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Witnessing the impact of the 1783–1784 Laki eruption in the Southern Hemisphere

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Abstract The Icelandic Laki eruption in 1783/1784 produced a large volume of lava while the associated aerosols were directly responsible for severe environmental and health effects in Iceland and northern Europe. The intense plume of smoke and sulphurous dry fog has been reported to have affected a considerable fraction of Eurasia and Northeastern Canada but no impact descriptions have been reported for the Southern Hemisphere. Here we reproduce the description of an abnormally high incidence of unusual dry fog and haze days during the years 1784–1786 in Rio de Janeiro (20° S, Brazil) obtained by Bento Sanches Dorta, a Portuguese astronomer. Using monthly averages of fog days registered by Dorta between 1781 and 1788 it is shown that the outstanding peak observed between September and November of 1784 might be linked to the Laki eruption. The vast majority of observational and modeling studies appear to contradict such hypothesis; however recent modeling studies of the impact of large high latitude eruptions support the existence of

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large-scale climatic anomalies in the Southern Hemisphere tropical region, and in particular the appearance of above-normal cloud cover over central Brazil.

1 Introduction

The Icelandic Laki eruption in 1783 corresponds to the largest basaltic lava flow since the Eldgjá eruption (also in Iceland) that took place in 934–940 (Thordarson and Self 1993; Thordarson et al. 2003). The unusually large eruption of Laki, also known locally as Lakagígar or the Skaftár Fires, started in June of 1783 and lasted until February of 1784 with intermittent periods of more or less activity. Recent studies have determined that the prolonged eruption produced an outstanding volume of lava and tephra on the order of 15.1 ± 1.0 km^3 (Thordarson et al. 1996) and roughly 122 Mt of SO_2 gas (Thordarson and Self 2003). It should be stressed that this volume of SO_2 is the largest in the last 1,000 years while the volume of magma is smaller than that of Tambora in 1815 (but considerably larger than that of more recent eruptions such as Krakatau in 1883 and Pinatubo in 1991). In recent years a significant number of papers have been published, focusing on different aspects of the Laki eruption. A comprehensive review on the human, environmental and climatic impacts associated with this event can be appreciated in Thordarson and Self (2003). The gases and resulting aerosols produced by the Laki eruption were directly responsible for severe environmental and health effects (Durand and Grattan 1999; Thordarson and Self 2003). The years of 1783–1784 were characterised by widespread destruction of pastures and cattle in Iceland (Steingrimsson 1998), and to a less extent in Ireland, England, France, Belgium, Holland. Increments in the death rate were observed in continental Europe (e.g. Grattan et al. 2005), particularly throughout the UK (Witham and Oppenheimer 2005). The predominant western and north-western winds transported the intense plume of smoke and dry sulphurous fog over northern Europe in just a few days (Stothers 1996; Demarée et al. 1998). By the end of June the dry fog affected almost the entire European continent (from Lisbon to Moscow), but with more intensity over the British Isles and areas surrounding the North Sea (Thordarson and Self 2003). The summer of 1783 was considered particularly warm throughout Western Europe with the warmest days often associated with the thick sulphurous dry fog (Grattan and Sadler 1999). Late June and early July were characterised by an intense quasi-stationary anticyclone over Europe that was responsible for transporting a considerable amount of aerosols towards the surface due to subsiding air (details in Figs. 6 and 7 in Thordarson and Self 2003). The following winter of 1783–1784 (with the eruption still active, albeit with decreasing intensity) was particularly cold over central and northern Europe, but also in the Northeastern USA, with seasonal anomalies reaching –3°C on both sides of the Atlantic (Písek and Brázdil 2006; Thordarson and Self 2003). The following years of 1784, 1785 and 1786 were characterised by colder than usual conditions in Europe and Northeastern USA (Thordarson and Self 2003). However, there have been no reports on witnesses located in the southern hemisphere or even close to the equatorial line.

Aerosols injected into the atmosphere in the aftermath of large volcanic eruptions located in the tropics (like the 1991 Mount Pinatubo eruption) usually spread over the entire globe. On the contrary, aerosols formed from high latitude eruptions typically remain in the hemisphere in which they were injected (Gao et al. 2007). Therefore the largest radiative forcing from Laki should be restricted to the northern hemisphere, a result that is overwhelmingly supported by the spatial extension observed for the dry fog and the climate anomalies in the following years (Thordarson and Self 2003). In recent years several authors have also applied modelling techniques based on the coupling of GCMs and chemistry transport models (Stevenson et al. 2003; Chenet et al. 2005). In a recent work Oman et al. (2006a) simulated the latitudinal distribution of the zonal mean visible optical depth during and after the Laki eruption. Their results confirm, once again, that the impact of this high latitude eruption is restricted to the corresponding hemisphere, concentrated between 70° N and 30° N and virtually vanishing south of 10° N.

The main objective of this work is to show that a Portuguese scientist based in Rio de Janeiro (Brazil), located at 20° S, witnessed several months of very unusual dry fog and haze during the years 1784–1786. We argue that the descriptions provided by this keen observer correspond, at least partially, to the effects of the Laki eruption, therefore providing the first direct account of the Laki eruption over the southern hemisphere.

2 Comments on dry fog by Bento Sanches Dorta

Bento Sanches Dorta (1739–1795) was a Royal Astronomer for the Portuguese Kingdom who performed frequent meteorological and astronomical observations (Carvalho 1985), for a period that spanned 1781 and 1788, in Rio de Janeiro (Brazil, a Portuguese colony at the time). Among other variables, he undertook an enormous amount of geomagnetic declination observations (circa 20,000) during this 8-year period, with an average rate of more than seven observations per day according to his publications in the *Memorias da Academia Real das Sciencias de Lisboa* (Sanches Dorta 1797, 1799a, b, 1812a, b, c). Bento Sanches Dorta (hereafter BSD) was a keen observer interested in all relevant astronomical phenomena (e.g. geomagnetic declination, eclipses, planetary occultation, zodiacal light, auroral episodes); he also registered a vast range of meteorological variables (e.g. temperature, precipitation, pressure, wind direction, humidity and cloud cover, fog days). As a member of the recently formed Portuguese Academy of Sciences he was particularly careful with his observations. In recent works the authors have made extensive use of Sanches Dorta's data, namely (a) to reconstruct solar activity (Vaquero et al. 2005), (b) to study ancient geomagnetic time series for Rio de Janeiro (Vaquero and Trigo 2005a), (c) to associate daily geomagnetic declination anomalies with rare auroral observations (Vaquero and Trigo 2005b), (d) to estimate stratospheric turbidity during total lunar eclipses (Stothers 2004). A complete assessment of BSD meteorological data (about 10,000 observations) is beyond the scope of this work.

Here, we have translated into English the four comments that BSD wrote in his meteorological diary on the dry fog phenomena.

> During this year [1784] several outstanding phenomena took place. The months of September, October and November were dominated by a certain kind of

> fog, or dense vapour, that obscured the Sun during the day and the stars by night; in such a way that although I should have been able to witness from this meridian, during these three months, the eclipse of Jupiter's satellites 48 times, I was only able to observe three events at the end of September. This fog was humid for a number of days, promoting the formation of dew, and even on the absence of dew the hygrometers would still indicate high levels of humidity in the atmosphere, and this would become reddish. (Sanches Dorta 1799a, b, p347)

> This year [1785] was characterized by hot and humid weather: it was an unusual year because the atmosphere kept alight for so many nights, particularly so during the month of September; moreover there were also many permanent foggy days and nights; there were months when I was totally incapable of finding planets and stars; in such a way that during the last four months I was only able to observe 12 eclipses of Jupiter's satellites from the 53 events visible from this meridian (Sanches Dorta 1799a, b, p369)

> We had here during this year [1786] the same thick foggy conditions that we first experienced in the year of 1784. This fog started in the middle of April and kept growing throughout the year; this fact totally jeopardized my scheduled astronomical observations in such a way that (during the entire year) I was only able to observe 12 eclipses of Jupiter's satellites from the 83 eclipses visible from this meridian: and I should stress that these 12 include one case observed in January long before the fog had started (Sanches Dorta 1799a, b, p369)

> This fog was continuous by day and night; however the air above it was serene as usual: the sun was able to appear when it was standing over the meridian or close to it; although reddish and devoid of its usual resplendent glow: in such a way that I could stare at it without any inconvenience for my eyes. This foggy weather was different from the standard fog events as it was persistent in time, with distinct density [optical thickness], and also because it was much drier, although it could sometimes trigger tiny dew [droplets].
> Sun rays had great difficulty to dissipate some of these fog droplets; a fact that is particularly relevant as we can testify that these rays are capable of quickly destroying the usual humid fog that rises from water. The hygrometer that I'm using, made of line thread, has always indicated to me that the atmosphere was dry. Usually while these fogs occurred the winds were variable in direction, but typically serene.
> Could I establish any link between this continuous fog and some kind of strong evaporation of very dense parts of our planet that might ascend to the upper region of the atmosphere; nevertheless fairly feeble so that it immediately descends to the surface?
> Could I attribute this phenomenon to smoke exhaled by a submarine volcanic eruption in the southern sea in the vicinity of this country [Brazil]? However, until now we have had no notice of such a volcanic eruption (Sanches Dorta 1812a, p70–71)

It is interesting to observe the similarity of terms and wording used by BSD and those employed by Benjamin Franklin (1785) when describing the nature of this unusual fog: "This fog was of a permanent nature; it was dry, and the rays of the sun seemed to have little effect towards dissipating it, as they easily do a moist fog, arising from water."

3 Results

Bento Sanches Dorta was a keen observer by day, performing on regular basis seven or eight measurements of variables with strong daily cycles, such as temperature and geomagnetic declination. However, he was particularly committed in the evening as, besides the standard meteorological variables, he would also look at all relevant astronomical events (e.g. Jupiter satellites, eclipses, auroras, zodiacal light, etc) and in the early hours. Therefore, any situation limiting his ability to observe the sky would be immediately noticed and reported.

The unusual haze observations recorded by BSD are mostly confined to the winter months of the SH, i.e. the period that runs from April to October. This makes sense because during those months the Inter Tropical Convergence Zone (ITCZ) is displaced further south, favoring the inter-hemispheric exchange of air masses.

Unfortunately, this period of the year is also characterized by the seasonal maximum values of cloud cover, precipitation and near surface fog. This fact diminishes the ability to distinguish among these different meteorological phenomena, and, therefore to identify the main mechanism that is obstructing the incoming light from stars and planets.

By the spring of 1784 BSD had already performed three years of continuous observations; this is why he states so emphatically that something very unusual happened that year related to the high frequency of haze in the atmosphere. However, he was continuously puzzled by the nature and characteristics of this phenomenon, sometimes describing it in conflicting ways, specifically with regard to the humidity level of this fog.

Probably the most interesting comment raised by BSD on his observations during these three years is his speculation about a potential link between his observations of the anomalously high levels of haze or dry fog with a nearby volcanic eruption. Having no access to additional information BSD suggested to link the anomalous dry fog frequency with the occurrence of a hypothetical volcanic eruption in the SH (preferably near Brazil). Nevertheless, his suggestion corresponds to an enormous conceptual prescience for someone living in an under-developed colonial society, far away from scientific societies in the NH. We could admit that, by his death, BSD must have known about Laki's production of a dry fog throughout Europe. After all, this topic was widely discussed in the popular press as well as in scientific journals for years, and the dry fog was observed even at Lisbon (Velho 1797). However, we must stress that the publication of the first volumes of the *Memorias da Academia Real das Sciencias de Lisboa* was greatly delayed, as discussed by the Portuguese Historians of Science (Carvalho 1985). In reality, BSD never returned to Portugal dying in 1795 in Brazil, 2 years before the publication of the first volume of the *Memórias* and, most probably, the original manuscript was kept unpublished for many years.

The evolution of the monthly number of fog days recorded by BSD between 1781 and 1788 is shown in Fig. 1. This figure shows the outstanding values with respect to the non-deseasonalised climatology. If we use the available 8 years of data, then the mean value of the monthly number of fog days (*nfd*) is 7.35 and

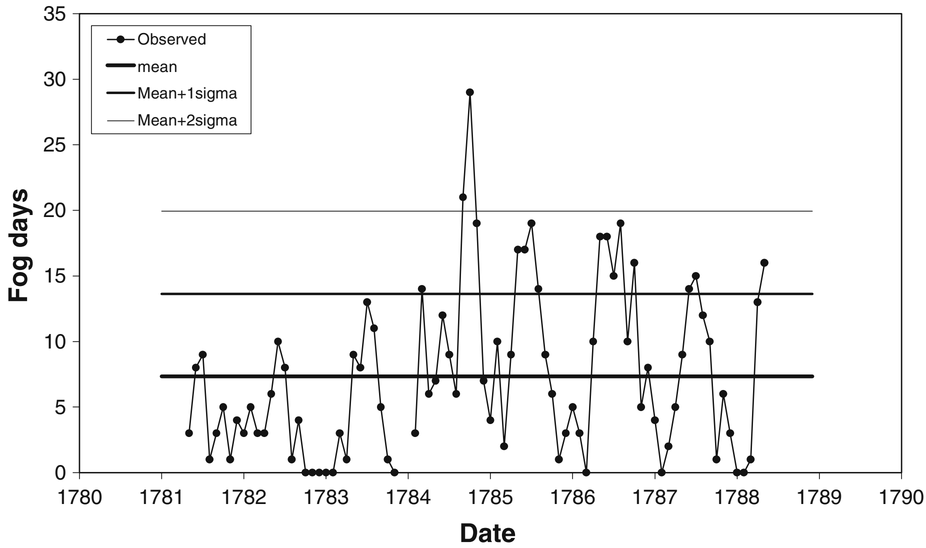

Fig. 1 Monthly values of number of fog days (*nfd*) recorded by BSD between 1781 and 1788

the standard deviation is 6.29. Thus, the values for the two consecutive months of September and October of 1784 (21 and 29 fog days respectively) correspond to two outstanding values ($nfd > \langle nfd \rangle + 2\sigma$). The high values of *nfd* mentioned by BSD for the two following years (1785 and 1786) present two distinct characteristics: (a) their magnitude is lower, not surpassing 19 days per month in both years and (b) the seasonal maximum peak of *nfd* (between May and August) is in phase with the annual climatological cycle for this variable.

We present also the monthly evolution of *nfd* values compared with the monthly climatology (Fig. 2). These values are represented by the thin solid line and correspond to the same data shown in Fig. 1. The bold solid line represents the monthly average *nfd* values while the two dashed lines correspond to the combined value of the mean plus 1σ and mean plus 2σ for the entire period 1781–1788. The outstanding values observed between September and November 1784 lie above the corresponding 2σ values for those 3 months. However, we should stress that we are using the available short 8-year climatology that is highly affected by these extreme values. Finally, it is worth mentioning again that the relatively high values of *nfd* obtained for the years of 1785 and 1786 are closely in phase with the annual evolution and are just slightly above the mean plus 1σ curve.

We have used the entire cloud cover data available for the Airport station (between 1973 and 2007), to make an additional analysis on the possible impact of El Niño events on the cloud cover of the Rio de Janeiro area. A simple statistical analysis reveals no significant differences between El Niño and non El Niño years, for both the average and standard deviation statistics. Therefore, our results should not be influenced by the eventual occurrence of an El Niño event in 1784.

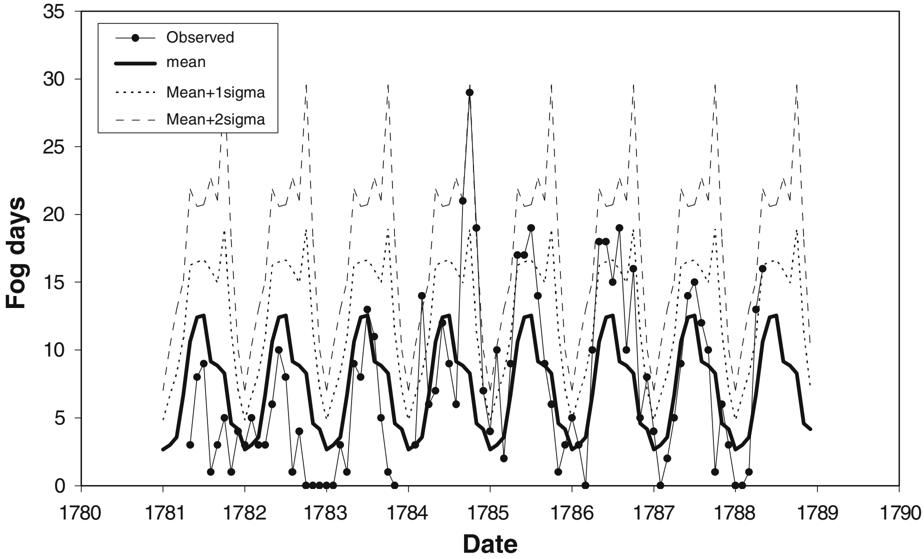

Fig. 2 As in Fig. 1 but using the monthly climatology

4 Discussion and conclusions

We have presented some evidence for an abnormal high number of "fog" days during the year 1784 in the region of Rio de Janeiro. Based on the relatively detailed observations and comments raised by BSD, we have concluded that there is a strong possibility that these events are linked to the outstanding eruption of Laki, Iceland, that took place in the previous year. However, we are aware that there are a number of conflicting arguments that can be used in favor or against such hypothesis.

4.1 Arguments in favor of the Laki–fog relationship

1. The reports written by BSD for the years 1784–1786 refer several times to the unusual occurrence of fog, using a description similar in many ways to that employed by northern hemisphere observers when describing the dry fog phenomenon that accompanied the Laki eruption event (Franklin 1785; Stothers 1996; Thordarson and Self 2003). Time series of monthly fog frequency (compiled by BSD) confirm the appearance of an outstanding peak between September and November of 1784. It is worth mentioning the similarity between the historical (BSD) and present time (Rio de Janeiro Airport, 1973–2007) seasonal cycle of fog frequency days with a clear maximum in winter months (June–August). However, the amplitude of these cycles is considerably different, possibly as a consequence of the distance between the two sites, their distance to the sea, and the influence of urban pollution.
2. It should be emphasized that BSD was a keen observer interested in all relevant meteorological and astronomical events. Therefore we are confident that the unusual fog reported by BSD was a real phenomenon and that his own hypothesis of a volcanic triggering mechanism should be seriously considered.

3. Most observational and modeling studies appear to contradict the hypothesis on the existence of a connection between the Laki eruption and the anomalous dry fog occurrence in Rio. However, as we will show later, recent modeling works on the impact of Laki on the tropical African monsoon (Oman et al. 2006b) and on the global climatic impact of very large high latitude eruptions (Oman et al. 2005) appear to contradict such simplistic views.

4.2 Arguments against the Laki–fog relationship

1. The remarks and measurements of BSD on the dryness of the fog events do not allow us to establish an unequivocal relationship between Laki's eruption and those abnormal frequent fog days. It is well known that the hygrometric measurements at the end of the eighteenth century lack the necessary robustness (e.g. Kington 1988). According to his relatively lengthy descriptions on measuring apparatus he performed hygrometer readings throughout this long period. Unfortunately, the Memoirs of the Portuguese Royal Academy only provide Tables with hygrometric values for the year 1788 (unlike the remaining variables, with all 8 years of data available).
2. Despite all his observation skills BSD was probably unable to clearly distinguish low and high altitude fogs (since the stratosphere was not discovered until 1883). This caveat can be particularly problematic for those months where Rio de Janeiro is also affected by low and wet "standard" fog days. Moreover we are aware that the sun as seen through water fog looks red if the drops are small enough to efficiently scatter the blue light (Minnaert 1954, p257).
3. No other evidence exists supporting the hypothesis that the Laki aerosol veil spread southward of about 30°N. On the contrary, a considerable number of the remaining sources of information on Laki appear to contradict this hypothesis, namely, (a) the theoretical modeling studies focusing on Laki (Chenet et al. 2005; Oman et al. 2006a); (b) the absence of any Laki signal in the Antarctic ice-core acidity records (Gao et al. 2007); (c) the absence of any Laki impact on the total lunar eclipse color in September 1783 (Stothers 2004).

4.3 Final remarks and further work

Large volcanic eruptions are known to have an impact on the average climate conditions of remote regions (Bradley and Jones 1992; Robock 2000; Robock and Oppenheimer 2003). For example, the impact of the 1991 Mount Pinatubo eruption (Philippines) reveals relatively large values of optical depth and aerosol extinction over large sectors of South America and southern Atlantic, including the Rio de Janeiro region (see Fig. 3 in McCormick and Veiga 2002). However, the current accepted view is that the spatial coverage of such climatic impact depends crucially on the location of those large eruptions, namely if they occur within the inter-tropical region (e.g. Tambora 1815; Krakatau 1883; Pinatubo 1991) or at high latitudes (e.g. Laki 1783/84; Katmai 1912). Diagnostic and modeling studies agree that the former have an impact on the entire tropical belt (but also over the higher latitudes in both hemispheres) while the latter are restricted to the mid-to-high latitudes of the Northern Hemisphere (Robock 2000; Oman et al. 2006a; Gao et al. 2007).

Nevertheless, recent modeling results have cast some doubts on this simple dichotomy between tropical and high latitude eruptions. The NASA Goddard Institute ModelE was used to show that the Laki eruption had a huge impact on the African monsoon regime and, as a consequence, on the Nile river flow (Oman et al. 2006b). Moreover a recent study on the global impact of a hypothetical high latitude large eruption (three times Katmai, not even Laki size), with a 20-member ensemble of the same model demonstrate the real possibility for large climate impacts extending towards the southern Hemisphere (Oman et al. 2005). In particular, these authors obtained a significant increase of cloudiness over the central sector of the Southern American continent, including southern Brazil, Uruguay and northern Argentina (see their Fig. 8). While we have to acknowledge the lack of proper validation for such studies, and that we cannot trust the model to put such a signal exactly in the right place, it is remarkable that the spatial coverage of the increased cloudiness was centered in southern Brazil, i.e. a spatial anomaly that matches the hypothesis raised by BSD. We are convinced that the excessive fogs observed and described by BSD were mostly stratospheric. Nevertheless, it is possible that there could have been an increment of both stratospheric and tropospheric fogs with the latter being associated to a climate system response.

A potential link between the unusual fog descriptions in Rio and the Laki eruption requires the probable southern hemisphere extension of some significant fragments of the stratospheric aerosol veil from Laki in 1784. However, this would not be the case if the fog is due to a circulation response to mostly NH aerosols. In recent years a number of works have presented reconstructed fields of large-scale atmospheric circulation for the late eighteenth century (e.g. Luterbacher et al. 2004; Gallego et al. 2006). These reconstructions are usually restricted to the northern hemisphere landmasses of Europe and North America, sometimes including the North Atlantic basin (Gallego et al. 2006). However, these efforts do not include the southern hemisphere, as a consequence of lack of information (ancient observations as well as robust proxies).

Recent efforts have been made towards modeling the impacts of the Laki eruption (Chenet et al. 2005; Oman et al. 2006a). These authors show that most of the Laki aerosol was limited to the northern hemisphere, with the stratospheric loading of SO_4 and SO_2 reaching the equator range (Oman et al. 2006a). However, observational studies like the one presented here and some other modeling studies (Oman et al. 2005) do appear to support the possibility of significant impacts further south.

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Appendix: Original texts in ancient Portuguese

Neste anno [1784] succedêraõ fenomenos incomparaveis com os dos mais annos. Nos mezes de Setembro, Outubro, e Novembro subsistio huma nevoa, ou vapor mui denso, que nos ocultou de dia o Sol, de noite as Estrellas; de maneira que havendo nestes tres mezes 48 Eclipses dos Satellites de Jupiter visiveis neste Meridiano, eu naõ pide lograr mais de tres no fim de Setembro. Este nevoeiro muitos dias foi humido, lançando hum continuo orvalho; e quando deixava de orvalhar, sempre os Hygrometros indicavaõ grande humidade na athmosfera, e esta tornava-se de côr avermelhada. (Sanches Dorta 1799a, b, p. 347)

O Temperamento d'este anno [1785], he quente, e humido: elle he notavel pela athmosfera se conservar tantas noites incendiada, principalmente en quasi todo o mez de Setembro: e pelas muitas nevoas permanentes de dia e de noite; havendo mezes, em que naõ pude descobrir Planetas, e Estrellas: de modo, que nos últimos quatro mezes, havendo visiveis neste Meridiano 53 Eclipses dos Satellites de Jupiter, só observei 12. (Sanches Dorta 1799a, b, p. 369)

Nos tivemos aqui este anno [1786] a mesma nevoa espêssa, que començámos a sentir no anno de 1784. Principiou este nevoeiro no meio d'Abril, e continuou indo-se sempre augmentando por todo o anno, o cual veio embaraçar todas as minhas observações Astronomicas que determinei facer; de maneira que havendo 83 Eclipses dos Satellites de Jupiter visiveis neste Meridiano, só me foi possivel observar 12 por esta causa: advertindo que ainda neste numero entra hum que observei em Janeiro muito antes que houvesse nevoeiro.

Este nevoeiro era continuo de dia e de noite; mas acima delle o ar estava de ordinario sereno: o Sol apparecia algumas vezes a traves do mesmo nevoeiro, quando estava no Meridiano, ou perto delle; mas avermelhado e destituido do seu resplendor; de maneira que eu o podia vêr fixamente sem o menor incommodo dos olhos. Esta nevoa era differente das nevoas ordinarias, tanto pela sua constancia, como pela sua densidade, e mórmente pela sua seccura, não obstante lançar algumas vezes orvalho miudissimo. Os raios du Sol parecia acharem difficuldade grande em dissipar algumas particulas deste nevoeiro; oque he tanto mais notavel, quanto nos vêmos, que elles destroen promptissimamente os nevoeiros humidos ordinarios, que se elevão ao cimo d'agua. O Hygrometro de corda de linho, de que me sirvo, sempre indicou secura na atmosfera. Em modo o tempo que durou este nevoeiro os ventos forão variaveis, mas muinto brandos.

Poderei eu attribuir a cuasa desta continúa nevoa a huma forte vaporação de partes muito densas do nosso Planeta, para subirem á região superior da atmosfera; e muito tenues para tornarem a descer? Poderei eu attribuir este fenomeno a alguma quantidade de sumo exhalado de algum Volcão, sahido do Mar do Sul na vizinhança deste Paiz? Mas até agora não temos noticia alguma desta apparição. (Sanches Dorta 1812a, b, c, pp. 70–71)

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