Changes in Extratropical Cyclone Dynamics in the North Atlantic in a Warming Climate

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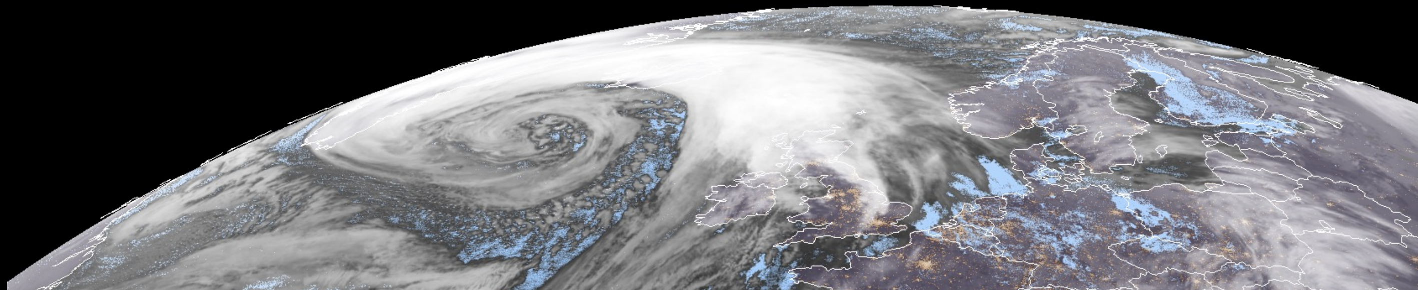
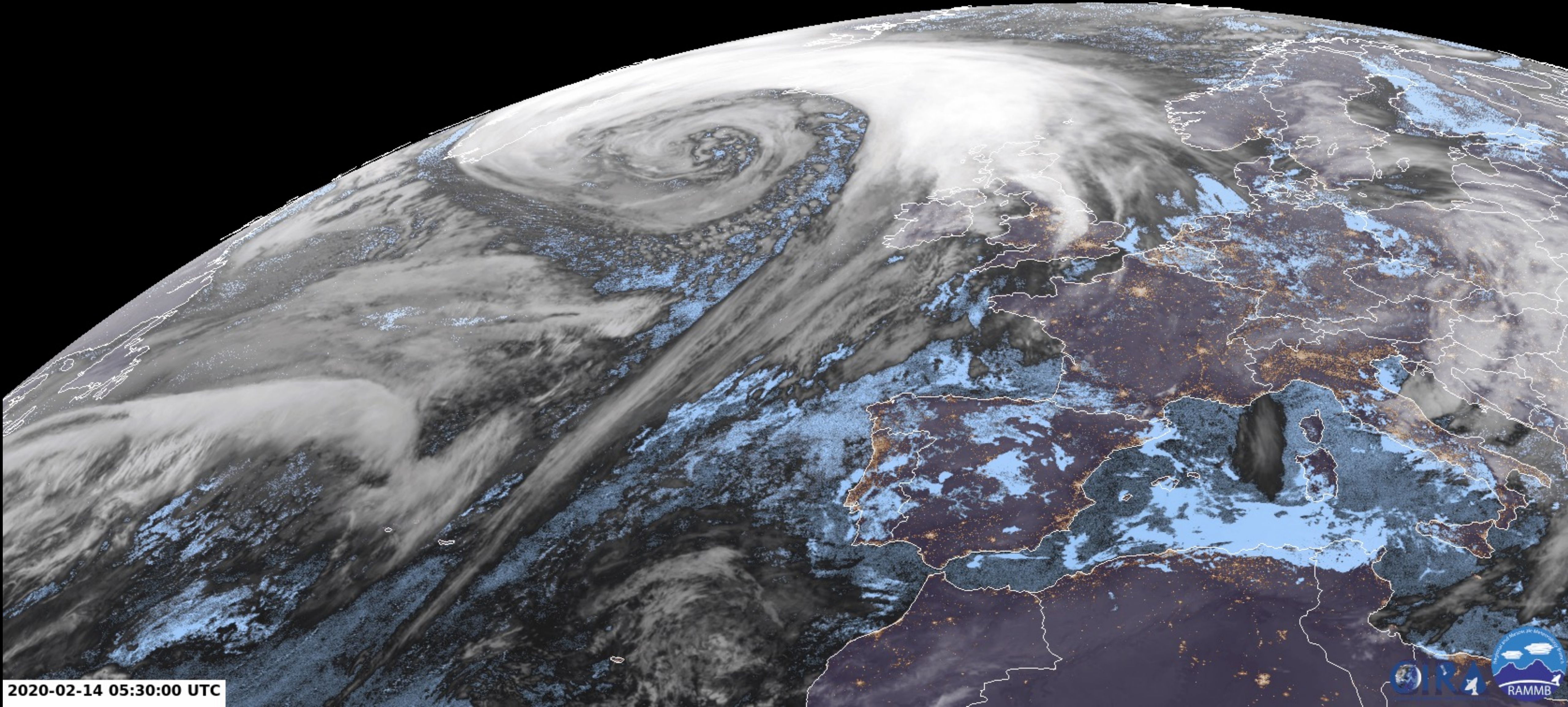
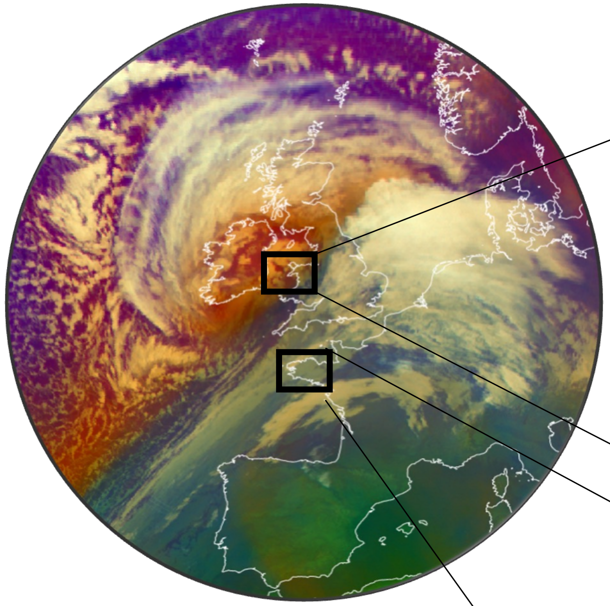
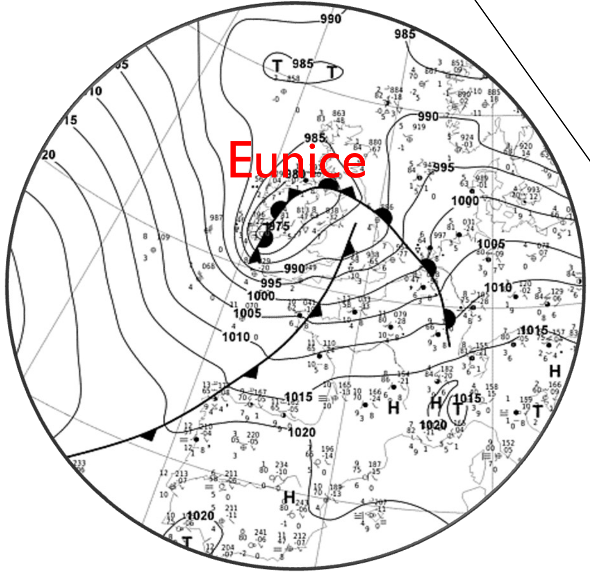


Satellite images



Introduction | Impact of mid-latitude cyclones





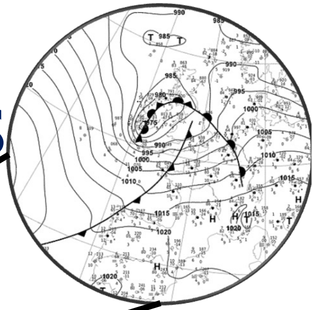
-Life-threatening weather conditions, economic losses,…

-Latent heat release during cloud formation
*Impact the atmospheric dynamics

https://view.eumetsat.int/productviewer
https://www.wetter3.de

https://www.dailymail.co.uk/
https://www.nasa.gov/audience/

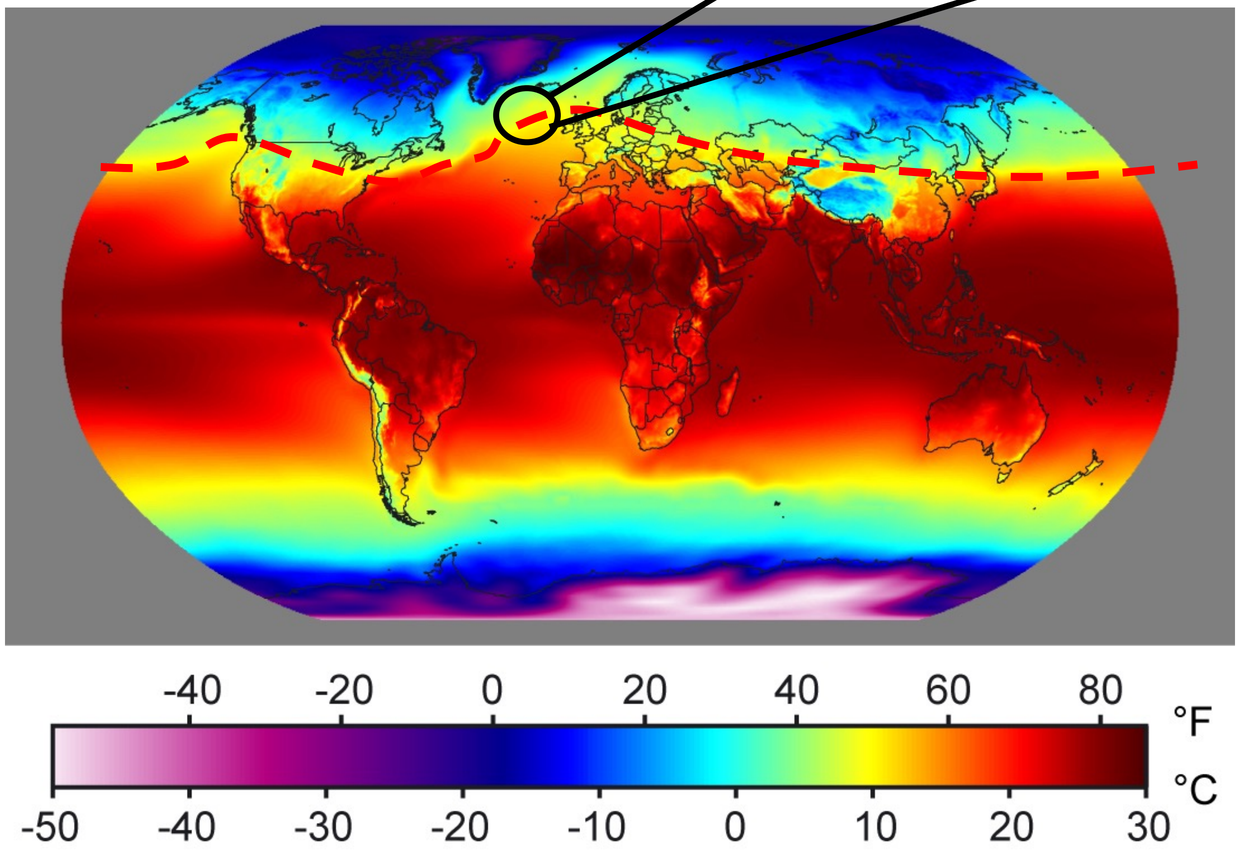
Introduction | Location of mid-latitude cyclones



-The Extratropical cyclones (ETC) development is associated with strong temperature gradients

-Move eastward along with the jet stream

-Regions with high frequency of ETC are known as storm tracks (e.g., the North Atlantic region)



Annual Mean Surface Temperature

Wikimedia
https://www.youtube.com/watch?v=Vwo9cuDxmVk

Introduction | Influence of climate warming

Future changes in cyclone activity: **"tug of war"** between opposing changes in:

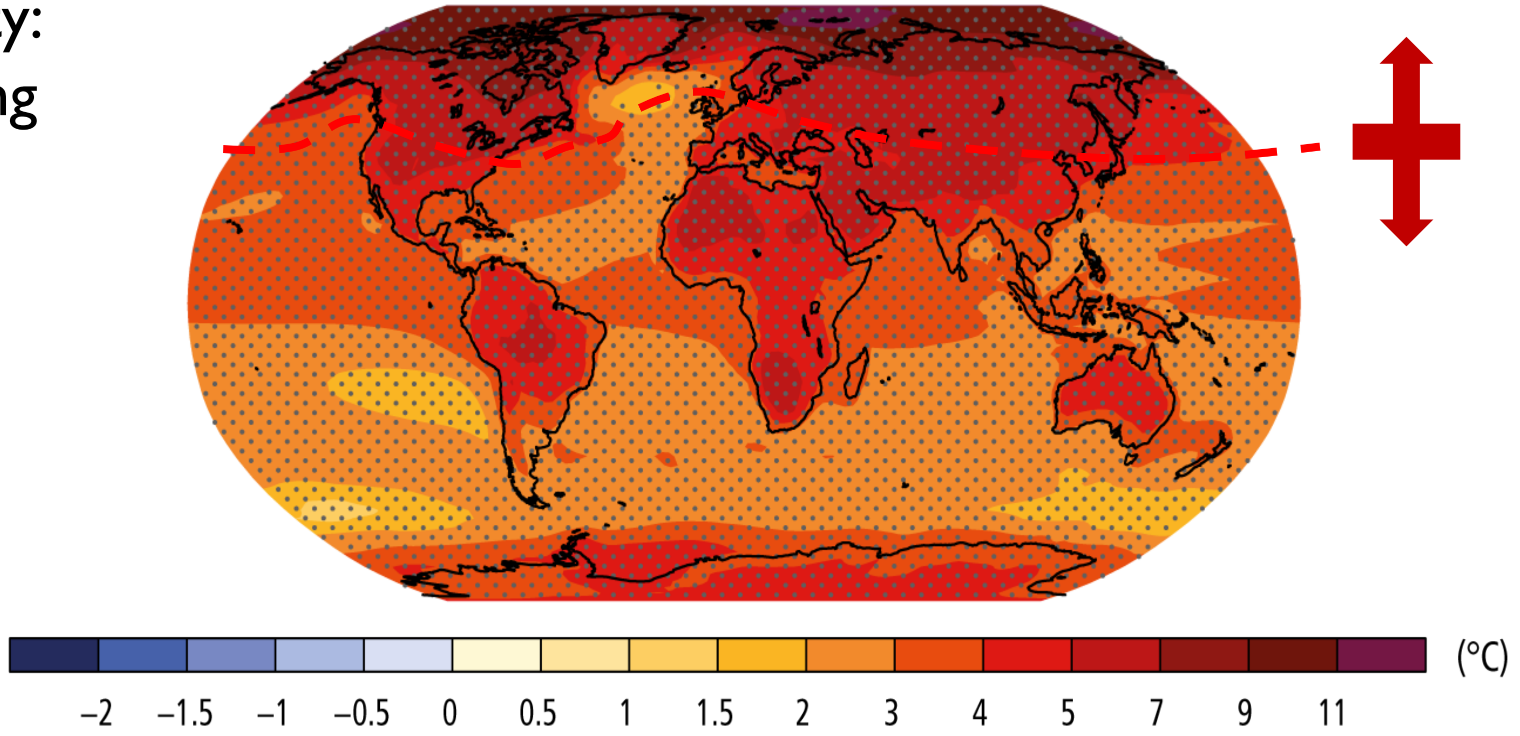
-horizontal temperature gradients:

*at low levels

*at upper levels

-vertical stability

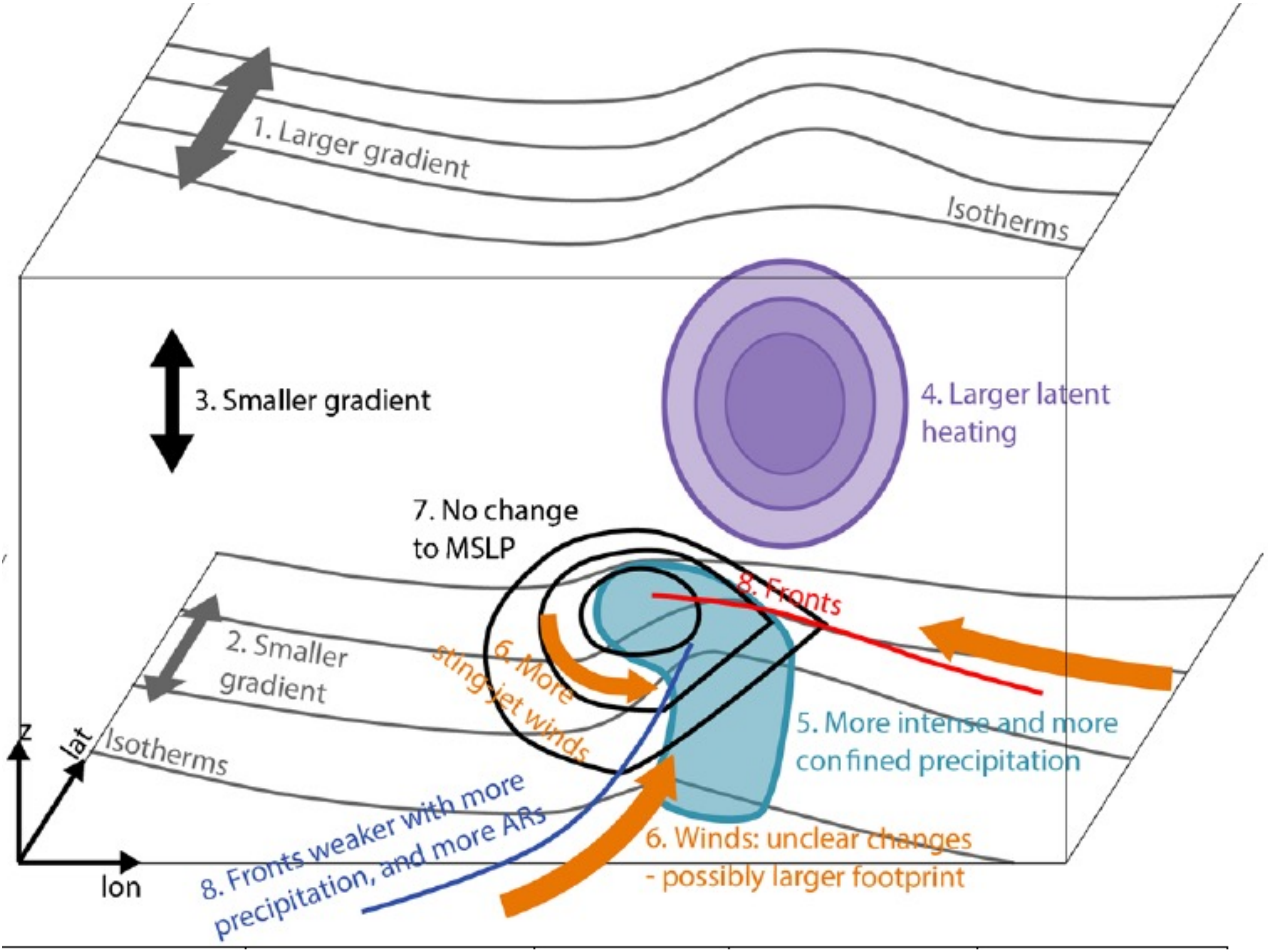
-latent heating in clouds



Simulated future change (2081–2100 compared to 1986-2005) in average surface temperature

IPCC report: https://ar5-syr.ipcc.ch/topic_summary.php

Introduction | Change in cyclone properties

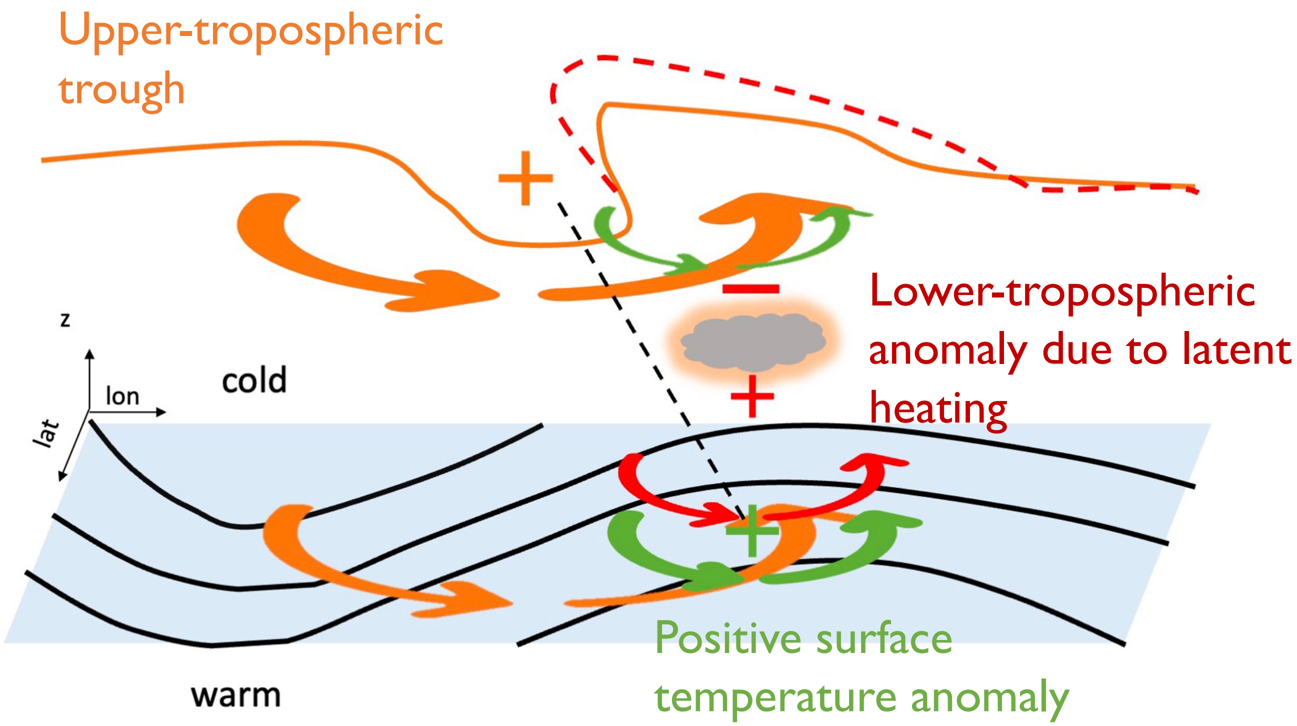


Properties	Confidence
5. More intense precipitation	High
6. Wind intensity/extension	Low

Catto et al., 2019

Introduction | Potential vorticity (PV) framework

PV anomalies linked to mid-latitude cyclones



$$PV = \frac{1}{\rho}\eta \cdot \nabla\theta \sim \frac{1}{\rho}(f+\zeta)\cdot\frac{\partial\theta}{\partial z}$$

absolut vorticity

Stability

PV tendency equation:

$$\frac{D\,\mathrm{PV}}{Dt} = \frac{1}{\rho}\boldsymbol{\eta}\cdot\nabla\dot{\theta} + F$$

diabatic PV generation

frictional effect

PV properties:

a) Conservation

b) Invertibility

Adapted from Colle et al., 2015

Introduction | Objectives

A better understanding of dynamic changes of extratropical cyclones over the North Atlantic in a warming climate

A) Identifying changes of cyclone structure

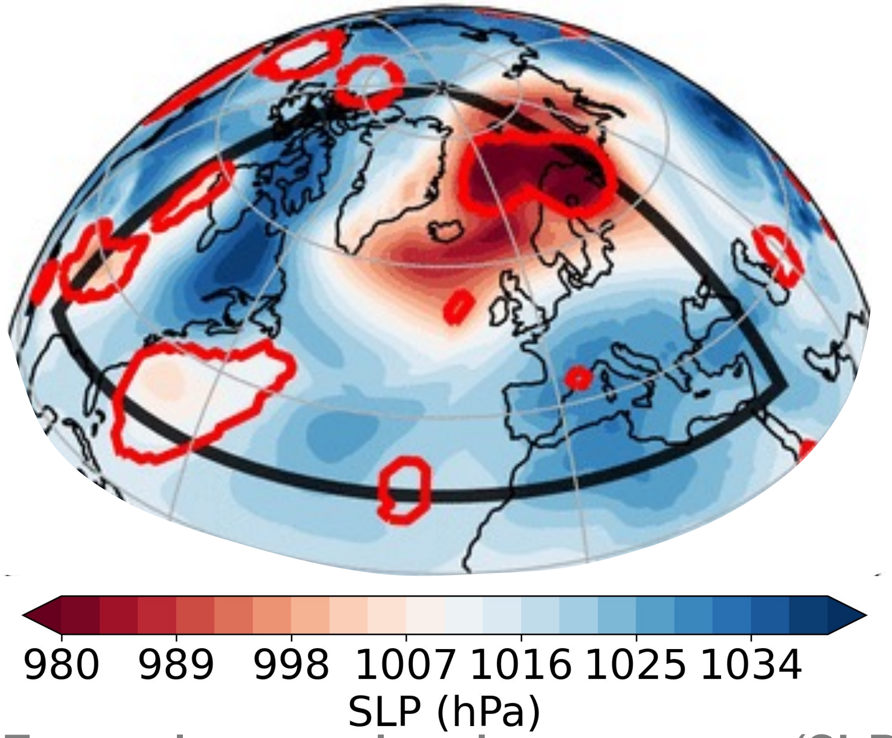
B) Link between PV anomalies and the cyclone circulation changes

C) Contribution of diabatic changes

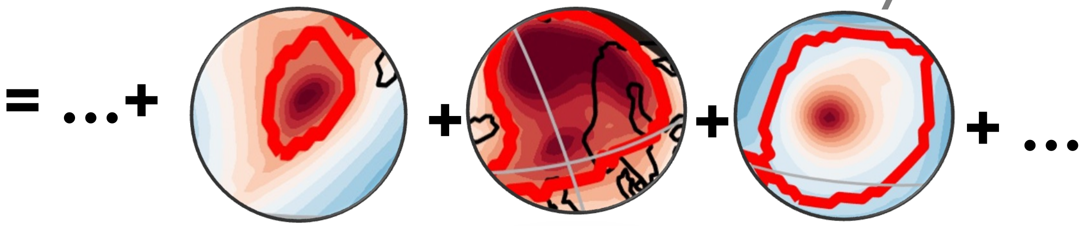
D) Dynamic contribution to precipitation changes

Method | Fully coupled climate simulations

- CESM-LE (Community Earth System Model Large Ensemble) climate simulations (10 members)
- Changes between **1990-2000** (present-day) and 2091-2100 (RCP8.5 future climate)
- Cyclone detection: Sea Level pressure contour
- **Cyclone centered composites** for the 10% strongest cyclones at the time of maximum intensity in the North Atlantic region



Example sea level pressure (SLP) distribution and identified-cyclones

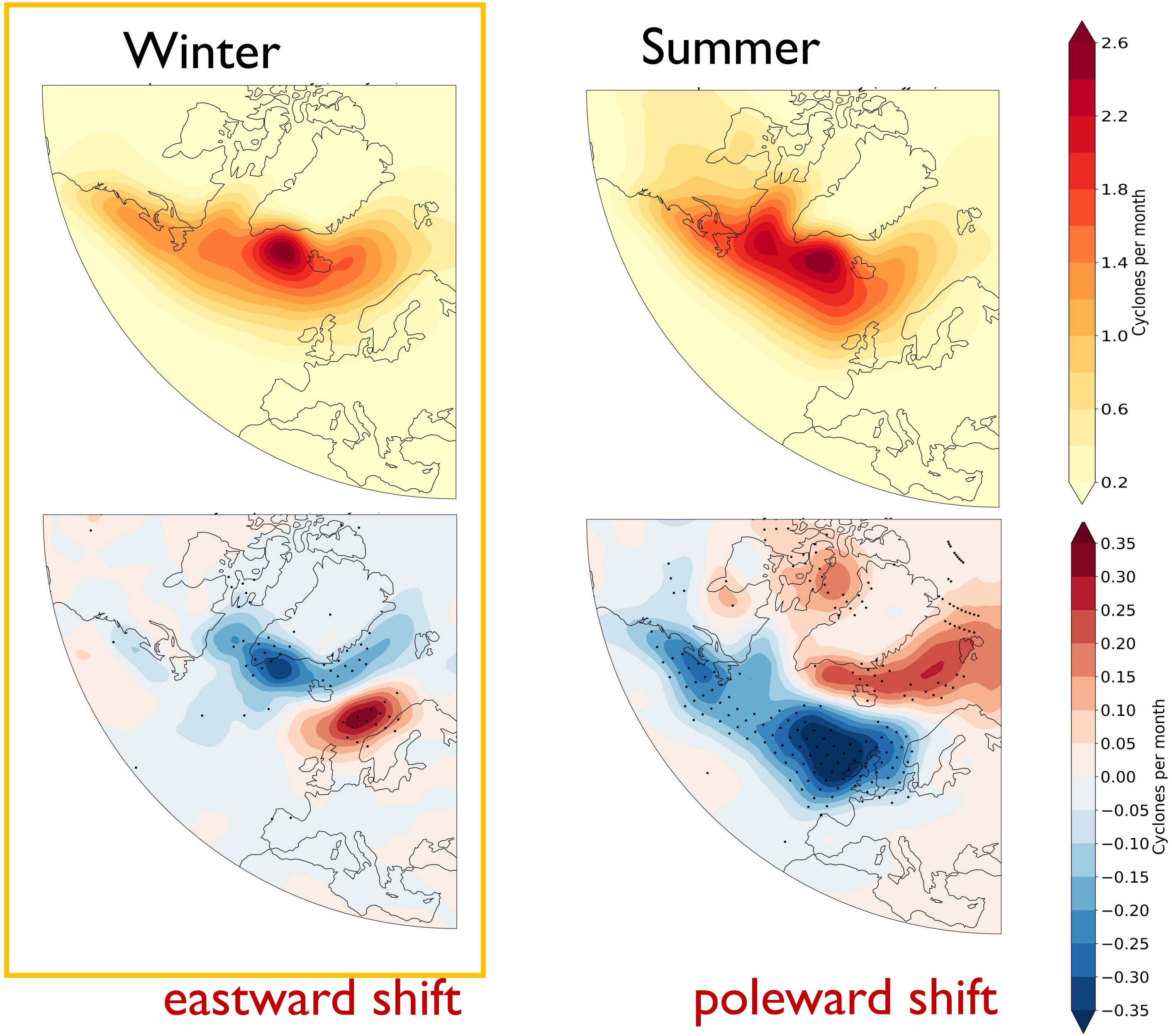


Kay et al., 2015
Wernli and Schwierz, 2006

Results | Storm tracks in the CESM-LE

Present track density

Track density response

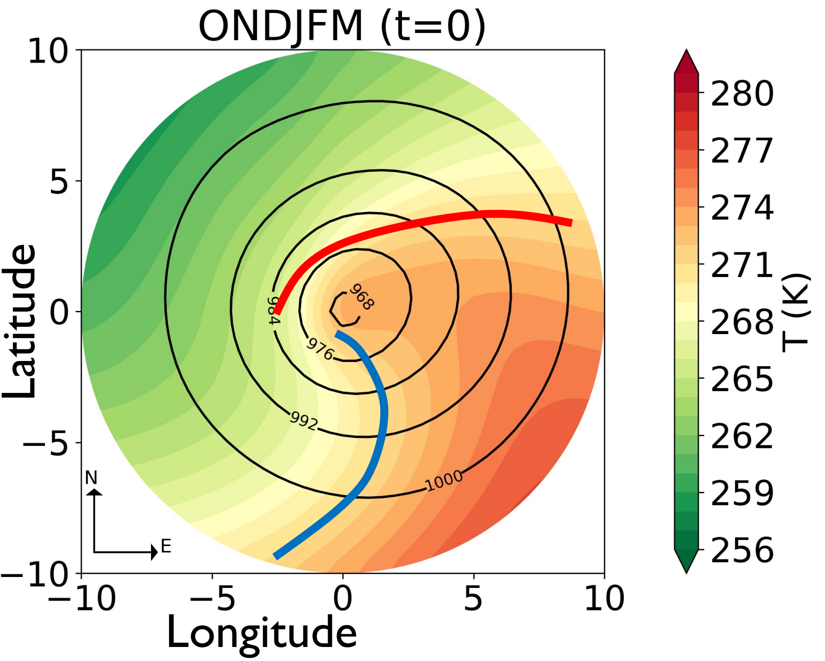


eastward shift

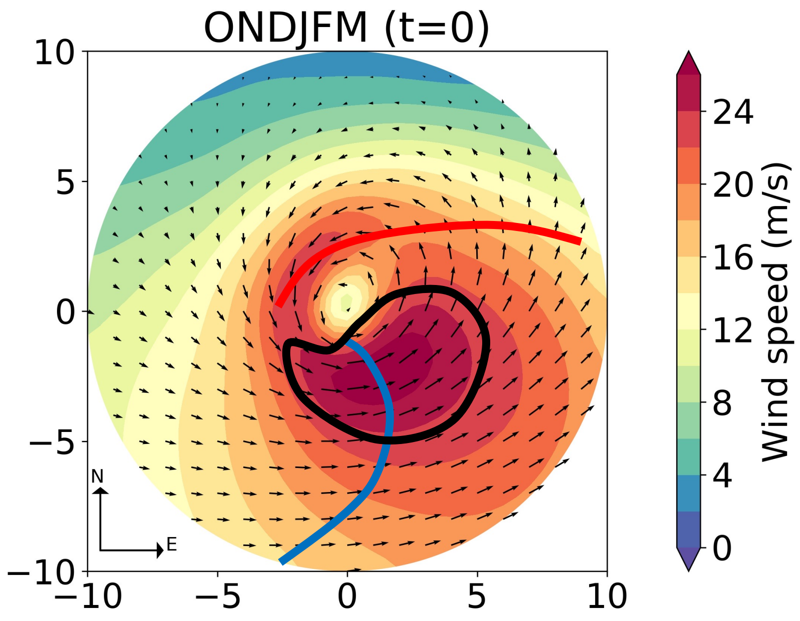
poleward shift

Results | Present composite mean in winter

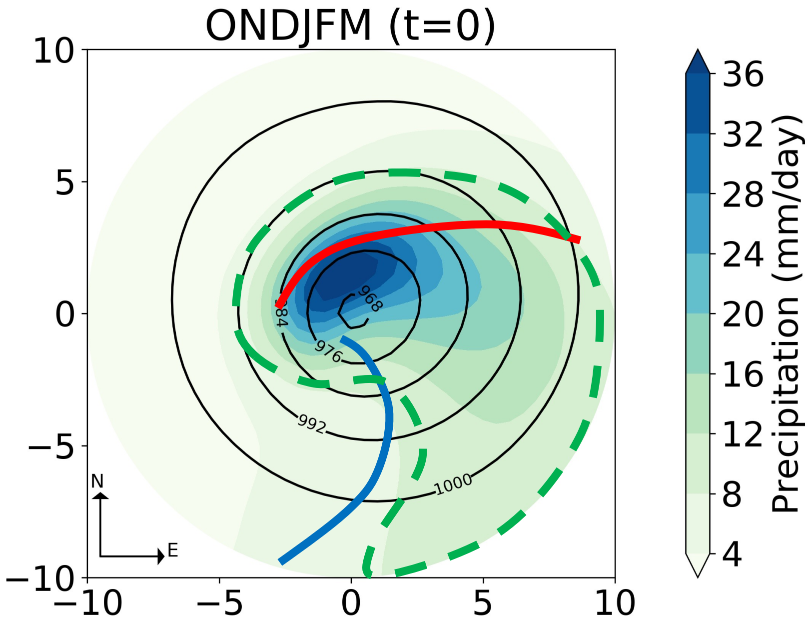
Temperature@850hPa



Wind@850hPa

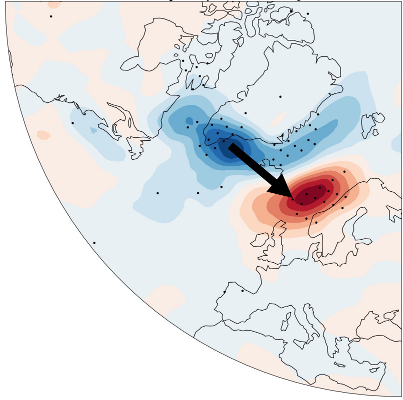


Precipitation

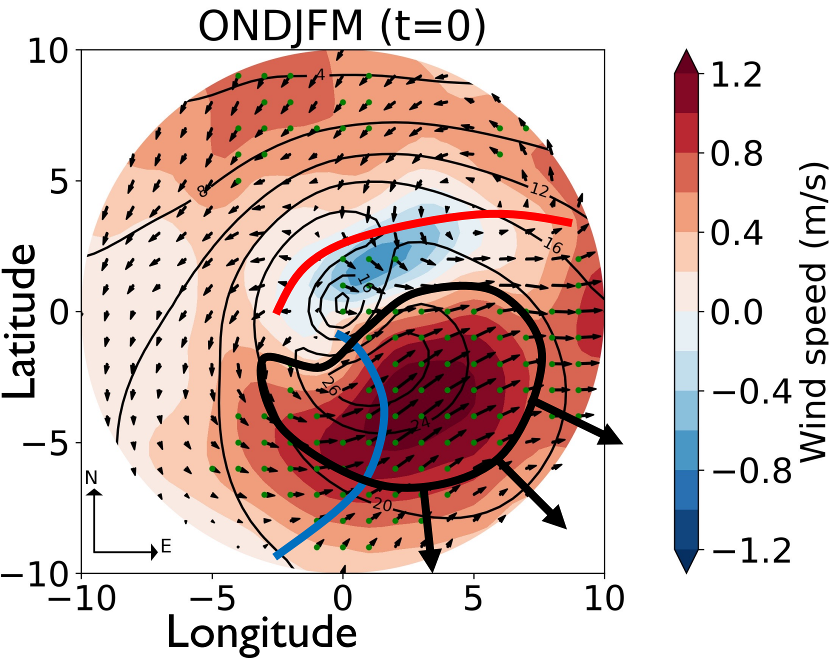


Contours = Sea level pressure

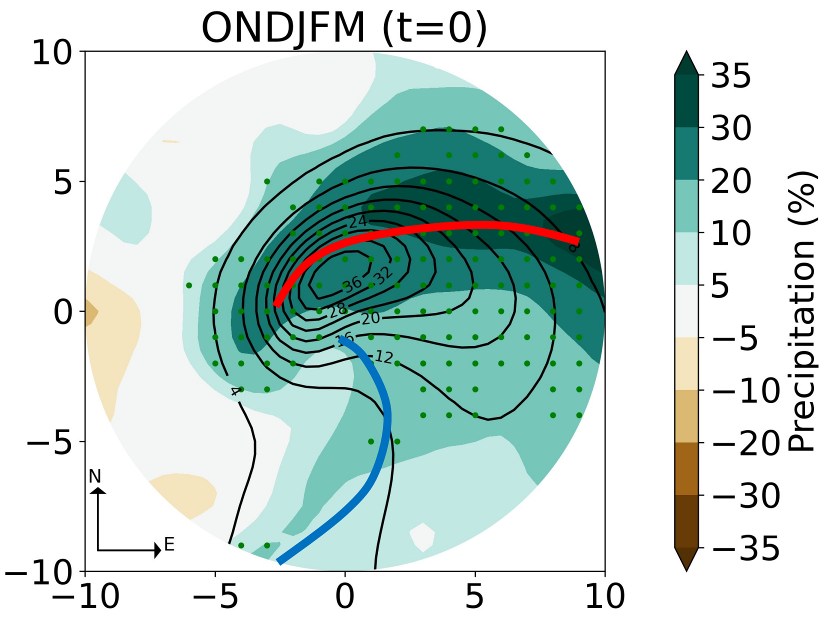
Results | Future composite changes in winter



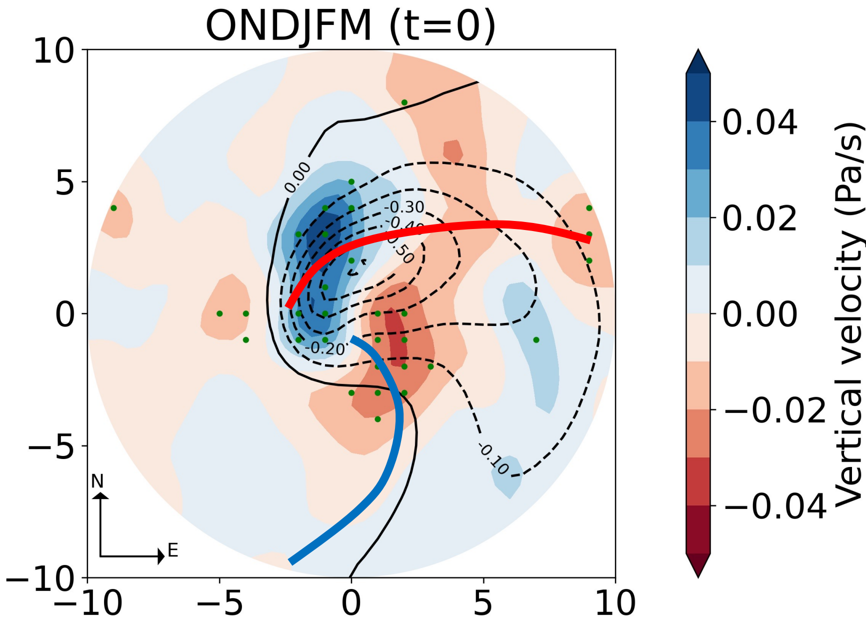
Wind@850hPa



Precipitation



Omega@850hPa



-larger footprint

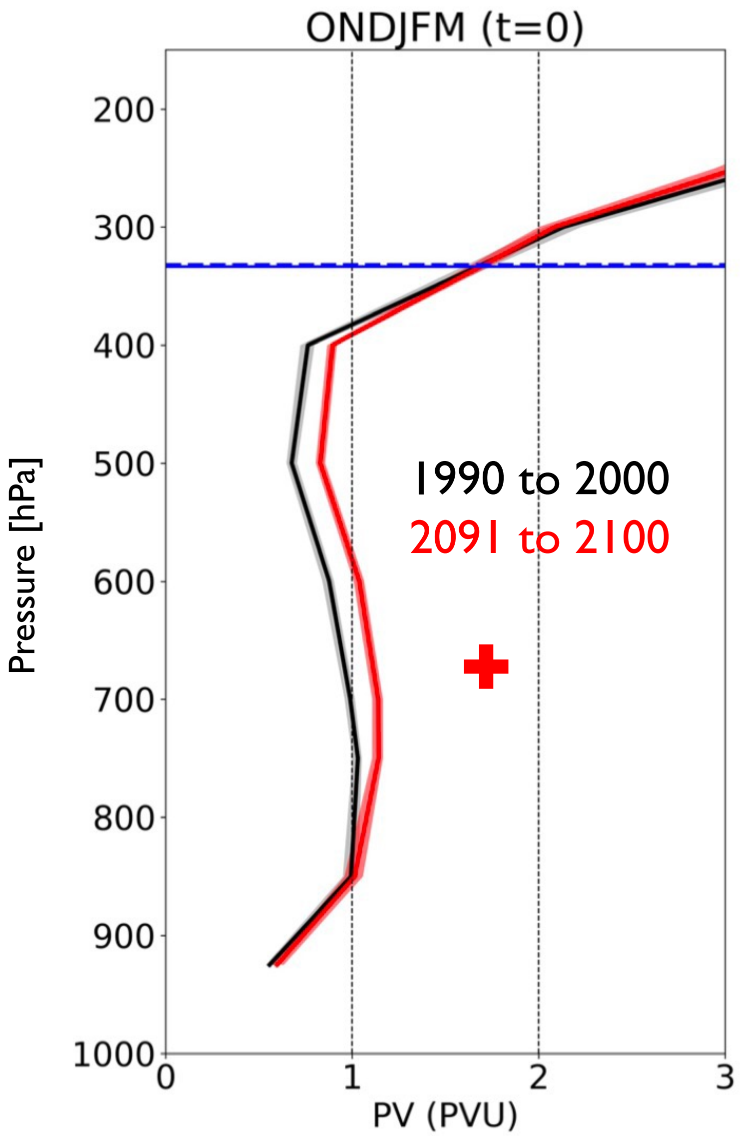
-more precipitation and stronger ascent downstream

>80% of members agree on sign of change

Contours = present-day

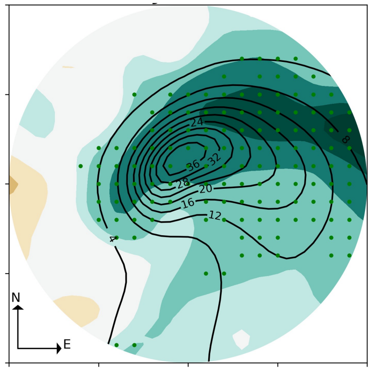
Shaded colors = future changes

Results | PV anomalies



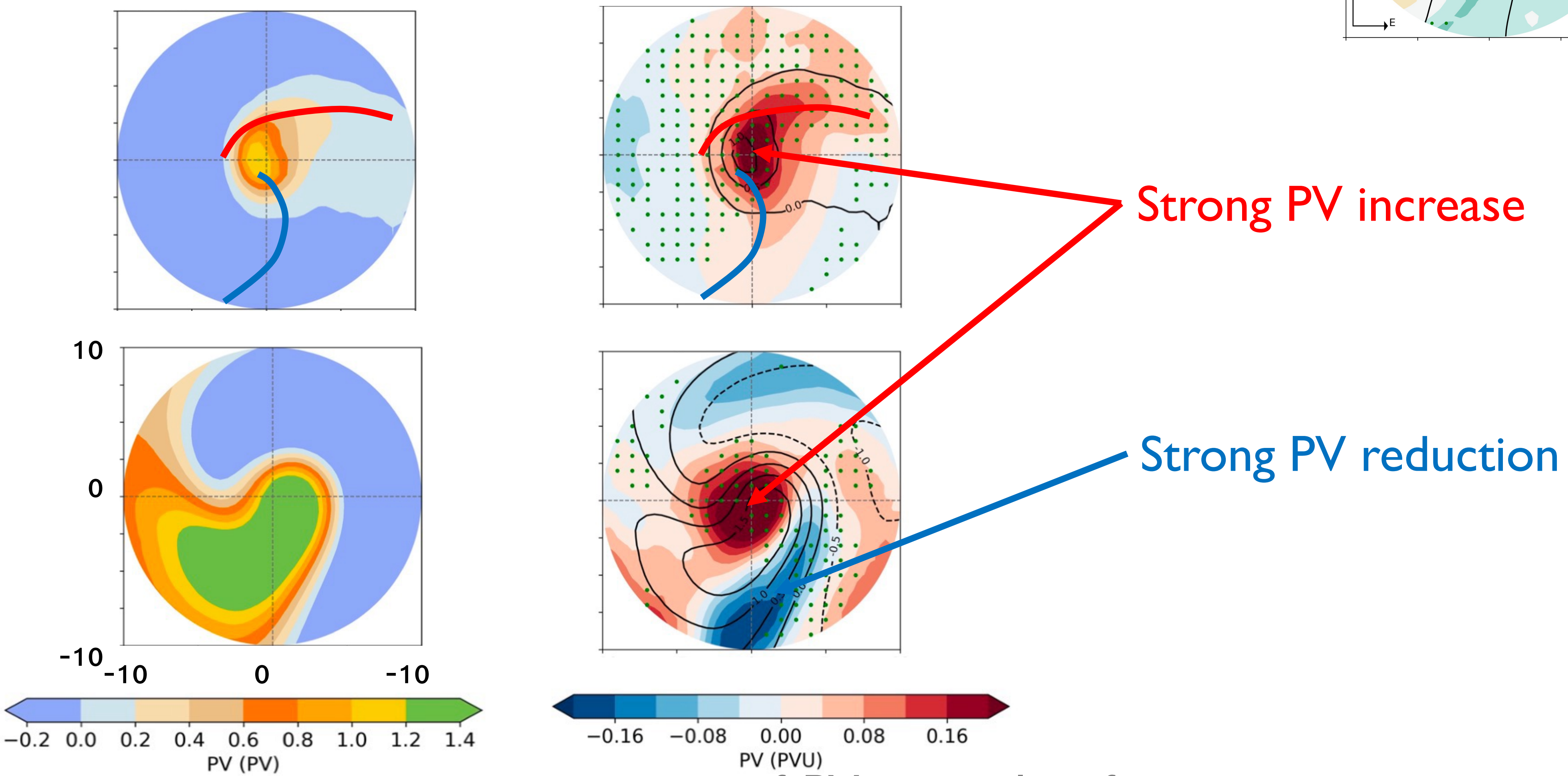
Vertical profiles of PV anomalies associated with intense Northern Atlantic winter cyclones in present-day and future climate, averaged in a radius of 2.5° around the cyclone center. Dynamical tropopause in present-day (solid blue line) and future climate (dashed blue line)

Results | PV anomalies

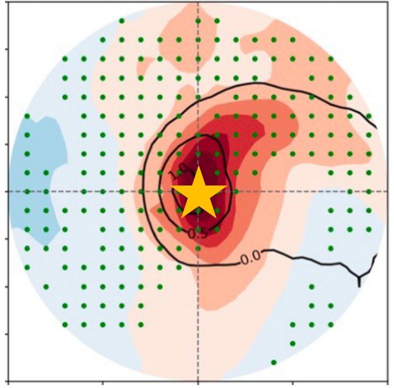


850-600 hPa

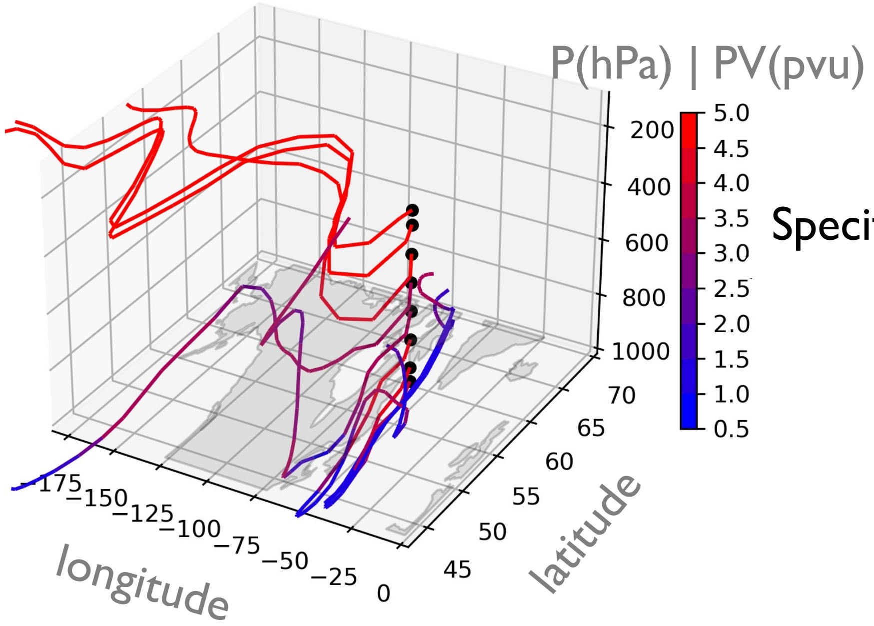
550-150 hPa



Present-day and future change composites of PV anomalies for **extreme cyclones** (1% strongest) in the North Atlantic region



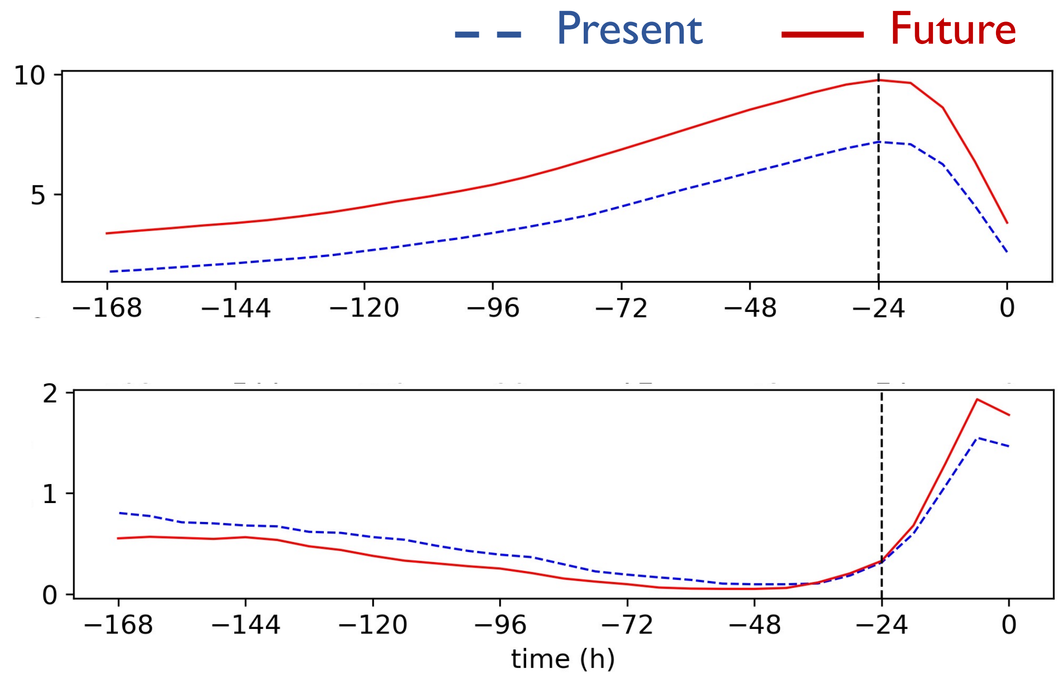
Results | Backward trajectories at low levels



7-days backward trajectories with LAGRANTO

Specific humidity (g/kg)

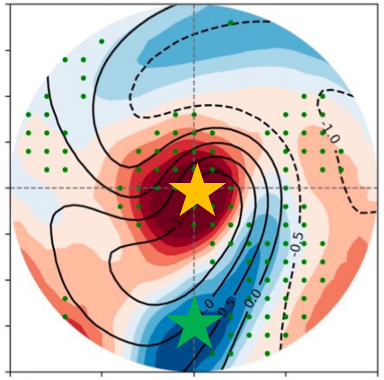
PV (pvu)

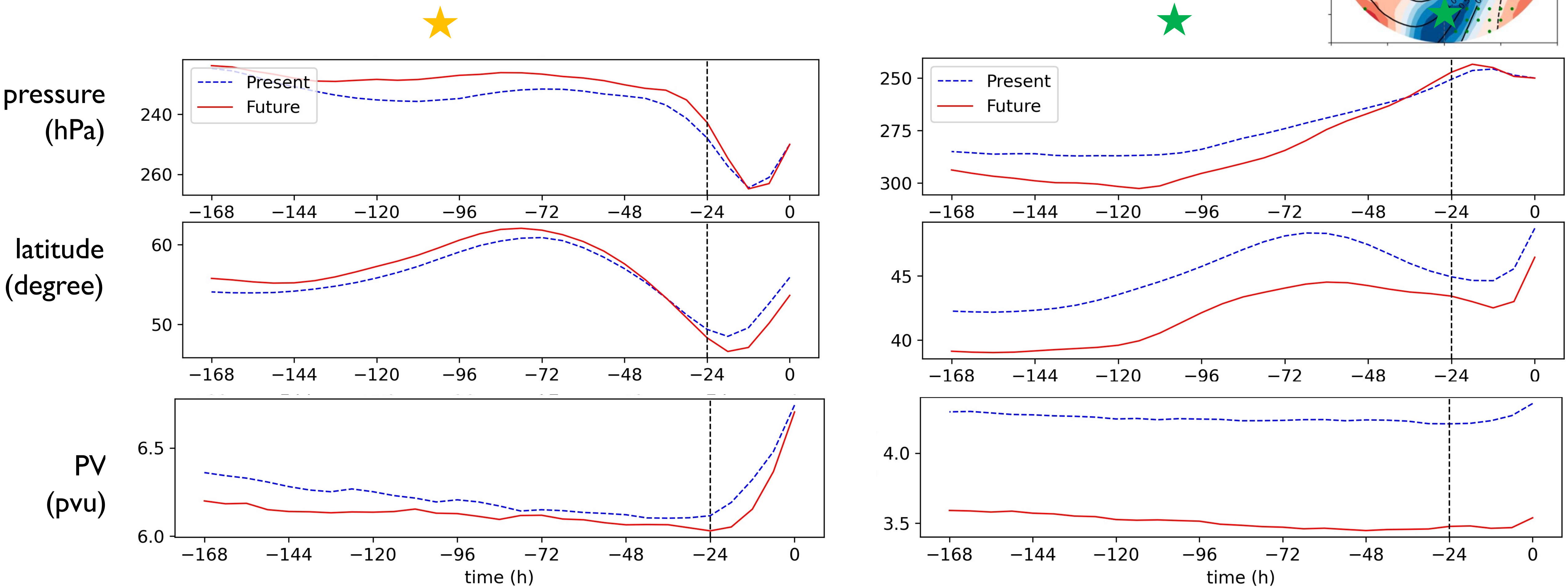


Mean evolution of PV and specific humidity along backward trajectories initialized in cyclone center at 700 hPa

Wernli and Davies, 1997, Sprenger and Wernli, 2015

Results | Backward trajectories at high levels





Mean evolution pressure, latitude and PV along backward trajectories initialized in cyclone center and to the south of the cyclone center at 250 hPa

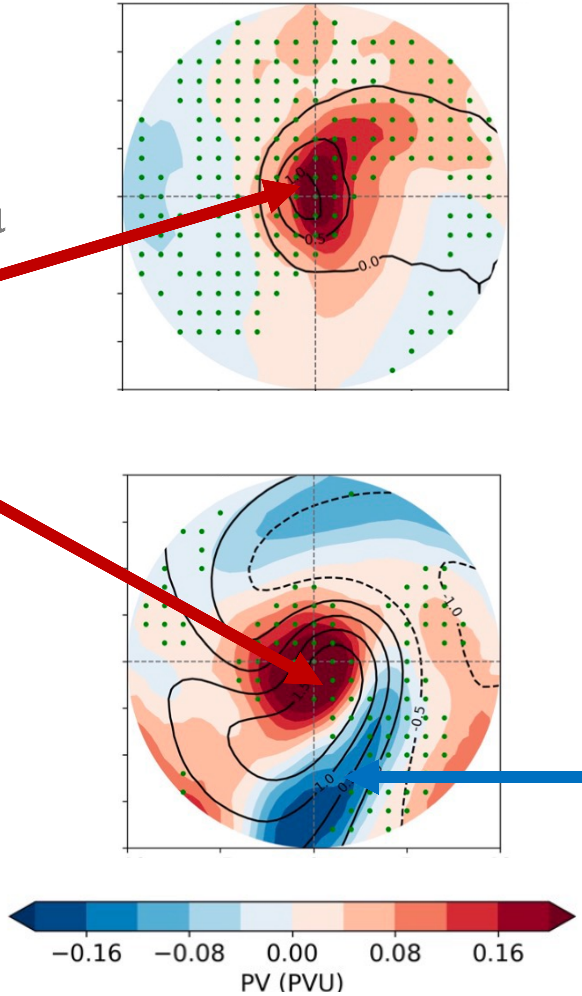
Results | Main drivers of PV anomaly changes

850-600 hPa

amplified diabatic heating

550-150 hPa

amplified northward transport of low PV air



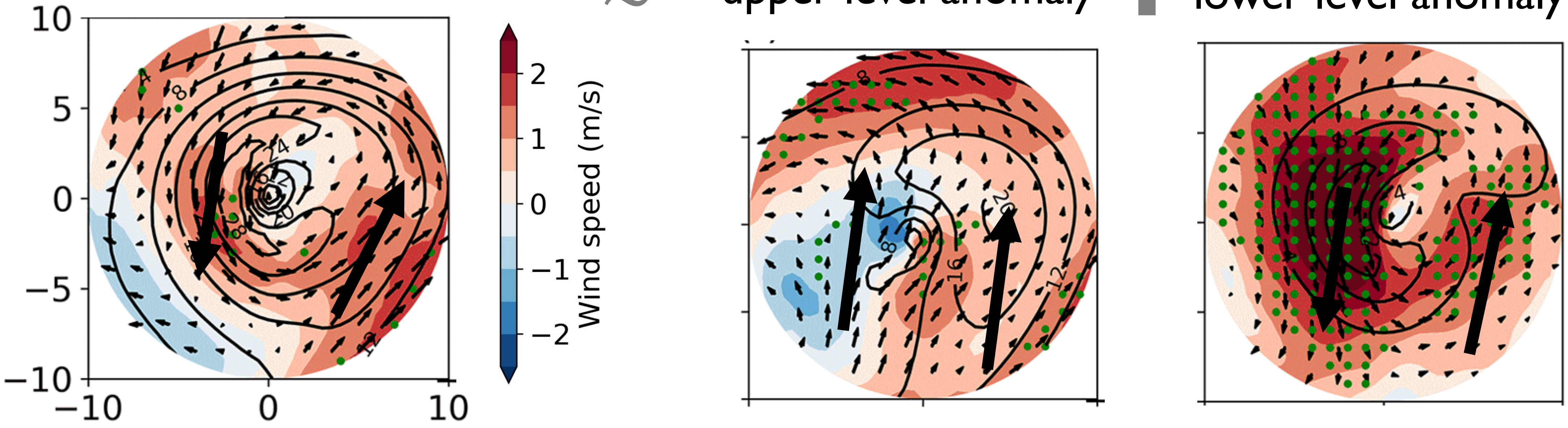
Present-day and future changes composites of PV anomalies for **extreme cyclones** (1% strongest) in the North Atlantic region

Results | Associated changes in wind velocity from PV inversion

Balance condition: $|\mathbb{V}_{\chi}| \ll |\mathbb{V}_{\psi}|$

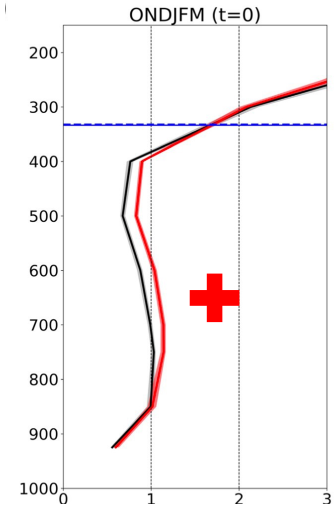
Contributions of PV changes at differents levels

balance flow ≈ upper level anomaly + lower level anomaly + …

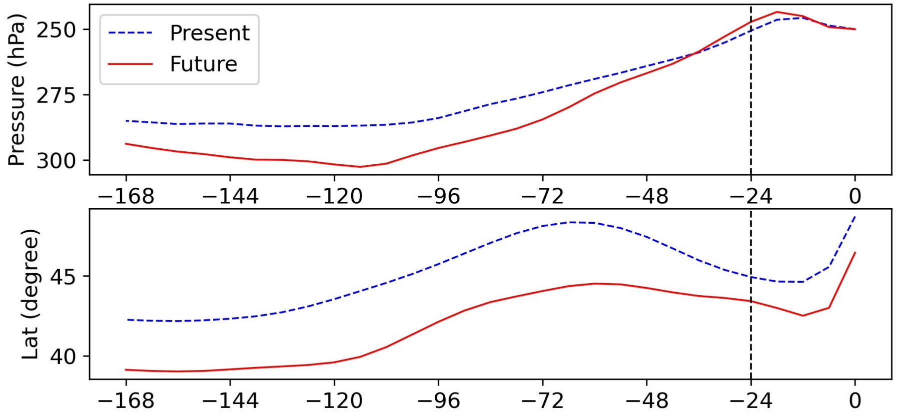


Composite changes in wind velocity at 850 hPa associated with **extreme** North Atlantic winter cyclones

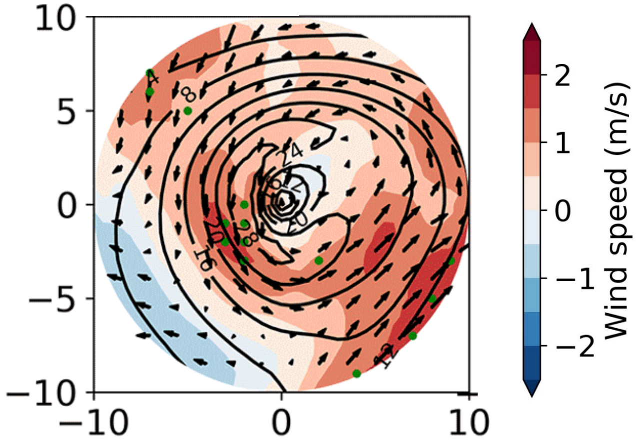
Conclusions



Increased latent heating in a warmer climate amplifies low- and mid-levels PV anomalies near the cyclone center *(Dolores-Tesillos, E., et al., 2022)*



Increased diabatic effects and advection of lower PV shapes the upper level PV anomaly pattern in a warmer climate



Future expansion of the near-surface wind speed footprint is not just the result of increased diabatic PV production but rather a sum of the upper and lower-level PV contributions *(Dolores-Tesillos, E., et al., 2022)*

¡Gracias! Danke schön! Thank you!