Solar activity, cold European winters, and the Little Ice Age

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Previous papers presented a theory, charge modulation of aerosol scavenging (CMAS), regarding the manner in which cosmic rays could be affecting weather/climate. Because the atmosphere is weakly conducting, the potential difference between the ionosphere and surface of the earth drives a downward 'fair-weather' return current, characterised by a small current density J_z, the size of which is modulated by five independent inputs, one of which is variation in cosmic ray fluxes into the atmosphere. Electromagnetic theory shows that charge will be present at locations where J_z passes through an electrical conductivity gradient. Since clouds are much less conducting than the surrounding atmosphere, charge will be present on both cloud droplets and aerosols at cloud tops and bottoms. The presence of this charge can modulate the scavenging of ice-forming nuclei by cloud droplets, resulting in the intensification of winter cyclones in the northern high latitudes. This paper explores a potential connection between a CMAS-induced intensification of North Atlantic cyclones and the severity of European winters during periods of low solar activity, including the Maunder Minimum, the coldest part of the 'Little Ice Age'.

Previous papers[1–3] presented the outline of a theory, developed by Brian Tinsley[4] of the University of Texas at Dallas, called charge modulation of aerosol scavenging (CMAS), which links changes in the 'fair-weather' ionosphere-to-surface current density J_z to variations in the amount of charge on aerosols and droplets within clouds. This topic may be of interest to readers of this journal for several reasons.

First, this issue has relevance to the 'global warming' issue. It is generally agreed that a major source of uncertainty in climate modelling is a lack of understanding concerning cloud behaviour. The 4th IPCC (Intergovernmental Panel on Climate Change) Assessment Report acknowledged this,[5] and it seems likely the final version of the 5th Assessment Report will, as well. Hence a better understanding of cloud behaviour could help clarify the amount of any possible warming that is occurring. Furthermore, there does seem to be a 'spiritual' component to the 'global warming' issue. This is evidenced by the general expectation that 'respectable' scientists unquestioningly affirm that anthropogenic contributions are a major factor in 'global warming' and that draconian environmental regulations are required. At least one anti-creation organization (the National Center for Science Education) has made the issue of 'climate change' a priority.[6]

Second, as noted by Klevberg and Oard,[7] a better understanding of the Little Ice Age (LIA), a period of cooler temperatures lasting from about AD 1350 to 1850, may help creation scientists gain a better understanding of the post-Flood Ice Age, despite the fact that these two events had different causes. If the CMAS mechanism was a contributor to the very cold European winters during the coldest part of the LIA, then a better understanding of this effect could help constrain models of the post-Flood Ice Age.

For a summary of the CMAS Theory see pp. 59–61.

A mechanism for CMAS-induced northern hemisphere winter cyclone intensification

A previous paper presented a possible mechanism by which the CMAS effect could modulate winter cyclone intensity in the northern hemisphere, as well as preliminary evidence from two independent data sets for such an effect.[3] More detailed descriptions of this research are given in Hebert[8] and Hebert *et al.*[9] A brief summary is presented here.

The CMAS mechanism would likely result in greater ice production through two different mechanisms. Since most ice-forming nuclei (IFN) have radii larger than ~ 0.1 μm,[10] the CMAS effect would increase the number of IFNs scavenged by supercooled water droplets within clouds. The presence of an IFN would cause these supercooled water droplets to freeze, resulting in greater ice production via contact ice nucleation. Also, since the CMAS effect is expected to narrow the droplet size distribution within a cloud (with an accompanying decrease in average droplet size), precipitation is more likely to be delayed, making it more likely that smaller droplets may be lifted by updrafts into a cloud's freezing level before they can precipitate as rain.[11] Both of these mechanisms would result in additional ice production within clouds in general, and within cyclonic clouds in particular.

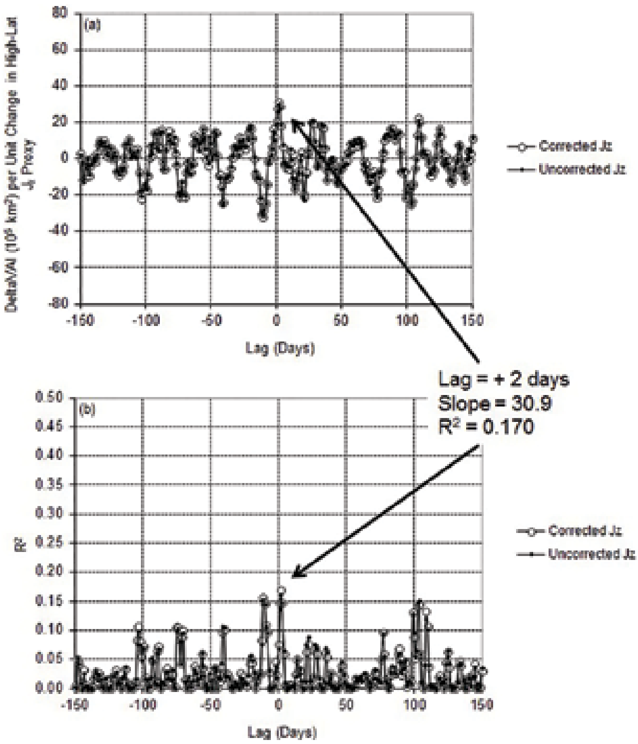

Figure 1. The vorticity area index (VAI) is a standard measure of the intensities and areal extent of northern hemisphere low-pressure (cyclonic) systems. For the 106 November–March, 1977–1982 values that served as proxies for the daily average high-latitude values of J_z thought to be modulating cyclonic vorticity, the peak positive VAI response (for 60°–80° N) occurred at a lag of +2 days. (After figure 5 in Hebert *et al.*[9])

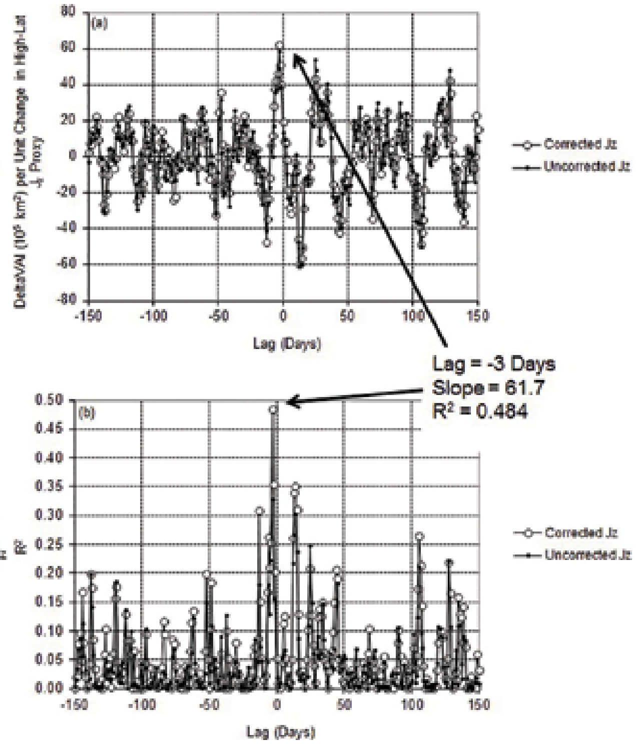

Figure 2. For the 32 November–March, 1960–1961 values that served as proxies for the high-latitude daily average values of J_z thought to be modulating cyclonic vorticity, the peak VAI response (for 60°–80° N) occurred at a lag of -3 days. (After figure 6 in Hebert *et al.*[9])

Increased ice production would result in greater latent heat release, which would warm the air within the cyclone's interior. Since warm air rises, this would result in a greater upward flow of air, provided that latent heat is a significant source of energy for updrafts within the cyclone interior. This would be especially true for 'baroclinic' cyclones[12] such as 'polar lows', which are found in high northern latitudes primarily during the long winter (November–March) months.[13] It is generally agreed that latent heat release is the most important diabatic (heat flow) process influencing baroclinic dynamics.[14]

This upward flow of warm air is accompanied by an inward flow of air from lower altitudes, resulting in more mass being brought closer to the cyclone's axis of rotation. As in the case of a spinning figure skater who draws her arms and legs closer to her torso, conservation of angular momentum requires that the rotation speed of the cyclone increase. This results in an increase in the cyclone's *vorticity* (essentially an intensification of the cyclone).

Because Eq. 2 on p. 60 shows that the amount of this space charge will be larger for higher values of J_z, one would expect increases in J_z to result in greater ice production within cyclonic clouds, with a consequent greater intensification of baroclinic cyclones. Hence one would expect higher J_z values to be positively correlated with increased northern hemisphere winter cyclonic intensity, especially in the high latitudes, where higher ionisation rates would result in higher average values of J_z (figures 1 and 2).

Circumstantial evidence for a CMAS-cyclone connection

Likewise, northern hemisphere winter cyclones have already been shown to respond to factors which modulate J_z. The 'quasi-biennial oscillation' (QBO) is a quasi-periodic oscillation of the equatorial zonal (west-to-east) stratospheric wind having a period of about 28 months. During west phases of the QBO that coincided with low solar activity, there was a noticeable increase in the number of mid-latitude low-pressure (cyclonic) January–February crossings at the 60° W longitude line, presumably resulting from increased cyclogenesis at such times.[15] Note that cosmic ray fluxes into the atmosphere are greater during periods of low solar activity, resulting in higher values of

J_z and (according to the CMAS mechanism) an expected increase in cyclonic intensity.

Likewise, another study found evidence of *decreased* winter vorticity (a measure of cyclonic intensity) about one day after moderate and large Forbush decreases.[16] Forbush decreases are sudden drops in galactic cosmic ray fluxes which accompany coronal mass ejections, large bubbles of plasma that are ejected from the sun over several hours.[17]

Still another study found an increase in North Atlantic vorticity shortly after the beginning of solar energetic particle (SEP) events, times of increased solar particle (mainly proton) fluxes into the high geomagnetic latitude stratosphere.[18] These events result in greater high-latitude stratospheric ionisation, with occasional increases in high-latitude tropospheric ionisation.[19]

Also, decreases in northern hemisphere winter vorticity have been observed about one day after heliospheric current sheet (HCS) crossings, provided that the crossing occurred during a period of high stratospheric aerosol loading.[20,21] During such crossings, fluxes of relativistic electrons into the stratosphere have been observed to noticeably decrease, resulting in higher values of S in Eq. 1 on p. 60. A more detailed discussion of HCS crossings is found in Hebert.[22]

Note that the 11-year solar cycle, Forbush decreases, solar energetic particle events, and the increases in S that occur shortly after HCS crossings (during times of high aerosol loading) all have something in common: *they all*

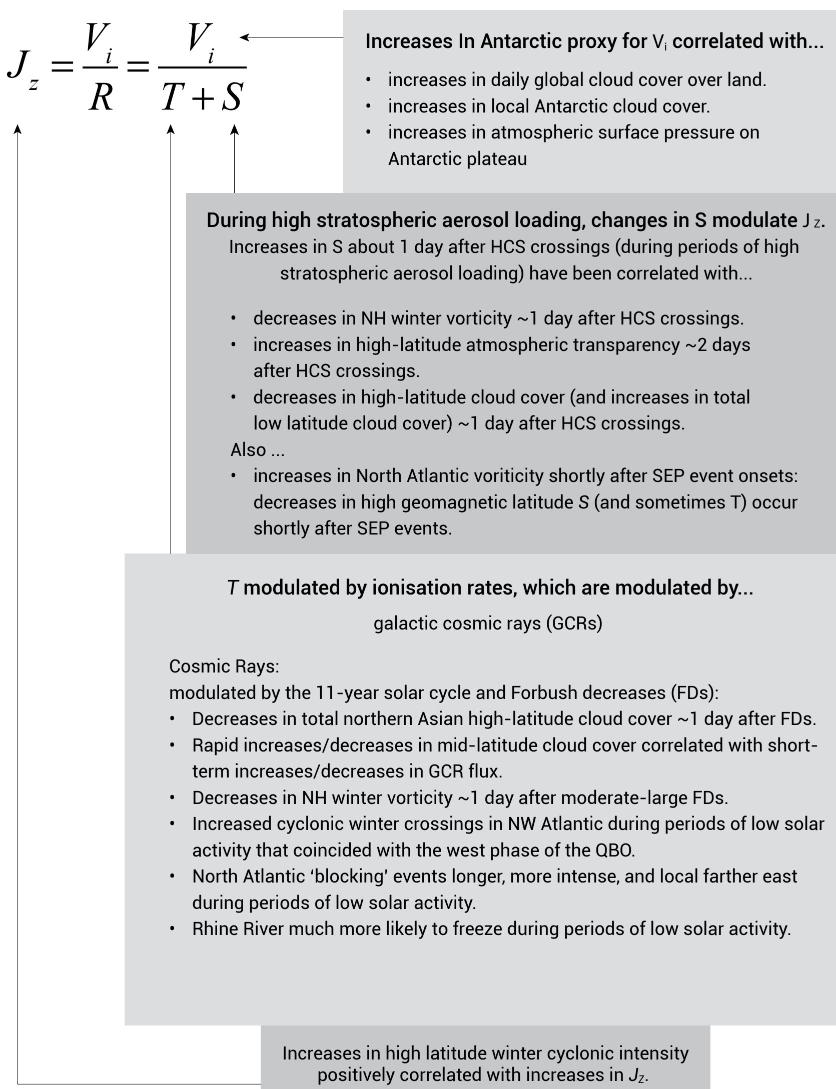

Figure 3. A partial list of meteorological responses to variables that modulate the 'fair-weather' ionosphere-to-surface current density J_z. Two trends are apparent from the observations: factors which increase/decrease J_z generally result in greater/lesser cloud cover. Likewise, factors which increase/decrease J_z tend to result in greater/lesser cyclonic intensity (vorticity). Details of these responses are found in Hebert[1–3] and this article.

modulate J_z via Ohm's Law. Note also that the responses are consistent with what one would expect from the CMAS mechanism: modulating factors which result in higher/lower values of J_z result in greater/lesser cyclonic vorticity (figure 3).

Hence, there is both direct and indirect evidence that J_z is modulating northern hemisphere winter cyclone intensities on both day-to-day and longer timescales.

It should be noted that the Icelandic Low (located between Iceland and Greenland) is a major high-latitude cyclogenesis region. During winter it enlarges to extend into the Barents Sea.[23] Because of the presence of so many cyclones in this area, it is a region of semi-permanent low pressure.[24] Hence one might expect cyclones in this sector to be especially affected by this mechanism.

Cyclonic intensification and downstream 'blocking'

The polar jet stream is a narrow, meandering ribbon of fast-moving air that flows generally from west to east in the middle latitudes, near the boundary between the troposphere and stratosphere. The northern hemisphere polar jet stream generally divides cold Arctic air from warmer low-latitude air. At times, this meandering ribbon will have a small meridional (north-to-south) amplitude (figure 4a), while at other times, this meridional amplitude will be more pronounced (figures 4b and 4c), with the polar jet stream pointing in some locations in a north-south direction.[25] Since strong temperature differences between cold and warm air masses are conducive to cyclone formation,[26] cyclonic activity is often associated with pronounced meridional meanderings of the polar jet stream.[27]

These meanders in the polar jet stream and the westerly winds that flow parallel to the polar jet stream are called atmospheric Rossby waves. A Rossby wave consists of a low-pressure trough or cyclone and an adjacent high-pressure ridge or anticylcone (figure 4c). An anticyclone will have nearly circular isobars (contours of constant pressure), whereas a ridge will have elongated isobars.[28]

Such high-pressure weather systems can sometimes be nearly stationary. The name for such a stationary weather pattern is called a 'block'. Such blocking events are often associated with extreme weather when they are of extended duration.[29]

Given this fact, it is not too surprising that cyclonic intensification is often accompanied by anticyclone or ridge intensification a half Rossby wavelength 'downstream' from the cyclonic system. Wiedennman *et al*., in a study that used 30 years o climatology data, showed that blocking events in the northern hemisphere were most persistent in winter over the Atlantic region.[30] Likewise, Lupo and Smith used three years of data to study climatological features of northern hemisphere blocking anticyclones. All 63 of the blocking anticyclones in the study followed an identifiable surface cyclone.[31] Most relevant to our study, Lupo and Smith also found that the intensity of an anticyclonic blocking event was positively correlated with the intensity of the precursor cyclone at the 95% confidence level, with the cyclone experiencing its most rapid deepening at least 36 hours before the onset of the blocking event. Like Weidenmann *et al*., they too found northern hemisphere blocking events to be most frequent in winter and that the eastern North Atlantic was one of several preferred

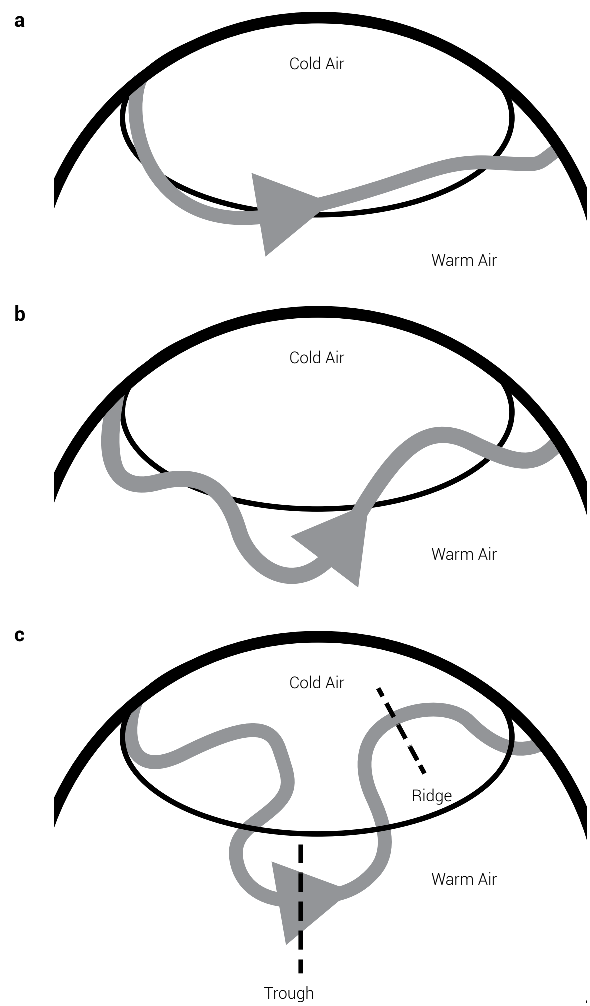

Figure 4. (a) The polar jet stream, which separates colder Arctic air from warmer low-latitude air, sometimes has a primarily west-to-east (zonal) flow, with a small north-to-south (meridional) amplitude. At other times, this meridional amplitude can become significantly larger (b and c). The stronger temperature gradients arising from these meanderings of the jet stream (and the associated 'westerlies') are conducive to cyclone formation, with associated high-pressure anticyclones or ridges 'downstream' from the cyclone.

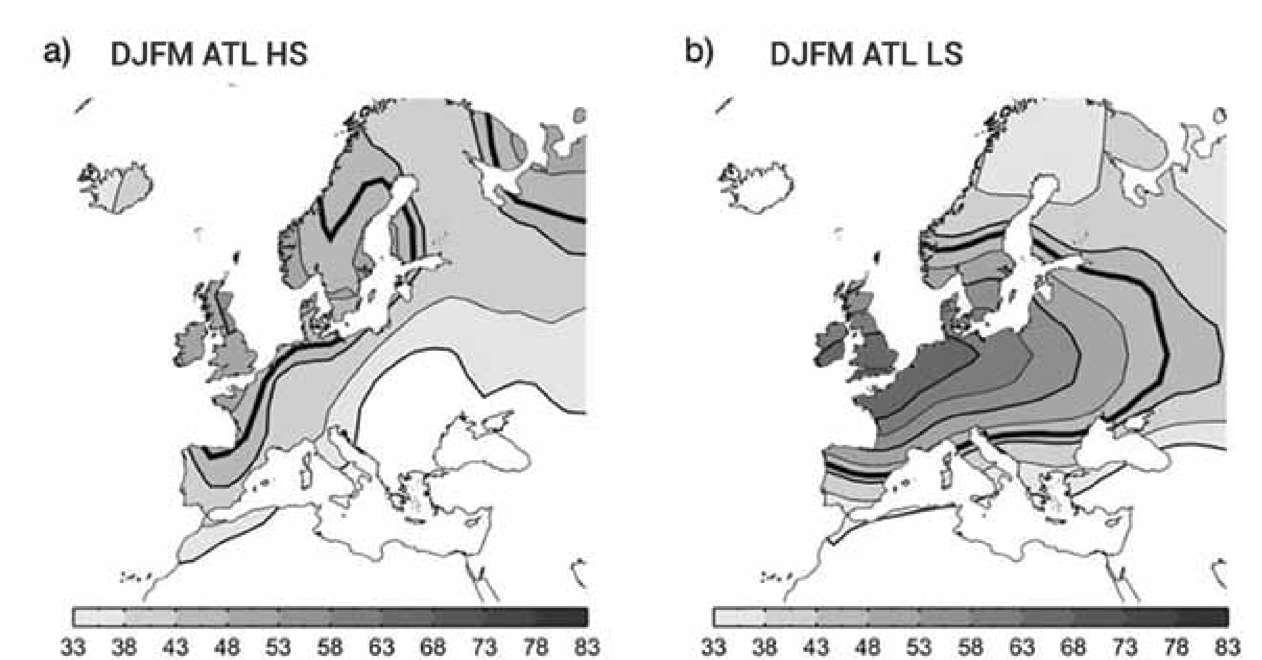

Figure 5. During periods of low solar activity, European 'blocking' events are more likely to be associated with extreme cold temperatures over a wider geographical area. Numbers on horizontal bars are the percentages of Atlantic winter blocking days having daily average temperature anomalies in the lower tercile of the winter temperature distribution. Solid black line denotes the 95% confidence threshold. (Figure 9 from Barriopedro, *et al.*[33])

blocking regions (the other two being the Pacific Ocean and the Ukraine/western Russia region).

If higher values of J_z do indeed result in greater intensification of winter cyclones in the northern high latitudes, and such intensification is followed by a 'downstream' intensification of anticylonic blocking events, then it logically follows that J_z is indirectly affecting the intensities of these blocking events. Furthermore, cosmic rays modulate J_z, and tropospheric cosmic ray fluxes are themselves significantly modulated by the 11-year solar cycle (cosmic ray fluxes into the upper atmosphere vary by ~15% over a solar cycle[32]). One then might expect to find evidence that the 11-year solar cycle is modulating these blocking events. Is this the case?

Solar activity and North Atlantic blocking events

Barriopedro *et al.* did indeed find evidence of a connection between northern hemisphere winter blocking events and the 11-year solar cycle.[33] Using data from 44 winters, they showed that northern hemisphere blocking events in both the Pacific and Atlantic Oceans were affected by the solar cycle. Of particular interest to our study is the effect on blocking events in the Atlantic. They found that during periods of low solar activity, blocking events were of greater duration, more intense, and located farther to the east than blocking events in periods of high solar activity. They found that some of these effects were dependent on the phase of the QBO: some responses to the solar cycle were present in both phases of the QBO, but were more pronounced during the west phase. They also found that, during periods of low solar activity, greater portions of Europe had high percentages of December–March 'blocking' days (figure 5) that were associated with extreme cold temperatures (lower tercile of the temperature distribution).

Other studies corroborate this conclusion. One would expect more intense blocking events in the eastern North Atlantic to cause a reduction in west-to-east zonal flow and a corresponding increase in meridional flow. Venne and Dartt showed that this did occur at the 700 hPa level in the North Atlantic region during periods of solar minima (relative to solar maxima), at least for the late winter (February–March) months, consistent with increased blocking events during periods of low solar activity.[34] Furthermore, one would expect increased meridional flow to be associated with a meridional deflection of storm tracks. A study using storm data from a 37-year period that included parts of five different solar cycles (including three solar maxima and minima) showed such an effect: winter (December–February) ocean storm tracks in the eastern North Atlantic/western Europe sector were shifted northward during periods of low solar activity, relative to the track locations during periods of high solar activity.

Specifically, storms northward of 50° N and within the longitude range 40° W to 30° E were shifted north during solar minima, with a maximum deviation of about 2.5° in latitude between 10° W and 10° E.[35] An updated study confirmed this result and verified that this deviation of storm tracks was most pronounced during west phases of the QBO coinciding with lower solar activity. At such times storm tracks were shifted northward ~6°, relative to the track positions during periods of higher solar activity.[36]

In light of these results, a recent paper which analyzed the ability of climate models to accurately simulate North Atlantic extratropical cyclones made an interesting comment:

> "In DJF [December–February], the North Atlantic storm track tends to be either too zonal or displaced southward, thus leading to too few and weak cyclones over the Norwegian Sea and too many cyclones in central Europe."[37]

Could this particular weakness of climate models be the result of a failure to include a possible link between solar activity and cyclonic intensity?

The CMAS mechanism and the Little Ice Age

The Little Ice Age was a period of lower global temperatures that is generally agreed to have lasted from about the mid-1300s to 1885.[38] However, as Fagan noted, the LIA appears to have been rather complex, characterised by rapid and irregular climate shifts that switched between extremes of very cold and hot.[39] Although we will not take time to discuss them here, there are good reasons to believe the LIA was indeed a global phenomenon.[40]

The Maunder Minimum (1645–1715) was a period of extremely low solar activity, as indicated by very low numbers of observed sunspots, despite the fact that systematic sunspot records were kept at the time.[41] The Maunder Minimum coincided with the coldest part of the LIA. During the Maunder Minimum, European winters were so cold that normally ice-free rivers froze solid, and people had 'frost fairs' on the ice![42]

The CMAS effect may help to explain the very cold winters during the Maunder Minimum. During the extremely low solar activity of the Maunder Minimum, galactic cosmic ray fluxes into the troposphere would have significantly increased. This would have resulted in a pronounced increase in tropospheric ionisation, with a resulting decrease in the tropospheric columnar resistances T. This would have resulted, via Eq. 1 on p. 60, in higher values of J_z, particularly at higher geomagnetic latitudes, where average cosmic ray fluxes are higher than at lower geomagnetic latitudes. Higher values of J_z would have resulted in greater amounts of space charge on aerosols and water droplets within clouds, via Eq. 2 on p. 60. This in turn would have resulted in greater ice production within cyclonic clouds via the mechanism presented earlier. This greater ice production would then result in a greater release of latent heat, with a resulting intensification of baroclinic cyclones. Because such cyclonic intensification would be particularly pronounced in the Icelandic Low cyclogenesis region, one would expect the numbers and intensities of anticylonic blocking events to be especially great 'downstream' from the Icelandic Low. These intense blocking events would block the west-to-east zonal flow of relatively warm, moist ocean air onto the European continent. Because water vapour is an extremely effective greenhouse gas, a decrease in this moist, warm air over western Europe would lead to an increase in radiative heat loss, which in turn would result in more severe winters.

Likewise, this mechanism may help to explain the particularly severe recent European winters (particularly those of 2009–2011), which occurred during periods of very low solar activity.

Severe European winters—historical evidence

A substantial body of historical data also points to a solar activity-weather/climate connection. Luterbacher *et al.* used a wide array of proxy and instrumental data to argue that central and eastern Europe experienced frequent blocking events during the late Maunder Minimum.[43] Likewise, a recent paper showed that Germany's Rhine River has historically (within the last 230 years) been more likely to freeze during periods of low solar activity (10 out of 14 freeze years occurred during the four winters adjacent to a local minimum in the sunspot cycle). The authors of the paper used a 'bootstrapping' technique to conclude that the result was statistically significant at the 99% confidence level.[44] Barriopedro *et al.* expressed some surprise that more attention had not been given to the role of blocking events in past severe European winters, given the 'vast' body of literature suggesting such a connection.[33]

Possible objections to the theory

A number of possible objections could be raised to the CMAS theory, most of them not too serious, in my opinion.

First, one might wonder why there is so far no evidence that the CMAS mechanism is modulating winter cyclone intensities in the southern hemisphere. Cyclones in the southern hemisphere generally tend to be weaker than those in the northern hemisphere. This is thought to be the result of greater zonal flow in southern hemisphere high-latitude regions, which results in smaller temperature contrasts that are less conducive to cyclone formation and intensification.[45]

Second, one may wonder why evidence for such a cyclone/blocking/CMAS link is confined to the extended northern hemisphere winter months. The answer is related to the answer to the previous objection. Temperature contrasts, which are most conducive to cyclone formation, are most pronounced during the winter months, when relatively cold continental air comes in contact with warmer ocean air.

Third, other major cyclogenesis regions exist besides the Atlantic's Icelandic Low, such as the Aleutian Low off the southwest coast of Alaska. Why then is the evidence for such an effect apparently greatest in the North Atlantic? This may be due to the fact that the Icelandic Low is at a higher geomagnetic latitude than the Aleutian Low, about 70° N geomagnetic, compared to about 50° N geomagnetic, latitude.[46,47] Since the earth's magnetic field modulates cosmic ray intensities, with higher cosmic ray fluxes at higher geomagnetic latitudes, average values of J_z will be larger at these higher geomagnetic latitudes. Hence, one would expect greater amounts of space charge to be present within cyclonic clouds at higher geomagnetic latitudes, with a correspondingly larger intensification than at lower geomagnetic latitudes.

Another possible link between solar activity and weather/climate?

Variations in solar activity could conceivably affect weather and climate in other ways. Recent measurements have suggested that variations in mid-ultraviolet flux (wavelengths of 200–320 nanometres) into the stratosphere might be 4–6 times larger than previously thought.[48] Because ozone is a very good absorber of UV radiation,[49] this part of the UV spectrum is a strong contributor to middle atmosphere heating. If these new measurements are accurate, then large decreases in stratospheric UV flux variations could conceivably result in much colder upper stratospheric air.[50] Climate model simulations suggest that this stratospheric temperature decrease would be greatest in the tropics. This temperature decrease would in turn lead to a decrease in the equator-to-pole temperature gradient. This equator-to-pole temperature difference is responsible for an equator-to-pole pressure gradient that (together with the Coriolis 'force'[51]) drives the westerly geostrophic winds.[52]

Hence, one might expect a pronounced decrease in stratospheric UV flux to be accompanied by a decrease in the strength of these westerly winds, and even an easterly flow. This cold easterly flow would then eventually 'burrow' its way down to the surface, resulting in colder European winters.[53]

However, it should be noted that, although variations in UV flux could possibly be a contributor to very cold European winters, it *cannot* be the sole link between solar activity and weather/climate. This is because (as acknowledged by even the mechanism's proponents) variations in stratospheric UV flux could only affect weather and climate on monthly to seasonal timescales.[53] It thus cannot be the cause of the many observed *day-to-day* meteorological responses to variations in cosmic ray fluxes, etc. that have already been discussed.

Conclusion

A recent paper concluded, based upon computer simulations, that 'polar lows', because they could affect ocean circulation in the North Atlantic, should be included in short-term climate predictions.[54] As noted earlier, 'polar lows' are baroclinic cyclones that one would expect to be strongly affected by the CMAS mechanism. Hence, the CMAS mechanism, if valid, could be an important key to improved meteorological forecasts, particularly in the North Atlantic region. Likewise, it might also be a key to obtaining a better understanding of the Little Ice Age, which in turn might lead to better constraints on models of the post-Flood Ice Age.

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