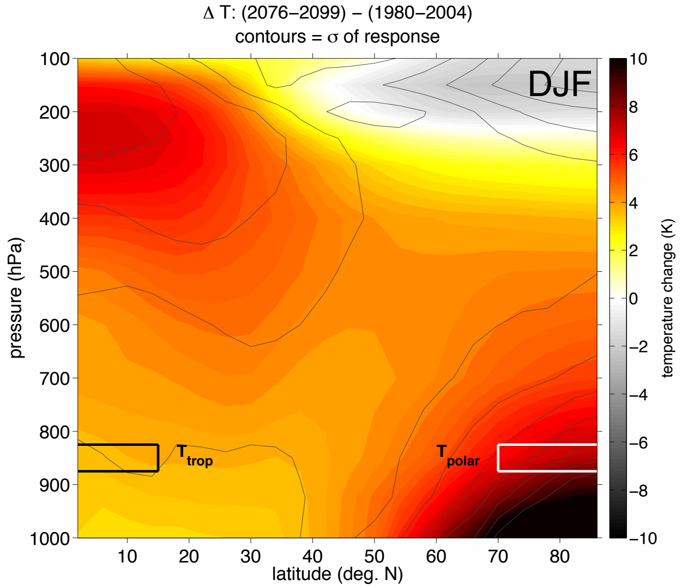
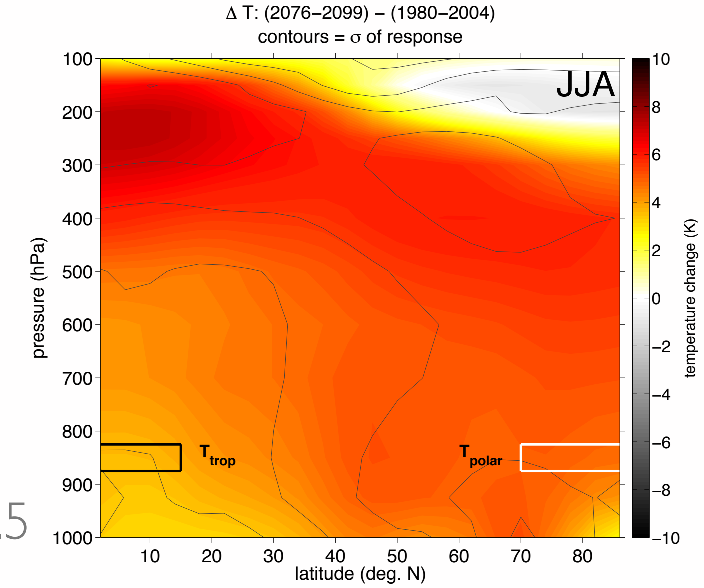
Seasonal response of the jet-stream to tropospheric warming

Elizabeth A. Barnes
Colorado State University

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





CMIP5 multi-model mean
temperature response under RCP8.5

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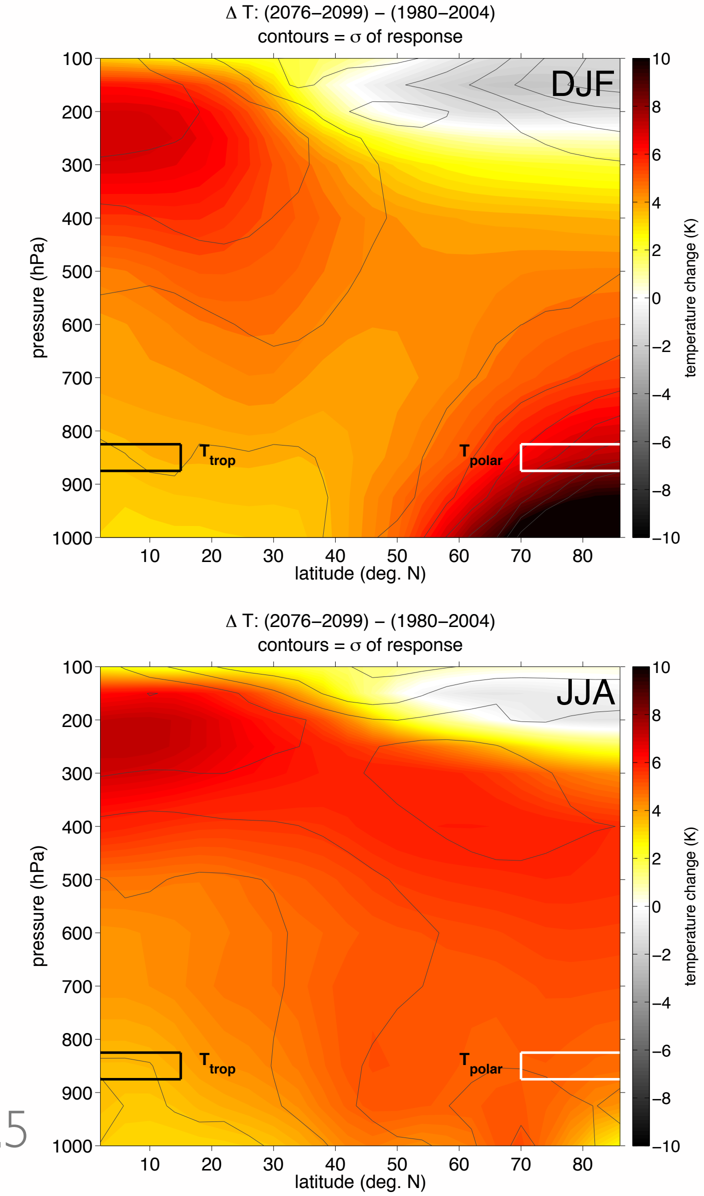
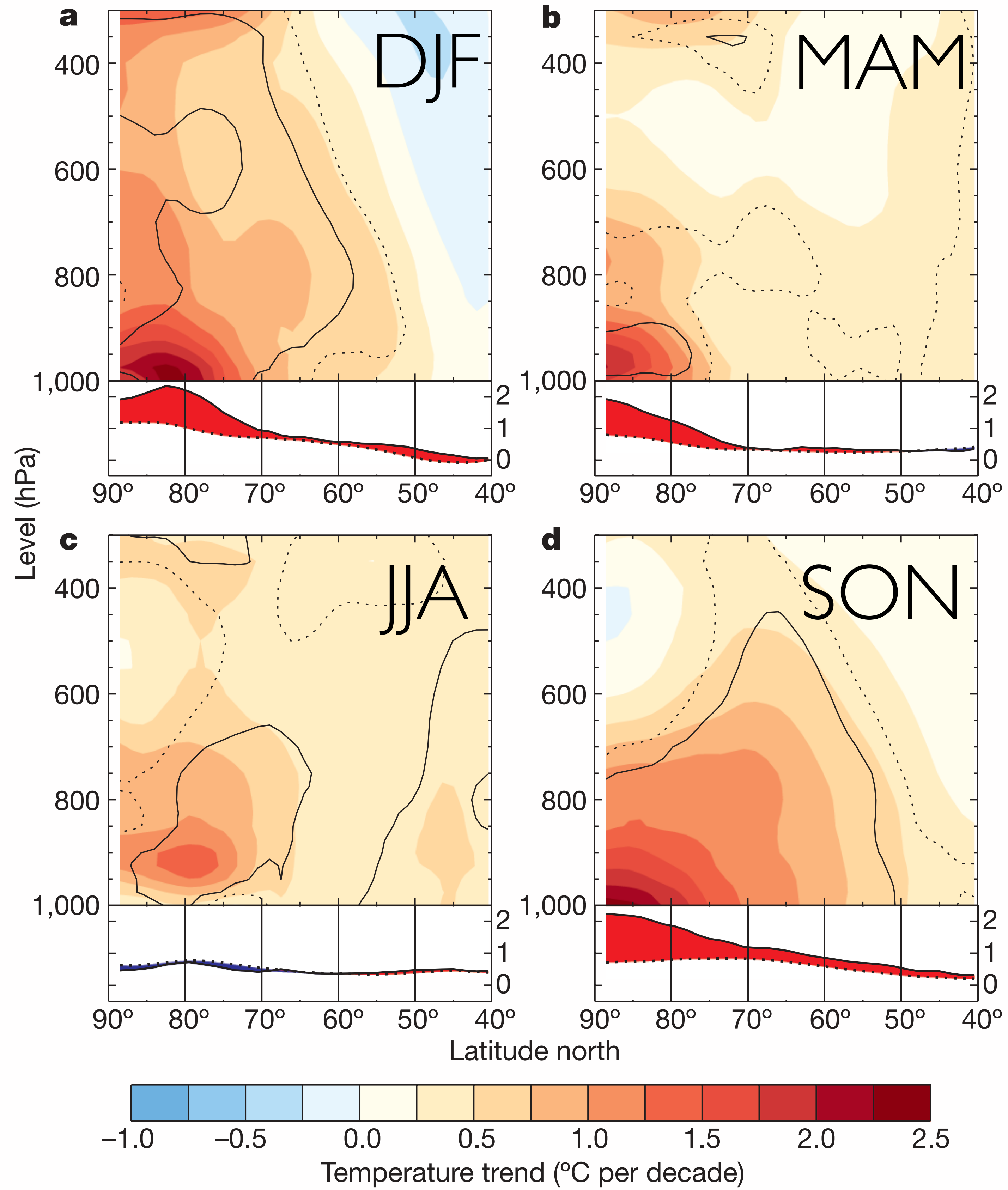
preliminary work



CMIP5 multi-model mean
temperature response under RCP8.5

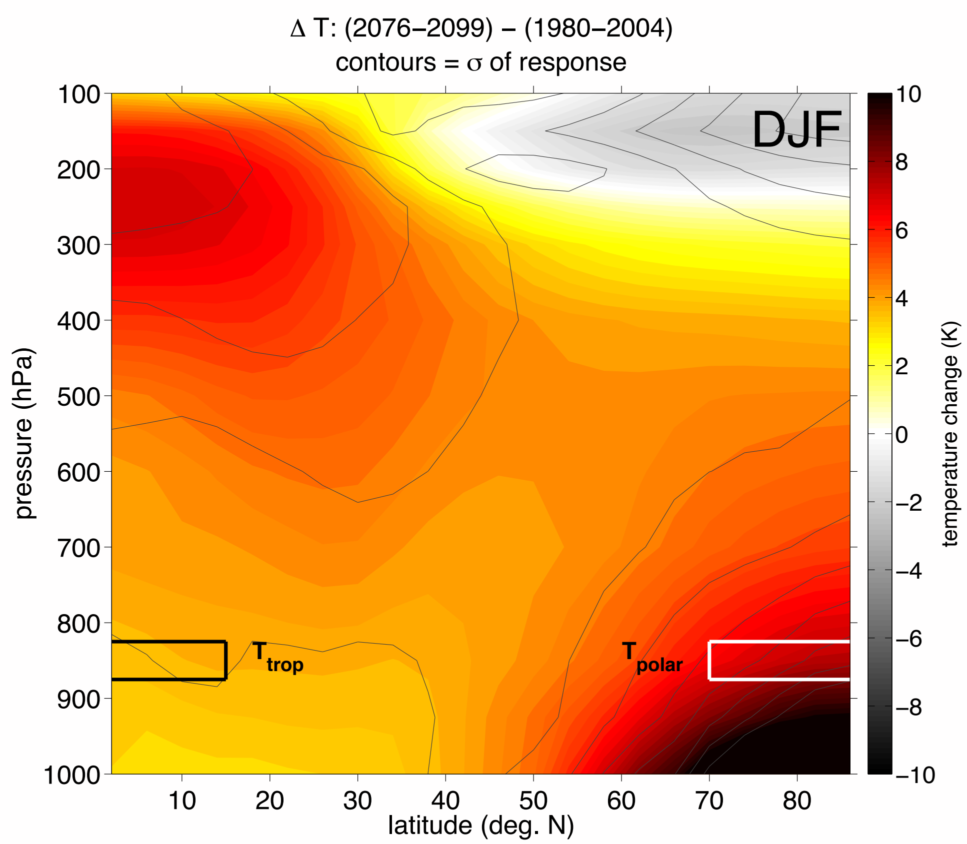
ERA-Interim temp. trends: 1989-2008

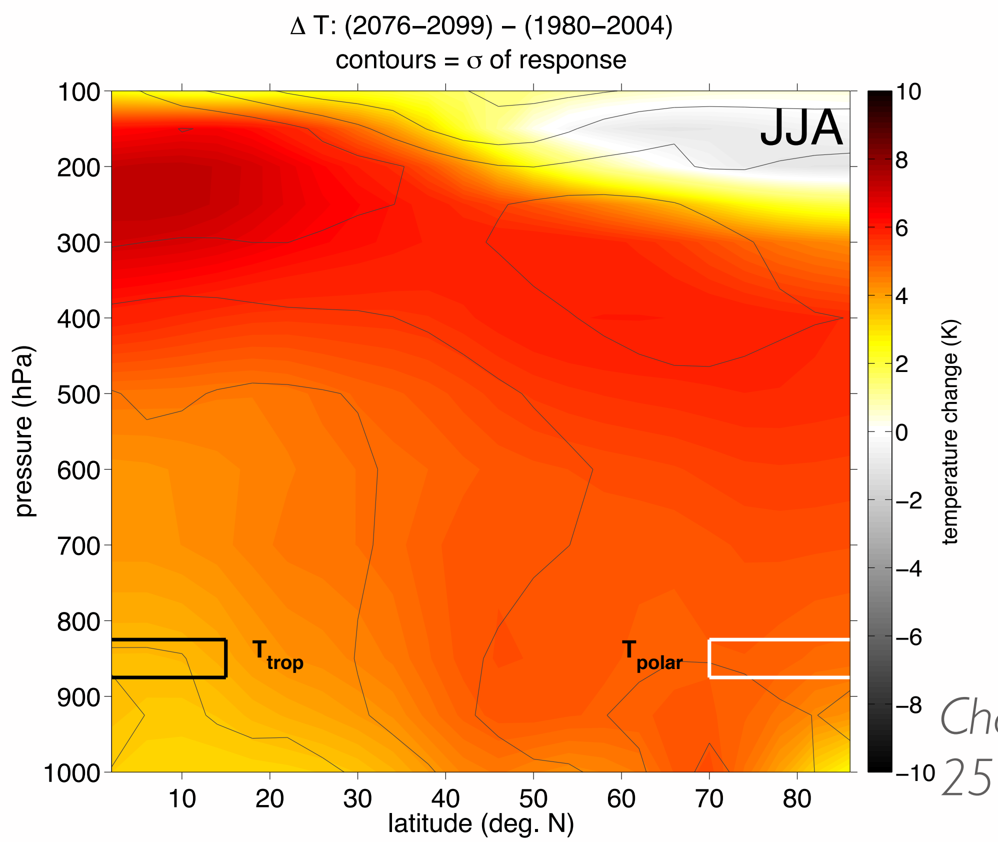
- Arctic has been warming substantially compared to other latitudes in recent years
- Some work suggested that the warming Arctic is influencing midlatitude weather by modifying the large-scale near-surface temperature gradient
  e.g. Francis & Vavrus (2012)



Screen & Simmonds (2010); NAT

CMIP5: temperature response by 2100

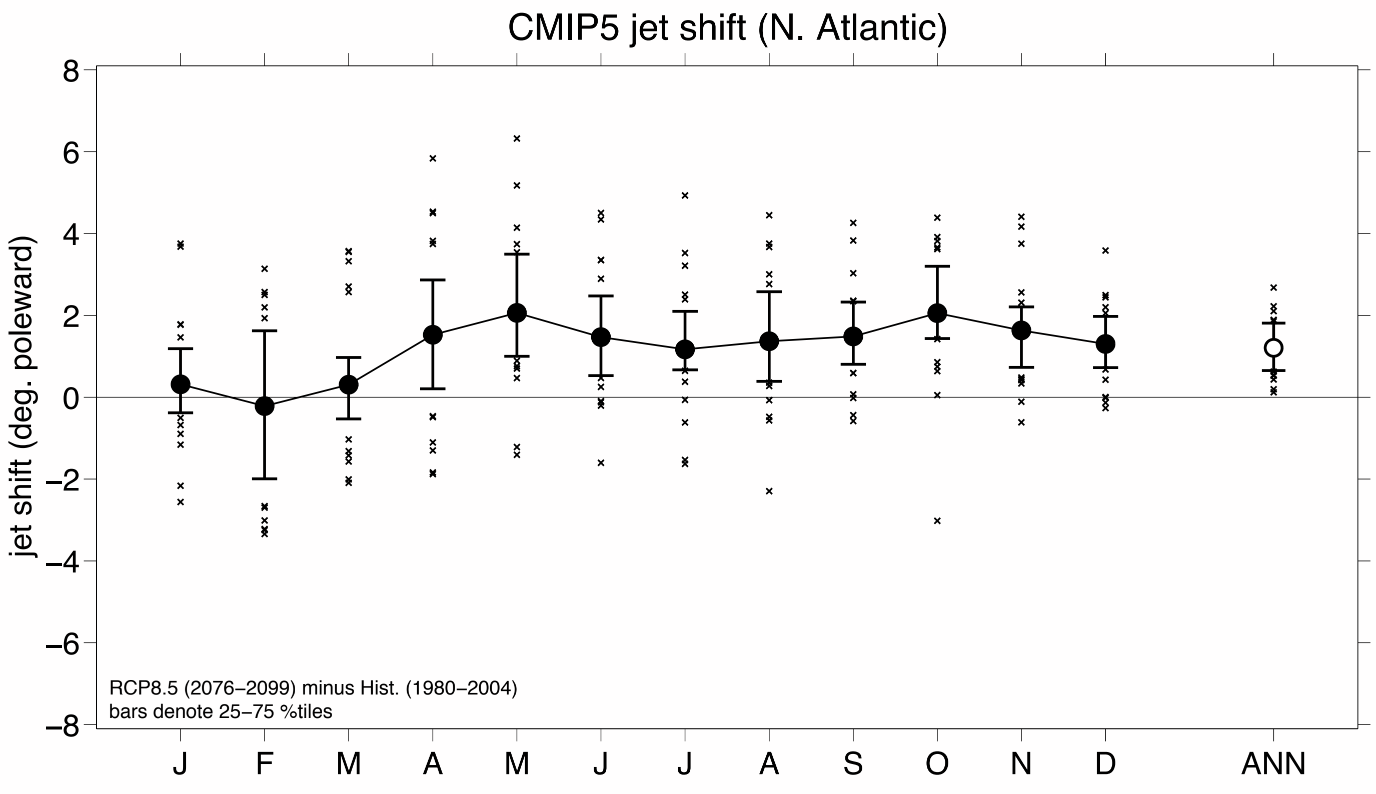


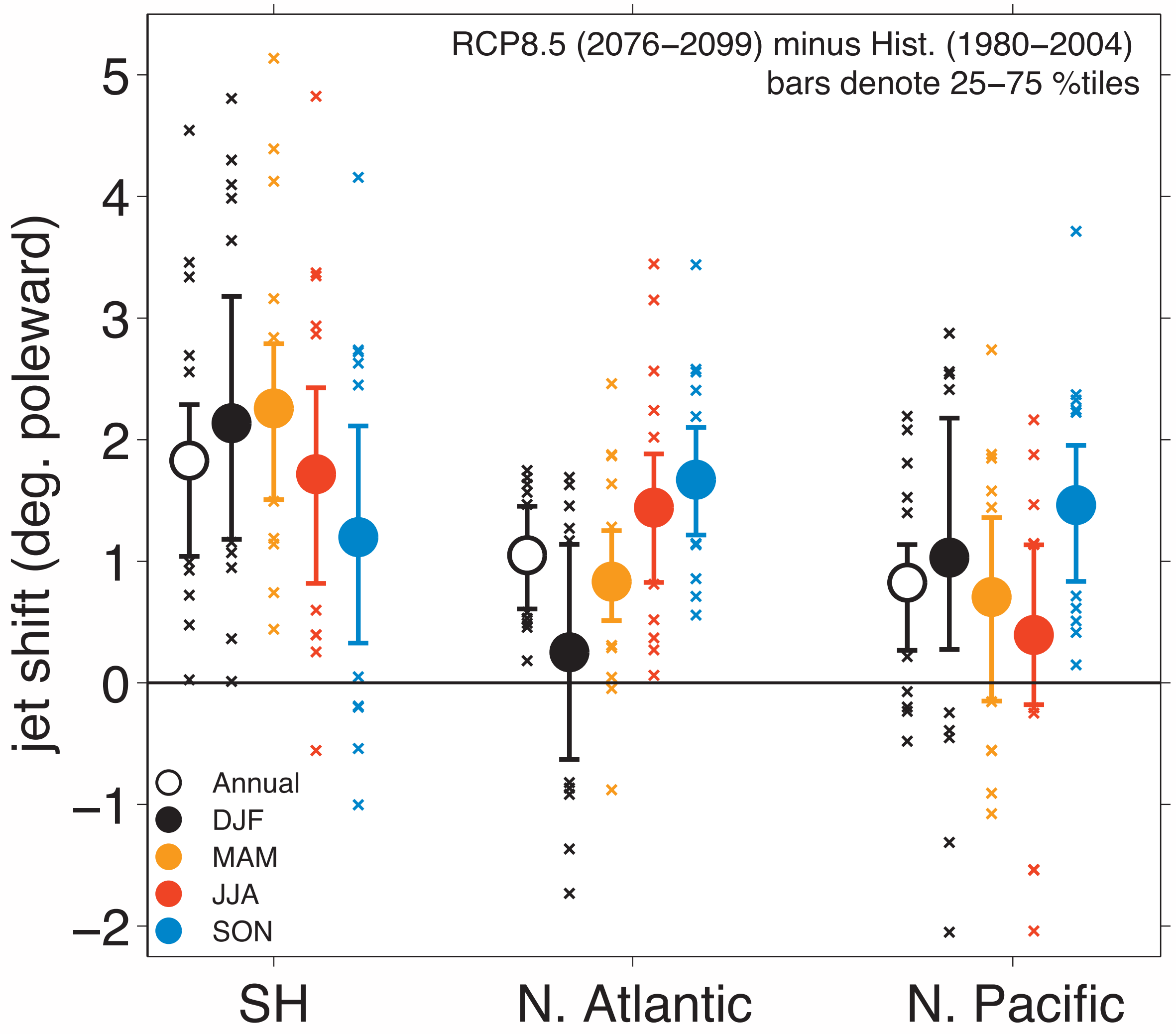


Change in zonal-mean temperature in 25 CMIP5 models under RCP8.5

- 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



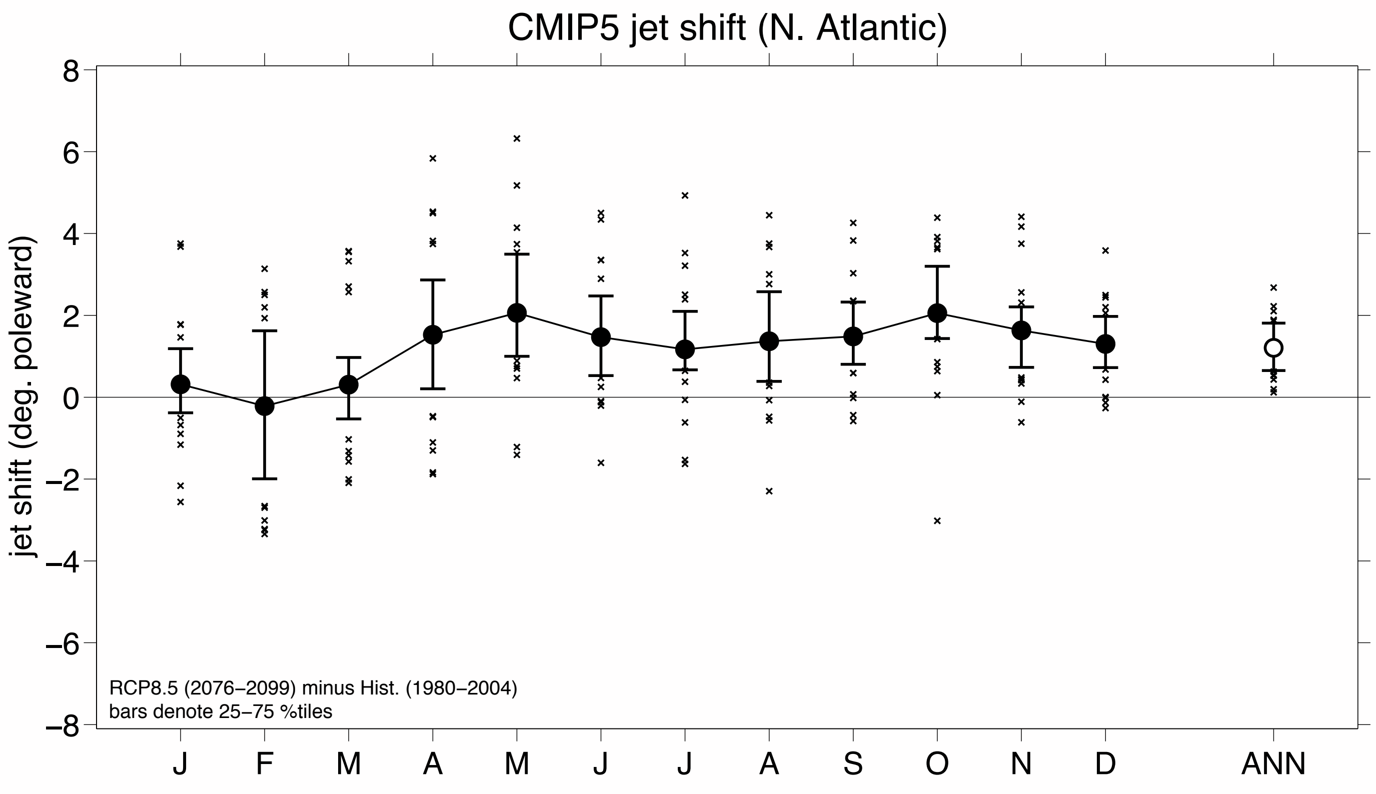


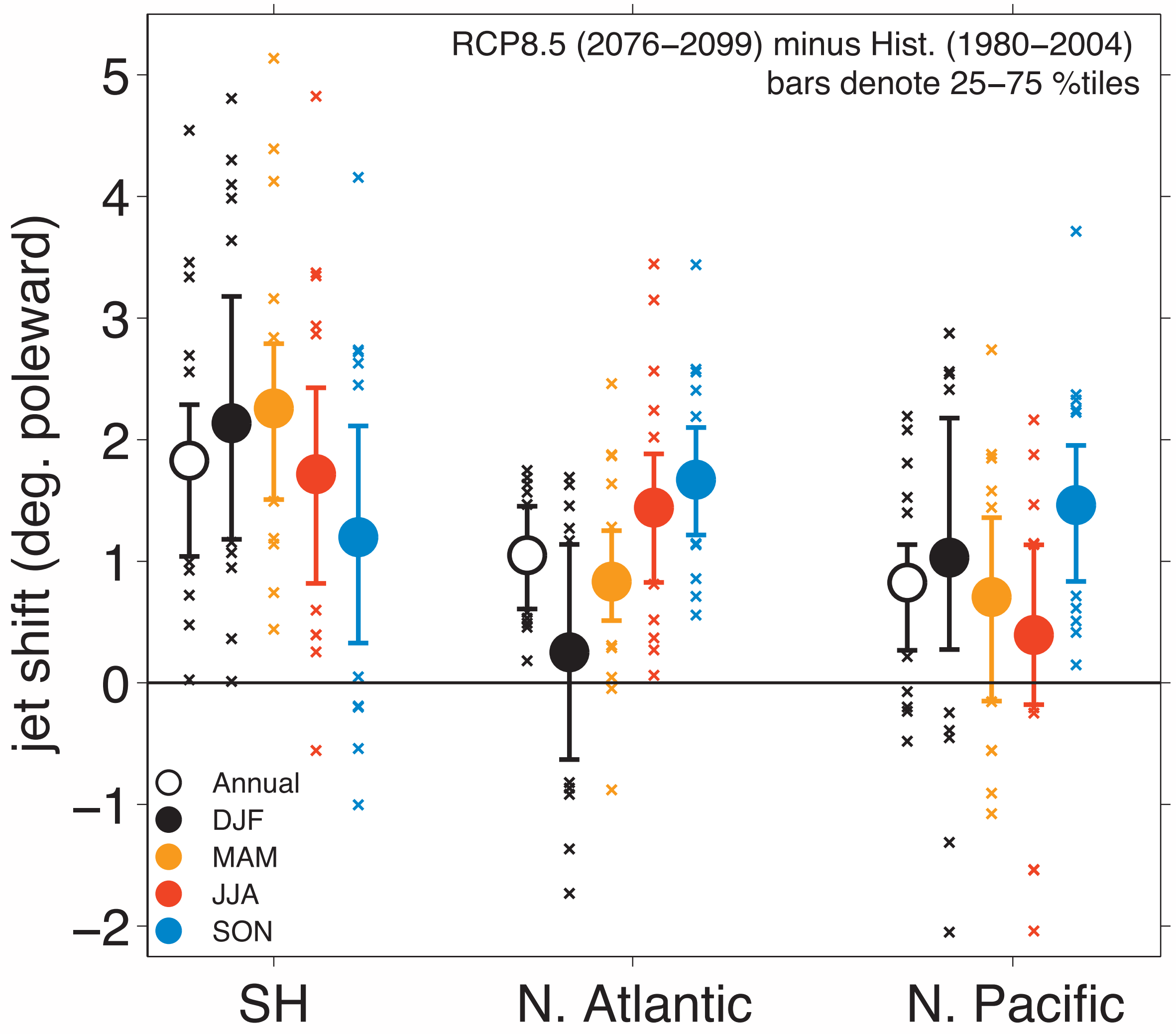
- jet shift has a rich seasonality
- could be due to a few factors

  (1) **seasonality of forcing** (e.g. sea ice loss and Arctic amplification)

  (2) **seasonality of the circulation** (even for constant forcing)

Large seasonality in CMIP5 future jet shift response





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(2) **seasonality of the circulation** (even for constant forcing)

Response to GHG independent of season?

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

ELIZABETH A. BARNES

Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York

NICHOLAS W. BARNES

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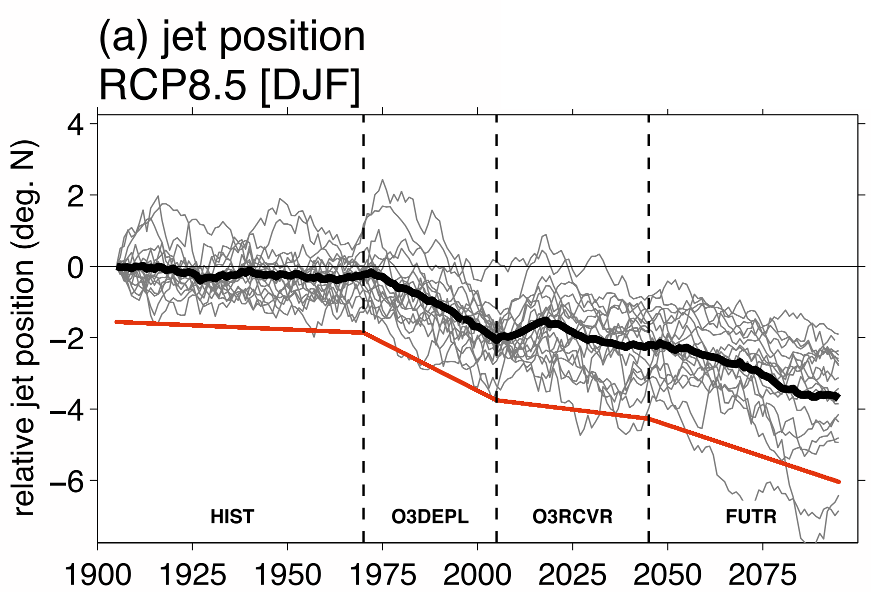
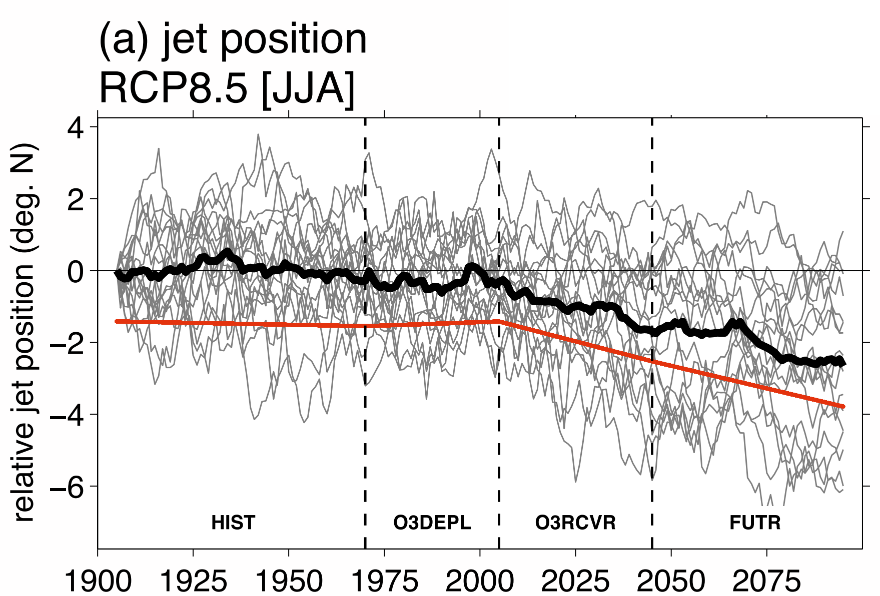
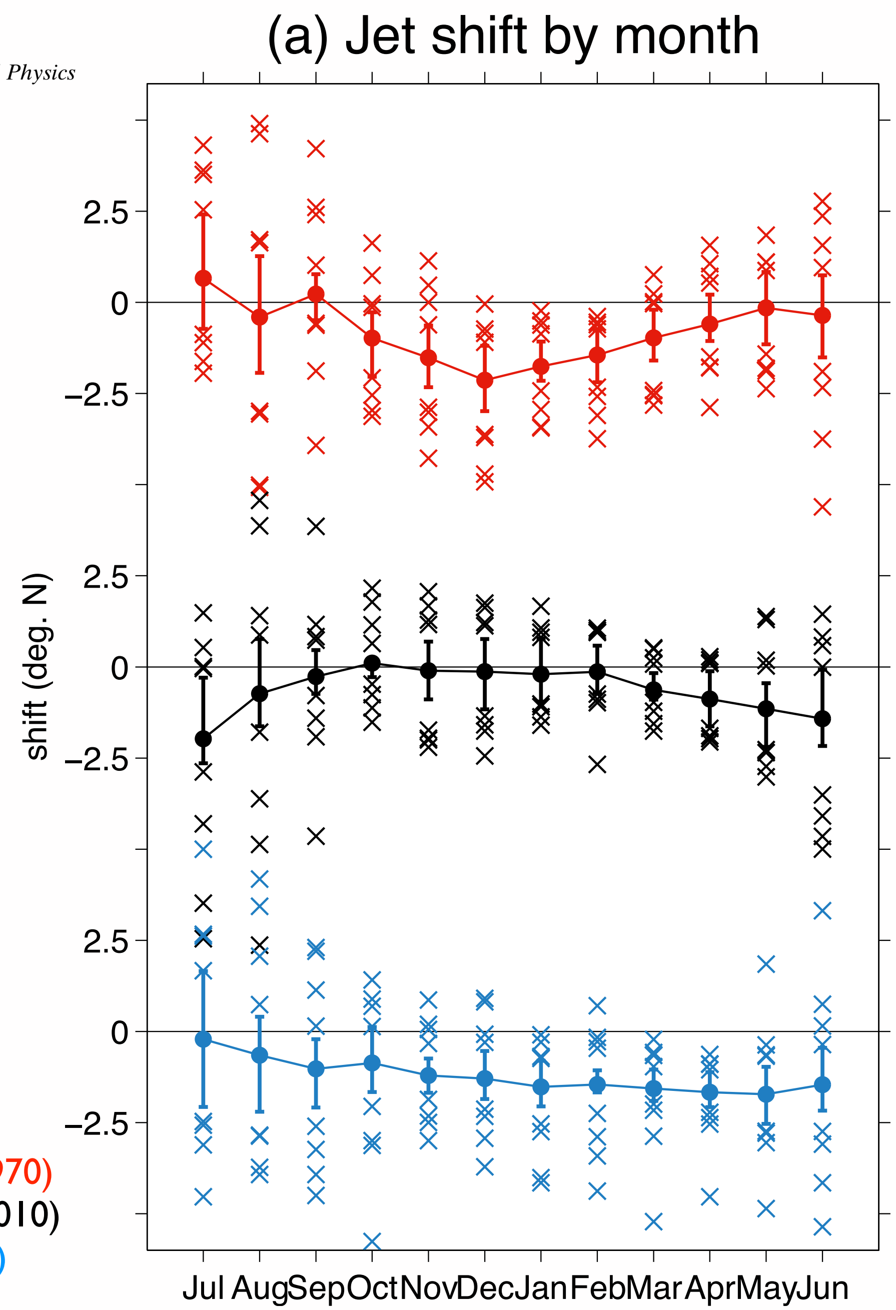
LORENZO M. POLVANI

Lamont-Doherty Earth Observatory, Columbia University, Palisades, and Department of Applied Physics and Applied Math, Columbia University, New York, New York

(Manuscript received 20 April 2013, in final form 5 August 2013)







O3DEPL: (2000-2010) - (1960-1970)
O3RCVR: (2040-2050) - (2000-2010)
FUTR: (2089-2099) - (2040-2050)

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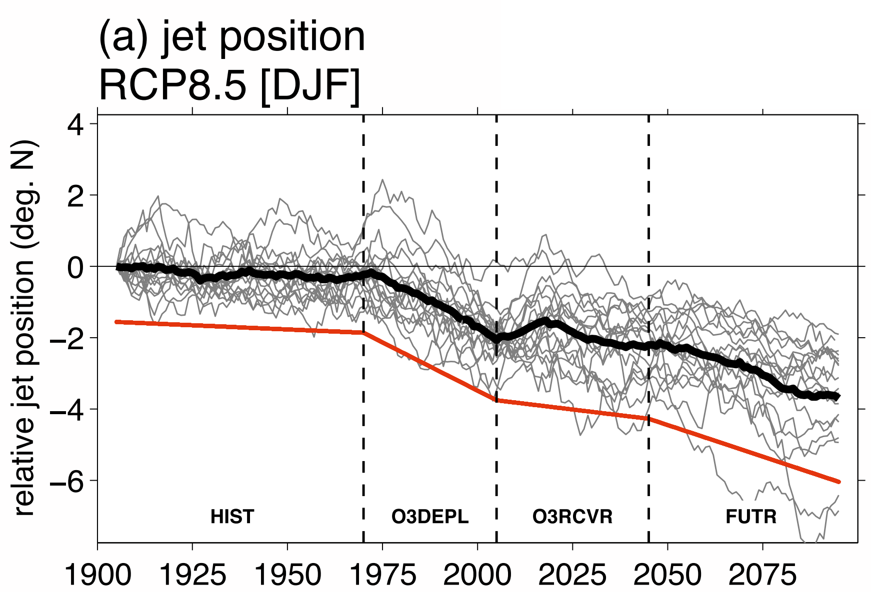
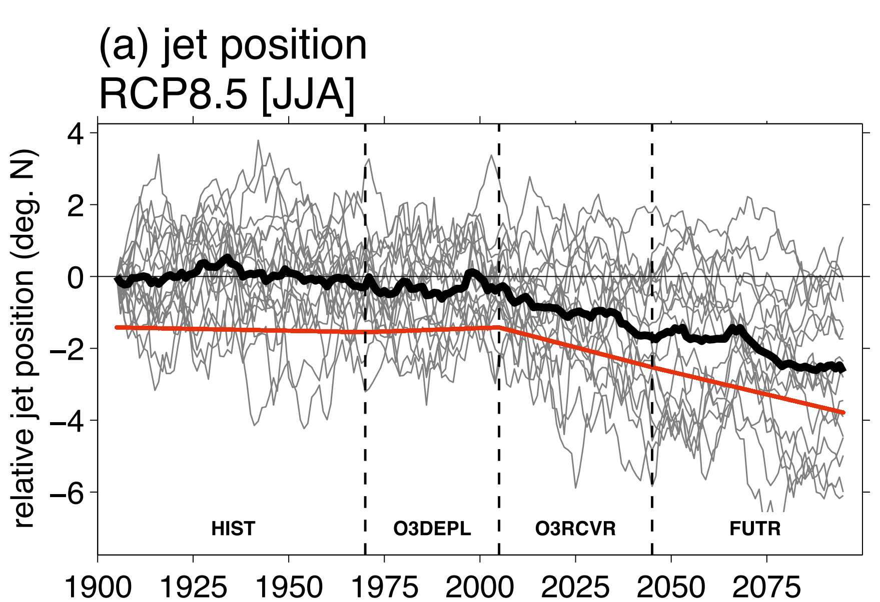
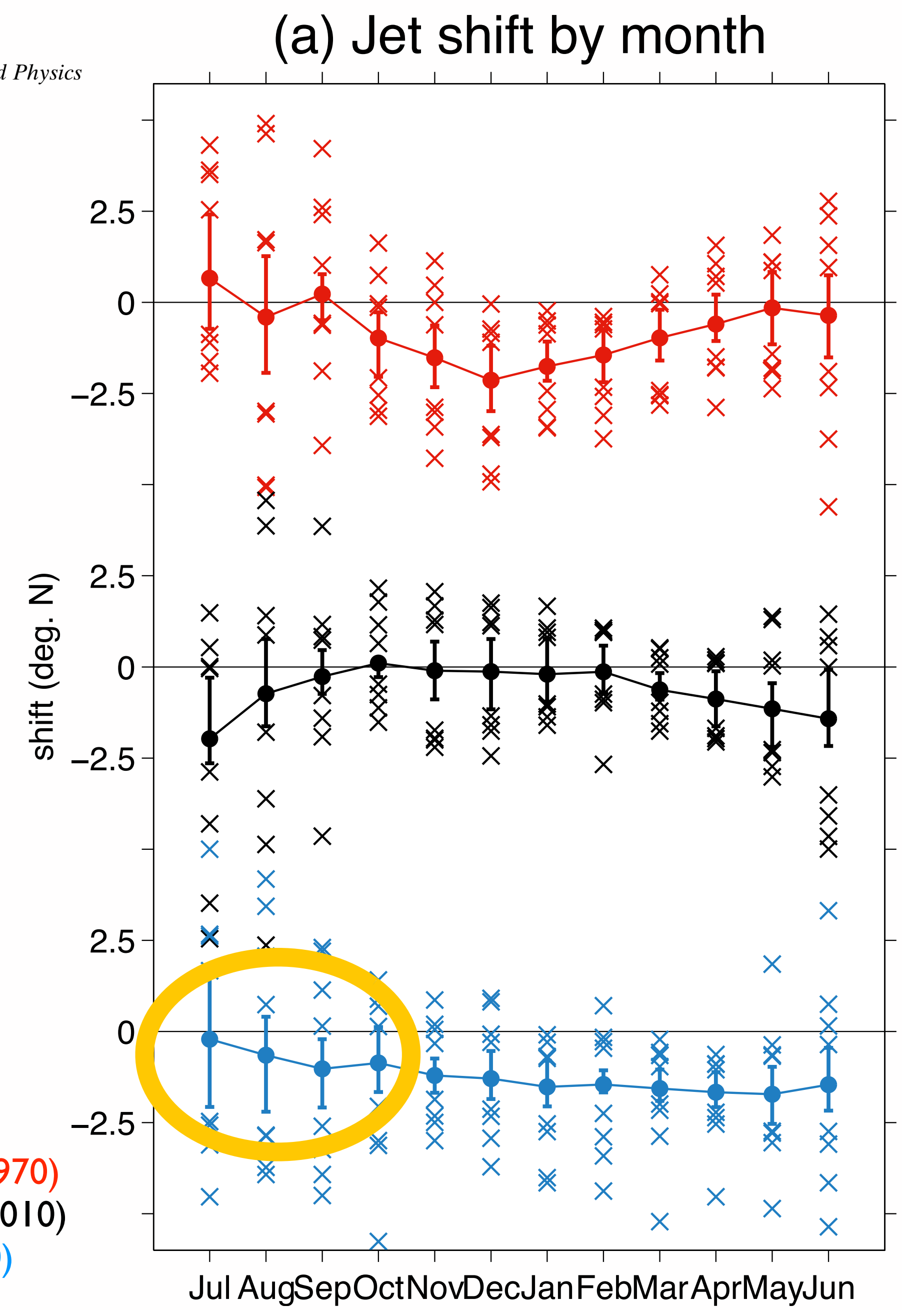






O3DEPL: (2000-2010) - (1960-1970)
O3RCVR: (2040-2050) - (2000-2010)
FUTR: (2089-2099) - (2040-2050)

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.

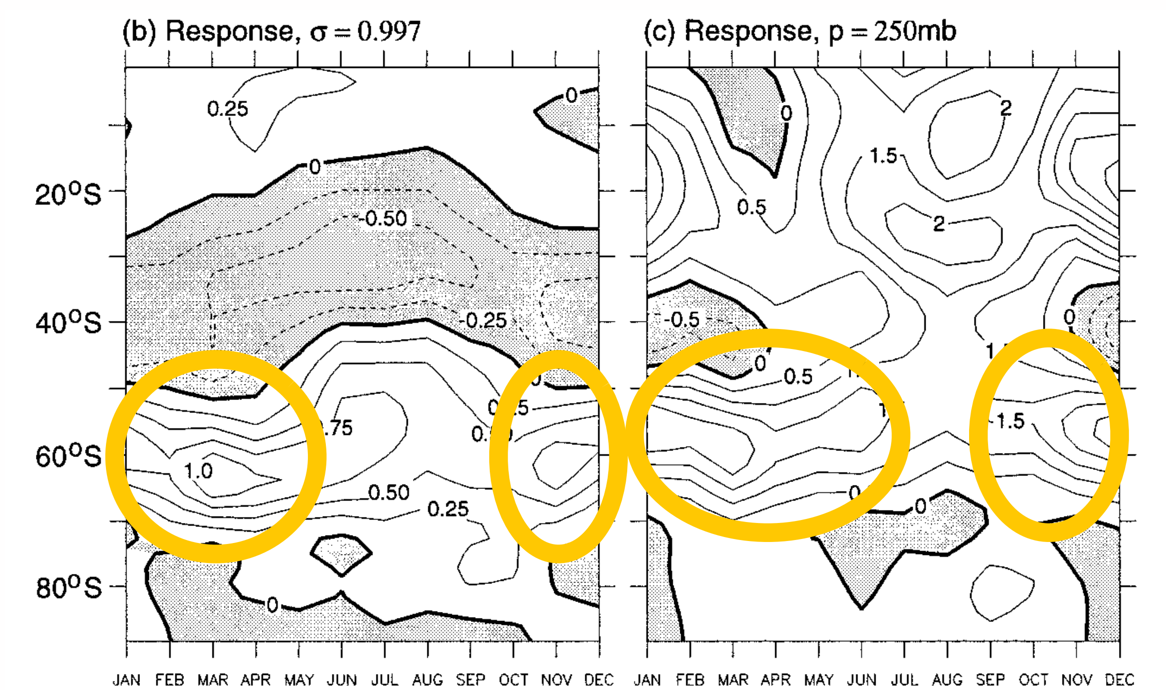
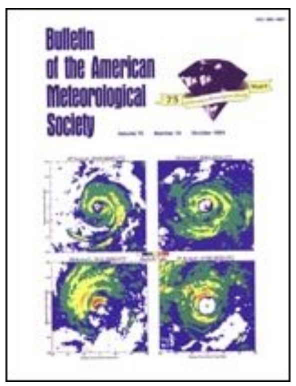


FIG. 4. The seasonal cycle of the climatological surface zonal-mean zonal wind for (a) the 800-yr time mean of the control integration, and (b) the ensemble mean response, years 2065–89. (c), (d) As in (a) and (b), but at 250 mb. Shading and dashed contours indicate negative values. Contour interval: (a) 2 m s^{-1}; (b) 0.25 m s^{-1}; (c) 5 m s^{-1}; (d): 0.5 m s^{-1}.

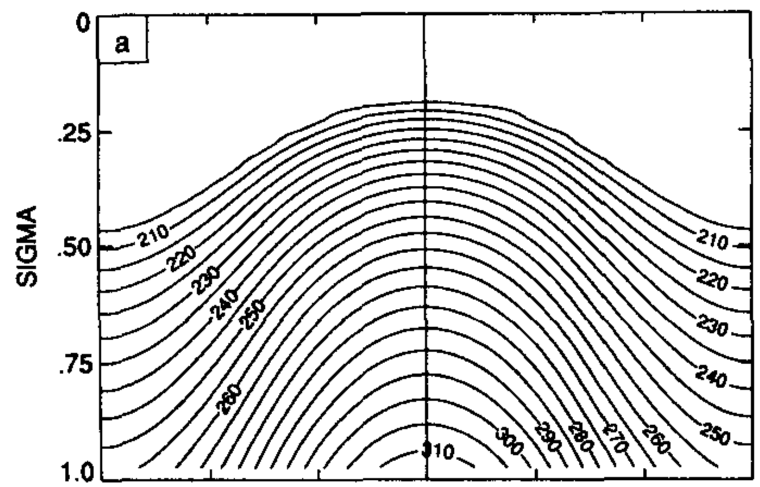
The model: dry dynamical core

A Proposal for the Intercomparison of the Dynamical Cores of Atmospheric General Circulation Models

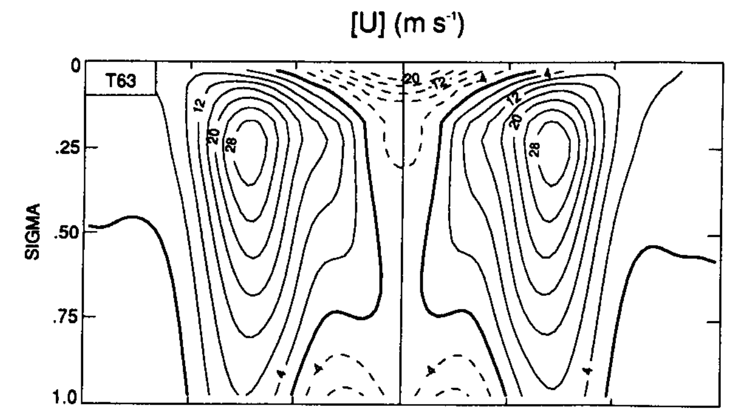
Isaac M. Held*
and Max J. Suarez**



equilibrium temperature profile



mean zonal winds



- 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)

Butler et al. (2010)

The Steady-State Atmospheric Circulation Response to Climate Change–like Thermal Forcings in a Simple General Circulation Model

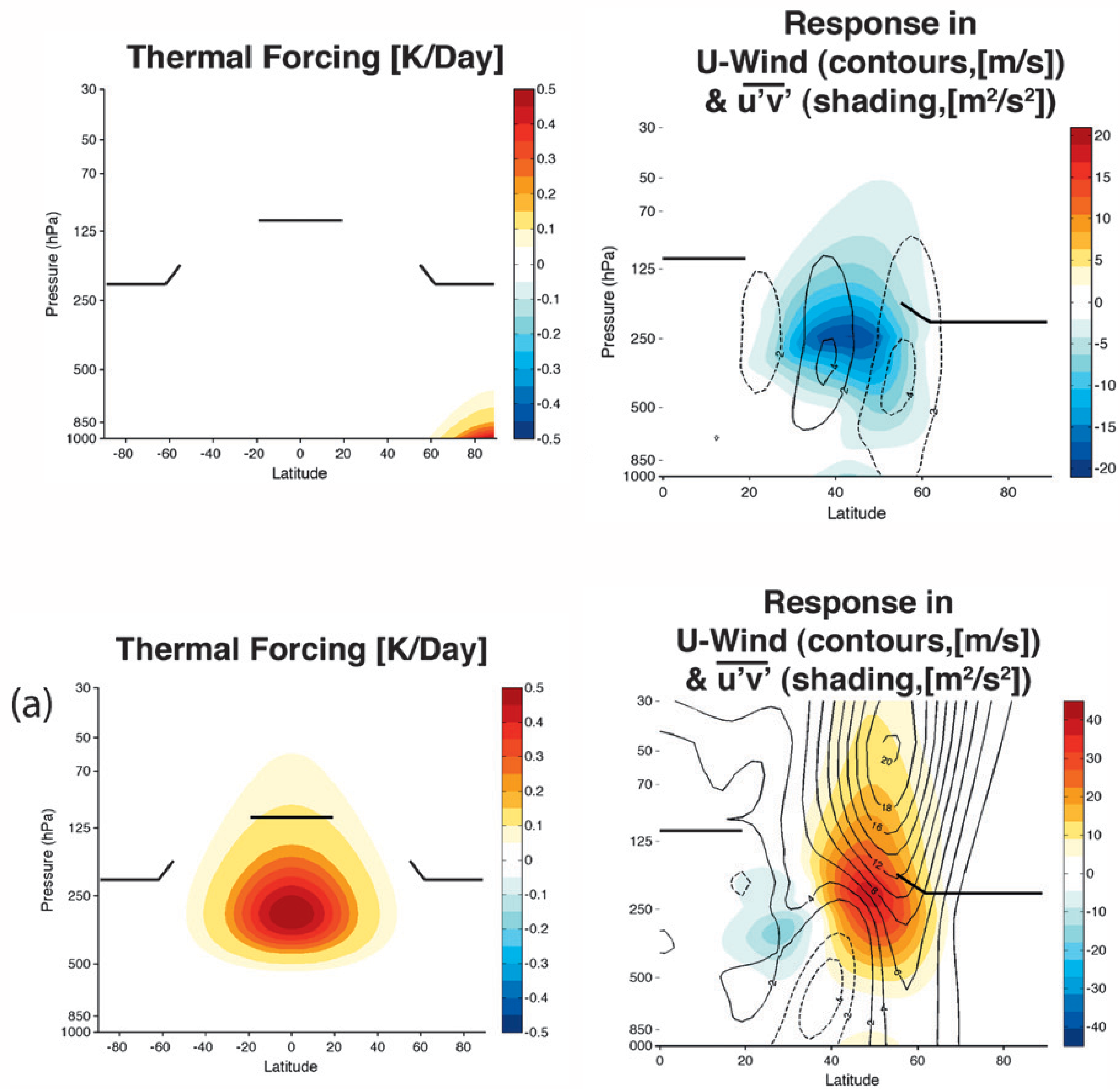
AMY H. BUTLER, DAVID W. J. THOMPSON, AND ROSS HEIKES

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

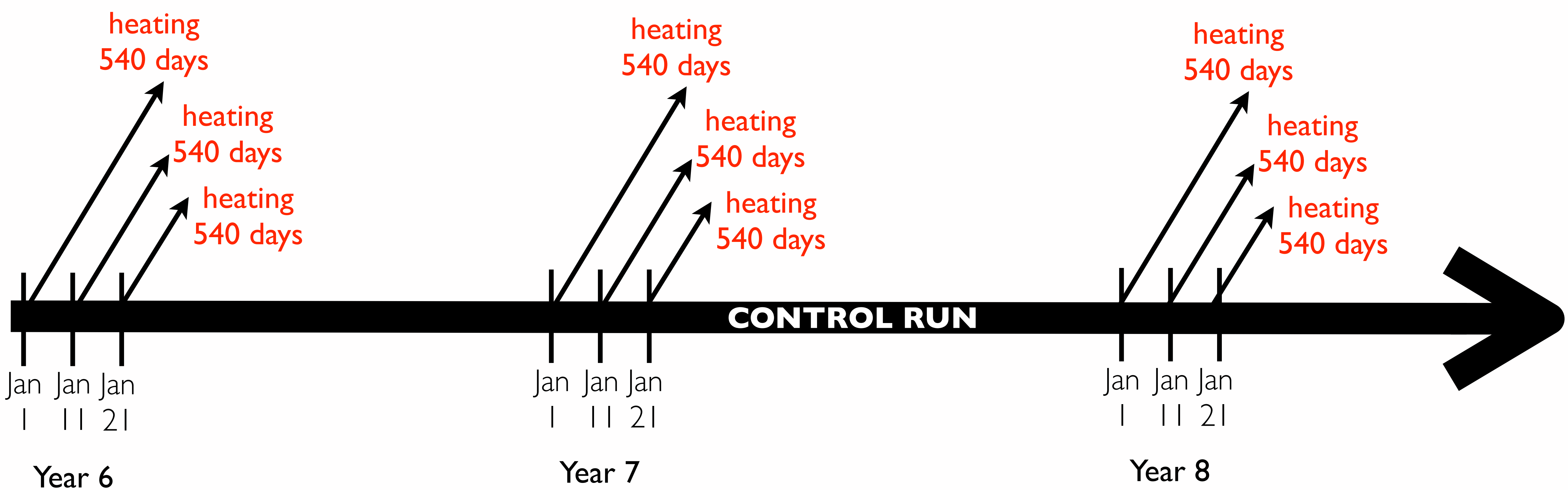
See how the circulation responds to forcing at different times of the year



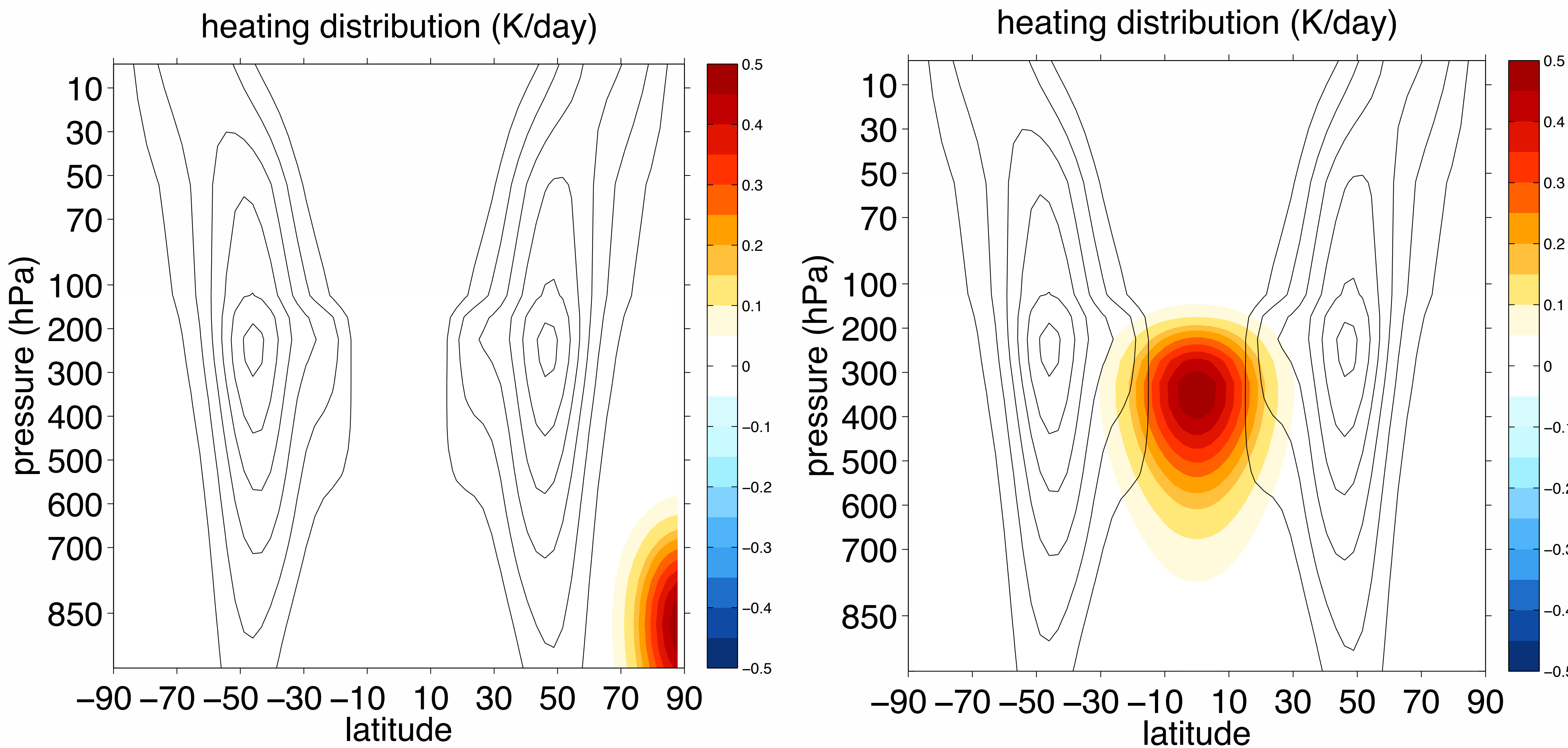
Butler et al. (2010)

Experimental setup

- <u>Control:</u>
  - spin-up for 3 years, 6 years for climatology
- <u>Heating runs:</u>
  - 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

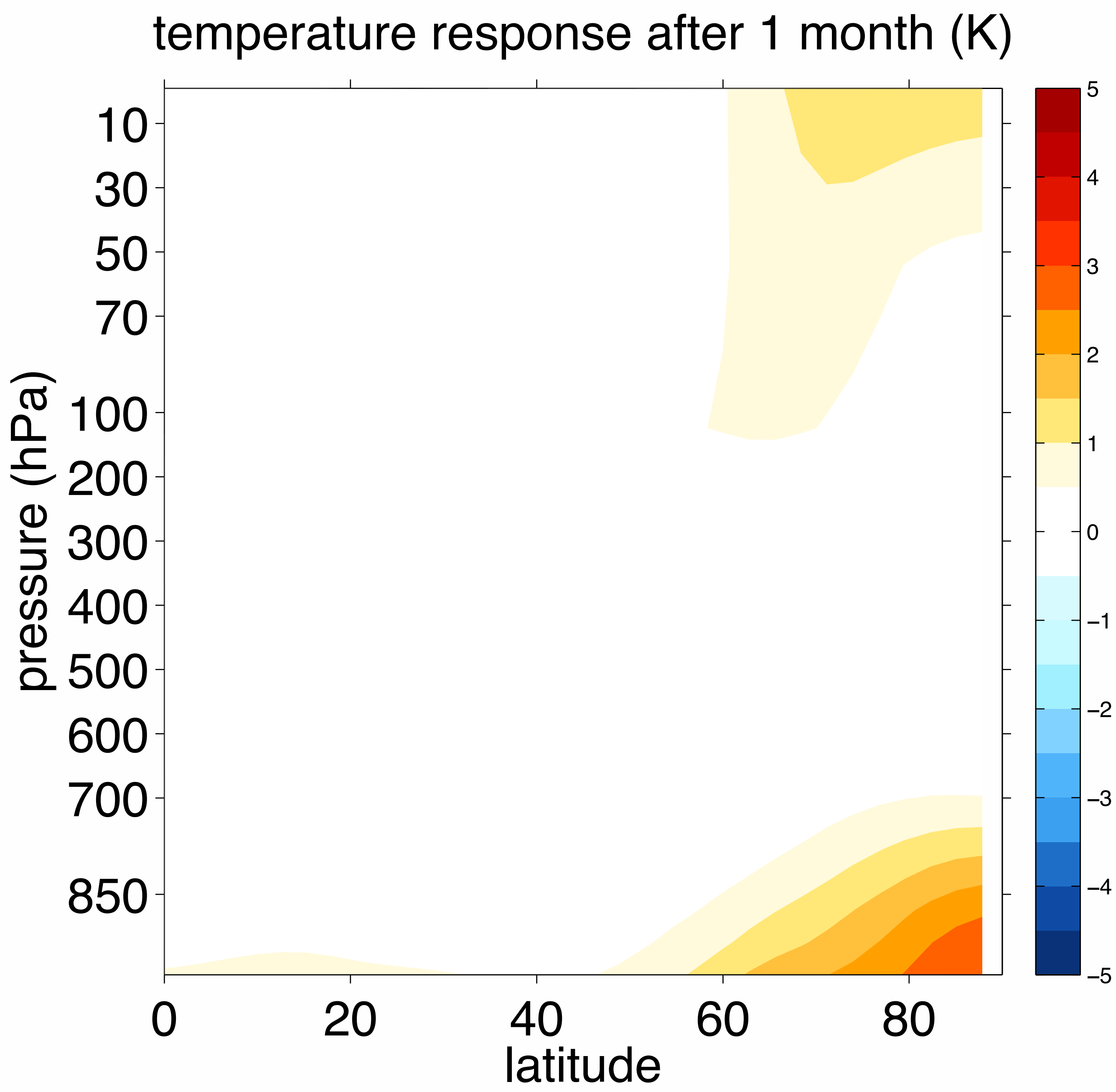


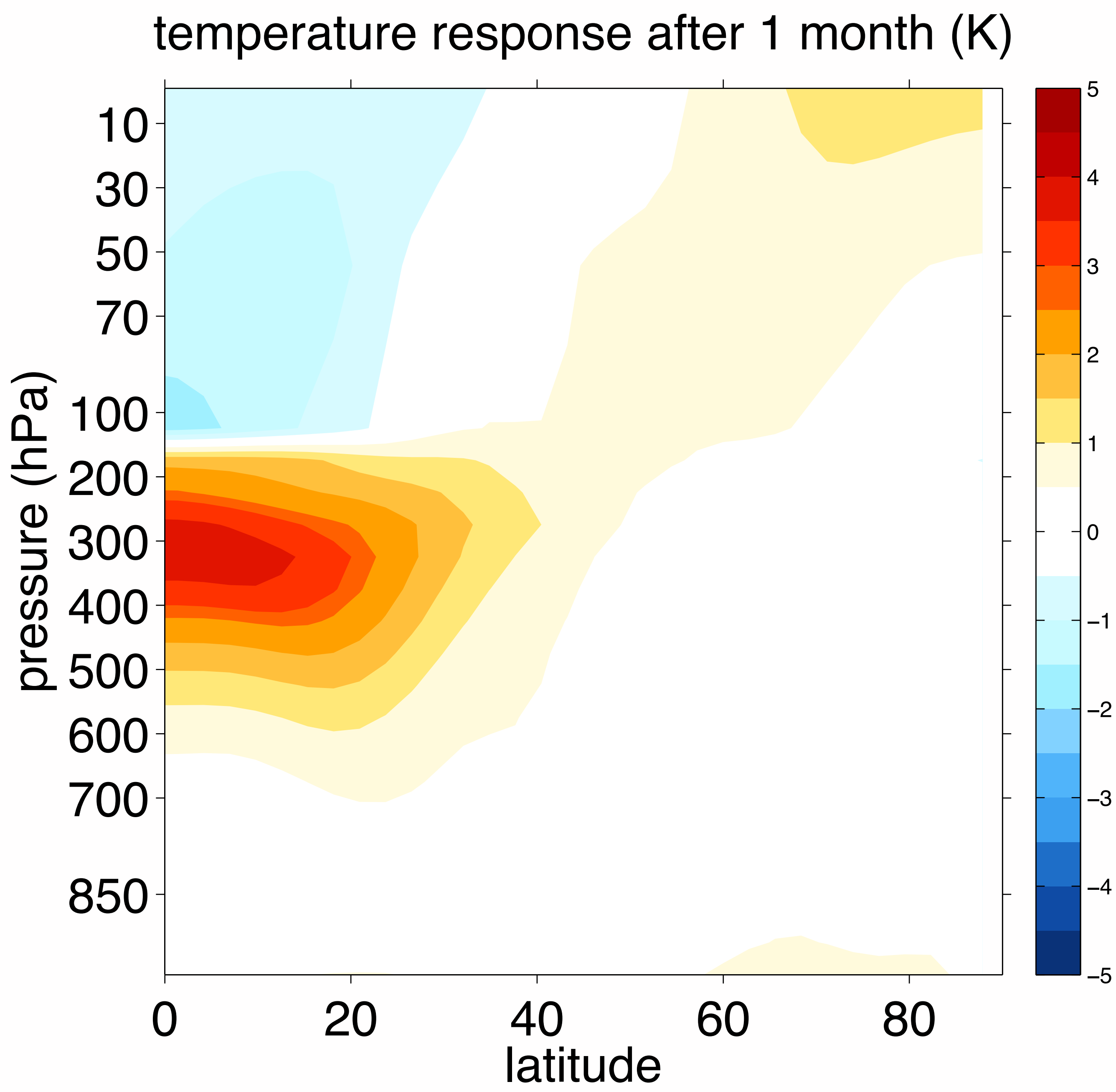
Heating profiles



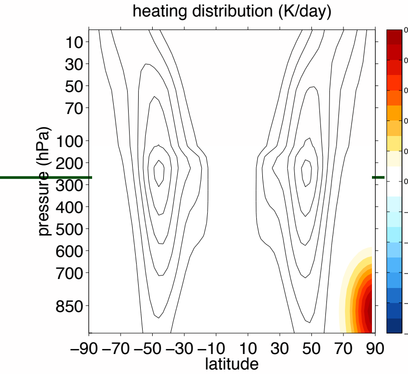
maximum heating of 0.5 K/day (similar to Butler et al. 2010)

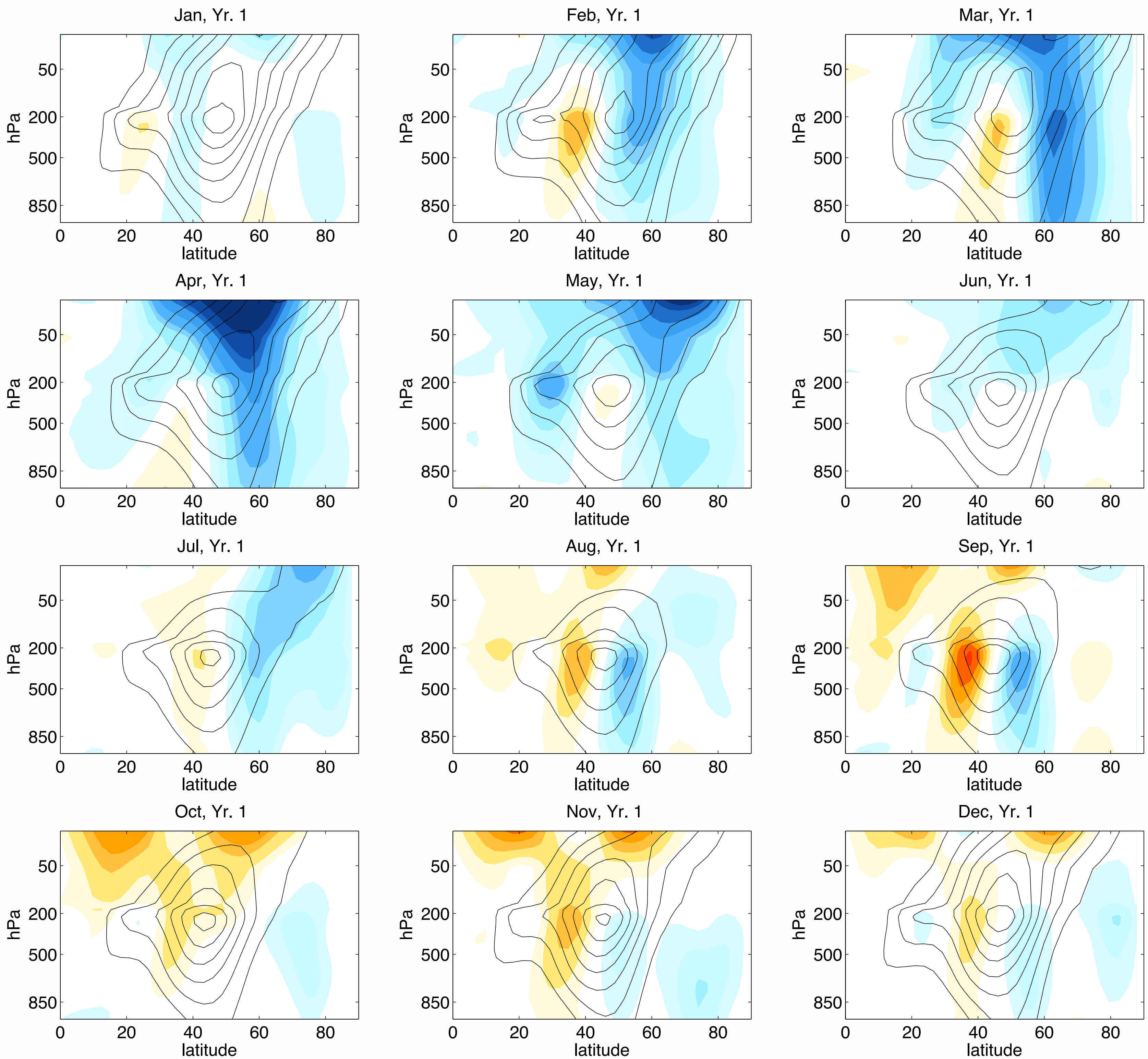
Temperature response in first month of Jan. heating





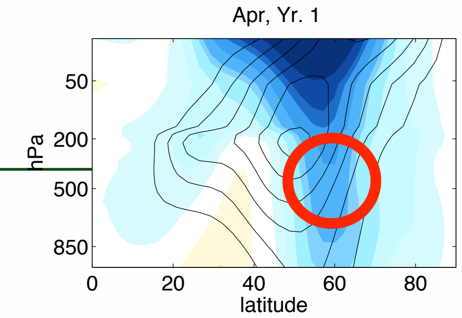
POLAR: zonal wind response to January heating

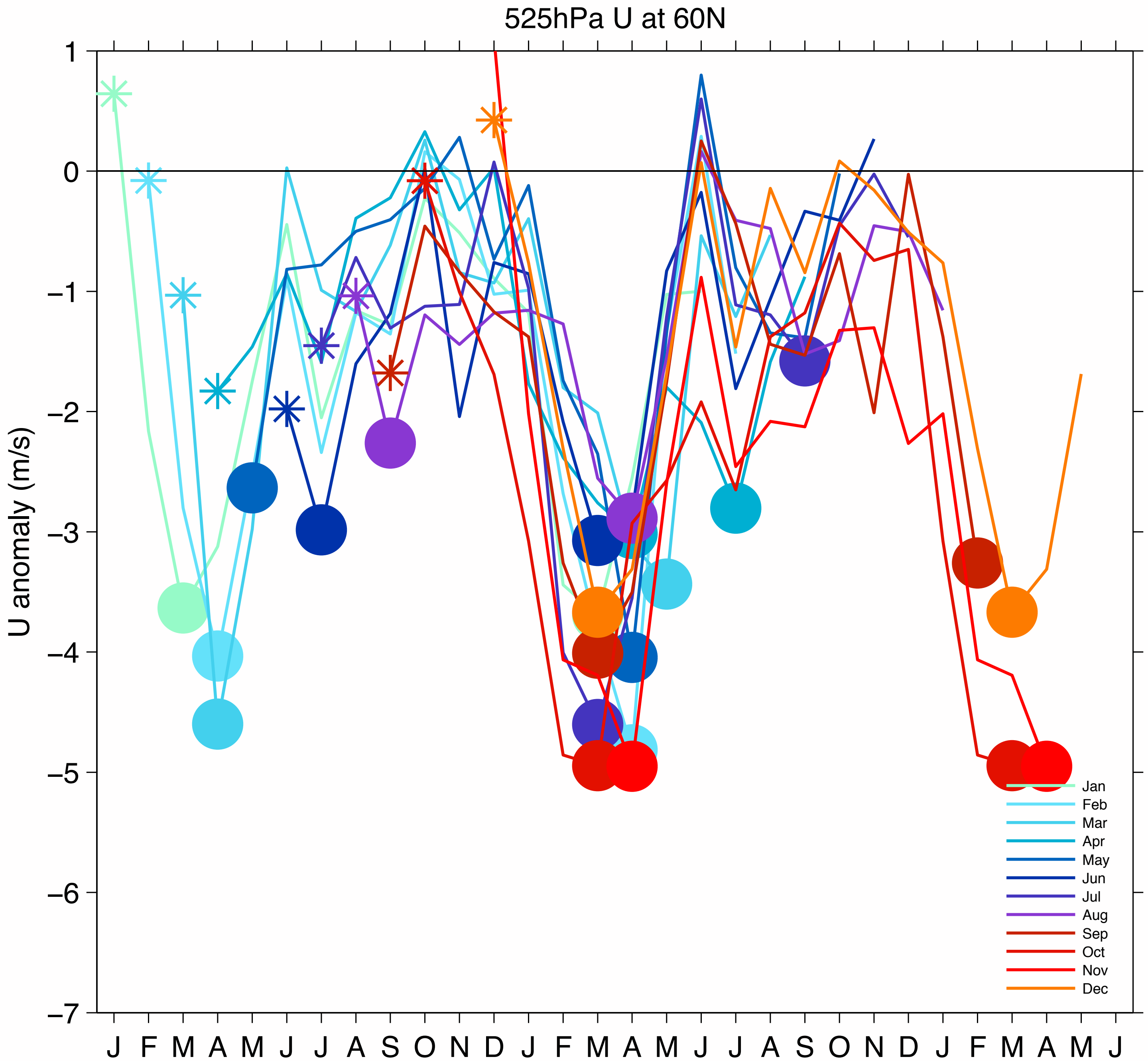


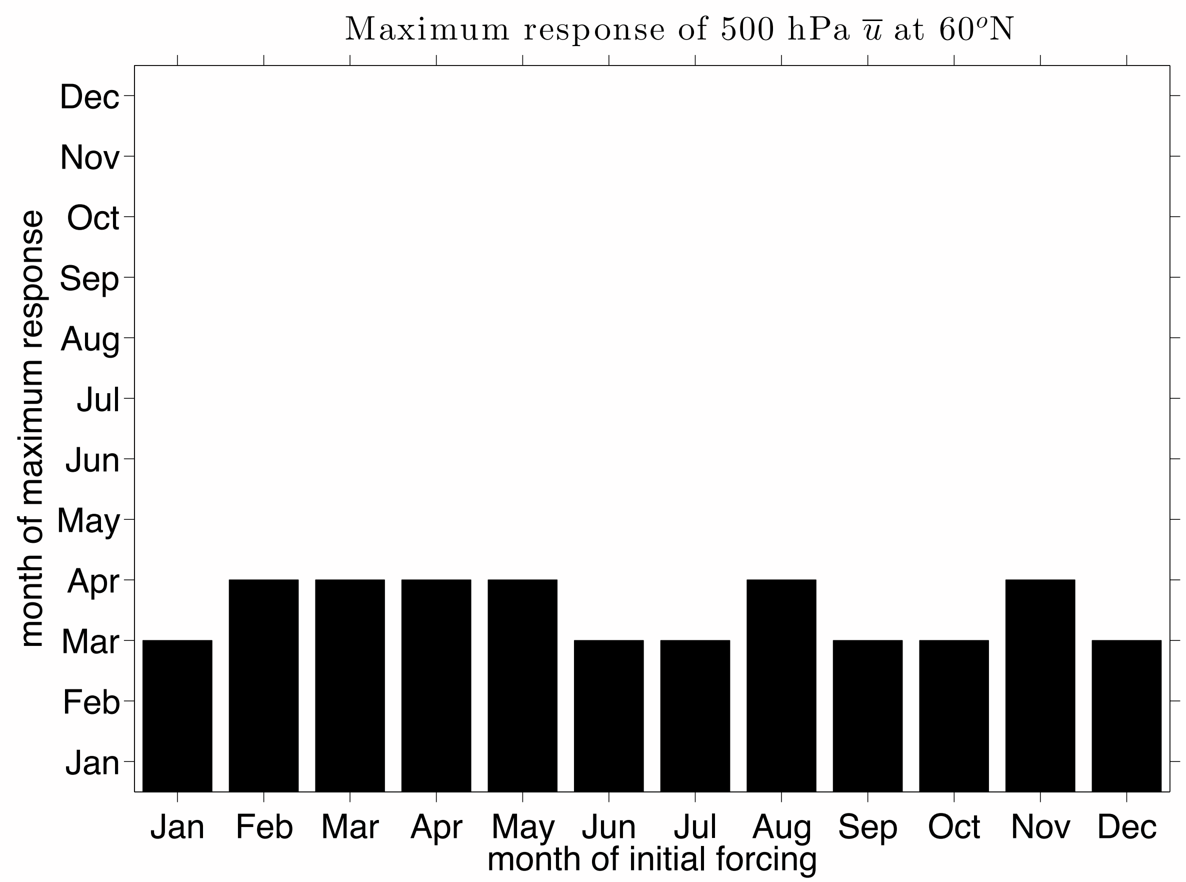


- response is a decrease in zonal winds
- response is an *equatorward* shift of the jet
- response to January heating is largest in **spring**

POLAR: seasonality of the response of u

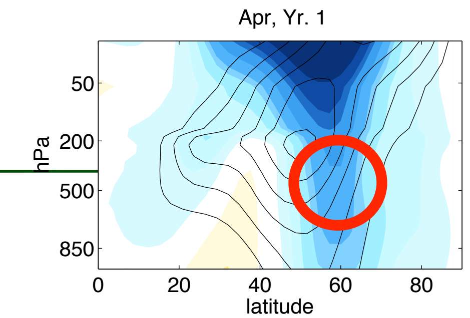


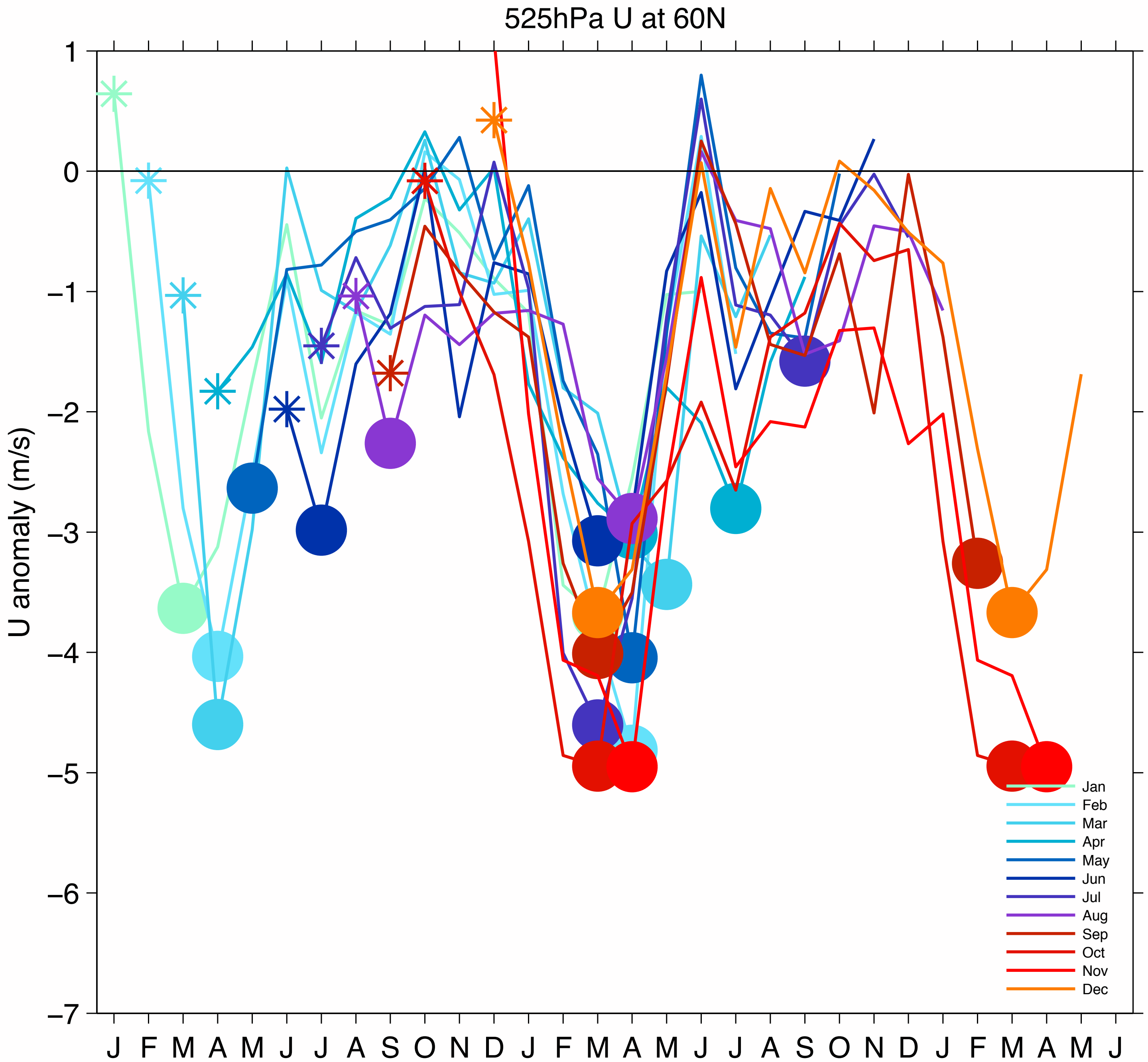


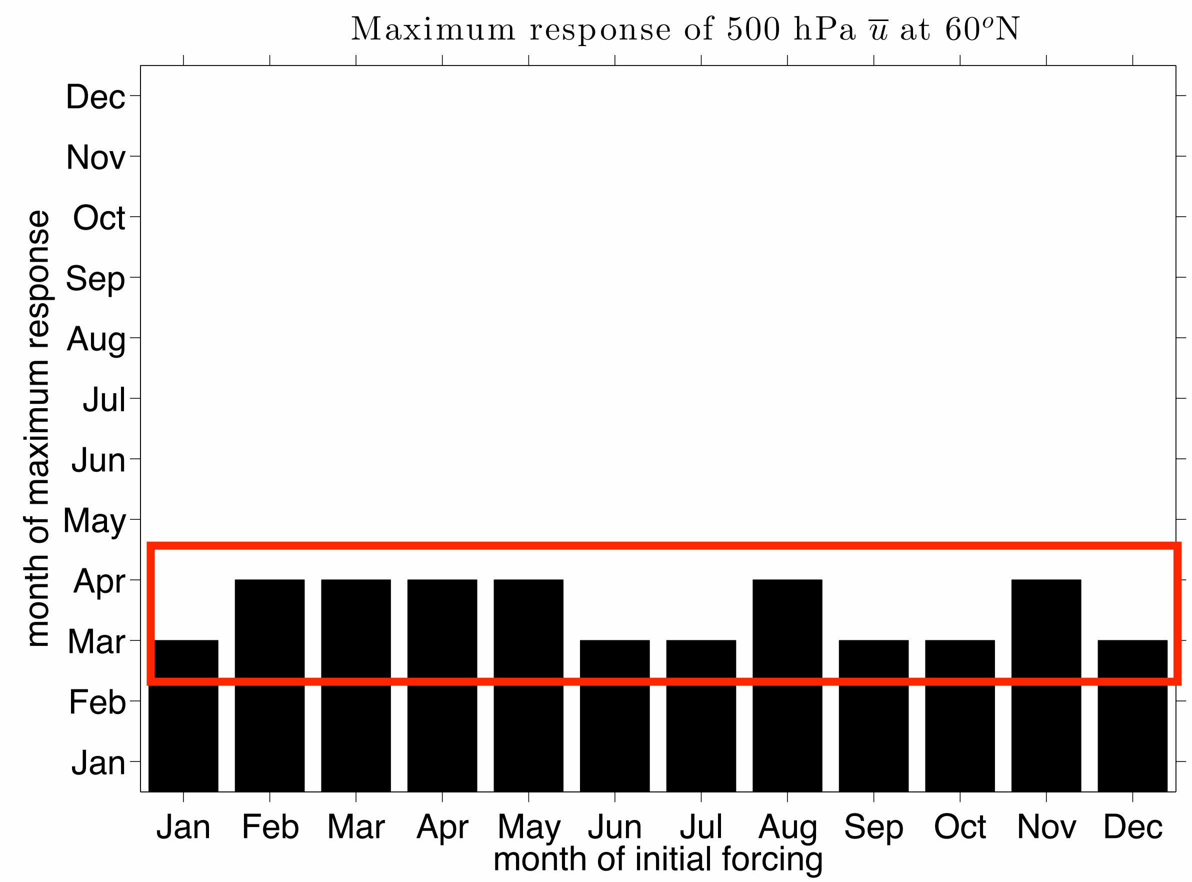


u response is largest in **March/April** no matter when the forcing is applied

POLAR: seasonality of the response of u

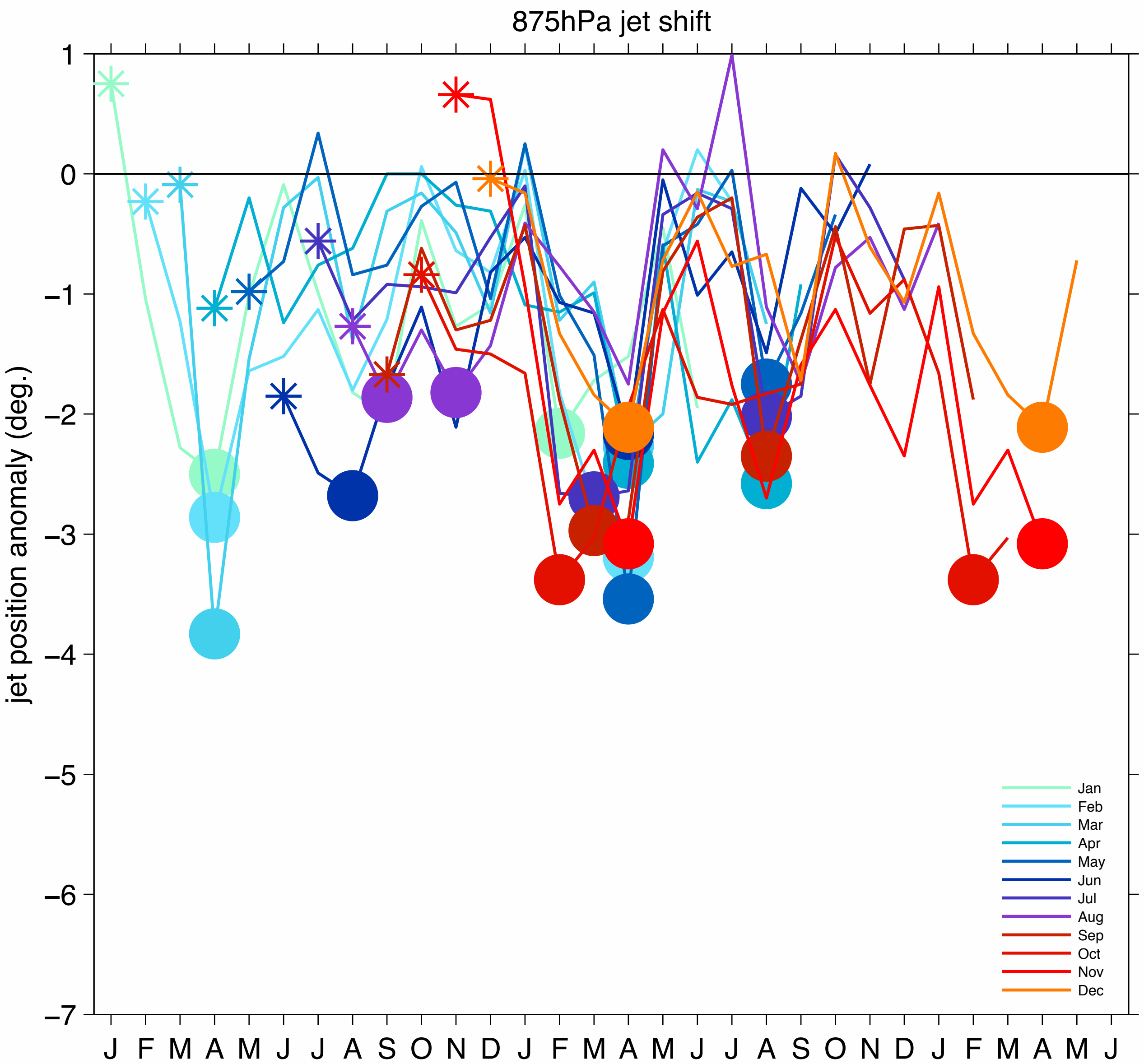


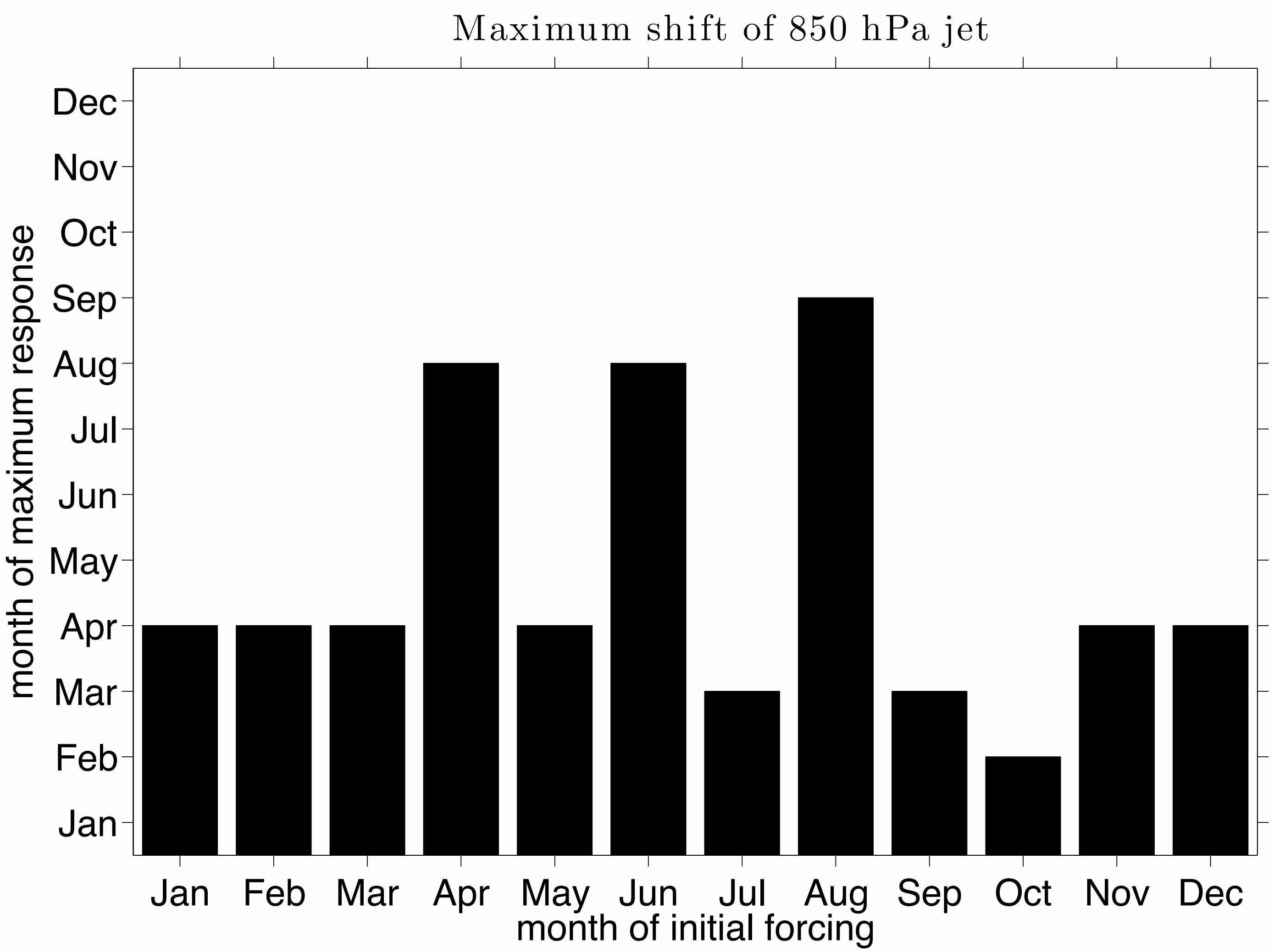




u response is largest in **March/April** no matter when the forcing is applied

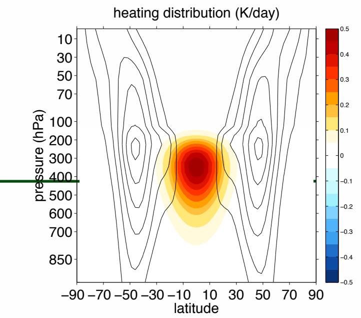
POLAR: seasonality of the response of the jet position

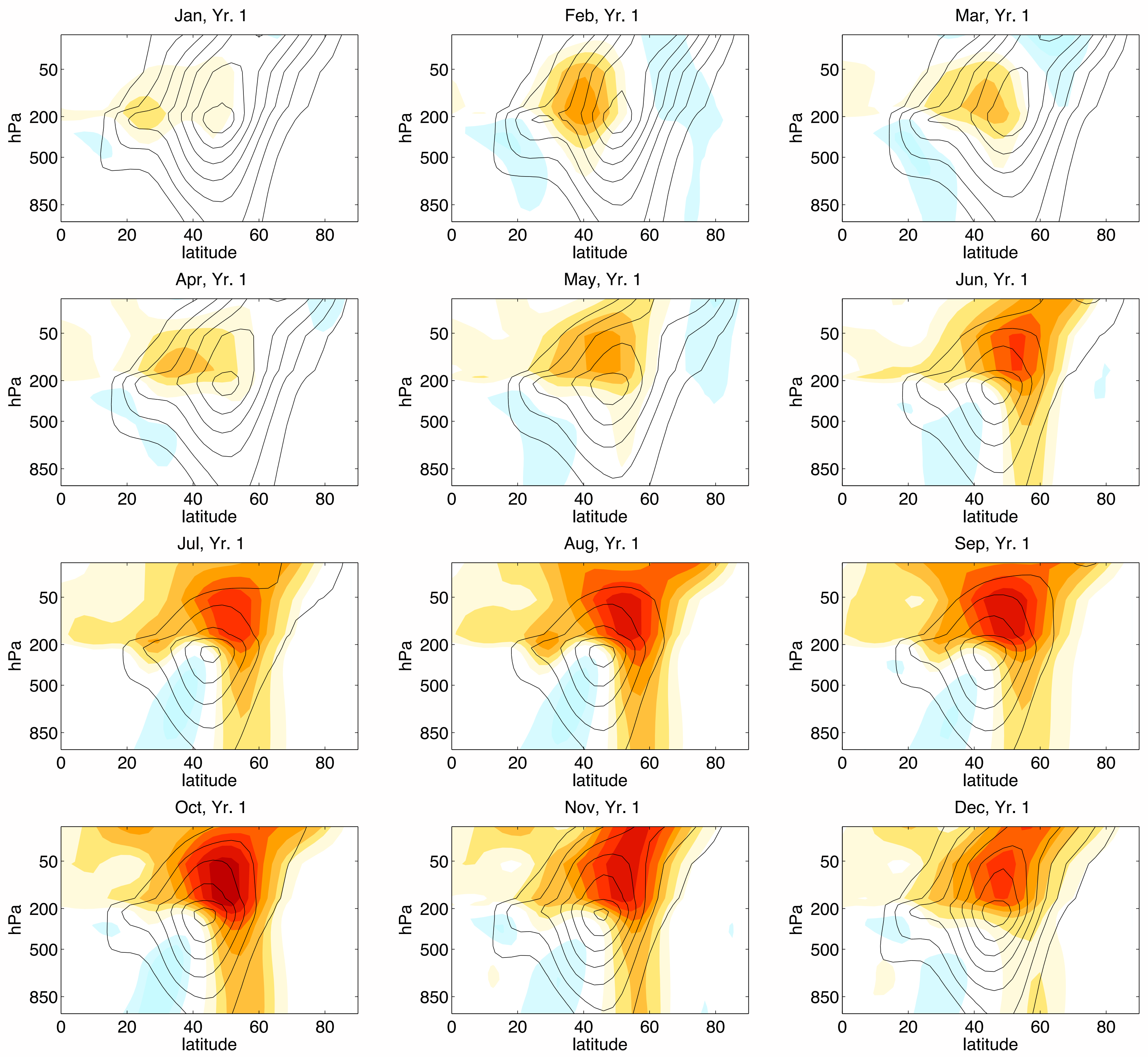




jet shift is generally largest in **spring,** although not as much agreement

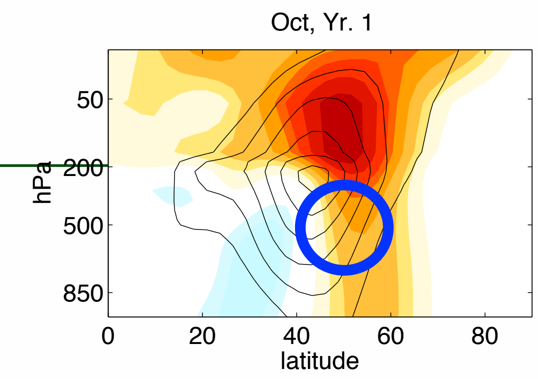
TROP: zonal wind response to January heating

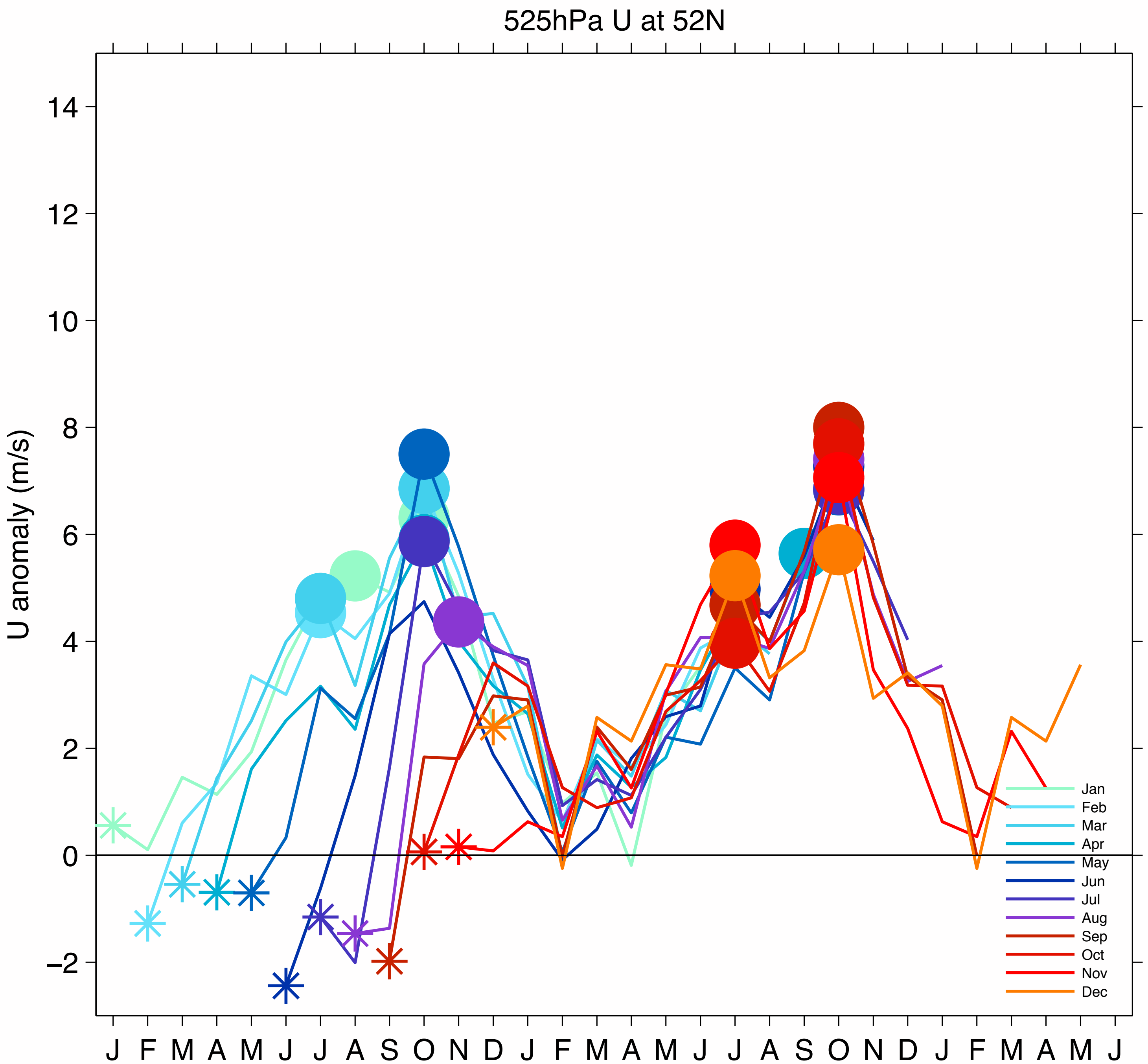


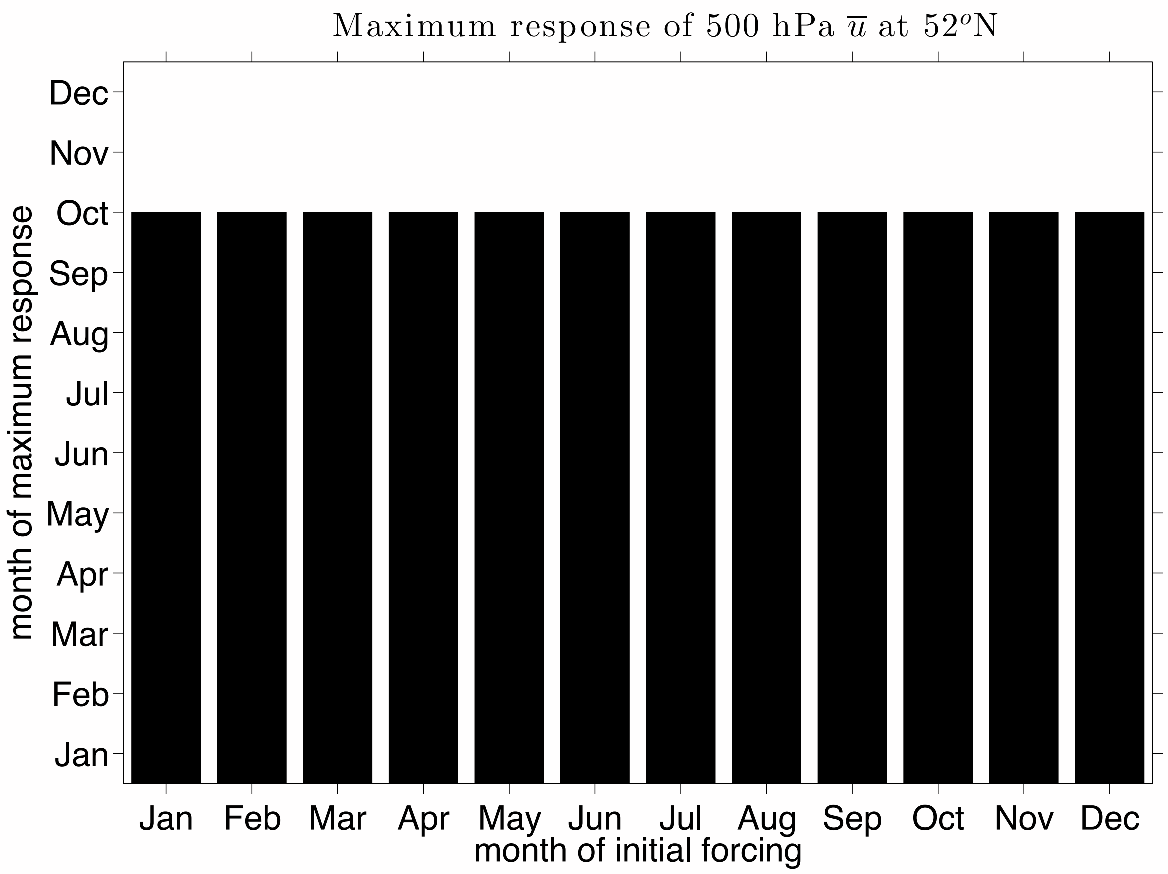


- response is an increase in zonal winds
- response is a *poleward* shift of the jet
- response to January heating is largest in **autumn**

TROP: seasonality of the response of u

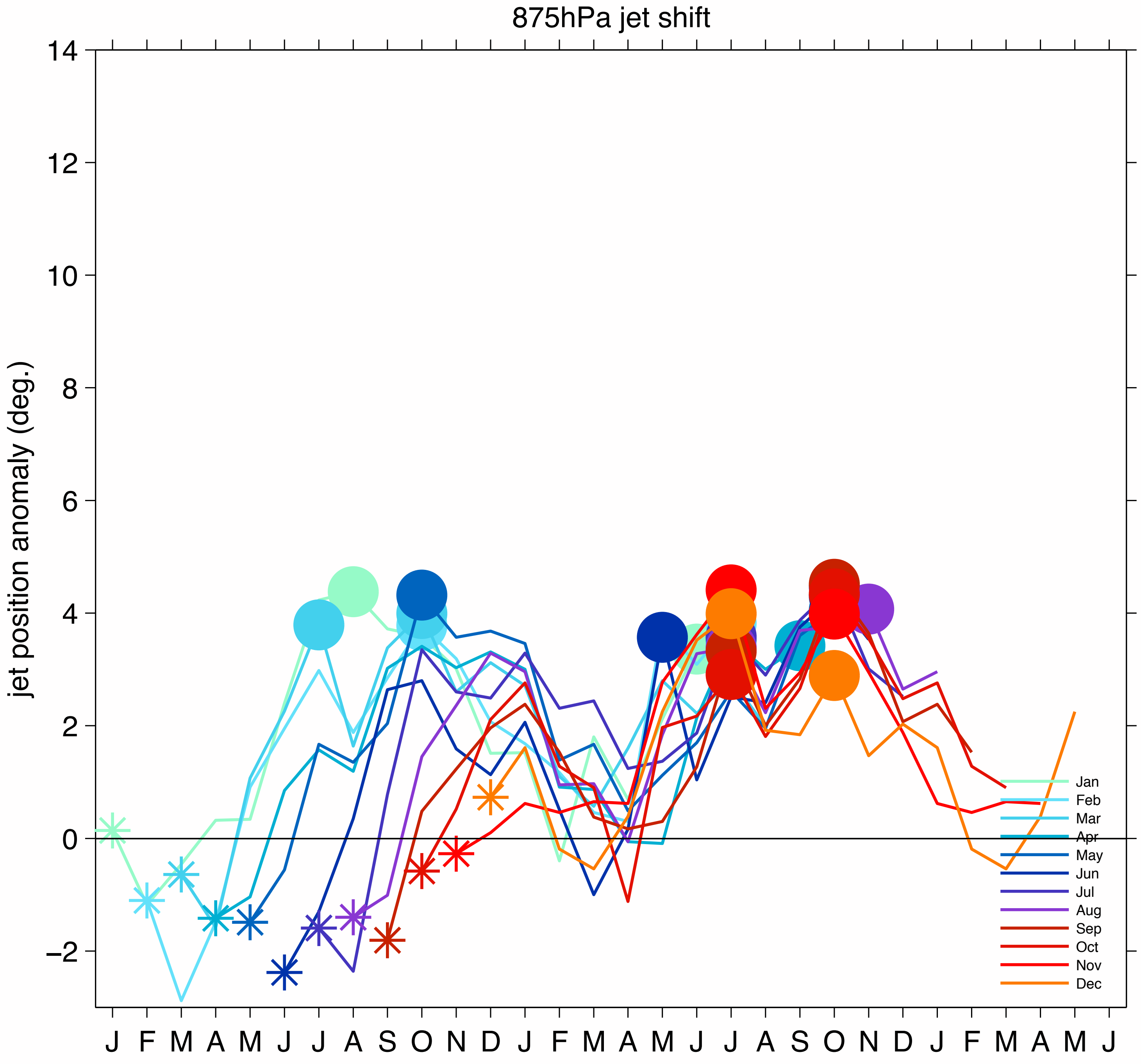


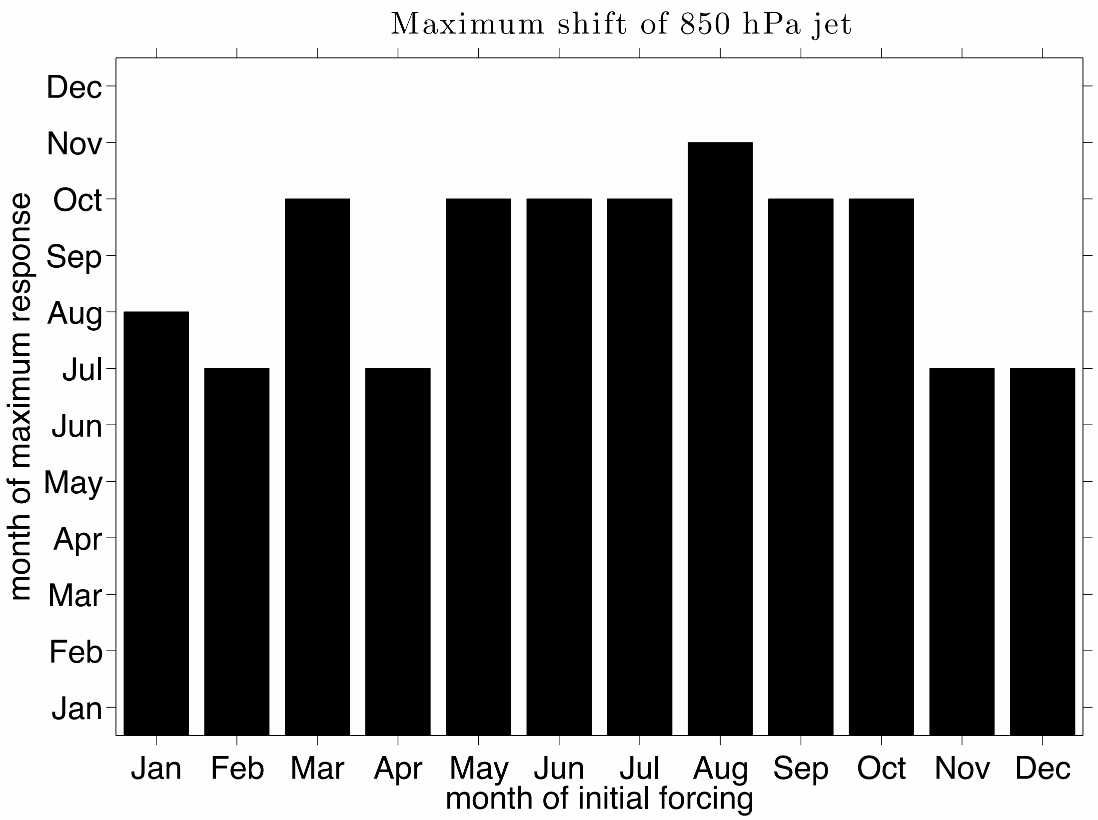




u response is largest in **October** no matter when the forcing is applied

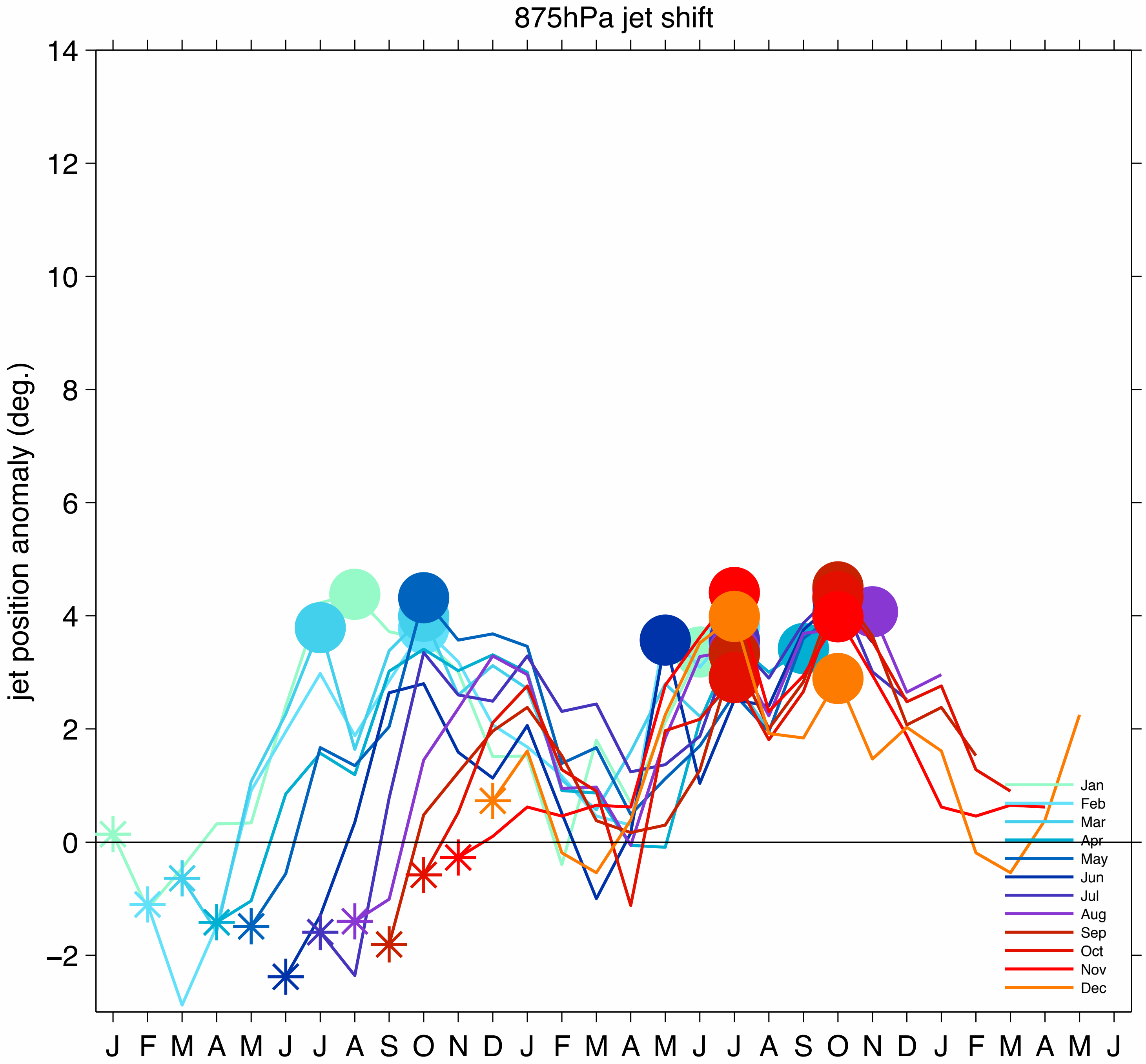
TROP: seasonality of the response of the jet position

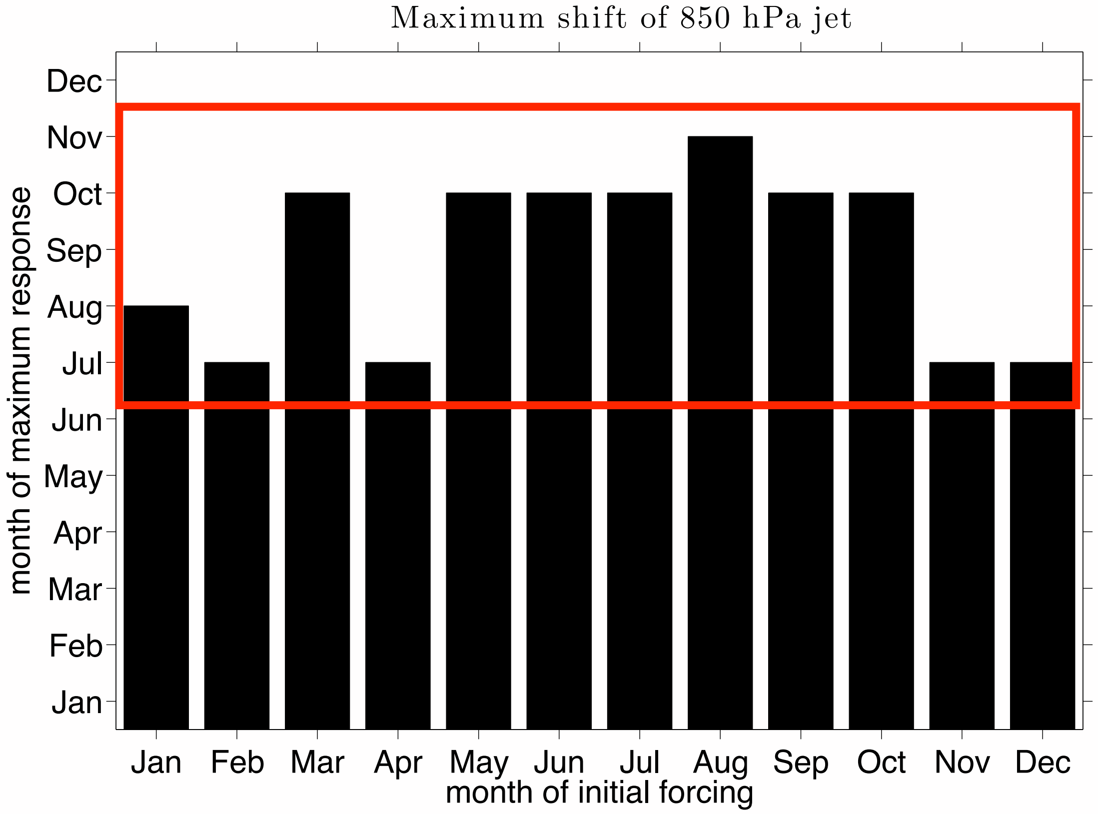




jet shift is generally largest in **late summer/autumn,** although not as much agreement as for u

TROP: seasonality of the response of the jet position





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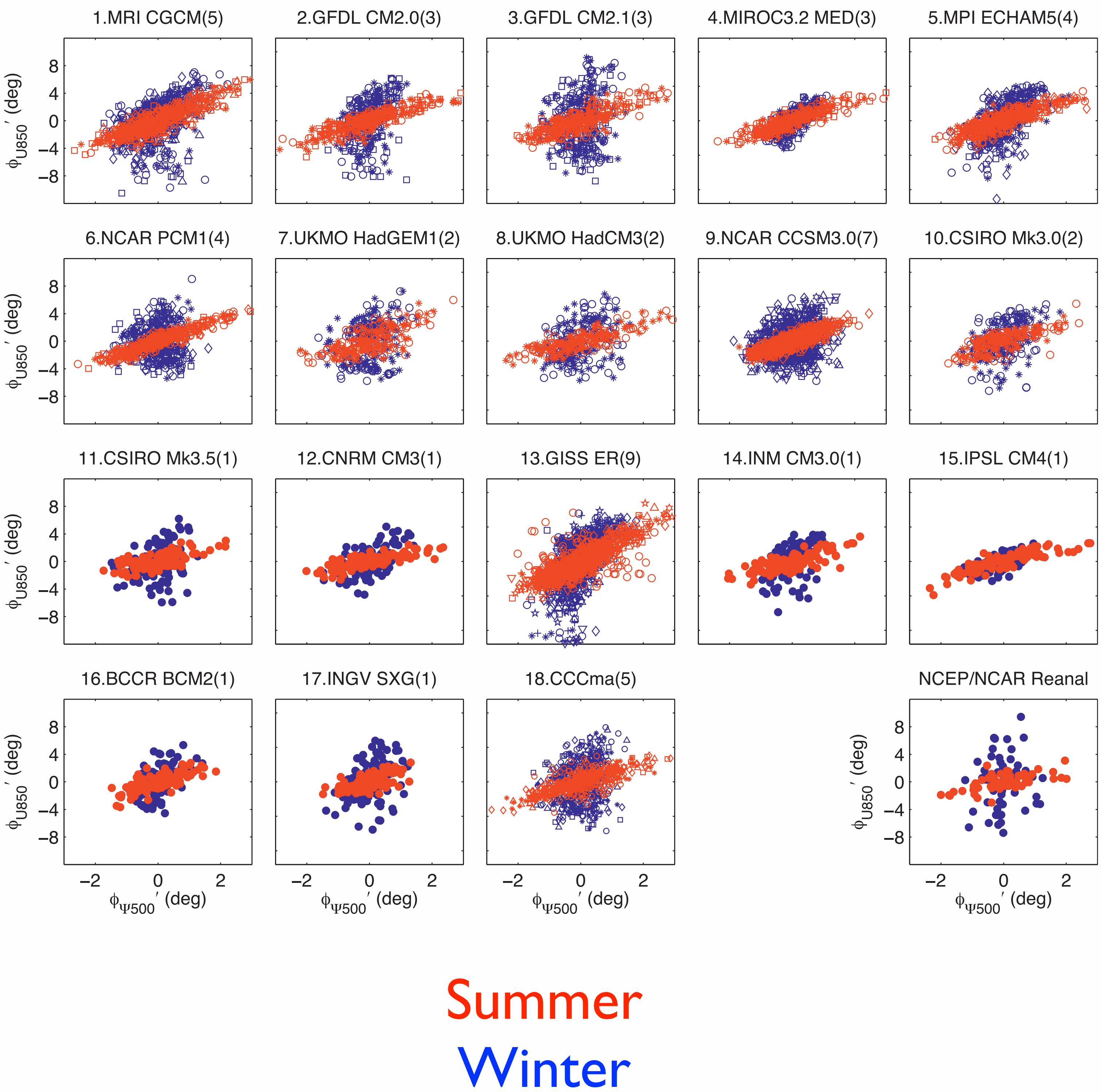
Hadley cell edge and midlatitude jet location

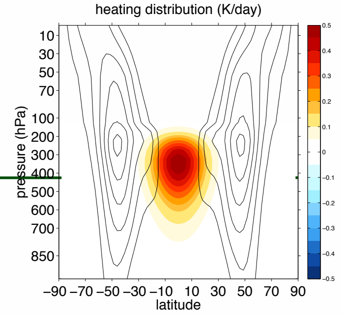


Ceppi & Hartmann (2013)

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)

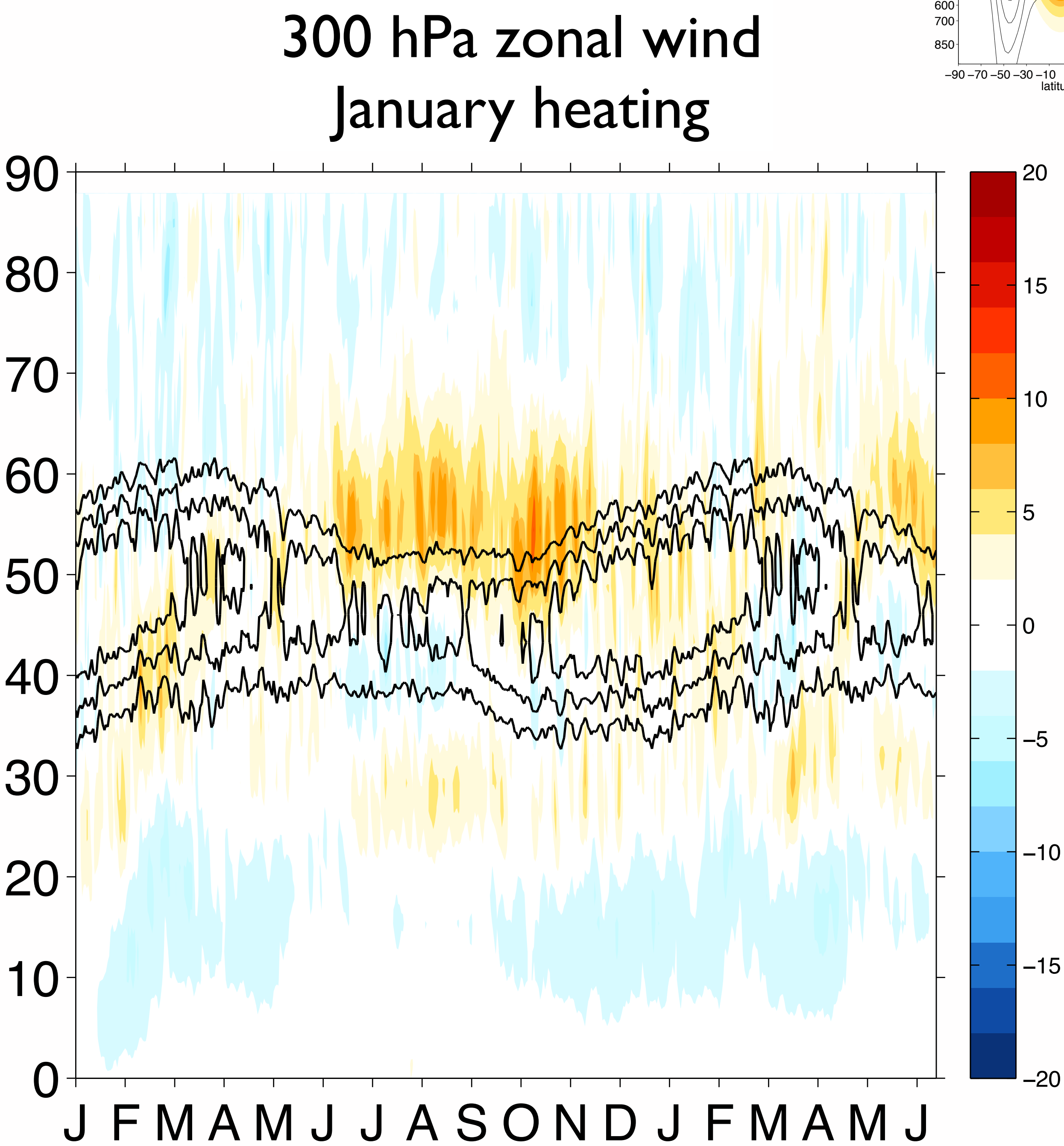
Kang & Polvani (2011)

TROP: wind response at 300 hPa



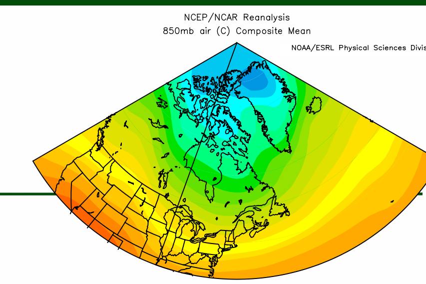
- response of u is largest for tropical heating in the summer/autumn when the zonal winds are weakest

- 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

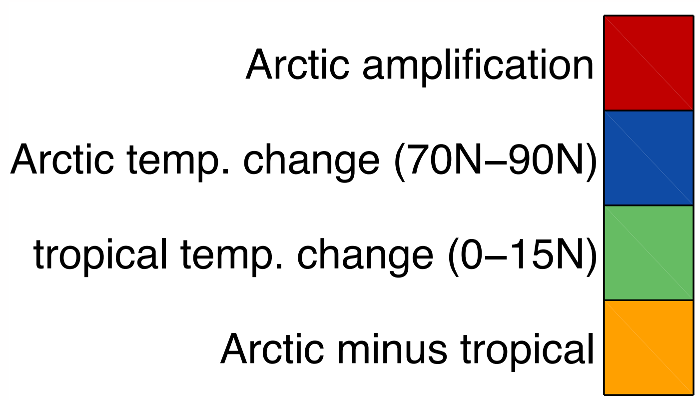


colors: response anomalies
black: control

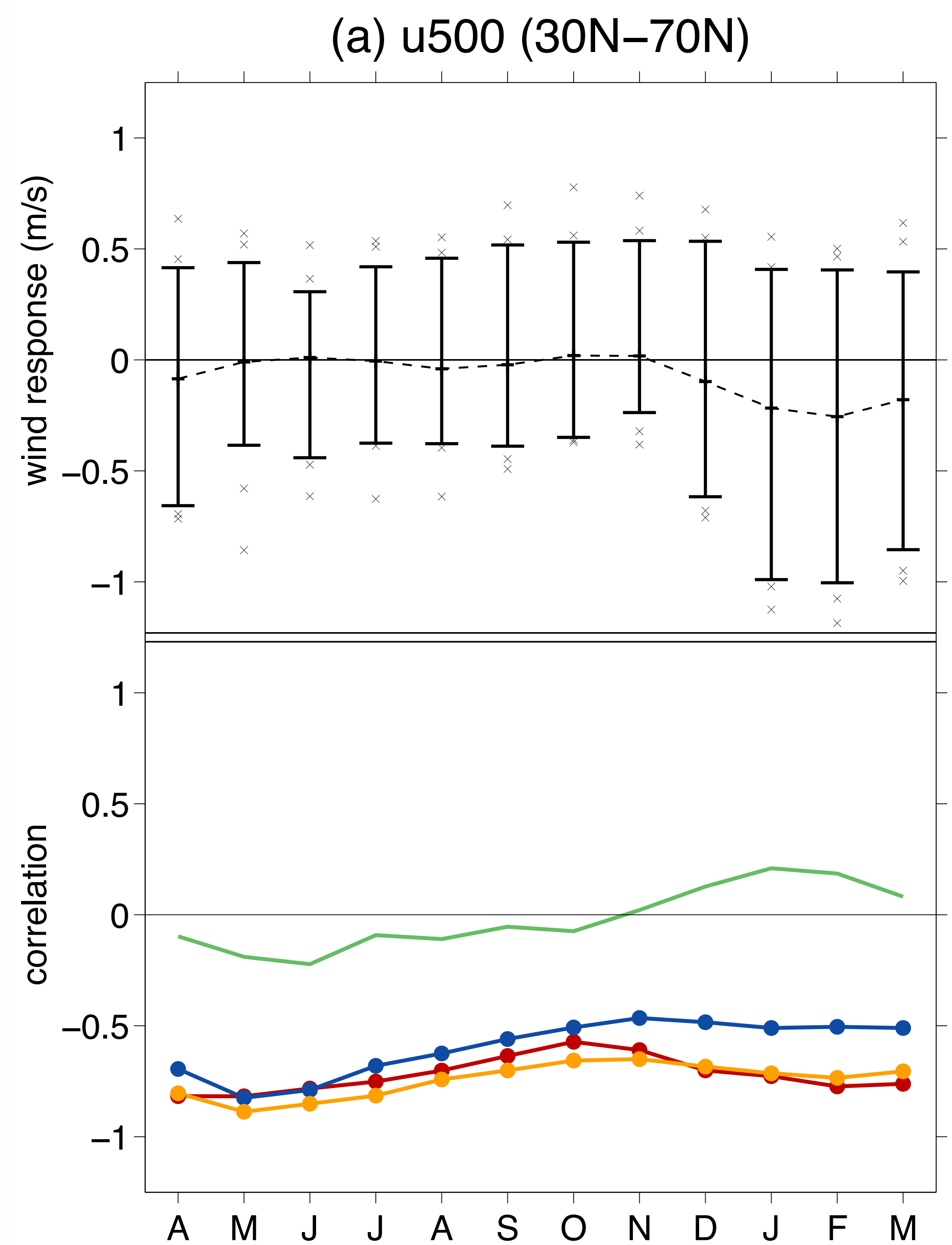
POLAR: Explaining CMIP5 model spread with AA



- 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)

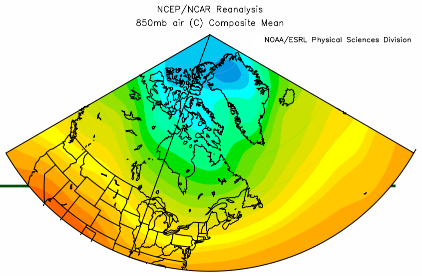


AA = 850 hPa temperature change over 70-90N; 230-350E



Barnes & Polvani (in prep)

POLAR: Explaining CMIP5 model spread with AA



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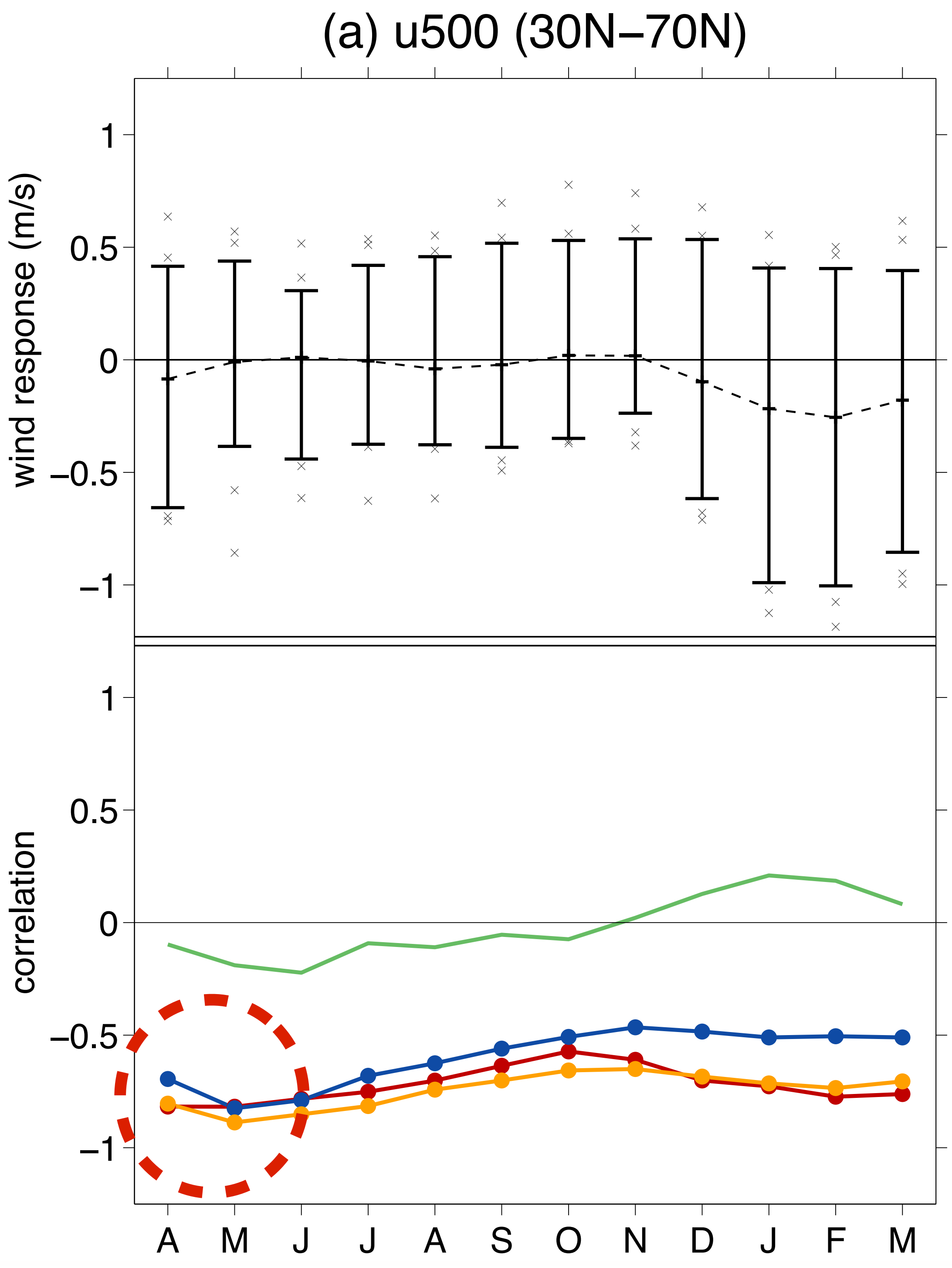
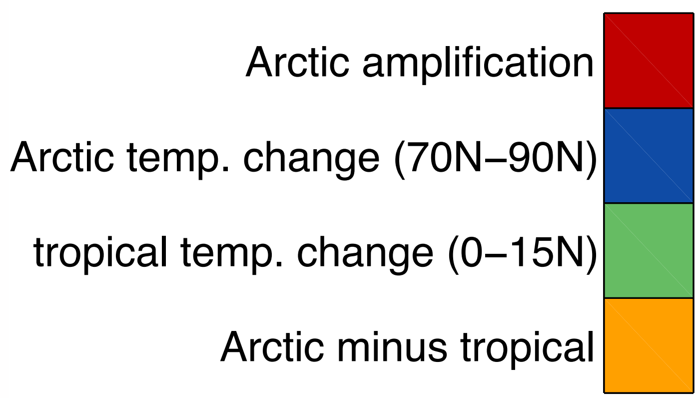




AA = 850 hPa temperature change over 70-90N; 230-350E

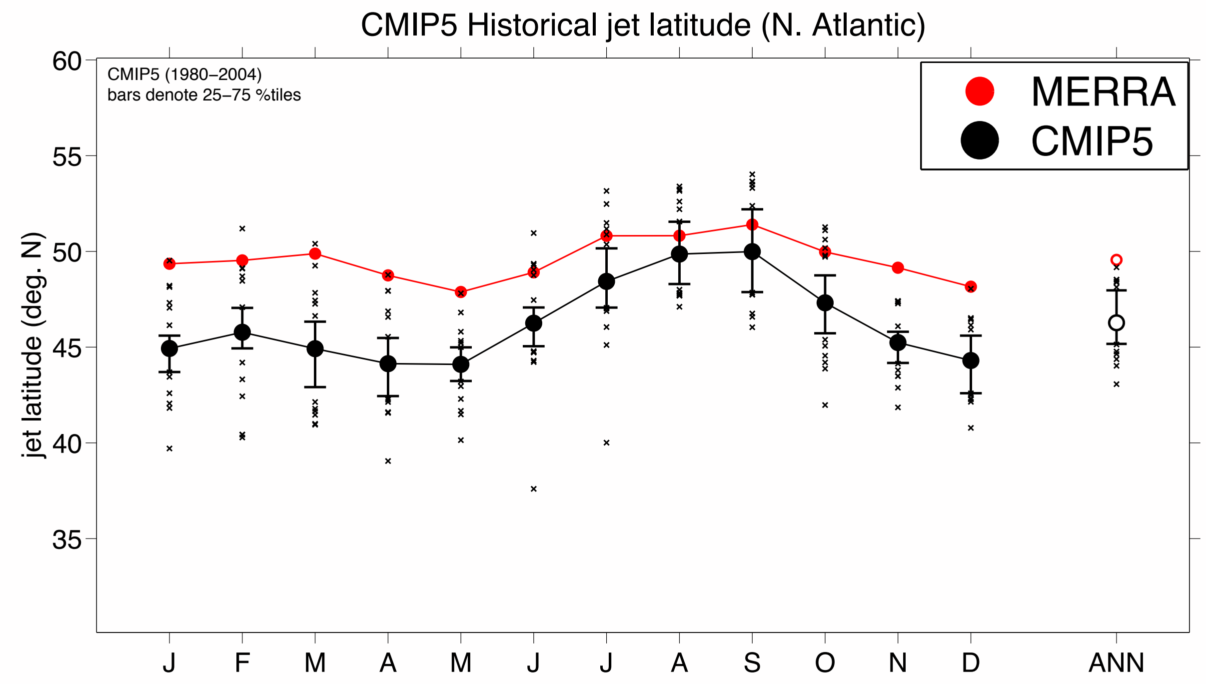
Barnes & Polvani (in prep)

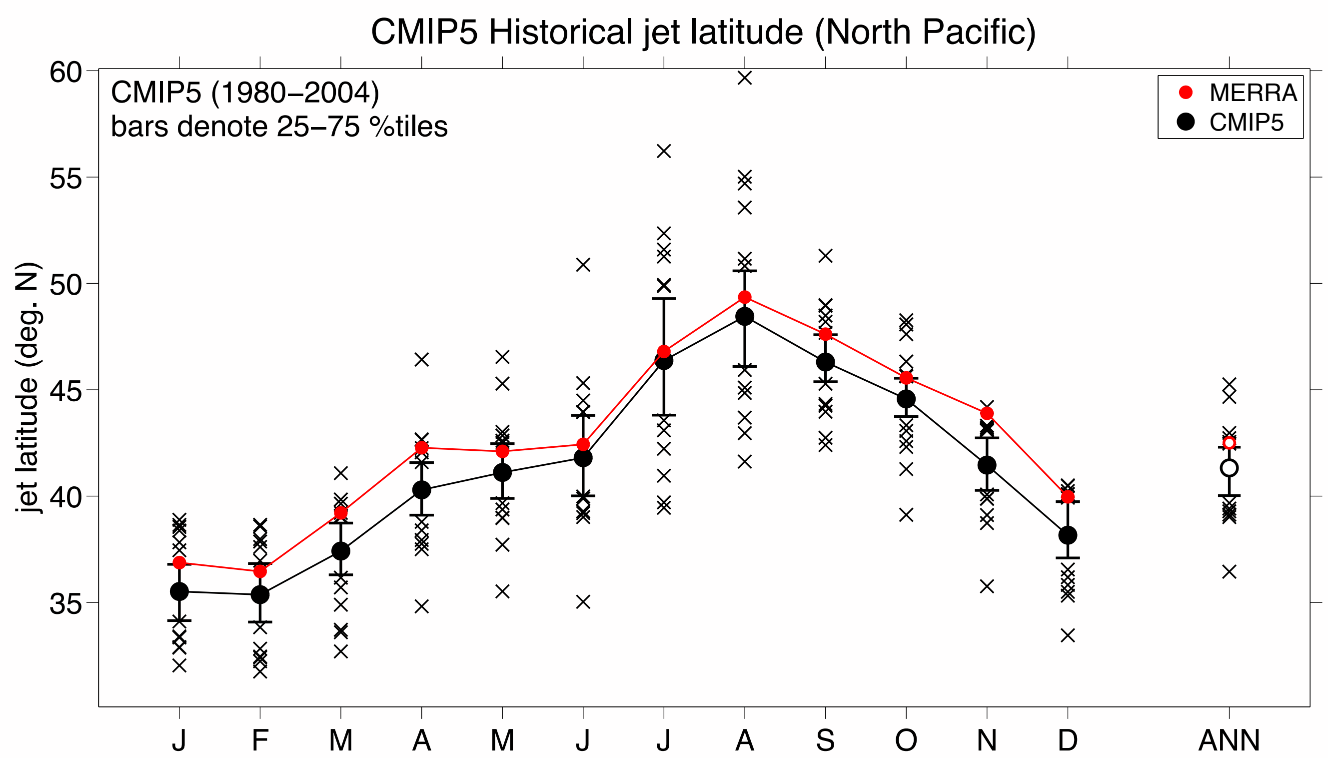
Final thoughts...

- **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

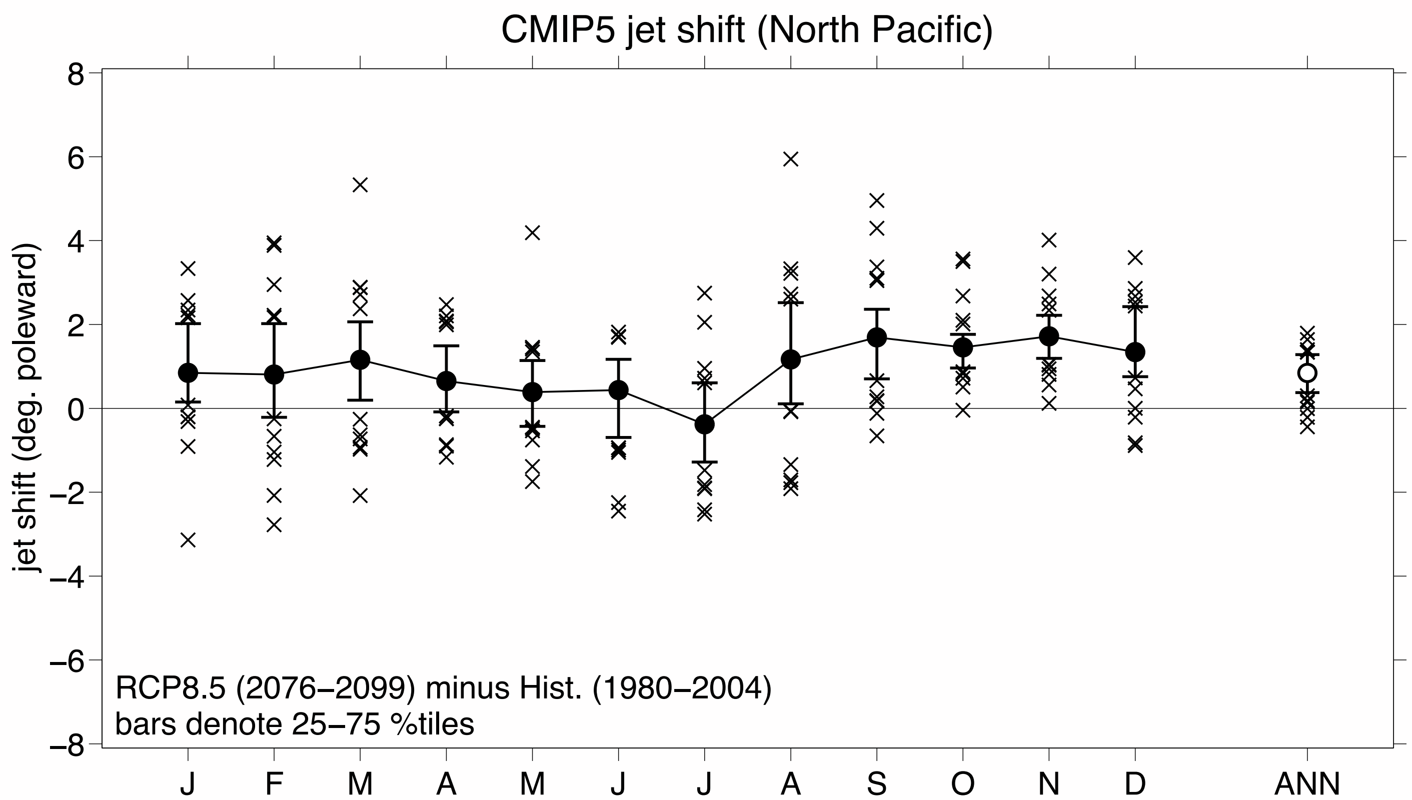
EXTRA SLIDES

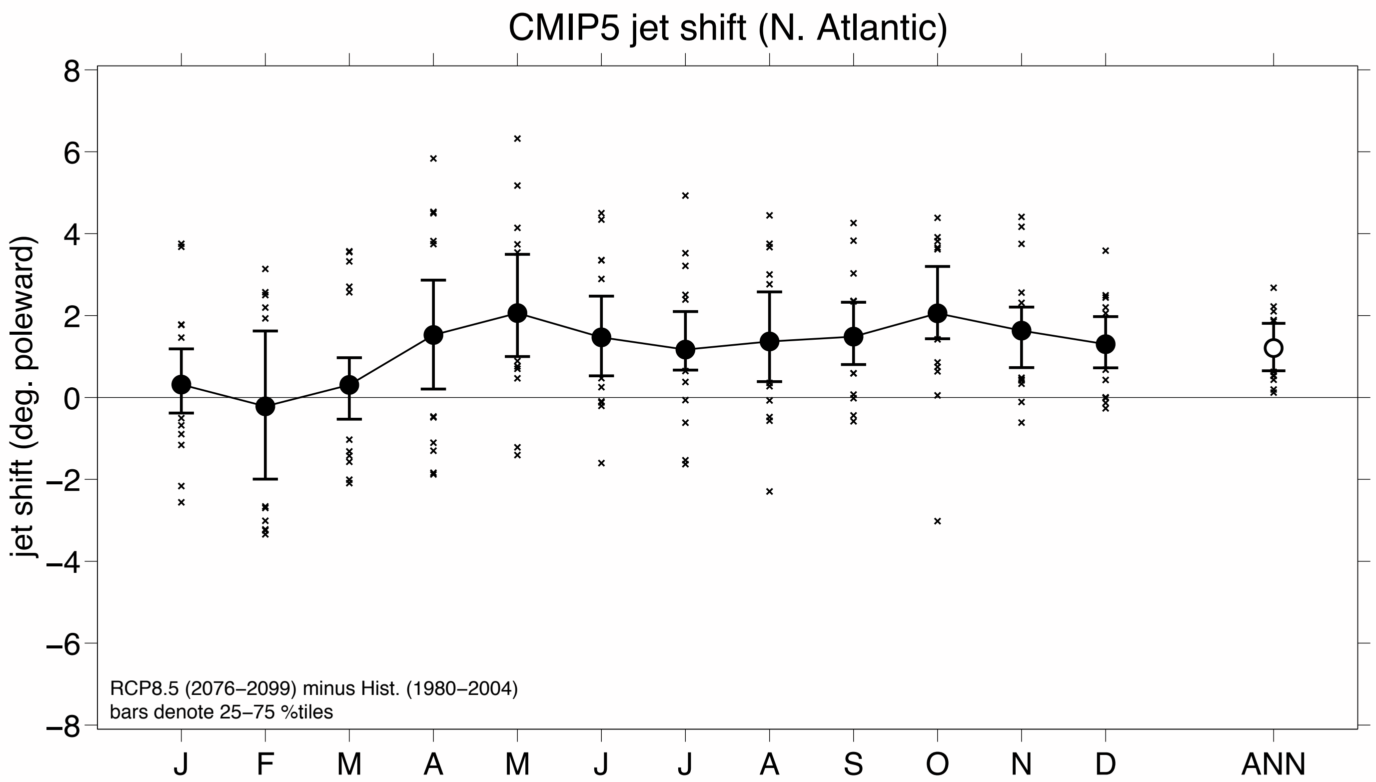
CMIP5 seasonality of historical jet-stream position





CMIP5 seasonality of jet-stream position response





Title here

Stratospheric Ozone Depletion: The Main Driver of Twentieth-Century Atmospheric Circulation Changes in the Southern Hemisphere

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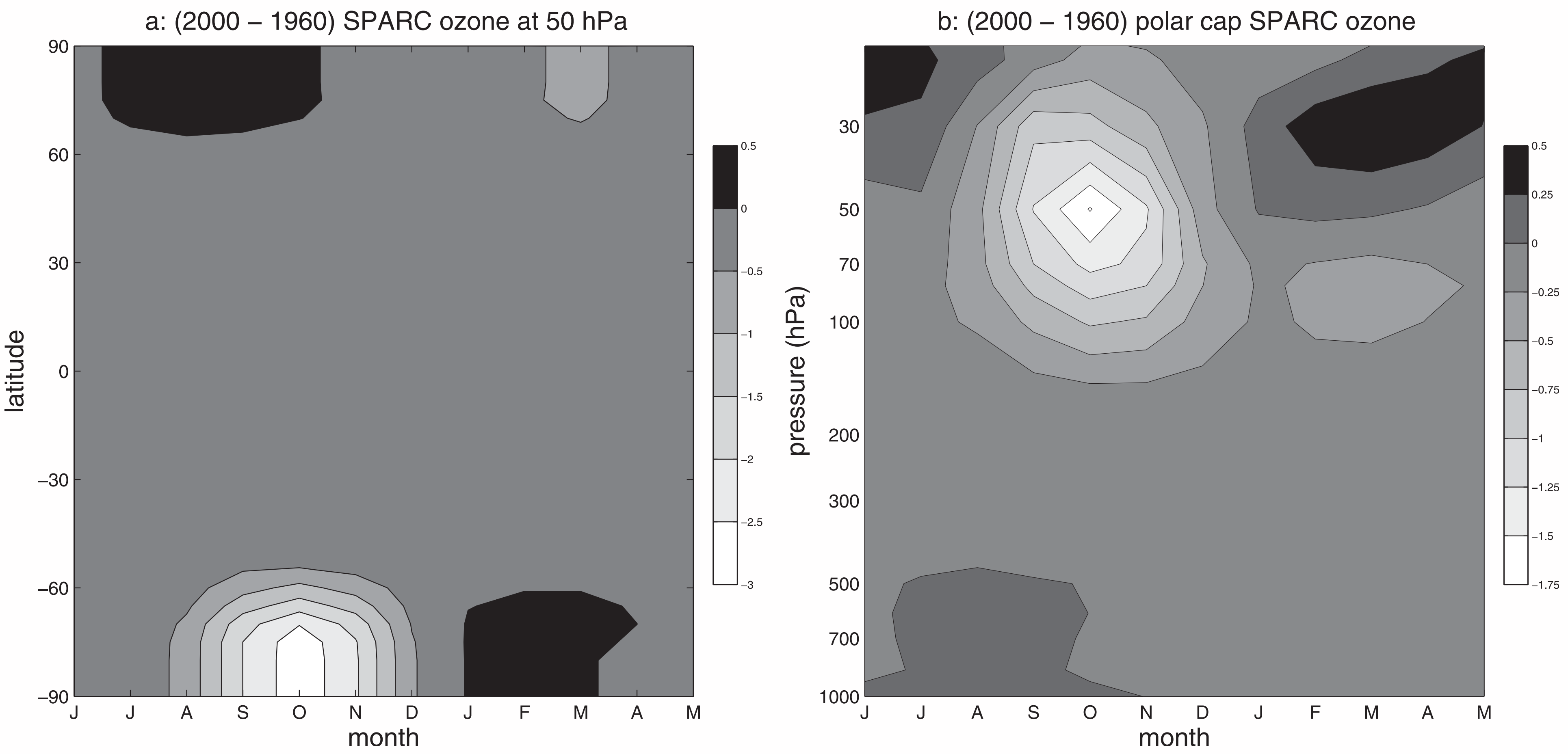

setting the seasonal cycle in the dry GCM

GEOPHYSICAL RESEARCH LETTERS, VOL. 29, NO. 7, 10.1029/2001GL014284, 2002

Tropospheric response to stratospheric perturbations in a relatively simple general circulation model

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[23] The tropospheric relaxation temperature is given by

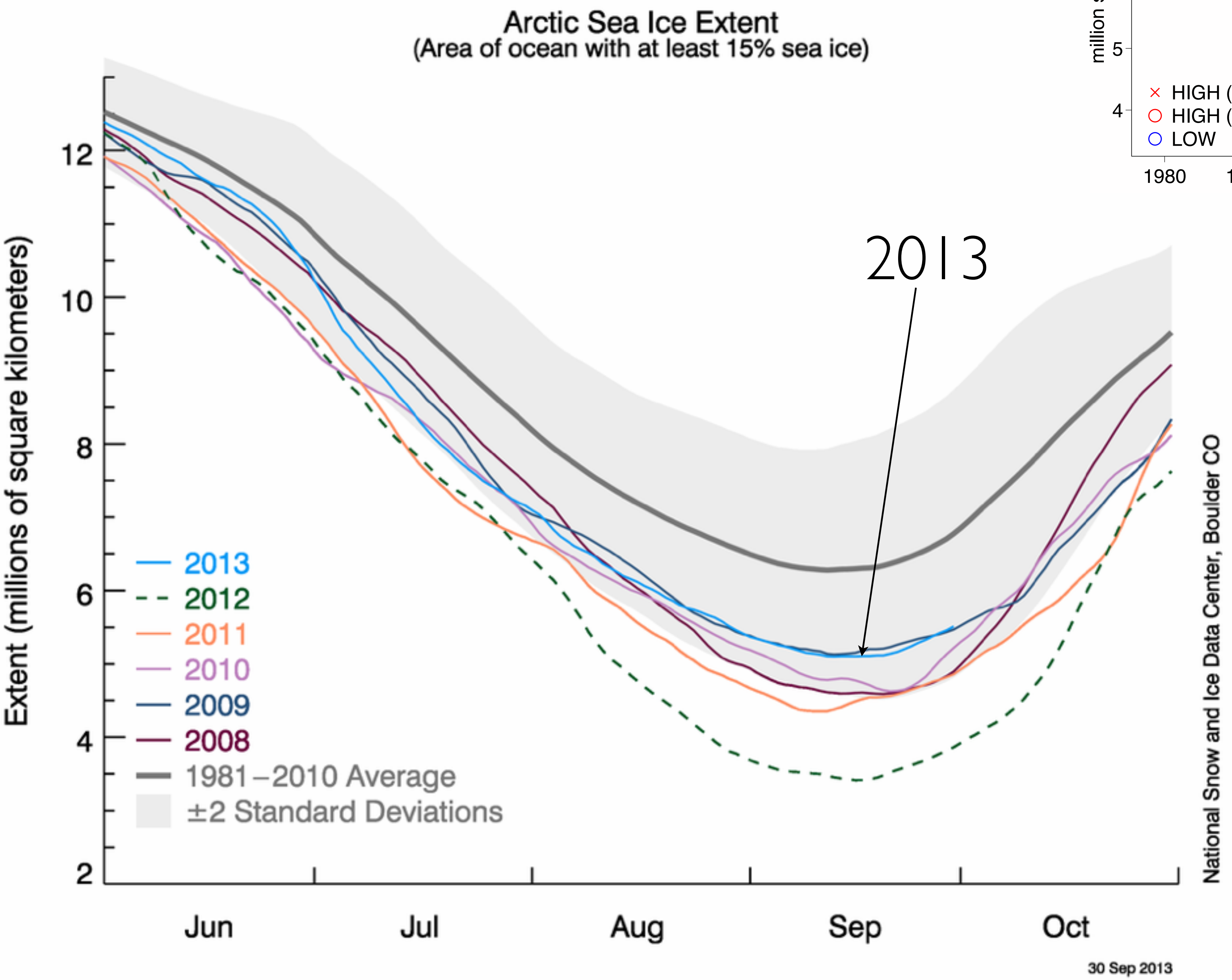
$$T_{eq}^{trop}(p,\phi) = \max[T_T, (T_0 - \delta T)(p/p_0)^{\kappa}], \qquad \text{(A3)}$$

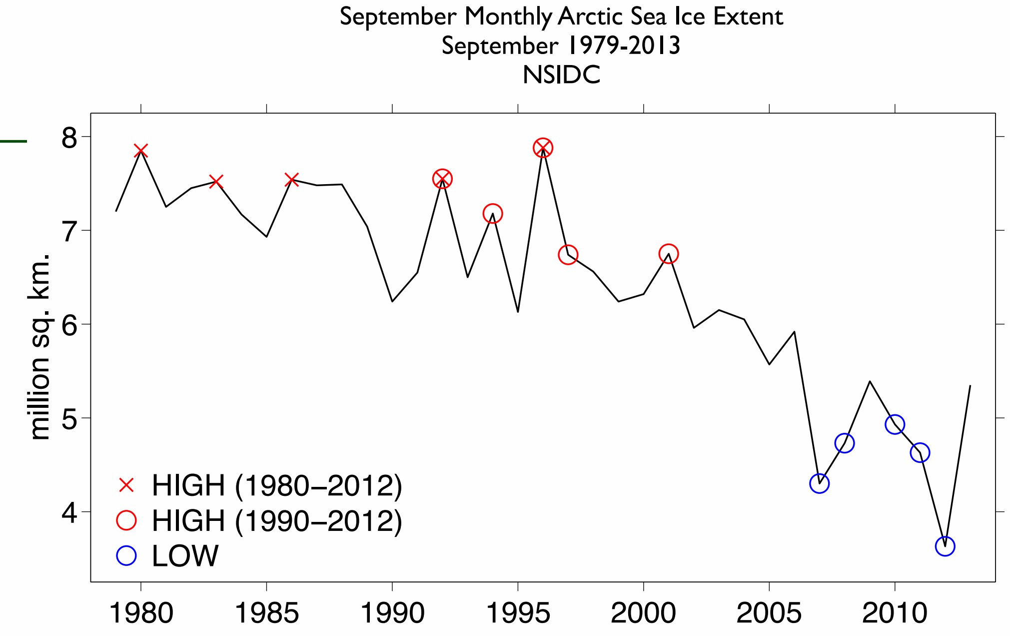
where T_0 = 315 K, p_0 = 1000 mb, and κ = 2/7, with

$$\delta T = \delta_y \sin^2\phi + \epsilon \sin\phi + \delta_z \log(p/p_0)\cos^2\phi \qquad \text{(A4)}$$

where δ_y = 60K, δ_z = 10K, and ϵ = 10K. The nonzero value of ϵ 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





Barnes, Polvani & Sobel (2013)

Table S1. Data availability of CMIP5 model output

Model name	Monthly u	Daily u, v
BCC-CSM1.1	x	x
BNU-ESM	x	x
CanESM2	x	x
CCSM4	x	
CMCC-CM	x	x
CNRM-CM5	x	x
CSIRO-Mk3-6–0	x	x
FGOALS-g2	x	x
FGOALS-s2	x	x
GFDL-CM3	x	x
GFDL-ESM2G	x	x
GFDL-ESM2M	x	x
GISS-E2-H	x	
GISS-E2-R	x	
HadGEM2-CC	x	x
HadGEM2-ES	x	x
INMCM4	x	x
IPSL-CM5A-LR	x	x
IPSL-CM5A-MR	x	x
IPSL-CM5B-LR	x	
MIROC-ESM	x	x
MIROC-ESM-CHEM	x	x
MIROC5	x	x
MPI-ESM-LR	x	x
MPI-ESM-MR	x	x
MRI-CGCM3	x	x
NorESM1-M	x	x