Does the Sun contribute to Climate Change

Pål Brekke
Norwegian Space Centre
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“The result of this review of the foregoing five periods is, that, from the price of wheat, it seems probable that some temporary scarcity or defect of vegetation has generally taken place, when the sun has been without those appearances which we surmise to be symptoms of a copious emission of light and heat.”

Historical sunspot records

I 1610 pekte Galileo og Thomas Harriot teleskopet mot Solen for første gang. Galileo skadet synet p.g.a. disse observasjonene.
What is the Solar Wind?

- A constant stream of particles «blowing» from the solar corona with a typical velocity of 1.5 million km/h (400 km/s). The solar wind reaches the outer part of the solar system and affects all planets. It pushes on our magnetosphere.
The electromagnetic spectrum
Effects from the Halloween storms

- More than 20 satellites and spacecrafts were affected (not including classified military instruments). Half of NASA satellites affected. One Japanese satellite lost.
- Severe HF Radio blackout – affected commercial airlines.
- FAA issued a first-ever alert of excessive radiation exposure for air travellers.
- Power failure in Sweden.
- Climbers in Himalaya experienced problems with satellite phones.
- US Coast Guard to temporarily shut down LORAN navigation system.
- Radiation monitor device on Mars Odyssey knocked out. Parts of the Martian atmosphere escaped into space.
Protonevents affects the ozone-content (ved 0.5 hPa eller ~55 km)

This event reduced the ozone content for 8 months (~42 km)

Source: Charles Jackman & Gordon Labow (NASA) og FMI
Climate Change - Forcings

**Anthropogenic climate change**
- Emission of greenhouse gases
- Emission of soot / dust (aerosols)
- Land Use Change (irrigation, deforestation, urban heat islands)

**Natural Climate Variability**
- Changes in the solar activity
- Volcanoes
- Internal dynamics in the climate system (El Nino, La Nina, ocean currents, water vapor, clouds)
  (The Earths orbit/tilt etc. are related to climate change on longer time)
Climate change - on a longer time scale

- MAAT in Norway and Denmark 2-3°C above present values
- North Greenland and Svalbard 4-5°C above present values
- Sahara covered with vegetation
- Stone age temperature maximum
- No glaciers in Norway
- Glaciers begin to reform
- Iron age temperature decline
- Roman Empire
- Landnam in Iceland and Greenland
- Little Ice Age
- NOW

Begin of temperature recordings
Temperature changes, according to GISP2 bore holes on Greenland (Alley 2004) and changes in atmospheric CO2 levels.

What caused these temperature changes?
The relatively small amplitude of TSI (0.2 W m\(^{-2}\)) is too small to explain the observed SST response of about 0.1 °C.

Thus, there must be some amplification mechanisms.
Solar effects on the Earth’s climate

**Top-down effect**
Ultraviolet radiation from the sun is absorbed by the stratosphere and warms it. This helps generate stratospheric winds, which affect the weather below. For example, strong winds boost the jet stream. In a solar minimum, the stratosphere receives less UV and winds are weaker, so the jet stream slows down. This makes weather systems stick around for longer and can lead to extreme weather events.

**Bottom-up effect**
Visible light filters through the atmosphere and warms the oceans. Warming is greatest in the tropics, where it increases evaporation, fueling rainfall along the intertropical convergence zone. A belt of thunderstorms that circles the Earth. During a solar maximum, more solar energy means more evaporation and rainfall, though the effect is weak.

**Cosmic rays**
Solar winds deflect solarizing cosmic rays away from Earth. Studies suggest that ionised particles cluster on clouds, creating layers of electric charge. These may make it easier for large water droplets to form, generating rain and shortening the cloud’s lifespan. Solar winds are stronger during solar maxima and weaker during solar minima, deflecting more or fewer cosmic rays, respectively. 

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Solar climate mechanisms

• Long term variations in total solar irradiance (TSI)

• Long term variations in UV/EUV irradiance - will lead to changes in chemistry (ozone), temperature and dynamics.

• Long term variations in solar wind/magnetic field
Total Solar Irradiance (TSI)

Sunspots, plages and bright network contributes to TSI
Total Solar Irradiance (TSI)

Large sunspots decrease TSI

Plages/Facular brightening increases TSI
Total Solar Irradiance (TSI)

MECHANISMS OF THE SOLAR TOTAL IRRADIANCE CYCLE

-Facicular Brightening
-Sunspot Darkening
-Total Irradiance Data
-Regression Model cc=0.93
Total Solar Irradiance (TSI)
Total Solar Irradiance (TSI)
Total Solar Irradiance (TSI)

There are three published TSI time series

- PMOD shows little trend
- ACRIM shows a more positive trend


Froelich el al 2008 (PMOD).
Reconstructing solar irradiance

Different methods and proxies are used (sunspot numbers, solar cycle length, Ca II images, other stars and geomagnetic indexes).
Reconstructing solar irradiance

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TSI variation between 0.1 (0.0) - 0.6% since 1750 (0.2% often used in climate models)
Recent reconstructed TSI

- Schrijver et al. (2011): finds an even smaller TSI variation than IPCC

- Shapiro et al. (2011): finds an increase up to 6 times more than assumed by IPCC

Shapiro et al.  Astronomy & Astrophysics 529, A67 (2011)
Total Solar Spectral Irradiance (TSI)

- The Sun's spectral irradiance back to 1700 (Fligge and Solanki, GRL, 2000)
  - TSI: 0.2%
  - UV <300 nm: 3.0%
  - NUV <300-400 nm: 1.3%
  - Visible 400-700 nm: 0.32%
  - Infrared >700 nm: 0.15%

- Since the UV radiation from the Sun controls the amount of ozone, scientists claim that variations in the UV will contribute to climate change (e.g. Haigh 1996)

Also here we find more recent conflicting results (Foukal et al. 2009, Ermolli et al. 2009...).
The solar EUV Sun - from min to max
Variations in the UV and climate change

- The North Atlantic Oscillation is assumed to be affected by natural variations (e.g. solar activity).
- NAO-index is important for the climate in Europe
- NAO can be reconstructed back to 1658 from pressure, temperatures and precipitation.
- Climate models suggest that low solar activity between 1400-1700 altered the atmospheric circulation.
- A “weaker” Sun reduced the westerly winds and cooled Europa.

NAO-index and effects on climate in Norway

+ NAO:
  - Warm and wet winters in N-Euroa

- NAO:
  - Cold and dry winters.

**NAO and Energy in Norway:**

- Norway experience cold winters during a negative NAO phase.
- Heating Oil consumption in Norway varies by 30% in good (anti) correlation with the NAO.
- Correlation with precipitation results in variability in hydropower generation.
Very deep Solar Minimum 2008-2010

- Total Solar Irradiance - lowest on record (1979)
- UV irradiance 6% lower than the two previous minima
- Solar cycle length > 13 year (longest since 1790)
- Solar wind/magnetic field lowest in 50 years
- GCR record high
Dim Sun causes cold winters in Europa?

Lockwood et al. 2010

The average of recent winters (2008/9, 2009/10 and 2010/11) shows cold conditions over northern Europe and the United States and mild conditions over Canada and the Mediterranean associated with anomalously low and even record low values of the NAO.

On decadal timescales the increase in the NAO from the 1960s to 1990s...may also be partly explained by the upwards trend in solar activity evident in the open solar-flux record....
Cosmic rays and climate - is there a link?

- GCR seeds low clouds (Svensmark +++)
- The GCR affects the electrical conductivity of the atmosphere through ion production (Tinsley +++)

Cloud Effects On Earth’s Radiation

![Cloud Effects On Earth’s Radiation](image)

![Graph](image)

![Diagram](image)
More active Sun than 100 years back:
• Less CGR today than before
• Less low clouds than before
• A warmer climate?
Cloud observations/modelling

- Many studies support AND disputing solar GCR cloud correlations (e.g. Usoskin 2006; Svansmark et al. 2009; Sloan & Wolfendale 2008; Erlykin et al. 2009; Harrison 2008......)

- Some modelling studies support or dispute this mechanism (Yu et al. ACP 2008, KAzil et al. APC2006, Pierce & Adams GRL 2009.....).
Natures own experiment
Are there short term effects from GCR?

- Svensmark et al. GRL, 36 (2009) studied the effects on low clouds and aerosols during several strong Forbush events. Found that both water content and amount of low clouds to vary (4%) ca 7 days after the reduction in GCR. The amount of aerosols also changed significantly (7%).


- Little or no effects: Kristjansson et al. 2008, Sloan & Wolfendale (2008), Kulmala et al. 2010, Calogovic el at GLR 37 (2010), Laken et al. GRL, 36, 2009
GCR - climate effects

- Siberian climate: Eichler et al GRL 36 (2009)
- Ice rafted debris: Bond et al. Science 294 (2001)
- Indian ocean monsoon: Neff et al. Nature 411 (2001)
- Rainfall, droughts, river floods etc....
Solar climate mechanisms - vs climate models

- Long term variations in total solar irradiance (TSI)

- Long term variations in UV/EUV irradiance - will lead to changes in chemistry (ozone), temperature and dynamics.

- Long term variations in solar wind/magnetic field
Natural forcing according to IPCC

However, the response to solar forcing could be underestimated by climate models (Hegerl & Crowly 2006).

Indirect effects...

What about other natural forcing (PDO/AMO.....)?
The five-year mean global temperature has been flat for the last decade, which we interpret as a combination of natural variability and a slow down in the growth rate of net climate forcing. --James Hansen et al., 15 January 2013
Will the Sun “save us”?

“A 0.1% decrease in the sun's irradiance has counteracted some of the warming action of greenhouse gases from 2002 - 2008,” says J. Lean. "This is the reason for the well-known 'flat' temperature trend of recent years." “May well slow down the temperature increase in the future”

Questions that may be asked:
• Will the Sun “save us” from the consequences from CO2 emission?

Sometimes we just don’t understand something all that well.....

The moral: aim low!
What about our future Sun?

Are Sunspots weakening?

“Sunspots may vanish by 2015” - William Livingston and Matthew Penn, National Solar Observatory at Kitt Peak
What is happening with the Sun?

A missing jet stream, fading spots, and slower activity near the poles say that our Sun is heading for a rest period.

Latitude-time plots of jet streams under the Sun's surface show the surprising shutdown of the solar cycle mechanism. New jet streams associated with a future 2018-2020 solar maximum were expected to form by 2008 but are not present even now, indicating a delayed or missing Cycle 25.


“Whither Goes Cycle 24? A View from the Fe XIV Corona” by R. C. Altrock.

“A Decade of Diminishing Sunspot Vigor” by W. C. Livingston, M. Penn & L. Svalgaard.
What will the Sun do in the future?

E.g. H. Abdussamatov (2009), Lockwood et al. (2009)
Global solar wind variations over the last four centuries

Solar activity which causes the aurora is expected to drop by a third by 2050s, say experts.

The Northern Lights could vanish from Scotland’s skies by the 2050s, according to scientists.
Global solar wind variations over the last four centuries

How will the magnetosphere and the aurora respond to a possible new Maunder Minimum?
Will fast CMEs be potentially more damaging?
Natural climate cycles

Pacific Decadal Oscillations (PDO), Atlantic Multidecadal Oscillation (AMO) and Southern Oscillation Index (SOI)
Natural climate cycles
Observed temperature vs IPCC scenarios

- **A2**: Red line
- **A1B**: Green line
- **B1**: Blue line
- **Constant composition commitment**: Orange line
- **20th century**: Black line

**Global surface warming (°C)**

- **Fremtidig temperatur**
- **Observervert temperatur**

**Year**

- 1900
- 2000
- 2100
Observe temperature vs IPCC scenarios

Climate Models Run Too Hot
Projections off by 53% (surface) and 147% (satellite)

Test Model: 32 CMIP5 RCP2.6 average, http://climexp.knmi.nl/
11-year running means, 2015 average of 8/9 months, all adjusted to zero 1979-82
The complex picture II - the way through the atmosphere

- **TSI**
  - Total solar irradiance variation
  - 1366 W/m², Δ=1.3 impacts Earth's surface

- **Solar wind/IMF**
  - Solar wind and interplanetary magnetic field variation
  - 0.0003 W/m² above 500 km alt.
  - Cosm c ray modulation
  - 0.000007 W/m² 0-90 km alt.
  - Production of tropospheric ionization
  - High/medium lat. lower atmosphere E fields
  - Transport of tropospheric ionization
  - Cyclone dynamics

- **Solar EUV/XUV**
  - Solar EUV/XUV particles solar & magnetospheric MeV and keV particle variations
  - ≤0.6 W/m², 90-130 km alt
  - Production of NO₃, HO₃, and ionization in middle atm and lower thermosphere
  - Middle atmosphere E fields
  - Changes in middle atm dynamics

- **Solar UV**
  - Solar UV variation
  - 16 W/m², Δ=0.15 0-50 km alt
  - Biological active UV

- **Ozone**
  - Production and loss
  - Stratospheric troposphere coupling

- **Cloud microphysics**
  - (contact ice nucleation?)

- **Troposphere Dynamics & Temperature**
  - Effects on biosphere
Summary

Neither anthropogenic or natural variations can alone explain the temperature variations the last 150 years.
  - It is not only CO2 and/or the Sun

Whatever mechanisms caused past climate change may work today and will most probably also work in the future.

Improve the climate models to better include natural variability (both past and the future).

The only thing we know for sure is that the Sun will NOT be constant the next 100 years.
Different solar and anthropogenic forcings may be restricted to certain areas!

Forcing functions MAY NOT operate globally.

Climate forcing functions MAY NOT operate immediately.

Crozier, Anderson & Alexander, Science 8 August 2008

Perry, Advances in Space Research, Vol 40, 2007