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An assessment of the North Atlantic Cyclones simulated by CMIP5 models

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1) Introduction

Extratropical cyclones are the dominant dynamical phenomena characterising mid-latitude weather and climate. Is therefore crucial that models correctly represent cyclones behaviour to provide a realistic simulation of the Earth's climate.

Systematic errors in cyclone activity have been observed in CMIP3 models by analysing the 2-6 days filtered variance of Mean Sea Level Pressure (MSLP) (Ulbrich et al, 2008). Direct assessment of cyclone behaviour using a tracking technique was not possible due to the lack of high frequency data. This work aims at filling this gap by providing a detailed analysis of the errors in the spatial distribution, number and intensity of North Atlantic cyclones in the CMIP5 models.

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 ($10^{-5}s^{-1}$).

Definition of Atlantic cyclones

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

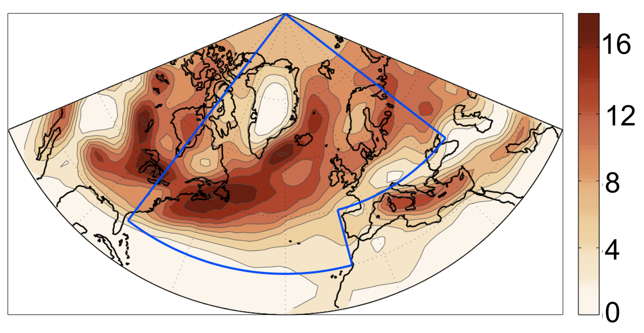


Fig 1: Track density (DJF). Data: ERA-INTERIM. Units: number density per month per 5 degree spherical cap.

CMIP5 models

#	Model	Horiz Grid Res (lat X lon)	# ENS
1	hadgem2-es	1.24 x 1.9	1
2	inmcm4	1.5 x 2.0	1
3	canesm2	2.8 x 2.8	5
4	ipsl-cm5a-lr	1.875 x 3.75	4
5	cnrm-cm5	1.4 x 1.4	5
6	bcc-csm1-1	2.8 x 2.8	3
7	noresm1-m	1.875 x 2.5	1
8	csiro-mk3-6-0	1.875 x 1.875	5
9	ec-earth	1.125 x 1.125	3

Table 1: Model label, name, atmospheric horizontal resolution expressed in degrees, number of ensembles

- CMIP5 Experiments: HISTORICAL (1976-2005), AMIP (1980-2008)
- Re-analyses: ERA-INTERIM, NCEP-CFS, JRA25, NASA-MERRA (1980-2009)

3) Spatial Distribution of cyclone activity

In Fig 2 we investigate the climate models systematic errors in:
Stormtrack: std of 2-6 days filtered MSLP
Track Density: Density of cyclone tracks
Track Intensity: Mean T42 vorticity at 850mb associated to tracks

The dominant systematics errors are:

DJF
- Too many tracks propagating into Europe
- Insufficient cyclones intensity and number over the Arctic region and East America.

JJA
- Weak intensity over East Atlantic and small number on the southern flank of the stormtrack

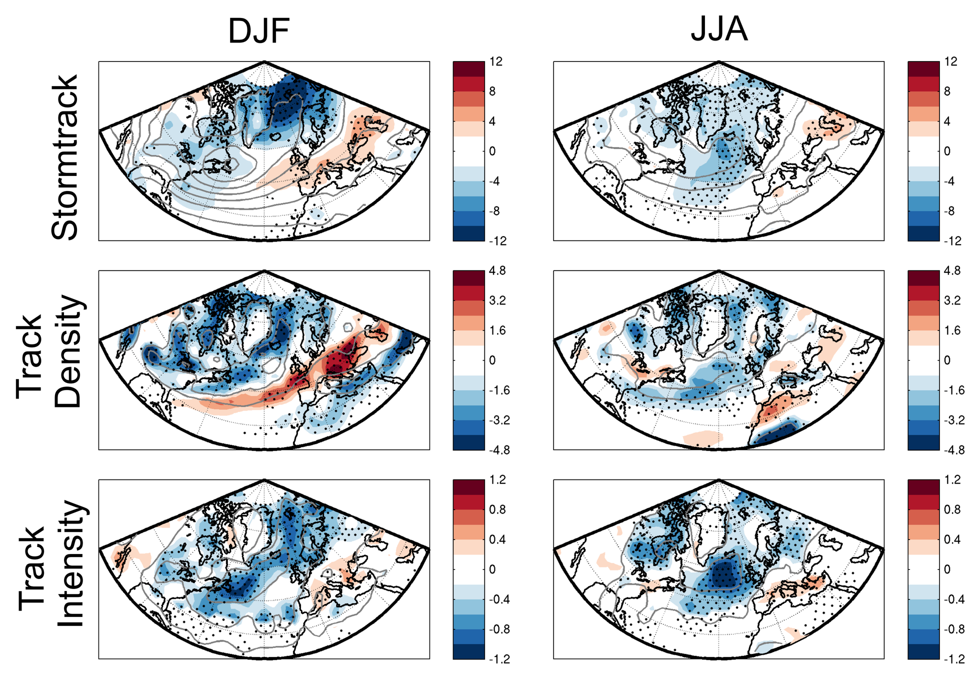


Fig 2: Multi-model mean error in stormtrack (dPa), track density (# density) and mean intensity (s^{-1}). Stippling denotes where the mean error is greater than the std of errors. For each field, ERA-INTERIM climatology is contoured in grey with isolines every 10 dPa, 6 (# density), 1.5 (s^{-1}), respectively.

DJF Spread in track distribution

The multi model DJF track density features errors in both the Atlantic and European regions. To further investigate these errors, the tracks latitude distribution of the single models on the western (60W) and eastern (0E) side of the Atlantic region is presented in Fig 3. The analysis suggests to group the models in three classes:

1 : Southward displaced stormtrack
2 : Too zonal stormtrack
3 : Tilt consistent with reanalysis

The DJF track density averaged among the models in each group is presented in Fig 4. By comparing Fig 4 with Fig 1, we note that only the models in group 3 capture the right latitude and tilt of the DJF Atlantic stormtrack.

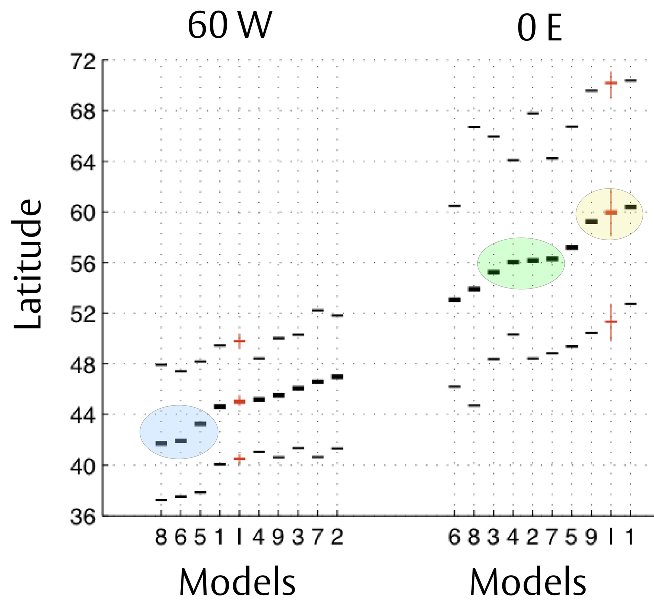


Fig 3: DJF Meridional distribution of cyclone tracks at 60W (left) and 0W (right). The three dashes refer to the 25th, 50th (thick dash) and 75th percentiles of the distribution. Each column represents a model. Values from ERA-INTERIM reanalysis are in red, with confidence intervals indicated as red vertical lines. The meaning of the ellipses is given in the text.

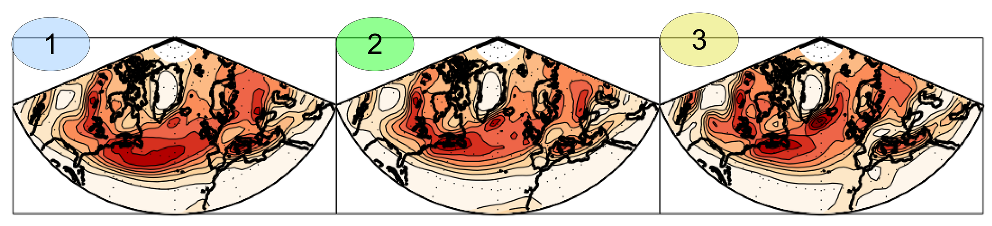


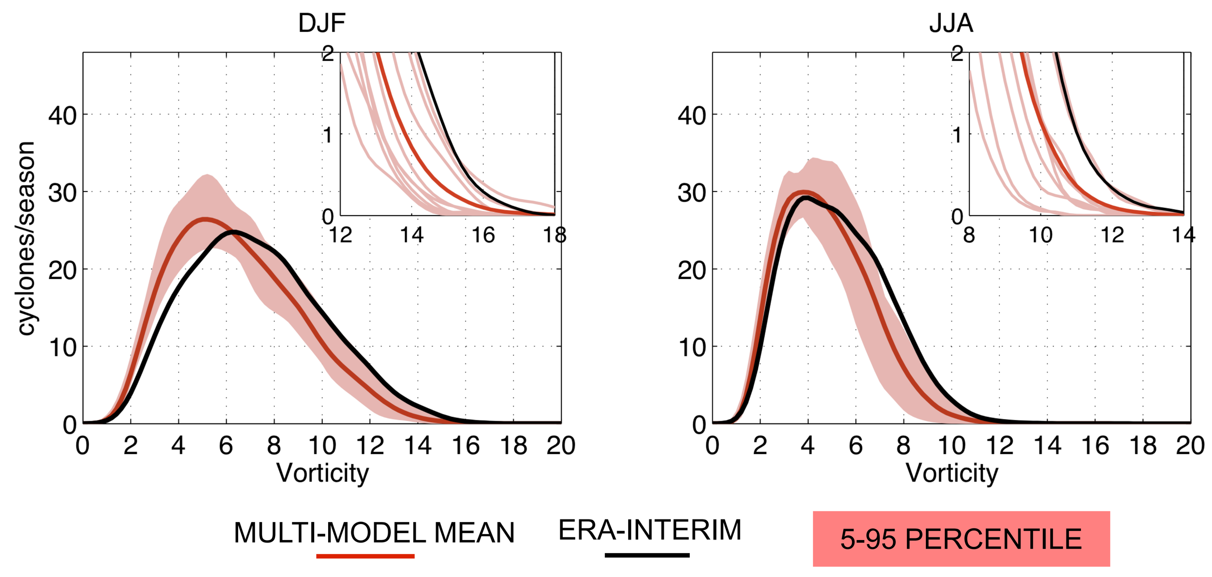
Fig 4: Multi model mean track density for the three set of models indicated in Fig 3.

4) Cyclone Number and intensity

Fig 2 suggested that models underestimate the mean cyclone intensity. To further analyse the problem, cyclone intensity is now defined as the maximum along-track T42 vorticity at 850mb.

The multi model mean DJF and JJA intensity distribution of Atlantic cyclones is displayed in Fig 5. In both seasons, models systematically underestimate the maximum along-track cyclone intensity. As revealed by the tail of the distribution, this problem also affects the intensity of extreme storms.

Fig 5: Probability Density Function (PDF) of the maximum along-track T42 vorticity at 850mb of Atlantic cyclones. The PDF is scaled to cyclones per season per $2s^{-1}$ vorticity bin. Pink shading covers the 5-95 percentile model spread.



In Fig 6 we explore an Intensity Vs Number space that allows a better quantification of these errors. As a single value metric for intensity we consider the mean of the intensity distribution displayed in Fig 5. The main results are summarised for each season below.

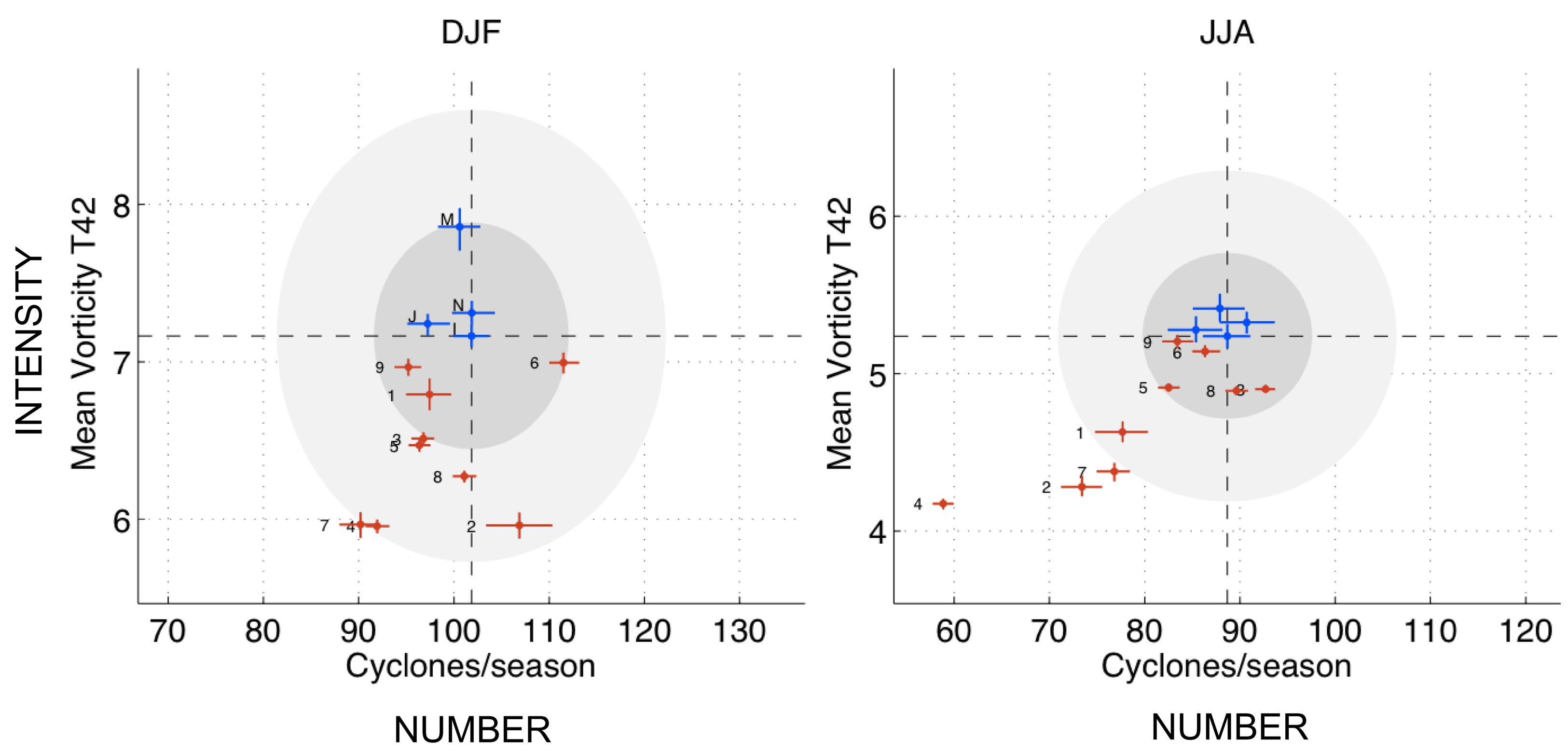


Fig 6: Scatter plot of mean cyclone intensity against mean number of Atlantic cyclones. Red (Blu) dots indicate models (Re-analyses). The crosses give the 95% confidence intervals. Numbers refer to the model labels given in table 1, while letters stand for: ERA-INTERIM (I), JRA-25 (J), NCEP-CFS (N), NASA MERRA (M). Dark (grey) shading delimit the 10% (20%) relative error respect to ERA-INTERIM.

DJF
- Right Number of cyclones
- Weak average maximum intensity
- NASA-MERRA reanalysis features stronger cyclones respect to other reanalyses. Where is the real world?

JJA
- Weak Intensity and Small Number of Cyclones
- Two models (6,9) are consistent with reanalyses ensemble.

5) DJF case: What can we learn from the Jet Stream?

- The too zonal character of the models can be inferred from inspecting climatological U at 250 mb (see Fig 7).
- But no information about the too weak intensity of storms could have been inferred from the mean jet !

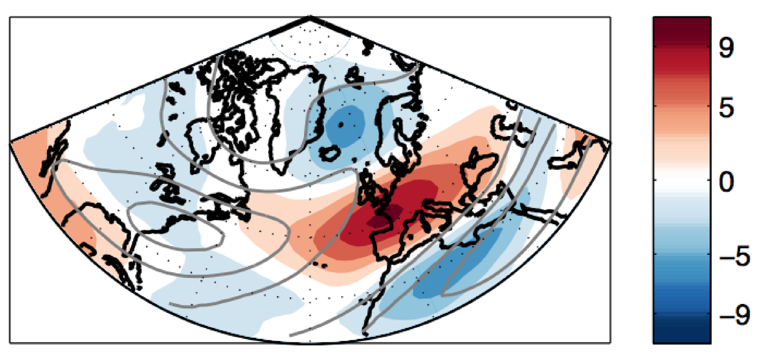


Fig 7: DJF Multi model mean error in U at 250mb. ERA-INTERIM climatology is contoured in grey, with isolines every 10 m/s

6) Conclusions

This work focusses on evaluating CMIP5 climate models with respect to the cyclone behaviour in the North Atlantic stormtrack. The following systematic errors are identified.

- **All seasons: Cyclone intensity is too weak. No model has cyclones stronger than in Reanalysis.**
- **DJF: total number of cyclones is correct, but the stormtrack is too zonal**
- **JJA: Too Small total number of cyclones, while the spatial distribution is roughly captured**

The same conclusions are found if minimum pressure, or maximum windspeed are used for measuring cyclone intensity. Comparison with AMIP experiments indicate that the errors are due to the atmospheric component of the model. The model spread is large, but some models are successful in roughly capturing the intensity, number, and spatial distribution of Atlantic cyclones.

Future work will focus on understanding dynamical relations between the errors in the intensity and in the spatial distribution of cyclones, and in assessing the relevance of these errors for future climate projections.

References

- Ulbrich et al, *J of Climate*, Vol 21, 2008
- Hodges K I, *Mon Weather Rev*, Vol 123, 1995

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CMIP5 data is obtained from PCMDI Earth System Grid website: http://pcmdi3.llnl.gov/esgcet

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