2. DYNAMICS OF CLIMATIC AND GEOPHYSICAL INDICES

Regular and reliable climate observations with measurement and calculation of principal climatic indices were started only about 150 years ago, when organized and consistent global ocean and atmosphere observation systems were initiated.

The averaged surface air temperature anomaly (dT) is widely recognised to be the most important index characterising the global climate changes including "global warming" (Bell *et al*. 1998; Anisimov and Polyakov 1999).

Another single index of climate change is the Atmospheric Circulation Index (ACI) that characterizes the periods of relative dominance of either "zonal" or "meridional" transport of the air masses on the hemispheric scale. ACI, also known as the Vangengeim-Girs Index, has been calculated from data on basic atmospheric activities in the Atlantic-Euroasian region for more than 100 years (Girs 1974).

George Vangengeim, the founder of ACI, is a well-known Russian climatologist. The Vangengeim-Girs classification is the basis of the modern Russian climatological school of thought. According to this system, all observable variation in atmospheric circulation is classified into three basic types by direction of the air mass transfer: Meridional (C); Western (W), and Eastern (E). Each of the above-mentioned forms is calculated from the daily atmospheric pressure charts over northern Atlantic-Eurasian region. General direction of the transfer of cyclonic and anticylonic air masses is known to depend on the distribution of atmospheric pressure over the Atlantic-Eurasian region (the atmosphere topography).

The recurrence of each circulation form (W, E, or C) during the year is expressed in days. Total annual duration of the three circulation forms sums therefore to 365 (or 366 in a leap year). The index is defined by the number of days with the dominant form of atmospheric circulation. It is more conveniently expressed as an anomaly (actual data minus the long-term average). The sum of anomalies can be displayed in a chart of the so-called integral curve of the atmospheric circulation. The annual sum of the occurrence of all circulation anomalies is equal to zero: (C) +(W) + (E) = 0.

The periods dominated by any single form of atmospheric circulation have alternated with a roughly 30-year period for the last 100 years. These periods were named "Circulation epochs". These may be pooled into two principal groups: meridional (C) and combined "latitudinal" epochs (W+E): (W + E) = - (C)

Meridional (C) circulation dominated in 1890-1920 and 1950-1980. The combined, "zonal" (W+E) circulation epochs dominated in 1920-1950 and 1980-1990. Current "latitudinal"(WE) epoch of 1970-1990s is not completed yet, but it is coming into its final stage, and so the "meridional" epoch (C-circulation) is now in its initial stage. (It will be useful for the reader to note here the relation that shows that the "transition" from C to W-E is continuous, and the equation balances to 100%, in the form of a simple graphic without any other variables included).

It was found that "zonal" epochs correspond to the periods of global warming and the meridional ones correspond to the periods of global cooling. (Lamb 1972; Lambeck 1980). The generalised time series on the atmospheric circulation forms for 1891-1999 were kindly placed at our disposal by the Federal Arctic and Antarctic Research Institute (AARI) in St. Petersburg (Russia). This is also consistent with the theories and observations described by Leroux (1998).

The third important index is Length of Day (LOD) – a geophysical index that characterizes variation in the earth rotational velocity. Full time series of LOD cover more than 350 years, with the most reliable data obtained in the last 150 years (Stephenson and Morrison 1995). The long-term LOD dynamics is in close correlation with the dynamics of the main commercial fish stocks (Klyashtorin and Sidorenkov 1996).

LOD Index is calculated as a difference of two values: actual (astronomical) length of day and the standard one. The continual registration of LOD and publication of the corresponding data is carried out by the International Time Bureau in Paris. The correlation coefficients were calculated using non-smoothed data ranges. Smoothed values, obtained using a Gaussian filter, were only used to improve the curve plots in the figures. Statgraphics (1988) software was used to detrend the time series.

Let us compare the dynamics global geophysical (LOD) and climatic indices for the last 150 years. For a more convenient visual comparison of the dT, ACI and the earth rotation velocity dynamics, the negative (-LOD) instead of the directly calculated LOD values was used. The dynamics of -LOD, dT and ACI for the last 140 years can be viewed as multi-decadal fluctuations against the background of age-long trends (Figure 2.1).

Global dT is known to have an ascending linear trend 1861-1999 with the increment of 0.059^{o} per 10 years (Sonechkin 1998).

Our planet as a whole conserves its angular momentum except for the known effects of external torque associated with the lunar-solar tide, which induces a gradual decelerating of the earth rotation velocity at a rate corresponding to the increase in the astronomic length of day (LOD) by about 1.4 millisecond per century (Munk and McDonald 1960). That is, -LOD has had a descending linear trend with the increment about 0.14 ms per decade (Figure 2.1). Different age-long linear trends of LOD and dT make it difficult to compare the dynamics of multi-decadal fluctuations of these indices. Figure 2.2a presents both -LOD and dT ranges, with the linear trends removed by fitting of linear regression and using a "detrending" procedure (Statgraphics 1988).

When detrended, the graphs of -LOD and dT are very similar in shape, and it is clear that -LOD runs several years ahead of dT, especially in its maxima. Shifting the -LOD curve by 6 years to the right (Figure 2.2b) results in almost complete coincidence of the corresponding maxima of the early 1870s, late 1930s, and middle of 1990s (Klyashtorin et al.1998).

The similarity in the dynamics of detrended -LOD and dT and ACI indices is clear: Large fragments of the curves are much alike not only in general shape, but in detail as well. In general, the long-term dynamics of both dT and -LOD have roughly a 60 year periodicity. The global climate system was reported to oscillate with a period of 65-70 years since 1850 (Schlesinger and Ramankutty 1994). The same 60-70 year periodicity has also been characteristic for the long-term dynamics of some climatic and biological indices for the last 150 years (Klyashtorin 1998).

Similarity between the -LOD and dT dynamics makes it possible to assume the existence of some common factors inducing and controlling the observable synchrony in geophysical (LOD) and climatic (dT) indices variation. The atmospheric circulation as a whole is strongly driven by the Equator-Pole Temperature Meridional Gradient. Greater warming in the polar region weakens this gradient in the lower troposphere, which leads to a general weakening of surface winds (Lambeck 1980).

The long-term dynamics of the atmospheric pressure fields over the Northern hemisphere during the last 90 years are characterised by the alternation of approximate 30-year periods ("circulation epochs") with relative dominance of either zonal or meridional atmospheric circulation (Dzerdzeevski 1969; Girs 1971; Lamb 1972; Lambeck 1980).

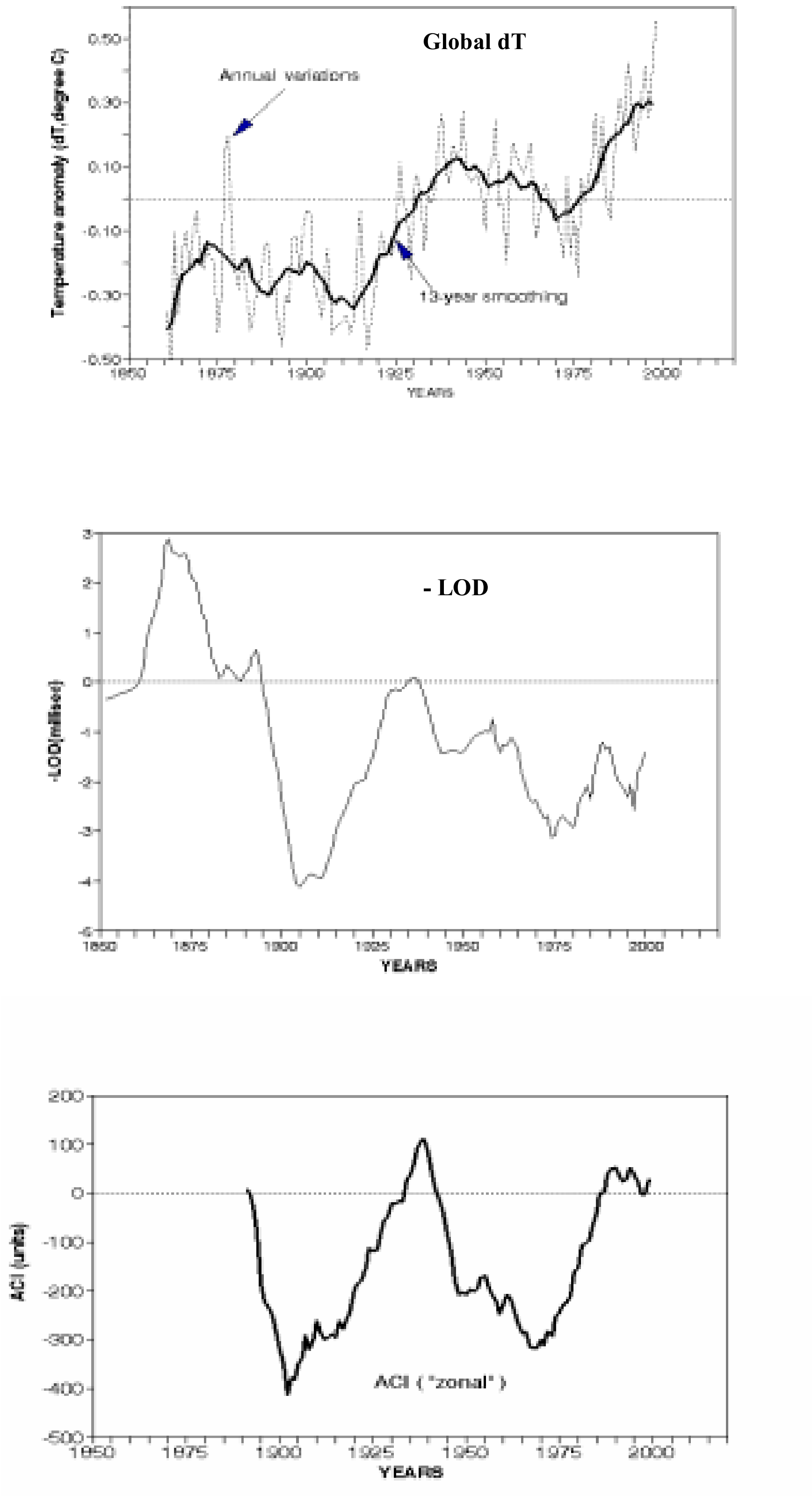
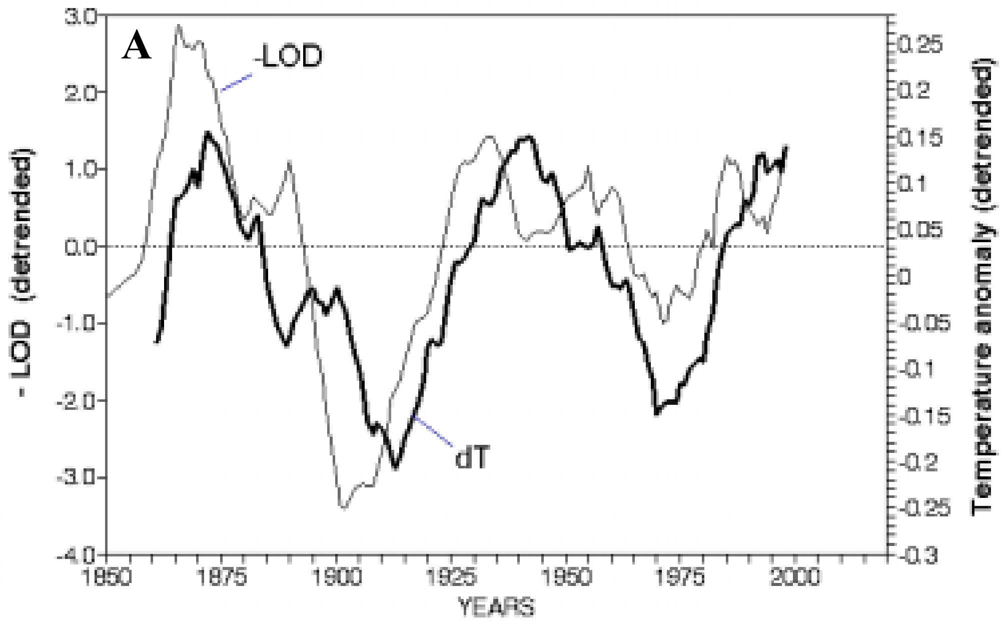


Figure 2.1 The dynamics of the global air-surface temperature anomaly (dT), 1861-1998, the negative Length of Day (-LOD), 1850-1998 and the “zonal” Atmospheric Circulation Index (zonal ACI), 1891-1999.



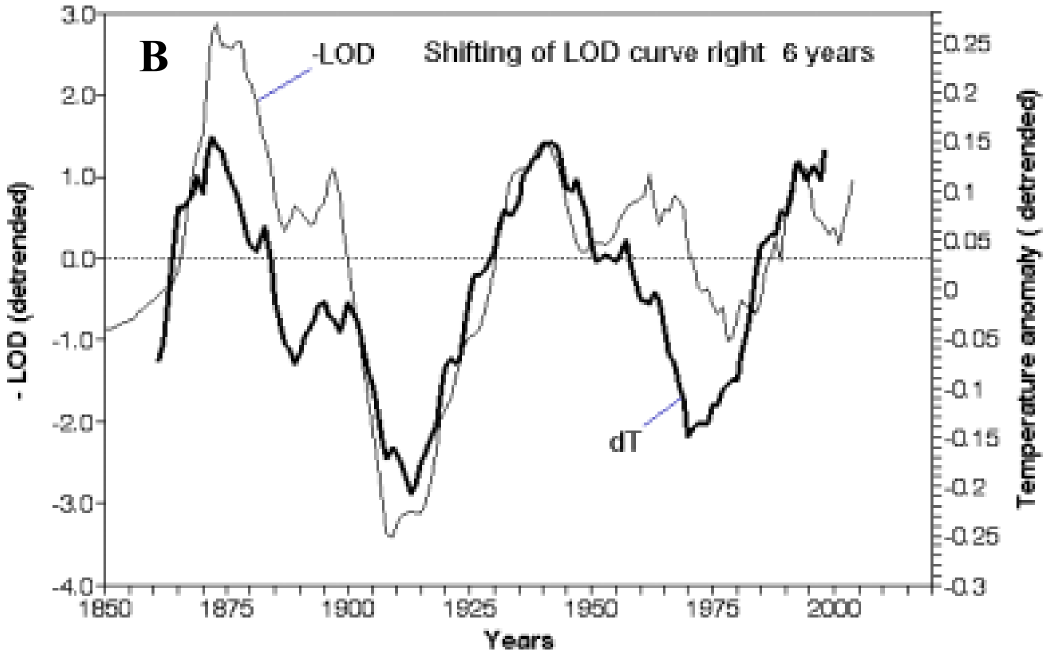


Figure 2.2 Dynamics of the detrended global temperature anomaly (dT) and detrended negative Length of Day (-LOD) (see text for details).The ACI ("zonal" form) has practically no pronounced general trend. Comparison of dT and ACI (Figure 2.3A) shows their close similarity in shape, but ACI runs several years ahead of dT. Shifting the ACI curve by 4 years to the right (Fig 2.3B) results in almost complete coincidence of the curve maximums of the early 1870s, late 1930s, and middle 1990s.

The first type, zonal circulation, is characterised by increasing intensity of the zonal circulation at all latitudes and pole-ward shift of the wind intensity maximums. The circulation is accompanied somewhat by a decrease in the overall range of surface-air temperature between the equator and poles and by an overall increase in the mean global surface-air temperatures. Ocean-surface temperatures tend to increase in high latitudes. The second type, meridional circulation, is characterised by weakening in zonal circulation, shift of the main atmospheric streams toward lower latitudes, and overall decrease in global temperature (Lamb 1972). Both easterly and westerly winds increase during the zonal type of circulation and both decrease in the periods of the meridional type of the circulation (Lambeck 1980).

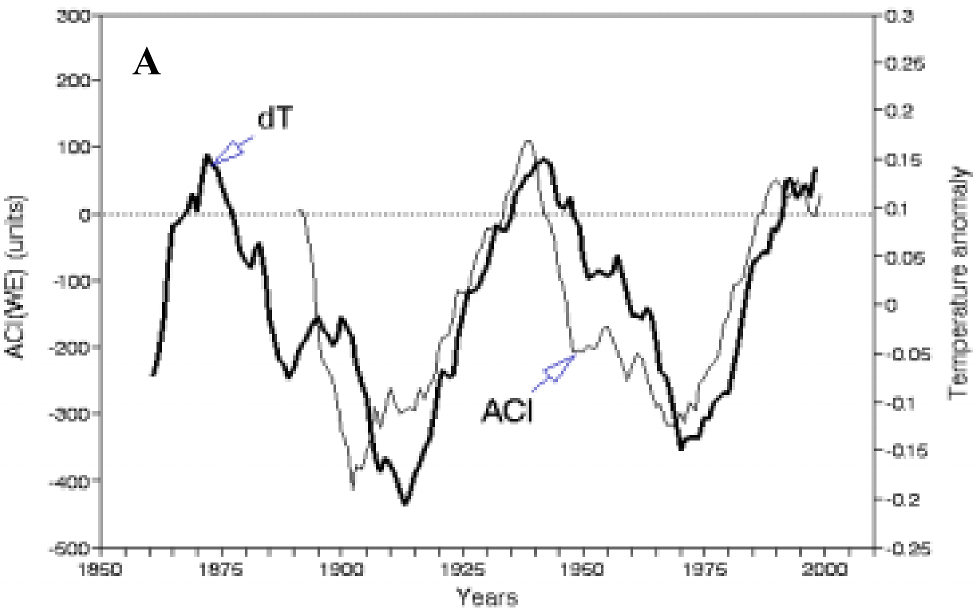
Atmosphere is the most variable component of the global geophysical system exchanging relatively large proportions of its angular momentum with the solid earth below compared with other components (Salstein *et al*. 1993). A number of publications suggest that seasonal, inter-seasonal and inter-annual variations of the earth's rotation velocity are directly proportional to the relative angular momentum at the atmosphere, which primarily depends on the velocity of zonal winds (Langley *et al*. 1981; Rosen and Salstein 1983; Robertson 1991). On longer time scales, changes in LOD are correlated with the El Niño Southern Oscillation (ENSO) phenomenon, and strong wind anomalies associated with ENSO events (Salstein and Rosen 1986; Dickey *et al*. 1992a,b)

A formal derivation of the dynamic relation between the atmosphere and solid earth make it possible to calculate the changes in the earth's rotational velocity from the large-scale distribution of the atmospheric pressure and dynamics of the wind fields (Barnes *et al*. 1983). These data are available from several of the world's weather services (Salstein *et al*. 1993).

Thus, on a wide range of time scales from several days to years, there is an agreement between the dynamics of the angular momentum in the atmosphere and solid earth, which come into view as small but important changes in the rotation of the planet.

It is conceivable that the multi-decadal fluctuations of the earth's rotation velocity results from the redistribution of the angular moment between the atmosphere and solid earth due to the alternation of multi-decadal epochs of "zonal" and meridional atmospheric circulation.

It was shown (Lamb 1972; Lambeck and Cazenave 1976), however, that the observable changes in speed and direction of the air mass transfer may explain seasonal and annual, but not multi-decadal, LOD variations. Only 10% of the long-term LOD variation can be explained by the observable changes in atmospheric circulation. The calculations suggest that the average speed of zonal winds would have to be an order of magnitude larger than they are to explain the remaining 90% of the LOD changes. It seems improbable that some other unevaluated meteorological factors could provide additional explanation. Therefore, the hypothesis that the climatic changes are a consequence of the LOD changes should be rejected (Lambeck 1980).



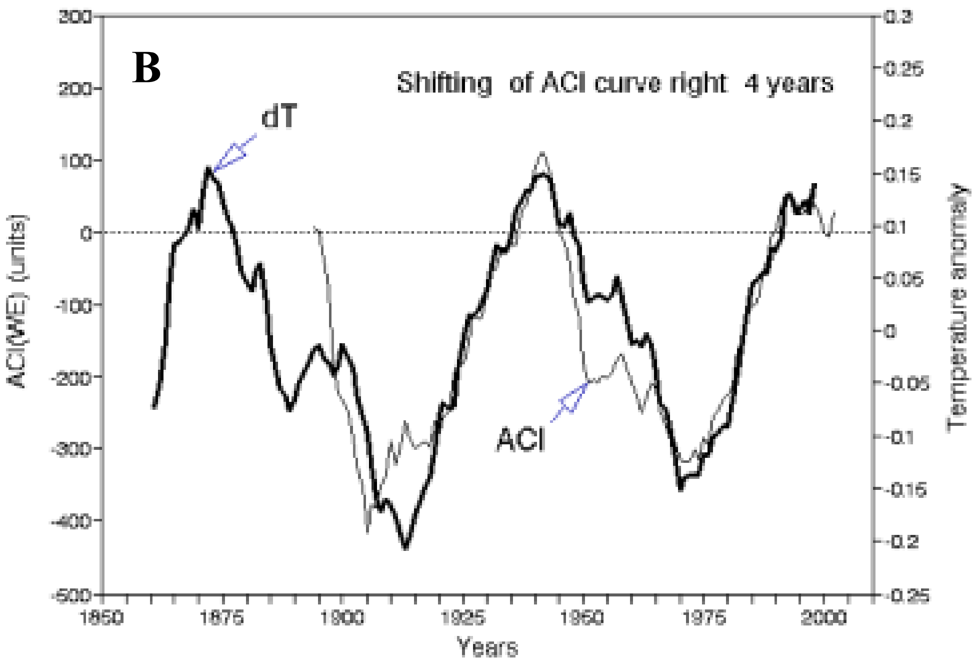


Fig 2.3 Dynamics of the detrended global temperature anomaly (dT) and the Zonal Atmospheric Circulation Index (zonal ACI) (see text for details).

2.1 SUMMARY

A phenomenon of close correlation between the main climatic index dT and geophysical index (-LOD) still remains an intricate puzzle of geophysics. Another challenging puzzle is the observable 6-year lag between the detrended run of dT and -LOD. Taking into account this lag, the LOD observations can be used as a predictor of the future climatic trends. Even without a mechanism for a causal relationship between the detrended climatic (dT) and geophysical (LOD) indices, the phenomenon of their close similarity for the last 140 years makes LOD a convenient tool to predict the global temperature anomaly (dT) for at least 6 years ahead.

Lambeck and Cazenave (1976) pointed out a high probability of an increasing global temperature trend in the 1970s and 1980s. Their prediction was correct.

Spectral density analysis of the LOD time series for 1850-1998 revealed clear, regular fluctuations with an approximate 60-year period length (see below). The multidecadal maxima of LOD took place in the early 1870s and mid-1930s, and the next maximum is likely to fall early in 2000. Based on this multidecadal periodicity of LOD, and the fact that LOD runs ahead of dT by 6 years, a gradually descending dT may be expected around 2005.

Although the interdependences between dT, ACI and -LOD may be complex, the empirical geophysical index (LOD) may still serve as a general predictor of future climate changes. This gives an opportunity to forecast climate change and, therefore, stock and catches of commercial species, which are related to climate.