Nonlinear Response of the Stratosphere and the North Atlantic-European Climate to Global Warming

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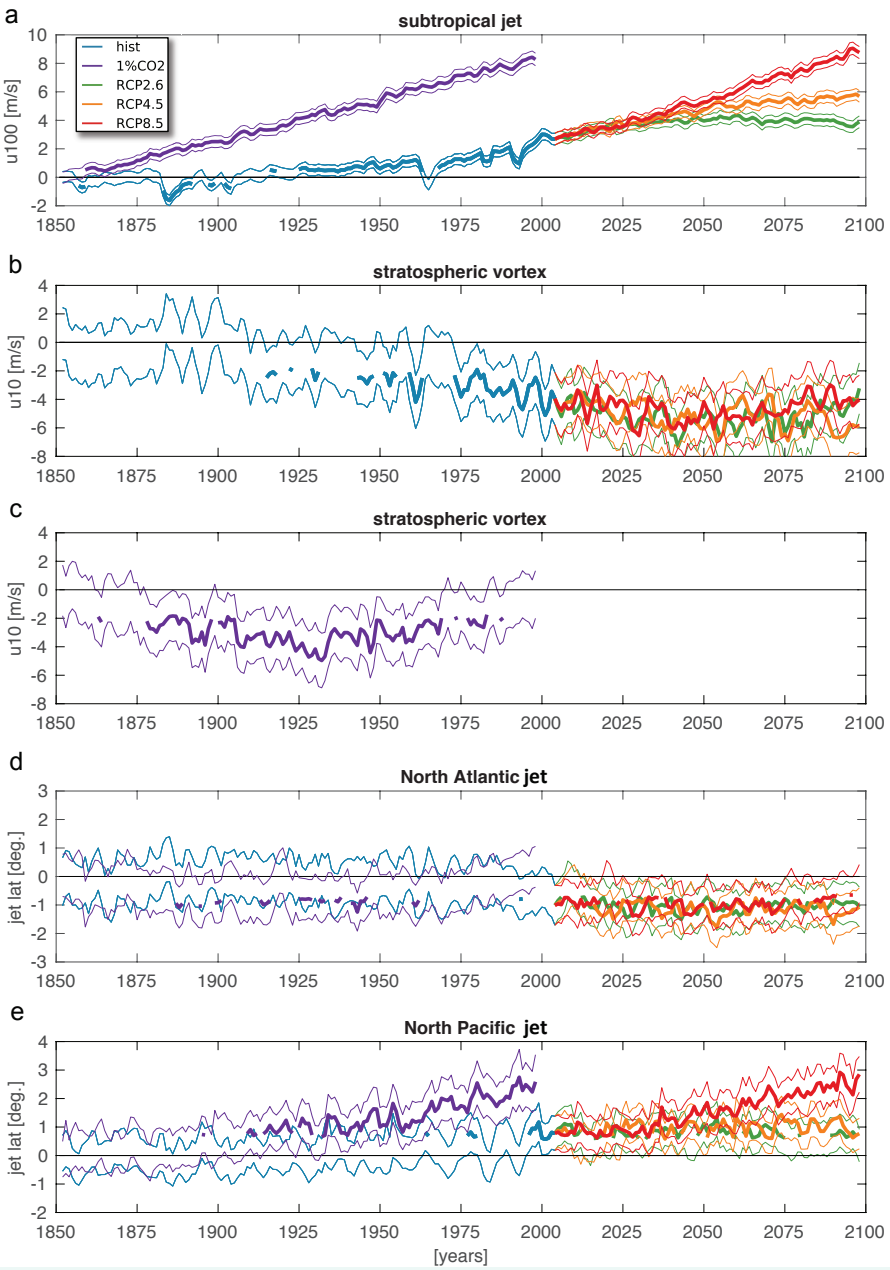
- **Transient response of the atmospheric circulation in a grand ensemble (100-member) of idealized scenario experiments**

Thanks: Alexey Yu Karpechko (Finnish Meteorological Institute)
Luis Kornblueh (Max-Planck-Institut für Meteorologie)

MPI Grand Ensemble (GE):

- **Ensemble of 100 realizations (members) of historical and scenario experiments performed with the MPI-ESM1.1 model**
- **MPI-ESM1.1: coupled atmosphere-ocean-seaice model**
- **Atmosphere component of MPI-ESM1.1 is the ECHAM6 model, with top @ 80 km. Resolution: T63L47**
- **Idealized scenario experiments: CO_2 concentration increase at 1%/year, till 4xCO_2. Aerosols, ozone and other GHGs are fixed**
- **Members initialized from different years of a 2000-year long experiment using fixed pre-industrial radiative forcing**
- **Monthly mean, as (almost) no daily data are available**

Indicators of circulation changes (January)



Subtropical tropospheric jet: zonal mean zonal wind [20-40 N] @ 100 hPa

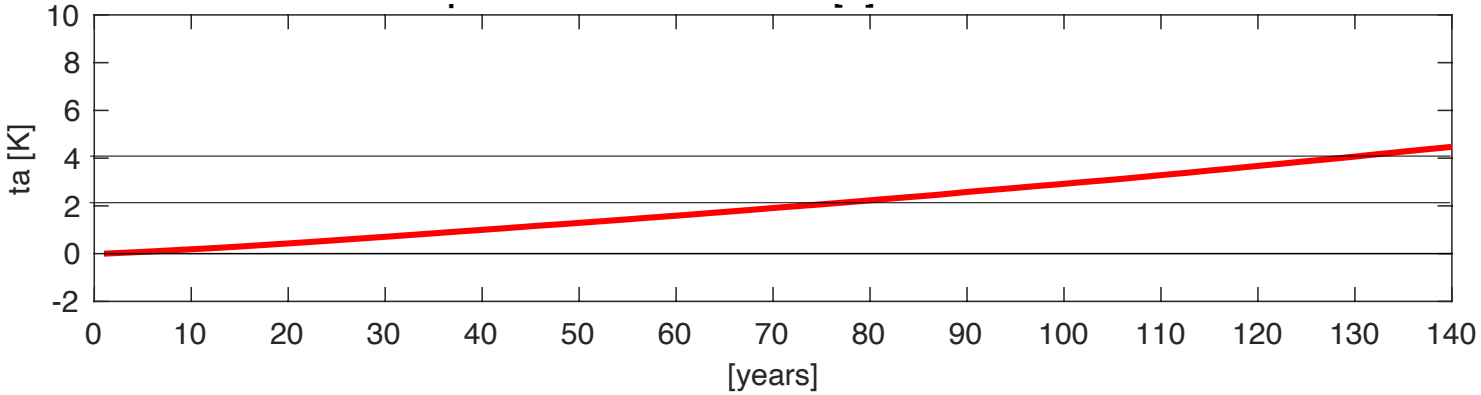
Stratospheric polar vortex: zonal mean zonal wind [70-80N] @ 10 hPa

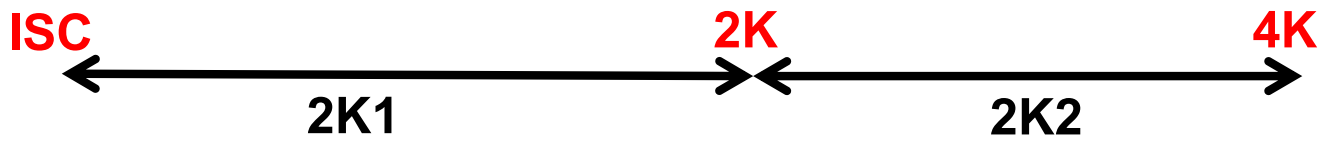
Latitude of tropospheric eddy-driven jet: max of [850-700 hPa] zonal wind, by ocean basin

Maher et al JAMES 2019

Bounds: 95% confidence Intervals

Annual global mean temperature @ 850 hPa



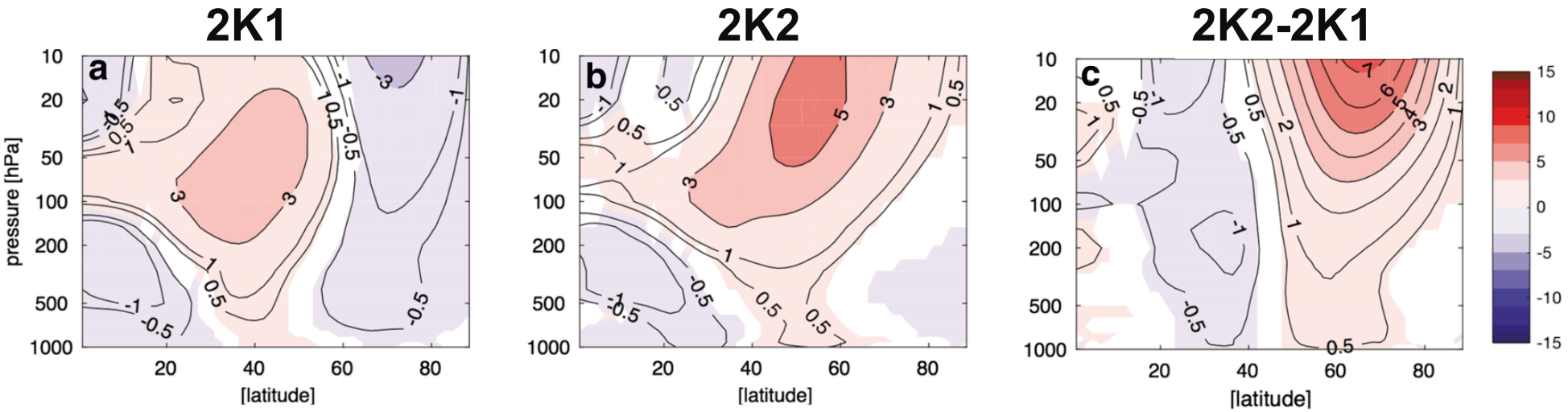


Initial State Climate: first decade of the experiment
2K Climate: global warming of 2 K (10-year average)
4K Climate: global warming of 4 K (10-year average)

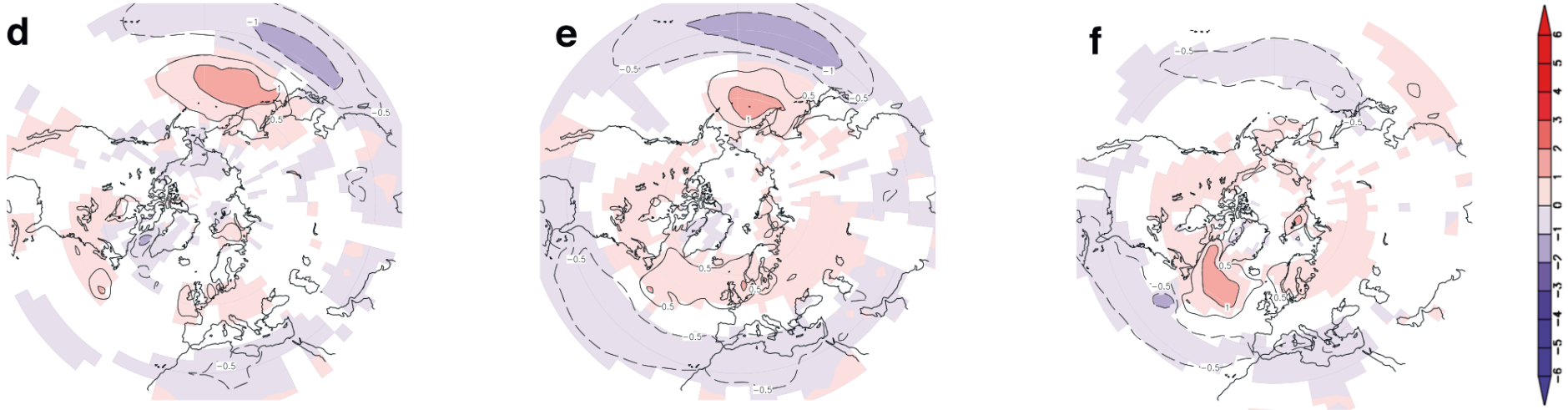
2K1 change: Difference between the second and first decade
2K2 change: Difference between the third and second decade

Nonlinear signature: Difference of the changes: 2K2-2K1

January zonal mean zonal wind [m/s]



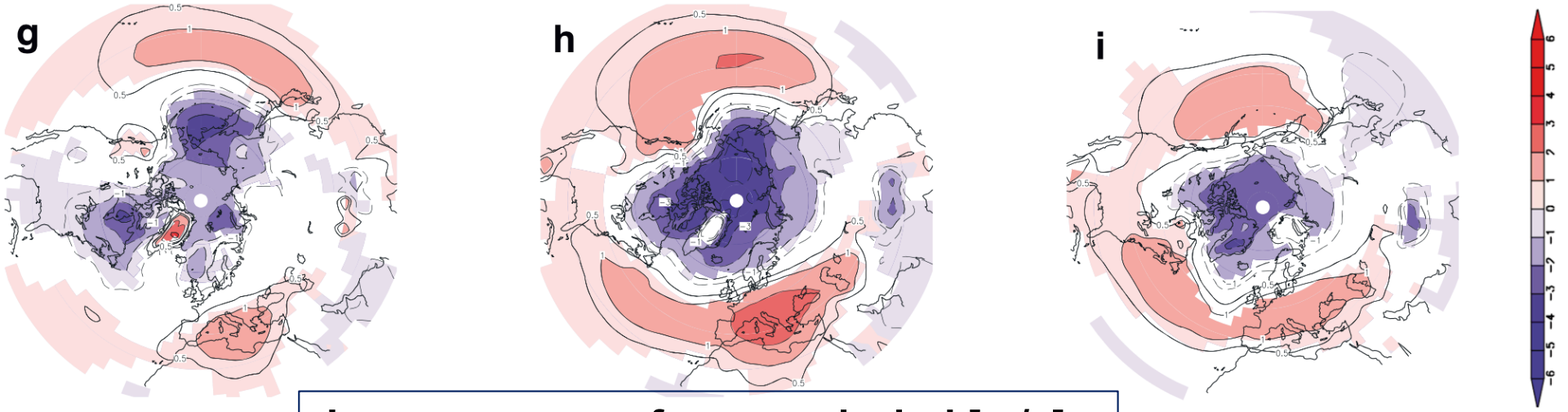
January near surface zonal wind [m/s]



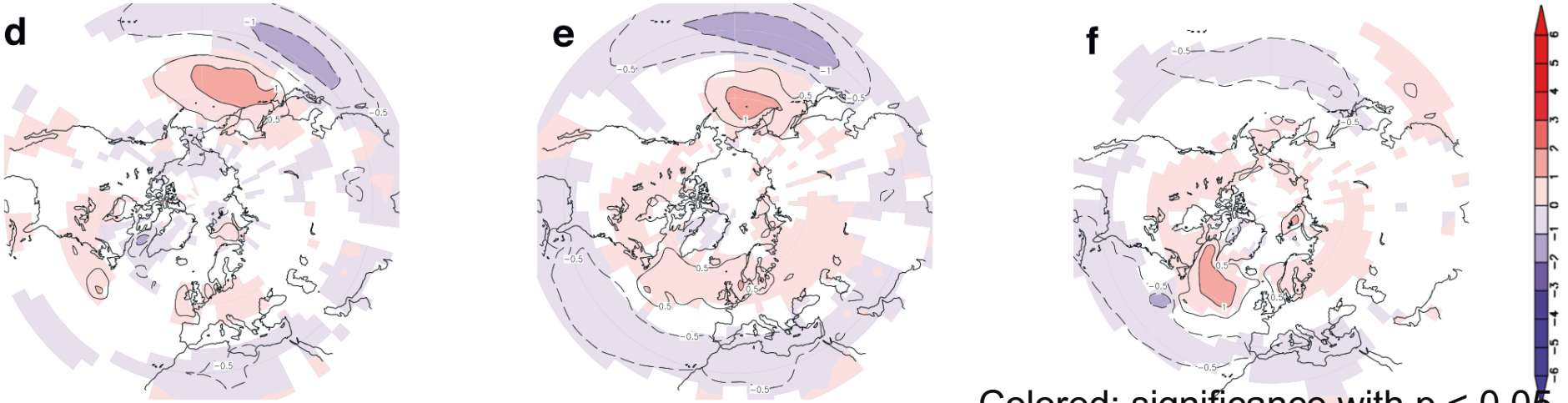
Colored: significance with p < 0.05

January pressure at sea level [hPa]

2K1 | 2K2 | 2K2-2K1

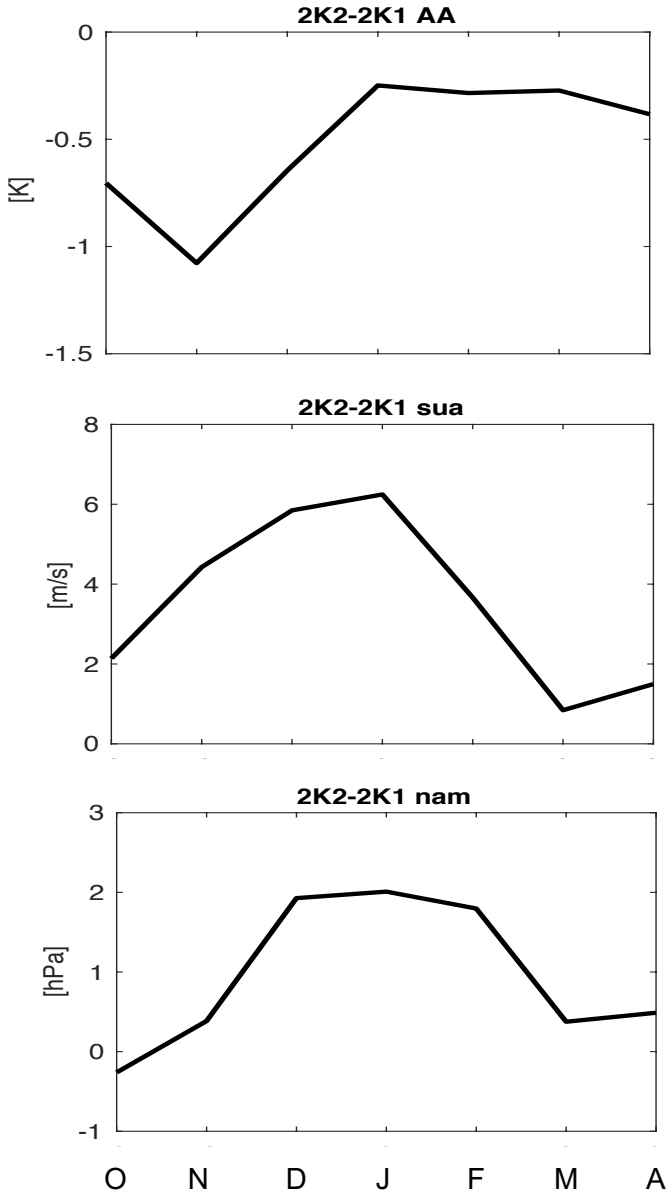


January near surface zonal wind [m/s]



Colored: significance with $p < 0.05$

Nonlinear signature, 2K2-2K1, the difference of the responses, Oct to April

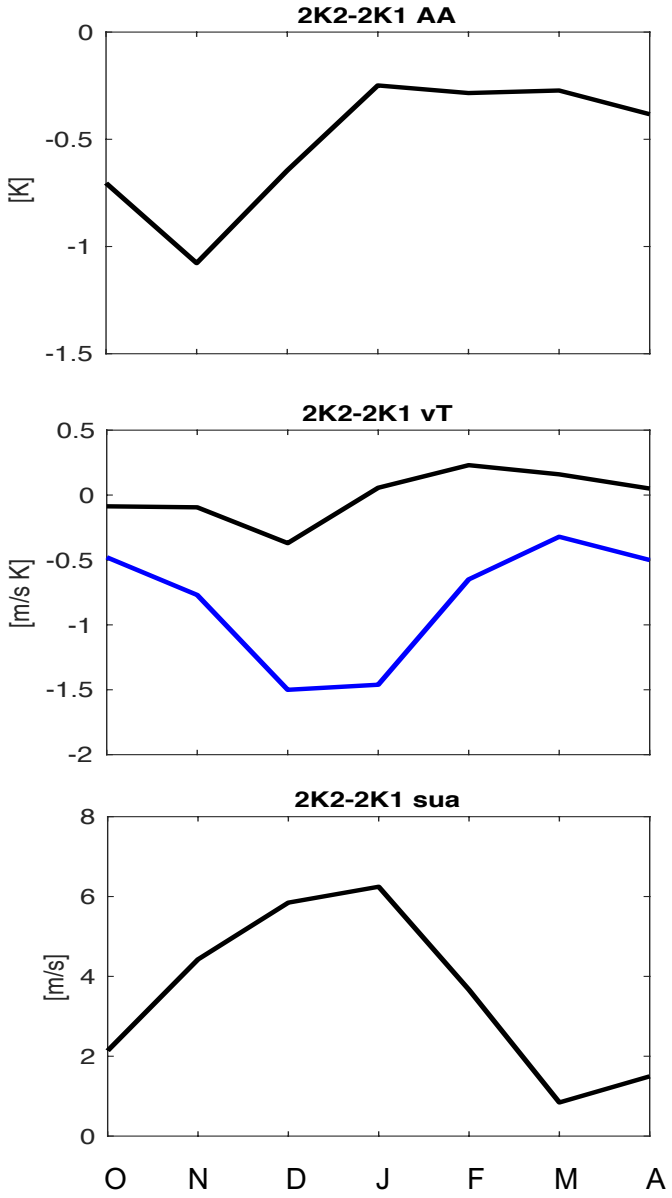


Reduction of Arctic warming
850-hPa temperature [60-90N]

Reduction in stratospheric polar vortex weakening @ 10 hPa

Increase in positive NAM change:
PSL [30-50N] minus [60-90N]

Nonlinear signature, 2K2-2K1, the difference of the responses, Oct to April



500 hPa

100hPa

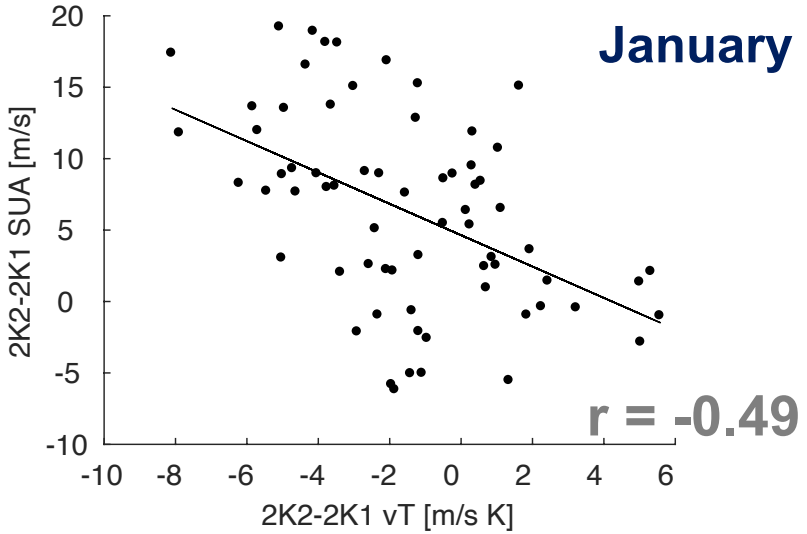
Reduction of Arctic warming 850-hPa temperature [60-90N]

Reduction of the increase in quasi-stationary heat flux change [54-85N]

Reduction in stratospheric polar vortex weakening @ 10 hPa

Nonlinear signature, 2K2-2K1, the difference of the responses, by member

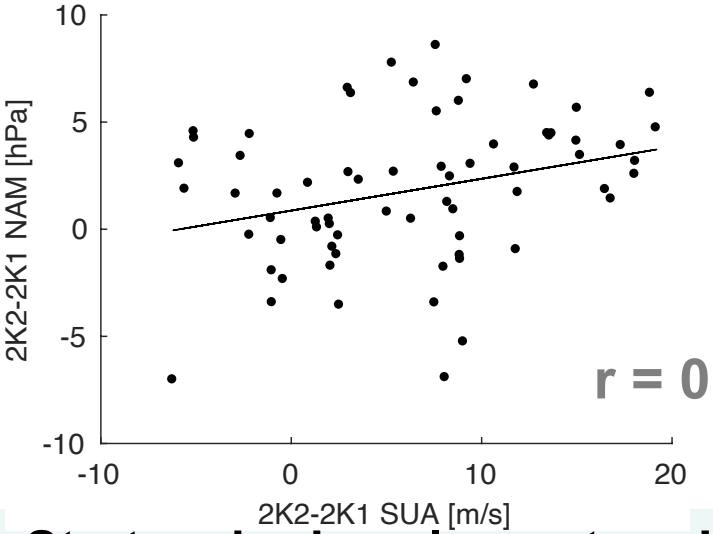
Stratospheric polar vortex



Quasi-stationary heat flux @ 100 hPa

Wave mean flow interaction in the stratosphere

NAM February

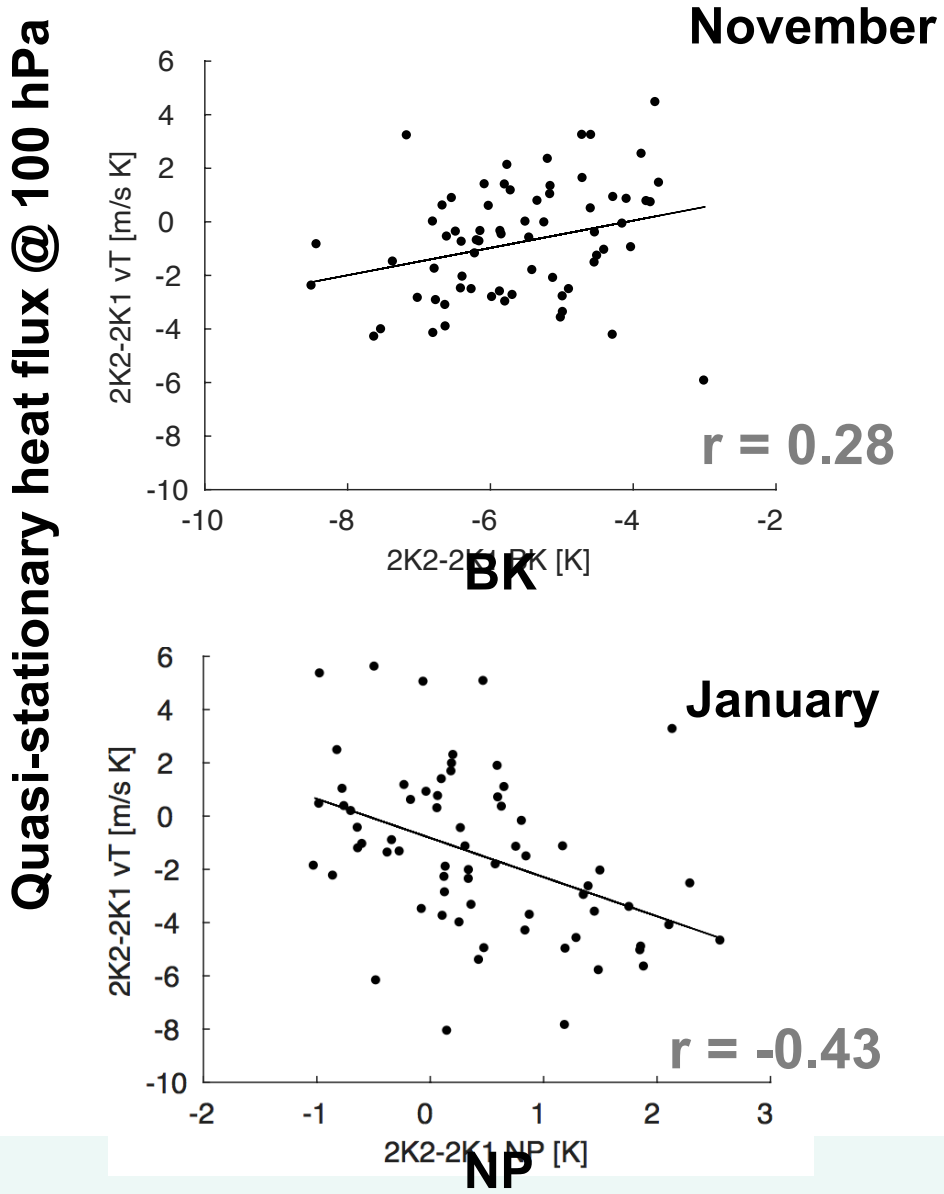


Stratospheric polar vortex, January

Lagged stratosphere to troposphere downward dynamical coupling

all relationships are significant with $p < 0.05$

Nonlinear signature, 2K2-2K1, the difference of the responses, by member

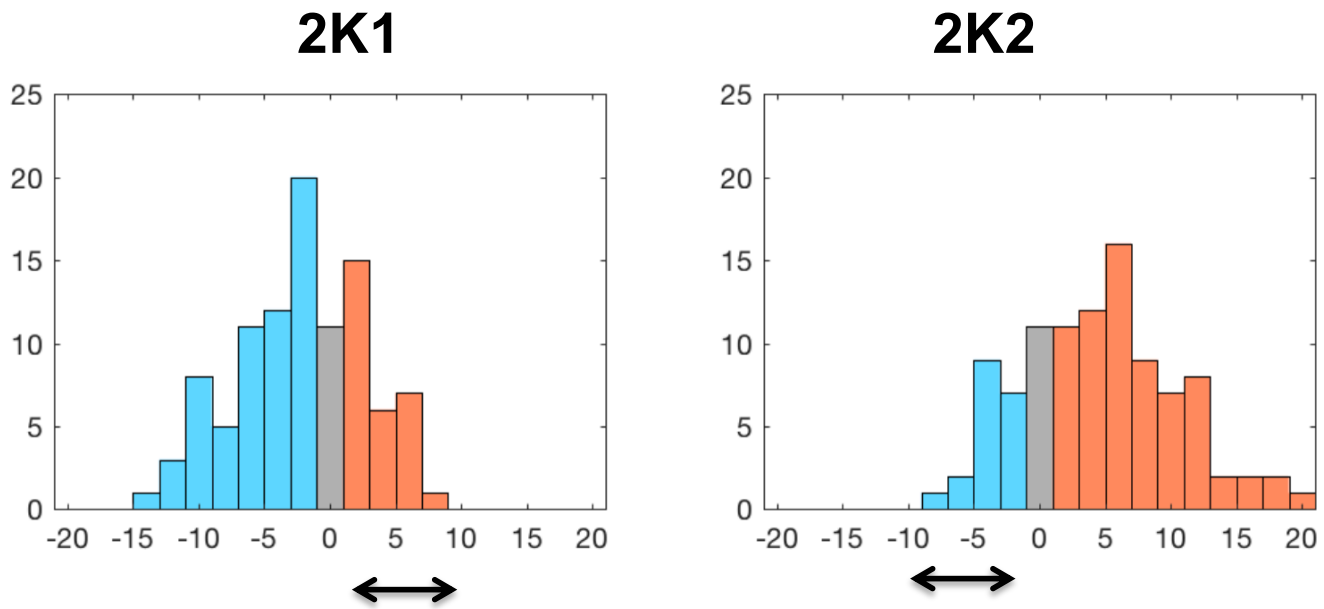


Reduction in BK seaice loss and reduction in the increase of q-s heat flux at 100 hPa

Increased warming in NP ocean and reduction in the increase of q-s heat flux at 100 hPa

all relationships are significant with $p < 0.05$

Frequency of occurrence of zonal wind response (70-80N @ 10 hPa)



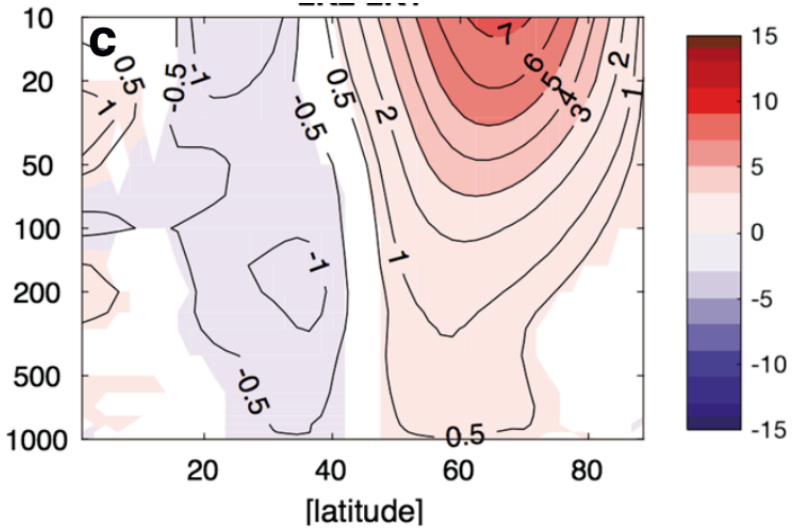
Disagreement with ensemble mean response: 20-30%

Summary

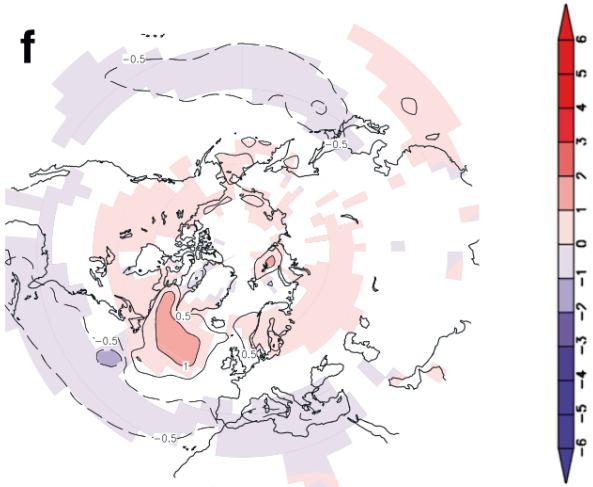
- **NH stratosphere & North Atlantic eddy-driven jet: Nonlinear changes**
- **Source of nonlinearity:**
  Arctic sea ice changes and November decrease in Arctic amplification
- **Stratosphere-troposphere coupling provides for the persistence of this nonlinearity throughout the winter**
- **Role of slow response of the ocean (North Pacific SST)?**
- **Atmospheric circulation changes are complex: contrasting influences**
- **2K1: Subtropical jet and stratosphere / seaice responses are contrasting drivers of the NH tropospheric eddy-driven jet change**
- **2K2: These drivers no longer counteract each other**
- **Internal variability: Stratosphere response of 20-30% of the members not in agreement with the ensemble mean response**

Non linear signature: The 2K2-2K1 difference of the responses, January

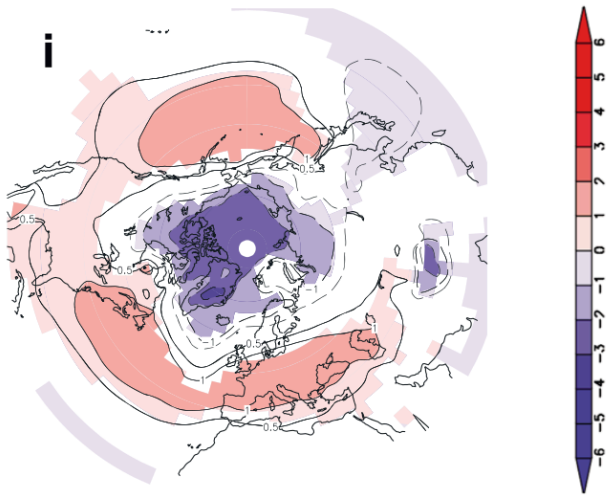
Zonal mean zonal wind [m/s]



Near surface zonal wind [m/s]

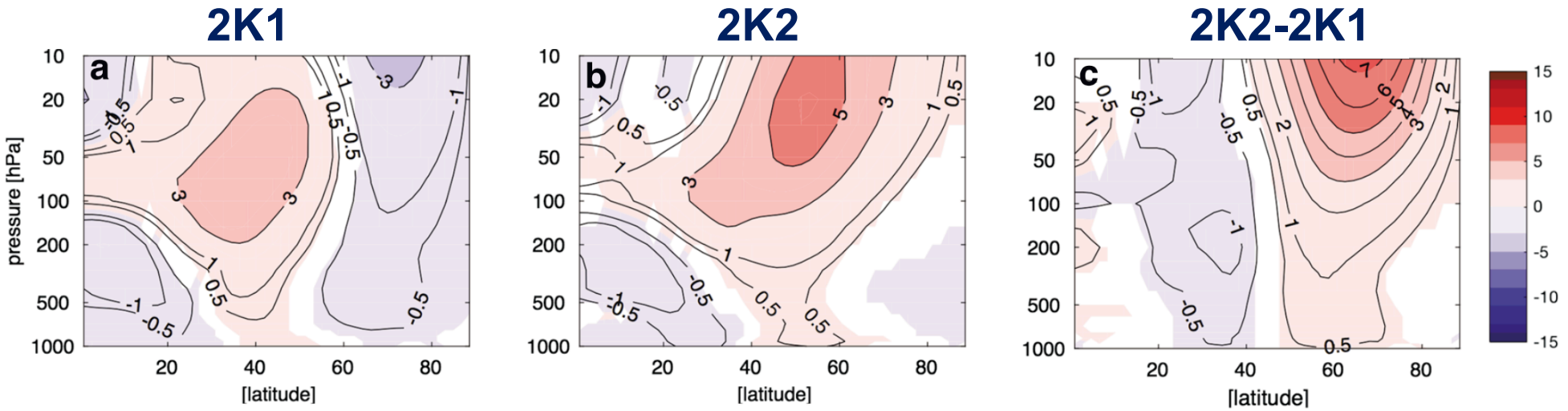


Pressure at sea level [hPa]

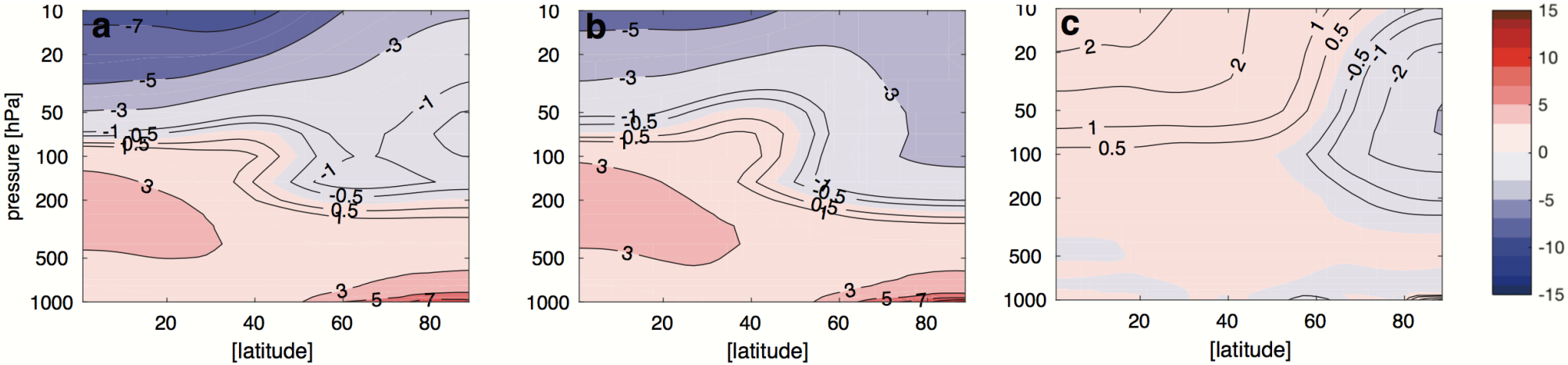


- **Nonlinear signature: positive phase of the annular mode of variability**

January zonal mean zonal wind [m/s]

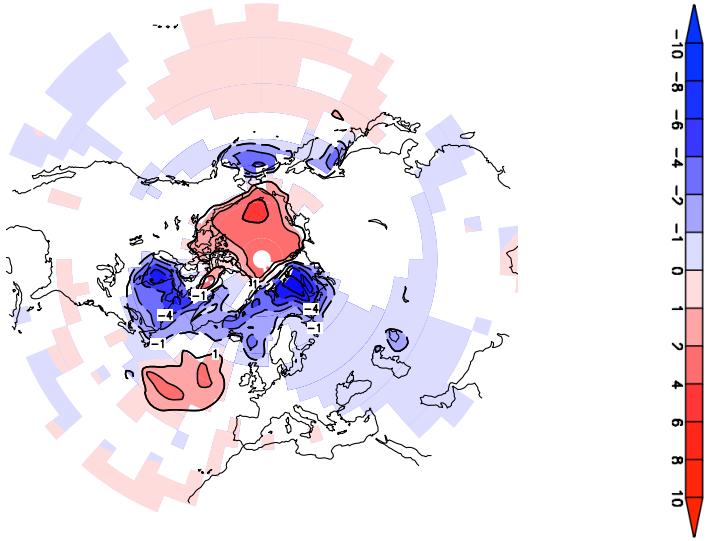


January zonal mean temperature [K]



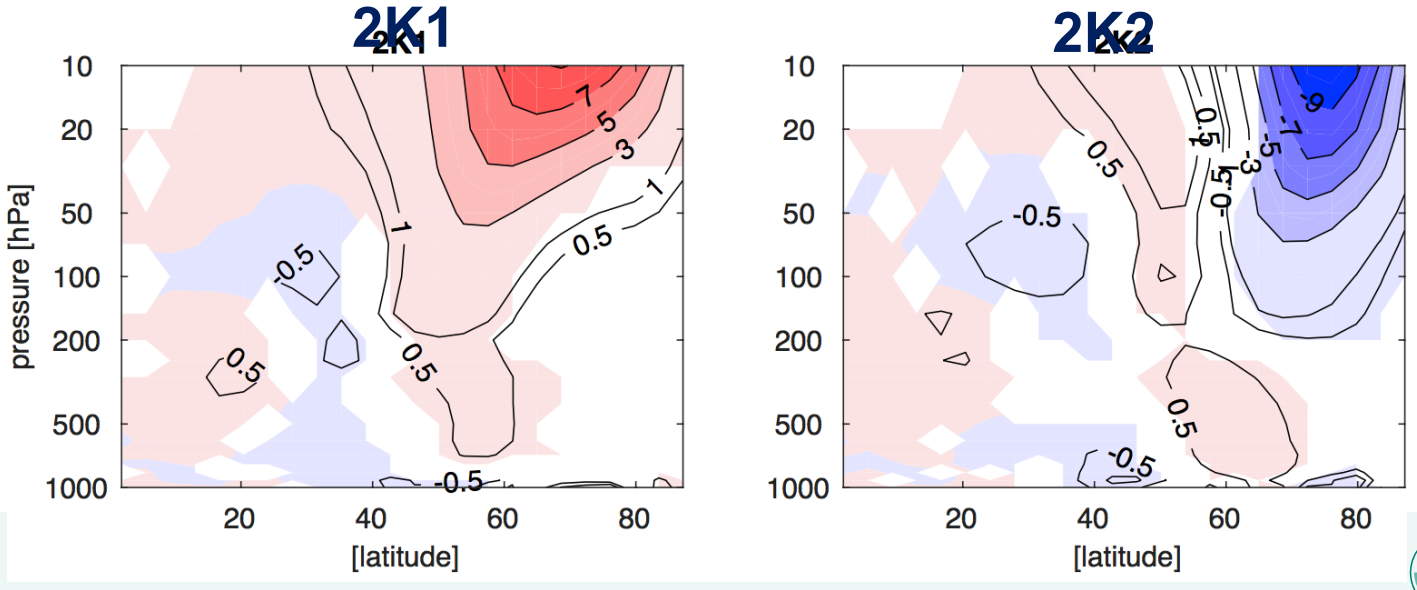
Non linear signature: 2K2-2K1 difference of the responses, January

2K2-2K1 air temperature at 2m [K]



- Reduction of warming hole warming in the North Atlantic
- Increased warming in the North Pacific
- Reduction in warming over ice freed regions

Quasi-stationary heat flux (K m/s), for the two periods, January



BLUE ACTION

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