Seasonal response of the jet-stream to tropospheric warming

Elizabeth A. Barnes
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with input from collaborator
Lorenzo Polvani, Columbia U./LDEO

Figure 6: Multi-model mean change in zonal-mean temperature of 25 CMIP5 models between the Historical (1980-2004) and RCP8.5 (2076-2099) simulations. Contours show the standard deviation of the response across models contoured every 0.25 K.

The third focus of this work is to quantify the potential for future Arctic warming to drive changes in the midlatitude atmospheric circulation, and thus, for a possible feedback between Arctic temperatures and water vapor transport into the Arctic. Many research efforts have focused on the midlatitude circulation response to tropical, rather than polar, warming. A robust result of these studies is that tropical warming tends to shift the midlatitude circulation poleward, into a more positive NAO-like state (e.g. [16, 85, 30]). However, Arctic sea ice loss tends to shift the circulation into a more negative NAO-like state (e.g. [52, 20, 21, 65]). Thus, the response of the midlatitude circulation to increasing GHG concentrations is a complex interaction of changes at all latitudes and heights, and the CMIP5 models show substantial disagreement in the amount the circulation will shift by the end of the 21st Century.

We will investigate the possibility of a two-way linkage between Arctic warming and the midlatitude circulation using a hierarchy of model experiments. Specifically, we will explore the role of the remote response of the midlatitude circulation to future Arctic warming in driving water vapor feedbacks within the Arctic. The specific objectives of Part III are:

- To quantify the sensitivity of the midlatitude circulation to polar and tropical warming.
- To determine how changes in the circulation due to Arctic warming may modify water vapor transport into the Arctic.

CMIP5 multi-model mean temperature response under RCP8.5
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preliminary work

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Linear regression approach: explaining model spread

Fig. 6 shows the change in zonal-mean temperatures projected by 25 CMIP5 models under RCP8.5. Arctic amplification emerges as a robust signal in DJF, while warming throughout the troposphere is more spatially uniform in JJA. The black contours denote the standard deviation of the model responses, and shows that the degree of warming in the polar lower-troposphere is the most uncertain. We hypothesize that a tug-of-war likely exists...
- Arctic has been warming substantially compared to other latitudes in recent years
- Some work suggested that the warming Arctic is influencing midlatitude weather by modifying the large-scale near-surface temperature gradient
  
  e.g. Francis & Vavrus (2012)
By 2100, models project that the near-surface temperature gradient will decrease in the cool months with Arctic amplification (DJF).

- The near-surface story in summer (JJA) is not as clear.

- Note that the largest uncertainty among models is in DJF as well.
Large seasonality in CMIP5 future jet shift response

- Jet shift has a rich seasonality
- Could be due to a few factors
  1. **Seasonality of forcing** (e.g. sea ice loss and Arctic amplification)
  2. **Seasonality of the circulation** (even for constant forcing)
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Response to GHG independent of season?

Delayed Southern Hemisphere Climate Change Induced by Stratospheric Ozone Recovery, as Projected by the CMIP5 Models

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(Manuscript received 20 April 2013, in final form 5 August 2013)
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(Manuscript received 20 April 2013, in final form 5 August 2013)
Largest response in summer?

- forced GCM with increased greenhouse gases
- found largest SH response zonal winds in summer (DJFM)

Southern Hemisphere Atmospheric Circulation Response to Global Warming

Paul J. Kushner, Isaac M. Held, and Thomas L. Delworth
NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey

(Manuscript received 24 February 2000, in final form 1 August 2000)

ABSTRACT

The response of the Southern Hemisphere (SH), extratropical, atmospheric general circulation to transient, anthropogenic, greenhouse warming is investigated in a coupled climate model. The extratropical circulation response consists of a SH summer half-year poleward shift of the westerly jet and a year-round positive wind anomaly in the stratosphere and the tropical upper troposphere. Along with the poleward shift of the jet, there is a poleward shift of several related fields, including the belt of eddy momentum-flux convergence and the mean meridional overturning in the atmosphere and in the ocean. The tropospheric wind response projects strongly onto the model’s “Southern Annular Mode” (also known as the “Antarctic oscillation”), which is the leading pattern of variability of the extratropical zonal winds.
The model: dry dynamical core

- Driven by Newtonian relaxation to equilibrium temperature profile
- Lin-Rood semi-Lagrangian scheme for horizontal advection & finite volume parabolic scheme for vertical advection
- No well-resolved stratosphere
- No moisture
- Add seasonal cycle (360 day year) by varying the equilibrium temperature profile following Polvani & Kushner 2002

Held & Suarez (1994)
The Steady-State Atmospheric Circulation Response to Climate Change–like Thermal Forcings in a Simple General Circulation Model

AMY H. BUTLER, DAVID W. J. THOMPSON, AND ROSS HEIKES
Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado

follow a similar setup to earlier idealized studies

1. near-surface warming at pole
2. upper-tropospheric warming at equator

See how the circulation responds to forcing at different times of the year
Experimental setup

- **Control:**
  - spin-up for 3 years, 6 years for climatology

- **Heating runs:**
  - 9 branching runs each of length 540 days
  - branches are 10 days apart in a month, so 3 per month per year
  - heating is held constant throughout the 540 days (initialized in specific month)
  - all quantities are first averaged over ensembles before any analysis
maximum heating of 0.5 K/day (similar to Butler et al. 2010)
Temperature response in first month of Jan. heating

Graph showing temperature response after 1 month (K) across different latitudes and pressures.
POLAR: zonal wind response to January heating

- response is a decrease in zonal winds
- response is an equatorward shift of the jet
- response to January heating is largest in spring
POLAR: seasonality of the response of $u$

525hPa $u$ at 60°N

Maximum response of 500 hPa $u$ at 60°N

$u$ response is largest in March/April no matter when the forcing is applied
u response is largest in March/April no matter when the forcing is applied
POLAR: seasonality of the response of the jet position

Jet shift is generally largest in **spring**, although not as much agreement.
TROP: zonal wind response to January heating

- response is an increase in zonal winds
- response is a poleward shift of the jet
- response to January heating is largest in autumn
u response is largest in **October** no matter when the forcing is applied
TROP: seasonality of the response of the jet position

Jet shift is generally largest in late summer/autumn, although not as much agreement as for u
jet shift is generally largest in late summer/autumn, although not as much agreement as for u
Hadley cell edge and midlatitude jet location

Ceppi & Hartmann (2013)

the strongest correlations between the Hadley cell edge and the jet will occur when the meridional gradient of the upper-tropospheric zonal winds is weakest (i.e. in summer when the winds are weakest)

Kang & Polvani (2011)
TROP: wind response at 300 hPa

- response of $u$ is largest for tropical heating in the summer/autumn when the zonal winds are weakest

- further work is needed to confirm that this is due to the Hadley circulation response being coupled to the midlatitude wind response in that season
POLAR: Explaining CMIP5 model spread with AA

- Results for the North Atlantic only
- Arctic warming explains the most model spread in the zonal wind response in spring
- This is not a measure of the model's climate sensitivity (green lines)

\[ \text{AA} = 850 \text{ hPa temperature change over 70-90N; 230-350E} \]

Barnes & Polvani (in prep)
POLAR: Explaining CMIP5 model spread with AA

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Barnes & Polvani (in prep)
Final thoughts...

- Preliminary results suggest that certain seasons may be “primed” for a larger jet response
  - this result is independent of the timing of the initial heating
- These results aren’t necessarily surprising
  - many studies have shown different sensitivities of the circulation to mean-state (e.g. jet latitude or subtropical jet proximity)
  - However, a thorough understanding of the circulation seasonality to a fixed forcing is likely required to understand circulation changes over the 21st Century
- Much more work to be done...
  - e.g. determine robustness to model setup, mean state, magnitude of forcing, sign of forcing
  - experiment with both polar and tropical upper-tropospheric heating imposed at the same time
CMIP5 seasonality of historical jet-stream position

CMIP5 Historical jet latitude (N. Atlantic)

CMIP5 Historical jet latitude (North Pacific)
CMIP5 seasonality of jet-stream position response

CMIP5 jet shift (North Pacific)

CMIP5 jet shift (N. Atlantic)

bars denote 25–75 %tiles
Stratospheric Ozone Depletion: The Main Driver of Twentieth-Century Atmospheric Circulation Changes in the Southern Hemisphere

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a: (2000 – 1960) SPARC ozone at 50 hPa

b: (2000 – 1960) polar cap SPARC ozone
Tropospheric response to stratospheric perturbations in a relatively simple general circulation model

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Paul J. Kushner
NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey, USA

[23] The tropospheric relaxation temperature is given by

\[ T_{eq}^{trop}(p, \phi) = \max[T_T, (T_0 - \delta T)(p/p_0)^\kappa], \]  

where \( T_0 = 315 \) K, \( p_0 = 1000 \) mb, and \( \kappa = 2/7 \), with

\[ \delta T = \delta_y \sin^2 \phi + \epsilon \sin \phi + \delta_z \log(p/p_0)\cos^2 \phi \]  

where \( \delta_y = 60\text{K}, \delta_z = 10\text{K}, \) and \( \epsilon = 10\text{K} \). The nonzero value of \( \epsilon \) provides a simple asymmetry between the winter and summer hemispheres. Continuity of \( T_{eq} \) at \( p = p_T \) results from the choice \( T_T = T_{US}(p_T) \).
Arctic sea ice loss

Arctic Sea Ice Extent
(Area of ocean with at least 15% sea ice)

Extent (millions of square kilometers)

2013

12
10
8
6
4
2

Jun
Jul
Aug
Sep
Oct

National Snow and Ice Data Center, Boulder CO

1981–2010 Average
±2 Standard Deviations

2013
2012
2011
2010
2009
2008

September Monthly Arctic Sea Ice Extent
September 1979-2013
NSIDC

HIGH (1980–2012)
HIGH (1990–2012)
LOW
Table S1. Data availability of CMIP5 model output

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