TEMPERATURE CHANGES IN THE LAST 100 YEARS

G.J. Kukla and D.A. Robinson

Lamont-Doherty Geological Observatory
Columbia University, Palisades, NY 10964, USA

ABSTRACT

The average annual surface air and free atmosphere temperatures in the northern middle and high latitudes peaked in the late 1930's and decreased thereafter. This trend was also observed in the eastern Pacific and the North Atlantic. Over the last 40 years the strongest cooling was observed in the northern high latitudes in autumn, but warming was found for July and August. In the low northern latitudes and over most of the Southern Hemisphere insufficient station density prevents a reliable assessment of long term trends. Secular variations in the extent of snow and ice fields are indirect indicators of climate fluctuations in the high and middle latitudes. Satellite observed winter and spring snow cover in the Northern Hemisphere appears to be more extensive during the late 1970's than that charted in the late 1960's. However, recent summer extent of Antarctic sea ice has decreased since 1975.

INTRODUCTION

Is the present climate changing ? If so, in which way ? Are we slipping back into an ice age as the natural periodicity demands at the end of each interglacial ? Or are we at the brink of a catastrophic warming caused by artificially released CO_2 ?

In 1950, Willett (1) published an annual average temperature curve for the Northern Hemisphere showing a temperature

Temperature changes in the last 100 years (with G. Kukla). in: (ed. A. Berger) Climatic Variations and Variability: Facts and Theories. D. Reidel Publ. Co., 287-301, 1981.

increase through the first half of the 20th century. Mitchell (2) in 1961 updated the study and found a reversal in the trend since 1940. Numerous researchers followed Willett and Mitchell's example, using zonally averaged annual surface air temperatures as the key indicator of climatic fluctuations. The annual zonal averages can be computed with relative ease and seem to yield similar results irrespective of differences in the data selection and averaging techniques.

The practical value of the zonally averaged annual temperatures can be questioned. It is doubtful whether any clear correlation exists between the annual average hemispheric air temperatures and the local or regional weather patterns. The interest in climate fluctuations is greatest over the densely inhabited sections of the continents because the economic impact of such variations is largest (3). However, the computation of zonal and hemispheric averages calls for inclusion of vast expanses of the oceans and of unpopulated deserts. Accuracy of the zonal averages is seriously downgraded where the meteorological network is sparse and data quality is low. The relatively small zonal mean departure obtained in such studies is almost always the result of balancing the large regional positive and negative anomalies. Future studies would perhaps do better to concentrate on seasonal weather patterns of individual economically important land regions and on changes of sea surface temperatures in the few well investigated segments of the world oceans. The global scale should then be handled as a composite of such high quality data sets combined with satellite derived information.

It is useful to realize, in this context, that over large low-latitude sections of the continents the variations of the surface air temperature have a small amplitude and a negligible economic impact. Precipitation is perceived as a key criterion of climate variability in such zones.

Literature on climatic fluctuations in the last decades and centuries is so voluminous that only a very superficial overview can be presented here.

Individual investigations differ according to the :

- climate indicator selected
- temporal resolution, length of the record, time averaging procedures
- spatial resolution, station density, limits of area studied, space averaging procedures.

CLIMATE INDICATORS

Surface Air Temperatures

Surface air temperature is measured about 2 metres above the ground, the arbitrary reference level of climate. Daily means, obtained as an average of minimum and maximum readings, are reduced to monthly or annual averages. Departures from the long-term mean values are then analyzed (4,5,6). The longest records in England and the Netherlands cover almost 300 years (33). Records over two-hundred years long are available (34), among others, from Stockholm, Sweden ; Trondheim, Norway ; Berlin, Germany ; Edinburgh and Lancashire, England ; Praha, Wien and Budapest in Central Europe ; Basel and St. Gotthard, Switzerland ; Paris, France ; and Boston and Philadelphia, U.S.A.

The advantage in the use of the surface air temperatures as a climate indicator are numerous : 1) the data directly refer to the reference level of climate ; 2) surface temperature is the key climate parameter ; 3) surface temperature has been gathered in a relatively dense station network by normalized procedures over much of the world for more than 100 years; and 4) surface air temperature variations have an outstanding impact on the economy over much of the land in the middle and high latitudes. The disadvantage of the surface air temperature is its high spatial variability due to the shifting position of the vortex and to orographic effects. In addition, urban warming (7,35) affects most of the stations with long records. Data are sparse and irregularly collected over the oceans.

Sea Surface temperatures (SST)

Sea surface temperatures are mainly gathered from ships. In earlier times the water sample to be measured was taken from the uppermost metre or so of the ocean, and raised onboard in a bucket. More recent SST readings have been taken from the injection water used to cool ships' engines. These are sometimes taken several metres below the surface. Infrared brightness images obtained by satellites relate to the "skin" temperature of the uppermost water lamina. Obviously, SST's obtained by the three different methods are not compatible (31). Measurement of injection waters show the lowest temperatures, while satellite measurements show the highest daily range.

SST data are abundant along the heavily traveled routes in the Atlantic and the north central Pacific, less abundant in the Indian Ocean, and very scarse in the Southern Hemisphere (8,9).

Free Atmosphere Temperatures

These are measured directly or calculated from the heights of standard pressure levels using radiosondes (10,11). The radiosonde network is sufficiently dense over most of the Northern Hemisphere continents. A 20 m change in the thickness of the atmospheric layer between the 500 mb and the 1000 mb levels corresponds to a temperature change of 1°C in the atmospheric column. Such approximation can, however, only be done over a sufficiently large area and over an interval of at least a month. Otherwise the results would be distorted by local departures caused by winds.

Free atmosphere temperatures have advantages over surface air data. The free atmosphere is well mixed and little affected by local influences such as, e.g. urban heating. Properly gathered information at a single station can be representative of a relatively large area.

The disadvantages include the relatively short length of the records (data available from 1949), and the possibility of systematic bias in the data due to gradual improvements of the instrumentation.

Circulation Types

The frequency of circulation types and the occurrence of the different atmospheric masses was studied in England (12), continental Europe and Russia (13).

The circulation pattern is most frequently identified by the dominant winds, and the atmospheric masses by humidity and surface temperature. Results are mostly regional and their correlation with outside study zones is difficult.

Circumpolar Vortex Area

This is determined in meteorological charts from the observation of upper winds (14). The vortex area increases with the expansion of cold air masses. Determinations suffer from constraints similar to the free atmosphere data.

Snow and Ice Covers

The area occupied by snow and ice is being charted in a relatively accurate fashion from satellite images and ground station reports (15), and is closely related to the zone with subfreezing surface temperatures. Some research suggests that snow and ice fields have an active role in climate change (36,37).

The advantage of snow and ice cover indices is that they are gathered in a relatively uniform, internally homogeneous pattern across both hemispheres (16). Disadvantages are the present inability of operational satellite systems to report snow under clouds, and the complicated dependence of snow on both temperature and precipitation.

Precipitation

This is a highly variable parameter both in space and time. Only changes in narrowly delimited regions have been studied. We know of no published attempt at assessing the changes in hemispheric totals of past precipitation (17).

TEMPORAL AND SPATIAL RESOLUTION

The network of meteorological stations became sufficiently dense and the quality of reporting sufficiently reliable for large scale comparisons about 1880, when most of the published series begin (2,18,19,20,32).

Much of the undesirable variance in temperature data can be removed by temporal averaging. For that reason many authors used decadal or pentadal means, or multiyear running averages (1,2,6,). Multiyear averaging also helps eliminate local and/or short-lived anomalies. As Faegri (21) found in paleoclimatic investigations, the longer the duration of an anomaly the larger the area similarly affected. The disadvantage of the long term averaging, on the other hand, is the loss of seasonal resolution.

Most researchers should realize the implications of high temporal variability in data sets and hesitate to recognize any trends in intervals shorter than several decades.

Another reason most authors work with the annual averages is that such an approach considerably reduces the volume of data to be handled. Only in the past few years have seasonal (24,25) and monthly (20) data been analyzed and published.

Long term means of surface temperature change in a highly complicated pattern dictated by the shape and persistence of planetary waves. Frequently persistent patterns of meridional circulation in the middle latitudes cause prolonged positive and negative anomalies within a single zonal band (Figure 6).

Willett (1) and Mitchell (2) demonstrated that the regions of equal sign of temperature anomalies are sufficiently large to be successfully sampled by a relatively open station network. More recently, principal component analysis was applied to the problem by several authors (22,23,).

They found that areas similarly affected are typically 1000-2000 Km across (24,25,26), which translates into a need of some 300 evenly distributed reporting stations per hemisphere. Reliable density is attained only in the middle and high latitudes of the Northern Hemisphere and over the southern continents.

Upper air temperatures and atmospheric thickness data, because of presumably more efficient mixing, require a less dense station network. Dronia (11) restricted his results to a zone north of 35°N (9). Angell and Korshover (14) are less conservative and characterize the whole Southern Hemisphere with a small number of upper air stations.

Data reduction

Two basic approaches are used (Figure 1) :

A. Most western authors directly average the station data by selecting approximately equally spaced stations within a specific latitudinal belt from the available network. Anomaly values are then arithmetically averaged within the belt. Unnecessary stations in densely observed areas are omitted.

B. Most russian authors analyze monthly temperature charts, showing interpolated anomaly isolines, produced from all available data. Grid overlays are then applied to the charts and the anomaly values are read at regular latitude and longitude intervals.

Approach A is more objective and thus more desirable over the areas where data is sparse such as the oceans or deserts. Over the remaining land approach B should give more accurate results.

The Study Area

Most authors report their results separately for individual latitudinal belts. The greatest station density and thus the highest data quality is in the northern middle latitudes 40-60°N where the land dominates. Least reliable are the data over the oceans, especially in the Southern Hemisphere.

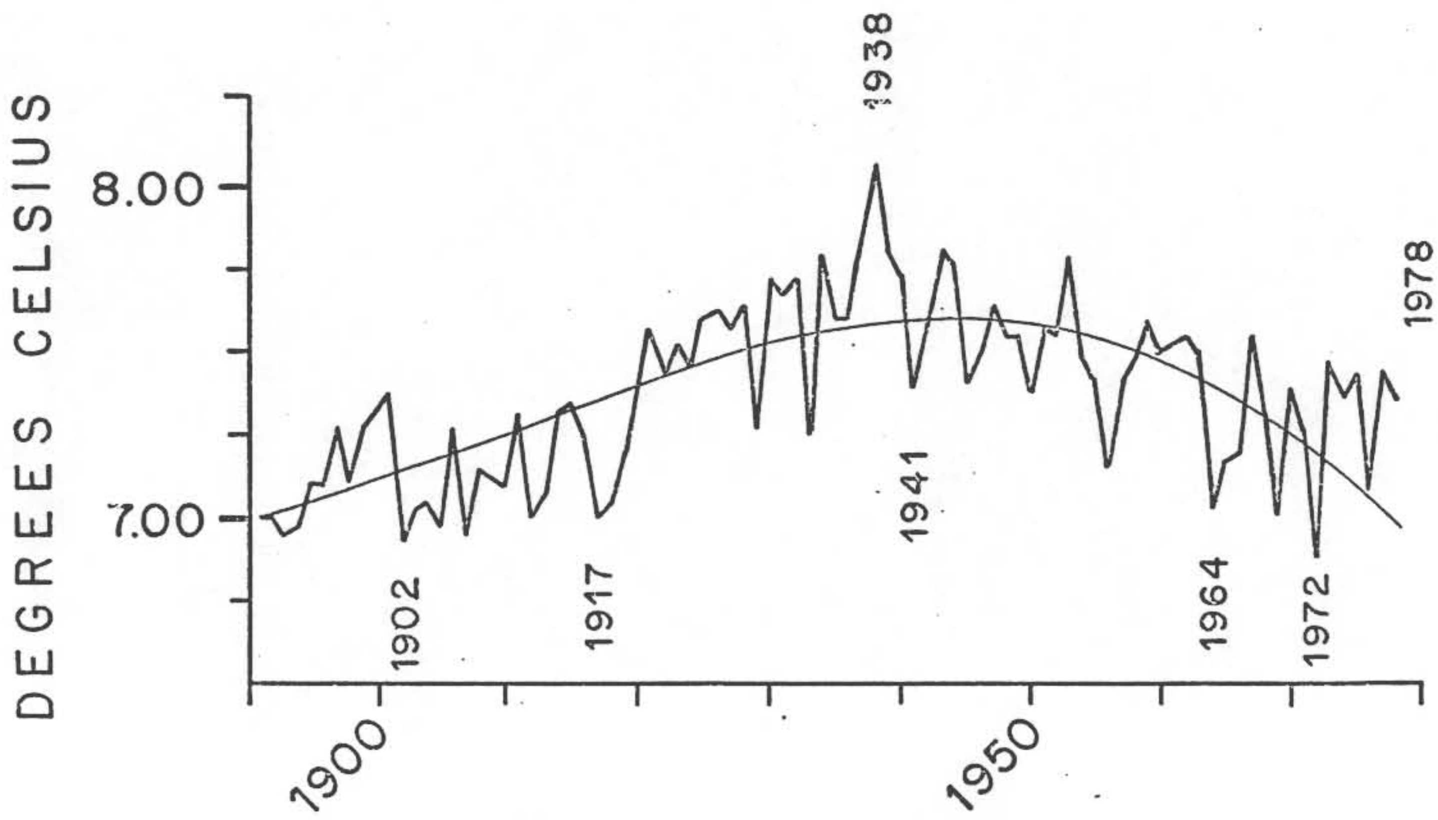

Figure 2 Mean annual surface air temperature in the Northern Hemisphere north of 30°N for 1891 through 1978, projected to sea level. From Gruza and Ran'kova, 1979, (27).

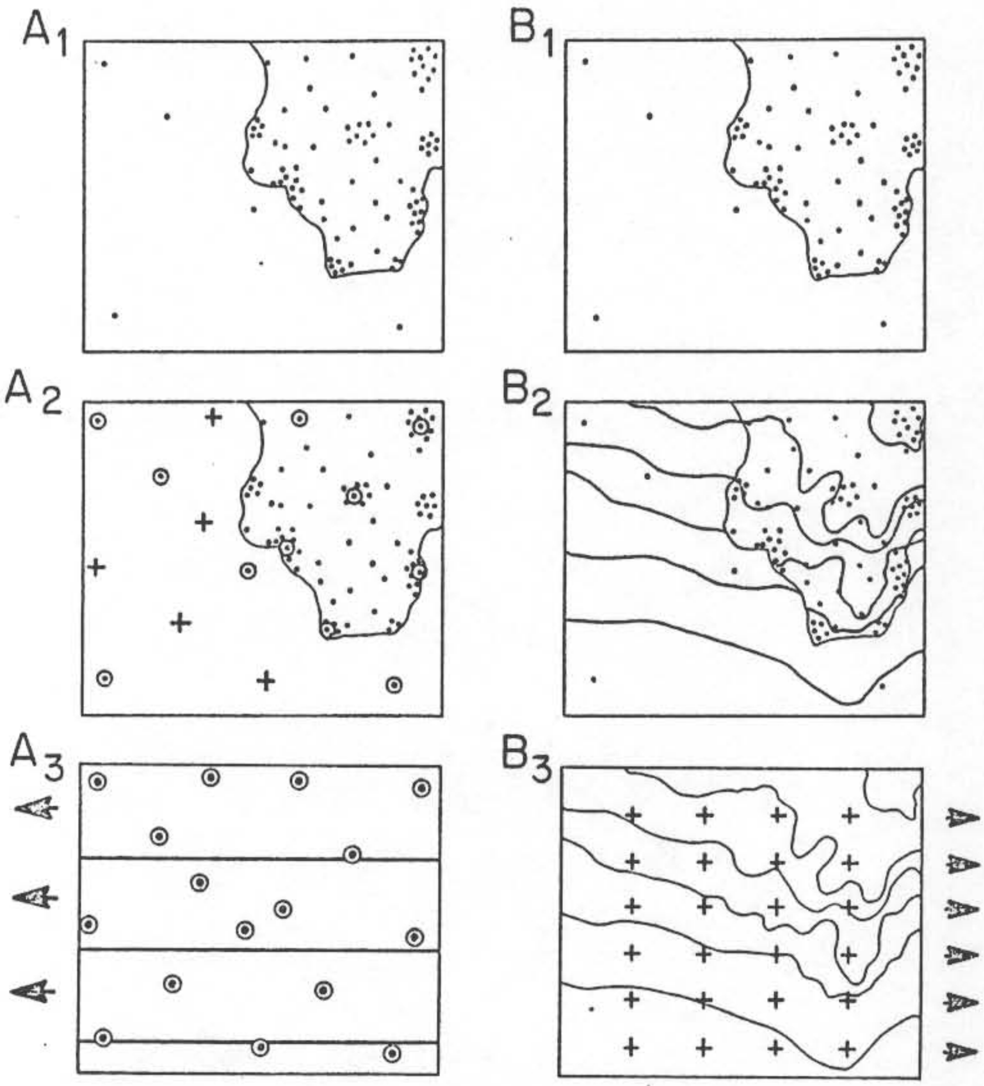

Figure 1 Two methods of spatial averaging temperature data. In A an arrangement of evenly distributed stations (circled dots) is selected from the dense network. Additional data points are interpolated (crosses in A_2) where stations are scarse. Then zonal averages are calculated with observed and interpolated data weighted equally (A_3). In B temperature anomaly isolines are charted (B_2). Anomalies are then read from the map in a regular grid (B_3).

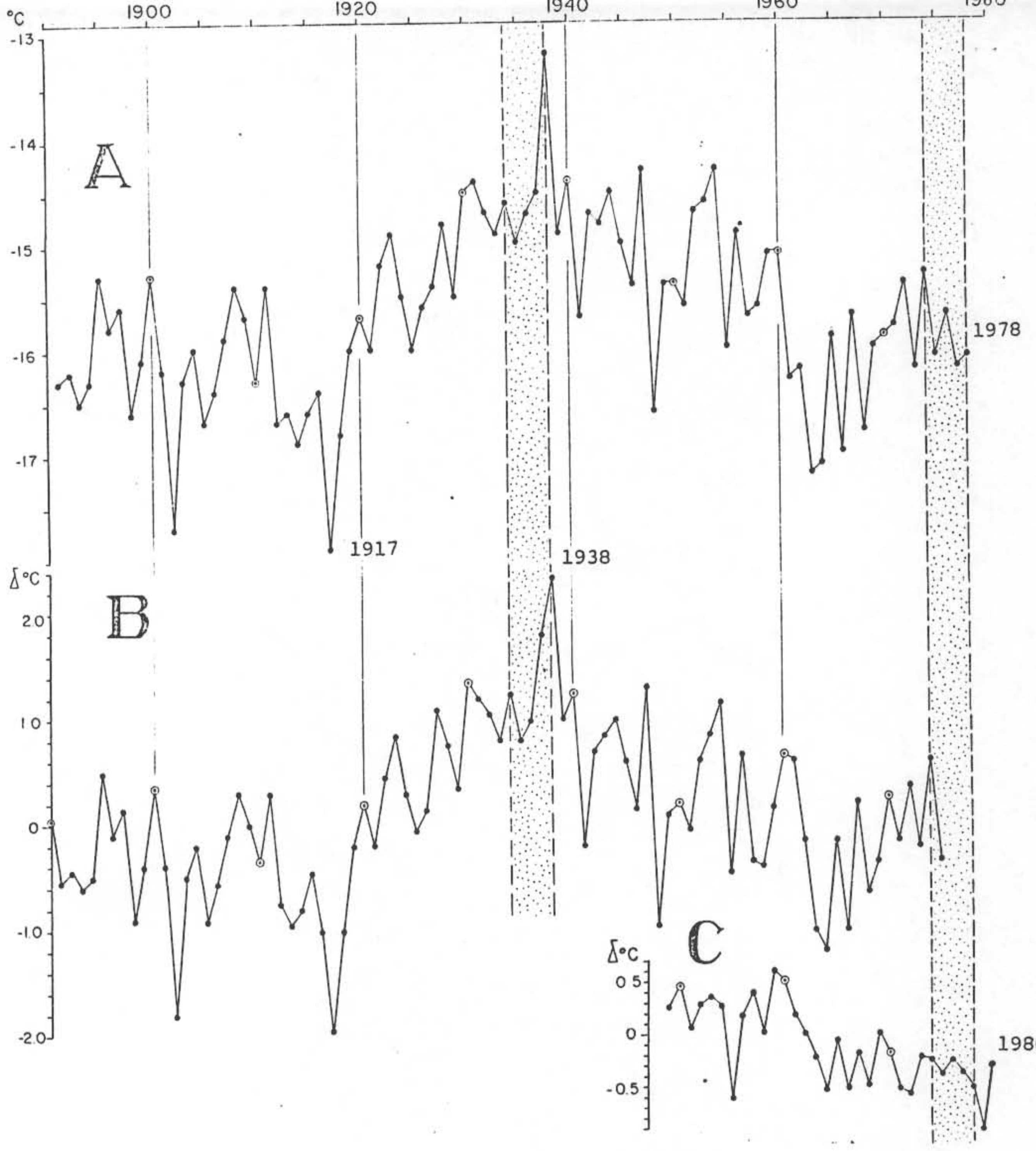

Figure 3 Mean annual surface air temperature in the high latitudes for 1890 through 1978 after A : Gruza and Ran'kova, 1979 (27) and B : Borzenkova et al., 1976 (19). Thickness derived temperature in the high latitudes C from Dronia, 1974 (11, and unpublished). Starting decade encircled. Pentades 1934-38 and 1974-78 stippled. A is the actual temperature in °C for 77.5°N and 82.5°N ; B shows departures in °C for the zone 72.5 to 87.5°N from a longterm normal ; and C is the equivalent temperature change in °C.

Sea Level Corrections

Several authors recently corrected the surface air temperature departures to sea level, attaching less weight to the anomalies at higher elevations where the air density is lower (19,20).

RESULTS

The principal conclusions of Willett (1) and Mitchell (2) on the warming of the Northern Hemisphere in the first half of our century and on the cooling in the second half were confirmed by a number of more recent studies (Figure 2) (18,19,20,27). The year 1938 seems to have been the warmest, at least in the high latitudes (Figure 3) (18,19,20,28,32). There is little doubt that the reversal of the trend occurred in the middle and the high northern latitudes. This conclusion is, however, disputable in the low northern latitudes and in the Southern Hemisphere (22,6).

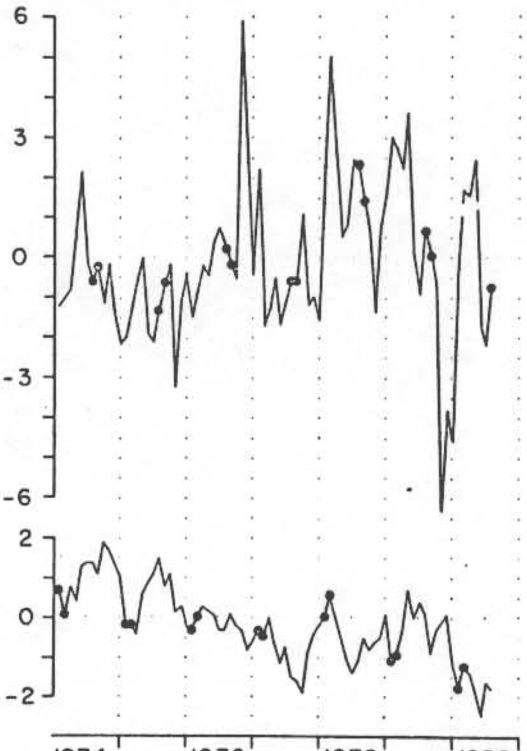

Figure 4 Anomaly of the monthly mean area covered by ice in the Southern Hemisphere (lower curve) and by [illegible] snow in the Northern Hemisphere (upper curve). Departures in % from the mean 1974-78 value. July - August, and January - February in heavy circles.

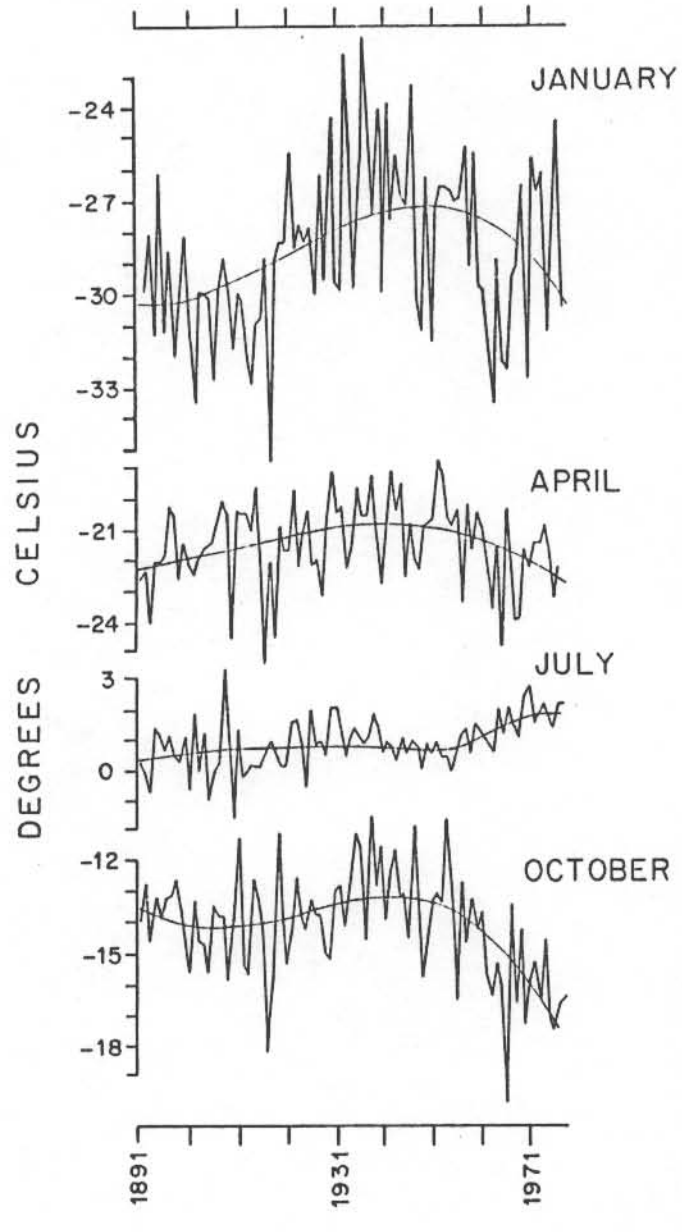

Figure 5 Seasonal breakdown of the temperature changes in the zone along 80°N from Gruza and Ran'kova, 1979 (27). Observe recent cooling in January, April and October, but warming in July.

No record is known from the middle and high southern latitudes to demonstrate the familiar warm peak of the late thirties. On the contrary, Vowinckel and van Loon (29) reported a warming over much of the oceans surrounding Antarctica from the 1930's decade to the post-war decade. Damon and Kunen (30) also claim a warming of the surface air in the Southern Hemisphere in the recent decade.

Our own study of satellite-derived sea ice charts shows an oscillatory decrease of the pack ice area between 1974 and 1980 but a slight increase of the snow cover area on land over the same interval (Figure 4).

One of the more recent reviews of the temperature changes at different levels of the atmosphere, as well as snow and ice cover, was presented by Kukla et al. (9). The multi-authored study compares the temperatures of surface air with the selected areas in the oceans, with the area of the vortex and with the temperatures of the free atmosphere obtained in two independent studies. A cooling of about 0.01 to 0.02°C/year was observed in most of the indicators from the Northern Hemisphere between 1951 and 1975, but mostly warming in the Southern Hemisphere.

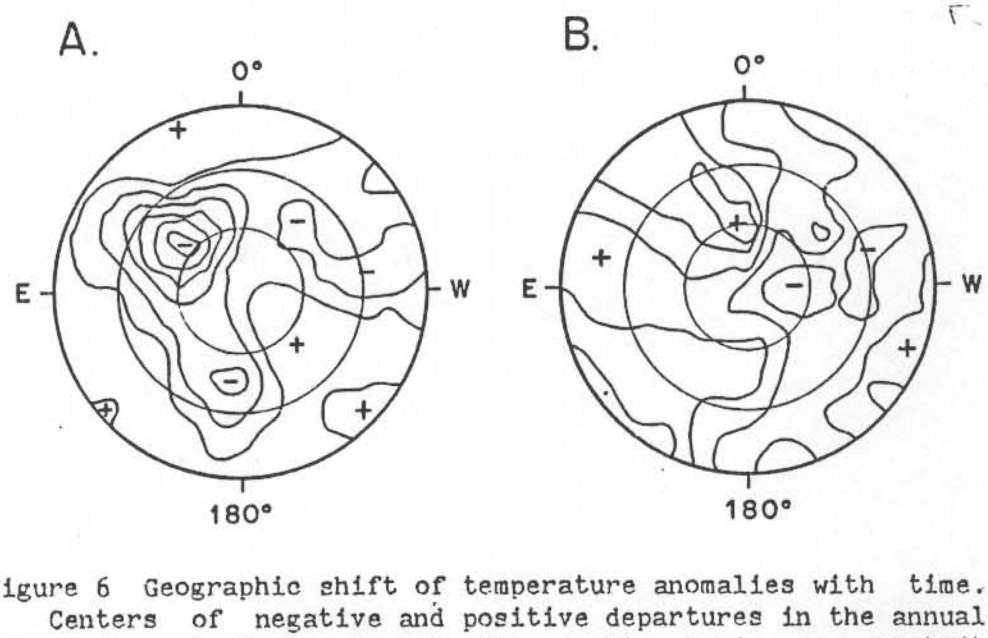

Figure 6 Geographic shift of temperature anomalies with time. Centers of negative and positive departures in the annual surface air temperature in the Arctic basin for 1954-64 (A), and for 1965-1975 (B). A switch of sign is apparent over Siberia. Simplified from Walsh, 1977 (23).

The authors warn that in their study large spatial inhomogeneities were suppressed by zonally averaging the data. The trends found are very small compared to the large temporal and spatial variability of the input data.

Van Loon and Williams (24,25,26) paid detailed attention to the seasonal and geographic structure of the observed temperature trends between 1942 and 1972. Kukla and Gavin (28) compared their results with computations made from Gruza and Ran'kova's data set (27). A remarkable general agreement was found. Especially large negative departures were observed in recent autumns in the Gruza and Ran'kova (27) set (Figures 5 ,7). The month of July in the high latitudes proves to be warmer now than during many previous decades.

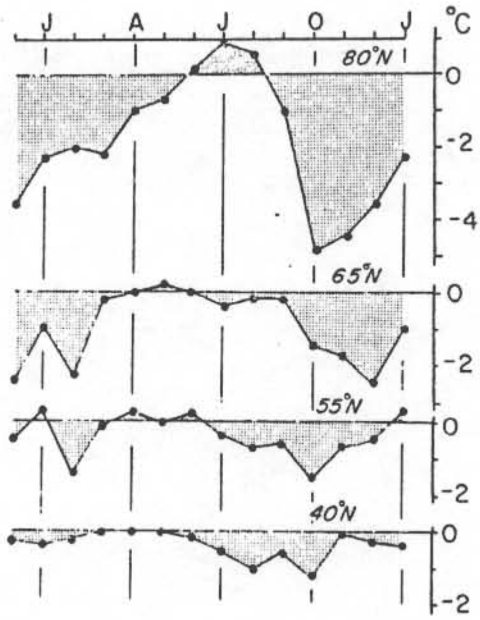

Figure 7 Difference of the mean monthly surface air temperature in 5° latitude wide bands, along selected northern latitudes, between the pentad 1934-1938 and 1974-78. December and January repeated. Observe the cold Octobers in the more recent pentad but warmer July's in the high latitudes.

Much work remains to be done before a clear picture emerges of secular variations in the temperature of the different elements of the climate system on a worldwide basis. Satellite sounding will probably significantly contribute to reaching that goal.

ACKNOWLEDGEMENTS

Thanks to R. Lotti for editing the manuscript, to J. Brown, J. Gavin, G. Jacoby, and L. Burckle for reading the manuscript and for offering helpful suggestions. This research was supported by National Science Foundation Grant ATM80-01470. This is Lamont-Doherty Geological Observatory of Columbia University of the City of New York contribution No. 3120.

REFERENCES

1. Willett, H.C. : 1950, Centennial Proc. R. Met. Soc., pp. 195-206.
2. Mitchell, J.M.,Jr. : 1961, Ann. N.Y. Acad. Sci. 95, pp. 235-250.
3. Kuznetsova, Il. and Nekhocheninova, V. : 1977, Meteorologia i Gidrologia 4, pp. 42-51.
4. Brinkman, W. : 1976, Quat. Res. 6, pp. 355-358.
5. Harley, W. : 1978, Mon. Wea. Rev. 106, pp. 413-416.
6. Yamamoto, R., Hoshiai, M. and Iwashima, T. : 1977, Arch. Met. Geoph. Biokl., Ser. B, pp. 105-115.
7. Dronia, H. : 1967, Meteorologische Abhandlungen 74, pp. 4.
8. Namias, J. : 1970, J. Geophys. Res. 75, pp. 565-582.
9. Kukla, G.J., Angell, J.K., Korshover, J., Dronia, H., Hoshiai, M., Namias, J., Rodewald, M., Yamamoto, R. and Iwashima, T. : 1977, Nature 270, pp. 573-580.
10. Angell, J.K. and Korshover, J. : 1977, Mon. Wea. Rev. 105, pp. 375-385.
11. Dronia, H. : 1974, Meteorol. Rdsch 27, pp. 166-174.
12. Lamb, H.H. : 1961, New York Acad. Sci. Annals 95, pp. 124-161, New York.
13. Dzerdzeevskii, B.L. : 1968, Meteorologischeskie Issledovaniya 16, pp. 252-272, Moscow.
14. Angell, J.K. and Korshover, J. : 1977, Mon. Wea. Rev. 105, pp. 19-25.
15. Wiesnet, D.R. and Matson, M. : 1975, Mon. Wea. Rev. 104, pp. 828-835.
16. Kukla, G. and Gavin, J. : 1979, Glaciological Data Report GD-6, pp. 9-14.
17. Winstanley, D. : 1973, Nature 245, pp. 190-194.
18. Budyko, M.I. : 1969, Tellus 21, pp. 612-619.
19. Borzenkova, I.I., Vinnikov, K.Ya., Spirina, L.P. and Stekhnovskii, D.I. : 1976, Meteorologia i Gidrologia 7, pp. 27-35.
20. Gruza, G.V. and Ran'kova, E.Ia. : 1980, Meteorologia i Gidrologia, pp. 6-17.
21. Faegri, K. : 1950, Centennial Proceedings Royal Meteorological Society, pp. 188-193.
22. Barnett, T. : 1978, Mon. Wea. Rev. 106, pp. 1353-1367.

23. Walsh, J.E. : 1977, Mon. Wea. Rev. 106, pp. 1527-1535.
24. van Loon, H. and Williams, J. : 1976, Mon. Wea. Rev. 104, pp. 365-380.
25. van Loon, H. and Williams, J. : 1976, Mon. Wea. Rev. 104, pp. 1003-1011.
26. Williams, J. and van Loon, H. : 1976, Mon. Wea. Rev. 104, pp. 1591-1596.
27. Gruza, G.V. and Ran'kova, E.Ia. : 1979, Dannye o strukture i izmenchivosti klimata (Data on the structure and variability of climate). Vsesoiuznyi Nauchno-issledovatelskii Institut Gidrometeorologicheskoi informacii Mirovoi Centr. Dannykh, Obninsk. 201 pp.
28. Kukla, G. and Gavin, J. : 1981, Cool Autumns in the 1970's. Mon. Wea. Rev. (in press).
29. Vowinckel, E. and van Loon, H. : 1957, Arch. Met. Geoph. Biokl. 8, pp. 84-102.
30. Damon, P.E. and Kunen, S.M. : 1976, Science 193, pp. 447-453.
31. Barnett, T.P., McLain, D.R., Larson, S.E. and Steiner, E.J. : 1981, Comparison of various sea surface temperature fields. COSPAR/SCOR/IUCRM Symposium "Oceanography from Space", Venice, Italy, 1980.
32. Vinnikov, I.Ia., Gruza, G.V., Zakharov, F.F., Kirillov, A.A. and Kovyneva, N.P. : 1980, Sovremennye izmenednia klimata severnogo polusharia. Meteorologia i Gidrologia, pp. 6-17.
33. Schuurmans, C. : 1981, Central England and De Bilt series. This volume.
34. Flohn, H. : 1981, Long series of temperature and precipitation in Europe. This volume.
35. Santomauro, L. : 1981, Air pollution effects on climate at urban scale. This volume.
36. Namias, J. : 1975, Short Period Climatic Variations, Collected Works of J. Namias, 1934 through 1974. University of California, San Diego, 905 p.
37. Namias, J. : 1980, J. Geophys. Res. 85, pp. 1585-1590.