Atmosphere and Ocean Responses to Extreme Low Solar Activity and Their Hemispheric Differences

Han-Li Liu¹, Matthias Rempel¹, Gokhan Danabasoglu², Stanley Solomon¹, Joseph McInerney¹

1. High Altitude Observatory, NCAR
2. Climate and Global Dynamics, NCAR

Partly supported by NASA LWS (NNX16AB82G)
SORCE Sun-Climate Workshop, 27-31 January, 2020 Tucson, AZ
Outline

• Motivation
• Method
• Results and analysis
  • Surface/troposphere/ocean responses
  • Stratosphere and troposphere responses
  • Hemispheric differences
Solar Signal in Surface Temperature?

Nominal solar maximum (SOLIN: 340.483 W/m²)
Nominal solar minimum (SOLIN: 340.107 W/m²)
Motivation

• Solar signal in the tropospheric climate is small compared with the large climate variability.

• Solar variability is large in stratosphere and above, but the downward impact is still unclear.

• Relying mainly on statistics and difficult to examine processes through which solar forcing affects climate.

• Climate sensitivity to solar forcing is thus still not clear.
Model Description

- NCAR WACCM CCMI (Chemistry Climate Model Initiative) setup with coupled ocean model.

- WACCM Numerical experiments (200 years for each one)
  - Nominal solar max (SOLIN: 340.483 W/m²)
  - Nominal solar min (SOLIN: 340.107 W/m²)
  - SSI/TSI from HD solar simulation (SOLIN: 337.521 W/m², 0.86% lower than solar max)
    - <350 nm nominal solar min; >350 nm HD (HD VIS)
    - <350 nm HD; >350 nm nominal solar min (HD UV)
  - SSI/TSI from weak B (48G) MHD solar simulation
Annual Average TS Time Series

Global mean TS_ann, HD

NH TS_ann, HD

EQU TS_ann, HD

SH TS_ann, HD

(Ts(smin) - Ts(smax) = -0.07 K)
Annual Average TS Time Series

Global mean TS_ann

NH TS_ann

EQU TS_ann

SH TS_ann

0.8K

1.9K

0.6K

0.7K

1.3K
Ts(SminHD) - Ts(Smax)

TS_minHD - TS_max Jan

TS_minHD - TS_max Jul

0-50 years

50-200 years
TS: HD/HDVIS/HDUV (0-50 yrs)
TS: HD/HDVIS/HDUV (50-200 yrs)
Atlantic Meridional Overturning Circulation (AMOC)
Atmosphere Zonal Wind and Temperature

UBAR_max and UBAR_HD–UBAR_max Jan

Colder

warmer

TBAR_max and TBAR_HD–TBAR_max Jan
### First several decades

<table>
<thead>
<tr>
<th></th>
<th>PW(NH)</th>
<th>T(NH)</th>
<th>U(NH)</th>
<th>PW(SH)</th>
<th>T(SH)</th>
<th>U(SH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiative</td>
<td></td>
<td>Cooling</td>
<td>Slower</td>
<td></td>
<td>Cooling</td>
<td>Slower</td>
</tr>
<tr>
<td>Dynamics</td>
<td>Weaker (BD Weaker)</td>
<td>Cooling</td>
<td>Faster</td>
<td>Stronger (BD Stronger)</td>
<td>Warming</td>
<td>Slower</td>
</tr>
<tr>
<td>Net</td>
<td>Strong Cooling</td>
<td>Variable</td>
<td></td>
<td>Variable</td>
<td>Much Slower</td>
<td></td>
</tr>
<tr>
<td>Tropo/Ocean</td>
<td></td>
<td>Cooling</td>
<td></td>
<td></td>
<td></td>
<td>Slower</td>
</tr>
</tbody>
</table>

![TS_minHD-TS_max Jan](image1)

![TS_minHD-TS_max Jul](image2)
<table>
<thead>
<tr>
<th></th>
<th>PW(NH)</th>
<th>T(NH)</th>
<th>U(NH)</th>
<th>PW(SH)</th>
<th>T(SH)</th>
<th>U(SH)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First several decades</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiative</td>
<td></td>
<td>Cooling</td>
<td>Slower</td>
<td></td>
<td>Cooling</td>
<td>Slower</td>
</tr>
<tr>
<td>Dynamics</td>
<td></td>
<td>Cooling</td>
<td>Faster</td>
<td></td>
<td>Warming</td>
<td>Slower</td>
</tr>
<tr>
<td>Net</td>
<td></td>
<td>Strong</td>
<td>Cooling</td>
<td>Variable</td>
<td>Variable</td>
<td>Much Slower</td>
</tr>
<tr>
<td>Tropo/Ocean</td>
<td></td>
<td>Cooling</td>
<td></td>
<td></td>
<td></td>
<td>Slower</td>
</tr>
<tr>
<td><strong>Later period</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiative</td>
<td></td>
<td>Cooling</td>
<td>Slower</td>
<td></td>
<td>Cooling</td>
<td>Slower</td>
</tr>
<tr>
<td>Dynamics</td>
<td></td>
<td>Recover</td>
<td></td>
<td>Stronger (BD Stronger)</td>
<td>Warming</td>
<td>Slower</td>
</tr>
<tr>
<td>Net</td>
<td></td>
<td>Cooling</td>
<td>Slower</td>
<td>Variable</td>
<td>Much Slower</td>
<td></td>
</tr>
<tr>
<td>Tropo/Ocean</td>
<td></td>
<td>Cooling+ (North Atlantic)</td>
<td></td>
<td></td>
<td></td>
<td>Slower</td>
</tr>
</tbody>
</table>
Summary

• Climate sensitivity to solar forcing studied using WACCM/POP simulations with a sudden decrease of SSI to an extreme low condition derived from solar HD/MHD simulations.

• Clear responses are found in the coupled middle atmosphere, troposphere, ocean and sea ice, and the responses in the two hemispheres differ significantly.
  • Downward impact on temperature and wind.
  • Different planetary wave response due to differences in air-sea interaction.

• Even with reduction only in the UV range (<350nm), similar tropospheric and oceanic changes—significant albeit with reduced magnitude—are found in the simulations.
  • Troposphere/ocean responses to UV change and VIS/IR change are in phase and thus enhancing.
Backup Slides
Corrected Sensible Heat Flux (W/m²)

DaSilva et al., 1995
Surface Short Wave Flux

Negatively correlated with ice cover

0-50 years

50-150 years
Zonal wind SH (0-50 years)
Comparison with Nominal Solar Min/Max

\[ \text{Ts(HD)} - \text{Ts (Smax)} \]

\[ \text{mean} = -0.80 \quad \text{rmse} = 0.95 \quad \text{K} \]

\[ \text{Min} = -3.99 \quad \text{Max} = 1.54 \]

\[ \text{Ts(Smin)} - \text{Ts (Smax)} \]

\[ \text{mean} = -0.07 \quad \text{rmse} = 0.12 \quad \text{K} \]

\[ \text{Min} = -0.82 \quad \text{Max} = 0.50 \]