Influence of Solar Activity Cycles on Earth's Climate

Task 6 – Modelling Potentials

WP 601 – External Forcing
WP 602 – Interaction Mechanisms

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1 Introduction

Under Task 5 various physical mechanisms whereby solar variability may influence climate were hypothesized. Here the tools required to test these hypotheses are assessed. In Section 2 the nature of the solar forcing for each mechanism is outlined and the necessary solar data identified. Section 3 suggests experiments with general circulation models (GCMs) designed to test the various mechanisms, the necessary configurations and feasibility of implementation.

2 External Forcing

In WP201 sources of data related to different aspects of solar variability were identified. In Table 1 the specifications for those required as input for assessment of the various hypothetical mechanisms are given.

Table 1 Solar forcing parameter requirements for each Mechanism.

Mechanism	**Solar input**	**Time-scale**	**Requirements**	**Availability**
TSI	Total solar irradiance	11-year cycle	Many cycles $\Delta t \sim 1$ month	Yes, for nearly 3 cycles, although absolute value and underlying trends not well established.
		Multi-decade to century	$\Delta t \sim 1$ month	Yes – based on proxy solar activity measures - but absolute value not known and large uncertainties in secular trend.
Radiative heating of the middle and lower atmosphere	UV/visible spectral irradiance	27-day cycle	$\nu \sim 4{,}000 - 86{,}000\text{cm}^{-1}$ $\Delta\nu \sim 4{,}000\text{cm}^{-1}$ Many cycles (at solar max) $\Delta t \sim 1$ day	Yes, for 3 solar maxima.
		11-year cycle	$\nu \sim 4{,}000 - 86{,}000\text{cm}^{-1}$ $\Delta\nu \sim 4{,}000\text{cm}^{-1}$ Many cycles $\Delta t \sim 1$ month	Yes, for nearly 3 cycles, but data not contiguous and uncertainties in spectrum.
		Multi-decade to century	$\nu \sim 4{,}000 - 86{,}000\text{cm}^{-1}$ $\Delta\nu \sim 4{,}000\text{cm}^{-1}$ $\Delta t \sim 1$ month	No

UV production / destruction of ozone	UV spectral irradiance	Solar flares	$\nu \sim 14,000 - 23,000 cm^{-1}$ $\Delta\nu \sim 200 cm^{-1}$ and $\nu \sim 28,000 - 86,000 cm^{-1}$ $\Delta\nu \sim 500 cm^{-1}$ Many flares $\Delta t \sim 1$ hour	Records of flare events but not of spectra.
		27-day cycle	$\nu \sim 14,000 - 23,000 cm^{-1}$ $\Delta\nu \sim 200 cm^{-1}$ and $\nu \sim 28,000 - 86,000 cm^{-1}$ $\Delta\nu \sim 500 cm^{-1}$ Many cycles (at solar max) $\Delta t \sim 1$ day	Yes, for 3 solar maxima.
		11-year cycle	$\nu \sim 14,000 - 23,000 cm^{-1}$ $\Delta\nu \sim 200 cm^{-1}$ and $\nu \sim 28,000 - 86,000 cm^{-1}$ $\Delta\nu \sim 500 cm^{-1}$ $\Delta\nu \sim 400 cm^{-1}$ Many cycles $\Delta t \sim 1$ month	Yes, for nearly 3 cycles, but data not contiguous and uncertainties in spectrum.
SPEs destruction of ozone	Solar proton flux spectra	Several days (for each event)	$E \sim 0.5$ - 500MeV $\Delta E/E \sim 1$ Many events $\Delta t \sim 1$ day Geographical distribution of insertion locations.	Yes
Solar wind	??			
Ionisation	??			

Table 2 identifies the data inputs and anticipated outputs of a scheme designed to test the various hypothetical mechanisms.

Table 2 Fundamental physical/chemical processes associated with each Mechanism.

Mechanism	**Process**	**Inputs**	**Outputs**
TSI	??		
UV	Direct heating by UV.	UV spectral irradiance. Distributions of radiatively active gases (esp. ozone). Cloud distribution and radiative properties.	Heating rates as a function of latitude, longitude, altitude and time.

	Dynamical coupling (within the middle atmosphere).	Solar heating rate anomalies as a function of position and time (with and without ozone response).	Response of the middle atmosphere to solar UV variation: temperatures, wind and wave activity. Any additional effects due to ozone changes.
	Stratosphere-troposphere dynamical coupling.	Solar heating rate anomalies plus the response to these of stratospheric temperatures and winds.	Response of tropospheric circulations to perturbations in the stratosphere.
	Production of ozone by UV.	UV spectral irradiance as a function of time. Distributions of source gases and temperature.	Photochemical production rate of ozone as a function of latitude, longitude, altitude and time.
	Ozone transport.	Dynamical response of atmosphere to enhanced UV (i.e. changes in wind distribution).	Response of ozone concentration distribution to solar UV as a function of latitude, longitude, altitude and time.
SPEs	Destruction of ozone by SPEs.	SPE flux spectra. Distributions (climatology) of temperature, wind and chemically active constituents.	Response of NO_x and O_3 to solar proton events.
Solar wind	??		
Ionisation	??		

3 Interaction Mechanisms

Something on modelling TSI mechanisms??

Modelling studies of the solar modulation of climate via UV have traditionally been carried out by first estimating the predicted ozone changes between solar minimum and solar maximum (or 20th century versus Maunder Minimum values) using 2-D models that include relatively sophisticated chemical schemes. These monthly-averaged, zonally-averaged ozone changes are then used as input to the radiation schemes of full GCM simulations. In this way, the temperature and circulation response to the ozone changes can be assessed, although there is no possibility for those temperature and circulation changes to interactively feed back onto the ozone distributions. The prime methodology employed to assess the impact of including these additional ozone changes is to carry out model simulations with only TSI changes and compare them with simulations with both TSI and ozone changes. Most 'process' modelling studies, that seek to simulate the solar signal and thence explore the process mechanisms, employ models that extend from the ground to around 80 km in order to fully resolve the ozone distribution in the stratosphere.

Most of the modelling studies are unable to reproduce the secondary temperature (and ozone) maximum in the lower stratosphere (see section 7 of WP403). This is important because it not only represents a deficiency in the simulation of the middle atmosphere itself but also means that the stratospheric anomaly required as forcing for any stratosphere-troposphere coupling mechanisms is not adequately provided. It suggests an underestimation of the modelled dynamical feedback through a modification of the meridional circulation and this requires further investigation. There are also many deficiencies in the model simulations of the interaction between the solar and QBO influences (Labitzke et al. 2002) and these may be related to the same dynamical problems. Very few of the models employed include an adequate gravity wave parametrization scheme and this may be one factor that requires improvement (Arnold and Robinson, 2003).

Because of computing resource constraints, GCM simulations of solar influence have usually consisted of two 20-30 year runs, under perpetual solar minimum conditions and perpetual solar maximum conditions respectively, and the difference between the two runs used as an estimate of the peak-to-peak solar signal. By running for many years in 'perpetual' mode like this, the statistical significance of the results is substantially improved. In order to gain the equivalent statistical significance from a single simulation in which the time-varying 11-year solar signal is imposed, the simulation would need to be many hundreds of years long. Employing a coupled ocean-atmosphere model in which the ocean temperatures can adjust to the imposed solar changes is inappropriate for integrations of this type employed for 11-year solar cycle studies, because the atmosphere is never actually in solar minimum or maximum for long enough for the ocean to adjust to any great extent. In this case, the models are used with observed or climatological-mean sea surface temperatures imposed at their lower boundaries. On the other hand, estimates of longer term solar changes, such as those between 20^{th} century and Maunder Minimum values, are more appropriately carried out using a coupled model in which the ocean temperatures are able to respond and feedback onto the atmosphere component of the model.

Recently, improved computing capabilities have allowed the development of GCMs that include fully-coupled chemistry schemes so that improved feedback is possible not only from the ozone changes on to the temperature and circulation patterns but vice versa. However, the use of these fully-interactive chemistry GCMs for studies of the solar cycle influence is still at a relatively immature stage (e.g. Labitzke et al. 2002, Tourpali et al. 2003, Egorova et al. 2004, Haigh et al. 2004, Langematz et al. 2005, Schmidt et al. 2006) and runs with both coupled oceans and chemistry have yet to be carried out.

Table 3 Proposed GCM experiments to test Mechanisms.

Mechanism	**Process**	**GCM experiment**	**GCM type/specification**	**Notes**
TSI	??			

UV	Effects of enhanced UV on the dynamical structure of the middle and lower atmosphere.	Time slice solar max and solar min runs.	Surface to mesopause. Good vertical resolution (need instrinsic QBO). Radiation scheme with adequate spectral resolution. [M0]	> 40 year runs.
		Mechanistic studies of wave effects in middle atmosphere.	Stripped-down M0. E.g. raise lower boundary to tropopause, remove tropospheric physics (clouds etc)	Multiple runs to investigate statistics of wave propagation, sudden stratospheric warmings, link to radiative forcing distribution.
		11-year cycle modulations	M0	> 20 cycles (~200 years).
		Role of ocean in 11-year cycle.	M0 with coupled ocean. [M1]	ditto
		Decadal-centennial scale response to solar UV..	M1	Need statistics from very long (~1000 year) control run of model.
	Coupling between dynamics and chemistry (ozone)	Time slice solar max and solar min runs, response of oceans.	M0 with coupled chemistry scheme [M2]	> 20 year runs.
		27-day cycle modulations	M2	~ 20 year run
		11-year cycle modulations	M2	Long runs with coupled oceans and chemistry not currently feasible.

		Decadal-centennial scale.		Long runs with coupled oceans and chemistry not currently feasible. Could repeat centennial run above with prescribed (varying) ozone.
	Stratosphere-troposphere dynamical coupling.	Mechanistic studies of tropospheric response to perturbations in stratosphere.	Adapted M0. E.g. lower top to mid-stratosphere, increase vertical resolution near tropopause, simplify radiation scheme.	Multiple runs to investigate dynamical processes, especially wave propagation, response to stratospheric heating.
SPEs	Destruction of ozone by SPEs.	Effect of enhanced NO_x, including subsequent transport of low O_3 air.	M2. Either extend upwards into ionosphere or specify downward flux of NO_x.	Each run few months. Need ensembles to confirm statistics.
		Combined effects of UV and SPEs.	ditto	>20 year time slice solar max and solar min runs with SPEs added during solar max.
Solar wind	??			
Ionisation	??			Aerosol "indirect" effect on cloud already parametrised.

4 Summary

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