Chapter

Causes and Mechanisms of Global Warming/Climate Change

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Abstract

Comparison of the average mean surface air temperature around the world during 1951–1978 with that for 2010–2019 shows that the bulk of the warming is around the North Atlantic/Arctic region in contrast to the Antarctic ice sheet. Obviously, the temperature change is not global. Since there is a substantial difference between solar heat absorption between the equator and the poles, heat must be moving to the North Pole by surface ocean currents and tropical cyclones. The cold, dry Arctic air coming from Siberia picks up heat and moisture from the open oceans, making the sea water denser so that the warm water sinks slowly down to c. 2000 m. A deep-water thermohaline flow (THC) transports the excess hot (c. 18°C) water south to Antarctica. It is replaced by a cold (c. 2°C) surface water from that area. The latter quickly cool western Europe and Siberia, and glaciers start to advance in Greenland within about 10 years. The THC flow decreases in Interglacials, causing the increased build-up of heat in the Northern Hemisphere (c. 60% currently stored in the Atlantic Ocean), and the ice cover in the Arctic Ocean thaws. Several such cycles may take place during a single major cold event.

Keywords: global warming, major cold events, asymmetrical warming of the Earth, thermohaline currents, agents of transport of heat around the globe, minor cold and warm events

1. Introduction

Climate change has become a major consideration for the public and politicians alike because of its economic importance. Naugebauer [1] provides a good summary of the history of its study, but the conclusion reached is that current theories and models do not adequately explain what is taking place. There is a universal assumption that climatic changes are worldwide. During the last two decades, many parts of the land areas of the Northern Hemisphere have experienced increasing mean annual air temperatures together with more extreme weather. The public, media, and politicians have been assuming that the warming trends seen in many places on land are the result of increased concentrations of atmospheric carbon dioxide, following the lead of a panel of climatologists appointed by various European governments that produces periodic reports on the amount and causes of the presumed warming, *e.g.,* IPCC [2]. However, many scientists have disagreed (*e.g.*, [3–15]) citing too many causes that are closely correlated with recent major climate changes that are clearly not associated with carbon dioxide concentrations. The overall recent increase in mean average daily temperature on Earth is similar to that on the other planets in the solar system.

The purpose of this paper is to examine the evidence for a universal system of climatic change throughout the globe, together with some of the proposed causes and mechanics of the climatic changes that have taken place during the late Pliocene and Quaternary Periods. This should determine the most likely causes of the cold events and recent changes in weather around the globe.

1.1 Definitions

Global warming can be defined in two ways. Firstly, it can be interpreted literally as referring to increased surface temperatures throughout the whole world, but the IPCC defines it as the increase in mean annual air temperature of the Earth since the beginning of the Industrial Revolution, assumed to be between 1850 and 1900 A.D. There is some disagreement as to when this began, but global warming enthusiasts and modelers assume that it is occurring everywhere on the Earth's surface.

Recently, many scientists are using the term climate change in place of global warming since there is strong evidence that the changes vary from place to place as they have done in the more distant past. These changes are closely related to the nature of the local environment and the relationship to both the distribution of land and sea, the continuing plate tectonics altering the arrangement and dimensions of the land and sea together with the current climate.

1.2 The Earth within the solar system

The Earth is essentially a closed energy system, the heat is supplied from the Sun and the geothermal heat flows from the interior of the Earth. The latter is regarded as being fairly constant at 0.06 W/meter squared at 30 degrees C while the incoming solar radiation is potentially 6000 times greater in its effect ([16], p. 37). It is determined by the so-called solar constant which is 1.37 kW × m^{-2} [16]. The total heat flux through the Earth's surface due to energy generated in the mantle and the crust is approximately 0.0257% of the total Earth's solar irradiation. There is an 11-year cycle of variation in solar irradiance, but this has not increased since 1950. The incoming radiation is modified by clouds, surface albedo, snow cover, soil moisture, vegetation cover, latitude, thermal conductivity, and soil latent heat. The world total energy production is estimated to be about 0.0077% of the total solar irradiation reaching the Earth. Thus, solar radiation supplies more than 99.95% of total energy driving the world climate [17].

1.3 Current patterns of climate change

When the average mean surface air temperature around the world during 1951–1978 is compared with that for the period 2010–2019, it is obvious that although warming has taken place, it is asymmetric (**Figure 1**). The bulk of the warming is in the northern hemisphere while the temperature changes in the southern hemisphere decrease southward and become negative in and near Antarctica. The same result is obtained from space satellites although the area with negative temperature change in the higher latitudes of the southern hemisphere increases. There are also differences between the oceans and land masses as well as between continents. Obviously, the temperature change is not global, nor is it concentrated in the regions of the maximum industry but varies regionally. Accordingly, we must be dealing with climate change, not global warming.

The First Law of Thermodynamics states that energy and matter cannot be created or destroyed, although they can change their form. In a closed system, a decrease in energy in one area must result in a comparable increase somewhere else.

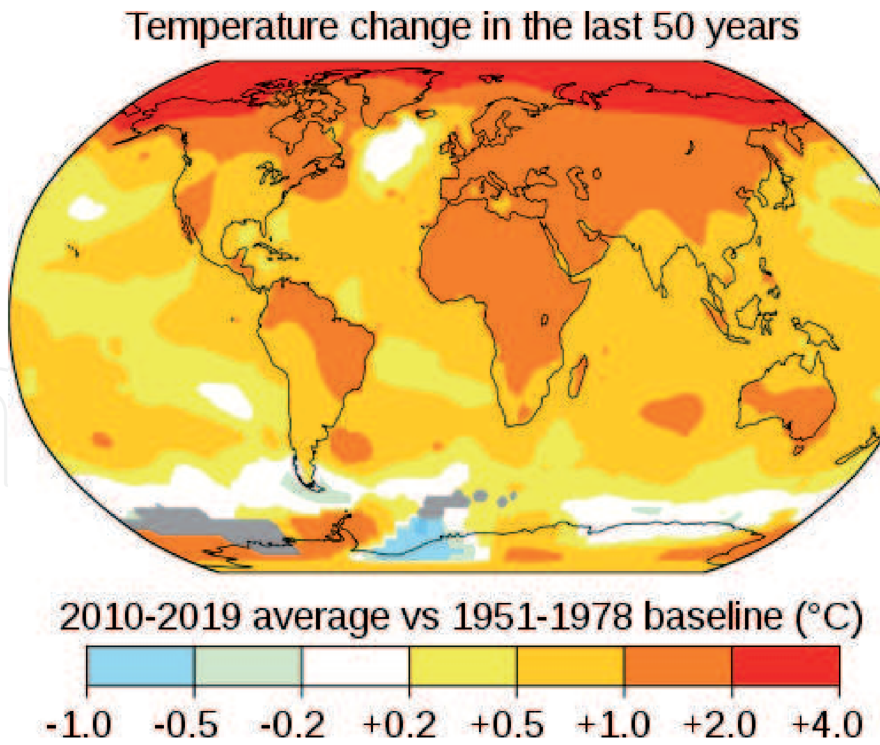

Figure 1.
The pattern of change in mean annual air temperature between the periods 1951–1978 and 2010–2019.

To get and maintain an asymmetric heat energy distribution as shown in **Figure 1**, there must be a set of forces preferentially moving heat energy towards the north polar regions as well as a mechanism to bring the energy back towards the South Pole. The rest of this paper will discuss the processes involved in the movement of heat energy around the globe in order to determine what may be happening. The conclusions must also explain the longer-term climatic history as we know it today.

2. Processes affecting the distribution of heat around the surface of the Earth

The Sun is far enough away that the solar radiation arrives at the surface of the Earth as a beam. Since the Earth is round, the bulk of the energy arrives within the Tropics, 23.5° north and south of the Equator. Under present-day conditions, the Sun does not rise for at least a day in winter at latitudes higher than 66.7° north and south due to the tilt of the axis of the Earth.

Figure 2 shows the typical fate of insolation in summer entering the atmosphere of the Earth at about 50°N latitude. In practice, the amount of insolation reaching the ground will also depend on the sum of the effects of numerous climatic cycles pulling in multiple directions [14, 18, 19]. There are a very large number of these interacting with one another, so they normally largely cancel one another out. However, they are also largely responsible for the continual noise in the climatic signal that makes it advisable to have a 30-year average of climatic data where possible.

There is one special group of cycles that are critical in determining the amount of solar radiation arriving at a given location on the surface of the Earth over long periods of time, *viz.*, the Milankovitch cycles first thought of by Adhemar (Croll [20, 21]). Milankovitch [22, 23] refined the calculations of the effect of the three types of Earth orbital movements that can alter the Sun's incoming radiation by up to 25% in the zone subtropical zones (30–60° north and south of the equator. They are the shape of the Earth's orbit (eccentricity, a 100,000 year cycle), the

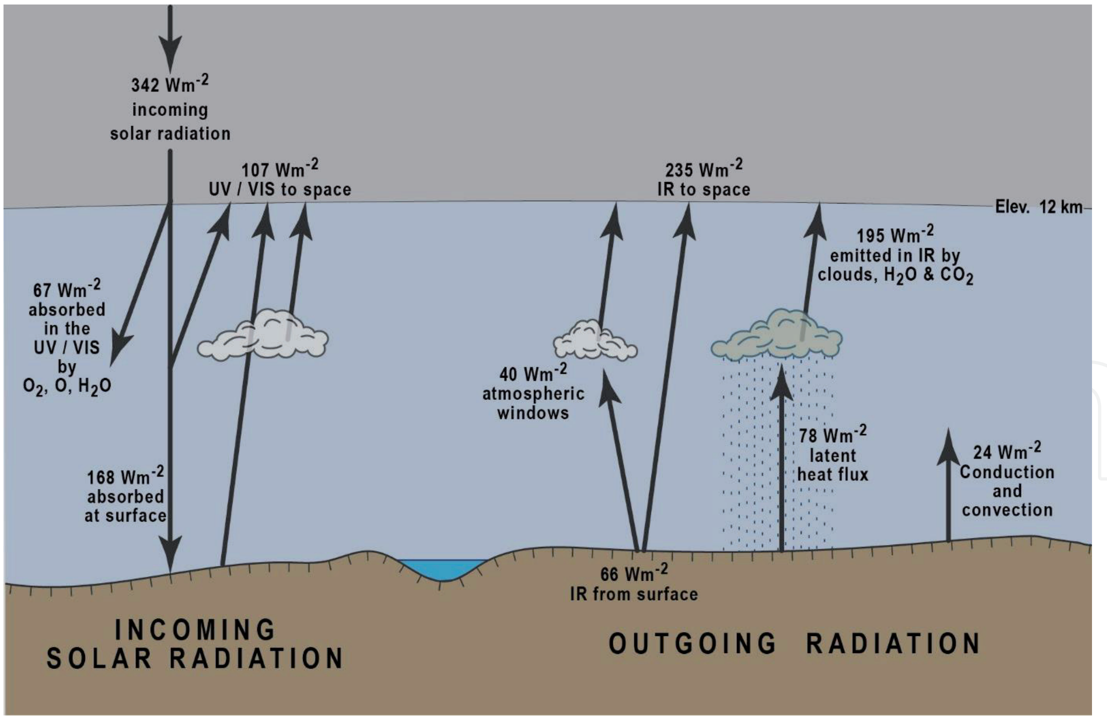

Figure 2.
Typical fate of the solar energy reaching the surface of the atmosphere and proceeding down towards the ground.

angle of tilt of the Earth's axis relative to the Earth's orbital plane (obliquity, from 21.1–24.5°in a 41,000 year cycle), and the direction of the Earth's axis of rotation is pointing (precession, in a 23,000 year cycle).

Milankovich calculated that cold events might occur approximately every 41,000 years and subsequent research confirms that they did occur at 41,000-year intervals between one and three million years ago. About 800,000 years ago, the cycle of the Ice Ages lengthened to 100,000 years, matching Earth's eccentricity cycle [24]. However, the cycles should not affect the data for the last two decades.

3. Movements of heat away from the Tropics

The fact that the bulk of the solar radiation arrives on the surface of the Earth along the zone between the Tropics of Capricorn and Cancer results in a tremendous imbalance of heat distribution between the Equator and the Poles. The amount of solar heating of the polar latitudes throughout the\year varies greatly, with the polar latitudes receiving considerably more solar energy in summer than in the winter when they receive no solar heat at all. As a result, in the winter hemisphere, the difference in solar heating between the equator and that pole is very large. This causes the large-scale circulation patterns observed in the atmosphere. The difference in solar heating between day and night also drives the strong diurnal cycle of surface temperature over land.

The seasonal imbalance results in about 30% of the heat absorbed in the Tropics currently moving towards the polar regions each year to partially make up the difference. As will be shown below, the effectiveness of the processes carrying out this transfer depends on the arrangement of the land masses and oceans as well as the connections between these two contrasting regions. Antarctica is situated over the South Pole and has a circular land mass with few indentations. The main exception is the Antarctic Peninsula that projects northwards into the path of the Antarctic Circumpolar Drift (**Figure 3**). This contrasts with the North Pole situated in a

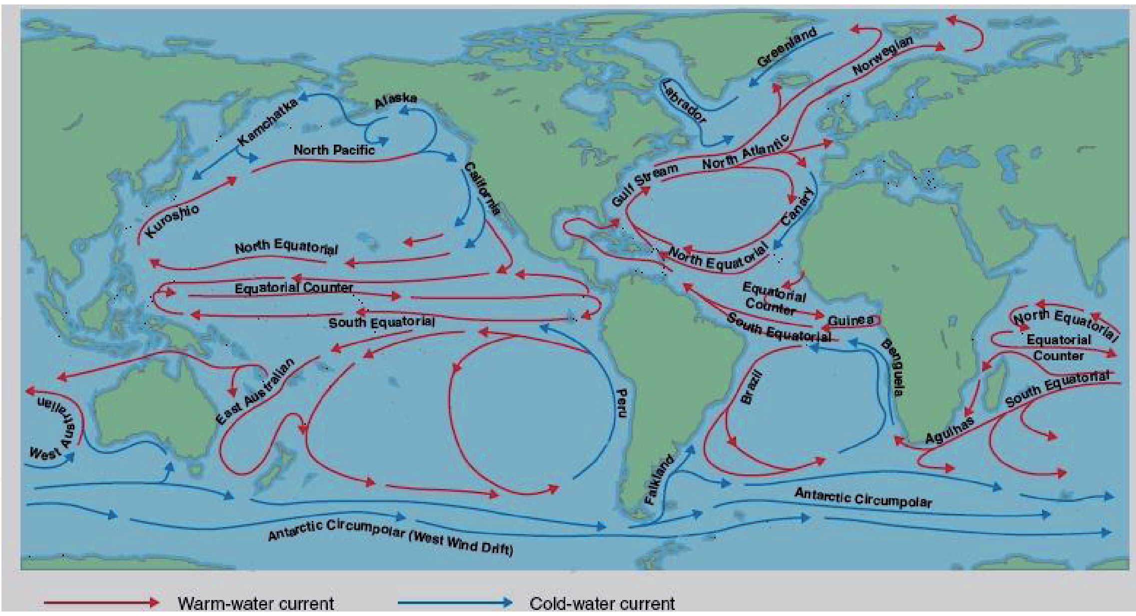

Figure 3.
Ocean currents, red being warm and blue being cold. The Gulf Stream/North Atlantic currents move the greatest amount of warm water, with the Kuroshio current moving the second-most amount. Both move north towards the north pole, but there are no comparable currents heating the shores of Antarctica.

generally frozen sea that is connected by north-south extending seas (gateways) to the tropical oceans ([14], **Figure 1**). In the northern hemisphere, there are large continents separated by oceans from one another. This distribution of land and sea causes a tremendous difference in solar warming of both land and sea as well as the transport of heat towards the poles. Without the ocean gateways, the northern polar areas would be as cold and inhospitable as Antarctica.

3.1 Agents of heat transfer around the Earth

There are two mediums for the transfer of large quantities of surface heat around the Earth, *viz*., the water in the oceans and the air in the atmosphere. However, the thermal properties of the water make it far more effective in moving heat towards the higher latitudes. Dry air is not nearly as effective in moving heat, but it can transport heat over the surface of land masses. Hot, humid air is intermediate in transporting power since it contains up to 5% water vapor in extreme cases.

3.1.1 Transport of heat by water

Although water is confined to the lower levels of the globe except for lakes, its thermal properties make it a very important transporting medium for heat, *e.g.,* in bringing heat from central boilers to the houses in many cities in Russia and for cooling engines in automobiles, etc. Water has a very high heat capacity (4.187 mJ/m^3 K) so that it can store or transport large quantities of heat in a given volume of water [25]. In addition, it absorbs over five times as much heat as soil or rock since it is translucent. Currents, convection, and wave action mix the water whereas transmission into a rock or sediments must be by conduction. Thus, ocean currents transport an enormous amount of water polewards (**Figure 3**), primarily in the northern hemisphere where the Gulf Stream and North Atlantic currents transport heat to north Greenland. Note the five ocean gyres at tropical and subtropical latitudes in the Atlantic, Pacific, and Indian Oceans. These accumulate large quantities of heat in the upper layers of the seas, spawning the monsoons and tropical cyclones that move towards the poles.

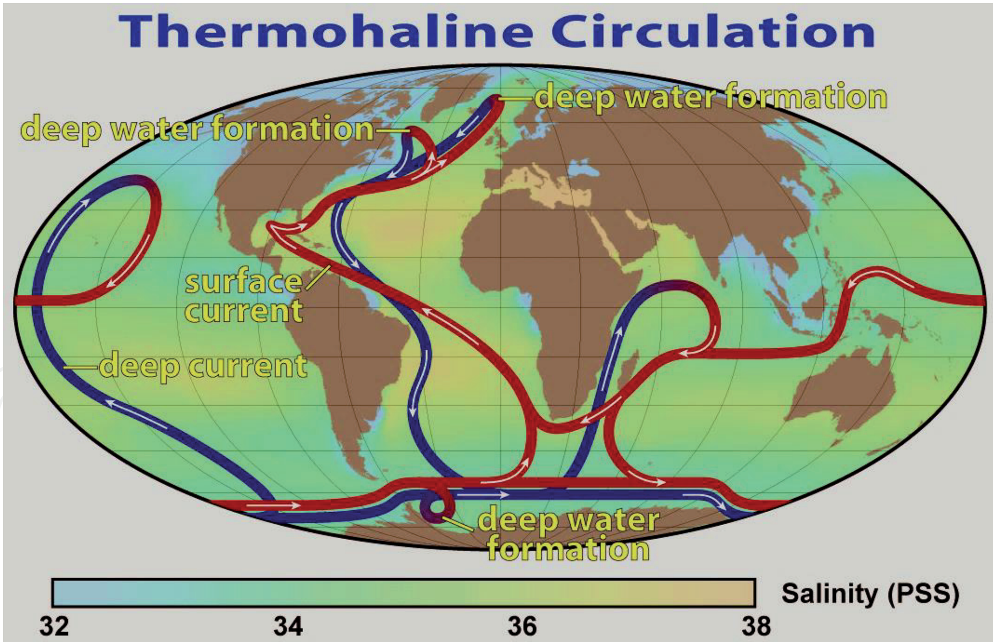

Figure 4.
The thermohaline circulation (THC) and the salinity of the surface waters (NASA).

Research during the past decades [26, 27] has shown that the North Atlantic Current is part of a vast system of fast-moving, deep thermohaline currents (THC) that moves heat down to the southern hemisphere and forms a global thermohaline circulation system (**Figure 4**). Periodically, the cold surface waters northward water off the coast of North America goes south to be replaced by cold water from Antarctica. Cold Antarctic surface waters must move north to replace this southerly current. This is believed to result in rapid cooling in Greenland and the Arctic regions whereas gradual warming take place in Antarctica [28–30]. This exchange was named the "bipolar see-saw" by Broecker [4].

The deep-sea thermohaline current goes south to the sea surrounding Antarctica via the Atlantic and its effects are discernible all the way to the North Pacific. This circulation pulls warm surface seawater north via the Atlantic because more water is needed to replace the dense, increasingly saline seawater that has sunk towards the ocean floor and subsequently participated in the conveyor belt. The total flow of the larger north-south exchange system is thought to be about 16–20 Sv, where Sv is a unit of ocean current flow, 1 Sv = 1 million m^3/s (million cubic meters per second).

During studies of the apparent warming on land in northeastern North America, it was found that about 60% of the energy increase was being stored in the adjacent seas. Levitus *et al*. [30] summarized the evidence showing that the warming was extending down to about 2000 m. Suddenly, the warm water disappeared [31], but was subsequently found having sunk and moved [32].

For the seawater to reach the great density required for it to become deep-sea water, the surface seawater must increase its salinity. This occurs when cold, dry Arctic air moves over the Arctic seas and sea ice, evaporating water, so concentrating the salts in the remaining waters. Deep-sea thermohaline water that forms in the northern oceans flows south over the ridge between Greenland and Iceland, Iceland and the Faroes, and between the Faroes and Scotland (**Figure 5**). Examination by a deep-sea array of sensors shows that the location of the sinking of the saline waters is no longer close to its source area near Newfoundland but has moved further east, perhaps due to an increase in movement of the cold Labrador current southwards [32]. The new path is shown in **Figure 5**. The second array of sensors at 25°N is showing a slowing of the Meridional flow at that location [33]. Galaasen *et al.* [34]

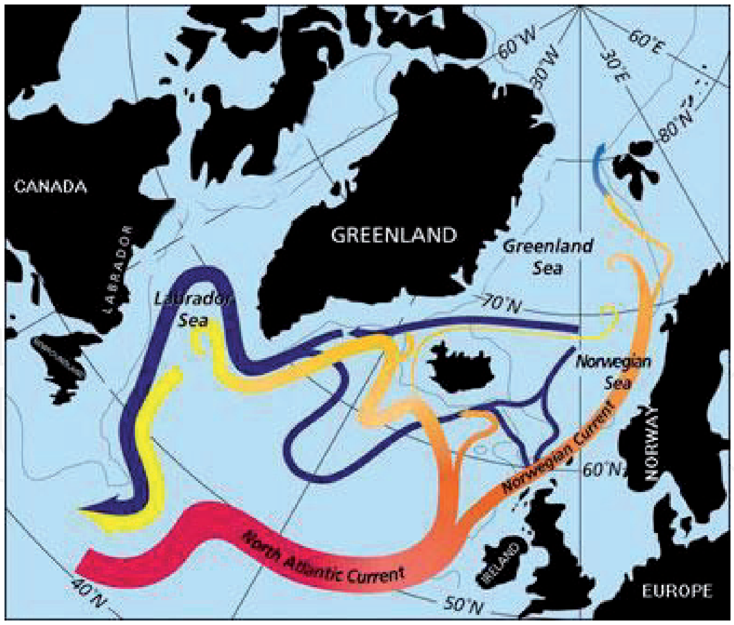

Figure 5.
New location of the saline North Atlantic water [32]. Blue is the return flow of deep warm water while the warm sinking waters are in orange.

reported that there was a rapid reduction in North Atlantic deep water (NADW) during the peak of the Last Interglacial Period (Eemian), and this may be what is happening again now.

Examination of the oxygen isotope variations in the skeletons of foraminifera accumulating on the sea floor shows an intricate pattern of change during the last 3.5 Ma B.P. (**Figure 6**). There are over 100 changes representing over 50 major cyclic fluctuations of ocean surface temperature. However, there are far fewer major cold events on land during that period [38]. This means that there must be at least two different temperature cycles operating simultaneously. The first is this oceanic heating and cooling cycle. This marine cycle produces glaciations with a periodicity of about 100 ka during the last 800 ka B.P. [39] although the exact height of the individual peaks varies somewhat. From c. 800 ka to 2.6 Ma, the cycles occurred every 41 ka but were of lower amplitude [24]. From 2.6 Ma until at least 3 Ma, this cycle was even smaller in amplitude and more frequent during the much warmer climates. These cycles may be related to the bipolar seesaw [4, 40]. Currently, we appear to be at or near the top of a warming cycle in the North Atlantic.

These cycles must be accompanied by rising and falling sea levels due to the expansion and contraction of the seawater due to their temperature changes and there would be the associated degassing of carbon dioxide into the air during the warming phases, however, the gas would re-enter the water during the cooling phase of these cycles. This would result in fluctuating contents of carbon dioxide in the air, which would change in tandem with the air temperature except for a minor delay. The exact cause of these marine temperature cycles and their fluctuations over time is nonproven but likely to be related to the export of warm (c. 18°C) North Atlantic deep water (NADW) in the high-speed hydrothermal bottom currents (THCs) to the South Atlantic (Antarctic Ocean) to be replaced by cold surface water from that area. The Antarctic cold water would cool Greenland and the Arctic regions in the north very quickly so that glaciers are thought to have developed in eastern Greenland within 12 years of the exchange. This contrasts with the warm water, which would warm the main Antarctic ice cap very slowly [28]. Heat would build up in the surface layers of the NW Atlantic Ocean until the next exchange, hence the name "bipolar see-saw" [4].

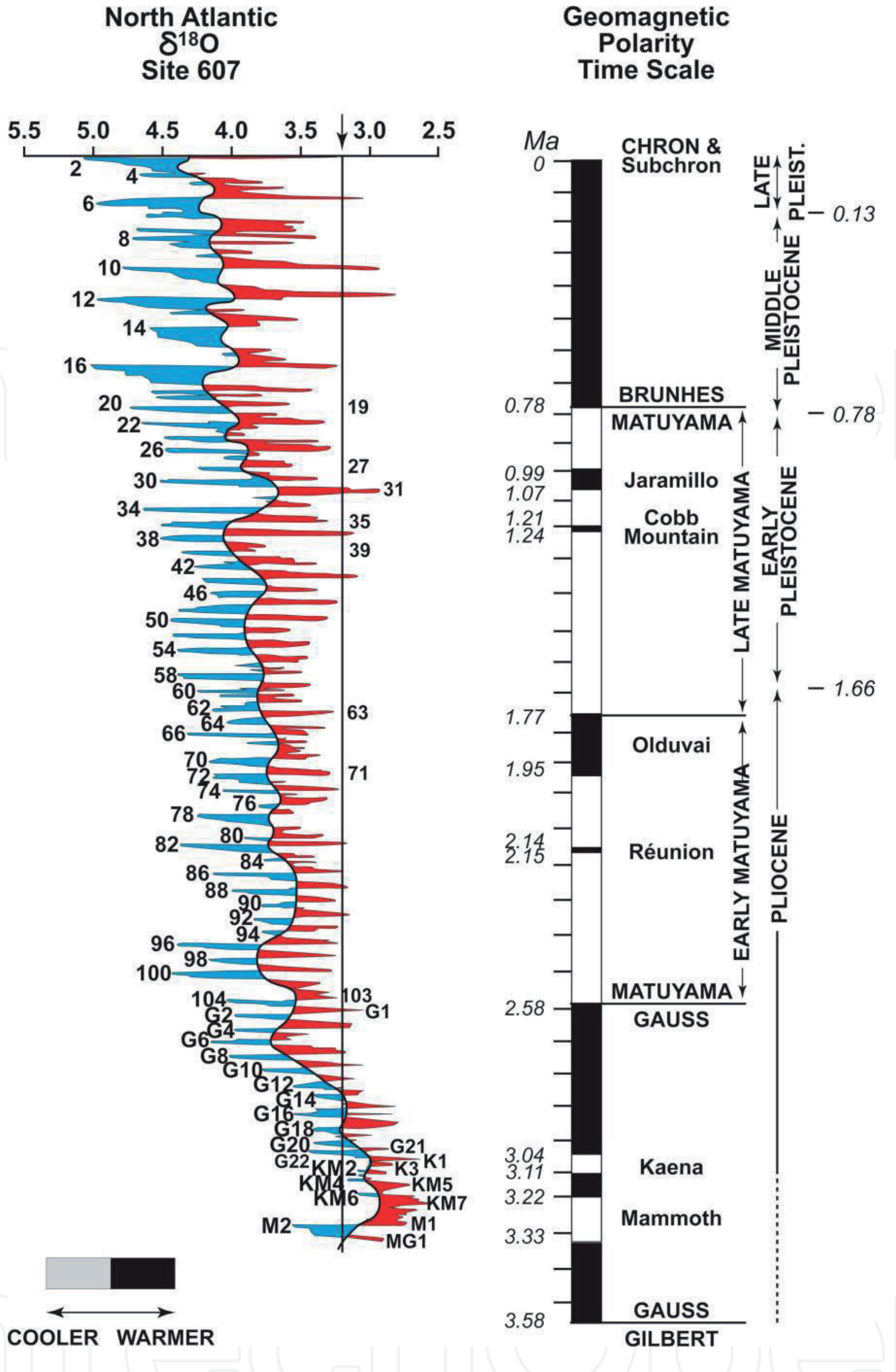

Figure 6.
Oxygen isotope palaeotemperature record [24, 35] and geomagnetic polarity timescale [36]. Black and white areas are normal and reversed polarity respectively. The arrow at the top indicates the mean Holocene oxygen isotope value. Numbers on the peaks and troughs are the isotope stages (modified from [37]).

The third set of cycles is seen in the ice cores from both the Greenland and Antarctic ice sheets. Seventeen of the smaller temperature cycles occurred in these between 65 ka and 5 ka B.P., spaced irregularly between 1.2 ka and 5 ka B.P. apart [41] during the first 14 peaks in **Figure 6**. They show an abrupt temperature change in Greenland cores but a gradual adjustment in the corresponding Antarctic ice cores, which also fits with the bipolar seesaw hypothesis. Thus it appears that the heating and cooling cycles experienced in the environs of the North Atlantic Ocean and eastwards through western Europe are part of the movement of part of the net solar energy from the Northern Hemisphere to the coastal regions of North America, the western European land mass and the Southern Hemisphere to partly warm those regions, preventing them from becoming more frigid than at present.

3.1.2 Transport of heat in the atmosphere

Dry air has a heat capacity of 0.00125 MJ/m^3 K and a thermal conductivity of 0.024 W/m K [25]. However, it contains variable amounts of water, *e.g.*, 2–3% on average at latitudes 50–60°N in the eastern Cordillera of the Rocky Mountains, under 1% in deserts, and up to 6% in Monsoons and tropical cyclones. It is the water content that determines the ability of the air to carry substantial quantities of heat, which it can subsequently unload as rain or snow. When an air mass moves over a water body such as a sea, it will increase its moisture content until the relative humidity reaches 100%, leaving the seawater more saline. Wet air changes temperature more slowly than dry air when rising over mountains since the heat given out by the condensing water vapor prevents the air from cooling as fast as unsaturated air. Dry, descending air warms more quickly as it descends producing the chinook/foehn effect, tending to dry and heat the ground over which it passes.

Unlike seas, the air masses can move in any direction over land or water bodies to places with lower air pressure. Wind speed depends mainly on the pressure gradient, which is also influenced by its temperature. Heavier gases such as carbon dioxide tend to collect in depressions. Lighter gases such as helium, hydrogen, and methane have low molecular weights and become lost to space with time. Those with the lowest molecular weights are lost most rapidly. The air becomes colder and decreases in pressure with altitude by expanding except where inversions occur. At higher elevations, there are fewer gas molecules to absorb incoming radiation.

The rotation of the Earth results in weather systems moving eastwards around the globe except at the Equator. It also causes moving air and water to slowly swing right in the Northern Hemisphere and left in the Southern Hemisphere due to the coriolis force.

There are several main climatic systems that transport large amounts of heat onto the nearby land areas, *viz*., tropical and subtropical monsoons, hurricanes/typhoons, and air masses.

3.1.2.1 Tropical and subtropical monsoons

Monsoons are one of the dominant modes of heat transport in the Tropics [42]. The tropical monsoons originate over seas with surface temperatures above 27°C. They are the classic monsoons that bring enormous quantities of heat from the ocean gyres near the equator onto tropical landmasses during part of the year. The climate of these landmasses includes a marked dry season when the deciduous trees drop their leaves and the bare ground heats up enormously. These have a separate climatic regime to that moving heat to the Antarctic Seas. The main one is the Indian Monsoon that brings enormous amounts of rain to the Indian subcontinent in June–September. Large areas of western and central India receive more than 90% of their total annual precipitation during the period, while southern and northwestern India receive 50–75% of their total annual rainfall from the monsoons. Kathagat *et al.* [17] point out that the variations in the Indian Monsoon precipitation and air temperature are closely correlated with the success of the various Indian empires over the last 4600 years, with the higher precipitation correlating with periods of success. The main controlling factors are the degree of heating of the surface waters of the Gyre in the Indian Ocean and the presence or absence of either La Niña, which produces more precipitation, or El Niño, correlated with shorter periods of precipitation ending in drought [42]. Borah *et al.* [43] report that a cold anomaly in the North Atlantic can cause drought by a steep decline in late-season rainfall in India. The Indian monsoon cools the lower land but brings heat and moisture to the upper part of the Himalayan Mountains. The hot high-pressure cell over Tibet in summer aids the upper levels of the Monsoon to cross those mountains to deposit snow on the high peaks and ridges and then the air descends 4000 m like a chinook to the deserts of North China. Its main effect is to bring dry heat from just south of the equator northwards into the semi-deserts and deserts of south-central Asia.

An offshoot of the Indian monsoon is found in North Australia and represents the southward movement of Monsoon weather during the Australian summer. It is the main source of moisture for northern Australia and is related to the eastern section of the Indian Monsoon affecting the area west of Borneo and north to the Philippines. It represents a method of limited relocation of heat energy southwards over the adjacent seas rather than a substantial poleward movement of energy, unlike the situation in Tibet.

The second tropical monsoon is the West African Monsoon affecting primarily the west coast of Africa south of the Sahel deserts, starting at c. 10°N–18°S. The heat comes onshore from the seasonal shifts of the Intertropical Convergence Zone (ITCZ) and produces the great seasonal temperature and humidity differences between the Sahara and the equatorial Atlantic Ocean. The ITCZ migrates northward from the equatorial Atlantic in February, reaches western Africa on or near June 22, then moves back to the south by October. Various factors control the monsoon variability including the variability of ocean sea surface temperature, continental land surface conditions, and atmospheric circulation. It does not move energy polewards but offsets the variations in the extent of the Sahara.

The East Asian summer monsoon is subtropical and develops as the trade winds modified by the Coriolis Force pick up moisture from the China Sea and the western Pacific Ocean. It provides moisture to southern Japan and the eastern shores of China (**Figure 7**). It ceased during the last glacial maximum (30–19 ka, [37, 45]) due to the lowered sea level leaving much of the South China Sea as land [46]. It is affected by the Tibetan Plateau high-pressure cell in Spring, drawing the moist, hot air upslope onto the NE shoulders of the Qinghai-Tibet Plateau [47]. Currently, the temperature increase on the adjacent land is decreasing the extent

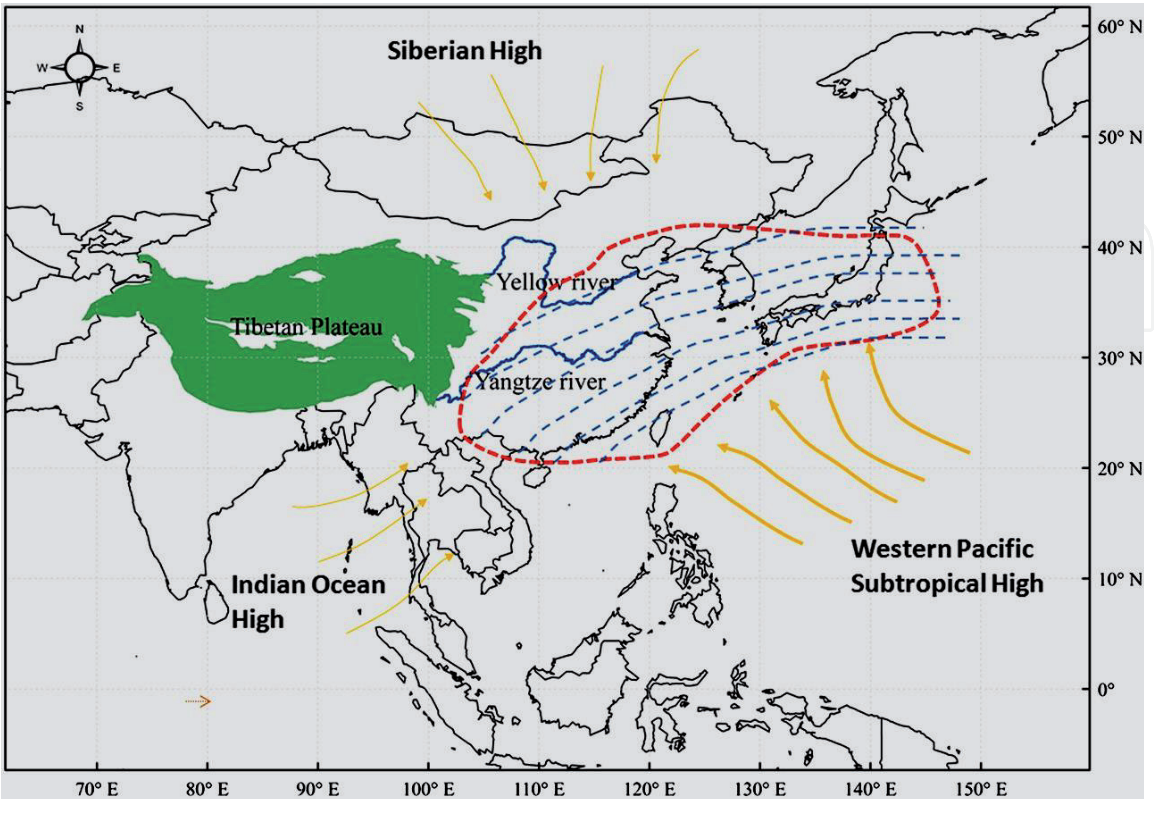

Figure 7.
Area affected by the East Asia monsoon (from [44]).

of this precipitation [48]. It brings moisture to the coastal areas and both heat and moisture to the higher land areas, which are otherwise semidesert.

The other subtropical monsoon is the North American Monsoon affecting the western and southern margins of the desert areas of Southwest USA and centered in northern Mexico [49]. It is a pattern of pronounced increase in thunderstorms and rainfall over large areas of the southern Cordillera, typically occurring between July and mid-September. During the monsoon, thunderstorms are fueled by daytime heating and build up during the late afternoon-early evening. Typically, these storms dissipate by late night, and the next day starts out fair, with the cycle repeating daily. The monsoon typically loses its energy by mid-September when much drier conditions are reestablished over the region. Lachnet *et al*. [50] found that it was much weaker during the last glacial maximum but strengthened after about 11 ka B.P. It is currently becoming more extreme but with fewer thunderstorms [51].

In summary, monsoons generally bring moisture onshore to areas that would otherwise be deserts or semideserts. Only on the north slope of the Tibetan Plateau does it bring heat energy northwards.

3.1.2.2 Tropical cyclones, hurricanes, and typhoons

Tropical cyclones are low-pressure centers that are widespread around the northern hemisphere (**Figure 8**) and include both hurricanes and typhoons. The difference is in the strength of cyclones, the stronger ones being referred to as hurricanes in North America and typhoons in Asia. There are divided into seven categories on the Saffir-Simpson scale on the basis of wind speed and strength.

They can vary in size from 100 to 2000 km in diameter. Unlike Monsoons, they move enormous quantities of heat polewards, primarily over the oceans in the Northern Hemisphere (**Figure 8**). Over land, they quickly decrease in strength since they no longer can replenish their heat and moisture from the ground.

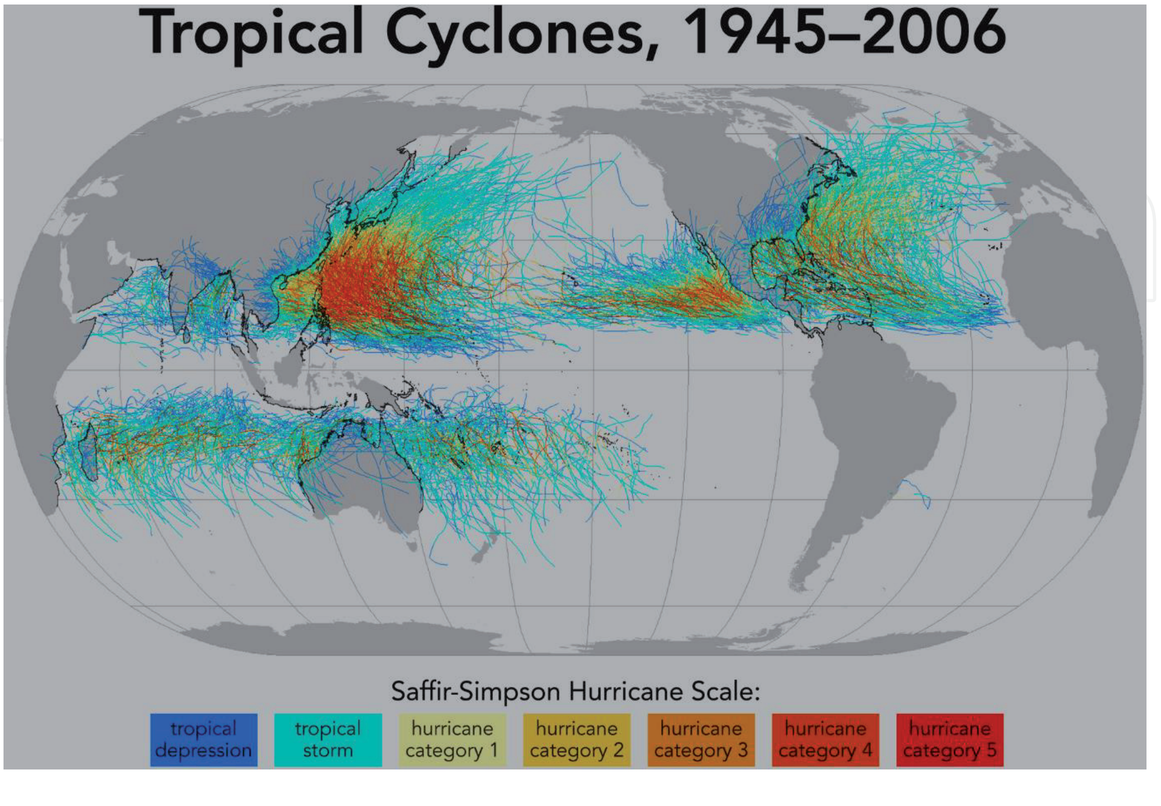

Figure 8.
Distribution of tropical cyclones between 1945 and 2006 around the world (NASA).

The strongest concentration of tracks of typhoons and hurricanes occurs along the east coast of Asia, where the warm precipitation is primarily dumped into the warm Kuroshio and North Pacific currents, thus augmenting their transport of heat to the North Pacific Ocean (see **Figure 3**). A combination of the Bering Land Bridge sealing off the connection between the Pacific and Arctic.

Oceans, when sea level drops more than 50 m and these warm currents, explain why the northern part of the Pacific Ocean did not freeze over during the last few glaciations. However, these two warm currents probably played a significant part in supplying the precipitation for Path 1 (**Figure 9**) that provided the relief valve for the Arctic air mass by producing the late (31–10 ka B.P.) glaciation in southern British Columbia. This greatly reduced the area covered by the Arctic air mass, allowing deglaciation of a substantial portion of the Northern Hemisphere ice sheets prior to 9 ka B.P. [52]. Currently, the typhoons affecting the Philippines are becoming more extreme [53]. A few typhoons also occur around the shores of India and near the Persian Gulf, but they are relatively infrequent.

South of the ITCZ, a band of Typhoons is found on the north coast of Australia west to Asia and Madagascar. They are mainly found over the Indian Ocean, but northern Australia and Queensland depend on the Monsoon rains from December to February to provide sufficient water for agriculture [54]. In El Niño years, there is increased precipitation whereas La Niña years result in shorter rainy seasons and drought. Similarly, Madagascar and the adjacent coast of southeast Africa depend on the tropical cyclones to provide enough water to sustain the seasonal growth of forest species. In all these areas, the monsoons cool down the land somewhat

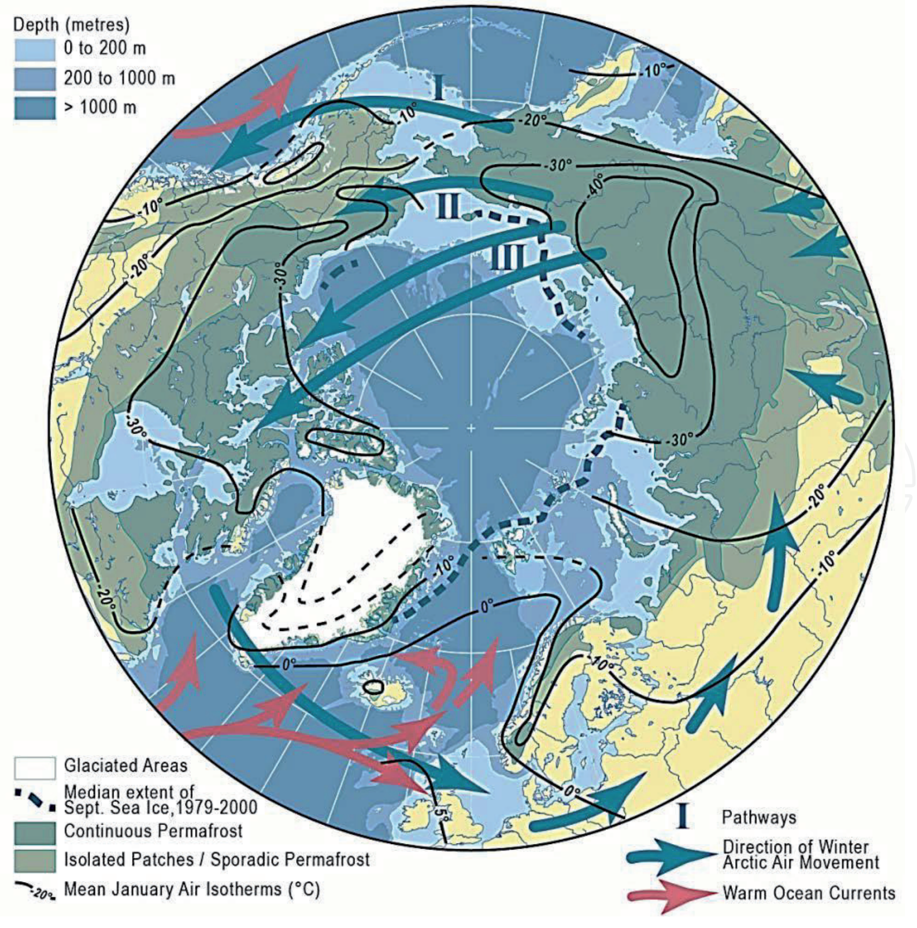

Figure 9.
Map showing the distribution of permafrost in the Arctic [37] together with the mean surface air January isotherms (°C) and the adjacent warm and cold ocean currents. Also shown are the three main paths (I–III) taken by the Arctic air as it moves from Asia to northern Canada, and the positions of the main warm ocean currents currently bringing heat from the Tropics.

along the margins of the adjacent deserts and/or semideserts. Over the ocean, these typhoons add heat to the underlying sea and may help supply heat energy to the warm surface thermohaline currents in the Indian Ocean.

The second-most concentration of hurricane tracks is found along the eastern side of North America, originating in the tropical Atlantic north of the ITCZ. These are becoming more numerous, of greater strength, and with high category numbers. They bring enormous amounts of heat and energy northwards with much of the precipitation falling into the Gulf Stream, thus adding to the heat energy bathing the east coast of the United States as well as the western shores of Europe. The warm currents enter the Arctic basin spreading westwards to eastern Greenland and eastwards towards Nova Zemla. The Arctic sea ice cover has been thawing since about 1920 (see Section 3.1.2.4 below) and Duk-Rodkin *et al.* [55] found evidence in the form of glacial and interglacial deposits on the eastern slopes of the Mackenzie Mountains that the Arctic Ocean had become ice-free prior to each of the last five glaciations. From then on, the Arctic air mass traversing the ocean will pick up moisture, increasing the salt content of the ocean in which case the water will tend to sink and later possibly take part in the deep-water thermohaline exchange.

3.1.2.3 General movement of air masses

The air masses can be divided into three main groups, *viz.*, the Equatorial air masses, the tropical air masses, and the Arctic air mass. As noted previously, the Equatorial air masses receive the most isolation and get sucked both north and south of the ITC to enter the dry, hot zone of the Horse Latitudes characterized by deserts on the land areas. The hot, dry desert surface heats the tropical air mass which forms an anticyclone over it, and the descending air then moves upwards and polewards or back along the surface to the Equator (**Figure 10**).

Each air mass operates as a distinct band around the globe, interacting with the others primarily along the boundaries between the air masses. Details of the operation of the Arctic air mass and its relationship with the tropical air mass will be found in [52]. It will be seen that the coldest air originates in northeast Siberia by reradiation of heat energy during the long, dark winter days. In cooling, it would

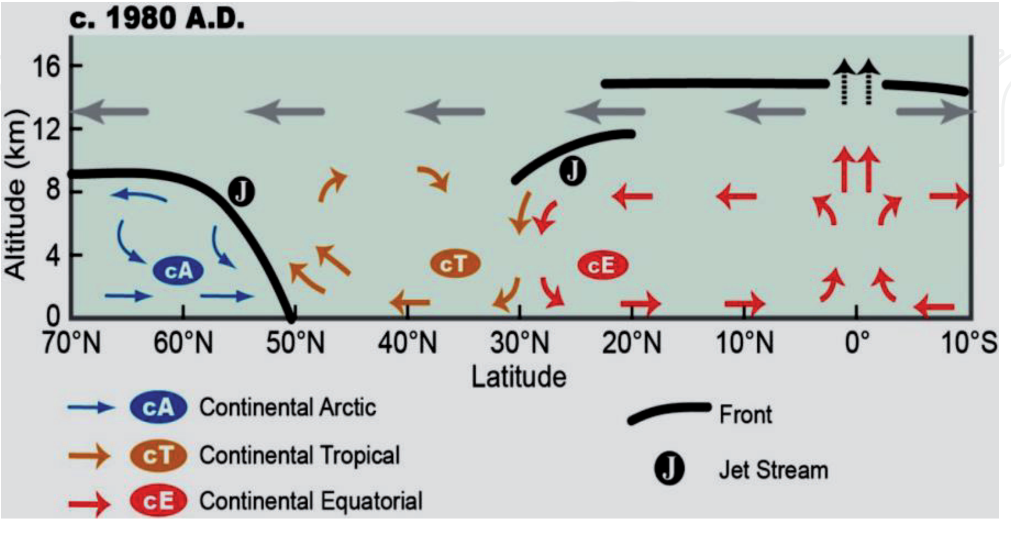

Figure 10.
North-south section through the lower atmosphere in western North America showing the circulation of the air masses under the climatic conditions occurring in 1980 A.D. [13]. Note that there are three basic air masses, viz., the Arctic, Tropical, and Equatorial, with jet streams along their margins. The more northerly black line marks the polar front, and the southern one is the subtropical front separating the tropical air (in orange) from the equatorial air mass (in red). The gray arrows indicate the air movement in the upper atmosphere.

deposit the excess water vapor as snow. The daily temperature can reach −66°C and stay there for several days before the air mass moves eastwards along the paths II and/or III in **Figure 9**. During the last major glaciation, paths II and III were followed to build up the Laurentide ice sheet. The cold air moved into northern Canada after picking up both heat and moisture crossing the Arctic Ocean. On arrival over the cold land, it cooled again by reradiation to become dense enough to push its way south, forming a lobe as it moved the tropical air out of the way, undercutting it and causing heavy snowfalls as the tropical air-cooled. This is the origin of the Rossby waves. **Figure 11** shows the evolution of the Rossby waves as they move eastwards.

When the Arctic air moves over the open warm water of the North Atlantic Ocean, it warms enormously while picking up large quantities of water thus aiding in the salinization of the surface seawater. Under the present climatic situation, it ensures that the northwest of Europe receives the warm, moist air at latitudes between southern Norway and central France with only relatively minor cold snowy spells in winter. It continues eastwards, cooling as it reaches the more continental parts of Central Europe, slowly modifying into dry, cold winter weather before it crosses the Urals and moves back to join the source area in NE Siberia.

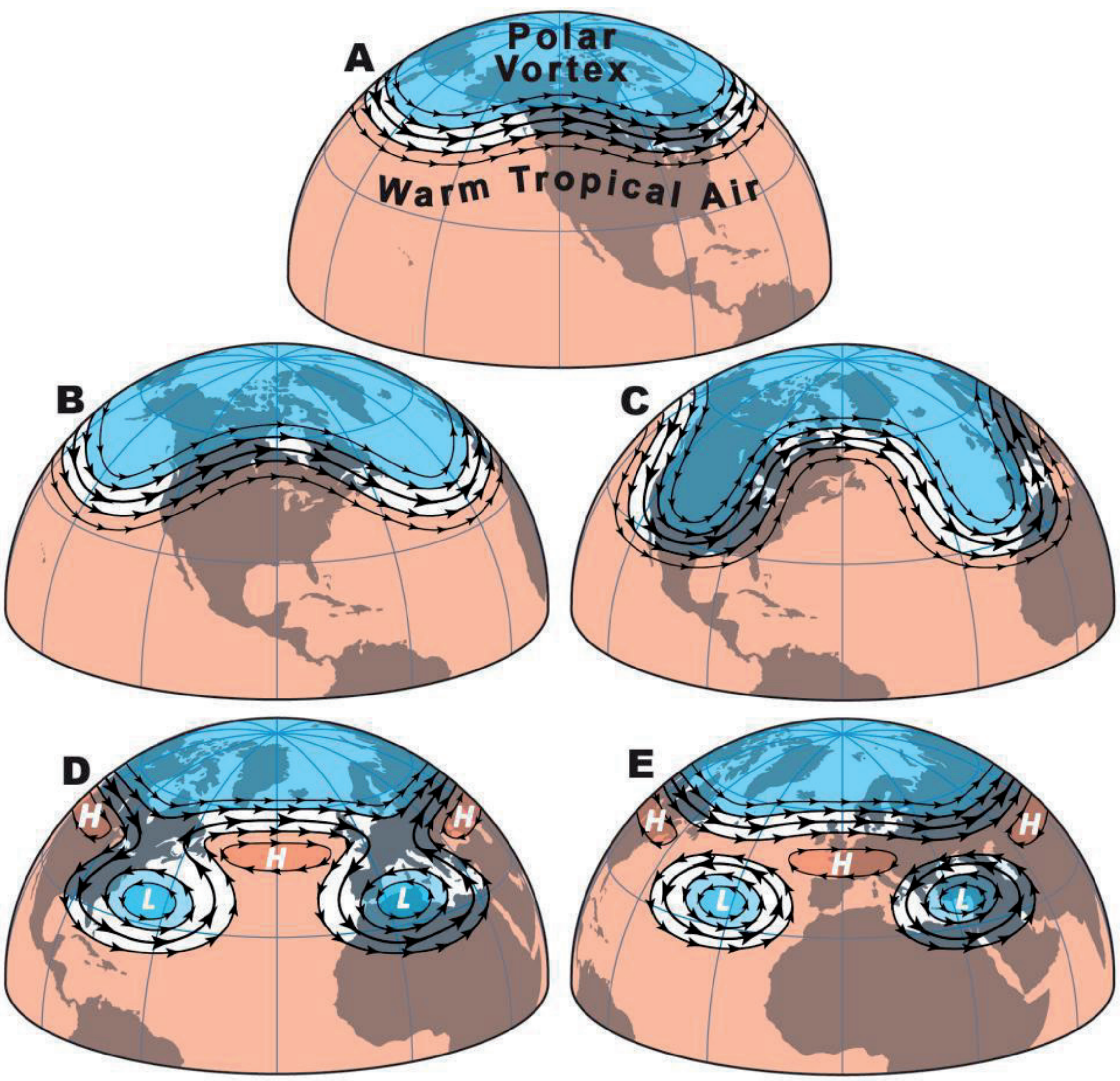

Figure 11.
Evolution of the southern edge of the Rossby waves as the cold air mass (in blue) moves eastwards [56]. H represents a high air pressure cell (an anticyclone) while L represents one of low pressure (a cyclone). Arrows show the direction of air movement while the Arctic Air mass is indicated in blue.

The tropical air of the semideserts and deserts on all the continents except Antarctica moves atmospheric heat polewards, *e.g.*, the Sahara, the Tibet-Plateau and Pamir Knot, the arid regions of the southwest United States and central Australia. If the supply of heat from the Equatorial regions increases, they expand into the surrounding areas. In Africa, the tropical air occupies today the vast Sahara desert and the semi-desert and savannah lands of the Sahel. The latter represents the transition zone between the desert in the north and the Equatorial and Monsoon lands of the west coast. The Sahara desert is tending to expand since the precipitation decreased in 1968, and the Sahel now has a more marked season [57, 58]. The Sahel-like conditions continue through Southern Sudan along with the interior of East Africa, but the precipitation there has decreased and become less reliable. In dry years, the anticyclone over the Sahara expands with the dry desert air extending over Italy, sometimes crossing the Alps to descend on to the north German Plain as a Foehn wind. This results in partial drying up of the Rhine River making it difficult for navigation. In East Africa, this expansion produces crop failure and famine, along with swarms of locusts.

3.1.2.4 Effect of sudden movements of large air masses

The coldest winter temperatures recorded in the northern hemisphere were obtained in the interior valleys of the mountains in northern Siberia at Verkhoyansk located at 67°33′N, 133°23′E. (−67.8°C on January 15, 1885), and equally cold temperatures were recorded at Oymyakon (located at 63°15′N, 143°09′E). These are sometimes referred to as the northern poles of cold. Similar cold temperatures (−65°C) have been recorded in a cold air drainage event in a mountain valley 100 km west of Fort Nelson, British Columbia [59]. These are still considerably warmer than the higher altitude stations inland in Antarctica.

In 2018, many stations in Antarctica experienced record colder temperatures, some 14°C colder than the previous record. The new current record low is −98°C at 81°S, 63.5°E. measured on the East Antarctic Plateau [60]. The bulk of Antarctica experienced a similar increase in cold, indicating that a considerable quantity of heat energy failed to go south during the Antarctic winter months. Since the deficit was near the South Pole, that missing energy must have gone north to the equatorial zone. This, in turn, would have upset the equilibrium between the Equatorial zone and the poles, and cause enhancement of the processes moving heat polewards from the Equator, primarily in the Northern Hemisphere.

This change appears to have triggered two particularly large, wide hurricanes that traveled along the East coast of North America dumping unusually large quantities of warm water into the Gulf Stream There was also a considerable increase in the number of Atlantic Hurricanes both in 2019 and 2020, and the hurricane season started earlier and lasted later than previously. The summer of 2019 saw unprecedented melting of the east side of the Greenland ice sheet which Tedesco and Fettweis [61] have tried to explain by changes in the atmospheric conditions over the Greenland ice sheet. This was also the time of the disappearance of the warm water from the Atlantic Ocean near the east coast of the United States, which has since been found near the west European coasts (**Figure 5**). The warm waters now go further north and bathe the northeast shores of Greenland and they may also be a cause of the exceptional melting of the ice sheet in 2019. The early arrival of the hurricanes in Quebec and New Brunswick meant that the warm rain fell on the remains of the isothermal winter snowpack resulting in major floods on the St John River and its tributaries. This resulted in exceptional flooding in many lowland areas.

In the case of the arid and semiarid areas, lack of precipitation caused by the expansion of the arid zone set up the conditions for large fires in Australia, Siberia, and the west coast areas of the United States. The wildlife was greatly affected in Australia, both by being caught in the fires and by the loss of suitable habitat. Expansion of the dry conditions in the Sahara and Sahel resulted in widespread famine in East Africa with the Victoria Falls dwindling to a trickle. Hordes of locusts compounded the problems in Somalia and Southern Sudan. In southern Europe, the drought severely affected the crops, *e.g.,* in Italy. In India, the Monsoon brought exceptionally heavy rains that resulted in\very difficult conditions for the inhabitants of the lowlands.

The most striking change that has occurred after the southern winter temperatures of 2019 is the enormous increase in the amplitude of the Rossby waves affecting the climate over the Northern Hemisphere, particularly North America. These waves have doubled in amplitude and resulted in remarkable changes in the autumn and winter weather. The western Prairie Provinces of Canada have also had exceptionally warm weather from mid November 2020 until late January 2021. The cold lobe of the Polar Vortex has missed this area but hit the Central and Southern United States and eastern Canada with heavy snowfalls and cold temperatures. Clearly, the lobes of extratropical heat have clashed with the Polar air mass-producing very high-pressure gradients extending far further south than usual.

From these results, it seems that any sudden movement of large quantities of energy to the equator has a very significant effect on the climate of the land areas particularly in the Northern Hemisphere. It can also bring about significant changes in the waters of the North Atlantic, probably speeding up the preparation of conditions suitable for a major seesaw exchange with the southern oceans.

3.2 Effects of mankind altering the processes of heat transfer

In general, the effects of the works of man in altering heat transfer between the hemispheres are both relatively puny and gradual. The processes discussed above are abrupt [62] and are not particularly susceptible to modification by humans. The main exception is the addition of heat artificially brought up from within the Earth during oil extraction from deep wells in Alaska [63]. The celebration commemorating the naming the Yakutsk Permafrost Research Station after Pavel Melnikov indicates that on completing studies at the top Russian School of Mines in the 1920s, he was posted to a head-up an Institute on Novo Sembla with the task of finding a way to thaw the sea ice along the Arctic coast of Russia. The heat from the oil and gas coming from within the ground needed to be largely removed prior to pumping through pipelines and could be used to thaw the ice. Within 8 years, he was appointed head of the fledgling Gas Prom which he continued to direct until his death. He also became President of the Russian Academy of Sciences. Under his guidance, many wells were situated near the Arctic coast and the pipelines were buried but not insulated in permafrost areas. They regularly float to the surface (see Figures 15.6 and 15.9 in [37]).

The end result for Russia was the establishment of a through route for shipping between European Russia the Orient after about 1990 A.D. This saved cargo vessels from having to go from Murmansk, around northwest Europe, and through the Suez Canal to get to the Orient. The effect of thawing the Arctic Ocean is that the open water will absorb more heat and so risk speeding the day when the warm saline waters of the North Atlantic Ocean take off south towards Antarctica and are replaced by cold Antarctic waters, thus precipitating a new cold event in the northern hemisphere. That would cause far greater problems for mankind than we face now.

A second problem is gas flaring. Around 2000 A.D., Russia flared off approximately 10 times the amount of natural gas as any other country. In 2009, the

Associated Petroleum Gas countries agreed to reduce the output of flared gas by 95% by January 2012. Unfortunately, Russia failed to meet these standards [64] although there had been a vast improvement. The effect of flaring is that it directly heats the passing Arctic air and combined with the geothermal heating of the air by the oil and gas in the pipelines, it causes a rise in the mean annual air temperature

Gas flaring volumes 2015–2019 (billion cubic meters)						
	2015	**2016**	**2017**	**2018**	**2019**	**Change 2019–2010**
Russia	19.62	22.37	19.92	21.28	23.21	1.93
Iraq	16.21	17.73	17.84	17.82	17.91	0.09
United States	11.85	8.86	9.48	14.07	17.29	3.22
Iran	12.10	16.41	17.67	17.28	13.70	−3.50
Venezuela	9.33	9.35	7.00	8.22	9.54	1.32
Algeria	9.13	9.10	8.80	9.01	9.34	0.33
Nigeria	7.66	7.31	7.65	7.44	7.83	0.39
Libya	2.61	2.35	3.91	4.67	5.12	0.45
Mexico	5.00	4.78	3.79	3.89	4.48	0.59
Oman	2.43	2.82	2.60	2.54	2.63	0.09
Malaysia	3.72	3.16	2.83	2.25	2.37	0.12
Egypt	2.83	2.83	2.34	2.26	2.34	0.08
Angola	4.18	4.49	3.80	2.79	2.33	−0.46
Saudi Arabia	2.15	2.38	2.32	2.29	2.10	−0.19
China	2.08	1.96	1.56	1.82	2.02	0.20
Indonesia	2.90	2.77	2.33	2.06	2.00	−0.06
Republic of the Congo	1.18	1.14	1.14	1.58	1.67	0.09
Kazakhstan	3.69	2.67	2.42	2.05	1.57	−0.48
Gabon	1.56	1.56	1.50	1.38	1.46	0.08
Australia	1.14	0.73	0.66	0.86	1.39	0.53
Qatar	1.11	1.08	1.03	1.00	1.34	0.34
Turkmenistan	1.84	1.84	1.67	1.50	1.34	−0.16
India	2.20	2.06	1.50	1.34	1.31	−0.03
Brazil	1.33	1.44	1.10	1.00	1.14	0.14
United Kingdom	1.32	1.34	1.35	1.21	1.11	−0.10
Canada	1.81	1.30	1.34	1.33	1.05	−0.28
Cameroon	1.08	1.10	1.04	1.06	1.04	−0.02
Argentina	0.65	0.56	0.51	0.70	0.94	0.24
Syria	0.52	0.55	1.19	0.69	0.93	0.24
Ecuador	1.06	1.15	1.07	0.90	0.92	0.02
Rest of the world	11.30	10.45	9.22	8.72	8.49	−0.23
Total	**145.59**	**147.64**	**140.58**	**145.01**	**149.99**	**4.98**

As of July 21, 2020.
Source: World Bank Global Gas Flaring Tracker Report.

Table 1.
Gas flaring volumes for 2015–2019 by country in billion cubic metres [65].

Town or city	Deformation rate (%)
Chita	60
Pevek	50
Amderma	40
Dudinka	35
Dickson	35
Yakutsk	27
Tiksi	22
Anadyr	20
Salekhard	>10
Labytnangi	>10
Vorkuta	>8

Table 2.
Table showing the number of buildings showing structural damage in various Russian towns and cities located in areas of permafrost that will eventually result in the buildings being uninhabitable (from [66–69]).

in proportion to the oil and gas production in unit time. The latter cannot readily be predicted in advance, so cannot be suitably planned for in construction work.

Subsequently, Russia has successfully reduced its flaring by 2015 to lower levels (**Table 1**), but the unfortunate consequence in Russia was the damage to the infrastructure by the warming of the Arctic air mass. Most of the BAM railway across Siberia has had to be rebuilt due to thawing of the permafrost beneath the track, and similar problems have plagued the road network. **Table 2** shows the number of buildings that showed structural damage in various Russian towns and cities located in areas of permafrost that will eventually result in the buildings becoming uninhabitable. While some are near oil wells or the Arctic coast, others such as Yakutsk are far to the east of the main oil-producing regions.

4. Relationship to past cold events in North America

The first ocean water temperatures below freezing point were appearing in North America starting about 3.5 Ma [38]. Sea temperatures are currently estimated to be 7°C higher today than during the Last Glacial Maximum and the air temperature is 10°C higher. Drill cores from the Greenland ice cap and cores from sea bed sediment have been used to conclude that fluctuations between warm and cold periods during an ice age are caused by changes in the sea currents in the North Atlantic, particularly with relation to the process called the Thermohaline Circulation (THC). The current thinking by Oceanographers is that the changes in water temperature and salinity are probably the main triggers causing repeated glaciations in North America over the last 3.5 Ma [5, 70]. Krissek [71] noted late Cenozoic ice-rafting records from Leg 145 sites in the North Pacific Ocean, concluding that they started in late Miocene times and intensified during the late Pliocene times. Mudelsee and Raymo [72] suggested that the first glaciers had developed by 3.6 Ma B.P. based on patterns of globally distributed marine $\delta^{18}O$ records. Haug *et al*. [73] argued that a saline arctic halocline had developed in the North Pacific Ocean by 2.7 Ma B.P. with warm sea surfaces.

Since nowhere had a complete section showing the full sequence of glacial tills been found, Harris [38] summarized the dated evidence for glacial events and permafrost in North America to provide a guide as to when and where the known locations of the products of past cold events have been found. Methods of dating included tephrochronology, magnetostratigraphy, radiocarbon dating, and potassium-argon dating. The oldest dated deposits from North America included subglacial tuyas with glassy, fractured upper surfaces dated at 3.5 Ma B.P. from Wells Gray Park, British Columbia [74]. Cioppa *et al*. [75] reported that the lowest allow formation of the Kennedy Drift (Unit 1) in Southwest Alberta and Montana has Gauss normal polarization indicating that it is older than 2.6 Ma B.P. The first evidence of an ice cap consists of the Klondike gravels recently dated at 2.64 Ma B.P. with late Gauss magnetism [76]. This is believed to be the most extensive ice cap to have formed in Alaska while its magnetostratigraphy suggests that the increased amplitude of the 41 ka obliquity cycle had already developed [77]. This icecap is regarded as resulting from the warm sea surfaces at that time as well as being the source of the North Pacific ice-rated debris in the marine cores. This ice sheet also altered the course of the Yukon river [78]. About 2.8–2.4 Ma B.P., the Panama Gateway between North and South America closed up so the ENSO currents could not pass into the Atlantic Ocean to take part in warming the North Atlantic.

Altogether, 13 major cold events were recognized in the late Pliocene-Pleistocene record from North America, although some minor events were missed, and the dating of some of the evidence has been changed as a result of more recent work. The sequence started off with isolated events, followed by definite ice sheets separated by large interglacials that decrease in size until 1 Ma B.P. After 750 ka, the 100 ka eccentricity Milankovich cycle has controlled the frequency of the cold events, separated by short (11–20 ka) interglacials.

Barendregt and Irving [79] showed that each time there was a change in the direction of the Earth's magnetism, there was a significant change in the areas affected by glaciations. This implies that there were tectonic changes to the landscape at those times. In the case of the last change c. 1.0–0.8 ka B.P., the mountain range that had separated the Hudson Bay drainage from the Arctic drainage sank to form the present-day Arctic Islands. Meanwhile, the Western Cordillera tilted northwards so that the highest land lay in northern Mexico. This caused the incision of drainage causing the deep erosion of the Copper Canyon in northern Mexico and the Grand Canyon in the southwest United States.

Tephrochronology and magnetostratigraphy both have their limitations. The first is only helpful if there are enough tephras that can readily be recognized that are widespread and have known ages. Magnetostratigraphy sorts the deposits by normal and reversed categories but it cannot prove which deposit is which within each group. In spite of this, it can be useful when determining the ages of a pile of different sediments using the known age sequence corresponding to the Quaternary deposits. Barendregt and Duk-Rodkin [80] produced maps of the distributions of normal and reversed tills corresponding to the four main magnetic zones in the period back to 2.8 Ma B.P., but they do not exhibit the former distribution of each former ice sheet.

During the last seven glaciations, each glacial cycle has spanned about 4 different marine temperature cycles (see **Figure 4**) but varies somewhat independently of them. The best indicator of the volume of ice present on land is provided by the changes in sea level (**Figure 12**). On land, the Wisconsin Glaciation began with the development of extremely cold winter temperatures in Siberia, northeast China, and Greenland with the cold air generating heavy snow accumulations over parts of eastern and northern North America [52, 56] corresponding to a reduction in sea level of c. 30–50 m, starting after 120 ka B.P. The growth of the ice centers continued during the Early Wisconsin glaciation for about 30 ka before a warmer period, probably due to the bipolar seesaw, heralded the commencement of the

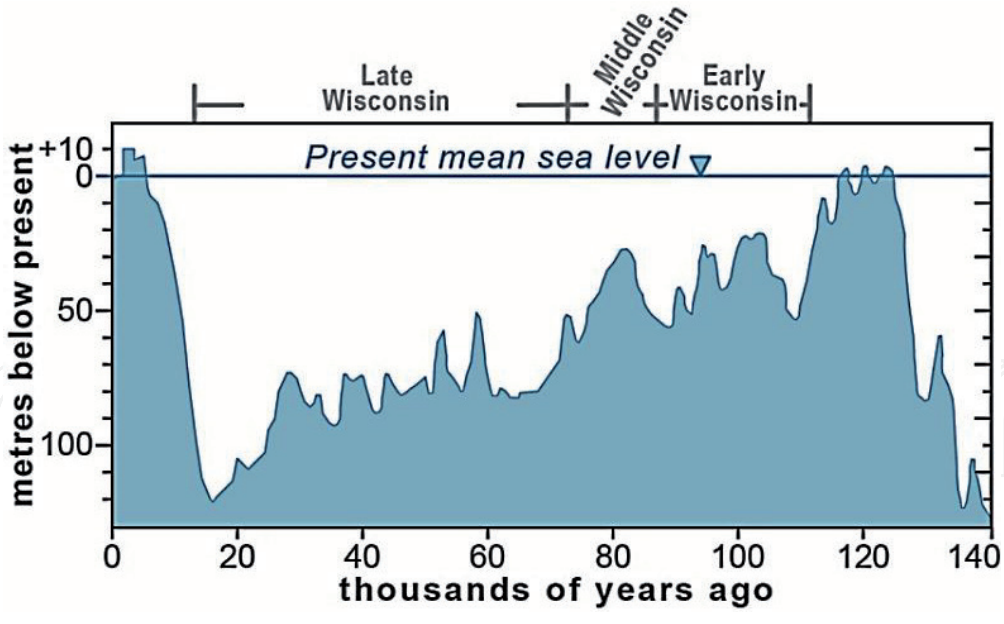

Figure 12.
Mean sea levels during the last 140 ka B.P. (http://rst.gsfc.nasa.gov/Sect16/Sect16_2html).

Middle Wisconsin Interglacial at about 75 ka B.P. (**Figure 12**). While the seawater warmed, the snow-covered ice caps reflected much of the incoming solar radiation back into space so that they only lost about half their ice mass. The next cooling of the seawater began around 70 ka B.P. with the commencement of the late Wisconsin Glaciation. Alternately cooling and warming seas resulted in fluctuating but alternating periods of glacial advances and retreats from the existing ice centers as the climate on land continued to cool. However, the southern Rocky Mountains south of the Peace River became ice-free by 59 ka B.P. and continued like that until 31 ka B.P. [81, 82]. It is thought that the climate there during that period was similar to today.

About 30 ka B.P., there was a major increase in the cold temperatures accompanied by a major drop in sea level of c.50 m that caused expansion of the ice sheets which advanced across the Canadian Prairies to the foothills of the Rocky Mountains. Concurrently in northeast China, there were extremely cold, dry conditions on the Tibetan Plateau, *e.g.*, [45, 83–86] and very cold air traveled eastwards to northern Canada along paths II and III in **Figure 9**, probably over open water.

At this time, the Arctic Front was well south of the USA border and the main ice sheets and displacement of biogeographic zones extended far to the south. In order to have deglaciation, a vast amount of Arctic air had to be turned into the tropical air. The tilt of the Earth was changing causing increasing insolation in the Northern Hemisphere resulting in expansion of the air masses, which was greatest over land areas in the south. This applied extra pressure on the Arctic air mass over the northern lands which were relieved by the activation of the path I in **Figure 9** because the air over the Pacific Ocean did not warm up much due to the increased heat being absorbed in the water [52, 53]. Since the cold Arctic air crossed the open Pacific Ocean, it picked up both heat and moisture, only to deposit the moisture as snow in the mountain cirques beginning in 31 ka B.P. The air then crossed the continental divide and continued east downslope as a dry Chinook wind, starting the retreat of the local glaciers. By 25 ka, the cirques on the west side of the Cordillera were full and the glaciers started to descend to the valley floors. After 20 ka B.P., tremendous mounts of snow were deposited covering the southern Cordillera [87, 88] and formed a dome covering the mountains at latitude 54°, so relieving the pressure on the dwindling Arctic air mass and causing the Arctic Front to migrate north to about its present position. From 15 ka to 10 ka, the flow from the Arctic air mass decreased so that the last active glaciers ceased expansion about 10 ka B.P. in the Fraser Valley and on the east coast of Haida Gwai. By then, the Laurentide Ice Sheet had retreated from the Prairies to form a mass occupying Hudson Bay. It is likely that this pressure release also permitted the Scandinavian-Russian ice cap and the bulk of the ice in the Swiss Alps to retreat at the same time [89–91].

5. Discussion and conclusions

There are marked differences in the thermal properties of water and air. Water has a very high heat capacity (4.187 mJ/m^3 K) so that it can store or transport large quantities of heat in a given volume and it absorbs over five times as much solar energy as soil or rock since it is translucent. Currents, convection, and wave action mix the water, whereas transmission of heat energy into a rock or sediments is primarily by conduction. Water also occupies about 70% of the surface of the Earth. Air has a relatively low heat capacity although this depends on the content of water vapor which can vary from under 1% over deserts to over 4% in monsoons and tropical cyclones. Soil and rock absorb only one-fifth of the solar energy absorbed by water, and they also do not reflect back into space nearly as much solar energy as snow. Thus, the distributions of these materials at the surface of the Earth determine what energy flows are needed to produce the thermal equilibrium between the equatorial regions that receive intense solar radiation and the polar regions that receive far less direct solar energy.

The pattern of temperature change in **Figure 1** is not that of global warming. Instead, it suggests that the Northern Hemisphere is receiving more heat than the Southern Hemisphere and this sets up a system of deep saline warm (c. 22°C) water flows to the Antarctic Ocean (THC's). These are replaced by a similar flow of cold (c. 2°C) Antarctic water with more normal salinity that then accumulates in the North Atlantic where it warms up. This is believed to produce a very rapid cooling of Greenland accompanied by the growth of the glaciers there. There would also be rapid cooling of the land to the east of the North Atlantic as occurred during the Younger Dryas event (>18°C cooling, according to Isarin [92]) whereas there would be only slow warming occurring on the Antarctic ice cap. This cold air flowing eastwards would result in greater winter cooling in Siberia, thus resulting in colder air moving into North America from the cold Siberian high-pressure center in winter.

The cause of this situation is the unequal heating of the land and sea coupled with the circular outline of the Antarctic shores compared with the north-south orientated oceans connecting through gateways into the Arctic Ocean. Warm ocean currents (Gulf Stream and the Kuroshio Current) carry large quantities of warm water northwards along the east coasts of continents in the Northern Hemisphere, aided periodically by deluges of warm water from Hurricanes and Typhoons. The North Atlantic stores a great amount of heat in its surface layers, but evaporation of water into the passing westerly winds increases their salinity. This causes the warm water to sink and accumulate in the deeper water channels.

There is evidence that there is a continual loss of THC water along the deep flow route south and a counter flow back to the North Atlantic. These have decreased in volume by 15% over the last 50 years, suggesting that the THC is weakest during the warmer interglacial times. The frequent rather random changes in water temperature indicated by the $\delta^{18}O$ data from marine cores indicate that periodically, abrupt outbursts of THC water occur relatively frequently but do not always indicate the developments of a cold event involving major glacial advances. However, they could well be involved in causing some or all of the relatively minor cold events whose origin is discussed by Warner *et al.* [93]. Deciding whether this is their origin or whether they are the result of Holocene outbursts of glacial meltwater into the northern oceans may be a problem.

These changes in ocean temperatures are aided by the warm Gulf Stream and Kuroshio currents that flow north along the east coasts of North America and East Asia. The shallow seas in the Bering Strait result in closing off the north Pacific Ocean from the Arctic Ocean when the sea level drops more than 50 m due to sequestering of water on land in the form of glaciers. The North Atlantic remained open to the Arctic Ocean during the last five glacial events, and the latter lost part or all of its ice cover. Cold, dry air flowing across open water picks up large amounts of moisture and heat, thus increasing the salinity and density of the sea surface. This denser water then sinks and becomes the water taking part in the THC.

The eccentricity of the Earth's orbit appears to be involved in causing the major cold events during the last 750 ka B.P., whereas obliquity caused a spacing of 41 ka between 750 ka B.P. and about 2 Ma B.P. There are numerous other cycles and one-time events that influence the day-to-day, week to week and other fluctuations in weather and climate that mask the underlying controls and movement of the plates making up the surface of the Earth slowly changed the overall pattern in terms of geological time.

There is still a lot to be found out about the thermohaline circulation in relation to climate change since the changes in sea temperature after at least 20 ka B.P. is the same for both the northern seas and the Antarctic ones [16]. It does, however, provide a viable mechanism for moving heat back from the Northern Hemisphere to the Southern Hemisphere when the difference in heat energy between the two hemispheres becomes too great.

These processes primarily affect the areas north of the Mediterranean Sea in Europe, the North Atlantic Basin, and Siberia [94]. They do not seem to affect the deserts nor the Sahel on the southern main landmasses [95, 96], while the climatic changes in Monsoon areas depend more on the climate over the source oceans.

There is no evidence to indicate that carbon dioxide is of any special importance in the processes so that the measures taken by governments to alleviate it as a problem are not needed. Society should not need to take special steps that damage or limit the economic health of economies unless it wishes to hurt itself. Data from the measuring devices in the arrays in the oceans and observations from the weather stations involved should make weather forecasting easier in the future.

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