Likely causes of the Ice Age

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Uniformitarian concepts for the cause of the Ice Age are inadequate in explaining the degree of cooling and variation in temperature, related to this world-changing event. The most widely accepted explanation is based on the orbital-variation theory of Milankovitch. However, the fluctuations in orbit are insufficient and most models invoke other unsubstantiated feedback mechanisms.

Creationists have suggested atmospheric and oceanic effects of the Flood as the most likely cause of the Ice Age. The massive amounts of volcanism, identified in Flood-related strata, indicate an obvious source of stratospheric dust and sulfates, capable of causing global cooling. However, the atmospheric persistence of single volcanic events is short and significant on-going post-Flood volcanism would be required.

An alternative cause of global cooling is loss of carbon dioxide (CO_2) from the atmosphere to the oceans. The Flood would have produced large-scale oceanic and atmospheric circulations, high levels of organic nutrients and increased water temperatures in the oceans. These conditions are ideal for massive phytoplankton blooms, which would result in a net loss of CO_2 from the carbon cycle and an increase in oceanic sulfate export to the atmosphere.

The combined loss of CO_2 to the ocean and increased sulfate aerosols, from both volcanic and oceanic sources, could account for both the degree of cooling and its persistence over several centuries.

Milutin Milankovitch developed the idea that changes in Earth's orbit relative to the sun were responsible for ice ages. He published his work in 1920,[1] although previous writers on this subject were Alphonse Adhemar (1842) and James Croll (1864). There are in fact three changes in the earth's orbit worthy of note with various periods. These are the *eccentricity* with an approximate period of 100,000 years, the *tilt* with a period of 41,000 years, and the *precession* with a period of some 23,000 years.[2] These changes in orbit are claimed to have led to a very gradual drop in northern-hemisphere temperature, with a glacial maximum some 20,000 years ago. Milankovitch's theory also proposes a gradual warming with the Ice Age ending approximately 8000 to 12,000 years ago.[3]

During the 1950s and 1960s geologists preferred carbon-14 dating as the basis for measuring the Ice Age period, based partly on discrepancies between Milankovitch's theory and geological findings. However, many scientists now acknowledge that radiometric carbon-dating methods are far from perfect, and Milankovitch's dating of the Ice Age is again accepted by non-creationist scientists as the best available.[4]

The main problems with Milankovitch's dating of the Ice Age, have not disappeared, or been solved. Changes in Earth's orbit do not allow for sufficient cooling without invoking positive-feedback mechanisms, which are tenuous and poorly understood.[5] Theoretical estimates suggest that the average global temperatures during the Ice Age itself were about 4°C or 5°C cooler than present-day levels.[6,7] Orbital variations are only expected to be capable of producing much smaller temperature changes, at a very gradual rate. The theory of Milankovitch is also unable to explain the rapid changes in temperature indicated in the ice-core records, which are possibly evident in the sudden and catastrophic break up of large ice caps and ice dams.[8–10]

But what might have caused the Ice Age, if changes in the earth's orbit were not responsible? Climatologists today recognize that releases of CO_2 and other gases into the atmosphere, such as sulfur dioxide (SO_2), are much more significant to our climate than changes in the earth's orbit around the sun.[11] Other suggestions for the cause of climate change have included the after-effect of an asteroid impact, or changes in the radiation flux emitted from the sun.[12]

Michael Oard has developed an Ice Age model within a creationist timeframe. He considers that release of volcanic dust and sulfate gas during the post-Flood period, along with loss of CO_2 to the ocean were sufficient to produce this cooling. Oard gives a 'ballpark' figure of 500 years for glacial maximum to occur, followed by 200 years of melting.[13] However, Oard's monograph gives a range from 174 to 1,765 years to reach glacial maximum[14] (earlier stated as 250 to 1,300 years).[5,15,16] This timescale is determined by consideration of the heat balance of the land, ocean and atmosphere and takes into account variations in volcanic activity and other climatological assumptions.

CO_2 is widely recognized as having a major impact on global temperatures as a greenhouse gas,[17] but the current scientific debate over global warming is both complex and uncertain with positive- and negative-feedbacks coming into play. We need to recognize that climate-change feedback mechanisms are poorly understood and the science of global warming is complex. The ideas presented here for the cause of the Ice Age, may or may not have significant lessons for our understanding of climate change today. The overall ideas presented in this paper are shown in figure 1.

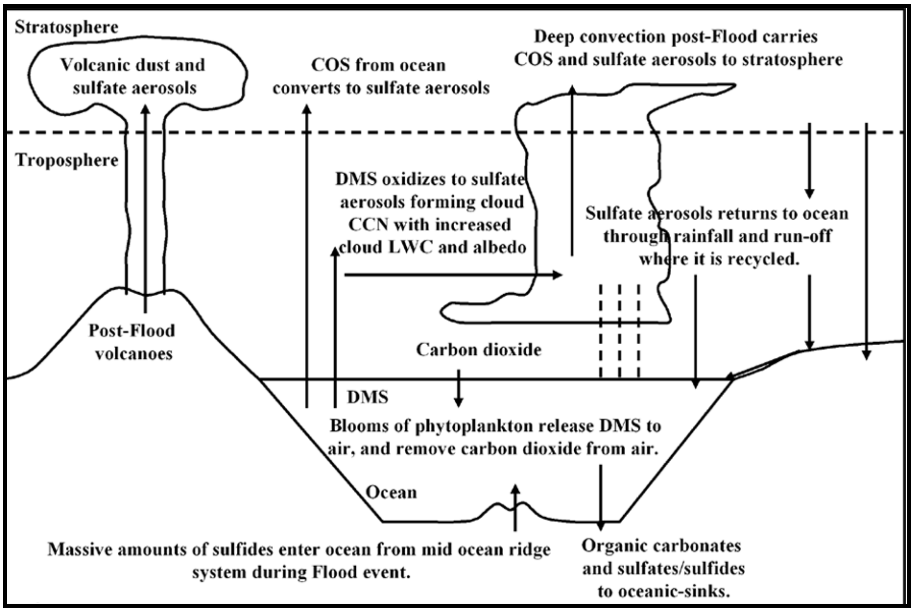


Figure 1. *The major geological, biological and chemical causes of post-Flood decrease in temperature. This shows transfer of atmospheric CO_2 to ocean sinks through phytoplankton blooms, and transfer of oceanic and volcanic sulfur compounds to the atmosphere, with enhanced oceanic sulfur concentrations following catastrophic tectonic events of the Noahic Flood.*
COS = carbonate sulfide, DMS = dimethylsulfide, CCN = cloud condensation nuclei, LWC = liquid water content.

The cooling effect of SO_2 emissions from volcanic activity

Flood models generally assume massive volcanic and tectonic activity, with vertical and horizontal movement of the earth's plates causing oceanic water to flood over the continents. While major tectonic activity would have ceased quickly at the end of the Flood, volcanic activity would have continued, although at a declining rate, possibly for several centuries.[18] This would have thrown considerable silicate dust and sulfates into the atmosphere, with corresponding atmospheric cooling over this period. Historical records show that volcanic emissions of sulfates and silicate dust have an immediate effect on global temperatures of a degree or more but the effect on global temperatures lasts only a few years.[11] A moderate frequency of post-Flood volcanic events would be required to sustain a prolonged period of cooling.

Sulfate aerosols and dust are effective in cooling the earth's atmosphere. Sulfate aerosols and silicate dust reflect, or backscatter, incoming sunlight and reduce the amount of short-wave radiation reaching the earth's surface. Solar radiation can also be absorbed and reradiated by sulfate aerosols in the stratosphere. In addition, sulfate aerosols will act as Cloud Condensation Nuclei (CCN); greater concentrations lead to more clouds with smaller cloud droplets and thus an increase in cooling effect from greater reflectivity. Fortunately, SO_2 and dust are washed out, or settle out quickly, often within a matter of months or a few years, even if thrown well up into the stratosphere.[11]

In contrast, the effect of CO_2 is to trap the heat of the earth in the atmosphere, causing an increase in temperature. CO_2 has a much longer residence time than SO_2 under present atmospheric conditions and much more CO_2 is released from volcanoes. However, the quantities released from eruptions are small, compared to that in the present atmosphere, and the cooling effect of sulfate aerosols and dust is far more dominant.

Historical volcanic eruptions

Examination of recorded volcanic events shows the possible scale of cooling. Mount Pinatubo erupted on 15 June 1991 and released some 5 km^3 of sulfates, ash and silicate dust to a height of 35 km, well into the stratosphere. The erruption released about 20 million tonnes of SO_2 with an observed cooling of about 0.5°C in global temperature.[19] However, the cooling effect was only apparent for some 18 to 24 months, with global temperatures soon returning to normal. Krakatoa, which left devastating results, is perhaps the most famous eruption. This volcano erupted in 1883, with a global temperature cooling estimated at 1.2°C. The effect on global temperatures from this eruption was noticeable for 5 years.[20]

Another historically recorded volcanic eruption is Tambora (1815), which ejected 150 km^3 of dust high into the stratosphere. Summer temperatures in North America were as much as 6°C cooler, with reports of a dimmed sun. In Europe, there were reports of crop failure, as summer temperatures remained 1.5°C below normal.[11] The average decrease in northern-hemisphere temperatures was 0.5°C, with temperatures returning to normal after 24 months.

The massive Yellowstone National Park caldera is 75 km by 45 km in size. Approximately 1,000 km^3 of ash was ejected into the atmosphere during its eruption. There is also evidence of older calderas in the Yellowstone Park, with the largest possibly ejecting 2,500 km^3 of ash and dust.[21] Other well-documented calderas from North America (with their estimated eruptive volumes of ash) include: La Garita Caldera, Colorado (3,000 km^3), Emory Caldera, New Mexico (1,450–2,050 km^3), Bursam Caldera, New Mexico (1,400 km^3), Long Valley Caldera, California (600 km^3) and Crater Lake Caldera, Oregon (75 km^3).[22]

While it has not been determined whether all these eruptions occurred during or after the Flood, it demonstrates the possible scale of atmospheric disruption. In addition to the above list there are many other large calderas around the world. Speculation over the size of atmospheric effects

The volcanic eruption of Tambora is 1815 caused temperature drops around the world.

Photo by NASA.

from the larger eruptions suggests a temporal 5°C reduction in average global temperature is likely,[23] with the formation of 'nuclear winters' considered possible by some scientists.[24] It is important to note that comparisons between size of volcano and temperature decrease are not always consistent, as the amount of sulfates released and the geographical location are more important than the amount of silicate dust, which settles out more quickly.[11,25]

Given the scale of past volcanism and the historically measured effects, it is likely that volcanic emissions would have played a significant part in the formation of the Ice Age.

The Dark Ages and the Little Ice Age

There has been much discussion about the events surrounding the Dark Ages. Evidence from tree-ring data shows that the climate was disturbed for about 15 years, with slower growth in trees from AD 536.[26] There are also many historical records of crop failures from around the world, during this period. Baillie has suggested that responsibility lies with an asteroid, or comet, impact. David Keys and Ken Wohletz have proposed that a massive eruption caused the temperature drop. Krakatoa may have been the culprit,[27] while others have proposed Rabaul in New Guinea.[11]

For a period of some 300 to 400 years from about AD 1400, the earth, and especially the northern-hemisphere gradually cooled with an increase in North Atlantic sea ice and growth of alpine glaciers. This is known as the Little, or Mini, Ice Age. Some have proposed that it coincided with the solar 'Maunder Minimum' of 1645 to 1715, although the evidence shows cooling was underway by around 1400.[28] There is disagreement as to the extent of the proposed reduction in solar activity, with some sources suggesting that a 0.25% reduction was sufficient to give the necessary cooling,[29] while other sources propose that the solar variation was only 0.14% and thus insufficient in magnitude and time,[12] as the earth did not really recover until the mid-nineteenth century. Warr and Smith compared the carbon-14 anomalies found in tree rings with the climatic record, and consider that a link between solar radiation and global temperatures is, at best, 'highly suggestive'.[30]

Warr and Smith also compare the Little Ice Age with volcanic activity and comment that:

> 'Some historic cool intervals in the Holocene, such as the Little Ice Age, correspond to periods of enhanced ice-core sulfate values, so there may be a link between volcanism and climatic change on the decade to century time-scale.'[31]

Warr and Smith also note that the recorded volcanic activity appears insufficient in accounting for all the measured cooling.

Recent studies have suggested that global warming may actually lead to cooler climates in north-west Europe.[32] It is suggested that the North Atlantic Ocean Circulation may change as less water sinks in the Norwegian Sea. This would have the effect of driving the Gulf Stream further south and would actually make the European climate colder. It is therefore possible that changes in ocean current led to the Little Ice Age, although this remains uncertain.

The cooling effect of reduced CO_2 in the air

Another possible cause of global cooling is the loss of atmospheric CO_2 to the oceans through a combination of nutrient-rich seas and phytoplankton blooms—mostly foraminera and coccolithophores.[33] It is widely recognized by climate-change scientists that the CO_2 flux between ocean and atmosphere is dependent on changes in water temperature, surface mixing and phytoplankton blooms. The Intergovernmental Panel on Climate Change (IPCC) scientific assessment commented:

> 'Carbon dioxide is transferred from the atmosphere into the interior of the ocean by the physical pump mechanism … caused by differences in the partial pressure of carbon dioxide in the ocean and the lowest layers of the atmosphere. Furthermore the annual ventilation of the seasonal boundary layer from the surface mixed-layer controls the efficiency of the biological pump by which ocean plankton convert dissolved carbon dioxide into particulate carbon, which sinks into deep water. These two pumps are responsible for extracting carbon dioxide from the global cycle for periods in excess of a hundred years. The ocean branch of the carbon cycle involves a flux of carbon dioxide from the air into the sea at locations where the surface mixed layer has a partial pressure of CO_2 lower than the atmosphere and vice versa. Mixed-layer partial pressure of CO_2 is depressed by enhanced solubility in cold water and enhanced plankton production during the spring bloom. The rate of gas exchange depends on the air-sea difference

> in partial pressure of CO_2 and a coefficient which increases with wind speed.'[34]

It has long been hypothesized that iron is a major limiting nutrient in ocean water, and a number of leading scientists have proposed that an increase in iron within the ocean would have a dramatic effect in lowering atmospheric CO_2 concentrations. Vardiman quotes John Martin as saying: 'Give me half a tanker of iron and I'll give you an ice age!'[33] Vardiman highlights two studies carried out in the Pacific in 1993 and 1995 in which large areas of ocean were seeded with iron sulfate.[35,36] This led to a doubling of plant biomass and a four-fold increase in phytoplankton production with the ocean visibility reduced to about 2 metres. The partial pressure of CO_2 in the air above this area was reduced significantly within 48 hours, although to only 10% of the possible reduction, if all available nutrients had been used up.[37] Control experiments in containers were much more vigorous, which suggested that, in the open ocean experiments, the iron was sinking out of the photic zone or becoming unusable through some other means. Other nutrients that limit phytoplankton production within the ocean include nitrates and phosphates.

More recent studies have shown that phytoplankton prefer iron already bound in organic molecules.[38,39] Prokaryotic phytoplankton, which are common in oceanic waters, prefer iron bound in compounds called siderophores. Another type, eukaryotic phytoplankton, common in rich coastal waters, prefer iron linked to porphyrins, similar in structure to chlorophyll and hemoglobin. Both of these chemicals are of organic origin and all types of phytoplankton find inorganic iron much harder to utilize.

Phytoplankton blooms during the Flood

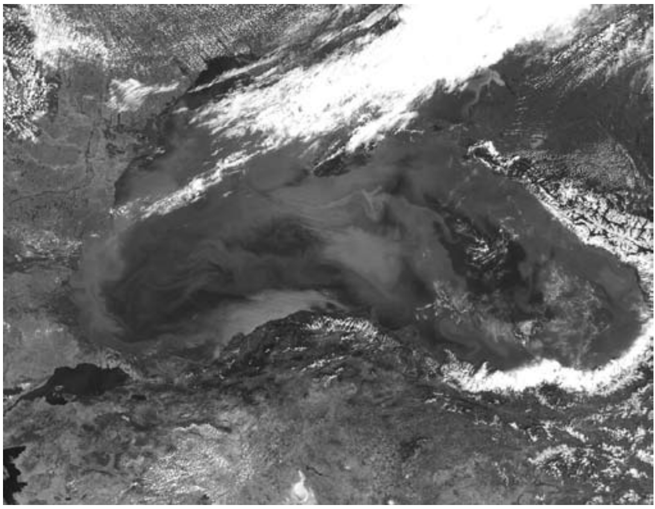
The oceans of the Flood and post-Flood periods would have been filled with decaying organic material, and the resulting organic, iron-rich chemicals would have enabled massive phytoplankton blooms to grow. In addition, the ocean would have been well mixed by tremendous convective activity as a result of the warmed ocean floor (due to the tectonic and volcanic activity). The effect of this large-scale oceanic mixing would be a continuing massive supply of nutrients and CO_2 within the ocean's photic zone, to maintain growth of phytoplankton blooms. Even though the post-Flood warm water would depress CO_2 flux to the ocean, it would have been swamped by the effect of phytoplankton blooms taking up carbon and thus reducing the partial pressure of CO_2 in the surface waters. The oceanic convection would also have transferred heat to the atmosphere to drive tropospheric convective currents. It is reasonable to assume that conditions would have been ideal for continued rapid growth of phytoplankton, with huge loss of atmospheric CO_2.

The ocean surface water biomass is relatively small today, estimated at 5 billion tonnes of carbon (table 1) but it has a very high turnover with phytoplankton grazed by zooplankton and remains falling through the ocean as detritus. Massively increased phytoplankton blooms would have produced an intense 'rain' of carbonate debris to the sea floor. The skeletons of coccolithophores and foraminifera are primarily calcium carbonate ($CaCO_3$). Normally, when they die they sink to the bottom and the $CaCO_3$ dissolves in the cooler ocean bottom. However, with a warm ocean throughout, and the high rate of $CaCO_3$ production, most $CaCO_3$ would not have gone back into solution at lower levels but settled out as sediment on the ocean floor.[40] Such a massive transfer of atmospheric CO_2 to the ocean sediment may have had a more prolonged and stable cooling effect on global temperatures than increased SO_2 from volcanic emissions. Massively increased phytoplankton blooms, because of the Flood, would also account for the Cretaceous rock layers as discussed by Snelling,[41] Woodmorappe[42] and Roth.[43]

Roth highlighted the fact that observed blooms of phytoplankton in Oyster Bay, Jamaica, can reach densities of 10 billion micro-organisms per litre of ocean water, probably caused by nutrients washed, or blown, from the land.[44] This is some 100 millions times more than normal concentrations. If such blooms were in evidence during the Flood, then it is possible that the Cretaceous sediments would have been laid down in a matter of days. Snelling gives a minimum estimate of 6 days for the formation of the chalk cliffs of Southern England,[41] although this may feasibly be stretched out over several months of the latter Flood period.

The carbon balance

Some of the deep-ocean carbonate sediments may have continued to accumulate for a period of decades or several hundred years, until the deep ocean was cool enough to cause carbonate to go back into solution at lower levels. Full utilization of the limiting nutrients by phytoplankton would also have caused the CO_2 flux to reverse at some stage



Credit: Jacques Descloitres, MODIS Land Rapid Response Team, NASA/GSFC

The pale shades of swirling phytoplankton blooms in the Black Sea contrast with the dark water of the adjacent Sea of Marmara (bottom left).

with the cessation of the blooms and carbonate 'rain'. As polar oceans cooled during the Ice Age, water near coastal margins would have begun to sink with the formation of the present ocean circulation. The effect of increased cold water at depth would have reduced the alkalinity of the ocean, with carbonate debris going back into solution as the Carbonate Compensation Depth (CCD) rose higher.[40] This would have reversed the net transfer of CO_2 from air to sea, increasing the CO_2 concentration in the atmosphere once again, and warmed the earth sufficiently to help melt the ice layers.

The sheer scale of the volumes involved are presented in table 1.[45] According to estimates, there is in excess of 2,000 times as much carbon locked up in carbonate rock layers as there is in the present-day ecosystem. If the present-day atmospheric CO_2 concentration of 0.03% is multiplied 2,000 times, we would have a pre-Flood CO_2 concentration approaching 60%, which is extremely unrealistic. It must be assumed that some of the 90 million billion tonnes of carbon existed in sedimentary layers prior to the Flood, before being reworked into later sediments. It is possible that considerably more CO_2 was released from volcanic activity during this period than the 44 billion tonnes quoted by Snelling.[41] However, trying to separate out the CO_2 that was present in the pre-Flood ecosystem and sinks from that which was released during the Flood period itself is problematic. Roth also suggests that uniformitarian estimates of carbonate sediment are far too high with the average deep-ocean sediment layer around 400 metres thick.[43]

Woodmorappe gives an estimate of 17.5 million km^3 of carbonate rock in the Upper Cretaceous and Tertiary layers.[42] This equates to 4.2 million billion tonnes of carbon.[46] If this were in the pre-Flood ecosystem it would give one hundred times more atmospheric carbon than in the present-day atmosphere, implying a 3% concentration, or 70,000 billion tonnes. This estimate may be at the low end of possible estimates if other carbonate rock layers are considered. If this data is applied to a recent global Flood model, it implies that the pre-Flood environment was hugely enriched in carbon in comparison to the present day. This also has implications for our understanding of the pre-Flood atmosphere, but discussions over its composition is beyond the scope of this paper.

Large changes in atmospheric composition may have occurred as a result of the Flood, with massive loss of CO_2 to ocean sediments. The current rate of flux of CO_2 between the atmosphere and ocean shows an approximately equal exchange each way of approximately 100 billion tonnes per year. Determining the rate of flux from air to ocean during the Flood and its immediate aftermath is difficult, although the scale of observed phytoplankton blooms makes a significant increase in flux rates feasible. CO_2 concentrations may have fallen off exponentially as the partial pressure reduced significantly below present-day levels, as a result of these massive phytoplankton blooms. CO_2 would also have been lost to the recovering plant biomass on land.

It is interesting to note that the IPCC assessment suggests historic CO_2 levels of 200 parts per million during the Ice Age,[47] which is approximately 70% of the pre-industrial value of the last 800 years.[48,49] Such a reduction in CO_2 would have allowed significant cooling of the planet.

Additional atmospheric cooling from oceanic sulfur emissions

When certain types of phytoplankton, such as coccolithophores, die or are eaten by zooplankton, dimethyl-sulfoniopropionate (DMSP $((CH_3)_2S^+C_2H_5COO^-)$) is released into the ocean where it breaks down into dimethyl-sulfide (DMS—$(CH_3)_2S$).[50] While a large part of the DMS remains in the ocean where it is recycled, a significant part escapes into the air. This release to the air occurs mostly where and when blooms of phytoplankton are observed.[51] Smaller amounts of DMS are released by land vegetation, and hydrogen sulfide (H_2S)is also released by the actions of bacteria on rotting organic matter.

In the troposphere, DMS oxidizes to sulfate aerosols. These aerosols then combine into tiny sulfurous particles through photochemical reactions to form Cloud Condensation Nuclei (CCN). With a greater concentration of natural CCN over oceanic water, cloud droplets become smaller in size. These smaller nuclei increase the albedo of the cloud

Table 1. *Present-day carbon sinks (after Porteous)*[45]

	Present day carbon sinks	**Billion tonnes of carbon (x10^{9}t)**
Atmosphere		700
Biosphere	Land: Plant biomass	550
	Marine: Phytoplankton	5
	Marine: Zooplankton, fish, etc.	5
	Land: Dead organic matter as soils and detritus	1,200
Oceans	Marine: Organic residues and sediments	3,000
	Dissolved in surface ocean	500
	Dissolved in deep ocean	34,000
Rock	Locked in carbonate rocks	90,000,000
	Locked in fossil fuels	10,000

cover, with greater atmospheric cooling effects.[52] From studies of ship exhausts, Radke *et al*. have shown that an increase in sulfate aerosol pollution leads to a greater number of smaller cloud droplets and to an increase in the cloud Liquid Water Content (LWC), with a likely increase in cloud albedo.[53]

Incidentally, greater LWC is probably a result of less water being washed out as drizzle. However, higher LWC may increase precipitation through the sub-zero Bergeron-Findeisen process,[54] when cloud is lifted and cooled along frontal boundaries, over hills, and from convective processes. Differences in vapour pressure between ice and water surfaces mean ice crystals grow rapidly at the expense of water droplets in sub-zero clouds. Thus, higher cloud CCN and LWC may have produced heavier precipitation over ice layers during the Ice Age period than current creationist estimates allow.

Another study by Lindzen *et al.*[55] has shown that warmer Sea Surface Temperatures (SST) also affects the type of cloud produced. A warmer SST gives more energy for the formation of convective clouds, with a reduction in high-level cirrus cloud and an increase in rainfall. As a result, long-wave radiation is allowed to escape more easily from the earth over warmer seas, which has a positive cooling effect.

With extensive phytoplankton blooms, the scale of DMS emissions into the air would likely have been significantly greater than the present rate of 40 millions tonnes per year.[56] When converted to SO_2, the present rate is roughly equal to the annual rate emitted from the burning of fossil fuels,[51] and twice the amount released by Mount Pinatubo. The massive amount of submarine volcanic deposits and sulfide emissions from the massive tectonic events during the Flood period would have greatly enriched the oceans in sulfur compounds.[57] Thus, the quantity of available sulfur would not have been a limiting condition. The release of sulfur compounds to the atmosphere through the ocean may have been more significant in terms of post-Flood global cooling than direct atmospheric volcanic release.

In addition to DMS, carbonyl sulfide (COS) is produced by the effect of photochemical reactions on organic matter in the surface water. COS is the dominant sulfate aerosol in the atmosphere today. It is relatively inert and escapes readily into the air, passing largely unchanged to the stratosphere,[58] where it is converted to sulfate aerosols by sunlight.[59] It is likely that during the post-Flood period, with vigorous atmospheric convection and greatly enriched oceanic sulfur compounds, stratospheric COS concentrations were significantly increased.

Modelling of global cooling

Larry Vardiman has modelled the likely post-Flood (SST) and considered their effect on rainfall[60] and extreme convection.[61] The increased Convectively Available Potential Energy (CAPE) would be able to carry tropospheric aerosols well into the stratosphere, creating greater precipitation in most maritime parts of the world.

The residence time of sulfate aerosol in the troposphere is only a few days or weeks, while the residence half-life of stratospheric sulfur aerosols is about one year.[17] These aerosols would have been washed back to the surface relatively quickly during the Ice Age for recycling by the phytoplankton. With 70% of the world covered by ocean, it is likely that the level of sulfate compounds in the post-Flood ecosystem would have been reduced only slowly, perhaps over decades as sulfate aerosols eventually became locked in sulfate sinks. Enriched concentrations of oceanic sulfur compounds post-Flood, and phytoplankton blooms would have maintained higher atmospheric loading of sulfate aerosols for some time.

Trying to quantify these changes is not easy, but Oard's calculated range provides a very useful starting point. If we assume that sulfate aerosol from oceanic sources were equally important in terms of global cooling, as volcanic sources during the post-Flood period, then the reduction in solar radiation absorbed by the earth-atmosphere system may be increased to 50% from Oard's assumed estimate of 25%. This would bring the period to glacial maximum down to 309 years post-Flood, based on Oard's range of values.[14] It may also be assumed that changes in cloud physics and loss of CO_2 allowed greater long wave radiation to escape to space. However, changes to Oard's outgoing radiation assumptions are not accounted for in this calculation.

It is important to point out that not all chemical aerosols produce cooling. Nitrous oxide (NO), for instance, is a greenhouse gas, which is also released into the air during massive organic growth.[62] Methane (CH_4), another greenhouse gas, would also have been released from rotting vegetation and bacteria after the Flood, and helped limit global cooling. The effects of these gases are not accounted for in this paper. Other changes in albedo during the post-Flood period would also have had significant effect on the earth's climate, but a full discussion is beyond the scope of this paper.

Conclusion

The effects of current atmospheric positive- and negative-feedback mechanisms are quite small, and observed changes in cloud physics and sulfate aerosol appear to partially *mitigate* the warming effects of the currently increasing levels of CO_2. Thus, the standard theory of ice age formation, which requires large feedback effects working on small climate changes due to orbital variations, is inadequate, and lacking in direct evidence, to explain the reduction in global temperatures during the Ice Age.

In contrast, the post-Flood conditions described in this paper involve catastrophic changes in atmospheric chemistry, which would have caused significantly greater changes in global temperature. Following the Flood, increases in sulfate aerosols, changes in cloud physics and reduced atmospheric CO_2 levels would have had a combined *positive* cooling effect.

Evidence from historic volcanic activity shows that sufficient emissions of sulfate aerosols and dust would provide the necessary cooling to account for an ice age. However, single volcanic eruptions cannot account for the persistence of temperature falls necessary for an ice age to form. The atmospheric effect of the largest recorded events could possibly be extrapolated up to a maximum of about 15 years. Thus, a series of ongoing massive eruptions in the post-Flood period would be required.

A significant alternative source of sulfate aerosols during the post-Flood period would have been oceanic production of DMS and COS, resulting from a combination of warmer ocean temperatures, large-scale ocean mixing and large quantities of organic nutrients and sulphides.

The loss of atmospheric CO_2, as a result of nutrient-rich seas enabling phytoplankton blooms, is also considered a significant factor in post-Flood cooling. Carbonate sediments from both the Flood and post-Flood periods may well bear witness to this massive sink in the carbon cycle.

Precipitation rates would also have been greater during the immediate post-Flood period, with warmer oceanic surface temperatures producing increased convection together with greater concentration of cloud CCN and LWC. This would result in increased long-wave radiation from the earth's surface and more sunlight being reflected back to space from the clouds. Both these effects would cause enhanced planetary cooling.

Loss of atmospheric CO_2, plus additional DMS and COS, would have a longer-lasting and more stable effect on global cooling than volcanic emissions alone. These combined effects could account for the amount of cooling necessary for an ice age to form, and its persistence over several centuries.

With the combined effects from CO_2, sulfates and positive feedback mechanisms the 'ballpark' figure of 500 years for glacial maximum determined by Oard may potentially be reduced. A reduced figure of around 300 years is considered feasible from Oard's estimated range under the scenario presented in this paper.

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