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Saverio Di Fabio
Universitá dell'Aquila
Guido Visconti
guido.visconti@aquila.infn.it

Universitá dell'Aquila

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Climatic effects of eruptions from Berkeley data

Saverio Di Fabio
CETEMPS, Universitá dell'Aquila, L'Aquila, Italy
Guido Visconti
Universitá dell'Aquila, L'Aquila, Italy

Abstract

In this paper we examine the content of the global temperature data of the Berkeley Earth (https://berkeleyearth.org) to find signs of cooling in the global system due to some huge volcanic eruptions. The ones taken into consideration are the Agung beginning in February 1963, El Chichon in March 1982 and Pinatubo in June 1991. These eruptions sent 10-20 Teragrams of aerosols in the lower stratosphere producing a warming there up to 2-3 $^{\circ}C$, which was clearly detected. On the other hand the radiative effect of this additional aerosol load on the lower troposphere had not the same evidence. The reason is that the weather noise in the lower troposphere is such to mask the expected decrease in temperature. This weather noise it is noted to have a strong affinity with simplified models of the atmospheric circulation. We present for the three eruptions the temperature variabilities for a ten years period centered on the eruption date and smoothed with a 12-month running average. We also present the histograms of the variabilities for the period of five years before and after the eruption. The change in the central values of such an exercise shows very marginal evidence of cooling due to the eruptions which seem to be present in the time series but it is masked by the variability. We conclude similarly to other papers that the volcanic eruptions may have a clear stratospheric effect but a very uncertain cooling of the lower troposphere. This conclusion may have implications on the geoengineering proposals to counter global warming.

guido.visconti@aquila.infn.it

Introduction

As discussed below, the assessment of the effects of volcanic eruption is mainly based on five events: Krakatau (1883, lat. 6°), Santa Maria (1902, lat. 14°), Agung (1963, lat 8°), El Chichon (1982, lat 17°), Pinatubo (1991, lat 15°). These eruptions released quantities of sulfur dioxide ranging between 6 and 20 Mt in a few days. An exception was the eruption of Tambora (lat. 8°) in 1815 which probably injected 60-70 Mt of material in the stratosphere. The large amount of material injected and the fact that the period is at the end of the *Little Ice Age* imposes a bit more discussion. Actually reliable data are available only for the last eruptions of El Chichon and Pinatubo and very sparse data exist for Agung. As discussed below the climatic effect of a large eruption is to warm the stratosphere and cools the troposphere because in the latter there is a decrease in the solar flux due to the reflective power of the injected aerosol while in the stratosphere the same aerosols are heated up by the absorbed solar radiation. The stratospheric warming is very clear in the data and is in the range of $1^{\circ}C$; the cooling of the troposphere is much less clear being masked by the much larger variability of this region (see for example Steiner et al. 2020). On the other hand, as we argue below, the troposheric signal is much less clear and we have decided to

study the variability using histograms that compare the measured variability resulting from the Berkeley Earth data five years before and after those major eruptions. The separation of these two histograms does not appear to be obvious as one would expect from a troposheric cooling. We noticed a quite surprising resemblance to the histograms obtained from the Lorenz chaotic model of simplified circulation.

Do the volcanic eruptions cool the planet?

Even for geophysics there are too few eruptions to support a theory. We also consider that only two cases (El Chichon and Pinatubo) have sufficient and reliable data. Different effects of these eruptions have been reported in a number of studies (Driscoll et al. 2012, Canty et al. 2013, Fujiwara et al. 2015, Wunderlich and Mitchell 2017, Swingedouw et al. 2017, Stevenson et al. 2017, Steiner et al. 2020). The results of Hansen et al. (1978) were quite puzzling in their apparent agreement with uncertain data. Some of these papers (Stevenson et al. 2017) report a more complex situation in which the direct radiative effect of stratospheric aerosols is overwhelmed by a dynamical effect at middle latitudes (the onset of a positive phase of the North Atlantic Oscillation (NAO)). In the tropics the data remain very noisy; a cooling tendency could be detected, but it remains well below the earlier estimate of 0.5 K. As a matter of fact, as reported by Fischer et al. (2007), large eruptions may produce cooling in the following summer but warming in the winter. As suggested by Polvani et al. (2019), the warming after Pinatubo should be regarded as a manifestation of climate variability. Driscoll et al. (2012) acknowledged that cooling was overestimated and that models are unable to simulate the complexity of the dynamical response. In the paper by Wunderlich et al. (2017) the conclusion reads: ….*Nevertheless, considering the first two years after the eruption of Mt Agung and El Chichón no clear tropical cooling in both the reanalysis and observation data was found. The model response to the eruptions showed a large uncertainty spread, suggesting a high dependence of the climate response on the atmospheric state during and after the eruption.*. Similar conclusions are reached by Fujiwara et al. (2015): ….*Evidently the temperature responses were different for different volcanic eruptions. In particular, widespread upper tropospheric cooling was observed only in the Mount Pinatubo case, and the lower stratospheric response of Mount Agung was found to be asymmetric about the equator. The characteristics of the temperature response are related to the transport of stratospheric aerosols and with the amount of sulphur species injected into the stratosphere. Depending on the location, season, and magnitude of the eruption, the climatic response can be very significant (e.g. Trepte and Hitchman, 1992). This needs to be taken into account when evaluating stratospheric sulphur injection as a geoengineering option, and thus accurate estimations of stratospheric circulation and transport are essential for assessing the climate impacts. It should also be noted that an accurate evaluation of naturally induced variability such as QBO, solar cycle, and ENSO is necessary to detect the effects of artificial injection*. Similar conclusions were reached in the very detailed analysis of Canty et al. (2013): *If further studies support our suggestion that the cooling after the eruption of Pinatubo and other major volcanoes has been overestimated*

by about a factor of 2. A preliminary conclusion is that to have detectable climatic effects the eruption must be at least in the range of 20-60 Mt of sulfur dioxide. It is clear that the key parameter is a type of sensitivity intended as the ratio of the global temperature change to the radiative volcanic forcing (Gregory et al., 2004). However, this sensitivity may depends on a number of parameters (such as latitude and duration of the eruption).

The Temperature Data

We have used the temperature data published by Berkeley Earth (https://berkeleyearth.org) and more precisely what they list as *Monthly Average Temperature (annual summary)*. These data refer to monthly averages starting from 1850 and the first attempt was to monitor the temperature for the three major volcanic eruptions, Agung (starting February 1963), El Chichon (starting March 1982) and Pinatubo (starting June 1991). The temperature anomalies for these events are plotted in **Fig1** together with the 12-month moving average. Apparently, a decrease in temperature is observed after the eruption of the El Chichon and Pinatubo (abut two years later) and a similar effect for a longer period is obsrved for the Agung eruption. The inferred change in temperature remains in the range of 0.1-0.2 K, which is quite hard to distinguish from the natural variability. Notice that because the anomalies are calculated with respect the average between 1951 to 1980, the three periods in the figure show the effect of the global warming with El Chichon and Pinatubo showing positive values of the variability. We have noticed a similar behavior in the simplified chaotic model illustrated by Lorenz (1984) for the atmospheric circulation which uses three variables, $X,\ Y$ and Z: X represent the symmetric encircling global western circulation, while Y and Z represent the cosine and sine phase of a chain of super imposed large eddies which transport heat poleward. As shown by Lorenz these variables obey a system of three equations

$$\begin{cases} \dfrac{dX}{dt} = -Y^2 - Z^2 - aX + aF \\ \dfrac{dY}{dt} = XY - bXZ - Y + G \\ \dfrac{dZ}{dt} = bXY - XZ - Z \end{cases}$$

The temperature anomalies for the eruptions of Agung (top), El Chichon (middle) and Pinatubo (bottom). The data are plotted for the period of five years before and after the eruption. The dashed line is the 12-month moving average.

where the terms XY and XZ represent amplification of the eddies through interaction with the westerly current which is possible at the expense of the current X because of the term $-X^2$, and $-Z^2$ as shown in the first equation.

The results of the integration of the system of equation (1). See the text for explanation.

We have integrated this system with the parameters $a = 0.25, b = 4.0, F = 8.0\ G = 1.0$ and then results are given in **Fig2**. These results suggested to analize the data in a way outlined for example by Sippel et al. (2020). For each run the simple average was found and the devations were used to obtain a histogram as show in **Fig3**. It is quite intriguing to discuss such instagrams except that the variations for Y and Z seem to group mainly in symmetric values around zero while the X deviations ar mainly concentrated around the average value of the variable which is near zero. This behavior confirms that Y and Z represent different phases of the large eddy fields. We did apply the same analisys to the data shown in **Fig1** and for each event we took a 10-year period which comprises the volcanic eruption and calculated the average for the five years preceding the eruption and the five years after the eruption with the associated variabilities. However in one cases the year of the eruption is included in the calculation of the histogram (left column in Figure 4) while in th other was excluded (right column). The average and the variabilites were calculated with the monthy data. The results are shown in **Fig4**. As illustrated in the figure the temperature difference are quite small . The righ column show emperature variation of -0.102 K, 0.0022 K and 0.0196 for Agung, El Chchon and Piantubo. When the year of eruption is excluded we get -0.1223 K, 0.023 K and 0.024 K fo the three eruptions. These results seem to indicate that the climatic effects of volcanic eruptions are at least dubious.

*The histograms of the variability for the run shown in **Fig2**. The two modes shown for the Y and Z indicate an evident periodicity.*

The histograms as described in the text for the three volcanic eruptions. The light blue refers to the period before the eruption while the orange refers to the period after the eruption. The left column include the year of the eruption while the right column do not.

Summary and conclusion

We have used the global temerature from the Berkeley data to study the effects of three major volcanic eruptions on the cliamte of the Earth. The eruptions are the Agung (1963), El Chichon (1982)n and Pinatubo(1991). The effects of the volcanoes are superimposed to the warming of the planet due to the increase of the greenhouse gases and in 30 years period we expect a warming of about 0.3 ˚ whic it s really found in the temperature anomalies that refer to the average between 1951 and 1980. We have noticed a strong resemblance of these variability to those of a chaotic model of the circulation envisaged by Lorenz (1991). Following the suggestion of Sippel et al. 2020) we have analyzed the variabilities of temperature in the ten year interval containing the eruption by making the instograms of such monthly variabilities. We have two case including in the first one the year of the eruption which was neglected in the other one. The average showed a maximum cooling of -0.123 K for Agung while the same effect was negligible for the other eruptions. We attribute this masking to the fact that with the global warming we expect a much larger

variability (Liu et al., 2026). In conclusion this analysis seem to show that the effects of these eruptions could be marginal on the global climate and this conclusion could have implications on the proposed solar managemnt technology (Ming et al., 2014)

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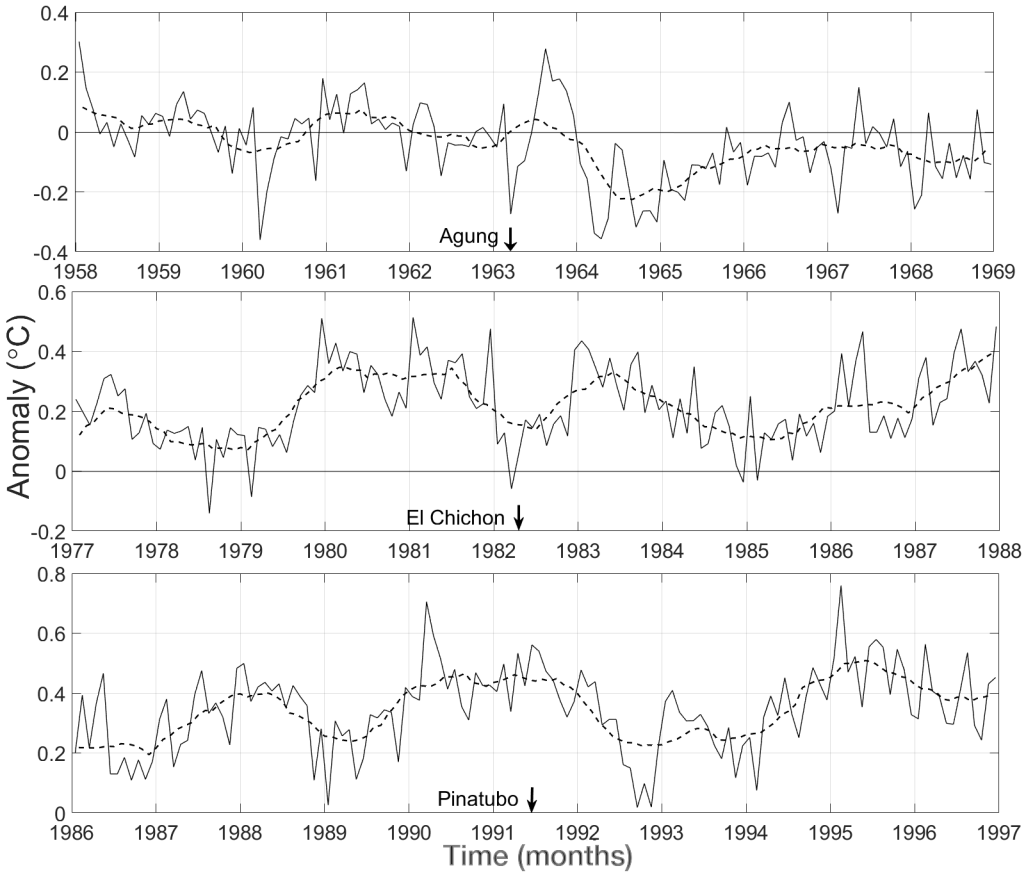
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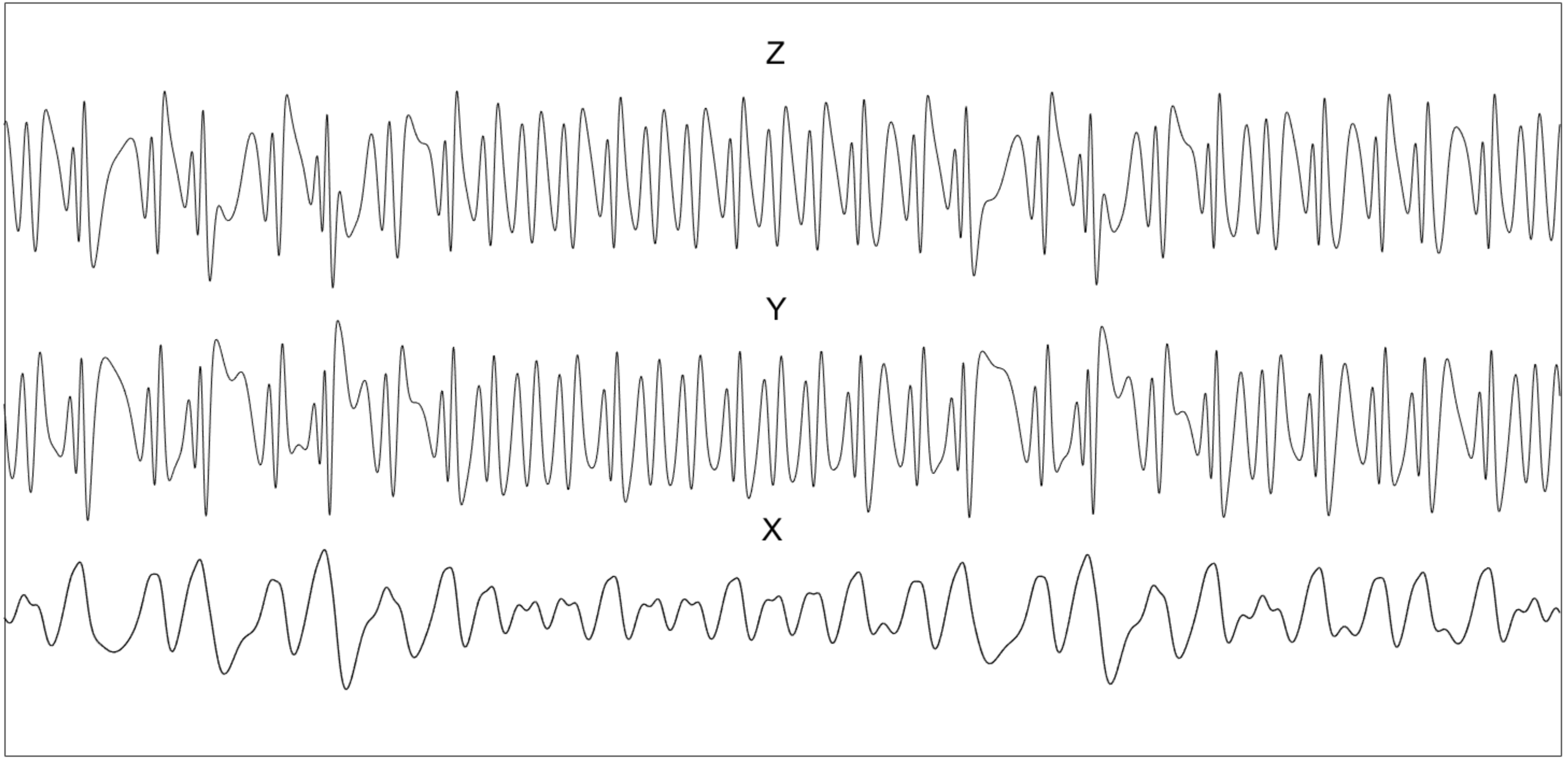
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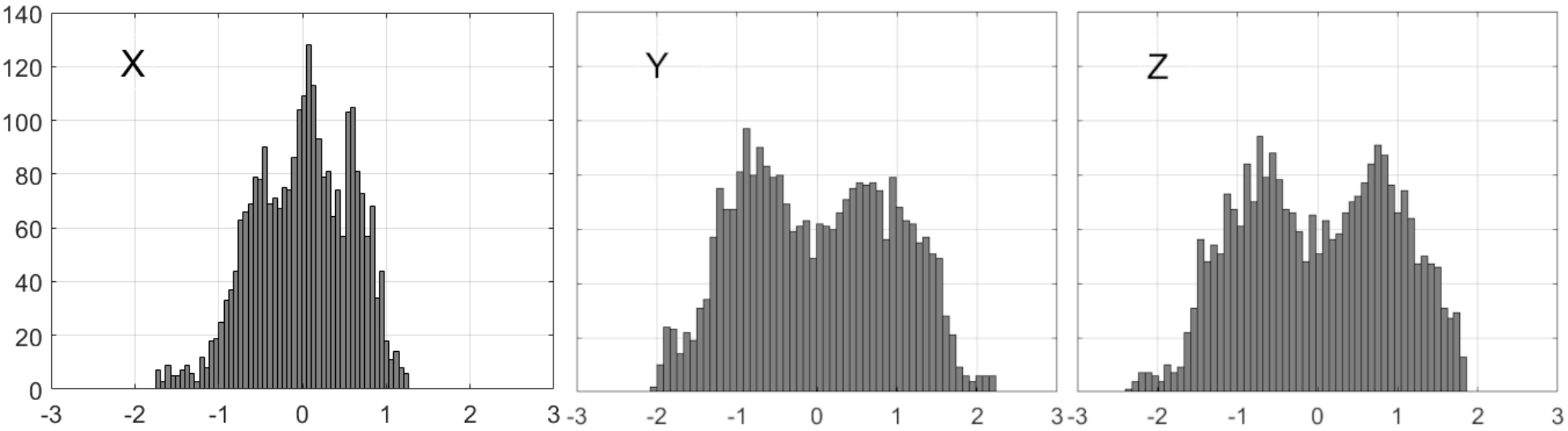
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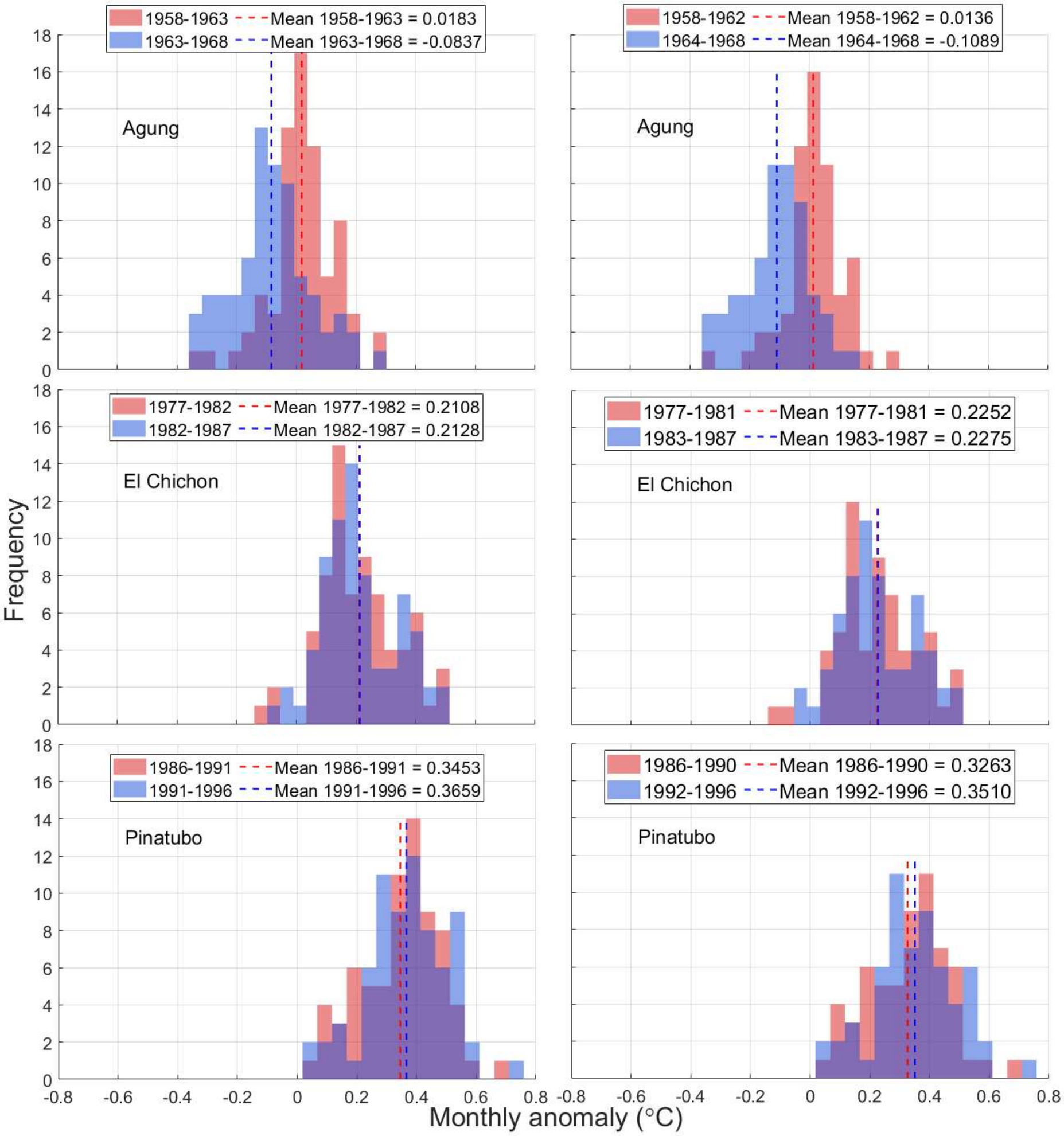
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Anomaly (°C)
Agung
El Chichon
Pinatubo
Time (months)


Z
Y
X
Time (arbiratry units)


X
Y
Z
140
120
100
80
60
40
20
0
-3
-2
-1
0
1
2
3


1958-1963
Mean 1958-1963 = 0.0183
1963-1968
Mean 1963-1968 = -0.0837
Agung
1958-1962
Mean 1958-1962 = 0.0136
1964-1968
Mean 1964-1968 = -0.1089
Agung
1977-1982
Mean 1977-1982 = 0.2108
1982-1987
Mean 1982-1987 = 0.2128
El Chichon
1977-1981
Mean 1977-1981 = 0.2252
1983-1987
Mean 1983-1987 = 0.2275
El Chichon
1986-1991
Mean 1986-1991 = 0.3453
1991-1996
Mean 1991-1996 = 0.3659
Pinatubo
1986-1990
Mean 1986-1990 = 0.3263
1992-1996
Mean 1992-1996 = 0.3510
Pinatubo
Frequency
Monthly anomaly (°C)