Drivers of biases in the extratropical storm tracks in CMIP6

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Dynamics of the atmospheric circulation in past, present and future climates

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Overview

- CMIP6 present the latest developments in earth-system modelling and are advances on the previous generation CMIP5 models
- Storm tracks are vital components in the global energy balance and also with regards to natural hazards through risks from severe wind, flooding, etc.
- CMIP5 models had persistent biases in the representation of the mid-latitude storm tracks such as:
  - Persistent zonal/equatorward biases in the NH winter (e.g. Zappa et al., 2013)
  - Equatorward bias in the SH winter/summer (e.g. Chang et al., 2012; 2013)
  - Under-estimation in cyclone peak intensity – particularly for the most intense cyclones

Research Aims

- Do the new CMIP6 models offer developments/advances from the biases seen in CMIP5 models
- What is the impact in horizontal atmospheric resolution on mean state biases?
- Are bomb cyclones adequately represented?
- Is it possible to link storm track biases to specific model mechanisms/drivers/large-scale features?

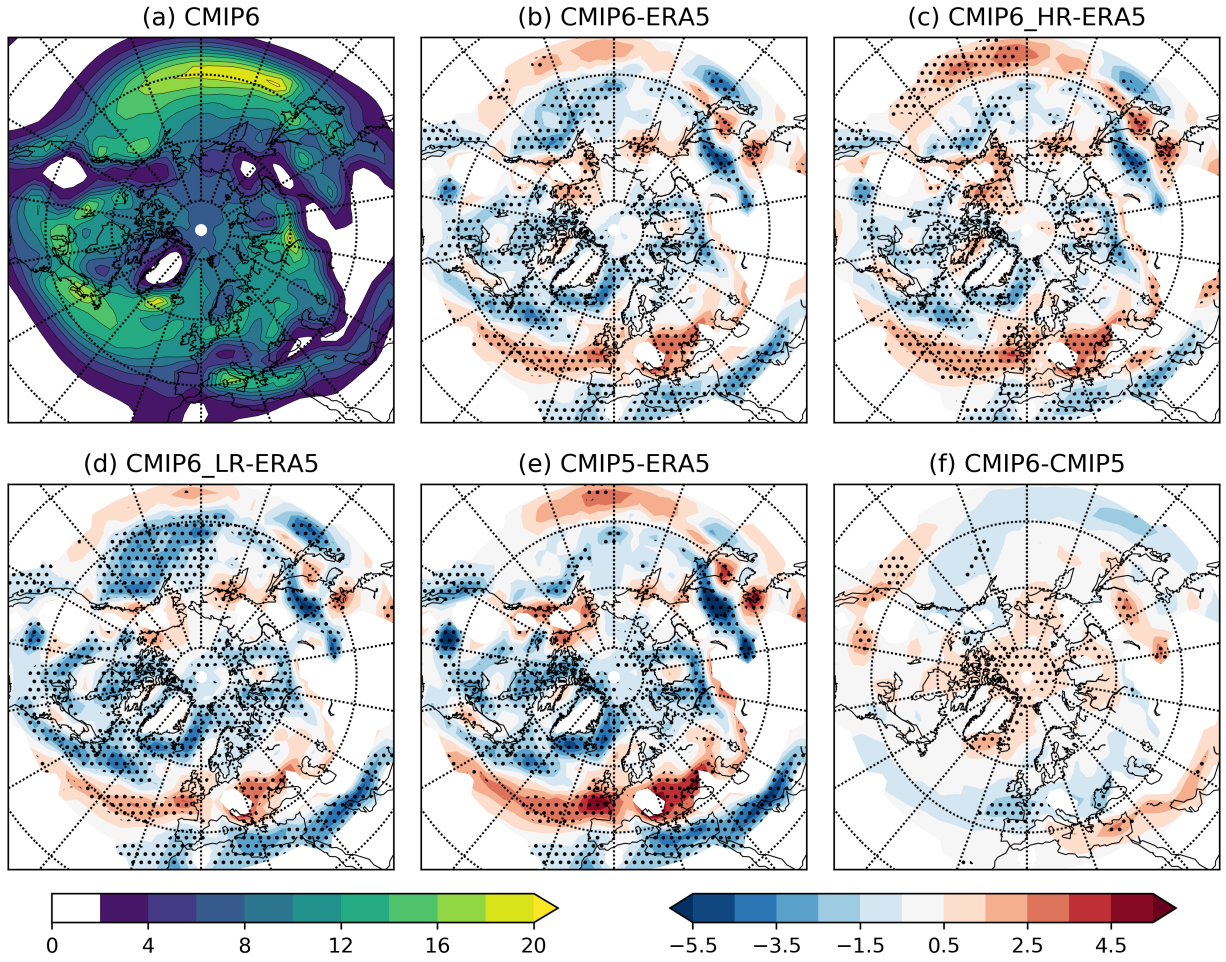
Data Usage & Identification Method

- 20 CMIP6 historical simulations (1979-2014)
  - 10 high-resolution (nominal atmospheric resolution 100km)
  - 10 low-resolution (nominal atmospheric resolution 250km)
- 16 corresponding amip runs
- 26 CMIP5 models (1979-2004)
- ERA5 used as a benchmark (1979-2014)

- Cyclones identified using Hodges (1994) method
  - Identifies cyclones using 6-hourly relative vorticity filtered to T42

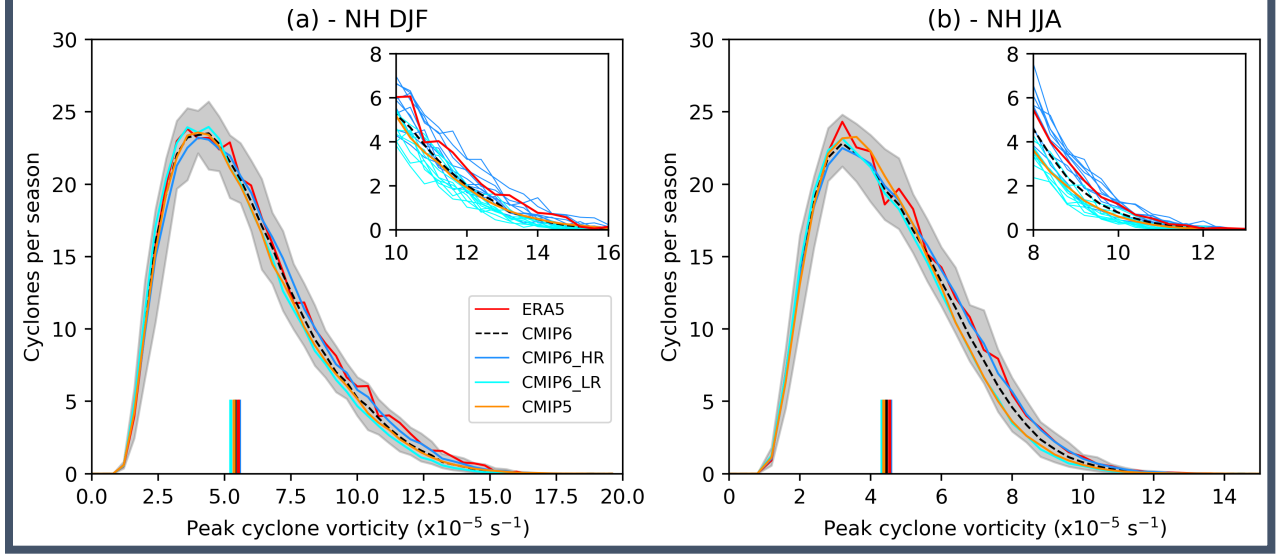
- Cyclone intensity defined as lifecycle peak T42 vorticity
- Bomb cyclones identified following definition of Sanders & Gyakum (1980)
  - Pressure drop of 24 hPa in 24 hours with latitudes scaled to 60°N/S

Biases in NH DJF



Seasonal Mean Storm Track Density and anomalies (units cyclones per month)

Seasonal Cyclone Peak Intensity (Vorticity)



- Biases that were present in the CMIP5 ensemble still remain – although to a lesser extent
  - e.g. Zonal bias in N. Atl, equatorward shift in N. Pac, extension into western Europe
- Improvements in storm track structure and number of cyclones with higher resolution
- Improvement in peak intensity of high intensity cyclones with higher resolution
- Under-estimation of numbers in JJA (further slides)

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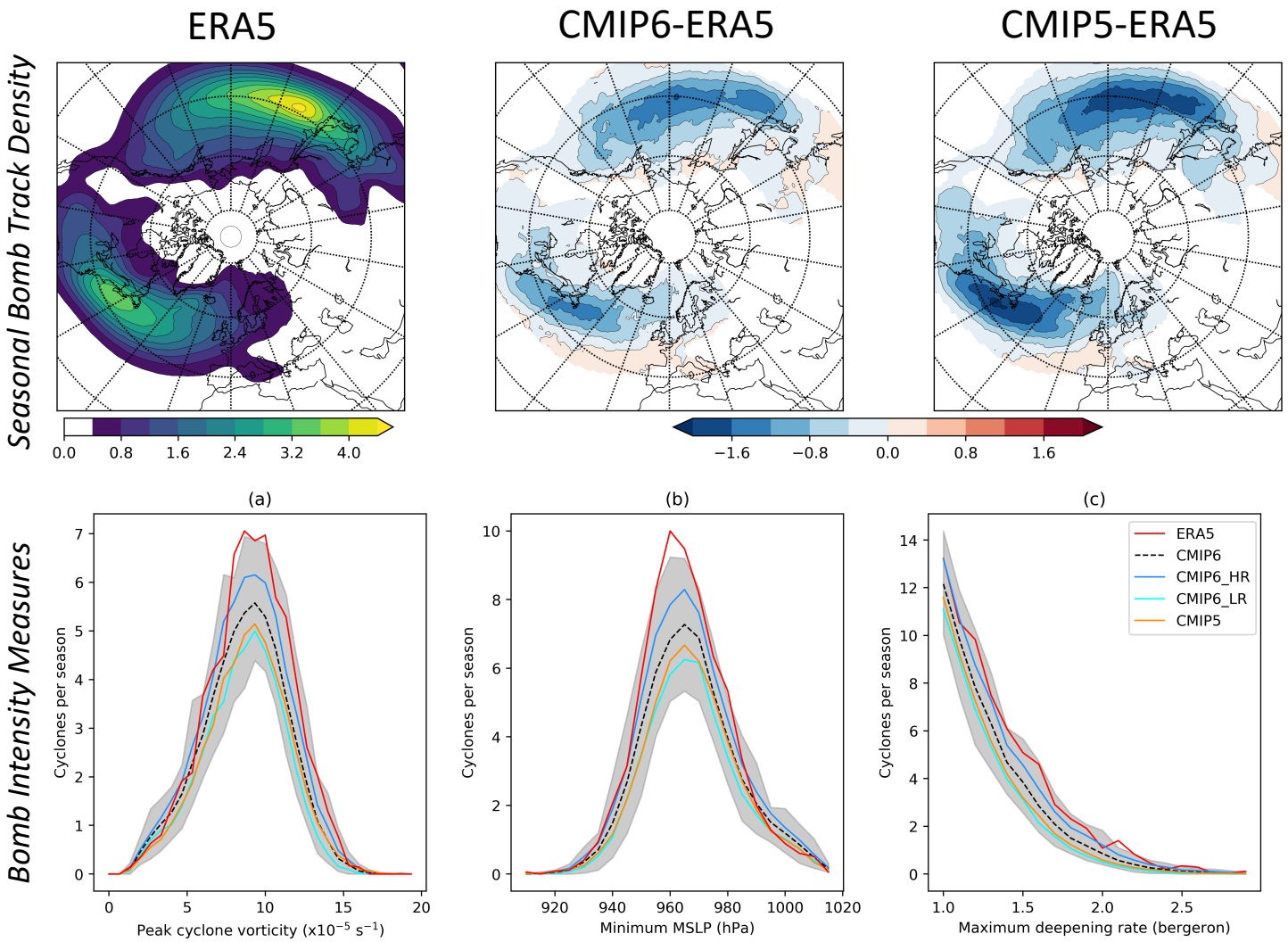
Biases in NH DJF bomb cyclones



- Both CMIP5 and CMIP6 models under-estimate the frequency of bomb cyclones
  - CMIP6 outperform CMIP5
- Location of cyclones well represented by models
- Peak intensities (shape of distributions) correct by models
- Under-estimation in frequency that is worse with lower resolution
- Reduced frequency appears to be from inability of models to capture rapid deepening of bomb cyclones
- Identical story for bomb cyclones in SH (further slides)

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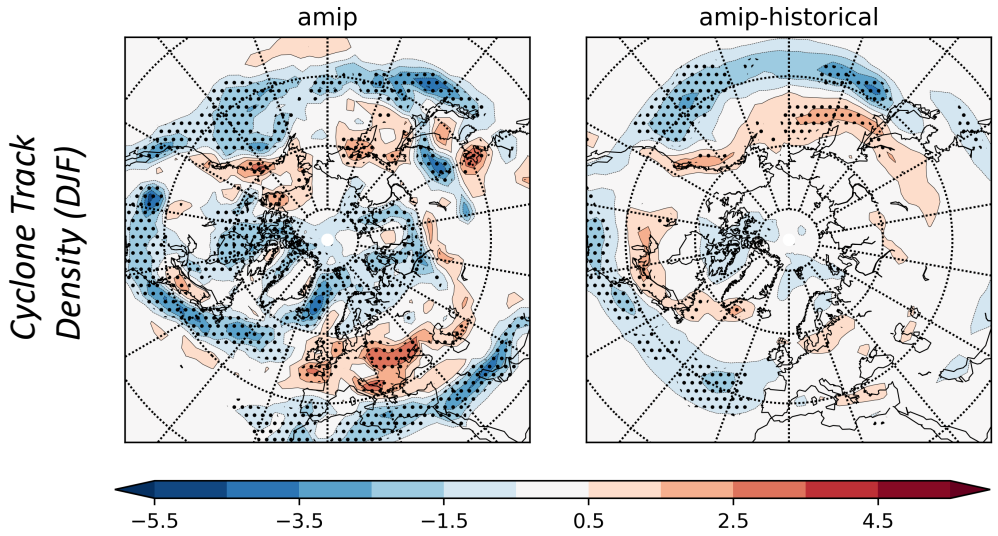
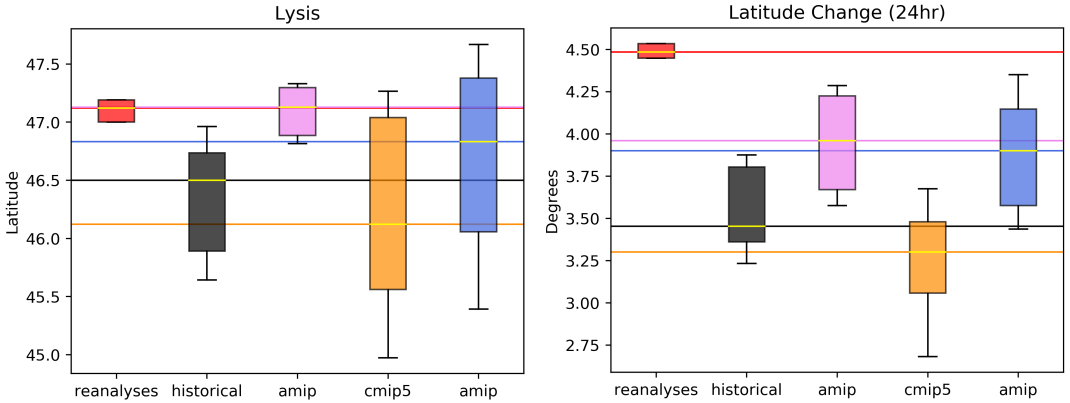
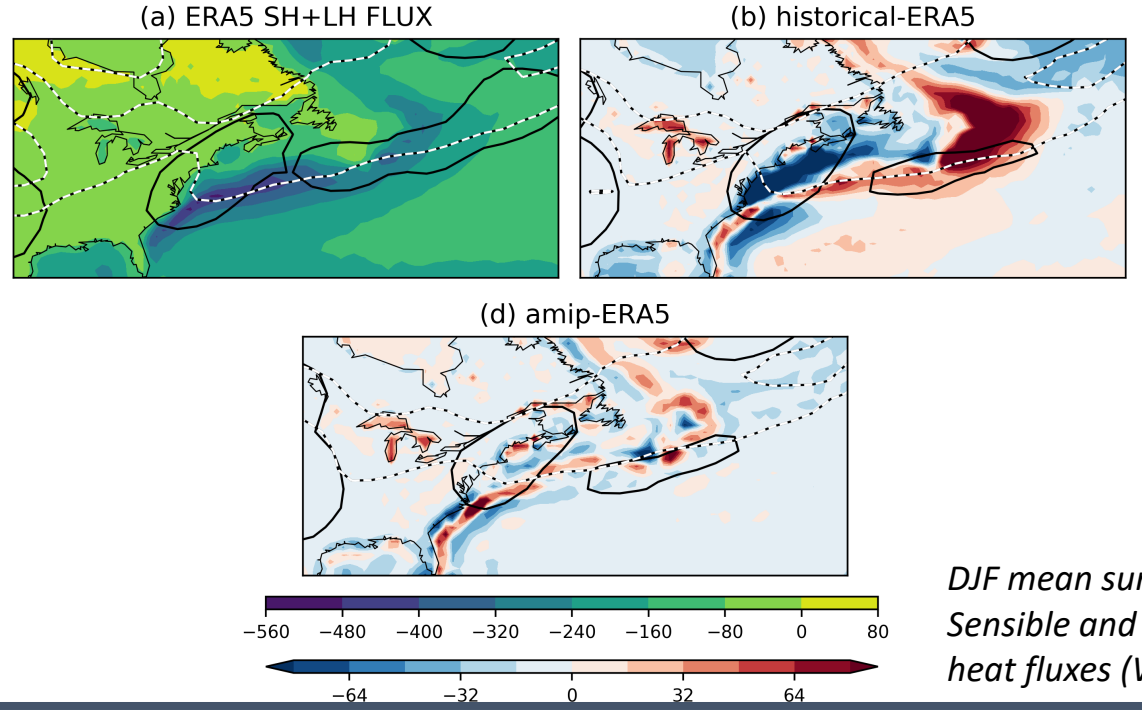
Drivers of NH DJF Biases





Model mean distributions of cyclolysis and poleward movement



DJF mean surface Sensible and latent heat fluxes (W m^{-2})

- Poleward shift in major storm tracks in amip runs
  - Reduces notable biases in N. Atl and N. Pac
- Minor shift in cyclogenesis latitude – large shift in cyclolysis latitude for amip
  - Larger poleward movement & reduction of zonal/equatorward biases
- Decreased sensible/latent heat fluxes from ocean to atmosphere in coupled runs associated with SST errors
  - Less heat flux = slower intensification = reduced poleward movement

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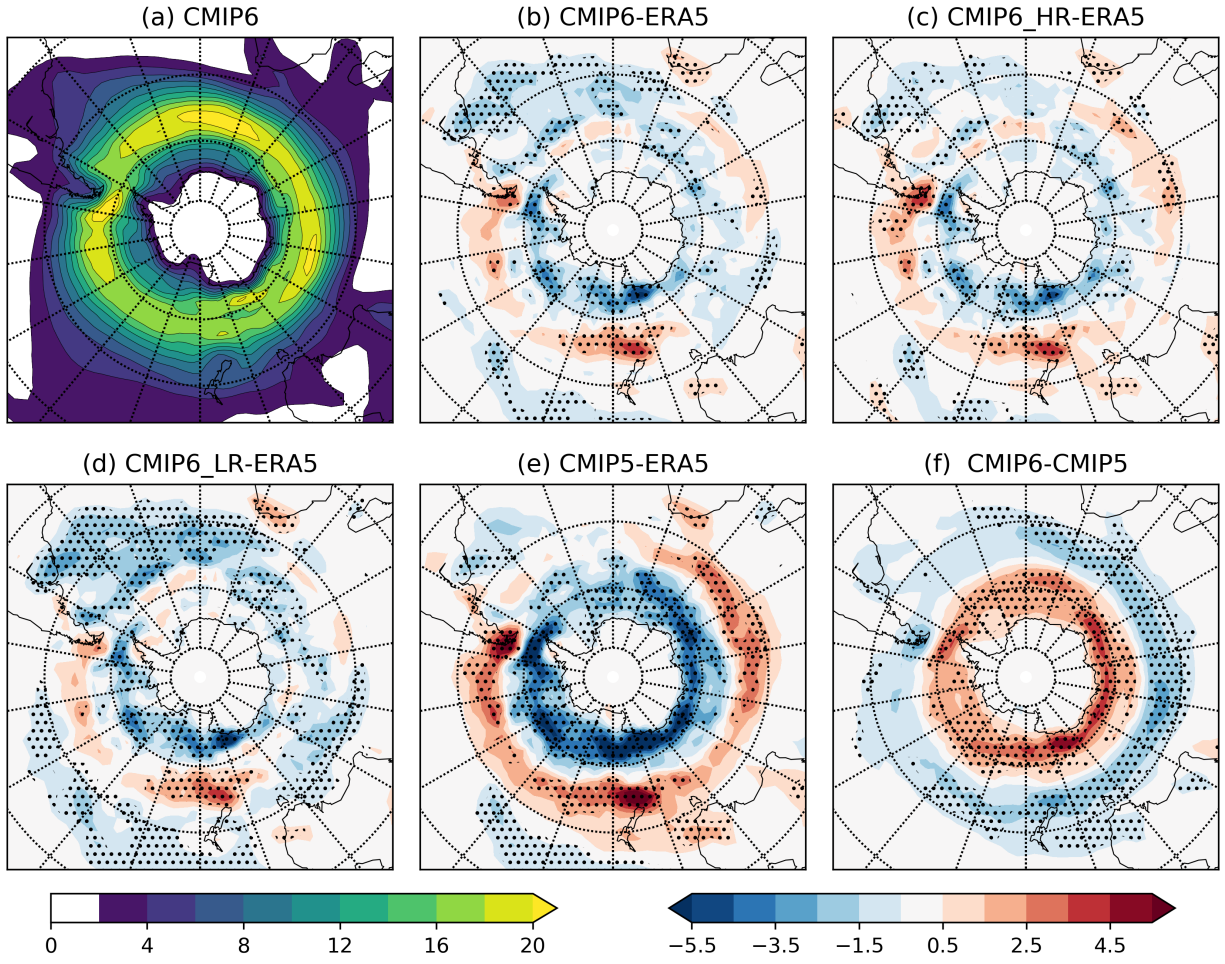
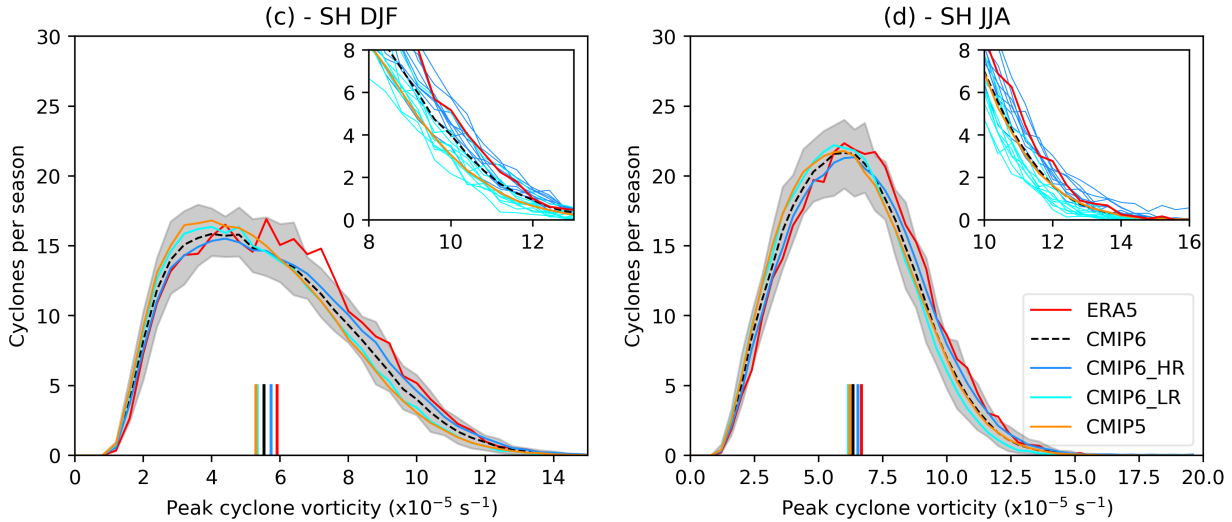
Biases in SH DJF



Seasonal Mean Storm Track Density and anomalies (units cyclones per month)

Seasonal Cyclone Peak Intensity (Vorticity)



- Some evidence of small equatorward bias of tracks in CMIP6 relative to ERA5 (South Pacific, Indian Ocean)
- Much reduced equatorward bias compared to the CMIP5 bias around entire hemisphere
- Less impact on storm track structure/cyclone numbers with resolution as seen in NH
- Tendency for higher peak intensity with higher resolution to more closely matching reanalysis
- Similar poleward shift in JJA, however, less pronounced (further slides)

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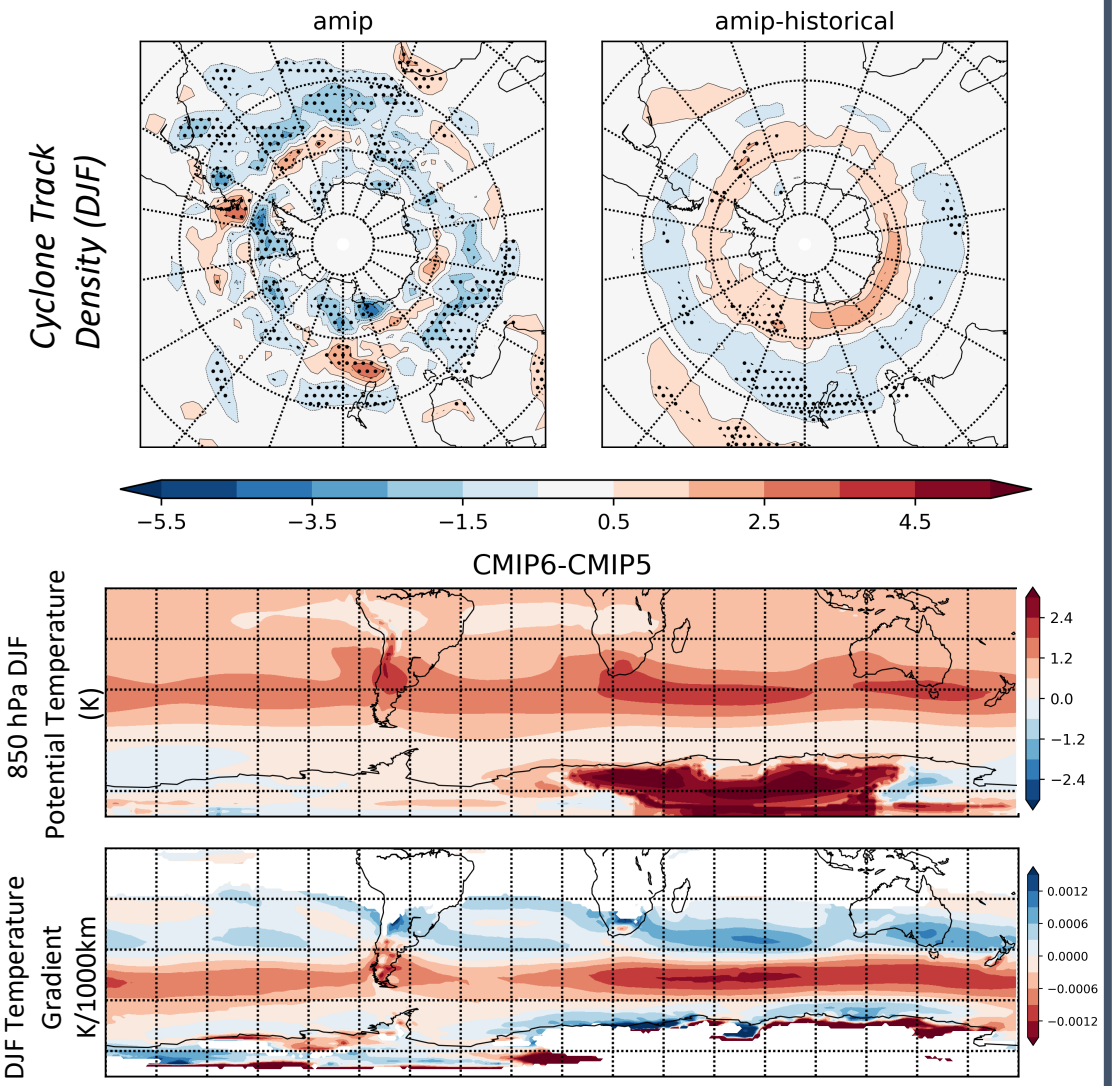
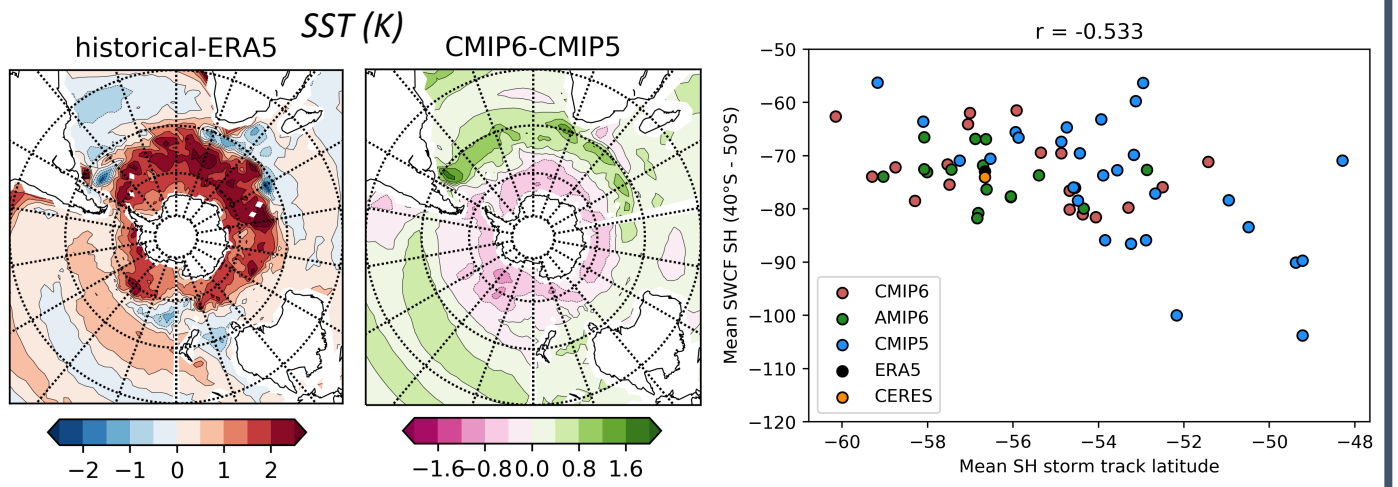
Drivers of SH Biases





- AMIP tracks shifted farther poleward for entire SH (as in NH)
- Poleward shift of hemispheric temperature gradient associated with large mid-latitude heat increase compared to CMIP5
- Heat increase associated with expansion of Southern Ocean SST anomalies – warmer than CMIP5 40-50°S
- Storm track latitude associated with reduced anomalies in shortwave cloud forcing
  - Less negative anomalies in shortwave cloud forcing – increased surface radiation – more ocean heat uptake

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Concluding Remarks

- CMIP6 models generally perform better than CMIP5 models with regards to simulating the mid-latitude storm tracks in both hemispheres
  - Same general pattern of the biases
  - Slightly reduced zonal/equatorward biases in the NH and improved cyclone numbers
  - Large poleward shift in the SH
  - Improved number of bomb cyclones, which improves with increasing resolution (although still under-estimated)
- Biases are reduced with amip runs – general poleward shift of storm tracks
- SST errors and associated reductions in latent/sensible heat fluxes negatively impact poleward movement of cyclones (and hence zonal biases of storm tracks) in NH coupled runs
- Poleward shift of temperature gradient (and storm track) in SH linked to elevated SSTs in CMIP6 relative to CMIP5
  - Driven by changes in cloud processes and increased heating of lower mid-latitude region

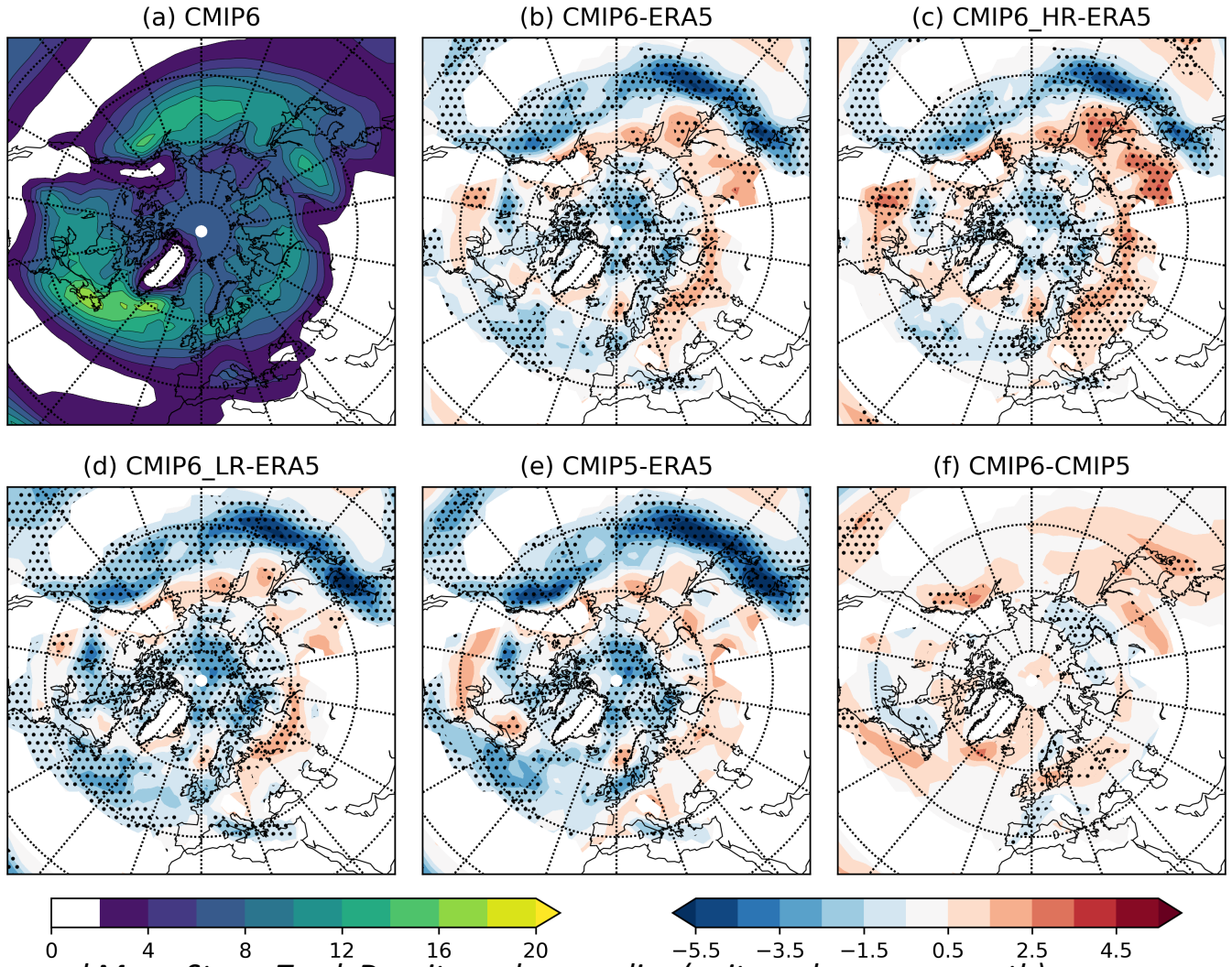
Take-Home Messages

- CMIP6 generally better than CMIP5 at representing extratropical storm tracks
- There are still biases in CMIP6 that persist from CMIP5
- Bomb cyclones under-estimated with number appearing very sensitive to atmospheric resolution
- Can trace errors in storm track to mean state biases in models such as SSTs and cloud processes

- Paper recently accepted on evaluation of storm tracks and CMIP5 comparison:

  Priestley M., D. Ackerley, J.Catto, K. Hodges, R. McDonald, R. Lee. *An Overview of the Extratropical Storm Tracks in CMIP6 Historical Simulations*. Journal of Climate. 2020.

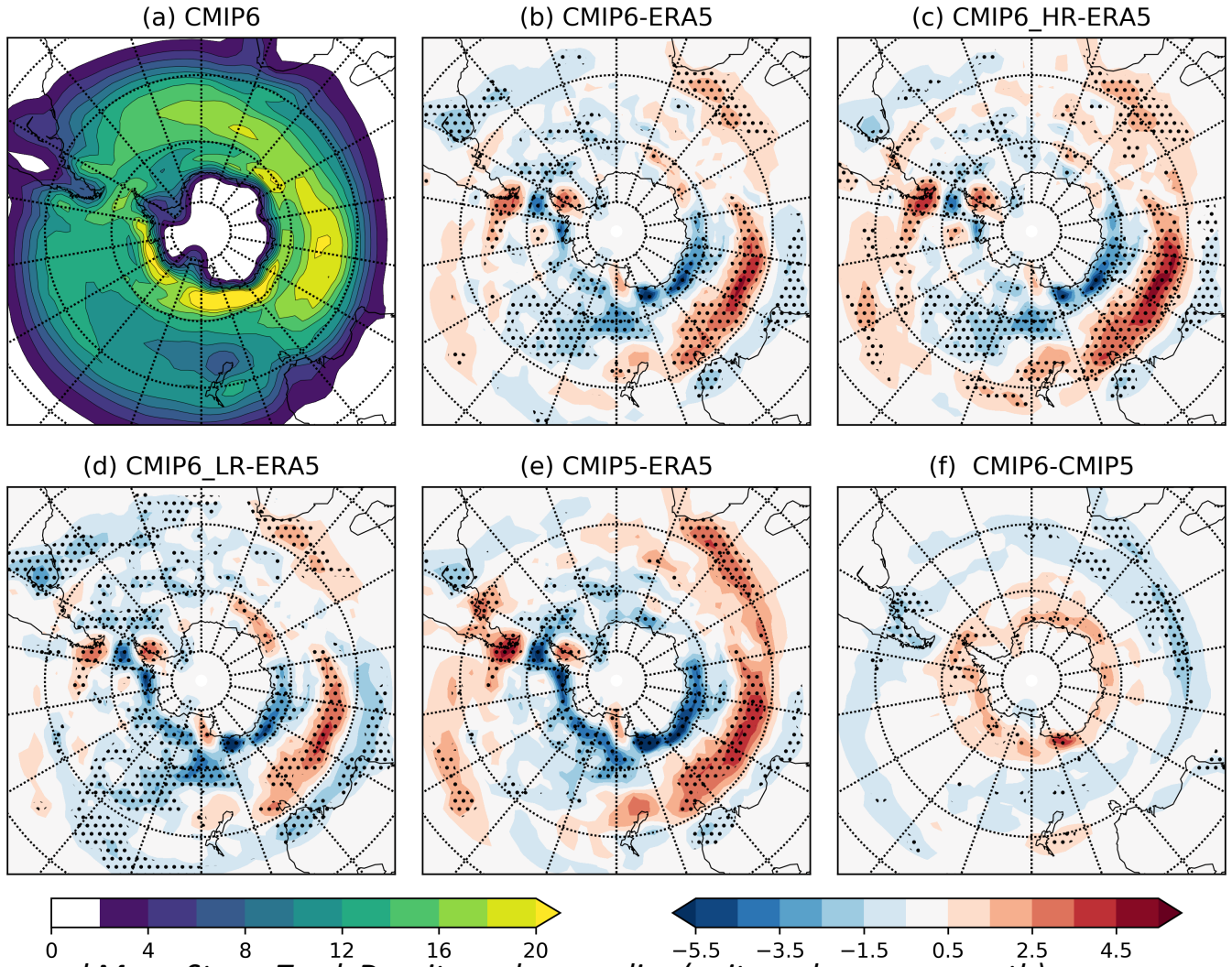
Further Slides – Storm Track Biases NH JJA



Seasonal Mean Storm Track Density and anomalies (units cyclones per month)

- Under-estimation of cyclone numbers for both main storm tracks
- Persistent feature over western North Pacific
  - Genesis latitude bias too poleward by several degrees
- Less reduction over western North Atlantic with increased resolution
- Slight improvement in cyclone numbers from CMIP5 to CMIP6

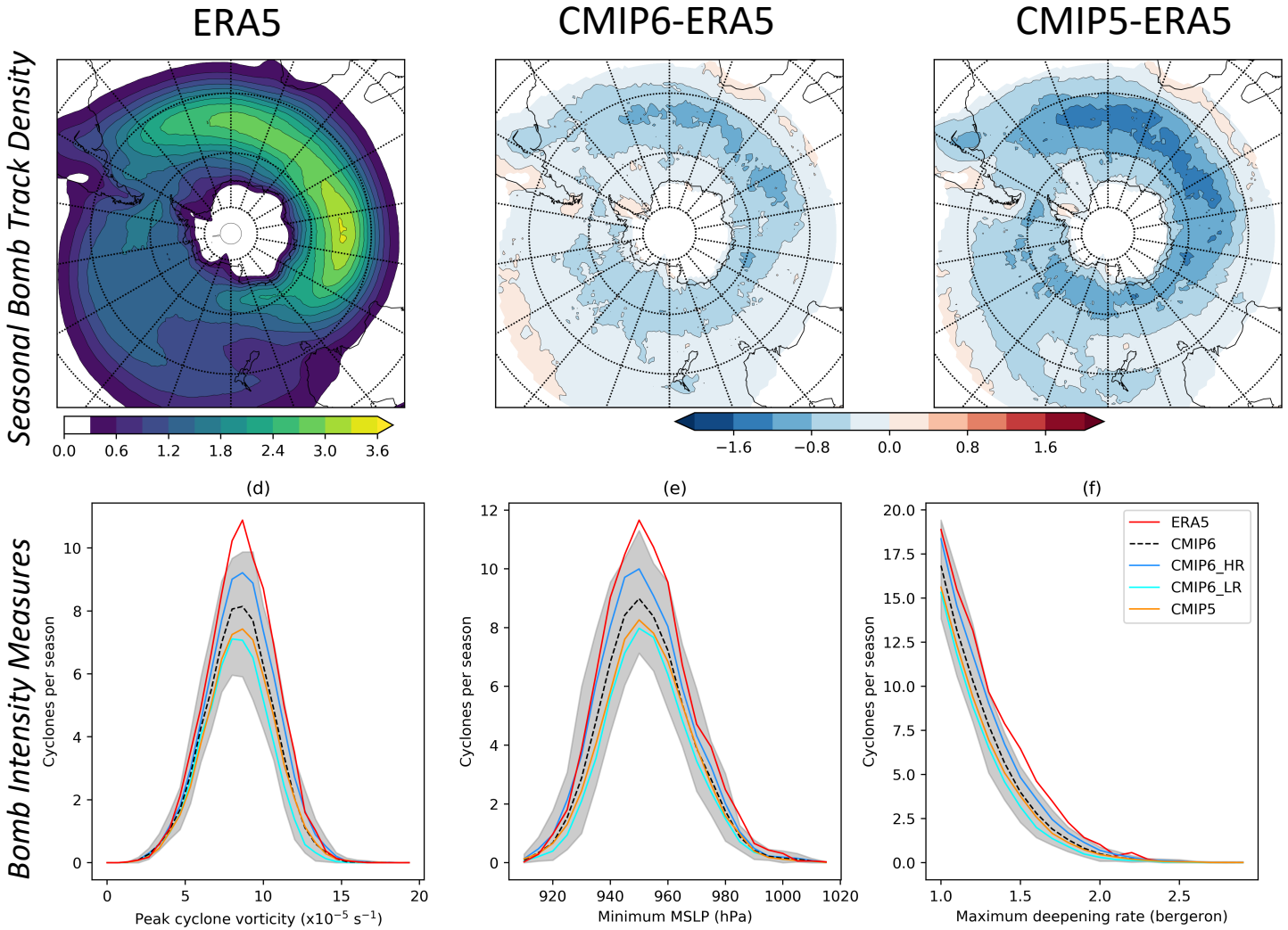
Further Slides – Storm Track Biases SH JJA



Seasonal Mean Storm Track Density and anomalies (units cyclones per month)

- Slight equatorward bias notable in Indian Ocean and South Pacific sectors
- Large bias to south of Australia that persists despite resolution improvements and model generation
- Reduced equatorward bias in CMIP6 relative to CMIP5

Further Slides – Bomb Cyclones SH JJA



- Under-estimation in bomb cyclone number for both CMIP5 and CMIP6 (as in NH)
- Improvement in number for CMIP6
- Resolution appears to have impact on number of bomb cyclones identified with higher resolution models better resolving rapid intensification processes