## CHAPTER 7 CLIMATOLOGY OF TYPHOONS



** Not Completed*

## 7.6 Interannual and Secular Variations

### 7.6.1 Interannual variations

The causes of the interannual changes in the frequency and tracks of tropical cyclones ~~or of the weather generally~~ are not yet fully understood. Variations in the paths followed by typhoons from year to year and changes in their number are known to be influenced by large scale changes in the characteristics of the wind flow in the middle and upper troposphere. These changes result in variations in position and intensity of the major surface pressure centres and such semi-permanent features as the equatorial trough. Most typhoons originate near this through and its latitude and relationship to waves in the upper tropospheric westerlies are important factors in determining the number of tropical cyclones which form each year. Namias has shown how these anomalies (departures from long period normals) in the broad scale atmospheric circulation can sometimes influence both the formation of tropical cyclones (Namias 1969) and their subsequent movement (Namias 1954).

We do not know exactly how the changes in the positions and intensities of the main features of the general circulation come about. However, the prime cause must be variations in the amount and distribution of the heat input to the atmospheric heat engine. Almost all the energy of atmospheric motion is ultimately derived from solar radiation. In the tropics the earth plus atmosphere gains more heat than it looses; in polar regions the reverse is true. Surplus heat energy from the tropics is carried towards the poles by the atmosphere circulation (90%) and by ocean currents (10%) however, the heat transport is complicated by many factors such as, for example, the earth's rotation, continents, mountains, typhoons and various physical processes. Although they carry only 10% of the heat, the oceans play an important part in year to year changes because they are vast reservoirs of heat and their temperature anomalies can carry across seasons. The atmospheric circulation itself affects ocean temperatures; low level winds drive ocean currents and cause upwelling and surface cooling, large areas of persistent cloud cover (or persistent clear skies) associated with the upper wind flow vary the incoming solar energy over large areas and also cause ocean temperature changes. There is, therefore a complicated interaction between the temperature of the oceans, at and near the surface, and the general circulation. Namais (1969) has ~~shown how~~ suggested that an area of cold water in the Atlantic Ocean in 1968, which originated from greater than normal cyclonic activity, was subsequently responsible for anomalies in the upper wind flow over the Atlantic which, in turn, resulted in the formation of less than the usual number of hurricanes. We also know that the sea surface temperature itself is a critical factor in the formation of tropical cyclones indeed, they cannot form where the water temperature is lower than 26.5°C (See Section ).

Summarising, the year to year variation in the weather generally, and of the number of tropical cyclones in particular, is dependent upon anomalies in the broad scale atmospheric circulation. These anomalies result from the redistribution of temperature in the atmosphere and oceans and over land but the relationships are complex because of strong interaction, the temperature anomalies themselves being influenced by the circulation.

### 7.6.2 Secular variations

#### 7.6.2.1 Climatic change

There was a great upsurge of interest in climatic change during the mid-nineteen seventies because it was then realized that a greatly increasing world population and a desire to raise living standards were having two potentially disastrous consequences. Firstly, the resulting increased pressure on natural resources of food, water and energy were such that the balance between supply and demand could be seriously upset by marginal changes in climate. ~~For example, world grain reserves are now only a few per cent of annual consumption and a quite small deterioration in the climate of a major food-producing area would cause serious difficulties~~. Secondly, human activities may inadvertantly cause significant changes in weather and climate through the release into the atmosphere of large amounts of carbon dioxide, aerosols and waste heat.

In the long term, a major natural change to a different climatic regime must be expected but, it is unlikely that any trend towards such a change would be perceptible in the short term as it would be obscured by the large shorter-term climatic variability. The shorter-term, natural or possible man-made, changes in climate are of immediate concern because of their important impact on human welfare and economic development. In 1976 the WMO Executive Committee urged that greater efforts be made to understand and predict short-term changes in climate due to natural causes and the impact of man's activities. Subsequently, several programmes were started to achieve these objectives and numerical models were developed to attempt to determine the sensitivity of the climate to natural or man-made changes in various relevant factors.

#### 7.6.2.2 Past climates

The instrumental period of meteorological observations goes back only 200-300 years. However, climatic variations over much longer time scales have been estimated by analysing various kinds of 'proxy' data in which past weather changes have been registered by associated physical or bilogical changes. Such studies have been made on tree rings, fossil flora and fauna in deep-ocean sediments, fossil pollen in layered soils, isotopic composition in ice cores from polar ice caps, changes in the extent of glaciers and sea levels, etc. From this information it is deduced that during the past two million years or so, there has been a long sequence of alternations between glacial and interglacial epochs of climate, in which the glacial epochs have tended to recur at approximately 100 000-year intervals. For about the past 8 000 years, the Earth has been in a comparatively warm interglacial phase of this ice-age sequence, with less ice than at any time in the past 100 000 years. Mid-latitude temperatures are today 5 to 8 $^{\circ}$C warmer, and sea levels 80 to 100 m higher, than those typical of extreme glacial stages, such as the Würm glacial maximum about 18 000 years ago.

Since the recovery of the Earth from the last glacial stage, about 8 000 to 10 000 years ago, the global climate has fluctuated within much narrower limits. There have been expansions and retreats of polar ice and mountain glaciations, at intervals of approximately 2 000 to 3 000 years, in what is described as a neo-glacial cycle. The Little Ice Age - a period with temperatures 1 or 2$^{\circ}$C lower than today and stormy conditions in the North Atlantic - lasted from about 1550 to 1850 A.D. and was a part of the neo-glacial cycle. Since then world temperatures generally have arisen about 1$^{\circ}$C as shown in Fig. 7, with the warming being especially pronounced during the first half of the twentieth century, with temperatures rising most rapidly (several $^{\circ}$C/50a) in the Atlantic sector of the Arctic. The wind belts and storm tracks of the northern hemisphere tended to be further north at that time. A similar shift occurs, on a shorter time scale, with the change from winter to summer each year.

The climatic trends characteristic of the first half of the twentieth century appear, generally speaking, to have reversed direction since then, at least in the northern hemisphere as a whole (Fig. 7 ). Temperatures have fallen especially in the Arctic and the Atlantic Sub-Arctic where the extent of sea ice has again been increasing. The atmospheric circulation of the northern hemisphere appears to have reverted to a pattern resembling that of the last part of the nineteenth century, with a tendency towards

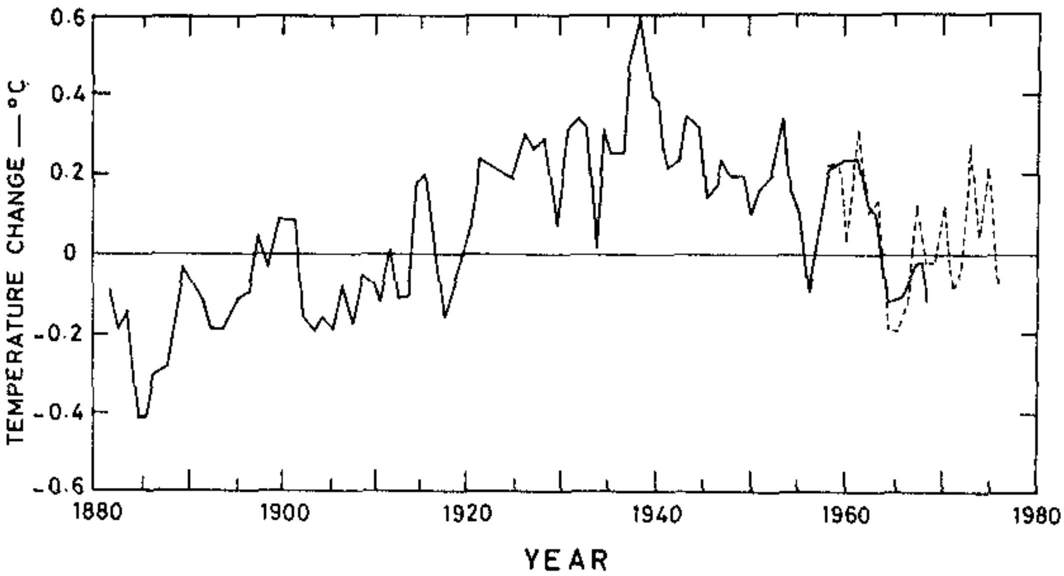


Fig. 7.6.1. Changes in the annual mean temperature of the northern hemisphere. The full line is from Budyko (1969) the dashed line corresponds to data from Angell and Korshover (1978).

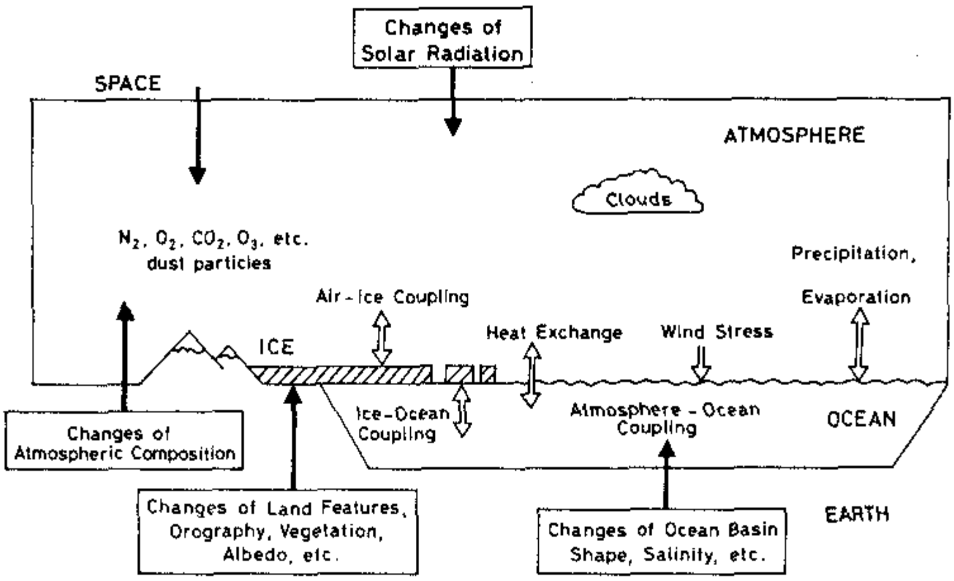


Fig. 7.6.2 Schematic illustration of the physical processes and properties that govern the global climate and its change. (From U.S. Nat. Academy of Sciences 1975).

greater variability of weather conditions in many areas. These changes may have begun to falter, if not actually to reverse yet again, in the last few years (Fig. 7.        ). To what extent shifts of tropical cyclone tracks, the monsoon belt and other circulation features in recent years are related to each other as part of a systematic fluctuation of climate is not clear.

7.6.2.3 General causes of climatic change

Present understanding of the causes of climatic fluctuations is rudimentary. A great many physical mechanisms have been proposed. The difficulty has been to verify which of these mechanisms are valid and to assess to what extent each contributes to the observed fluctuations. The relative importance of these causes differs with the time scale being considered. Many potential mechanisms exist to produce internal variability of the climatic system, on a wide range of time scales. These follow directly from the highly non-linear interactions (feedbacks) occurring between the different parts of the ~~climatic~~ system (Fig. 7.6.1) and the widely disparate reaction times involved.

Climatic fluctuations may also arise in part from influences originating outside the climatic system. There are variations of the radiant energy output of the sun (sect 3.4) although their magnitudes and effects are unclear, variations of the quantity of particles in the upper atmosphere originating from volcanic eruptions, and the accumulation of carbon dioxide in the atmosphere from fossil-fuel combustion.

One unstable interaction that probably contributes significant variability to the climatic system is that between snow cover, reflection of solar radiation, and air temperature. If a small decrease of temperature occurs which favours the development of a snow cover, the greater reflection of solar radiation from the snow will locally reduce solar heating of the Earth's surface and atmosphere. The reduced heating will then lower air temperature still further, preserving the snow and perhaps favouring additional snowfall over a wider area to accelerate the process. If the starting point is a small increase of temperature a similar chain of events in the opposite direction may follow. The end effect is both to amplify small climatic disturbances, and to prolong them.

However, no one such mechanism can be realistically considered in isolation from others. All must be considered together in a general physical framework before we can claim a useful understanding of climatic fluctuations. We have neither an adequate conception of all the mechanisms that may be involved, nor are we certain of the physical framework required to encompass them. Those who are developing numerical models of the climatic system have to solve these and other related problems before they can reproduce the essential behaviour of the real system.

7.6.2.4 Solar radiation and climate

That the sun has an effect on the earth's climate is a trivial assertion. But whether solar changes are followed by climatic changes is a difficult question which still awaits an answer. Solar flares affect the upper atmosphere causing ionospheric and magnetic disturbances and auroral displays on a day to day basis but these are attributable to variations in the emission of ultra-violet and corpuscular radiation and amount to only 0.1% of the total solar radiation. Changes in climate due to possible changes in the radiation of the sun - the solar constant of sect 3.4 - have not yet been established. Calculations with relatively simple models indicate that one per cent overall increase in solar radiation would produce an average rise of 0.6$^{\circ}$C in the global surface temperature. However, measurements of the solar constant whether on the ground or from space or for a day or several years shows that if it does change with the sunspot cycle the amount is less than one per cent of the total. Refinements in observational techniques are in hand to obtain ~~a series~~ observations of higher accuracy ~~readings~~ from space over a sunspot cycle.

The search for climatic periodicities linked with the 11-year and 22-year sunspot cycle has continued unabated for more than 100 years without yielding statistically conclusive results. Correlations exist only over periods of a few decades and then fade away in "noise" or appear to change phase (Bell 1977). Pittock (1978) critically reviewed the literature on long-term sun-weather relationships and found deficiencies in the statistical treatment of much of the data that has been presented. He concluded that little convincing evidence has yet been produced for real correlations between sunspot cycles and weather and climate. However, Pittock accepted that there is evidence for correlations between some atmospheric phenomena and solar events on the time scale of days. In particular, Roberts and Olson (1973) related a "vorticity area index" - essentially a measure of the intensity of troughs at 300 mbar over the north Pacific and north America - to the passage of solar magnetic sector boundaries. The latter rotate with the sun sweeping across the earth several times each month. Knight and Sturrock (1976) found a relationship between the same vorticity area index and a geomagnetic activity index (Ap.) However, Williams and Gerety (1978) have recently challenged the significance of the correlations of solar vorticity-area index relationships.

Between 1645 and 1715 the number of sunspots reported was unusally low, generally lower than the normal minimum of the eleven-year cycle. This period - known as the Maunder Minimum after the Greenwich Observatory superintendent who studied the data in detail - coincided with the "Little Ice Age". The sun's extended magnetic field modulates cosmic ray activity and hence radiocarbon $^{14}C$ production in the atmosphere. The ratio of $^{14}C$ to non-radioactive carbon $^{12}C$ in wood formed when solar activity is high i.e many sunspots, should be low, whereas wood grown during the Maunder Minimum should show high ratios as indeed, is found to be the case. The ratio of $^{14}C$ to $^{12}C$ in tree rings in dateable wood shows evidence for a 2 500-year cycle. It is still possible therefore that some variation of solar output may occur over periods of thousands of years. However, there is as yet no generally accepted theory as to how such small variations in solar output would affect the climate.

Apart from possible variations of the sun's radioactive output, changes in the earth's orbit would change the geographical distribution of the intensity of the seasonal and annual radiation incident on the earth's atmosphere. Changes in the eccentricity, obliquity and precession of the earth's orbit are known to occur with periods averaging about 96 000, 41 000 and 21 000 years respectively. Milankovitch (1930) proposed that the accompanying re-distribution of solar radiation would cause major glacial-interglacial cycles. The seasons themselves are the result of similar astronomical changes of shorter period. Milhankovitch's theory is therefore attractive. Mason (1976) has shown that these orbital changes are of the right order of magnitude and phase to invitiate the succession of major advances and recessions of the ice sheets. Furthermore, recent studies of the longest ocean-bed sediment cores seem to have established beyond doubt that cyclical variations of about 100 000, 40 000 and 20 000 years are the main control of the timing of ice-age and interglacial variations. In addition, numerical experiments with general circulation on models using different values of eccentricity, obliquity and longitude of perihelion (Gilchrist 1976) yield results of the kind expected from Milankovitch's theory. For these reasons it is now generally believed that cyclical changes in the earth's orbit are the prime cause of the major glaciations.