Arctic stratosphere dynamical response to global warming

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Motivation

- Stratospheric circulation is known to influence the troposphere during winter
- Future changes in stratospheric circulation will affect the troposphere
- How will the Arctic stratosphere change?

Kidston et al. 2015
The Arctic SLP decreases in response to climate change
- Dynamical warming of the Arctic stratosphere offsets the SLP response to climate change
- SLP response influences climatic responses
- In particular, Northern Europe (Mediterranean) gets more (less) precipitation in climate changes scenarios
- The precipitation response is reduced due to the changes in the stratospheric circulation

Motivation (2)

Karpechko and Manzini 2012
Arctic polar vortex changes -> ?

In the Northern Hemisphere future changes in the Arctic polar vortex remain poorly understood

- Equatorward shift of the polar night jet
- Most common response to GHG increases in stratosphere-resolving models (~70% of CMIP5 models)
  
  but
  - ...not robust across models
  - unknown mechanisms

Large uncertainty

Manzini et al. 2014
CMIP5 Amip experiments

The experiment:
- 12 models in amip4K and amipFuture experiments
- Constrained atmospheric warming, ~ similar across all models
CMIP5 Amip experiments

The experiment:
- 12 models in amip4K and amipFuture experiments
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The response:
- Strengthening of the subtropical jet
- Weakening of the extratropical winds in the stratosphere and troposphere
- Temperature change in the stratosphere dominated by equator cooling /polar warming pattern
  - The pattern suggests a dynamical origin of the temperature changes

*Karpechko and Manzini 2017*
Causes for dynamical heating of the stratosphere

Changes in wave generation: more wave activity is generated in the troposphere

or / and

Changes in transmitting properties of the atmosphere: wave activity more effectively influences polar vortex (e.g. Sigmond and Scinocca 2010)

Diagnosed by increased eddy heat flux at 100 hPa
Dynamical driving of stratospheric changes

- Eddy heat flux at 100 hPa
- Separated into stationary (monthly scale) and transient (sub-monthly scale) components
- Eddy heat flux increases in extratropics during winter
- The increase is mostly due to stationary wave component (and mostly wave 1 component)
- The increase is remarkably robust across models and similar in both amip4K and amipFuture scenarios

Karpechko and Manzini 2017
Dynamical driving of stratospheric changes

- Eddy heat flux due to stationary wave 1 in NDJF
- The heat flux increases through most of the stratosphere
- The heat flux increases in mid-latitude troposphere, suggesting increased wave generation followed by increased upward and poleward propagation of wave activity
- The increase is remarkably robust across models and similar in both amip4K and amipFuture scenarios

Karpechko and Manzini 2017
Changes in tropospheric waves

- Eddy geopotential height response at 500 hPa averaged during Nov-Feb
- The response features a wave train across North Pacific and North America
- The strongest response is a low in North Pacific (also a high in North America)
- The response is remarkably robust across models and similar in both amip4K and amipFuture scenarios

Karpechko and Manzini 2017
Changes in tropospheric waves (cont.)

- A low in North Pacific is consistent with warming of the Arctic stratosphere both in models and in ERA-I.
- A low in North Pacific is consistent with increased wave 1 eddy heat flux to the Arctic stratosphere both in models and in ERA-I.
Proposed mechanism

1. Strengthening of UTLS winds
2. Increased generation and poleward propagation of planetary waves
3. Increased upward propagation of wave activity due to wave-1
4. Dynamical warming of the Arctic stratosphere
Arctic stratosphere warming correlates with changes in tropospheric waves in North Pacific across models

Changes in tropospheric waves in North Pacific correlates with changes in subtropical winds across models

Changes in subtropical winds correlates with Arctic stratosphere warming across models

The above statistics provide support for the mechanism and suggests that a dynamical warming of the Arctic stratosphere is the most likely response.
Summary

- The Arctic stratosphere warms, and the sub-polar stratospheric westerly winds weaken in the CMIP5 amip experiments with prescribed SST warming.

- The stratospheric changes are driven by increased wave activity flux into the stratosphere.

- The increased stratospheric wave activity is mostly due to increased generation of stationary wave 1 in the troposphere.

- The above changes are remarkably robust across all models participating in the experiments.

- We propose that the increased wave activity and Arctic stratosphere warming are ultimately related to increased wind speed of the subtropical jet stream, a robust response to the global warming.
Mechanism

- Stronger subtropical winds
  - Increased generation of planetary wave activity
    - Larger amplitude of stationary wave 1 in the troposphere
      - Larger wave activity flux into the stratosphere
        - Stronger stratospheric meridional circulation
          - Warmer polar stratosphere/weaker polar vortex