CLIMATIC CHANGE AND ATMOSPHERIC POLLUTION

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SUMMARY: Increased atmospheric carbon dioxide content was concluded to have had an ambiguous climatic influence and may be less important than sometimes considered. Several studies have suggested increased turbidity has produced a recent global cooling trend. An examination of some climatic effects of volcanic eruption was made in relation to the prediction that the effect of 500 supersonic transport aircraft would be comparable over the North Atlantic to the amount of stratospheric injection from the 1963 Mount Agung eruption. World glacial advance over the past three centuries was shown to be synchronous with volcanic eruption ($p < 0.01$) and with poor harvests ($p < 0.001$) and lower world temperatures were significantly related to volcanism ($p < 0.01$). These relationships support the results of a previous study and suggest that the effects of 500 supersonic transport aircraft may lead to reduced surface temperatures and possibly an intensification of alpine glaciation.

INTRODUCTION

The climatic effects of two physical changes in the atmosphere which have resulted from pollution by man will be examined: (1) increase in carbon dioxide, (2) increase in turbidity.

INCREASE IN CARBON DIOXIDE CONTENT

There has been an increase in atmospheric carbon dioxide content during the past century, which has been attributed to increasing human technology (Callendar 1957). The magnitude of this increase has been difficult to ascertain. Of five unweighted comparisons, all showed increases, but none were statistically significant (Bray 1959). Of seven comparisons weighted by an estimate of accuracy of chemical analytic technique, all showed increases and three were significant. The increase for weighted yearly non-urban values was from 293 p.p.m. in 1857–1906 to 319 p.p.m. in 1907–1956. A positive influence of increased atmospheric carbon dioxide content on terrestrial temperature has been deduced from knowledge of its heat absorptive properties at certain wave lengths (Plass 1956). The quantitative magnitude of this relationship has been questioned, especially with regard to possible interference by water vapour. The apparent increase in terrestrial temperature in the first half of the 20th century was ascribed by Callendar to the accompanying increase in atmospheric carbon dioxide. This relationship may be partly, or wholly, coincidental since there has been an apparent downturn in world temperature since around 1940 while atmospheric carbon dioxide concentration has continued to increase. The Massachusetts Institute of Technology symposium on critical environmental problems in 1970 concluded that climatic changes resulting from increase in carbon dioxide concentration in the 20th century would probably be small, but the possibility of climatic consequences over a longer period was not discounted (Carter 1970).

INCREASE IN TURBIDITY

McCormick and Ludwig (1967) found that there had been a 57% increase in turbidity over Washington, D.C. from 1903–1907 to 1962–1966 and an 88% increase over Davos, Switzerland, from 1903–1907 to 1957–1959. They suggested that a 10% increase in atmospheric turbidity could result in a 1.5% increase in albedo (reflectivity) which would cause a 0.5% to 0.8% decrease in solar radiation at earth's surface. They suggested that increased aerosol production by man may be responsible for the temperature decrease which started in the 1940s. Peterson and Bryson (1968) found a similar increase in turbidity at Mauna Loa, Hawaii, of from -0.3 to -0.5 Linke turbidity units in 1957–1958 to $+0.2$ to $+0.4$ units in 1967–1968. Bryson is quoted by Gates (1970) as believing that the increased turbidity in the atmosphere from volcanic activity, dust storms and man's pollution, has overshadowed the carbon dioxide increase and is producing a cooling trend in the global climate.

In August of 1970, the Massachusetts Institute of Technology symposium examined the question of increased turbidity (Carter 1970). Estimates were made on the effect that 500 supersonic transport aircraft (SST) would have on the upper

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atmosphere, and the conclusion was reached that "... the SST fleet, by discharging combustion products such as soot, hydrocarbons, nitrogen oxides, and sulfate particles would cause stratospheric smog, a condition that might be especially pronounced over the North Atlantic. The group said that the amount of fine particles formed as a result of SST operations might be comparable to the amount put into the stratosphere by the volcanic eruption of Mount Agung in Bali in 1963 . . . ". If this prediction is correct then the following evidence suggests a temperature reduction at the earth's surface.

Lamb (1969) showed a close similarity in (i) the amount of polar ice off Iceland and great vol-present and (ii) English temperature and a Vol-canic eruptions in Iceland from A.D. 800 to the canic Dust Veil Index from A.D. 1500 to the present. Lamb concluded that great volcanic eruptions which produced long-lasting dust veils in the stratosphere had resulted in a number of statistically significant relationships with wind circulation patterns, prevailing temperatures and Arctic sea ice conditions over the succeeding three to seven years. These conclusions are supported by analysis of the climatic effects of volcanism.

CLIMATIC EFFECTS OF VOLCANISM

Volcanic Dust Veil Indexes compiled from A.D. 1680 to the present by Lamb (1969) are listed in Table 1 for all intervals of four years or less in which there was a total Dust Veil Index of 1000 or greater. Dates of all poor harvests caused by excessive cold which resulted in famine are listed from A.D. 1500 to present for England and Scotland (data from Lamb 1959, 1964), Norway (Lamb 1959, Hoel and Werenskiold 1962) and Japan (Arakawa 1955). Also listed in Table 1 are all intervals of up to a maximum of 11 years in which there had been five or more glacial advances which reached the maximum ice terminus as defined and compiled in Bray (1968).

The information in Table 1 shows a neatly aligned sequence of events, with many of the volcanic eruption intervals followed by years with poor harvests or by glacial advance or both. A statistical analysis was made by counting the number of glacial advances in the 10 years surrounding the start of each volcanic eruption interval and the start of each period of poor harvest. A 10-year period for compilation of glacial advance was used

TABLE 1. *Volcanism, poor harvests and glaciation*

MAJOR VOLCANIC ERUPTIONS		POOR HARVESTS	GLACIATION	
A.D.	Dust Veil Index	A.D.	A.D.	No. of advances
		1590–1600	ca 1600	10
1680	1400			
1693–1694	1500	1693–1700	1706–1715	6
		1740–1742	1740–1750	20
1752–1755	1700			
1763–1768*	4000		1760–1770	7
1772–1775	1250 }			
1783–1786	1150 }	1783–1786	1775–1785	7
1803	1100			
1807–1810	1500		1807–1811	5
1815	3000	1816	1818–1825	5
1831–1833	1000 }			
1835	4000 }	1833–1839	1835–1844	10
1845–1846	1250		1845–1853	8
		1866; 1869		
1875–1878	1550			
1883	1000			
			1890–1900	8
1902	1000			

* Two overlapping intervals

because of the time lag between ice accumulation and maximum glacial advance (Bray and Struik 1963) and a minimum estimate of ± 5 years in the accuracy of many of the glacial advance dates. There were 64 glacial advances in the 133 years of the 10-year intervals which surround the first year of the 15 volcanic eruption intervals. This was compared by χ^2 analysis with the 41 advances in the 148 remaining (i.e. non-volcanic) years ($\chi^2{\uparrow} = 7.8$, $p < 0.01$). Similarly, there were 36 glacial advances in the 70 years of 10-year intervals surrounding the first year of the seven poor harvest intervals compared with 88 advances in the remaining 381 years ($\chi^2_1 = 17.5$, $p < 0.001$).

Of the six intervals of poor harvest since Dust Veil Indexes became available, four followed within one year of major volcanic eruptions, and one of these was directly attributed to volcanism by Arakawa (1955). Of the remaining two poor harvest intervals, the effects of the 1866 and 1869 poor harvests in Japan were intensified by the social unrest at the end of the Tokugawa feudal period. In the famine of 1740–1742, however, barley and oats did not ripen for three successive years, an unlikely random event but one easily explained by a preceding volcanic eruption with a heavy dust veil lasting for three years.

TABLE 2. *World temperature departures preceding and following 13 major volcanic eruptions,* A.D. *1750–1920*

Year	−2	−1	0	+1	+2	+3	+4	+5
No. positive departures	8	6	8	2	4	6	8	5
Mean temperature departure °C.	+0.07	0.00	+0.08	−0.31	−0.27	−0.07	+0.15	−0.28

The validity of the sequence which apparently led from volcanic eruption to poor harvests as a result of cold summers and ultimately to glaciation is supported by world temperature data. These data are summarized from Köppen for 1750–1871 and from Humphreys for 1872–1920 as presented in Arakawa (1955). Temperature departures for the two years preceding to the five years following the 13 volcanic eruptions with a Dust Veil Index of 1000 or greater are shown in Table 2. In the first year after eruption, only two of 13 temperature departures were positive and in the second year after eruption, only four were positive. A χ^2 test (1 df) applied to the two years preceding eruption (14 of 26 positive) and to the two years following eruption (six of 26 positive) gave a value of 7.5 ($p < 0.01$) indicating a significant relationship between volcanic eruption and below normal temperatures. Mean world temperature in the two years following major volcanic eruption was 0.3°C. lower than average.

DISCUSSION

The existence of a statistically significant decrease in temperature following volcanic eruptions with Dust Veil Indexes of 1000 or greater in the past suggests that smog produced by supersonic transport aircraft may cause a temperature decrease. Since this smog has been predicted to be similar to that of the Mount Agung eruption which had a Dust Veil Index of 800, it might be expected to result in a slightly smaller temperature decrease than for Dust Veil Indexes of 1000 or greater. Smog produced by supersonic transport aircraft will be continuous, however, and to a certain extent cumulative, assuming the atmospheric residence time of particles is similar to the 3- to 7-year period usual for the removal from the atmosphere of volcanic debris. The result of smog produced by supersonic transport aircraft could be, therefore, a permanent mean world temperature decrease similar to and perhaps greater than the 0.3°C. from past volcanic eruptions.

The apparent control of glacial periodicity by volcanism does not imply that volcanic activity was the cause of the renewed glaciation of the A.D. 1550–1900 Neoglacial phase, but that it regulated its timing and perhaps stimulated its occurrence given suitable ice production potential ("Eiszeitbereitschaft"). In view of the general world cooling which is apparently now in progress, it is reasonable to suggest that a direct result of the supersonic transport aircraft might be an intensification of alpine glaciation.

It is becoming more apparent that there must be regulation of any of man's activities which may result in significant climatic change. The earth is in a fairly precarious temperature balance given its present distribution and density of human population and agricultural production. A cooling trend could lead to continental glaciation in the middle latitudes. This tendency could be reversed by the use of carbon dust spread on snow and ice to reduce albedo and induce melting, but this method has been stated by Gates (1970) to be financially unrealistic. Warming could result in a rise in sea level and the immersion of coastal plains and cities. The injection of aluminium or other reflective strips at high altitudes in the atmosphere to increase albedo has been suggested as a method of reversing this trend. I have found no estimates of whether this would be economically feasible.

Given the failure of the various national states to prevent the explosion of nuclear weapons, another source of atmospheric pollution, it is doubtful whether these same states will be able to control their present industrial air pollution. For this (and other reasons) the present division of humanity into sovereign states seems a dangerous anachronism. The federation of mankind into a world parliament would be one alternative which would permit the adoption of pollution controls sufficiently stringent to prevent climatic alteration and its social and economic consequences.

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