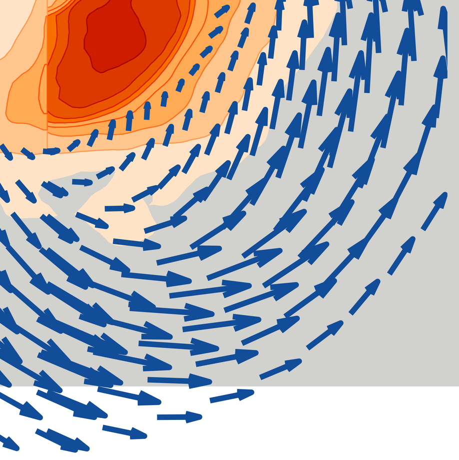

Circulation Response to Short-Term Arctic Warming

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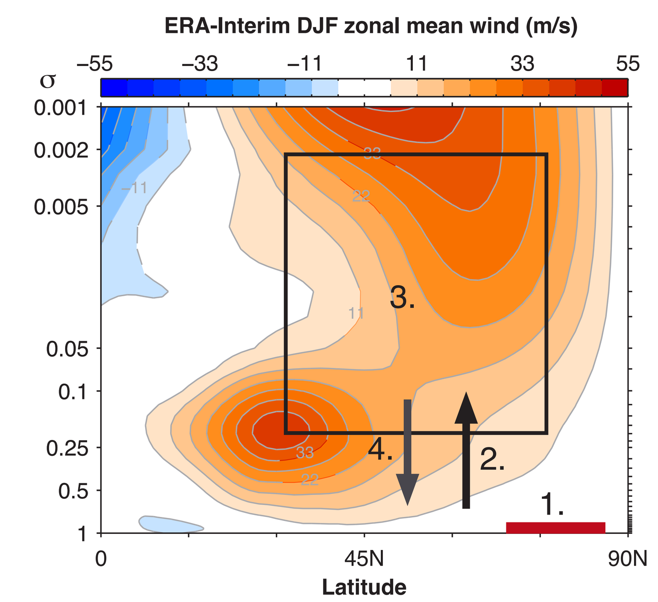
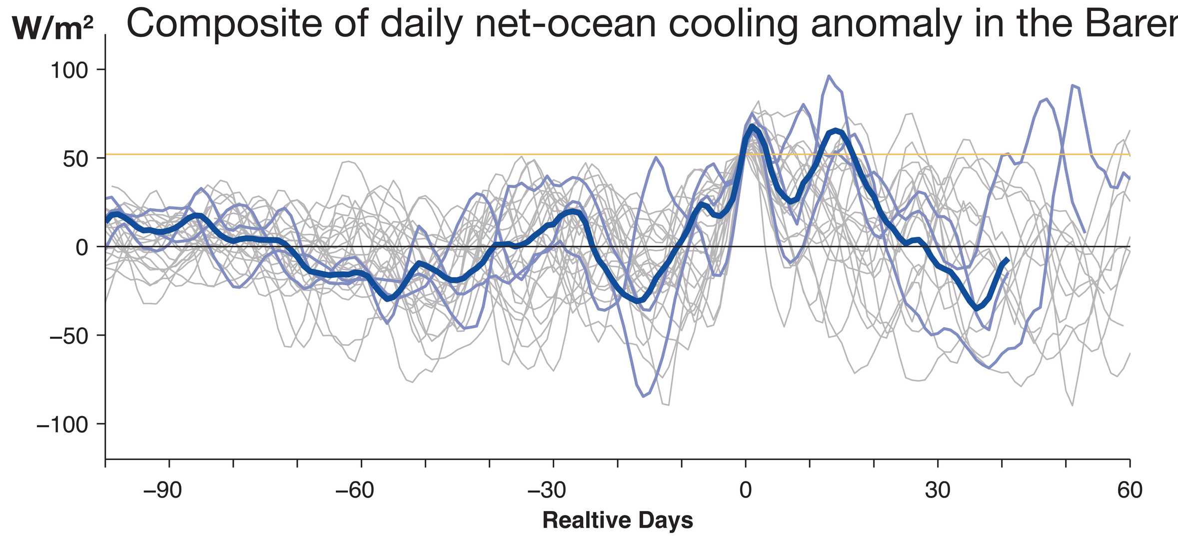
How does Surface Warming perturb the Stratospheric Vortex?



It has been suggested that anomalous heat fluxes in polar regions caused by sea ice retreat in fall/early winter can induce late winter/early spring mid-latitude weather anomalies (*Cohen2014,Barnes2015b*). We use an idealized aqua planet GCM to investigate how such longer-term and far-field responses to transient perturbations at polar surfaces can arise. The core questions we try to answer are:

1. Can polar surface perturbation induce Stratospheric Vortex Events (SVE) in an idealized model?
2. What is the tropospheric pathway?
3. What are the governing dynamics?
4. Do these stratospheric anomalies propagate downward?

W/m² Composite of daily net-ocean cooling anomaly in the Barents-Kara Sea



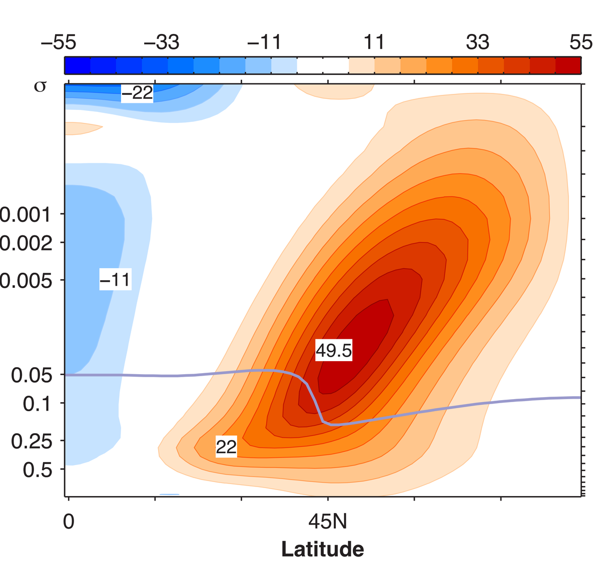
Years '89,'01,'12 shifted — Years '89,'01,'12 mean — Years 1979-2012 shifted

Each Grey line indicate a fall season (October to January) exceeding 2 std (orange line = 50 W/m²). Thin blue lines are the years of maximum ocean cooling and the thick blue line is the mean of these years. The data is derived from ERA-Interim by subtracting the seasonal cycle and using 5-day-running-mean.

Methods

Ensemble runs with moist idealized general circulation model

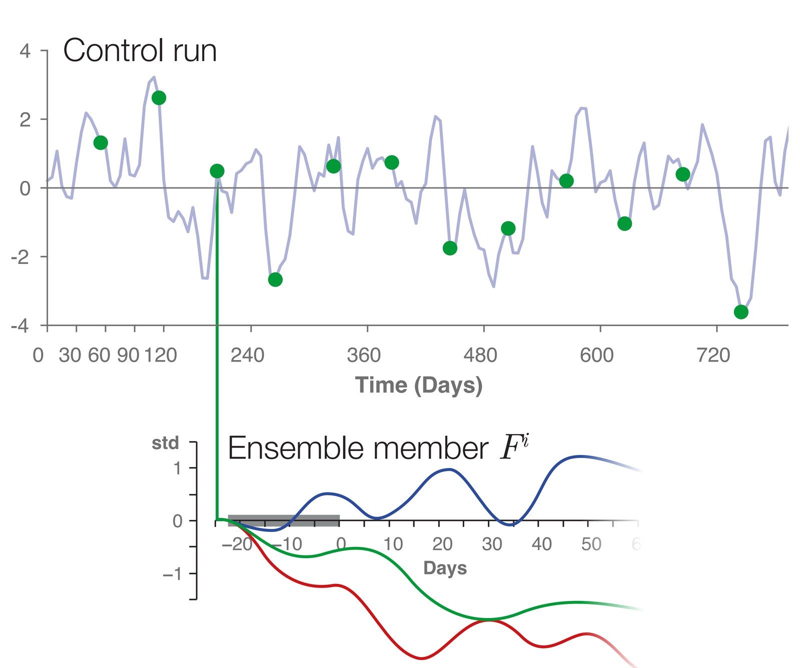
O'Gorman & Schneider [2008] and Frierson [2006]



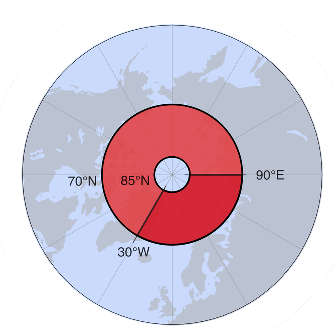
Model zonal wind climatology (m/s)

- T85 spectral resolution, 30 vertical levels unequally spaced
- No seasons, solar insolation in equinox in DJF-like conditions
- Slab ocean, zonally symmetric
- Equatorial Q-flux convergence of 60 W/m² at peak to adjust Hadley Cell width
- Polar long-wave absorption efficiency reduced for increased lower-troposphere stability in high latitudes.

Schematic of ensemble definition



Ensemble configuration

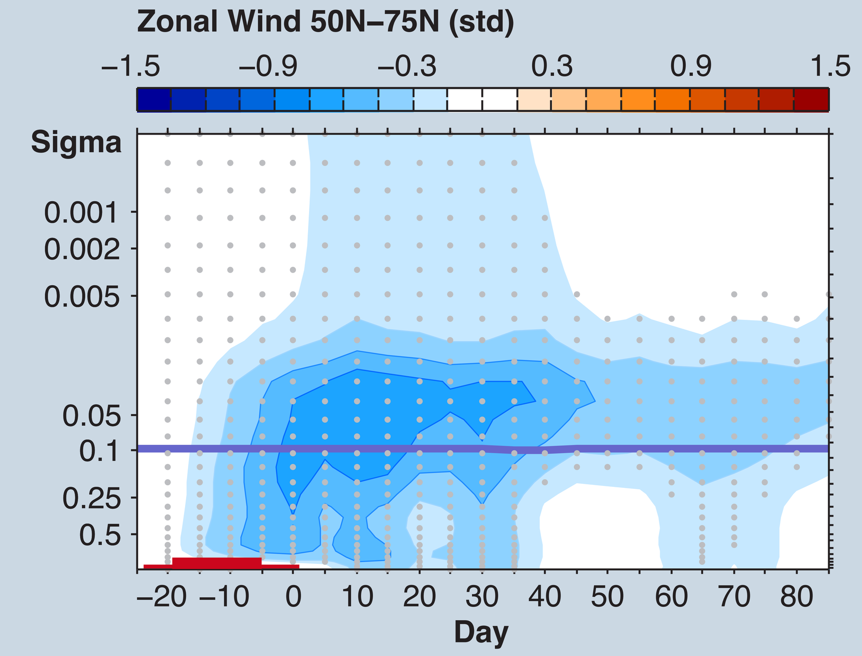


- Initial conditions are picked from an unperturbed control run
- 100-paired members in each ensemble (50 with Q-flux divergence, 50 with convergence)
- Each ensemble member has two realizations, one with Q-flux convergence and Q-flux divergence.
- **25-day polar-cap forcing equivalent to 200 W/m2 in the Barents/Kara-Sea or 66 W/m^2 polar-cap.**
- Several 100-member ensemble are realized for different forcing strengths and areas
- Signal S is independent from control variability

$$S = \langle F^i_{conv} \rangle - \langle F^i_{div} \rangle$$

Zonal-Mean Response

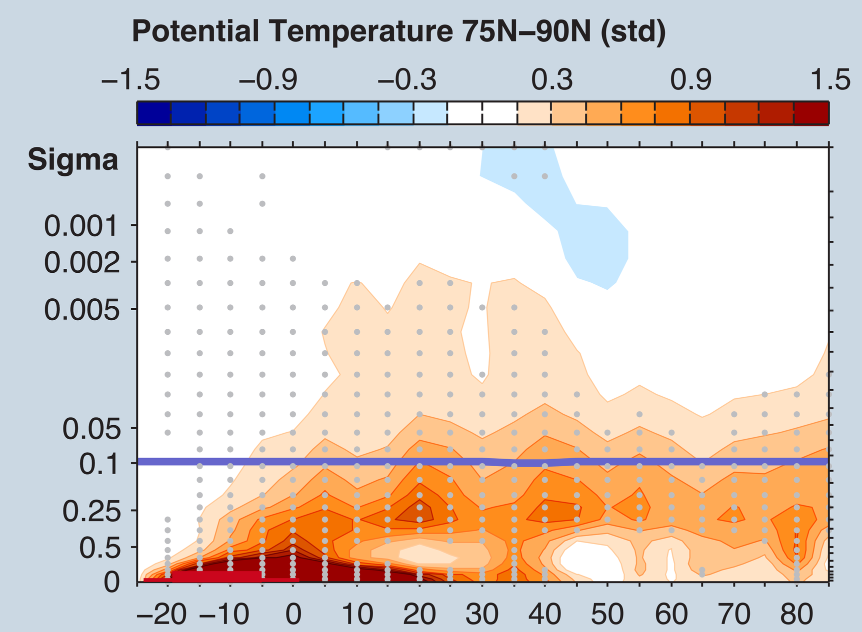
Short-term Arctic surface warming perturbs the Stratosphere



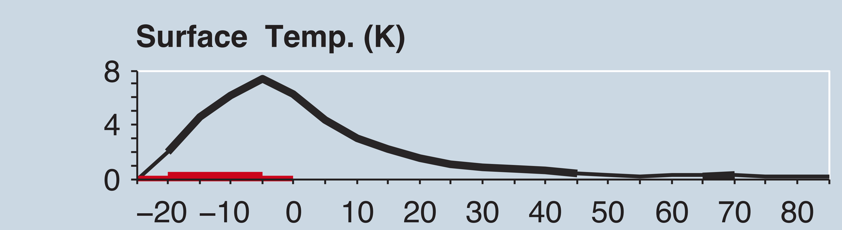
Arctic Surface warming leads to long **zonal wind weakening** (as in observations *King2015, Garcia-Serrano2015, Yang2016*)

Stratospheric Vortex weakens and leads to persistent changes in the lower Stratosphere

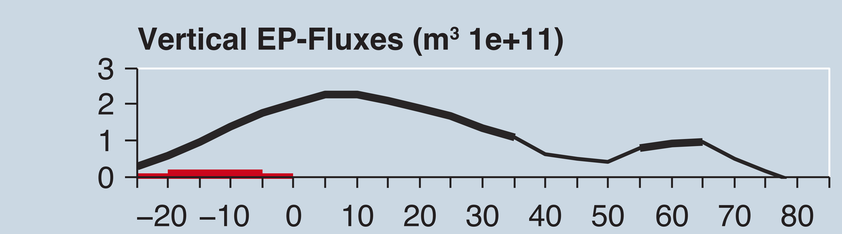
Stratospheric anomalies may reconnect to the lower troposphere (*Baldwin & Dunkerton, 2001*)



Dynamics can be separated in **thermal adjustments** and **stratospheric responses** to eddy heat-fluxes



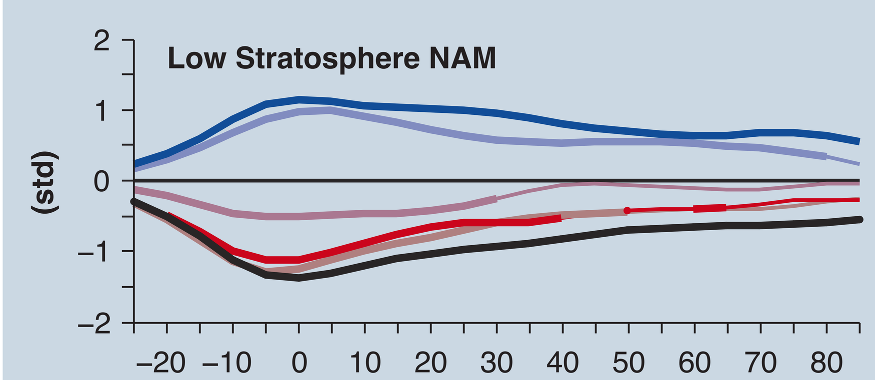
Direct surface response to symmetric polar heating (*day -20 to 0, red bar*). Surface signal decays symmetric around day 0



Upward heat-fluxes ($\overline{v'\theta'}$) proceed stratospheric zonal wind weakening (*Polvani and Waugh, 2004*)

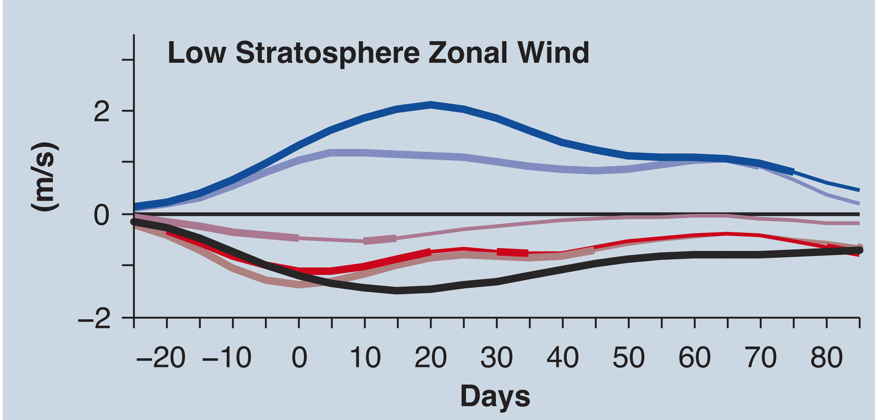
Linearity and Symmetry

Comparing forcing strengths & sign



The **response amplitude** scales with forcing-strength. Cooling and warming ensembles have the **same amplitude**: We assume linearity and focus on the mid-latitude response

Stratospheric response is **independent of forcing symmetry** with comparable Q-flux divergence: Stationary waves are not the key driver.



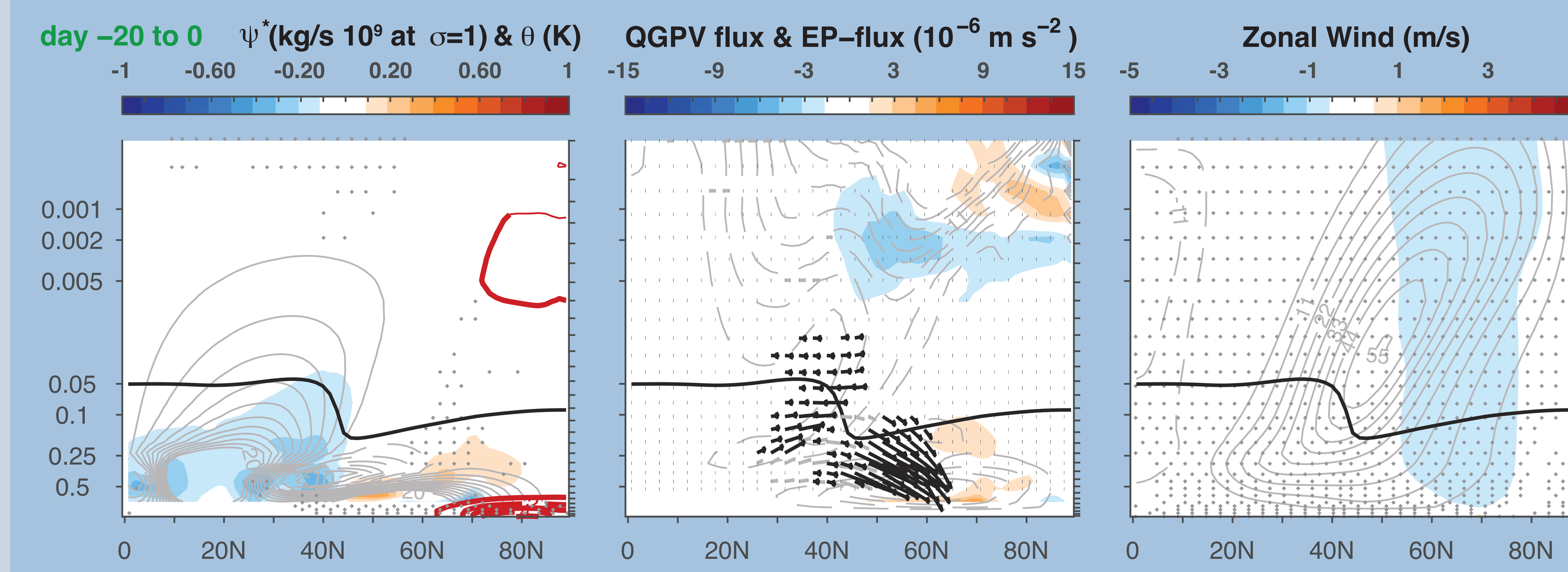
O 66.6 W/m²
O −66.6 W/m²
O 66.6 W/m²
200 W/m²
−200 W/m²
O 33.3 W/m²

Eddy-Driven Stratosphere Weakening

Residual circulation drives stratospheric vortex events

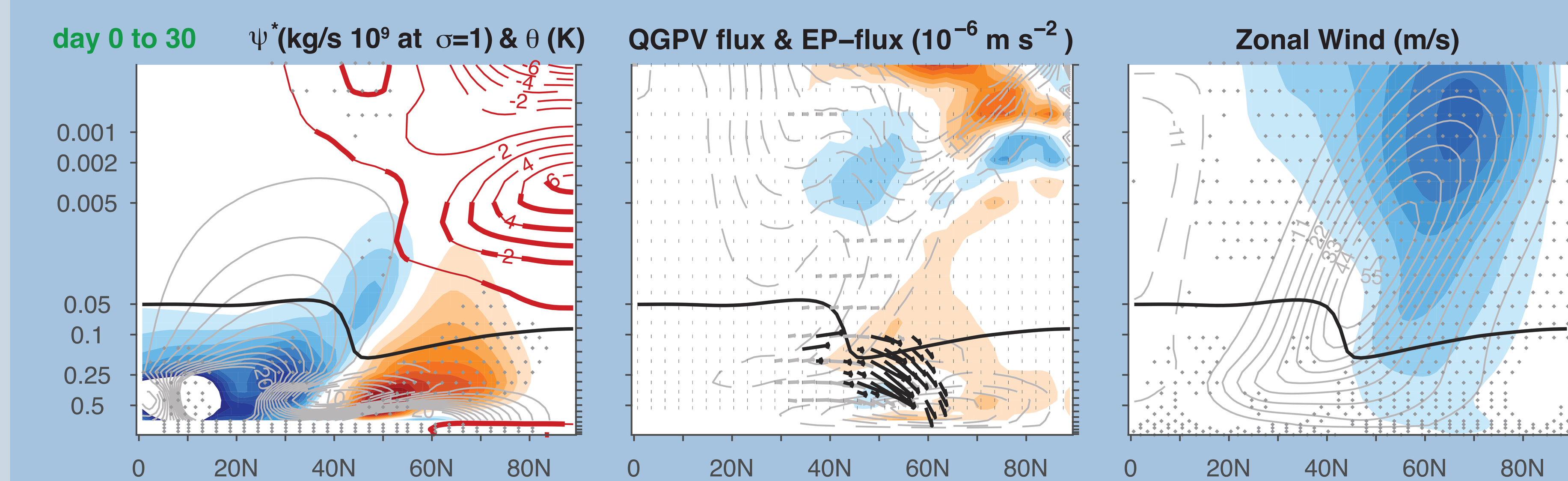
- **Grey** climatology
- **Black** tropopause
- • Significance
- ψ^* residual circulation
- – θ pot. Temperature
- → EP-fluxes

Vertical EP-fluxes, there divergence and ψ^* are scaled with log(1/sigma)



Left Arctic surface warming lead to a reduces boundary layer temperature gradient and chances EP-flux budget.

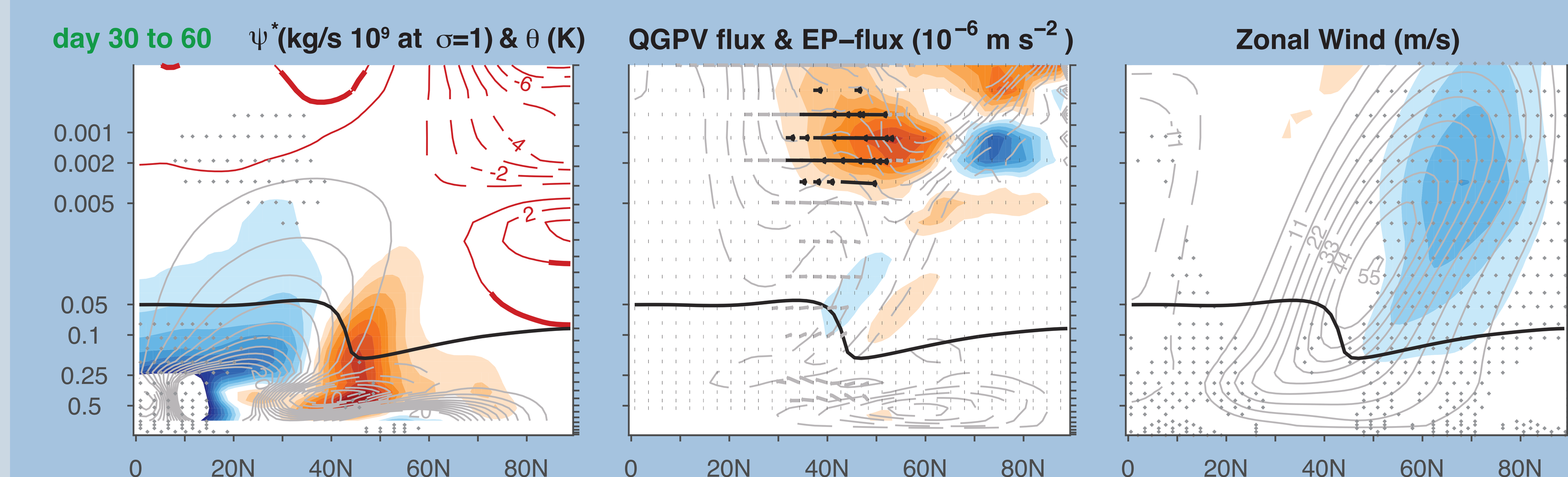
Right thermal adjustment zonal wind.



Center less upward eddy heat-fluxes lead to a local eddy-flux divergence that drives the residual circulation ψ^*.

Left The residual circulation ψ^* lead to an additional temperature anomaly in the upper stratosphere.

Right The vertical structure of the stratospheric jet is a super position of thermal adjustment and eddy-driven responses.



Left Surface temperature anomaly disappeared.

Right Stratospheric zonal-wind weakening and residual circulation decay slowly, but are still significant after 80 days (*Kushner & Polvani 2006*).

$$\frac{\partial \overline{u}}{\partial t} - f\,\overline{v}^* - \overline{\mathcal{F}} = \nabla \cdot \mathbf{F}$$

$$f\,\overline{u}_p - R\,\overline{\theta}_y = 0$$

$$\overline{v}^*_y + \overline{\omega}^*_p = 0$$

$$\frac{\partial \overline{\theta}}{\partial t} + \overline{\theta}_p\,\overline{\omega}^* - \overline{\mathcal{L}} = 0$$

$$\overline{v}^* = \overline{v} - \frac{\partial}{\partial p}\frac{\overline{v'\theta'}}{\overline{\theta}_p}$$

$$\overline{\omega}^* = \overline{\omega} - \frac{\partial}{\partial y}\frac{\overline{v'\theta'}}{\overline{\theta}_p}$$

Summary

- Polar surface perturbation can Induce stratospheric anomalies and SVE up to 85 days after the surface anomaly.
- Stationary eddies are not necessary to troposphere-to-stratosphere connection
- Response amplitude scales linear with the energy input.
- Two possible dynamics to perturb the residual circulation:
  - A) Reduced mid-latitude tropospheric/surface baroclinicity drives eddy-flux divergence.
  - B) Adjustments within the Arctic perturb waves on tropopause level (as Ueyama et al. 2013).

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References

Baldwin, Mark P., and Timothy J. Dunkerton. 2001. "Stratospheric Harbingers of Anomalous Weather Regimes." Science 294
Cohen, Judah, James A. Screen, Jason C. Furtado, Mathew Barlow, David Whittleston, Dim Coumou, Jennifer Francis, et al. 2014. "Recent Arctic Amplification and Extreme Mid-Latitude Weather." Nature Geoscience 7 (9): 627–37.
García-Serrano, J., C. Frankignoul, G. Gastineau, and A. de la Cámara. 2015. "On the Predictability of the Winter Euro-Atlantic Climate: Lagged Influence of Autumn Arctic Sea Ice." Journal of Climate 28 (13): 5195–5216.
King, Martin P., Momme Hell, and Noel Keenlyside. 2015. "Investigation of the Atmospheric Mechanisms Related to the Autumn Sea Ice and Winter Circulation Link in the Northern Hemisphere." Climate Dynamics, May, 1–11.
Kushner, Paul J., and Lorenzo M. Polvani. 2006. "Stratosphere–Troposphere Coupling in a Relatively Simple AGCM: Impact of the Seasonal Cycle." Journal of Climate 19 (21): 5721–27.
O'Gorman, Paul A., and Tapio Schneider. 2008. "The Hydrological Cycle over a Wide Range of Climates Simulated with an Idealized GCM." Journal of Climate 21 (15): 3815–32.
Polvani, Lorenzo M., and Darryn W. Waugh. 2004. "Upward Wave Activity Flux as a Precursor to Extreme Stratospheric Events and Subsequent Anomalous Surface Weather Regimes." Journal of Climate 17 (18).
Thompson, David W. J., Elizabeth A. Barnes, Clara Deser, William E. Foust, and Adam S. Phillips. 2015. "Quantifying the Role of Internal Climate Variability in Future Climate Trends." Journal of Climate 28 (16): 6443–56.
Yang, Xiao-Yi, Xiaojun Yuan, and Mingfang Ting. 2016. "Dynamical Link between the Barents–Kara Sea Ice and the Arctic Oscillation." Journal of Climate 29 (14): 5103–22.