Oceanography and Inferences from Time-Series

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The top few metres 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). The ocean transports as much heat 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 50 watts per square metre (Stommel 1987: 72), it warms the adjacent land.[1]

The ocean contains 50 times as much CO_2 as the atmosphere and the flux of CO_2 across the air-sea interface is 20 times greater than the amount released by the burning of fossil fuels. The ocean is, for these reasons, invaluable to climate modelers as a place in which to hide things. Any imbalance in heat budgets (*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. According to Walter Munk: "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 a reservoir for ignorance" (Munk 1993).

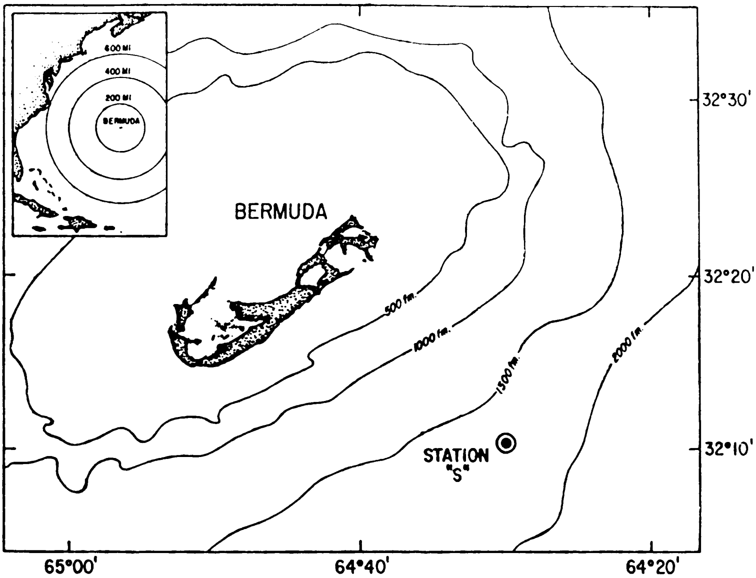
By looking at the evidence from the extratropical North Atlantic Ocean and adjacent land, this chapter examines the validity of propositions about systematic warming of the globe found in the latest reports of the Intergovernmental Panel on Climate Change (IPCC I 1996; IPCC III 1996).

The North Atlantic Ocean is a region of particular importance to the global climate system: it contains one of the small number of sites in the world where downwelling creates deep-ocean water[2] and one of the major surface currents, the Gulf Stream. Working Group I of the 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 and Pocklington 1995). We have found them; but they may not be what the IPCC was anticipating.

Data sources and methods of analysis

Records of monthly mean surface-air temperatures for land stations to 1990 were initially obtained from World Data Center-A, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA (NDP-020/R1 Rev. 1990). I emphasize that these are the same data of land surface-air temperatures developed by P.D. Jones and colleagues (Jones *et al.* 1994) that are used to produce the global and hemispheric anomaly time-series featured in IPCC Climate Change reports. We updated our stations to the end of 1996 by using *Monthly Climatic Data for the World*, the official publication of the World Meteorological Organization (WMO), provided by the National Climatic Data Center in Ashville, North Carolina, United States. Ocean 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. Pentades (periods of 5 years) were used for comparison rather than decades because

Figure 1 Location of hydrographic station S, southeast of Burmuda. The smoothed bathymetry is plotted at one kilometer depth increments. Reprinted with permission from *Oceanus* 39,2: 15.



this enabled us to compare the first pentade (1991–95) of the current (unfinished) decade with those that came before.

Regional marine climates

Bermuda

In 1969, I went to work at the Bermuda Biological Station for Research (BBSR)where I was responsible for physical and chemical measurements at their famous hydrographic station S (also known as the "Panulirus" station), which lies southeast of Bermuda at 32°10'N, 64°30'W, in 3200 metres of water close to the centre of the subtropical North Atlantic Ocean. While serial observations on land extending back a century or more are not uncommon, no such record exists for any location in the ocean and station S, which has been occupied regularly 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. The sampling frequency—on average, twice a month—is dense enough to show real periodic phenomena such as variability of temperature at subsurface depths (Schroeder and Stommel 1969)

and trends in the data are indicative of change over much of the subtropical North Atlantic.

The station had been running long enough to look for consistent trends in the time-series[3] and, in 1972, after eliminating the annual seasonal cycle from the record, I detected a cooling in the subsurface waters (to 1000m) that had persisted 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). Additional evidence of cooling in the region was available (*e.g.* from data for the period from 1966 to 1973 at Ocean Weather Station "Echo" at 35°N 48°W)and all of the available data implied that the atmospheric cooling trend continued down the water column and that further declines in water temperature at Bermuda could be expected.

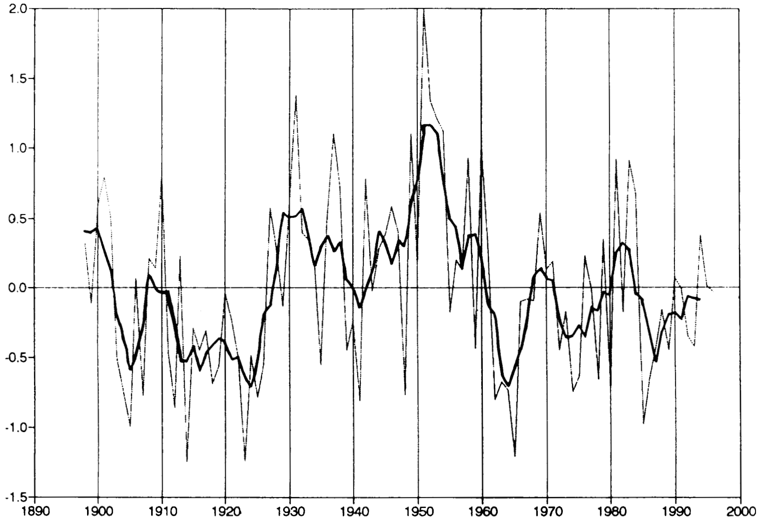
By 1975, the cooling trend in subsurface waters revealed in the station S time-series had been reversed and for the past two decades the waters off Bermuda have become steadily warmer, though at many depths they remain cooler than they were at the start of the series (Michaels and Knap 1996).

If observations at this station S had begun in the mid-1970s, this warming trend would have been seen as a clear sign of "greenhouse warming." Since the series began in 1954, however, 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. And 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 available for study.*

Atlantic Canada and Labrador

Sable Island, located at the edge of the Nova Scotian continental shelf, is an excellent example of an isolated station that, because it is uninhabited except for weather station personnel, is unaffected by the "heat island effect" (*i.e.* local increases in temperature) caused by urban growth. It is one of the global sites used to monitor the partial pressure of CO_2 in the atmosphere. The record of surface-air temperature since the 1890s (figure 2) shows an initial decline to a low in the mid-1920s, then an increase until the early 1950s, followed by a decline to the present time. The most obvious feature of figure 2 is the warming to the middle of the record and its subsequent rapid decline. The rise and decline was substantial (almost 2°C). The

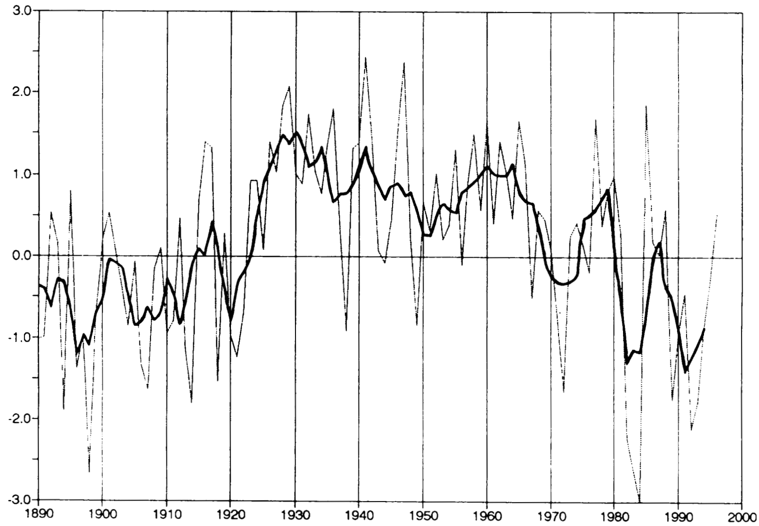
Figure 2 Surface air temperature record: Sable Island, Nova Scotia, Canada. Annual temperature anomalies (departures from the mean) in degrees Celsius (*y*-axis) are plotted against year (*x*-axis) beginning as early as possible. The sequence of annual means is shown by the lighter, dashed, line; the five-year running mean trend by the heavier solid line.



station is cooler now (mid-1990s) than it was 100 years ago at the beginning of the instrumental record. Other long-term coastal stations in Atlantic Canada (Charlottetown, Prince Edward Island; Sydney, Nova Scotia; St. John's, Newfoundland) show the same pattern of increase to mid-century, then decline to the present time. The data-base for the coast of Labrador and Baffin Island is patchy prior to 1940. Nevertheless, the pattern of warming to a peak in the 1950s followed by cooling to the present can be observed. Sea-surface temperatures (*i.e.* temperatures of the water in the top metre of the ocean) south and east of Newfoundland also show a similar pattern but the decline comes later (since 1965) than it does for air temperatures (Ocean Weather Station C, 52°45'N, 35°30'W; Levitus *et al.* 1994), reaching its coldest in 1993.

These climatic fluctuations have economic consequences for the fishery. Water temperature influences the timing of codfish reproduction (Hutchings and Myers 1994), and affects recruitment (the number of young that survive long enough to enter

Figure 3 Surface air temperature record: Godthab, west Greenland. Annual temperature anomalies (departures from the mean) in degrees celsius (y-axis) are plotted against year (x-axis) beginning as early as possible. The sequence of annual means is shown by the lighter, dashed, line, the five-year running mean trend by the heavier solid line.

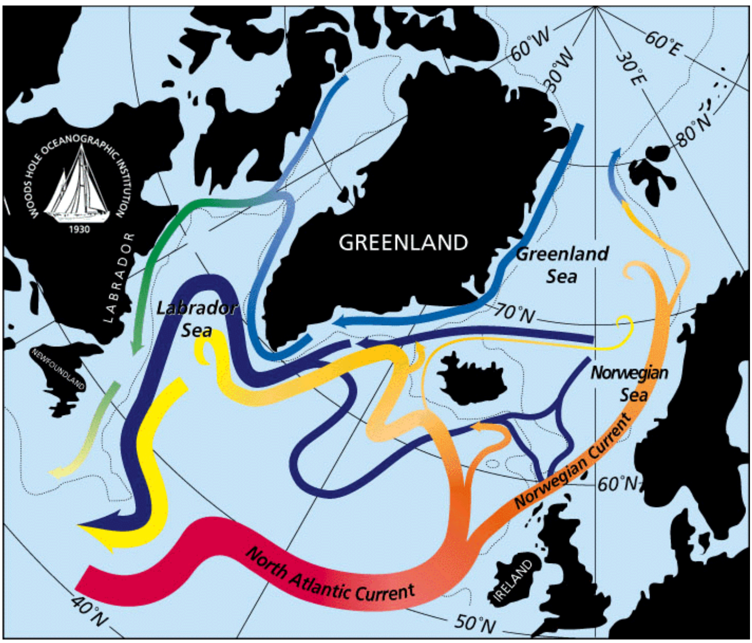


the fishery). During the last 10 years of extremely cold temperatures in the region, recruitment from Labrador to the Grand Bank has been poor (Drinkwater 1996); the sea temperature declines since the mid-1980s are responsible for approximately half of the recently observed decrease in "size-at-age" 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 waters.

Greenland

An increase in surface-air temperature off both the west coast (Godthab) and the east coast (Angmagssalik) of Greenland through the first decades of this century culminated, during the late 1920s, in the warmest pentade of the record. Since that time, both coasts have cooled; in the west, to the lowest values on

Figure 4 Track of currents carrying cold water down the east coast of Canada (green), part of the northern North Atlantic oceanic circulation. 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.)



record and, in the east, to a minimum in the 1970s, followed by warming to the long-term mean. These changes in temperature have had profound effects upon the fishery. The most dramatic was the rise and fall of the west Greenland cod fishery. During the late nineteenth century, no cod were found on the offshore banks. In 1908 to 1910, a few were found and, in 1912, 24 tons were caught. By the 1930s, annual catches had increased to 70,000 tons and, in 1945 and 1949, good year-classes (*i.e.* many healthy fish born in that year and surviving to maturity) increased the stock until catches reached 450,000 tons in the late-50s and early-60s. The last good year-class was in 1963 and the last significant one in 1968; cod fishing is now banned off west Greenland. The temperature record from Godthab (figure 3) charts the rise and fall of a great fishery, aided and abetted by overfishing.

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 global warming. Then, my daughter, who was at that time in high school, was assigned a science project studying “Greenhouse Warming”. Although I thought that this was an interesting hypothesis to investigate, I was astounded that she and other children were being taught that “Greenhouse Warming” was an established fact.

I immediately asked one of my colleagues why, if the world in general and the northern hemisphere in particular were supposed to be warming, our time-series of temperatures showed nothing but cooling. He explained that the Arctic is warming as a consequence of the “greenhouse effect” and that this causes greater volumes of cold water to leave the Arctic and pass down the eastern seaboard and give lower sea and air temperatures locally. To anyone with even a cursory knowledge of North Atlantic oceanic circulation (figure 4), this explanation sounds plausible. Moreover, it has testable consequences. If more cold water is moving out of the Labrador Sea on the western margin of the North Atlantic, a compensatory flow of warm water on the eastern margin should be warming those shores. We decided to look for such warming off the western coasts of Europe.

The stations in the northern North Atlantic all follow the pattern of warming from cold decades at the start of the century to a later maximum, with a subsequent cooling trend. In table 1, the stations are listed from west (Iceland) to east (Russia), then north (Ireland) to south (Azores); the length of record, then warmest and coldest pentade, with comments.

Iceland

Three locations in Iceland (Stykkisholmur, Reykjavik, Akureyri) on the west and north coasts all warmed to a maximum around 1940, over a decade later than the maximum across the Denmark Strait (Angmagssalik) through which the cold East Greenland Current flows southward into the Irminger Sea. Icelandic waters are located at the boundary between warm Atlantic water and cold Arctic water (Malmberg and Kristmannsson 1992); a branch of the warm Irminger Current flows north then east around northwest Iceland. This is the flow that should have the greatest

Table 1 Stations off Europe with long-term records of surface-air temperatures

Station/Location	Record from	Number of years	Warmest pentade	Coldest pentade	Comments
STYKKISHOLMUR / Iceland	1846	134	1937–41	1865–69	coastal station; closed 1980
REYKJAVIK / Iceland	1901	95	1938–42	1979–83	moved to airport
AKUREYRI / Iceland	1882	114	1938–42	1884–88	moved to airport
SVALBARD / Norway	1910	86	1979–83	1938–42	moved to airfield in 1975
JAN MAYEN / Norway	1921	75	1930–34	1967–71	coastal station
THORSHAVN / Faeros	1930	66	1945–49	1977–81	coastal station
STORNOWAY / Hebrides	1931	65	1932–36	1977–81	coastal station
LERWICK / Shetland	1931	65	1932–36	1977–81	coastal station
BERGEN / Norway	1816	180	1988–92	1836–40	moved to Florida airport
TRONDHEIM / Norway	1761	220	1934–38	1835–39	coastal station, closed 1980
TROMSO / Norway	1920	76	1989–93	1939–43	moved to Langnes airport
BJORNOYA / Norway	1920	76	1934–38	1962–66	coastal station
VARDO / Norway	1829	167	1934–38	1864–68	coastal station
MURMANSK / Russia	1919	77	1934–38	1965–69	coastal station
VALENTIA / Ireland	1869	127	1945–49	1888–92	coastal station
PLYMOUTH / England	1865	131	1865–69	1885–89	coastal station
PONTA DELGADA / Azores	1865	131	1887–91	1969–73	coastal station

influence upon these land stations. Temperature at sub-surface (50 m) depths at a hydrographic station in north Icelandic waters (Station S-3 off Siglunes near Akureyri) peaked around 1955, a decade and a half later than the land stations, then declined precipitously to 1969. Though it subsequently recovered somewhat through 1991, it is still over 2 °C below the maximum. Clearly no influx of warm to compensate for efflux of cold occurred.

It is noteworthy that the coldest pentade at the two stations with a record longer than 100 years fell in the nineteenth century. This is 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 the 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.

Northern island stations

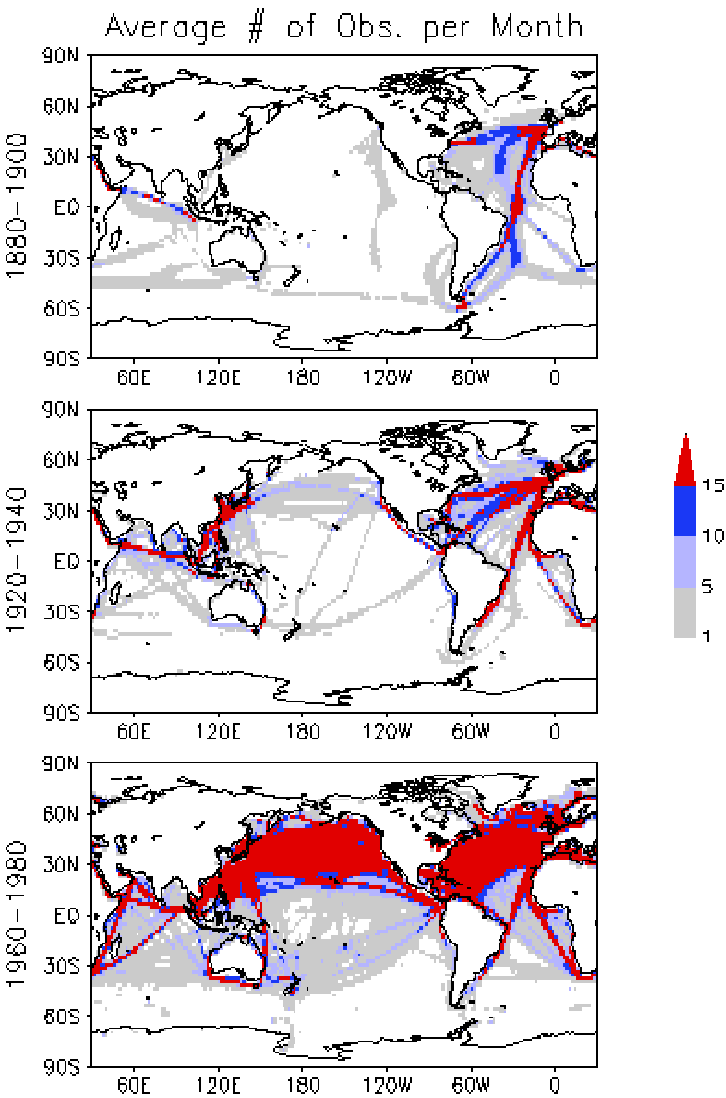
Svalbard (Spitzbergen), north of the Arctic Circle with a record from 1910, did have its warmest pentade around 1980 but is as cold today as it was in the coldest years of record. Note also the three stations in table 1 with their warmest pentade in the last three decades had their locations moved to airports. It is suspicious that, as these meteorological observation stations have been moved to airports, their local temperature trend has been upward and often divergent from nearby rural stations. The probable explanation for these results is that airports are heat islands because paved runways and the burning of aviation fuel keep adjacent air warmer than the surrounding ambient air.

Jan Mayen, Stornoway and Lerwick were all warmest in the late 1930s (Thorshavn in the late 1940s) and are all cooler now. Sea-surface temperatures in the vicinity of Rockall (55°N to 60°N, 10°W to 15°W) since 1920 show an increase to a peak in the late 1950s, a little later than the coastal stations, followed by cooling to the present.

Norway and Russia

At coastal stations in mainland Norway (Trondheim and Vardo), at Bjornoya, and at our eastermost station, Murmansk in Russia, the time-series show that the main period of temperature increase was that up to 1938. This is confirmed locally by Hanssen-Bauer *et al.* (1996). The two recently warm stations in our list (Bergen and Tromso) had been moved to airport locations.

Figure 5 Geographical distribution of weather reports over the world ocean. coloured areas show the average number of weather reports per month in each 2° latitude by 2° longitude square for each of the time periods indicated. White areas have no reports. (Reprinted with permission from Dr. Clara Deser, National Center for Atmospheric Research.)



United Kingdom and Ireland

At the Valentia Observatory off southwest Ireland, the time-series is similar to the one at Plymouth in southwest England. From the 1860s to the 1890s, temperature decreased, then increased to a peak in the late 1940s that has yet to be surpassed.

Azores

At Ponta Delgada in the subtropical North Atlantic, the range of interannual temperature variation (+/–1°C) is much less than it is to the north. Even so, we see the same pattern of warming through the first half of this century, cooling to a minimum in the mid-1970s followed by some warming to the present.

Conclusion

Surface temperatures in the extratropical North Atlantic are currently close to (or below) their long-term means, and below those reached in the warmest decades of this century (or earlier). In all cases, the warmest pentade came before the 1990s and the current decade is (so far) most uninteresting: there is no evidence that the region has warmed or cooled dramatically during the 1990s. The pattern of general cooling manifest at all island stations cannot be explained by the simplistic interpretation that cold meltwater is coming out of a warming Arctic. Whatever is taking place, it is general, not local. We have constructed a simple unweighted average of our North Atlantic stations and compared it to the familiar IPCC time-series of the northern hemisphere (Pocklington *et al.* 1993). The two are in accord to 1920, then our index "overshoots" the warming of the 1930s and 1940s, but declines in line with the hemisphere through 1970, after which our North Atlantic average continues to decline, whereas the average for the northern hemisphere shoots upwards. Divergence between predictions of a popular general circulation model (GCM) for the northern hemisphere and the data also appears around 1965.

Whatever is supposed to be happening globally, it does not include our region. This is strange because the North Atlantic is without doubt the most extensively and intensively sampled of all the oceans (figure 5). In temperate latitudes of the adjacent continents (eastern North America and northwestern Europe) are found the longest time-series of temperature, some extending back to the time when the first instrumental records were made in the eighteenth century. If we cannot find evidence

of “global warming” here, are we supposed to believe that it is occurring based on evidence from central Siberia or remote regions of the southern hemisphere? Apparently, the answer is yes. The Eurasian warming is said to be centred between 55°N and 75°N and 70°E and 100°E (figure 6; note that the Mercator projection used here is not equal-area and exaggerates the extent of warming on land in the northern hemisphere.), The warming in the southern hemisphere is all at sea in that mainly watery hemisphere.

Further, recall the importance of the length of the temperature time-series at Station S: if observations at this station had begun in the mid-1970s, this warming trend would have been seen as a clear sign of “greenhouse warming” 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. In the 1970s, Werner Deuser of Woods Hole Oceanographic Institution (WHOI) began the collecting of what is now 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. Additionally, deep-sea cores of sediment have been taken on the Bermuda Rise to the east of Station S. The data from these two observations has been combined with the temperature time-series from Station S 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* (specifically, *Globigerinoides ruber*), past changes in the temperature (and salinity) of surface waters of the Sargasso Sea can deduced (figure 7). This figure shows that the range of sea-surface temperature is much greater than what has been observed since 1954 at Station S. Features such as the Little Ice Age (200 to 400 years ago), when temperatures were cooler by nearly 1°C than they are today, and the Medieval Warm Period (500 to 1000 years ago), when they were warmer by up to 1.5°C, are clearly evident. Claims that the warming of one-half degree since the late nineteenth century to the present day is exceptional and requires a special explanation—the “Greenhouse Effect”—to account for it are poorly supported by this data. As we said earlier, *the inferences that can be drawn from any time-series are highly dependent upon the length of series available for study.* In the words of the late Henry Stommel: “without adequate models, we just make political statements.”

Figure 6 Change from 1975–94 to 1955–74 of annual land-surface air temperature and sea-surface temperature.Source: fig. 9, page 27, Technical Summary, IPCC I 1996; prepared by David Parker. This figure supposedly indicates that the earth's surface has been, on average, warmer (predominating orange) over the past 20 years compared to the preceding 20 years. "The cooler blue areas show, however, that the warming has not been universal." (IPCC I 1996). Reprinted with permission.

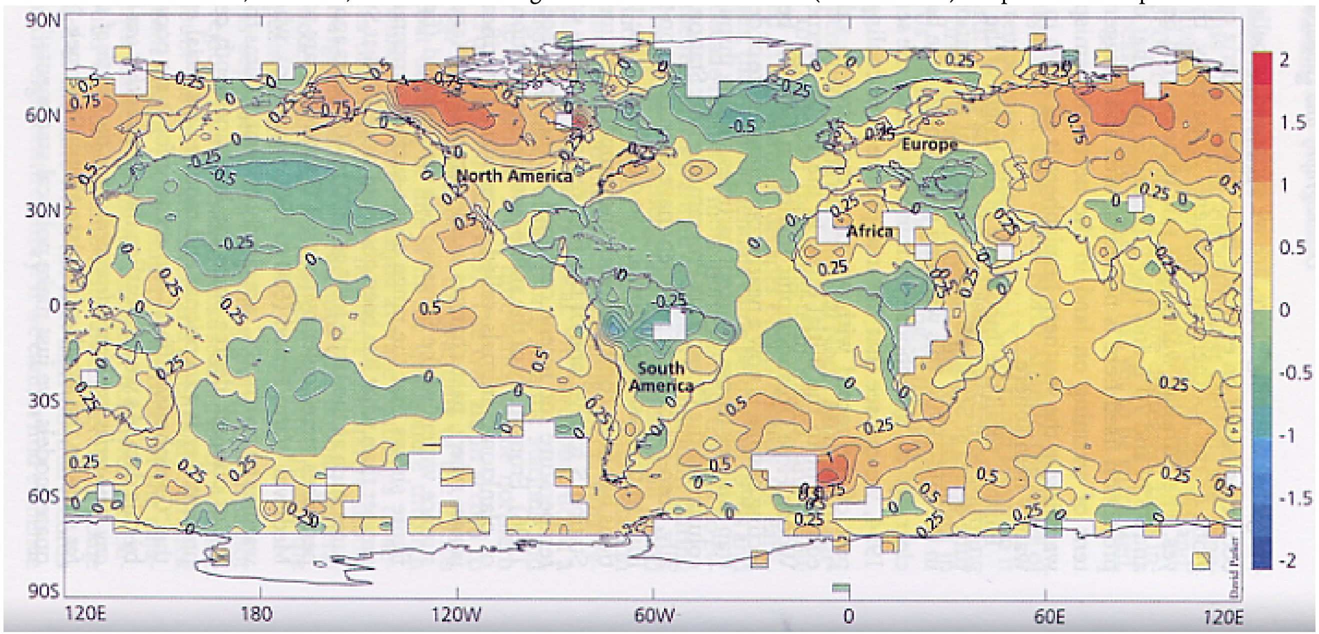
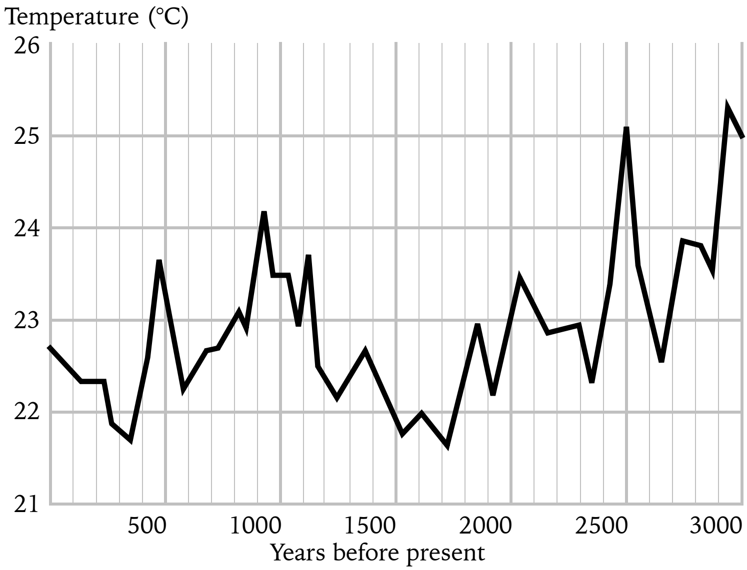


Figure 7 Estimated sea surface temperatures from Station S annual averages and from *Globigerinoides ruber* shell-oxygen isotopes averaged at intervals of 50 years. Note that the range of sea surface temperature is much greater than that observed since 1954 at Station S. (N.b. that the *x*-axis (last 3000 years) reads as a geologists scale and reads "right to left"; *i.e.* the past is to the right.) Adapted, with permission, from *Oceanus* 39,2: 18.



Acknowledgments

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Fisheries (Canada). None of this work could have been done without the active participation of Cmdr. M. Richard Morgan, RCN (Rtd.), who after a lifetime of practical marine meteorology really knows his island meteorological stations.

Notes

1 To put this flux in a "Global Warming" perspective, an increased surface flux of two watts per square metre is what is calculated to be the result of the increase in atmospheric carbon dioxide (CO_2) that has occurred since the beginning of the Industrial Revolution.
2 This site, north-east of Iceland, is where surface seawater is cooled until, by reason of its increased density, it sinks and forms a narrow, deep current—North Atlantic Deep Water—hugging the eastern side of Greenland.
3 This had been one of Stommel's original intentions for the station.

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