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Climate change impact on the North Atlantic Cyclones: projections from the CMIP5 ensemble

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1) Introduction

A number of studies has investigated the impact of increasing levels of greenhouse gases on the behaviour of North Atlantic cyclones. Some results emerging from these studies are:

- **A decrease in the total number of cyclones (Bengtsson et al 2009)**
- **Enhanced cyclonic activity over the British Isles during DJF (Ulbrich et al 2008)**
- **Increased precipitation associated with cyclones (Bengtsson et al 2009)**

Less consensus is found about how the dynamical intensity of cyclones will change, and on whether cyclones of extreme intensity will become more frequent (Lambert and Fyfe 2006, Bengtsson et al 2009). This uncertainty is partly due to the use of different methodologies and measures of intensity on different models. Here, we try to assess the robustness of such changes by using the same methodology to analyse the climate models participating in the CMIP5 ensemble.

2) Methodology and Data

Extratropical cyclones are identified as relative maxima in six hourly relative vorticity (T42) at 850mb, and their propagation tracked using an objective feature tracking algorithm (Hodges, 1995). Constraints are applied on minimum lifetime (2 days), minimum propagation (1000 km) and minimum intensity (10^{-5} 1/s).

Definition of Atlantic cyclones

- Maximum cyclone intensity (Vorticity T42) has to occur in the region delimited in blue in Fig 1.

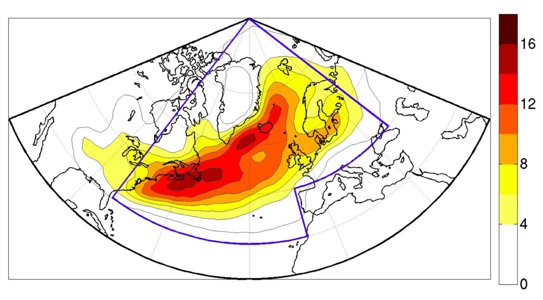


Fig 1: Track density (DJF) of the Atlantic cyclones identified from ERA-INTERIM data. Units: number density per month per 5 degree spherical cap.

CMIP5 models

Model	Horiz Res (lat X lon)	# HIST	# RCP	Precipitation
Hadgem2-ES	1.24 X 1.9	1	1	X
inmcm4	1.5 X 2.0	1	1	V
canesm2	2.8 X 2.8	5	1	X
Ipsl-cm5a-lr	1.875 X 3.75	4	4	V
bcc-csm1-1	2.8 X 2.8	3	1	V
noresm1-m	1.875 X 2.5	1	1	V

Table 1: Model name, horizontal resolution expressed in degrees, number of ensembles for the HISTORICAL (#HIST) and RCP4.5 (#RCP) runs, availability of precipitation data.

Analysed Experiments

- RCP4.5 climate change scenario (2070-2099)
- HISTORICAL control run (1976-2005)

Climate change signals are evaluated from the differences in cyclone statistics between the RCP4.5 and HISTORICAL simulations.

3) Climate change impact on cyclone distribution

The climate change signal of the multi model mean track density (see Fig 2) shows a:

- Decreased total number of cyclones. The decrease is more marked on the Southern edge of the Stormtrack (DJF-MAM-JJA-SON)
- Slight increase in the number of cyclones on the northern side of the Stormtrack (MAM-JJA-SON)
- Decreased track density over the Norwegian sea, slight indication of increase over British Isles and Western Europe , and marked decrease over the Mediterranean (DJF)

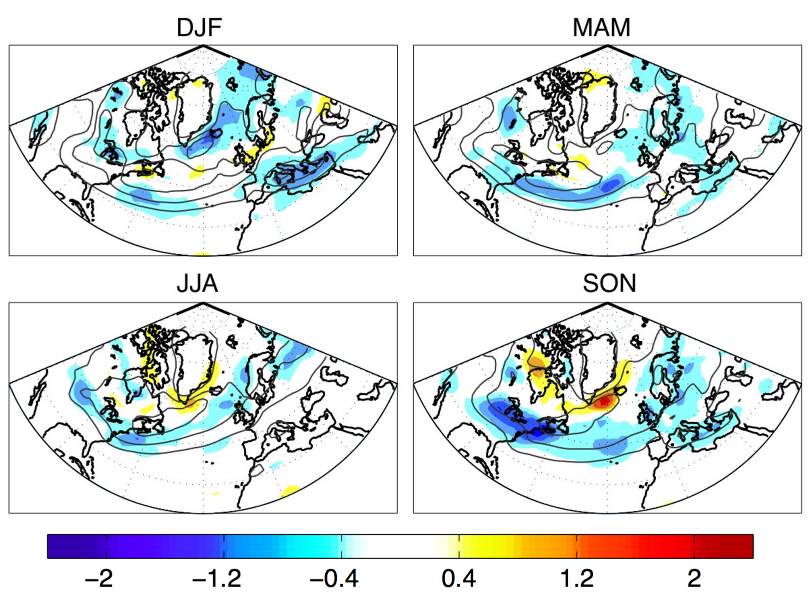


Fig 2: Multi model mean track density in the HISTORICAL run (contours, c.i. 4) and track density difference between RCP4.5 and HISTORICAL (shaded).

Stormtrack latitude and tilt

To assess the model spread in the meridional displacement of the stormtrack, in Fig 3 we plot the change in the mean latitude at which storms cross the 60W and 20W meridians. These correspond to the western and eastern sides of the Atlantic ocean, respectively.

The response in the mean latitude of the tracks changes with the season (see Fig 4):

DJF

An increased mean track latitude at 60W is accompanied by a decrease at 20W. This can be interpreted as a decreased mean tilt of the Atlantic stormtrack

MAM-JJA-SON

Models show an average tendency to an higher mean track latitude at both 60W and 20W.

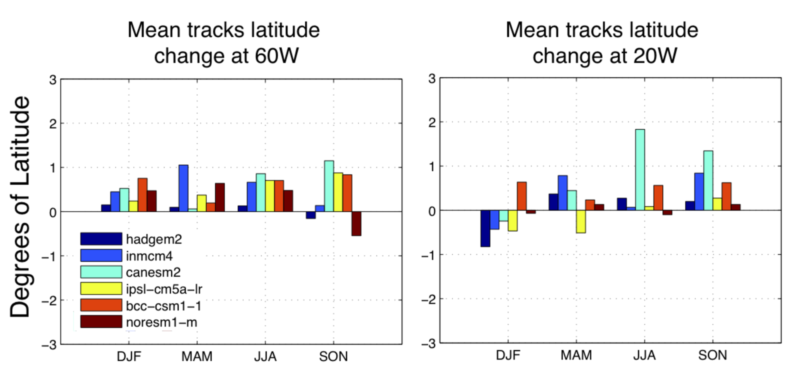
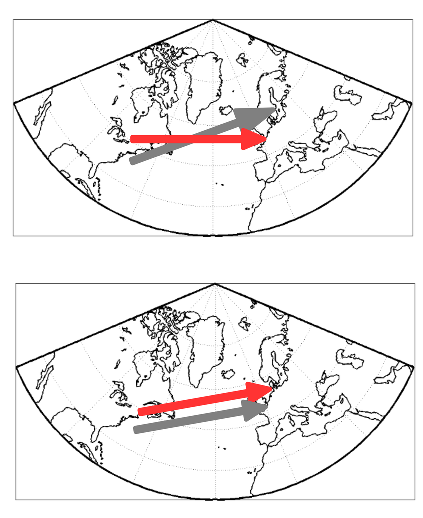


Fig 3: Meridional change in the mean latitude at which track cross the 60W (left) and 20W (right) meridians. Each column represents a model

DJF



MAM
JJA
SON

Fig 4: Idealised representation of the different structure of the change in the Atlantic stormtrack orientation between seasons. The grey (red) arrow refers to present day (future) climate.

4) Climate change impact on cyclone Intensity

The intensity of a cyclone is evaluated using two metrics:

- WIND: Maximum along-track wind speed at 850 mb in a 5 degrees spherical cap
- PRECIPITATION: Maximum along-track area averaged precipitation in a 5 degrees spherical cap

The multi-model-mean intensity distribution of Atlantic cyclones, for present day and future climate conditions, is plotted in Fig 5. The dominant changes are listed under the figures, and a quantitative analysis is given in table 2. Strong cyclones are defined as those whose maximum intensity is higher than the 75 percentile of the HISTORICAL intensity distribution of that model and season.

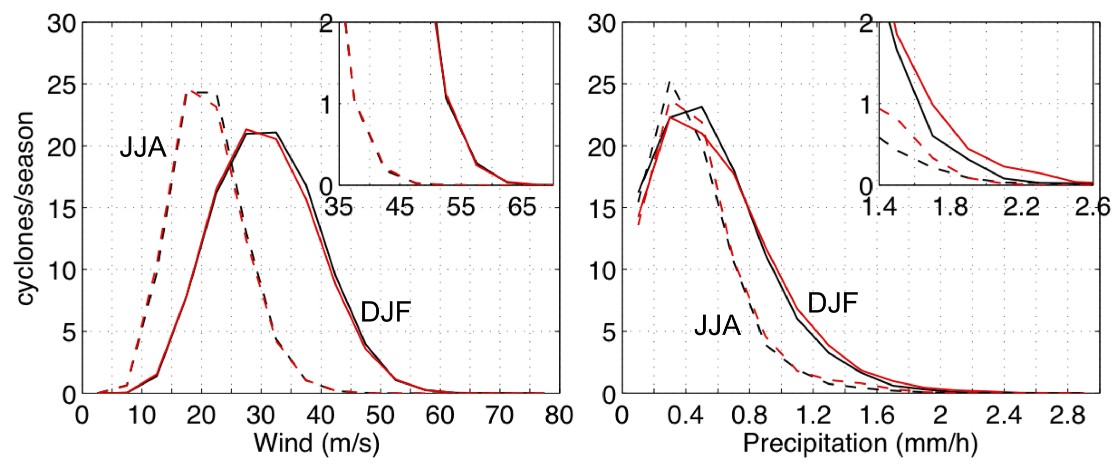


Fig 5: Multi-model-mean along-track maximum wind speed (left) and area averaged precipitation (right) distribution for the HISTORICAL (black) and RCP4.5 (red) runs. Full (dashed) lines refer to DJF (JJA). Bin size: 5 m/s (0.2 mm/h) for wind (precipitation).

- Decrease in the mean
- Decrease in the number of strong cyclones
- Increased skewness

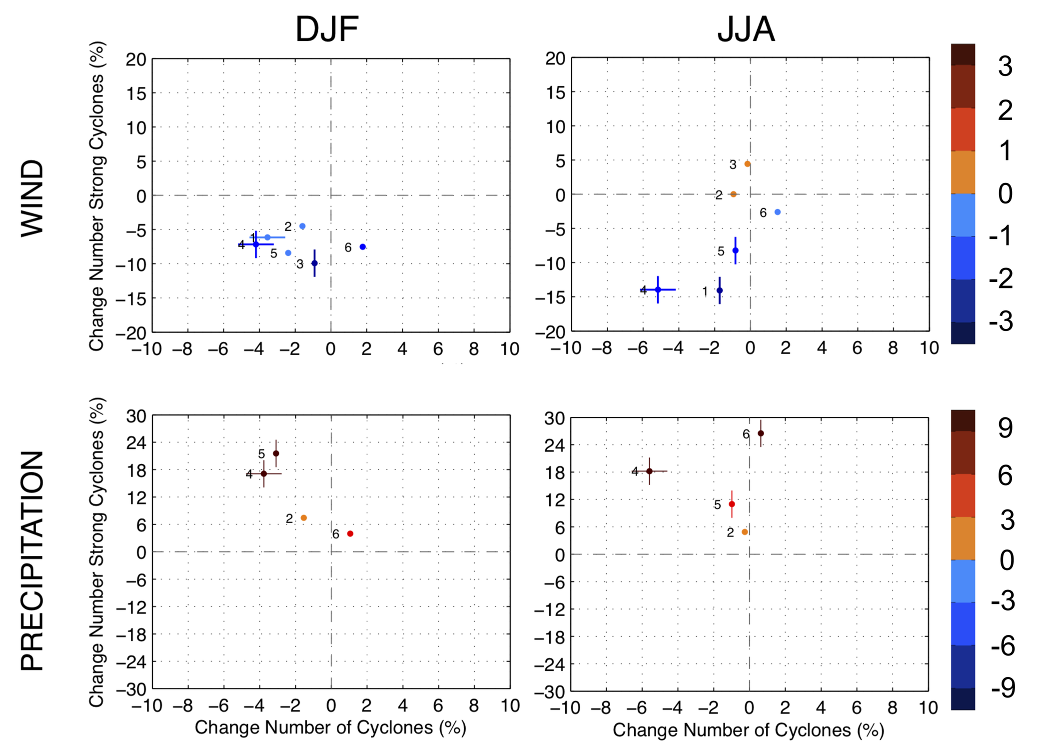
- Increase in the mean
- Increase in the number of strong cyclones
- Thickening of the tail of the distribution

	Total number of cyclones	Wind			Precipitation		
		Number Strong Cyclones per season	Mean (m/s)	Skewness	Number Strong Cyclones per season	Mean (mm/h)	Skewness
DJF	99.1 (-1.8)	24.8 (-1.8)	30.9 (-0.3)	0.21 (0.03)	25.7 (3.0)	0.55 (0.03)	0.79 (0.02)
JJA	77.6 (-0.8)	19.4 (-1.0)	21.0 (-0.2)	0.39 (0.05)	19.7 (2.8)	0.43 (0.02)	0.82 (-0.12)

Table 2: Basic statistics of the multi-model-mean wind and precipitation intensity distribution of Atlantic cyclones. HISTORICAL values are in black, and absolute changes with respect to RCP4.5 in red.

Spread in intensity change

Table 2 suggests that the intensity of winds and precipitation of Atlantic cyclones are affected differently by increasing greenhouse gases. To assess the robustness of such results, the changes in the total number of cyclones, in the number of strong cyclones and in the mean cyclone intensity are separately computed for each model. Results are presented in Fig 6.



Wind

Models are consistent in indicating a decrease wind speed intensity in DJF. Higher spread is found during JJA

Precipitation

All models feature increased precipitation during both DJF and JJA. However, the intensity of the change is found to be highly model dependent.

Fig 6: Scatter plot of the relative change (RCP4.5-Historical) in the number of strong cyclones against the relative change in the total number of cyclones. Each dot is a model and horizontal (vertical) bars are added to indicate statistically significant changes at the 95% confidence level in the total number of (number of strong) cyclones. Colours indicate the relative change in mean cyclone intensity.

5) Conclusions

Changes in the Atlantic cyclones behaviour by the end of the 21st century, under the greenhouse forcing given by the RCP4.5 scenario, are investigated in CMIP5 models.

It is found that the number of cyclones decreases. Precipitation associated to cyclones increases, while winds seems to become on average weaker. On the Atlantic basin scale, despite an increased skewness in the wind intensity distribution, no clear evidence of wind storms becoming more extreme is found.

While the direction of the changes is found to be consistent across the models, the amplitude of the changes shows some spread, which is particularly large for precipitation.

Despite the overall dynamical cyclone weakening, some models (not shown) reveal an increased storminess over the British Isles and Western Europe. This is associated with the decrease in the stormtrack tilt. However, many CMIP5 models simulate a too zonal present day stormtrack. Future work is required to understand how such systematic errors can influence the projections of future changes in the stormtrack tilt and European storminess.

References

- Ulbrich et al, *J of Climate*, Vol 21, 2008
- Hodges K I, *Mon Weather Rev*, Vol 123, 1995
- Bengtsson et al, J of Climate, Vol 22, 2009
- Lambert and Fyfe, Climate Dynamics, Vol 26, 2006

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