If that grounding line reaches land, then ice loss will contribute to sea-level rise.

The situation on Greenland is similar. While there are no ice streams feeding the shelves, as on Antarctica, there are outlet glaciers that play a similar role. Because these glaciers existed during the glacial periods when sea level was lower, the anchoring of the glacier to bedrock is under water. When sea level was lower, the glaciers had bulldozed large quantities of rock into a hill outlining the maximum extent of its advance. Hills of jumbled sediment and rock pushed by a glacier are known as moraines. The termini of these glaciers are now far recessed from that maximum outline. The cartoon below illustrates the profile of this description.



The moraine shows the maximum extent of glacier during past glacial periods when sea level was much lower and the glacier was entirely on land.

Since deglaciation, sea level has risen. The glaciers, once on land, are now partially under water. The grounding line – the line along which the ice is anchored to the bedrock below the ocean's surface – continues to retreat due to natural conditions of deglaciation.

The glacier in this picture is called a tidewater glacier. It flows from the high elevations of Greenland to the ocean in deep channels below sea level. These channels were carved by the glacier when sea level was much lower, during the previous glacial periods.

The grounding line marks the point between where the glacier is grounded to bedrock and the portion of the glacier that is free-floating.

The floating ice shelf is a few hundred meters thick.

- The moraine creates a special environment close to the glacier's base. It prevents deeper seawater from reaching the grounding line. Close to the glacier's base, the water is fresh and cold. The water seaward of the moraine is salty and warmer.
- If the moraine is breached, this deeper seawater can reach the grounding line.
- With the barrier breached, the pressure exerted by the incoming seawater on the ice increases; this has the effect of lowering the melting point of the ice (ice skater phenomenon). Rapid melting of the glacier occurs.
- If the subsurface water is warmer, as Levitus et al.'s work suggests, this process is amplified.
- Breaching of the moraines is unrelated to global warming. But once breached, the effects of global warming, according to this hypothesis, can augment the impact.
- Conjecture abounds on possible future scenarios. As with the situation in Antarctica, no one knows what to expect. Model output relies on input, thereby precluding reasonable assessment. Climate history thus far fails to reveal mechanisms. Much of the process is natural; warmer subsurface water is only one small component of the process.

In conclusion on sea-level rise due to shrinking polar ice caps, evidence does not currently support a net mass loss of ice on either Greenland or Antarctica due to melting, as snow accumulation has thus far compensated for the melting. The mass loss hovers around zero for the two regions combined; although slight variations in the total net change occur on a yearly basis. Less land area in Greenland is covered by snow than in past decades of the recent past, despite the zero mass change. This changes albedo – lowering it. This is a positive radiative forcing, meaning that less incoming radiation is reflected away – a warming process. Not enough time has passed to support a viable conclusion on the longevity of this pattern or the consequences realized from this change.

Loss of polar ice could occur on a massive scale due to changes in ice dynamics. If increased drainage of interior ice accumulations occurred through accelerations of outlet glaciers on Greenland and ice streams on Antarctica, then sea level could rise quickly and notably. “Binge-purge” cycles dot the Antarctic record, indicating that such increased drainage has occurred on a quasi-cyclic basis in the past – not necessarily correlated with warmer temperatures or higher sea level. Lower sea level has correlated with such behavior, as well. Indications in the proxy record also suggest that the West Antarctic ice sheet endured the last interglacial. But did Greenland? The observation that sea level was higher by three to five meters during the last interglacial begs the question: Did the loss of ice come from Greenland? Could the drainage via outlet glaciers rid the Northern landmass of substantial portions of its ice inventory? The possibility is clearly there. Is this something that would occur without an increase in temperature? Would the breaching of the moraines, the mechanism enabling warm, salty intermediate water to reach the outlet glaciers’ grounding lines, be *the* reason for the collapse of the Arctic ice shelves, or is it the warming of the deeper waters that would be the ultimate mechanism? In other words, could this collapse occur regardless of an increase in a few tenths of a degree temperature in the intermediate water? Could it just be a matter of time for the breaching of the once-land-based, now submerged moraine? Could the lowering of melting temperature of ice due to increased pressure of intruding sea water resulting from a moraine breach be mechanism enough? Is this a natural process inherent in the interglacial cycle?

Remaining to be discussed in regards to sea-level rise is the “other” ice. What contribution to sea-level rise does this other ice – mountain glaciers and the like – make to sea-level rise?

Location	Volume (km^3)	Potential sea-level rise (m)
East Antarctic ice sheet	26,039,200	64.80
West Antarctic ice sheet	3,262,000	8.06
Antarctic Peninsula	227,100	.46
Greenland	2,620,000	6.55
All other ice caps, ice fields, and valley glaciers	180,000	.45
Total	32,328,300	80.32

- Total melting of the polar ice sheets would lead to just under an 80 meter increase in sea level.
- Complete melting of all other ice reservoirs would total less than half a meter of sea-level rise.

Melting of mountain glaciers:

In a nutshell, retreat of mountain glaciers is poorly correlated to global warming. Intuitively, it seems obvious that if the temperature goes up, glaciers will melt. Oddly, the relationship is less than clear, the dynamics, complex.

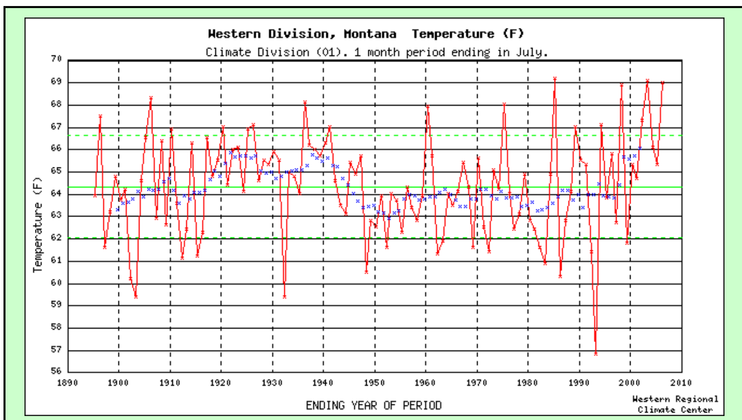
There exist an estimated 160,000 glaciers in the world. Only 67,000 of these have been inventoried for the past 50-plus years. Much research needs to be done; only the surface has been scratched.

Less than four percent of glacial ice is non-polar glacial ice. Within this inventory of non-polar ice are mountain or alpine glaciers. Most of these glaciers are considered to be warm glaciers, meaning they exist at or close to their melting point. These are often referred to as temperate glaciers. Glacial ice and liquid water co-exist within a temperate glacier for all or part of the year. Little perturbation is required to initiate significant melting in a warm glacier.

During the Little Ice Age, snow accumulation was rapid; advance of the glaciers was substantial. Since the end of the Little Ice Age 150 years ago, some temperate glaciers began their retreat, but not all. Retreat is not a simple process.

Alaska has warmed at a faster rate than the global average. This is likely due to the oscillation (Pacific Decadal Oscillation (PDO)) that suddenly reversed in 1976 - the Pacific Climate Shift. Some mountain glaciers began their retreat at the end of the Little Ice Age; others did not begin their retreat until 25 years later. Scientists don't know why. Some Alaskan glaciers are stagnant. Others are thickening and advancing, about twenty of them. Again, scientists don't know why. In some cases, two glaciers exist under seemingly identical conditions, side-by-side; one is advancing; one is retreating. Scientists cannot explain this.

In Montana's Glacier National Park, mountain glaciers are melting. This was a big news story just before 9/11. NBC warned that the average summer temperature had increased 3.5°F since 1950. But….if one looks at the data for these temperatures from 1890, one might develop a different view.

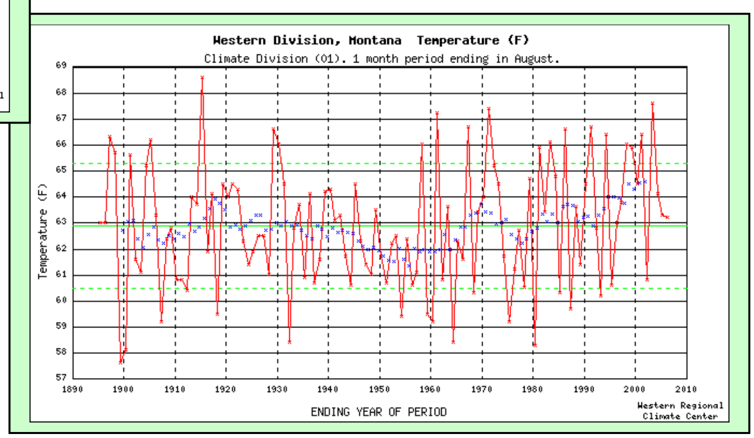


Here are two graphs of the region that includes Glacier National Park.

- The top left graph shows the temperature averages for the month of July from 1890 to 2002.
- The bottom right graph shows August temperature averages for the same time and region.

According to data available from the Western Regional Climate Center, the temperature in Montana's Glacier National Park jumps up and down by considerable margins, but, over time, balances out to an unchanging average.

The green solid line shows the trend, which is zero in both graphs.
The blue dots represent the 10-year running mean.



What is notable from these graphs is that, choosing a temperature trend depends upon what years you choose. The average temperatures range from 57° to 69°F in July and 57.5° to 68.5°F in August. But the average over this 100-year-plus period is unchanged.

There is no evidence to suggest that the trend is changing. So, has the temperature risen? Yes….and no, depending…

The point to take away is, what does that temperature pattern tell us about glacial melting? …And, what does this tell you about data? And science? And news reports????

Let's go to the big one, Kilimanjaro. It is a glacier on a mountain, but, unlike the ones discussed so far, this is *not* a temperate glacier. It does not exist at or near its melting point. You can see the terminology can get confusing. There is quite a debate among glaciologists about this one. One, Lonnie Thompson of Ohio State University, who is often featured by the media, suggests that global warming is responsible for the retreat of Kilimanjaro and similar glaciers. He gets a lot of press time. It might be a more accepted correlation for some glaciers, but not this one. There is a raging fight going on about how global warming applies to disappearing glaciers on Kilimanjaro. We don't hear much from this "other side".

A large debate is raging about the reason for ice disappearing from Kilimanjaro.

The history of ablation (reduction of ice) on Kilimanjaro is not straight-forward. It began at the end of the 19th century. In the early part of the 20th century, during a period of global warming that was not due to CO2, Kilimanjaro lost 45% of its aerial extent. Between 1953 and 1976, during a time of global *cooling*, another 21% disappeared, and since the Pacific Climate Shift of 1976, another 12% has vanished, albeit at a slower rate than dominated in the late 19th and early 20th centuries.

In the region of Kilimanjaro, at 5000 meters-plus, annual temperatures (-7.1°C) show no significant increase over the last century. And, because it is only a few degrees south of the equator, Kilimanjaro experiences no seasonal cycle of temperature. There is a daily cycle of temperature and an annual cycle of moisture. Since the end of the 19th century, the moisture levels have dropped dramatically; temperatures have not changed.

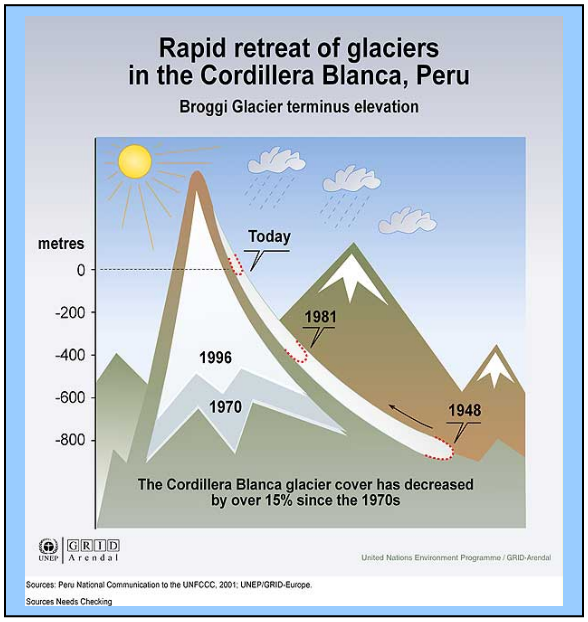
Precipitation, cloud-cover, and geothermal heat are suggested by several scientists as reasons for the disappearance of Kilimanjaro glaciers. If glaciers aren't "fed" by precipitation, they slowly disappear by sublimation. Think of long-forgotten ice cubes in your freezer. Obviously, in the freezer, they aren't melting, but if they've been there a while, they are disappearing. They are actually sublimating, or going from a solid to a vapor – no liquid state involved. As long as there is no ice added to the ice cubes, they will sublimate. Evidence for sublimation comes in the shape of remaining ice as the process proceeds. Sharp edges and sculpted cliffs are characteristic features of evaporation versus melting. These are prevalent on Kilimanjaro.

The cloud-cover plays a role by its absence. In the Kilimanjaro area, the pronounced absence of cloud cover in recent decades allows the solar radiation to penetrate the snow surface, thereby heating the surface locally without heating the atmosphere significantly. In the case of solar radiation on the snow, there is melting of the surface, but due to the snow heating up from direct radiation, not from an increase in the air temperature. The "proof" of this can be seen in the distribution of ablation. The north side shows a slight preference for melting. Located at 3°S, the Sun is at its high point at noon, which, for a location south of the equator, is to its north. Cloud cover appears to fluctuate on a quasi-decadal pattern.

Geothermal heat, in localized areas on this volcanic mountain, seems to be responsible for some melting - from the bottom, up - on Kilimanjaro. This can be seen in the variability of the geothermal heat flux. In regions of higher measured flux, this localized melting is greater.

But there is another interpretation. It concerns a suggested *indirect* connection to global warming: that a dearth of precipitation, which began in the late 19th century, has resulted from the warming. This is explained by a remote connection, reaching to the tropical zones of the oceans. The thought is that increased sea-surface temperatures have altered atmospheric circulation, resulting in drier air. A "skeptic" might respond with the following: if that modification of atmospheric circulation is due to increased sea-surface temperatures, what is the reason(s) for sea-surface temperature increases. Global warming is a candidate. Then there is the matter of the Atlantic Multidecadal Oscillation, which is a natural multi-decadal oscillation of sea-surface temperatures in the Atlantic Ocean. In addition, there is the El Nino in the Pacific and a smaller "Atlantic Nino" in the Atlantic, both of which warm sea-surface temperatures and both of which have no identifiable or substantiated correlation to global warming.

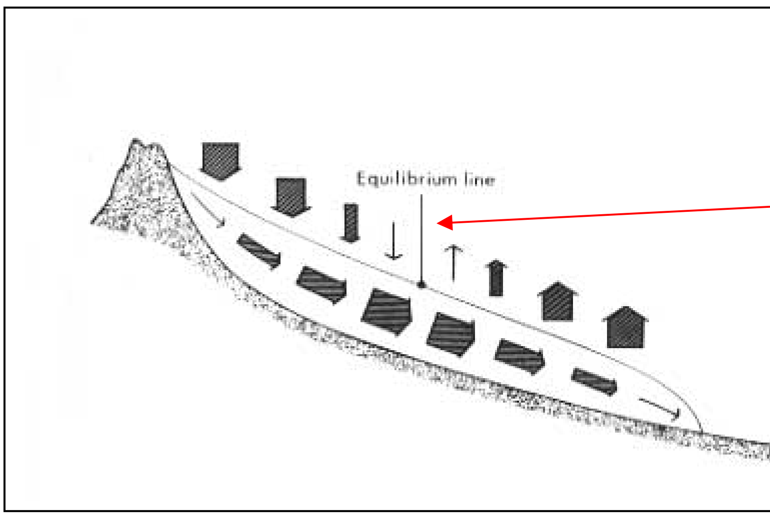
Some glaciers do appear to be retreating due to global warming, whatever its cause(s). Peruvian glaciers fall into this category. They have been retreating for 150 years; there has been no warming at the altitude of the glaciers, except for in 1976 – the Climate Shift. Warming does not need to be occurring at the top of the glacier for retreat to occur. If it occurs at the base, this can cause a glacier to retreat.



Peruvian glaciers are retreating due to global warming –

Solar variability may be part of that equation.

The way a glacier works is that the snow falling at the top of the glacier adds weight. Snow flows vertically downward and then horizontally down, like a conveyor belt, of sorts. Snow at the top feeds the bottom. The top is cold; the bottom is in warmer temperatures. Ice is lost at the bottom either due to falling into an ocean or lake or due to melting. One can imagine a line drawn perpendicular to this downhill motion at a point that would divide the area of snow accumulation from the toe portion where there is snow ablation. This line represents a balance between the things that make the glacier grow and the things that make it shrink.



If precipitation goes down at the top or temperatures go up at the toe, this dividing line between accumulation and ablation will move uphill. This describes retreat. There is no doubt that there are some tropical mountain glaciers are suffering this fate, and that the cause may well be global warming. But glaciers are complex things.

A 1500-year reconstruction of climate history and glaciation of nearby Venezuelan Andean glaciers shows four glacial advances from 1250 to 1810. These advances coincided with minimum levels of activity of solar output. During solar minima, precipitation increased and temperature decreased. We are currently in a period of heightened solar activity, known as the Modern Maximum, upon which the sunspot cycle is superimposed. Perhaps an increased output of solar radiation is responsible for conditions that are opposite of those found during solar minima. Radiation would be able to locally warm the ice surface and cause localized melting. The answers are not known.

It's just not so simple!!!! If you can't remember any of these details a week from now, all I want you to remember is that the entire matter of cause and effect just isn't so simple. Global warming MIGHT be causing all of these things. While the possibility exists, the evidence isn't there with certainty, or even with high probability. The correlation seems reasonable, but simplistic correlations always appear reasonable.

To conclude on sea-level rise, I offer my critical review of an editorial written by the editor-in-chief of a highly regarded science journal. What you have learned to date should help you critically evaluate his assertions.

An editorial written by the editor-in-chief of a prestigious multi-displinary science journal speaks to the topic of sea-level rise and ice-sheet behavior in the context of global warming. His words reach many highly educated readers who are not necessarily broadly informed on the nuances of the complex topic of climate change. This audience includes "climate scientists". Clearly, due to the vastness and the intertwined intricacies of the subject, few "climate scientists" can be fully informed on the diversity of aspects presented in this piece. The topic is simply too broad. If even they cannot be fully informed on all aspects, other readers are at an even greater disadvantage. Given the high profile of this publication, credibility of its information is assumed. This assumption may not be reasonably awarded. Note the annotated text.

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EDITORIAL

Ice and History

Don Kennedy is editor-in-chief of *Science* – a highly regarded science journal.

Donald Kennedy[1] and Brooks Hanson[2]

If you paused at the table of contents, you noticed that there is a lot about ice in this issue. Ice is important not only because we are losing it but also because it is an archive that has told us much about past climates. But the climate-change debate has focused perhaps too much on the past few hundred years. That baseline has told us much about what has been happening to global temperature lately, but it may not be the best baseline to use in exploring our future.

For that, the relationship between greenhouse gas levels and temperature, evident in data from ice cores, illuminates climates in the geological past and may be a more useful guide to the future. Fifty million years ago, CO_2 levels may have topped 1000 parts per million by volume (ppmv) and sea levels were about 50 meters higher than those today. CO_2 levels gradually decreased as marine organisms fixed carbon through photosynthesis and then buried it by sinking into the ocean basins. This reduction and a corresponding decrease in temperatures allowed ice sheets to develop in Antarctica starting 30 to 40 million years ago. By 3 to 4 million years ago, CO_2 levels probably dropped to or below the preindustrial level of about 290 ppmv, and permanent ice sheets appeared in the Northern Hemisphere. As subsequent glaciations came and went, CO_2 concentration and temperature were tightly linked. When both went down, ice sheets grew and sea levels sank, lower than today's by more than 100 meters. When both went up, there were relatively stable warm periods with high sea levels.

In past climates, changes in atmospheric CO2 lagged changes in temperature by hundreds of years. It is likely that ocean-circulation changes, prompted by changing conditions, governed the changes in CO2. CO2 then amplified the initial temperature changes.

A central feature of this long baseline is this: At no time in at least the past 10 million years has the atmospheric concentration of CO_2 exceeded the present value of 380 ppmv. At this time in the Miocene, there were no major ice sheets in Greenland, sea level was several meters higher than today's (envision a very skinny Florida), and temperatures were several degrees higher. A more recent point of reference, and the subject of two papers in this issue, is the Eemian: the previous interglacial, about 130,000 to 120,000 years ago. This was a warm climate, comparable to our Holocene, during which sea levels were several meters higher than today's, even though CO_2 concentrations remained much lower than today's postindustrial level.

The Eemian interglacial was warmer. Sea level was higher. That CO2 levels were lower than today's reveals the complexities between temperature and CO2 levels.

It is unreasonable to compare conditions of the Miocene to today. Ocean circulation differed dramatically; the Panama Seaway connected the Pacific and Atlantic Oceans; the Bering Strait was not open; the size of the Pacific basin was much larger; El Nino did not exist, at least not in the oscillatory manner that it does today, nor did other Pacific patterns that significantly impact climate today. To invoke such a comparison based solely on CO2 content is to expose a lack of understanding for climate's complexity.

So what should the appropriate baseline be for estimating our present climate prospects? Is it the relatively recent evidence of climate change, or is it the developing knowledge from ice cores and the geologic record about past climate equilibria? The Holocene, over its 10,000-year life, has provided us with a comparatively stable period. Now we are changing an important parameter. Evidence presented in two papers, a News story, and two Perspectives in this issue demonstrates an accelerating decay of ice sheets in Greenland and Antarctica. Given the concurrent rapid recent rise in CO_2 concentration, history suggests that we should expect other changes. Will these changes return us to a climate like the Miocene or earlier? Or will we experience a repeat of the Eemian?

...cord suggests that an "equilibrium" climate model is the ... comparison. We are in the midst of a highly kinetic ...e past, dramatic climate changes have taken place in ...es. Our comfort in the Holocene may have heightened our sense of security, but the expectation that change is unlikely is not a reasonable position. The central question of today's climate policy discussions centers on whether the change in average global temperature over the past century represents the result of new climate forcing or instead simply reflects natural variation.

That question invites us to examine recent statistics on climate variation and then test the current excursion for significance. But if one is interested in risks and in preparing to meet them, the more interesting question is what the deep historical record can tell us about the circumstances under which climates have changed rapidly in the past and the severity of the consequences. Considered in that way, accelerated glacial melting and larger changes in sea level (for examp... should be looked at as probable events, not as hypothetical possibiliti... We don't have to abandon the short-term baseline, but the longer one may give a more realistic picture of our future.

Donald Kennedy is Editor-in-Chief of *Science*.

Throughout climate history, wildly unstable climate has occurred whenever threshold conditions were surpassed – extreme warmth (end of Permian) or extreme cold (Snowball Earth). But, during the last two million years – throughout the Ice Ages – ***warm periods have hosted stability; cold periods have hosted pronounced instability.***

In addition, boundary conditions between glacial periods and interglacials differ. Ice cover is different; greater ice cover is often correlated with heightened climate sensitivity. Notable are the ocean circulation differences that exist between interglacials and glacials.

Comparison to past climates is instructive in what it can tell us and what it can't. To benefit from what past climate cannot tell us, one must critically assess differences in boundary conditions, not just CO2 content or temperature.

Possible, but not based on CO2 inventory; recall, CO2 levels were lower in the Eemian; sea level was higher; temperatures were higher.

Noting the sometimes abrupt changes and the different conditions resulting from ***natural variability*** should highlight the need for deliberate and responsible living. Establishing large cities along coastlines; expecting island communities to witness no change; developing sprawling cities that demand dependence on energy sources; encouraging population growth in arid and semi-arid environments; postponing attention to the growing problems of shrinking supplies of potable water and "security-friendly" energy sources is to court disaster, regardless of what climate does in the long run! Natural variability - colder *and* warmer - is evident throughout even this "stable" Holocene. "Global warming" may dampen, enhance, or do nothing to change that. Too many uncertainties exist to know, despite assertions to the contrary. Living wisely and working toward greater flexibility and energy independence would seem to be solutions to the more immediate and tangible threats to our existence.

Disappearing Sea Ice:

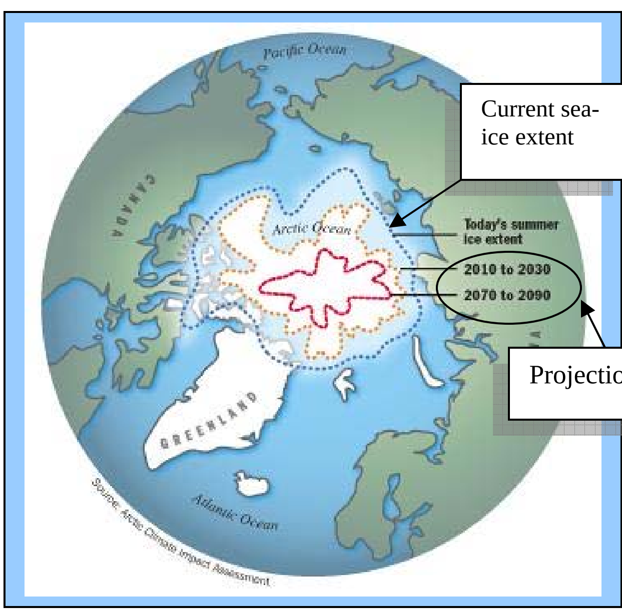
<u>"The North Pole is Melting"</u> – headlined the front page of the August 19, 2000 edition of the *New York Times*. The article was written about a journey taken on a Russian icebreaker – the Yamal - to the Arctic by a group of environmental scientists representing the Intergovernmental Panel on Climate Change – the IPCC. The article went on to say that "the last time scientists can be certain that the pole was awash in water was more than 50 million year ago." Apparently they hadn't done their homework.

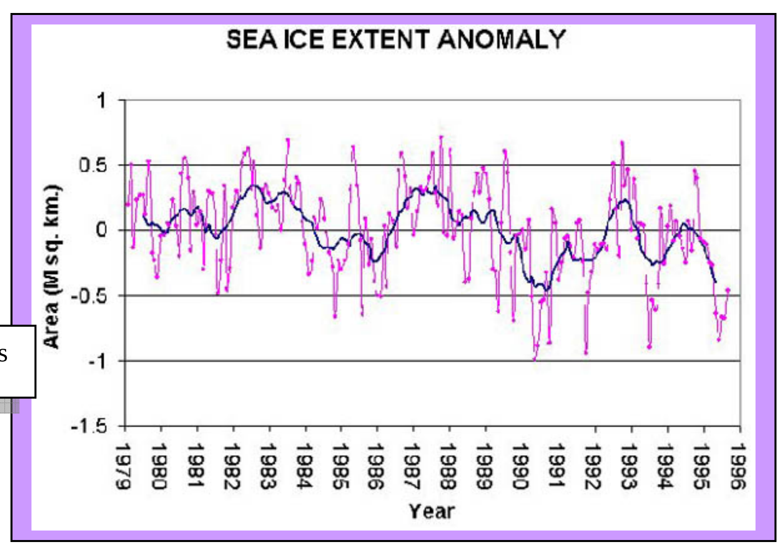
In 1817, in the midst of the Little Ice Age, a British naval explorer, who had come upon open waters in the Arctic, wrote "*It will, without doubt, have come to your Lordship's knowledge, that a considerable change of climate, inexplicable at present to us, must have taken place in the Circumpolar Regions, by which the severity of the cold that has for centuries enclosed the seas in the high northern latitudes in an impenetrable barrier of ice, has been during the last two years, greatly abated*...." (President of the Royal Society, London. To the Admiralty; November 20, 1817.)

Indeed, such an occurrence of open water, particularly after months of twenty-four hour per day sunlight, is not rare. The *New York Times* journalist was not aware of the non-uniqueness of what he was witnessing. These areas of open water are known as **polynas**. Polynas are stretches of open water measuring tens of miles long and wide, punctuating the northern latitudes of the Arctic.

The *New York Times* article quoted above was met with the ire of many experts on the Arctic environment who noted that the region is commonly riddled with long stretches of open water during the summer. In 1817, the open stretches of water were found not in late summer, but in the colder months of late autumn. By the 29th, the *Times* wrote a retraction, page D-3, admitting that they had mischaracterized the true condition of polar ice, admitting that about 10% of the Arctic Ocean is open in the summer, and that sometimes those regions extend to the pole. Indeed, open waters at high latitudes in late summer are common.

While the New York Times article may have fallen victim to sensationalism versus science, the inventory of Artic sea ice does appear to be diminishing.

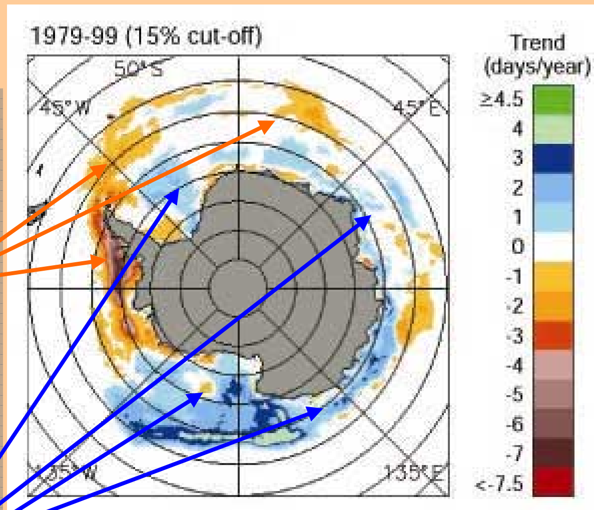


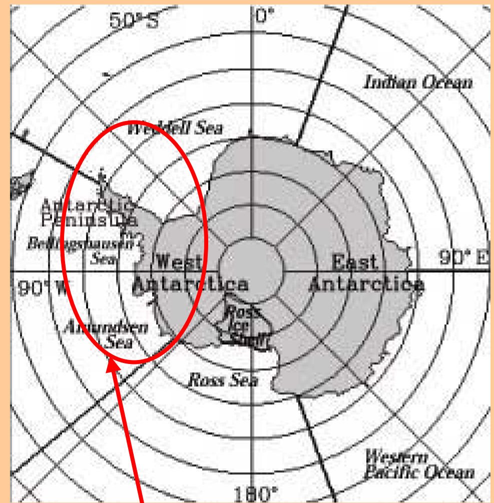


Antarctic sea ice is increasing overall. The sea-ice distribution is roughly aligned with temperature distribution, which is likely governed by the Antarctic Oscillation.

Duration of the sea-ice season is shortening over about 3 million kilometers.

Sea ice duration is increasing over 5.6 million kilometers.

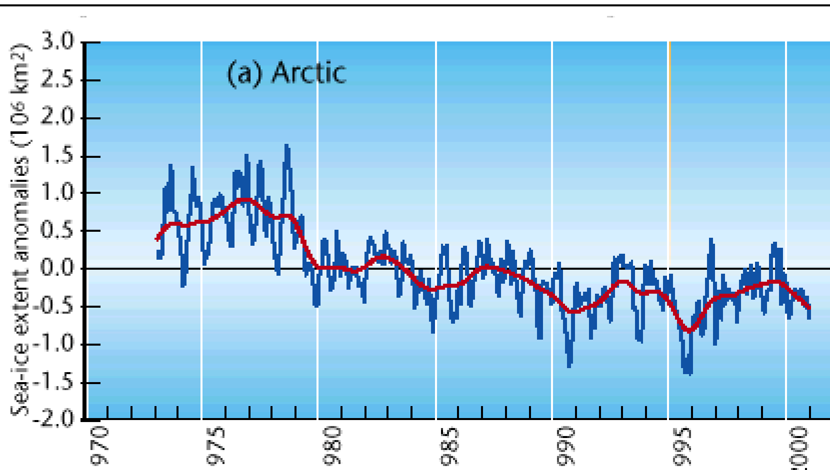




Whether sea-ice is thinning, thickening, losing or gaining aerial extent, these changes do not affect sea level. Such changes can affect planetary reflectivity, can change heat-flux direction between atmosphere and ocean, can influence the ocean's capacity to store or emit CO_2, can affect biological productivity, and through effects on salinity of surrounding water, can impact the globally spanning thermohaline circulation. This collection of consequences involves both warming and cooling effects. Teasing out one consequence of changing inventories of sea ice is impossible.

Area of pronounced warming. Likely due to the prevailingly positive Antarctic Oscillation pattern. Coincides with shortened sea-ice season.

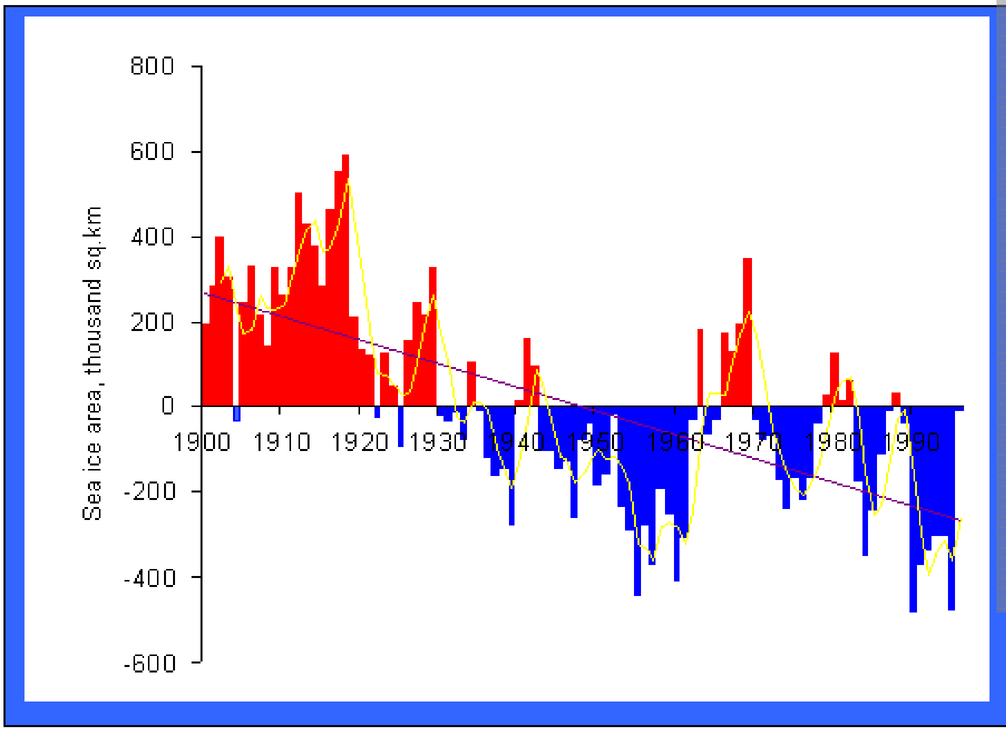
The difference in patterns between the Northern and Southern Hemispheres is striking. There are many things that affect sea-ice formation – temperature being one. Wind is another. In the Antarctic, phases of El Nino and La Nina determine the region of enhanced and diminished sea-ice formation. Certain oceanic oscillations, in addition to the atmospheric oscillation of the polar annular modes, influence sea-ice distribution, as well. An oscillatory pattern of sea-ice extent can be seen in the record (refer to previous figure, last page). Interaction of sea ice with its environment is far from understood. Model projections must be considered with this limitation in mind.



This graph is similar to the one on the last page, but there is a significant difference:

- The "start" of this graph is at the peak of the cool era in the Arctic and at the peak of sea-ice extent.

2002 showed a minimum of sea-ice extent in the Arctic.



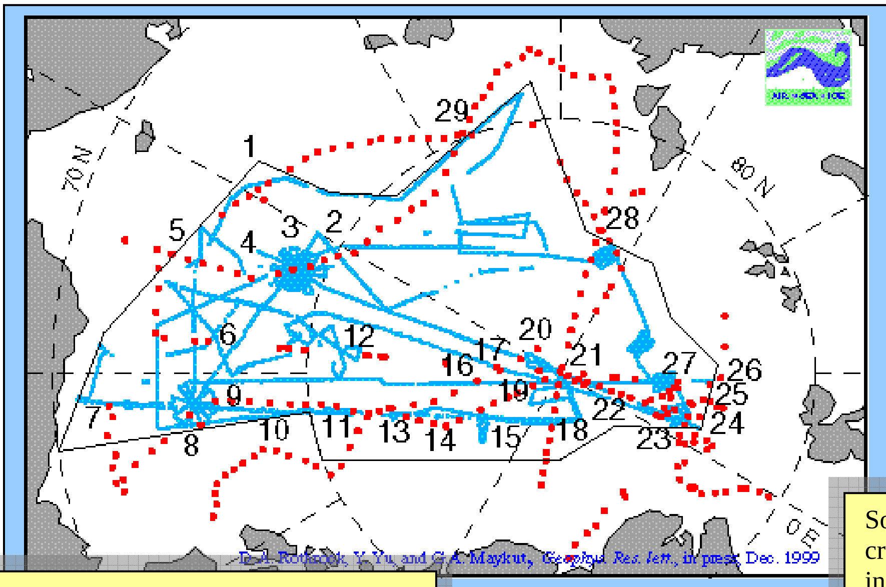
And here is yet another perspective, including the early part of the century, emerging from the Little Ice Age only a few decades before, and throughout the Arctic warm period from the 1930s through the 1950s.

So yes, sea ice extent is diminishing in the Arctic, and it may be due to warming temperatures (although you've seen that temperatures in the Arctic haven't been uniformly or consistently warming), and it may due to warming by CO2, but we don't know. And, temporal perspective allows for a better chance of understanding what might be going on.

In the relatively recent past, it can be seen that ice extent always rebounded from a minimum. This is more due to wind strength and direction orchestrating the confinement within or exit from the Arctic region. Concern now is that even if this pattern is dictated by a natural atmospheric oscillation, the ice has diminished to such a great extent that it has surpassed its ability to recover. If this is the case, we would be entering new boundary conditions. This may hasten planetary warming due to the reduced reflectivity. Then again, it may not. If Antarctic ice extent is increasing, this further complicates the global picture.

Sea-ice thickness is another aspect of the sea ice controversy. Recent claims of a 40% decrease in Arctic sea-ice thickness added to the already heightened alarm. The study leading to this headline was conducted in 1999. Another study, a year later, confirmed the result. But there were other studies whose results were largely unreported. These studies found that method, not an accurate observation, led to the conclusion.

Sea-ice thicknesses are determined by sonar instrumentation aboard submarines. Because the winds tend to control the distribution and coverage, *where* the ice is measured becomes important. Satellites are not confounded by this limitation, but submarines are. In the '99 study (Rothrock et al.), the submarine navigated along familiar routes, taking measurements of ice thickness. From these measurements, *extrapolations* were made of the area *not* traveled over. Thus, the study used both direct measurements and *inferred* estimates. The route taken by the submarine followed along a path where thinning was at a maximum (logistical tact; easier passage). These measurements were input into a computer model to determine the average sea-ice thickness of the entire region. You see where this is going.



Comparisons between the differently acquired data can be made, but differences should be noted:

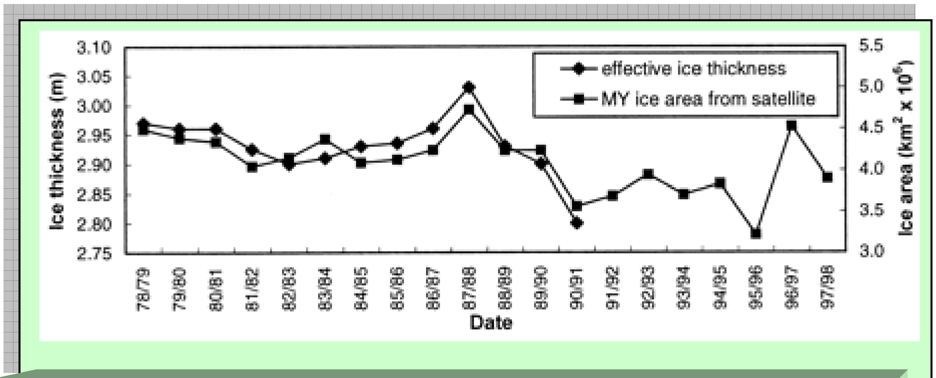
- Cruises in the 1990s were taken only in late summer and early fall – when sea-ice extent in the Arctic is at a minimum.
- Cruises in the late 50s through the 70s were not confined to a particular time of year.
- Tracks where data were collected are similar, but not exact.

Sonar tracks from submarine cruises in the 1990s are shown in blue.

Military submarine data from 1958 through the 1970s are shown by the red dots.

Upward directed sonar measures the “draft”, or hull-like area of the sea ice – the portion below the sea surface.

Next, Johannessen et al. ’99 used passive microwave satellite measurements and surface-based measurements to evaluate Arctic sea-ice.



One can see some of the study’s data graphed at left.

The conclusion was that ice thickness (and extent) had decreased by ~ 14% between 1978 and 1991.

Rather than relying on the written conclusion, I urge the reader to look at the graph.

NOTE what happened between:

- ’78 and ’87
- ‘87/’88 and 88/89
- ‘89/90 and ’90/’91
    - Most of the “decline” occurred in one or two years.

Then, consider that this was a 1999 study.

- Should the years between 1995 and 1997 be more heavily considered?
- And finally, how does the data point at 1997/98 compare to that at 1978?

The authors state that "the balance of evidence thus indicates an ice cover in transition" and that "if this apparent transformation continues, it may lead to a markedly different ice regime in the Arctic." And, in the same issue, in a related News of the Week story written by Richard Kerr (1999), Kerr poses a question in the title of his commentary: "Will the Arctic Ocean lose all its ice?"

Johannessen et al.'s conclusion showed less sea-ice loss than Rothrock et al.'s. Is it any more reliable? Caveats in methodology, time frame convered, and data presentation must be evaluated before the conclusion can be fairly assessed…

Other scientists added to the controversy in the following years. It continues today. Many point to natural variability. Satellite altimetry data collected and used for a study by Laxon et al. 2003 revealed greater variability in extent and thickness than before realized, occurring every few years, not just fluctuating decadally. The amplitude of variability was shown to be large, as well. "Sea ice mass can change by up to 16% within one year." Models do not capture the frequency or amplitude of such variability.

Timing of measurements and under-sampling can miss subtleties of distribution, rendering evaluation of sea-ice extent difficult in the Arctic. Winds sometimes carry the ice away from the central Arctic out to the North Atlantic through the Fram Strait and push it also into regions closer to the Canadian territory. When the winds switch, the opposite distribution pattern prevails.

Changes in cloud type and cover in the Arctic, with a measured increase in the amount of warming clouds, may impact sea-ice extent. Whether changes detected in the clouds are attributable to greenhouse warming or to oscillatory patterns or to something else not yet identified, is not known. It is all far too complex to claim certainty.

In closing on the ice inventory of the globe, polar ice has the most potential to raise sea level. Melting is not the main concern at the poles, as snow accumulation compensates to render an ice-mass balance that hovers near zero globally. Changing ice dynamics involving ice streams (Antarctica) and outlet glaciers (Greenland) are the major concern where sea level is considered. Will the ice shelves fed by these moving paths of ice collapse? Too little is known to guess at what might happen. Historically, Antarctica shows cycles of "binge-purge". Whether this portends well or not is not known. Historically sea level was higher, during the last interglacial. Was this from collapse of ice shelves on either polar landmass? This is not known.

Melting of mountain glaciers is complex, as well. Its contribution to total sea-level rise is comparatively small.

Sea ice extent is increasing on Antarctica and decreasing in the Arctic. The extent of sea ice in Antarctica coincides roughly with temperature distribution. Storm tracks associated with El Nino and La Nina phases and other such oscillations contribute to its patterns.

In the Arctic, sea ice extent is governed largely by winds. According to the prevailing annular mode, winds may usher the ice to the central Arctic or they may push the ice to the Canadian perimeter of the Arctic and south, out of the Arctic into the North Atlantic through the Fram Strait. Variability of sea ice is pronounced, especially in the Arctic. That variability occurs on a number of time frames, including interannual to decadal. Amplitude of variability confounds discernment of a clear trend. This last statement is couched with a little caution, as most recent admonitions warn that sea-ice extent may have diminished to so great an extent that it will be unable to recover, regardless of natural variability. Time is necessary to know if this concern is valid.

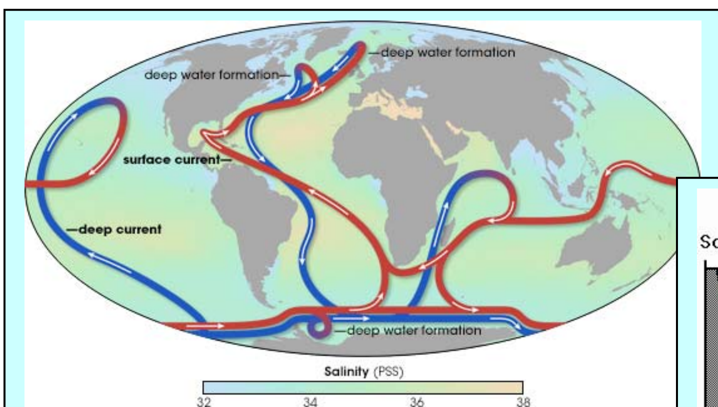
It is known that change peppers the record. Natural variability dominates the past. Warm periods and high sea levels show the greatest durations and degrees of stability. But transition is the glitch. We modern humans have not designed our lives around potential transitions. We have built a world where the desire is to maintain relative immobility. We may face transition regardless of human activity. We may postpone or hasten a transition through our human activities. We simply do not know! For that reason, it is best to simply live wisely. Consider Earth your home, to be managed frugally and carefully. Prepare for surprises, but do not stop living. Don't "prepare" simply because of the threats of climate change or sea-level rise; threats to national security and of depletion of finite resources stand as uncontestable reasons to live with deliberation. To predicate actions on uncertainties of future climate change forces polarization of views and forces people to hold onto paradigms in order to "make them work", regardless of the evidence. Live wisely because it makes sense to do that, regardless of the climate…

Next, we go more quickly through the remaining list of possible and often cited consequences of climate change.

Will the thermohaline circulation slow and cause temperatures to plummet?

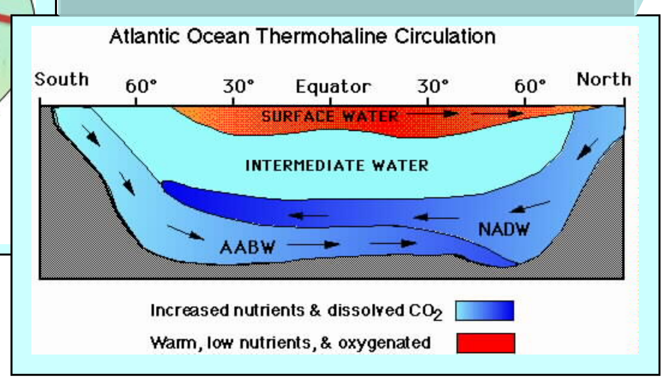
The possibility is there, but is the evidence?

The "conveyor-belt" like ocean circulation that courses the globe vertically and laterally, ushering tropical warmth to the high latitudes in the Atlantic, hastens and slows on a quasi-decadal cycle.



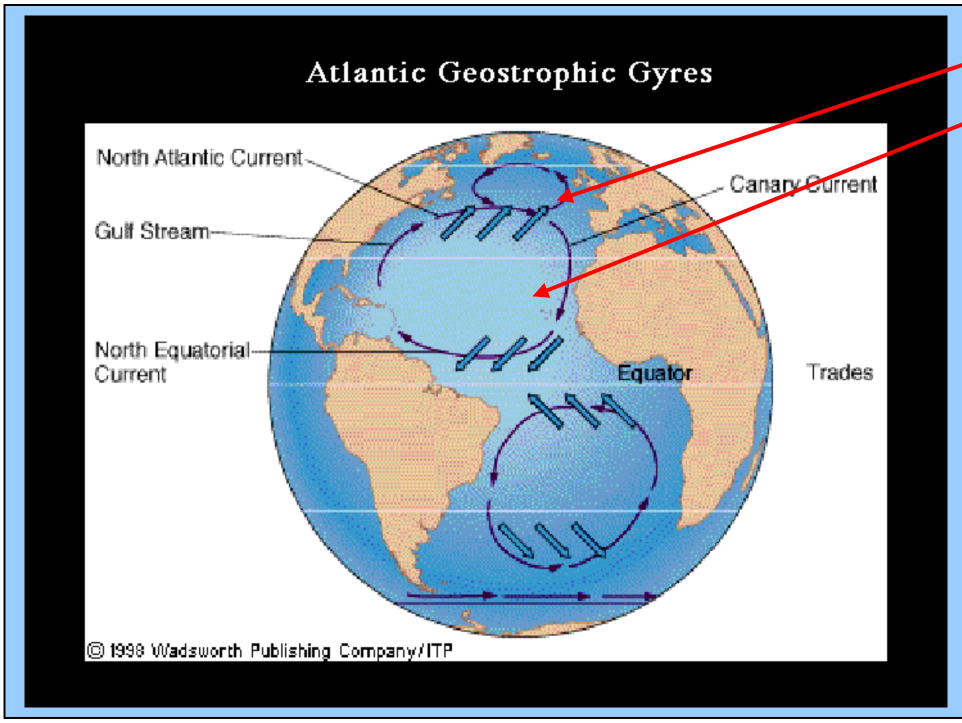
A simplified view:

- Saline water cools at high latitudes in the Atlantic sector, becoming dense enough to sink.
- At depth, water flows (as shown in blue)
- After centuries, water will resurface, and flow along the surface (red) until dense enough to sink again.



A cross-sectional view from Antarctica (left) to the North Atlantic (right) shows the vertical stratification of water masses.

Fears were raised a few years back when newly implemented measuring methods captured a slowing of one section of the current. Aside from the obvious caveats in attempting to measure such a behemoth, satellite measurements of surface expressions of the current show a reversal of the measured slowing. Seems there are two oppositely spinning gyres in the North Atlantic. But there's more to the story:



One gyre pulls in fresh water, the other warm, saline water. It appears that when one speeds up, the other slows down, leading to fluctuations in the amount of salinity delivered to the "starting point" of this conveyor.

With more salinity, the current flows faster

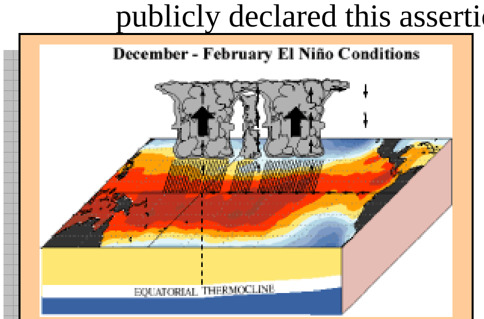
In 1993, the gyre delivering fresh water (top, counterclockwise) was strong and the saline gyre (middle, clockwise) slow.

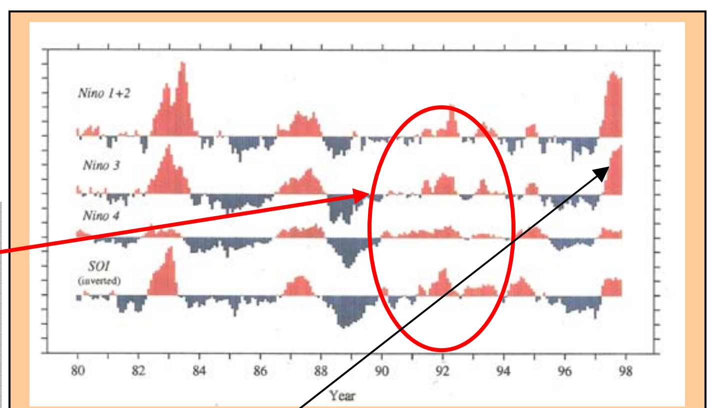
In 1998, that reversed. Now the "starting point" has been supplied with increased salinity.

This would match observation – that the current hastens and slows on an interdecadal basis.

<u>Increased El Ninos?</u>

A well-known atmospheric modeler and meteorologist at NCAR thought there was no doubt of a connection between an increase in El Nino activity and global warming. He publicly declared this assertion in the late 1990s.





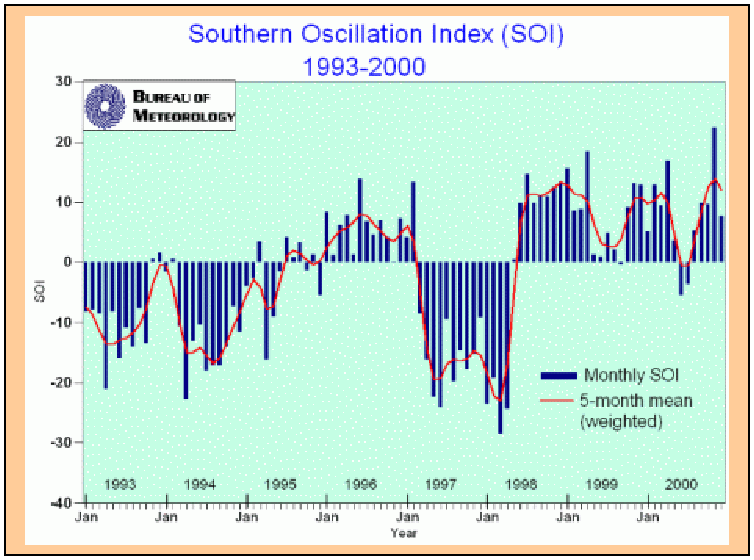
Conditions were unusual in the equatorial Pacific during the 1990s. It appeared that there was a perpetual El Nino throughout that decade.

Shallow vertical meridional circulation had slowed in the Pacific and temperatures were warm along the eastern side of the basin.

Since the mid-1970s, the tropical Pacific was more prone to hosting El Nino events.

Then the "big one" hit in 1997/98. Alarm was at a peak.

Then the pattern reversed. What had seemingly started in 1976 was reversing, and quickly. Within a matter of years, the shallow meridional circulation had rebounded, temperatures had lowered, and La Ninas and non-El Nino years had replaced El Ninos in frequency.

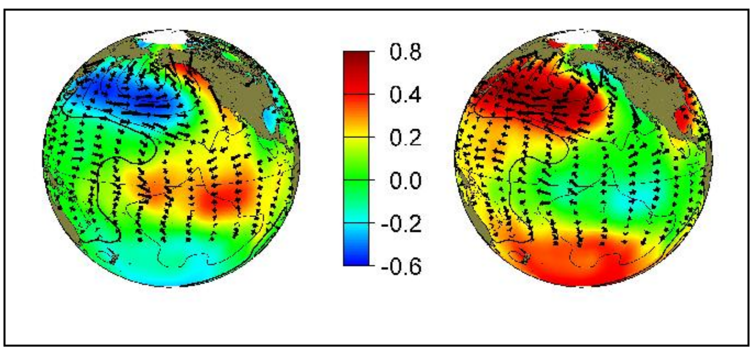


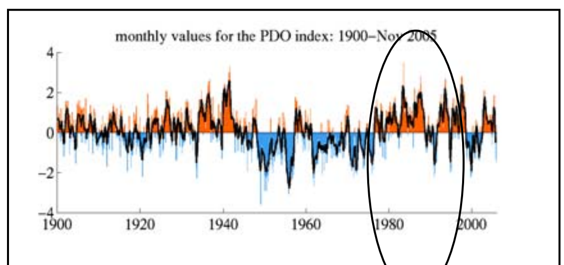
This graph shows the sea-level pressure difference involved in determining whether an El Nino forms or not.

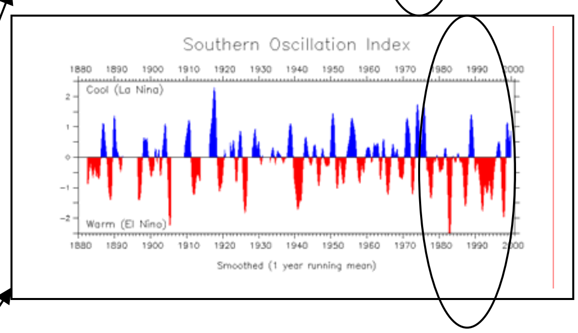
When the SOI is negative (below the line), El Ninos are more likely.

Note the years of the 1990s as compared with right after the "big one" in 1998. One can see the reversal.

While an interannual variability has ushered El Nino events to the equatorial Pacific every two to seven years throughout historical times, intensities have varied according to archival and proxy data. It seems that again we are seeing effects of an oscillation. The one here is the Pacific Decadal Oscillation, discussed earlier. It influences intensity and frequency of El Ninos on a quasi-cyclical basis.







Warm phase PDO:
Warm (red/orange) along tropical Pacific and NA coast, into Alaska.

Cool phase PDO:
Opposite of warm phase. Warmth along western side of Pacific basin; equator is cool.

At this writing, there is no evidence to support a positive correlation between El Nino events and "global warming", regardless of cause for the latter.

Note the similarity between graphs:

- **Top graph** = phases of PDO. Red = warm phase
- **Bottom graph** = phases of El Nino/La Nina. Red = El Nino
- Note circled region = 1976 (Pacific Climate Shift) through 2000

Hurricanes:
It was October, 2004 when the controversy erupted. The atmospheric modeler at NCAR mentioned in the El Nino section, splashed controversy over the headlines when he was quoted as saying that the busy 2004 hurricane season appeared to be proof of global warming. This modeler is a brilliant atmospheric scientist. His name is Kevin Trenberth. He has long been respected for his meteorological contributions. This quote took hurricane experts by utter surprise. They were certain the media had mis-portrayed his comments. Turns out, they did not. Furthermore, the IPCC's director, Rajenda Pachauri condoned Trenberth's statements, echoing the sentiment. Pachauri is an engineer and economist.

This incident led to the resignation of Trenberth's colleague, Chris Landsea, from the IPCC. Landsea had been asked by this modeler to participate on the IPCC as the hurricane expert and to contribute to the next IPCC report on the matter. The resignation letter from Landsea was presented earlier in this reading.

Six months after this episode, Roger Pielke, Jr, professor at CU who studies the social effects of hurricanes and related climate events and son of Roger Pielke, Sr, climatologist, posted a paper to the *Bulletin of the American Meteorological Society*. The gist of the paper was that there was little to no sign of global warming in hurricane patterns, that most of the destruction seen was due to changing demographics. Trenberth told the press the paper should be withdrawn, that it was "a shameful article".

Following Trenberth's pronouncement came two papers relating hurricane activity to global warming. Those, plus Hurricane Katrina within another busy hurricane season in 2005, have fueled a frenzy over the "obvious" connection. The story follows.

I'll back up a little. In July of 2001, a study was published in *Science*, a prestigious science journal. The study involved the North Atlantic Ocean. According to the authors (Goldenberg, Landsea, Mestaz-Nunez, and Gray), an increase in storm activity had been observed since 1995.

Science journals feature full articles of studies as well as summaries of one or two selected studies from the same edition. Many readers of the journal - journalists, science writers, and scientists - look to summaries to give them the rundown on the study. This may not be the best way to get one's science.

The summary of the Goldenberg et al. article, published in *Science* and written by a science writer, not one of the authors of the study, introduced his interpretation of the study as follows: "Warmer, Stormier Weather in Store…One consequence of global warming could be an increase in storminess." (hurricane activity).

Ironically, the *actual* article indicates that the more active hurricane seasons, which have occurred between 1995 and 2000, *have been ushered in by <u>natural</u> oceanic and atmospheric variations*. There was no mention of global warming. The natural variations to which they refer include the AMO (Atlantic Multidecadal Oscillation). They also implicate the QBO (quasi –biennial oscillation, an atmospheric oscillation near the equator) and the AO/NAO. Each oscillation operates on a different periodicity. The study went on to state that during the 20th century, the AMO exhibited two cool phases – 1905 to 1925 and 1970 to 1990. Throughout much of these time periods, Atlantic hurricane activity was minimal. Most recently, between the years of 1971 and 1994, the Atlantic experienced unusually low hurricane activity. Warm phases of the AMO, a time ripe for heightened hurricane activity, occurred from 1930 to 1960 and began again in 1990. Hurricane activity was in full gear between 1926 and 1965, coinciding closely to the favorable AMO phase. Goldenberg warns that the intensity of this predicted hurricane activity during this renewed positive phase of the AMO will be much like the heightened activity of the period from 1926 to 1965. A statistic that supports that view is that between 1995 and 2001, the number of major hurricanes increased 2.5 fold. There has been a five-fold increase in the number of hurricanes affecting the Caribbean. Of course, with more people than ever populating hurricane prone areas, no doubt lulled there by the seeming absence of storm activity, the impact of hurricane activity is magnified. **Goldenberg et al, predict that the increase in hurricane activity will continue for another ten to forty years, as that is the duration of the natural cycle of oceanic oscillations.**

One of the authors of this study, William Gray, renowned hurricane specialist and professor at Colorado State University, closed an interview on the issue with the following statement, “Here is a Mack truck coming right down at us, and we are looking up and we are worried about some nebulous future climate problems (referring to ‘global warming’) that *may* be there.”

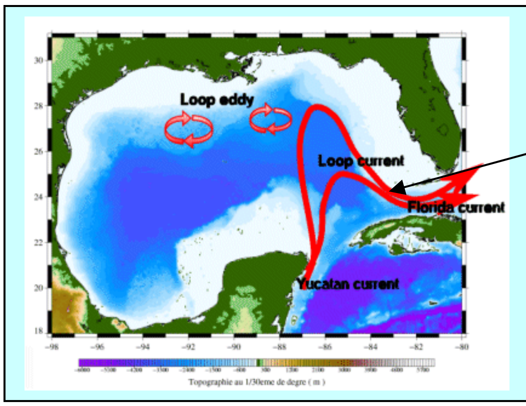
So, the authors never said, nor ever thought, that global warming was involved in increased hurricane activity, they predicted a flurry of storms in the coming years. But somehow the science writer in this prestigious journal decided to add what he assumed must be true.

Then, here comes the substantiation of Goldenberg et al.’s prediction, and Trenberth declares it a consequence of global warming.

Less than a year later, in the summer of 2005, a study was presented by MIT hurricane specialist, Kerry Emanuel. He contended that the destructive power of hurricanes in the North Atlantic and North Pacific had been increasing over the last 30 years and that it was due to global warming. The sea-surface temperatures in these basins have risen by about 0.5°C over this same period, half this increase attributed to natural oscillations by Emanuel. Not everyone was impressed by the methodology used by Emanuel. Emanuel calculated this power index by using the wind strength cubed and integrated it over the life of the storm. This may look like solid science, but what is overlooked is that it requires measurements of wind speed. Wind speeds during the 1930s, when activity was very strong, winds were not measured in the same way. Much estimation went into the figures. Today, we take direct measurements with satellites. Emanuel admits that the increase in power observed might be partially reflective of reporting practices. But doubts about Emanuel's conclusions disappeared in the minds of many when Katrina hit a few months later.

Late August of 2005 – Katrina hit. New Orleans was devastated. Now no one, not even the climate scientists featured here, believe that Katrina had anything to do with global warming. But few scientists are stepping forward to make that clear to the public. The media has had a heyday with this purported connection.

The fallacy between the Katrina-global warming connection is that if sea-surface temperature, was the predominant driver of intensification, Katrina should have strengthened gradually with time. Instead, Katrina approached the east coast of Florida as a tropical depression. There, she strengthened to a category 1. Then she entered the Gulf and jumped from a category 1 to a category 5. She didn't stop at categories 2, 3, and 4. This just doesn't happen… An explanation is offered by Sharoo and Cornish '05.



There is a warm current in the Gulf that enters the Gulf from the south and then loops north and east and back out of the Gulf into the Atlantic, ultimately connecting to the Gulf Stream. This is called the Loop Current. As Katrina strengthened to a category 1 from a tropical storm, she had passed near the current over the region where it merges with the Gulf Stream. She entered the Gulf as a category 1. Then Katrina jumped in strength again, this time immediately to a 5! Again, she was near the Loop Current.

Through satellite tracking, it was recognized that each jump, the first one to a category one and the second one, the leap to a category 5, had happened over what is known as a warm-core eddy. Imagine shooting a stream of blue fluid into clear water. You would see eddies spin off to the sides as the stream of blue moved through the water. The same happens to all currents coursing through the oceans on the globe. Depending on source, some eddies are warm; others are cold. Katrina happened to be situated directly over a warm-core eddy when she went from a tropical depression to a category 1 and from a category 1 to a category 5. The eddies are warm not just at the surface, but to great depth. This is what gives them so much energy – the vertically integrated heat. But the features are warm because of the source region of the current off which they were spun, not because of global warming.

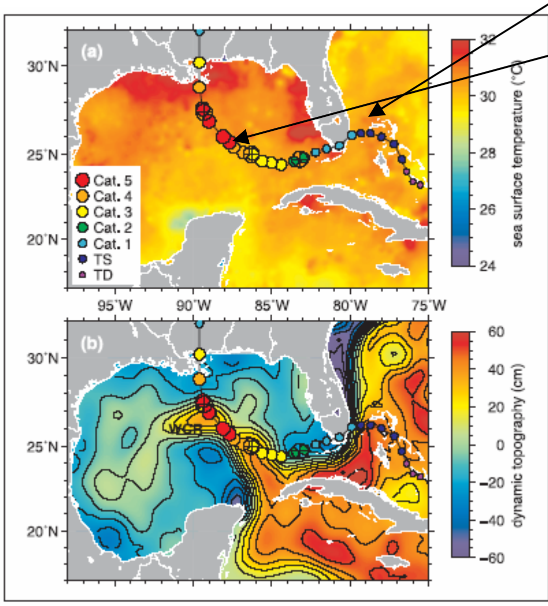


Fig. 2. The location and intensity of Katrina at intervals of six hours (circles indicate data from National Hurricane Center advisories) show two intensification events. (a) Intensification is not correlated with sea surface temperature (from POES high-resolution infrared data). (b) In contrast, the intensifications correlate well with highs in the ocean dynamic topography (from Jason 1, TOPEX, Envisat, and GFO sea surface height data). The Loop Current can be seen entering the Gulf south of Cuba and exiting south of Florida; the warm-core ring (WCR) is the prominent high shedding from the Loop Current in the center of the Gulf. The crosshair symbols on the storm tracks show the storm position at the times of the three rows of panels in Figure 1.

Katrina was a category 3 when it hit land, not a particularly powerful storm. The disaster that followed in New Orleans was a human disaster, not a natural one. New Orleans is like a bathtub, with the ocean held back by one of the sides of the bathtub – just not a good design. Fossil-fuel use can be blamed, but not because of CO2 emissions. In this case, the extraction of the resource that brought economic stability to the region has hastened the land's subsidence, pushing New Orleans even further below sea level. Natural processes of sedimentation have contributed too. The human contribution is found in the levy construction. The levies that held the water back were apparently not built to the highest standards, allowing some allocated monies to fund other, seemingly more pressing projects. Disaster was waiting in the wings.

But the public was convinced. The disaster was a natural one, due to global warming. Emanuel's paper took on super-hero status. It predicted what Nature presented. Its August 4th 2005 publication in the journal *Nature* was timely for the public – three weeks before Katrina hit.

Close behind Emanuel's article was Peter Webster's. He too studied hurricane activity over the last few decades, in his case, for 35 years. He asserts that the frequency of hurricane activity has not increased, but the proportion of those of category 4 and 5 status is increasing, while the maximum wind speed attained in these storms is not getting stronger. In short, the strongest storms are not getting stronger, but the proportion of strong storms is increasing and the proportion of weaker storms is decreasing. Webster goes on to say "We conclude that global data….this trend is not inconsistent with recent climate model simulations that a doubling of CO2 may increase the frequency of the most intense cyclones, although attribution of the 30-year trends to global warming would require a longer global data record and, especially, a deeper understanding of the role of hurricanes in the general circulation of the atmosphere and ocean, even in the present climate state." In short, there remains much to understand.

The study was limited to a time of low hurricane activity. Webster stated that the time of study was dictated by the availability of satellite data – available since 1970. Other scientists take issue with this claim, offering that wind-speed data was available from hunter aircraft from the late 1940s. While not exactly the same as satellite instrumentation, this would have provided a bit more perspective. Records from the aircraft measurements do indicate that the percentage of category 4 and 5 hurricanes was higher from the late '40s to the mid-60s, after which, this percentage dropped precipitously, only to rebound again in the '90s.

Note the story told by the graphs on the next page. The time of data coverage determines the conclusion.

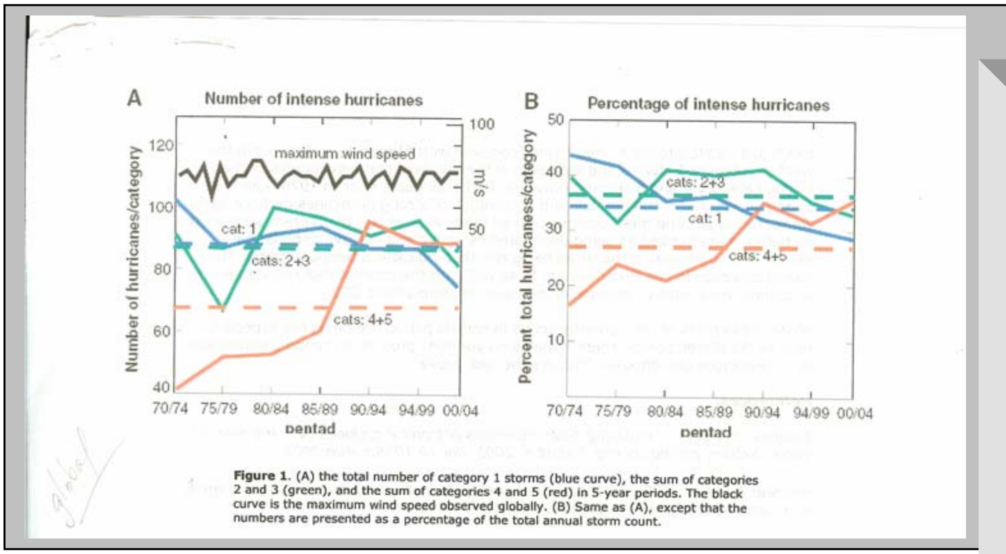


Figure 1. (A) the total number of category 1 storms (blue curve), the sum of categories 2 and 3 (green), and the sum of categories 4 and 5 (red) in 5-year periods. The black curve is the maximum wind speed observed globally. (B) Same as (A), except that the numbers are presented as a percentage of the total annual storm count.

At left are graphs from the Webster study.

Note that:

- A = the number of intense Atlantic hurricanes
- B = % of intense hurricanes

Note also the years measured:

- The 1970s ushered in a time of low hurricane activity.

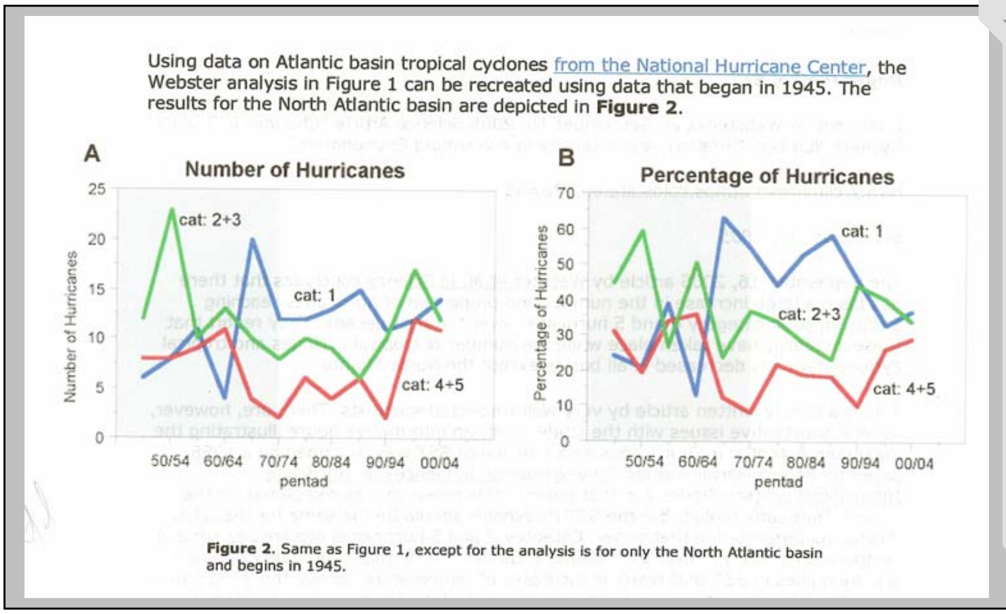


Figure 2. Same as Figure 1, except for the analysis is for only the North Atlantic basin and begins in 1945.

Note this graph adapted from the one above.

Added to Webster's data are data from more active hurricane years. Note how the perspective on trends changes.

Another criticism of the study was that if sea-surface temperatures were responsible for an increase in percentage of strong storms, then basins with temperatures as warm as or warmer than the Atlantic basin should also have a greater percentage of category 4 and 5 storms. This is not the case. Clearly, factors other than sea-surface temperature influence hurricane activity and strength. Upper-air dynamics are critical to the development of a hurricane. For example, El Ninos affect upper-air patterns in such a way as to destroy Atlantic hurricanes. There are several other factors that influence a hurricane's evolution.

The temperature-hurricane correlation, while possible, remains to stand the test of time.

Following on the heels of this paper, NOAA issued a statement in November, 2005 supporting the conclusion that the increased hurricane activity was correlated to natural oscillations of the tropical Atlantic, stating that the "nation is now 11 years into an active era that could easily last several decades…"

Worldwide, there is no increase in hurricane frequency or intensity. According to Philip Klotzbach, globally, sea-surface temperatures have increased between 0.2° and 0.4°C. Since 1986, while there has been an increase in intensity and longevity in hurricanes in the North Atlantic, there has been a decreasing trend in the North Pacific and no trend elsewhere. While Klotzbach finds a slight global increase in the hurricanes of categories 4 and 5 strength, he attributes this to improved observational technology.

In the late 1990s, as we discussed earlier, Trenberth had suggested that increased El Nino activity of the 1990s was a consequence of global warming. Then in 2004, Trenberth asserted that increased hurricane activity in the North Atlantic was a consequence of global warming. Just a note for those who listen carefully: El Ninos shear off the tops of Atlantic hurricanes. Strong El Ninos and active North Atlantic hurricane seasons do not occur simultaneously.

Narrowing our focus to just the North Atlantic, a 2006 study by Michaels et al. highlights the complexity of hurricane development. A simple relationship between rising SSTs (sea surface temperatures) and stronger Atlantic hurricanes does not exist. The relationship is complex. From this study, it was found that there is a connection between SSTs and storm intensity in the sense that it appears necessary for a storm to cross over a temperature threshold of about 28.25°C to develop into a category 3 or higher, but SSTs higher than this threshold value do not further increase the storms' intensity. Not all storms that cross this threshold attain a category 3 status.

The authors looked at two sets of data on hurricanes – one for hurricanes in the North Atlantic for the years between 1982 and 1994 and another for hurricanes in the North Atlantic for the years between 1995 and 2005. The significance of this distribution is that the former group occurred when hurricane activity in the Atlantic was less active, the latter group when activity noticeably increased. More storms encountered the threshold temperature in the second time period than in the first – 124 storms versus 71. In addition, the *percentage* of those storms encountering 28.25°C waters and subsequently developing into category 3 or higher storms increased from 22.5% to 33.8%. This changing relationship illustrates that it is not merely the SST value reached that determines the storm's development. It appears that since the "switch" in 1994-95, other factors in the Tropical environment have come into play to enhance the intensity of the storms. Numerous factors are involved in the evolution or suppression of a hurricane – vertical wind shear, moisture characteristics, how temperature changes with altitude (lapse rates), etc. These cannot be overlooked. What these factors are, why they have changed, and what has contributed to changes in SSTs (changes in the quasi-cyclical multi-decadal Atlantic hurricane regime, global warming due to the enhanced greenhouse effect, or a combination of the two), are issues that remain open for research. To pretend we understand the dynamics shows an underestimation of Earth's complexity.

There are some that claim no oscillation is involved in observations, only a global-warming signature. And finally, there is Greg Holland at NCAR who tells the press that it must be global warming, because he can't think of anything else.

Before putting this topic to rest, I must mention a more political aspect of the research. In late September 2006, the journal *Nature* reported that a government agency blocked the release of a report from NOAA (National Oceanic and Atmospheric Administration) that had suggested a connection between global warming and the frequency and strength of hurricanes. NOAA spokesman, Jordan St. John responded to the *Nature* article: "The White House never saw it, so they didn't block it." The document in question was to be part of a press kit package that was to be distributed in May of 2006. According to NOAA, the document was not ready in time to be included in the press kit. An assumption was made somewhere along the line that the Bush government had its hand in obstructing scientific reporting, an assumption that has been put forth numerous times. Reading beyond the headlines often leads to vastly different conclusions.

And most recently, a conference – the Sixth World Meteorological Organization International Workshop on Tropical Cyclones – convened in late fall of 2006; a conclusion on the correlation between global warming and hurricane activity was not forthcoming. Hurricane experts from around the world, more than one hundred of them, were compelled to draft a consensus statement in response to the heightened attention being devoted by media and scientists to the topic. The consensus states that evidence exists both for and against an influence of anthropogenic climate change on hurricane activity. No link can be established between anthropogenic forcings and hurricane behavior. The experts noted that some studies assigned measurements of increased intensity, wind speeds, and cyclone numbers to increasing sea-surface temperatures, whereas other studies suggest that changes in instrumentation, degree of monitoring, and method of gathering data can account for the changes perceived. Noted also was the natural background of decadal variability. It can create or mask identification of a trend.

Civility has been totally abandoned in the discussion among scientists on the issue of hurricane activity as it relates to global warming. This breakdown in decorum coincided with the devastation of Katrina. Those holding opposing viewpoints refuse to attend conferences together. Vicious name-calling and malicious assaults on once-stellar reputations have usurped the dignity once thought to be a signature of well-educated people. It can only be hoped that this newly released consensus of those who are actually experts on the topic can work to calm the situation to a point where science can once again be the primary goal of all seeking answers to nature's quirks.

Increased Drought?:

Drought has numerous definitions. For a farmer, an agricultural drought exists when soil moisture is so depleted as to affect plant growth. Clearly, such a drought can be said to be dependent upon the type of crop planted. There are seasonal droughts, where dryness is simply a function of sun angle and migrating pressure systems – a natural occurrence. A meteorological drought is defined as a departure from average moisture at any spot. And recall, “average” is the mean of what has transpired over a thirty-year period. “Average” changes over time.

With it held in mind that ‘drought’ is a very broadly defined term, climatologically, if an area receives less than 60% of the average rainfall, that area is technically experiencing a drought. A typically dry area, receiving its average amount of rainfall in a year may be far drier and more parched than another area that appears lush and green, but if that other area is receiving little more than half its typical rainfall, it is experiencing a drought. Drought is not a rare occurrence. During any given month, 4.4% of the U.S. is experiencing extreme drought.

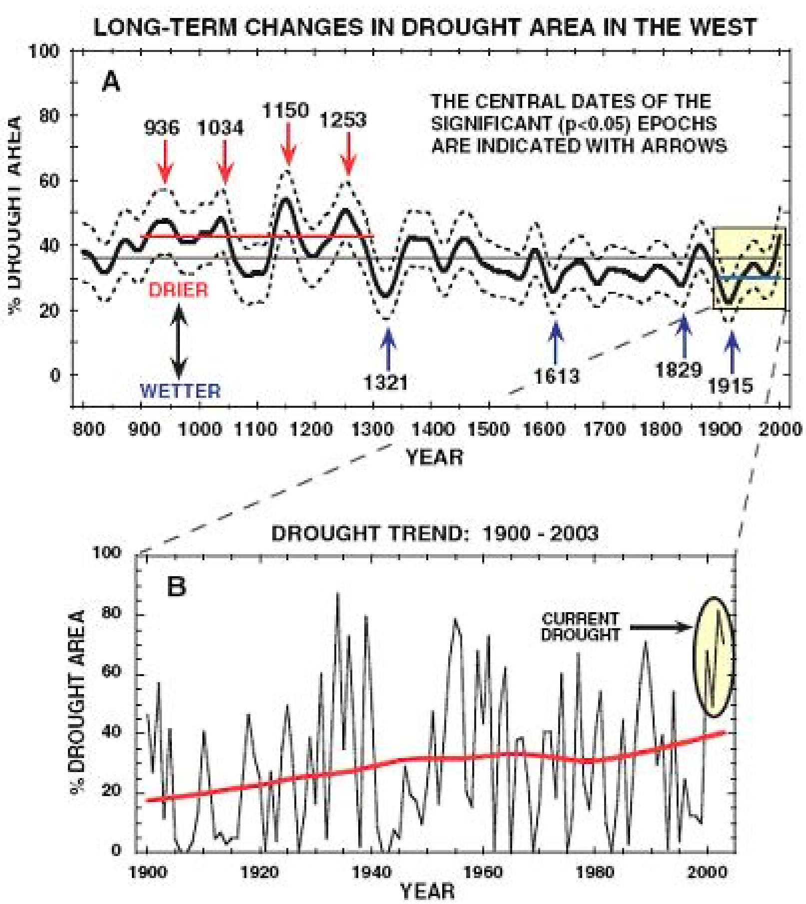
It is significant to note that drought is a combination of a lack of rain and increasing evaporation, the latter potentially enhanced by higher temperatures. But it is equally significant to note that warmer temperatures do not necessarily lead to increased evaporation. Winds and relative humidity of the overlying air contribute to efficiency of evaporation. Of course, the western United States hosts conditions conducive to increased evaporation – low humidity and frequent winds, so increasing temperatures are likely to augment evaporation. But, rainfall has increased, as well, in recent decades, confounding simple assessment of the situation. Obviously, water usage and land-use changes play unprecedented roles in depleting moisture reserves. Teasing all contributors out from the backdrop of global warming becomes increasingly difficult.

Some intriguing connections are being linked with cooling in the East Pacific and warming in the Indo-Western Pacific Ocean. La Nina-controlled chilling of East Pacific temperatures coupled with warming in the Indo-Western Pacific Ocean may combine to generate widespread drought along the mid-latitudes. Computer model runs, based on this premise, show a pronounced tendency toward mid-latitude drought during such situations. The modeled drought conditions may be a result of altered circulation patterns in the atmosphere due to shifting of warmth along the tropical Pacific corridor when these two features coincide, as they did in ‘real life’ during the time period between 1998 and 2002. What remains speculative at this point is the underlying cause for the warmth in the Western Pacific. Solar forcing? For years scientists have suspected a link to the Hale cy greenhouse gases? A possibility. The jury is out. Further studies may soon illuminate these possibilities. And then again, the correlation may be perceived but not real. Far more research is required to determine a solid link.

Media attention can skew our perception though. The summer of 1999 saw an intense drought in the mid-Atlantic region of the United States. Even though the overall drought conditions were mild country-wide – only 1.98% of the country was experiencing drought – Americans were certain ’99 was a dry year and that global warming caused by mankind was to blame. In a speech referring to the disastrous drought gripping the nation’s capital, then President Clinton declared on August 6th, 1999, “As weather disruptions become even more common, and they will, they will demand a more coordinated response by the national government.”

Drought "trends" past and present:

In contrast to the 1.98% of the country affected by drought in 1999, in the midst of a decade of cool temperatures - in 1934 - nearly half of the U.S. was experiencing severe drought – almost 25 times the average. In fact, droughts were frequent and widespread throughout much of the last century. From 1895 to the mid-1930s, drought was a persistent hardship for much of the country. Interestingly, since the time of the most substantial CO_2 increase (80% of the anthropogenic emissions have been emitted since 1940), the frequency and area affected by drought have decreased. By the end of the 20th century, the trend since 1945 had been away from drought and toward more moist conditions, especially in the North American interior. Researcher Tom Peterson suggests that the trend away from drought is associated with an increase in low cloud cover. The cloud cover, he suggests, minimizes the amount of incoming solar radiation and reduces the evaporation rates. (Nature, '95, Tom Peterson) Regardless of cause, the only visible trend is one of decreasing incidence of drought. Of course, there have been deviations from this trend. The year 1954 was a bad year for drought, as were the years 1965, 1976, 1988, and the early part of the 21st century. (Reconstructions of western U.S. drought history from Cook et al., 2004)



Paleoclimatic data indicate that prior to the 16th century – during cold conditions – droughts of great magnitude and frequency occurred. The record suggests that droughts of intensities greater than any witnessed in the twentieth century occurred before the 16th century. It appears from the data that the worst drought on the North American continent that occurred since the 1700s was the drought of 1930. (Science, vol 289, 9/22/00, p2069)

Further back in time, proxy evidence reveals megadrought conditions around 936, 1034, 1150, and 1253 CE (AD). Current droughts have not matched these episodes in terms of duration. (Cook et al., 04, Science 206, p 1015 – 1018)

There is no linear trend. Perhaps there is a trend, but it appears not to be related to greenhouse gas content in the atmosphere. Globally, with isolated exceptions such as in the African Sahel – southern Sahara – where there is a slight tendency to dry, little evidence exists for changes in frequency or intensity of drought across the globe. (Geo. Res. Letters, 1990, "Are Droughts Becoming More Frequent or More Severe in the U.S.)

Perhaps the consequences have changed:
"We have seen dry periods that have been longer and more extreme than today's," climate researcher Roger Pielke Sr. of Colorado State University (now of University of Colorado, Boulder (2006)). Pielke, Sr, quoted in July of 2002, was speaking of the drought being experienced in Colorado at that time. He pointed out that rivers in the state had not been at such low levels within the last 100 years, but that drought conditions experienced by the state had been worse in the last 100 years. "…For a given level of precipitation, impacts are worse today than in the past." He speculated that the more severe consequences of diminished precipitation were due to changes other than climate. He posited that perhaps there was more use, or perhaps more water-guzzling trees and vegetation lining the riverbeds.

Pielke was merely observing and speculating. He cautions that investigative studies need to be undertaken to evaluate the situation. It does appear, though, that greater numbers of people, and the land-use changes that accompany population shifts, play a great role in how weather affects us. (Daily Camera article, Sunday, July 7th, 2002, front page, Katy Human, staff writer)

In addition, drought conditions, once initiated, are self-perpetuating. Little moisture can be evaporated from the parched soil; contribution to the formation of rain clouds is minimal. Forest and grass fires are more common during drought conditions. Smoke from these fires contains small particulate matter. These particles act as cloud condensation nuclei. Because the nuclei are small and numerous, an abundance of small rain droplets accumulate within the atmosphere. Too small to have the weight needed to overcome buoyancy, the tiny droplets formed from the scant moisture available remain airborne, unable to precipitate as rain.

A study has illustrated a connection between dust storms from the perpetually parched Sahara Desert and increased cloud cover in Florida. Global winds commonly carry dust across vast distances, to be deposited in areas quite remote from the source. Dust from the Sahara has been spotted in the skies over Florida. An interesting consequence of this is a change in the cloud cover.

A process that generates much precipitation within the middle latitudes begins with clouds of ice crystals. Development of ice crystals does not occur within the atmosphere at water's freezing temperature of 0°C. Instead, pure water droplets suspended in air will not freeze until temperatures reach -40°C (-40°F). Water, in liquid form, below 0°C is considered to be supercooled. Supercooled water will freeze more readily upon contact with solid particles. Think of skiing through the cold, clear air finding your hat and hair covered with ice crystals – same concept. Such solid particles are called freezing nuclei. Typically, these nuclei are sparse in the atmosphere. They rarely allow water to freeze until temperatures have dipped below -10°C (14°F).

Dust can act as nuclei for developing ice crystals, allowing water droplets to freeze at warmer temperatures. In fact, this study has shown that ice crystals initiate formation at warmer-than-usual temperatures, at about -5°C to -8°C.

While far from understood, the scientists speculate that increased concentrations of suspended dust may trigger precipitation in low-altitude clouds, allowing ice formation in clouds that otherwise were too warm, clouds that would not have produced rain until having convectively grown into higher altitudes. In addition, the dust, by acting as nuclei, may prompt formation of high-altitude clouds.

What this general scenario, and the Sahara's dust over Florida in particular, portends for future climate is uncertain. High-altitude clouds tend to warm via greenhouse absorption; low-altitude clouds tend to cool via enhanced albedo. Furthermore, if precipitation is enhanced from low-level clouds, less water is available to be carried to higher altitudes via deep convection. A reduction of moisture to high altitudes has a significant effect on the greenhouse behavior of water vapor, actually reducing its warming effect rather than augmenting it. But…then again, studies show that not all dust leads to enhanced precipitation. In some cases, dust actually delays precipitation, creating highly reflective low-level clouds.

And, in addition to the Saharan dust affecting rain production in Floridian clouds, rain forests in the Amazon depend upon dust from the Sahara in Africa for fertilization! It has been found that more than half (> 50 million tons of dust every year) of the dust needed for fertilizing these lush forests ultimately comes from the Sahara. Just a climatic note: these forests draw down huge amounts of CO2 from the atmosphere.

All that is clear when we assess the various studies related to drought and its potential consequences – dust and its possible impacts being only one - is that our understanding falls far short of complete. Much study lies ahead.

Increased Wildfire Activity?

Snowmelt and temperature – these are key components driving wildfire activity in the western U.S. This set of parameters has been implicated as being responsible for increasing wildfire activity in the Western U.S. in recent years. Numerous papers have been published establishing a connection between these two parameters and wildfires.

The popularized interpretation of the studies is that global warming is responsible for the outcome.

Authors of the studies are less committed to a solid conclusion, leaving the case a bit more open: example – "Whether the changes observed in western hydro-climate and wildfire are the result of greenhouse gas-induced global warming or only an unusual natural fluctuation, is presently unclear." (Westerling et al. '06) While the correlation between temperature in the West, snowmelt date, and wildfire activity appears robust, it does not speak to cause of fire or to cause of snowmelt and temperature changes. Such changes have occurred in the past, long before greenhouse-gas emissions were a concern. During the Medieval Warm Period (~ 1050 to 650 years BP ("BP" meaning before 1950)), there were frequent large-event fires. Fire frequency lessened with the Little Ice Age (~ 1300 to 1850). Low fire frequency characterized the Dark Ages Cold Period (after 200 CE (AD)) and higher fire frequency dominated the Roman Warm Period (200 BCE (BC) to 200 CE (AD)). But, one can find contradicting results from studies on boreal forests in eastern Canada and in Finland. During the Holocene Climatic Optimum ~ 6 to 9 ka (thousand years ago), fire frequency was about half of that of the 20th century fire frequency (Carcaillet et al. '01, Pitkanen '03).

The fact that increased episodes of wildfire activity occurred prior to significant anthropogenic influence on climate demands that one look to natural influences as part of the equation. Three climate oscillatory patterns play a prominent role in drought, and therefore fire, conditions. The first is the El Nino/La Nina oscillatory system in the tropical Pacific. Correlated with a strong El Nino is a pattern of drought and fire in the Northwestern region of the United States; correlated with La Nina is drought and fire prevalence in the Southwestern U.S. Another oscillation that influences temperature and precipitation patterns in the U.S. is the Pacific Decadal Oscillation (PDO) in the North Pacific. A third oscillation is the Atlantic Multidecadal Oscillation (AMO) in the North Atlantic. ENSO, PDO, and the AMO each involve movement of warm water masses in conjunction with shifting atmospheric pressure systems. They shift over a short period of time, about a year, and can (but not necessarily) endure in the reversed regime for decades at a time. There are two periodicities of the PDO; one is ~ 15 to 25 years, the other is 50 to 70 years. The periodicity of the AMO is on the order of 50 to 70 years. ENSO (the system of El Nino and La Nina) is dominant; in fact, it is a dominant factor for global climate in general. PDO and AMO play auxiliary roles, amplifying or diminishing the general influence imposed by ENSO.

A study published in the December 26th issue of the Proceedings of the National Academy of Sciences by Thomas W. Swetnam et al. demonstrates a strong correlation between the phases of these natural cycles and pronounced seasons of drought and wildfire activity over the last 450 years. The authors add that a major difference between today's fires and those of the past is the amount of fuel available to be burned. It is much greater now. This is due to our past policies of fighting the fires, fires which otherwise would have eliminated much of the quick-to-burn debris and undergrowth. This factor further amplifies the influences imposed by interacting oscillatory patterns.

One can be certain there are many factors that play into past and present occurrences of fire. No doubt that warming temperatures play a significant role, regardless of cause, at least in the Western U. S., but human activities, land-use changes, precipitation changes, and forest policy decisions, to name a few, play equally significant roles.

Increased Floods?

Will there be more floods? Probably, but not necessarily because of global warming or increased atmospheric CO_2. The possibility of a connection is there, but the evidence is not there at this point.

The oscillations of ocean currents and atmospheric pressure systems, in large part, dictate moisture conditions. The positive phase of the AO/NAO, which was dominant throughout much of the last couple of decades, brings not only warmer temperatures to the Northern Hemisphere, but also moister conditions. As it is not established that the positive phase of the AO/NAO is related to atmospheric content of greenhouse gases, one cannot assume this increased moisture is anything but a result of natural oscillation patterns. There remains much to tease out from natural rhythms.

According to statistics compiled for the period from 1910 to 1990 for the United States, precipitation had increased overall. Despite this increase in precipitation, no trend in flooding has been detected. Although no trend has been detected, news reports leave the public with a contradictory view. The reason for this may lie with demographics. Where populations settle can skew the perception of flood impact. Unwise choices for home and business location have become more commonplace in recent times. Too often residents and builders ignore past flooding history along rivers or coastlines.

The occurrence of flooding may not have increased, but our vulnerability to flooding has increased. Land use changes often render soils less permeable, leaving the ground impermeable to runoff, elevating the risk of flooding. Hardened soils, impenetrable asphalt, or concrete covers much area within a city or town. Where waters once had a chance to soak into the ground before doing severe damage, they quickly build to flood levels.

Although statistics tell us that no trend in increased flooding can be detected, history can perhaps provide insight. During the Holocene Climatic Optimum, during which temperatures were about 2°C (3.6°F) warmer than today's, yet CO_2 levels were lower, on par with pre-industrial levels, the incidence of flooding in the tropics was far greater than it is today. Statistics, projections, and history – it's no easy task to predict the future of a chaotic system such as climate.

Increased Storminess?

There likely will be greater cloudiness with increased warming, although you read earlier that cloudiness has decreased in recent years, likely adding to Earth's heat quotient. But that reduction in cloudiness is thought to be associated with an increase in solar radiation and a decrease in incoming cosmic radiation. If warming is unrelated to increases in solar output, it is assumed that increased warmth will lead to increased evaporation, and thus, to increased cloudiness. But, as the reader can see, the understanding is far from clear.

The issue of storminess is less clear. There should be more rainfall with increased warming. It appears that there has been an overall global increase in land surface precipitation, but many areas exhibit no trend. Much of the observed increase in precipitation has occurred mostly at the mid and high northern latitudes. In the United States, increased rainfall has been noted in the southern Mississippi River valley, the Southwest, Midwest, and Great Lakes region. And, as is often the case, with increases in some areas across the globe, there are decreases in others. Rainfall has diminished in the tropics.

It can be difficult to decipher a trend. For example, many areas have experienced no increase in their average total precipitation total but have witnessed an increase of isolated heavy precipitation events. The frequency of ‘heavy precipitation events’ is somewhat subjective, further confusing the tally. In some regions, heavy precipitation events have increased in one season and decreased in another, balancing out the yearly total.

It is often claimed that the weather is getting more and more bizarre, that “extreme events” are getting more common. Different scientists and observers of weather employ different criteria in determining what qualifies as an “extreme event”. This subjectivity confounds attempts to detect a pattern from the data of the last century of weather events. (Science, 289, 9/22/00, p 2069;IPCC 1996)

Increased thunderstorm activity likely:
As far as storminess in general, certain kinds may increase and certain others should decrease. Surface heating would lend itself to increased convective cells. Increased thunderstorm activity seems likely.

Cyclogenesis activity should decrease:
On the other hand, extreme regional storm events should decline in frequency. This has to do with the fact that many of the mid-latitude storms develop in response to a sharp temperature gradient between higher and lower latitudes. As this gradient is expected to diminish with global warming, such heat-transferring storms should diminish as well. Recall that cyclogenesis thrives when the polar jet stream velocities are at a maximum. Because of the reduced polar-equatorial temperature gradient, the jet stream’s velocities will decline. Records support this prediction; severe storm activity in the extratropics has not increased over the last 50 years, despite global warming.

Increased Tornadoes?
Tornado activity seems to have increased. Perhaps this is a real phenomenon or perhaps a perceived phenomenon. Improvements of technology used for spotting the cyclones, more media coverage, and greater number of people across regions prone to cyclones – any of these may explain the apparent increase. But again, the increase could be real.

Tornadoes require warm, moist air near the surface, warm, dry air nearby, and cold, dry air aloft. If, as a result of increased warming, the temperature gradient between the poles and the equator were to decrease, the strength of the jet steam would dampen. Looking exclusively at these parameters, one might conclude that tornado activity would decrease. But, looking at other parameters, ones conclusion might differ. Predicted to be concomitant with an in temperature is an increase in moisture. An increase in moisture would increase tornado activity. It appears that the two opposing factors, both offspring of a warmer world, would negate one another.

Historical records show that the number of deaths from tornadoes during cool years was greater that the number of deaths in some of the hottest years of the recent past. In 1953, a cool year, there were over 500 deaths. Fatality numbers range from 150 to 300 in other cool years – 1957, 1965, 1971, and 1974. Compare this to 122 deaths in 1998 and 1984, two warm years. Coincidence or evidence? The bottom line is that the answer on this matter is not yet clear.

Declining Coral Populations?

It does appear that coral reef bleaching events have been on the increase for the last couple of decades. Global warming is one likely possibility. There are other possibilities as well – some natural, some anthropogenic.

Shallow, tropical waters along shores of islands and continents provide conditions necessary for the survival of coral reef systems. Coral reefs are comprised mostly of calcium carbonate that has been secreted from living and once-living corals. Numerous plants and animals use the coral reefs as their home.

Coral species live in regions of low nutrient availability. They also live within a narrow temperature margin. Little changes in their watery surroundings can wield enormous and deleterious impacts on these fragile systems.

Coral bleaching is a result of something that has gone wrong with the single cell algae, known as **zooxanthellae**, which lives symbiotically within coral polyp tissues. The zooxanthellae, through photosynthetic activity, provide to the coral various nutrients. The coral repays the organism by providing shelter and a steady supply of carbon dioxide. The zooxanthellae living within tissues of the coral impart the beautiful colors to the coral. When something goes wrong with the zooxanthellae, the color disappears. The coral is said to be bleached.

If the loss of zooxanthellae is on the order of several weeks to a few months, both the coral and the zooxanthellae usually recover. Sometimes the coral is repopulated by a different collection of zooxanthellae strains. If the loss is prolonged, the zooxanthellae populations will not likely recover and the host coral perishes.

The incidence of coral bleaching appears to have increased since the 1980s. This may be entirely fact or it may be partly appearance. It is postulated that part of the increase can be attributed to greater public and scientific awareness, and therefore greater observation and notation of such occurrences.

Temperature increases and temperature drops can both cause bleaching. A drop of three to five degrees Celsius (5.4-9°F) over a period of five to ten days can bring about bleaching. Such events might occur as a result of seasonal cold-air outbreaks or an oceanic upwelling event.

Elevated ocean temperatures of only one to two degrees Celsius (1.8-3.6°F) over a period of five to ten weeks can precipitate a bleaching event. A warm summer can easily initiate such an event. Larger temperature increases over just a few days can wield the same damage.

Between 1986 and 1988, the Caribbean experienced widespread coral bleaching. That occurrence, combined with warm temperatures in the summer of 1988, brought to the minds of many a connection between coral bleaching and global warming.

Surprisingly, ocean temperatures taken in that region during that time did not reflect any significant warming. This does not mean that warm temperatures are not culpable for coral bleaching, but it does suggest that other factors must be invoked for at least some of the bleaching events.

Keep in mind, warming of sea surface temperatures can result from many causes, global warming being only one. Bleaching events related to elevated sea surface temperatures typically occur at the end or near the end of a protracted warm period or at the end of the summer season. Global warming is more evident in wintertime temperatures and higher minimum or nighttime temperatures. Global warming may very well be the cause, but again, maybe not. And, the reasons for global warming can be natural; there is rarely one factor at play.

Solar radiation is a suspected agent of coral bleaching. Many incidents of coral bleaching have occurred during periods of low wind strength, calm seas, low turbidity, and clear skies. These conditions are favorable for penetration of short wavelength radiation.

Also, at times of low water level, or due to tectonic uplift, if the corals are exposed to the air, not only are they subjected to more intense solar radiation, but also to temperature extremes, as they are not buffered by a watery insulator, and to desiccation. Ozone depletion may play a role in the amount of ultra-violet radiation to which the coral is subjected.

Flooding, heavy downpours, runoff from storm activity, and the like can flush a great amount of fresh water into the waters where coral live. This can lead to bleaching, but is a more isolated and infrequent event. It likely only contributes a minor amount of the bleaching recently seen.

Other possible causes for coral reef bleaching, and none of them particularly exonerating of anthropogenic interference, include over-fishing, overexploitation, nutrient overloading, and increased sedimentation.

Examples of increased sedimentation include those derived from an unexpected cause – beach nourishment. Shorelines along continental coasts are locations of dynamic change. Humans, rarely allowing nature's processes to deter their wants, have attempted to place immovable structures on moving coastlines. Technological innovation has failed to permanently and economically secure such investments. To date, the only "solution" to saving structures and tourism from disappearing beaches is sand nourishment. This expensive, temporary, and not always successful solution has also led to the unexpected result of coral reef degradation. A case in point involves Waikiki Beach in Hawaii. Soft, muddy calcareous sand was hauled in to rebuild beaches there. Shortly thereafter, coral reefs rimming the coast began to die. The culprit: muddied waters. Seems the sand brought in was not the coarse calcareous sand indigenous to the region. Instead, the sand was soft, muddy calcareous sand. Breaking waves interacting with this softer, muddier sand soon clouded the waters with turbidity-suspended particles. The result was the devastation of offshore coral reefs. The same fate has befallen coral reefs off the coast of Miami Beach, where sand replenishment, at a cost of 64 million dollars for a 24-kilometer stretch (15 miles) is required every 10 to 12 years. The process continues despite the consequences suffered by the coral reefs.

Natural impacts can affect the health of coral reefs. Such impacts include violent storm activity, flooding, El Nino, sub-aerial exposures due to tectonic uplift or tidal extremes, disease, and predatory outbreaks. One such predatory outbreak devastated many stony coral reefs in the southwest Pacific Ocean during the 1960s. The predator was the crown-of-thorns starfish.

Bleaching of coral reefs is a signal that something is changing. Whether the change is long-term or short-term, isolated or globally reaching, and whether that change is indicative of natural or anthropogenic causes, it is important to consider all the possibilities, and then assess the situation. Jumping to an easy conclusion does not make the situation more solvable.

Disappearing Species and Changing Migrating Patterns?

Dwindling Fish Populations:

Possibly the dwindling of certain fish populations signals a warming trend of Earth's climate, or at least of a local or regional climate, but one must use caution in assigning blame exclusively to this parameter. One must be especially disciplined not to assign changes detected in ecosystems immediately to global warming *as caused by mankind*. Global warming and global warming as caused by mankind are two distinct parameters. Furthermore, global warming, whatever its cause, is but one of numerous possibilities involved in changes in any ecosystem.

The list of variables affecting fish populations is lengthy: over-fishing, contaminated gene pools, disease, parasites, land-use changes, artificial nighttime lighting, changes in the chemistry and pH of runoff entering rivers and streams, to name some of them.

Land-use changes are an indisputably large consequence of mankind's activities. Land-use changes involve damming of rivers, farming, clearing of forests, application of pesticides and chemicals, irrigation systems, the building of canals, of cities, and other society-related structures. All wield an influence on ecosystems – directly or indirectly through climatic influences. We tackle one of those land-use changes below.

The Glen Canyon dam, built along the Colorado River, creating Lake Powell in 1963 has markedly altered fish populations. Sediment, once plentifully distributed along the hundreds of miles of river, is now accumulating behind the dam. Water is collected behind this dam and many other dams in the western United States to generate electricity and provide water for western cities, Los Angeles, Phoenix, and Las Vegas, to name a few. Intermittently, water is released at the bottom of the dam in order to generate electricity via the large turbines housed inside the dam's walls. Water is also released during monsoon season in the desert southwest. The maximum release of water is only a third as much as that of natural floods that coursed through the canyon prior to the building of the dam.

Some environmentalists say we need to increase the frequency of and the amount of water in dam releases. Others say we need less. In 1996, waters released from the dam artificially flooded the canyon. For 16 days the water flowed, releasing massive quantities of sediment into the sediment depleted river channels. It seemed to be a success, but one that was short-lived. Most of the beaches today are smaller than they were prior to this flood.

Regardless of what the "right" approach will be determined to be, the fact is that the Colorado River, and its fish and wildlife population is not, and never will be the same as it was before the dam was built.

A warm river, choked with sediment characterized pre-dam days. Eight fish species were native to the river. Chub was the dominant native fish. Shrubbery on river beaches was sparse, wiped out with every major flood – natural floods which occurred every year or so. Small trees grew above the high-river mark and prevented erosion at this higher stand.

Today, without the natural high floods, these trees at high-water line fail to spread their seeds and regenerate. Shrubbery covers available beaches. Frigid water released from the dam has turned this ecosystem into a cold-water river. The lack of sediment has left the water clear. The consequence of this is beautiful scenery in the eye of the tourist and a complete upheaval of the natural ecosystem in the eye of the environmentalist. Of the eight native fish species, only four remain. Alpine-adapted rainbow trout have out-competed most of the one-time inhabitants. They and other non-native fish attack or feast on the remaining chub. The clear waters have left many of the now ill adapted fish vulnerable to the predation of raptors.

The Glen Canyon Dam is but one of many dams throughout the world. All change the ecosystems, and thus of the fish populations of the rivers dammed. Other factors affect fish populations as well.

Artificial nighttime lighting is a topic that can roughly be categorized as a land-use change. The lights that illuminate our streets, our tall towers, our buildings, and our homes are something to which we all have grown accustomed, but not all organisms have adapted favorably to our well-lit world. Both the light source and the consequent sky glow effect created seem to affect both physiology and behavior of nocturnal organisms.

This topic has not attracted widespread research, but there has been enough data collected to alert us to a phenomenon that does negatively affect certain species of flora and fauna. A few studies have focused on light's effects on insects, sea turtles, birds, and certain plants. Anecdotal observations have exposed new concerns involving fish and amphibians.

Researcher Barbara Nightingale of the University of Washington in Seattle pointed to the effects of lighting on certain river-navigating species – salmon, herring, and sand lance. She pointed to the fact that in areas of unnatural lighting along sections of waterways, these fish congregate. The concern she expresses is that such unnatural concentrations of fish leave the fish at a heightened vulnerability to predation. The fact that the collection of fish is well illuminated only adds to predation vulnerability.

Artificial lighting does not play a major role in declining fish populations, but it is yet one more variable straining the viability of this collection of species.

Fisheries' researchers revile modern fishing practices. Marine fishermen have been accused of selectively culling from the sea those fish at the top of the food chain – cod and grouper, for examples. Daniel Pauly, a fisheries scientist from the University of British Columbia in Vancouver, uses the phrase, "fishing down the food chain". This phrase is used to describe the practice of over-fishing larger, more valuable predatory fish, to the point where so few are left, that the fishermen must then target those less desirable fish lower on the food chain. Scientists such as Pauly warn that if disciplined measures for conservation in marine fishing are not adopted, fish populations and oceans will suffer beyond measure. (Nature, 3/16/95; Science, 2/6/98, p860; Science 11/20/98 p 1383 – all by Daniel Pauly)

In the North Atlantic, off the coast of Scotland, natural salmon stocks are in peril. The culprit: escapees from the local fish farms. It seems that most recently, over 100,000 farmed salmon have escaped from an area off the north coast of Scotland. These fish, and their offspring, contaminate the gene pool of the hardy salmon. Salmon must surpass numerous odds to swim upstream where they spawn before dying, ensuring that a future generation of salmon will be born. Many of the farmed fish have developed genes that leave them less hardy, and therefore incapable of making the arduous upstream journey. Of course, farmed fish don't need to make the journey. But when they interbreed with native salmon, the offspring are handicapped by some of these less hardy genes, dooming future breeding. Where farmed fish have interbred with native ones, the second generation is most likely to be affected. Out of such a hybrid population, 30% fewer fish make it to the spawning grounds than do from a non-hybridized group. It is claimed that about a million salmon have escaped from farms in Scotland alone since 1998.

Not only are the genetic compositions of farmed fish interfering with native populations, but farmed fish, if introduced into the natural habitat, often carry with them disease, and even lice. Natural salmon runs in Norway, Scotland, and Canada are at heightened risk because of this. (Nature, vol 416, p571, 4/11/02)

Pathogens are sometimes inadvertently introduced to an area against which the indigenous fish have no inherent defense. Populations are decimated.

A parasitic organism, originally native to Eurasia, was introduced into North America in the 1950s. The organism – Myxobolus cerebralis – penetrates the head and spinal cartilage of very young fish - trout and salmon being most at risk. The organism multiplies rapidly, soon putting pressure on the organ of equilibrium. The infected fish swims erratically, around in circles, unable to dodge predators and unable to catch food. Death soon follows. Some of the few fish that escape mortality grow up to be deformed. If they reproduce, the offspring will not have the disease unless infected after birth. Those that survive the infection are few in number.

The disease has spread at an alarming rate across the United States. As of this writing, twenty-two states are affected: all western states with the exception of Arizona, many states in New England and a few in the South. The parasite can be spread easily by fish, birds, and humans who transport it inadvertently on shoes, waders, and other fishing or river-exposed equipment. Rainbow trout are the most conspicuously affected at this point. Brown trout can become infected and pass on the disease, although they rarely show signs of being directly affected by the parasite. Some salmon species are vulnerable, as are mountain whitefish and cutthroat trout.

The spores of the parasite linger for years, virtually indestructible. They appear capable of withstanding freezing temperatures, desiccation, and can survive twenty or thirty years in a stream until it infects another host. The rapidity and ease of transmission of this parasite, and the indestructible nature of it, has led to devastating losses of trout and salmon species in the United States, where it is a foreign introduction. Fish farms distribute their fish into streams infected with the parasite, temporarily bolstering fish populations. Adult fish are not affected by the parasite, but their offspring are. In this manner, the parasite claims increasingly more victims. (www.whirling-disease.org/)

It is imperative that when temperature-related influences affect aspects of an ecosystem, one keeps an open mind as to the cause of the temperature fluctuation. Global warming as caused by anthropogenic introduction of greenhouse gases is but one variable – an important one, but only one. Natural oscillations in ocean and atmospheric systems occur now and have been occurring for years, long preceding modern mankind, probably longer.

Past 2200-year record of Alaskan sockeye salmon:
A study of sediments cored from lake bottoms of Kodiak Island, Alaska was undertaken to assess the fluctuations in Alaskan sockeye salmon population throughout the last two

millennia. This area, the most productive in the North Pacific, is considered to be representative of the entire Alaskan region. Reconstruction of the 2200-year paleo-record strongly illuminates the fact that pronounced declines in the sockeye salmon population can and do occur without the influence of fisheries and other anthropogenic interference.

Scientists looked for evidence of salmon derived nutrients in the form of a certain isotope of nitrogen. From the various concentrations of the nitrogen isotope ratios, scientists inferred when an abundance of salmon had returned from swimming in the North Pacific Ocean to natal lake and stream regions in order to spawn and subsequently die. A percentage of their remains, communicated to scientists through the nitrogen ratio, was deposited and isolated within the lake sediment.

The information gleaned from this sediment was a time frame of abundances and declines in the fish population. From about 100 BCE to around 800 CE, fish populations were low. This time frame roughly corresponds with warm global climate. From 1200 CE to 1900 CE, a time roughly corresponding to the pronounced cooling of the Little Ice Age, salmon populations were high.

Climate impacts the plankton on which the salmon feed. This link explains the climate – salmon population connection. Planktonic booms and busts are not easily assigned to one cause, nor are they fully understood. A variety of interrelated factors work to boost or devastate planktonic populations. Climate appears to be directly and indirectly the ultimate cause for the rise and fall of planktonic populations.

Sockeye salmon numbers have followed an inconsistent pattern of decline since 1900. The overall decline is assumed to be in part due to over-fishing and in part due to a warming climate. Whether the warming can be partly or wholly attributed to industrialization is not clear to scientists. After reading this text, it should not be wholly clear to the reader either.

The conclusion that can be taken from this study is that populations of sockeye salmon have varied markedly on multi-century scale timeframes, and that the fluctuation in abundance is well correlated with global, and likely regional, temperature regimes. Warming coincides with a decline in the sockeye salmon population; cooling coincides with an increase. Furthermore, it appears that relatively small climate changes can lead to disproportionately large fluctuations in salmon populations.

Recall that the Pacific Decadal Oscillation – PDO - has kept much of the Northern Pacific warm over the last twenty-some years, since 1976. In 1998, the PDO flipped to a cool phase. Whether or not this is a 'blip' or a trend is not known at this point. Interestingly, though, salmon populations reflected the temperature reversal. In 1997, 123 million salmon were caught off the coast of Alaska. In 1999, 216 million were caught. I can offer no easy explanations. (Nature, vol 416, 4/18/02, p 729-733, also, from same issue, article by John Witfield)

Amphibian decline:
A decline in the western toad population (Bufo boreas) in northwestern North America has been noted since the 1980s. Similar declines have been observed in the golden toad (Bufo periglenes) population of the mountains in Central America. Declines in frog and lizard populations have also been seen in Central America and Australia. Scientists are scrambling to determine if one uniting cause underlies these declines or if the contemporaneous declines are coincidental and caused by a variety of factors, possibly including climate change, increased exposure to ultraviolet radiation, fungal pathogens, habitat destruction, artificial lighting, herbicides and pesticides, and disease.

As mentioned in the section on fish populations, artificial lighting seems to pose a negative influence on certain nocturnal species. Frogs and salamanders are among these. Bryant W. Buchanan, a frog researcher from Utica College in Utica, N.Y. has noted that nocturnal frogs, when suddenly exposed to artificial light, freeze all motion while exposed to the light. They remain motionless until long after the light has been extinguished. Obviously, reproductive and feeding behaviors are inhibited in this period of suspended animation. Speculation points to this being a possible factor involved in the decline of some frog populations.

The navigational ability of salamanders is thwarted by exposure to red or yellow lighting. Disorientation corrupts the salamander's successful journey from one pond to another. If confused, and left wandering on land, a salamander may fall victim to predation or may die of exposure to cool nighttime temperatures

A popular herbicide – atrazine - used for killing weeds has long been considered to be one of the more benign pesticides. This herbicide's effect on amphibians has been studied and vindicated in the past. It has been shown to not cause premature death or abnormal growth in amphibians.

Its effect on reproductive health had been overlooked, though. Recent research by developmental endocrinologist Tyrone Hayes of the University of California, Berkeley, (*Proceedings of the National Academy of Sciences by Tyrone Hayes, et al)* involving lab frogs, has shown that a small concentration of the herbicide – a concentration well within the range allowed by the Environmental Protection Agency – damages the endocrine system. Scientists think that the atrazine activates an enzyme called aromatase. When this happens, the enzyme converts male hormones – androgens - to female hormones - estrogens. In short, it turns male frogs into hermaphrodites – organisms possessing both male and female reproductive characteristics.

It is assumed, but difficult to assess if, this process is occurring in the wild. An additional study conducted by Hayes - as-of-yet-unpublished - involving wild northern leopard frogs in North America suggests that the effect of atrazine on these wild frogs is even greater than the effect seen on laboratory frogs. As endocrine damage is not externally visible, evaluating such damage is not readily accomplished. If this chemical is indeed causing endocrine damage, it is assumed, but not proved, that reproductivity of amphibians is affected. A link between endocrine damage and sexual reproductivity has not been confirmed; it remains only an assumption at this point.

In short, while this herbicide appears to be a prime suspect in at least some of the decline of amphibian populations over the last decade or so, more studies must be done to declare it a definitive cause. It is well worth keeping in mind. (Science, vol 296, 4/19/02, p 447)

A study of western toads in the lakes of the Cascade Mountains of northwestern North America concludes that low water levels are causing the demise of the indigenous population of toads. The connection between low water levels and the declining populations involves exposure to solar radiation and decreased immunity to infectious agents.

Embryos are laid in the shallow lakes and ponds. They appear to develop normally for a few days only to turn black and die thereafter. Exposure to increased levels of ultraviolet radiation, in particular, UV-B, is a likely culprit. Such exposure, resulting from the unusually low lake and pond levels, renders the developing embryos compromised physically, increasing their susceptibility to disease. Indeed, a fungus known as Saprolegnia ferax is infecting these toad embryo populations.

What some say:
Some are quick to say that global warming due to anthropogenically introduced greenhouse gases is to blame for the low water levels in lakes and ponds. An article summarizing this study points out that "...a separate debate is focused on climate change and its relationship to greenhouse-gas emissions. Today, there is little doubt that both phenomena – amphibian declines and global warming – are real. If there is indeed a link between the two, as the work of Kiesecker et al. suggests, there is clearly a need for a rapid transition to cleaner energy sources if we are to avoid staggering losses of biodiversity. " The author (J. Alan Pounds)- communicates the impression that the study's authors – Kiesecker et al. - concluded that anthropogenically caused global warming explains the amphibian demise and portends the indiscriminate demise of biodiversity worldwide.

What the authors of the study say:
The authors of the study are not as quick to connect the anthropogenically caused warming and amphibian decline. Nor do they attempt to suggest how mankind can alter the future outcome. They, instead, report their findings and emphasize the need for further study. The authors are more cautious in their choice of words as to the ultimate cause of the decline. They suggest that climate change might result in greater UV-B exposure or climate change coupled with stratospheric ozone depletion might result in greater UV-B exposure. The climate change to which they refer is couched in terms of El Nino/Southern Oscillation cycles. They note that precipitation patterns of the Pacific Northwest are influenced by El Nino events. They note that the frequency of El Nino events has increased during this time frame (since the mid to late 1970s) in step with the warming of the tropical Pacific. The cause for this climate change – whether natural or anthropogenic – is not given, as it is unknown. Climate change is invoked as a heavily

contributing factor; climate change caused by industrial emissions of greenhouse gases is not invoked as a factor. The two are separate.

Brief reminder on the cause of Pacific oscillations:
As you might recall from earlier in this text, the cause for the tropical Pacific warming and the details of the ENSO cycles are far from understood and far from being seen as being linked to greenhouse-gas induced global warming.

The conclusion of this study vividly illustrates how a series of interactions can result in unexpected consequences. This may or may not be the final word on the declining populations of amphibians. The link to climate in the Pacific appears to be convincing. If that climate has been "changed" by anthropogenic forces or has oscillated according to a natural pattern remains to be determined. Much study lies ahead, precisely what the authors declare. (Nature, vol 410, p681; & the summary article, p 639)

Will global warming disrupt animal and bird migration patterns and hasten the spring bloom?

Phenology:

Observations of **phenology** – the timing of seasonal activities of flora and fauna - suggest that climatic conditions influence the timing of seasonal events. Warmth appears to correlate with an earlier onset of springtime behavior of numerous species. But then there are numerous exceptions.

Although global warming has, through a staggered pattern of ups and downs, resulted in a ~ 0.7°C increase over the last century, the timing of springtime activities do not advance with the global trend, but rather with regional or local temperature trends.

Regional temperatures governed by an oscillation phase of an adjacent ocean basin may or may not coincide with globally averaged temperatures. For example, global average temperatures were cooler than "normal" throughout most of the 1970s, into the 1980s. For much of central and northern Europe, this was not necessarily the case.

The NAO – the North Atlantic Oscillation – the natural and multi-decadal oscillation of atmospheric pressures over the North Atlantic, controls wintertime temperatures in much of central and northern Europe and the northern and central coastal regions of North America – a *regional* phenomenon. It is likely a sub-cycle of the polar oscillation, the Arctic Oscillation. Debate continues on that topic. A positive phase of the NAO brings warm, balmy conditions to Europe during winter. The NAO has been mostly in a positive phase since the 1970s. The 1990s have witnessed a pronounced positive phase of the NAO. Warmer than 'normal' temperatures across much of Europe during this time supports observations that a positive phase of the NAO correlates with warmth in the mid-latitudes across much of the Atlantic, particularly the eastern Atlantic – central and northern Europe.

From 1950 to 1970, the NAO was mostly in the negative phase. Cool temperatures dominated in Europe and parts of North America throughout this period. Before that, a mostly positive – warm - phase dominated throughout the time period from 1905 to 1950. Is there a trend? Does it coincide with emissions of greenhouse gases? Is this a natural oscillation that is confusing our interpretation of what mankind causes and what he does not cause? Or has mankind disturbed the natural oscillation? Recall earlier the study that concluded greenhouse gases could push the polar oscillations into a more positive phase.

In any event, scientists of a recent study – Walther et al. – observed phenological patterns over the last thirty years – a time coinciding with a strong positive phase of the NAO. The study focused on central and northern Europe. Their findings follow. The data are mostly qualitative; little quantification was presented.

Plants:
Seventy-one percent of 13 plant species from 137 localities "revealed responses" to the NAO. Early-blooming, herbaceous plants were more inclined to "show responses" than late-blooming, woody plants were.

Migratory patterns of birds:
Some short-distance, early-migrating birds arrived at their nesting sites slightly earlier over time. In contrast, long-distance, late-migrating birds arrived either at the same time or later. Also, phenological phases were delayed in both birds and plants in southeastern Europe. Later bird arrivals were noted in the Slovak Republic and the commencement of the growing season of plants was delayed in the Balkan region.

It was further noted that activities of migratory species are well documented, but a long-range shift in activity was difficult to ascertain because the arrival times of these birds to their respective breeding sites fluctuated from year to year. In contrast to migratory species, sedentary species do appear to shift their range geographically along a more linear trend.

The authors assert, "simple correlations with temperature changes are not always observed." "In addition, climatic extremes – related to natural oscillations and underlying long-term trends – are also important in driving the present range changes." The authors admit that most ecological studies attempting to find a climatically prescribed phenological trend are challenged by the time constraints. Most studies have been short-term – on the order of a few decades. Climatology, they concede, "encompasses much larger spatial and temporal scales. As a consequence, it remains difficult to link population and community-level dynamics to the global-scale studies of atmospheric and oceanic processes.

The researchers note that geographical range shifts among sedentary (non-migratory) species are rarely gradual; they tend to be "episodic". The rate of range shift varies, not only among species, but within a species, as well. The authors state that "butterflies appear to track decadal warming quickly."

The Butterfly shift:
The butterfly shift is an observation presented in a separate study of butterfly movements in 35 species of non-migratory butterflies in northern Europe (Parmesan, C. Nature 399, 1999, p579-583 & Nature 382, 1996, p 765-766) by one of the authors of this study. The shift has been documented, but a conclusive reason for the shift has not been established. The shift appears to be directly linked to temperature change. Indeed, temperature-sensitive species appear to shift their range northward, abandoning their southerly-most range due to an exceeded thermal limit; even if the temperature cools again, the return shift southward does not occur.

The facts - a third *shifted* north; two-thirds *expanded* north:
In about a third of the butterfly species studied, extinction occurs at the southern boundary (in the Northern Hemisphere) and colonizes at the northern boundary. For about two-thirds of the species studied, the range extended northward while the southern boundary stayed in tact. A small percentage actually shifted southward.

Species adapt to their newer, more poleward environs. This presence of the new residents will likely force local changes among the native residents. Good, bad, or simply change – it's difficult to assign a judgment. Why the change? Again, it's difficult to say with certainty.

Although a temperature link is visible, the butterfly study's author declines to give evidence to support any connection between greenhouse gas global warming and range shifts. The shifts are regional. Greenhouse warming caused by man may be a reason, but there is no direct evidence for such. The only direct evidence for a temperature link in the examples cited in this article is the warmth in northern Europe. This warmth is a direct result of the positive NAO. The NAO's relationship to greenhouse gas concentration in the atmosphere as a causative factor has not been established.

Although natural systems have been adjusting to changes for far longer than mankind has been around, the concern echoed by many scientists is that if climate change, forced by anthropogenic activities, occurs "too quickly", adaptation by species may be made more difficult, if not impossible. If species are interdependent, the synchrony between the activities must stay in tact for the survival of all. Warmer early spring weather in Europe has been implicated in the disrupted synchrony of the hatching of the winter moth, the oak bud burst, and the hatching of the great tit nestlings. In other words, when the birds need insects for food, the peak availability has passed. (Nature, vol 416, 3/28/02, p 389-395 & Nature, vol 391, 1/1/98, p 29-31 (two articles))

That brings us to another study with interesting results. A study conducted by Grieco et al. involving the bird - the blue tit - shows those lessons learned by the birds one year can alter behavior of the birds the succeeding year.

Birds were put into experimental and control groups. Those birds that were given supplemental food supplies throughout the breeding and hatching season - those that "had it easy" - slightly delayed their egg-laying date the following year. As a consequence, by the time the eggs hatched, the natural peak food (caterpillar) season had passed. On the other hand, birds not given supplemental food supplies, those that were left to the vagaries of Nature, advanced their egg-laying date the following year. As a consequence, when their eggs hatched, they were synchronized to the peak of the caterpillar season. This observation suggests, according to the authors, "that the synchrony between the timing of the brood and the natural food availability experienced by the female is involved in the fine-tuning of the timing of reproduction in tits in an adaptive manner." "…organisms recalibrate their "decision rule" according to their past experience." (Science, vol 296, 4/5/02, p 136-138)

Much data concerning phenology over the last century has been collected from amateurs. The opening of leaves, the arrival of birds, etc. has been documented in diaries of numerous nature enthusiasts.

Amateur-collected data valuable, but with caveats:

Did I see that correctly?

Not all scientists embrace this information, valuable as it is. Some caution that bias can arise in a variety of ways. Different observers may interpret phenomenon differently. Some may not observe accurately. "When the weather gets good, people go outside, and they tend to see things that they don't see when the weather is bad," says Marcel Visser, ecologist at the Netherlands Institute of Ecology in Heteren, pointing out one caveat in taking these data as fact. If a person had been working all week or had gone on a vacation, observations might easily have been skewed as a result. In later years, that same observer may no longer work. Chances are he/she might detect the arrival of a species during what used to be a workweek.

Time frame is another caveat, for amateur and researcher alike. Data covering a time frame of less than fifty years are unreliable. Natural patterns in climate take place over time scales of fifty, seventy, eighty years and more. Others occur on time scales of fifteen hundred-plus years. Such natural patterns are best pulled from long-term records. We get lost in the detail when time frames are short. Year-to-year variability is enormous. If we get lost in these large variations and misinterpret them as trends, we have done no service to the pursuit of science.

How long is a year? Another caveat to keep in mind:

A calendar year does not equal a vernal equinox year:

Another caveat in analysis of phenology is the small discrepancy between the length of a calendar year and the actual time between vernal equinoxes of succeeding years. The discrepancy is miniscule, but adds up, especially when the advances in springtime activities are reported as being on the order of a day or two over thirty or fifty years.

Our average Earth-year lasts 365.25 days. Because of precession (axis and orbital "wobbles", the average time between vernal equinoxes in successive years is 365.2422 days. This is known as the 'vernal equinox year'. This small amount adds up, especially when we skip a leap year.

Each regular year has 365 days in it. The extra quarter of a year is "put in storage", so to speak. After four years of "storing" this yearly extra quarter, we generally fix the situation by throwing in an extra day – February 29th. This is our leap year. Each year the difference between a calendar year and a vernal year is 0.2422 days, the vernal equinox year being longer. After four years, the difference between the calendar date and the vernal equinox date is 0.9688 days, the vernal equinox year being longer. But, when the leap year comes along and the extra day is added in. The difference after four years is now 0.0312, the calendar year being longer (1.0-0.9688 = 0.0312). This means, that every four years, because of our leap year additions, our calendar "says spring has arrived" 0.0312 days after the Sun's position "says spring has arrived". This miniscule amount of time adds up over a century. After a 100-year period, after about 25 leap-year adjustments, the difference between the calendar year and the vernal equinox year is 0.78 of a day. This means, after 100 years, the "arrival" of true spring comes almost a day earlier than it did a century before.

Discrepancy largest at century's end; re-setting the calendar:
This trend of an artificially earlier arriving spring is usually broken with the ushering in of a new century. This is because we skip leap years if the year is divisible by 100. That means that for most century marks – 1300, 1400, 1500, 1800, 1900 etc, we don't add a day. When this happens, the calendar year does not get longer. We "loose" an entire day. The vernal equinox was shorter by .78 of a day by century's end. The shorter vernal equinox year is balanced by the shorter calendar year. The timing is "re-set".

When the calendar is not re-set:
Leap years can occur on the century mark if that year is divisible by four. In such a case, such as the year 2000, the losses of the vernal equinox year continue. After one hundred years, from 1900 to 2000, the loss is 0.78 days. Real spring arrives 0.78 days earlier in the year 2000 than it did in the year 1900. If, at the century mark, another leap year is added, as it was in the year 2000, the loss grows to 0.8112 days. The loss continues to grow over the succeeding 100 years until we get to a century that is not divisible by four. By the year 2100, true spring will be arriving over one and a half days earlier than the calendar's spring.
It isn't much, but phenological advances aren't large either. This factor, minor as it seems, must be kept in mind. As with all "insignificant" factors, they add up. (Nature, vol 414, 12/6/01, p 600)

Polar-Bear Extinction:
Polar bears evolved from Grizzly bears around the end of the last interglacial, about 125,000 years ago. They are well adapted to polar climates and to navigating across the sea ice of the Arctic.

Concern has developed over the polar bears' fate. Diminishing inventories of sea ice translate to loss of habitat for the bear. There is no doubt; this is an area of concern, even if the sea-ice inventory is governed, at least in part, by natural fluctuations of the Arctic Oscillations. But it does us a disservice to be deprived of the fuller story.

In the 1950s, the estimated population was about five thousand. Between 1965 and 1970, the population had increased to between eight and ten thousand. In 1984, a peak in population growth occurred; there were an estimated 25,000. Current populations are estimated at between 22,000 and 25,000 bears. Low numbers during the '50s and 60s were due to unrestricted hunting.

The story becomes further expanded when one learns that the heightened concern over the polar bears' future stemmed mostly from one study. The study area was restricted to the Western Hudson Bay. No one contests the results which show a 20 to 25% decline in the bear population over the last decade in this region. But what is not readily apparent is that there are regions where the bear population is not dwindling. The Canadian bear population has increased by that percentage, 25% over the last decade, from 12,000 to 15,000.

Obviously, there have been warm times in the past – the 1930s for example. The bears survived both the warmth and the unrestricted hunting. This is not to say that they should not be protected; that is a policy decision. What it is to say is that there is more to the story than "a 25% decrease in polar bear population in the past decade illustrates the dire consequences of global warming"…Perspective is always healthy.

Will Climate Become More Extreme? Will There Be More Blocking High?

No one really knows. Some climate models suggest that with global warming comes a greater variability in temperatures; others predict less variability. The global warming that has occurred is reflected mostly in warmer daily minimum temperatures. The difference between the daily high temperatures and daily low temperatures has decreased.

There is expected greater warming at high latitudes. With this, the gradient between the polar latitudes and mid-latitudes would lessen. With this lessening, extratropical cyclone activity will likely minimize. With a lessened polar-tropical gradient, the jet stream carrying along these disturbances might slow. With this slowing, the jet will likely meander to greater extremes than it does today, resisting zonal movement. What that may augur is a tendency for blocking highs to develop. High-pressure system brings descending air and clear skies. During summer months, such a stalled high could bring sweltering temperatures over an area for an extended period of time, as the meander, with less energy to push forward, may be inclined to languish over one region. Adjacent to this region would likely be a region with quite the opposite meteorological regime, yet one equally stubborn to move along.

The way that global warming works, it is unlikely to usher in record-setting daytime high temperatures in summer. Although some summers will seem unbearable and there will be those summers with a string of record-setting hot days, it probably will have less to do with global warming than with natural variability. The observed global warming over the last hundred years seems to have taken place mostly at night and during the winter months. Scientists assume this pattern of warming will continue if the globe continues to warm. Record-setting warmth can and has occurred during summer months that lie sandwiched between frigid years. During the 1400s, six of the coldest years on record in

Europe occurred in the decade of the 1420s. Interspersed within these six years was the hottest summer on record. Such excursions appear random and occur on numerous time scales.

Ocean Acidification:

Over geologic time scales, excess carbon in the atmosphere is stored in sediment, rock, and in the deep ocean water. Other than rocks, the deep ocean is the largest repository of CO2 on the planet.

The surface ocean takes in CO2 from the atmosphere. The more CO2 in the atmosphere, the more the surface ocean takes up, and vice versa. But the upper ocean is merely a holding zone. It can easily lose the CO2 back to the atmosphere. If the CO2 can reach the deep ocean, below the thermocline (discussed in chapter two - the division between the upper and lower oceans, characterized by a sharp density difference), then it can be sequestered from the atmosphere for thousands of years or more.

Chemical changes within the ocean occur as a result of this "clearing the air" of CO2. With an increase in CO2 in the oceans, chemical reactions occur that enable the ocean to absorb even more CO2. The reactions result in less calcium carbonate being preserved. Thus, one can loosely say that the oceans will become more acidic.

It is an alarming thought – acidification of the oceans. But the oceans will not become acidic. The oceans are slightly alkaline. If this diminishment of calcium carbonate preservation comes to fruition, the oceans will become a little less alkaline with the dissolution of CO2 in the seawater, but they will remain slightly alkaline.

This is not to say that this is a good thing for the chain of life. Some of the key components of the food chain would be affected. That this will occur remains hypothetical at this point, as the study suggesting this fate was based not on observation, but on model studies. The authors were careful to point out that conditions in a laboratory fail to capture the interrelated nuances of various components of the ocean system, and thus the results must be considered in that light.

But scientists point to history to support their view. There is an analogue in the past, about 55 million years ago. Mentioned in the history of climate section, this was an event of sudden and profound warming. It occurred, likely due to the dissolution of methane clathrates in sediments on the continental slopes; these are little icy cages with methane molecules locked inside. Methane, a potent greenhouse gas, was likely released. The ocean responded by absorbing excess CO2 (much of which was oxidized from methane) and became highly "acidified" (less alkaline). This didn't favor marine life. It was good in that it "cleared out the air", but it was bad in its devastating effects on the marine ecosystem. This is an extreme example, and not expected in modern conditions; rather a modified scenario is being suggested.

There are some things to consider that could potentially mitigate this outcome. With a warmer globe, the hydrological cycle should be enhanced. More streams and rivers will be carrying more water to the ocean. In these streams, more of the chemical “needed” to absorb increased quantities of CO_2 will be delivered to the ocean. This delivery could balance out the acidifying effects without sacrificing as many calcium carbonate shells. In addition, with melting ice, more land is available to be weathered. Dust from exposed land is a major contributor to CO_2 drawdown. It carries with it nutrients that allow life forms to proliferate, and therefore to drawdown more CO_2, competing with the limiting effects of CO_2 dissolution.

And, then I offer a point to illustrate how things can take scientists by surprise - the story of volcanoes and CO_2. After some major eruptions in recent years, El Chichon and Mount Pinatubo, there was the expected cooling. Although the short-term effect of explosive volcanic activity is to cool via emission of reflective sulfate particles, the long-term effect should be an increase in CO_2 – a longer-lived component of volcanic emissions. Because of this, it was assumed that measurements would reveal elevated levels of CO_2. Instead, after major eruptions, dramatically lowered levels of CO_2 were found.

Investigation led to the surprise that cloudiness, resulting from diffuse light, leads to enhanced CO_2 drawdown. What was realized was that the sulfate particles that are injected into the stratosphere by explosive eruptions will reflect away enough incoming radiation so that incoming light is rendered more diffuse, dimmer. The surprise was the response of plants to that diffuse light; the efficiency of their utilization of CO_2 was enhanced significantly, augmenting the drawdown of CO_2.

So, the point to be taken away is that Earth systems interact in dynamic ways of which we are largely ignorant. Much lies beyond our current understanding and beyond our ability to fathom. This is not to say that we should abandon reason and live carelessly. We should not. But Earth systems have always worked to restore balance and Earth has been assaulted by perturbations more extreme than our imaginations can conjure. Live moderately, but see the bigger picture!

As you can see, the story of global warming is not a simple one. That is probably why it is more popular to believe that global warming is the culprit for all things undesirable. It takes a lot of energy and mental stamina to reason through each purported connection.

<u>Scientific “no-no”s and other “not-so-wise” actions….And a bit of an opinion, from me!</u>

“No-no”s include:

- To infer a long-term trend from a short-term observation.
- To allow emotion to influence policy decisions, as this almost assures the law of unintended consequences will follow.

We’ve all been there. The guy on the median is standing there in his shabby dress and deflated posture, promoting his promise that all he needs are a few coins for food or bus fare. The sight tugs at our emotions. We hand him a dollar, telling ourselves the dollar will get him the food, or the transportation. That action allows us to believe we have been a small part of the solution. If the guilt penetrates more deeply, one might give the dollar and go a step further by assigning blame and responsibility for this poor soul's plight to intangible entities, such as the government, society in general, or to capitalist greed. By pointing the finger at them, one's contribution to the greater good feels substantial.

The delusion that you have "done something" obscures the reality that the guy likely went to buy things that won't contribute to his overall well-being. Your "doing something" might have actually resulted in a greater detriment than a greater good. But, you feel better. You did your part.

So it is with the desire to prevent this impending global doom that you know is happening because you are told it day in and day out. Media professionals, scientists, politicians, they are all saying it. It must be true; the news shows hourly the "wicked weather". It is everywhere, all the time. We don't remember such horrifying scenes of flooding and tornado damage when we were young, back before we needed enough news to fill broadcasts 24 hours a day, when every twenty minutes a "news alert" was announced with fear-laced emotion, before hoards of memory-deprived, reality-denying individuals built bulging subdivisions in long-time stomping grounds of clashing air masses, not-always quiet streams, and typhoon incubators. It must not have happened then, or at least it must have gotten worse since. So we must act because this feeling of guilt is overwhelming.

This scenario embodies the two no-no's above: We have concluded doom based on a short-term, poorly understood observation, and we are allowing emotion to influence policy decisions, dulling our reasoning powers, ensuring that it will backfire, ensuring that we remain blind to effective solutions.

I offer an example of emotion blinding reasoning ability. When the discussion of Kyoto was brought up in a classroom situation recently, I noted that Kyoto would result in essentially no temperature reduction. I pointed out that most countries in Western and Eastern Europe and Russia that have signed on (in the hopes of economic gain, not environmental good) are not doing well at meeting their goals, and if they are succeeding, it is by selling credits, not reducing emissions, the latter being acknowledged as a potential and likely threat to their economic stability. These points cannot be contested and no one attempted to do so. But, there was a response. It was not from a student, but rather from a frequent visitor – a young NCAR scientist. With anger in her eyes, clear disdain for my observation, and a measured, stifled response, she asserted, "Well, at least THEY are doing *something*…" Yes, they are handing a dollar to the guy on the median.

China's role in carbon trading can provide an example: **the law of unintended consequences**.

China is second only to the U.S. in emissions of CO2. China is classified as a developing nation. It, therefore, is excluded from the Kyoto mandate. But, countries that are held to the Kyoto mandate can work with China to offset their carbon footprint. In brief, an industrialized "developed" nation that is part of the Kyoto accord is required to cap emissions. The goal is to reach at least 5% below 1990 emissions. Cutting emissions is not the only strategy to achieve this goal. If a country is emitting more than its target, it can buy carbon credits from a country that either has exceeded its goal or a country that is not bound by the accord. This is where China comes in.

China is not yet restricted in its emissions of carbon or in its manufacture of a refrigerant, HCFC-22. A by-product of the manufacture of HCFC-22 is a gas which, just like its banned cousin – CFCs, not only destroys stratospheric ozone but is also a potent greenhouse gas. This gas, HFC-23, is thousands of times more potent that CO_2.

Western nations that are Kyoto-bound can purchase carbon credits that involve this gas. The cost is about eight dollars a CO_2-equivalent ton. The money goes to the companies that make the refrigerant. They are then to destroy the gas. This deal is a bargain for the Western nations, a gold mine for the Chinese. The actual cost of destroying the gas is only a dollar per CO_2-equivalent ton. Thus, we have a win-win situation. What could be better! Despite recent revisions - the Chinese government is constantly revising the system, imposing rules, minimum carbon-credit prices, and taxes - both sides appear to be benefiting at the moment. These revisions could lead to a slowdown of the very investment the program was intended to promote.

Income in China is soaring. Demand for the unrestricted refrigerant is soaring in tandem. If this weren't bad enough, many fear/think that some Chinese companies are actually manufacturing more HCFC-22 than is needed in order to profit from its destruction. Furthermore, many point to the trade as a diversion of investment funds away from supporting projects that could generate more clean energy – wind turbines, natural gas plants for example.

I'll mention one other unintended consequence that comes to mind: the hydrogen-powered car. This technology, not yet perfected, promises to be a source that is both clean and abundant. It simply needs to be made from water – splitting apart the molecules. Of course, that is the glitch; it takes a lot of energy made the conventional way (emitting CO_2) to get those molecules apart, but, putting that step in the process aside, running our vehicles on hydrogen would produce only water. No pollution! This is great. Energy to run the car comes from controlled oxidation of the hydrogen molecules. There is a potential problem. Somewhere along the line of manufacture, transport, and storage, there is bound to be some leakage of hydrogen. The H_2 will easily make its way to stratosphere. Here, where Earth's inventory of "good" ozone is, the H_2 will oxidize to water vapor, a greenhouse gas. In the stratosphere, a greenhouse gas cools. If this happens in the lower stratosphere, where most of the ozone is, this will disturb the ozone chemistry. In addition, by cooling the stratosphere, a type of cloud that leads to further ozone destruction, will increase in abundance. (Tromp et al.)

This is mentioned here only because we are never able to prevent all the negatives from our actions. We can certainly try to do things that benefit the Earth, but even with our best attempts, we may fail. We just need to recognize that with everything, there is a trade-off, whether anticipated or not.

Final words:
It is important to step back and view Earth's climate history from a broad perspective. Earth has spent much of its history bathed in atmospheric carbon dioxide concentrations ten times the present, and endured CO_2 fluctuations from concentrations slightly lower than that of today to sixteen times that of today. The globe has spent most of its time without continental ice sheets, but has experienced mountains of ice come and go in a "blink of an eye" in recent history, geologically speaking. The Sun's energy output has peaked and waned, sometimes according to a discernable pattern, sometimes not. Throughout all of this, Earth's temperature has stayed pretty much within a ten-degree Celsius (18°F) range. Our current temperature does not come close to either the maximum or the minimum that Earth has endured. We would benefit from knowing how Earth's feedback mechanisms have succeeded in maintaining a fairly stable climate scenario that supports life, in varying forms, on this planet. Much, much work lies ahead.

You ask, "Is the temperature rising?" The answer can only be, "Yes". In what context, what time frame, for how long, how much, and to what societal consequence, there is no definitive answer. Ask again in a hundred years.

Many believe that the assumed link between fossil fuel consumption and global warming is clear enough to discourage the continued societal reliance on petrochemicals. It is hoped that, from this text, the reader recognizes that the 'cause and effect' connection is far from absolute. But the uncertainties involving the extent, trend, and cause of global warming should not minimize society's motivation to explore economically viable energy alternatives to fossil fuels. There are many reasons, environmental being only one of them, that would support such an endeavor, but we must toss aside our idealism if we are to effectively work toward making this change. As a society, we have been talking about implementing alternative forms of energy for well over thirty years. Obviously, something has stood in our way.

A free market society, such as ours, is an ideal birthing environment for revolutionary ideas and solutions. Be that as it may, such a society is driven by economics. Research, development, and commercial implementation come at no small cost. Cheap energy prices, strict environmental controls, and development of new energy sources make for an unrealistic combination. Renewable energy sources abound, each with its own set of environmental and economic advantages and disadvantages. Technologies exist in various states of feasibility. Artificially holding energy costs down ensures that the alternate sources will not make it to market. Whatever "the answer" is, I hope it is recognized that "the answer" to the changing nature of climate is riddled with a burden of complexities, just as is the answer of how to keep our modern world energized, clean, and affordable, all at the same time. Bottom line, climate needs not be the reason to revamp our energy priorities, but reasons do abound for us to revamp our energy priorities, nevertheless. An issue for another book!