Explanation for the Poster **Space Weather and Earth´s Climate**

Ulrich von Kusserow

On the one hand, the magnetic Sun, whose properties change significantly over the course of periodic sunspot cycles, is the main driver of Space Weather, which describes the temporally varying state of the Interplanetary Medium in the Heliosphere of our Solar System, especially in the Earth's Magnetosphere and Ionosphere. On the other hand, the constantly changing Magnetic Sun is the energetic driver of the Earth's temporally and spatially varying Climate, which describes the average values of the weather parameters in the Earth's atmosphere and on the Earth's surface.

Since the 1990s, I have also been intensively researching the extent to which the magnetically variable Sun and Space Weather also influence the Earth's Climate. Eckart Marsch and I already touched on this topic in the last chapter of our book "The Magnetic Sun - Solar Flares, Solar Winds and Space Weather," published in 2023. Unfortunately, this chapter was omitted from the English edition of our book, which was just published end of April this year. I'm currently writing much more intensively about this in a German article series titled "Sunspots and the Earth's Climate," which will be fully published end of 2025.

Driven by dynamos, a multitude of complex, often nonlinear feedback processes take place in the plasma of the magnetosphere and the various atmospheric layers of both the Sun and Earth, allowing the occurrence of a wealth of fascinating, interacting phenomena to be observed. Time-varying UV radiation emitted by the Sun, high-energy particles accelerated in flares, and interplanetary coronal mass ejections moderate the various magnetized Solar Wind streams, which also impact Earth's Magnetosphere and Ionosphere. In addition to the Solar Wind, which determines the time-dependent influx of cosmic radiation into the Earth system, other processes related to the evolution of the Solar System, its repeated passage through regions of stellar activity in the spiral arms of the Milky Way, or changes in planetary constellations can also be responsible for changes in Space Weather, and on much longer timescales, also in Space Climate. Frank Stefani will report on the latter in his lecture.

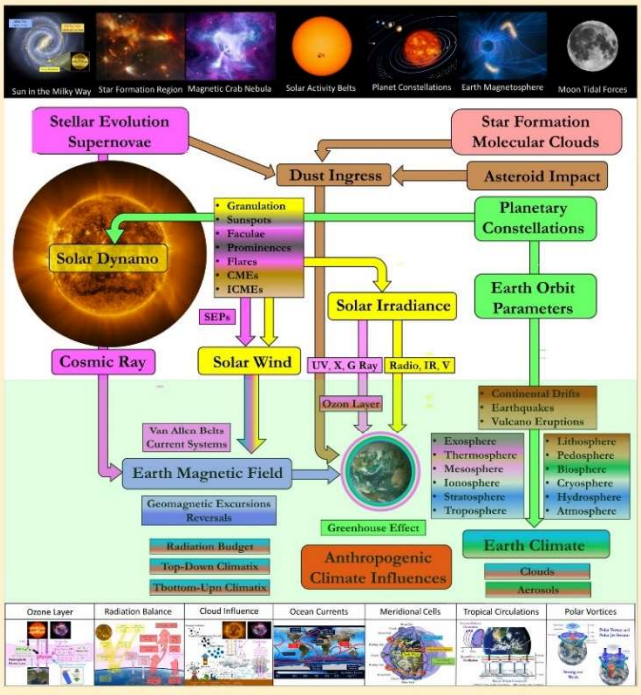
Basics

Firstly, the **Magnetic Sun** is the primary driver of **Space Weather**, which describes the temporally varying state of the interplanetary medium in the **Heliosphere** of our **Solar System**, and especially in the **Earth's Magnetosphere** and **Ionosphere**. The **Dynamo Processes** occurring in highly electrically conductive, flowing fluids, **Plasma** matter, or liquid metals are what generate the more or less periodically or chaotically changing **Solar** respectively Geo-**Magnetic Fields** in this context. In particular, the Sun emits significantly varying **UV Radiation**, depending on the intensity of **Solar Activity**, which is characterized by the relative **Sunspot Number**. The release of magnetic energy accelerates High-Energy **Solar Particles** in **Flare Processes**, and after **Eruptions** of **Solar Prominences**, massive **Coronal Mass Ejections** can occur into interplanetary space, which, among other things, moderates the **Solar Wind** continuously flowing from the solar corona toward Earth. The varying strength of the **Heliospheric Magnetic Field** during the **Sunspot Cycle** influences the strength of the influx of **Cosmic Ray** from the distant Universe into the Solar System and the Earth's magnetosphere.

Secondly, the constantly changing **Magnetic Sun** is the **Energetic Driver** of the **Earth's Climate**, which varies over time and space. Under the influence of the changing **Planetary Constellations** within the solar system over the course of its evolution, the **Earth's Parameters** also change periodically, causing significant changes in the latitude-dependent **Solar Irradiation** on Earth and thus also in its climate over large timescales. The natural **Greenhouse Effect** is of central importance for the Earth system's **Radiative Energy Budget**, but humans have increasingly influenced it in recent decades. In addition to radiation processes and various **"Top-Down"** and **"Bottom-up" Climatic Factors** in the Earth's system, **Heat Transport** in the **Oceans** and in the stratospheric and tropospheric **Atmospheric Layers** from the equator to the polar regions as well as the **Human Influence** also plays a significant role in **Changes** in the **Earth's Climate**.

Finally, the question arises as to the extent to which **Space Weather**, mediated as well by **Magnetic Fields**, can also exert a significant **Influence on** the **Earth's Climate**.

Variety of Complex Interaction Processes



Aspects of Space Weather

Space Climate Changes in the **Solar System** related to the ...

- Faint Young Sun Problem
- Passage through Spiral Arms of the Milky Way
- Encounter with dusty Molecular Clouds
- Eruption of a Supernova located not far away
- Changing Solar Dynamo Processes caused by Planetary Constellation changes

Space Climate Changes in the Earth´s Magnetosphere related to ...

- Changes of the Earth´s Dynamo processes, magnetosphere, Van Allen Belt
- Excursions or Reversals of the Earth´s Magnetic Field

Space Weather Changes related to ...

- Moderation of the Solar Activity and Solar Wind
- Moderations of the influx of Cosmic Ray by changes in the Heliospheric Magnetic Field

Aspects of Earth´s Climate

- **Changes of Earth Orbit Parameters** Milankovitch Cyles, lunar tides
- **Lithospheric and Pedospheric Changes** Continental drifts, earthquakes, vulcano eruptions
- **Radiative Energy Budget** under sunlight absorption, reflection, scattering, refraction, reemission, greenhouse gas, aerosol and cloud influence
- **„Top-Down" Climatic Influencing Factors** stratospheric ozone dynamics due to solar UV radiation, cloud formation and albedo effect, Aerosol influence and greenhouse effects, Earth surface processes, ice albedo effect
- **Bottom-Up" Climatic Influencing Factors** driving atmospheric circulations, generation of natural and anthropogenic aerosols, propagation of atmospheric waves
- **Heat Transport** in the **Atmosphere** and **Oceans** under solar influence, convection cells, circulations and oscillations, ENSO, QBO, polar vortex
- **Anthropogenic Influences** growth of world population, energy demand, waste, environmental pollution, exhaust and greenhouse gases, aerosols out of industry, commerce, transport, and settlement, rainforest deforestation, ozone hole formation by chlorofluorocarbons, ...

Summary

Together with other influencing factors, the **Magnetic Sun** determines the **Heliospheric Space Weather** and, more or less directly, the development of the **Earth's Climate**. A multitude of **Complex**, non-linear, often more or less periodic positive and negative **Feedback Processes** interact in the solar atmosphere and solar wind, in the magnetosphere, ionosphere, and the various atmospheric layers of the Earth, as well as on the Earth's surface, in the biosphere, and in the oceans. Their **Effects** on the Earth's climate can **Overlap** in an unmanageable way. Even if **Correlations** between **Climate Parameters** previously considered insignificant are much better understood and integrated into the theoretical framework in the future due to better **Data** and the results of **Model Calculations**, scientists should always bear in mind the general **Limits** of **Gaining Knowledge** in such **Complex Systems** with so many system parameters.

Literature

C. J. Schrijver, G. L. Siscoe (Eds., 2010) Heliophysics – Evolving Solar Activity and the Climates of Space and Earth. Cambridge University Press
U. v. Kusserow, E. Marsch (2023) Magnetisches Sonnensystem – Solare Eruptionen, Sonnenwinde und das Weltraumwetter. Springer Sachbuch
J. Vinós (2023) Solving the Climate Puzzle: The Sun's Surprising Role. Critical Science Press
V. Bothmer, J. A. Daglis (2024) Space Weather: Physics and Effects. Springer Praxis Books
U. v. Kusserow (2025) Sonnenflecken und das Erdklima. Artikelserie in ASTRONOMIE+RAUMFAHRT im Unterricht (uvkusserow@t-online.de)

Image Rights

NASA/JPL; NASA, ESA, CSA, K. Pontoppidan (NASA's JPL), J. Green (STSI); NASA/CXC/SAO, NASA/STScI; NASA-JPL-Caltech; SDO, NASA; NASA/JPL; NASA/GSFC; NASA (Editing: U. v. Kusserow
U. v. Kusserow, ESA/NASA/Solar Orbiter/EUI Team, E. Kraaikamp (ROB), NASA (8), ESA (2), NASA/GSFC Scientific Visualization Studio

Due to the world's continuing strong, now only linear, growth in population, increasing energy consumption and transport, growing industrialization, urban sprawl, environmental destruction, and ecological mismanagement, human society can certainly contribute to climate change in many ways. Since the more pronounced global warming that began in the

1980s, many people today assume that, in addition to the influence of clouds and the changing albedo of the Earth system, current Climate Change is caused almost exclusively by the increasing concentration of the Greenhouse gas CO_2 and the associated drastic increase in water vapor. Because the overall intensity of solar radiation has changed very little since that time, the Sun is now considered to have only a negligible influence on climate change, unlike before. I would like to discuss with you, not only during the poster session, the extent to which the influence of the Magnetic Sun, the Solar Wind, and Space Weather as a whole can have a very noticeable impact on weather and climate events in the Earth system.

It is not sufficient to blame the current warming solely on changes in the atmospheric radiation balance, especially on human activity alone. On the one hand, a multitude of other, so-called "top-down" and "bottom-up" climate influencing factors can interact on very different spatial and temporal scales from above or below in the atmosphere, exerting a significant influence on weather and Climate. For example, the influx of solar UV radiation and high-energy particles, which varies greatly over the course of Solar Activity Cycles, as well as Cosmic Radiation, causes strong changes in the stratospheric Ozone Layer, which can very well have an impact on the Climate. Because solar activity, which varies on a wide range of time scales, moderates the influx of charged cosmic radiation, the number and properties of the Cloud condensation nuclei that form also change, which can significantly alter cloud formation processes and the climate-relevant cloud albedo.

Second, the processes of heat transport from the equator to the polar regions must also be taken into account for climate influence. These processes occur in the turbulent, globally oscillating Ocean Currents, driven by the Sun, as well as in the Stratosphere and tropospheric atmospheric layers. Meridional tropospheric energy transport effectively occurs in the Hadley, Ferrel, and polar convection cells, the characteristics of which depend on the intensity of solar activity.

While solar radiation is most intense in the equatorial region, the transport from the Earth system into interplanetary space occurs primarily in the Polar Regions. Under the influence of strong solar radiation, large-scale tropospheric Walker circulation cells form over the equatorial Pacific, in connection with which the El Niño Southern Oscillation events and Madden-Julian Oscillations, which have a strong impact on weather and climate, occur. In the equatorial stratosphere, so-called Quasi-Biennial Oscillations occur. Brewer-Dobson circulations describe the transport of air masses that are strongly heated above the equator, rise into the stratosphere, flow toward the polar regions, sink there, and flow back toward the equator in the upper troposphere.

The inflow of heat into the polar regions and its outflow from the Earth system are strongly regulated by the stratospheric and tropospheric Polar Vortices, whose strength and topology influence the formation of polar Jet Streams, which have a significant impact on weather and climate, and the associated development of high- and low-pressure areas. The increased inflow of cosmic particles near the poles along Earth's magnetospheric structures, through the

plasma and ionosphere, can be considered one of the Gatekeepers of these processes in this context.

By the way, on timescales of millions of years, the passage of our Solar System through molecular and dust clouds is also likely responsible for Climate Change, on time scales of tens of thousands of years, in connection with the Milankovitch Cycles, strongly as well the change in Earth's Orbital Parameters due to varying Planetary Constellations

A wide variety of factors, often influencing in a more or less periodic, cyclical manner, and non-linearly interacting processes are responsible for climate development on our planet. Their superposition can have complex and even unpredictable consequences. Close correlations between climate parameters, proven and scientifically justifiable for a certain period, can lose their validity because the influence of other factors suddenly dominates. Even causal relationships previously considered insignificant should be more thoroughly researched in the future to gain a deeper understanding of the connection between Space Weather and Earth's Climate. However, the limits of human knowledge acquisition should always be taken into account. The truth will always change from time to time.

Ulrich v. Kusserow
Besselstraße 32-34
D-28203 Bremen
Tel.: 0421-75160
E-mail: uvkusserow@t-online.de
Internet: https://www.ulrich-von-kusserow.de