Chemical/Dynamical Interactions and Consequences for Climate

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Antarctic Minimum Total Ozone

1988 minor warming

2002 major warming
Variability of Antarctic Ozone

pre-1980: little variability

much increased day-to-day and interannual variability

South Pole
Syowa

Solomon et al. 2005
Feedback

ODSs

PSCs ↑

O$_3$ ↓

UV

$\tau \sim 2$ months

adiabatic warming ↓

Mixing ↓

BDC↓ (?)

T ↓

Vortex ↑

-waves / wQBO (random)
greenhouse gases (systematic trends)

Photo-Chemical (PC)

Dynamical-Chemical (DC)
Basic Strategy

• Hypothesized positive feedbacks should
  o increase persistence on intraseasonal time scales, and
  o increase variability on interannual time scales.

• Feedback response = results from
  (models with feedbacks) minus
  (models in which feedbacks are turned off)
CCMVal-2

• Coupled chemistry-atmosphere models; multi-model means of 5 common models
• Transient simulations: 1960-2100

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<thead>
<tr>
<th>name</th>
<th>forcings</th>
<th>factors</th>
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</thead>
<tbody>
<tr>
<td>B2</td>
<td>varying GHGs and ODSs</td>
<td>DC + PC + ↑CO₂</td>
</tr>
<tr>
<td>B2b</td>
<td>1960 ODSs</td>
<td>DC + ↑CO₂</td>
</tr>
<tr>
<td>B2c</td>
<td>1960 GHGs</td>
<td>DC + PC</td>
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SAM (Z50)
CCMVal-2 model

SH Z50, January

B2 (GHGs + ODSs vary)

Slowly varying trend removed

Increased variability

B2b (fixed ODSs, GHGs vary)
SAM (Z50) Interannual Variability

Ozone depletion vs. ozone recovery period

Month

interannual variability (m)

CCMVal-2 1980-2011

NNR 1980-2011

CCMVal-2 2068-2099

CMIP3 1979-1999
GFDL-CM3

- Coupled chemistry-climate model
- Long time-slice simulations (500-2000 years)

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<th>name</th>
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<tr>
<td>CTRL</td>
<td>1860</td>
<td>DC</td>
</tr>
<tr>
<td>DEPLO3</td>
<td>1990 CO₂ and ODSs</td>
<td>DC + PC + ↑CO₂</td>
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<tr>
<td>FIXO3</td>
<td>1860, fixed ozone</td>
<td>-</td>
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- Caveats
  - DEPLO3 has no Arctic ozone depletion
  - DEPLO3 has changing CO₂
  - FIXO3 has more SSWs (46%) than CTRL (36%) or DEPLO3 (35%)
• TOZ and SAM anomalies last for several months
• On average, TOZ has longer time scale than SAM
• PC strongly increases TOZ persistence
• DC influence is noticeable
Cross-Correlation: TOZ & SAM10

- Correlations between TOZ and SAM are strongly positive, in particular during austral spring
- Correlations are larger when SAM leads TOZ
- Correlations are larger in DEPLO3 than in CTRL (not shown)
Cross-Correlation: TOZ & SAM10

- Correlations between TOZ and SAM are strongly positive, in particular during austral spring
- Correlations are larger when SAM leads TOZ
- Correlations are larger in DEPLO3 than in CTRL (not shown)
- Correlations are larger than auto-correlation of SAM in FIXO3 (= no-feedback null-hypothesis)
Polar Vortex: U10 @ 60°S

First 100 years each
Polar Vortex: U10 @ 60°S

Mean

Interannual Variability

CTRL
FIXO3
DEPLO3
SAM Interannual Variability

GFDL-CM3

Geopotential height, October

Pressure (hPa)

CTRL
FIXO3
DEPLO3
SAM Interannual Variability

CTRL

DEPLO3

FIXO3

(percentage change)

PC + ↑CO₂

DC
SAM Interannual Variability Change

CCMVal-2 vs. GFDL-CM3

B2 – B2b: PC

B2 – B2c: ↑CO₂

DEPLO3 – CTRL: PC + ↑CO₂

(percentage change)
NAM Interannual Variability Change

CCMVal-2 vs. GFDL-CM3

B2 – B2b: PC

B2 – B2c: ↑CO₂

DEPLO3 – CTRL: PC + ↑CO₂

(percentage change)
Conclusion

• Our results are consistent with the hypothesized feedbacks
  – feedbacks increase Antarctic climate variability
    • up to 80% in stratosphere
    • 5% in troposphere
  – photo-chemical feedback (PC) strongly amplifies dynamical-chemical feedback (DC)

• Anthropogenic ozone depletion increases climate variability
  – impact on sea ice variability and detectability of trends

• Models without interactive chemistry underestimate natural climate variability