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Solar variability and climate dynamics: a framework for analysis

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The paper outlines a framework for the analysis of relationships between solar variability and climate in which the key solar variables are the independent and key climate variables are the dependent variables

The independent variables are:

1. the Sun's variable output of:
   (a) o radiation, and
   (b) o matter;
2. the Sun's variable electromagnetic field;
3. the Sun's variable gravitational field; and
4. The variable topology of the Sun/Earth relationship.

These solar variables, which are not entirely independent of each other, interact, amplifying total solar impact.

The key dependent variables are:

1. The coupled atmospheric, oceanic systems;
2. The ocean systems;

3. The Rossby and Kelvin waves;
4. The Earth's rotation;
5. Atmospheric angular momentum;
6. The Earth's dynamo;
7. The Earth's electromagnetic field; and
8. The global electric circuit.

Like the solar variables, these variables are not entirely independent of each other. They interact with each other, sometimes amplifying total solar impact.

Effects of the independent variables can be anything from hours to some hundreds of years later after the solar event. For example, the climate impact of coronal mass ejections and solar proton events can happen within hours of the solar event. In contrast, the climate effect of the solar wind may be almost one hundred years after the solar event.

Other relevant factors include:

- The gravitational effects of the other planets on the Sun, Earth, and Moon system. Although tidal effects of the other planets on the Earth are very small, the planets can modify the shape of the orbits of the Earth and the Moon which has climate consequences.
- The interaction (if any) between the orbits of the planets and the orbit of the Sun around the center of mass of the solar system.
- Ever present in the background is the gradual, subtle, and complex change in the structure of the Earth/Sun geometry, giving rise to the Milankovitch processes.
- The natural internal variability in the climate system, including nonlinear processes, randomness and sensitivity to perturbations.
- Phase synchronisation between solar electromagnetic and gravitational oscillations (i.e. between the solar activity cycles and the lunisolar tides) and the Rossby and Kelvin waves.
- Resonant amplification between solar activity and climate cycles and between cyclical sub-systems within the climate system.

- The Earth's reflectance (albedo) and incidence of cosmic rays both modulate total solar impact.

If the global climate system, the dependent variables, is a heat engine, then all forms of solar activity together with these other relevant factors (the independent variables) are the sources of its energy.

The main relationships between independent and dependent variables may be summarised as follows:

- Solar wind: warming; atmospheric angular momentum; Earth's rotation; planetary waves.
- Coronal mass ejections and solar proton events: reduced ozone; cooling; atmospheric chemistry.
- Electromagnetic field: Earth's rotation; electrofreezing; photochemistry; clouds; hurricanes; cyclones, amplification of the global electric current; planetary waves.
- Gravitational field: atmospheric and global electric current oscillations; planetary waves; ocean churning; geomagnetism; movements in the Earth's crust resulting in volcanos and earthquakes.
- Short wave radiation: upper atmosphere warming; photochemistry; ozone; ionisation; clouds; planetary waves.
- Long wave radiation: lower atmosphere, surface and ocean warming; reflectance.

The paper shows that the climate change effect of each of the electromagnetic field and the solar wind is greater than that of radiation; that in long run the climate change effect of the solar wind is greater than that of coronal mass ejections and solar proton events, but that in the short term, the climate change effect of coronal mass ejections and solar proton events can be dramatic; and that the climate change effect of short wave radiation is greater than that of long wave radiation.

As the time series of all the phenomena are non-linear and non-stationary, it is necessary to use those methodologies of time series analysis that make as few as possible assumptions about the data and which allow the data to speak as clearly as possible about the phenomena measured.

The paper goes some way towards answering the question: *Does the Sun affect the Earth's climate?* by having regard to the variability of all solar processes, interactions between them, all the climate processes they affect and interactions between the climate processes.

The paper draws implications for hydrological and other climate phenomena.