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The Volcanic Record and Climatic Cycles

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Previous Wisconsin Studies

In the 1970s Dr. Brian Goodman, then a graduate student with a background in Astronomy, was asked to do a master's thesis on the history of the measured transparency of the atmosphere (1978). Some partial Soviet studies had been done, such as that of Pivovarova (1977), and it was known that systematic measurement had begun in 1883 at Montpelier, in France. It was also known that that the first station for regular measurement of the atmospheric transparency in the United States had been established in Madison, Wisconsin about 1904.

This alone seemed to be rationale enough to enlarge the study, but the Center for Climatic Research (CCR) had also been engaged in field measurement of atmospheric transparency from aircraft. This culminated in a round-the-world flight in an instrumented Navy aircraft and the doctoral dissertation of Dr. Jim Peterson (1968).

In the 1970s, as a CCR project, K. Hirschboeck had scoured the literature for records of historically observed volcanic eruptions and had put together a list of about 7000 cases (1980). Later this list was almost exactly duplicated by the Smithsonian Institution (Simkin and Siebert, 1994).

In the 1970s, Bryson and Goodman had been accumulating a database of radiocarbon dated eruptions and had developed a database of about 900 cases (1980a, 1980b; Bryson, 1982, 1988) This was used by Goodman to show that most of the variation of atmospheric transparency could be explained by the volcanic record (1984). In the 1990s, the database was extended to about 2600 radiocarbon dated eruptions by Robert Bryson (2006). It is this record that we shall use in this discussion. (See Fig. 1)

It had been generally assumed, up to the eruption of Mt. St. Helens in southern Washington State, that the major effect of a volcanic eruption on the transparency of the atmosphere was due to the "dust" of fine rock particles blasted into the atmosphere by the volcano (see e.g. Lamb, 1972). This probably led to the concept of only large eruptions capable of blasting the fine tephra into the stratosphere where a longer fallout time would produce a greater climatic effect. After the intense research associated with the Mt. St. Helens it became clear that it was mostly the very small droplets of saturated sulfuric acid converted from volcanic (and industrial) sulfur dioxide that had a sufficiently long half-life in the stratosphere to be climatically important. It was also established at that time that the sulfuric acid droplets in the "Junge layer" had a very small absorption to backscatter ratio, and thus always produced cooling. The sulfur dioxide did not need to be "blasted" into the stratosphere, so the importance of a volcano became greater as it's sulfur dioxide content rose, not by how much solid tephra was produced.

Current Studies

As a consequence, in our investigations here at Wisconsin, we included all sizes of eruptions, for two medium eruptions might introduce as much or more sulfur dioxide into the stratosphere as one large eruption. It is also now obvious that the tropopause is not a ubiquitous barrier, for isentropes from the lower troposphere in lower latitudes are continuous into the stratosphere in higher latitudes. The senior author has personally followed the New York City pollution plume from the ground into the stratosphere over Iceland.

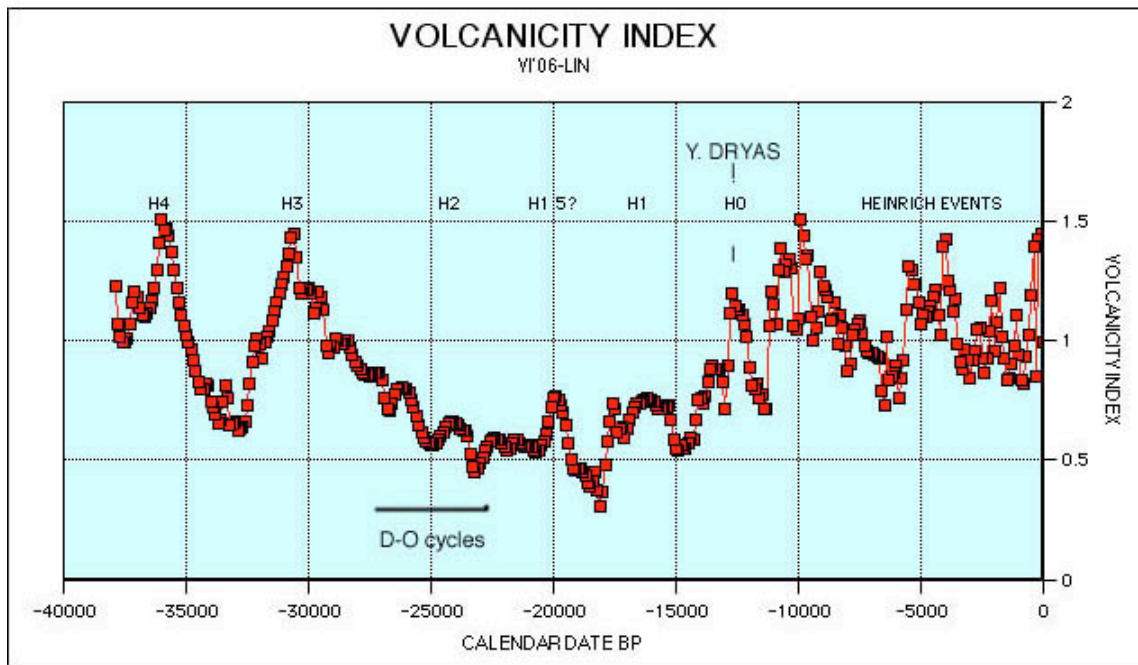


Fig. 1: The one-century resolution history of the Volcanicity Index (from Bryson, et al 2006), showing the correspondence of the peaks of global volcanism with the published times of Heinrich Events and the clear presence of Dansgaard-Oeschger cycles in the volcanic record.

Looking at the Volcanicity Index (VI) record, one is immediately struck with the apparent regularity of the variations. A spectral analysis or Fourier Transform shows that the appearance of regularity is indeed borne out. There are very significant periodicities in the record (Fig. 2). Of particular interest is the extremely significant concentration of variance in the Heinrich event (HE) frequency range and lesser but still highly significant variance at the Dansgaard-Oeschger frequency (DO). These are sufficiently strong that they stand out in figure one without the spectral analysis.

The concentrations of variance at higher frequencies with very little variance between appear to represent, at least in part, harmonics of the Heinrich and Dansgaard-Oeschger frequencies, suggesting that there is a non-linearity involved, or that it was introduced in the production of the spectrum. The spectrum was done on the cube root of the VI to avoid the “ringing” of the spectra done on the raw data. Ringing is what one gets when doing a Fourier transform on a highly periodic time series that also has a highly skewed distribution of values.

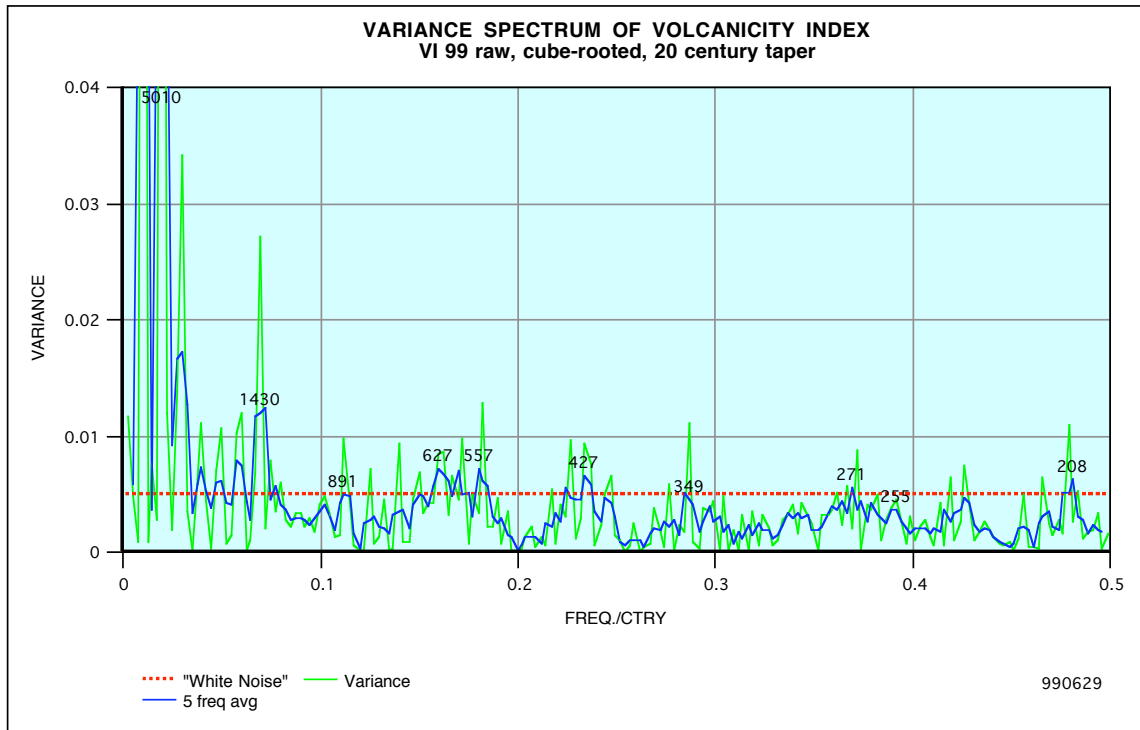


Fig. 2: Fourier transform (spectrum) of the volcanicity time series showing the Heinrich and Dansgaard-Oeschger signatures, as well as harmonics of the two cycles, beats and aliases. The whole numbers next to the curve are the periods in years that correspond to the variance peaks.

It does not seem physically logical that the appearance of the Heinrich and Dansgaard-Oeschger Events in the volcanic record should be due to oceanic or atmospheric forcing, but it does make physical sense to say that volcanism, through its effect on atmospheric transparency might drive those events. This need not be a direct cause and effect relationship. It is possible through complex oceanic and atmospheric responses to the modulation of incoming radiation by volcanic aerosols. Some of these intermediate processes were discussed some time ago by Bond and Lotti (1995).

A Simple Application of the Volcanic History

A simple application of the volcanicity index is a test of its utility in reconstructing the gross hemispheric mean temperature. This was done by treating the carbon dioxide content of the atmosphere as a dependent variable and introducing an atmospheric transparency dependent on the volcanicity index. The translation of the VI to transparency followed the work of Goodman (1978, 1984). The result is shown in Figure 3.

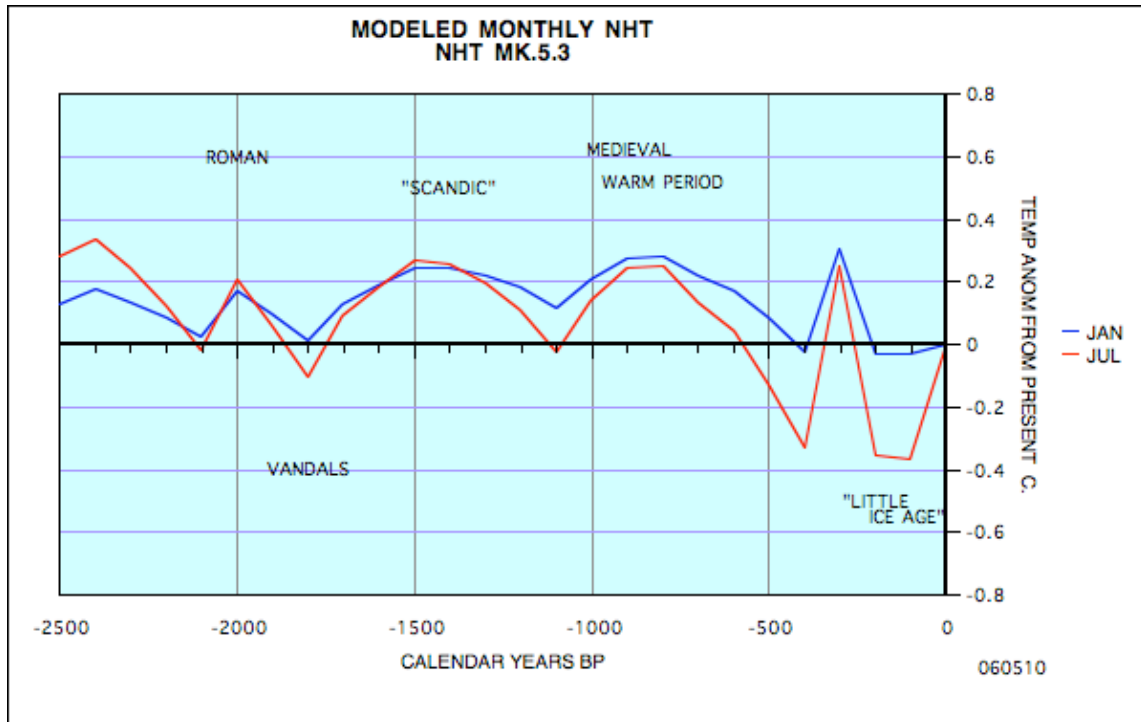


Fig. 3 Modeled mean surface temperature of the most recent 2.5 millennia with the transparency of the atmosphere determined by the volcanic aerosol content. The “present” or zero time on this diagram is 1955 AD.

The results of this simple modeling exercise are very satisfactory in both timing and magnitude including the recently recognized double nature of the “Little Ice Age”. It would appear that the Volcanicity Index is a variable to be considered in paleoclimatic modeling.

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