5. Has the Earth Warmed?

With a reluctant nod to the Clinton administration, this seemingly simple question depends upon what the definitions of ‘‘has’’ and ‘‘earth’’ are. Depending upon that definition, we can answer yes, no, or do not know. Why? Because the earth’s temperature is hardly constant. The earth has warmed and cooled for billions of years, and the current ice-age regime is one of the most variable periods in that inconstant history. It is an astounding fact to behold that this planet is around five billion years old but has likely seen large areas of glacial ice for only around one half of 1 percent (a crude estimate at best) of its total history.

This Ice Age is hardly over. We are merely between glacial phases; indeed, we are due for a reglaciation, if the history of the last million years or so is any guide.

The Ice Age Earth is a planet whose temperature fluctuates wildly, and we just happen to be here during that era, cheerily emitting compounds into the atmosphere that are themselves known to change the surface temperature. Finding the human fingerprint on an atmosphere at the height of chaos is a daunting task indeed.

So what do ‘‘has’’ and ‘‘earth’’ mean? If they mean the surface of the planet in the last 100 years, there is doubtless a warming. If we mean the ‘‘free troposphere’’ (the atmosphere largely removed from surface disturbance, all the way up to the stratosphere) in the last two decades, the answer is that there is no net change. Further, what we see depends upon what we use for measurement.

At first glance, it would seem easy to determine if the planetary temperature has been increasing over the past century. Many weather records throughout the world extend for more than a century. In theory, we should be able to assemble those records, check for trends, and easily determine whether or not the world is warming. This exercise has been carried out and, based on the results, the world is indeed warming.

Many global temperature records are available from the thermometer network of the world, including the NASA temperature history.

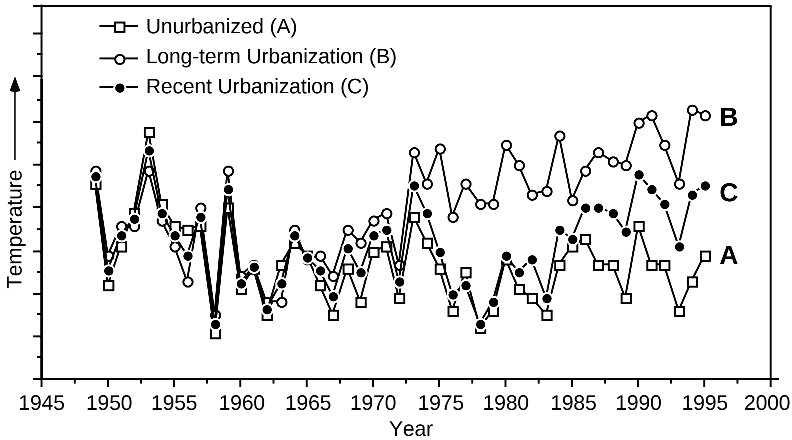
But the most popular and widely used record has been developed and maintained by Phil Jones of the Climate Research Unit at the University of East Anglia. That data set is based on the records of several thousand land-based stations and millions of weather observations taken at sea. He converts the monthly station observations into 5° latitude by 5° longitude grid-box data, and all values are expressed as deviations (anomalies) from a reference period defined as 1961 to 1990. The grid box anomalies may then be areally averaged for each hemisphere, and the two hemispheric values are averaged to determine the estimate of global temperature.

The most popular version of Jones's history is the one employed by the United Nations Intergovernmental Panel on Climate Change (IPCC). That record blends land and sea temperatures to create a global average. The blending technique is hardly straightforward, as land-based and sea-based temperatures are not exactly commensurate. Consider that most land temperature records originate from standard ''shelters'' a few feet above the ground, while most ocean temperatures originate from some type of ship-based platform. The differences between a thermometer shelter and a ship are rather obvious. Further, the method of taking oceanic temperature has changed over the century, from canvas buckets thrown overboard and retrieved to engine intake tube measurements. Reconciling the changes has required a lot of assumptions and guesswork.

These considerations aside, another more fearsome problem emerges. A long-term climatic history is, by definition, made up of long-term stations. Why and where were most weather stations established? The long-term records almost all originate at some type of commercial center. In other words, cities have a way of growing up around their weather stations.

This situation induces a slight but real warming trend that has nothing to do with the ''true'' temperature. Sometimes this ''urban effect'' is recognized, and the ''official'' station is moved to a more rural location. In Chicago, for example, the ''official'' station was first moved from the central city out to Midway Airport. As one of the nation's busiest airports during the piston-powered era, Midway attracted a lot of commerce, and the city eventually grew out to and around it. In the 1960s, the ''urbanization'' of the Midway record became obvious, so the ''official'' station became O'Hare field, then a largely underused concrete elephant amidst fertile cornfields. Anyone who travels knows it is now a very different environment whose

Figure 5.1
SCHEMATIC EFFECT OF URBANIZATION ON TEMPERATURE TRENDS



NOTE: Records A, B, and C all show the same variation from year to year, but B has an upward trend, indicating urbanization, and it is removed from global temperature histories. Record C begins to warm only in recent years, so it is erroneously retained in the global history.

urban characteristics do not differ much from Midway or the rest of the city.

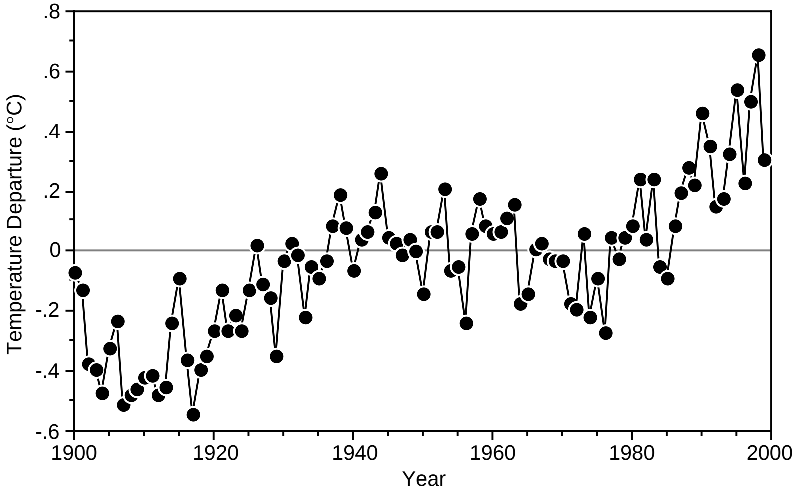
Jones and others have attempted to deal with the problem as best they can. Two nearby temperature records are compared year-to-year. If they go up and down together, but one of them has a warming trend that does not appear in the other, the former record is assumed to be suffering from urban warming and is removed from the history.

So far, so good. In Figure 5.1, these appear as ''A,'' an unurbanized station, and ''B,'' an urbanized one that clearly shows a trend. Year to year, though, the records bounce up and down together.

Despite the wishes of the many, cities have a way of sprawling into the surrounding countryside, and airports have a way of adding concrete. So a relatively pristine station such as the 1960s-era O'Hare has changed from a patch of stone embedded in cornfields, to one surrounded completely by masonry, buildings, and automobiles.

The problem is that a station like O'Hare does not begin to show the signs of urbanization until fairly late. ''C'' in our example represents such a station. The ups-and-downs match very well through

Figure 5.2
NORTHERN HEMISPHERE ANNUAL TEMPERATURE HISTORY, 1900–1999



SOURCE: IPCC, 1995 and updates.

NOTE: This is the 20th-century Northern Hemisphere surface temperature history the IPCC uses.

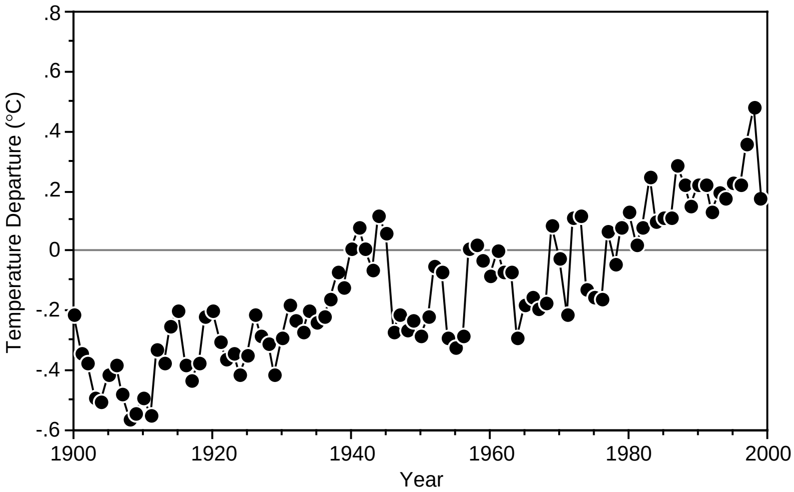
the entire record, but the warming only shows in the last decade or so. Any statistical tests to isolate this are likely to fail because the year-to-year variation swamps the very real but short-term urban warming.

Population continues to grow, though not as fast as some had warned. The largest increments are in the most recent years, so the probability that a weather station ‘‘goes urban’’ increases significantly near the end of its history—precisely at the point for which we have no objective mechanism for isolating the effect.

The bottom line is that Jones and the IPCC have largely removed the urban effect when it dominates a temperature record for many decades. But for the last 10 or 15 years, no known method exists to get rid of it. The urban effect is here, and it will grow exponentially.

Plotting the IPCC temperatures leaves little doubt that the earth's mean surface temperature has warmed during this century (Figures 5.2 and 5.3). The degree to which this is consistent with forecasts of *human* induced change is highly debatable, as shown in the next

Figure 5.3
SOUTHERN HEMISPHERE ANNUAL TEMPERATURE HISTORY, 1900–1999



SOURCE: IPCC, 1995 and updates.

NOTE: This is the 20th-century Southern Hemisphere temperature history the IPCC users.

chapter. The linear trend in the entire 1890 to 1995 period is 0.6°C (1.1°F); In the Northern Hemisphere, where there is much more data than in the sparsely settled (and mainly water) Southern Hemisphere, temperatures rose about 0.4°C (0.7°F) from 1900 to the mid-1930s. They then fell about 0.3°C (0.5°F) through 1975. Since 1975, surface readings have warmed and now stand a mere 0.2°C (0.4°F) above values typical of the 1930s, or six decades ago. The 13 warmest years on record all occurred from 1980 onward, and the 15 coldest years all occurred before 1920.

But the urbanization effect is difficult to remove from the end of the record. What is more, these thermometric surface air temperature estimates are fraught with other problems as well, including the lack of data in remote and oceanic areas, changes in the network over the past century, changes in instruments and observation practices, and microclimatic changes near the weather equipment, such as a growing tree near a weather station.

All GCMs predict that, away from the polar regions, the atmosphere above the surface warms more than the surface, especially in the tropics. Often known as the ''free troposphere,'' this zone, from 5,000 to 30,000 feet, is largely independent of the earth's varied surface and should behave in a much smoother fashion, responding nicely to the increase in greenhouse gases. Above the troposphere, as noted in the last chapter, a general cooling is predicted for the stratosphere.

We are fortunate to have three records of free tropospheric temperature. One is a satellite-based time series that extends from January 1979 to the present, originally published by Roy Spencer of NASA and John Christy of the University of Alabama in *Science* magazine in 1990 and updated monthly. The satellite senses the temperature by measuring microwave emissions from molecular oxygen in the lower atmosphere. Microwaves are able to penetrate the atmosphere with little attenuation, and the amount of energy the satellites receive is directly proportional to the temperature there. On a global scale, the accuracy of the satellite temperatures is thought to be ±0.01°C (0.02°F). The instrument package, called the Microwave Sounding Unit (MSU), rides an orbit inclined to the pole and therefore covers virtually the entire planet twice a day.

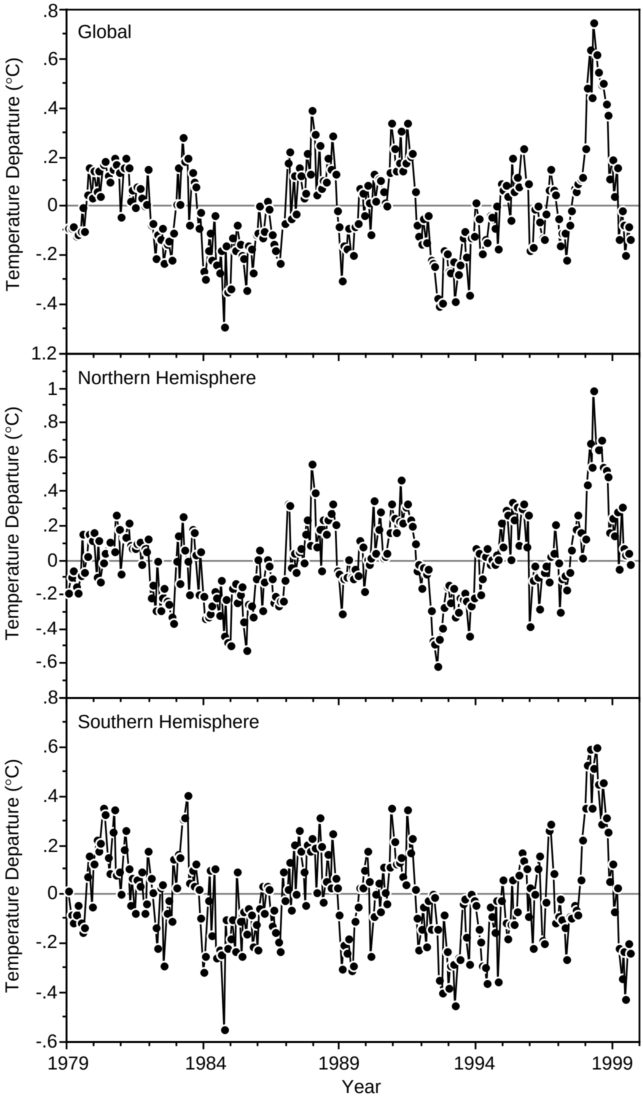
A plot of the resultant global temperature anomalies (Figure 5.4) certainly looks different from the surface record. The satellite-based global temperatures reveal a statistically significant warming of 0.05°C (0.09°F) per decade in the Northern Hemisphere; over the same time period the near-surface air temperatures warmed by 0.15°C (0.27°F) per decade—three times the satellite-observed amount. In the Southern Hemisphere the satellite finds no significant change, although surface records show a warming.

The slight warming trend in Northern Hemisphere and global MSU temperature is purely driven by the heat of the 1998 El Niño working its way out to space. Take that year away and there is no trend. Figure 5.5 shows another representation of the MSU data, in *daily* readings expressed as the departure from the long-term average since January 1, 1997. It is obvious that temperatures peaked in March 1998 and have been on a rather steady decline since then as El Niño waned.

The reason we know that 1998's heat has to do much more with El Niño than with the greenhouse effect has to do with stratospheric

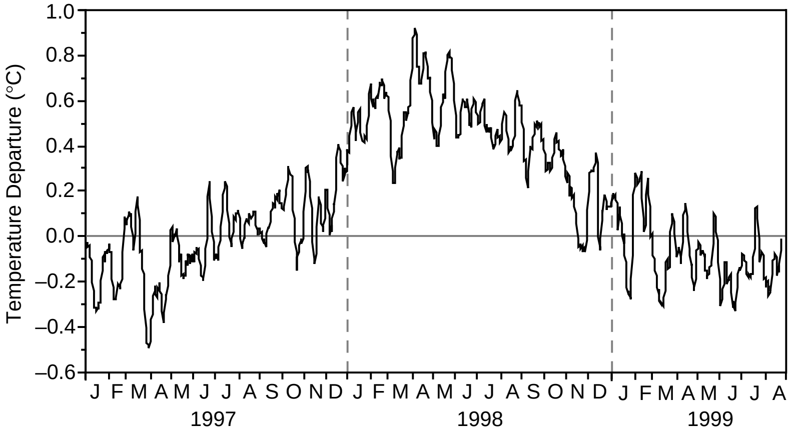
Figure 5.4

MONTHLY TEMPERATURE HISTORIES FROM THE MSU SATELLITE SENSORS



NOTE: These figures show global (top), Northern Hemisphere (middle), and Southern Hemisphere (bottom) temperature histories from the MSU satellite sensors.

Figure 5.5
GLOBAL DAILY SATELLITE TEMPERATURES



NOTE: This plot of daily satellite temperatures beginning in 1997 shows the pronounced spike from the big El Niño. It also reveals that temperatures returned to below the long-term average by early 1999.

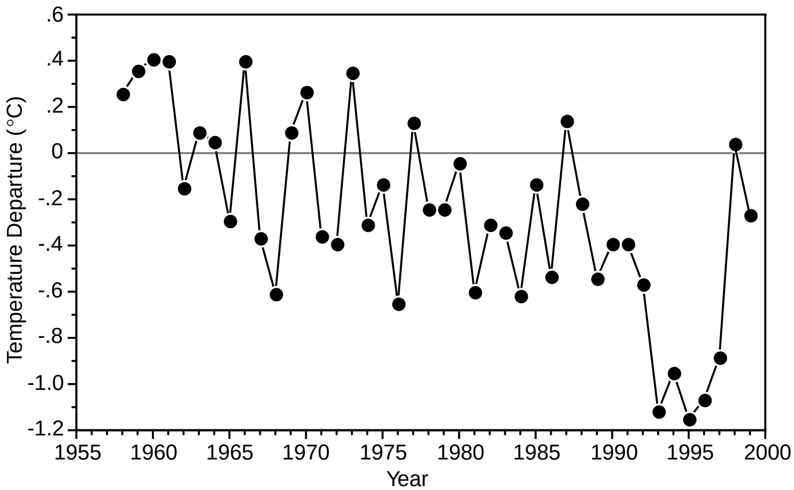
temperatures. As we noted in chapter 3, changing the greenhouse effect should induce a tropospheric warming coupled with a stratospheric cooling. That cooling is everywhere to be found in the weather balloon records published by Angell et al., whose global record begins in 1958 and extends to the present.

El Niño warmth behaves differently, however. It is a true pulse of heat from the oceans that wafts spaceward, working its way through the entire atmosphere. So when there is a spike in surface temperature followed by a spike in the stratosphere, that must be El Niño and not the greenhouse effect. With greenhouse changes, warming of the troposphere is accompanied by cooling of the stratosphere.

Our plot (Figure 5.6) of Angell's stratospheric temperatures clearly indicates that 1998 showed the warmest stratospheric temperatures in a decade and that there is a clear overall negative trend in the stratosphere consistent with a changed greenhouse effect.

''We've got to do something about the satellite,'' said the Union of Concerned Scientists' Harold Ris at a White House global warming pep rally held in October 1997, prior to the UN meeting in Kyoto designed to make the climate treaty ''legally binding.''

Figure 5.6
LOWER STRATOSPHERIC TEMPERATURES



SOURCE: Angell, 1994, and updates.

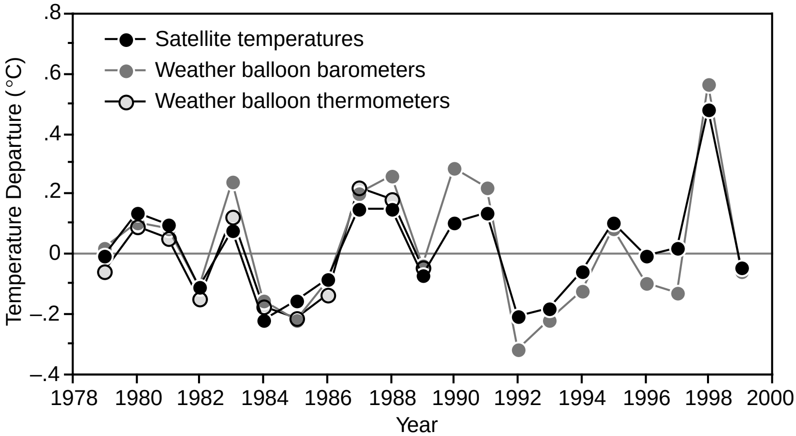
NOTE: The lower stratospheric temperatures archived by the Department of Commerce's James Angell show a steady decline since they began in 1958 that is highly suggestive of an expected greenhouse signal. The spike in 1998 is the warmth of El Niño superimposed on the expected cooling.

In turn, California rocket scientist Frank Wentz calculated that the slight drag that the very thin atmosphere exerts upon the MSU satellites should induce a tiny decay in the orbit that would result in their drifting ever closer to the earth. The resultant smaller ''footprint'' for the MSU sensor, left uncorrected, would induce a small but spurious negative (cooling) trend in the data. Rather than wait for the customary peer review, Wentz made sure his finding went straight to the top—to none other than Vice President Al Gore, whose staff let every environmental journalist in the nation know that the satellite data were, in their words, about to be ''discredited.''

Wentz calculated that the orbital decay of the satellite would induce an artificial cooling trend of 0.12°C (0.22°F) per decade. When coupled with the satellite-observed (1979–97) cooling of 0.04°C (0.07°F) per decade, this left a ''true'' warming of 0.08°C (0.14°F) per decade. This is still more than twice as low as the mean value

Figure 5.7

MSU SATELLITE, WEATHER BALLOON TEMPERATURE, AND WEATHER BALLOON BAROMETER READINGS



NOTE: These three independent measures all show the same year-to-year variation and have no warming trend (except the now-departed El Niño spike of 1998).

predicted by the sulfate-greenhouse models described in the last chapter, but it represented a small victory—at least it was the right sign!

Note that our satellite temperatures do not display much warming at all. That is because Wentz neglected two other drifts in the satellite, known as east–west and time-of-day. This corrected version of the satellite data has been accepted for publication in the refereed journal *Atmospheric and Oceanic Technology* and will appear in early 2000; this book uses the corrected data.

Wentz completely ignored that there were two other measures of free tropospheric temperature that meant the satellite was still right. Twice every day, weather balloons are launched to provide a vertical profile of the atmosphere in order to initialize (start) the computer-generated daily weather forecast models. The instruments are all known and standardized. The balloons carry electronic temperature and pressure sensors (barometers), and their altitudes are carefully checked.

As Figure 5.7 shows, temperatures measured by weather balloons between 5,000 and 30,000 feet line up perfectly with the temperatures sensed by the satellites. So Wentz, in essence, is arguing that somehow the weather balloons and satellites are making the very same errors in temperature measurement—day after day, for more than 7,000 days. The temperature record we use is the same one Oort published in the journal *Climate Dynamics* in 1989 and the same one used by federal climatologists in their comparisons of modeled and observed temperatures.

Ironically, the satellites are so good that they were ultimately used to correct an error in some Australasian weather balloon readings that developed when the supplier for the temperature sensor was changed. This has led some people to argue that the two sets are now so confused that they have lost their independence. But that is not the case for another record we use—this one from Angell of the U.S. Department of Commerce—which consists of temperatures calculated barometrically.

Thermometers measure temperature directly. But another way to measure the temperature takes advantage of this equation, which a few readers may remember from college chemistry: $PV = nRT$.

This is the ''ideal gas law,'' which states that if you know the pressure and volume (P and V) of a gas, and you know how many molecules there are (n), then using the constant, R, you can calculate the temperature, T. The weather balloon measures P (pressure) and its height is known. The ascent path can be considered constant, which means that height times the path gives volume. Standard atmospheric tables give n, and R is the same everywhere, known as the ''universal gas constant.''

So the balloons' barometers provide an independent check of the temperature. In addition to the satellite and the temperature data between 5,000 and 30,000 feet, our graph shows the temperature in that layer calculated from Angell's barometric pressure readings. All three readings go up and down in unison for each of the 20 years that make up the entire record, and there is no warming trend (except the big El Niño spike in 1998).

The satellite begins in 1979, but the global weather balloon record extends back to 1958. In the 5,000-to-30,000-foot slice, the balloon record shows a linear warming trend of 0.09°C (0.16°F) per decade. The surface temperature trend is virtually the same at 0.10°C (0.18°F) per decade. This is about four times less than the greenhouse-only models of the last chapter predicted and is a bit more than two times what the sulfate-greenhouse models forecast.

How can we reconcile the obvious disparity between the last two decades (where there is no trend, after allowing for 1998's El Niño) and the entire (1958–present) weather balloon record, which does show a trend? How can we reconcile the fact that surface thermometers since 1979 show a warming trend of 0.15°C (0.27°F) per decade while the satellites and weather balloons show nothing?

The National Research Council (NRC) attempted to do this in a report, *Reconciling Observations of Global Temperature Change*, released in January, 2000. Indeed, the NRC concluded that the difference between the satellite, balloon and surface temperatures was real, *and that it revealed a serious flaw in the climate models*. In their words:

> ''It is clear from the foregoing that reconciling the discrepancy between the global-mean trends in temperature is not simply a matter of deciding which of them is correct or determining the ideal ''compromise'' between them. In the long term, it will require *major advances* [emphasis added] in the ability to interpret and model the subtle variations in the vertical temperature profile of the lower atmosphere.''

NRC panel chairman John Wallace, of University of Washington, told the *Washington Post* on January 13, ''There really is a difference between temperatures at the two levels that we don't understand.'' In fact, most climate models predict that the temperatures measured by the satellites and the balloons should be rising faster than those at the surface.

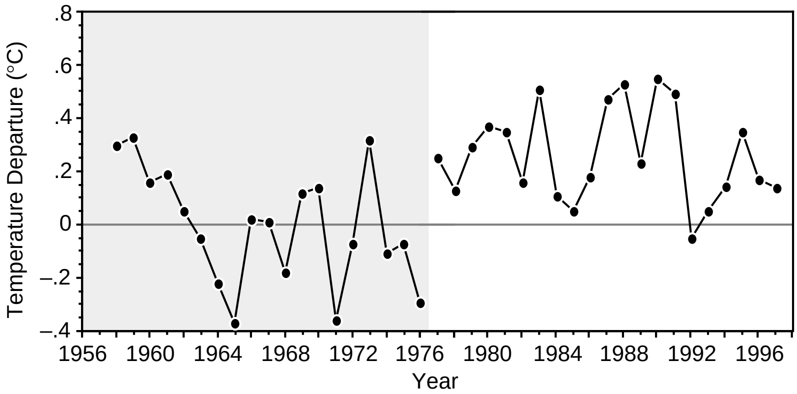
The NRC report is a watershed and underscores the arguments made throughout this book. But what it doesn't say nonetheless reveals the some remarkable behavior by the IPCC. In their 1995 report, the ''Policymakers Summary'' contains not one mention of the word ''satellite''. Many of the authors of that report were also on the NRC panel. Where is the explanation of this very blatant attempt to mislead those who shape global warming policy?

In fact, the combined behavior of the surface and satellite records underscores two great mysteries of the atmosphere.

Mystery No. 1: What if there were a sudden and dramatic warming, and no one noticed?

Given that the weather balloon record from 5,000 to 30,000 feet shows no warming in the last 21 years, but does have an overall trend in it when extended back to its 1958 beginning, you might

Figure 5.8
ANGELL'S COMPLETE 5,000-TO-30,000-FOOT TEMPERATURE HISTORY, 1956–96



NOTE: An examination of the entire history reveals a distinct jump in 1976–77 that explains all the warming trend in the entire record.
SOURCE: Angell et al., 1994.

conclude that there had to be a pretty healthy warming trend in the first two decades, from 1958–78. Not true. For reasons that are largely unknown, all of the warming in the balloon record is compressed into one year—roughly the 12 months surrounding January 1, 1977. Figure 5.8 shows the annual average temperature in the entire balloon record in two segments, 1958–76 and 1977–96. In both sets of data there is no warming trend, but the offset between the two averages is about 0.35°C (0.63°F).

Amazingly, this sudden climate change was not even *noticed* by the scientific community until 1990! And the science editors of the nation's daily newspapers did not catch on until *1998*, 22 years after it occurred, when Thomas Guilderson and Daniel Schrag, writing in *Science*, described what is now known as ''The 1976 Pacific Climate Shift.''

By measuring the nutrient uptake history from Pacific corals (which reflect annual temperature in a fashion somewhat analogous to the more familiar tree-ring histories), Guilderson and Schrag found that ''the vertical structure of the eastern Tropical Pacific changed in 1976.'' They hypothesized that the change may be responsible for the relatively strong and frequent El Niño events that have occurred since then.

At the same time, John McGowan and two other scientists at University of California, San Diego, found interesting changes in the distribution of marine life in the Pacific. In the early 1980s, there were disastrous fishing seasons in the Pacific Northwest. Seabirds and sea lions starved. Plankton abundance dropped, disrupting the primary link in the food chain. Cheerleading for global warming–related disasters (even though the authors made no such implication), the wire services trumpeted the bad news.

They forgot the good news. McGowan et al. also noted that Alaskan fisheries had ''spectacular shifts upward'' in catch, particularly salmon. Pollack, hake, and cod yields also rose dramatically, but have declined a small amount since the mid-1980s.

And it did not look much like global warming, either. McGowan et al. wrote that all of this had happened before. ''Many fish and invertebrates were found well north of their usual range in the summer of 1926,'' they wrote. California fishery production dropped dramatically in 1960, following the 1958–60 El Niño, which they described as ''one of the largest in the past 80 years.''

What McGowan did not mention was Steinbeck's 1945 novel *Cannery Row* about the destitution of Monterey, California, resulting from a dramatic decline in sardine fishery after a similar shift in ocean temperature.

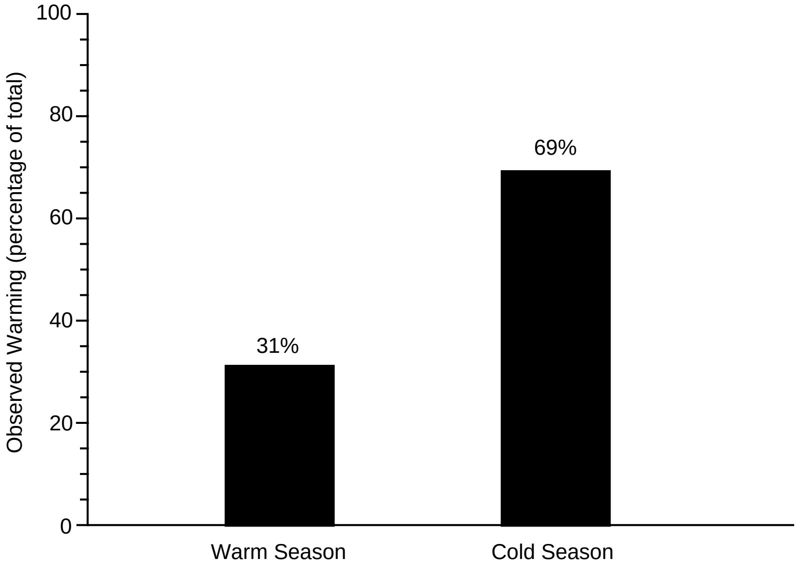
A final note: There has never been an adequate explanation for the sudden warming of the midatmosphere in 1976–77.

Mystery #2: Why does not warming disperse? Why is it trapped in very cold air masses?

Figure 5.9 (insert) makes clear that there is a substantial postwar warming during the cold portion of the year in Siberia and northwestern North America (and much less elsewhere). At various levels above the surface—from 5,000 feet all the way to the stratosphere—there is no warming at all in the last two decades. This is where and when we should expect the greenhouse effect to be rapidly toasting everything.

A comparison of winter half-year warming with the summer half-year in the Northern Hemisphere (Figure 5.10) shows a considerable

Figure 5.10
OVERALL NORTHERN HEMISPHERE POSTWAR WARMING, WINTER AND SUMMER



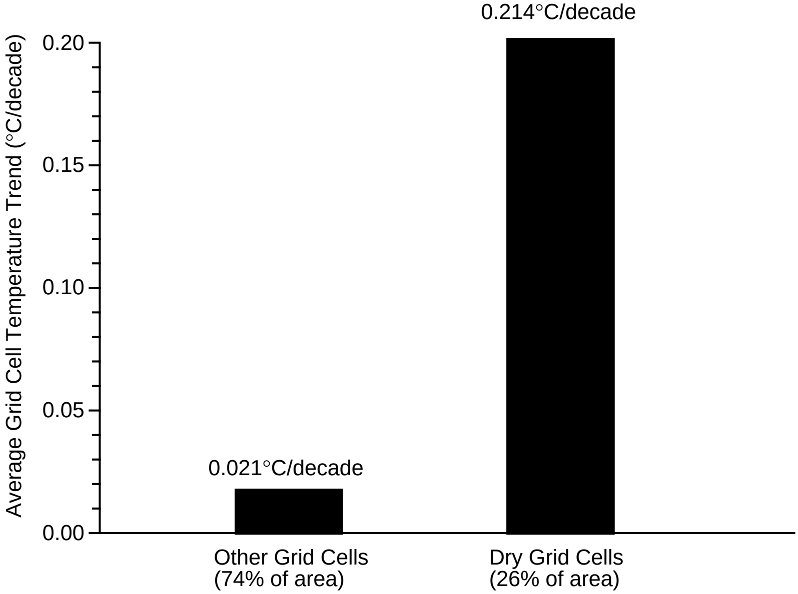
SOURCE: Michaels et al., 2000.

NOTE: The ratio of winter to summer warming is greater than two to one.

difference. Sixty-nine percent of the postwar warming is in the winter. How much of the winter warming was confined to the very cold high-pressure systems of Siberia and northwestern North America? The stunning answer? Seventy-eight percent. We just published these results in the journal *Climate Research* (Michaels et al., 2000).

Obviously, a warming of the very cold and deadly winter air masses is a pretty good thing; after all, winter temperatures are so far below freezing that a few degrees of warming could not possibly melt polar ice. A major summer warming would be more fearsome. How much of the warming of the last 50 years is in this exceedingly cold air? Do the math: 69 percent of total warming is in the winter; 78 percent of that warming is in the deadliest air masses (Figure 5.11). That means more than half of the warming is occurring in these air masses. They only cover, on a seasonally adjusted basis, 12 percent of the area. So warming is compressed—by a factor of

Figure 5.11
NORTHERN HEMISPHERE OCTOBER–MARCH WARMING



SOURCE: Michaels et al., 2000.

NOTE: The average winter half-year warming in cold dry air masses is more than 10 times the warming over the rest of the hemisphere.

four—into the most obnoxious air masses we know of, mitigating their deadly frigidity.

The air masses that have absorbed the lion's share of the warming average only around 4,000 feet in depth. As balloon (and satellite) records show, no warming whatsoever has occurred from 5,000 feet all the way to the top of the troposphere in the last 20 years, after allowing for the now-departed 1998 El Niño.

Climate models in the 1990 IPCC report predicted that the entire troposphere should be warming at the rate of about 0.4°C (0.75°F) per decade. The later sulfate-greenhouse versions, which serve as the basis for major emissions reductions proposals, dropped their warming to about 0.25°C (0.4°F) per decade by the addition of sulfate aerosol as a cooling factor, prompted by the embarrassing disparity that was developing between what was predicted and what happened.

Why is the warming confined to the bottom 10 percent of the troposphere? If the theory of transfer of infrared radiation is correct in the models, then 10 times as much warming should be observed if it is confined to one-tenth of the space. In other words, if warming is confined to the bottom 4,000 feet, we should be warming at about 2.5°C (4.5°F) per *decade* for sulfate-cooled models and 4°C (7°F) per decade for basic greenhouse models. Instead, we are seeing 0.15°C (0.27°C) per decade, largely crammed into a very small, very cold area in the dead of winter.

What is so bad about this type of warming? Can it be explained away by sulfate aerosols tempering greenhouse warming?