Future Arctic Temperature and Ozone: The Role of Stratospheric Composition Changes

Ulrike Langematz, Stefanie Meul, Katja Grunow, Erik Romanowsky, Sophie Oberländer, Janna Abalichin and Anne Kubin

Freie Universität Berlin
Germany
Arctic Ozone in March 2011

- Unprecedented Arctic ozone loss
- Comparable to Antarctic ozone hole
- Due to
  - persistent cold lower stratosphere from early winter into spring
    - early onset of denitrification
    - long-lasting enhanced chlorine activation
  - large $V_{PSC}$

Is there a risk that such extreme Arctic ozone-hole-like events will become more frequent in a future with climate change?

Manney et al., 2011
Questions

• What is the effect of increasing GHG concentrations on the Arctic polar lower stratosphere?
  
  Radiative cooling → More PSCs → More ozone loss
  
  or

  Dynamical forcing → Arctic warming → Less ozone loss

• How will the meteorological conditions in the Arctic lower stratosphere change with rising GHGs?
• How will ozone be affected?
• How do GHG increases modify the ODS effect on ozone?
Method

Analysis of chemistry climate model (CCM) data from 1865 to 2100

Model

EMAC

- ECHAM-MESSy Atmospheric Chemistry model (EMAC) (Jöckel et al., 2006; Röckner et al., 2006)
- Interactive chemistry model MECCA (Sander et al., 2005)
- Improved shortwave radiation scheme FUBRad (Nissen et al., 2007)
- Resolution: T42 (2.8° x 2.8°), L39 (top at 0.01 hPa, ~80 km)
- Contributed to CCMVal-2
Simulations

- transient, 1960-2100

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Period</th>
<th>Greenhouse Gases</th>
<th>ODSs</th>
<th>SSTs/SICs</th>
<th>Background &amp; Volcanic Aerosol</th>
<th>Solar Variability</th>
<th>QBO</th>
<th>Ozone and Aerosol Precursors</th>
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</thead>
</table>

- timeslices (40 years)

<table>
<thead>
<tr>
<th></th>
<th>R1865</th>
<th>R1960</th>
<th>R2000</th>
<th>R2045</th>
<th>R2095</th>
<th>S2045</th>
<th>S2095</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHGs</td>
<td>1865</td>
<td>1960</td>
<td>2000</td>
<td>2045</td>
<td>2095</td>
<td>2045</td>
<td>2095</td>
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Stratospheric cooling due to GHG increases?

Temperature change 1960-2099
[K/decade]

• Cooling in early winter, but no significant change in mid-winter and spring
• Due to GHG increase (as no change in NCC simulation)
More future cold Arctic winters?

Arctic minimum temperatures

REF, November/December

$-0.18 \pm 0.03 \, \text{K/dec}$

NCC, November/December

$-0.01 \pm 0.03 \, \text{K/dec}$

REF, March

$+0.13 \pm 0.06 \, \text{K/dec}$

Future decrease in minimum temperature only in early winter
Seasonal evolution of Arctic minimum temperatures for individual forcings

Range of $T_{\text{min}}$ in EMAC agrees with observations. ODS lead to lower $T_{\text{min}}$ in late winter; GHGs in early winter.

Pawson and Naujokat, 1997
Arctic polar vortex persistence

Zonal wind transition, 65°N, 50 hPa

summer ➔ winter

winter ➔ summer

REF: -1.12 ± 0.45 days/dec.

Earlier buildup of polar vortex with increased GHGs

REF: -0.18 ± 0.44 days/dec.

Individual late breakdown with high ODS, but no significant change
Stronger dynamical forcing of the stratosphere?

100 hPa eddy heat flux

Enhanced planetary wave forcing from troposphere in mid-winter due to GHG increase
What is the effect on Arctic total ozone?

Maximun $V_{PSC}$ with climate change during 1st half of 21st century

Rex et al., 2006
Potential PSC area with $T < T_{\text{NAT, mod}}$

50 hPa, 40°-90°N

Enhanced PSC formation potential in early winter due to GHGs
Potential PSC area with $T < T_{\text{NAT,mod}}$ as a function of height

40°-90°N

Improved conditions for PSC formation in the middle stratosphere due to GHG induced cooling
Accumulated potential PSC area fraction

50 hPa, 40°-90°N

Strong increase by ODS in **late** winter
Strong increase by GHG in **early** winter

Maximum accumulated $V_{PSC}$ in 2045
Arctic total ozone in March

Anomalies from 1960 average

Δ = -8.42577

Δ = 0

Δ = -19.5525

Δ = 35.0697

Δ = 12.4542

Δ = 52.8797

Δ = 15.773
Arctic total ozone in March

![Graph showing Arctic total ozone in March](image)
Conclusions

- Future cooling of Arctic lower stratosphere in early winter, but no significant change in mid-winter and March
- Extended future lifetime of Arctic polar vortex due to earlier build-up
- Enhanced future dynamical forcing of the stratosphere in mid-winter
- Future decrease in minimum temperature only in early winter
- Lower early winter temperatures lead to higher PSC formation potential in future, however no enhanced Arctic spring ozone losses due to dynamical impact
- Increase of future increase in $V_{PSC}$ not confirmed for 2nd half of 21st century
- No tendency to future Arctic ozone holes, but individual events possible