National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

University of Reading

The Response of the Northern Hemisphere Storm Tracks and Jet Streams to Climate Change in the CMIP3, CMIP5, and CMIP6 Climate Models

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Study submitted to JGR: Atmospheres

Quick Summary

- Storm track biases in the CMIP3, CMIP5 and CMIP6 ensembles have very similar spatial patterns, but the magnitudes of the biases in CMIP6 are substantially lower – SEE SLIDE 6
- The climate change responses of the storm tracks also share similar spatial patterns across the CMIPs, but with some important regional variations – SEE SLIDE 9

Introduction

- Understanding and predicting how extratropical cyclones might respond to climate change is essential for assessing future weather risks and informing climate change adaptation strategies
- Climate model simulations provide a vital component of this assessment (with the caveat that their representation of the present-day climate is adequate)
- What we do here: Evaluate the representation of the NH storm tracks and jet streams and their responses to climate change across the three major phases of the Coupled Model Intercomparison Project: CMIP3 (2007), CMIP5 (2012) and CMIP6 (2019)
- Aim: To quantity how biases in the NH storm tracks and jet streams have evolved with model developments, and to further our understanding of their responses to climate change

Diagnostics

Storm track

RMS(2-6 day bandpass-filtered MSLP)

- Widely-used variable capturing lower-tropospheric synoptic activity from daily MSLP output
- Enables a comparison across the CMIPs (more sophisticated storm tracking diagnostics are not possible with CMIP3 output)

Jet stream

Zonal wind at 250 hPa

- Monthly mean output

Data

CMIPs 3, 5 and 6 are used from "present-day" and "future" experiments:

	Present-day experiment (# models)	Future experiment (# models)
CMIP3	20C3M (19)	SRESA1B (17)
CMIP5	Historical (38)	RCP4.5 (31)
CMIP6	Historical (14)	SSP2-4.4 (12)

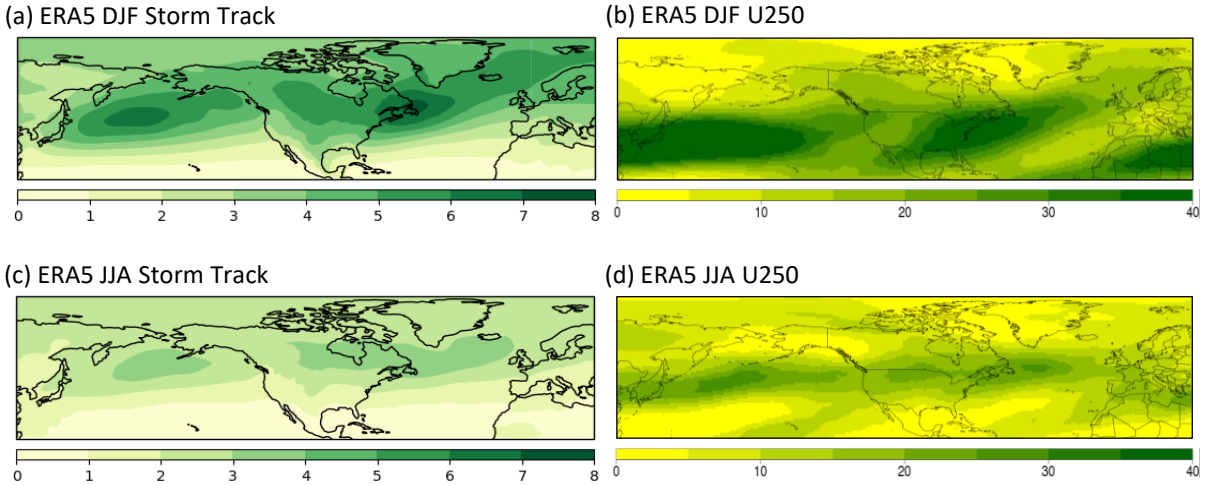
- We use the most recent 30-year period from the present-day simulations and the final 30 years of the 21st century from the future simulations
- We use a single ensemble member from as many models as possible (results are unchanged using ensemble mean for each model)

Present-day experiments are compared with the ERA5 reanalysis product

ERA5 climatology

Overview

- The two storm track maxima are the North Atlantic and North Pacific storm tracks
  - ➢ The jet stream maxima are located slightly to the south of the storm tracks
- In summer, the storm tracks and jet streams shift northward of their wintertime positions
  - ➢ Consistent with the seasonality of the Hadley Circulation
- In addition, the jet streams are more zonally-orientated in summer than they are in winter



ERA5 time mean (left) storm track [hPa] and (right) U250 [m/s] during (top) DJF and (bottom) JJA

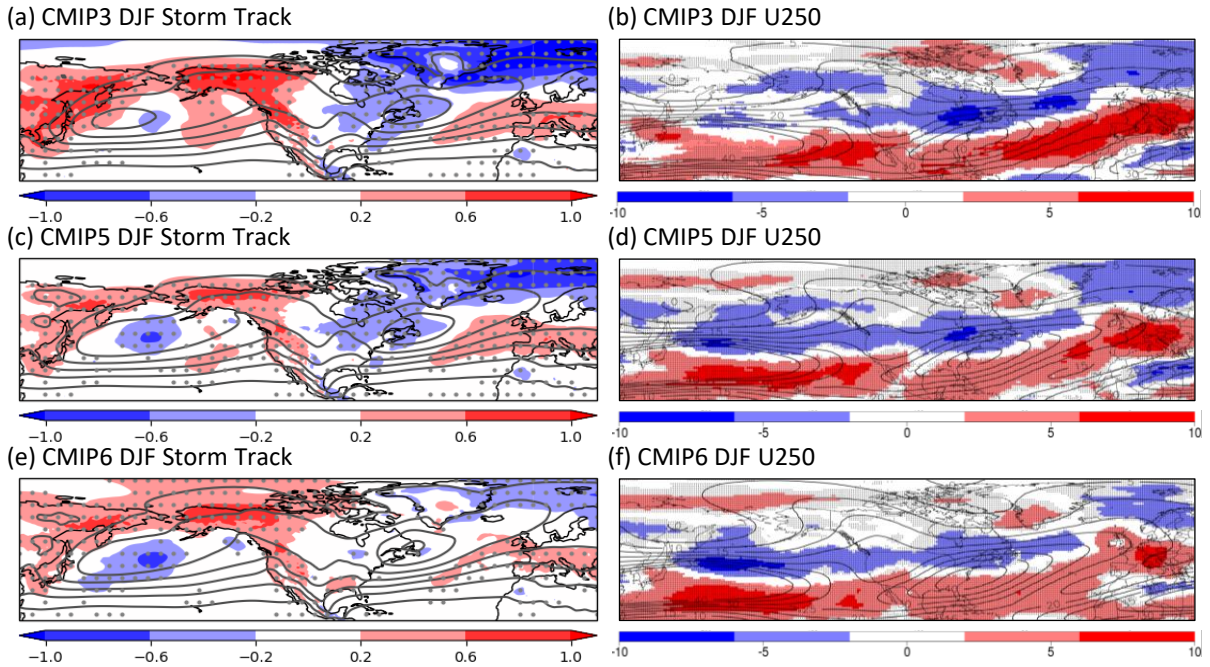
Wintertime BIASES - I

North Atlantic

- Storm track is too zonal in CMIP3
  - ➢ This is a well-known climate model bias (too many storms in Europe)
- There's a clear improvement with each new CMIP
  - ➢ But the spatial pattern stays the same
- The jet stream biases also reduce with each new CMIP, but not as dramatically as the storm track
  - ➢ The jet streams remain too far south in the CMIP6 models

North Pacific

- There's no clear improvement in either the storm track or jet stream across the CMIPs



Multi-model mean "present-day minus ERA5" bias of (left) the storm tracks [hPa] and (right) U250 [m/s]. The contours show the corresponding present-day climatology for each CMIP.

Wintertime BIASES - II

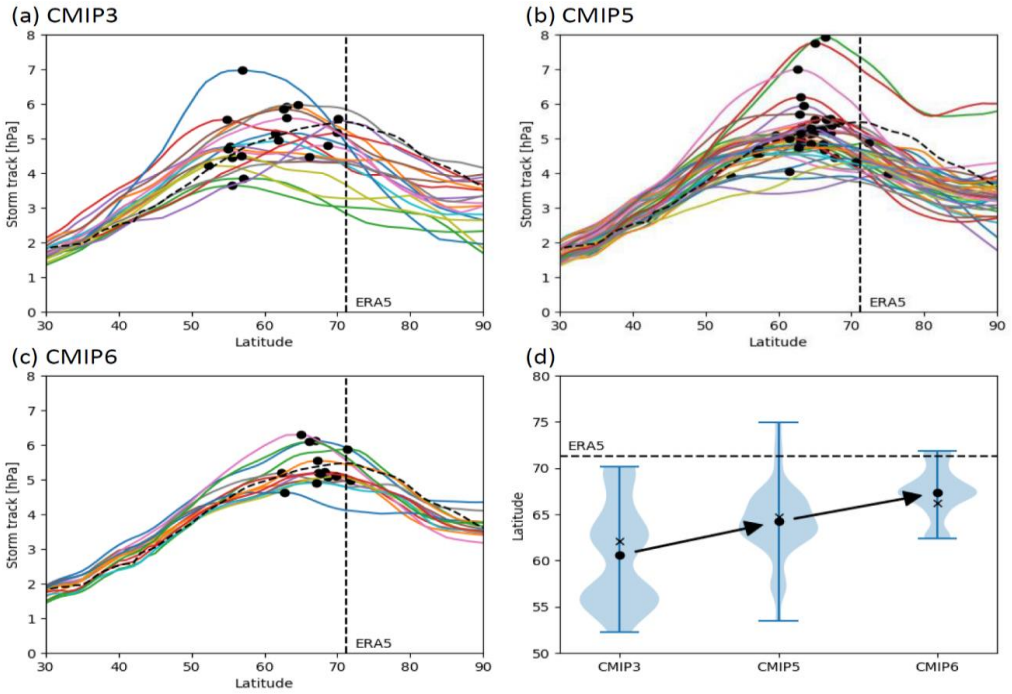
<u>The zonal bias of the North Atlantic storm track over western Europe in more detail</u>

- CMIP3 and CMIP5 have a large inter-model spread in the latitude of the storm track over western Europe

➢ They also place the storm track too far south on average

- The inter-model spread in the latitude of the storm track is substantially smaller in CMIP6

➢ There is also a marked improvement in the mean position



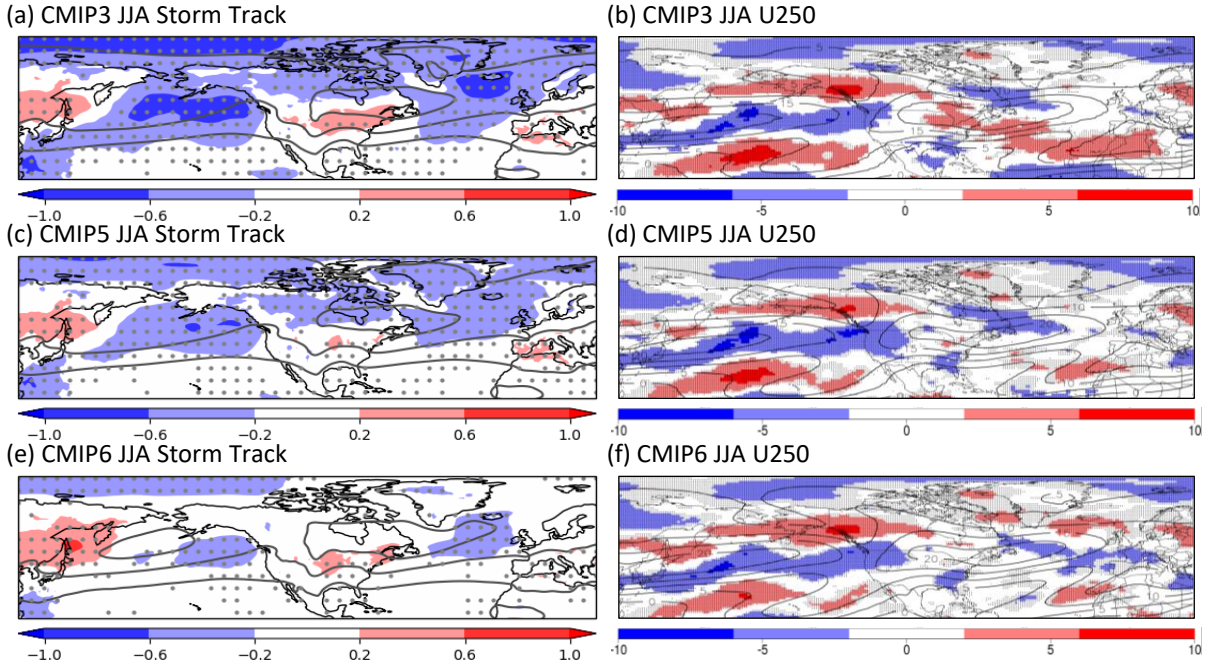
Meridional storm track profiles at 0E for each model. Black dots indicate the position of the maximum in each model. Dashed lines show ERA5. Panel (d) shows the distribution of maximum latitudes in each CMIP (dots=mean, crosses=median).

Summertime BIASES

- In CMIP3 both storm tracks are weaker than observed, whilst there is more storm activity over Eurasia and North America

- There is a marked improvement in storm track intensity going from CMIP3 to CMIP5 and from CMIP5 to CMIP6
  - ➢ CMIP6 bias is around 1/3 of the CMIP3 bias (similar spatial structure)

- The jet stream also shows some improvement in the North Atlantic, but not much change in the North Pacific

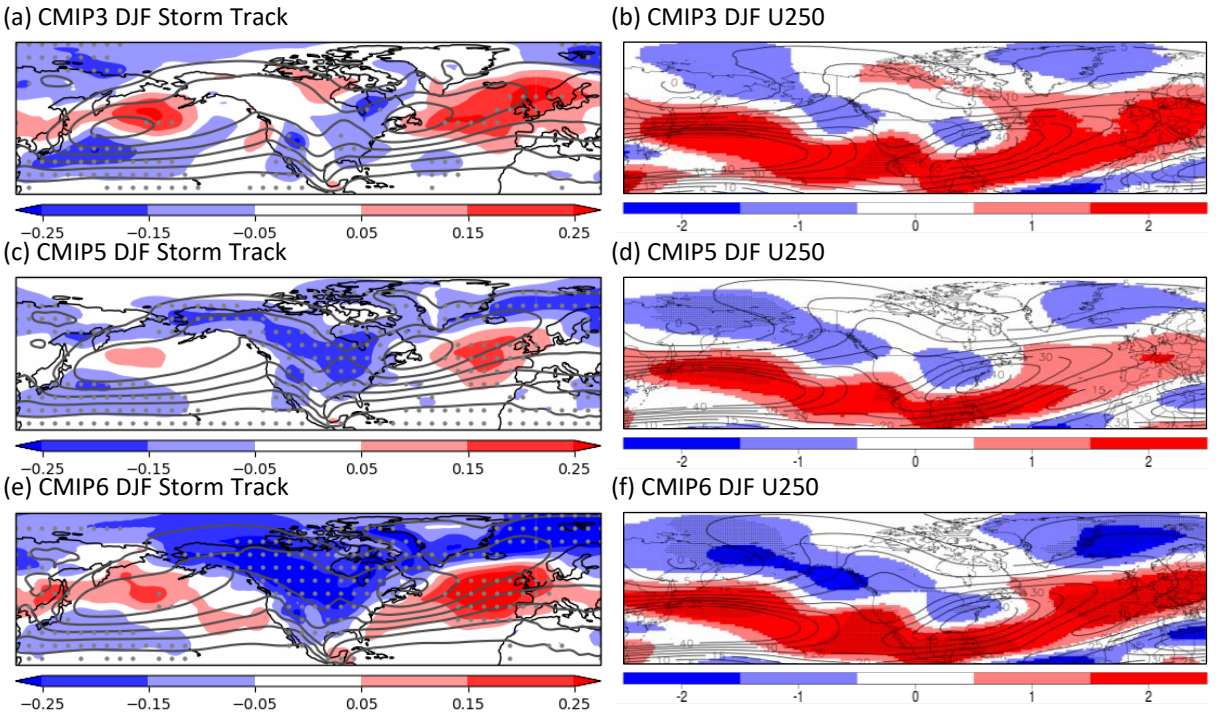


Multi-model mean “present-day minus ERA5” bias of (left) the storm tracks [hPa] and (right) U250 [m/s]. The contours show the corresponding present-day climatology for each CMIP.

Wintertime RESPONSES

North Atlantic

- CMIP3 storm track strengthens and extends into NW Europe
  - ➢ It also weakens slightly on its northern and southern flanks
- In CMIP5 the weakening on the northern flank is more pronounced, while the extension towards Europe is weaker
- Very similar pattern of response in CMIP6 but with a 50% larger magnitude
  - ➢ This is despite CMIPs 5 & 6 having the same forcing scenario – a result of larger climate sensitivities in CMIP6?



Multi-model mean “future minus present-day” response of (left) the storm tracks and (right) U250. The contours show the present-day climatology for each CMIP.

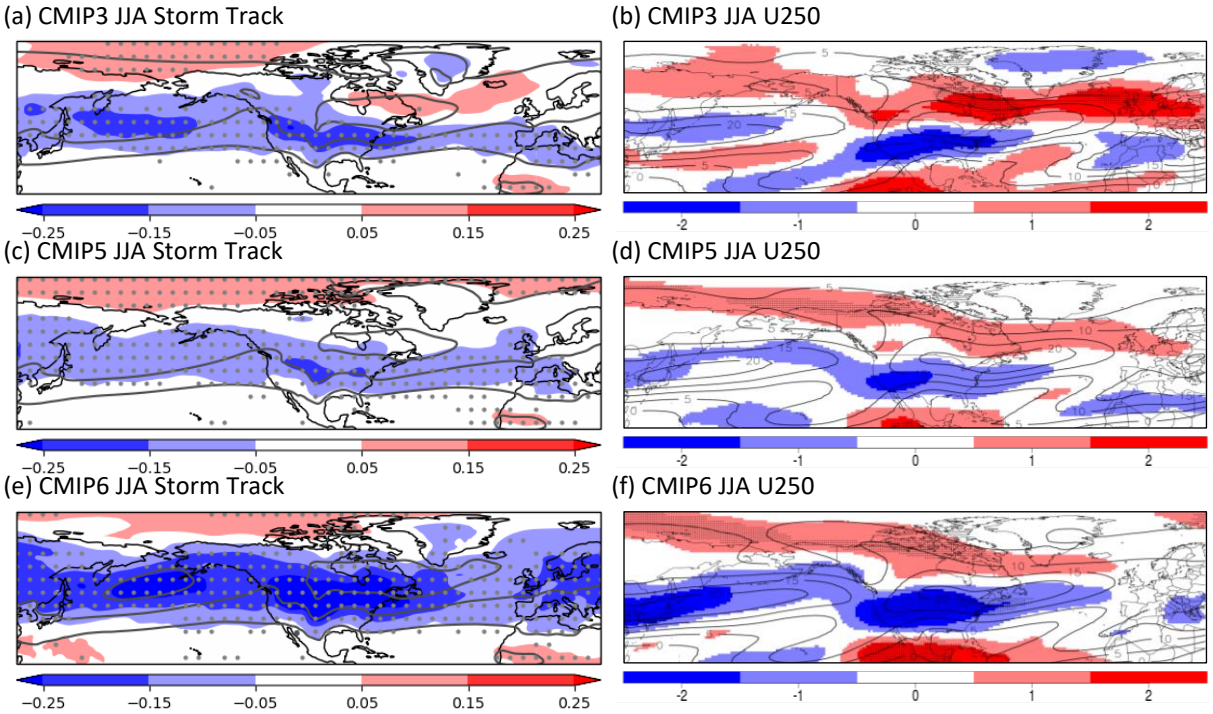
Summertime RESPONSES

North Atlantic

- Primarily a northward shift in the position of the storm tracks and jet streams in all CMIPs
  - ➢ Also a weakening of the storm track in CMIPs 5&6
- As in winter, it is interesting that the CMIP6 response is substantially larger in magnitude than in the CMIP5 response

North Pacific

- Response is dominated by a weakening of the storm track



Multi-model mean “future minus present-day” response of (left) the storm tracks and (right) U250. The contours show the present-day climatology for each CMIP.

Summary

- The spatial pattern of biases in the CMIP3, CMIP5 and CMIP6 models is similar, but the magnitude of biases in CMIP6 is substantially lower
- The spatial pattern of the climate change response in the NH storm tracks and jet streams is similar in the CMIP3, CMIP5, and CMIP6 models
- The SSP2-4.5 response in CMIP6 is larger than the RCP4.5 CMIP5 response, consistent with the larger climate sensitivities in CMIP6

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