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ABSTRACT. In this paper, four decades of true meteorological data, obtained by Louis Morin at Paris between 1676 and 1712, are added to all the reconstitutions of climatic variation and sunspot activity which are known to date for Europe. These meteorological statements show that the temperature was subject to a large drop, of an average 0.8 °C, during the decade 1690-1700.

What is more, the analysis of the daily reports of the sun observations in the Paris Observatory clearly proves the weakness of the sunspot activity during the three last decades of the XVIIth century, and a significative increase from 1703, before the end of the Maunder minimum period (1645-1715).

The analysis of older historical data shows more uncertainty. Furthermore, taking into account the observations of low and middle latitude aurorae, one can deduce the minimum level of the sunspot activity, particularily during another cold period (1560-1630), the coldest period of the Little Ice Age, before the Maunder minimum.

It is shown that, if the solar activity was indubitably extremely weak during the cold decade (1690-1700), relatively high levels of sunspot and auroral activity were reported during the coldest period of the Little Ice Age. Therefore, with these historical data, it is impossible to affirm a relationship between these phenomena.

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1. INTRODUCTION

The apparent coincidence between the low number of sunspots, reported by observers of the XVIIth century — mainly during the Maunder minimum, 1645-1715 — and the climatic cooling which occurred around XVIth-XVIIth centuries, conducted some authors to draw up a relation between the solar activity and the terrestrial climate (Eddy, 1976).

Although the effect of solar activity can be felt throughout the world, and that, in this paper, the climatic inferences cannot be extended beyond Europe, the analysis of all the available historical data brings some new precisions on climatic changes and solar activity during the XVIIth century.

The climate will be the topic of the first section, in which the 40 years of meteorological observations by Louis Morin at Paris, bring us valuable original numerical data.

The solar activity will be discussed below, naturally taking into account sunspots and aurorae observations, but trying above all to elucidate how many times the sun was really observed.

A comparison of both variations for two cold periods, before and near the end of Maunder minimum will form the basis of our conclusions.

2. EVOLUTION OF THE CLIMATE

In the absence of other data, the variation of the mean value of the air temperature, obtained by every proven method (based on natural phenomena), is the best way of representing the climatic variation. We have such a reconstitution made with the « vintage dates » and the winter severity data, over five centuries, from the XVth century to the present (Legrand, 1978 ; 1979).

Moreover, fortunately, we have an exceptionally precise data set available : about four decades (1676-1712) of true daily meteorological observations by Louis Morin, almost like those of today, where we can find temperature, pressure, cloudiness, rainfall, cloud and wind direction (Legrand and Le Goff, 1987). These decades will be shown with special attention in § 2.2.

2.1. Temperatures from 1400 to 1960

Figure 1 shows the five century reconstitution : the curve is a ten year mean value, computed every decade. It can be seen that two main drops in temperature (0.5 to 1 °C) occurred in the XVIth-XVIIth century period. The first, lasting for 70 years, from 1560 to 1630, caused the largest extension of the

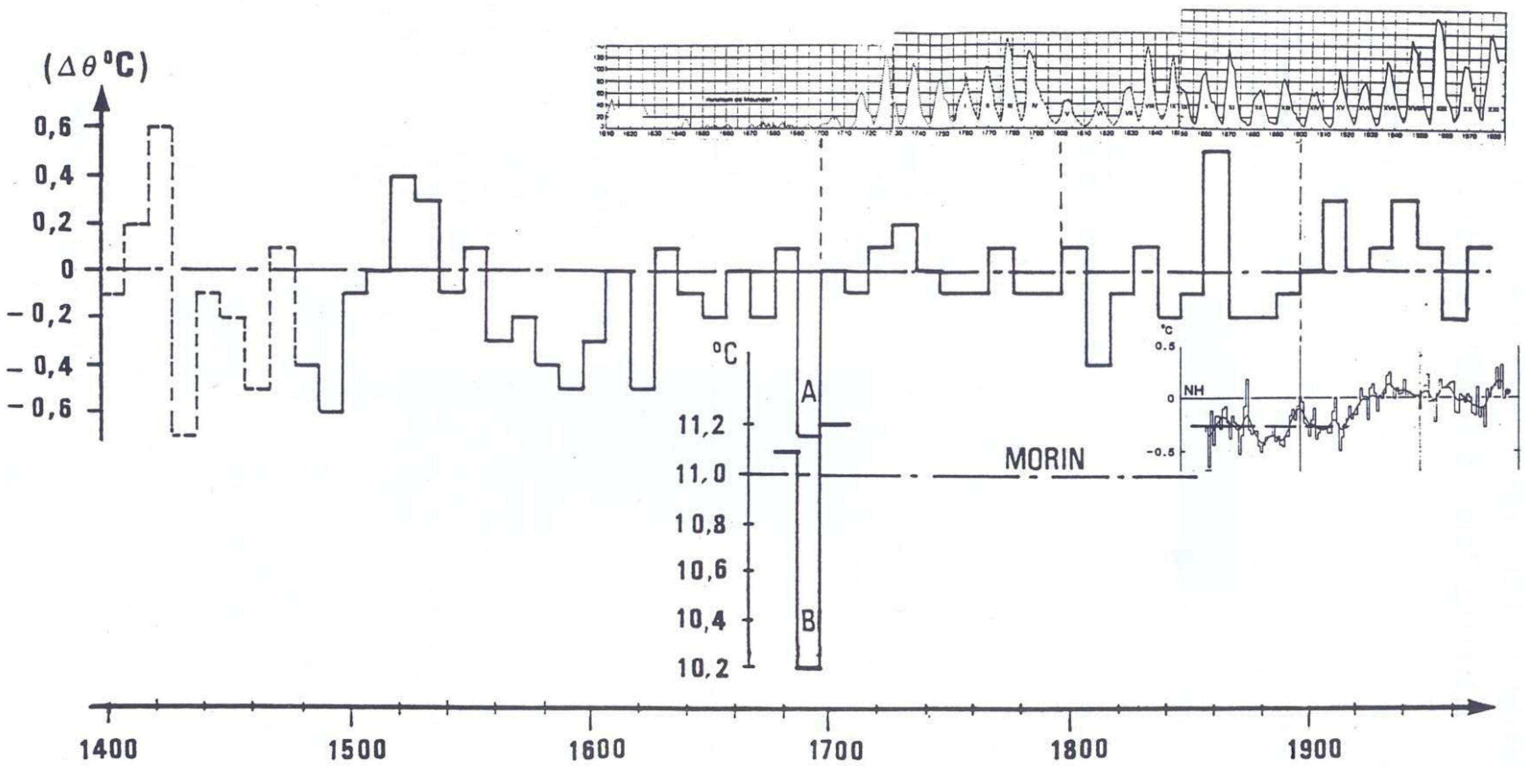

Figure 1

Variation of temperature from 1400 *to* 1960 *restored from « vintage date » and winter severity in western Europe. The panel corresponds to the mean value of the temperature variations averaged over a decade. The solar cycles are plotted at the top right side of the figure. To the right of the Morin figure (B), the warming of temperature observed over the northern hemisphere during the last decades is shown (after T. M. L. Wigley, in* Climate Monitor, **15** (3), *p.* 69, 1985).

glaciers (Le Roy Ladurie, 1967). The second, brief one, from 1690 to 1699 (A), which was that « measured » by Louis Morin (B), clearly appears on this same figure.

2.2. Meteorological observations of Louis Morin between 1676 and 1712

The Morin temperature data are real measurements, recorded three times each day, with a precision never seen before. Louis Morin (1635-1715), a French doctor, member of the Académie des Sciences, who lived in Paris, was really a pionneer of meteorology.

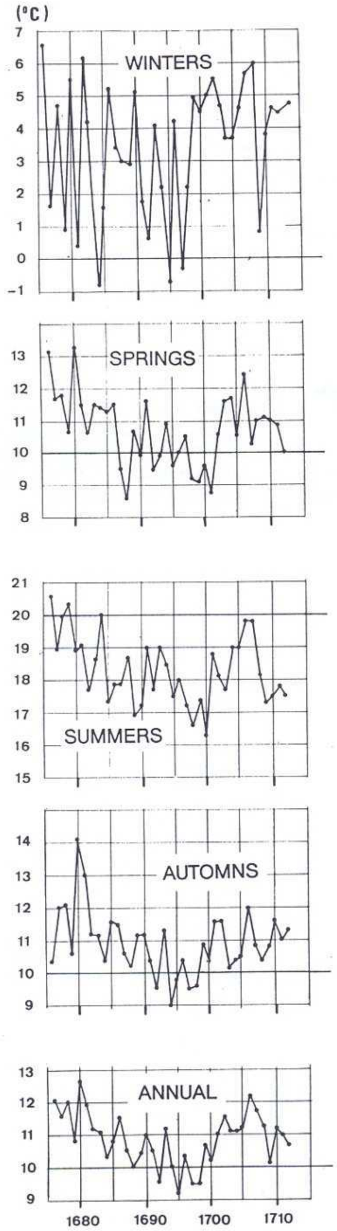

Figure 2
Air temperature observations for different seasons and years. These values are the means of the measurements made by Louis Morin from 1670 to 1715, with a liquid dilatation thermometer located at Paris.

His thermometer, which was graduated by about 0.4 °C intervals, has been calibrated by a comparison with measures made by Lahire, and with other modern daily data series of air temperatures (Legrand and Le Goff, 1987). The results obtained with his thermometer confirm *a posteriori* the method chosen by Legrand, which gives the five century curve of Figure 1, relative to ten year mean values. Now, with Morin's temperatures, it can be seen, more precisely in Figure 2, that the 1690-1699 cooling concerned all the seasons. This cooling is confirmed by the works of Manley (1974) and Lamb (1982) for England and those of Pfister (1980) for Switzerland.

Morin's data are so complete that even the cause of the large but brief cooling can be specified : from the analysis of the number of cloudy days and the cloud directions, with or without rain, one can deduce that frontal passages, associated with a strong nebulosity, were more numerous in 1690-1700 than during the other decades. Further, one can add that an anticyclone was frequent over Ireland, Scotland and the North Sea. This anticyclone caused a permanent cloud covered sky, associated with a drop in temperature due to a dominant north wind.

Figure 3 summarizes the weather changes during these four decades in four panels showing the number of days when the nebulosity (or cloudiness) was strong (quoted 4 — highest figure — by Morin), less strong (quoted 3) with and without rain. For the cold decade, the number of days with a nebulosity 4 increases significantly.

3. EVOLUTION OF SOLAR ACTIVITY DURING THE XVIIth CENTURY

The well-known curve of sunspot activity is shown in Figure 4. Very few new reports of sunspots can be used to date, which could refine this curve in the XVIIth century or before. But, we also know now that there is a correlation between the appearance of aurorae at middle or low latitudes and sunspot activity (Legrand and Simon, 1987 ; 1989). Care should be taken for the selection of aurorae of this kind, in order to use this activity as a good indicator of solar activity. Unfortunately, the lists of aurorae observations do not contain enough information concerning the position of aurorae, and this activity must be taken with caution.

Not all these data are on the same true level and, according to their origins, they can be classified into three separate periods : 1582-1645, 1645-1670 and 1671-1712, as shown in Figure 4.

3.1. Period from 1582 to 1645

The first direct observations of sunspots were made after 1610, date of the invention of the telescope by Galileo. Galileo himself and other astronomers like Fabricius and Kepler, observed very numerous sunspots. Observations made by Father Scheiner, published in Rosa Ursina (1630), show that, in spite of this poor set of data, the sunspot activity was at a relatively high level before 1630 (« peaks » in Fig. 4).

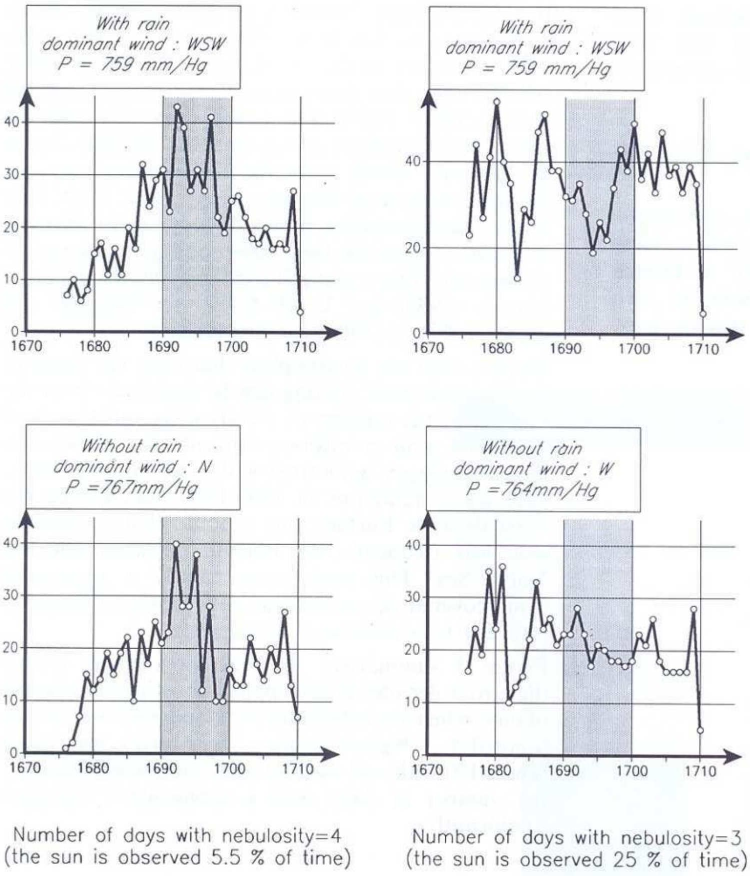

Figure 3

Nebulosity observations made by Louis Morin. The pressures and the dominant winds are averaged over all the days taken into account in each diagram.

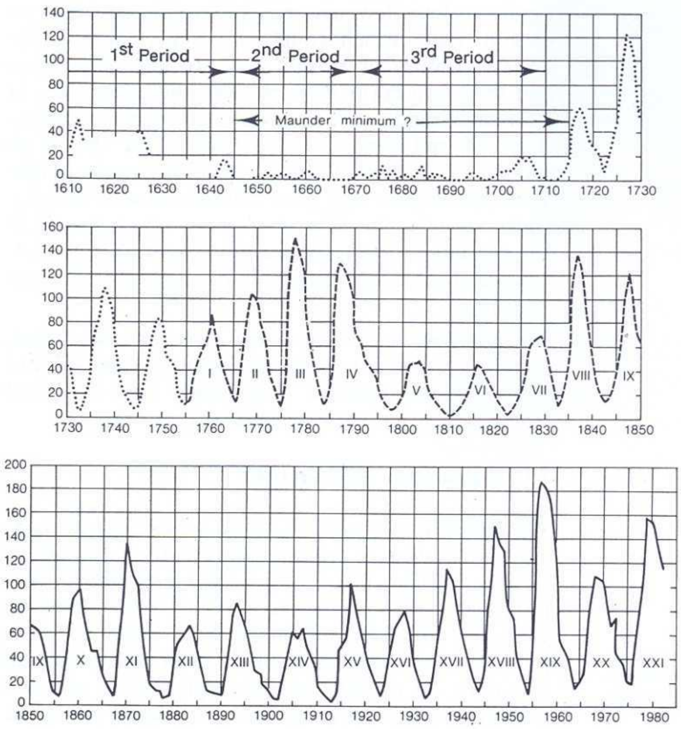

Figure 4

Sunspot cycles (ordinates are Wolf's numbers).

One can add : Sakurai (1980) find a Wolf's number of 98.6 for three months of observations by Galileo, June, July, August 1612 ; Lalande (1776) pointed out, in the Father Scheiner observations, 122 transits or births of sunspot(s) between 1624 December 18 and 1627 November 28, say 41 per year, and in the Hévélius reports, he counted 49 between 1642 November 2 and 1644 October 9, say 25 per year.

A lot of aurorae were reported during that period. The number of aurorae borealis, observed each year by Tycho-Brahe at Uraniborg (Denmark), shown in Figure 5, is such that 75 aurorae were seen between 1582 and 1592 (Brekke and Egeland, 1983). The aurorae which occurred in central Europe, quoted by Schröder (1989), were also numerous : between 1550 and 1640, an average of 30 aurorae by decade was observed with a maximum of 48 from 1580 to 1589.

3.2. Period from 1645 to 1670

Very few sunspots were mentioned. However, the frequency of solar observations being unknown, this small number is probably not representative of the real sunspot activity.

The auroral activity, as deduced from the European chronicles by Link (1964) and Schröder (1979, 1988), was about an average of 25 to 30 aurorae per decade, just a little less than during the preceding period.

3.3. Period from 1671 to 1710

This period is the first for which it is possible to know, with a reliable precision, the frequency of sunspot appearance. Indeed, for the adjustment of the clocks of the Paris Observatory, and for the determination of the ecliptic parameters, the sun was regularly observed, when it was crossing the meridian. Besides time observations, two astronomers of that period, Picard and La Hire, recorded carefully the sunspot positions. It can be seen in Figure 6 (top) that, apart from the period 1677 to 1682, not many 13 day periods passed without observations (this 13 day period is the maximum duration of a sunspot visibility). To these data, other single days of sunspot appearance were added. Those reported by J. D. Cassini, the first of this prestigeous line of astronomers (quoted in Journal des Savants, 1678), and those reported by the Kirch family in Germany (Landsberg, 1980). It can be seen also, that the increase in the number of cloudy days (as shown in Fig. 3), does not produce any visible effect on the frequency of the sun observations : The increase of the number of cloudy days by a factor 1.5 is accompanied by a much larger decrease, at last by a factor 10, of the number of days of sunspot observation. Figure 6 (bottom) shows firstly, that very few sunspots were observed before 1700 and secondly, that only one group was seen (in

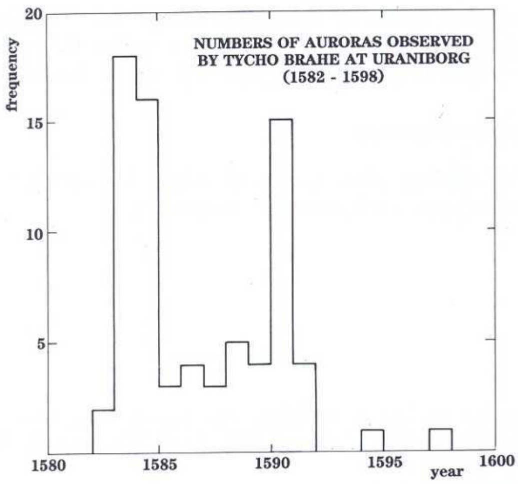

Figure 5

Annual frequency of aurorae observed by Tycho Brahé at Uraniborg, Denmark (Brekke and Egeland, 1983).

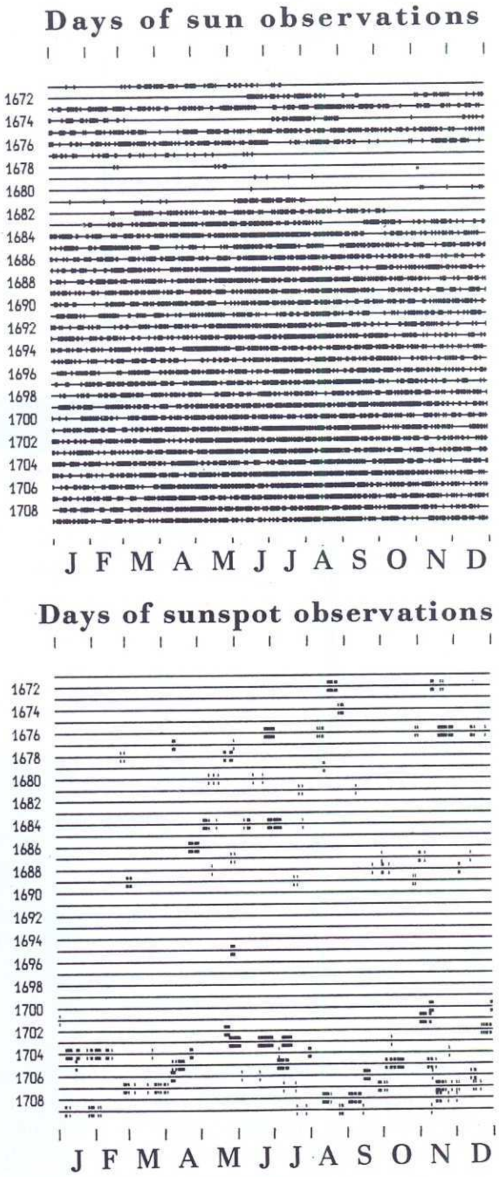

Figure 6

Observations of the sun from 1671 to 1709 ; the top panel corresponds to the frequency of observation and the bottom panel to the frequency of sunspot appearance.

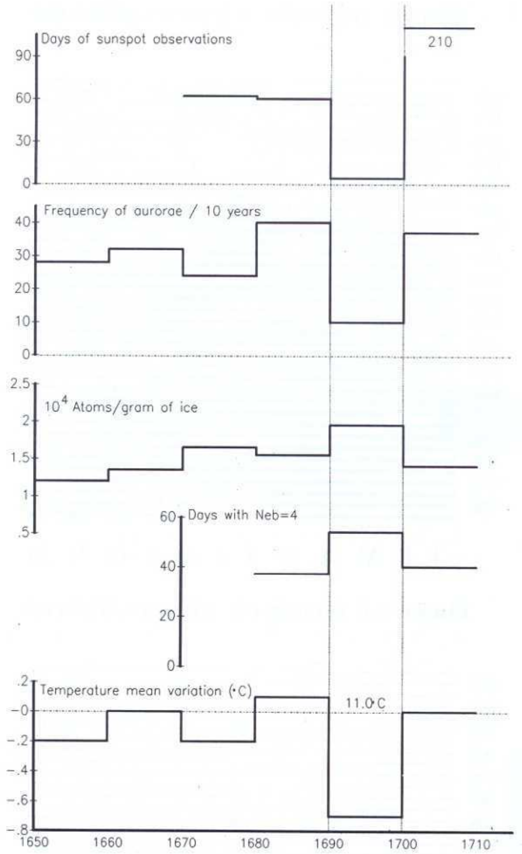

Figure 7

Various geophysical parameters concerning solar, auroral, cosmic ray and meteorological activities around the period of sunspot minimum which occurred from 1690 *to* 1700. *The frequency of aurorae shown on this figure includes aurorae observed over Europe and Asia (Fukushima,* 1987 ; *private communication).*

May 1695) in the 1690-1700 decade. This sunspot rarity was such that every appearance was followed by a memorandum of the Paris Academy of Sciences. After 1704, the increase of sunspot activity rapidly brought about the disappearance of these reports !

Furthermore, the observation reports of Picard and La Hire brought us a very important piece of information. From 1672 to 1704, all of this low sunspot activity was exclusively limited to the southern sun hemisphere. Later, on November 27th 1707, when Cassini and Maraldi observed a sunspot in N lat. 16°, they remarked that they did not remember having seen any in this hemisphere before, except that of April 1705 (Spoerer, 1889 ; Maunder, 1922).

One can condense the observations of Picard, Cassini, Kirch and La Hire, by the annual means of the number of births or transits of sunspot(s) : 1671-1679 : 1.7/year ; 1680-1689 : 2.2 ; 1690-1699 : 0.1 ; 1700-1709 : 4.8.

Auroral activity was also decreasing up to 1700. Only 8 aurorae were reported in Europe during that 1690-1700 decade, whereas 28 were counted during 1680-1689, and 17 during 1670-1679. Adding the aurorae which were observed in Asia (Fukushima, 1987, private communication), one can draw the histogram of the auroral activity of Figure 7.

Also on Figure 7, the decrease of the solar activity is portrayed by the production rate of Be 10 in polar ice (Beer *et al.,* 1983).

4. DISCUSSION AND CONCLUSION

Finally, from all these results and by comparison of the variations of the two phenomena, we may conclude :

— Before 1630, it is undeniable that the solar activity was relatively intense. Therefore, the extended cooling from 1560 to 1630, the coldest period of the Little Ice Age, does not correspond to a low solar activity.

— The sunspot minimum activity period seems to end about 1703. However, it is difficult to pin point its beginning but, from 1630 to 1690 the temperatures were close to the normal value (Fig. 1).

— The cloudy weather, now known from the data of Morin, was not the « cause » of the sunspot disappearance during 1690-1700, as certain authors supposed (Kopecky and Kuklin, 1987). This almost non existent solar activity is confirmed by all the observations we know, and summarized in Figure 7. It is during this same decade that the temperature was subject to one of the largest drops of recent centuries.

It is certain that an anomaly of the « solar machinery » occurred at the end of the XVIIth century : the exclusive southern hemisphere low activity demonstrates this. But, quite obviously, it is still hazardous to conclude any influence upon the terrestrial climate.

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