# Long-Range Forecasting and Climate Research

## The climate of the world

### V — Climate change: the instrumental period

by

**C.K. Folland and D.E. Parker**



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# THE CLIMATE OF THE WORLD
# V - CLIMATIC CHANGE: THE INSTRUMENTAL PERIOD

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C. K. FOLLAND AND D.E. PARKER

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Met O 13 (Synoptic Climatology
Branch)
Meteorological Office
London Road
Bracknell
Berkshire RG12 2SZ

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BY

C K Folland and D E Parker

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# INDEX TO SERIES

# ADVANCED LECTURE No 8

## CLIMATES OF THE PAST. III - INSTRUMENTAL ERA

### 8.1 Summary

The reality and nature of fluctuations in climate in the last 300 years are discussed in the light of the quality and quantity of instrumental data. Emphasis is placed on trying to link the "Little Ice Age" fluctuations with the modern era and on evidence for climate variation over the most recent century.

### 8.2 Introduction

This lecture covers climatic fluctuations on time scales from a decade to a few centuries and bridges the gap between studies of interannual variability and paleoclimatology. The approach to climatic fluctuations in the instrumental period has traditionally differed from the approach to interannual variability, with necessary emphasis on a few long well-documented local or global time-series of data, mainly those of temperature and PMSL rather than on statistical and physical links between atmospheric behaviour in different parts of the globe. The bias remains in this lecture.

### 8.3 Observations of changes in temperature

The beginning of the instrumental period (say the early eighteenth century) coincides with the latter part of the "Little Ice Age" and part of the problem that must be tackled is whether temperature (and atmospheric circulation) have really varied appreciably since that time. Referring back to Fig 7.26, lecture 7, $\delta^{18}O$ measurements from tree rings in W. Europe at least suggest a rise of winter/early spring temperature since the late seventeenth century, exceeding 1°C up to 1940. Of equal interest is a marked increase in temperature in 1720-1740 which quickly reversed. Fig 7.26 also showed temperatures for January - March in Central England for the period after 1700. Central England Temperature (CET) is the longest available, mostly instrumental, temperature series and we shall first look at CET in detail.

#### 8.3.1 Central England Temperature and the problems of homogenising ancient thermometer readings

A fundamental problem in constructing a local time-series is to ensure that the data are as temporarily homogeneous as possible: in other words, that a given meteorological reality has always resulted in the same value in the series. Only to the extent that this is true can the series be used to make reliable deductions about local climatic fluctuations. A time series of temperature in a restricted locality may, however, reflect fluctuations of climate on a larger scale as local temperature is sensitive to much larger scale changes in atmospheric circulation.

Manley (1974) constructed a monthly temperature series for Central England and a smoothed updated series (Storey, Folland and Parker (1985)) is shown in Figure 8.1. Manley chose to represent an area, rather than to reduce his series to a single point, because of the scattered locations of most of the early observations, and because the only concentrated observations were in London and thus were eventually affected by heating resulting from urban expansion. He adjusted the monthly data to compensate for the following variables:

i) Different times of observation: the traditional mean temperature computed as $^1/_2$ (max + min) differs from eg the mean of 8 am and noon, by amounts which vary with season but can be estimated from modern data. The problem of different observation times can be quite acute when studying very long time-scale temperature changes.

ii) The change of calendar in September 1752 when 11 days were omitted in that month. Daily data facilitated this adjustment.

iii) Housing of thermometers: in the 18th Century this was often an unheated north-facing room attached to a house; in later years, use was often made of either north-wall observations, or of Glaisher screens, which preceded Stevenson screens. The problem of changing thermometer screens may be a serious problem which has probably never been adequately investigated.

iv) Types of thermometer: pressure corrections were needed for early thermometers which consisted of a U-tube with one open end. Also different scales had to be converted to modern units. Unreliable instruments were excluded from Manley's compilation.

v) Geographical region and site: Manley found from modern data that so long as frost-hollows and other unrepresentative sites are excluded, the monthly deviations from a long-term average, or the successive differences between months of the same name, are almost uniform for English inland stations. Thus he could work with temperature differences rather than absolute temperature values, and produce a single series from overlapping records at sites scattered through much of England. This technique also aided cross calibration of early temperature scales and the effects of changing observing time and instrumentation.

Manley checked his compilation against a series for Utrecht (Holland) and found good agreement. Also, in periods of sparse data he noted observations of wind direction and snowfall.

It can be seen from Manley's series (Fig 8.1) that, except in summer, much of the 20th Century in Central England has been warmer than the previous 250 years: the peak warmth was in the mid-20th Century except in winter when it was earlier. The late 17th Century was particularly cold, corresponding to the supposed peak of the "Little Ice Age". There was notable warmth in the 1720's and 1730's however. These features are also found in instrumental temperature series for Utrecht and for other locations in Northwest Europe. Other major features are the warming in October between 1890 and 1975 and the sharp cooling in April in the past 25 years.

Fig 8.2(A) shows a power spectrum analysis of the unsmoothed annual mean CET data from 1659-1975. The most significant peak is labelled 76 years and mainly reflects the temperature fluctuations between about 1890 - 1975 and 1700 - 1770. (bottom diagram of Fig 8.1). Fig 8.2(B) shows a power spectrum reported by Lamb (1972), due to Siren, of tree-ring widths in N. Finland which mainly reflect summer temperature (it is thought). The shape of Figs 8.2(A) and 8.2(B) are surprisingly similar with more power in Fig 8.2(B) at the 70-200 year time scale presumably because of the longer (497 year) data series. The 23 year peak, like the 76 year peak, is statistically significant (using an "F" test) and has sometimes been linked with the "double sunspot" cycle of magnetic activity on the sun. (The double sunspot cycle is constructed from the sunspot series shown in lecture 3 by reversing the sign of the values in the sunspot series between alternate sunspot cycles (which have opposite magnetic polarity)). Fig 8.3 (Folland (1983)) shows that a band-pass filtered time series of annual CET whose filter function is centred on the 23 year time scale bears no consistent long-term phase relationship with the double sunspot cycle. Indeed the 23 year peak disappeared after 1880 whereas the double sunspot cycle increased slightly in amplitude. Nevertheless the true origin of this CET fluctuation and the reason for its disappearance is of interest. The meaning of power spectra such as Fig 8.2 can only be gradually uncovered by a worldwide study of temperature and circulation fluctuations as improved data and physical understanding permit. A clue to some of the variations of CET may come from the diagram shown at the end of lecture 4; there it was suggested that a century-time scale fluctuation in the temperature of Lamb westerly types in Central England over the last century may be related to parallel fluctuations in N. Atlantic SST (see also section 8.8).

Fig 8.4 shows an attempt (Lamb (1972)) to estimate Central England temperatures back to the beginning of the Medieval "climatic optimum" including assessments of their uncertainties. Prior to 1680, the temperatures have been derived from a mixture of botanical and documentary evidence. A clear minimum in mean annual and winter CET is suggested around 1600 - 1700 with winter temperatures in the period 1900-1950 similar to those during the "Medieval optimum".

8.4 Possible effects of urban heating on temperature records

The possible undesirable effect of urban heating on long time series of temperature, mostly avoided by Manley, is illustrated for Paris in Figs 8.5(A) and (B) (after Dettwiller (1978)). Central Paris has warmed by 1°C since 1900 when its temperature is compared with that of the surrounding countryside; much of the warming has been in the minimum temperatures as is typical of urban heating. Studies like that of Dettwiller can only be used to correct urban data if long series of homogeneous rural data exist. The problem of the effects of urbanisation is serious as many long temperature series have been kept in what are now large cities; Fig 8.6 compares a long time series of annual mean temperature for Vienna with that for an observatory on a low mountain in S. Germany (Hohenpeissenberg) 600 km to the west. (Angell and Gruza (1984)). A relative warming of Vienna since 1920 appears to have occurred but it is not easy to determine if urbanisation is the main cause. The higher frequency fluctuations tend to be in phase however and a very long period temperature fluctuation with a flat minimum around 1880-1890 is common to both series; the period around 1800 is relatively warm though, unlike in Central England.

## 8.5 Hemispheric Temperature Fluctuations

Hemispheric scale air temperature variability, mainly over land, has received increased attention in recent years despite the problems cited above. Fig 8.7 shows the variations in mean annual N. Hemisphere air temperature (mainly but not wholly over land - but no ship data is included) from two authors: Vinnikov et al (1980) for 1881-1978 and Jones, Wigley and Kelly (1982) (JWK) for 1881 - 1981. Vinnikov et al's analysis only extends to 17.5°N. However the correlation between the two hemispheric series is 0.97 (Angell and Gruza (1984)). Of interest is the fact that the interannual variability of hemispheric temperature is much less than that for local series like Vienna, Hohenpeissenberg or the unsmoothed Central England series (mean year to year variation of hemispheric temperature is about 0.15°C compared to 0.8°C in the Vienna and Hohenpeissenberg series). Despite this, the (decadally-averaged) century time-scale fluctuations are comparable, being in the range 0.5°C - 1°C.

The reality of a coherent long time-scale N. Hemisphere temperature fluctuation this century is suggested by Figs 8.8(A) and (B), taken from Jones and Kelly (1983). The warming between 1917-1939 is quite coherent over mid and higher latitudes (Fig 8.8B); also the Arctic series is rather like that for the N. Hemisphere as a whole but with larger amplitudes of fluctuation. Groveman and Landsberg (GL) (1979) used regression formulae relating a near-hemispheric grid-point data series of N. Hemisphere air temperature which had been previously constructed by Borzenkova et al, (1976) to temperature values constructed for a few very long-period stations. These series had to be based on a mixture of botanical and documentary data in the pre-instrumental era. In this way a continuous N. Hemisphere temperature series was estimated back to 1579 (Fig 8.9). Confidence limits for the series are shown and are comparable to the magnitude of the climatic changes suggested by the series. Nevertheless, a cold period around 1600-1700 is suggested in common with European series, with a hint of warmth in the 1730's. The large temperature fluctuation in the first half of the nineteenth century is less expected but the early twentieth century warming (based on instrumental data) is clearly visible in GL's series and is comparable in magnitude with that of JWK or Vinnikov et al.

## 8.6 Can we believe the evidence concerning land surface temperature changes?: the associated circulation fluctuations

### 8.6.1 Atlantic Sector

The chief evidence for circulation fluctuations in the last few hundred years comes from the Atlantic sector and is to be found in:-

(a) diaries kept by careful observers of wind direction and weather.

(b) Since the eighteenth century, we have many measurements of pressure at station level.

One of the most interesting and lengthy series of type (a) was put together by Lamb (1972), (of necessity rather subjectively), (Fig 8.10), and shows variations in the frequency of south westerly winds in S.E. England.

A relatively low frequency of south westerly winds during much of the 17th century and a peak in the 1730's is in accord with the variations in CET (i.e. outside the summer season; in summer, the level of CET is not well-related to the frequency of south westerly winds). A minimum frequency of south westerly winds has been confirmed for a few years in the late 18th century by Kington (1980) who has constructed daily weather maps for the period 1781-86. At this time, due to a briefly successful interlude of international cooperation, a well-distributed network of pressure observations was made in Europe. Lamb and Johnson (1966) have also constructed monthly-mean PMSL charts for the N. Atlantic for January and July since 1750, and in later years, for much of the N. Hemisphere.

The most convincing evidence of a circulation fluctuation (in winter) in the N. Atlantic sector over the last century is probably provided by Fig 8.11(A). The data from the two stations shown are of good quality, have been carefully scrutinised and both are situated near sea-level. They provide an index of Atlantic circulation where the strength (or location) of the mid-latitude N. Westerlies is reflected by the size of the difference in PMSL between the Azores and Iceland. The long-term trend in this index in winter roughly parallels the trend of Manley's CET; greatest warmth in the winter parallels the strongest westerlies earlier in this century, but correspondence is somewhat poorer in the late 19th Century. Fig 8.11(B) shows variations in a more subjective index: that of Lamb "Westerly" types over UK which were introduced in Lecture 1 (from Lamb (1977)). Allowing for differences in the location and definition of the indices, (UK is 30°E of Azores and Iceland) Fig 8.11(B) is acceptably similar to Fig 8.11(A) though some details do differ.

Focussing on a shorter period, Fig 8.12 shows differences in PMSL during January over the N. Hemisphere between 1951-70 and 1901-30 taken from Folland, Parker and Newman (1985). Some of the differences will not be reliable but most of those over the N. Atlantic between 20°N and 75°N should be. In the period 1901-30, a very strong mid-latitude south westerly wind anomaly (of magnitude 3-4 m/s over Scotland) existed in January relative to 1951-70. Scrutiny of Fig 8.1 (where the 20 year running mean of CET is plotted against the last year of the 20 year period) shows that between 1911-30, January CET averaged about 1.2°C higher than in the latter period. 1.2°C is a large change in mean temperature; e.g. during the recent 30 year period (1951-80) a month with an anomaly of 1.2°C from the mean is just enough to place that month into the top 20% of the January temperature probability distribution. The larger warming in October between 1890 and 1975 can be shown to be partly due to an increase in the frequency of south westerly winds in that month. The warming is so large that a very mild month (top 20% of the ranked distribution of October temperatures in the period 1870-1900) could easily have the same temperature as a rather cold month (bottom but one 20% of the 30 year ranked distribution of October temperature) in the period 1951-80. The sharp cooling in April since 1961 has been associated with a strong increase in blocking and thus in east-north-east winds in that month. So (mainly) as a result, there have been no very warm Aprils in Central England since 1961.

### 8.6.2 Evidence of Circulation variations on the global scale

A comprehensive analysis of all available quality-controlled PMSL data on land and at sea has yet to be carried out. However the potential value of such analyses is suggested by Fig. 8.13 taken from Tan and Yasunari (TY) (1983). TY analysed July PMSL over much of the globe using station, including island, data but excluding the Atlantic Ocean sector 0-60°W. The data was analysed into a grid point format. Fig 8.13 (A) shows the first two eigenvectors (EOFs) of an EOF analysis of 11 year running mean PMSL data; this averaging time-scale was chosen to highlight the long time-scale variations. The first EOF (31% of the variance) is negative north of about 20°N and positive to the south; the time series suggests a progressive reduction of PMSL in the S. Hemisphere relative to the extratropical N. Hemisphere over the last century with a temporary halt to this tendency between about 1900 and 1930. Fig 8.13(B) shows the second EOF (19% of the variance), a variation of PMSL between the Pacific and Indian Ocean on the one hand and the surrounding continental areas on the other. Relatively low pressure over land and high pressure over the oceans is suggested in the late nineteenth century and mid-twentieth century, with a reversed pattern around 1900-1920. Both eigenvectors are clearly dominated by century time-scale variations. Could these PMSL eigenvectors reflect century-time scale fluctuations in relative air temperature between continents and oceans or even between whole hemispheres? It must be emphasised though that away from the mid latitude N Atlantic region most existing grid point data sets of PMSL must be viewed with great caution. Parker (1980) has shown that substantial disagreements exist, especially over the N. Pacific, between several well-known N. Hemisphere PMSL data sets, (TY's data set was not tested), of sufficient magnitude to obscure past real circulation changes in some regions unless they have been large. Other authors have shown that PMSL data sets have been subject to sudden, unrealistic, changes in the mean value of derived PMSL over some mountainous regions and are e.g quite unreliable over the Canadian and Siberian Arctic prior to about 1930.

### 8.7 Changes in Troposphere and Stratosphere Temperatures

These data series are generally too short to indicate much about climate change; the series are presently much more useful for studying interannual variability, especially the effects of El Nino, for which the data have yet to be fully exploited. Radiosonde data are unfortunately subject to severe problems of changing instrumental biases, especially upper atmosphere temperature measurements; biases vary between countries and therefore may be geographically variable. This problem results from a combination of changes in instrumentation and changes in correction procedures. The main difficulty has been the need to compensate adequately for solar heating of radiosonde thermometers; the problem is acute in the lower stratosphere. Fig 8.14 shows time series of fluctuations in tropospheric and stratospheric temperature reported by Angell and Gruza; the N Hemisphere stratospheric changes at 26-55 km are far too large to be due to the expected cooling influence of increasing carbon dioxide. It is possible that a careful synthesis of these data and surface data may become feasible in the next few years.

## 8.8 A recent study of climate variations using worldwide SST and Night Marine Air Temperature (NMAT) Observations

The first reasonably comprehensive analysis of worldwide SST and MAT, including attention to the problems of data quality, especially those due to changing measurement biases, has been carried out by Folland, Parker and Kates (1984) and Folland, Parker and Newman (1984). They used the Meteorological Office Historical Sea Surface Temperature data set (MOHSST) (see Minhinick and Folland (1984)) and the corresponding night marine air temperature data set (MOHMAT) (Parker 1984). Folland, Parker and Kates (1984) discuss the problems of the changing biases in the SST and MAT observations; the biases in the latter were reduced by only using night-time observations of air temperature, thereby eliminating most of the problems due to heating of the ship's fabric in bright sunshine. Despite the fact that problems are known to still exist with these data, the apparently reasonable agreement between variations in SST and in MAT on many time and space scales has suggested that useful information about climate change over the oceans can be obtained from them. Fig 8.15(A) indicates the amount of data available and Fig 8.15(B) gives an idea of the worldwide SST (or NMAT) data coverage in the 1870's; nowadays data are reasonably complete on a seasonal time scale north of 45°S except west of Chile and in parts of the Tropical central Pacific.

### 8.8.1 Main Results of the Marine Analysis

Fig 8.16(A)-(D) shows the main results on the global space scale. Fig 8.16(A) shows the SST and NMAT time series before correction; the data are expressed as anomalies from a 1951-60 average. The main correction to the NMAT data concerned compensation for a progressive increase in the heights of screens above the ocean surface as ships have become larger. In addition, pre-second world war SST data were too cold due to the predominant use of canvas or leather buckets to collect sea water which suffer from evaporative cooling on the time scale of the SST measurement procedure. Fig 8.16(B) shows the series after correction. A century time-scale fluctuation in SST and NMAT is indicated of range about 0.5°C - 0.6°C; part of the superimposed "noise" is related to the influence of El Nino (see lecture 5). Fig 8.16(C) shows that the time series of SST and NMAT anomalies have a remarkably similar shape in all calendar seasons (or months); this is similarly true for most regions of the world. The development of EL Nino tends to be locked to the seasonal cycle and the increased interannual variance of global SST and NMAT between October and March in Fig 8.15(C) would be expected as a result. Fig 8.16(D) shows a comparison of corrected NMAT averaged over the N. Hemisphere and a digitized version of Jones, Wigley and Kelly's land surface temperature data. After 1900 the agreement is very good, surprisingly so perhaps as:-

(a) The data are completely independent in origin and
(b) largely independent in the areas they represent.
(c) the surface ocean air temperatures show the same interannual and long-time scale magnitudes of variation as those on the land, a result not expected by some authors due to the thermal inertia of the oceans.

Fig 8.17(A) shows zonally and decadally averaged changes in SST between 1856-1980 (anomalies expressed from a 1951-60 average). Relatively warm conditions at most latitudes are suggested around 1861-1875 (data was sparse but widely spread) followed by a slow cooling. A more rapid cooling followed in the N. Hemisphere between 1891-1910, especially in middle and sub-tropical N. Hemisphere latitudes. Warming then commenced in all latitudes with peak warmth around 1950. After 1951-60, cooling occurred in the N. Hemisphere until 1971-80 but further slight warming is evident in the S. Hemisphere. Interestingly, in the light of the PMSL analysis in Fig 8.13(A), the S. Hemisphere was relatively coldest compared with the N. Hemisphere around 1871-1880 and relatively warmed until about 1891-1900 with only slow relative warming thereafter. After a sharp relative cooling around 1930-50, further relative warming started. Despite the limitations of both Fig 8.17(A) and the non-global coverage of Fig 8.13(A), a direct link between the SST and PMSL changes is possible as relative warming of one hemisphere should cause its PMSL to fall relatively to the other hemisphere. Fig 8.17(B) shows the worldwide SST anomalies in the coolest decade, 1903-12, compared with 1951-60, which was (probably) the warmest decade. The worldwide nature of the century-time scale SST fluctuation is brought out, with smallest changes in the Tropical central and W. Pacific and largest (reliable) changes in the tropical and sub-tropical Atlantic.

Fig 8.18(A) shows the first correlation eigenvector, EOF1, of seasonal 10° x 10° area SST anomalies calculated between 1901-1980. This eigenvector accounts for about 11% of the variance of SST on the 10° x 10° space scale measured in all areas; Fig 8.18(B) compares the time series of this eigenvector with that of the global, seasonal, SST anomalies shown in Fig 8.16(B). The correlation is over 0.9. (The arrows point to years judged to experience an El Nino warming event). EOF1 indicates that relative to the local variance of SST, the largest long time scale changes in SST have occurred in the tropical and subtropical Atlantic, in the N. Indian Ocean and near Japan. Only a small region near Greenland has fluctuated with a weak opposite phase to that of the remainder of the world, i.e. the long-term variations have probably been truly worldwide. In fact individual time series of most individual 10° x 10° areas show a common long time scale SST or NMAT fluctuation of similar phase in all seasons.

Fig 8.19(A) shows maximum entropy power spectra of SST and NMAT for the Northern and Southern hemispheres for 1861-1980. The dominant peak in the N. Hemisphere represents the century time-scale fluctuation; in the Southern hemisphere this peak is large but shorter time scale fluctuations in the period range 2.5-10 years are more prominent - mainly related to El Nino. The peak near 17 years (SST) or its equivalent near 20 years in NMAT is unexplained but merits investigation. Fig 8.19(B) shows a spectrum of global SST between 1951-80 when long-time scale fluctuations (averaged over the globe as a whole) are not very evident. ENSO-related fluctuations dominate the spectrum though the 8-10 year time scale fluctuations, prominent in the original time series, are not clearly only the result of successive ENSO events. Fig 8.20 highlights the relative changes in S. and N.Hemisphere SST (effectively on a 5-10 year time scale). The relative warming of the Southern Hemisphere since about 1960 is shown and currently exceeds 0.3°C or over half the range of the long term trend in global SST.

Figs 8.21(A) and (B) suggest a possible link between the long term trend in land and ocean surface temperatures and recent fluctuations of some European glaciers, despite the complexity of the climatic factors that influence individual glacier advances and retreats. Figs 8.21(A) and (B) show that the percentage of advancing and retreating glaciers in

Switzerland (derived from a large sample and quoted by Untersteiner (1984)) and variations in N. Atlantic SST north of 35°N seem to be related. Autumn was chosen as being the most critical season affecting glacier advances and retreats though in the N. Atlantic all seasons show broadly similar SST fluctuations. The advance of the Swiss glaciers in the early twentieth century seems to correspond with the cool period in the N. Atlantic (and over the globe) around 1900-1915; the subsequent retreat peaked around 1950 again seems to be nearly phase locked to the variations of SST. Most convincing is the recent advance that corresponds well with the fall in N. Atlantic SST up to about 1980. The changes in SST may not of course be the direct cause of the glacier fluctuations - both may be the result of a third common factor.

## 8.9 The Sahel Drought

The Sahel drought has been a special theme of these lectures. So it is perhaps fitting that we should complete the trilogy of lectures on climatic variations with recent evidence that the drought is not just a regional phenomenon but seems to be related to large scale changes in atmospheric circulation and possibly of SST. Fig 8.22 repeats for convenience the graph, due to Nicholson (1985) of Sahel rainfall anomalies shown in lecture 1. Fig 8.23(A) and (B) show for July and August separately maps of PMSL differences for the N. Hemisphere derived from the Met O 13 grid point PMSL data set for the most recent dry Sahel period (1968-84) minus the wet period (1950-59). The two maps are remarkably similar and the regions of difference that are statistically significant at the 5% level (shaded) cover similar areas. These areas total about 25-35% of the N. Hemisphere north of 20°N, the southern limit of the analysis. The chance area is about 5-7%. Except near the Himalayas, the central N. Pacific and over Greenland, the PMSL changes should mostly be reliable. The largest changes occur near Scotland; as a result, rainfall averaged over England and Wales (EW) in July and August has been declining since about 1955-1960 with a small reduction in June also. Fig 8.24 shows unsmoothed standardised (EW) rainfall totals for July and August since 1901. The possible link between the Sahel drought and UK drought is heightened by the fact that since 1975 four of the 11 driest summers (June-August) recorded in EW since 1767 have apparently occurred. The EW series used is due to Wigley et al (1984). The summers include the driest (1976) and second driest (1983). (1984 was probably the sixth driest). Recent work (Folland, Palmer and Parker (1986)) has shown that recent hemisphere scale SST changes (which have been considerably larger in the N and S Atlantic sector) are related to the Sahel drought. This possibility is currently being explored using the Meteorological Office 11-level AGCM. Rowntree and Bolton (1983), in an investigation of the effects of large scale soil moisture deficits over W. Europe in summer, have provided evidence from experiments with the Meteorological Office 5-level AGCM of a possible positive feedback between dry conditions over W. Europe and over the Sahel; (the fundamental cause of dryness in either region would have to lie elsewhere however). The feedback is conceivable as a drier than normal origin of the N.E. trade winds that converge toward the W. Africa ITCZ near 20°N in July and August could play a part in further suppressing deep convection just to the south.

### 8.10 Conclusion

The nature, even the real existence, of climate change and variation in the instrumental era is only now being exposed. As yet, except for the role of El Nino, there are few convincing explanations of the observed fluctuations but the role of the oceans is likely to be crucial on most time scales. Meanwhile a wide-ranging critical review of current evidence for climate change in the instrumental period has been prepared by Ellsaesser, MacCracken and Walton (1986); it is recommended as providing an excellent summary.

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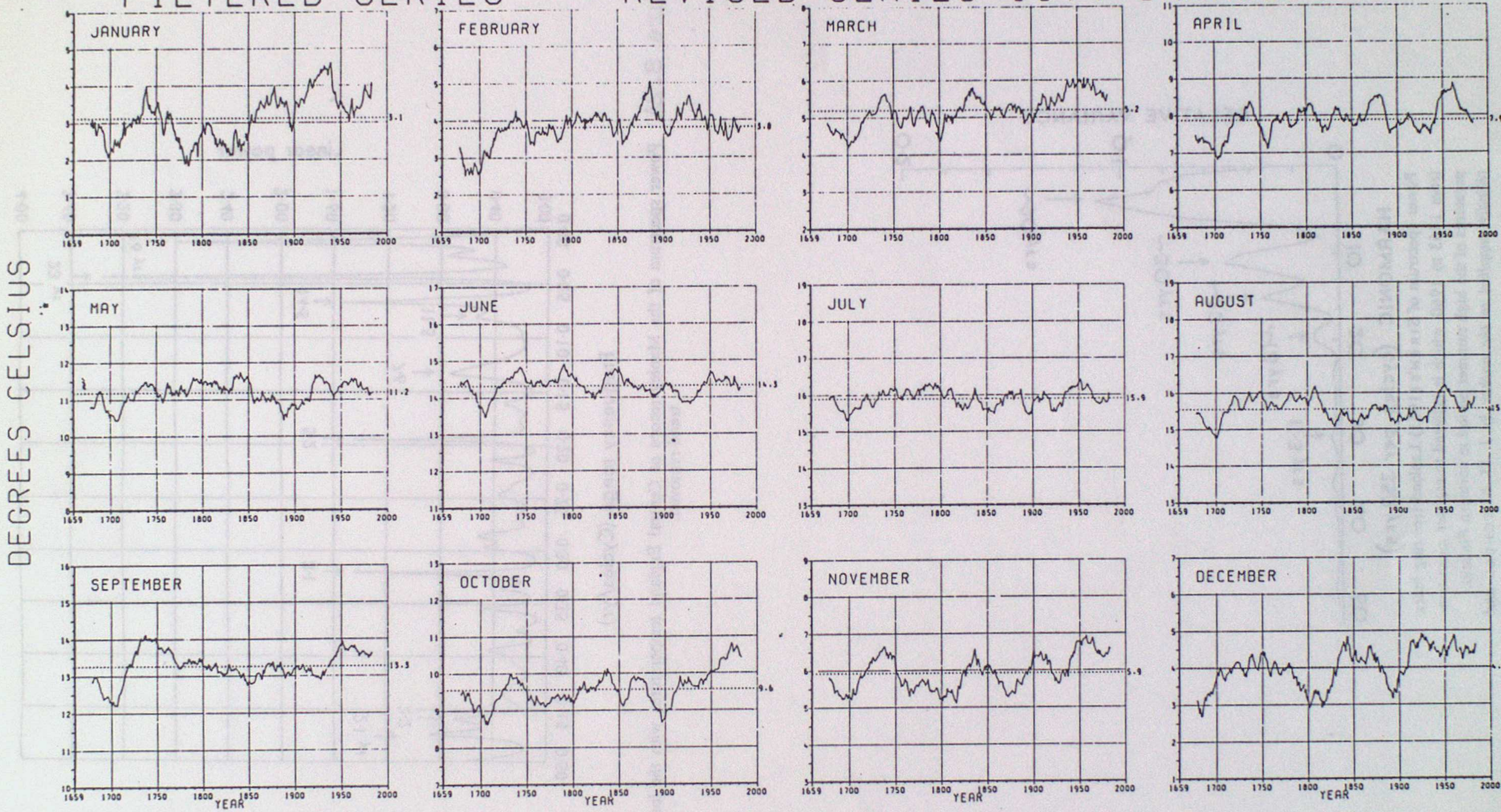
Figure 8.1

# CENTRAL ENGLAND TEMPERATURE 1659 TO 1983

## FILTERED SERIES    REVISED SERIES 1974 ONWARD



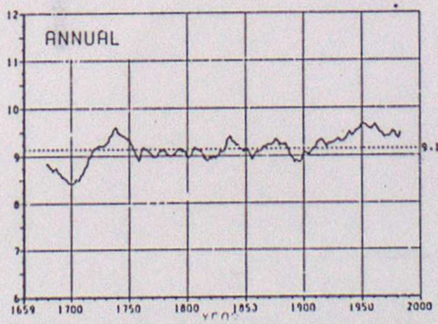

NOTES

MEANS PLOTTED AS BROKEN LINE

RUNNING MEANS PLOTTED ON FINAL YEAR OF SAMPLE

20 WEIGHTS WERE USED COMMON VALUE 1.0

Values up to 1973 from Manley (1974)



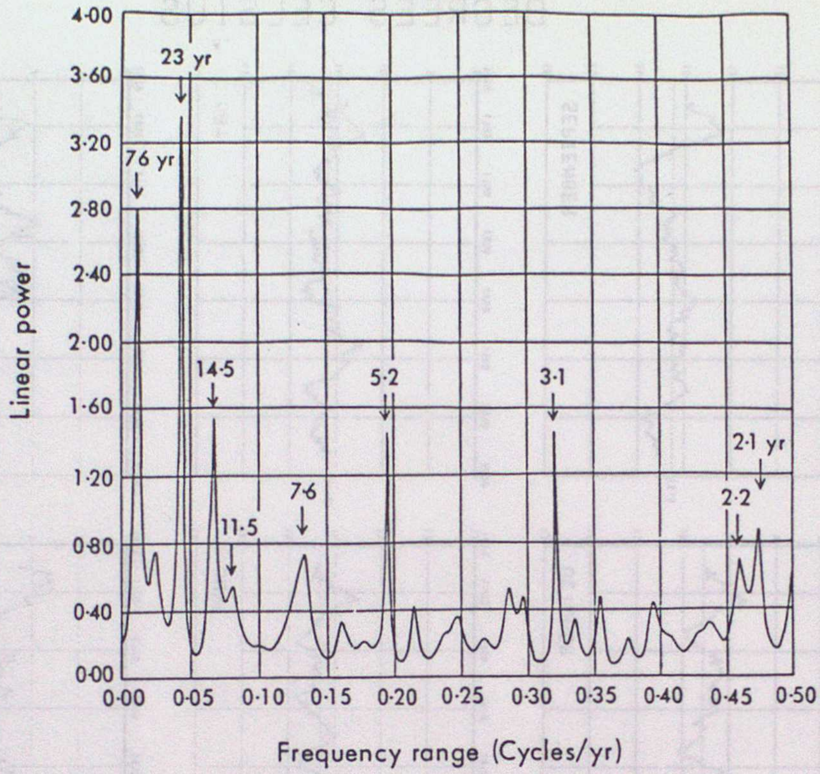
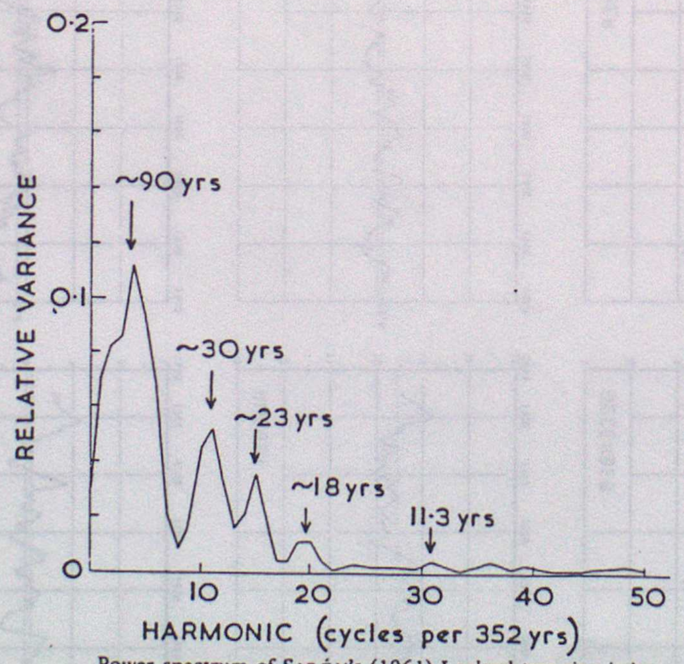
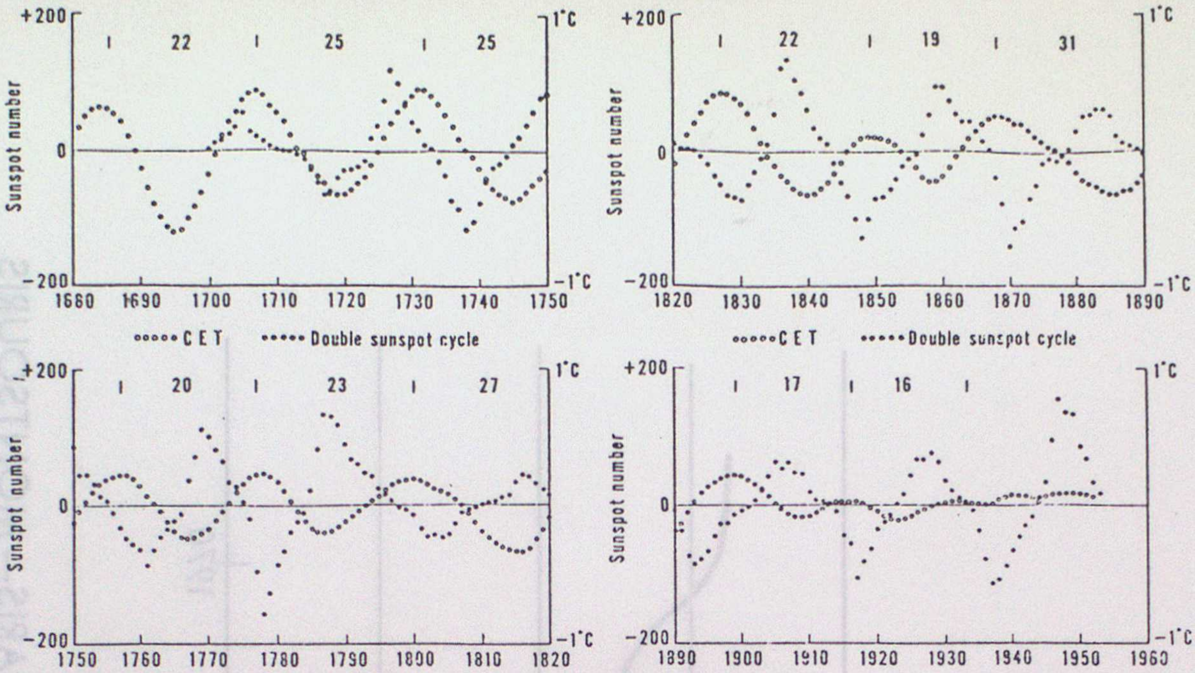



Figure 8.2A Power spectrum of the Manley record of Central England temperatures with the long-term trend removed.



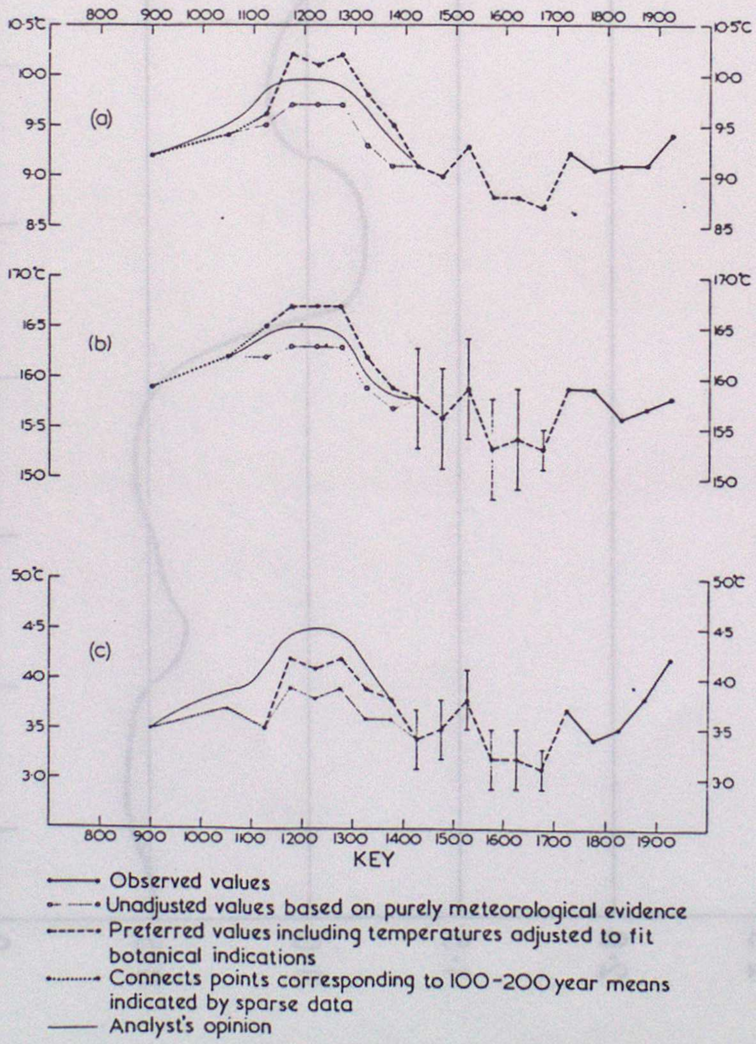

Power spectrum of SIRÉN's (1961) Lapland tree-ring index from 1463 to 1960, which is believed to register mean temperatures of the high summer period in northern Finland. (*Kindly supplied to the author by* J. M. MITCHELL *and reproduced by permission.*)

Figure 8.2B From Lamb (1972)




The '23-year' wavelength band-pass filtered series of annual mean Central England Temperature and the 'Hale' or double-sunspot cycle.

Figure 8.3 From Folland (1983)




Temperatures (°C) prevailing in central England, 50-year averages:

(*a*) Year

(*b*) High summer (July and August)

(*c*) Winter (December, January and February).

Observed values from 1680, as standardized by MANLEY. Values for earlier periods as derived by LAMB (1965). The ranges indicated by the vertical bars are three times the standard error of the estimates.

Figure 8.4 From Lamb (1972)

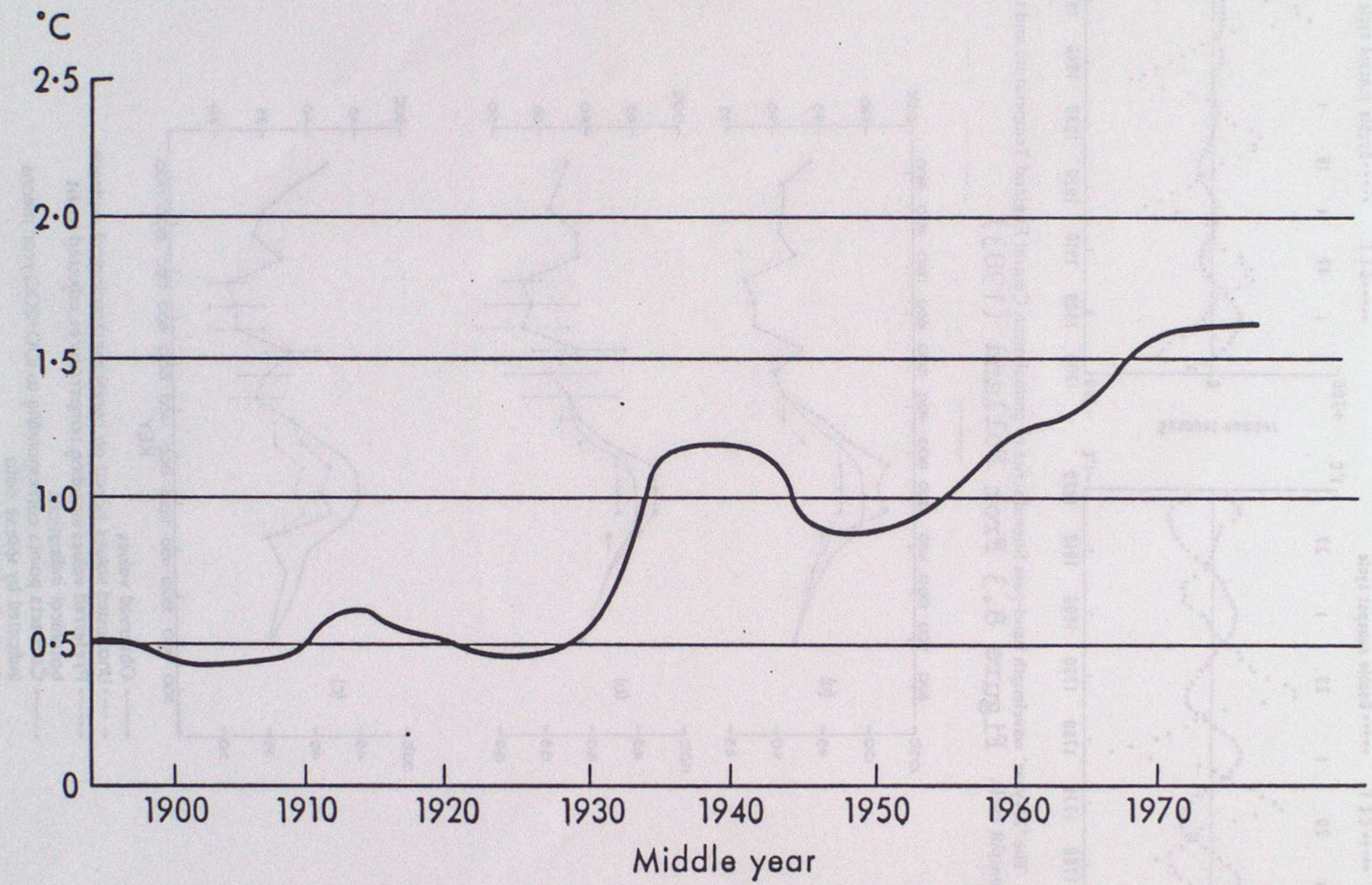
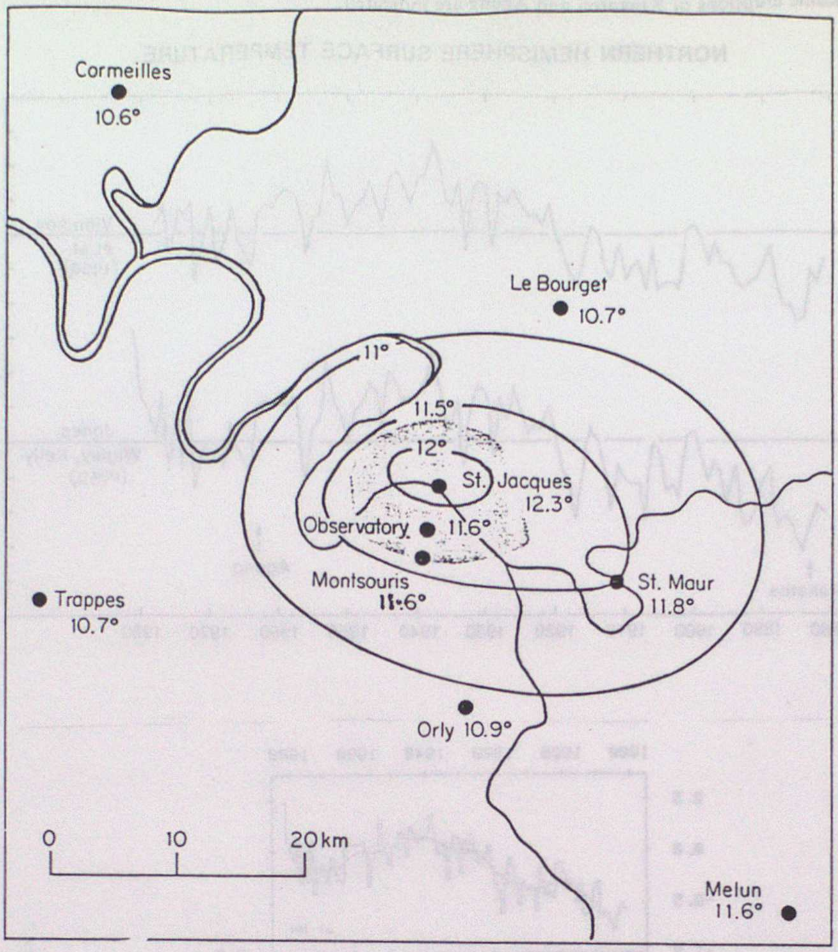



Figure 8.5A ANNUAL MEAN TEMPERATURE DIFFERENCE, PARIS—MONTSOURIS MINUS BESANCON (AFTER DETTWILLER 1978). Values are 10-year running means.




Mean annual surface temperatures of Paris and vicinity, °C. (After Dettwiller.)

Figure 8.5B After Dettwiller (1978)

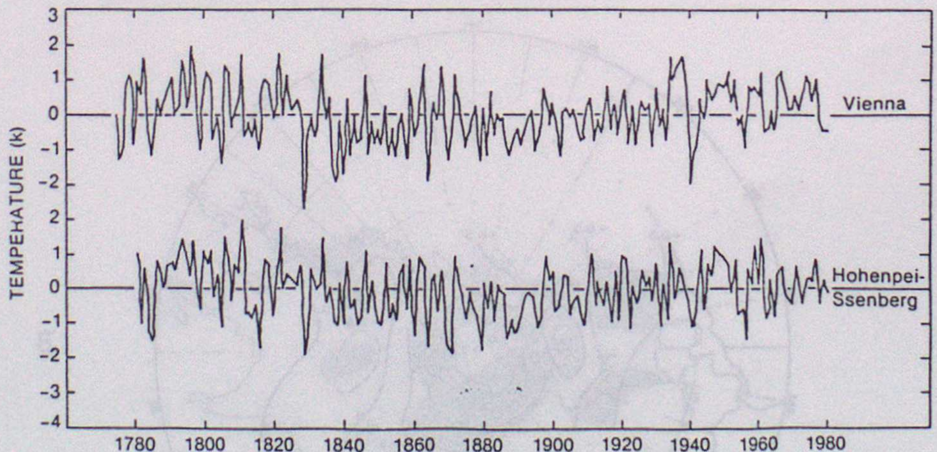



Figure 8.6 Variation in mean annual temperature at Vienna and Hohenpeissenberg. From Angell and Gruza (1984)

Variation in mean-annual NHST according to Vinnikov *et al.* (analysis only to 17.5°N), and Jones, Wigley & Kelly. The volcanic eruptions of Krakatoa and Agung are indicated.

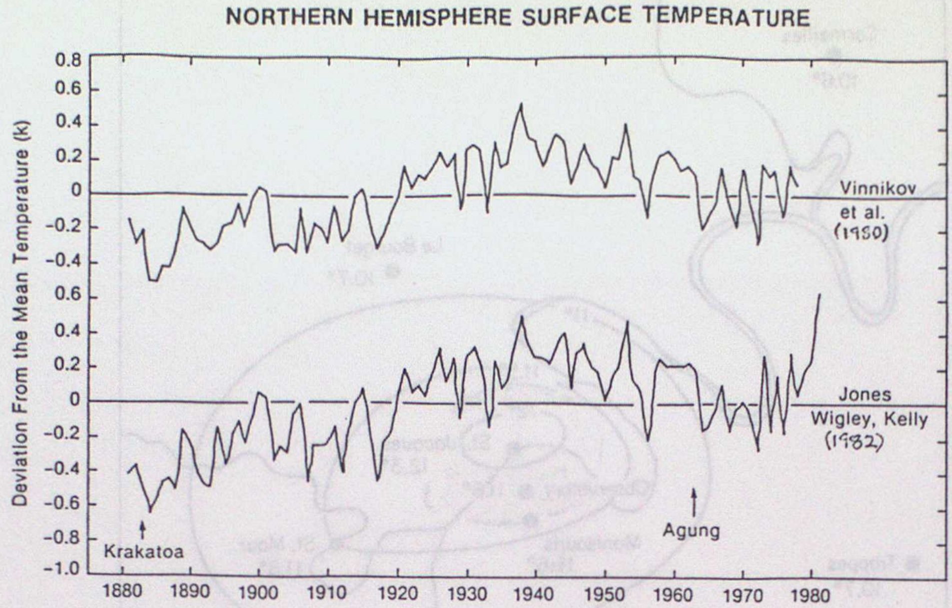
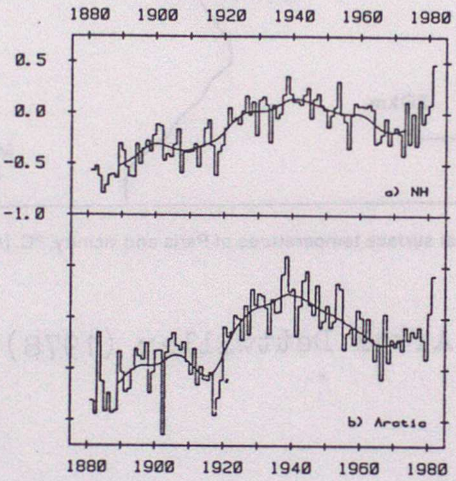
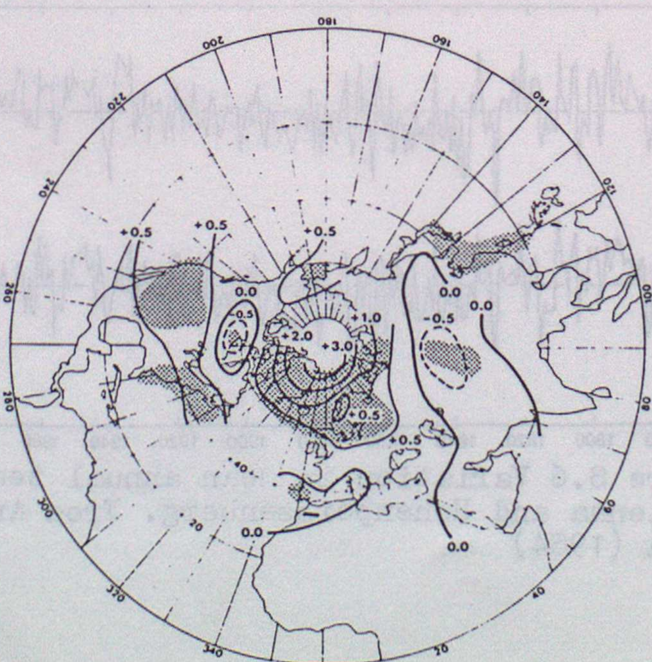



Figure 8.7
After Angell
and Gruza (19




A

Annual means of surface air temperature for the Northern Hemisphere and for the Arctic (expressed as departures in °C from the 1946–1960 reference period). Data for 1981 are included in this figure but have not been analyzed. The smoothed curves show the data smoothed with a binomial filter designed to suppress variations on time scales of less than 20 years




B

Linear trend of gridpoint temperatures over the period 1917–1939 (°C/y × 10⁻¹). Shaded areas are significant at the 5 per cent level

Figure 8.8 From Jones and Kelly (1983)

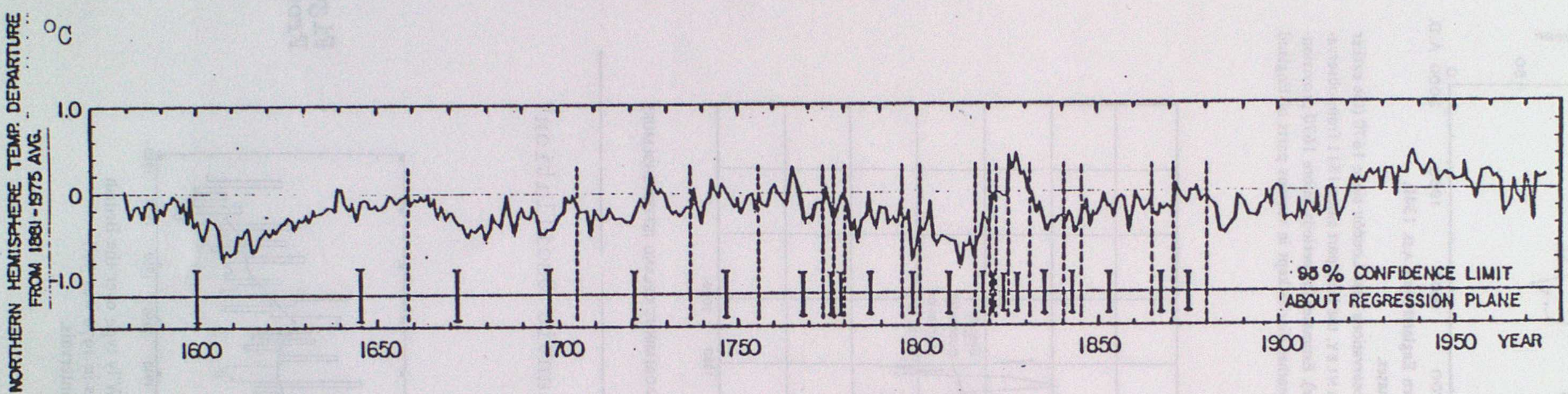



Figure 8.9. From Groveman and Landsberg (1979).

Reconstructed annual temperature departures (1579-1880) for the Northern Hemisphere followed by data of Borzenkova et al., (1976). Confidence limits of regressions at bottom of graph .

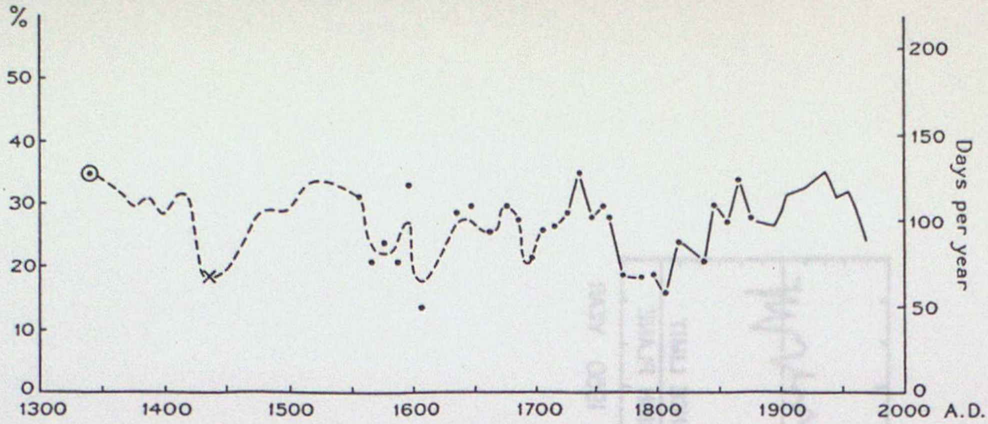
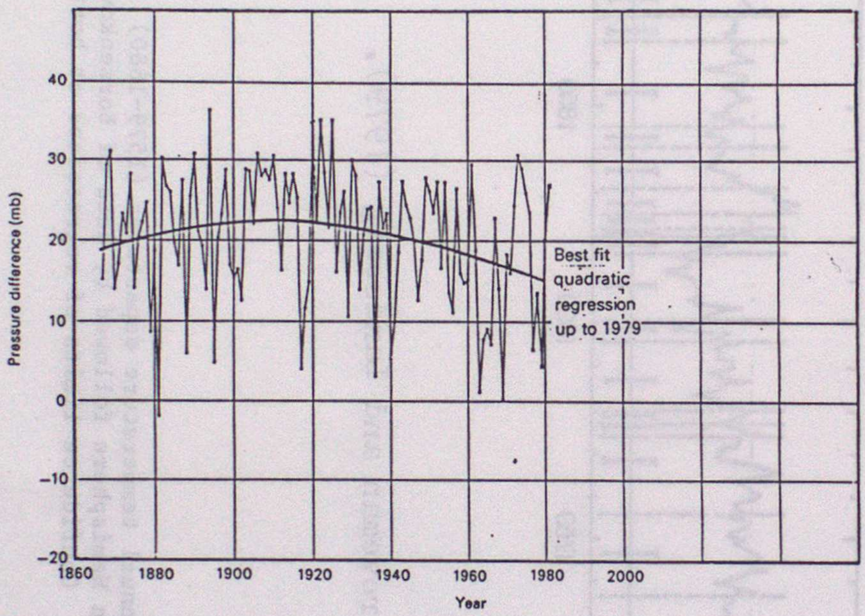



Figure 8.10
From Lamb
(1972)

Frequency of SW'ly surface winds in southeastern England since A.D. 1340.
Approximately 10-year average values and estimates.
Composite record derived directly from daily observations near London since 1670 (the earlier part worked up from manuscript sources by MANLEY, the later part since 1811 from observations in the archives of the Meteorological Office). Estimates for periods before 1670 provisionally derived from indirect evidence including weather diaries kept in various parts of England and neighbouring parts of Europe.




TIME SERIES OF AZORES (PONTA DELGADA) MINUS ICELAND (STYKKISHOLMUR) SEA LEVEL PRESSURE IN WINTER, 1867–1981.

Figure 8.11A "North Atlantic Oscillation"

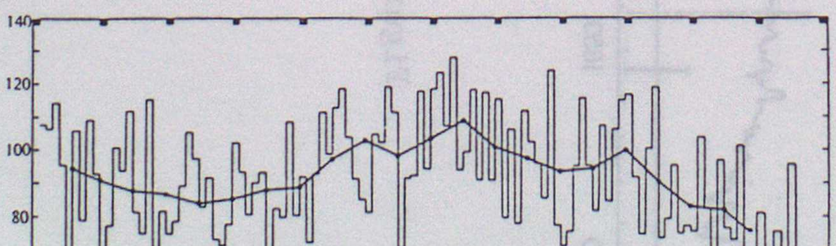
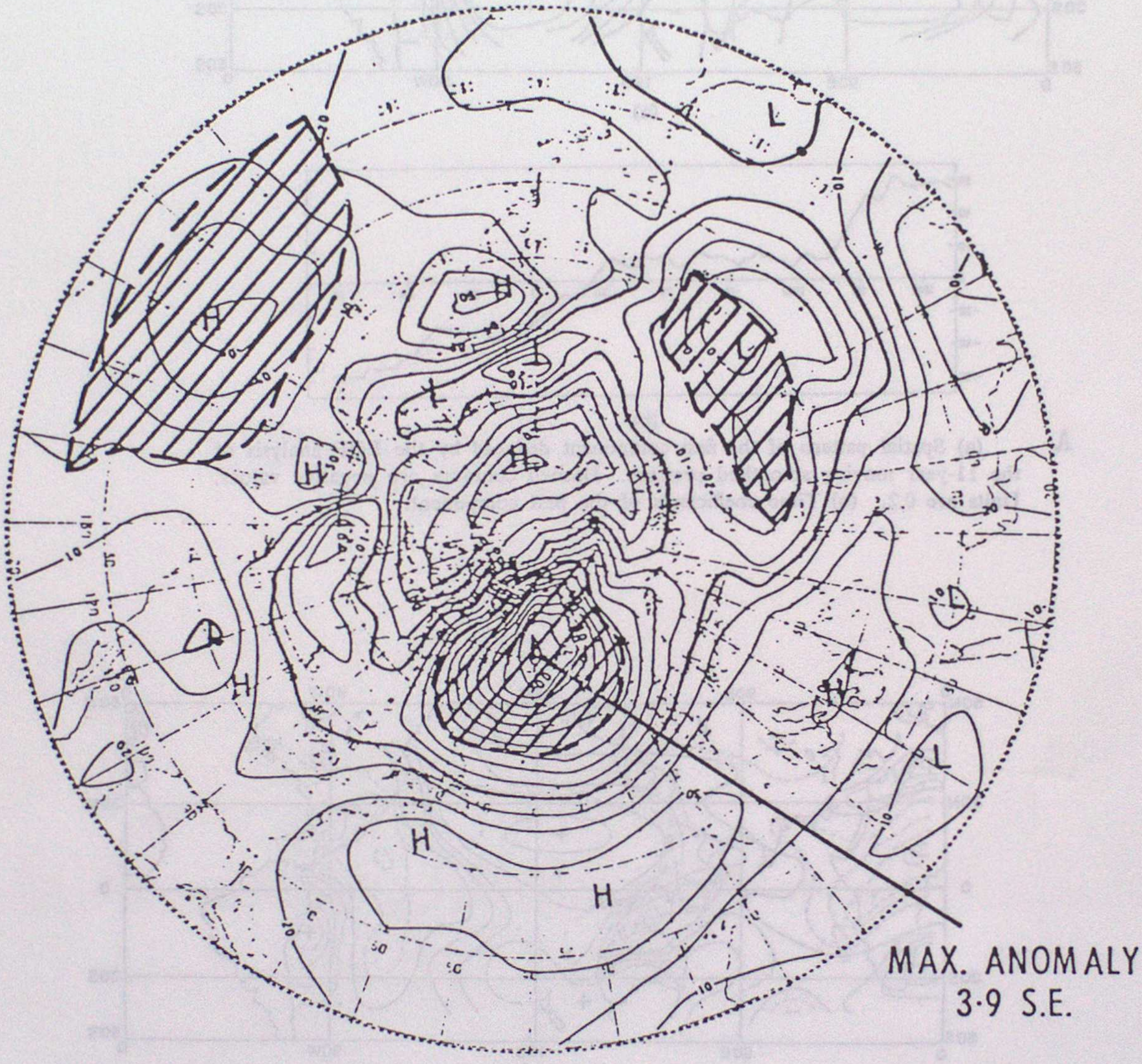



Figure 8.11B
From Lamb (1977)

Number of days each year of general W'ly type over the British Isles: 1861 to 1975. (The number of W'ly type days in 1976 was 59.)
Individual years and 10-year means at 5-year intervals.

JANUARY 1901-30 MEAN SURFACE PRESSURE ANOMALY (1951-70 BASE PERIOD)

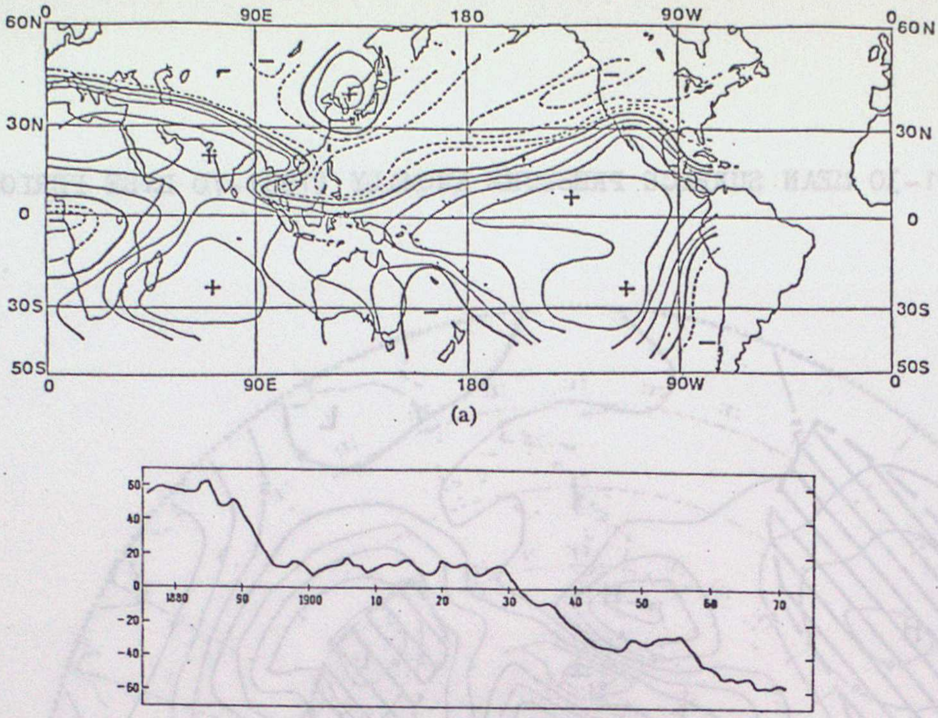



anomaly mb x 10

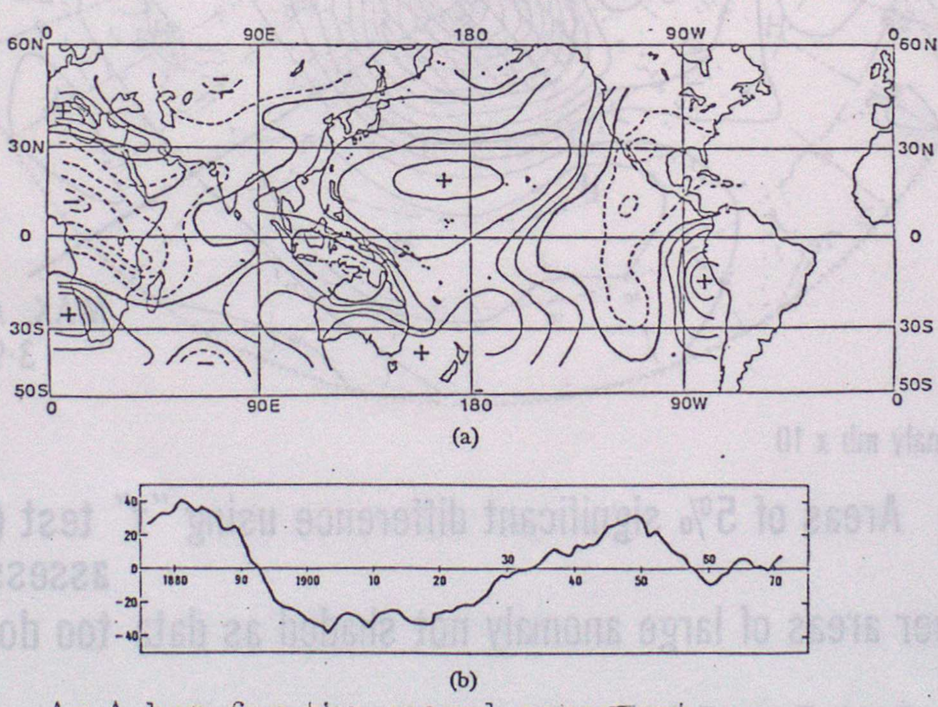
Areas of 5% significant difference using "t" test (approx assessment)

NB Other areas of large anomaly not shaded as data too doubtful

Figure 8.12. From Folland, Parker and Newman (1984)




A (a) Spatial pattern of the first component deduced by the EOF analysis of the 11-year moving smoothed pressure. Dashed contours are negative values. Units are 0.2. (b) Time coefficients of the first component.




B As A but for the second component

Figure 8.13 After Tan and Yasunari (1982)

A

. Variation in surface temperature, and mean temperature in the 85–30 kPa layer, in the five climatic zones. A 1–2–1 weighting (divided by 4) has been applied twice to successive seasonal values, except at the beginning and end of the record (northern spring of 1982) where a 1–1 weighting (divided by 2) has been applied twice.

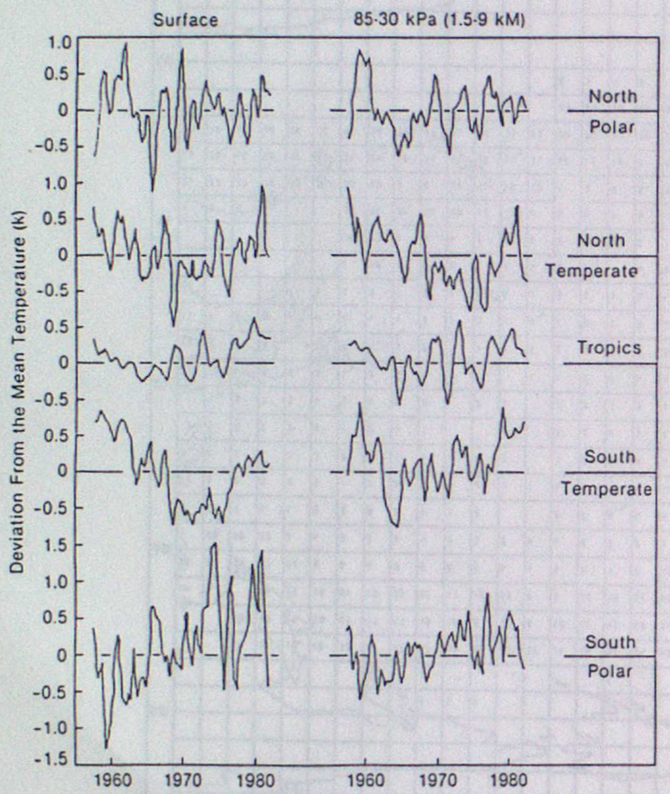
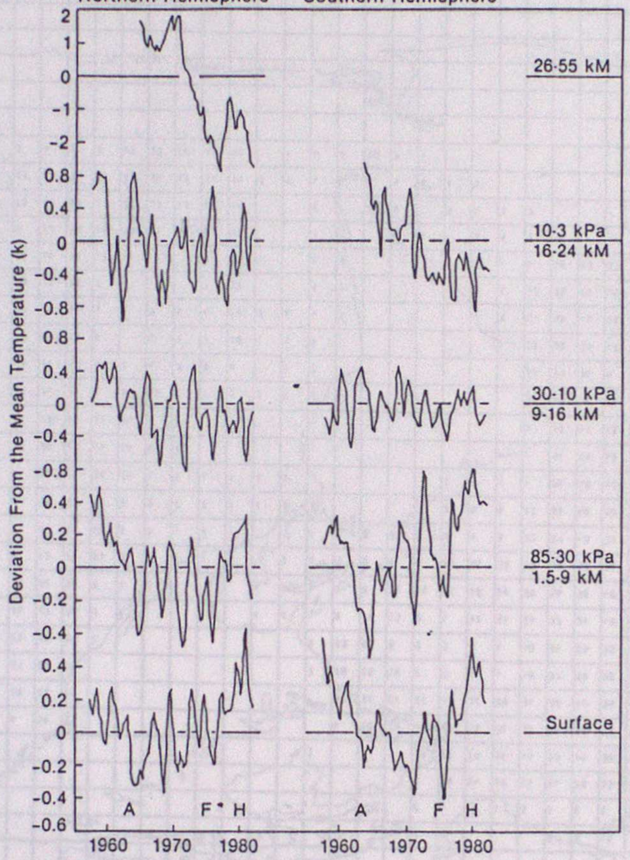
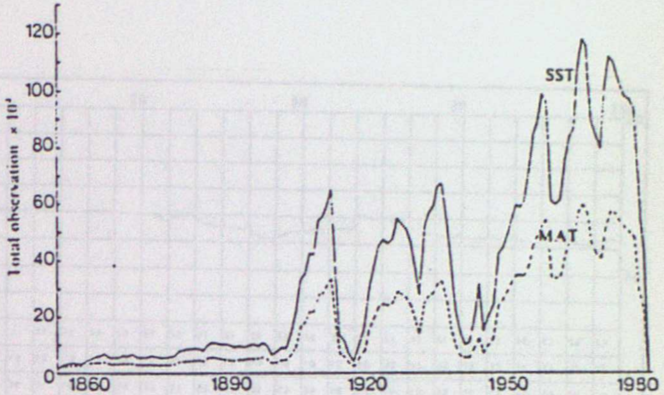



Figure 8.14 After Angell and Gruza (1984)

B

Variation in temperature in given height layers of northern and southern hemispheres. The temperatures for the 26–55 km layer of the northern hemisphere are based on rocketsonde data mostly in the western quadrant. Note the change in ordinate scale at left. Otherwise, see A.




Annual numbers of marine temperature observations for the globe. SST, sea-surface temperature; MAT, nighttime marine air temperature.

Figure 8.15A. From Folland, Parker and Kates (1984)

COUNT OF SEASONS WITH DATA IN MOHSST (3)

YEARS 1871 TO 1880 MAXIMUM NUMBER OF SEASONS =40

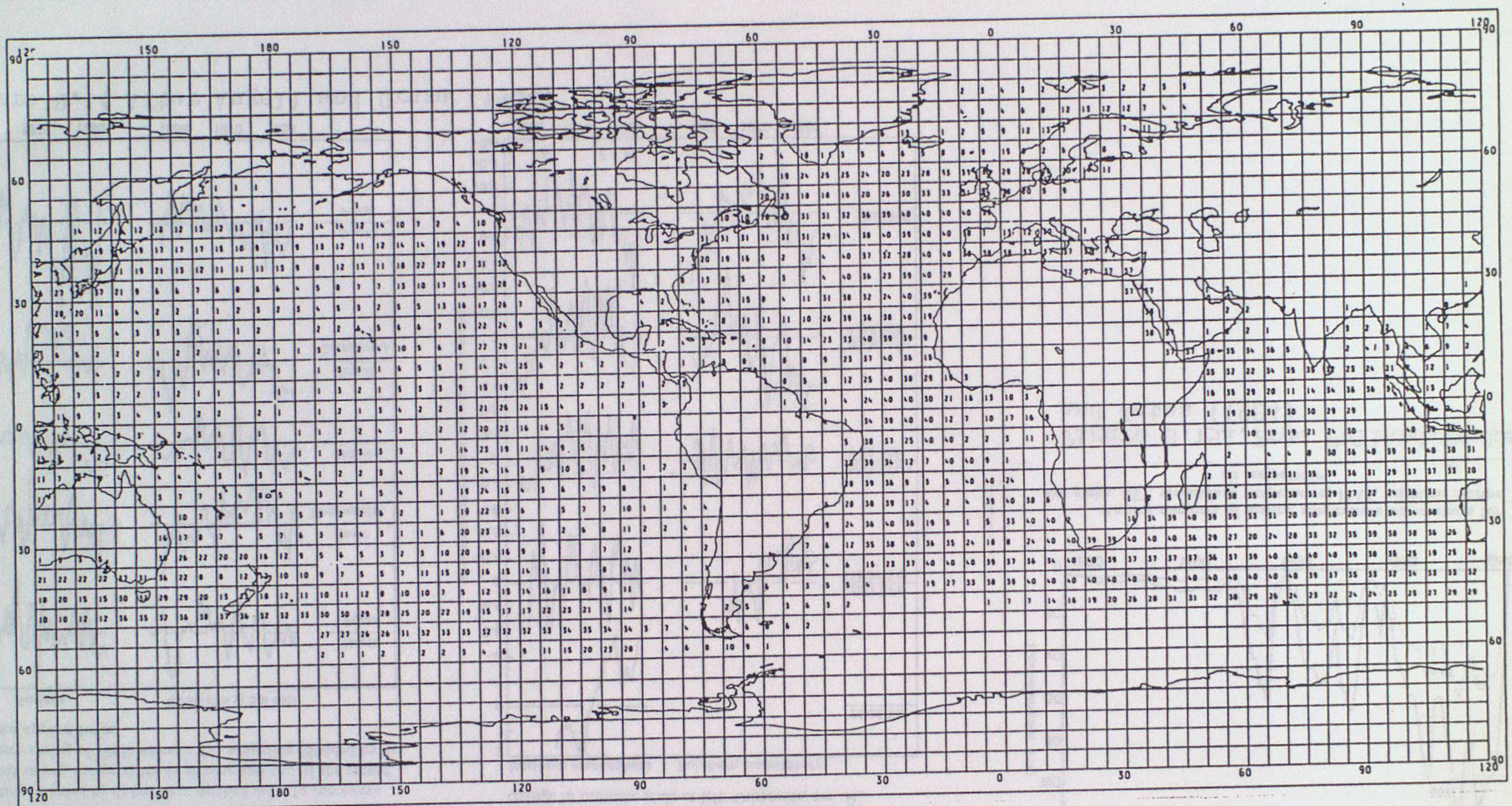
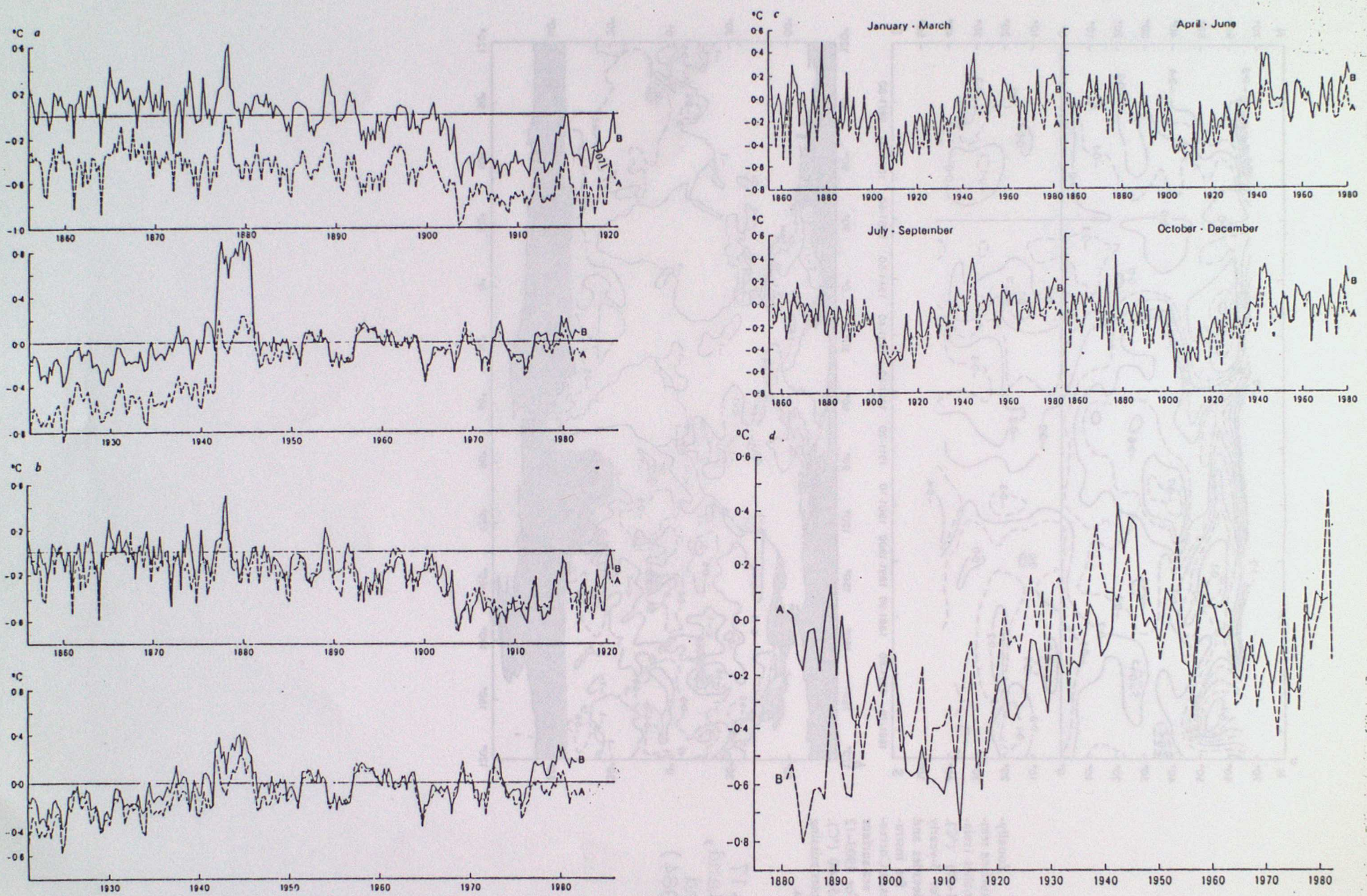
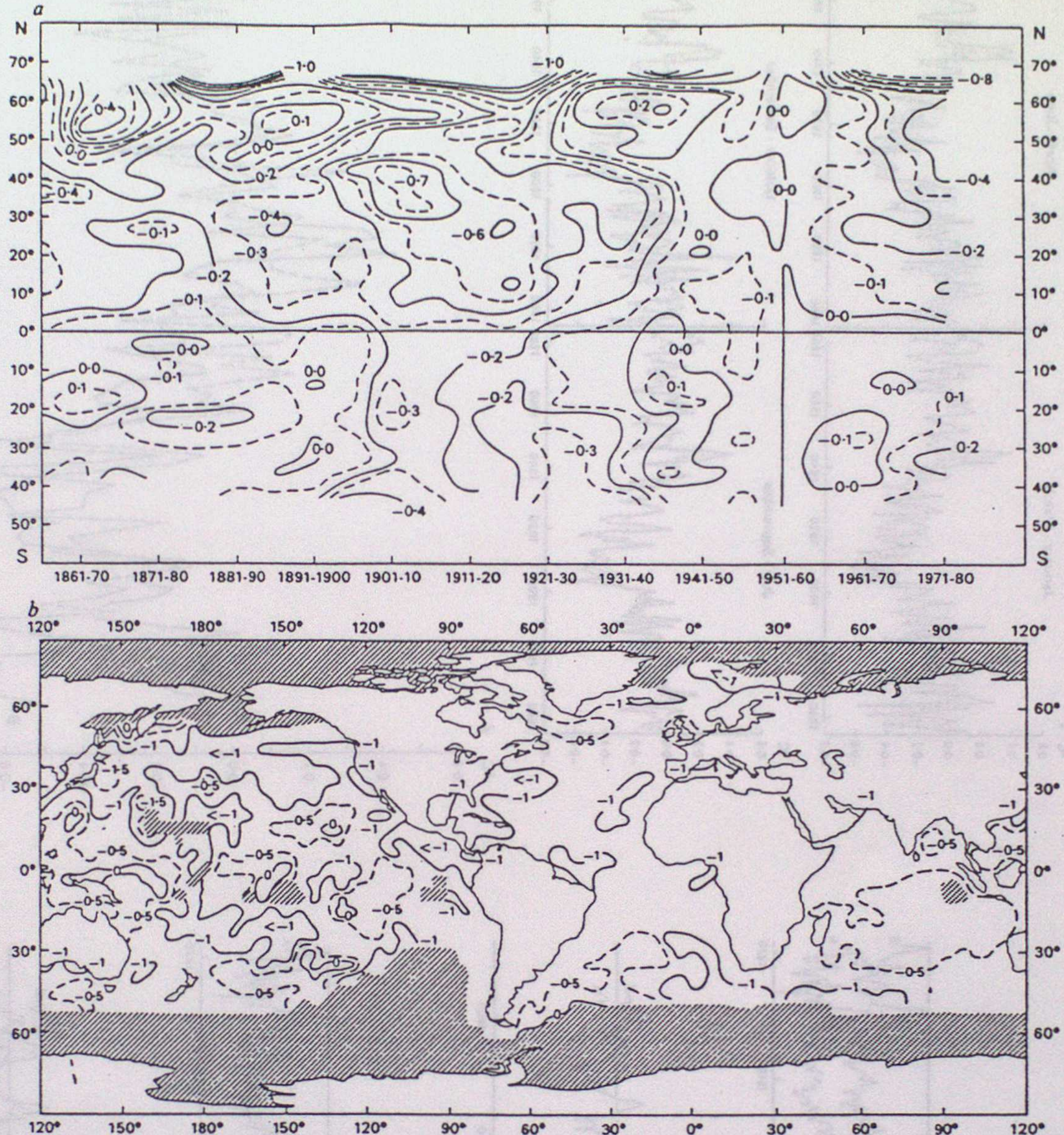


Figure 8.15B




*a*, Uncorrected anomalies (relative to 1951–60) of: A, global sea-surface temperature; and B, nighttime marine air temperature. *b*, Corrected anomalies (relative to 1951–60) of: A, global sea-surface temperature; and B, global nighttime marine air temperature. *c*, Corrected anomalies (relative to 1951–60) of: A, global sea-surface temperature, and B, global nighttime marine air temperature, for the seasons taken separately. *d*, Annual anomalies (relative to 1951–60) for the Northern Hemisphere of: A corrected nighttime marine air temperature; and B, mainly land temperature after ref. 17.

Figure 8.16 From Folland, Parker and Kates(1984) ("Ref 17" is Jones, Wigley and Kelly (1982))




Zonally-averaged sea-surface temperature anomalies (relative to 1951–60) (°C). Values are for 5-yearly overlapping decades and are corrected for instrumental changes. *b*, Corrected decadal sea-surface temperature for 1903–12 relative to 1951–60 (°C). Hatching denotes missing data.

Figure 8.17
From Folland,
Parker and
Kates (1984)

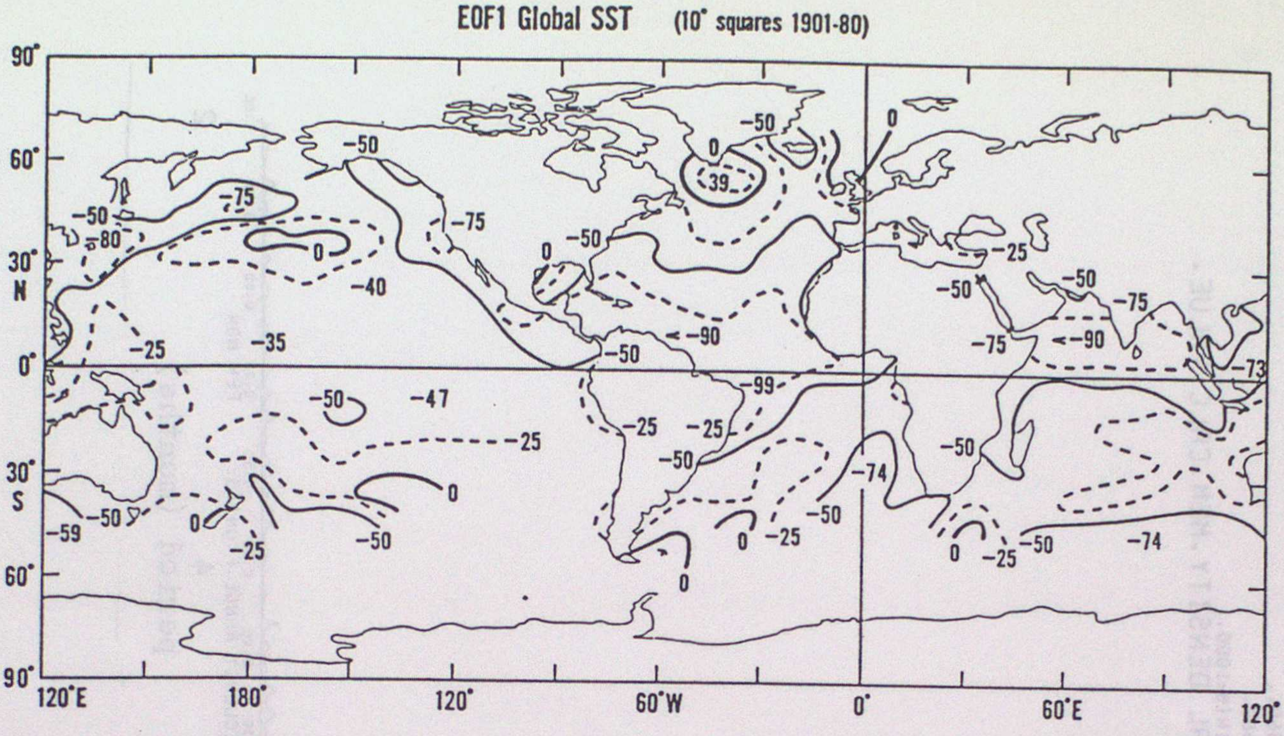



Figure 8.18A From Folland, Parker and Newman (1984)

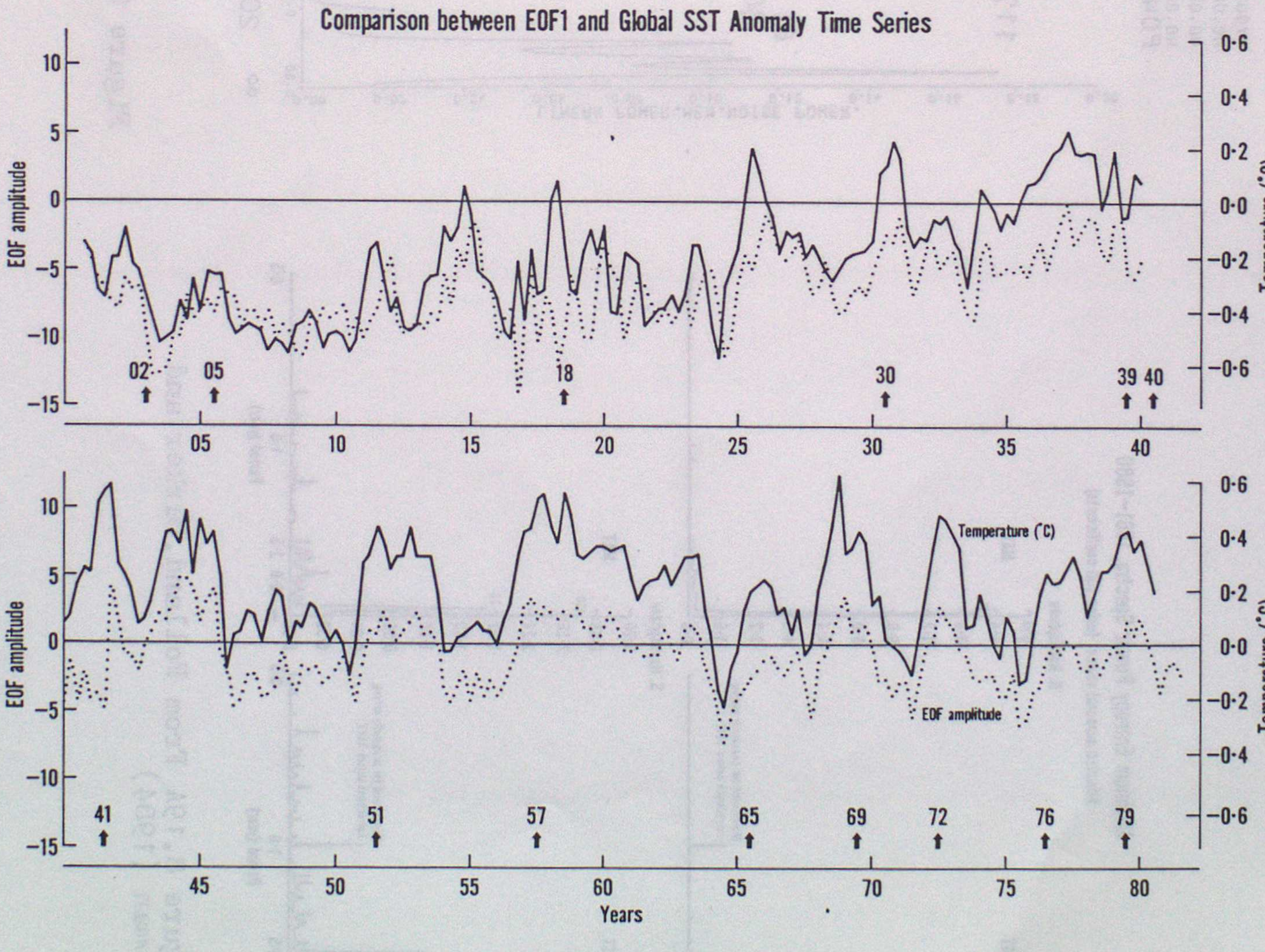



Figure 8.18B From Folland, Parker and Newman (1984)

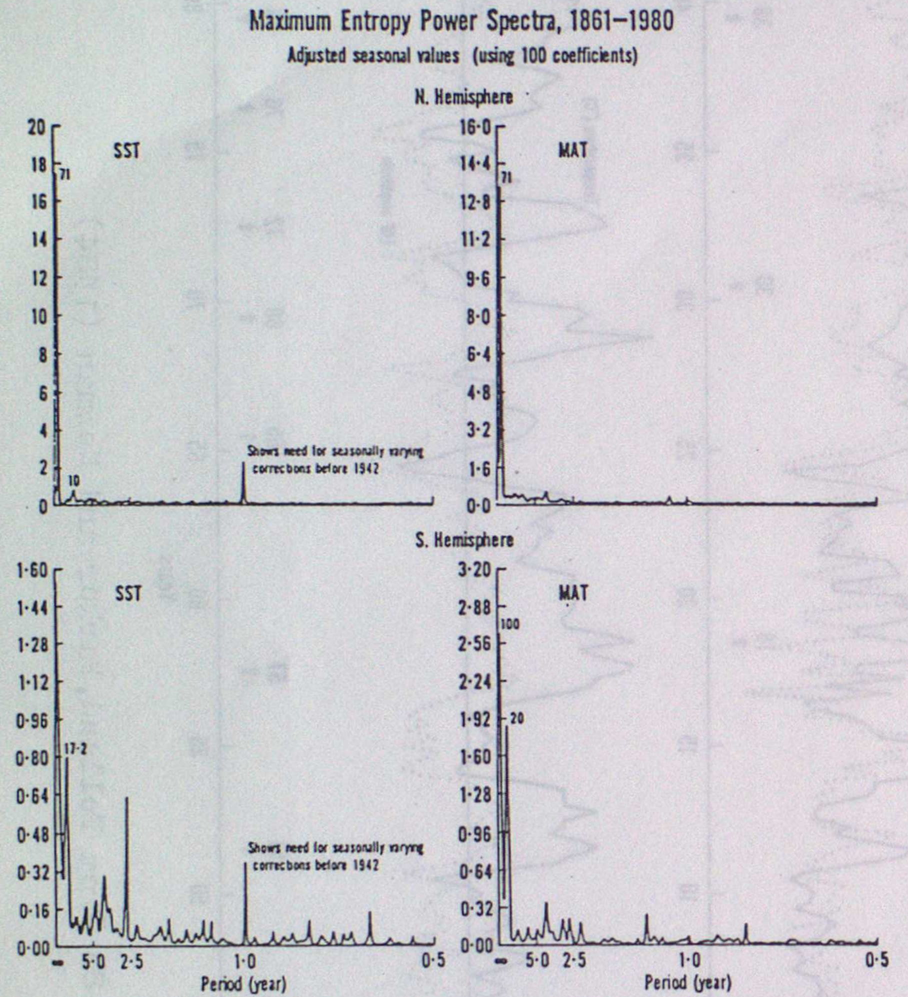



Figure 8.19A From Folland, Parker and Newman (1984)

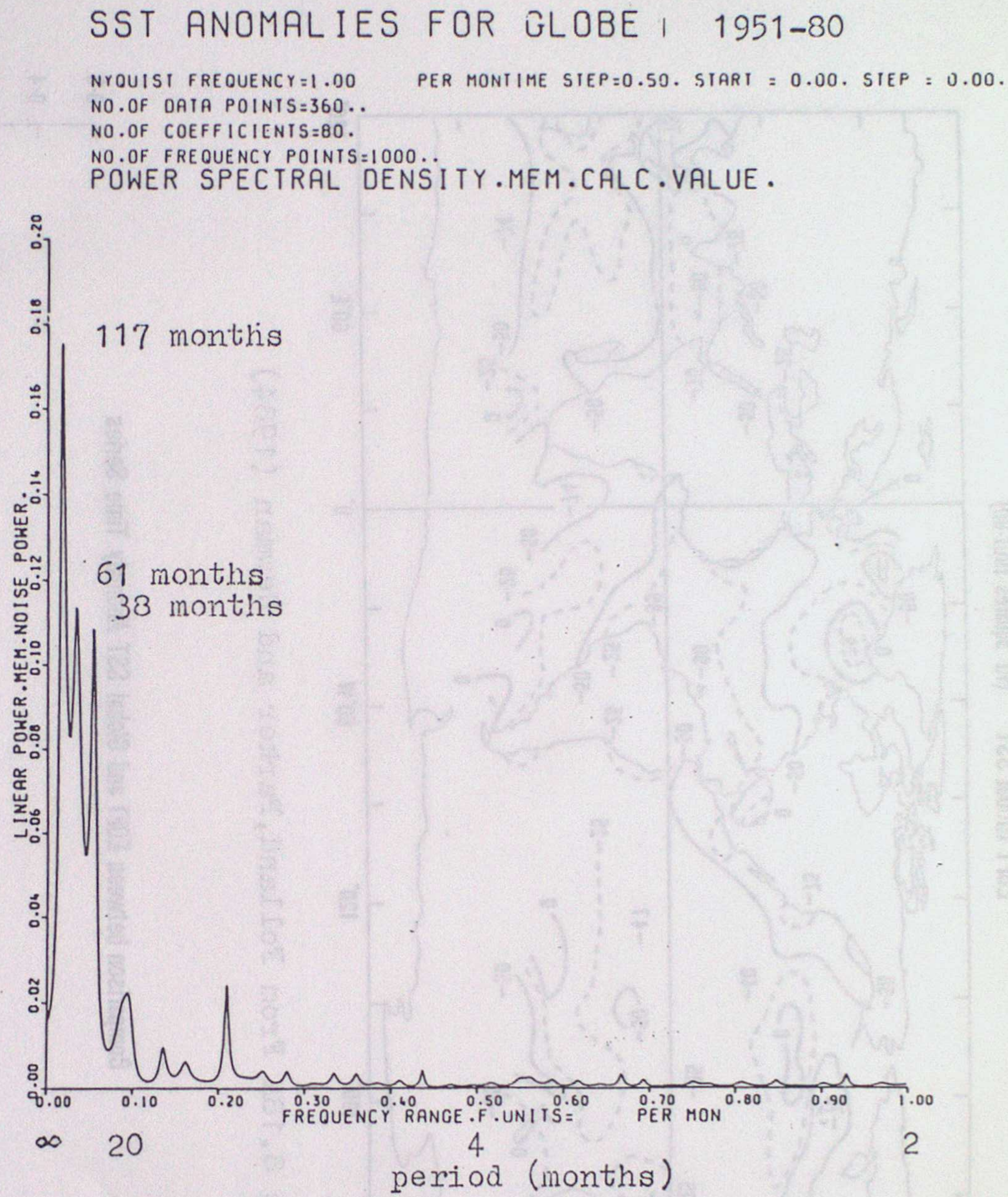



Figure 8.19B

Figure 8.20 Filtered seasonal SST and night marine air temperature anomalies in the N and S Hemisphere 1856-1984. The filter used was a triangular one of 41 terms (10½ years) total length.

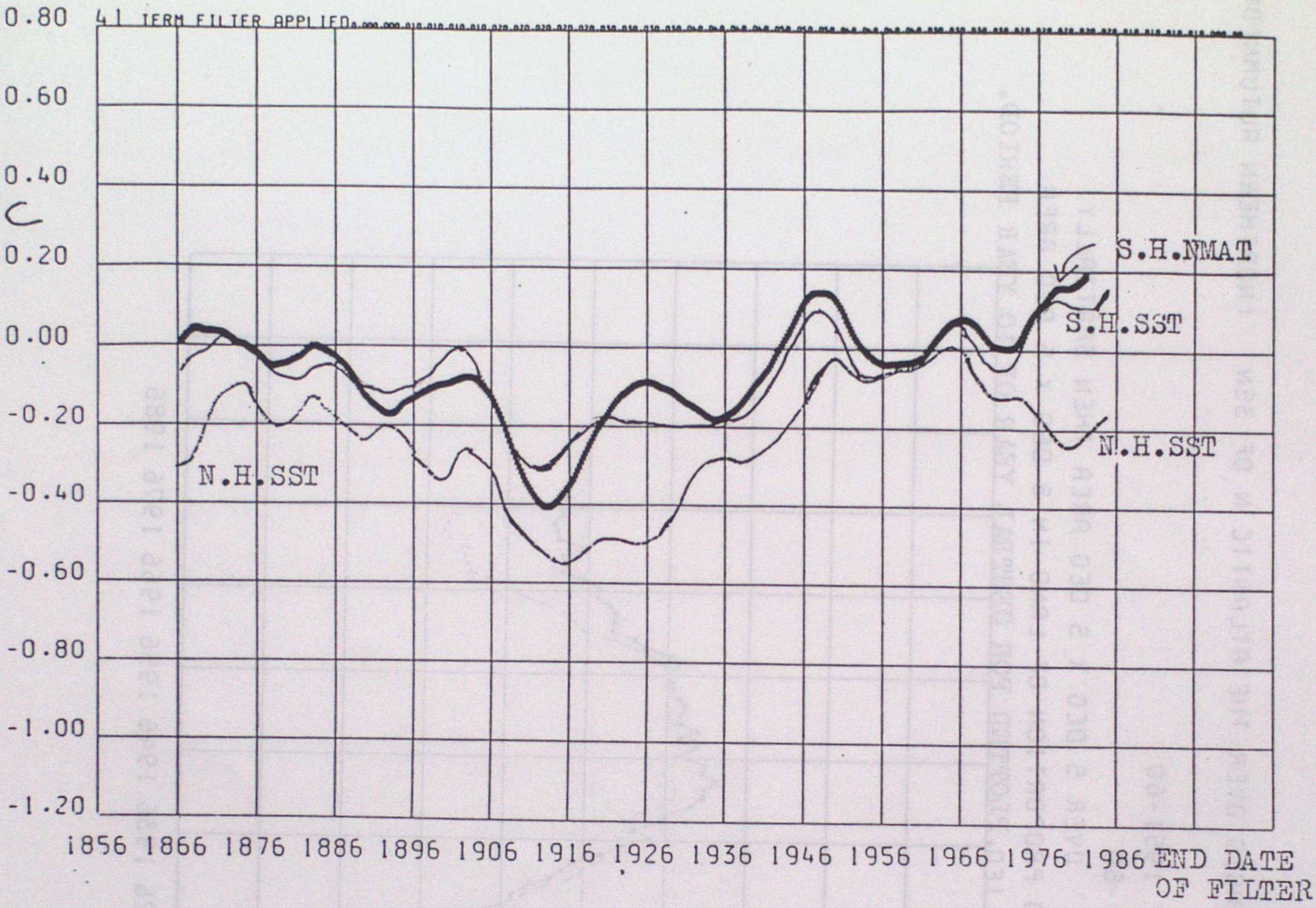



Figure 8.21A From Untersteiner (1984)

Percentage of advancing and retreating glaciers in Switzerland, 1891–1975, showing the increase of advancing glaciers since the mid-twentieth century. (From Kasser & Aellen, 1981.)

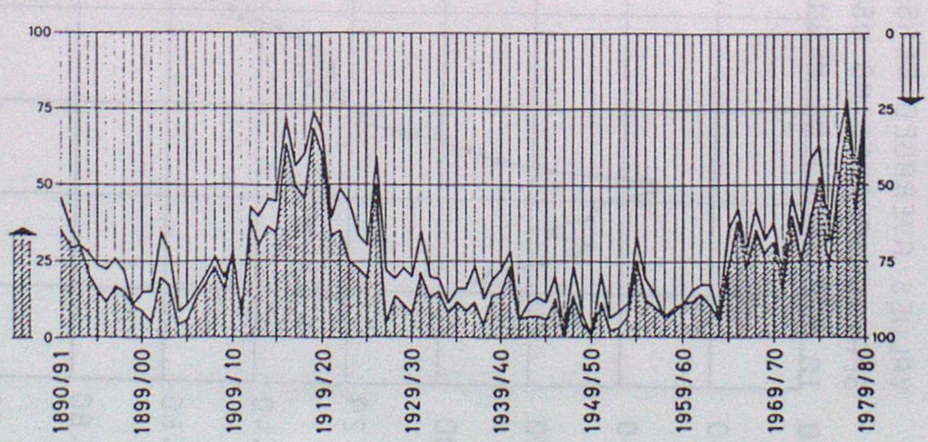


Figure 8.21B

ANOMALY FOR YEARS 1856 TO 1981 AVERAGED OVER THE ATLANTIC N OF 35N (NORTHERN AUTUMN(OND) ONLY)

INSTRUMENTAL CORRECTIONS APPLIED

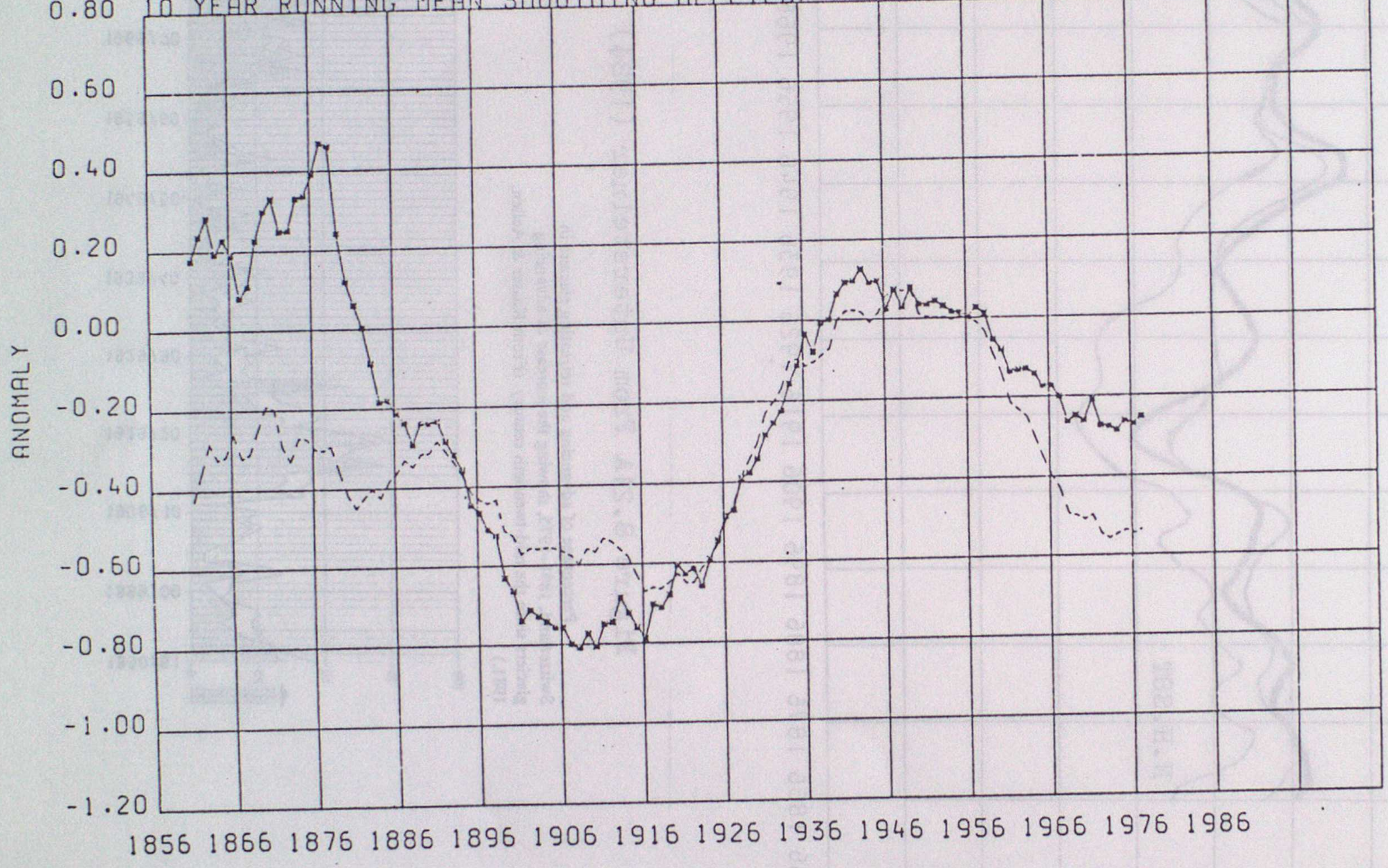
SOLID LINE IS NIGHT MAT ANOMALY WRT 1951-60

DASHED LINE IS SST ANOMALY WRT 1951-60

VALUES AVERAGED SEASONALLY OVER 5 DEG X 5 DEG AREA THEN SPATIALLY

SPATIAL AVERAGING USES COS(LAT) AND PROPORTION OF LAND IN 5 DEG X 5 DEG AREA

10 YEAR RUNNING MEAN SMOOTHING APPLIED. PLOTTED FOR CENTRAL YEAR OF 10 YEAR PERIOD.



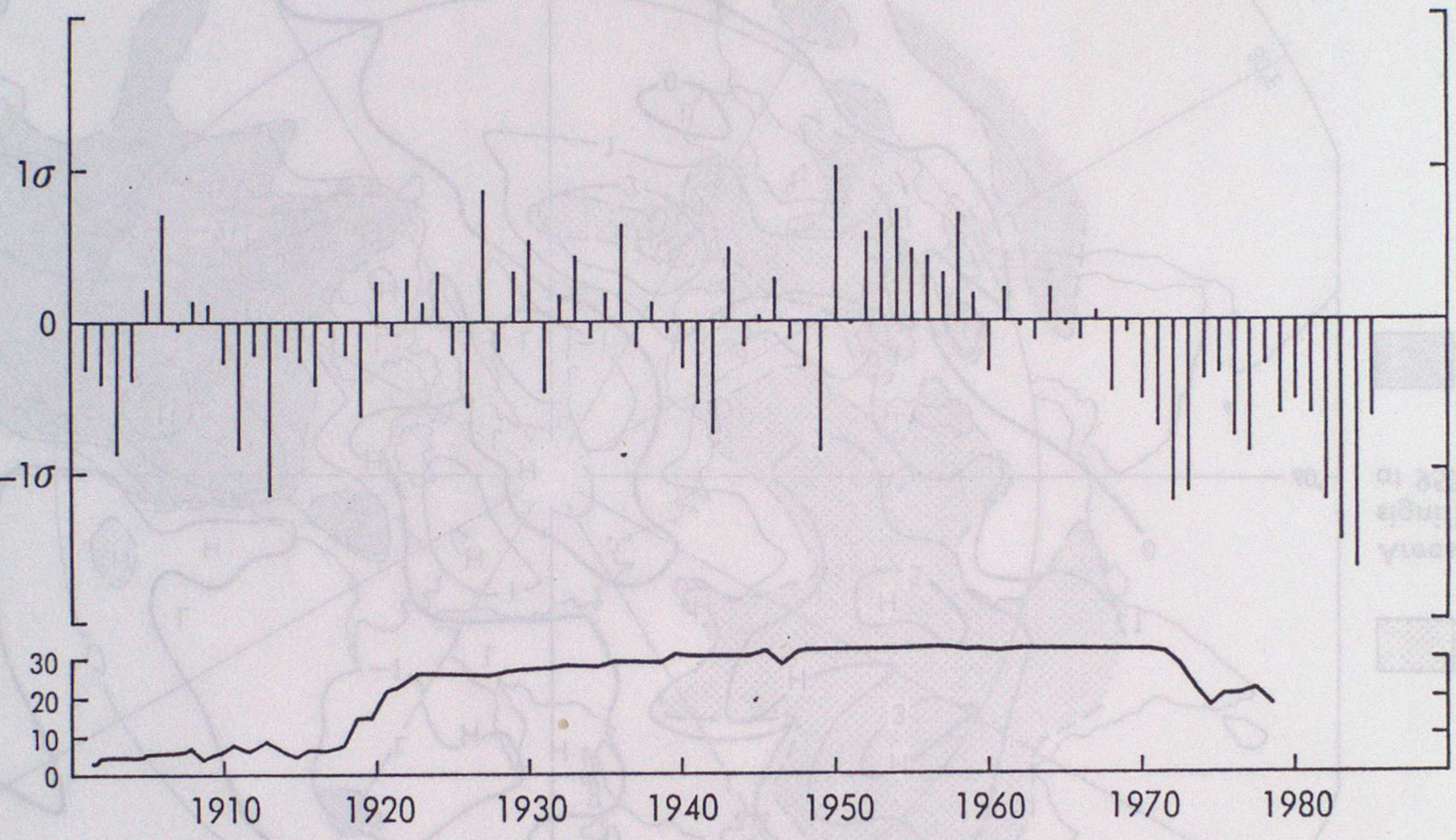



Figure 8.22. Upper panel: Standardised annual rainfall anomalies for the Sahel, 1901–85. Values to 1984 after Nicholson; 1985 estimated from CLIMAT reports.

Lower panel: Number of stations used.

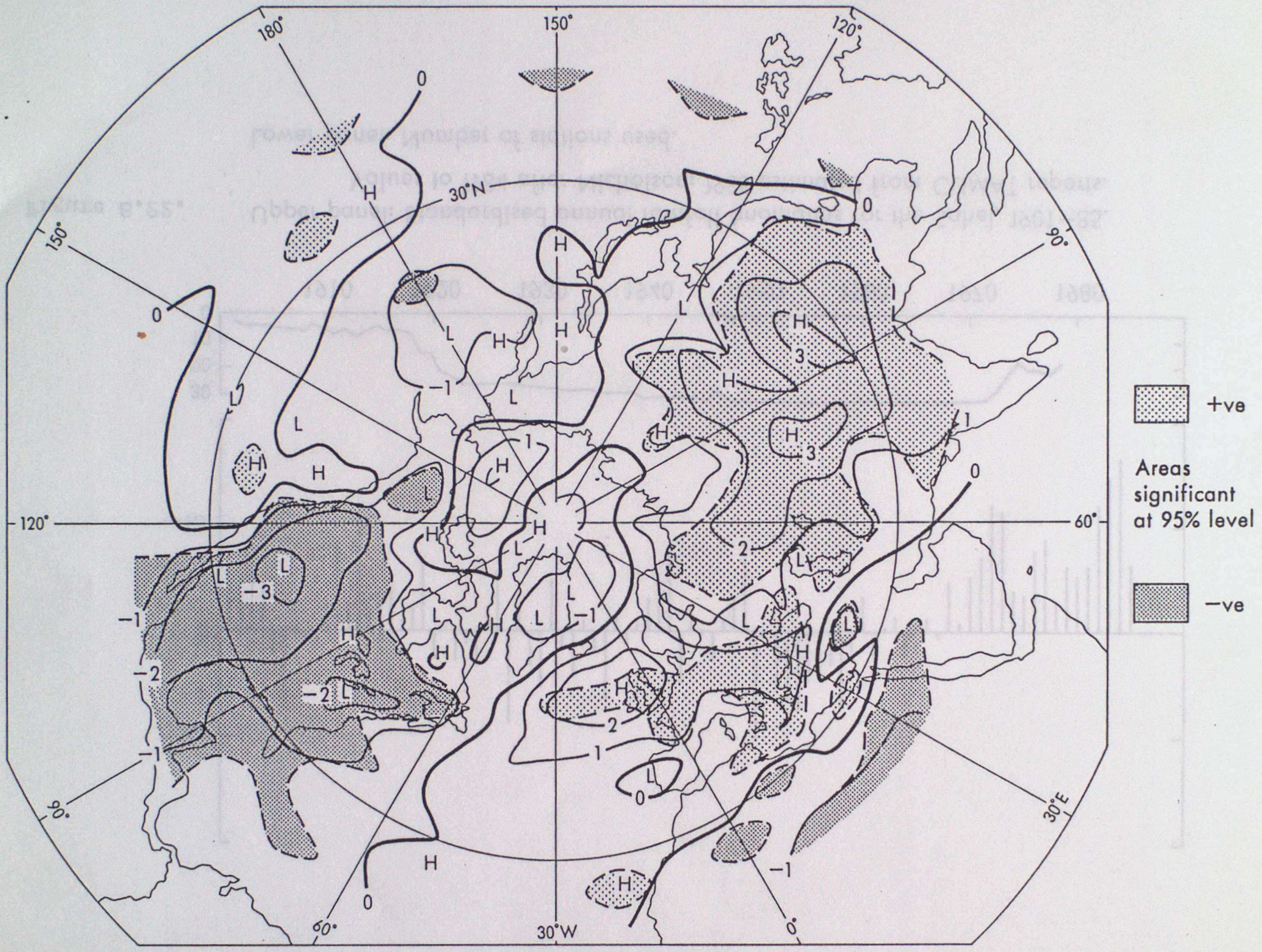



Figure 8.23A. PMSL difference (mb) 1968–84 minus 1950–59 JULY

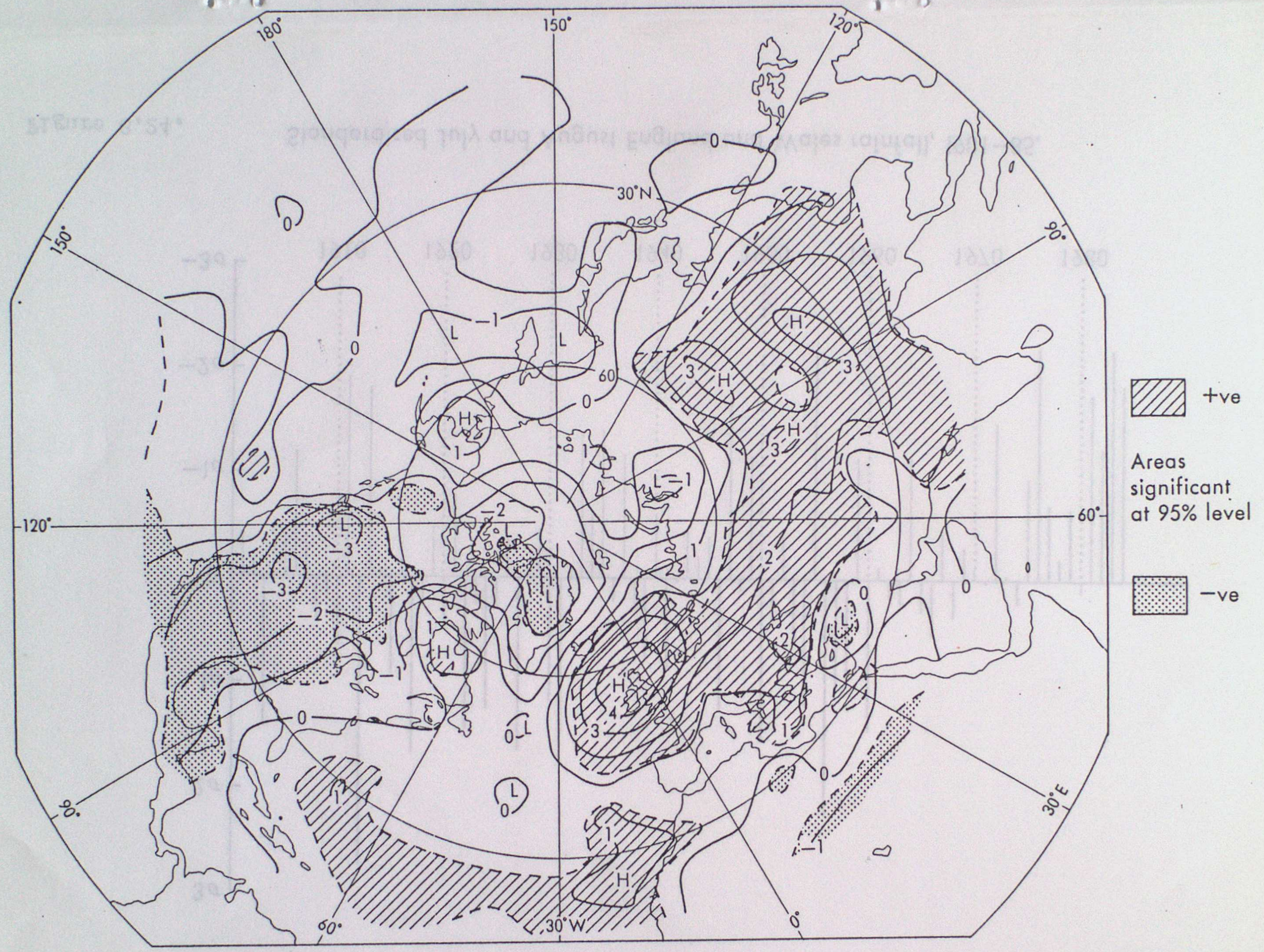



Figure 8.23B. PMSL difference (mb) 1968–84 minus 1950–59 AUGUST

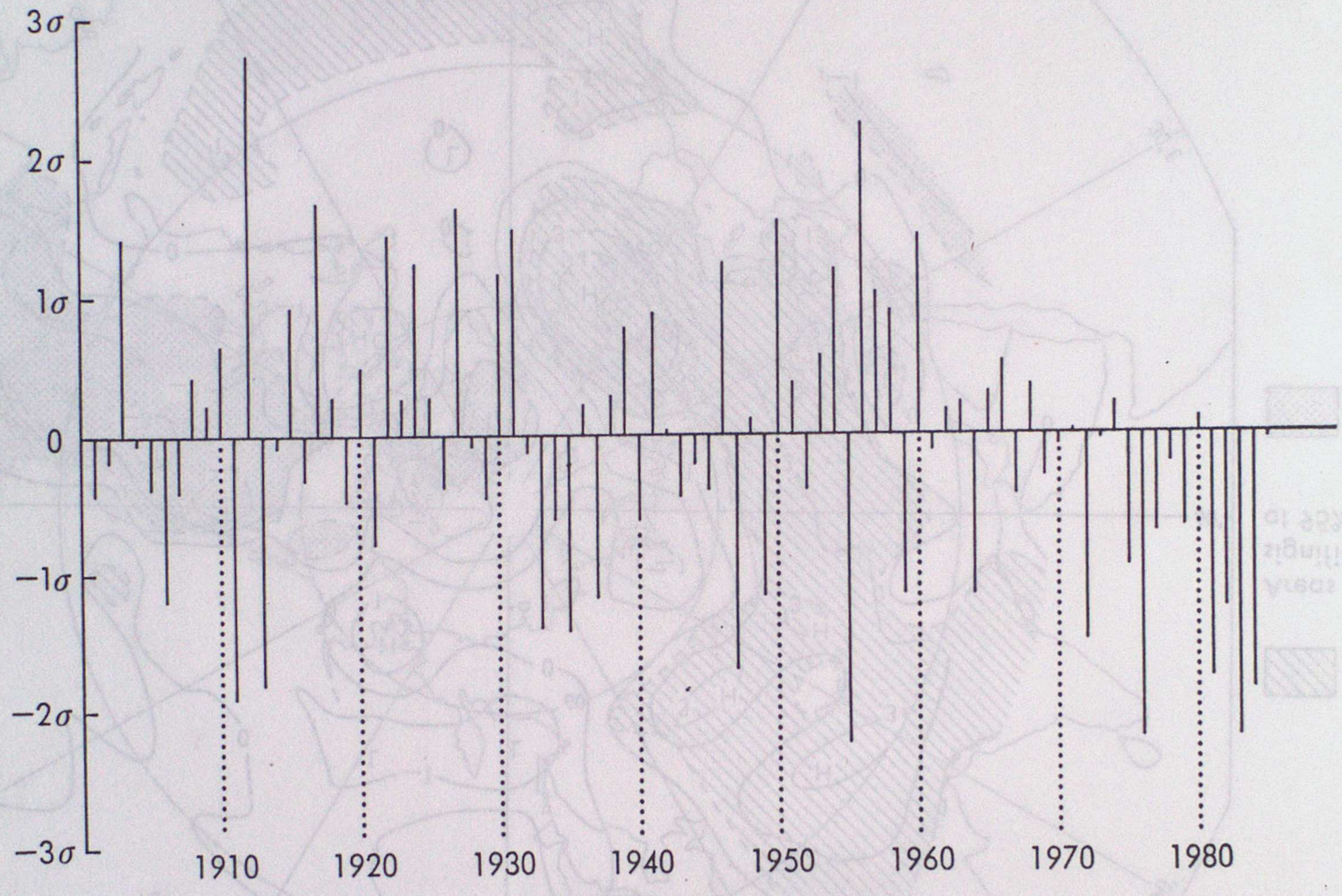



Figure 8.24. Standardised July and August England and Wales rainfall, 1901–85.