A Comparison of Extratropical Cyclones in CMIP5 Models

Robert W. Lee | Kevin I. Hodges

University of Reading

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1 Introduction

Cyclones are an important and influential part of day to day weather, climate and the general circulation. Assessing and understanding future changes in cyclone properties associated with climate change is therefore an important area of research.

The IPCC AR4 suggests "extratropical storm tracks are projected to move poleward, with consequent changes in wind, precipitation and temperature patterns" but states there is large uncertainty[1]. To explore in more detail, here extratropical cyclones are identified and compared using 6-hourly data from the CMIP5 multi-model ensemble archive.

2 Data & methodology

Institute	Model	Resolution	Ensemble size*
BCC	bcc-csm1-1	2.81 x 2.81 , L26	3,1,1
CCCMA	CanESM2	2.81 x 2.81 , L35	5,1,1
CNRM-CERFACS	CNRM-CM5	1.41 x 1.41 , L31	1,1,1
INM	inmcm4	1.5 x 2 , L21	1,1,1
IPSL	IPSL-CM5A-LR	1.875 x 3.75 , L39	4,3,2
MOHC	HadGEM2-ES	1.25 x 1.875 , L38	1,1,1
NCC	NorESM1-M	1.875 x 2.5 , L26	1,1,1

Table 1. CMIP5 multi-model ensemble output used here.
* Note: ensemble size in order of historical, RCP4.5, RCP8.5

The CMIP5 historical, Radiative Concentration Pathways (RCPs) 4.5 and 8.5 experiments are analyzed for the models listed in Table 1. Results are presented for the standard IPCC AR5 periods 1986-2005 and 2081-2100 for the historical and RCP experiments respectively. RCPs are labelled as the top of atmosphere radiative forcing difference at the year 2100. RCP 4.5 has similar CO_2 concentrations to the older SRES B1 and RCP 8.5 to A1F1.

An objective feature tracking algorithm[2,3] is applied to the 850 hPa relative vorticity (ξ_{850}), at 6-h frequency, filtered to T42 for reliable tracking. A 2-day and 1000 km filter is applied to the cyclone tracks.

3 Results

3.1 Track density – model verification

The ERA-Interim reanalysis (1986-2005) is used for verification of the historical experiment, multi-model mean for the winter season (Fig. 1). A full climatology and comparison between reanalyses is presented in Hodges et al. (2011)[4].

- In the Northern Hemisphere (NH; Fig. 1, left) the multi-model mean shows the Atlantic storm track too zonal relative to the reanalysis. The Pacific track is also more zonal however the problem is less severe. It should be noted there is strong model to model variation.
- In the Southern Hemisphere (SH; Fig. 1, right) the models are generally poor at simulating the spiraling of the storm track from South America, around Antarctica, to the Antarctic Peninsula possibly associated with the representation of the winter split jet.

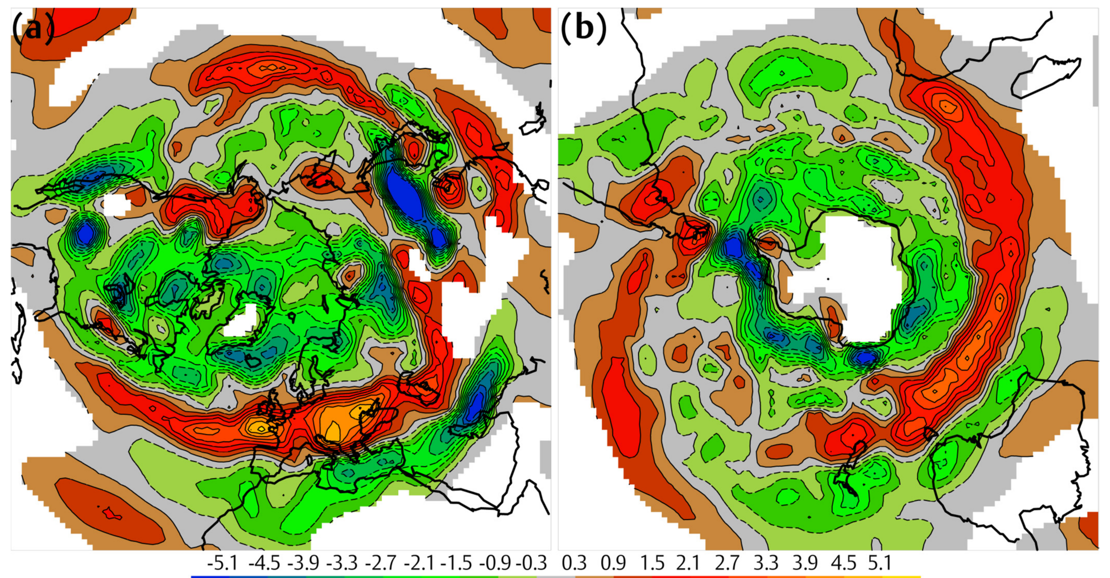

Figure 1. Difference in ξ_{850} extratropical cyclone track densities for the winter season: 7 member multi-model mean historical experiment – ERA-Interim for (a) NH, DJF, and (b) SH, JJA. Densities are in units of number density per month per unit area, where the unit area is equivalent to a 5° spherical cap (~10^6 km^2).

3.2 Track density – climate change experiments (winter)

Fig. 2 shows the change in the storm track densities between the historical, RCP 4.5 and 8.5 experiments.

- In the NH (top) there is a decrease in density on the equatorward flanks of the storm tracks, there is no clear increase in density on the poleward side and so no clear 'poleward shift'.
- In the SH (bottom) there is a larger decrease in density on the equatorward side than increase on the poleward side of the storm track but there is an apparent poleward shift.
- RCP4.5 (left) produces a weaker response than RCP8.5 (right), especially in the SH.
- The spread in locations and magnitudes of density changes varies between models, particularly in the NH Pacific track shown in Fig. 3. The CNRM-CM5 and NorESM1-M models best highlight this.

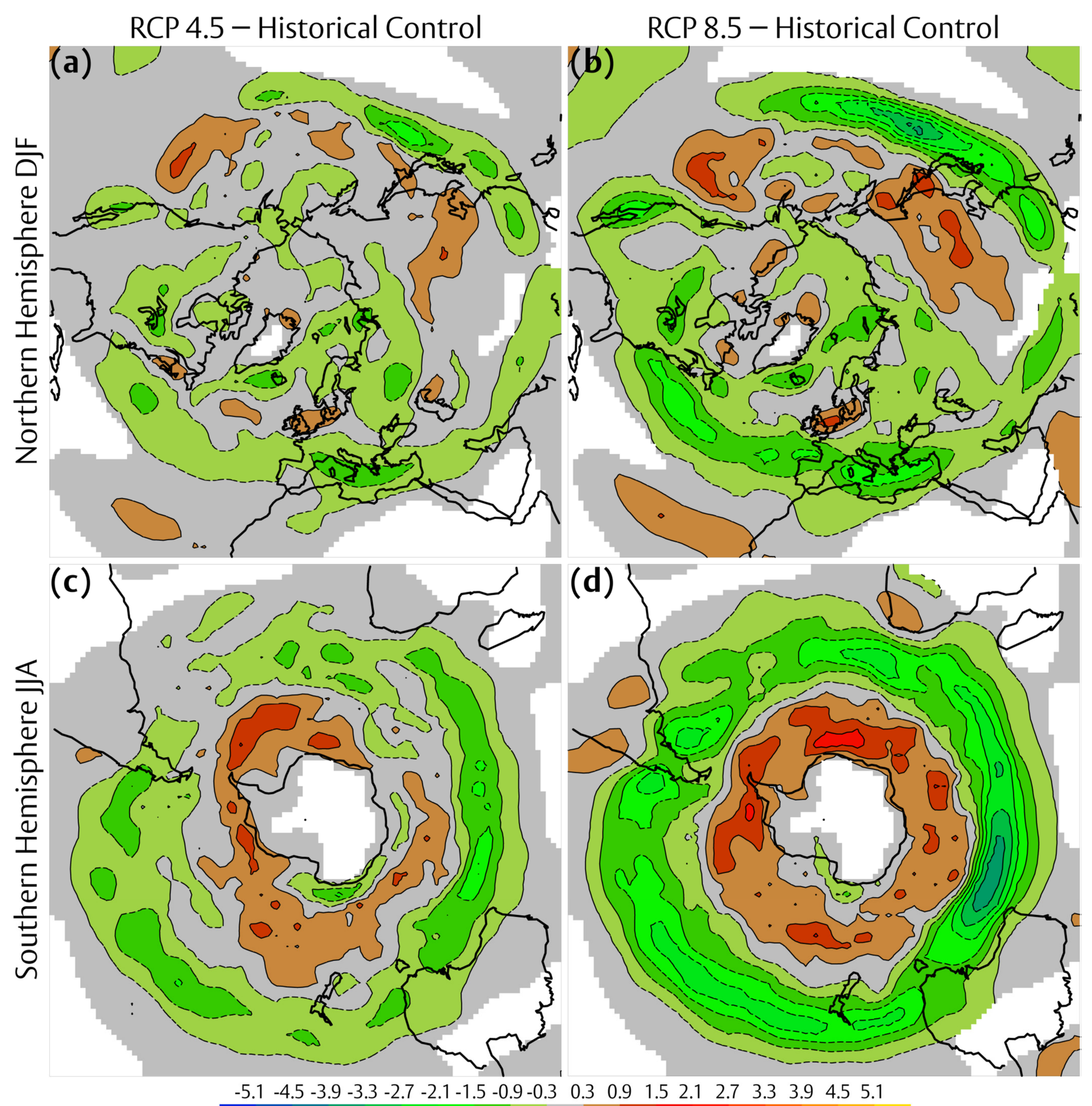

Figure 2. Difference in ξ_{850} extratropical cyclone track densities between late 21st and 20th centuries in the multi-model mean for the winter season: (left) multi-model mean RCP 4.5 – historical for (a) NH DJF, and (c) SH JJA; and (right) multi-model mean RCP 8.5 – historical for (b) NH DJF, and (d) SH JJA. Densities are in units of number density per month per unit area.

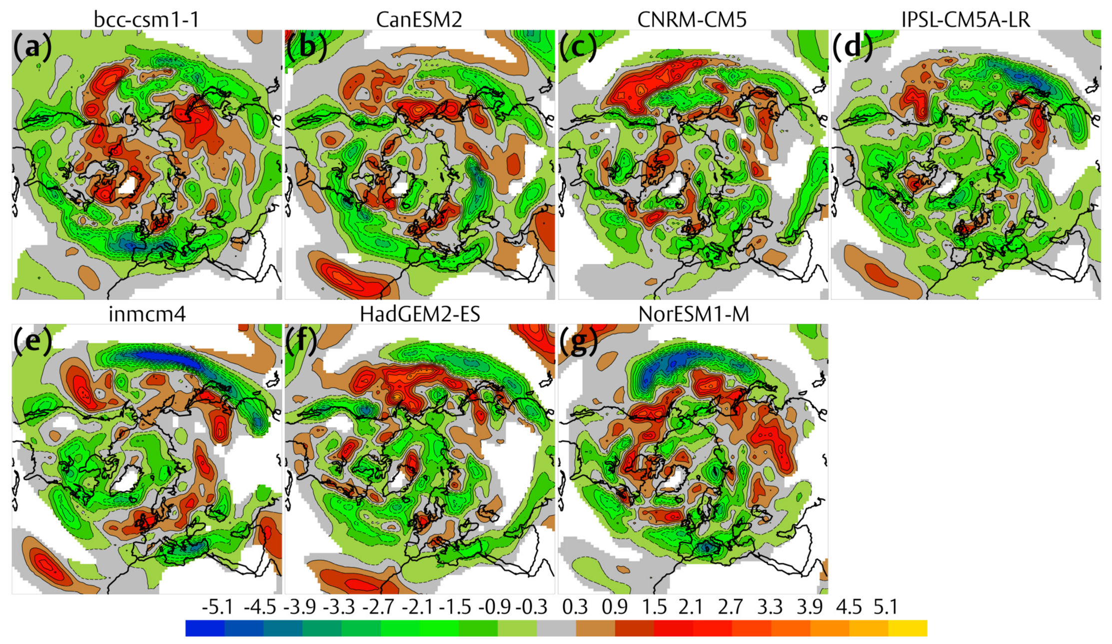

Figure 3. Difference in ξ_{850} extratropical cyclone track densities between late 21st and 20th centuries for the individual models, RCP 4.5 – historical for the winter (DJF) season in the NH: (a) bcc-csm1-1, (b) CanESM2, (c) CNRM-CM5, (d) IPSL-CM5A-LR, (e) inmcm4 (f) HadGEM2-ES, and (g) NorESM1-M. Densities are in units of number density per month per unit area.

- There are robust changes such as the Mediterranean track and southern flank of the NH Pacific storm track., with all models predicting a decrease in density.
- There are also large variations in the SH (not shown).

3.3 Track density – climate change experiments (other seasons)

- Fig. 4 shows the changes in storm track densities in the summer season, indicating a strong poleward shift in the SH RCP8.5 experiments and a weak poleward shift in the NH, whereby magnitudes of decrease and increase are roughly similar on poleward and equatorward sides of the main storm tracks.
- Not shown, the spring season is qualitatively similar to the winter season, and autumn similar to the summer season.

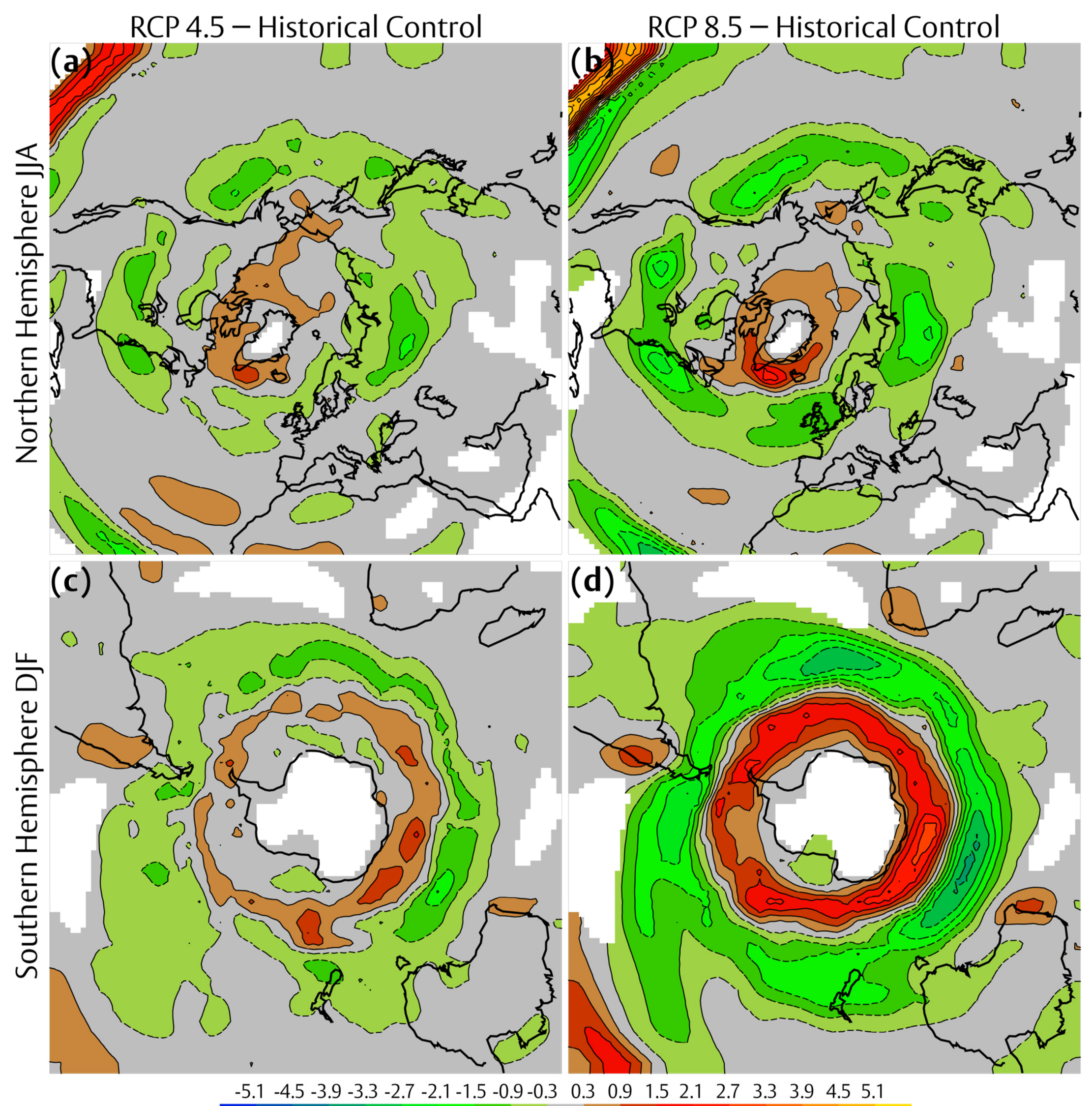

Figure 4. Difference in ξ_{850} extratropical cyclone track densities between late 21st and 20th centuries in the multi-model mean for the summer season: (left) multi-model mean RCP 4.5 – historical for (a) NH JJA, and (c) SH DJF; and (right) multi-model mean RCP 8.5 – historical for (b) NH JJA, and (d) SH DJF. Densities are in units of number density per month per unit area.

4 Conclusions

- A poleward shift in the storm tracks is indicated by the CMIP5 models tracked to date in the SH across all seasons. In the NH this shift is more dependent on season, with summer and autumn suggesting this poleward shift, whereas winter and spring indicate just a decrease in the southern flank of the Atlantic and Pacific storm tracks.
- The RCP 8.5 experiment indicates a larger change in storm track densities than RCP 4.5, particularly in the vicinity of the main storm tracks.
- The magnitudes of the multi-model mean response to the RCPs is less than the historical experiment multi-model mean biases when compared with ERA-Interim reanalysis.
- The current CMIP5 models have been designed with added complexity rather than increased resolution. As a result the study of extremes is more difficult as resolution has a large impact on extratropical cyclone properties[5].

5 Future work

Work is ongoing and is updated as successive models are released to the CMIP5 archive. Other future work will include:

- analyzing the changes in intensities of precipitation and winds,
- analyzing the relationship between the storm track density and intensity changes to the large scale, focusing on temperature gradients and jets,
- exploring genesis and lysis densities along with growth rates.
- analyzing other experiments including paleoclimate, pre-industrial control, AMIP and RCPs 2.6 and 6.0.

Updated plots are available online (see contact information).

References

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Contact information

- Robert Lee, ESSC, Department of Meteorology, University of Reading, 3 Earley Gate, RG6 6AL, UK
- Email: r.w.lee@pgr.reading.ac.uk
- www.met.reading.ac.uk/~tz000214/