

The response of the stratosphere-troposphere system to changes in solar irradiance in past, present, and future climates

Veenus Venugopal^{1,*}, Michaela I. Hegglin^{1,2}, Tobias Spiegel³, Theodore G. Shepherd^{2,4}, Wenjuan Huo⁵, Gerrit Lohmann^{3,6}

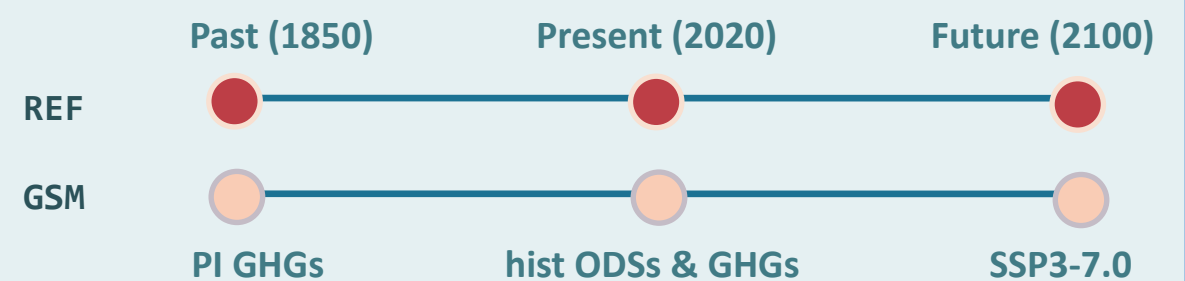
¹Institute of Climate and Energy Systems - Stratosphere (ICE-4), Forschungszentrum Jülich, Jülich, Germany | ²Department of Meteorology, University of Reading, Reading, UK
³Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research, Bremerhaven, Germany | ⁴Jülich Supercomputing Centre, Forschungszentrum Jülich, Jülich, Germany
⁵GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany | ⁶University of Bremen, MARUM - Center for Marine Environmental Sciences, Bremen, Germany
 *v.venugopal@fz-juelich.de

Grand Solar Minimum - GSM

The response to changes in solar radiation remains an important source of uncertainty in future climate system projections. The increasing greenhouse gases add further complex feedback loops. The present study investigates how a Grand Solar Minimum would affect the stratosphere-troposphere system and how it is different from an increasing greenhouse gas response (GHG).

Experimental design

The present study uses the fully coupled chemistry-climate model EMAC (ECHAM5/MESSy Atmospheric Chemistry) to examine the response to a reduction in solar irradiance of 5.5 W/m², similar to the Maunder minimum, under past (1850, pre-industrial/PI), present (2020, historical/hist), and future (2100, scenario/SSP3-7.0) climate conditions.



How does the GSM response differ from that of GHGs?

The troposphere cools in GSM and warms with rising GHGs; the stratosphere cools in both GSM and rising GHGs

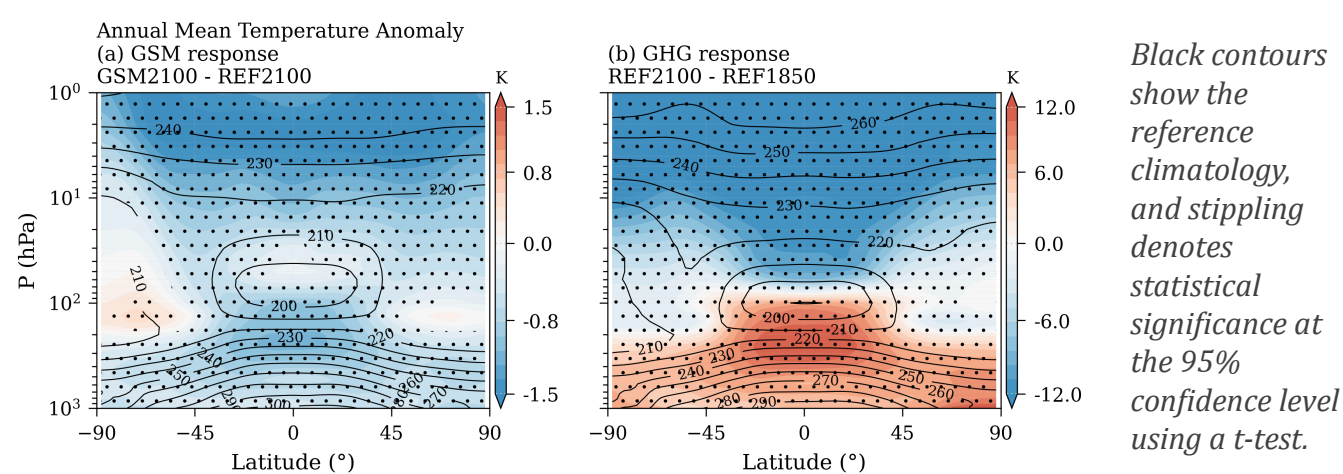


Fig. 1: Annual mean zonal-mean temperature anomalies for (a) the GSM run compared to the Reference state in the future and (b) the effect of increasing GHGs evaluated from Reference states of future and past. Note the different colour scales in the two panels.

GSM weakens the SH polar night jet, GHGs strengthen it; summer easterlies strengthen on poleward side in GSM

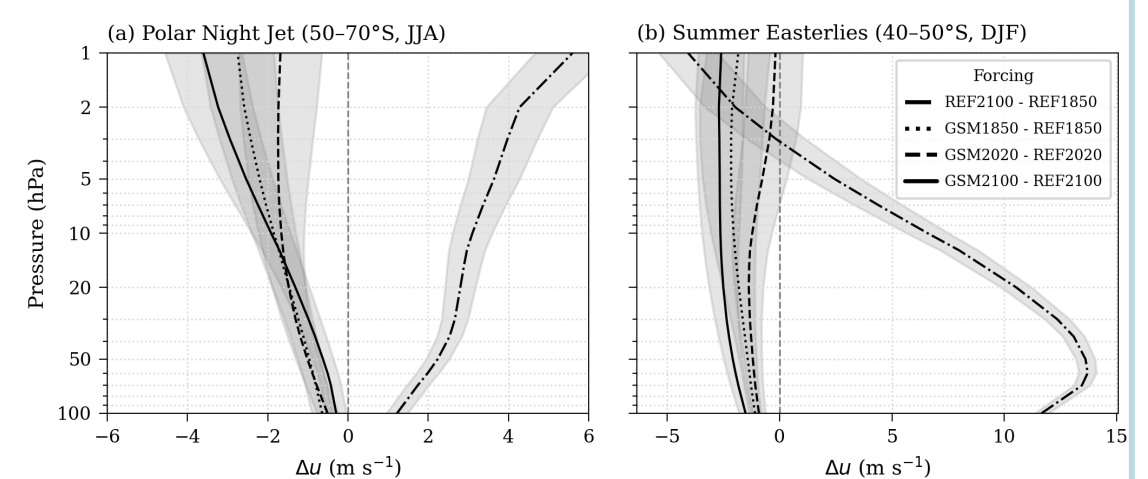


Fig. 2: Vertical profiles of zonal-mean zonal wind differences in the SH for (a) the polar night jet (PNJ), during JJA, (b) the summer easterlies during DJF.

The final warming is earlier in GSM; GHG rise delays final warmings

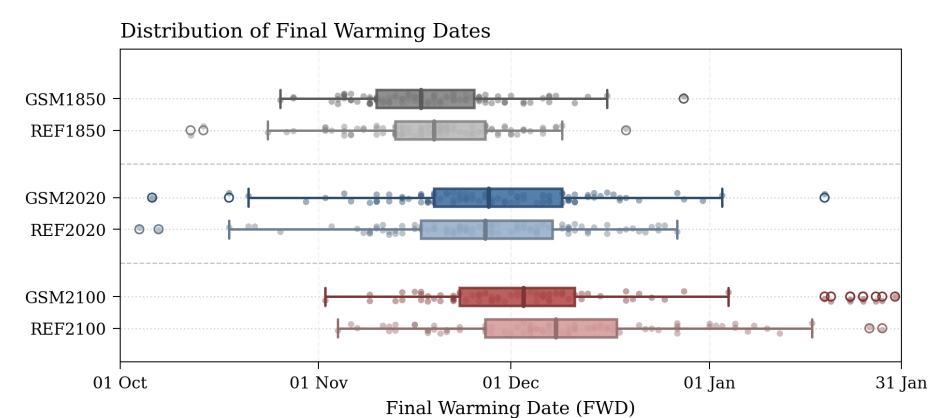


Fig. 3: Distribution of final warming dates (FWD) for the Southern Hemisphere at 50 hPa and 60°S for GSM and REF simulations. The FWD is defined as the first date after which the zonal-mean zonal wind consistently falls below 10 ms⁻¹.

ODSs induce enhanced spring polar cooling under GSM and stronger jet

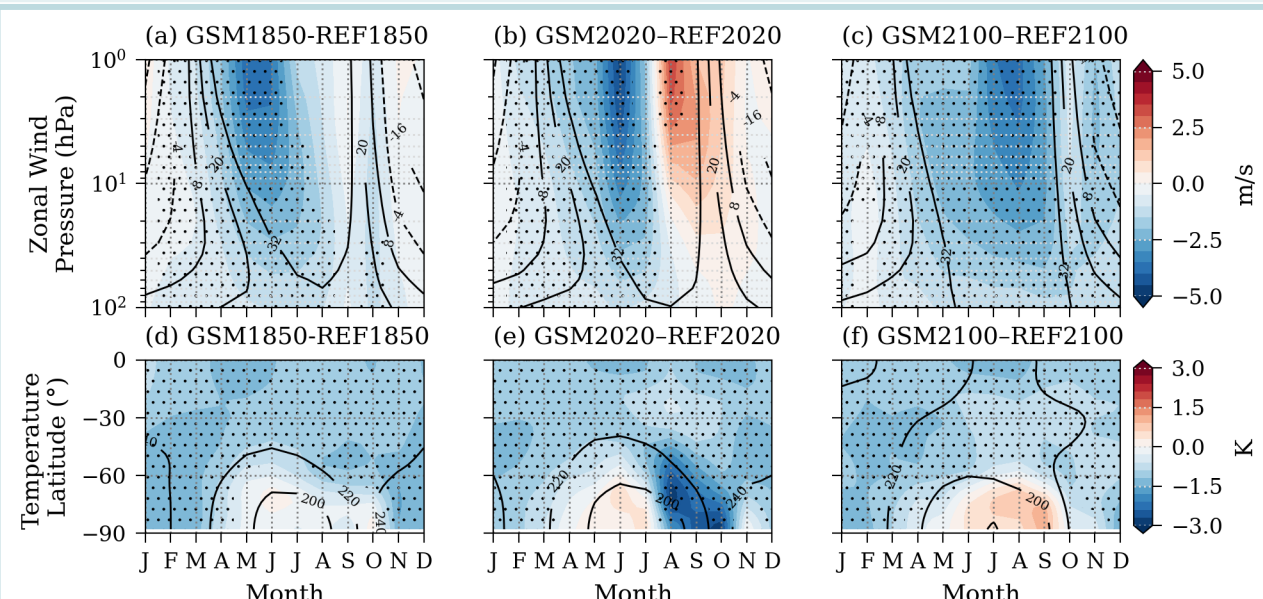


Fig. 4: Monthly evolution of (top panel) vertical profile of zonal-mean zonal wind averaged from 40°S to 60°S, and (bottom panel) latitudinal distribution of temperature anomalies at 10 hPa pressure level.

GSM shifts surface westerlies equatorward; reduces precipitation at 50-70°S

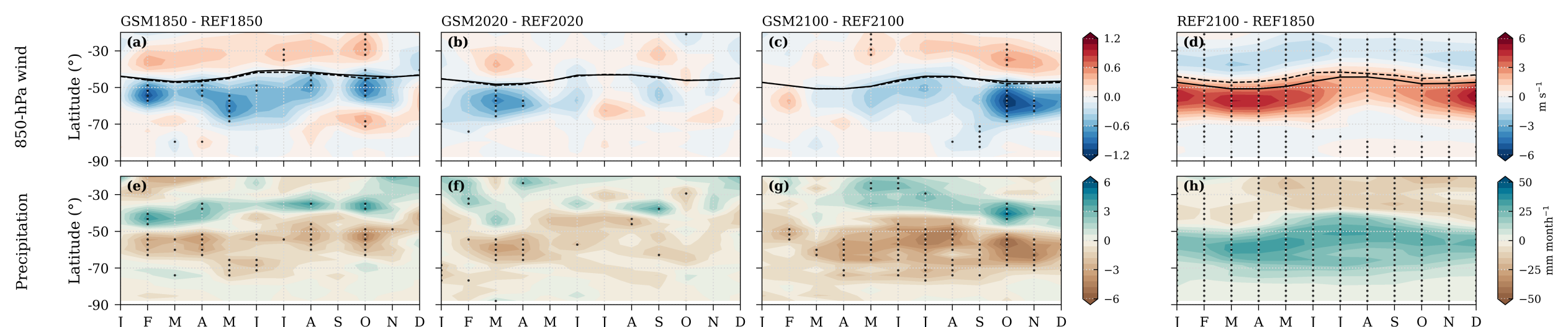


Fig. 5: The seasonal evolution of latitudinal distribution of zonal mean zonal wind at 850 hPa, and precipitation. The black lines in the first row denote the position of maximum jet speed.

Concluding Remarks

- GSM cools the tropics and weakens the polar night jet while strengthening the poleward side of the summer easterlies
- The PNJ undergoes its final breakdown earlier in GSM, whereas in the present ozone-hole-induced strengthening of the springtime jet overrides the model's intrinsic tendency towards earlier breakdowns
- The surface westerlies at 850 hPa show the most impact in the late winter in the future. There is a reduction in precipitation over the poleward side of the westerlies, with a colder polar cap (not shown) under GSM.

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