Changes in the ITCZ under combined greenhouse gas and solar forcings: Insights from the Geoengineering Model Intercomparison Project

RICK RUSSOTTO, TOM ACKERMAN, JANE SMYTH, TRUDE STORELVMO
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Solar geoengineering: How to cool the Earth from the SW side?

- Mirrors/Dust in Space
  - Bewick et al., 2012

- Stratospheric Aerosol Injection
  - Climate Central

- Marine Cloud Brightening
  - John McNeill
Why study geoengineering with climate models?

Science to inform policy debate
- Could it work?
- How much is necessary?
- Drawbacks/side effects/risks?

Better understand climate response to solar vs. greenhouse forcings
- Detection/attribution of climate change
- Paleoclimates
- Aerosol & volcanic forcings
The Geoengineering Model Intercomparison Project (GeoMIP)

**Experiment G1: equal, opposing forcings**

Abruptly quadruple $\text{CO}_2$

Reduce solar constant for zero net forcing/zero global mean temperature change

**Analysis procedure:**

Average years 11-50

Subtract out CMIP5 piControl average

### G1: Participating Models
(fully coupled atmosphere-ocean GCMs)

<table>
<thead>
<tr>
<th>Model</th>
<th>Country</th>
<th>Solar constant reduction</th>
<th>Global mean temperature change (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNU-ESM</td>
<td>China</td>
<td>4.4 %</td>
<td>0.03</td>
</tr>
<tr>
<td>Can-ESM2</td>
<td>Canada</td>
<td>4.0 %</td>
<td>-0.01</td>
</tr>
<tr>
<td>CCSM4</td>
<td></td>
<td>4.1 %</td>
<td>0.23</td>
</tr>
<tr>
<td>CESM1-CAM5.1-FV</td>
<td>USA</td>
<td>4.7 %</td>
<td>-0.16</td>
</tr>
<tr>
<td>CSIRO-Mk3L-LR</td>
<td>Australia</td>
<td>3.2 %</td>
<td>0.03</td>
</tr>
<tr>
<td>GISS-E2-R</td>
<td>USA</td>
<td>4.5 %</td>
<td>-0.29</td>
</tr>
<tr>
<td>HadGEM2-ES</td>
<td>United Kingdom</td>
<td>3.9 %</td>
<td>0.24</td>
</tr>
<tr>
<td>IPSL-CM5A-LR</td>
<td>France</td>
<td>3.5 %</td>
<td>0.11</td>
</tr>
<tr>
<td>MIROC-ESM</td>
<td>Japan</td>
<td>5.0 %</td>
<td>-0.07</td>
</tr>
<tr>
<td>MPI-ESM-LR</td>
<td>Germany</td>
<td>4.7 %</td>
<td>-0.01</td>
</tr>
<tr>
<td>NorESM1</td>
<td>Norway</td>
<td>4.0 %</td>
<td>-0.04</td>
</tr>
</tbody>
</table>
Map of precipitation change

Global mean precipitation is reduced because sunlight reduction reduces surface evaporation.

Strongest in tropics, except equatorial Atlantic/Pacific.

Multi-model mean map: hatched where fewer than 9 of 12 models agree on sign of change

(Kravitz et al., *J. Geophys. Res. Atmos.*, 2013a)
ITCZ shifts in individual models

If one hemisphere is preferentially cooled, tend to have ITCZ shift towards other hemisphere.

Russotto and Ackerman, *Atmos. Chem. Phys.*., 2018
Anticorrelation with cross-equatorial energy transport

Useful for attributing sources of inter-model spread.

Russotto and Ackerman, *Atmos. Chem. Phys.*, 2018
Attribution experiments with moist EBM

Following procedure of, *e.g.*, Frierson and Hwang (2012)

Plug TOA radiation changes associated with various physical processes into EBM. How does cross-equatorial MSE transport respond?

Cloud adjustments largest source of inter-model spread.

Russotto and Ackerman, *Atmos. Chem. Phys.*, 2018
Seasonal migration of ITCZ

Seasonal migration dampened in geoengineered climate.

Reason: preferential cooling of summer hemisphere.

Multi-model mean ITCZ position

Waliser and Gautier, *J. Climate*, 1993
Seasonal migration of ITCZ

Damping occurs in every model.

Key
- JFM
- Annual Mean
- JAS
- piControl G1

Smyth et al., *Atmos. Chem. Phys.*, 2017

Climatology

Waliser and Gautier, *J. Climate*, 1993
ITCZ shift vs. inter-hemispheric temperature change in seasons

Boreal Summer

Boreal Winter

Smyth et al., Atmos. Chem. Phys., 2017
Summary

Under 4xCO$_2$ and reduced solar constant, such that net forcing is zero:

- Some models exhibit ITCZ shifts.
- The cloud response is the largest source of inter-model spread therein.
- The seasonal migration of the ITCZ is weakened due to preferential cooling of the summer hemisphere.

Unresolved questions:

- How much of annual mean ITCZ narrowing is due to the seasonal migration reduction?
- CO$_2$ + solar responses: how linear?
Slides taken out
What if we injected in only one hemisphere?

Precipitation change from injecting 5 Tg SO$_2$/year into Northern Hemisphere (a) or Southern Hemisphere (b) in HadGEM2-ES model. (Haywood et al., 2013)
Climatological Northward Energy Transport by the Atmosphere

Atmosphere moves energy from equator to poles.
Change in Northward Energy Transport

*Decrease* in poleward energy transport!

Opposite of global warming case.

Moisture transport accounts for discrepancy.

The reduced poleward energy transport limits the polar warming.