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STUDIES PROGRAM

CLIMATE CHANGE:

INSIGHTS FROM OCEANOGRAPHY

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PREFACE

The global warming establishment asserts that the science underlying the Kyoto Protocol is "settled," that the "consensus of scientists" has spoken, and that all the rest of us need do is get on with the business of saving the planet.

The Competitive Enterprise Institute respectfully disagrees. "Consensus" is a term of politics rather than of science, and nothing could be less "settled" that climate science, which is still in its infancy. Hypotheses, even elaborate hypotheses like the computer models underpinning the Kyoto Protocol, have no scientific standing until they have survived repeated confrontation with the facts. In science, the only test of truth is experiment, or at the very least, observation – empirical data.

What do real-world observations tell us about the global warming hypothesis? That question might be called the "central organizing principle" of the lecture series the Competitive Enterprise Institute has been running on behalf of the Cooler Heads Coalition.

How fitting, therefore, that Dr. Roger Pocklington of the Bermuda Biological Station for Research, an oceanographer who has monitored North Atlantic climate conditions for over a quarter century, delivered the first Cooler Heads science lecture on climate change on May 22, 1998. Herewith a few highlights from Dr. Pocklington's lecture:

- Analysis of surface-air and sea-surface temperatures in and around the northern Atlantic Ocean shows that the region has been cooling, not warming, during the past 50 years.

- Such warming as has occurred since the 19^{th} century is not outside the natural range of climate variation.

- Dr. Wallace Broecker's disaster scenario is interesting but highly speculative. Broecker projects that global warming would increase rainfall and river discharge into the North Atlantic. That would lower surface water density (fresh water is less dense than salt water). The lower density surface water would not sink, and so would not "pull" warm surface water from the Equator up towards Europe. The paradoxical result: global warming would plunge Europe into another Ice Age! Dr. Pocklington points out, however, that Broecker assumes a 50 percent increase in precipitation and increasing wetness in Central Asia and North America (where river flow into the North Atlantic originates). Yet the Intergovernmental Panel on Climate Change (IPCC) projects only a 5-10 percent increase in North Atlantic precipitation and predicts that Central Asia and North America will become more arid. Broecker presents as almost likely something that has very little probability of happening.

—*Marlo Lewis*
Vice President for Policy and Coalitions

CLIMATE CHANGE:

Insights from Oceanography

Dr. Roger Pocklington

I hope this doesn't sound too pretentious, but I was born into a world where people, with whom I presonally had no quarrel, were trying to kill me by dropping bombs on my head. The intervention of your nation in what was for you a foreign war turned the tide, and that's probably why this talk is in English and not in German.

I grew up in a world of a certain amount of deprivation. If you remember from George Orwell's *1984* the rather miserable circumstances of life he described, they were pretty well based on our experiences in the UK after World War II. General George Marshall, who I hope will be remembered again at this anniversary of the Berlin Airlift, was instrumental in getting your nation to send considerable wealth across the Atlantic. That turned the tide there, economically and socially, which is probably the reason I'm giving this talk today in English and not in Russian.

If all that sounds a little too high-minded, it was from the heart and to perhaps lighten the tone, I should say that I'm here today from St. George's, Bermuda. St. George's is the original capital of Bermuda and it shares an intimate connection with this city, your capital. For it was from St. George's in 1814 that a fleet sailed over and burnt down the original Capitol and other public buildings in Washington. But at least you got the stirring words of "The Star Spangled Banner" out of that one.

On any day of the year, at some weather station on earth, the extreme value of something is being exceeded.

More recently, Bermuda was the site of the US Naval air station on St. David's island, from 1949 to 1991, that gave us our weather records for that time-interval. And, by the way, before we go further, I know no one in this room is naïve enough to confuse weather and climate, but they do get confused by the general public - sometimes every extreme weather event is attributed to "greenhouse warming" (GW). They are obviously unaware of Pocklington's Postulate, which states that: "On any day of the year, at some weather station on earth, the extreme value of something is being exceeded." So those are weather events. We are going to talk about climate. Climate is long-term average weather. By international agreement, a 30-year averaging period is used for climate, anything less is weather (US Department of Commerce 1992). Mark Twain, who was a great fan of Bermuda (though he didn't particularly like taking the ship to get there, agreeing with Dr. Samuel

Johnson that being at sea was like being in jail with the additional possibility of getting drowned), gave what I think is the best common-sense definition of the difference between climate and weather. He said: "You buy your clothing for the climate; you wear your clothing for the weather."

It's obviously impossible that one individual could cover the whole topic of oceanography and global climate. My approach to things is practical not theoretical. Unless I qualify it otherwise, I'm telling you about work that I have done, about which I have personal experience. This is perhaps an antidote to hearing from people who tell you authoritatively all kinds of things of which they have no personal experience.

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WHY THE OCEAN IS IMPORTANT

The ocean is important in this whole debate because of its vastness. The top few meters of the ocean have a heat capacity equivalent to that of the whole atmosphere. Due to this huge heat capacity, the ocean provides a buffer for the atmospheric system, smoothing out its continental excesses (something to which anyone living by the sea can attest). In Bermuda last fall, we must have gone about a month and a half when we thought the outdoor thermometer was stuck. It registered 23 degrees Celsius (C) day and night, exemplifying the moderating effect of an oceanic climate. This was very different from where I just visited — Arizona — where there are large differences between daytime and nighttime temperatures.

The ocean transports as much heat, we believe, from equatorial to temperate and polar regions as does the atmosphere. When it releases this heat from, for example, the ocean west of the British Isles where there is a continuous outward flux of heat equivalent to about 50 watts per square meter, it substantially warms the adjacent land (Stommel 1987: 72). To put that number in some kind of perspective, an increased surface flux of about two watts per square meter is calculated to be the result of the increase in atmospheric carbon dioxide (CO_2) since the beginning of the Industrial Revolution (ca. 1750), and that's what this GW debate is all about.

The ocean contains about 50 times as much CO_2 as the atmosphere and the flux of CO_2 from the ocean surface is about 20 times greater than the amount released by the burning of fossil fuels. So the ocean is great in its capacity to produce and absorb CO_2 and in its capacity to move heat around the planet. The vastness of the ocean has been very useful to climate modelers, because it has given them a place in which they can hide things. For instance, an imbalance in the heat budget (e.g. an increase in mean surface temperature only half of that calculated), or in carbon budgets (e.g. two gigatonnes of carbon a year missing from the atmosphere) can be attributed to the ocean and nobody will notice any difference. To quote the wise words of Walter Munk (1993): "The ocean plays three roles in this game: it serves as a reservoir of

TABLE 1

ATMOSPHERIC CO_2 BUDGET (AS OF MID - 1998)

	Gt C / year
CO_2 sources	
Fossil fuel combustion + cement manufacture	5.5 +/- 0.1
Tropical deforestation + land use	1.8 +/- 0.2
Total sources	7.3 +/- 0.3
CO_2 sinks	
Atmospheric accumulation	3.2 +/- 0.1
Ocean uptake (calculated from models)	2.0
Northern hemisphere forest regrowth	0.6 +/- 0.1
"Missing CO_2"	1.5 +/- 0.1
Total sinks	7.3 +/- 0.3

To put these figures in perspective: the atmosphere contains 750 GtC; the surface ocean contains 1,000 GtC; vegetation, soils, and detritus contain 2,200 GtC; intermediate and deep ocean waters contain 38,000 GtC.

Annually, the surface ocean and the atmosphere exchange an estimated 90 GtC; vegetation and the atmosphere, 60 GtC; marine biota and the surface ocean, 50 GtC; and the surface ocean and intermediate and deep waters, 100 GtC.

In light of the magnitude these reservoirs and the annual exchange rates between them (plus the uncertainties in these estimates), any definitive statements about the origin of the recent increase in partial pressure of carbon dioxide in the atmosphere should be viewed with caution.

carbon; it serves as a reservoir of heat; and, most of all, it serves as a reservoir for ignorance".

I shall attempt to dispel some of this ignorance by looking at physical evidence from the region that I know best — the northern Atlantic Ocean and adjacent land — which is a region of particular importance to the global climate system as it contains one of the few sites in the world where the deep water of the ocean is formed (see later). It is undoubtedly the most extensively and intensively sampled of all the oceans.

Figure 1 shows the coverage we have of surface ocean observations over the years broken down into three time periods. Before 1900, only the western approaches to Europe, across the North and South Atlantic Oceans, had more than 15 weather reports per month. These came mainly from "ships of opportunity," i.e. ships that are primarily going for another purpose (usually commerce) but give us some measurements we can use. They are so much more abundant than actual oceanographic vessels. Through the 1920s and '30s, after the Panama Canal had opened, there's somewhat better coverage of the western Atlantic, plus better coverage off east Asia, but still vast areas of the globe for which there is essentially no coverage. Even as we come to the most recent decades, you will see that the North Atlantic is still the best-covered ocean, though the North Pacific is greatly improved, but there are still large areas that are not sampled on a regular basis.

The ocean is important because of its vastness. The top few meters have a heat capacity equivalent to the whole atmosphere.

So, for the North Atlantic we can make a case that it's important and is the most intensively sampled ocean. Working Group I of the International Panel on Climate Change (IPCC) in the Summary for Policymakers of their Second Assessment Report stated that: ". . . analyses of meteorological and other data over large areas and over periods of decades or more have provided evidence for some important systematic changes" (IPCC I 1996: 4). For more than two decades, my colleagues and I have looked for important systematic changes in the North Atlantic region (Pocklington 1972; Pocklington 1980; Morgan & Pocklington 1995). We have found them, but they may not be what the IPCC was anticipating.

DATA SOURCES AND METHODS OF ANALYSIS

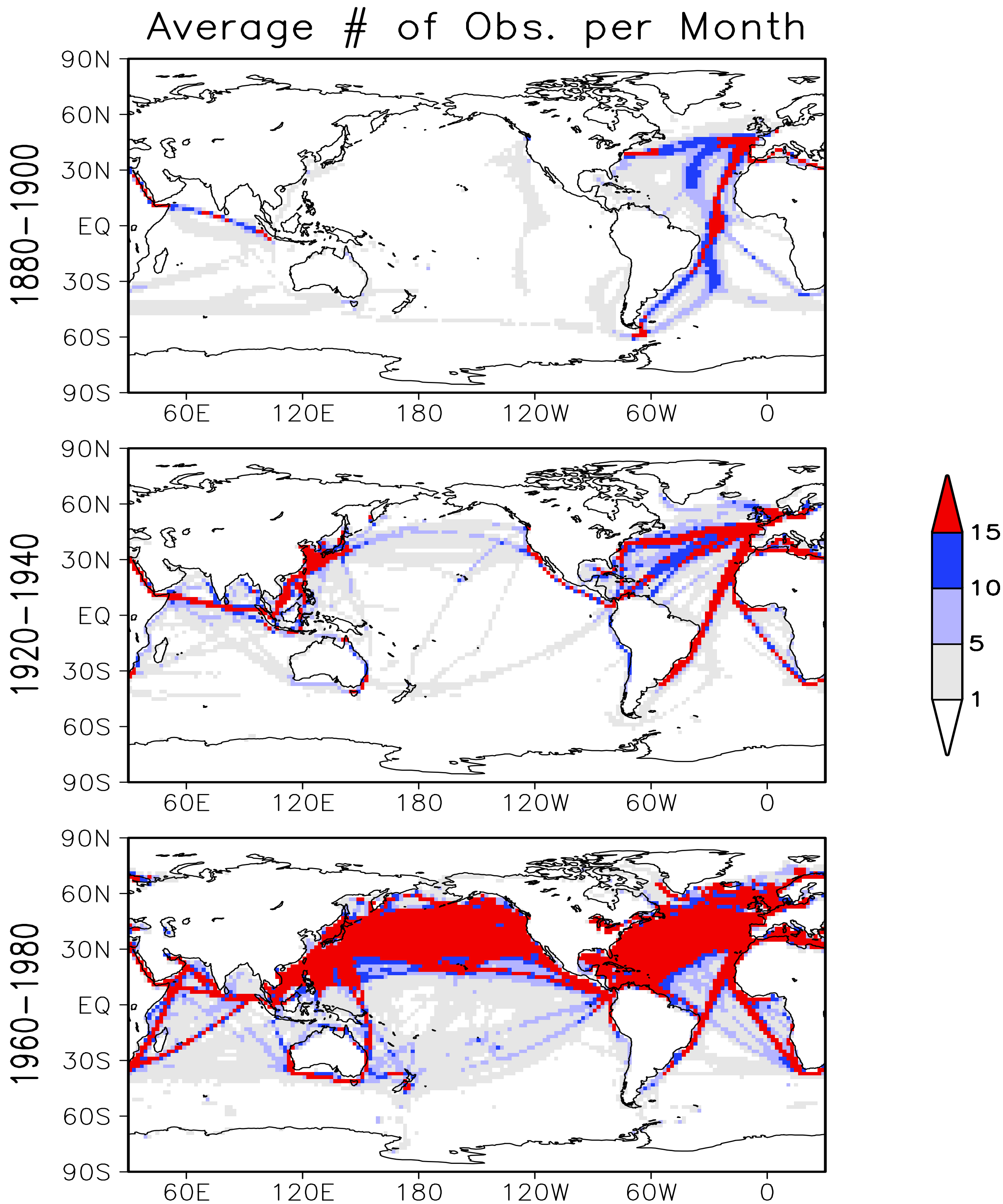
I emphasize that the data for land stations that I present are the same as those used to produce the global and hemispheric anomaly time-series featured in IPCC Climate Change reports (Jones et al. 1994). We updated our meteorological records to the end of 1997 by using *Monthly Climatic Data for the World*, the official publication of the World Meteorological Organization. Marine data are our own, or as noted in the references. We calculated annual means as simple averages of the 12 monthly means; we calculated annual anomalies as departures from the long-term mean at each station. Pentads (five-year periods) are used rather than decades for comparison, because this enables us to include the first pentad (1991-95) of the current (unfinished) decade. (In climatology, the year 2000 will be the last year of the decade of the 1990s that began on the first of January 1991.)

"The Ocean plays three roles in this game: it serves as a reservoir of carbon; it serves as a reservoir of heat; and most of all, it serves as reservoir for ignorance."

Here we are in Washington, DC, the nation's capital. I know that you know you're at the center of your nation, perhaps the center of world, maybe the center of the universe. I know this because I have good friends who work in Ottawa, our nation's capital. They see themselves as the center of everything. Now looking at the real center of things — here is Bermuda, 570 miles off the North Carolina coast and 867 miles due south of the place I was working until recently — Halifax, NS, on the east coast of Canada.

FIGURE 1

GEOGRAPHICAL DISTRIBUTION OF WEATHER REPORTS OVER THE WORLD OCEAN



Colored areas show the average number of weather reports per month in each 2 deg. latitude by 2 deg. longitude square for the time periods indicated. White areas have no reports.

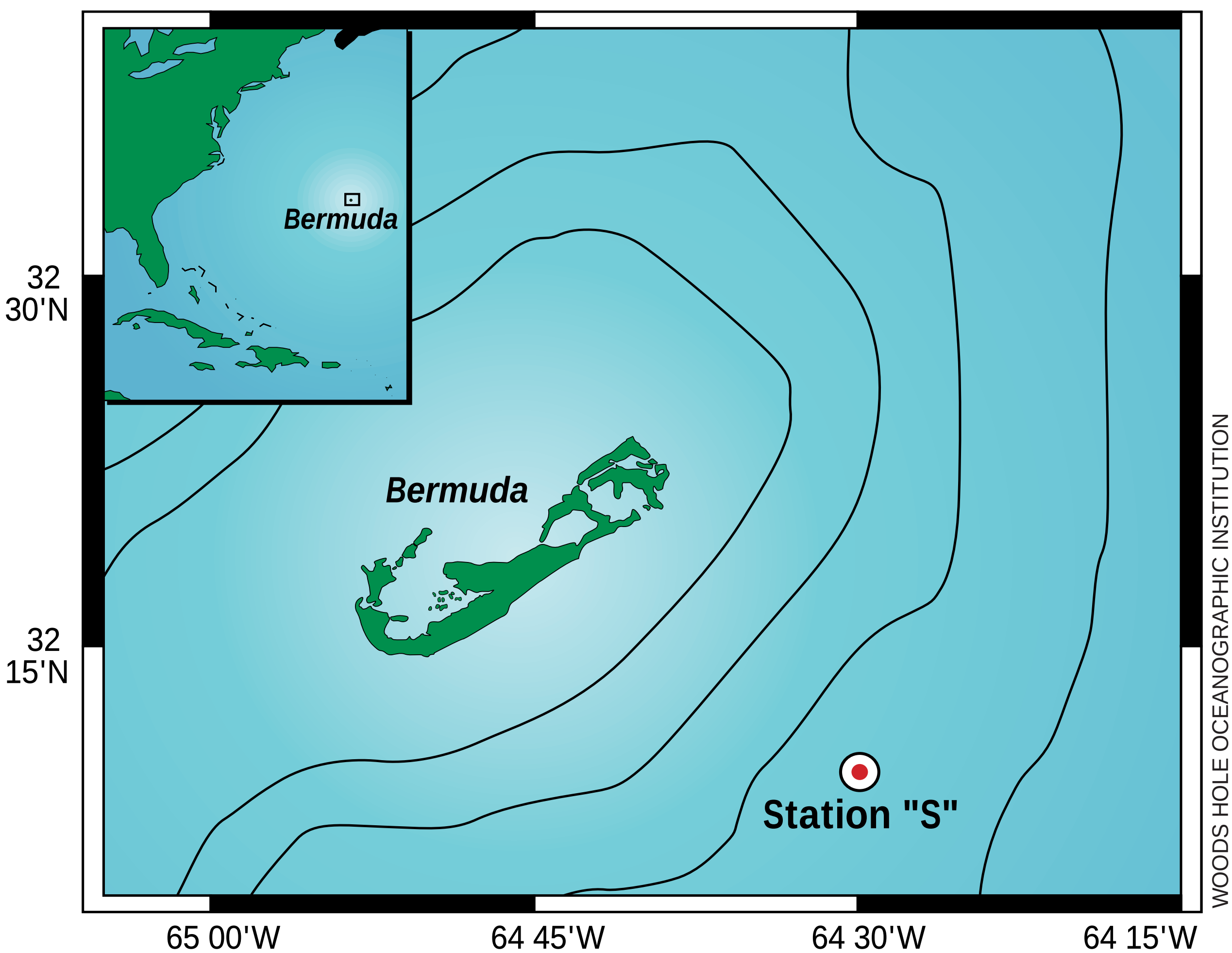
(Reprinted with permission from Dr. Clara Deser, National Center for Atmospheric Research.)

The northern Atlantic Ocean is undoubtedly the most extensively and intensively sample of all the oceans.

REGIONAL MARINE CLIMATES
BERMUDA

The Bermuda Biological Station for Research (BBSR; where I worked from 1969-71 and to which I recently returned) is responsible for physical and chemical measurements at the famous "Panulirus" station or station "S," which lies southeast of Bermuda at 32 10 N, 64 30 W in 3,200 meters of water close to the center of the subtropical North Atlantic gyre closed circulating current system. While serial observations on land extending back a century or more are not uncommon (as we shall see), no such record exists for any location in the ocean. Station "S", which has been occupied regularly (on average, twice a month) by the staff of BBSR since the observations were initiated by Henry Stommel of Woods Hole/MIT in 1954, is the longest continuous series that we have in the deep sea. The sampling frequency is dense enough to show real periodic phenomena such as variability of

FIGURE 2



Location of hydrographic station S, southeast of Bermuda. The smoothed bathymetry is plotted at one kilometer depth increments. (Reprinted with permission from *Oceanus* 39, 2: 15.)

temperature at sub-surface depths (Schroeder and Stommel 1969) and temporal trends there are indicative of change over much of the western North Atlantic Ocean.

Station "S" is the longest continuous series that we have in the deep see.

In 1972, after eliminating the annual seasonal cycle from the record, I detected a cooling trend in the sub-surface waters (to 1,000m) that had persisted for over a decade and a half (Pocklington 1972). At that time, the mean surface-air temperature of the whole Northern Hemisphere was known to have declined since the 1940s and informed opinion was that a return of the Ice Age was imminent (Mathews 1976), which implied that further declines in water temperature at Bermuda could be expected. But by 1975, the cooling trend in sub-surface waters had been reversed, and for the past two decades the waters off Bermuda have become steadily warmer, though at many depths they still remain cooler than they were at the start of the time-series (Michaels & Knap 1996).

If the observations at this station "S" had begun in the mid-1970s, the warming trend would have been hailed as a clear sign of GW. But since the series began in 1954, we can see that the true picture is of cooling in the first part of the record with warming thereafter to values not yet equivalent to the initial ones. From this we should learn the salutary lesson that the inferences that can be drawn from any time-series are highly dependent upon the length of series presented for study. So, be very careful when presented with a time-series. We'll be looking at a few of them. Always ask: "What happened before the year you chose to show me as the beginning?" A common sense analogy I like to draw is with the people who are trying to sell you mutual funds. They always begin that magnificent graph reaching to the stars the day after the market suffered its most recent serious setback. Where you choose to start makes a big difference to the conclusion you draw about any time-series.

Let's move north from Bermuda to the Atlantic coast of Canada.

Sable Island, located at the edge of the Nova Scotian continental shelf, is an excellent example of an isolated station that, because it has always been uninhabited except for weather station personnel, is unaffected by urbanization. The heating effect caused by urban growth is the most serious source of systematic error in land temperature time-series (IPCC 1990: 209). It is one of the global sites used to monitor changes in the CO_2 content of the atmosphere. The record of surface-air temperature since the 1890s shows an initial cooling to a low in the mid-1920s, then a rapid warming to the early-'50s, followed by a sharp cooling to the mid-'60s, since when there has been a slight recovery, but you have a hard time seeing any overall trend either up or down. The most obvious feature of Figure 3 is the warming to the middle of the record and its subsequent decline. The increase and decline was substantial - almost 2 degrees C. The station is cooler now (mid-1990s) than it was 100 years ago (late-1890s) at the beginning of the instrumental record.

When presented with a time-series always ask: "What happened before the year you chose to show me as the beginning?"

The station is cooler now (mid-1990s) than it was 100 years ago (late-1890s) at the beginning of the instrumental record.

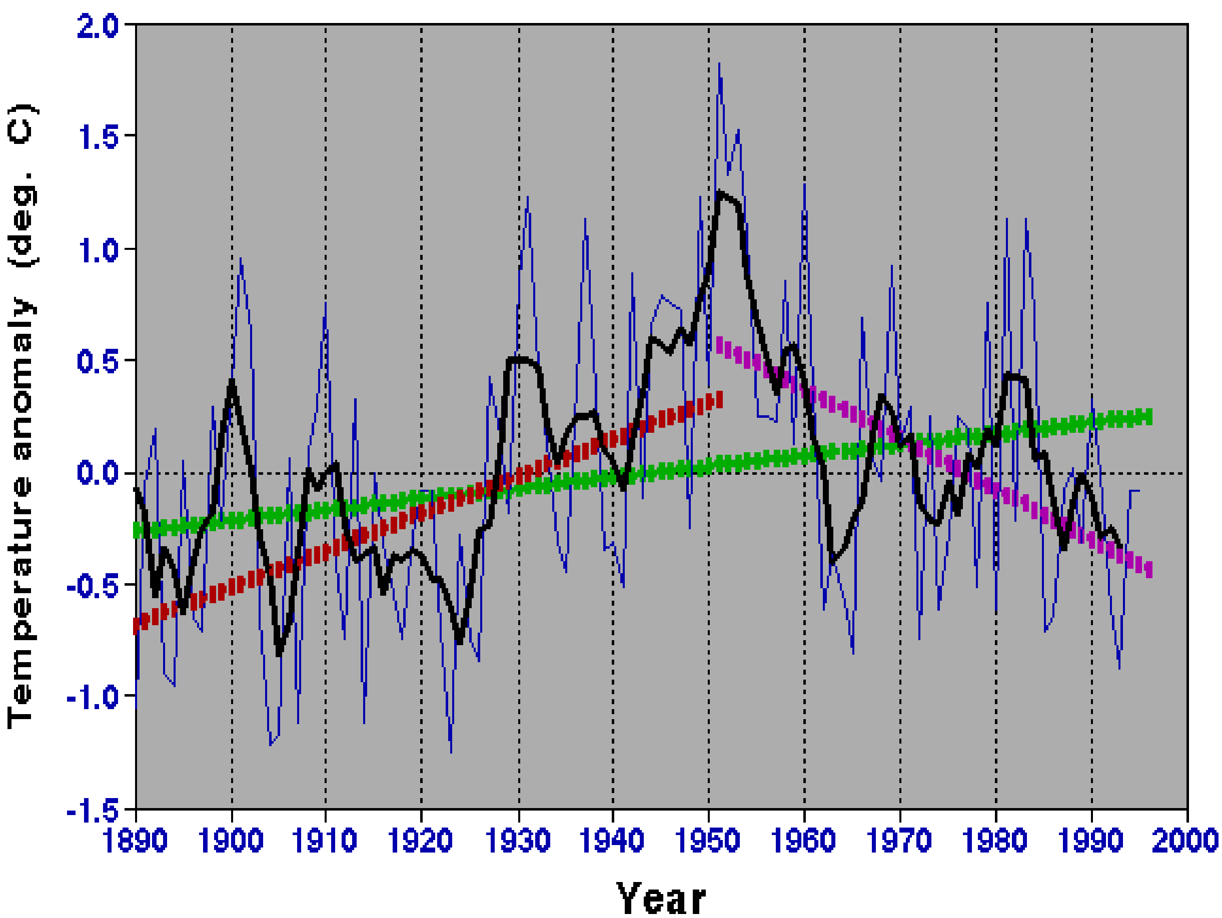
Combining the record from Sable Island with the two other long-term coastal stations in Maritime Canada (Charlottetown, Prince Edward Island and Sydney, Nova Scotia) gives a Maritime Composite record.

Looking at different sections of Figure 4, you can see a trend upwards (1890-1950) and a trend downwards (1950-1995) but overall there is no trend. This is best expressed in the other official language of Canada as: "Plus ca change, plus c'est pareil "- the more it changes, the more it stays the same. Temperatures at the sea surface south and east of Newfoundland since 1900 also show a similar pattern of warming into the '40s and 50s, followed by a decline to date (Deser 1996).

Even though the land-station data-base for the coast of Labrador and Baffin Island is patchy prior to 1940, the sequence of warming to a peak in the

FIGURE 3

MARITIMES COMPOSITE
SABLE ISLAND, SYDNEY, CHARLOTTETOWN



Surface-air temperature record for Sable Island, Nova Scotia, Canada.

Sequence of annual mean anomalies (deg.C) is lighter, dashed line; five-year running mean trend is shown by the heavier, solid line.

’50s followed by cooling to date is followed there also, in the waters of the Labrador Basin, where Labrador Sea Water has its source. (Labrador Sea Water is a subpolar water mass that is a major contributor to the deep water of the Atlantic.) The pattern is similar, but the decline comes later (1970) than it does for air temperatures, reaching its coldest in 1993 (Curry and McCartney 1996). These temperature declines have had economic consequences for the fishery. During the last 10 years of extremely cold temperatures in the region, recruitment from Labrador to the Grand Bank has been poor (Drinkwater 1996); the sea temperature declines since the mid-1980s are responsible for approximately half of the recent observed decrease in “size-at-age” of Atlantic cod on the Nova Scotian shelf and off Newfoundland. Temperature-dependent effects are not restricted to natural stocks: decreasing minimum temperatures in winter have caused mass mortalities in captive stocks of salmon in facilities in southern New Brunswick (Bay of Fundy), and currently restrict the expansion of aquaculture in Newfoundland.

Decreasing minimum temperatures in winter have caused mass mortalities in fish stocks.

I mention this because if you read some of the popular literature on the subject of GW, you would imagine that our fishery was on the verge of recovery because of all kinds of tropical species swimming up into our waters, which is simply not true. The problem we’re facing is a problem of continuing cold, not of expanding warmth.

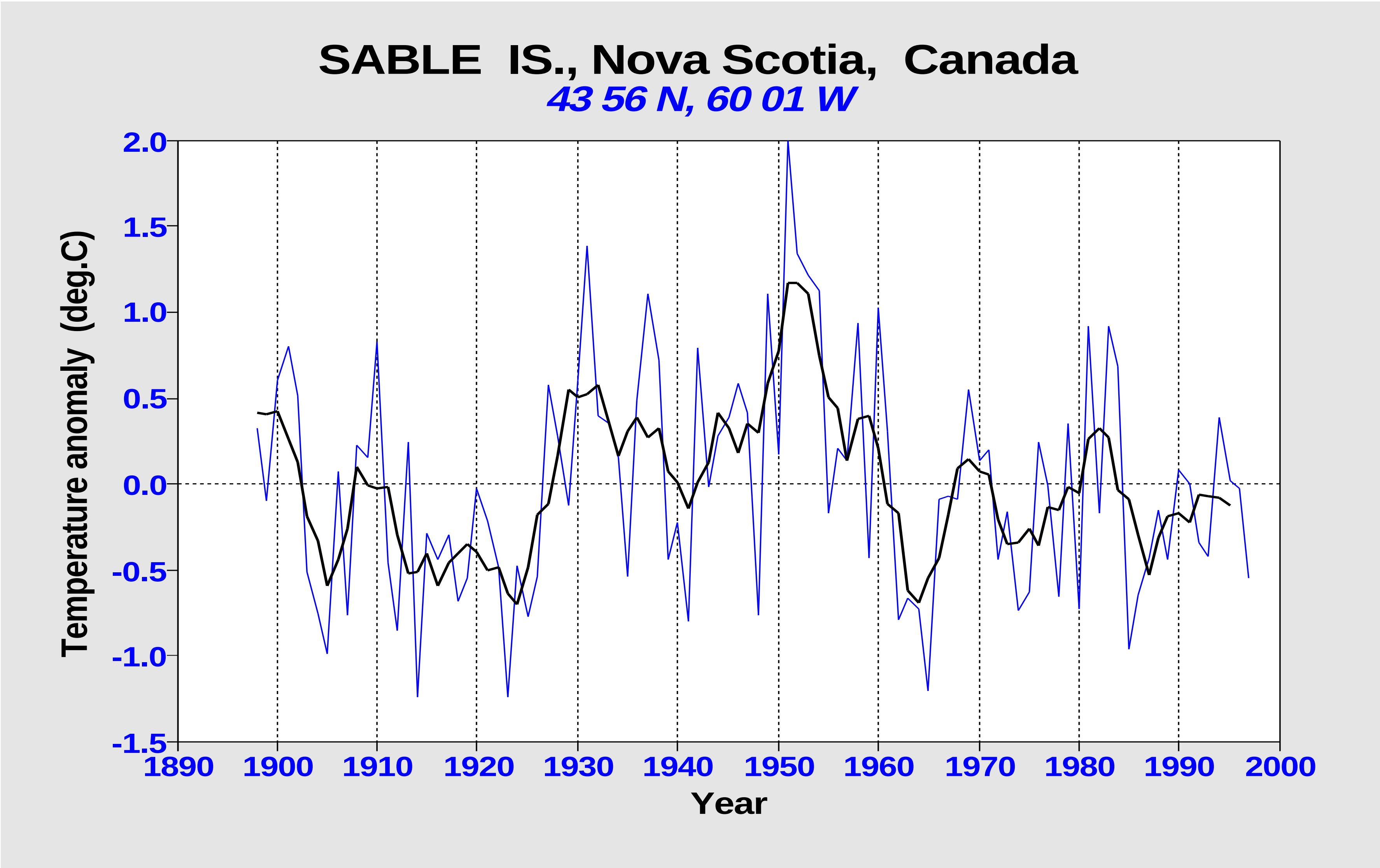
Moving across Baffin Bay to the west coast of Greenland, here is a record that has a similar pattern of warming through the first decades of this century culminating, during the late 1920s, in the warmest pentad of the record. Since that time, it has cooled to the lowest values on record. Figure 5 charts the rise and decline of the world’s greatest cod fishery. There was essentially no cod fishery around west Greenland in the early years of this century. It increased to a maximum in the 1930s and ’40s, then steadily decreased until the late ’60s; cod fishing is now banned off west Greenland. The disappearance of the fishery was aided and abetted by overfishing, but the climatic effect was paramount. The IPCC in their first report (IPCC 1990: Fig. 9.5, p.271) also recognized that Greenland has been cooling since the 1930s.

The problem we’re facing is a problem of continuing cold, not of expanding warmth.

GLOBAL WARMING AND OCEAN TEMPERATURE RECORDS

Until 1989, my colleagues and I, in investigating the marine climate, had been studying regional variations in temperature and their effects upon fisheries. We had not thought to look at our results in light of GW but we began to wonder why — if the world in general and northern high latitudes in particular were supposed to be warming — our time-series of temperatures from the western North Atlantic showed nothing but cooling. We decided to look further afield, all around the northern Atlantic Ocean and off the western coasts of Europe. I could show you the graphs of all the individual stations until you’d fallen asleep or left the room, but our results are conveniently summarized in Table 1, in which the stations are listed from west (Sable Is.,

FIGURE 4



Composite surface-air temperature record for Maritime Canada
Sequence of annual means is the lighter, dashed line; of five-year running means is the heavier, solid line.

Canada) to east (Murmansk, Russia), and north (Svalbard, Norway) to south (Kindley Field, Bermuda). The length of record with the warmest and coldest pentad, is given for each location.

These stations all follow the same general pattern of warming from cold years at the start of this century to a later maximum, with subsequent cooling. It is noteworthy that the coldest pentad at all stations with a record from 1885 or before (i.e. longer than 110 years) falls in the nineteenth century (except for the Azores). This is also true of all long-term stations in northwest Europe (Balling 1995; Pocklington and Morgan 1996), which is why any time-series beginning in the period from mid-nineteenth to late nineteenth century and continuing to the present day — as the global and hemispheric time-series of the IPCC do — cannot fail to show an overall warming. (This implies no particular reason for the warming. It simply shows, as we said before, that if you start low and end high, you cannot fail to get an upward trend.) Note that the three stations in Table 1 with their warmest pentad in the last three decades all had their locations moved to airfields. Airfields are heat islands. Their paved runways and the burning of aviation fuel keep adjacent air warmer than ambient. As meteorological observation stations have been moved to airfields, their local temperature trend is upward and is often divergent from that of nearby rural stations. Sea-surface temperature records from the vicinity of Rockall (55N to 60N, 10W to 15W; since 1920) show an increase to a peak in the late 1950s, followed by cooling to the present.

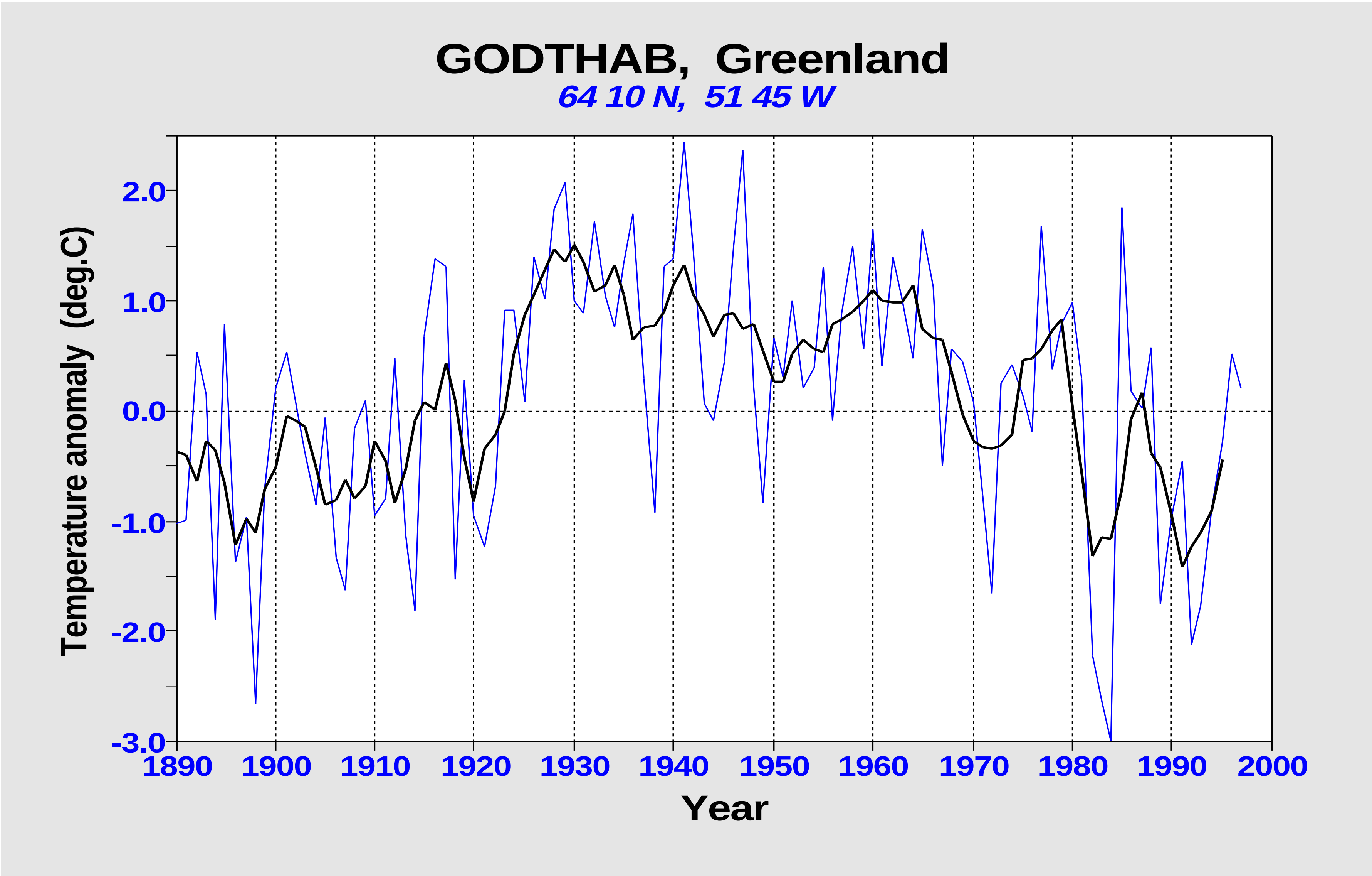
If the northen high latitudes are supposed to be warming, why do our time-series of temperatures show nothing but cooling?

The conclusion is inescapable: surface temperatures in the northern Atlantic Ocean are currently close to, or below, their long-term means and below the values reached in the warmest years of this century (or earlier). In every case, the warmest pentad came before the 1990s. The current pentad is so far most uninteresting: there is no evidence that the region has warmed dramatically during the ’90s, supposedly containing the warmest years in History.

So how have these results from the northern Atlantic been received by our more theoretical colleagues? To understand this, you must realize that an earlier generation of General Circulation Models (GCMs, three-dimensional mathematical models of the climate system; IPCC 1990: Fig. 5.4, p. 165 et seq.) calculated a warming of eight degrees C or more during northern winter in, for example, the Atlantic northeast of Iceland, for a doubling of CO_2 concentration in the atmosphere. We are half way to an effective doubling now (i.e. when the concentrations of all “greenhouse gases” are added) and this shows no sign of happening; the region was one to two degrees below the long-term mean as recently as last year.

Our results went through the same process as any novel idea: “. . . we first doubt its veracity (1), then we assert its familiarity (2), and we end by rejecting its importance (3).” (Fernandez-Armesto 1995: 736). 1) “This can’t be right; you’ve just selected those stations that make your point.” **Answer:** “These

Figure 5



Surface-air temperature record from Godthab, west Greenland.
Sequence of annual means is the lighter, dashed line; of five-year running means is the heavier, solid line.

are all the long-term stations in the region — the same ones that you use in constructing your global and hemispheric averages.” 2) & 3) “Well, everybody knows this, and besides, it’s only one-twelfth of the Earth’s surface.” **Answer:** “But the best-sampled one-twelfth; wouldn’t you feel better if the evidence in favor of GWcame from the best, and not from the worst, sampled portions of the globe?”

Note that the three stations in Table 1 with their warmest pentad in the last three decades all had their locations moved to airfields. Airfields are heat islands.

But the modelers went one step further. Four years ago at an international conference in Halifax (Pocklington et al. 1994), I had the dubious pleasure of being told that the models now predict the cooling in the northern Atlantic that we had found. I was a bit taken aback by this and said: “Where were you in 1972 ?” I find it difficult myself to accept that someone can predict an event that’s already happened. Perhaps “postdict” would be a better word. Nevertheless, I was pleased that the reality we had found had worked its way into a model - the information given by the real world must be used to update the models. However, if the current cooling in the northern Atlantic is now predicted in the models, two questions occur:

1) “Had we found warming in the northern Atlantic, would this be taken as evidence against your model ?” **Answer:** “No, eventually it will warm”. So warming in the North Atlantic would be evidence in favor of this hypothesis and cooling in the North Atlantic is taken as evidence in favor of it. This is an hypothesis, but hardly a scientific one as it appears impossible to falsify.

2) “As the observed cooling — which is having a devastating effect upon Canadian fisheries — is now in your model, when is it going to stop ?” **Answer:** “Our models are global; we cannot yet give reliable regional predictions.” So local and regional data can be fed into the models, but apparently you cannot get anything useful on a local or regional scale out.

Here we see, in the latest IPCC (1996) report, that the northern Atlantic is indeed shown as cooling.

So the cooling is accepted as real, and more reassuring than that, we are told that it can also be accommodated by theory. Figure 6 also shows strong cooling in the eastern Mediterranean, which has implications for the North Atlantic because the Mediterranean is an evaporative basin that produces salty water that is returned to the North Atlantic through the Straits of Gibraltar to spread at intermediate depths (of which more later). The North Pacific is also shown as cooling.

Surface temperatures in the northern Atlantic Ocean are currently close to, or below, their long-term means.

However, I should be pleased that attention has focused upon the northern Atlantic. As I mentioned earlier, it contains one of the small number of sites of formation of deep ocean water northeast of Iceland where surface seawater is cooled until, by reason of its increased density, it sinks and forms a narrow, deep south-flowing current hugging the eastern side of Greenland that is called North Atlantic Deep Water (Figure 7).

TABLE 1

North Atlantic stations with long-term records of surface-air temperature

TABLE 1: N. Atlantic stations	*with*	*long-term*	*surface*	*air temperature records*
STATION / Location	*record from*	*Warmest pentad*	*Coldest pentad*	*COMMENTS Hydrographer of the Navy (1993)*
SABLE IS. / Nova Scotia	*1898*	*1950-54*	*1922-26*	*coastal station*
SYDNEY / Nova Scotia	*1895*	*1949-53*	*1922-26*	*moved to airfield*
CHARLOTTETOWN / PEI	*1895*	*1949-53*	*1903-07*	*moved to airfield*
ST. JOHN'S / Newfoundland	*1880*	*1951-55*	*1880-84*	*moved to airfield*
GODTHAB / Greenland	*1866*	*1928-32*	*1882-86*	*coastal station*
ANGMAGSSALIK / Greenland	*1895*	*1926-30*	*1902-06*	*coastal station*
STYKKISHOLMUR / Iceland	*1846*	*1937-41*	*1865-69*	*coastal station; closed in 1980*
REYKJAVIK / Iceland	*1901*	*1938-42*	*1979-81*	*coastal station*
AKUREYRI / Iceland	*1882*	*1938-42*	*1884-88*	*moved to airfield*
SVALBARD / Norway	*1910*	*1979-83*	*1938-42*	*moved to airfield in 1975*
JAN MAYEN / Norway	*1921*	*1930-34*	*1967-71*	*coastal station*
THORSHAVN / Faeroes	*1930*	*1945-49*	*1977-81*	*coastal station*
STORNOWAY / Hebrides	*1931*	*1932-36*	*1977-81*	*coastal station*
LERWICK / Shetland	*1931*	*1932-36*	*1977-81*	*coastal station*
BERGEN / Norway	*1816*	*1988-92*	*1836-40*	*moved to airfield*
TRONDHEIM / Norway	*1761*	*1934-38*	*1835-39*	*coastal station; closed in 1980*
TROMSO / Norway	*1920*	*1989-93*	*1939-43*	*moved to airfield*
BJORNOYA / Norway	*1920*	*1934-38*	*1962-66*	*coastal station*
VARDO / Norway	*1829*	*1934-38*	*1864-68*	*coastal station*
MURMANSK / Russia	*1919*	*1934-38*	*1965-69*	*coastal station*
VALENTIA / Ireland	*1869*	*1945-49*	*1888-92*	*coastal station*
PLYMOUTH / England	*1865*	*1865-69*	*1885-89*	*coastal station*
PONTA DELGADA / Azores	*1865*	*1887-91*	*1972-76*	*moved to airfield*
KINDLEY FIELD/ Bermuda	*1891*	*1952-56*	*1913-17*	*moved to airfield in 1949*

Figure 7 is a generalized picture of circulation in the North Atlantic. At the surface is the North Atlantic Current (red through orange), which includes elements of what further south you know as the Gulf Stream, bringing warm, salty water northeastward. I noted earlier how much heat is released from this current to the atmosphere, warming the coasts of Europe. The Norwegian Current keeps the coast of Norway open all year long (not ice-bound as in comparable latitudes off Labrador). This water goes up into the Greenland Sea and beyond into the Arctic Ocean. Seawater cooled at the surface there (shown by the blue line) comes around Greenland (Cape Farewell) into Baffin Bay, then combined with water from the Canadian Arctic archipelago (green) passes along Labrador coast and east of Newfoundland to the Tail of the Grand Bank. The latter portion follows the track of the iceberg that sank the Titanic (Brown 1983).

Global warming is not a scientific hypothesis, if it is impossible to falsify.

In the Norwegian-Greenland Sea, the red-to-purple transition indicates the formation of North Atlantic Deep Water (NADW) that flows south well below the surface across the Greenland-Iceland Ridge.

Professor Wallace S. Broecker of the Lamont-Doherty Earth Observatory of Columbia University has recently reiterated the idea that one of the possibilities of GW - more freshwater addition to the northern Atlantic - will make the "ocean conveyor belt" (the process by which seawater sinks from the surface of the ocean into the interior, flows between ocean basins, then returns to the surface) stop, and dreadful things will happen in consequence (Broecker 1997). This conjecture has since been popularized, e.g. by Suplee (1998) in which the writer said: "Perhaps the most feared catastrophe [it's all about catastrophes!] is an abrupt collapse in the huge Atlantic 'conveyor belt' system that brings warm water north from the Equator, keeping Europe several degrees warmer than it would otherwise be". As Broecker's conjecture has now entered the popular domain, I have been asked to comment upon it. Details are given in Table 2.

General circulation models fail to spontaneously reproduce the abrupt changes in temperature and rainfall pattern so clearly recorded in the geological record.

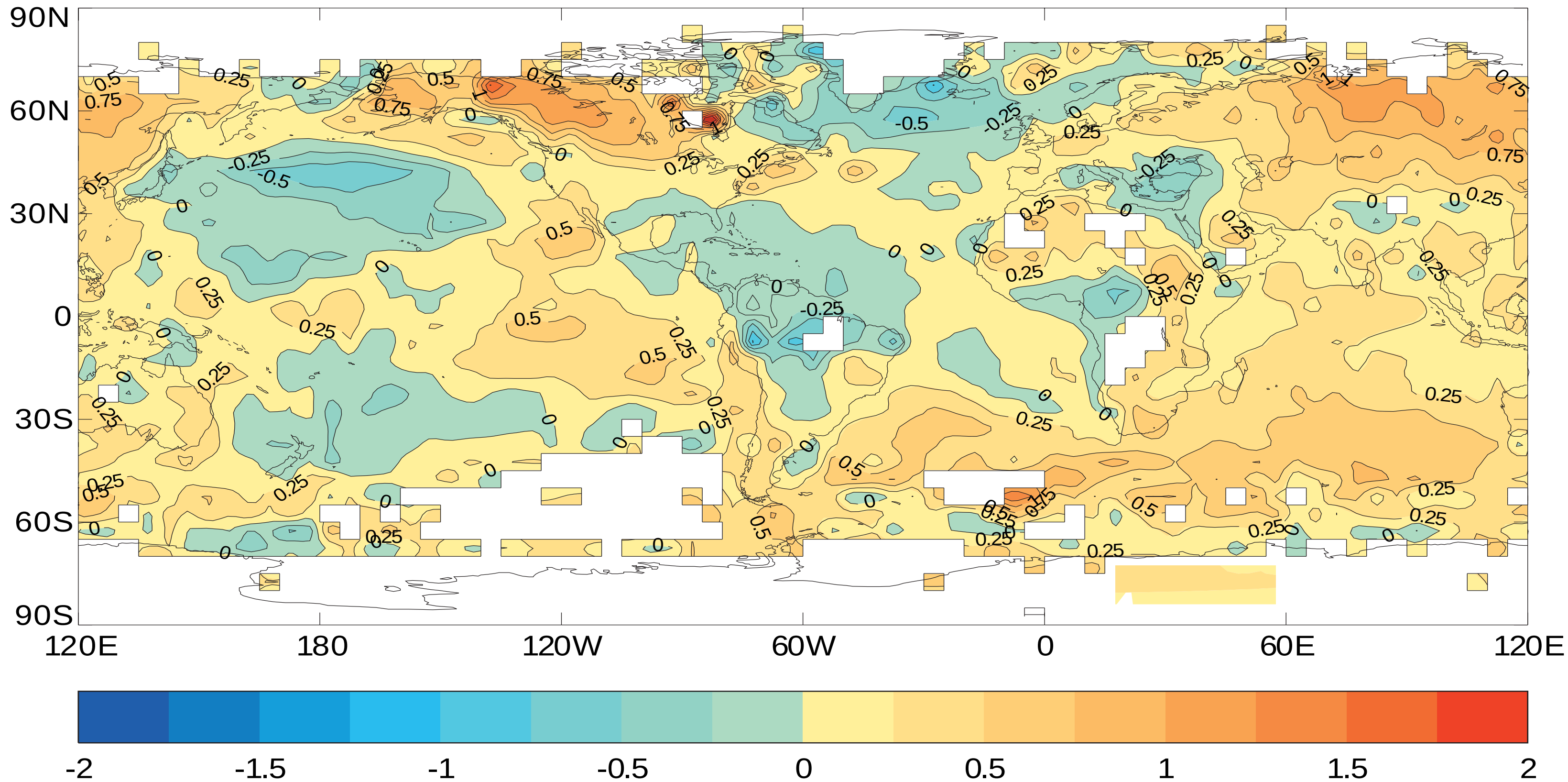
As you see, Broecker's paper actually contains important statements such as:

1) the big warming at the end of the last glacial event occurred before the onset of an increase in methane;
2) 8,000 years ago, temperatures had reached near or above recent levels;
3) Earth's dominant greenhouse gas is water vapor, capable on its own of creating major climate shifts;
4) general circulation models fail to spontaneously reproduce the abrupt changes in temperature and rainfall pattern so clearly recorded in the geological record.

These statements are more deserving of public attention than the disaster scenario that was seized upon in the media.

FIGURE 6

Annual surface temperature change for the period 1975-1994 relative to 1955-1974.



Note: Because maximum warming in all GCMs is concentrated at high latitudes, the use of the Mercator projection in this figure presents a highly distorted view of the globe as it overemphasizes regions of warming in the northern hemisphere N of 60N. The IPCC caption states: "The cooler blue areas show, however, that the warming has not been universal". This should read: "The cooling blue areas show, however, that warming is far from universal." Source: fig. 9, page 27, Technical Summary, IPCC I 1996. (Reprinted with permission.)

The "global conveyor belt" is a model that's been around for quite some time and many people have been associated with the idea (Toole 1996). Broecker (a geo-chemist) has been successful in using isotopes and other chemical tracers to try to understand physical mixing and chemical cycling in the ocean. Bear in mind, however, that this "global conveyor belt" is an oversimplification of the actual oceanic circulation. It must be so, because we really don't know enough about the deep ocean circulation yet to express these ideas as certainties. At least one of my colleagues regards it as a dangerous oversimplification, because it makes it appear that we know things that we do not know. Remember, it was the humorist, Will Rogers, who said: "It isn't the things we don't know that get us into trouble, it's the things we think we know that ain't so."

The natural range of variation in temperature is much greater than we've seen in the short period of instrumental record.

However, we should bear in mind that the geochemical record on the bottom of the ocean does appear to show that a rapid oceanic shift occurred at least once in the past 10,000 years. So Broecker has built upon an event that happened in the past — most likely a cessation or severe reduction in the oceanic circulation system, the evidence for which is in the sediments at the bottom of the ocean — to build an hypothesis about how this might happen again in the future. It is an extrapolation from the partially known to the unknown.

The sedimentary record does indicate climatic changes in the past. For evidence of that, let us return to Bermuda, where in the 1970s, collection of a nearly continuous suite of deep sediment trap samples (these intercept particles sinking through the water column) at the Ocean Flux Program site near Station "S" was begun by Werner Deuser of WHOI. Additionally, deep sea cores of sediment have been taken on the Bermuda Rise to the east of Station "S." These have been combined with the "Panulirus" series to give one of the first reconstructions of sea-surface temperature for recent centuries in the open ocean (Keigwin 1996). From study of the stable isotope composition of the shells of planktonic animals called foraminifera, past changes in the temperature (and salinity) of Sargasso Sea surface waters can be deduced.

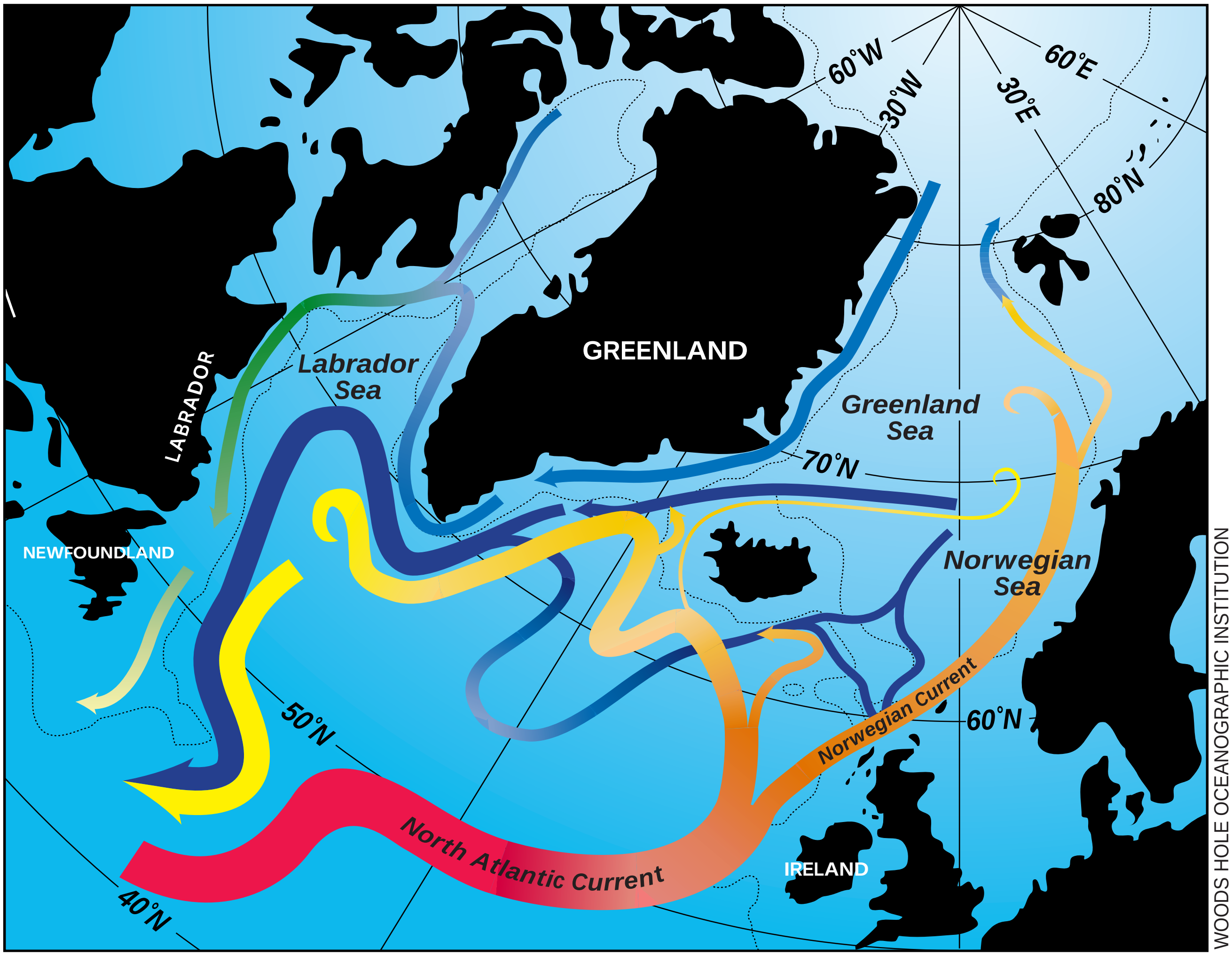
This is the geologists' scale with the past to the right — the inverse of the scale on our time-series plots. The following are clearly evident:

- a range of sea-surface temperature much greater than what has been observed since 1954 at Station "S",
- the Little Ice Age (200 to 400 years ago) when temperatures were cooler than today by one degrees C; and
- the Medieval Warm Period (500 to 1200 years ago) when it was up to 1.5 degrees C warmer than today.

By these ingenious studies of ocean sediments on the Bermuda Rise, we are able to link what has happened at Station "S" in recent years to the past.

FIGURE 7

NORTHERN ATLANTIC CIRCULATION (NORTH ATLANTIC NORTH OF 40 DEG. N)



The red to yellow transition is cooling of warm subtropical water as it moves northeast and northwest. Blue is cold surface water flowing out of the Arctic, and purple is the deeper north Atlantic Deep Water outflow. (Source: *Oceanus* 39, 2: 19. Reprinted with permission.)

Even in subtropical Bermuda we are about a degree cooler at the surface of the ocean today than in the year (982) that the Vikings first sailed to Greenland. (The Vikings stayed in Greenland until around 1400 – throughout the Medieval Warm Period, which is here in this record.) There were also previous periods both cooler and warmer than today. What deserves emphasis is that the little bit of variation we've seen at Station "S" (our only long-term oceanic station) ties in with the palaeo-record to show that the possible range of variation in temperature is much greater than we've seen in the short period of instrumental record.

My own inference about this whole debate is that we are seeing effects within the range of natural variation, however that may be caused. The half-degree of warming since the late nineteenth century to the present is in no way

TABLE 3

THERMOHALINE CIRCULATION, THE RIVER STYX OF OUR CLIMATE SYSTEM
COMMENTS ON WALLACE S. BROECKER SCIENCE 28 NOV 1997

QUOTE	*COMMENTS*
p. 1582 "... projected population of 11 to 16 billion,..."	No reference is given but presumably IPCC's estimate. See critique by Gray (1998) of these high estimates.
Fig 1. The present-day large-scale thermohaline circulation pattern ...	**Fig 1.** Should read: "*Model* of present-day ... " The "global conveyor belt" is an oversimplification of the actual oceanic circulation (Wunsch 1996).
p. 1584 "If the excess of precipitation plus runoff over evaporation were to be increased by 50% ..."	Why should it increase by this huge percentage? Precipitation is predicted to increase on average in middle and high latitudes by only 5-10% (IPCC 1990).
"... model simulations of the ocean's thermohaline circulation are particularly sensitive to freshwater input"	Not all GCMs are. Some ocean models are much less sensitive to freshwater input and give no "halocline catastrophe". (Cubasch *et al.* 1992).
"... locations of fresh water input required to trigger a Conveyor shutdown."	*Location, Location, Location* ! Arctic rivers, essentially those of Russia and Siberia (only one major North American river - the Mackenzie - discharges directly into the Arctic Ocean) draw their waters from the interior of the Asian continent (Pocklington 1987). You cannot simultaneously forecast a drying out the Asian continental interior (*e.g.* Hadley Centre 1998) and yet provide more fresh water input to the ocean.
"Abrupt shifts in the atmosphere's methane content were *synchronous with (my emphasis)* Greenland's abrupt air temperature shifts,"	Here is evidence that changes in the atmospheric content of methane - one of the principal "greenhouse gases" - do not lead, but follow, temperature change.
"about 8000 years ago after temperatures had reached near *or above (my emphasis)* recent levels." Also at end of **p. 1586**	Broecker accepts that temperatures were higher than today's in the past (when there were certainly human societies on this planet; we are not now experiencing the "highest temperatures in History."

THERMOHALINE CIRCULATION, THE RIVER STYX OF OUR CLIMATE SYSTEM

"Such a reduction in the content of Earth's dominant greenhouse gas (that is H_2O) is sufficient to account for the ... cooling of the tropical ocean surface during glacial times."

This is what has always been known to scientists, but is not made clear to the lay public, that **water vapor** is the dominant greenhouse gas in the atmosphere and is capable on its own of causing global-scale climate changes.

p. 1585 "The failure of general circulation models to spontaneously [(i.e. without tuning; *my comment*)] reproduce the abrupt changes in temperature and rainfall pattern so clearly recorded in the geological record ...

Broecker's mild comment is that the models are "somehow deficient". If they cannot reproduce the changes of the past, how much credence can be given to their forecasts of the future?

p. 1587 " the warming and freshening of polar waters necessary for a thermohaline shutdown will not occur."

Warming certainly is *not* occurring in the "Conveyor's" source region in the northern Atlantic and subpolar seas. These have been *cooling* since the middle of this century (many papers, see bibliography) which should make them *more*, not less, prone to sink.

"after 1980 no significant further ventilation of the deep Greenland Sea has taken place."

Colleagues at the Bedford Institute of Oceanography have established that there have been individual winters with no deep convection (e.g. 1996), but lack of ventilation has not become the norm.

p. 1588 Summary

"Everyone would agree that the smaller the CO_2 buildup the less the likelihood of dire impacts."

Even if the "Conveyor" does operate as Broecker hypothesizes and could be stopped by global warming (as might have happened during the Younger Dryas), the result would be a sharp *cooling* i.e. an antidote to the warming we are supposed to be about to suffer.

"To this end I see a ray of hope" *et seq.*

I too see a "ray of hope" if we leave the last word on these oceanic speculations with Carl I. Wunsch, Professor of Physical Oceanography, MIT

"Climate change is inevitable, and the ocean is a major factor in that change. Unless you understand what the ocean is doing today, you won't be able to predict how it might behave in the future.
However, our immediate goal is not to predict the ocean, but to determine *to what degree it is predictable.*" (my emphasis)

Thermohaline Circulation, the River Styx of Our Climate System?
[thermo = temperature, haline = salinity (saltiness). The Styx is the River of Hades into which Achilles' mother dipped him (holding him by the heel) to make him invulnerable - but not to a poisoned arrow.]

exceptional from an historical perspective and requires no special explanation (e.g. GW) to account for it. To me the GW hypothesis is simply unnecessary, and — even if deemed by some people to be necessary for other (economic, political, or social) reasons — it is unsubstantiated scientifically. I don't need any explanation in terms of increasing anthropogenic "greenhouse gases" in the atmosphere to account for what I see in the oceanic climate record. Thank you.

The IPCC models all say that the land surface is going to warm, then the surface waters of the ocean are going to warm, yet many of the best-sampled parts of the ocean, surface waters, are not warming, but cooling.

Q: Address the hypothesis about the icecaps melting and catastrophic sea-level rise.

DR. POCKLINGTON: The IPCC models have nothing to do with the melting of ice floating on seawater. If you look at the simple physics of that, ice that is floating on water has already displaced the equivalent quantity of water and when it melts it has no additional effect. The IPCC models all say that the land surface is going to warm, then the surface waters of the ocean are going to warm. (I just showed you how in many of the best-sampled parts of the ocean, surface waters are not warming, but cooling.) Then by thermal expansion of the surface layer of seawater, global sea level will be raised (IPCC 1990: 266).

Q : Is there an icecap large enough to raise the sea level significantly?

DR. POCKLINGTON: You're probably thinking of Antarctica, where the ice is on land. That is the only circumstance where if ice attached to land slides off into the ocean - as we know large tabular icebergs do in the natural course of things in the southern ocean - these do then displace seawater. So in that case, the formation of that type of iceberg coming from land to the ocean and displacing water could raise sea-level. How much ? If you do the calculation that you instantaneously melt all the ice on Antarctica (highly unlikely) and put all that water into the ocean at once, you get a global rise of about 5m (IPCC 1990).

If you instantaneously melt all the ice on Antarctica (highly unlikely) and put all that water into the ocean at once, you get a global rise of about 5m (IPCC 1990).

Q : With regard to Wally Broecker's paper, I read it very carefully and I see he has an immense reputation as a scientist. But I read his paper, I read other people's papers and what bothers me is what they leave out. And he didn't mention the satellite record or the oceanic record that you just mentioned. In other words, I assumed he accepted the computer models showing that there is warming and let it go at that. Are you at all familiar with how he thought about the temperature record?

DR. POCKLINGTON: If I understand Professor Broecker's paper correctly, he had little to say about that. Basically, Broecker has a model, and in the absence of a better competing model, you have to give it some credence. You have to give some credence to the fact that something did happen dramatically different in the North Atlantic 10,000 years ago. Something happened to the surface water, the evidence of which is on the bottom. If a lot of icebergs come from the land carrying stones with them, they carry the stones out to sea, melt, and drop them in the ocean. That's the only way you can get stones of that size out there, because they simply can't wash out on their own. So the geo-record does seem to imply that you can have a rather rapid flip in the conditions in the northern Atlantic. To what extent this is a consequence of the "conveyor belt" model, or of something entirely different, we really don't know.

Professor Broecker has jumped the gun a bit, has presented something as almost a likelihood which has a very low probability of happening.

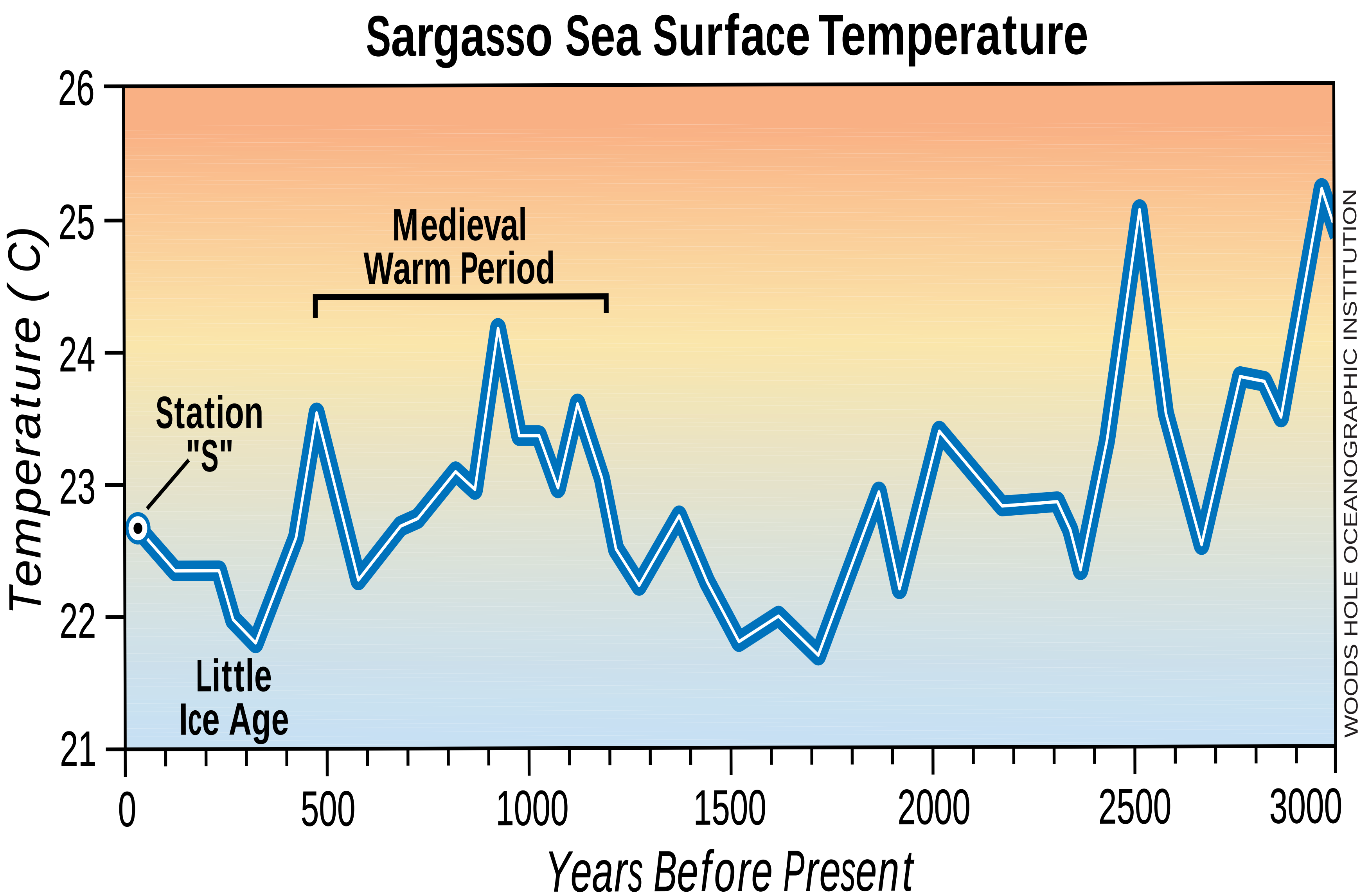
But how the projected warming of our present world is supposed to give us a repeat of what happened in a totally different world — we're not living in the world of 10,000 years ago with ice all the way down to Wisconsin — I have some difficulty in comprehending. Perhaps he'll work that out in future papers. It's a speculation, not an established fact. In Table 2, I left the last word with a colleague, who certainly knows more about this than I do. He's somebody you might want to take this up with. But a number of people in the field do think that Professor Broecker has jumped the gun a bit, that he has presented something as almost a likelihood which has a very low probability of happening. By the way, if you want to read a really smart man on the subject of "greenhouse warming" try Richard Lindzen. If any of you have attended Professor Lindzen's presentations, you have been fortunate. My wife (a marine scientist) read his presentation to the Senate (on the Internet) and afterwards said, "Having read that, how can anybody believe this greenhouse warming hypothesis ?"

Q: One thing it leads to is a ridiculous proposal like partially damming up the Mediterranean to prevent this change of the conveyor belt. This was published in *Eos* a couple of months ago – a really weird paper.

Analysis of ice cores suggests that increases in carbon dioxide and methane concentrations do not lead, temperature increase.

DR. POCKLINGTON: You would have to give me as much time as you gave me already for temperature to get into salinity. We have touched on temperature, but the density of seawater [specific gravity] is a function of temperature and salinity. What Broecker has done, is to shift the ground of the debate from temperature to salinity. The temperature case for GW is looking weaker all the time — you mention conflicting time-series from satellites. The debate has now shifted to salinity, which is influenced by many more things. Looking at the global hydrological cycle and asking, "What if a whole lot more rain fell here and the rivers ran more fresh water in and then the seawater couldn't sink?" is the basis of his speculation. There are so many gaps in it, we can't get into them all. If Broecker says we need to have more freshwater, where is it to come from? River runoff and sea ice meltwater are the major contributors to the freshening of northern Atlantic surface water; direct precipitation is inconsequential. Where does the fresh water come from that flows into the northern oceans — the interior of North America and Asia. You cannot dry out the interior of the northern continents — as the models do (e.g. Hadley Centre 1998) — and simultaneously enhance the discharge of the Arctic rivers so that more freshwater arrives in the northern Atlantic, freshening the surface layer and stopping surface seawater from sinking.

FIGURE 8



Estimated sea-surface temperatures from the vicinity of Station "S" over the last 3000 years. (Adapted, with permission, from *Oceanus 39*, 2: 18.)

*You cannot dry out the interior of the North America and Asia — as the models do — and simultaneously enhance fresh-water discharge into the Northern Atlantic — as Broec**ker's con-veyor-belt shut** down catastrophe assumes.*

As I say, it is premature to get into this. I'm sure a lot of voices other than mine, and people more competent than I — I've already mentioned Professors Lindzen and Wunch — will respond to Professor Broecker. And perhaps some of this has been taken further than Professor Broecker himself would have wished. But I say to you again, it's an hypothesis. The conveyor belt isn't proven. It's a working tool, a working hypothesis. The fact that something dramatic apparently happened 10,000 years ago — in a very different world from today — is no predictor that the same thing will happen again as a result of postulated global warming.

Q: Could you tell us what we've learned from the ice cores in terms of the relationship between carbon dioxide and temperature? In other words, the ice cores are used to show that a rise in carbon dioxide in the atmosphere is followed by heating, but other people say that it's the other way around. Could you talk about that?

DR. POCKLINGTON: You raised a very important point. Again, I'm stepping outside my direct area of professional competence, but anybody who looks into the literature can see this for himself. All that has ever been demonstrated in those ice cores, and let's forget all the quibbles about dating them for now, is that when the world was cold, there was apparently less CO_2 and methane in the atmosphere. I don't find it hard to see why, in a world with ice covering a whole lot of the trees, marshes, and all the other things that produce CO_2 and methane, that there were less of these gases in the atmosphere. So global cold = less CO_2 & less methane. As I've said to my colleagues, "The only way you can prove your point is to show that the concentration of CO_2 and methane went up before the temperature increased. And it doesn't do that." The traditional excuse was: "The time resolution in our cores is inadequate to establish that." But now that the resolution in the cores is getting better, guess what it shows? Carbon dioxide concentration and methane concentration lag, do not lead, temperature increase. The world warms up first, and then there's every good reason for a warmer world to have more CO2 and more methane in the atmosphere (IPCC 1990). They don't have a causal relationship, they have a correlation. This whole debate is bedeviled by correlations, things that happen at about the same time and are imputed to be in cause-and-effect relationship. Correlation is a good start, when you're looking for a cause-and-effect relationship, but it isn't a cause-and-effect relationship. In the real world, causes precede their effects.

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ADDENDUM

These data are public. You have paid for them already through your taxes. You may downloaded them from web-sites such as:

National Climate Data Center at: http://www.ncdc.noaa.gov/onlineprod/prod.html
Canadian national temperature data at: http://www.tor.ec.gc.ca/bulletin/annual95/ttab95sn.htm
Datasets for Central England Temperature at: http://www.cru.uea.ac.uk/~mikeh/datasets/uk/cet.htm
Trends Online is available at: http://cdiac.esd.ornl.gov/trends/temp/jonescru/jones.html

ABOUT THE AUTHOR

Roger Pocklington received his Ph.D. (1970) in Chemical Oceanography from Dalhousie University. From 1971 to 1997, he was research scientist at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia, Canada. He worked from 1969 to 1971 as research associate at the Bermuda Biological Station for Research, where he has now returned as Visiting Scientist. Since 1991, in conjunction with colleagues in physical meteorology, Dr. Pocklington has analyzed temperature trends at coastal stations around the North Atlantic that are critical to identifying changes in ocean climate. He has been an advisor to governments and industry on energy and environmental issues, and served as a member of the Canadian Review Committee, Intergovernmental Panel on Climate Change, Working Group III. His publications on North Atlantic climatic trends include "Secular changes in the ocean off Bermuda," *J. Geophys. Res.* 77: 6604-07; "Year-to-year changes in sea-surface temperature, North Atlantic and North Sea, 1948 to 1974" (1980), *Deep Sea Res.* 27:971-72; and (with M.R. Morgan) "Cooling in the North Atlantic region in relation to secular climate change," in R. W. Shaw, ed., *Climate Change and Climate Variability in Atlantic Canada* Occasional Reports. No 9 (Halifax, NS: Environment Canada: Atlantic Region): 21-29. A Member of the British Ornithologists' Union, and a Life Fellow of the Royal Society for the Protection of Birds, Dr. Pocklington has also published scientific papers in marine ornithology.

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