ETH zürich

IAC Institute for Atmospheric and Climate Science

NORTH ATLANTIC JET STREAM RESPONSE TO WARMING: TRENDS AND DRIVERS

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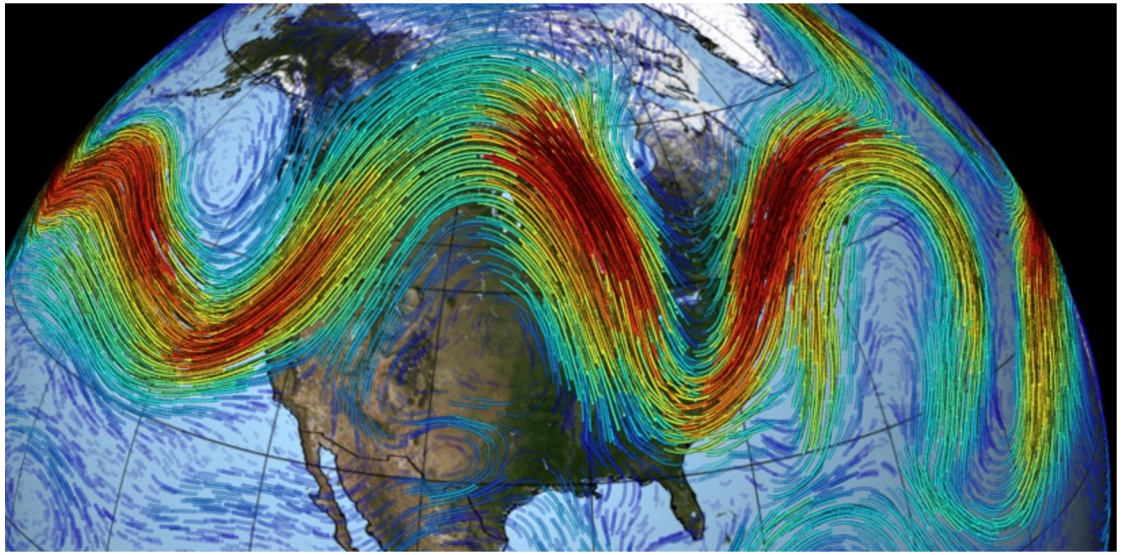
TRAMPAS meeting 24/10/2023

INTRODUCTION

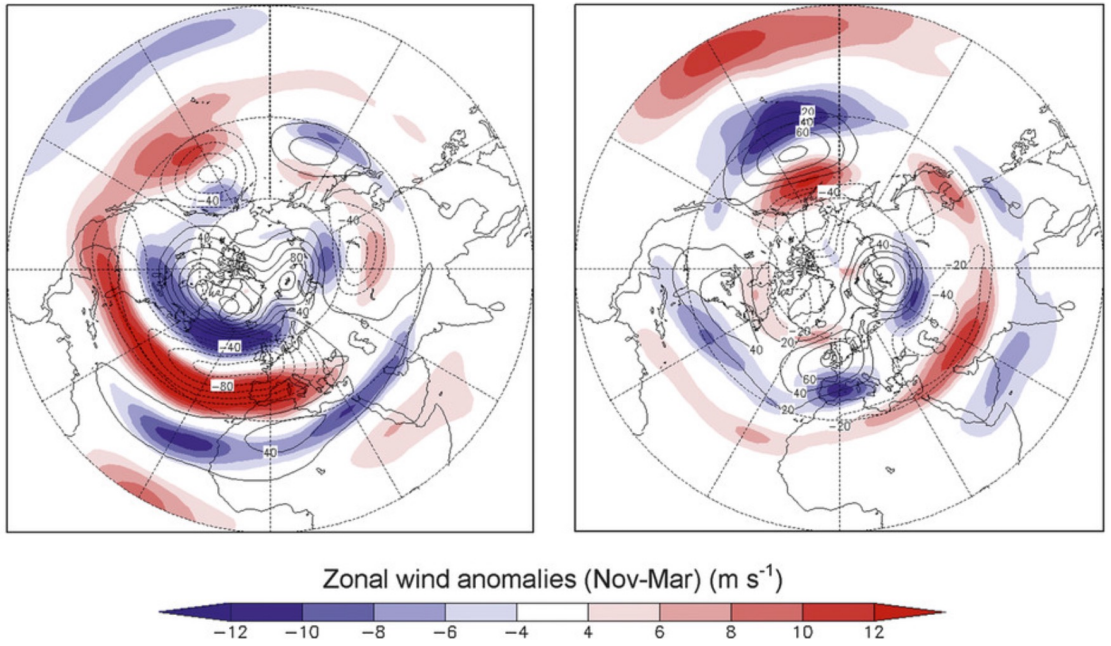
Jet stream



- Narrow and strong air currents flowing from west to east in both hemispheres
- Important influence on weather variability and extremes

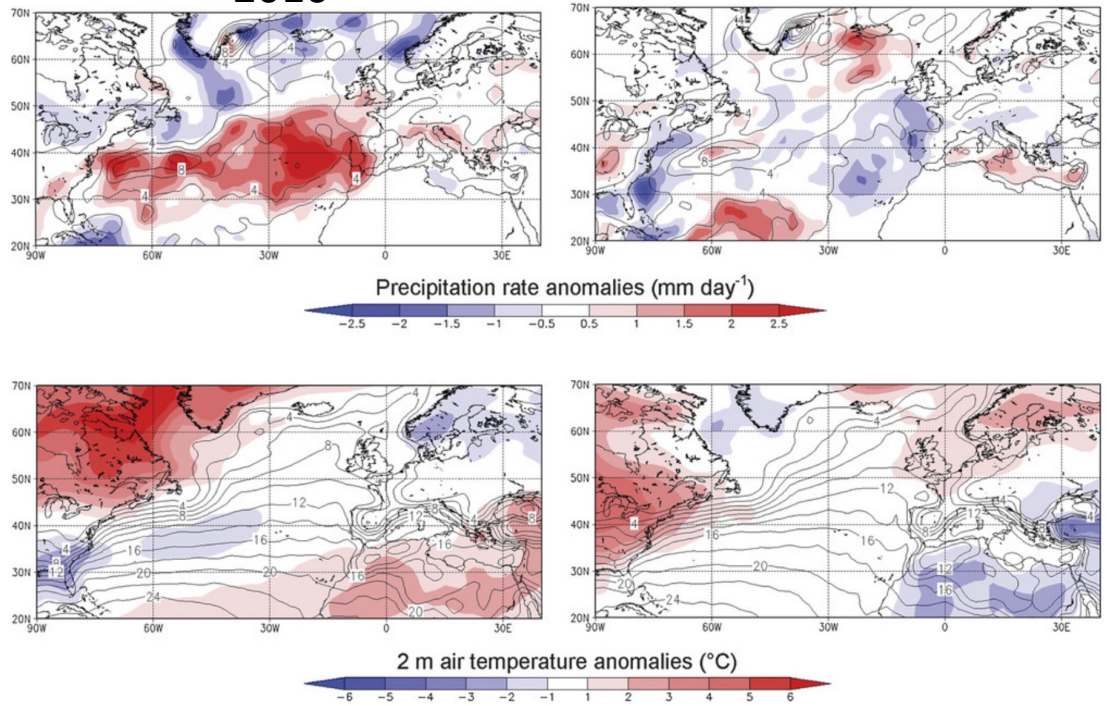
Exemple of impact of jet variability (Santos et al. 2013)

2010 2012



Anomalies of zonal wind at 250 hPa

2010 2012



Anomalies of precipitation (top) and T2 (bottom)

Relevant processes

- Main mechanisms affeting the jet:
  - Areas of high baroclinictity -> development of Rossby waves -> eddy momentum flux convergence
- Local effect of diabatic heating
  - PV anomalies, which can intensify the jet

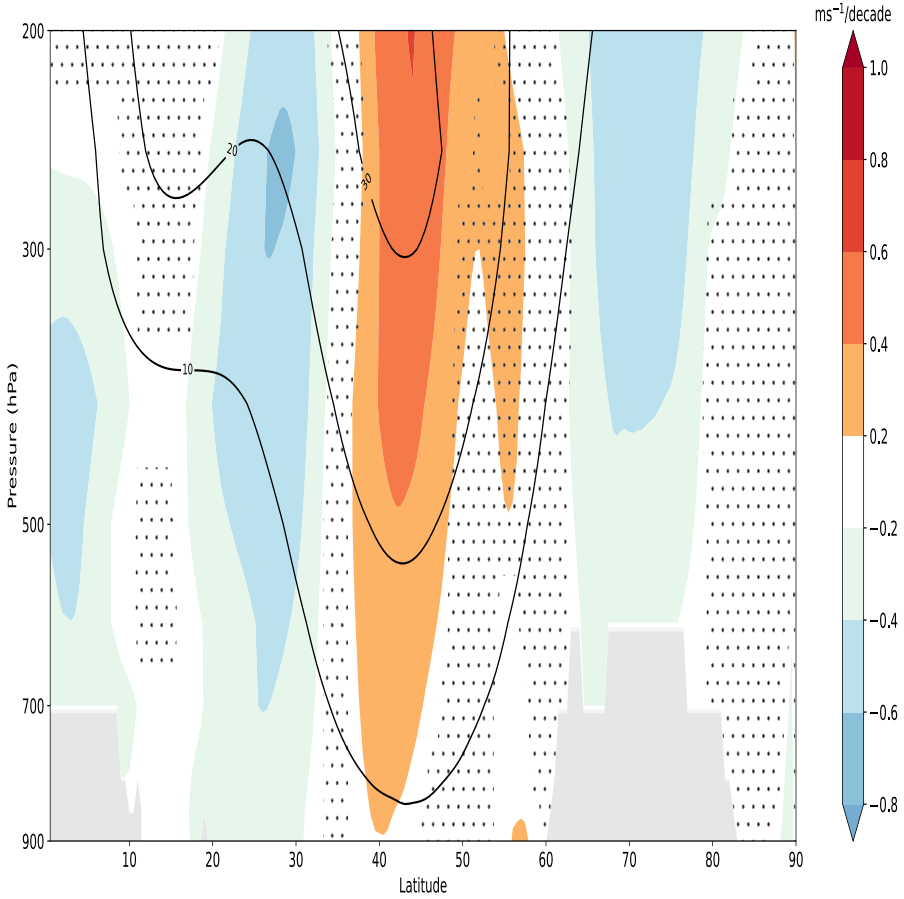
Objective and data

- Analysis of jet stream trends (observed and projected) in winter (DJF) over the North Atlantic
- Understanding the mechanism leading to the observed trends

- Data
  - **ERA5** (1979-2022)
  - Idealised **2D frontal-geostrophic simulation**. Sawyer-Eliasen eqution with diabatic heating
  - Idealised **aquaplanet simulations**. Control and uniform warming (4 K) + SST front
  - **CESM2 simulations**: 5 ensemble members, 1980-2100, SSP370 from 2015

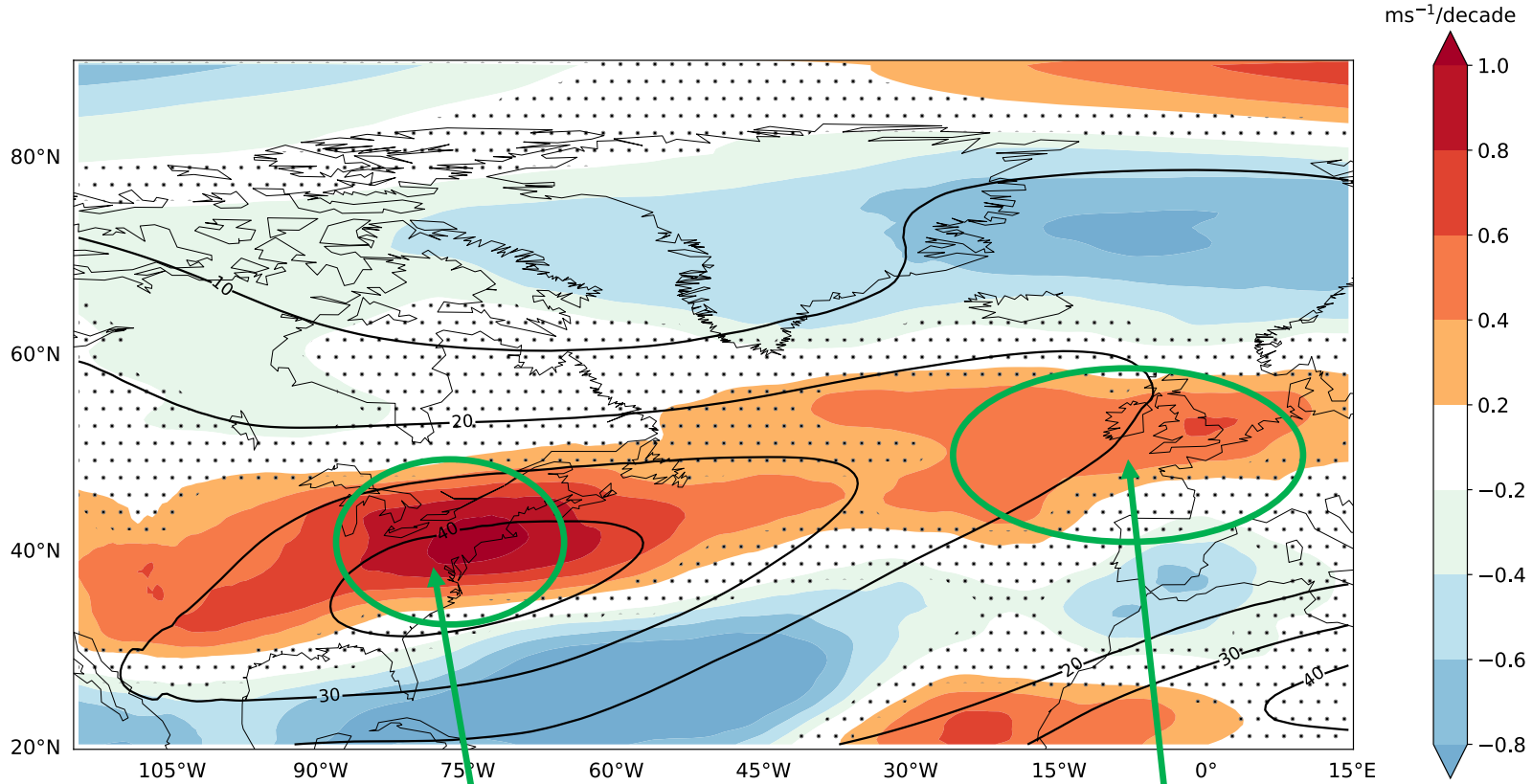
Trends in ERA5

Jet trends



Zonal mean 80 – 15 W

Shading: zonal wind speed trend
Black contours: climatological mean
Stippling: non-significant trends



Trends at 250 hPa

Intensification of the jet, slight poleward shift

Extension over Europe
Slight equatorward shift downstream

E vector

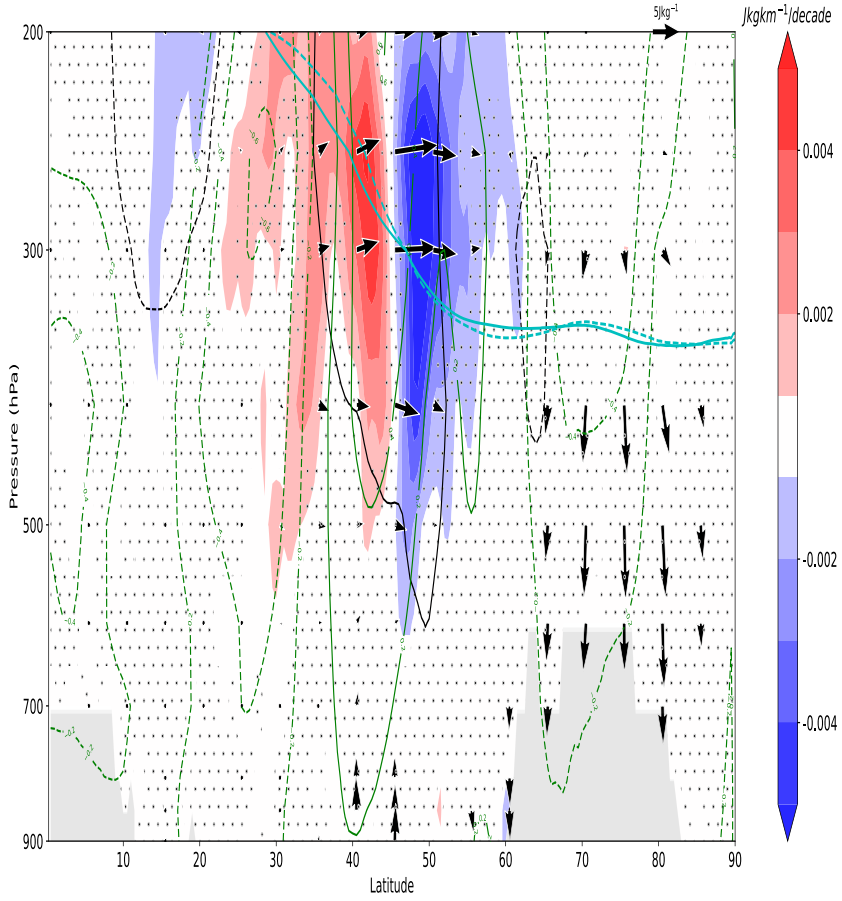
$$\mathbf{E} = \left(\overline{v'^2 - u'^2}, \overline{-u'v'}, \frac{f}{\partial\theta/\partial p} v'\theta' \right)$$

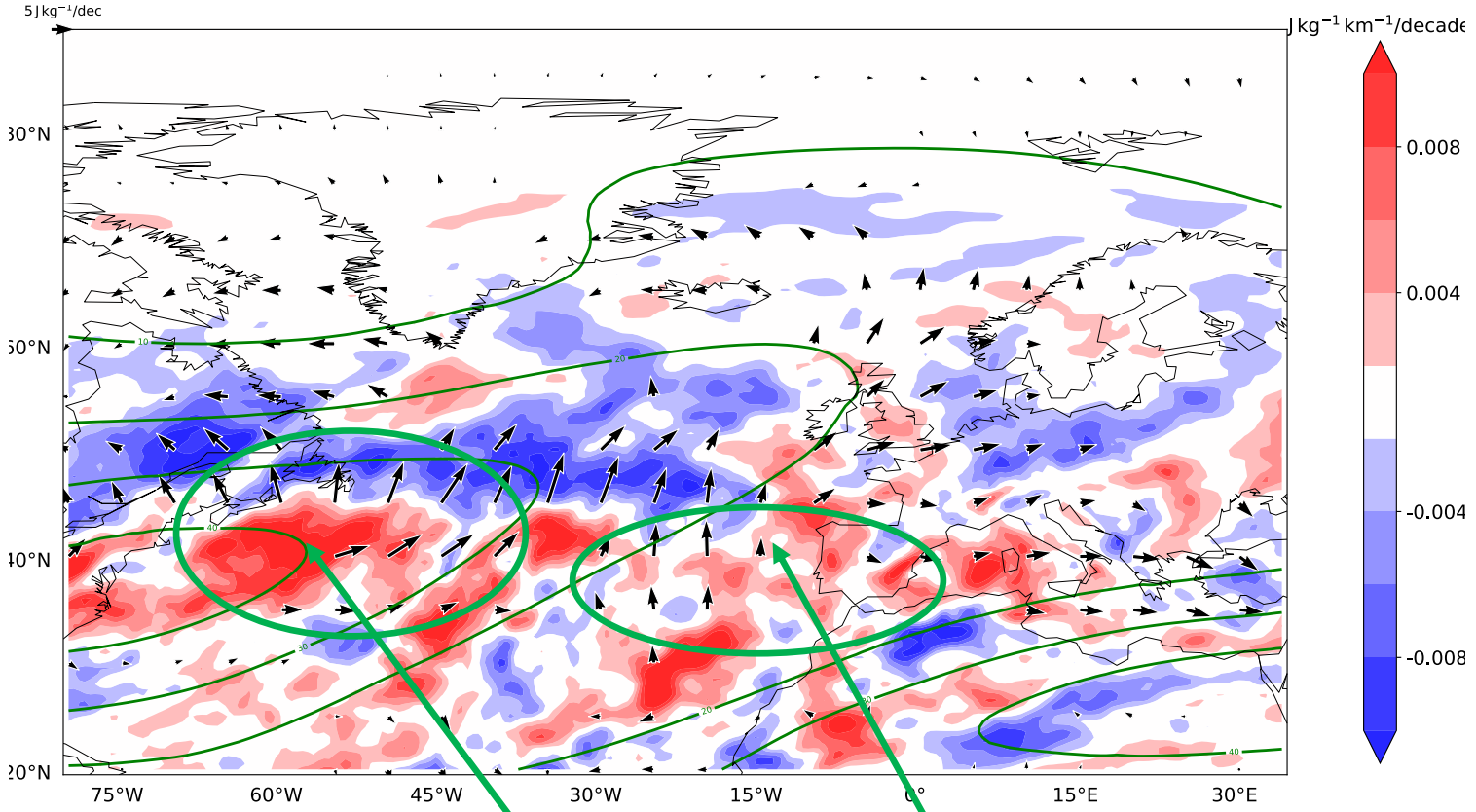
Horizontal components: Eddy momentum flux

Vertical component: Eddy heat flux

E vector divergence -> Eddy momentum convergence

E vector trends





Trends at 250 hPa

Zonal mean 80 – 15 W

Shading: E vector divergence trend

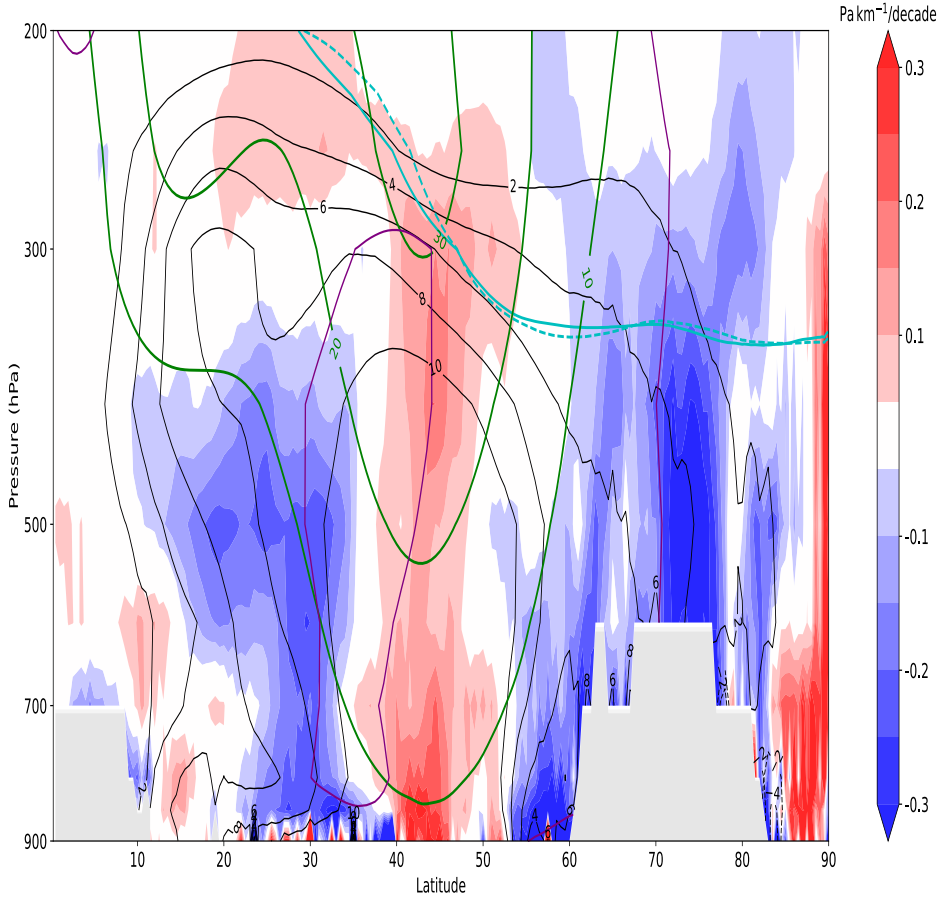
Black contours: E vector divergenceclimatological mean

Green contours: Zonal wind trend (left)/ climatology (right)

Blue contours: Tropopause level (2PVU)
in first and last decade

Increase of eddy momemtum convergence
around the jet core and equatorward downstream

Slope trends



Zonal mean 80 – 15 W

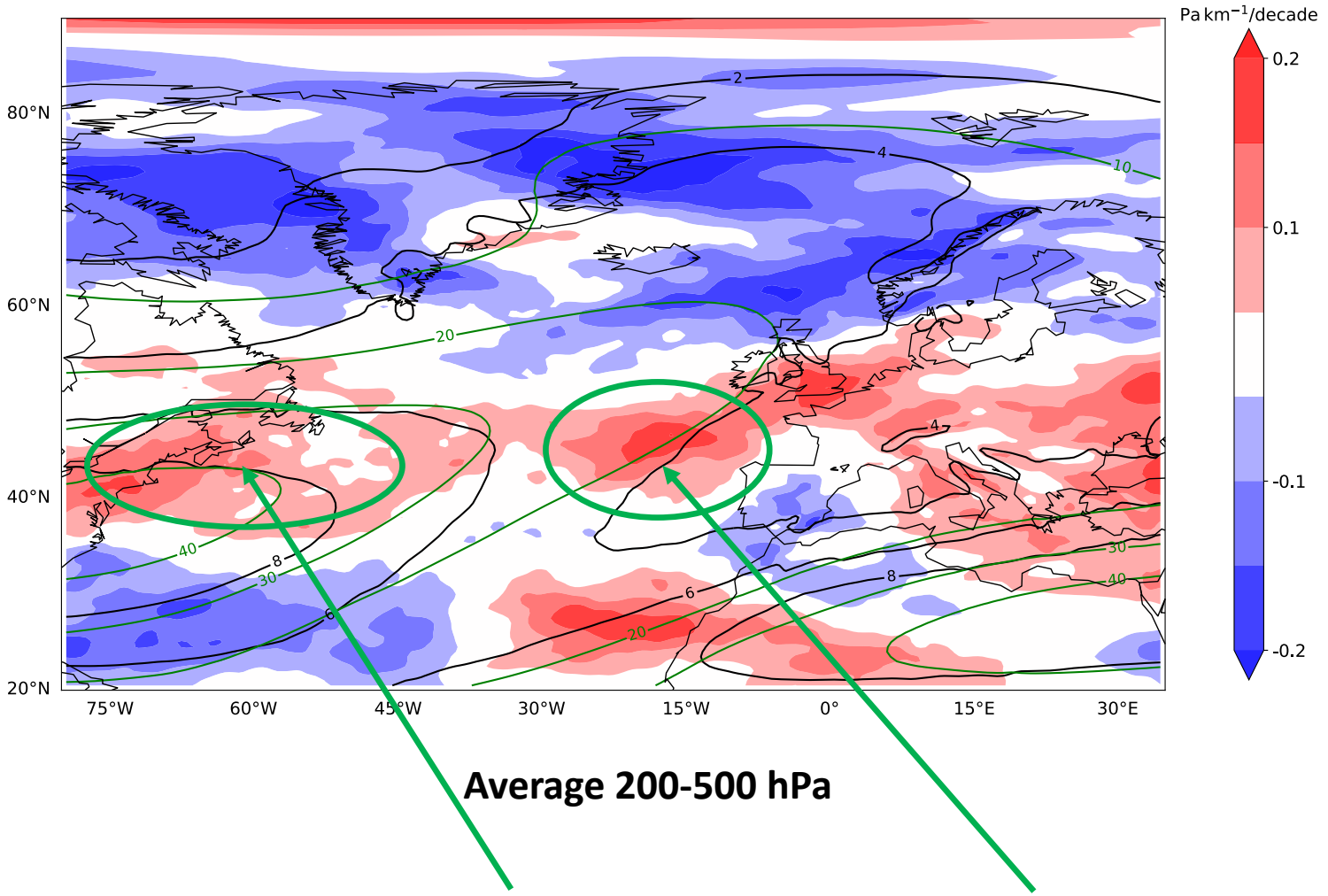
Shading: slope trend

Black contours: climatological mean

Green contours: Zonal wind speed climatology

Purple contour: Region of strongest potential temperature trend

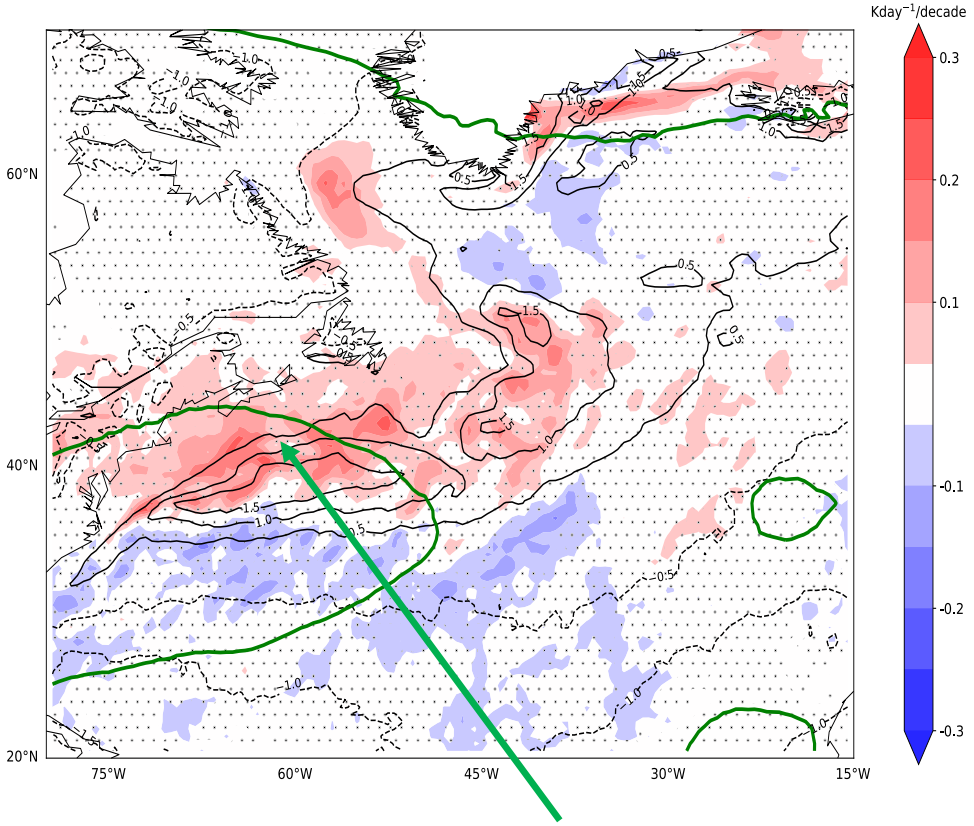
Blue contours: Tropopause level (2PVU) in first and last decade



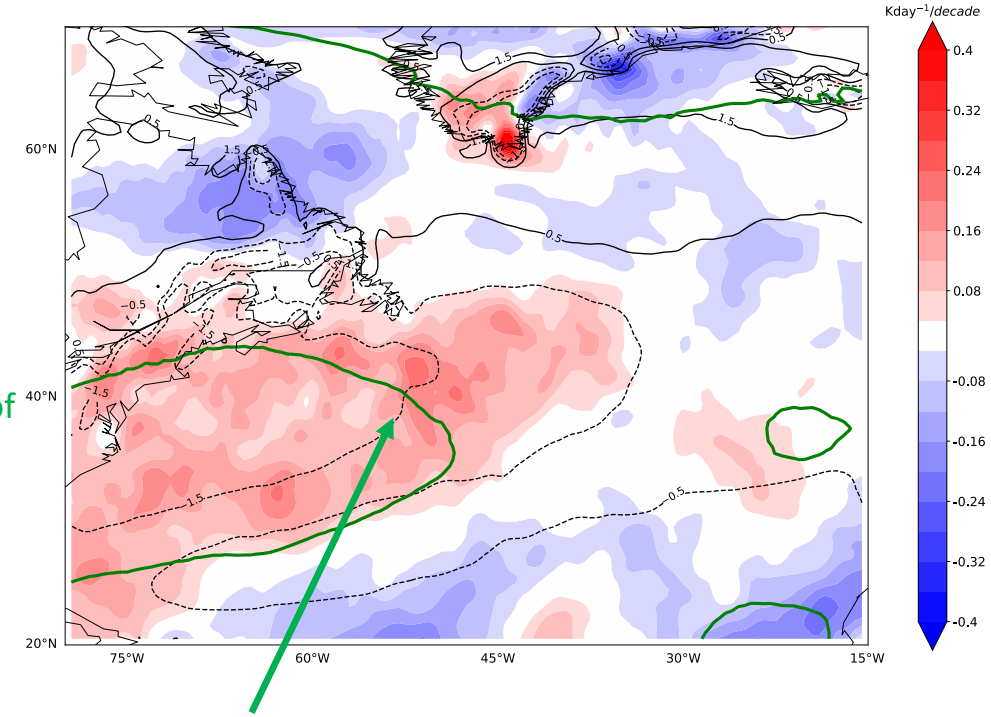
Average 200-500 hPa

Slope increse around the climatological jet position over the Gulf stream and downstream

Diabatic heating and advection trends



Shading: trends
Black contours: climatological mean
Green contour: Region of strongest potential temperature trend



Increase over the Gulf Stream
North of area of strongest potential temperature trend

Reduced cold advection over western NA -> reduced land-sea contrast
Coincident with area of strongest potential temperature trend

Diabatic heating trend (300 – 850 hPa)

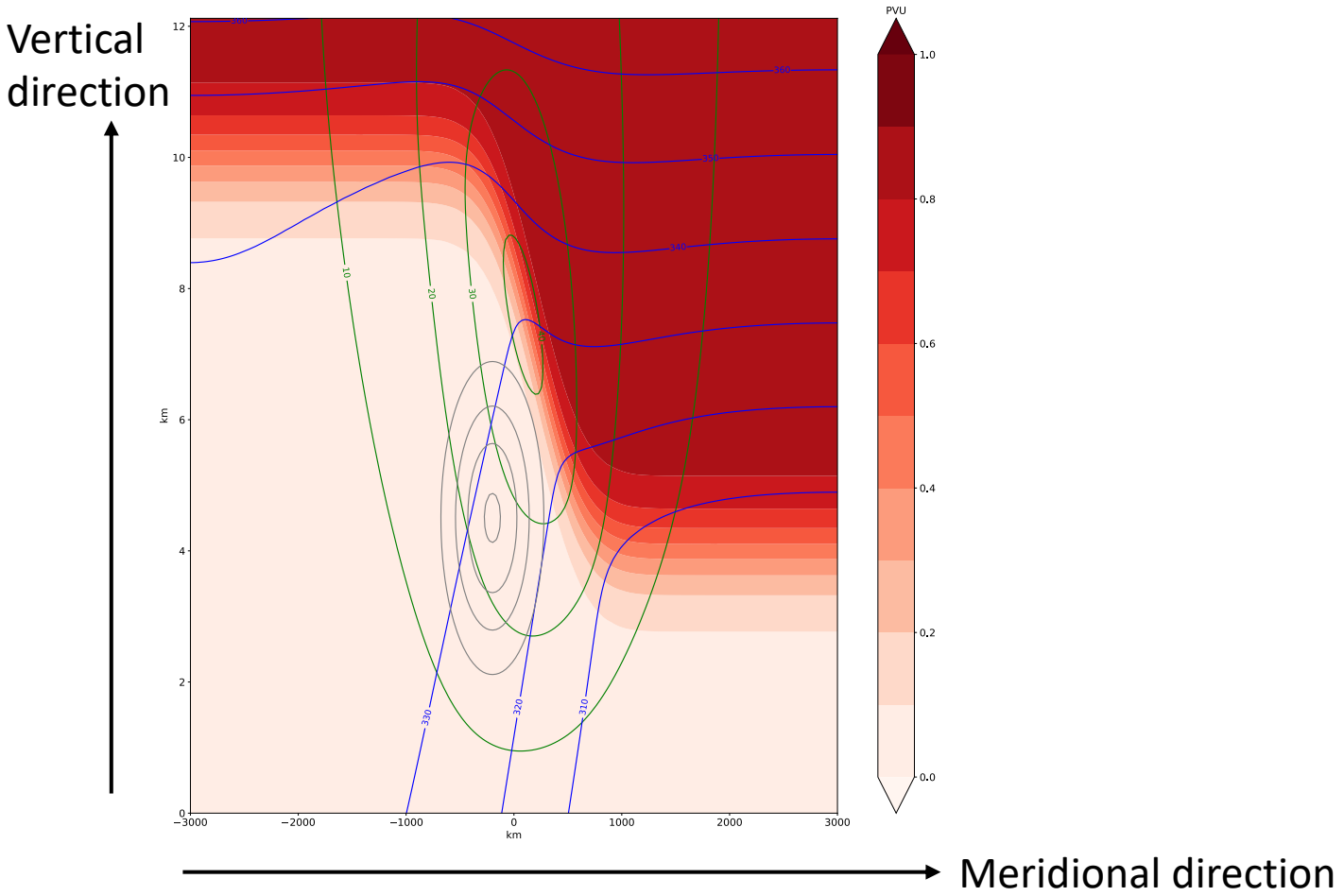
Advection trend (300 – 850 hPa)

Semi-geostrophic simulation: Local effect of diabatic heating

2D semi-gesotrophic simulation

- Evolution of a zonally symmetric flow on an f-plane
- Zonal momentum $\mathrm{m} = \mathrm{u} - \mathrm{fy}$ and θ advected on a y-z plane and modified by heating
- Meridional circulation obtainned from thermal wind balance between m and θ
- The elliptic Sawyer-Eliassen equation for the streamfunction provided that PV is positive over the entire domain

2D semi-gesotrophic simulation: Setup



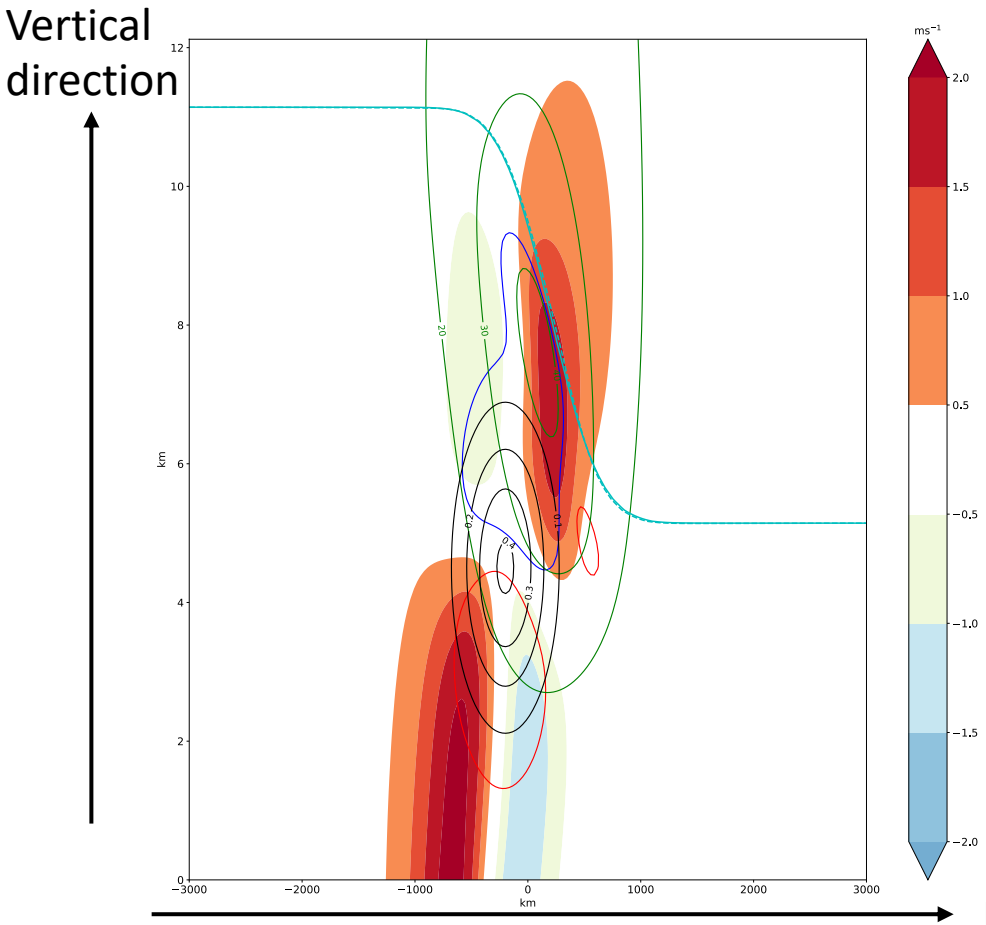
PV (shading

zonal mean wind (green contour)

Potential temperature

Diabatic heating (black contours)

2D semi-gesotrophic simulation: Results

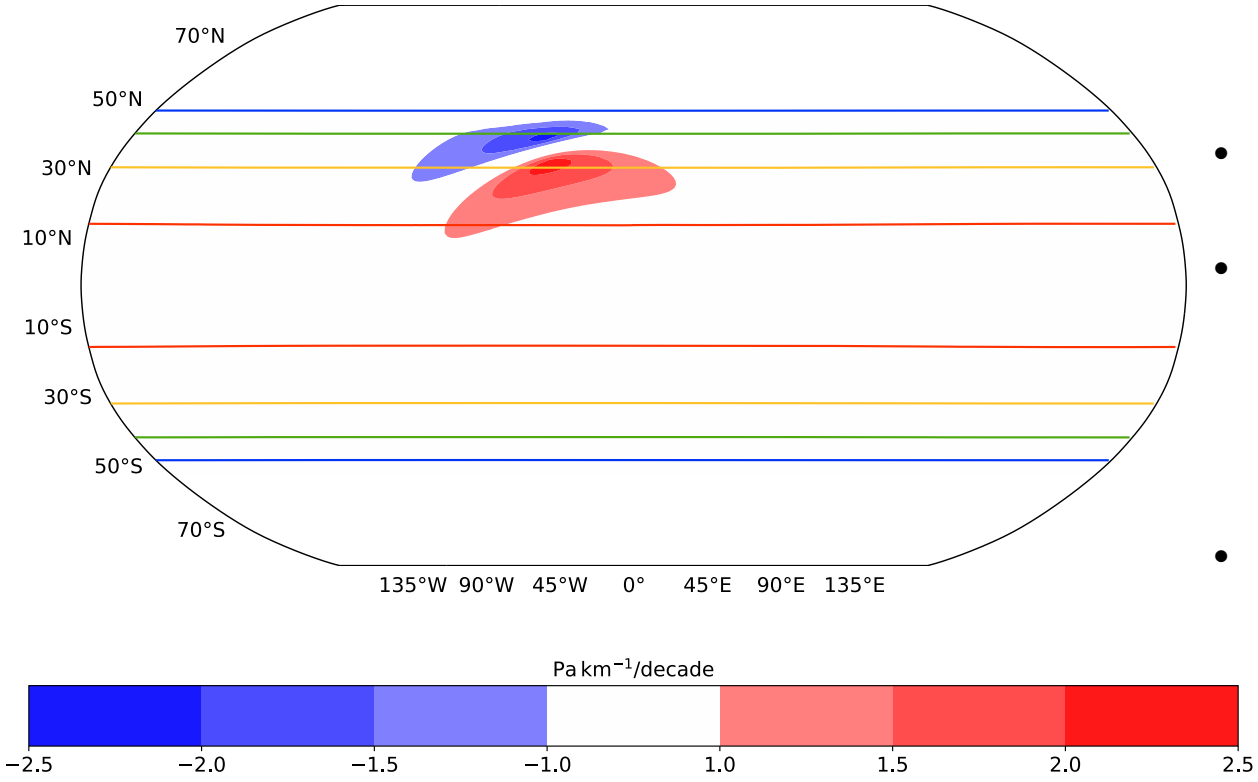


PV anomaly (red/blue contours)
Initial zonal mean wind (green contour)
Diabatic heating (black contours)
Change in zonal wind (shading)

- Negative PV anomaly above heating
- Intensification and slight poleward shift of the zonal wind (shading)
- Similar to zonal wind trend in ERA5 in the entrance region

Aquaplanet simulations: Eddy-mean flow feedback

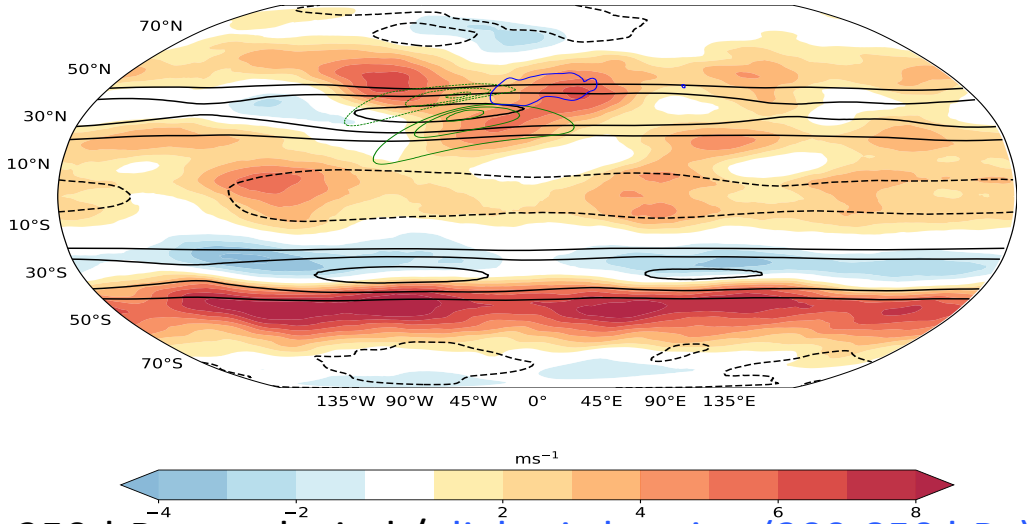
Aquaplanet simulations: Setup



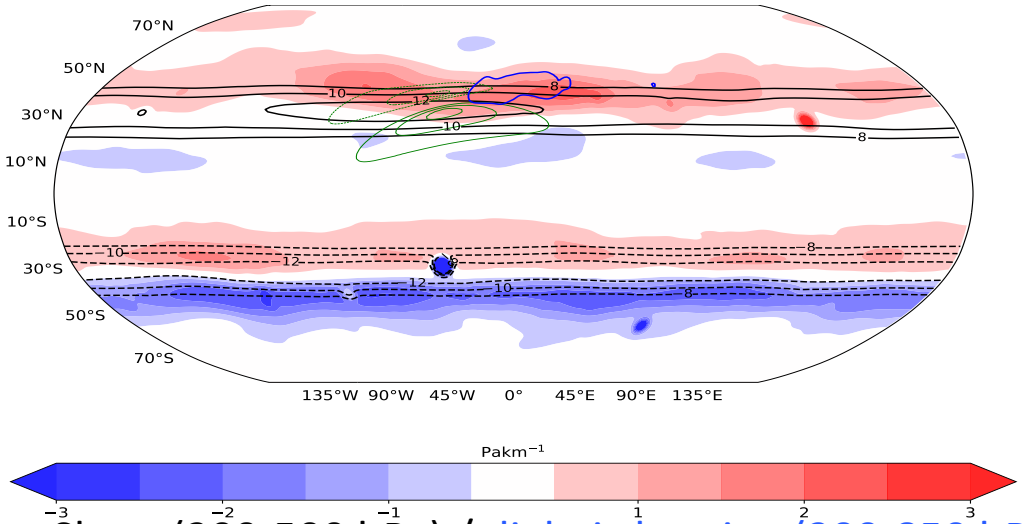
- ICON model v2.6.5, 80 km horizontal resolution
- **Control simulation:** Baseline SST profile + SST front (idealized land-sea contrast) at 30°W and different latitudinal positions (38, 39 and 43°N)

- **Warmed simulation:** Same setup with uniform warming (4K)

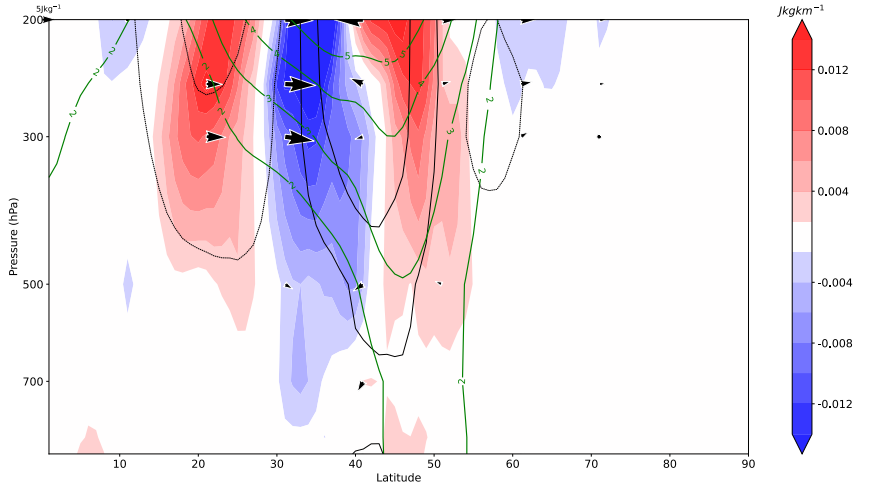
Aquaplanet simulations (front at 39N)



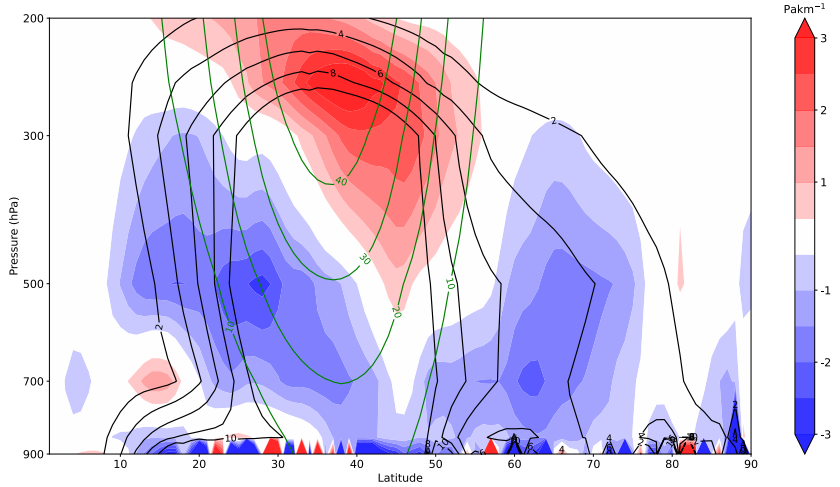
250-hPa zonal wind / diabatic heating (300-850 hPa)



Slope (200-500 hPa) / diabaic heating (300-850 hPa)

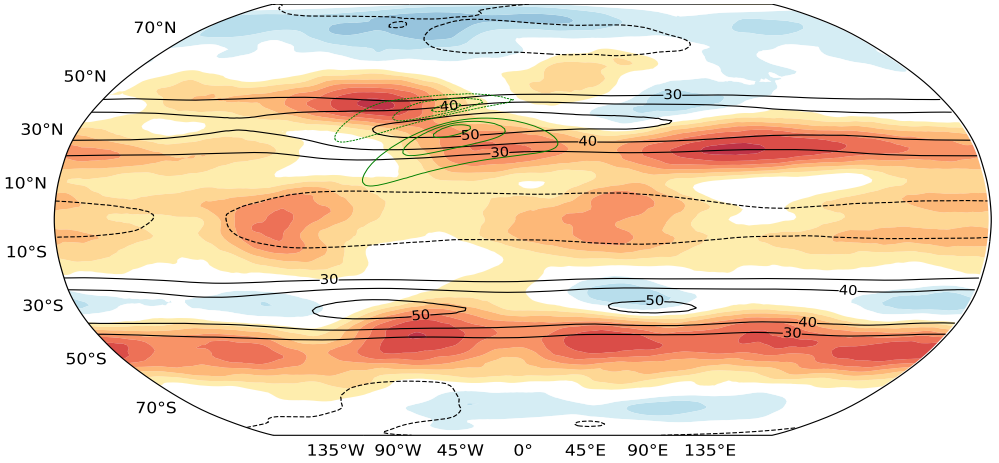


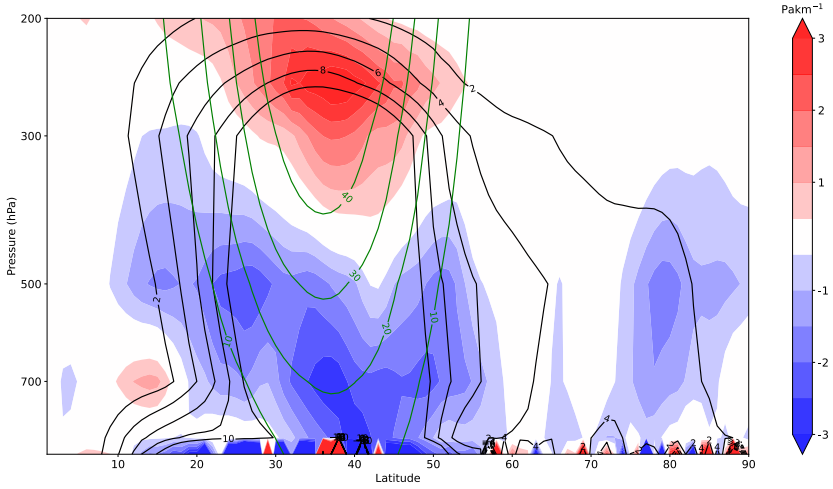
E vector divergence / zonal wind speed difference



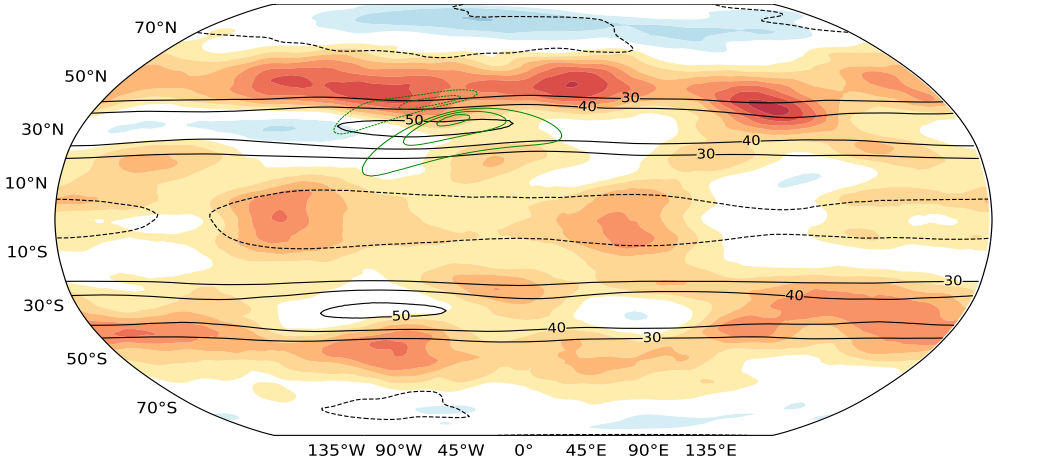
Slope difference/ zonal wind climatology (cntl)

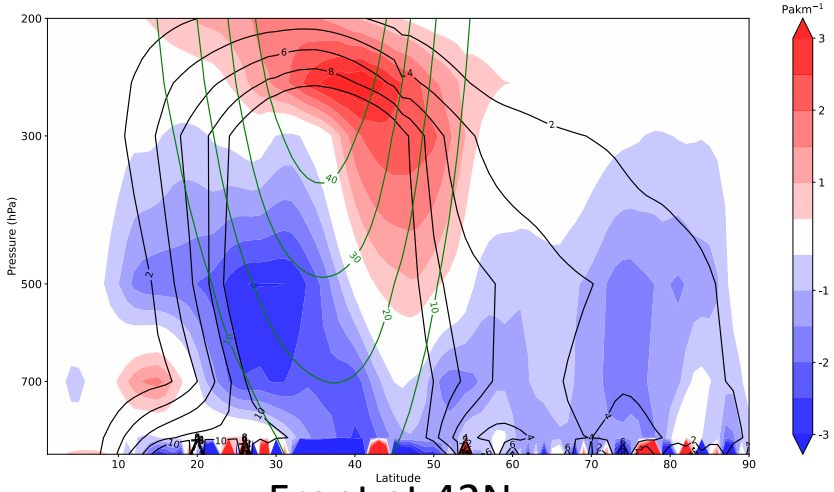
Sensitivity to SST position





Front at 38N





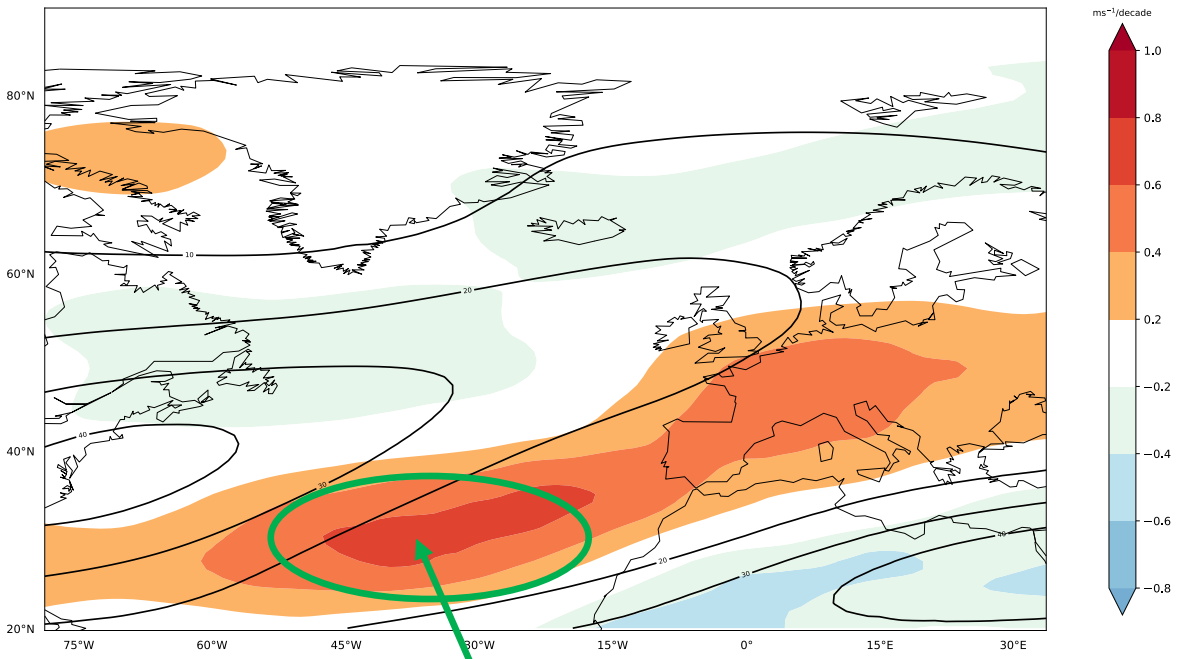
Front at 42N

Fully-coupled CESM simulations

CESM simulations

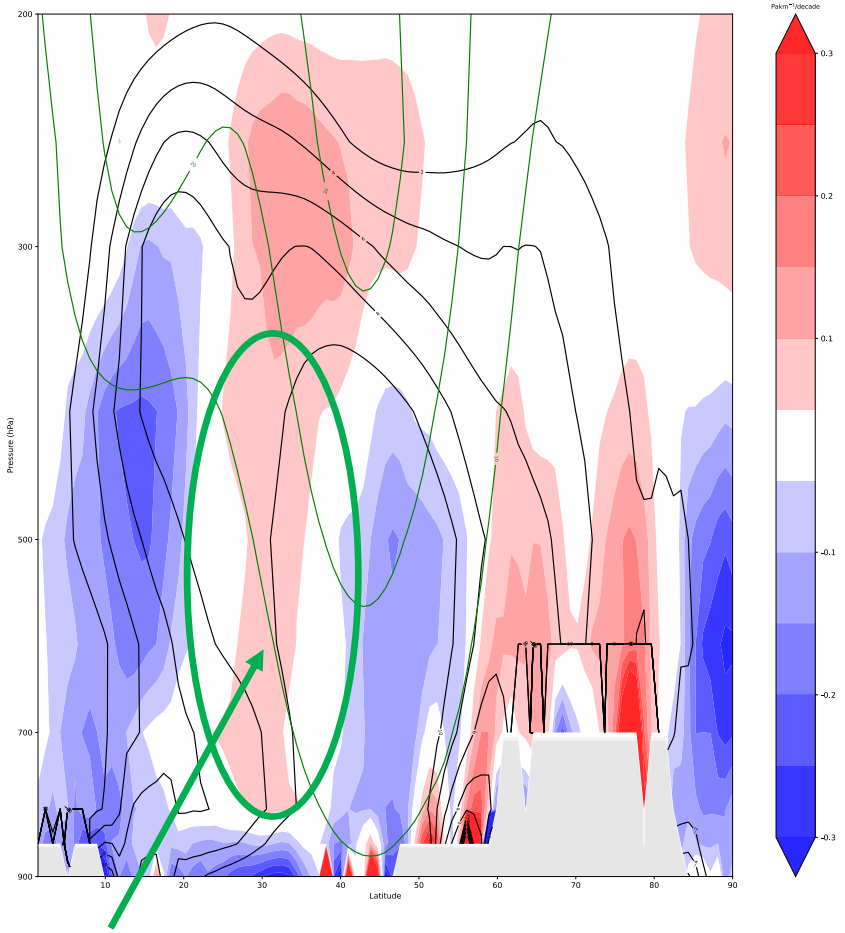
- Community Earth System model version 2.1.2
- Fully-coupled model
- 1° horizontal resolution
- Historical forcing up to 2015 and SSP3-7.0 emissions scenario from 2015 onwards
- 5 ensemble members

CESM trends (ensemble mean 1980-2022)



Equatorward shift of the jet
Different to ERA 5 over the Gulf Stream

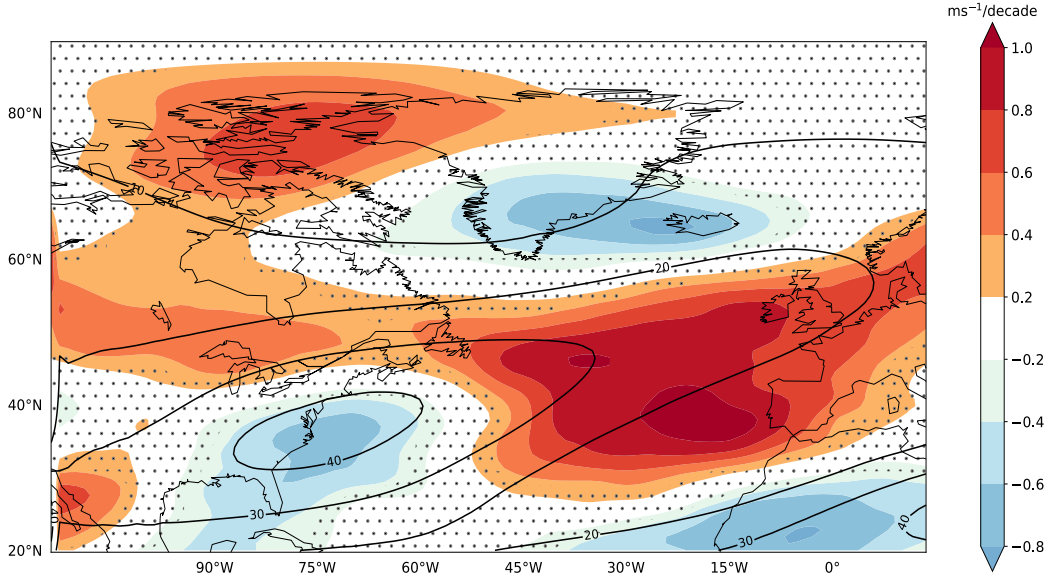
Zonal wind trend at 250 hPa

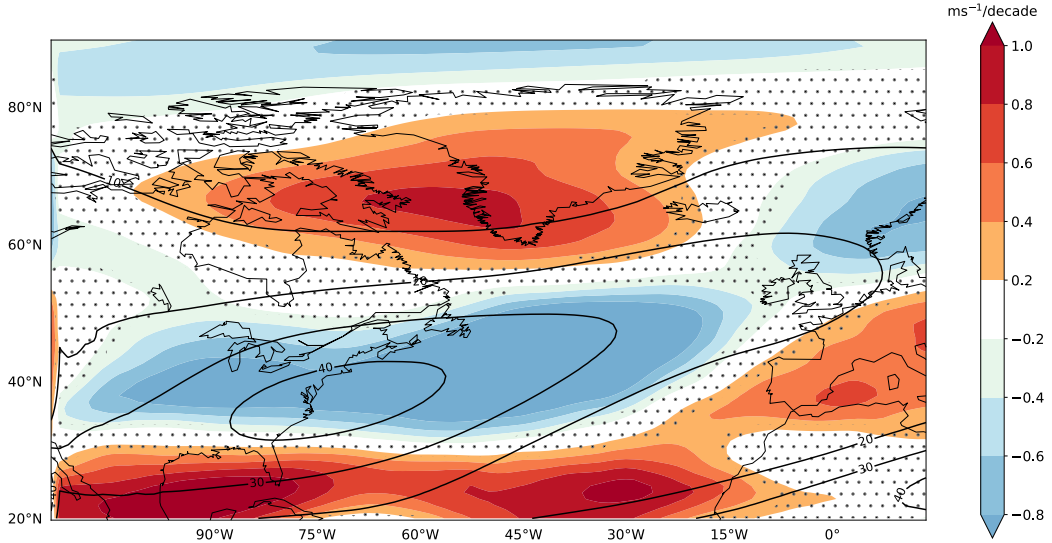


Increase of baroclinicity coincident with positive jet trend

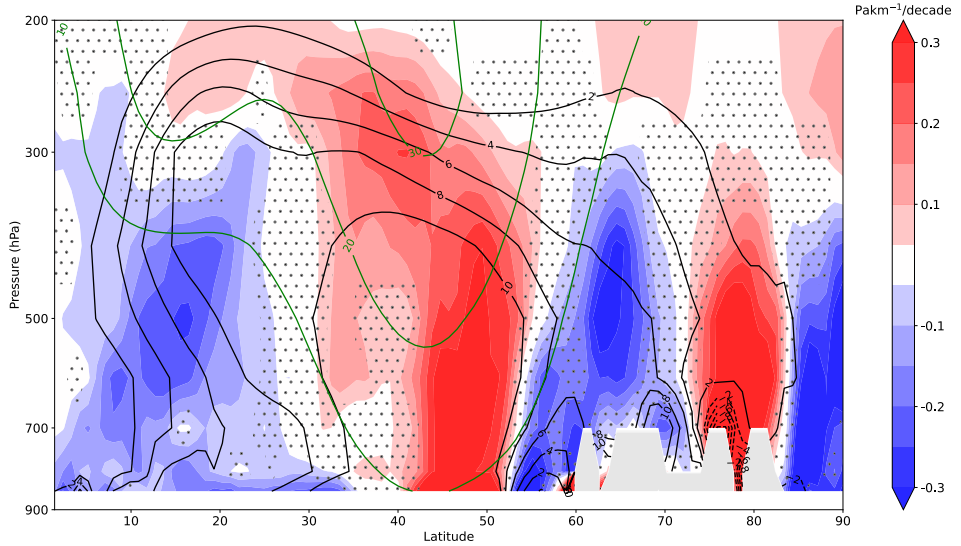
Slope trend (zonal mean 80 – 15 W)

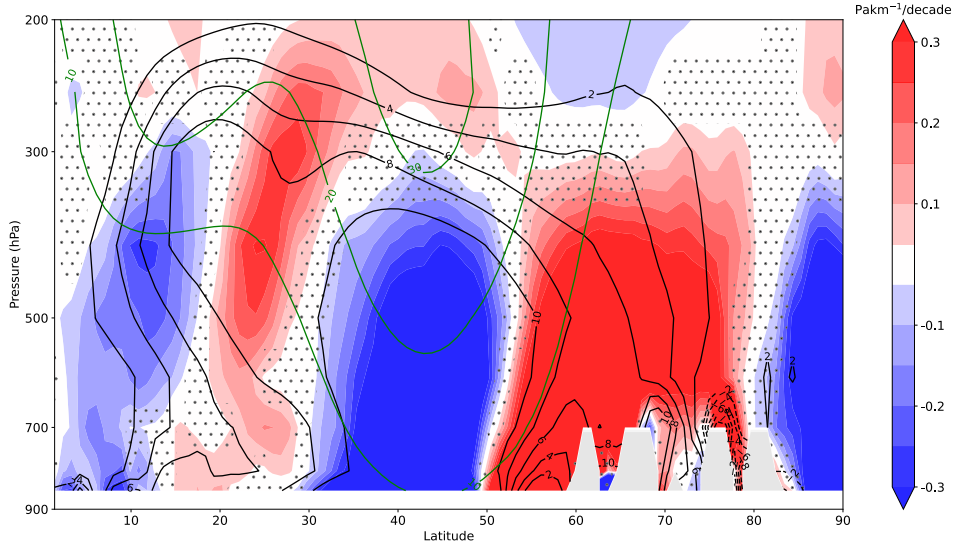
Some individual members (1980-2022)





Zonal wind trend (250 hPa)

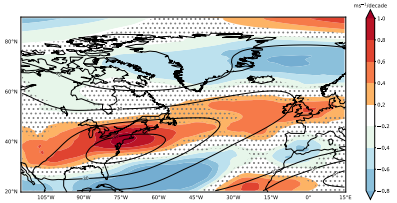




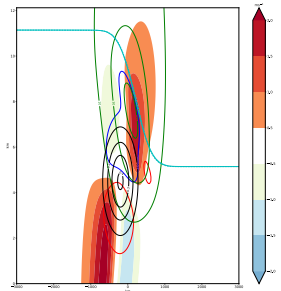
Slope trend (zonal mean 80 – 15 W)

Conclusions

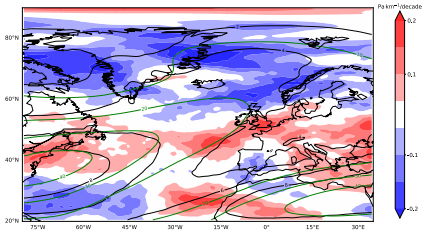
- The North Atlantic jet strem has slightly shifted poleward over the Gulf Stream and equatorward downstream



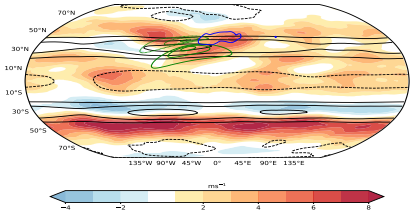
- The increase in diabatic seems to be responsible for the local jet trends



- An increase in baroclinicity and eddy momentum convergence accelerates the jet in a zonal band, extending over Europe



- These mechanisms are mostly reproduced in an aquaplanet setup, except the diabatic heating



- Trends in the fully-coupled climate model are different from ERA5 over the Gulf Stream