6 August 1976, Volume 193, Number 4252 SCIENCE

Global Cooling?

No, Southern Hemisphere warming trends may indicate the onset of the CO_2 "greenhouse" effect.

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According to Mitchell (*1, 2*), there has been a systematic fluctuation in global climate during this century characterized by a net worldwide warming of about 0.6°C between the 1880's and the early 1940's followed by a net cooling of 0.2° to 0.3°C by 1970. A recent press account (*3*) has suggested a somewhat greater cooling of 0.35°C and has impressed on the public consciousness the potential adverse economic consequences of a continuation of this trend.

Damon (*4*) has pointed out that global cooling since the early 1940's is not in accord with the well-known studies by Abbot (*5*) and co-workers from the Smithsonian Astrophysical Observatory or with data from recent balloon investigations in the Soviet Union and the United States (*6*) which indicate a relationship between solar energy (S) and solar activity as measured by the sunspot or Wolf number (N). These studies suggest that S increases by 2 to 2.5 percent as N increases, reaching a maximum at $N \sim 80$ to 100, after which it decreases to an intermediate value at the highest values of N.

More recently, Schneider and Mass (*7*) have combined the hypothesized solar energy effect with the effect of volcanic dust and CO_2 in a climate model. Global surface temperatures computed from this model rise from the early 1880's through the early 1940's in agreement with Mitchell's global temperature curve, but the computed warming trend persists to the early 1950's, followed by temporary cooling through the early 1960's and renewed warming from then until the present. Thus, the model of Schneider and Mass does not predict Mitchell's global cooling since the early 1940's, although it is in accord with the prior warming trend. Schneider and Mass would be the first to admit uncertainties in the model, but we have also been led to question the concept of global cooling.

We became aware of the current warming trend in New Zealand during the late spring of 1974 (*8*) and began a study of Southern Hemisphere temperature trends. Since then, the data of the New Zealand Meteorological Service have been published by Salinger and Gunn (*9*). Temperature trends in New Zealand, perhaps fortuitously, are in striking accord with the trend of calculated global surface temperatures for the 20th century by Schneider and Mass. Salinger and Gunn suggest that the current warming trend in New Zealand is common to a wider range of latitudes in the Southern Hemisphere. For example, they point out evidence for a warming trend since the 1940's for seven of eight Australian urban centers, Scott Base in Antarctica, and Orcadas Island at latitude 64°43′S near South America. The warming trend in Australia has been corroborated by Tucker (*10*), who observed that a large part of the Australian continent experienced an increase in excess of 1°C during the 7-year period from 1967 to 1973. Coughlan (*11*) showed that two-thirds (24 of 35) of the Australian weather stations indicate rising average annual maximum temperatures during the last 30 years, but he pointed out that a recent reversal of the trend over large areas is probably a result of the heavier rainfall in 1973 and 1974, which affected 95 percent of the Australian continent.

The purpose of this article is to report the results of an analysis of 67 weather stations in the Southern Hemisphere (see Table 1 and Fig. 1). Except for Australia and New Zealand, we find no evidence for significant climate change from the equator to 45°S latitude. Our analysis confirms the warming trend in Australia and New Zealand and strongly suggests a marked warming trend at higher southern latitudes, which may exceed in magnitude the cooling trend in high northern latitudes. Although confidence in the analysis is limited by the sparsity of weather stations, the level of confidence has been analyzed statistically.

Data Base

Currie (*12*), using the maximum entropy method, has demonstrated a variation of surface air temperature during the solar cycle for 226 weather stations (78 from North America) whose records span 60 years or more. The amplitude of the temperature variation is 0.05° to 0.2°C. A variation of this magnitude represents a significant fraction of the global cooling postulated by Mitchell and, if not taken into consideration, it could seriously affect arbitrarily chosen pentad or decade averages. For this reason, we decided to take averages centered around the last three solar cycles. The 23rd solar cycle extends from mid-1943 to mid-1953, the 24th solar cycle from mid-1953 to mid-1963 and, for the purpose of this article, we have taken the 25th cycle to extend from mid-1963 to mid-1974. With this in mind, the following criteria and approximations were initially used in handling the temperature data, which were taken from the *World Weather Records* (*13*) and *Monthly Climate Data for the World* (*14*).

1) Stations must include surface air temperature data from 1943 through 1974.

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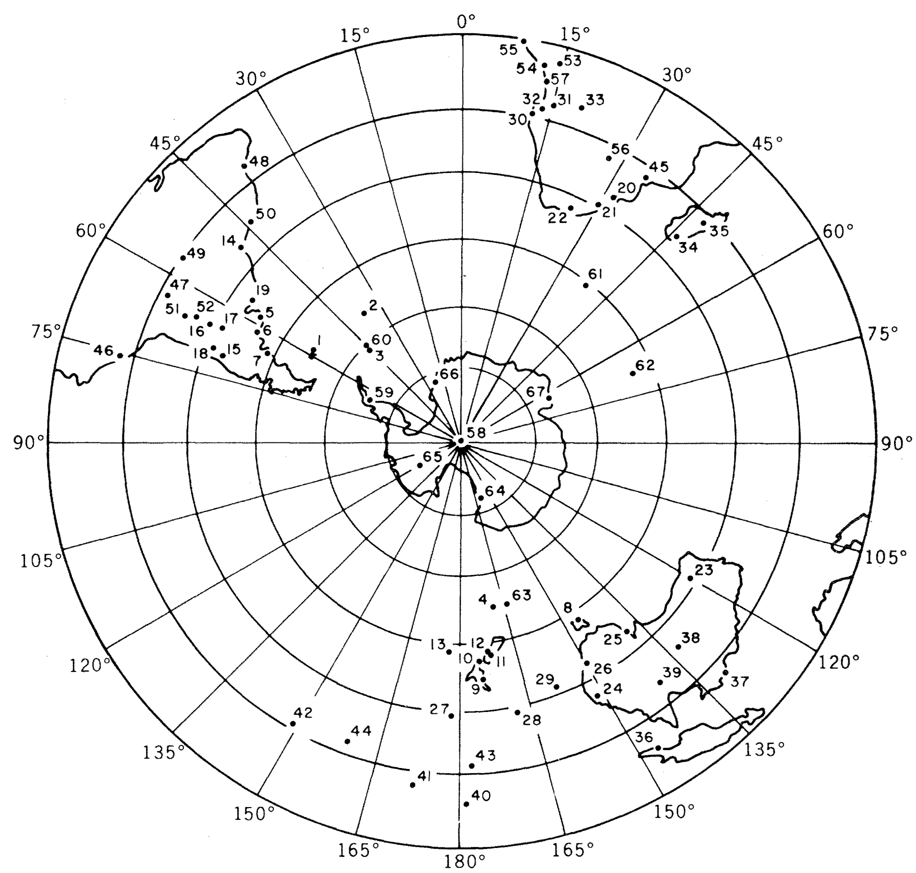


Fig. 1. Locations of Southern Hemisphere weather stations used in this study.

2) All stations that had more than minimal site changes were discarded.

3) All stations were discarded for which more than 10 percent of the annual data were missing.

4) For stations meeting the above criteria, a missing year was interpolated by using the average of the five preceding and the five following years (10-year average).

5) If three or less months were missing for a particular year, data for the month in question for the 5 years before and after were averaged (10-year average). If a year was missing more than 3 months' observations, the year itself was determined as in item 4 above.

6) In averaging for any classification of stations, the average was carried out to an additional significant figure, such as 20.57°C, even though the measurements for any single station were accurate only to 0.1°C.

Only 57 Southern Hemisphere stations met criteria 1 to 3. These 57 stations were used in the initial analysis. Later, the first criterion was relaxed to add ten additional stations for latitudes 45° to 90°S, where data were available for the four pentads from 1955 to 1974. This al-

Table 1. Weather stations and temperature data used in study.

Station	Location	Temperature (°C)						
		Solar cycles			Pentads			
		23rd	24th	25th	1955–1959	1960–1964	1965–1969	1970–1974
1. Stanley, Falkland Islands	51°42′S, 57°52′W	6.0	5.7	5.6	5.8	5.8	5.6	5.6
2. Grytviken, South Georgia Islands	54°16′S, 36°30′W	1.7	2.0	2.1	2.1	1.8	2.2	2.2
3. Islas Orcadas (Laurie Island), South Orkney Islands	60°43′S, 44°43′W	−4.6	−3.5	−3.8	−3.5	−3.4	−3.5	−3.7
4. Campbell Island	52°33′S, 169°07′E	6.7	6.3	7.1	6.9	7.1	7.1	7.0
5. Mar del Plata, Argentina	38°08′S, 56°58′W	13.6	13.6	13.8				
6. Bahía Blanca, Argentina	38°44′S, 62°11′W	15.1	14.7	14.9				
7. Trelew, Argentina	43°14′S, 65°18′W	13.8	13.3	13.4				
8. Hobart, Tasmania	42°53′S, 147°30′E	12.1	12.3	12.4				
9. Auckland, New Zealand	36°51′S, 174°46′E	15.3	15.8	15.2				
10. Wellington, New Zealand	41°17′S, 174°46′E	12.3	12.8	12.4				
11. Hokitika, New Zealand	42°43′S, 170°57′E	11.3	11.4	11.5				
12. Christchurch, New Zealand	43°32′S, 172°37′E	11.4	11.9	11.5				
13. Chatham Island, New Zealand	43°58′S, 176°33′W	11.0	11.4	11.2				
14. Curitiba, Brazil	25°25′S, 49°17′W	16.2	16.7	16.4				
15. Santiago, Chile	33°27′S, 70°42′W	14.6	14.6	14.1				
16. San Miguel de Tucumán, Argentina	26°48′S, 65°12′W	19.2	18.8	19.8				
17. Córdoba, Argentina	31°24′S, 64°11′W	17.8	17.2	17.4				
18. San Juan, Argentina	31°37′S, 68°32′W	17.6	17.4	17.6				
19. Montevideo, Uruguay	34°58′S, 56°12′W	16.6	16.7	17.4				
20. Lourenço Marques, Mozambique	25°58′S, 32°36′E	22.3	22.6	22.3				
21. Durban, South Africa	29°50′S, 31°02′E	20.5	20.2	20.3				
22. Port Elizabeth, South Africa	33°57′S, 25°37′E	17.7	17.0	17.3				
23. Kalgoorlie, Australia	30°45′S, 121°30′E	18.4	18.3	18.4				
24. Eagle Farm, Brisbane, Australia	27°28′S, 153°02′E	20.3	20.6	20.7				
25. Adelaide, Australia	34°56′S, 138°35′E	16.5	16.8	16.3				
26. Sydney, Australia	33°52′S, 151°12′E	17.6	17.8	17.9				
27. Raoul Isle, Kermadec Islands	29°15′S, 177°55′W	18.9	19.0	18.7				
28. Norfolk Island	29°03′S, 167°56′E	18.6	18.9	18.8				
29. Lord Howe Island	31°31′S, 159°51′E	19.2	19.1	19.3				
30. Moçâmedes, Angola	15°12′S, 12°09′E	21.0	20.3	20.2				
31. Nova Lisboa, Angola	12°46′S, 15°44′E	18.7	18.7	18.6				
32. Sá da Bandeira, Angola	14°55′S, 13°29′E	17.9	18.5	18.5				
33. Luso, Angola	11°47′S, 19°55′E	20.5	20.4	20.3				

lowed us to strengthen the evidence, suggested from the initial analysis, for a warming trend at high southerly latitudes.

Analysis of the Data

For an average temperature change between solar cycles or pentads to be considered significant, it seemed to us that the following two conditions were reasonable.

1) The temperature change between any two solar cycles or pentads must be $\geqq$ 0.1°C.

2) There must be at least a four-fifths chance (> 80 percent confidence) that the difference is significant, as determined by the standard t-test, where

$$t = \frac{\bar{x}(n - 1)^{1/2}}{s}$$

$\bar{x}$ is the mean difference in temperature for the set of n stations, $(n - 1)$ is the number of degrees of freedom, and s is the standard deviation of the mean ($\bar{x}$) for the set of n stations. From the value of t, the confidence level can be determined from standard tables.

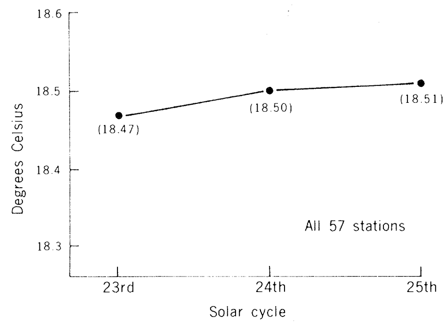


Fig. 2. Mean temperatures for the 23rd to 25th solar cycles for all 57 stations.

For example, data from all 57 stations that meet the criteria given above are plotted in Fig. 2. The increase in temperature between the 23rd and 25th solar cycles is only 0.04°C and the confidence level is only 70 percent. Thus, if the above criteria are accepted, no significant change in temperature since 1943 is indicated by the 57 Southern Hemisphere stations.

There remains the possibility that the set of 57 stations has been affected by artificial heating of urban centers, as demonstrated by Dronia (*15*) and Mitchell (*16*). Figure 3 shows that artificial heating has affected Southern Hemisphere cities with populations greater than 750,000. These cities show a steady warming trend, where the difference between the 23rd and 25th solar cycles is approximately 0.2°C and is significant at the 85 percent confidence level. Two of the three cities with populations between 500,000 and 750,000 (stations 14, 17, and 21) do not contribute to the warming trend, and so we conclude that in this analysis the urban effect is negligible for cities with populations below 750,000. Subtracting the urban centers from the original set of 57 stations does not affect our conclusion that the data show no significant trend in temperature for Southern Hemisphere weather stations since 1943.

This conclusion does not obviate significant regional temperature trends, and Fig. 4 demonstrates that there have been significant changes on a continental scale. The stations for subequatorial Africa show a pronounced cooling trend of 0.16°C between the 23rd and 24th solar cycles, significant at the 95 percent confidence level. This is followed by a leveling off between the 24th and 25th solar cycles. The Australian stations show the warming trend (significant at the 95 per-

Table 1 (continued).

Station	Location	Temperature (°C)						
		Solar cycles			Pentads			
		23rd	24th	25th	1955–1959	1960–1964	1965–1969	1970–1974
34. Fort-Dauphin, Malagasy	25°02′S, 46°49′E	22.7	23.0	22.9				
35. Tananarive Observatory, Malagasy	18°55′S, 47°33′E	18.7	18.2	18.2				
36. Port Moresby, New Guinea	09°26′S, 147°13′E	26.8	27.0	26.7				
37. Darwin, Australia	12°28′S, 130°51′E	27.3	27.4	27.6				
38. Alice Springs, Australia	23°38′S, 133°52′E	20.3	21.3	21.1				
39. Cloncurry, Australia	20°43′S, 146°30′E	25.1	25.3	25.8				
40. Funafuti, Ellice Islands	08°31′S, 179°12′E	28.0	28.0	27.8				
41. Apia, Samoa	13°48′S, 171°46′W	26.6	26.6	26.4				
42. Tahiti, Society Islands	17°32′S, 149°34′W	26.1	25.8	25.7				
43. Lauthala Bay (Suva), Fiji	18°09′S, 178°28′E	25.0	25.1	24.9				
44. Rarotonga, Cook Islands	21°12′S, 159°46′W	23.8	23.7	23.9				
45. Beira, Mozambique	19°50′S, 34°51′E	24.3	24.3	24.4				
46. Lima, Peru	12°06′S, 77°02′W	18.4	18.2	18.1				
47. Santa Cruz, Bolivia	17°47′S, 63°10′W	23.8	24.4	24.8				
48. Salvador, Brazil	13°00′S, 38°31′W	24.7	25.1	25.3				
49. Cuiabá, Brazil	15°36′S, 56°06′W	25.6	26.1	25.6				
50. Rio de Janeiro, Brazil	22°54′S, 43°10′W	23.3	23.4	23.7				
51. La Quiaca, Argentina	22°06′S, 65°36′W	9.4	9.2	9.4				
52. Salta, Argentina	24°51′S, 65°29′W	17.2	16.3	16.3				
53. Brazzaville, Republic of Congo	04°15′S, 15°15′E	24.8	24.9	25.1				
54. Pointe Noire, Republic of Congo	04°49′S, 11°54′E	25.2	24.8	24.7				
55. Port Gentil, Gabon	00°42′S, 08°45′E	26.3	25.8	25.7				
56. Bulawayo, Southern Rhodesia	20°09′S, 28°37′E	19.2	19.0	18.9				
57. Luanda, Angola	08°51′S, 13°14′E	24.5	24.3	24.2				
58. Amundsen-Scott Base	90°00′S				−49.0	−49.3	−49.8	−49.2
59. Argentine Island	65°15′S, 64°16′W				−5.2	−4.6	−4.5	−2.7
60. Signy Island	60°43′S, 45°36′W				−2.9	−2.7	−3.3	−3.7
61. Marion Island, South Africa	46°53′S, 37°52′E				5.1	5.2	5.0	5.4
62. Port aux Français, Kerguelen	49°20′S, 70°13′E				4.6	4.1	4.3	4.3
63. Macquarie Island	54°30′S, 158°57′E				4.7	4.6	4.6	4.7
64. McMurdo Station	77°50′S, 166°36′E				−18.0	−18.1	−16.9	−16.0
65. Byrd Station	80°00′S, 120°00′W				−28.2	−28.2	−27.6	−26.4
66. Halley Bay	75°31′S, 26°36′W				−18.6	−19.4	−18.0	−19.0
67. Mawson	67°36′S, 62°53′E				−10.7	−11.3	−12.0	−11.7

cent confidence level) previously noted by Salinger and Gunn (*9*), Tucker (*10*), and Coughlan (*11*). The South American stations show no overall trend between the 23rd and 25th solar cycles, but, a significant cooling did occur in the 24th solar cycle, followed by a return to the temperatures prevalent in the 23rd solar cycle. These regionally averaged temperature trends are probably associated with circulation changes on the scale of long waves, as recently demonstrated for the Northern Hemisphere by Van Loon and Williams (*17*).

The data were also classified into categories representing (i) all continental stations (36 stations) compared to all oceanic stations (21 stations); (ii) coastal continental stations (19 stations) compared to inland continental stations (17 stations); and (iii) large islands (9 stations) compared to small islands (12 stations). No significant temperature trends were observed for these categories between the 23rd and 25th solar cycles.

Figure 5 shows that there is no consistent latitudinal variation at latitudes below 45°S. However, the four stations (stations 1 to 4) at latitudes above 45°S (51° to 61°S) show a pronounced warming trend of 0.3°C, but the number of stations is insufficient to establish confidence that the trend is representative of the entire zonal area.

To ascertain whether the indication of a high-latitude warming trend is statistically significant, we decided to analyze high-latitude data for the last four pentads (1955 to 1974). In this way, by relaxing criterion 1 above, we increased the number of stations from 4 to 14 (stations 1 to 4 and 58 to 67) at latitudes above 45°S (Fig. 6). The set of 14 stations shows a 0.12°C decrease from the 1955–1959 pentad to the 1960–1964 pentad, followed by an increase of 0.37°C to the 1970–1974 pentad, significant at the 90 percent confidence level. The same trend is observed for the eight stations at latitudes above 60°S and the six stations at latitudes above 65°S, but the warming trend is much more pronounced for the stations at higher latitudes. The warming between the 1960–1964 and 1970–1974 pentads is significant at the 90 percent confidence level for the stations above 60°S and at the 95 percent confidence level for the stations above 65°S. The increase above 65°S is approximately 1.0°C. Five of the six stations above 65°S show a warming trend (stations 58, 59, 64, 65, and 66). Only Mawson station (station 67), Antarctica, shows a cooling trend which continues to the 1965–1969 pentad, followed by warming during the 1970–1974 pentad. The warming trend is dominated by Argentine Island (station 59, 1.9°C), McMurdo (station 64, 2.1°C), Byrd Station (station 65, 1.8°C), and Halley Bay (station 66, 0.4°C). It occurred to us that these four stations might be biasing the data for the entire set of 14 stations. However, excluding these stations, the six stations between 45° and 60°S also show a warming trend of 0.12°C, which in itself is significant at the 85 percent confidence level.

Although 14 stations are obviously inadequate to cover the entire portion of the globe between 45° and 90°S, the regional distribution is fairly good. Three stations, besides Mawson, show a cooling trend since the 1960–1964 pentad. One of these is in the Falkland Islands (station 1, −0.2°C) and the other two are from the South Orkneys (station 60, −1.0°C, and station 3, −0.3°C). It is these two stations from the South Orkneys which depress the curve for 60° to 90°S below that for 65° to 90°S in Fig. 6.

Summarizing, the following generalizations are warranted by the data.

1) The set of 57 weather stations meeting our initial criteria show no significant trend in surface air temperature from 1943 to 1974. Since 53 of the 57 stations are between 0° and 45°S, the data provide no evidence for a consistent, overall trend of surface air temperature for that part of the Southern Hemisphere below 45°S.

2) However, sectors of the Southern Hemisphere below 45°S do show significant temperature trends, which are balanced by opposite changes in other sectors. For example, a cooling trend in subequatorial Africa is offset by a warming trend in Australia and New Zealand.

3) There is an urban artificial heating effect of approximately 0.2°C for cities above 750,000 inhabitants; however, this has been taken into consideration and

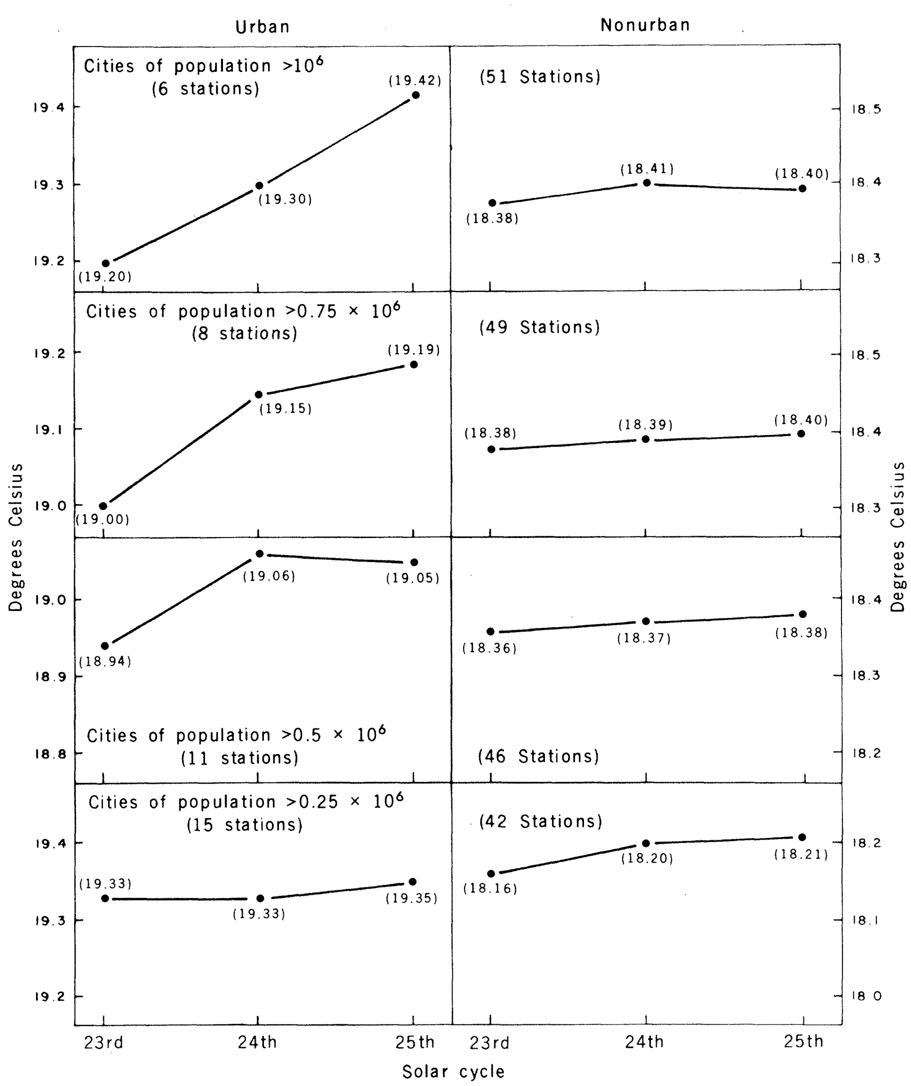


Fig. 3. Effect of urbanization on surface air temperature. Graphs on the left are for urban stations of different sizes. Graphs on the right are for all remaining stations after the urban stations on the left are subtracted. Numbers in parentheses are the mean surface air temperatures for the corresponding solar cycles. The warming trend is significant for cities with more than 750,000 inhabitants at the 95 percent confidence level.

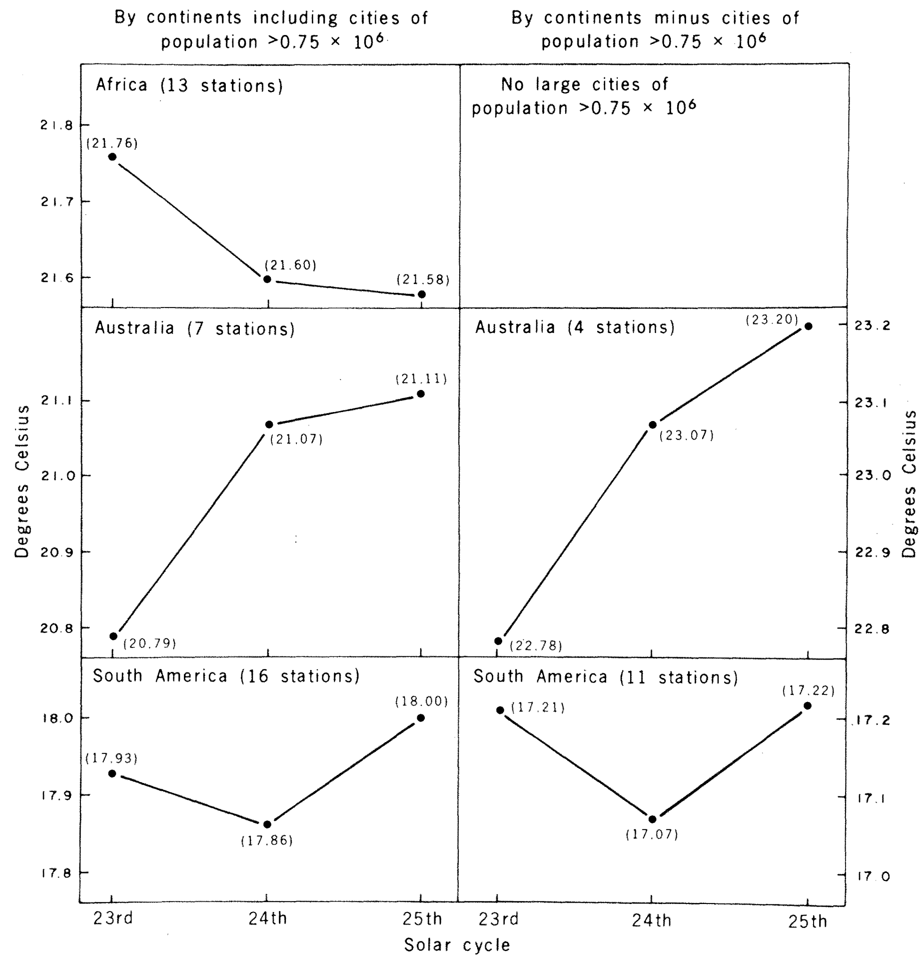
does not affect the statements above.

4) Fourteen stations between 45° and 90°S for which surface air temperature data for the four pentads from 1955 to 1974 were available show a mean decrease of 0.12°C from the 1955–1959 pentad to the 1960–1964 pentad, followed by an increase of 0.37°C to the 1970–1974 pentad. This apparent warming trend appears to be amplified at higher latitudes.

5) At least one sector at high latitudes, the sector including the South Orkney Islands and Falkland Islands, shows a cooling trend in opposition to the apparent warming trend for the Southern Hemisphere as a whole at latitudes above 45°S.

Discussion of Results

According to Mitchell, "meteorological data reveal a systematic fluctuation of global climate in the past century . . . [which] is presumed to reflect a systematic change of the overall heat budget" (*2*, pp. 440–441). We must conclude that this statement is not necessarily valid for the "global" heat budget during the period from 1943 to 1974. Cooling since the early 1940's is not necessarily global in extent; rather, it seems to be largely limited to part of the Northern Hemisphere (*17*) and some Southern Hemisphere sectors such as subequatorial Africa. Cooling is most evident at high northern latitudes. The data for 60° to 80°N account for "about one-half the net secular trend of that hemisphere, despite the small geographical area represented by the added data" (*18*). Thus, cooling at high northern latitudes seems to be balanced by warming at high southern latitudes since the 1955–1959 pentad. The



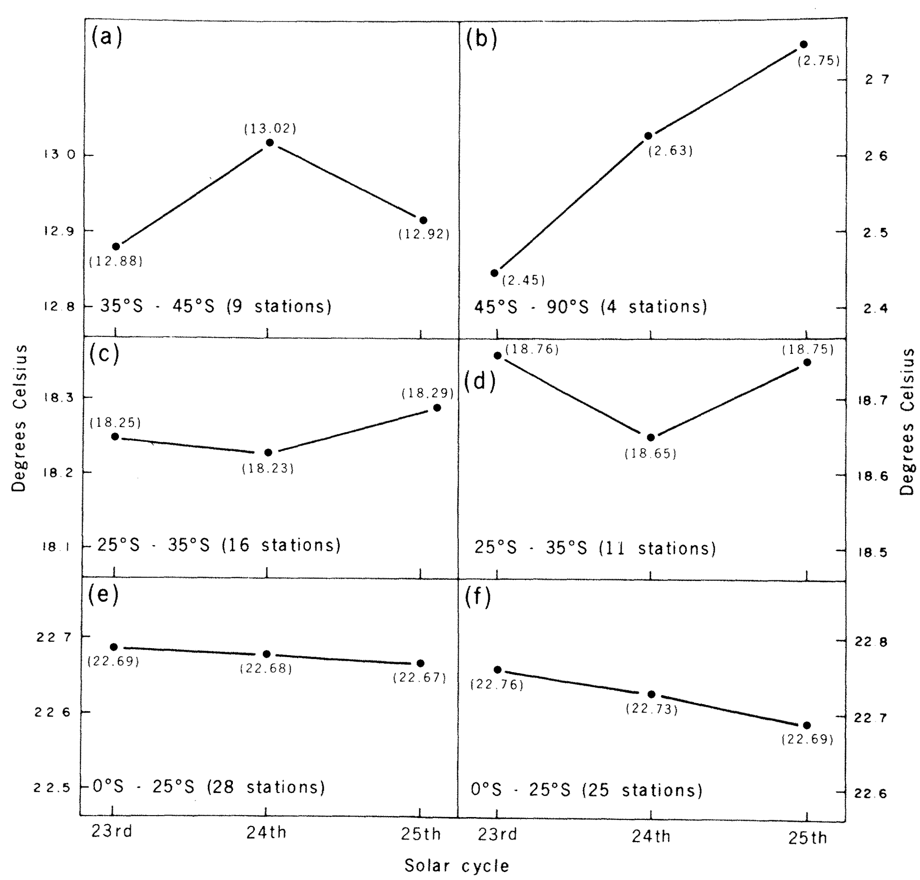


Fig. 4 (top). Variations in continental surface air temperature. Graphs on the left include urban centers with populations $> 0.75 \times 10^6$ and graphs on the right exclude them. The African cooling trend and the Australian warming trend are significant at the 95 percent confidence level. South American stations also show a significant warming trend between the 24th and 25th solar cycles, following cooling from the 23rd to the 24th solar cycle. The numbers in parentheses are the mean surface air temperatures for the corresponding solar cycles. Fig. 5 (bottom). Surface air temperatures for different latitudes: (a) all stations between 35° and 45°S; (b) all stations between 45° and 90°S; (c) all stations between 25° and 35°S; (d) all stations between 25° and 35°S except those with populations $> 0.75 \times 10^6$ inhabitants; (e) all stations between 0° and 25° S; and (f) all stations between 0° and 25°S except for those with populations greater than 0.75×10^6. Numbers in parentheses are mean surface air temperatures for the corresponding solar cycles.

data do not permit a conclusion concerning the overall global heat budget.

Making allowance for the expected amplification at high latitudes (*19*), the curves in Fig. 6 are compatible with the climate model of Schneider and Mass (*7*) in which the temperature rise is approximately equally divided between the CO_2 atmospheric ("greenhouse") effect and an increment due to increased solar energy during the last solar cycle. If the correspondence between theory and observation is not coincidental, then some other phenomena must be depressing temperatures in the Northern Hemisphere. Reitan (*20*) and Hirschboeck (*21*) have suggested volcanism as a significant contributing factor. Bryson and Wendland (*22*) have attributed the cooling to the rapid rise of atmospheric turbidity as a by-product of human activity. Particulate matter entering the atmosphere has a short residence time (*2*) and would largely be restricted to the highly populated Northern Hemisphere. The effect of particulate matter is complex (*23*), but the addition of condensation nuclei by pollution leading to an increased hemispheric albedo (*24*) may be the dominant effect.

Assuming that the data, based on 67 weather stations, adequately demonstrate opposite trends in surface air temperature at high latitudes in the two hemispheres, an assumption that might be contested because of the limited areal coverage, two working hypotheses occur to us as reasonable explanations.

1) The observations represent natural fluctuations on a regional scale in an atmospheric system which has been negligibly affected by human activity.

2) The expected increase in temperature due to an increase in solar energy coupled with the CO_2 greenhouse effect since the 1960–1964 pentad is observed in the Southern Hemisphere. It is overwhelmed in the Northern Hemisphere by cooling due to an increased effective albedo caused by man-made particulate pollution with, possibly, a significant contribution due to different intensities of volcanism in the two hemispheres (*21*).

Conclusions and Recommendations

We are certain that large regions of the Northern and Southern Hemispheres have experienced opposite changes in surface air temperature during the last three decades. Salinger has suggested that "divergence between Northern Hemisphere and Southern Hemisphere temperatures may be a phenomenon of the past 50 yr" (*25*, p. 311). However,

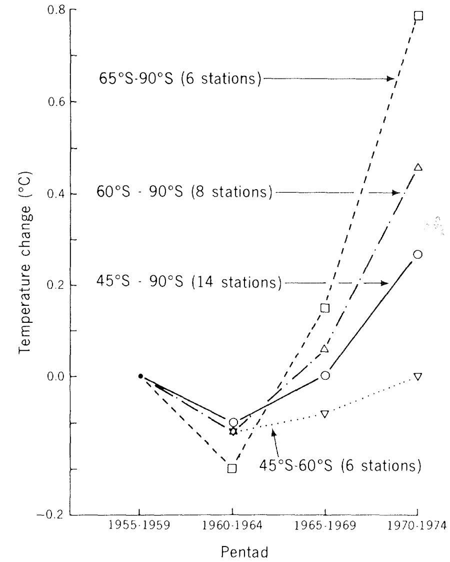


Fig. 6. Mean surface air temperatures for the last four pentads as a function of latitude. Confidence levels for significance of the warming trend from the 1960–1964 pentad to the 1970–1974 pentad are: 45° to 60°S, 85 percent; 45° to 90°S, 90 percent; 60° to 90°S, 90 percent; and 65° to 90°S, 95 percent.

the data are insufficient to precisely and confidently specify the trend in global climate as a whole. According to the climate model of Schneider and Mass (*7*), human activity may already have contributed significantly to the trend of global surface air temperatures, and Broecker (*26*) has predicted that the current cooling trend at high northern latitudes will soon give way to a warming trend due to the CO_2 greenhouse effect coupled with one of the more or less periodic temperature fluctuations observed in the Greenland ice core oxygen isotope record (*27*). Considering the complexity of weather phenomena and the sparsity of data, it is not yet certain that current trends in global climate are significantly influenced by human activity.

Carbon dioxide and particulate matter are the two major pollutants that may be affecting current climate trends. The major source of both of these pollutants is the highly populated and industrialized Northern Hemisphere. Hoffert (*28*) has demonstrated that the difference in CO_2 concentration between the Northern and Southern Hemispheres will be small because of the relatively fast latitudinal mixing rates of CO_2 in the atmosphere. On the other hand, Mitchell (*2*) has pointed out that, because of the short atmospheric residence time of particulate matter, particulate pollutants are unlikely to become thoroughly mixed throughout the global atmosphere like CO_2 molecules. Consequently, the climatic effect of CO_2 will manifest itself almost equally in both hemispheres, whereas the effect of particulate matter pollution will be most intense in the Northern Hemisphere. There seems to be general agreement that the effect of the increasing burden of atmospheric CO_2 will be global warming, although the exact magnitude of the effect is still debated (*29*). However, the direct effect of particulate matter pollution can be either cooling or warming, depending on the size and distribution of the particles. It may well be that the indirect effect of particulate pollution discussed by Twomey (*24*) will be dominant—that is, increasing cloud coverage and increasing planetary albedo with consequent cooling. There seems also to be general agreement that climatic trends will be amplified at high latitudes in both hemispheres.

This trend of thought leads us to the final conclusion and recommendation of this article, which is the urgent need for a more intensive and coordinated international world weather watch. It is of utmost importance to human welfare that factors affecting climate and reflecting trends in climate be continuously and adequately monitored. This includes all factors affecting planetary albedo, such as cloud, ice, and snow coverage. It should also include a definitive study of solar energy variations during an entire 11-year solar cycle. Retrospective monitoring, such as isotopic and thermal studies of ice, could help establish trends. Of utmost importance is the observation of climatic trends at high latitudes (> 60°) in both hemispheres. If the CO_2 greenhouse effect causes a global warming trend, it will most probably become apparent first in Antarctica. A warming trend was observed at five of six Antarctic weather stations used in this study. Is this the first indication of an imminent global warming? If so, what will be its effects on agriculture, the stability of the polar ice masses, and sea level?

Summary

The world's inhabitants, including scientists, live primarily in the Northern Hemisphere. It is quite natural to be concerned about events that occur close to home and neglect faraway events. Hence, it is not surprising that so little attention has been given to the Southern Hemisphere. Evidence for global cooling has been based, in large part, on a severe cooling trend at high northern latitudes. This article points out that the Northern Hemisphere cooling trend appears to be out of phase with a warming trend at high latitudes in the Southern Hemisphere. The data are scanty. We cannot be sure that these temperature fluctuations are not the result of natural causes. How-

ever, it seems most likely that human activity has already significantly perturbed the atmospheric weather system. The effect of particulate matter pollution should be most severe in the highly populated and industrialized Northern Hemisphere. Because of the rapid diffusion of CO_2 molecules within the atmosphere, both hemispheres will be subject to warming due to the atmospheric (greenhouse) effect as the CO_2 content of the atmosphere builds up from the combustion of fossil fuels. Because of the differential effects of the two major sources of atmospheric pollution, the CO_2 greenhouse effect warming trend should first become evident in the Southern Hemisphere. The socioeconomic and political consequences of climate change are profound. We need an early warning system such as would be provided by a more intensive international world weather watch, particularly at high northern and southern latitudes.

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Calibrating Duckweeds: Light, Clocks, Metabolism, Flowering

Special characteristics of Lemnaceae may offer unique insights into plant development.

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Experimental organisms with special, seemingly atypical characteristics often facilitate advances in biology. *Drosophila* in cytogenetics, *Neurospora* and *D. pneumoniae* in biochemical genetics, and the *Avena* coleoptile in plant growth regulation are classic examples. In contrast, work on sexual reproduction in higher plants—a process crucial to agriculture, horticulture, and forestry—has exploited unusual systems to a lesser degree. This is partly because of the importance of working with economically valuable forms, but it also reflects reluctance to use atypical material. Nevertheless the Lemnaceae, small floating plants commonly called duckweeds, seem particularly suited for research on flowering and related processes. This article begins with a summary of the general biological context and then describes some experiments on the Lemnaceae, concluding with an extended account of current work on a basic control mechanism.

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Photoperiodism: Phytochrome, Timing, and Florigen

Much of our knowledge about flowering and other aspects of plant growth derives from the discovery more than 50 years ago of photoperiodism (*1*), the control of development by the timing of light and darkness. Photoperiodism is now widely known among animals as well as plants. Thus, reproduction in many species can be controlled by manipulations of the light-dark regime, such as exposure to daily light periods longer or shorter than some critical value, or interruption of the daily dark period by a short "light break" (*2*). In plants, the effects of light breaks are mediated by phytochrome, a blue-green protein that is activated by low energies of red light (about 660 nm) and inactivated by far-red light (about 730 nm). In some systems, activation and inactivation are repeatedly reversible, so that phytochrome can act like an on and off switch. Many plant processes other than flowering, including seed germination and leaf growth, can be controlled in this way. Phytochrome appears to be associated with membranes, and may act by modulating the flux of various ions (*3*).

Photoperiodic responses often involve remarkably precise timing: some plants