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Closing Remarks: Astronomical

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Over the past two days, we have covered many facets of the basic interactions between the solar activity and the Earth's climate. As an astronomer, I should perhaps first comment on the fact that solar activity is not the only astronomical or astrophysical phenomenon to influence physical conditions in the biosphere. Over a very long timescale of thousands of millions of years the evolution of the Sun from a pre-main-sequence star to a star of G type has not only fundamentally controlled the physical and chemical processes in the formation of the planets but has controlled their surface physical characteristics. Over timescales an order of magnitude less, the location of the Solar System in the Galaxy may have influenced life on Earth. For example it has been noted that when the Sun crossed the spiral arms of the Galaxy and their dense dust clouds, some catastrophies might have resulted; the disappearance of the dinosaurs could be accounted for by such phenomena, as was once suggested by Sir William McCrea, F.R.S.; but nearby supernovae, grazing comets, and on large meteorites might very well have played a decisive role in the evolution of species and of our Earth. On a smaller timescale, a million years, the variation in solar energy falling on the Earth, due to secular changes in the terrestrial orbit parameters (Milankovitch–Berger theories), would have caused climatic changes and have been shown to account for the successive ice ages of the Quaternary. While bearing this in mind the role of solar activity on the timescale of recent millennia, but also on shorter timescales, is of obvious importance to society and, as we have seen in this meeting, is only now being properly investigated.

The Sun is a complex generator of radiation, particles and magnetic fields sent far into space. Even if the total radiation emitted is constant, the amount of radiation received by the Earth changes with time: this change is complex and involved with a redistribution of energy emitted at different solar latitudes than to a real change in solar luminosity. We should not forget that our location, almost in the solar equatorial plane, favours the radiation coming from the solar low latitudes; the polar solar phenomena are strongly affected by foreshortening. These changes in the Earth's illumination may be function of the wavelength, and have various effects in different layers of the Earth's atmosphere. The Sun also emits particles of all energies. Some of them find their way through the magnetopause, giving rise to auroras, to magnetic storms, to ionospheric disturbances and the like. The possible climatological effects are yet obscure: the more energetic particles affect more directly the low terrestrial latitudes; they have a broader entrance door! Is therefore the Wolf number, used as a unique parameter for solar activity, suitable for all climatological studies? Clearly, spots of high latitude and of low latitude give rise to different particle paths; 'young' spots and 'old' spots are not surrounded by the same type of activity, of flares or prominences: why should they enter in a single activity index?

The Earth also is a very complex machine. Paths of particles in the geomagnetic field, propagation of phenomena and transfer of energy from ionosphere to troposphere, all of this involves difficult physics. Climate in polar zones is influenced by solar activity probably more than in equatorial zones. Averaging phenomena over the Earth's surface is not a satisfactory method. However, couplings exist and one cannot reduce the response of the Earth's atmosphere to the solar input to simple physics.

Actually, neither the understanding of solar activity, nor the physical description of the terrestrial response, are very far advanced. We are far from a completely causal detailed description of the interaction, even though the existence of this interaction seems fundamental to our discussion. This thought makes me quite cautious about the use (perhaps the abuse) of power-spectrum analysis of the time series. There is no doubt that the undecennal cycle of the Sun exists; and there is no doubt that the Sun rotates in about 27 days (though complicated by differential rotation). Finding in terrestrial phenomena the 11-year or the 27-day signature gives us some hint about the reality of the solar influence. But it should be considered as not much more than a hint! One has afterwards to look for one-to-one relations, say, between some type of flares and some type of meteorological change. And then one has to understand the physical mechanisms at work. And only then shall we be able to derive sound conclusions of a climatological nature.

The climate depends upon the solar activity. Vice versa, the climate is a good proxy, or should be a good one, to determine the past variation of solar activity. In this meeting, I must say that I have been a little disappointed about developments in this direction, possibly because of lack of understanding of all the physical mechanisms involved. In particular, the doubt about the Precambrian records (are they a signature of the solar cycle, as I would hope them to be, or of the tidal effects of the Moon?) is to an astronomer most frustrating, even though I do not doubt the importance of studies of varves *per se*!

Is the Earth, or are the other planets, such as Jupiter, influencing, within the Solar System, our star the Sun? This matter has hardly been touched upon. However, this field could be looked at: small, even very small tides, due to Venus and Jupiter, may well trigger the emergence, at the solar surface, of magnetic flux tubes if they are in a situation of near equilibrium.

A first conclusion, on the astronomical side, is at this stage obvious: to understand the solar terrestrial relations better, one should pursue regularly, unceasingly, the so-called 'routine' observations, from ground-based stations and from space, of solar phenomena of all timescales, including 'long' cycles (Gleissberg's cycle, or cycles covering several centuries, suggested by Link for example). One should also include in the solar programmes, studies, 'out of the ecliptic', of the polar regions of the Sun of which at present our knowledge is scanty because of our location with respect to the Sun.

A second, and more general conclusion, is clear. The sensitivity of human behaviour and of conditions of human life to even a small change in climatic conditions, is very large. The Sahel drought, and the Bangladesh floods are dramatic illustrations of this sensitivity. Therefore a good knowledge of solar–terrestrial physics is most relevant for mankind, a political need, as our understanding of the phenomena is necessary to predict them; and their prediction is necessary to help the populations to face climatic catastrophies. May this last conclusion be heard by decision-makers!