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COMMENTS ON
GLOBAL EFFECTS OF METEORIC IMPACTS AND VULCANISM

by

Andrew A. Lacis

NASA Goddard Space Flight Center
Institute for Space Studies
New York, NY 10025

and

Sergej Lebedeff

MA/COM Sigma Data, Inc.
2880 Broadway
New York, NY 10025

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COMMENTS ON GLOBAL EFFECTS OF METEORIC IMPACTS AND VULCANISM

Andrew A. Lacis and Sergej Lebedeff

Abstract

There is general consensus that volcanic eruptions can inject light~~-~~scattering particles high in to the stratosphere, thereby ~~which~~ reduc~~e~~ing solar radiation transmitted to the ground~~, and thereby~~ and ~~thus result in a~~ cooling ~~of~~ the surface temperature. However, comparison of ~~with~~ global temperature measurements with known volcanic eruptions ~~is anything but reassuring~~ that the expected cooling really occurs. We examine some examples where agreement is found. We conclude that it is hard to define a 'volcanic climate signal' unless the optical thickness of the volcanic aerosol, its composition and particle size distribution, and its global distribution are known. Particle size distribution is particularly critical, since this can determine whether the volcanic aerosol will heat or cool the surface temperature.

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Qualitatively, it seems reasonable to expect that highly energetic events described by Lal (1983) such as impact by a small asteroid or the eruption of a very large volcano, aside from the obvious local devastation, might also have a significant impact on the global climate of the earth. It is much more difficult to be quantitative about the climatic changes produced by perturbations that are orders of magnitude greater than ~~we have~~ our observational experience ~~to apply~~ to date. Proportionally, a large meteor impacting the earth is similar to a bullet or even an artillery shell fired into a football stadium. We can imagine the local impact to be very severe, but it is hard to believe that the whole stadium (or earth) would ever become uniformly covered with a thick layer of smoke or aerosol. Now, explosive volcanos do produce a global haze cover, but the cases we have experienced thus far have produced moderate optical thicknesses, and it may be that a relatively uniform global distribution is possible because the aerosol-producing material was injected in gaseous form. Our primary concern is that we have difficulty in fully understanding the climatic impact of even relatively small perturbations where we ~~hope~~ expect that the relevant physics will behave linearly ~~according to our expectation~~. For very large perturbations, we should not expect linear extrapolations to hold up. It may be interesting to speculate about cataclysmic events, but we should remember that the uncertainty applicable to small perturbations is magnified at least in proportion to the size of the perturbation.

To help illustrate the nature of the problem, we look at the temperature record of the northern latitudes over the decades preceding and following the June 30, 1908 Tunguska meteor fall. Fig. 1 shows the monthly mean temperature trends after the mean seasonal cycle has been subtracted out. The arrows indicate various volcanic eruptions which may or may not be associated with dips in the surface temperature. The noise in the surface temperatures suggests that searching for a volcanic climate signal is like looking for a needle straw in a haystack. Of the major volcanos, only Katmai (1912) appears to have a plausible temperature signal. For many of the other volcanos, temperature decreases seem to precede the volcano eruption. The temperature record is not inconsistent with a temperature dip due to the Tunguska meteor, but there does not appear to be any prolonged temperature decrease in the decade following the meteor fall.

Turco et al. (1982) analyzed the circumstances of the Tunguska meteor in considerable detail. They note that the spectral dependence of optical extinction measurements in the Chappuis band of ozone suggests significant ozone depletion following the meteor fall. Their analysis suggests that the falling meteor could have generated up to 30 Megatons of NO, and that the photochemical consequences of the large NO injection resulted in a 35 - 45% ozone depletion in the northern hemisphere. Because some of the photochemical components, N_2O and HNO_3 in particular, also produce a greenhouse warming, it is not clear whether the estimated $0.3^{\circ}C$ temperature decrease due to the ozone depletion and aerosol loading included all contributors. The Tunguska meteor appears to be an interesting case which needs further study and analysis.

Global temperature records have been analyzed by many investigators trying to extract an empirical climatic response for volçanic eruptions (cf. Oliver, 1976; Taylor et al., 1980). Basically, the results of their analysis show that there is indeed climatic cooling of short duration associated with volcanic eruptions, but that there is also significant statistical uncertainty involved. It is abundantly clear that volcanos are not identical in their impact on climate, and that statistical analysis of eruptions and temperature trends can not hope to provide more than qualitative information about the volcanic climate signal. We must go a step further and check the radiative properties of volcan~~os~~ic ejecta (their optical thickness) against the temperature record.

Fig. 2 shows the optical depth measured at Mauna Loa Observatory after removal of the background value. The solid line shows GCM simulation of volcanic aerosol transport computed with the GISS tracer model for the following eruptions: Agung (1963), Awu (1966), Fernandina (1968), and Fuego (1974). Global optical thicknesses for these volcanos were obtained by normalizing the tracer model results to the observed optical thickness variations measured at Mauna Loa. Fig. 3 shows the corresponding global temperature record with the seasonal cycle removed. We can with reasonable confidence identify the temperature decrease due to Agung, and to a lesser degree the temperature decreases of the other volcanos. These results tend to corroborate the analysis by Hansen et al. (1978) of the Agung eruption in that a significant cooling of the surface temperature was obtained (see Fig. 4).

As noted by Hansen et al. (1978), the size distribution of the volcanic aerosol is crucial in determining the net radiative effect. This is because two opposing effects are operating. On the one hand, the volcanic aerosols scatter and reflect solar radiation. This tends to cool the surface temperature. On the other hand, sulfuric acid and silicates have strong absorption cross-sections in the 10 μm region. This provides a greenhouse warming effect which, for particle size distributions only moderately larger than 1 μm, can overpower the solar albedo effect and warm the surface temperature. Thus, not only is it important to know the global optical thickness of the volcanic aerosol, it is even more important to know the aerosol particle size.

As a case in point, Hofmann and Rosen (1983) measured the effective particle size distribution a month after the El Chichon eruption to be about 1.5 μm. For this size distribution, the thermal greenhouse component predominates and causes a surface warming to occur. Some six months later, the particle size had decreased to an effective radius less than 0.5 μm due to fallout of the larger particles. For this size distribution, the solar component is stronger, leading to a cooling of the surface temperature. Evidently, to effectively model the climatic signal of a volcanic eruption, a careful time evolution of the optical thickness and particle size distribution is neccessary.

The longterm climatic impact of volcanos is difficult to assess since the radiative effects of a volcano last only a few years whereas the time constant for the ocean to respond is many decades. It is possible that volcanos may act to trigger an impending ice age or to perhaps delay the ending of an ice age. Clearly, a sustained forcing over long periods of time seems to be the likely cause for major changes in climate.

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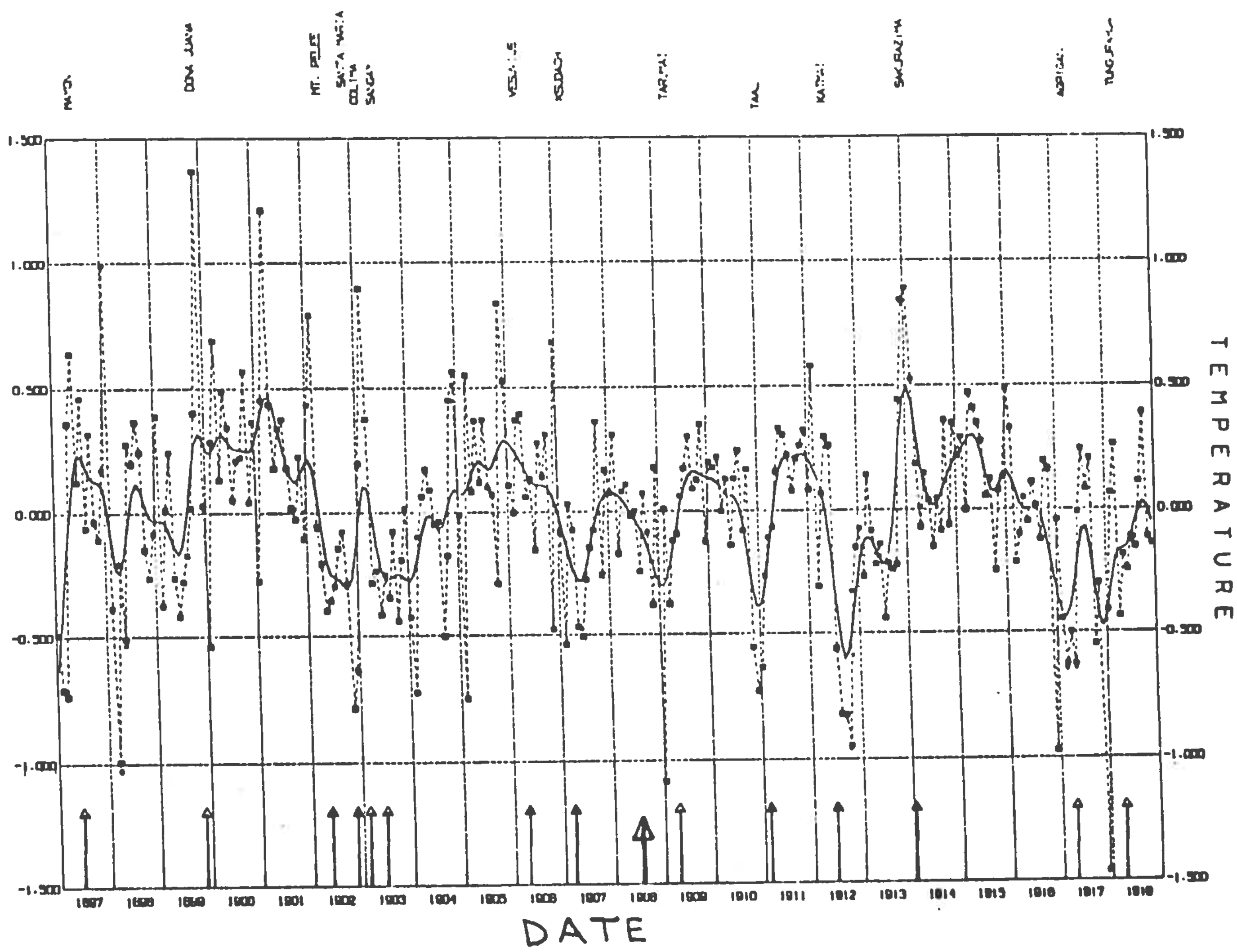

Fig. 1. Northern latitude temperature trends preceding and following the June 30, 1908 Tunguska meteor fall. Monthly mean temperatures are plotted after subtraction of mean seasonal cycle. Arrows indicate volcanic eruptions.

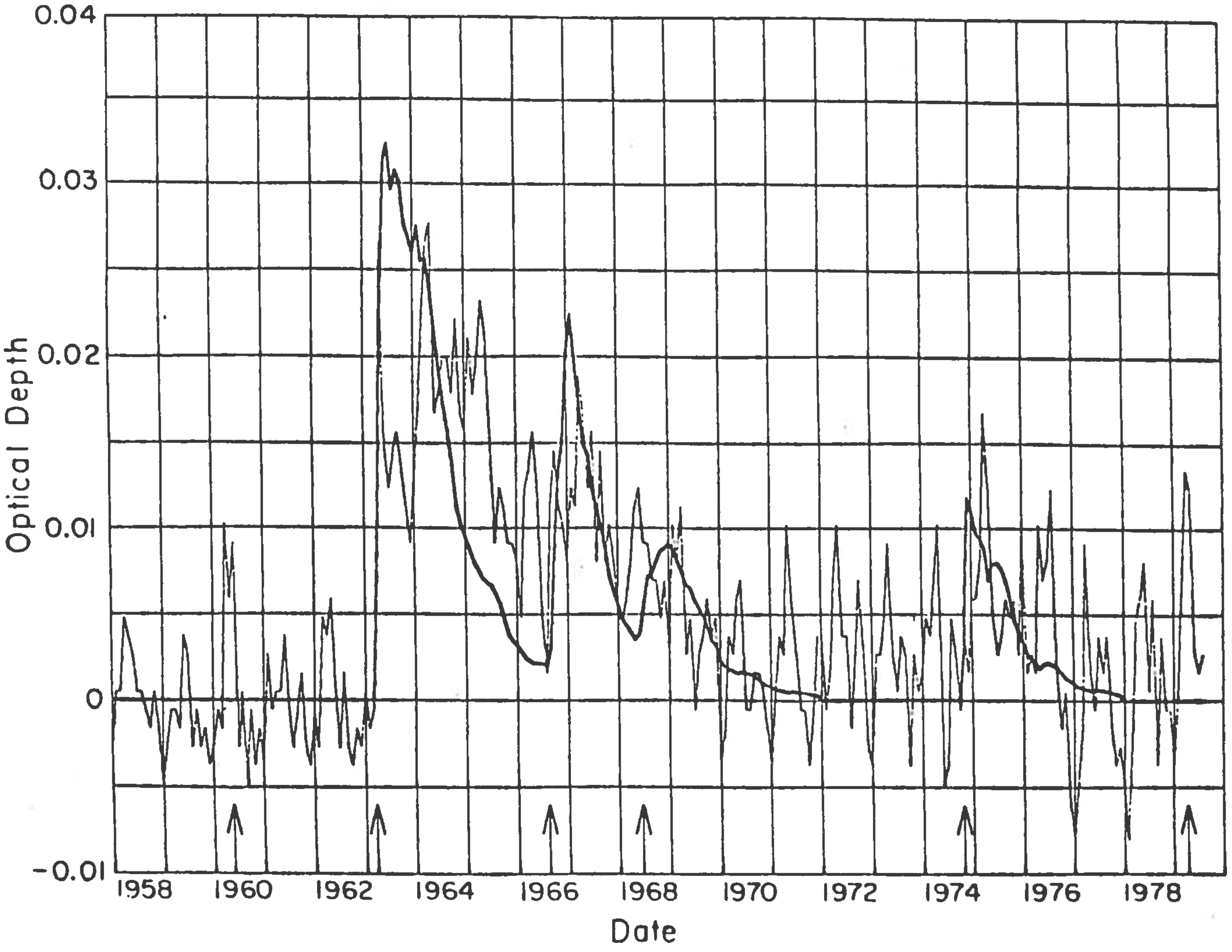

Fig. 2. Optical depth measured at Mauna Loa Observatory after subtraction of background average. The solid line is the normalized fit of tracer model simulations to Mauna Loa observations. The arrows indicate the principal volcanic eruptions during the past two decades.

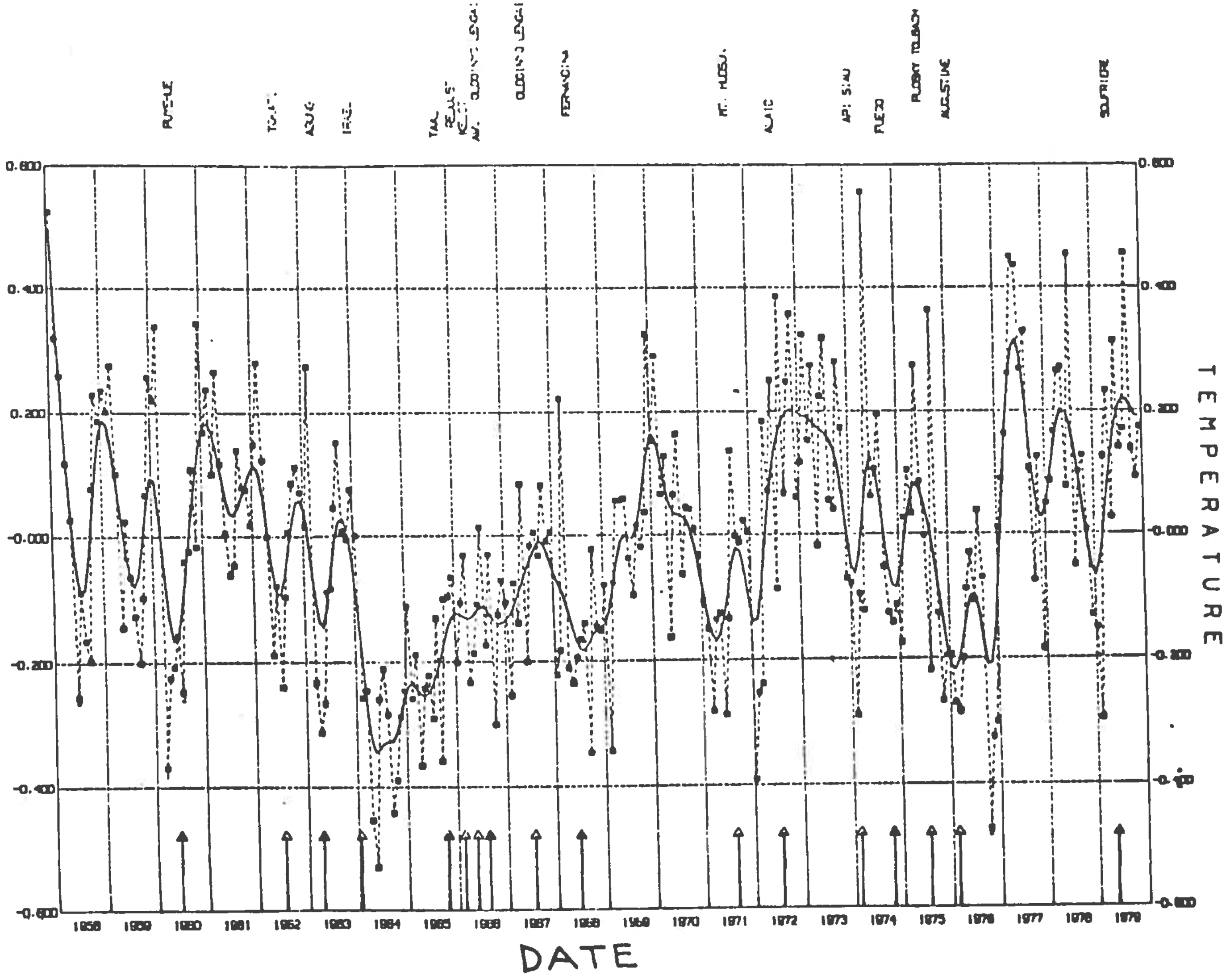

Fig. 3. Global temperature record for the past two decades. The dots are monthly mean temperatures after subtraction of mean seasonal cycle. The solid line is a running mean average. The arrows depict volcanic eruptions.

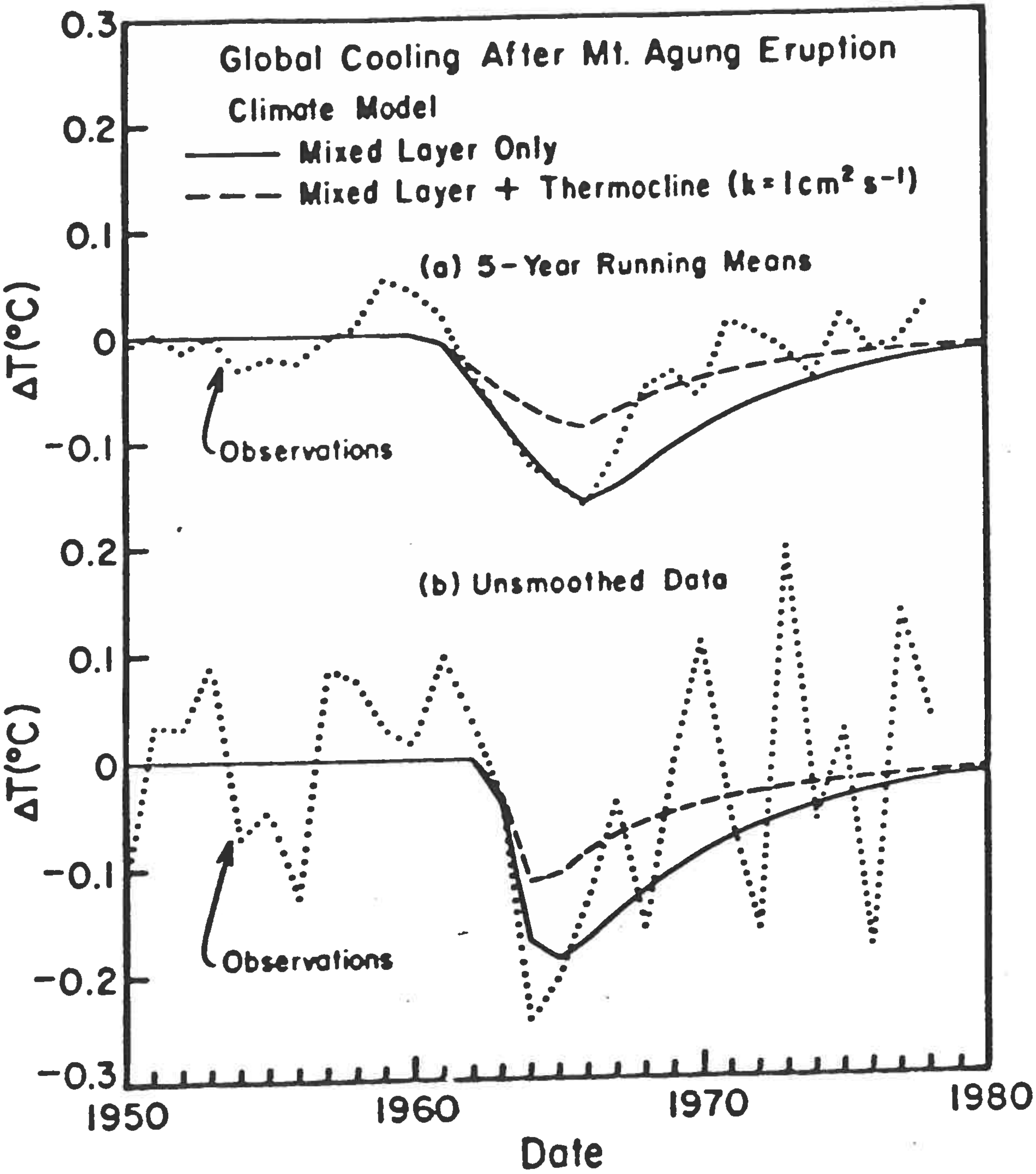

Fig. 4. Global cooling simulation of the Agung (1963) eruption. The solid line shows the cooling trend with the mixed layer heat capacity only. The dashed line includes heat diffusion into the thermocline.