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Climate Responses to Solar Variability

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During the past three decades a suite of space-based instruments has monitored the Sun's brightness as well as the Earth's surface and atmospheric temperatures. The 11-year solar irradiance cycle, shown in Figure 1, is now well characterized, having approximately equal amplitudes of ~0.1% during the past three solar activity cycles. Solar cycle irradiance variations result from the competing effects of dark sunspots and bright faculae, whose variations are shown separately in Figure 1. But the extant space-base data record is, as yet, too short and of insufficient long-term precision to reliably establish whether longer-term changes are occurring in addition to the solar cycle. Historical solar brightness changes must therefore be estimated indirectly. One approach combines a model of the contemporary irradiance changes in terms of their solar magnetic sources (dark sunspots and bright faculae) with simulated long-term evolution of solar magnetism (Wang et al., 2005). In this way, the solar irradiance increase since the Maunder Minimum is estimated to be slightly larger than the increase in recent activity cycles, and smaller than early estimates, which were based on variations in Sun-like stars and cosmogenic isotopes.

A variety of empirical analyses have detected surface and atmospheric temperature changes driven by solar irradiance variations (e.g., Haigh, 2003). Climate responses to solar variability must be determined concurrently with other sources of climate variability, including anthropogenic gases, the El Niño Southern Oscillation (ENSO) and volcanic aerosols. A multiple regression analysis that included natural and anthropogenic effects, shown in Figure 2, indicates that the 11-year solar irradiance cycle produces a surface temperature increase of about 0.1 K, globally. In comparison, the 1997 "super" ENSO warmed the globe 0.2 K and the 1992 Pinatubo volcanic eruption cooled the globe 0.3 K. At higher altitudes, in the atmosphere, responses to the solar cycle are larger than at the surface, reaching 1 K near 50 km.

None of the natural processes (ENSO, solar or volcanic activity) can account for the overall warming trend in global surface temperatures since the 1880s. The grey lines in Figure 2 are linear temperature trends associated with these three influences. In each case, the associated warming is at least an order of magnitude smaller than the observed surface temperature trend reported by IPCC (2007). According to the scenario in Figure 2, solar variability contributed 10% of surface warming in the past 100 years and, if anything, a very

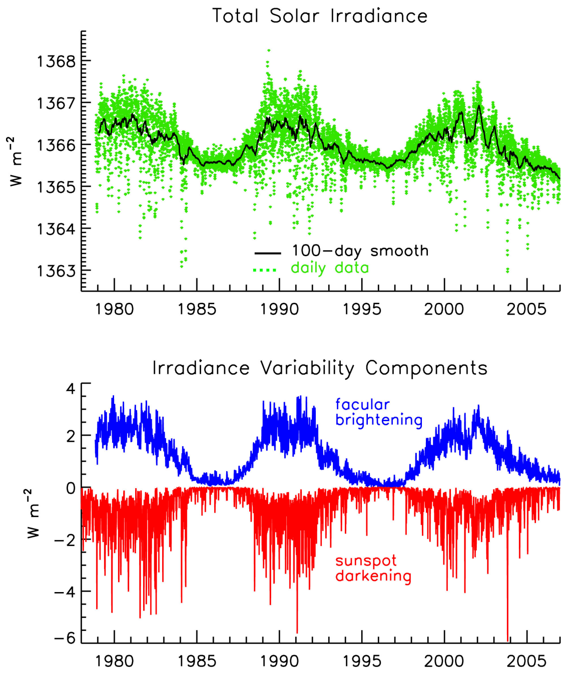

Figure 1. Shown are variations in total solar irradiance since 1978 (upper panel) and in the two primary sources that produce the net variability (lower panel).

slight overall cooling in the past 25 years. This contradicts recent claims that solar variability contributed 65% of C20th warming and 20-30% of the warming since 1980 (Scarfetta and West, 2008).

Climate responds to solar variability with distinct geographical and altitudinal patterns. The spatial patterns in Figure 3 compare the surface temperature response to solar variability with that for the ENSO, volcanic and anthropogenic influences, Zonal means of the patterns, also shown in Figure 3, do not increase nearly as rapidly from mid to high latitudes as climate models indicate. The geographical patterns of the climate response to solar variability, shown in Figure 3, provides a framework for interpreting the sun-climate connections evident in geological records at specific sites.

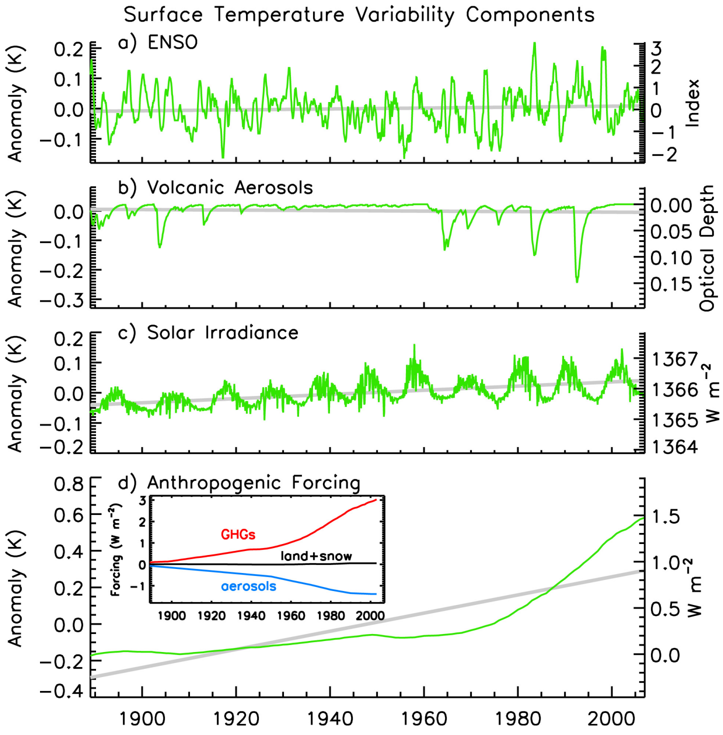

Fig. 2. Shown are the contributions to monthly mean global surface temperatures by individual ENSO, volcanic, solar and anthropogenic influences. The grey lines are linear trends for the whole interval.

Ongoing studies are beginning to decipher the causes of the empirically-determined Sun-climate connections as a combination of responses to direct solar heating of the surface and lower atmosphere, and indirect heating via solar UV irradiance impacts on the ozone layer and middle atmosphere, with subsequent communication to the surface and climate. Climate models with extended atmospheres and ozone chemistry can reproduce some aspects of the observed climate response. However, the temperature response to solar forcing occurs more rapidly than the models suggest (within months rather than years) and the response pattern relates to existing tropospheric circulation patterns, which suggest that the pathways involve dynamical motions not simply the thermal transfer of heat to the deep ocean that the models assume. Solar variability appears to modulate existing dynamical and circulation atmosphere-ocean couplings, including the ENSO and the Quasi-Biennial Oscillation, which the models are deficient in replicating. With the goal of using geographical patterns, such as in Figure 3, to quantitatively constrain simulated climate change, detailed comparisons with the GISS Middle atmosphere GCM are underway (Rind et al., 2008).

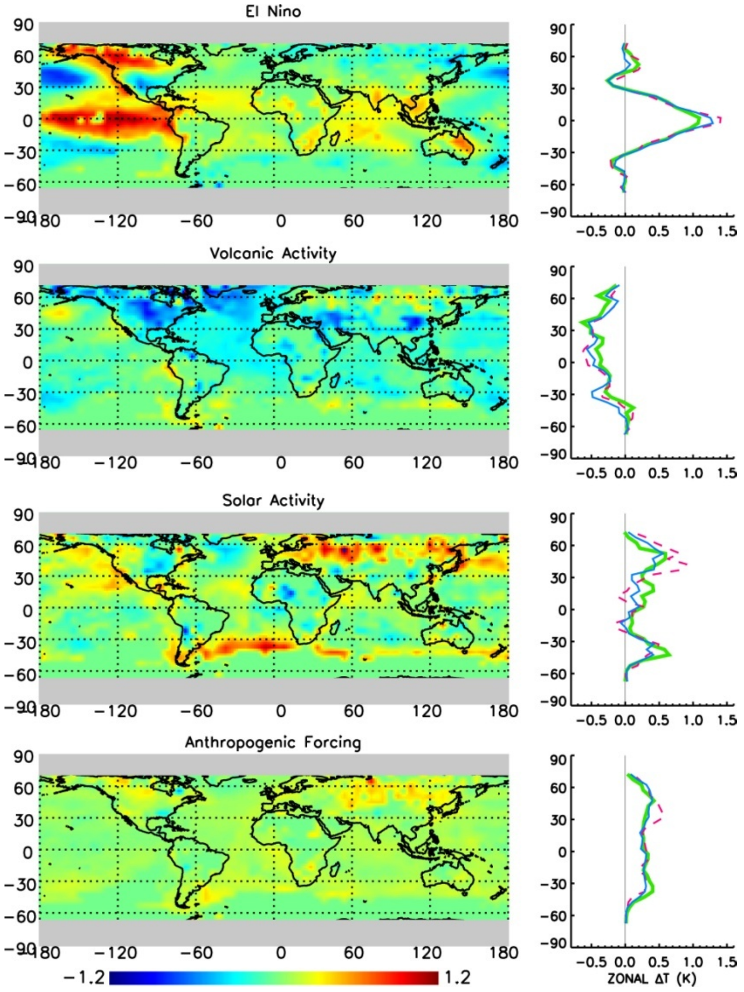

Fig. 3. Compared (on the left) are geographical response patterns, each normalized to a 0.1 K global temperature change, due to ENSO, volcanic, solar and anthropogenic influences, derived from the monthly historical surface temperature records (1889-2006). Also shown (on the right) are zonal means of the geographical responses from the regression of data in three different epochs.

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