Temperature and Ozone Response to the 11-year Solar Cycle in the Tropical Stratosphere as Revealed by Ensemble Simulation of Chemistry-Climate Model

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• **Objectives**

• To investigate the 11-year solar signal in the ensemble (five members) simulation of the MRI coupled chemistry-climate model (CCM) forced by observed forcings (the CCMVal REF1 scenario).
MRI-CCM  (Shibata et al., 2005)

GCM : MRI/JMA98 (Shibata et al., 1999)
Chemistry module : full chemistry and transport process

Chemistry
  · 36 long-lived species including 7 families
  · 15 short-lived species (which are diagnosed)
  · 35 photodissociations and 80 gas phase reactions
  · 9 (6+3) heterogeneous reactions on PSCs and sulfate aerosols

Transport – **hybrid semi-Lagrangian scheme**
  · Horizontally, simple semi-Lagrangian scheme (quintic interpolation)
  · Vertically, flux-form semi-Lagrangian scheme (piecewise rational function method)

Resolution
  · 68 layers (del_z = 500m from 100 to 10hPa)
  · eta-ordinate (Surface to 0.01hPa)
  · T42 (64x128 Gaussian Grids: 2.8 deg)

**Gravity Wave Drag**
  · Hines (1997) parameterization with enhances source in the tropics
## CCMVal Simulations

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Core Time Period</th>
<th>GHG (N2O, CH4, CO2)</th>
<th>Halogen (CFCs..)</th>
<th>SSTs</th>
<th>Volcanic &amp; Background Aerosol</th>
<th>Solar Flux</th>
<th>QBO</th>
</tr>
</thead>
<tbody>
<tr>
<td>REF1</td>
<td>1980 - 2004</td>
<td>Observed WMO/UNEP 2002 runs</td>
<td>Observed WMO/UNEP 2002 runs</td>
<td>Observed HadISST1</td>
<td>Observed</td>
<td>Observed</td>
<td>Spontaneously Generated</td>
</tr>
</tbody>
</table>
Five members of the REF1 scenario run

1979

Fixed forcing run

2004

Spin-up integration period ~ 10 years

$T_{\text{QBO}} \sim 27$ mon
Evolution of total ozone
Multiple Linear Regression Analysis

\[ O_3(t) = A + B \times t + C \times QBO \,(50 \, \text{hPa}) \,(t) + D \times QBO \,(20 \, \text{hPa}) \,(t) + E \times \text{Pinatubo} \,(t - \alpha) + F \times \text{El Chichon} \,(t - \beta) + G \times \text{ENSO} \,(t) + H \times \text{Solar Flux} \,(t) + \text{Residual} \,(t) \]

To fit seasonal variability, the coefficients \( A, B, C, \ldots, \) and \( H \) are expanded as

\[ A = A_0 + A_1 \cos(\omega t) + A_2 \sin(\omega t) + A_3 \cos(2\omega t) + A_4 \sin(2\omega t) + A_5 \cos(3\omega t) + A_6 \sin(3\omega t) \]

\((\omega = 2\pi / (12 \, \text{months}))\)
QBO signals in a linear multiple regression analysis

**Model**

- **U-wind**

**ERA-40**

- **QBO 20hPa**
- **QBO 50hPa**
Temperature solar signal (ensemble mean)

ERA-40

Model
Zonal-wind solar signal (ensemble mean)

ERA-40

Model
Ozone solar signal (ensemble mean)

SBUV

Model
Temperature solar signal in each member
$w^*$ solar signal in each member
Ozone solar signal in each member
• **Summary**

  – MRI CCM successfully reproduced the upper stratospheric maximum warming, the lower stratospheric second warming over the tropics.

  – MRI CCM also simulated similar structure in ozone.

  – Quantitatively, however, the simulated temperature and ozone solar signals are underestimated.

  – Difference in the temperature and $w^*$ solar signals among the members suggests that the upper stratospheric upwelling and middle stratospheric downwelling are interrelated in the tropics.

  – **Difference in the solar ozone signal**

    • Very small in the upper stratosphere

    • Large below the middle stratosphere
w* signal (ensemble mean)