ATMOSPHERIC SCIENCE

# Solar cycle and climate predictions

The impact of solar activity on climate has been debated heatedly. Simulations with a climate model using new observations of solar variability suggest a substantial influence of the Sun on the winter climate in the Northern Hemisphere.

Katja Matthes

The Sun is the fundamental energy source of the climate system. The unusually low solar activity in the past few years[1] has therefore intrigued both scientists and the public. Together with volcanic activity, solar variability could be an important source of natural climate variations, superimposed on the human-induced warming since the late twentieth century[2]. Because of its prominent 11-year cycle, solar variability offers a degree of predictability. If the Sun's effect on climate is substantial, foreseeable fluctuations in solar output could help reduce the uncertainty of future climate predictions on decadal time scales. Writing in *Nature Geoscience*, Ineson and colleagues[3] provide intriguing, albeit somewhat provisional, evidence from a climate model that includes the upper levels of the atmosphere, suggesting that during solar minimum, the Northern Hemisphere winter climate may be pushed towards a state that resembles the negative phase of the North Atlantic Oscillation (NAO), bringing cold and snowy winters to northern Europe and the US.

Solar variability is difficult to measure precisely. The most recent and advanced observations come from the Spectral Irradiance Monitor (SIM) aboard the satellite mission on solar radiation and climate experiment (SORCE)[4]. The SIM measurements of solar mid-ultraviolet variations are four to six times stronger for the period 2004 to 2007 than UV variability estimates that have typically been used in modelling studies[5]. The reasons for these differences — better measurements or instrument artefacts — are still debated. The issue is significant, because radiation in the ultraviolet (UV) spectrum is especially important for heating the stratosphere — the atmospheric layer that extends between altitudes of about 12 km and 50 km — and for ozone chemistry.

Even small changes in UV radiation can induce noticeable climate changes in the lower atmosphere and at the surface[6,7]. For example, changes of a few per cent in UV solar radiation during the 11-year solar cycle can cause changes on the order of a few per cent in the ozone concentration, of 1 K in tropical upper temperature and of up to 25% in wind speeds in the stratosphere. Through a series of dynamical interactions that are still under investigation, these stratospheric responses to solar variability affect the atmosphere below, and the Earth's surface.

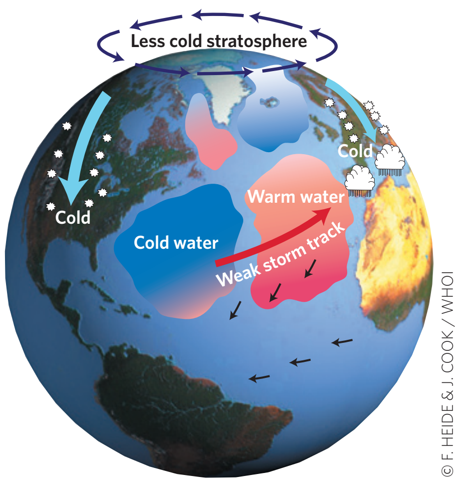


**Figure 1 |** The negative phase of the North Atlantic Oscillation. When the NAO index is low, as it has been in the winters from 2008/9 to 2010/11, the North Atlantic storm track is weak, and northern Europe experiences cold winters. Climate model simulations by Ineson and colleagues[3] suggest that the change in solar UV radiation from solar maximum to solar minimum — estimated from measurements during the SORCE[4] — nudges the atmosphere in the Northern Hemisphere towards the negative phase of the NAO.

Solar activity during the last solar minimum peaking in December 2007 has been unusually low, showing levels that are unprecedented since the beginning of the twentieth century. Solar minimum conditions have been related to the occurrence of cold and snowy winters in Europe since 1650[1]. The climate influence of the stratosphere, which in turn is affected by solar UV radiation, has also attracted much interest. Only when climate models include stratospheric variability can they reproduce the strong positive trend between the 1960s and the 1990s in the index of the NAO[8], a dominant mode of atmospheric variability that controls temperature and storm tracks in the Northern Hemisphere.

Ineson and colleagues[3] conduct idealized experiments with a climate model that fully simulates the ocean as well as the atmosphere up to the mesosphere at altitudes of 85 km. They investigate the impact on Northern Hemisphere climate of the large variations in solar UV radiation (at wavelengths between 200 and 320 nm) estimated for the entire solar cycle from the SIM measurements between 2004 and 2007. In their simulations, the surface response to the stronger UV forcing in the middle atmosphere is substantially more pronounced than previously calculated, and the model responds with a clear signal throughout the depth of the extratropical winter atmosphere. The simulated surface response resembles the negative phase of the NAO during solar minimum and is of similar magnitude to observed differences in surface climate between solar minimum and solar maximum conditions. These results are consistent with the observed cold winters in northern Europe and the US, and mild winters over southern Europe and Canada in 2008/9, 2009/10 and 2010/11.

Ineson and colleagues point out that the effect of the 11-year solar cycle on surface climate is regional, and that there is little change in globally averaged temperature. They also suggest that the regularity of the 11-year solar cycle and its apparently substantial contribution to typical year-to-year variability in parts of the Northern Hemisphere help improve decadal climate predictions in the densely populated extratropical regions that are affected by the NAO. And the findings are in line with the previously aired idea[1] that the trend in the NAO index towards positive values between the 1960s and 1990s might be partly explained by the upward trend in solar activity evident over this period in the open solar magnetic flux record.



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These results are intriguing, but as always there are a number of caveats. First, the study neglected any effects of solar variability on ozone chemistry, which would probably amplify the signal. Second, the simulations consider only the limited UV wavelength range, which is in phase with the solar cycle, but not the visible or the near-infrared wavelengths. In the visible and near-infrared range, SIM measurements are out of phase with the solar cycle, contrary to previous understanding of 11-year solar variability. The SIM data have been used in a radiative-photochemical model[9] and in climate models[10,11], to assess the atmospheric implications of the radiation changes across the entire spectrum of wavelengths, but without explicit simulation of full ocean dynamics. However, these simulations did not attempt to quantify the impact of changes in solar activity on surface climate in the region under the influence of the NAO. Finally, the trends seen in the SIM observations are still under discussion and remain to be confirmed.

The results reported by Ineson *et al.* are unique, in that the impacts of changes in solar UV radiation on surface climate have never before been simulated with a climate model that encompasses a dynamic ocean as well as the atmosphere up to altitudes of 85 km. Moreover, the decadal-scale surface signal resembles observations strikingly well. If the SIM measurements are correct and the spectral distribution can be confirmed over a full solar cycle, then a reproduction of the decadal signal in a similar model, but including variations in solar radiation in the visible and near-infrared wavelengths, could provide exciting perspectives for decadal-scale climate predictions.

The study by Ineson and colleagues[3] hints at a strong effect of the 11-year solar cycle on decadal surface climate during Northern Hemisphere winter. But the findings await confirmation of the large amplitude of variability in solar UV radiation with SIM measurements taken over a longer period, and an incorporation of the full spectral variability in climate model simulations that consider the stratosphere, ozone chemistry and full ocean dynamics. ❐

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CLIMATE SCIENCE

# Roofs and roads

Around half of the world population now lives in cities, a staggering amount given that urban areas cover just a small portion of the land surface. These dense centres of human activity are characterized by their own, unique environment. They are home to carbon dioxide domes, soaring levels of ground-level ozone and particulate matter and, in some developing countries, a shortage of clean water.

Cities are also built with materials that retain heat and disrupt the flow of moisture and energy between the ground and the air above. As a result, urban areas tend to be warmer than their rural surroundings, particularly at night, when the heat stored up in the day is radiated back out to the atmosphere. This phenomenon, known as the urban heat island effect, is thought to be mainly of local importance.

Now, Mark Jacobson and John Hoeve suggest that urban surfaces could account for 2–4% of gross global warming — that is, warming in the absence of aerosol cooling — in the first quarter of the twenty-first century (*J. Clim.* http://dx.doi.org/10.1175/JCLI-D-11-00032.1; 2011). They model the impact of roofs and roads in all urban areas on global climate over a 20-year period, starting in 2005. According to their simulations, urban surfaces raise global temperatures by an average of 0.06–0.11 K over this time frame.

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Climate feedbacks seem to enhance the warming induced by urban islands. Roof and road surfaces increase sensible heat flux from the ground to the atmosphere in populated areas, but reduce the flux of moisture. The net result is a reduction in relative humidity and cloud formation, and a concomitant increase in the amount of solar radiation reaching the surface. In this way, a positive feedback ensues.

A number of geoengineering schemes have been proposed to dampen urban heating, including the use of reflective roofing materials. In an additional simulation, Jacobson and Hoeve tested one such scheme: painting roofs white in urban areas. The scheme lowered temperatures locally, owing to an increase in the proportion of incoming solar radiation reflected back to space. However, the scheme raised globally averaged temperatures, owing to a reduction in cloudiness brought on by an increase in atmospheric stability, and a range of other feedbacks. Although the researchers note that the effect on global temperatures is highly uncertain at this stage.

As urban areas continue to be developed at breakneck speed, careful thought regarding their construction could help to alleviate some of the climatic toll, at least on a local level.

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