Storylines of atmospheric circulation change for European climate impact assessment

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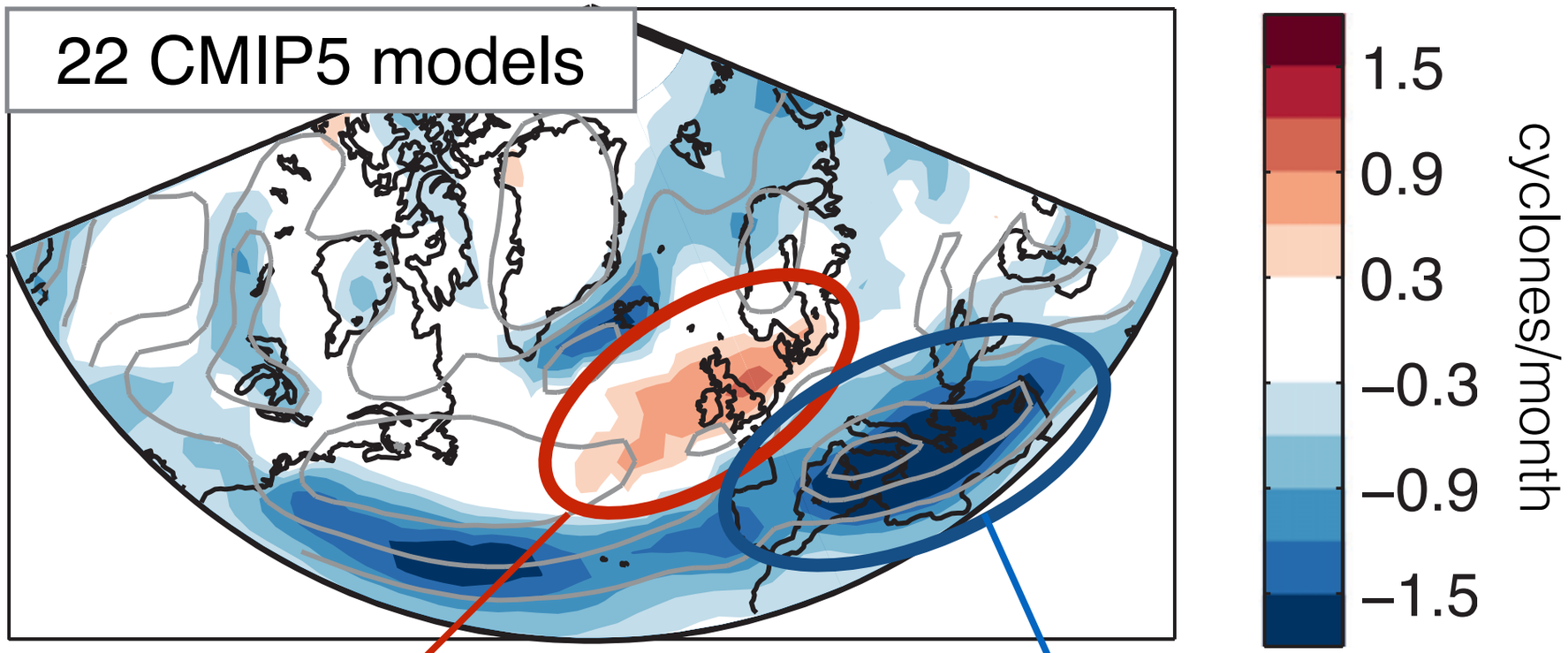
European Research Council
Established by the European Commission

University of Reading

Two projected European climate impacts

Projected future response in the number of extra-tropical cyclones
RCP8.5 (2070-2099) minus Historical (1976-2005)

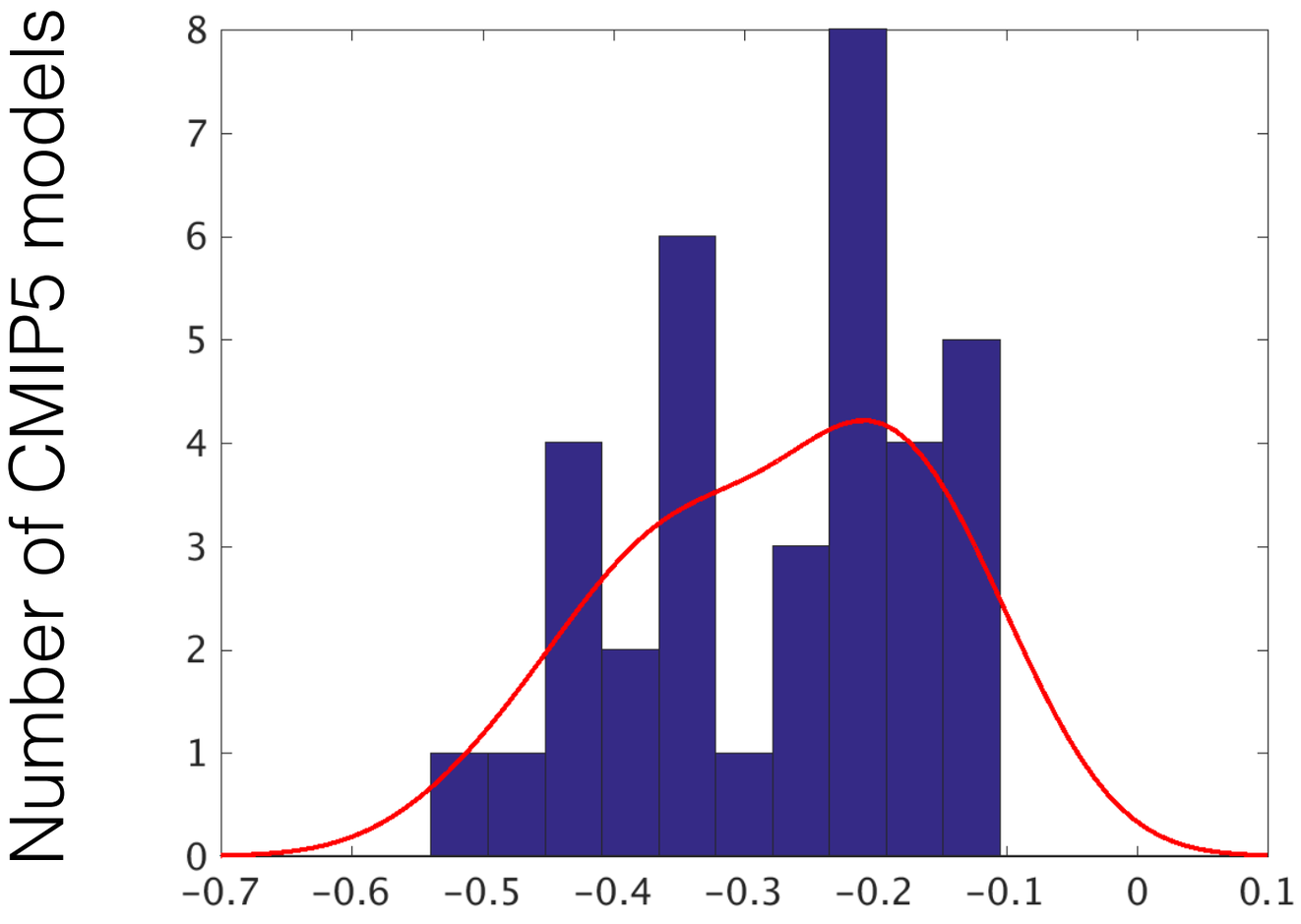


Central European
storminess and windiness
increase

Mediterranean
storminess and precipitation
decrease

Zappa et al, 2013

Interpreting multi-model ensembles

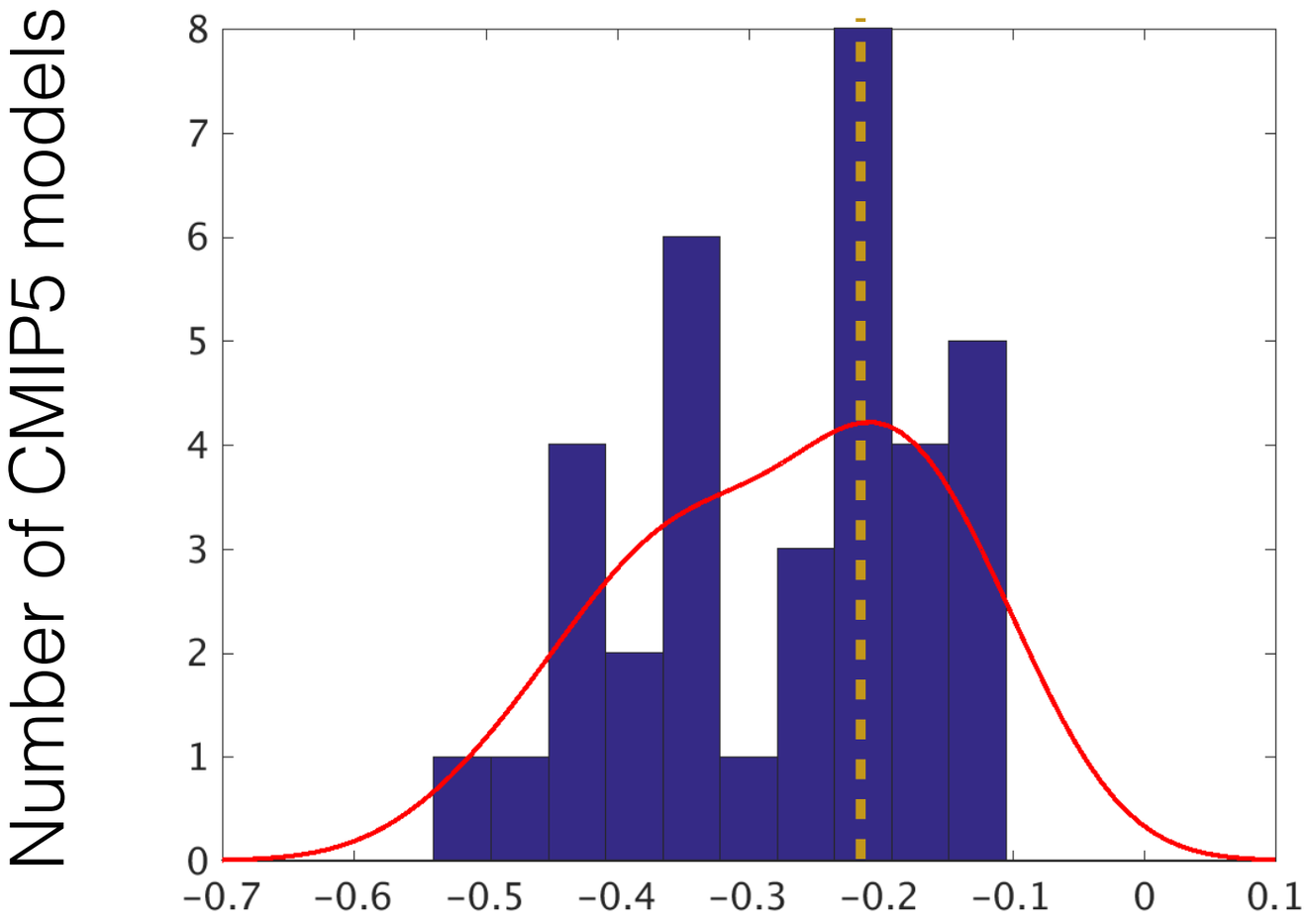


But there is still considerable spread in the associated windiness and precipitation impacts

How do we interpret this?

Interpreting multi-model ensembles

Most likely response



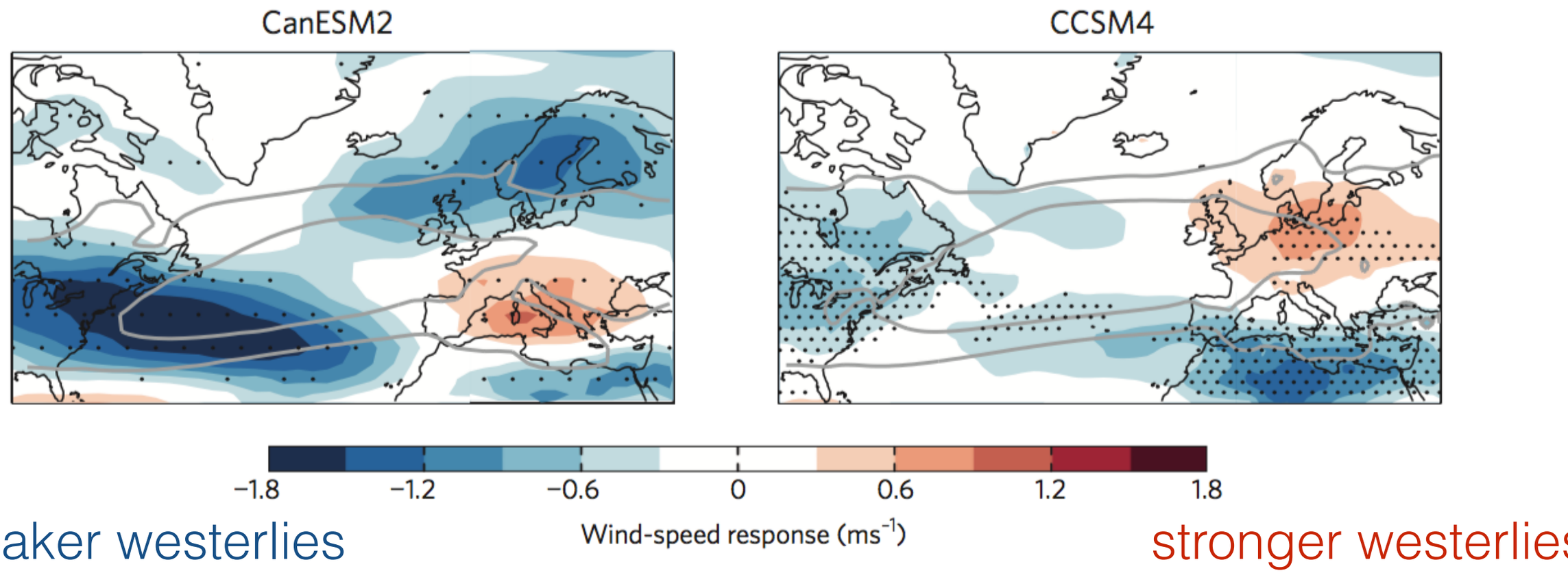
Probabilistic
IPCC style approach

- One model, one vote
- Likelihood informed by distribution responses
- But models share code - not really *independent*
- Have similar biases and unrepresented processes

Different models, different patterns

- Furthermore the multi-model mean averages qualitatively different circulation patterns

Zonal wind response at 850 hPa (RCP8.5-HIST) in 2 CMIP5 models

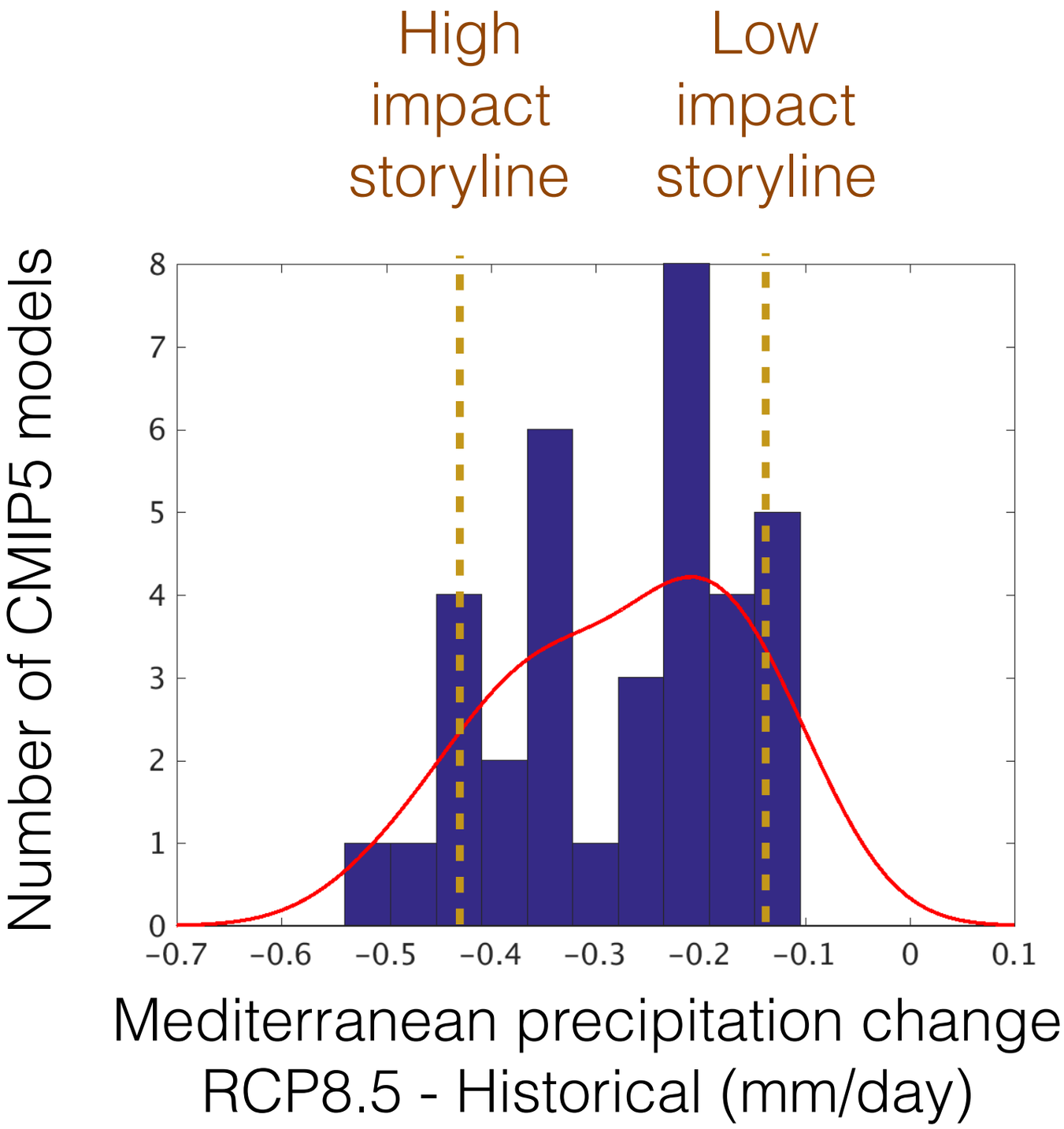


weaker westerlies

stronger westerlies

Shepherd 2014

Interpreting multi-model ensembles



Storyline approach

- Identify storylines to describe different plausible responses
- No probability attached to each storyline
- Develop a physical understanding for each storyline

Interpreting multi-model ensembles

High

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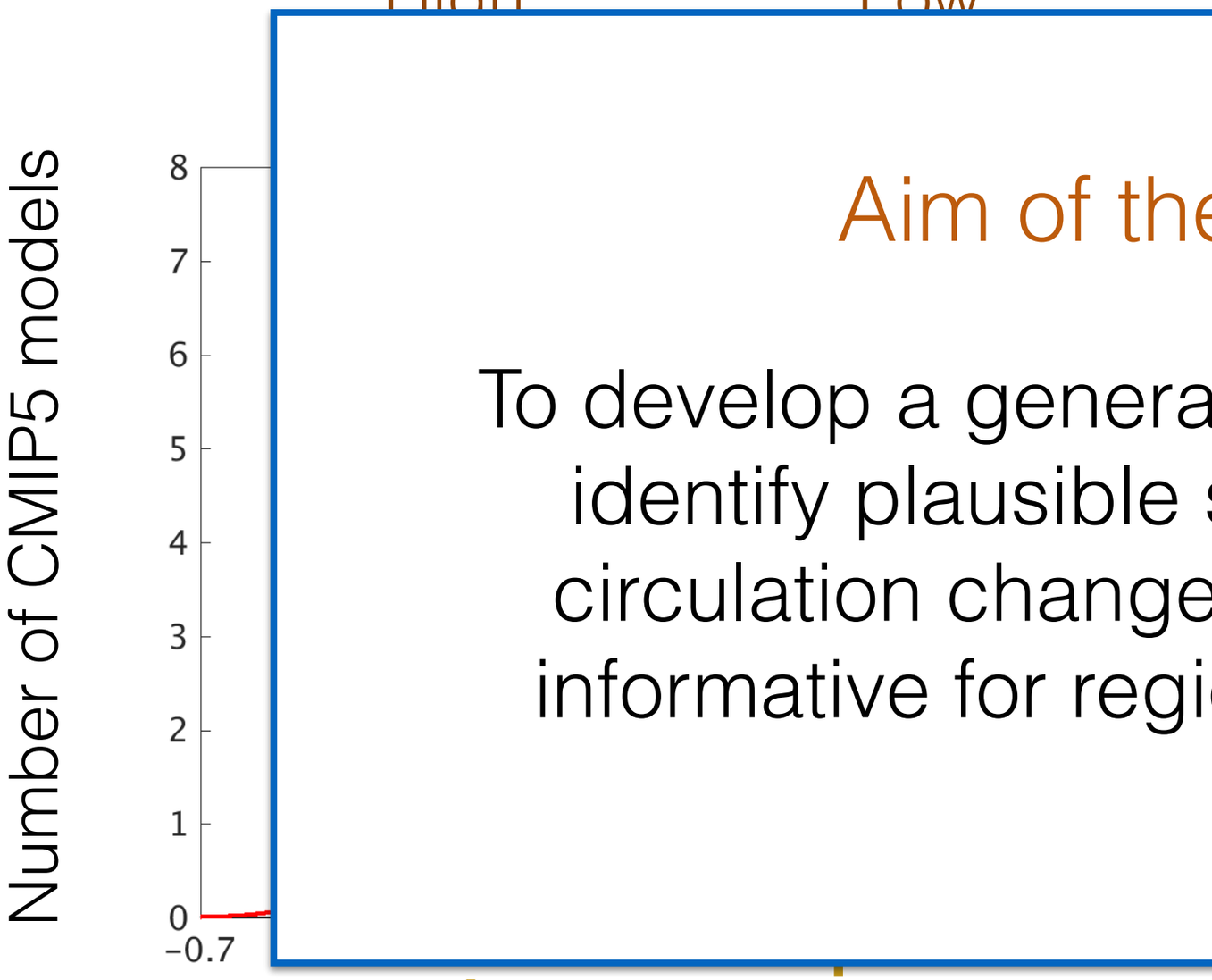
or each



storyline

Aim of the talk

To develop a general framework to identify plausible storylines of circulation change that can be informative for regional impacts

Identifying storylines of circulation change

- Amplitude of the atmospheric circulation response tends to increase with global warming (Pattern Scaling Assumption)

- But, the pattern of the circulation response can be strongly model dependent - it needs to be related to regional drivers

Pattern scaling

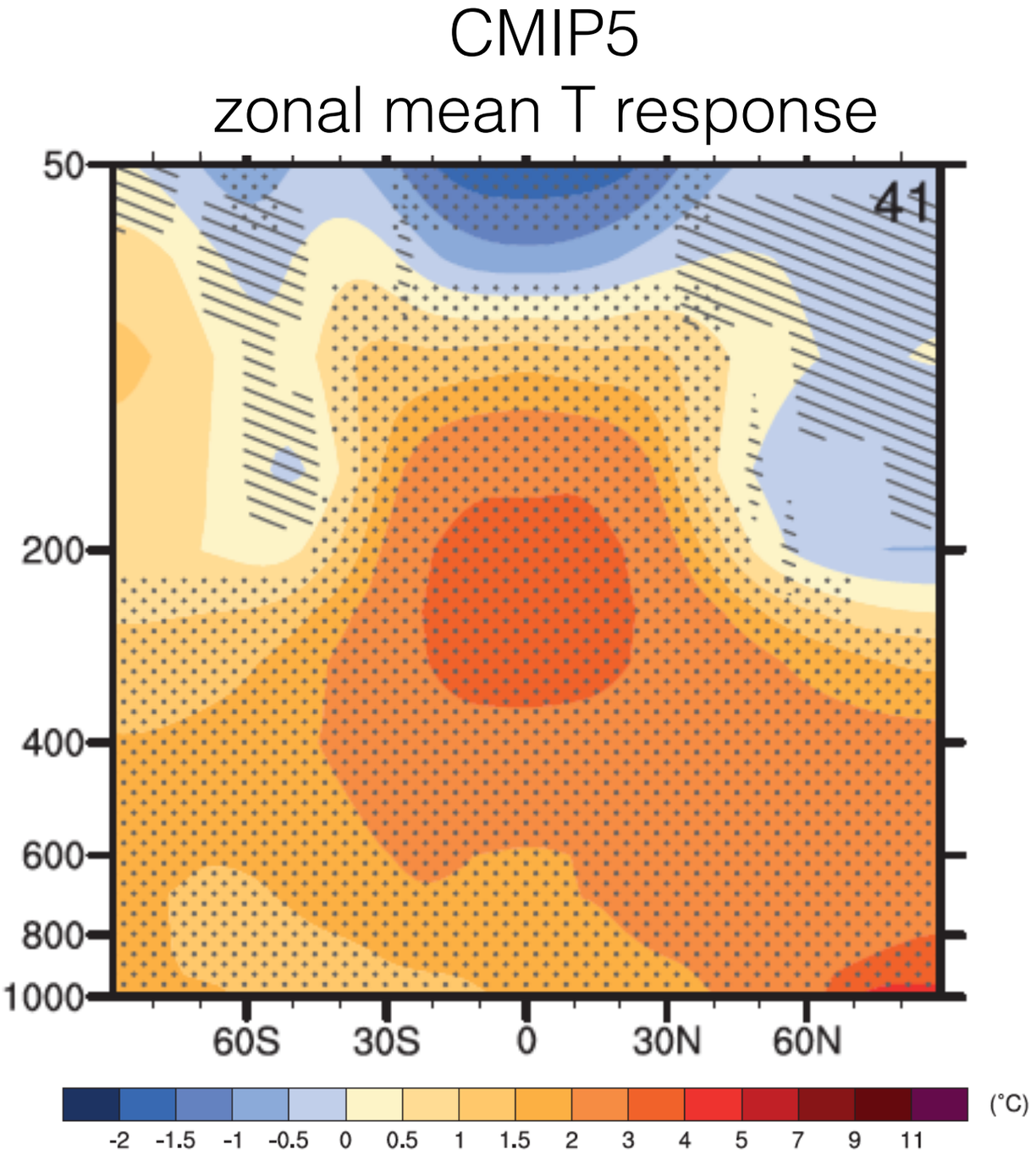
$$\delta C_{mx} \sim \delta T_m \cdot P_{mx}$$

Regional Circulation change

Global warming

Pattern of change

Large scale drivers of circulation

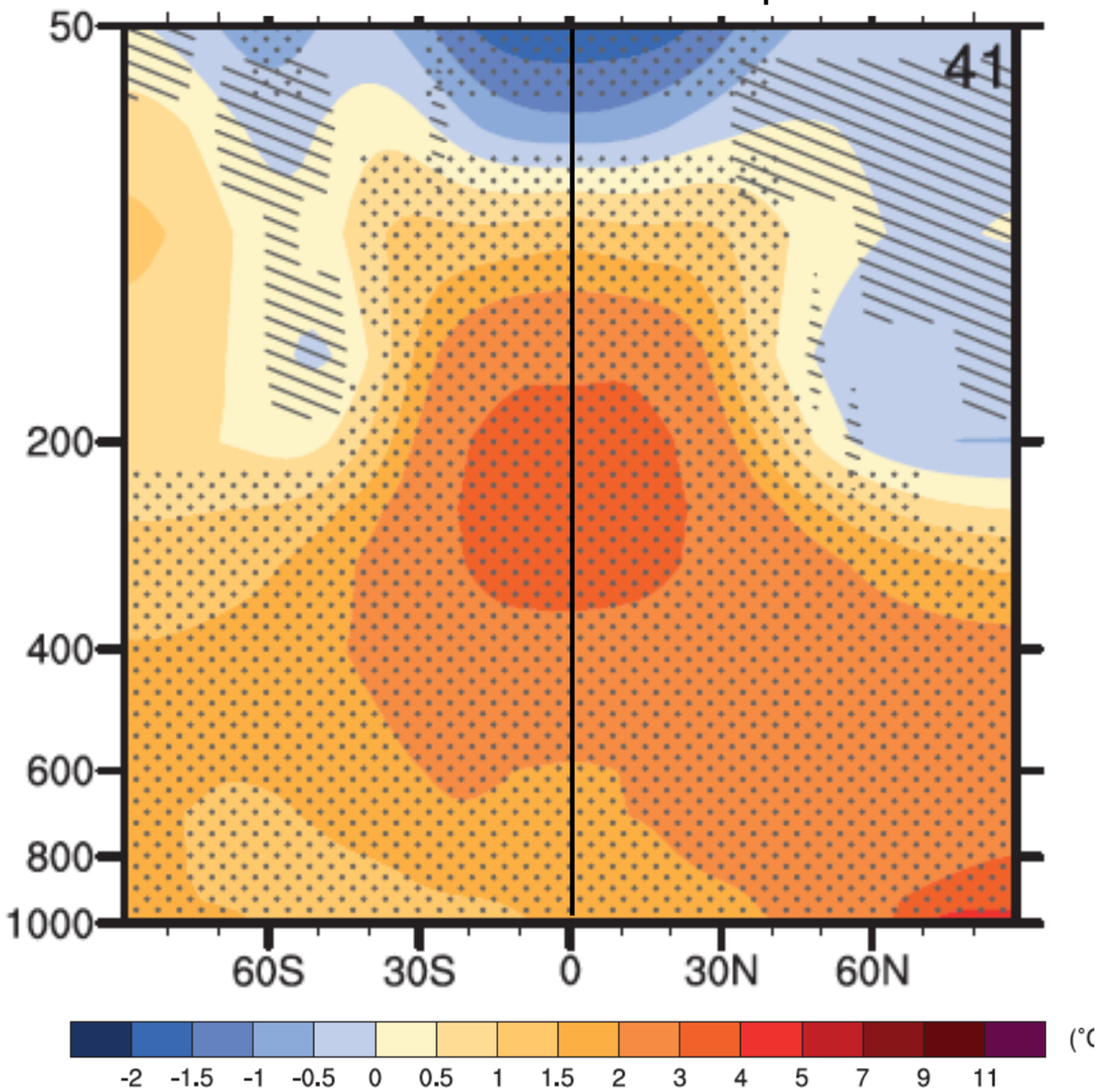


IPCC-AR5

- Meridional temperature gradients are projected to change
- This can affect the atmospheric circulation response (e.g. Harvey et al 2015)

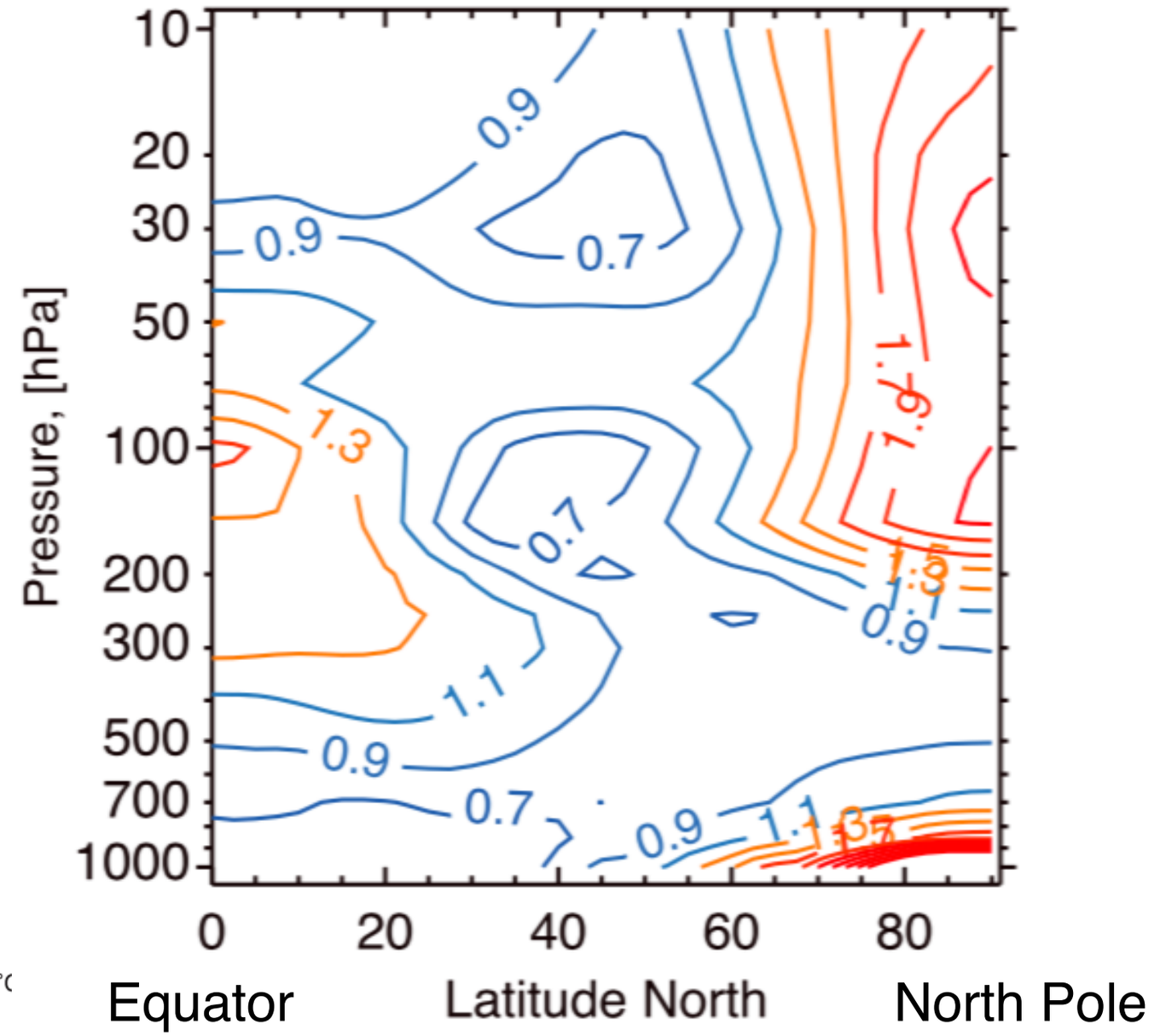
Large scale drivers of circulation

CMIP5
zonal mean T response



IPCC-AR5

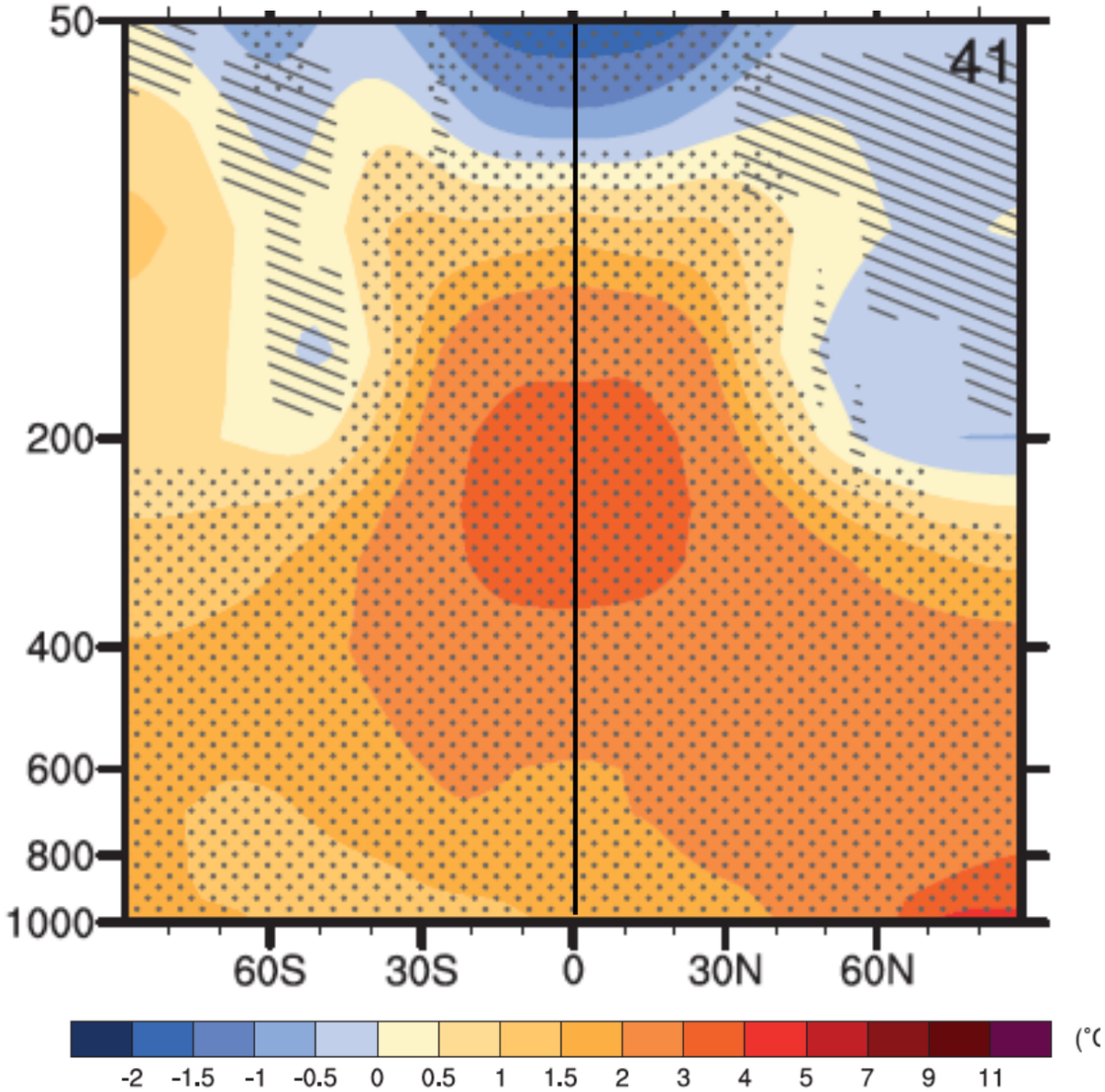
CMIP5 spread in
zonal mean DJF T response



Manzini et al 2014

Large scale drivers of circulation

CMIP5
zonal mean T response



IPCC-AR5

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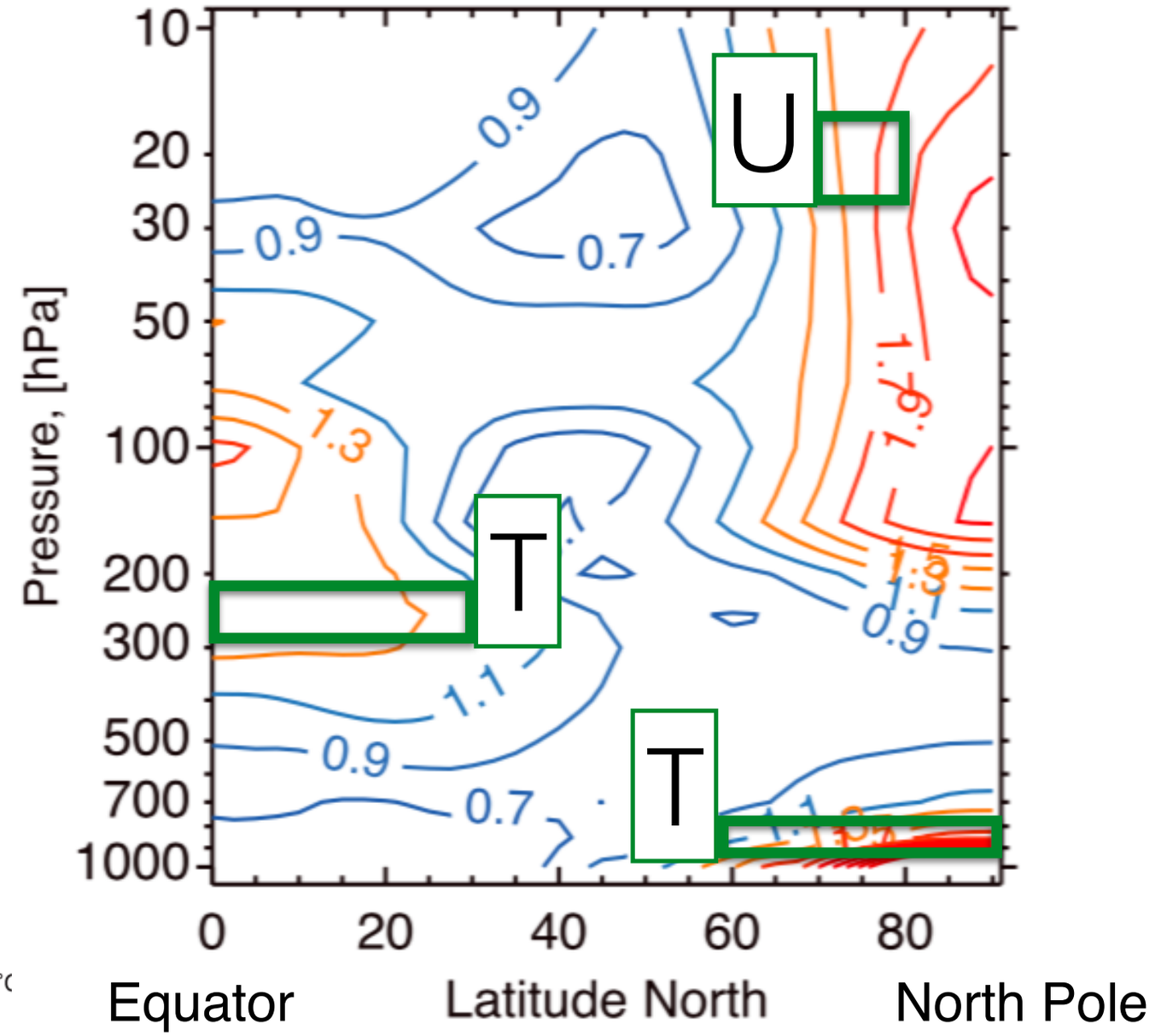


Manzini et al 2014

Statistical framework

Pattern scaling + Competing effects from different large scale drivers

$$\delta C_{mx} = \delta T_m \cdot P_{mx}$$

$$= \delta T_m \cdot L\left(\frac{\delta T_{polar}}{\delta T}, \frac{\delta T_{trop}}{\delta T}, \frac{\delta U_{strat}}{\delta T}\right)$$

Global warming as a multiplicative factor (quantitative uncertainty)

Pattern uncertainty depends on scaled drivers (qualitative uncertainty)

Statistical framework

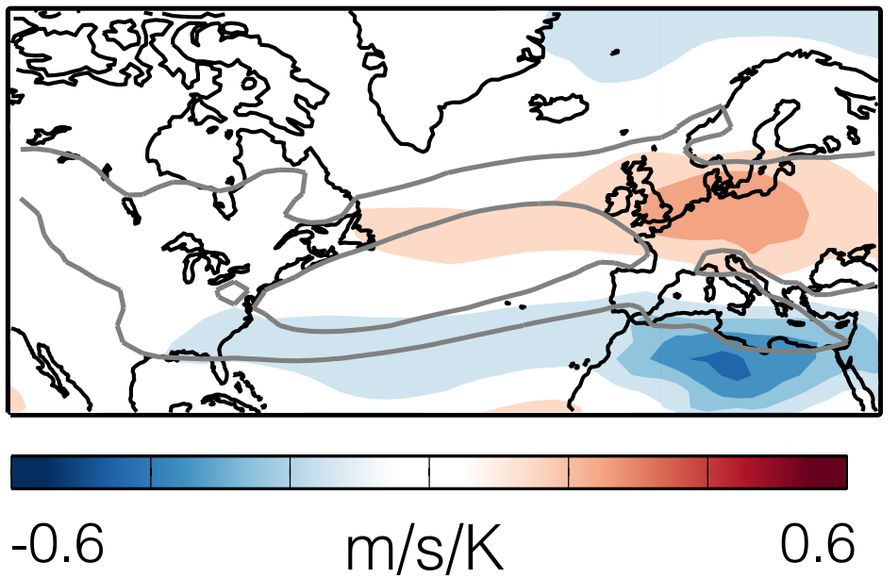
- Fit the regression framework to the output from 32 CMIP5 climate models (NDJFMA) under the RCP8.5 scenario

- Analysed variables:
  - Mean **zonal wind** at 850 hPa (large scale circulation)
  - 95 percentile daily **windspeed** 850 hPa (impacts)
  - Mean **precipitation** (impacts)
- Climate response: 2070-2099 minus 1960-1990

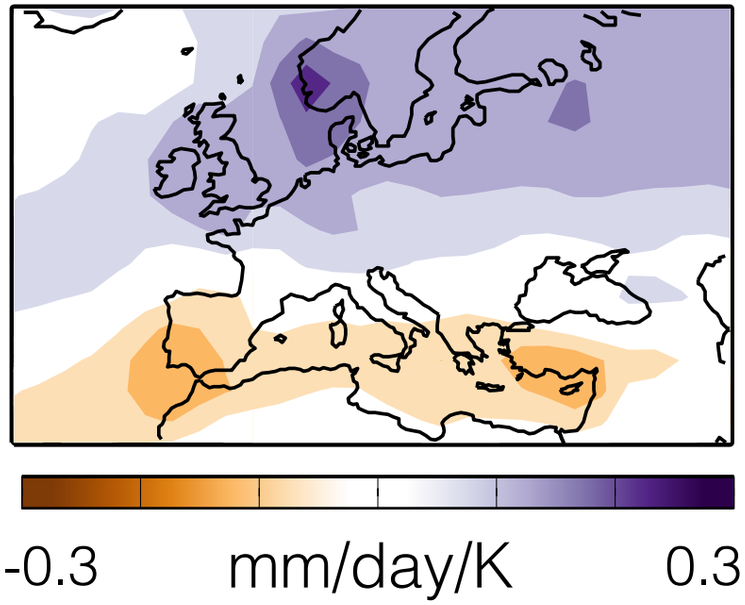
The mean response

Multi-model mean CMIP5 response scaled by global warming (RCP8.5)

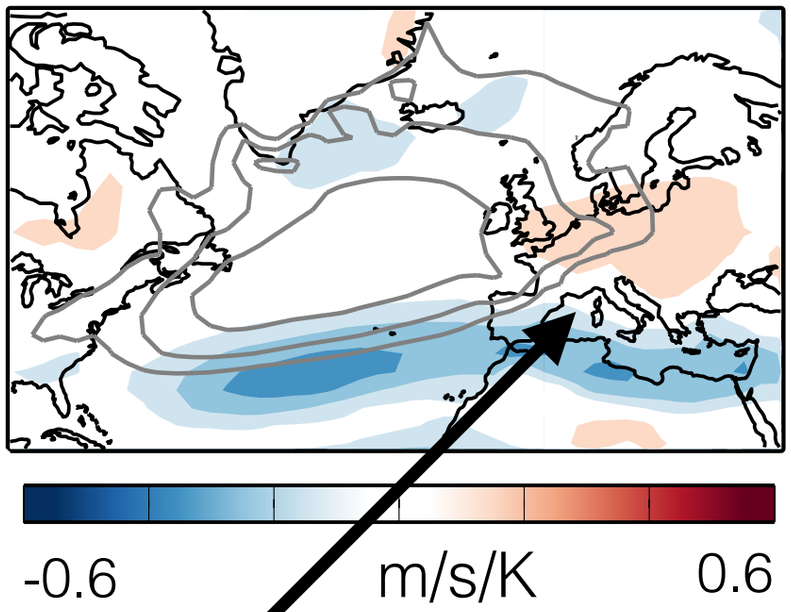
U 850 hPa



Mean Precipitation



Extreme windiness



Only small windiness increase in the mean (~0.5% / K) !

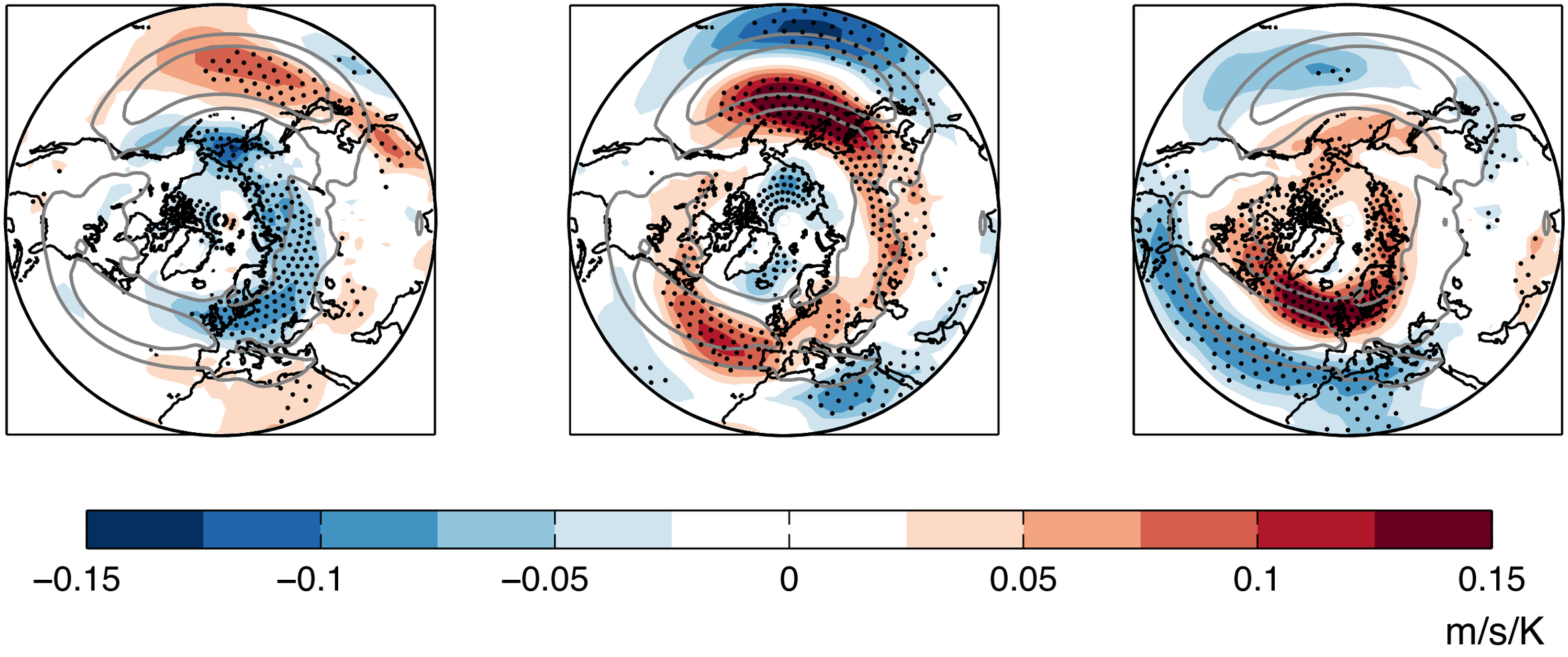
Sensitivity of U850 to remote drivers

- Regression of U850 response on the remote drivers uncertainty using the pattern scaling framework

Sensitivity to polar amplification

Sensitivity to tropical amplification

Sensitivity to vortex strength



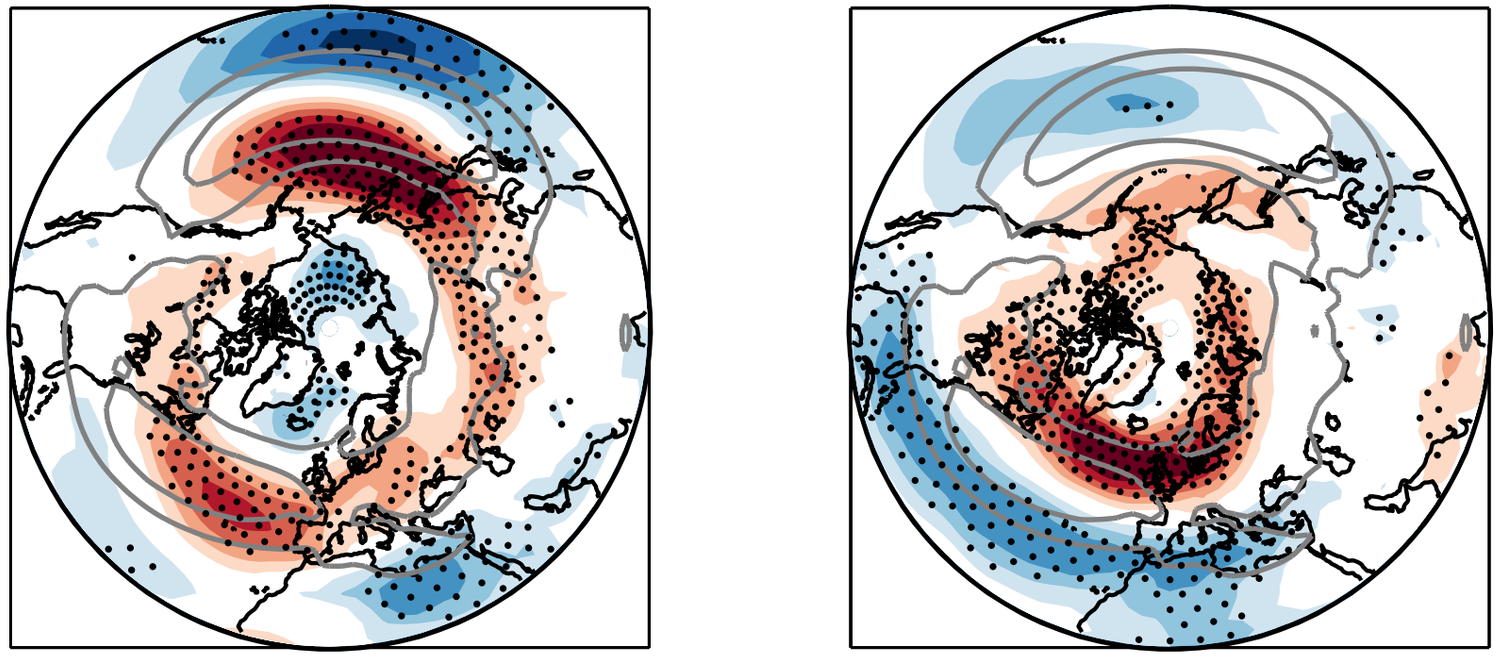
Sensitivity of U850 on remote drivers

- Regression of U850 response on the remote drivers uncertainty using the pattern scaling framework

Most relevant for European windiness and precipitation responses

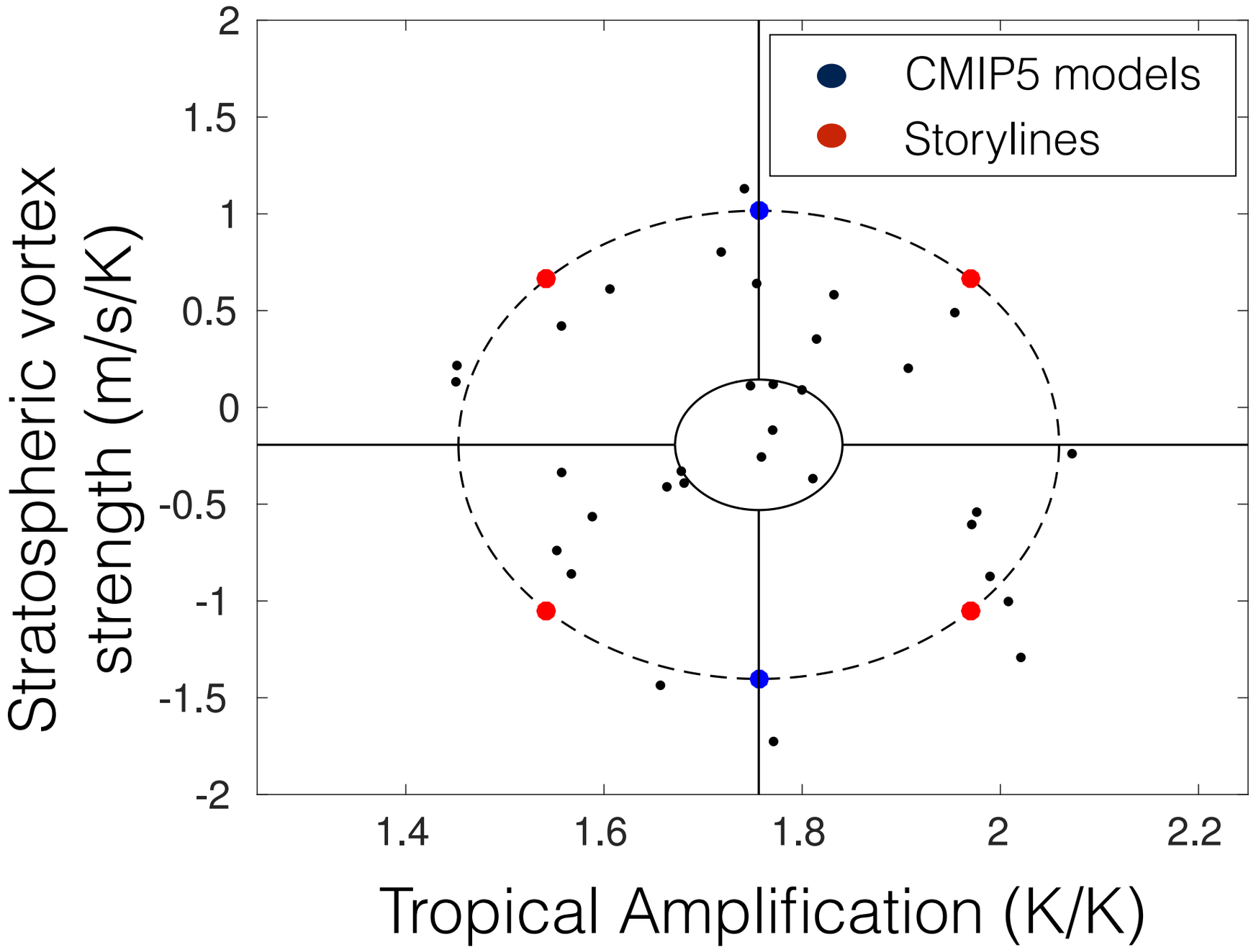
Sensitivity to tropical amplification

Sensitivity to vortex strength



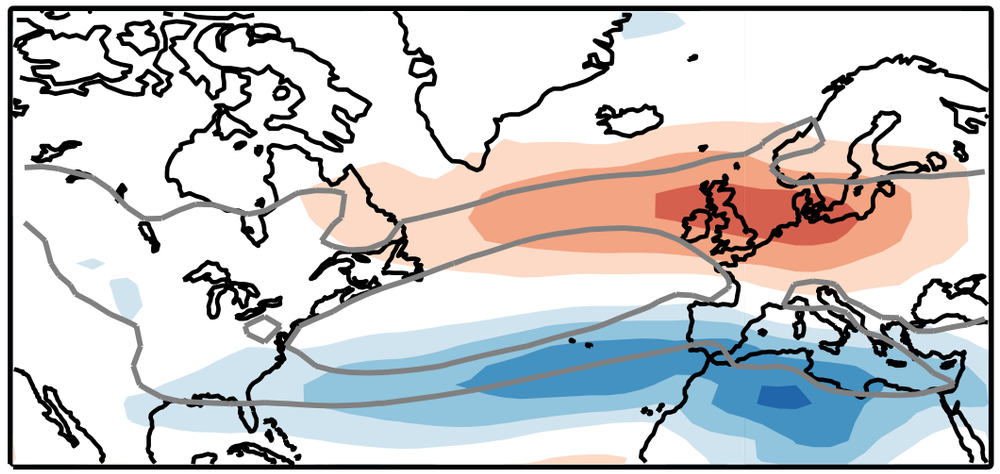
Stratospheric vortex vs tropical amplification

- Storylines: Expected response conditional on the response of the remote drivers



Storylines of circulation change

Low tropical amplification
strong vortex



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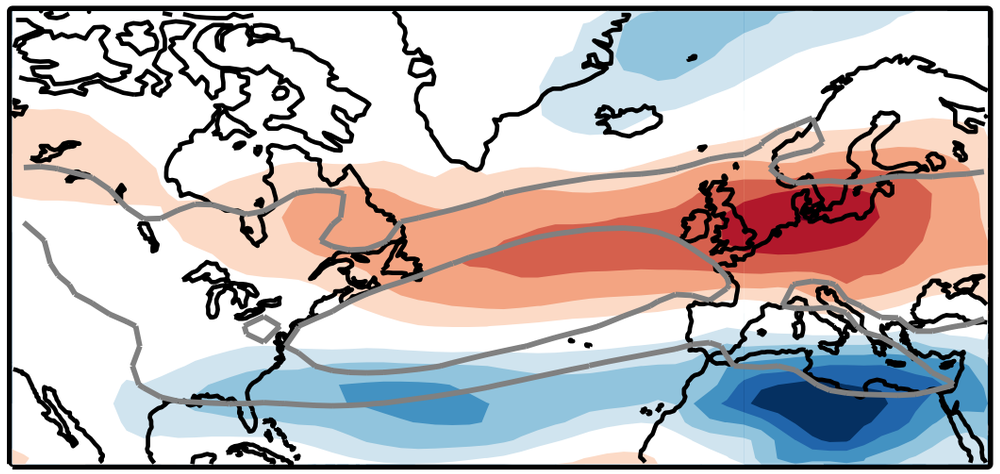
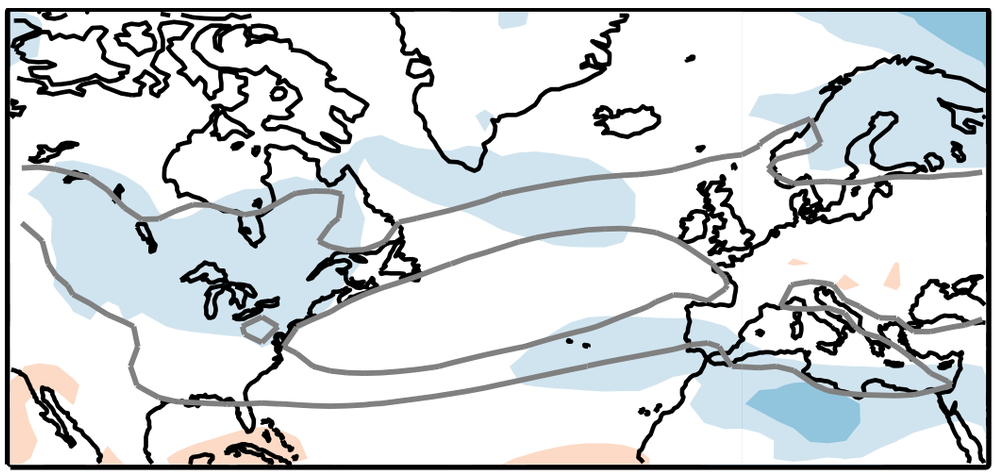
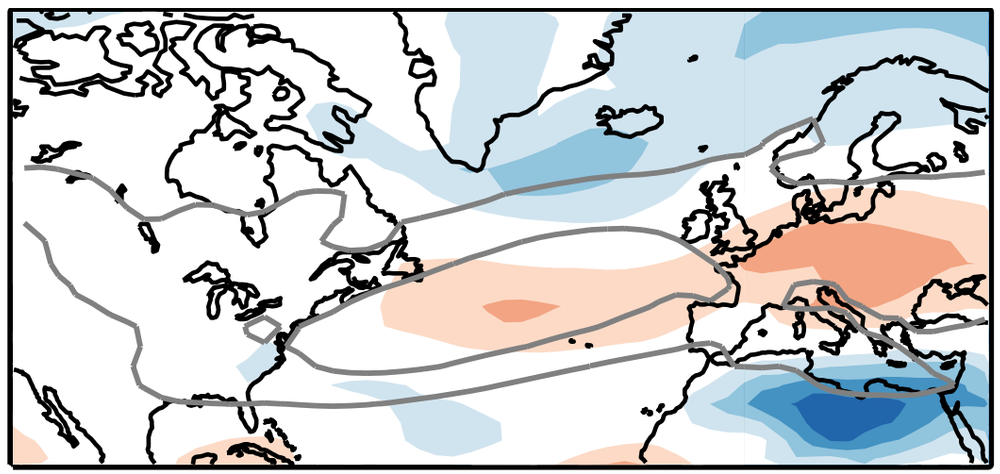
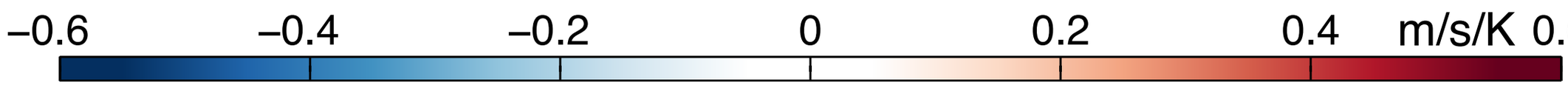


Low tropical amplification
weak vortex



High tropical amplification
weak vortex

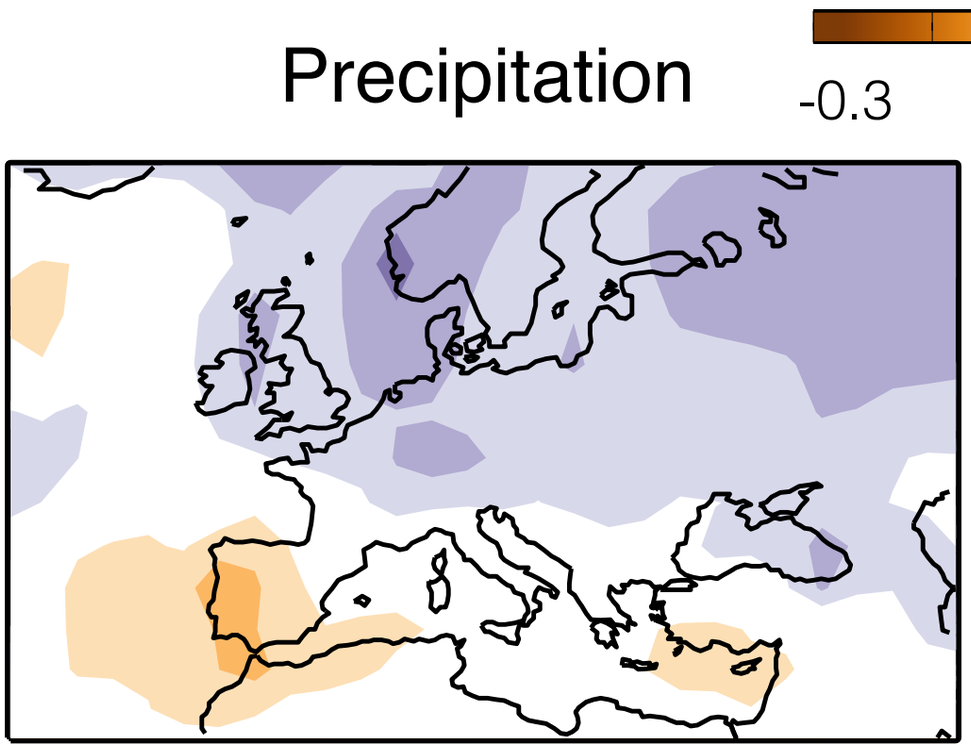




Low tropical amplification
Weak vortex

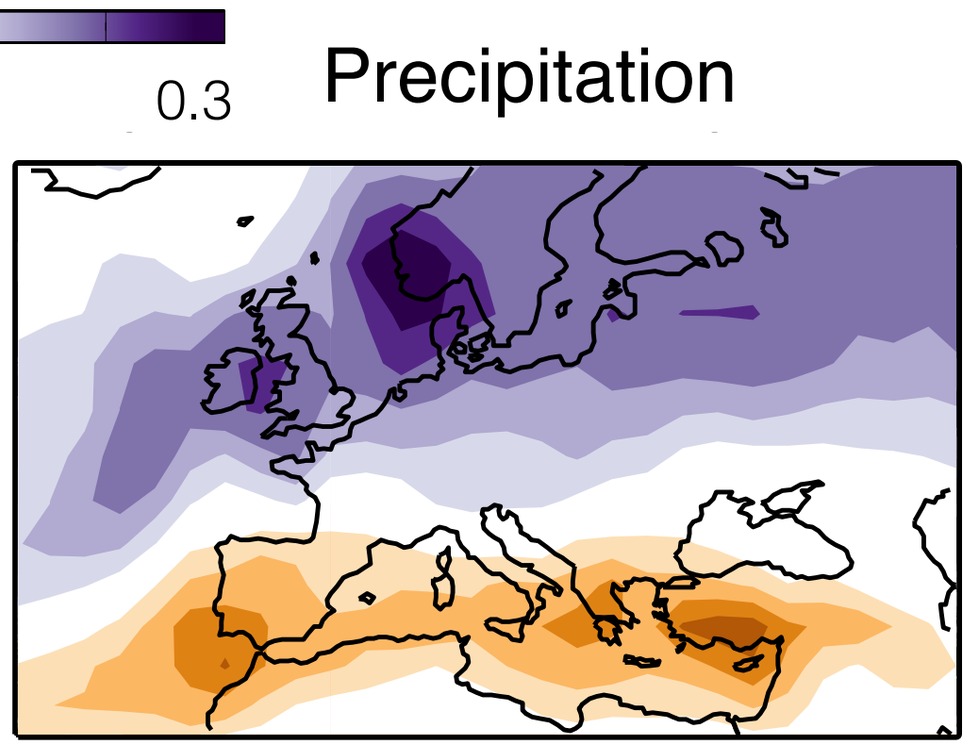
High tropical amplification
Strong vortex

Precipitation



-0.3 mm/day/K 0.3

Precipitation



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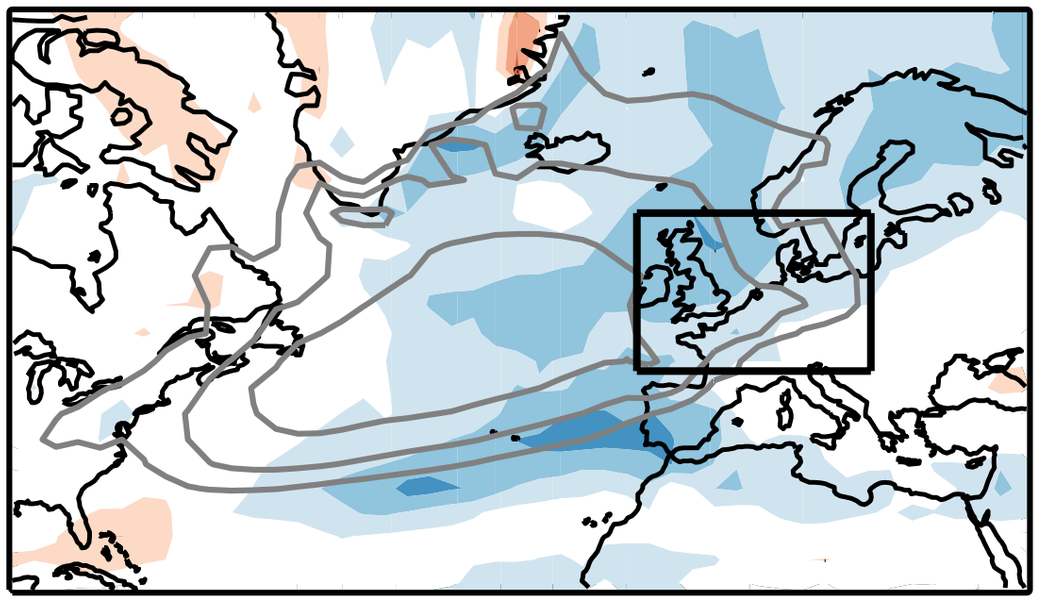

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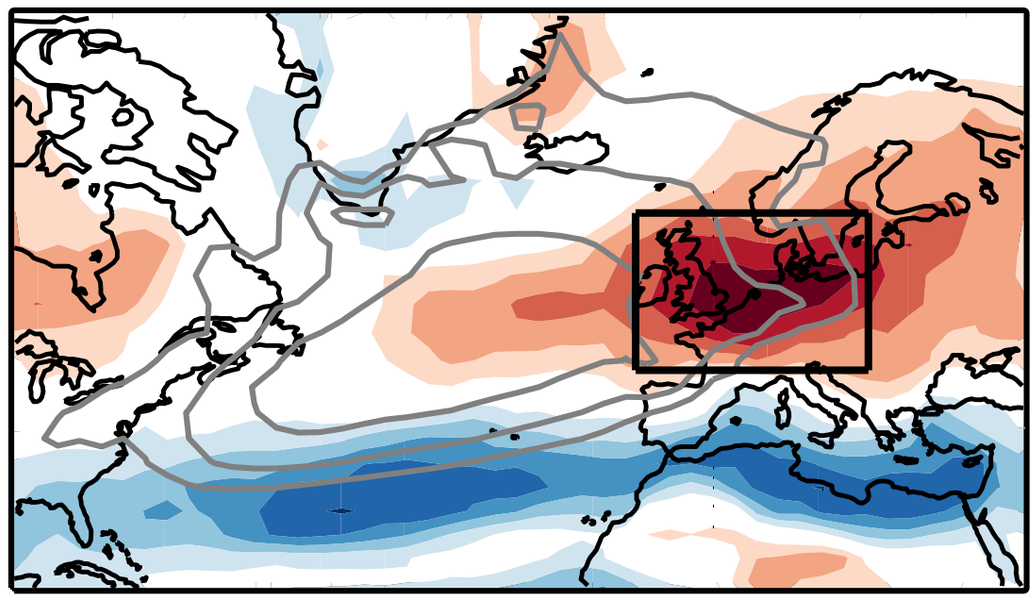
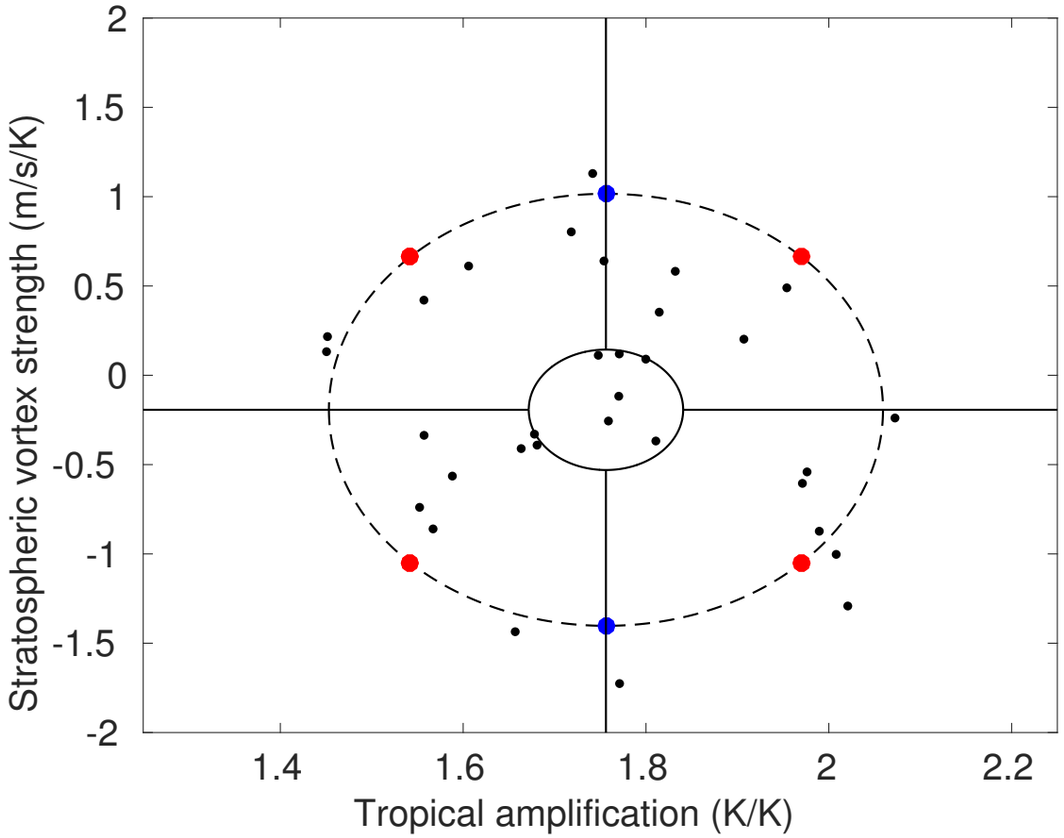


-0.6 m/s/K 0.6

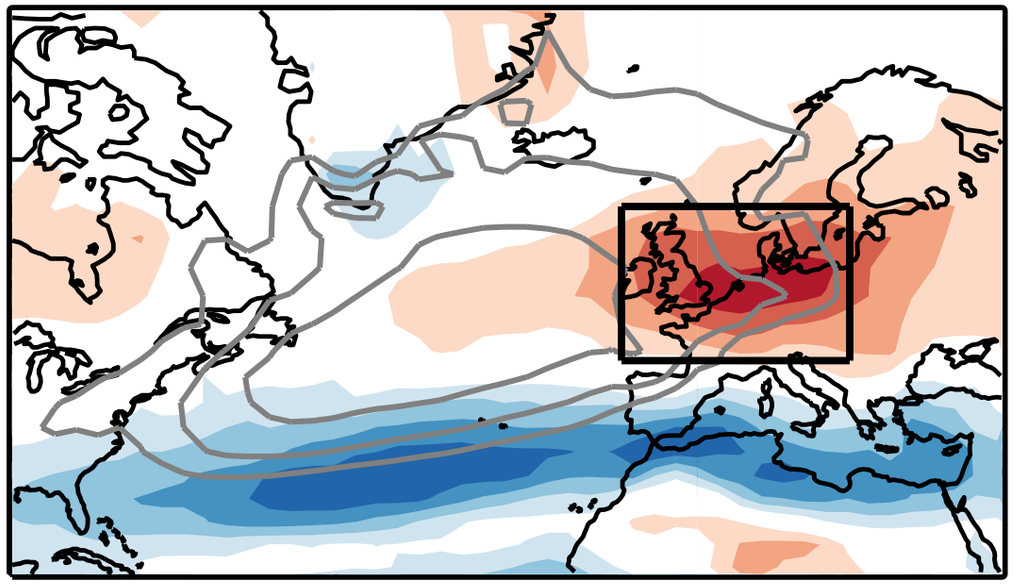
m/s/K

Impact on windiness

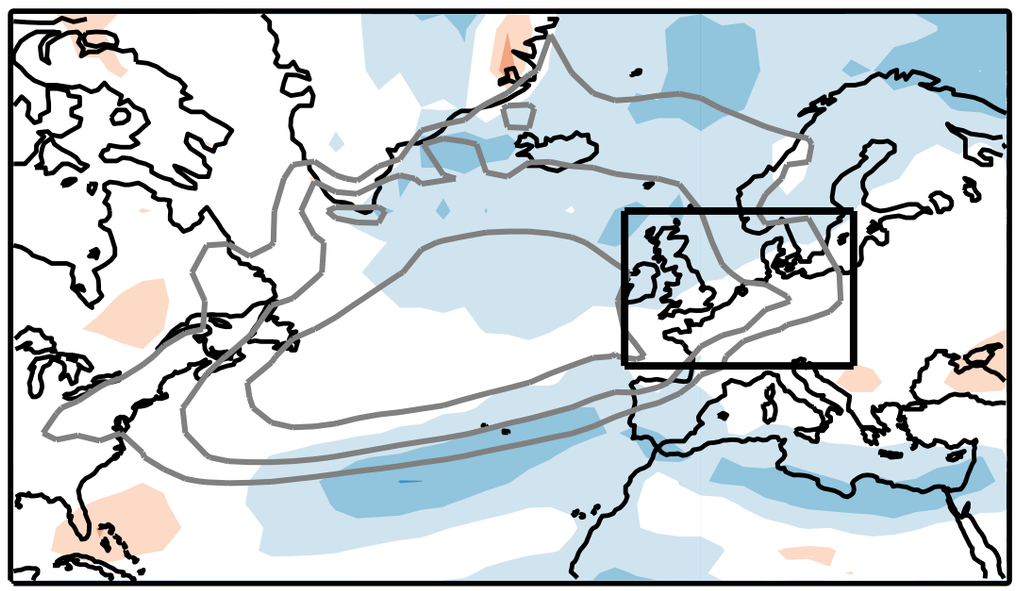
- European windiness particularly linked to stratospheric uncertainty
- Two storylines capture most of the spread



Strong vortex



Weak vortex

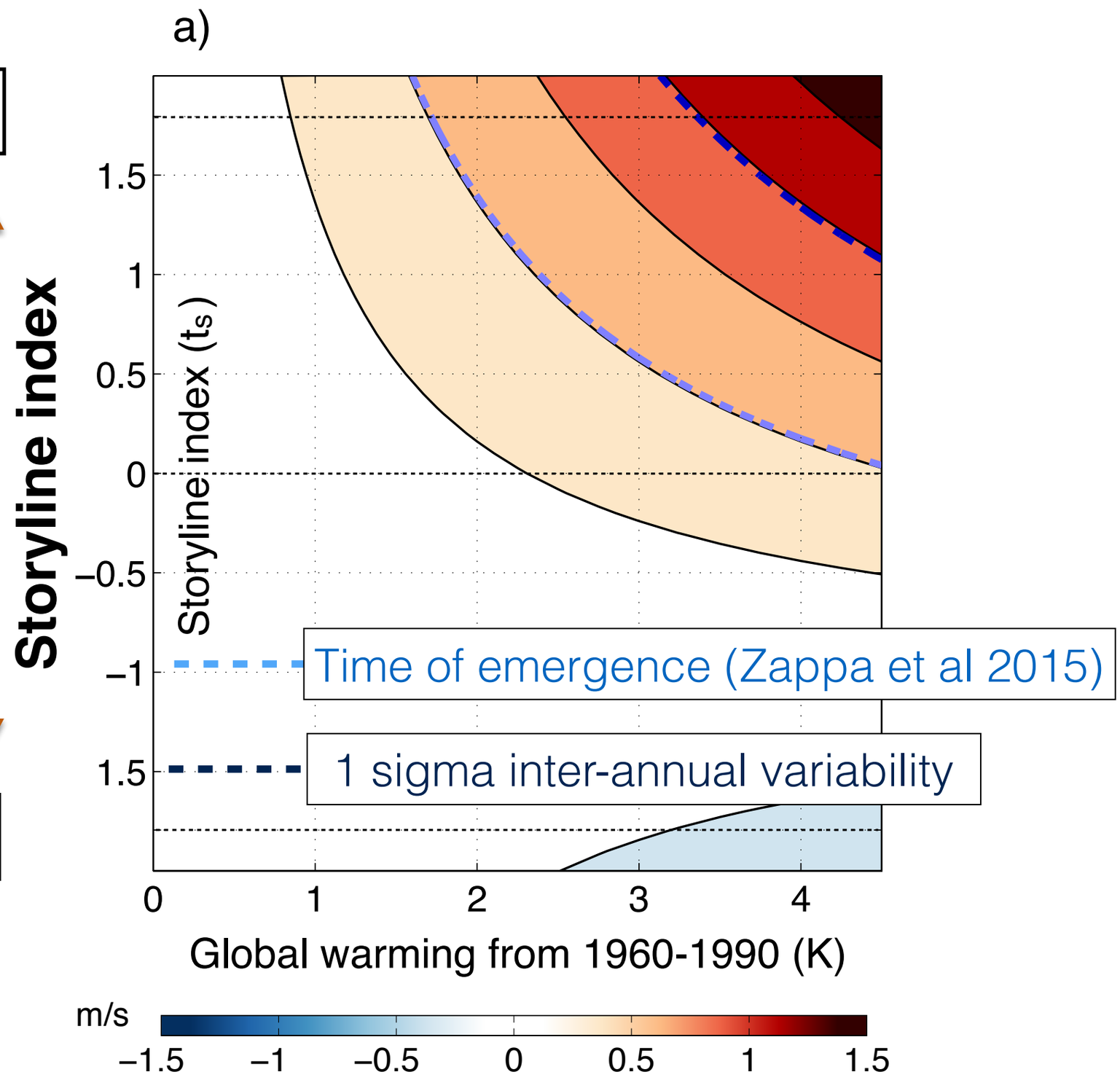


Global warming vs storyline uncertainty

Strong Vortex

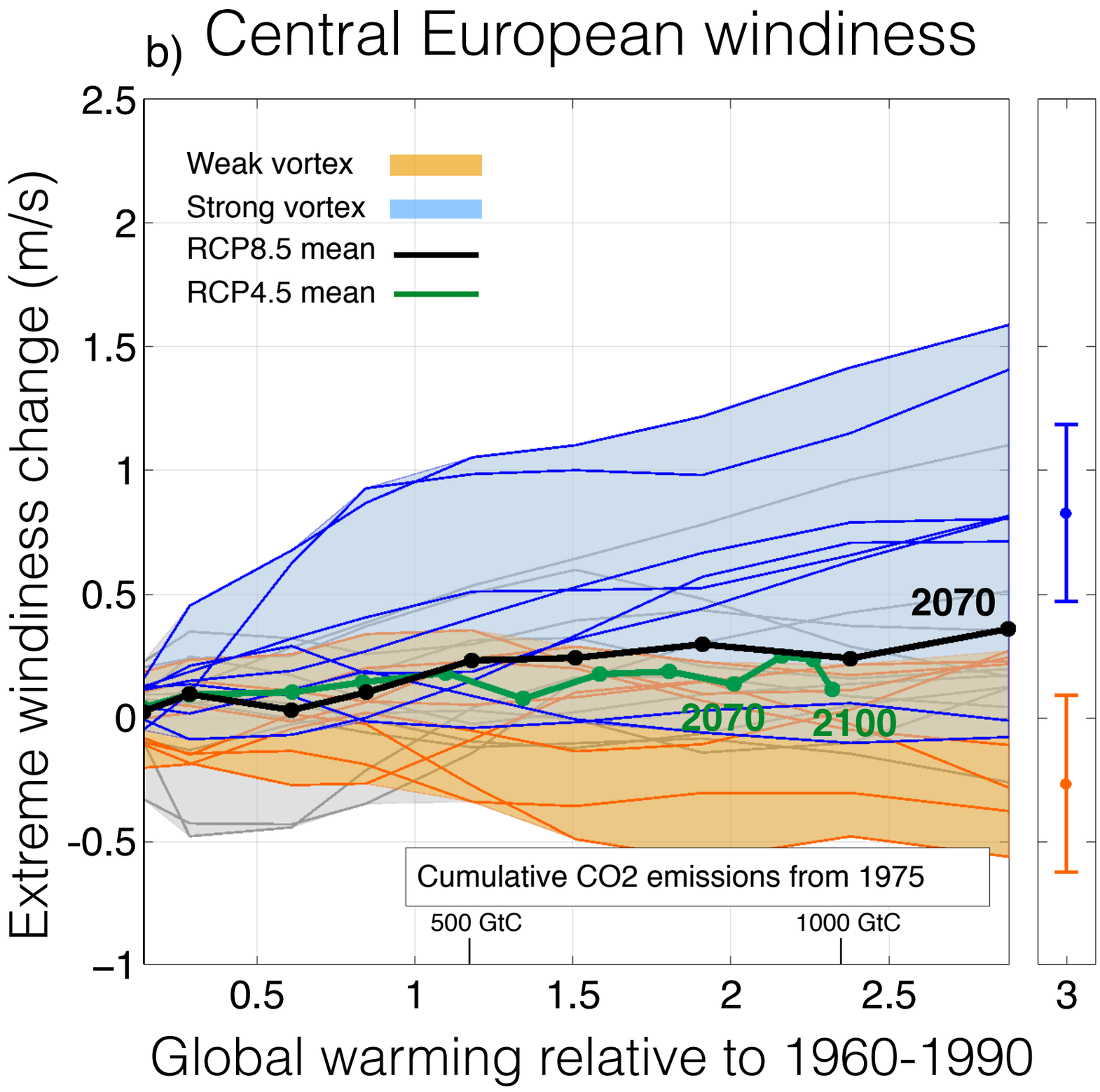
Multi-model mean

Weak Vortex



Global warming vs storyline uncertainty

- A consistent picture is revealed by looking at the individual model responses



Conclusions

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Conclusions

- Regression framework to separate uncertainty due to global warming and atmospheric circulation on regional impacts

- High global warming (~4 degrees) in the strong vortex storyline is associated with large increase in Central European windiness compared to variability

- High Tropical amplification + Strong Vortex is a high impact storyline of European climate change

- Regional climate projections need to account for these different large scale storylines of circulation change

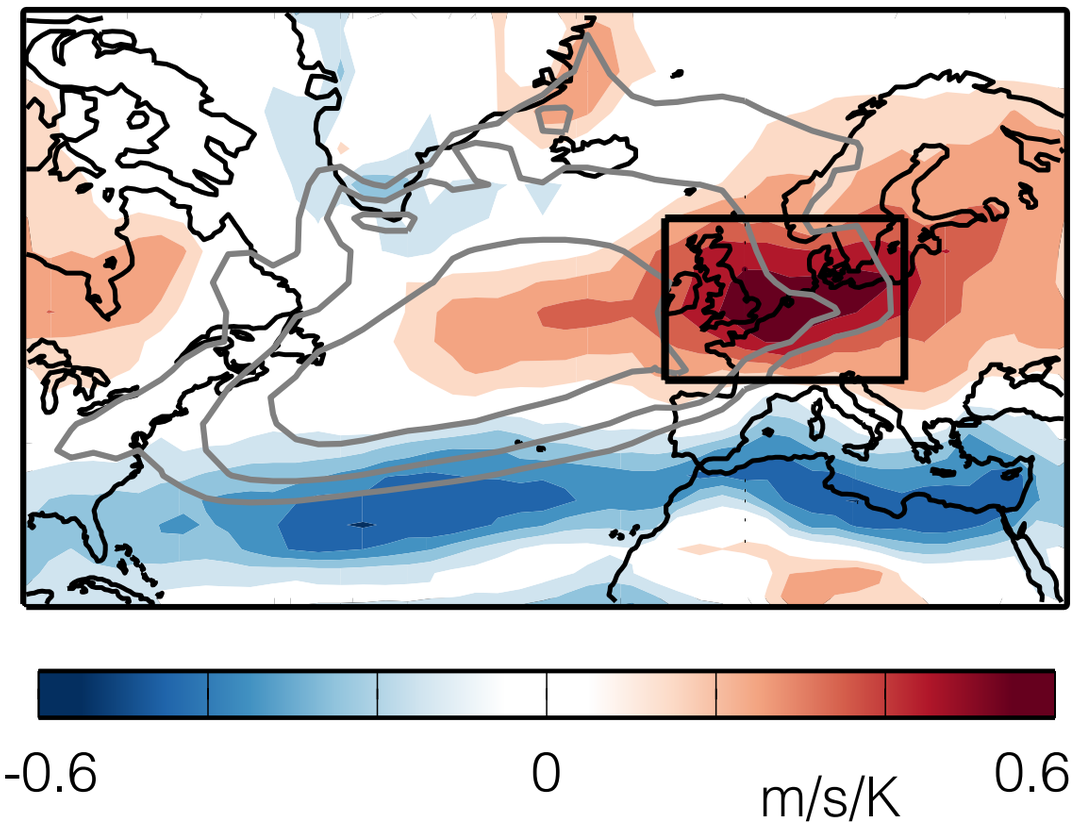
Thanks for your attention!

G Zappa and TG Shepherd: Journal of Climate, 2017 (in press)

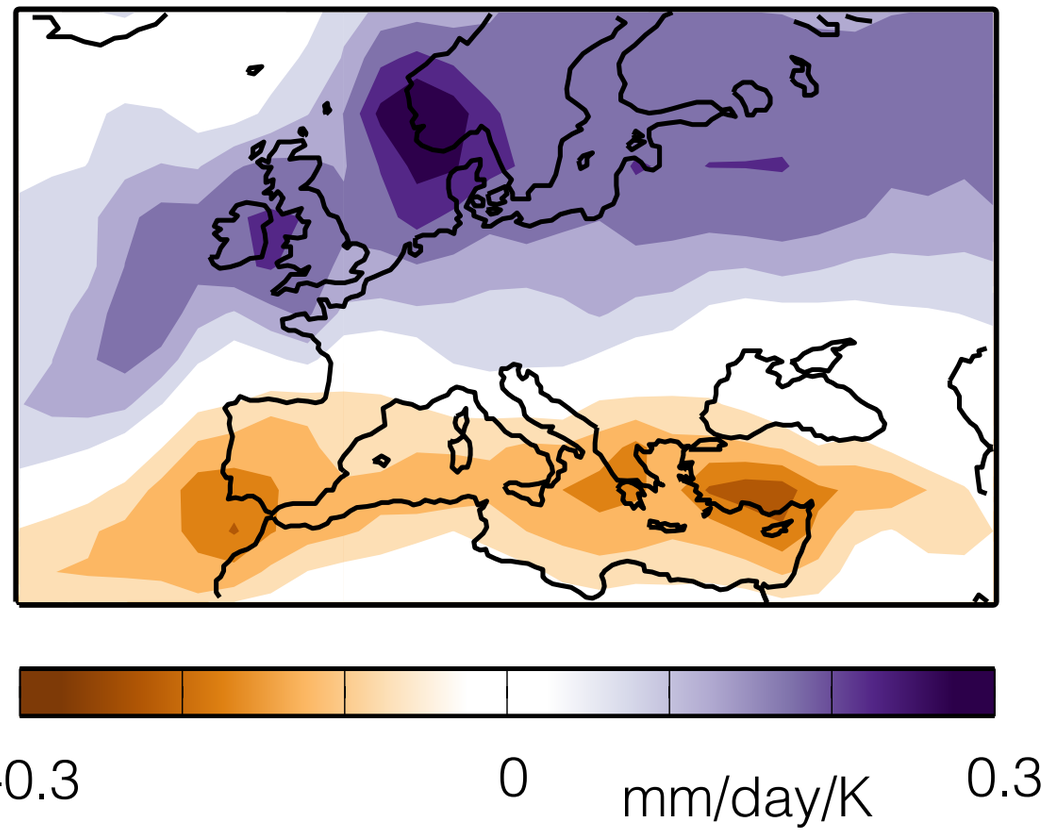
Compound risk

- Storylines enable to identify compound risk across regions
- High tropical amplification - Strong vortex high impact storylines for European climate change

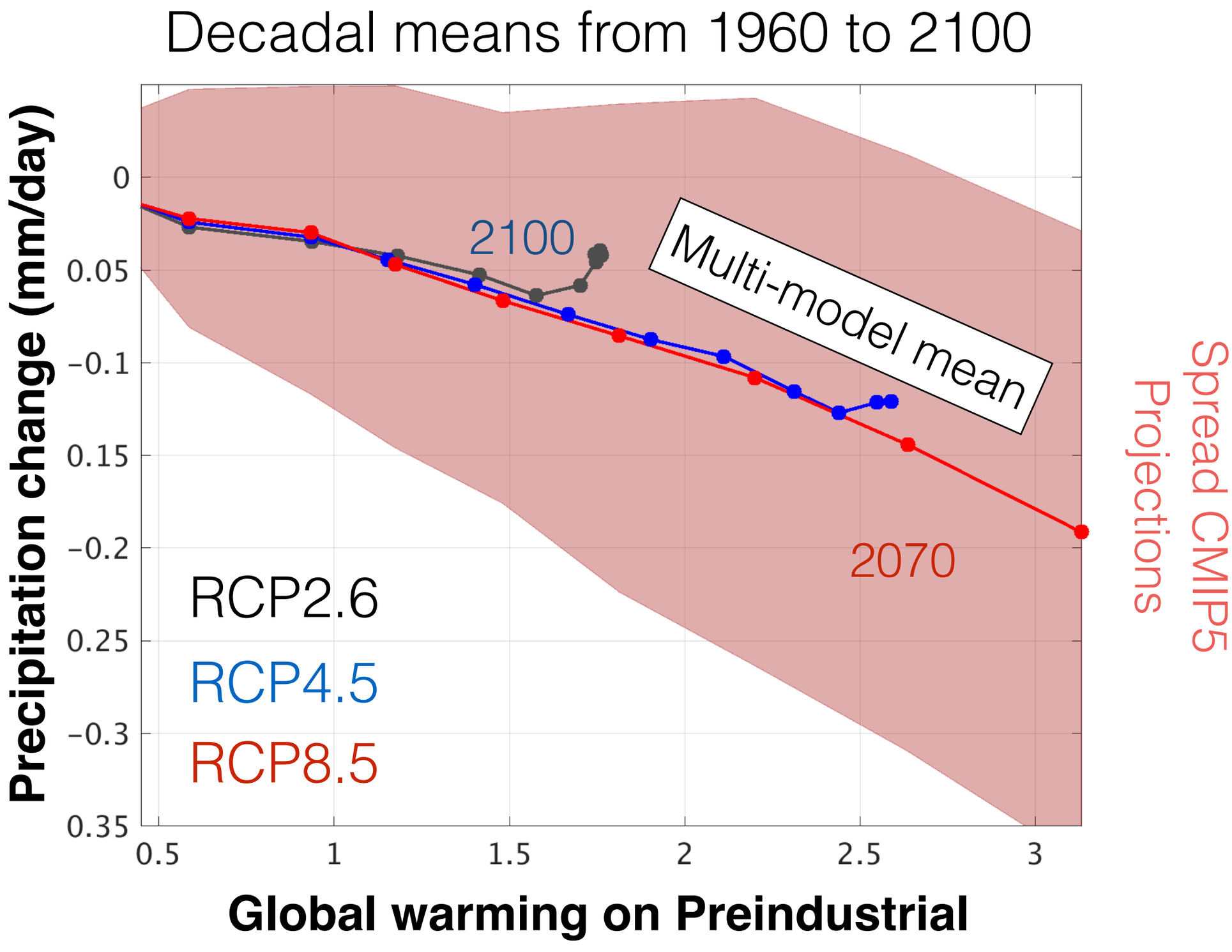
Windiness response



Precipitation response



The pattern scaling assumption



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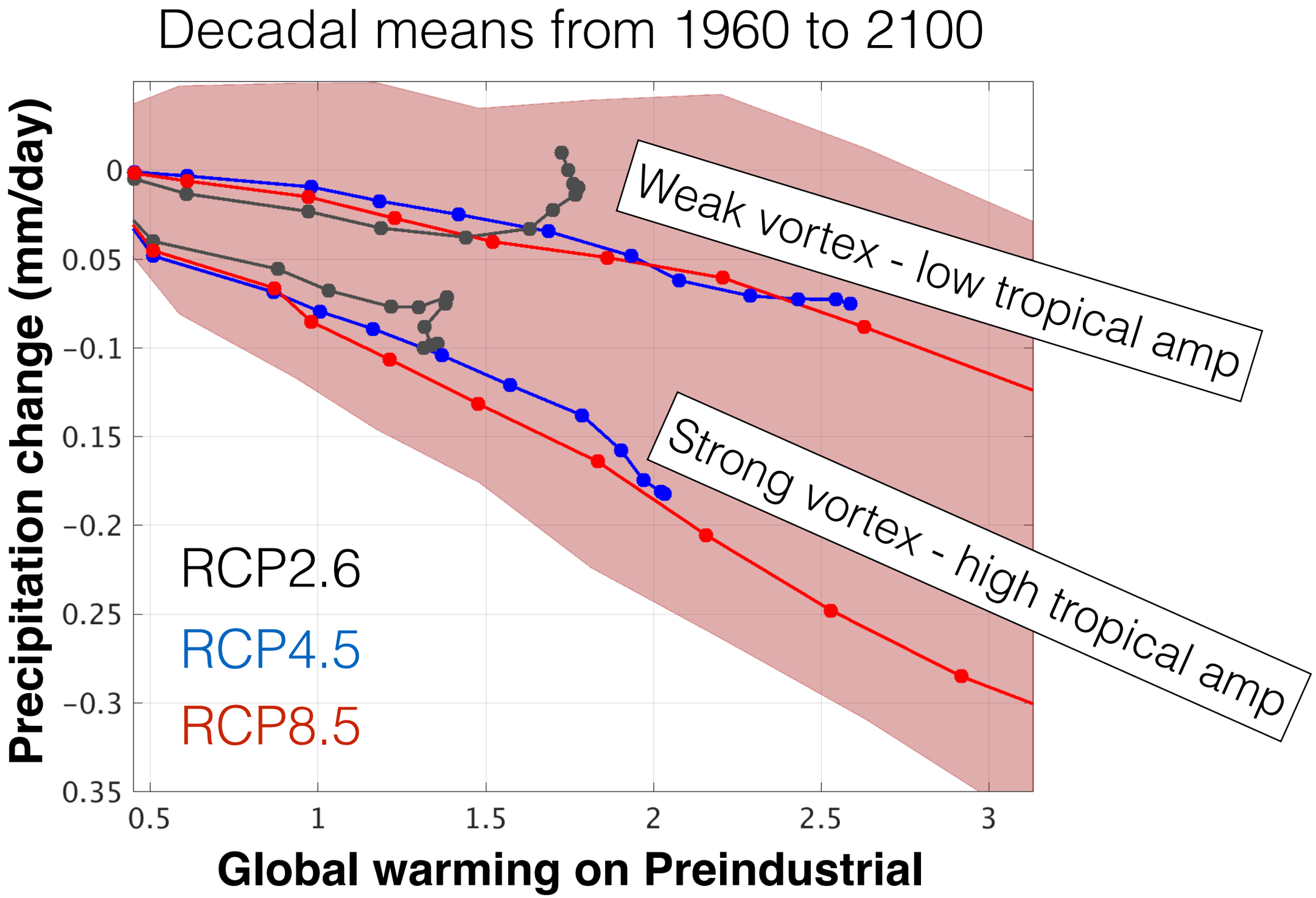
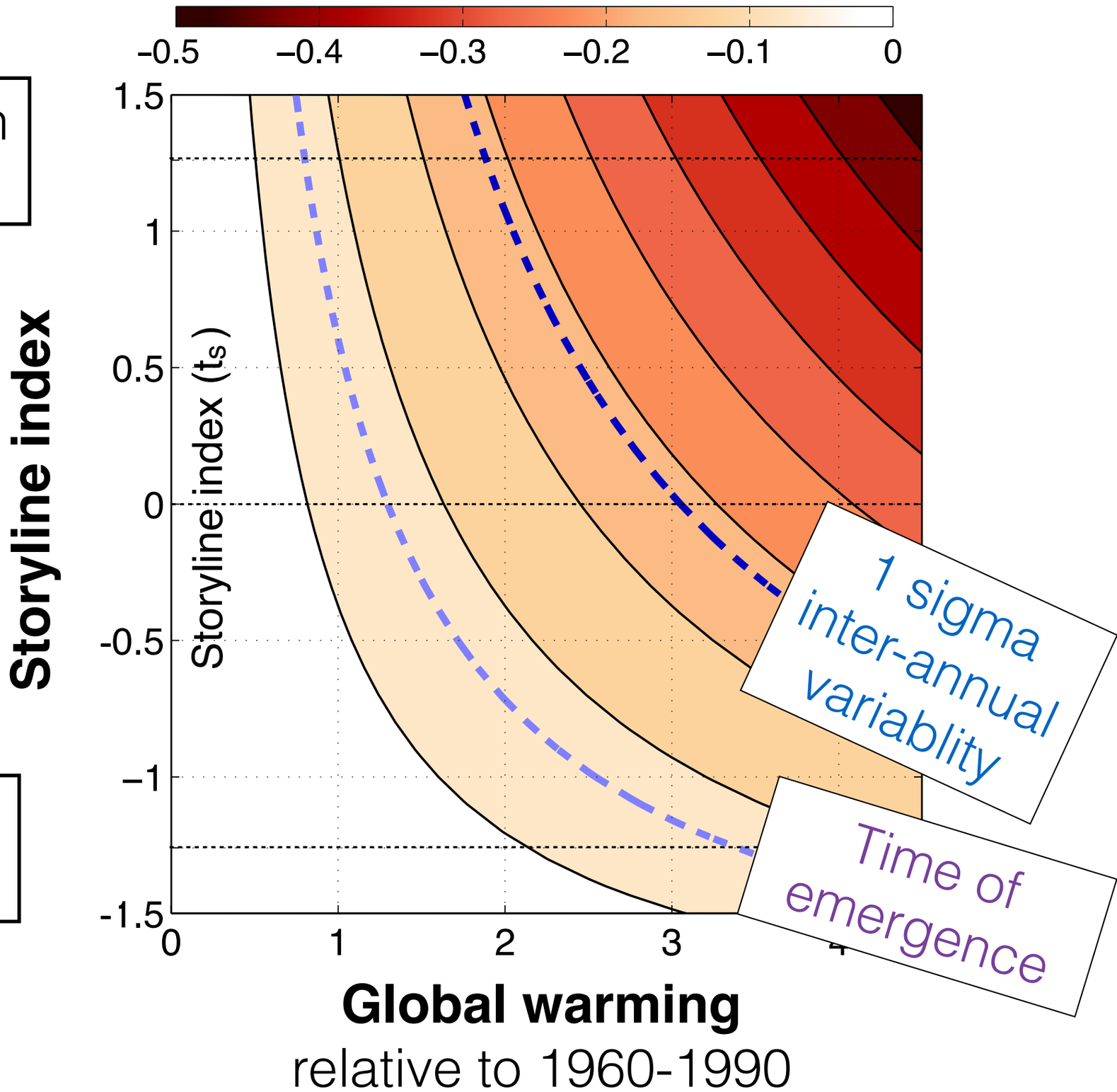


Global warming vs storyline uncertainty

High Tropical Amplification
Strong Vortex

Multi-model mean

Low Tropical Amplification
Weak Vortex



a) Control state

BCCR-BCM2.0
CNRM-CM3
INGV-SXG
*CNRM-CM5
*EC-EARTH
GFDL-CM2.0
GFDL-CM2.1
*GFDL-ESM2M
*GFDL-ESM2G
*GFDL-CM3
*GFDL-CM2.5
ECHAM5/MPI-OM
*MPI-ESM-LR
*MPI-ESM-P
*MPI-ESM-MR
*CMCC-CM
*MIROC5
CSIRO-Mk3.0
CSIRO-Mk3.5
*CanESM2
UKMO-HadCM3
UKMO-HadGEM1
*HadGEM2-CC
*HadGEM2-ES
*ACCESS1.0
*ACCESS1.3
CCSM3
*CCSM4
*CESM1(FASTCHEM)
*CESM1-BGC
*CESM1(CAM5)
*CESM1(WACCM)
*NorESM1-M
*NorESM1-ME
*BCC-CSM1.1
*FGOALS-g2
*FIO-ESM
*FGOALS-s2
ECHO-G
MRI-CGCM2.3.2
ERA40/GPCP
NCEP/CMAP
CGCM3.1(T47)
CGCM3.1(T63)
IPSL-CM4
*IPSL-CM5A-LR
*IPSL-CM5A-MR
*IPSL-CM5B-LR
*MRI-CGCM3
*CSIRO-Mk3.6.0
*GISS-E2-H
*GISS-E2-R
INM-CM3.0
PCM
MIROC3.2(hires)
*MIROC4h
MIROC3.2(medres)
*MIROC-ESM
*MIROC-ESM-CHEM
*INM-CM4
GISS-EH
FGOALS-g1.0
GISS-AOM
GISS-ER

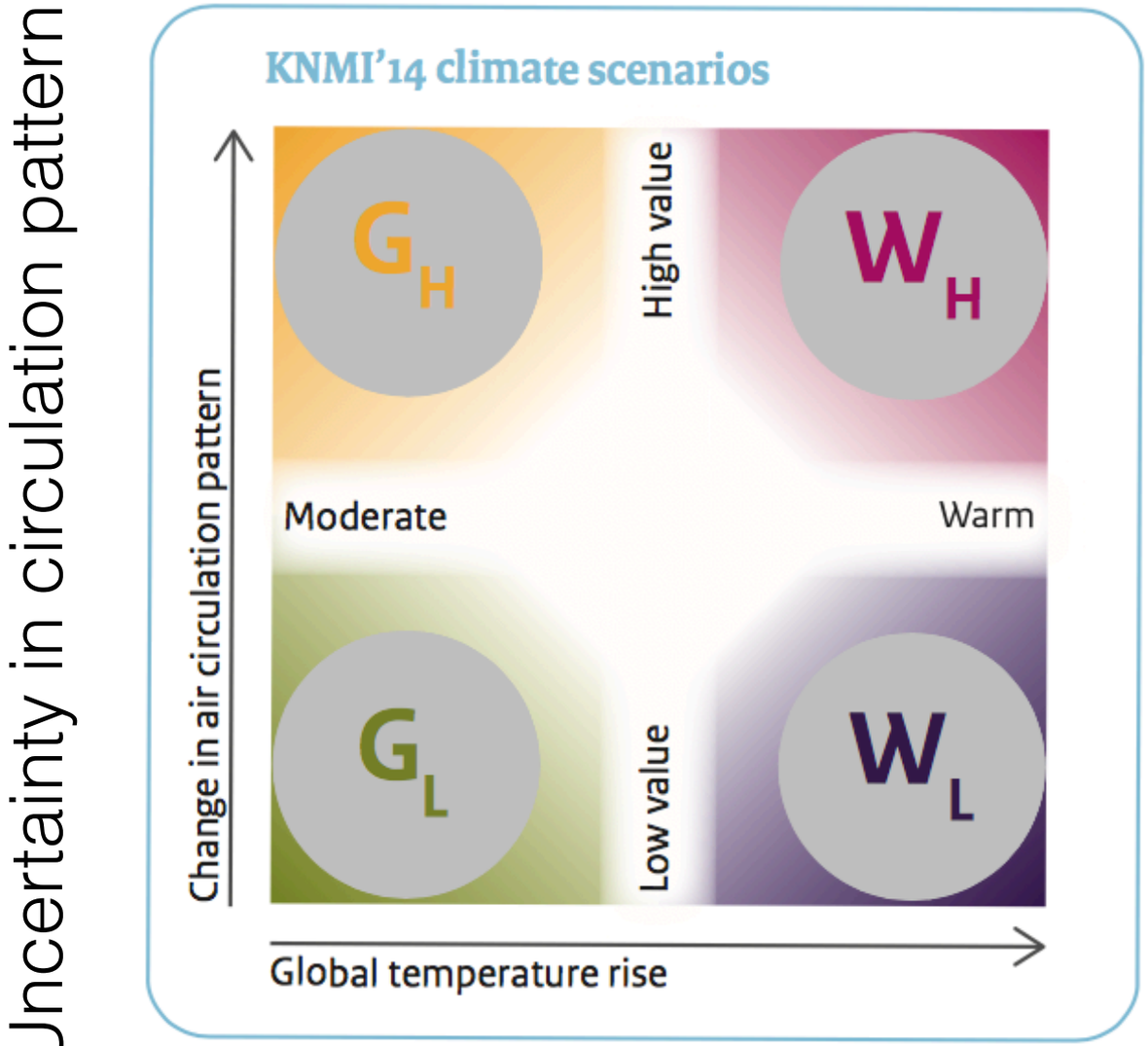
b) Projected change RCP8.5

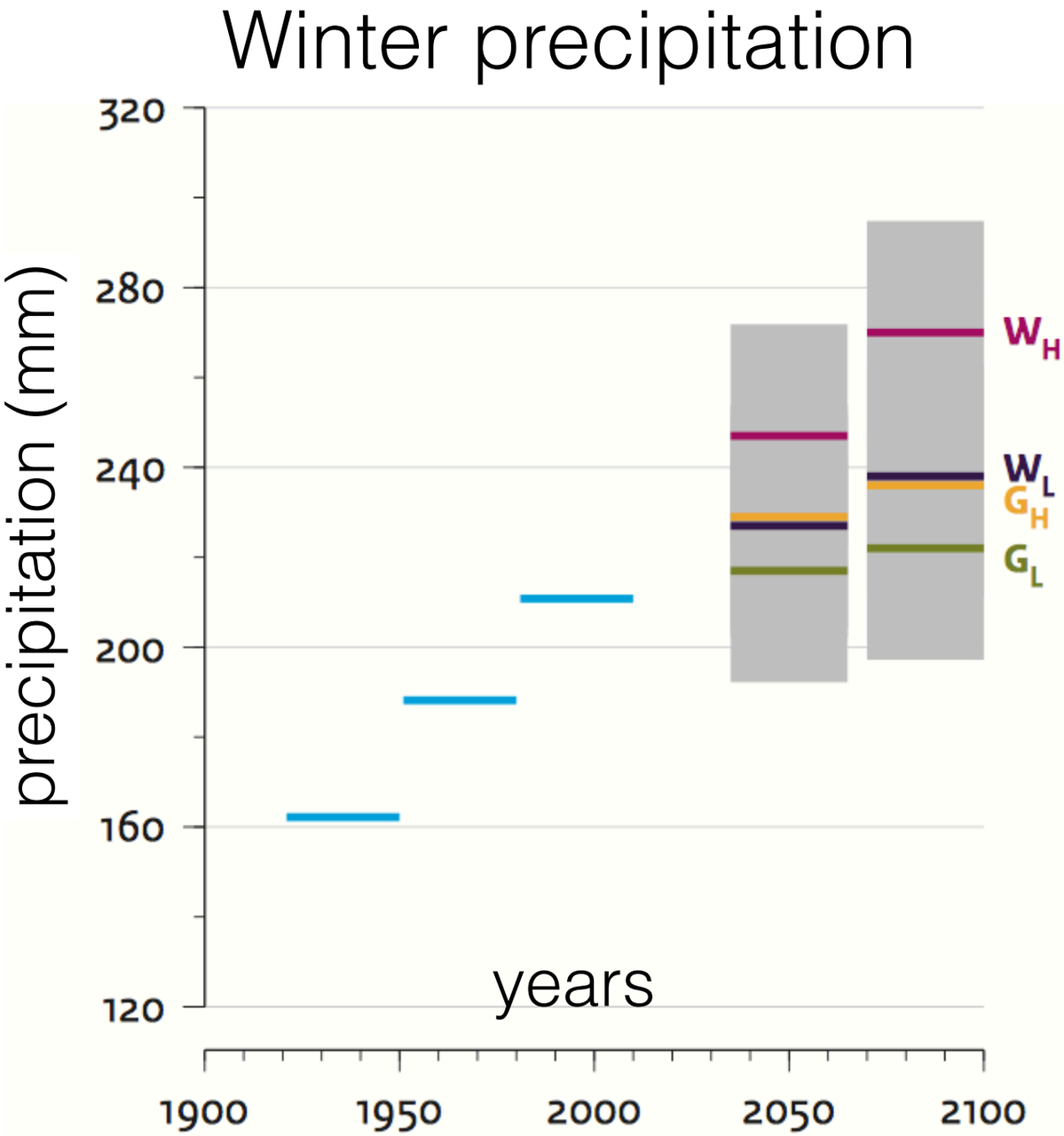
*ACCESS1-0
*ACCESS1-3
*HadGEM2-CC
*BCC-CSM1.1
*CNRM-CM5
*EC-EARTH
*MIROC5
*NorESM1-M
*CMCC-CM
*MPI-ESM-LR
*MPI-ESM-MR
*GFDL-CM3
*GFDL-ESM2G
*MRI-CGCM3
*GISS-E2-R
*INM-CM4
*HadGEM2-ES
*CanESM2
*CCSM4
*CESM1-BGC
*CESM1-WACCM
*CESM1-CAM5
*FIO-ESM
*FGOALS-s2
*IPSL-CM5A-LR
*IPSL-CM5A-MR
*CSIRO-Mk3-6-0
*FGOALS-g2
*MIROC-ESM
*MIROC-ESM-CHEM

CMIP models similarity based on temperature and precipitation climatologies

Colors: models that share code

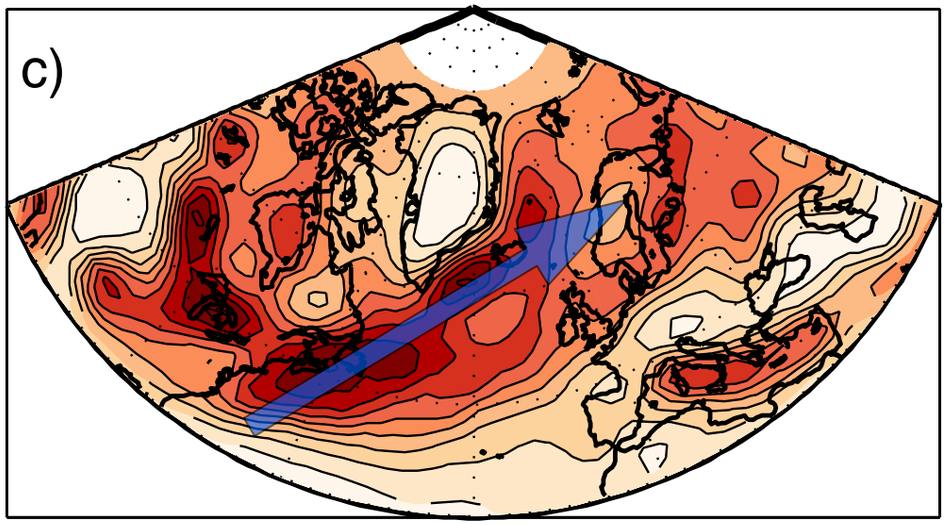
KNMI14: impact scenarios for the Netherlands



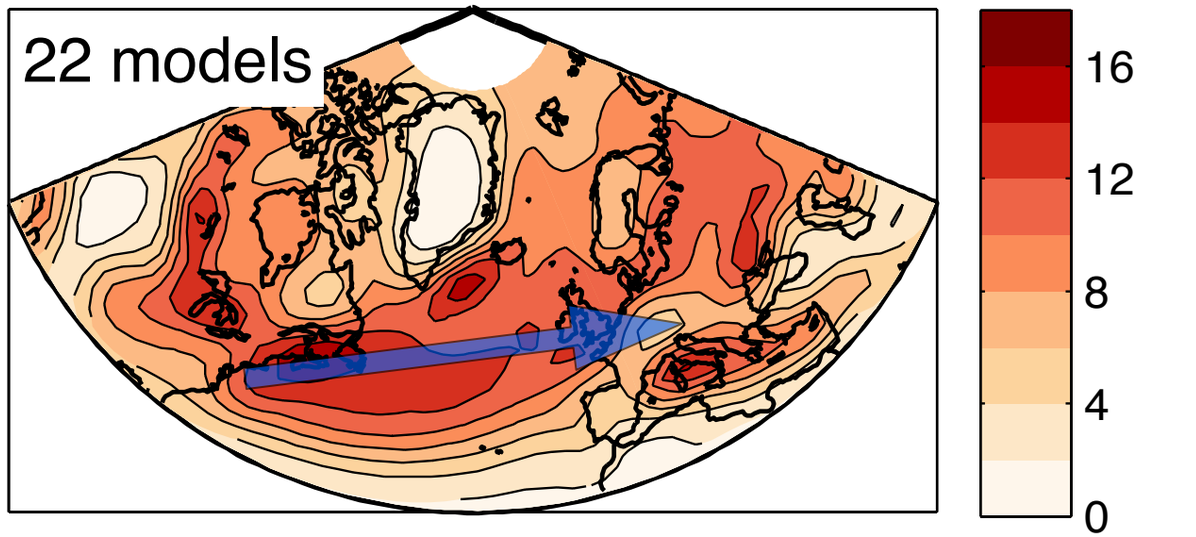


Model have systematic biases

ERA-INTERIM (1980-2009)

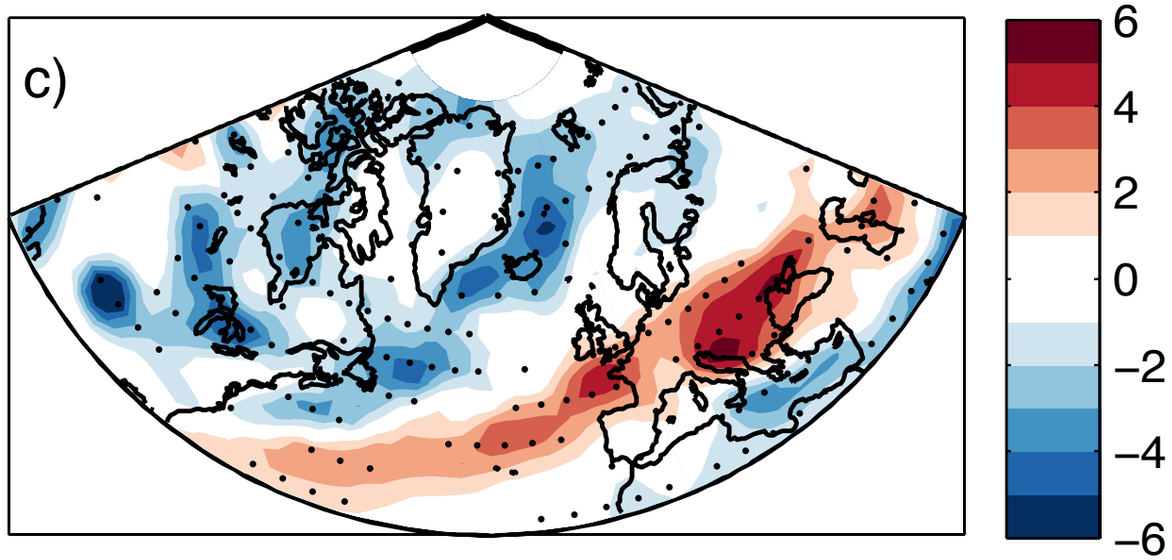


CMIP5 Multi model mean (1976-2005)



- Too few storms in Greenland sea and Mediterranean
- Too many storms in central Europe

Mean bias (CMIP5-ERAI)

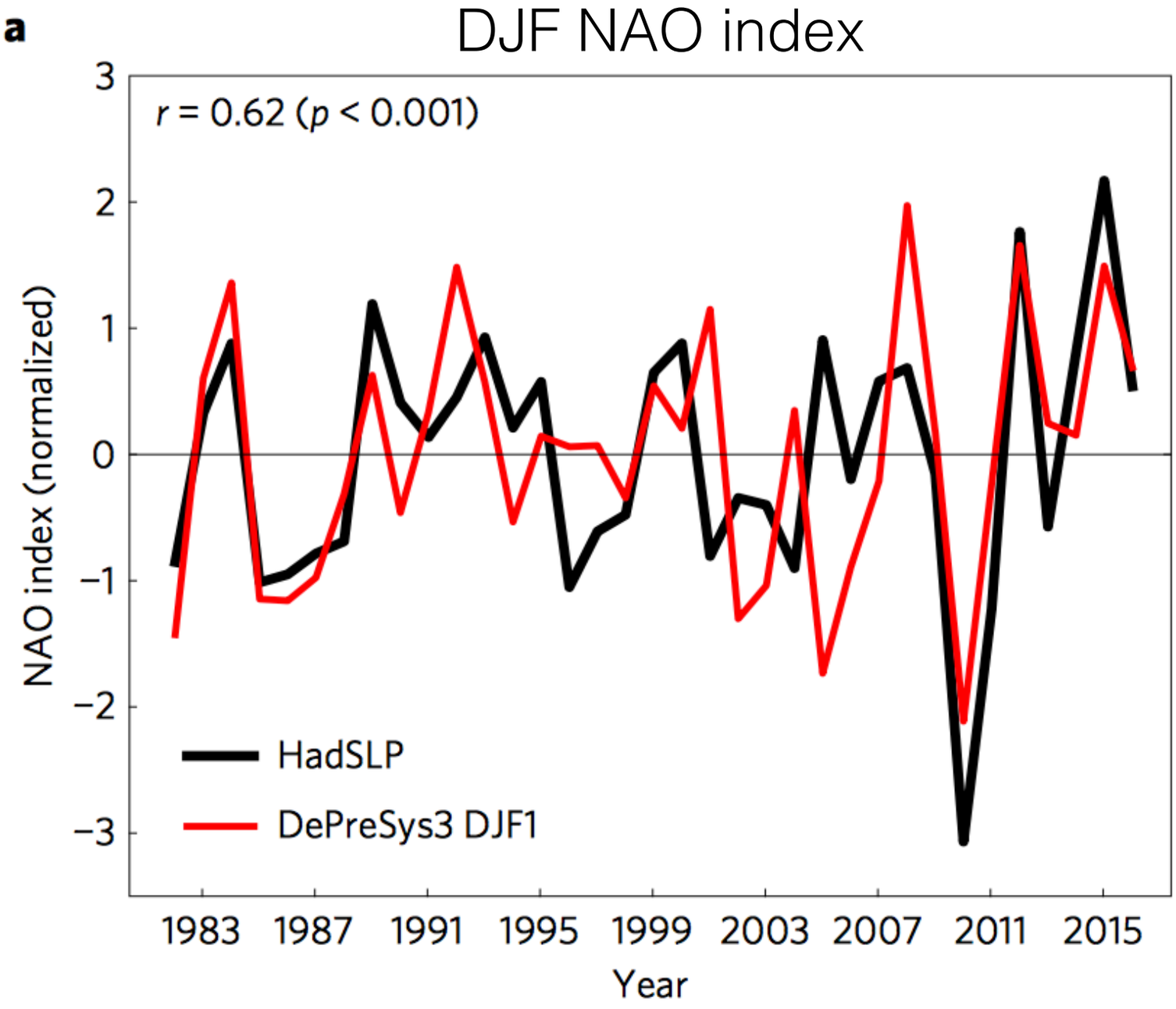


Global drivers of regional circulation

Atmospheric circulation can respond to remote drivers

Sources of seasonal predictability

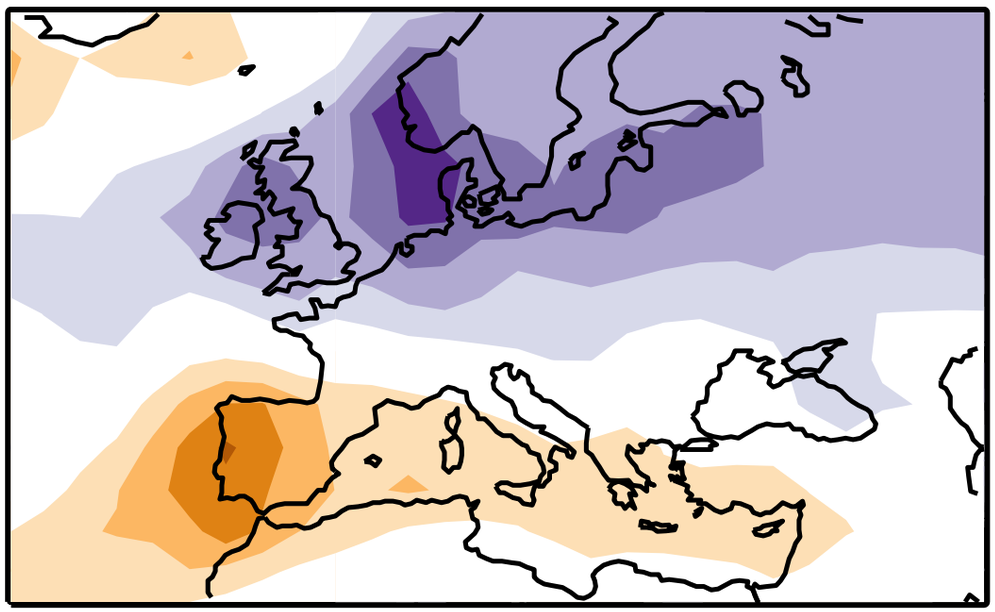
- Tropical SSTs
- Arctic sea ice
- Stratospheric state



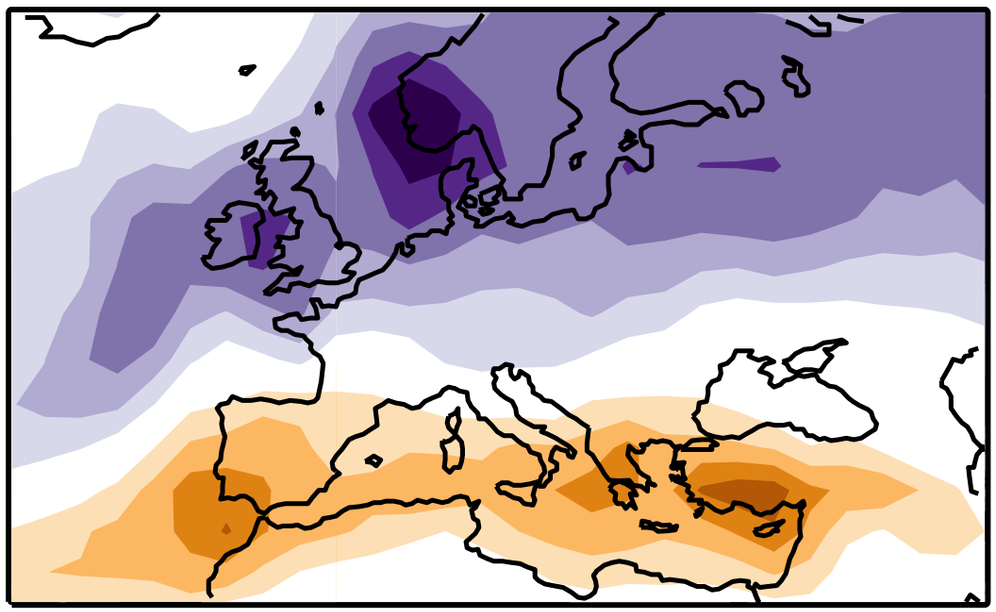
Dunstone et al 2016

Impact on precipitation

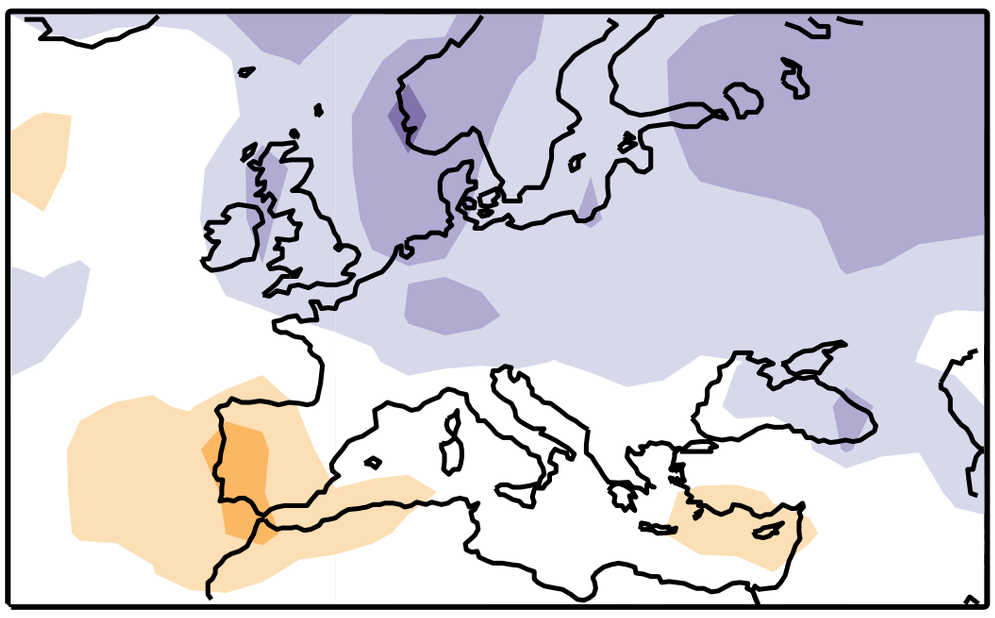
Low tropical amplification strong vortex



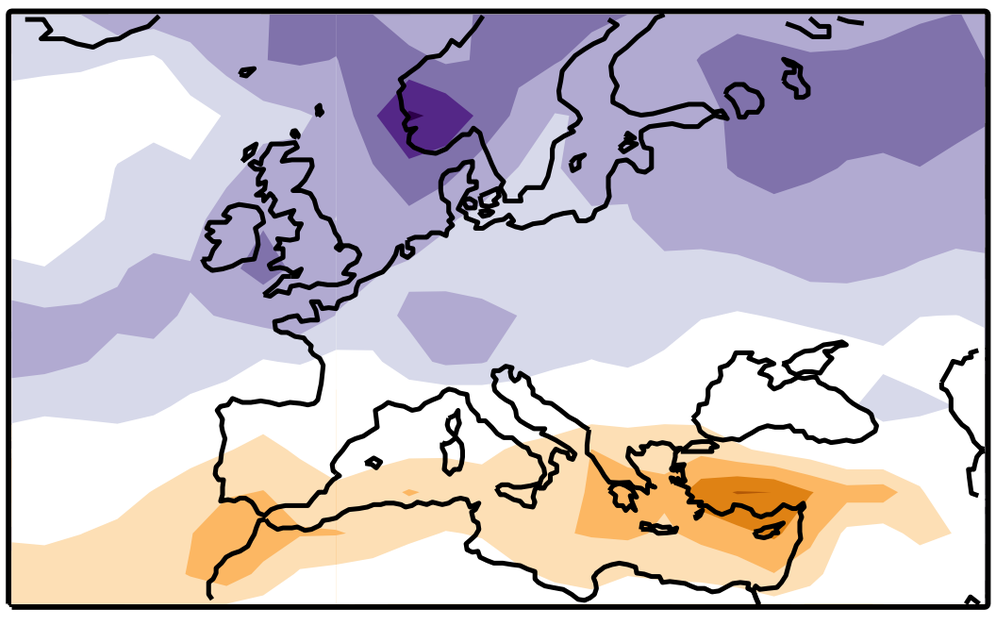
High tropical amplification strong vortex

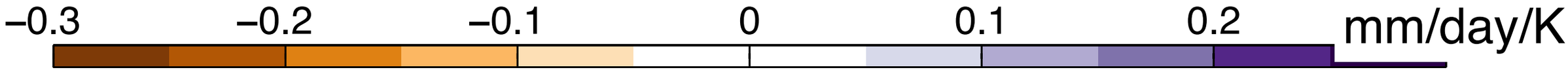


Low tropical amplification weak vortex



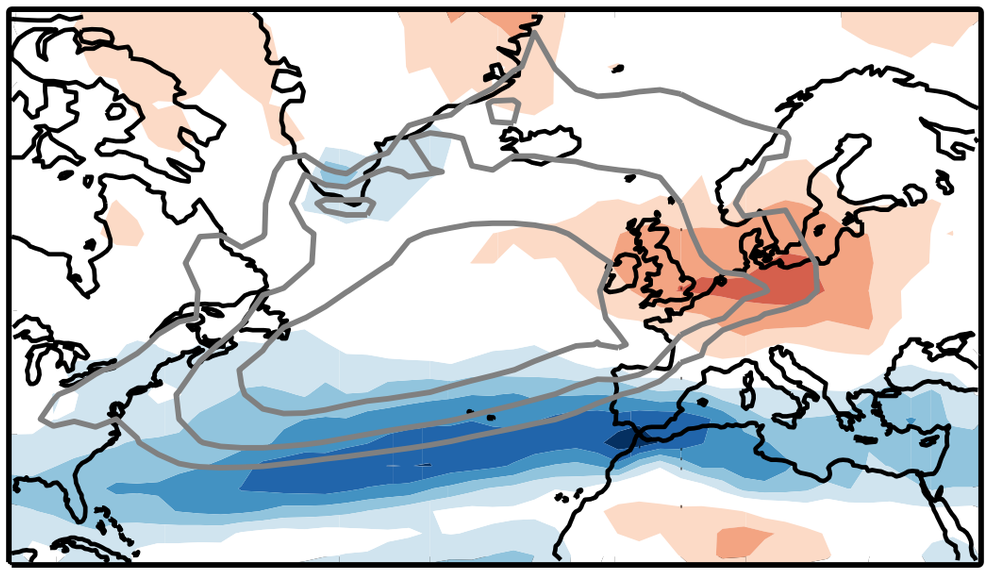
High tropical amplification weak vortex



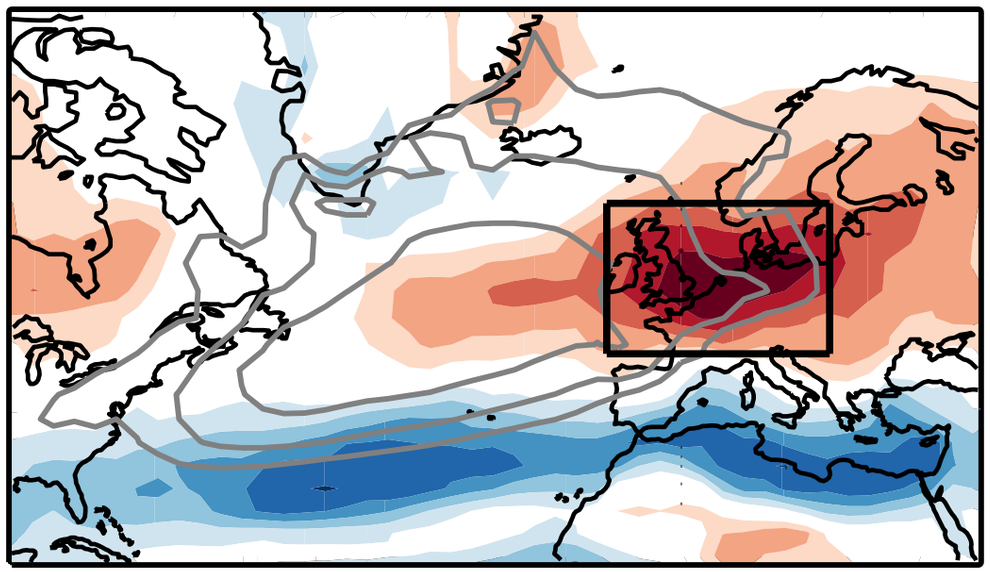


Impact on windiness

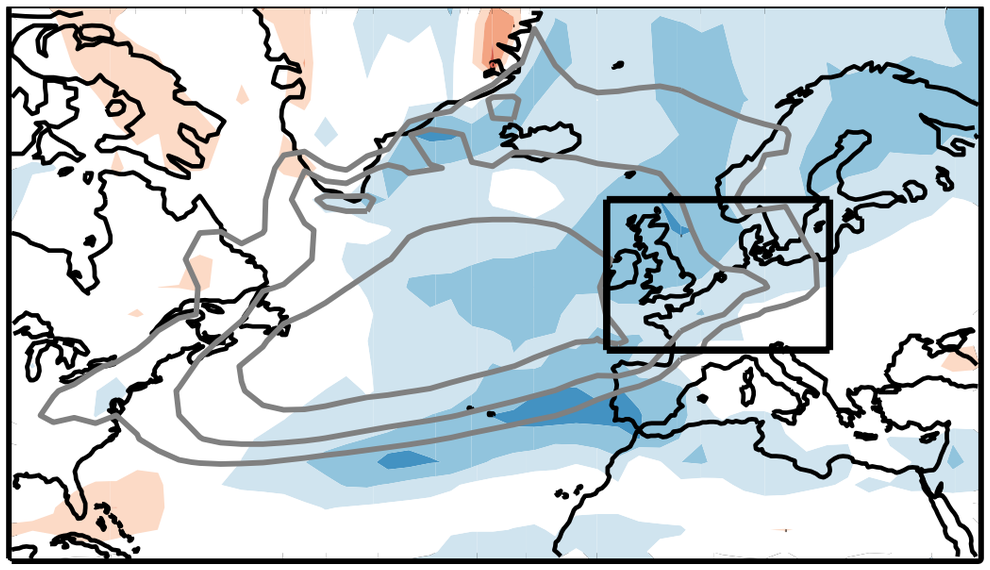
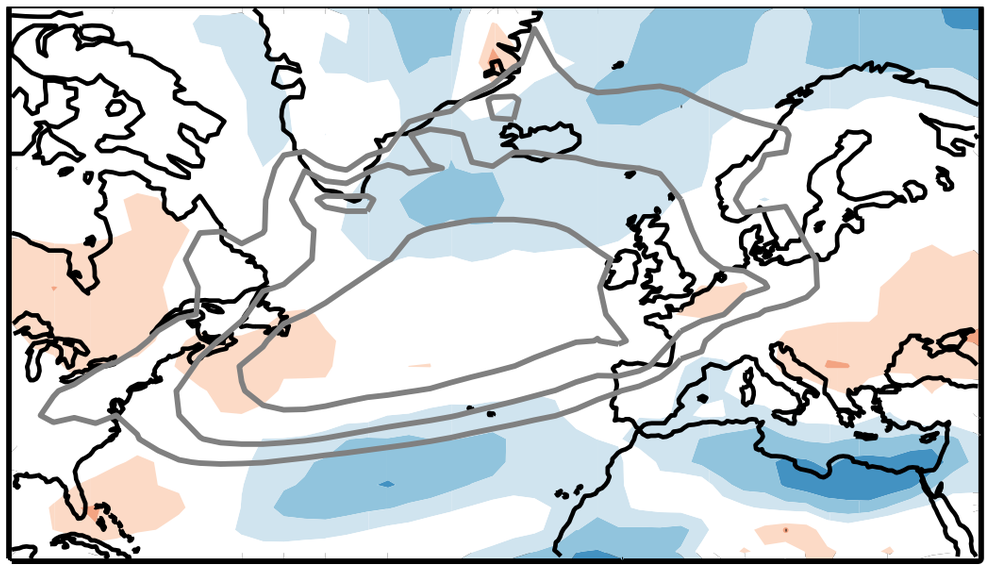
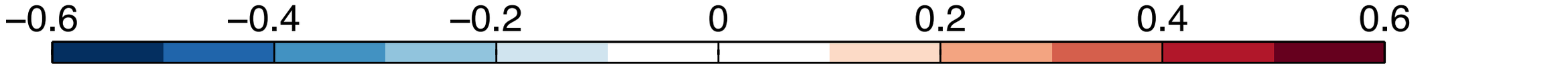
Low tropical amplification strong vortex



High tropical amplification strong vortex



Low tropical amplification weak vortex



High tropical amplification weak vortex