5. LONG-TERM AND SHORT-TERM TIME SERIES OF GLOBAL CLIMATIC INDICES AND FISH STOCK

To begin with, it is necessary to clarify the term "climate" in the context of this study. Climate can simply be defined as weather conditions statistically generalized over a time period large enough to smooth annual and decadal fluctuations (Battan 1983, Monin 2000). According to common practice and recommendations of the Climatological Congress of 1933, climatic events should be described using 10 and 30-year averaging periods for areas of many thousands square miles. The term "climate" is not used to describe meteorological events of several days to several months scale, but refers to the expected, or "average" weather, which we have seen, based on 30-year periods over the last century or so.

The time series of the climate indices at our disposal can be divided into two main groups: (1) Long-term time series of hundreds and thousands of years and (2) short-term time series covering the period of instrumental observations (100–150 years).

5.1 LONG-TERM CLIMATIC TIME SERIES

Surface air temperature for the last 1420 years reconstructed using ice cores sampled from a Greenland glacier ("Ice core temperature").

Polar glaciers contain paleo-climatic information in the form of the isotopic composition of the oxygen as described by the delta-function: the parts per thousand (‰) deviation of the heavy oxygen isotope (^{18}O) concentration in the ice from that of Standard Mean Ocean Water. Continuous delta-profiles of the oxygen isotope down the polar ice cores are interpreted in terms of climatic variation. The most suitable location to perform global paleo-temperature reconstruction using this method is the central region of the Greenland ice sheet, where the conditions for snow and ice accumulation are believed to have remained stable over the last 1500 years. «Nowhere else in the world is it possible to find a better combination of a reasonable high accumulation rate, simple ice flow pattern (which facilitates the calculation of the time scale), high ice thickness (which offers a detailed record, even at a great depths) and meteorologically significant location (close to the main track of North Atlantic cyclones).» (Dansgaard *et al.* 1975). Analysis of the ^{18}O content in the ice core at more than 500m in depth (with an annual section of 0.29 m) made it possible to reconstruct the mean annual air surface temperature for the last 1423 years, from 552 to 1975 (Fig 5.1A)[2].

Summer surface air temperature for the last 1400 (500-1900) years reconstructed from the tree rings of Scots pine.

The tree growth in the polar region takes place only in the warm (late spring–summer) season, which makes the tree ring widths clear enough to perform reliable, long-term measurements (Briffa *et al.* 1990). The temperature data reconstructed from the tree rings are different from those obtained using the ice cores. The average-annual dT calculated from the ice cores display the annual fluctuations depending primarily on the winter temperature regime, whereas the temperature dynamics estimated

[2] Dr. W. Dansgaard (Geophysical Isotope Laboratory, University of Copenhagen, Denmark) kindly provided these data, which belong to the Institute of Geography, Russian Academy of Sciences. I am very grateful to Dr. V.A. Nikolaev from this institute for his permission to use the data.

using the tree rings characterize the summer temperature regime (Fig. 5.1B). Thus, both time series reflect the long-term climate changes, but each series has its own particulars.

Sardine and anchovy populations reconstructed from the data on fish scales in varved sediment cores.

Varved sediments of southern California provide a historical record of pelagic fish populations. Anaerobic conditions in layered sediments preserve fish scales and produce a yearly record of pelagic fish population structure. The variation of sardine and anchovy abundance in the Californian upwelling were obtained from layer-by-layer analysis of the sediment cores, and be can be determined from the resolution of a 10-year sampling window (Baumgartner *et al.* 1992). The author presented direct data on the variation in fish abundance for almost 1700 years. The data suggest that the sardine and anchovy outbursts have occurred regularly for 1700 years with a period about 60 years. The fluctuations of sardine and anchovy stock (and catches) in the last century, when subject to considerable fishing pressure, are not different by period nor magnitude from the corresponding fluctuations during the past 1700 years when the fishery effect was obviously negligible.

Figure 5.1c and Figure 5.1d present the reconstructed time series of sardine and anchovy populations biomass reproduced from the originals by Baumgartner *et al*. (1992). The time series of temperature reconstructed by the Greenland Ice cores ("Ice core temperature") and by Tree ring analyses present the annual values, whereas the fish population indices are averaged over ten year periods.

5.2 SPECTRAL ANALYSIS OF THE LONG-TERM TIME SERIES

Spectral analysis was used to distinguish the most regular dominant oscillations in all these time series. The low-frequency part of the time series is omitted in the picture for clearer comparison. Figure 5.2 shows similar spectral characteristics between those of the "Ice core temperature" and sardine abundance for the last 1500 years: principal maxima of the spectral density in both time series are of 54-57 and 223-273 years. The first fluctuation period (54-57 years) is similar to both "Ice core temperature" and sardine biomass and is of greatest importance for fishery forecasting.

The spectrum of anchovy fluctuations is significantly different from the spectrum of "Ice core temperature", but close to the spectrum distribution of "Tree ring temperature". Dominant fluctuation periods in this case are about 100, 70 and 55 years. The maximum of 30 years is also well pronounced.

The sardine outbursts occur in phase with the increase in global temperature and "zonal" epoch of atmospheric circulation (see above), whereas the anchovy maxima fall on the periods of global temperature decrease and "meridional" epoch of atmospheric circulation. This dependence is likely to determine the observable differences in the spectra of these two species.

A generalized spectrum (Fourier-aggregated signal) of four of the time series is presented in Figure 5.2. The figure includes only the oscillations common for the four time series (individual details are omitted). The most pronounced peak is around 58 years, but oscillations of 44, and 30 years are significant as well.

For comparison, Figure 5.3. presents the full spectrum of annual (non-smoothed) values of "Ice core temperature" for the last 1420 years. It is clear that the period of 54 years is the only dominant multidecadal frequency, with similarly pronounced oscillations only at a much higher frequency (13 and 19 years).

The low-frequency oscillations with a period of 160 years are also well manifested. This type of periodicity is not of direct significance for our purposes, though it may be a useful tool to understand better the present age-long increase in the global temperature anomaly (dT) commonly referred to as “global warming”.

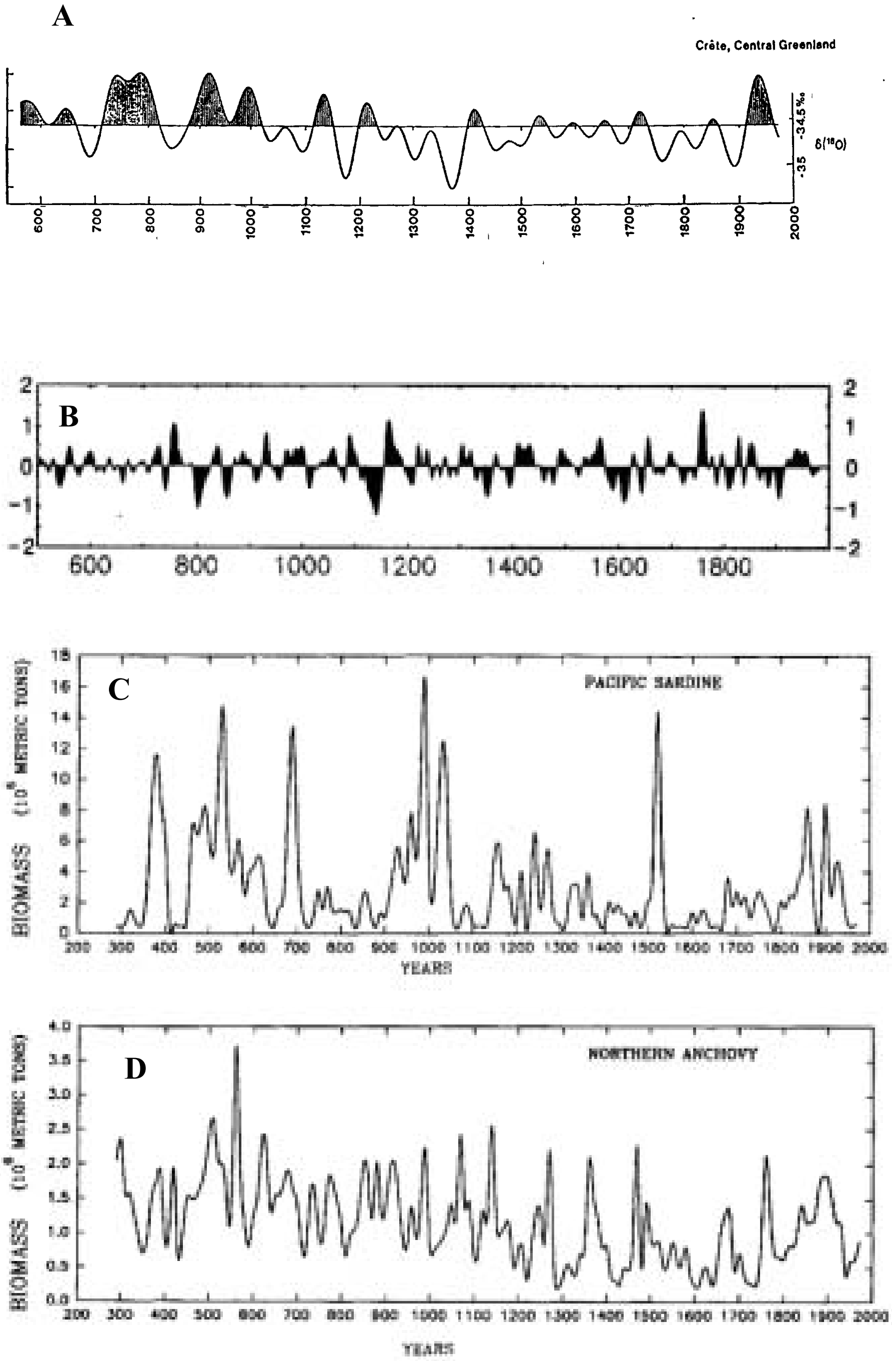

Figure 5.1. Reconstruction of: A - air-surface temperature by Greenland Ice Cores O^{18} for the last 1420 years (Dansgaard *et al.* 1975); B - summer temperature by Scots Pine Tree Rings for the last 1400 years (Briffa *et al.* 1990); C and D – sardine and anchovy biomass estimated from Californian varved bottom sediments for the last 1700 years (Baumgartner *et al.* 1992). Time series of sardine and anchovy abundance are averaged by 10-year sections. Cyclic fluctuations of climate and commercial fish stocks are believed to have a period of at least several decades.

Power spectra estimates - Burg's maximum entropy method, AR-order = 20, (relative variance).

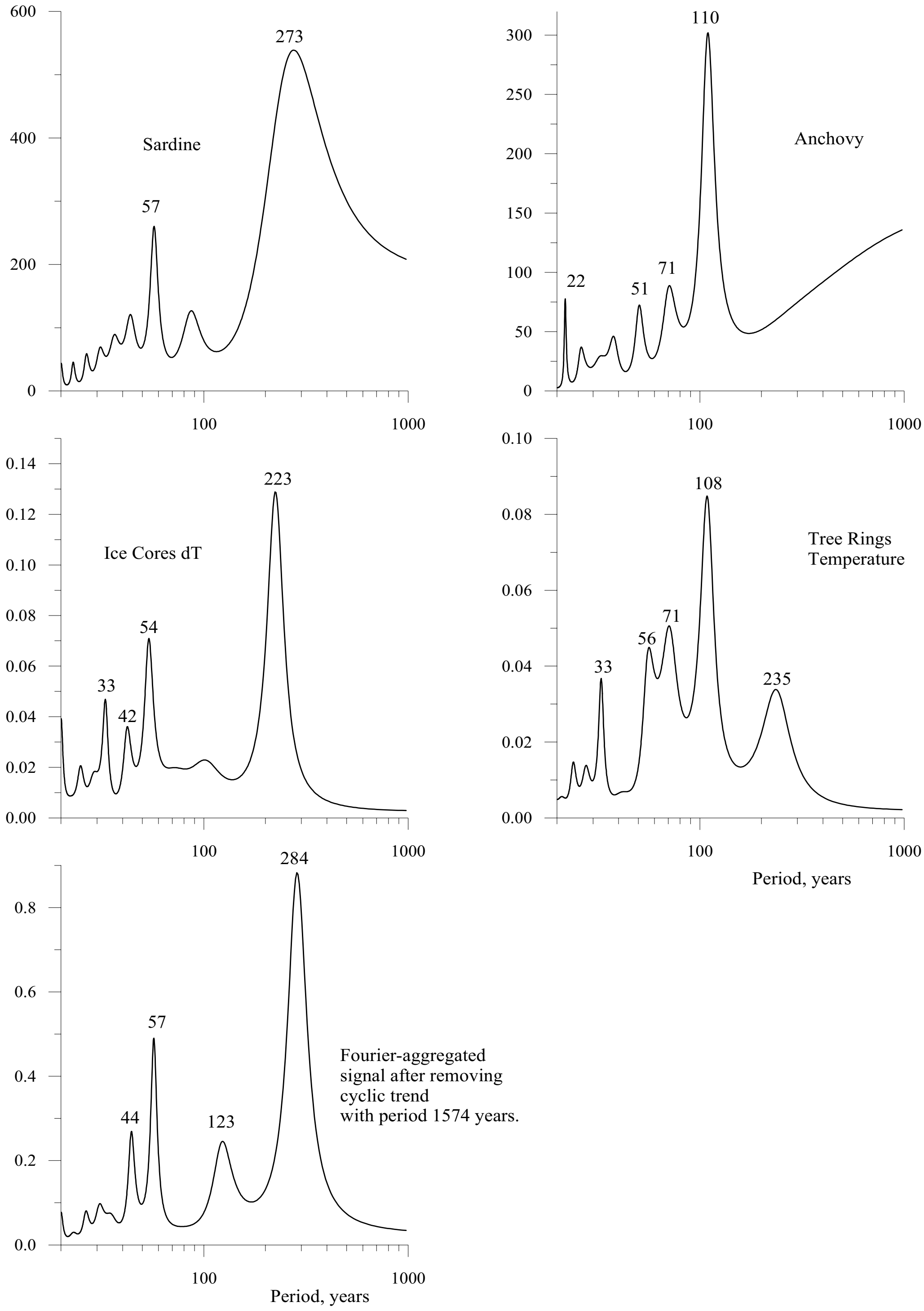

Figure 5.2 The spectra of the reconstructed time series of temperature based on samples from ice cores, tree rings, and sardine and anchovy biomass estimates for the last 1500 years. (All data were smoothed by a 10 year moving average).

5.3 SPECTRAL ANALYSIS OF THE TIME SERIES OF THE "INSTRUMENT MEASUREMENT PERIOD"

As was shown in Chapter 3**,** average annual values of global temperature anomaly (dT)**,** that have been measured since1861 are characterised by high interannual variability. Use of dT as a climate index is possible only after 10–13 year moving average smoothing of the time series, which considerably limits its utility as a predictive index. Moreover, the dT dynamics exhibit a significant age-long trend, which restricts its comparison with the dynamics of commercial fish stocks.

Length of Day index (LOD) is less variable, since it is measured using precise astronomical methods and data on its actual dynamics can be obtained anytime. However, LOD is a geophysical index that is not only directly dependent upon global climate changes. Its dynamics have a range of causes, and is complicated by the age-long trend, which limits its direct application as a reliable predictor.

The Atmospheric Circulation Index (ACI), as shown in Chapter 3, although measured over the Atlantic-Eurasian sector of the Western Hemisphere, almost coincides in dynamics with both observed dT and LOD. It can therefore be considered as a global scale index. It has no age-long trend and may be directly compared with fishery parameters, such as catch dynamics.

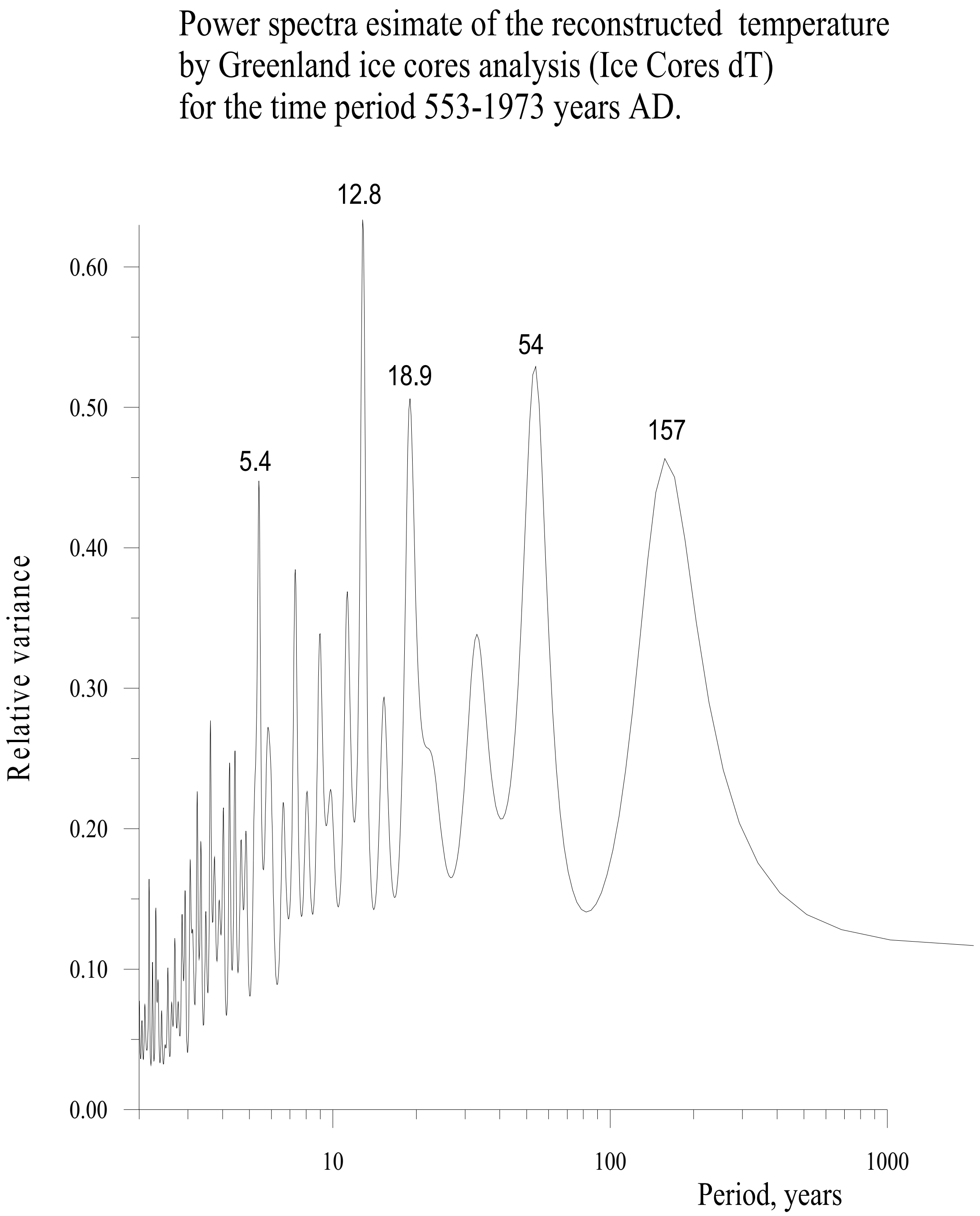

Figure 5.3 The full spectrum of unsmoothed reconstructed temperatures from ice core samples for the last 1420 years.

Spectral analysis of the time series of dT, ACI and LOD are presented in Fig 5.4. It is clear that the spectra of dT, ACI and LOD are rather similar. Primary maxima of dT and ACI are 50-55 years, and the period of the LOD cycle is 64 years. Other maxima are less pronounced, although there are clear peaks of ACI and LOD values (19 and 23 years, respectively) in the high frequency (left) range of the spectrum. The latter indicates that there is a global climate cycle with a frequency of about 20 years. Its effect on biota should be taken into account.

Table 5.1 Primary and secondary spectral maxima of measured and reconstructed time series.

Climate indices	Time period (years)	Primary Maximum	Secondary Maxima	
Global temperature anomaly (dT)	(1861 - 1998)	55	18	5
ACI	(1891- 1999)	50	19	8
LOD	(1850- 1998)	64	23	9
"Ice core temperature"	(552 - 1973)	54	42	33
Anchovy	(500 - 1970)	110	71	51
Tree rings dT	(500 - 1970)	108	71	56

Table 5.1 compares the spectral characteristics of long-term (1500 year) and short-term (150 years and less) time series. The table suggests that primary spectral maxima of dT, ACI, LOD, "Ice core temperature" and Sardine peaks are similar (the average maximum is about 56 years). On the other hand, the fluctuations of "Tree ring temperature" have a periodicity closer to the anchovy outbursts. The maximum in this case occurs at about 110 years, which is close to double the periodicity of the other time series (dT, ACI, LOD, "Ice core temperature", and sardine). Additional studies are necessary to clarify these phenomena. The spectra of long-term anchovy stock dynamics have pronounced maxima with the periods of 51 and 71 years.

5.4 COMPARING THE DYNAMICS OF MEASURED (DT) AND RECONSTRUCTED ("ICE CORE TEMPERATURE") TIME SERIES

It is important to know whether the long-term temperature oscillations reconstructed by ^{18}O content in the ice cores corresponds to the dynamics during the shorter recent period for which direct temperature measurements are available. Figure 5.5 presents the spectral signal of "measured dT" in comparison with the reconstructed "Ice core temperature". The dynamics of reconstructed temperatures based on Greenland ice cores is practically the same as that estimated from direct measurements of global dT. Therefore, both time series are coherent during the last 112 years (1861–1973), which confirms the reliability of the reconstructed time series.

5.5 SUMMARY

The most pronounced spectral maximum of the long-term fluctuations for all "long-term" time series (excluding anchovy) varies within the interval of 54–58 years. The corresponding climate cycles (both measured and reconstructed) vary within the range of 50–65 years (in average, 56 years). Other, less significant cycles (13- and 20-year fluctuations of summer temperature) may also be of interest, but no reliable correlation between these cycles and commercial catch fluctuations has been found.

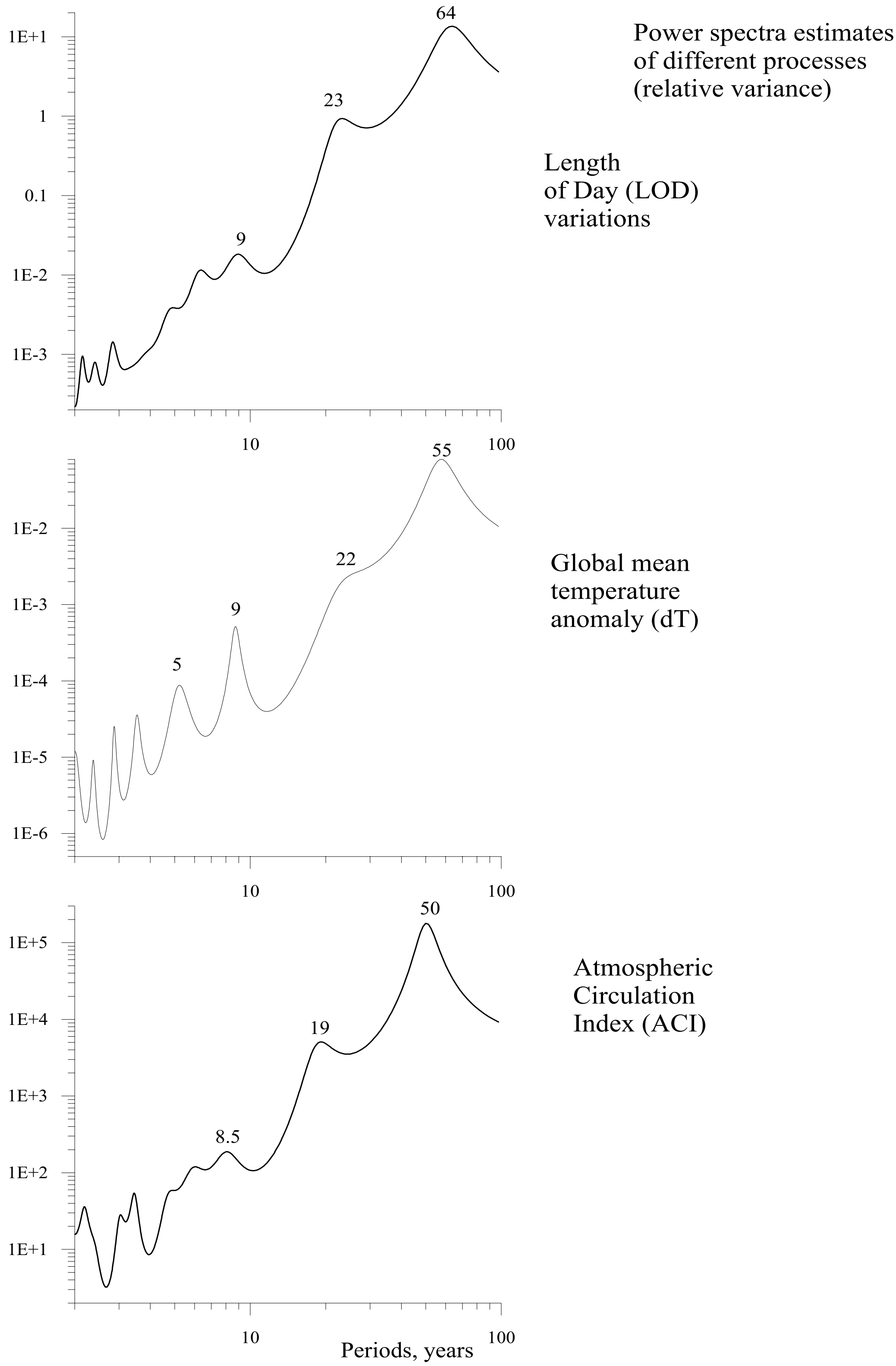

Figure 5.4 .The spectra of the instrumental time series LOD, dT and ACI (see text for details).

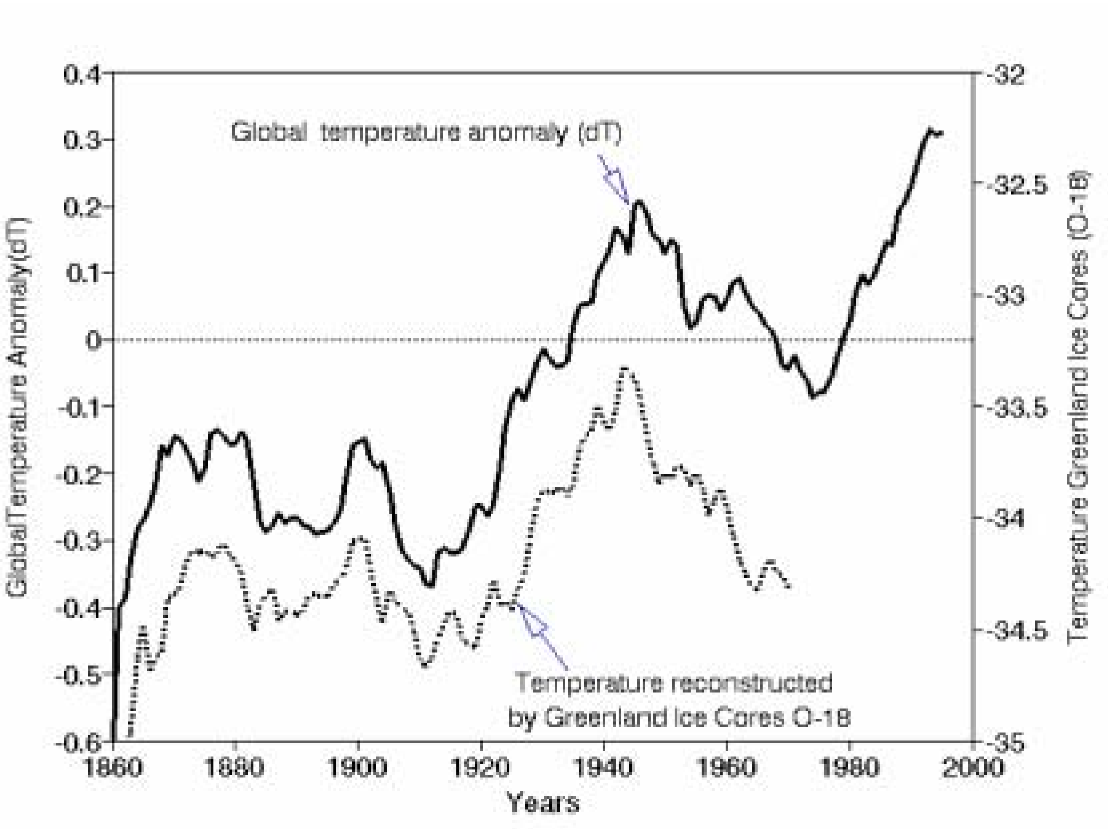

Figure 5.5.Comparing the dynamics of measured global temperature anomaly (dT) and temperature reconstructed by Greenland Ice Cores ^{18}O.