The large scale atmospheric circulation in CESM2 and comparison with other CMIP models

Isla Simpson

+

CAM/WACCM development teams,

Climate and Global Dynamics Laboratory, NCAR

Aug 7, 2019

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Data

(All comparisons made over 1979-2014. All fields re-gridded to a 2deg grid. Only DJF and JJA considered)

- Observation based:

  Reanalyses: ERA5 (primary observational baseline), ERA-Interim, MERRA2, JRA-55, ERA20C, 20thC

- CESM2

  CESM2-CAM6 coupled historical (BCAM6) x 11
  CESM2-WACCM6 coupled historical (BWACCM6) x 3
  CESM2-CAM6 prescribed observed SST, historical (FCAM6) x 3
  CESM2-WACCM6 prescribed observed SST, historical (FWACCM6) x 3

  (B = coupled
  F = prescribed observed SSTs)

- CESM1

  Large Ensemble coupled historical + rcp8.5 (LENS) x 40

- CMIP

  CMIP5: 35 monthly (all available members), 16 daily (one member)

  CMIP6: 17 monthly (all available members), 14 daily (one member)

Quantifying Errors

Normalized Mean Square Error (NMSE):

$$NMSE(X_{mod}) = \frac{\overline{(X_{mod} - X_{obs})^2}}{\overline{(X'_{obs})^2}}$$

Williamson (1995)
Kiehl et al (1998)
Collins et al (2006)
Neale et al (2013)

X_{mod}= model field X_{obs}= observed (reanalysis) field

$\overline{(\,.\,)}$= spatial mean $(\,.\,)'$= deviation from spatial mean

Quantifying Errors

Normalized Mean Square Error (NMSE):

$$NMSE(X_{mod}) = \frac{\overline{(X_{mod} - X_{obs})^2}}{\overline{(X'_{obs})^2}}$$

Williamson (1995)
Kiehl et al (1998)
Collins et al (2006)
Neale et al (2013)

$$U = \left(\frac{\overline{X_{mod}} - \overline{X_{obs}}}{\sigma_{obs}}\right)^2$$

Unconditional bias

$$C = \left(r - \frac{\sigma_{mod}}{\sigma_{obs}}\right)^2$$

Conditional bias

$$P = (1 - r^2)$$

Phase error

X_{mod}= model field X_{obs}= observed (reanalysis) field

$\overline{(.)}$= spatial mean $(.)'$= deviation from spatial mean

σ_{mod}= standard deviation of model field σ_{obs}= standard deviation of observed field

r = correlation between modelled and observed field

Quantifying Errors

Normalized Mean Square Error (NMSE):

Williamson (1995)
Kiehl et al (1998)
Collins et al (2006)
Neale et al (2013)

$$NMSE(X_{mod}) = \frac{\overline{(X_{mod} - X_{obs})^2}}{\overline{(X'_{obs})^2}}$$

$$U = \left(\frac{\overline{X_{mod}} - \overline{X_{obs}}}{\sigma_{obs}}\right)^2 \qquad C = \left(r - \frac{\sigma_{mod}}{\sigma_{obs}}\right)^2 \qquad P = (1 - r^2)$$

Scaled Variance Ratio ⟶ $$SVR = \left(\frac{\sigma_{mod}}{\sigma_{obs}}\right)^2 \times NMSE(X_{mod})$$

X_{mod}= model field X_{obs}= observed (reanalysis) field

$\overline{(\,.\,)}$= spatial mean $(\,.\,)'$= deviation from spatial mean

σ_{mod}= standard deviation of model field σ_{obs}= standard deviation of observed field

r = correlation between modelled and observed field

Quantifying Errors

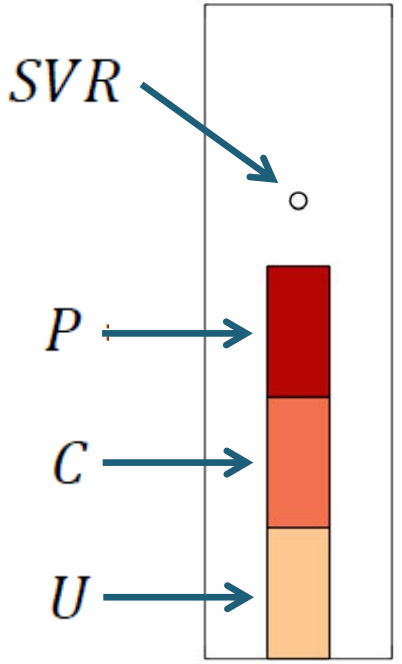
Normalized Mean Square Error (NMSE):

Williamson (1995)
Kiehl et al (1998)
Collins et al (2006)
Neale et al (2013)

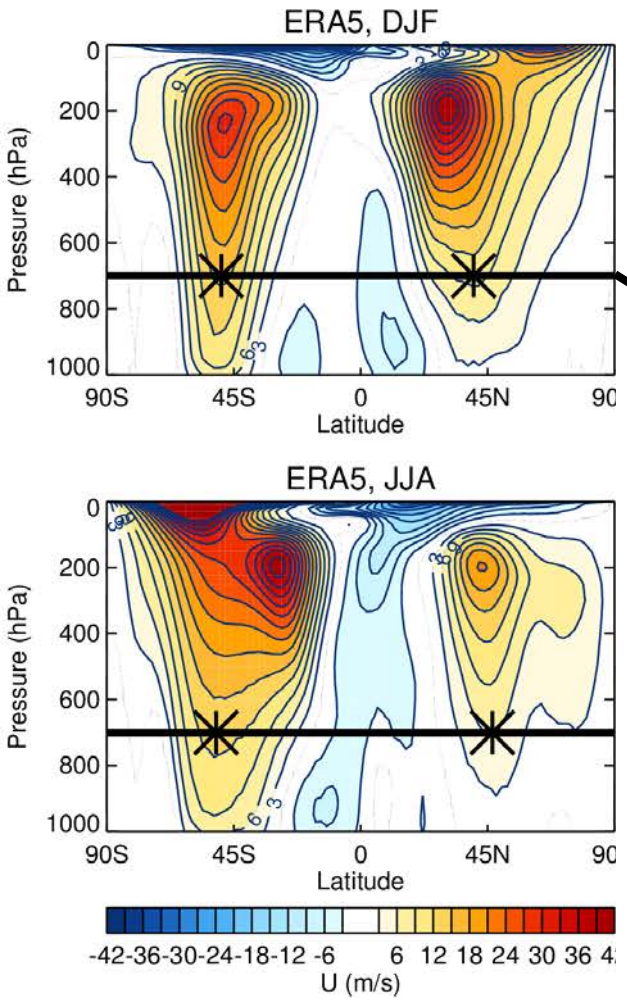
$$NMSE(X_{mod}) = \frac{\overline{(X_{mod} - X_{obs})^2}}{\overline{(X'_{obs})^2}}$$

$$U = \left(\frac{\overline{X_{mod}} - \overline{X_{obs}}}{\sigma_{obs}}\right)^2 \qquad C = \left(r - \frac{\sigma_{mod}}{\sigma_{obs}}\right)^2 \qquad P = (1 - r^2)$$

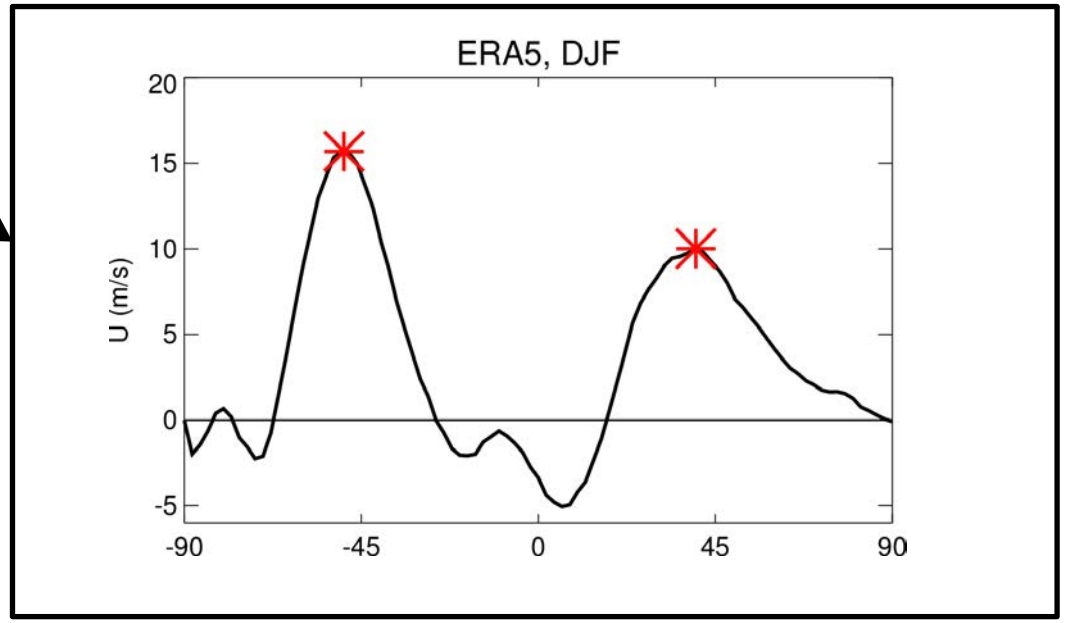
Scaled Variance Ratio → $$SVR = \left(\frac{\sigma_{mod}}{\sigma_{obs}}\right)^2 \times NMSE(X_{mod})$$



Southern Hemisphere zonal mean jet latitude and speed

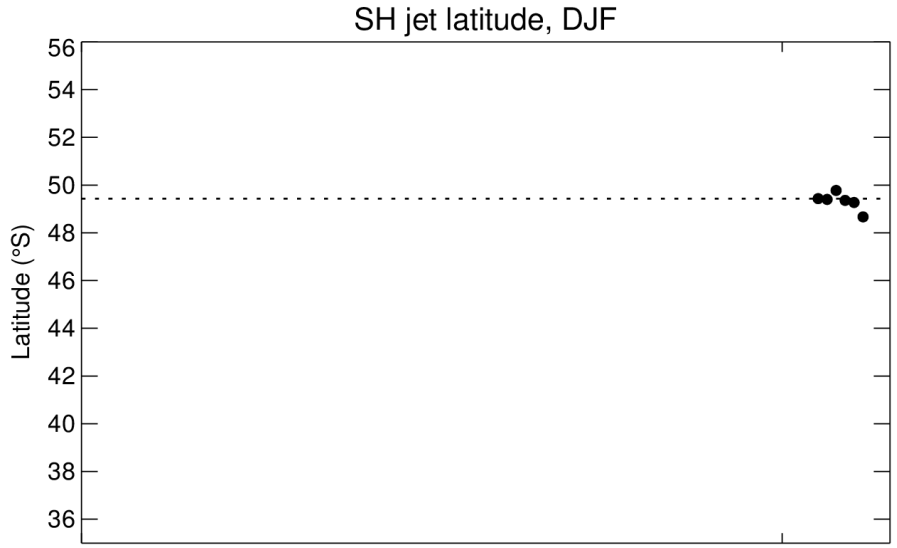


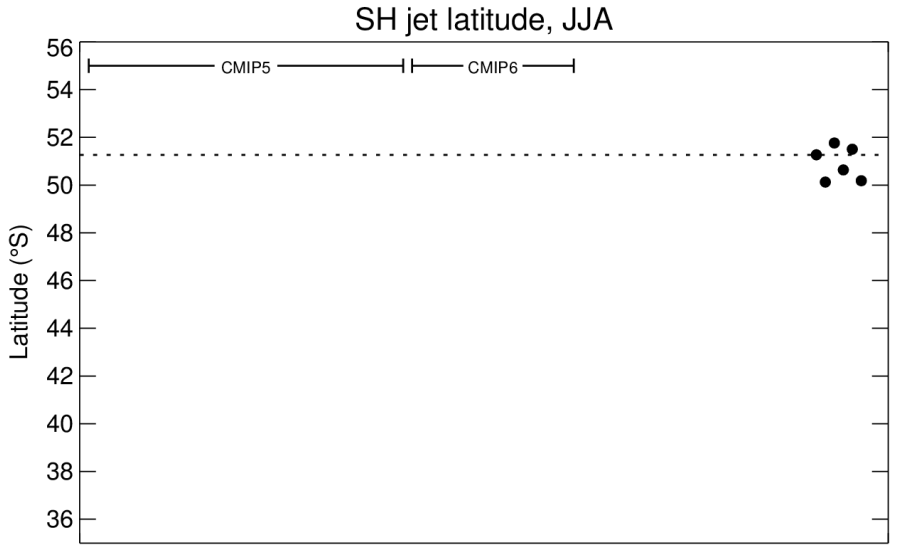
Calculated using 700hPa zonal mean zonal wind



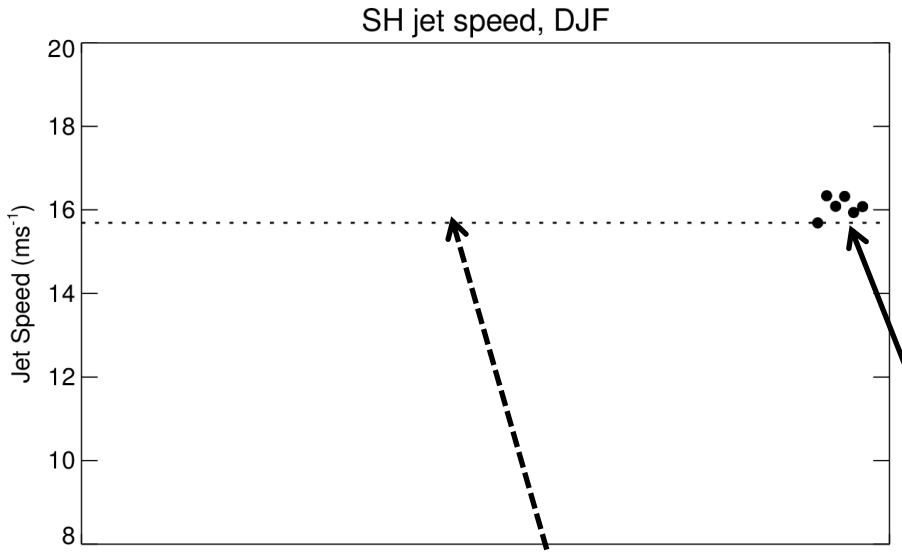
Many CMIP5 models exhibited an equatorward bias in the SH jet latitude (Fyfe and Saenko 2006, Kidston and Gerber 2010, Swart and Fyfe 2012, Wilcox et al 2012, Barnes and Polvani 2013, Bracegirdle et al 2013, Simpson and Polvani 2016)

Jet Latitude



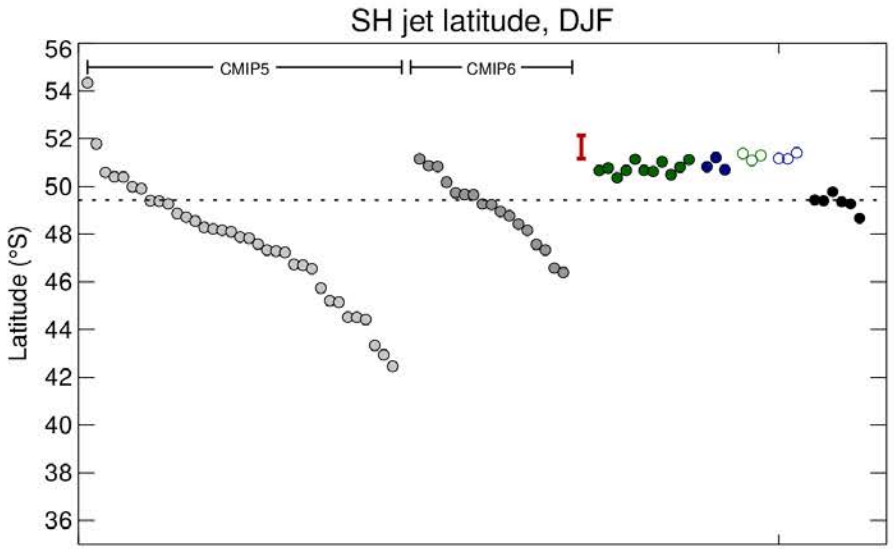


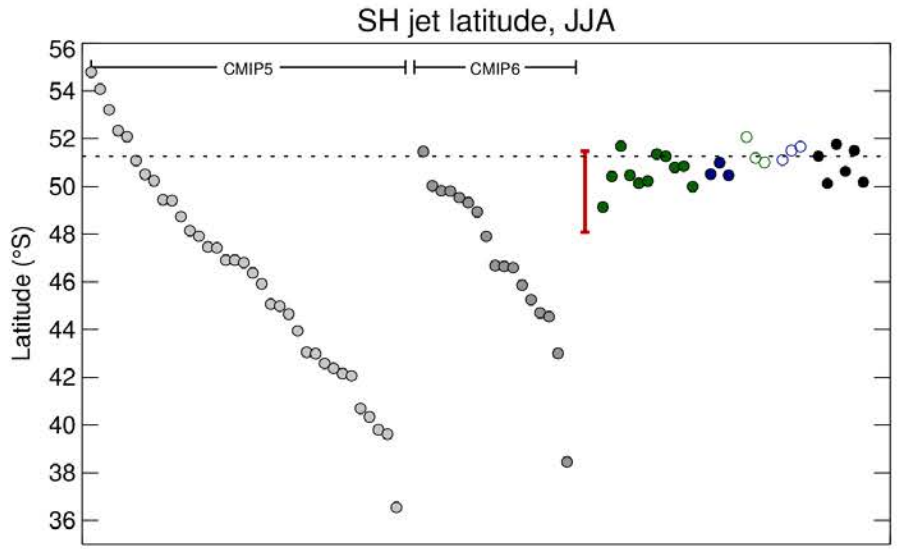
Jet Speed



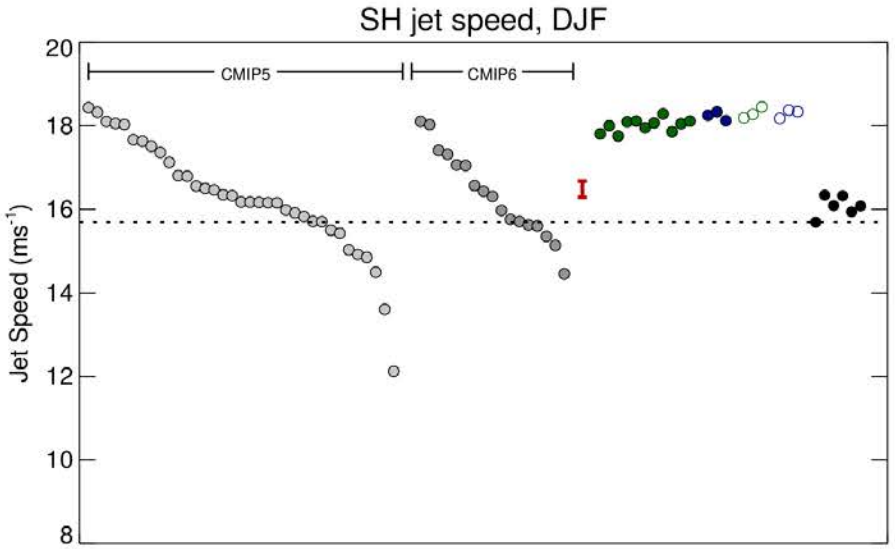
Realyses: ERA5, ERA-Interim, MERRA2, JRA-55, ERA20C, 20CR

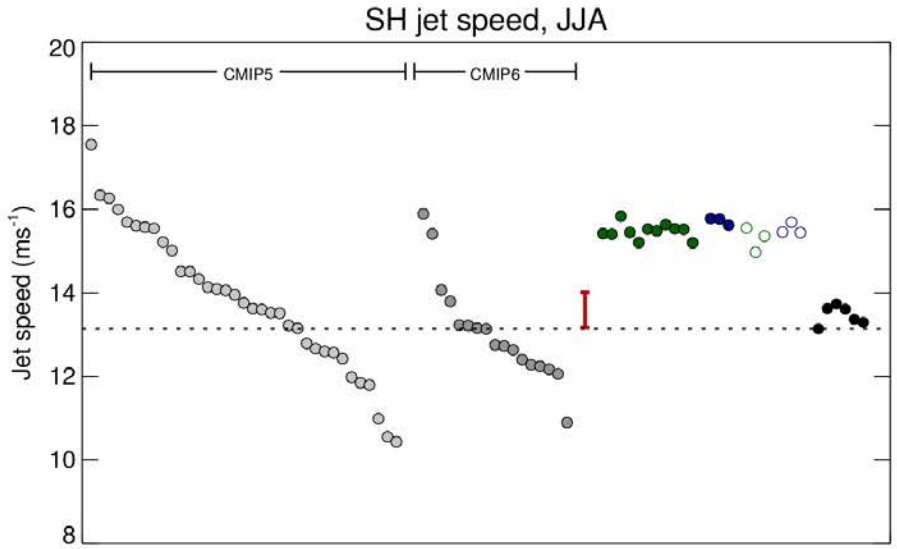
Jet Latitude





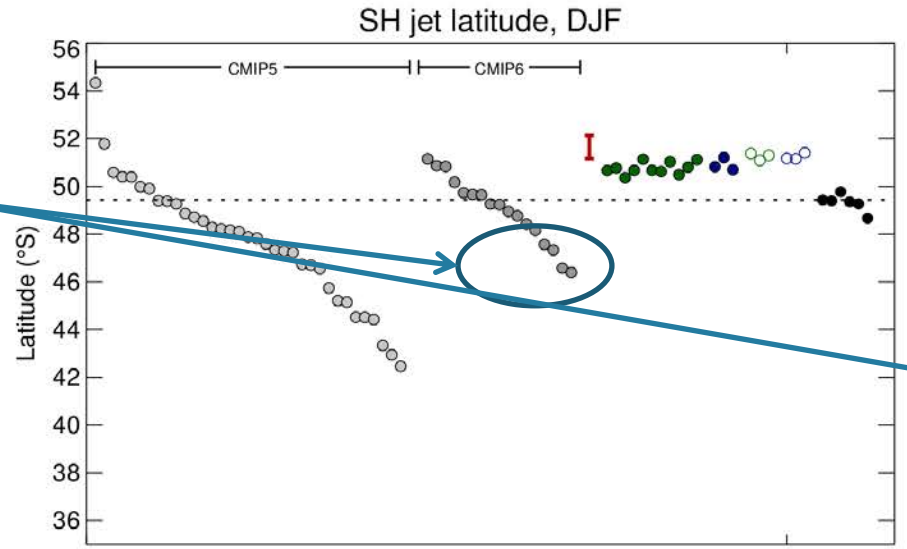
Jet Speed

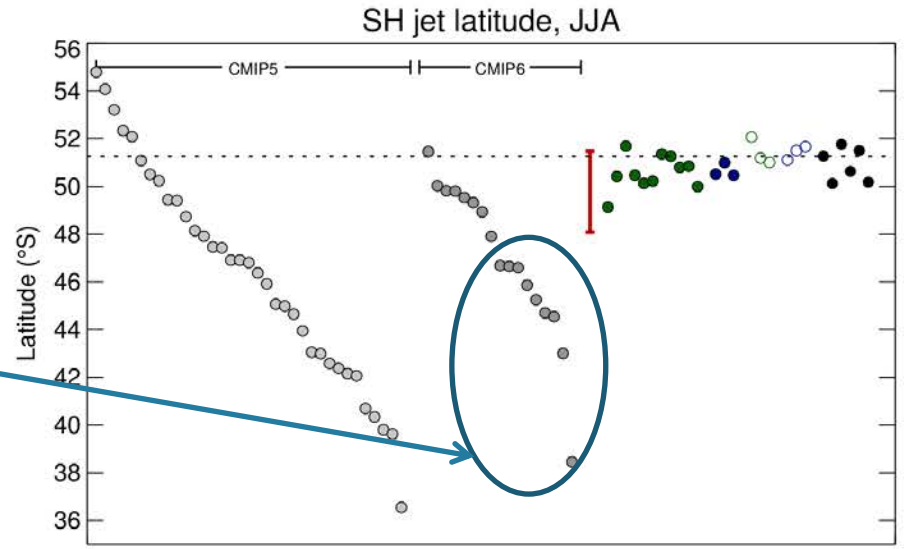


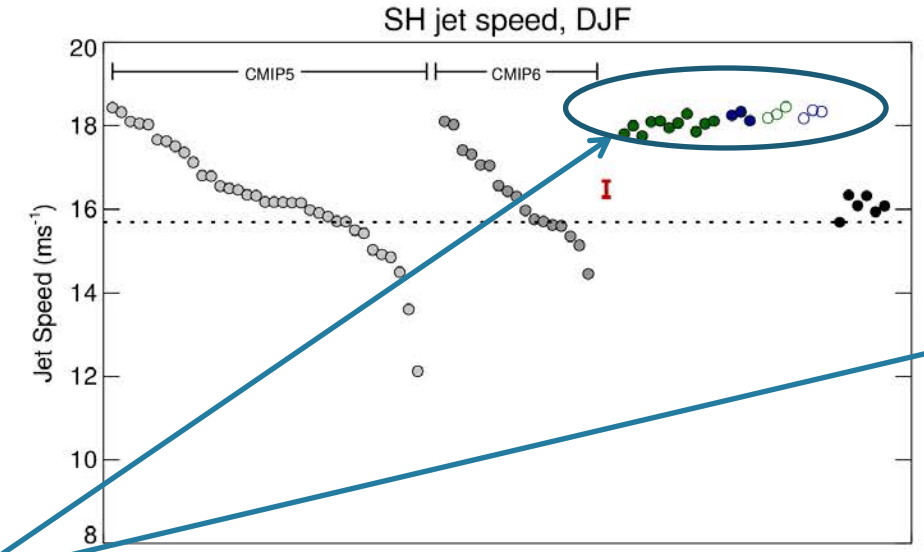


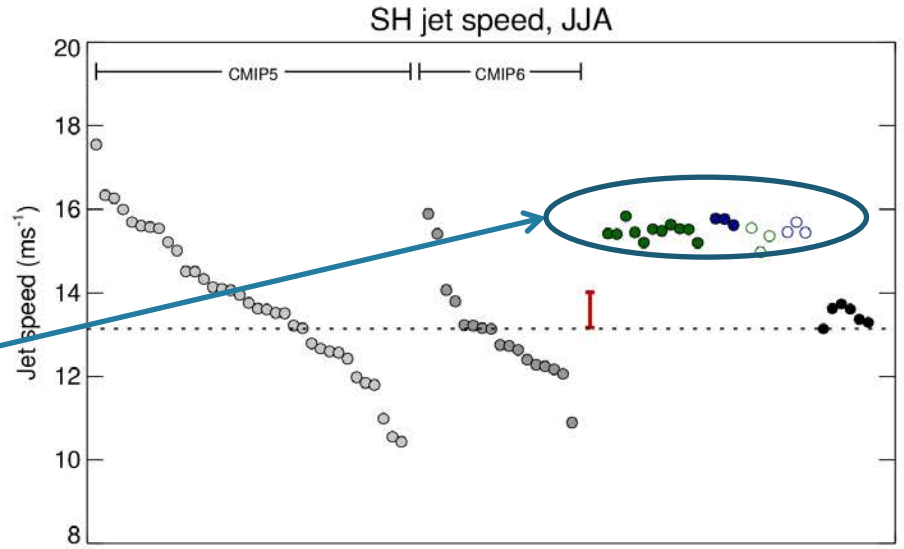
CMIP5 CMIP6 LENS range BCAM6 BWACCM6 FCAM6 FWACCM6 Reanalyses ERA5

Still a wide spread in SH jet latitudes, Many models still with substantial equatorward biases. CESM pretty good.





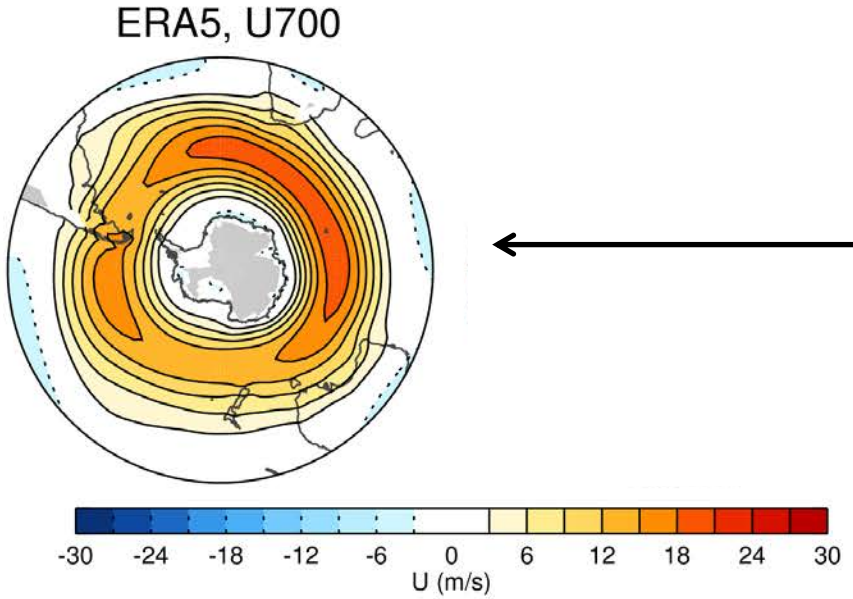




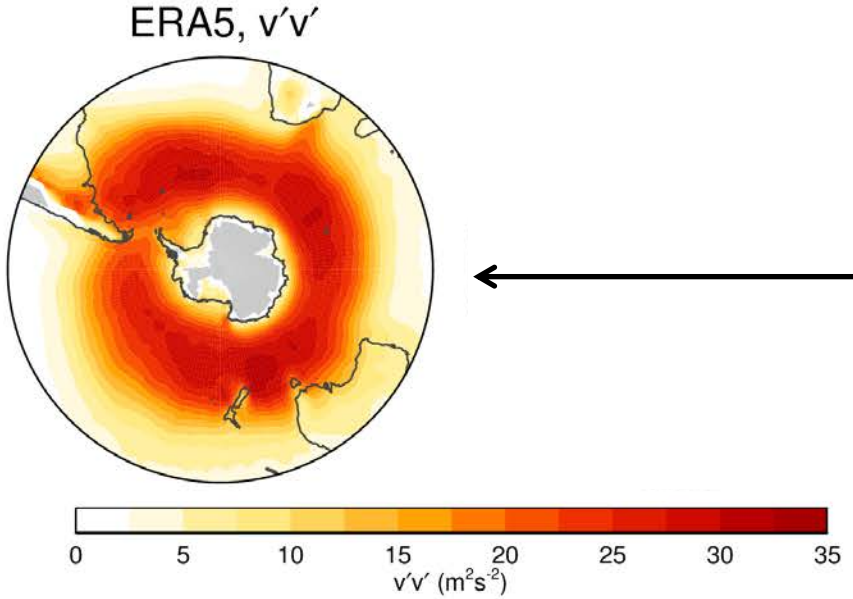
Biases in jet strength not so systematic, but many too strong. CESM2 too strong and degraded compared to CESM1

CMIP5 CMIP6 LENS range BCAM6 BWACCM6 FCAM6 FWACCM6 Reanalyses ERA5

Local SH jet stream and storm tracks (DJF)

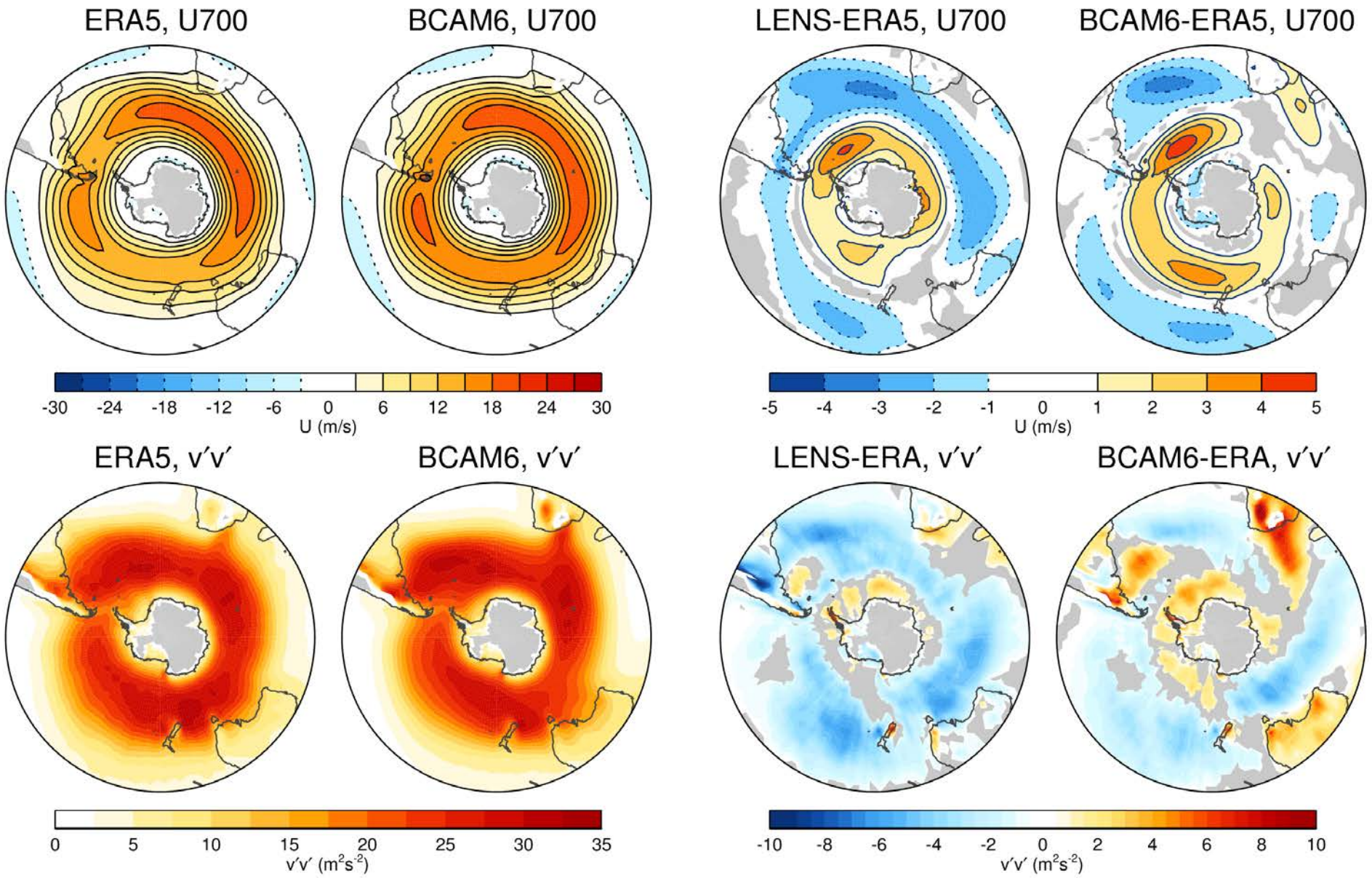


700hPa zonal wind



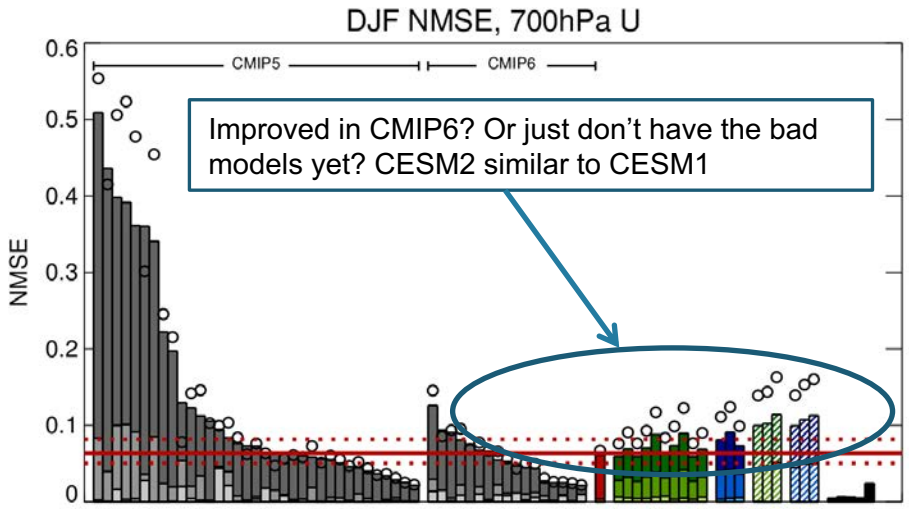
850hPa, 10 day high pass eddy meridional wind variance

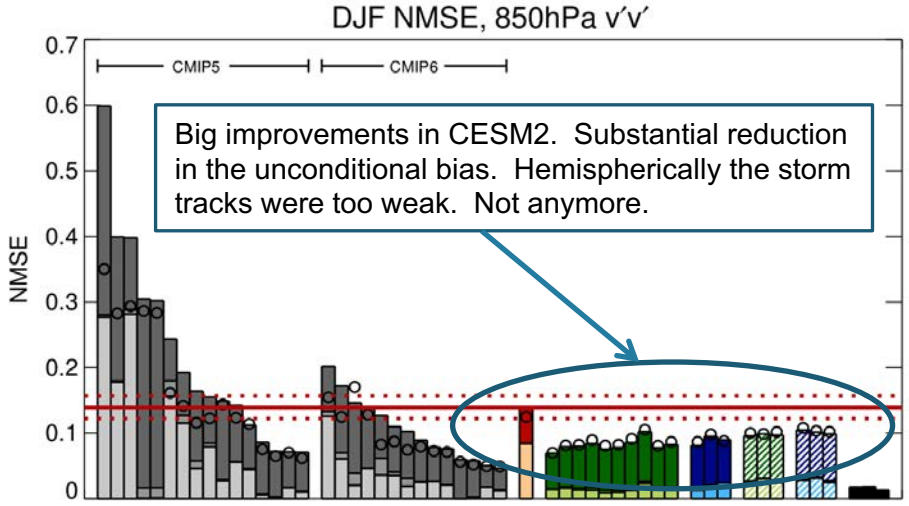
Local SH jet stream and storm tracks (DJF)

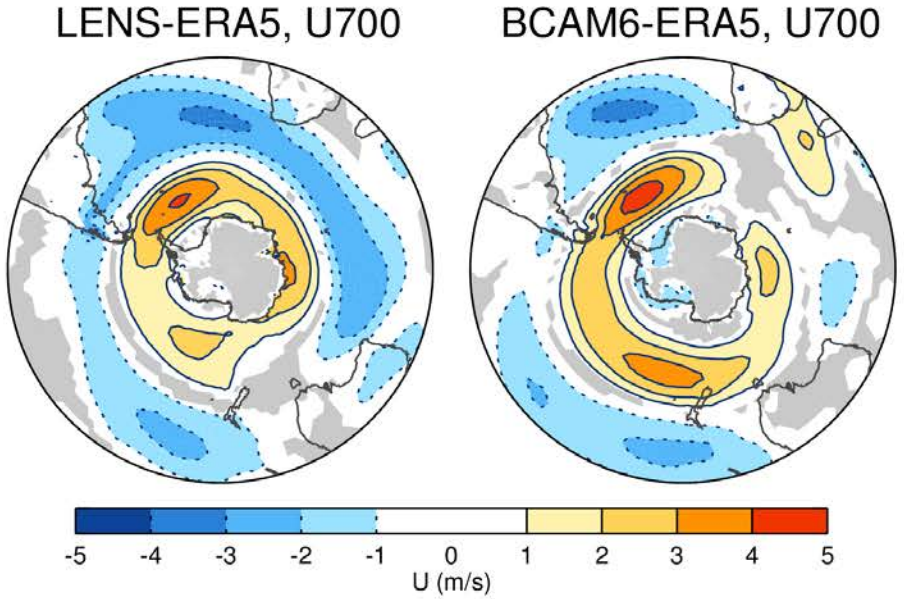


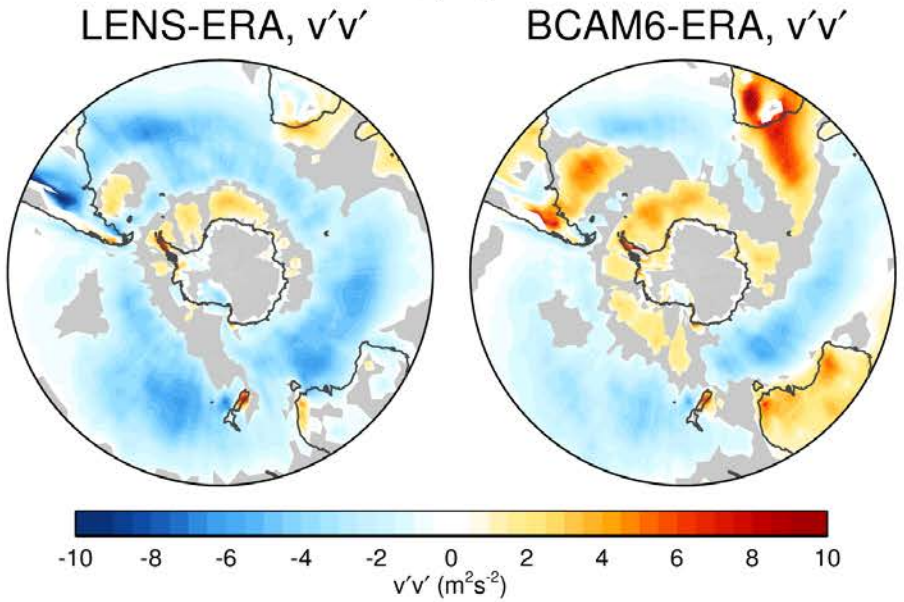
Grey = where ERA5 lies within the ensemble member spread

Local SH jet stream and storm tracks (DJF)



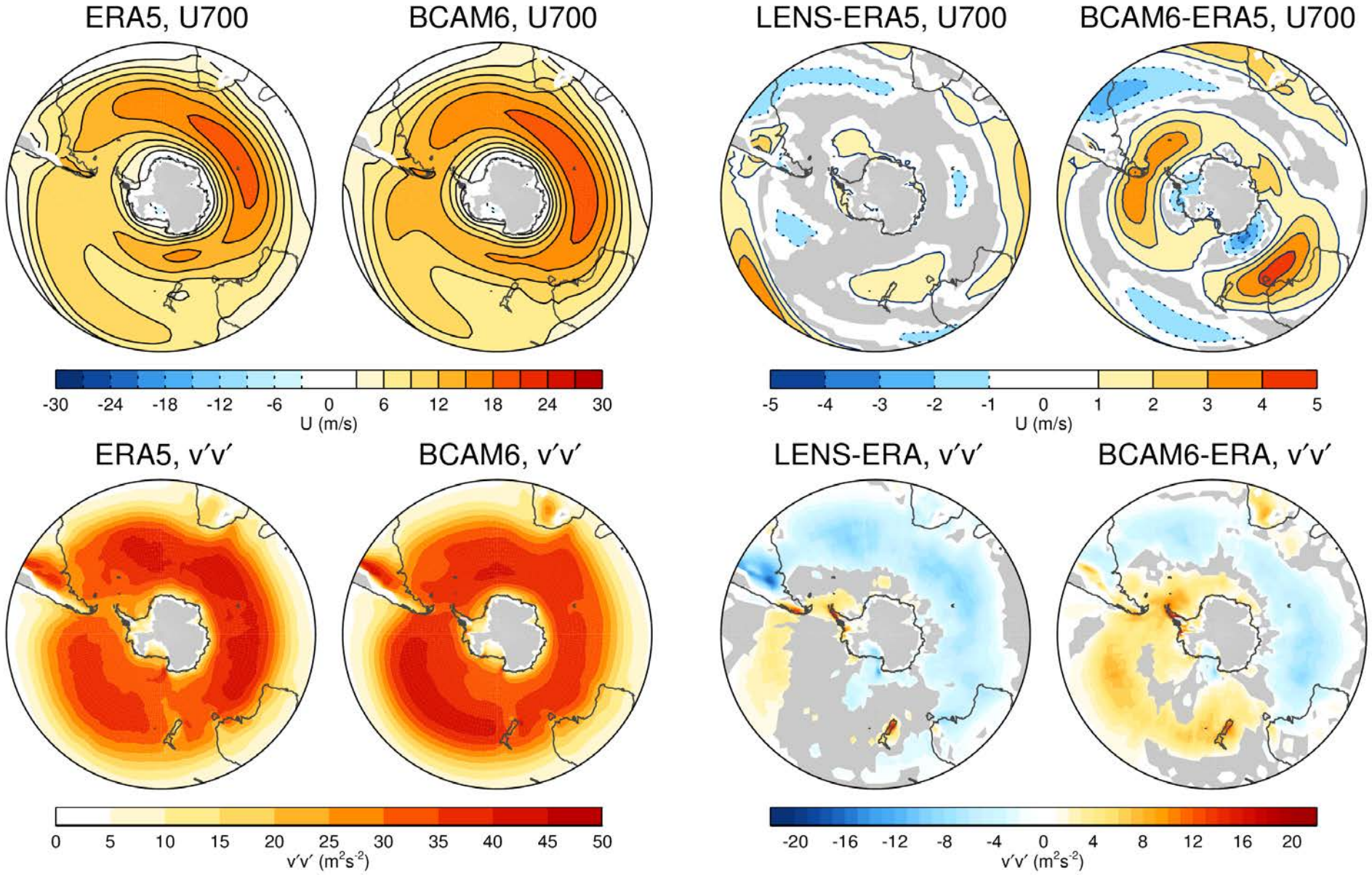






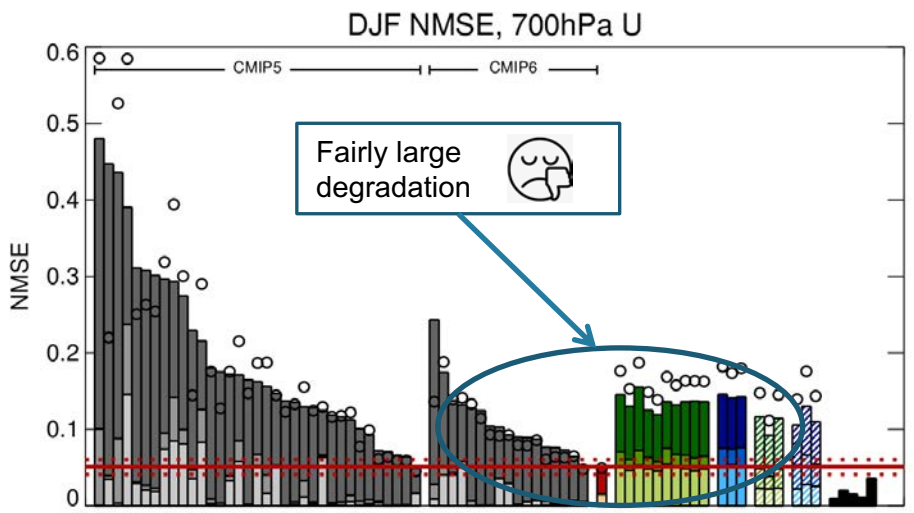
Grey = where ERA5 lies within the ensemble member spread

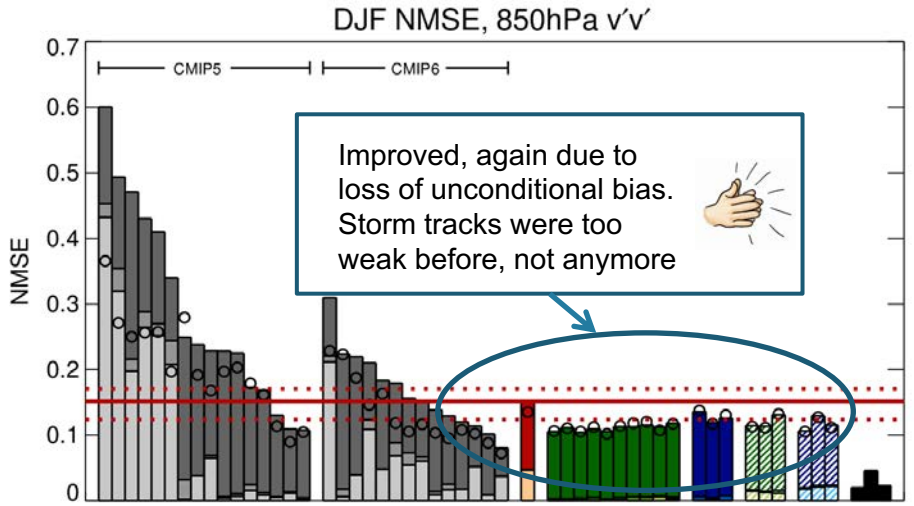
Local SH jet stream and storm tracks (JJA)

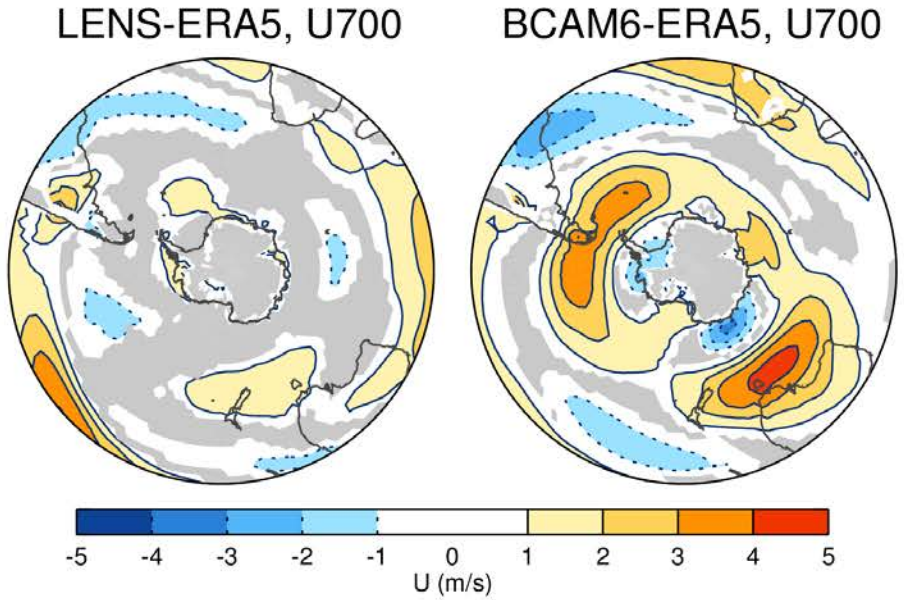


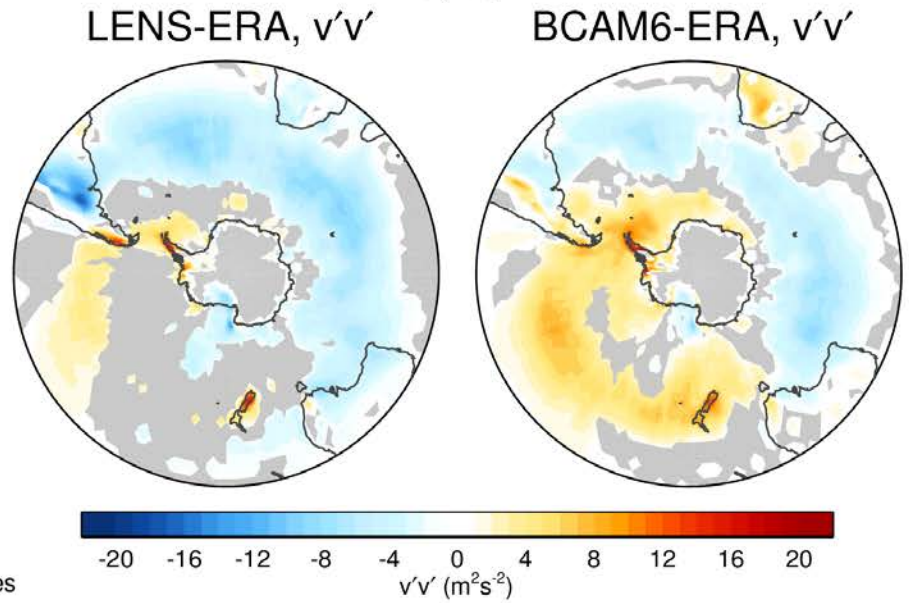
Grey = where ERA5 lies within the ensemble member spread

Local SH jet stream and storm tracks (JJA)



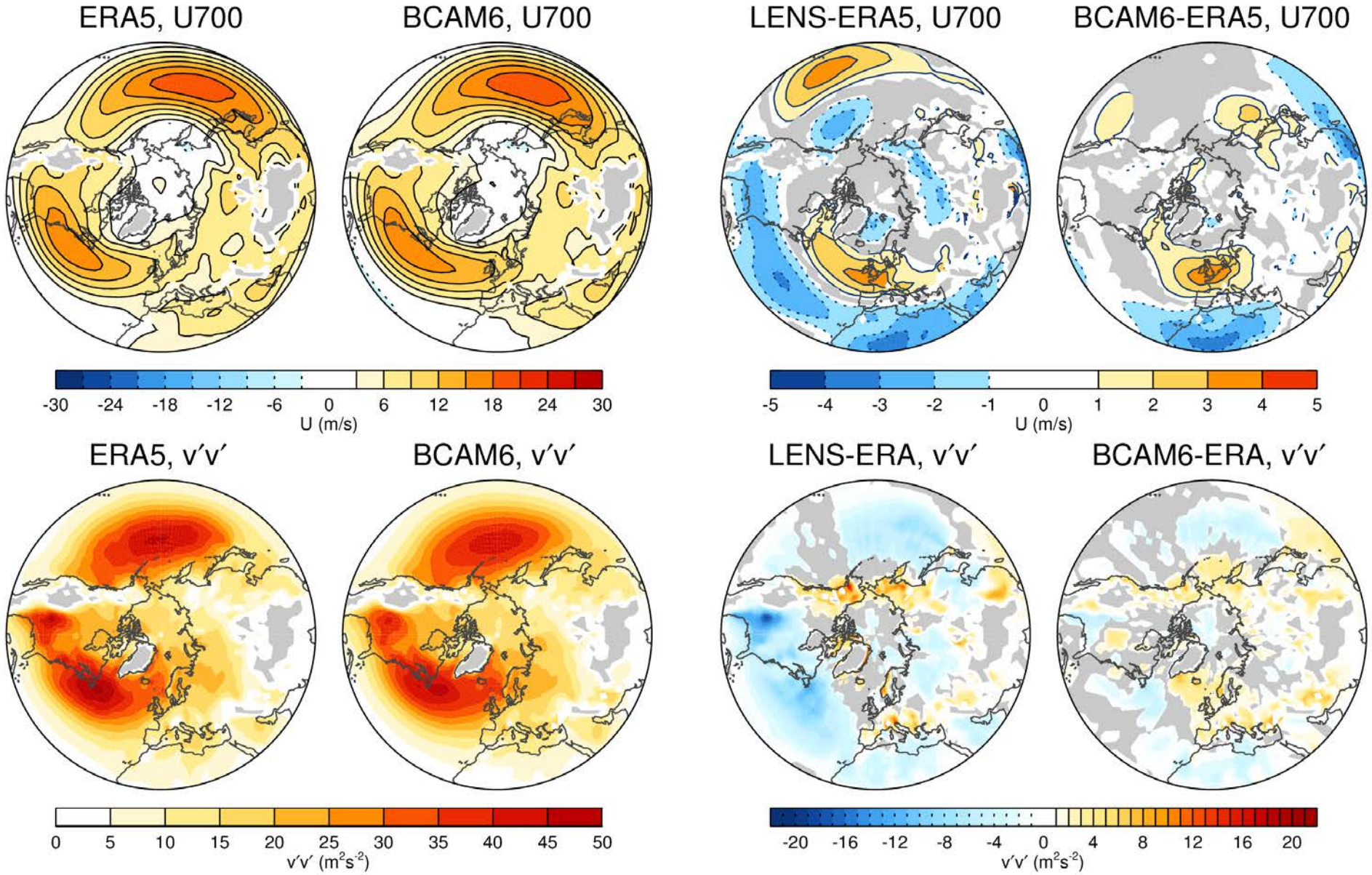






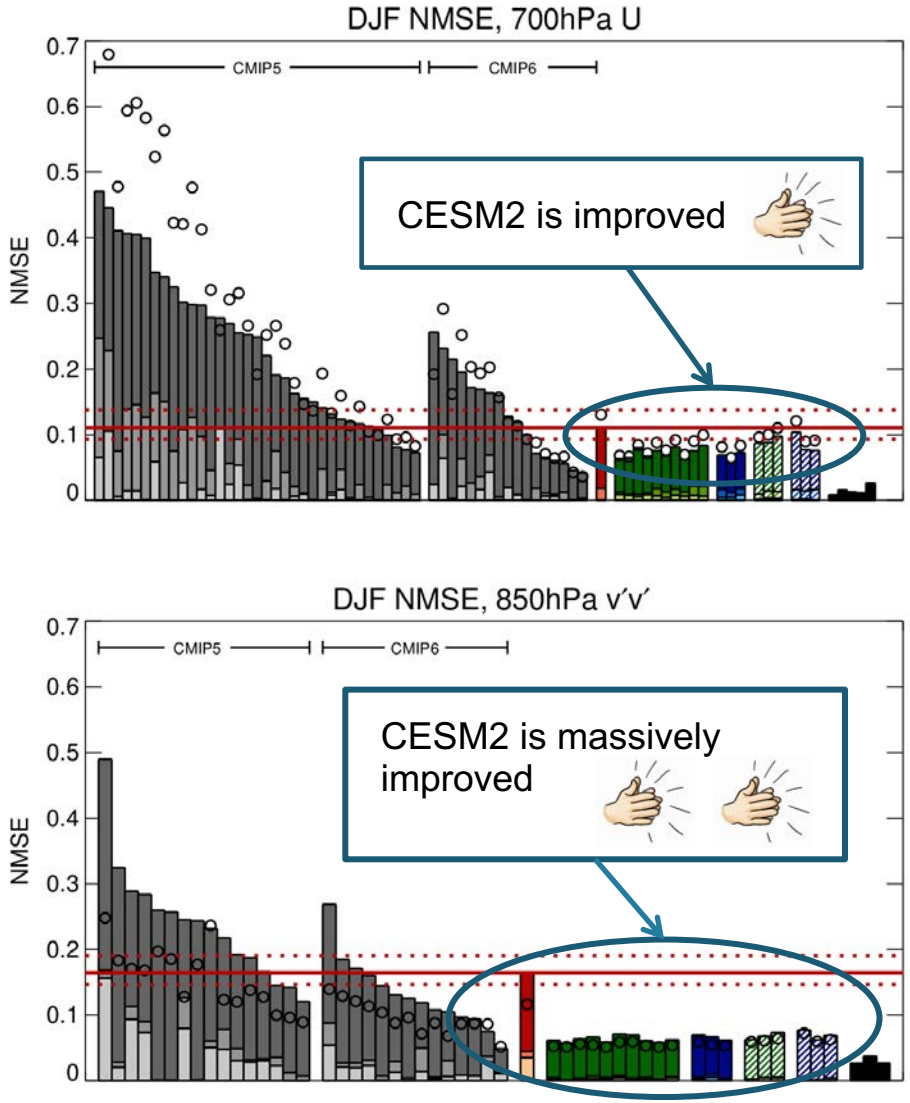
Grey = where ERA5 lies within the ensemble member spread

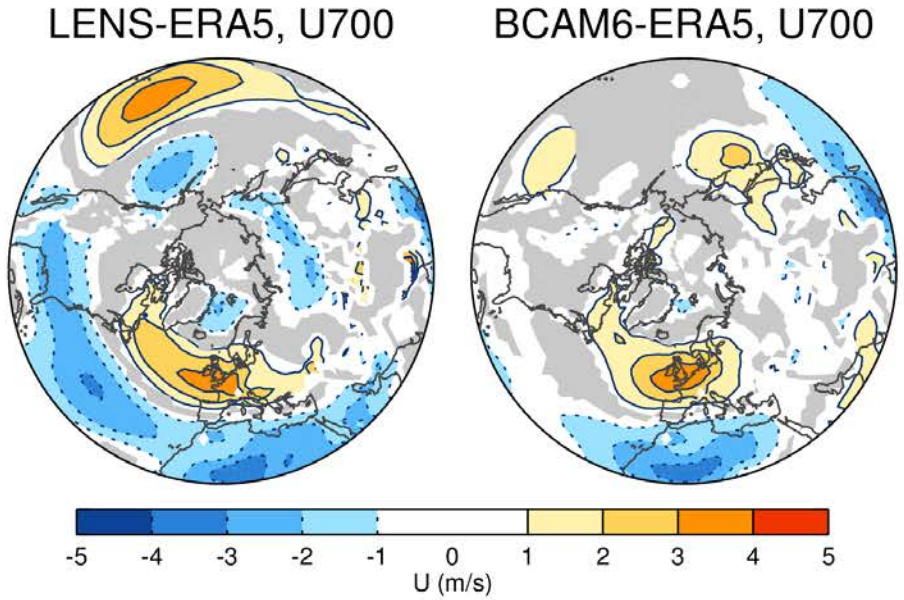
Local NH jet stream and storm tracks (DJF)

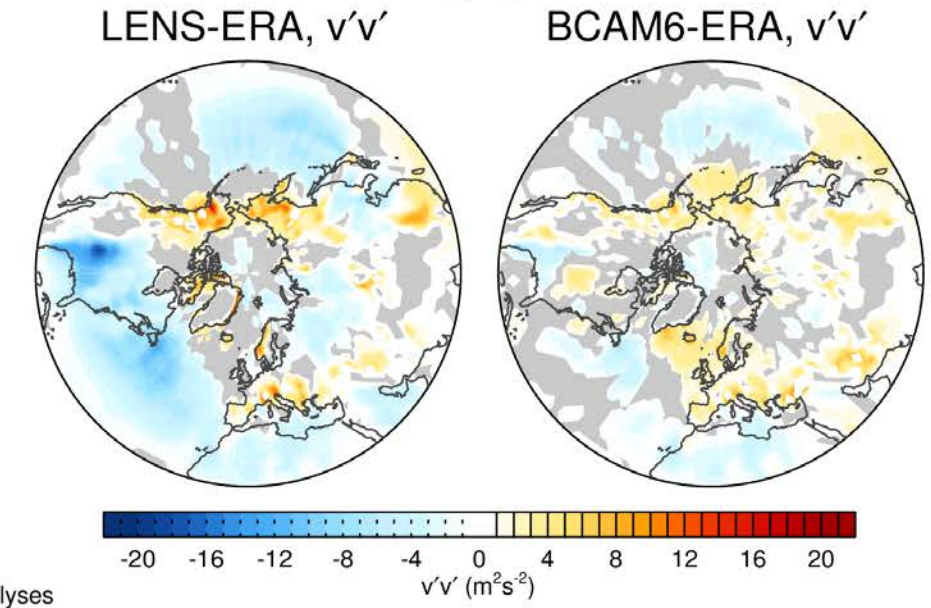


Grey = where ERA5 lies within the ensemble member spread

Local NH jet stream and storm tracks (DJF)

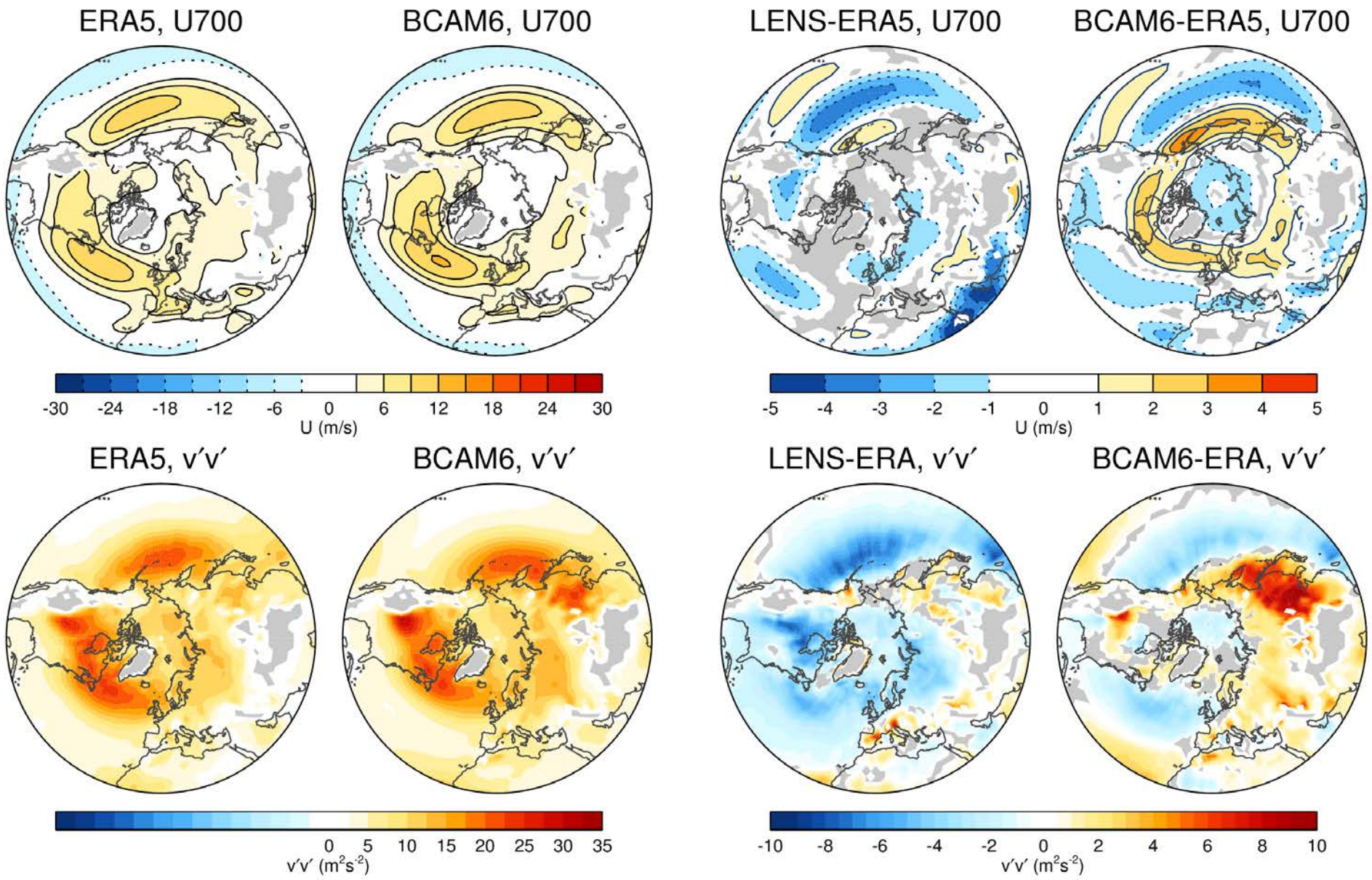




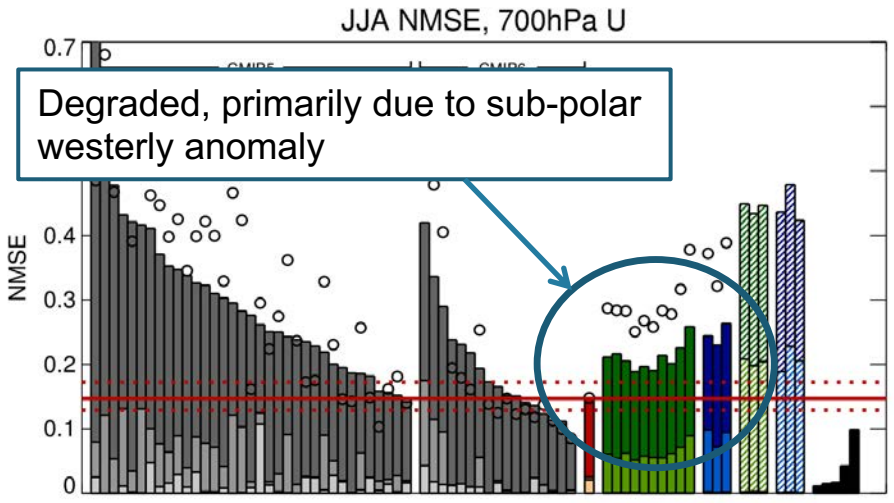


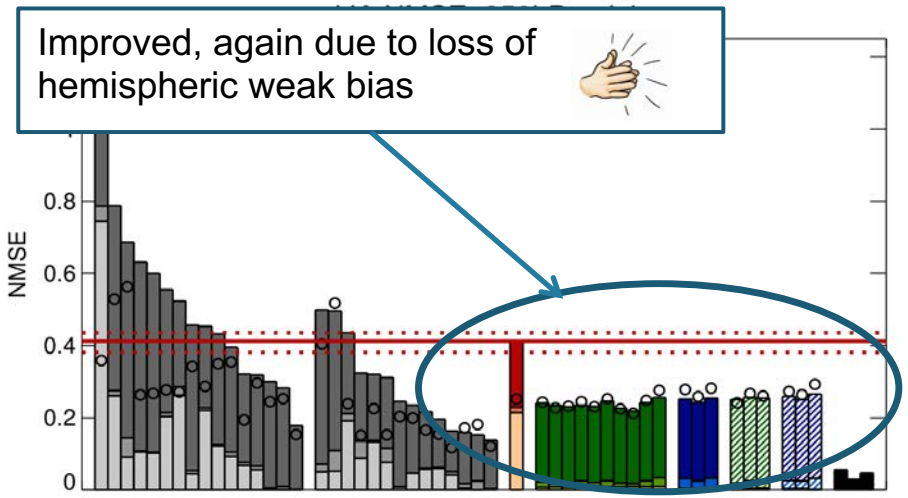
Grey = where ERA5 lies within the ensemble member spread

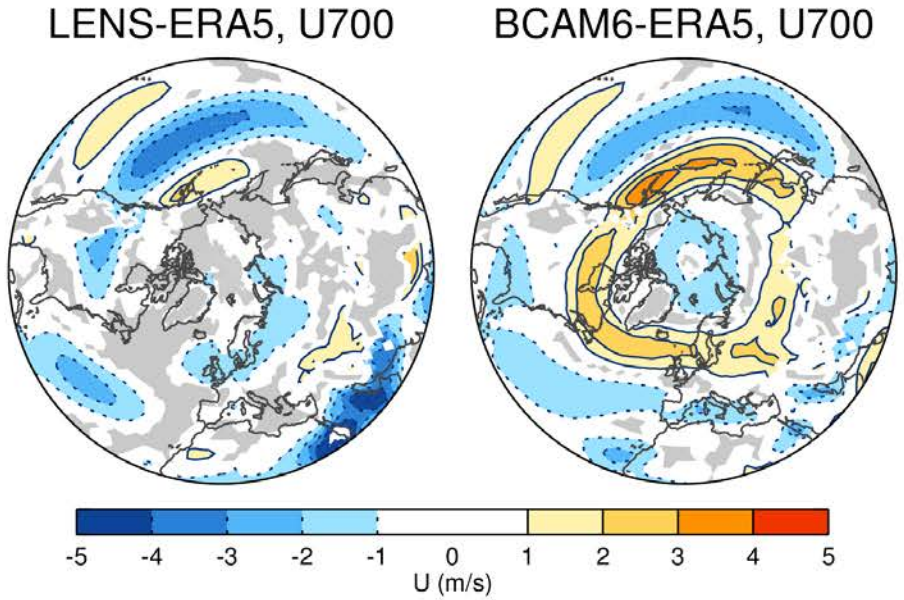
Local NH jet stream and storm tracks (JJA)

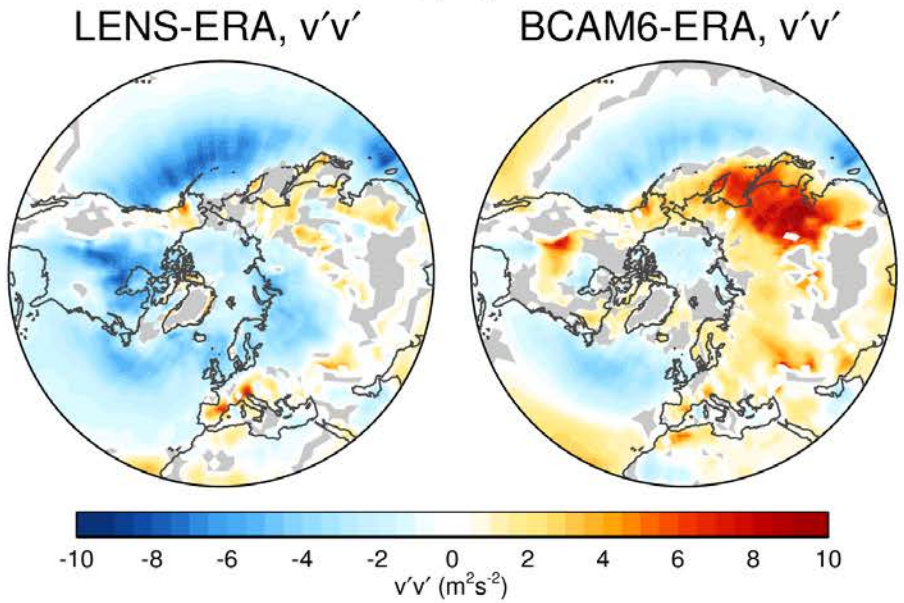


Local NH jet stream and storm tracks (JJA)



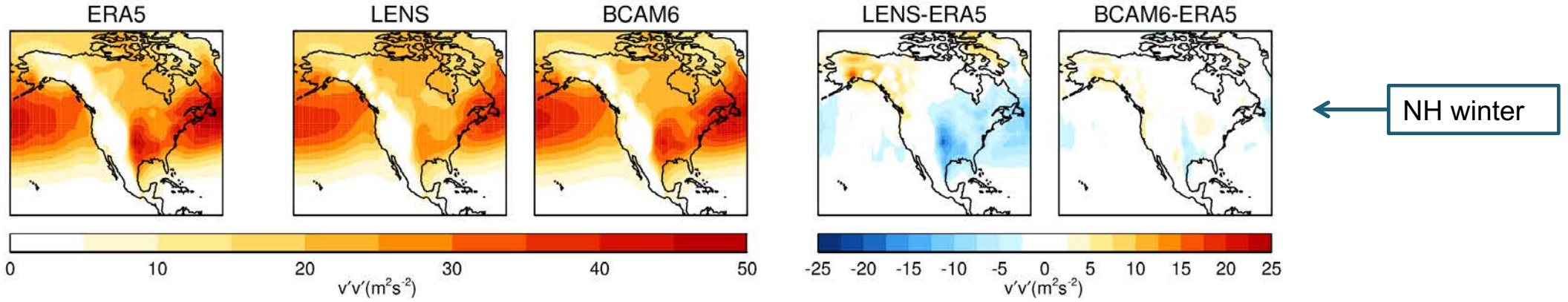






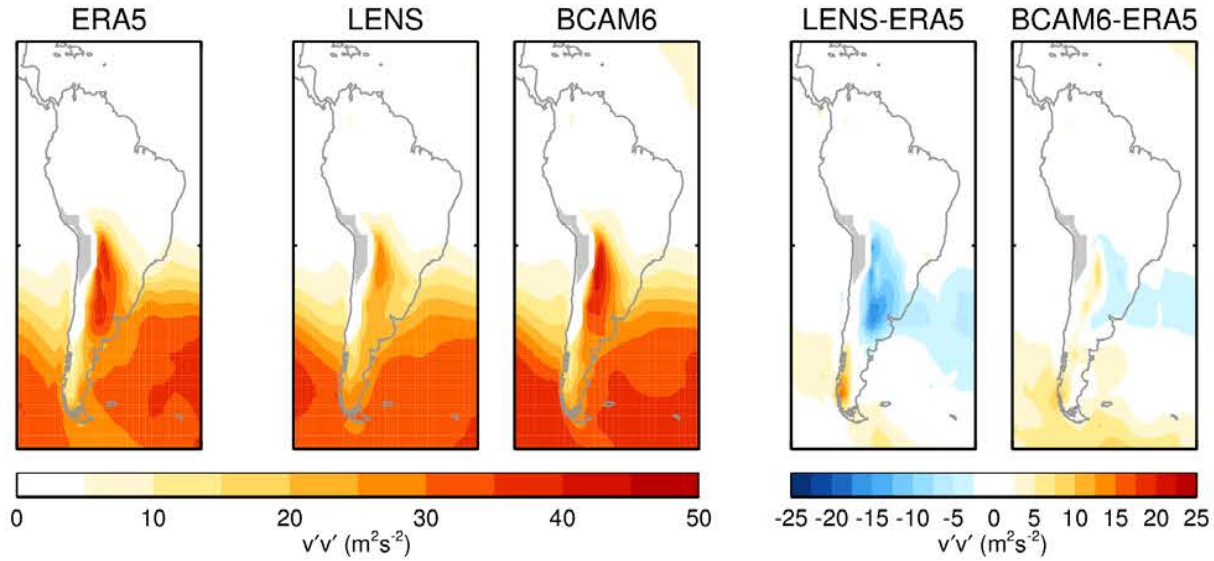
Big improvements in v'v' in the lee of mountains

10 day high pass filtered eddy meridional wind variance



NH winter

SH winter



CESM2 has substantial changes to the orographic drag and blocking parameterizations (Julio Bacmeister)

Planned investigations into the role of the new orographic schemes in alleviating the hemispheric weak bias in storm track activity.

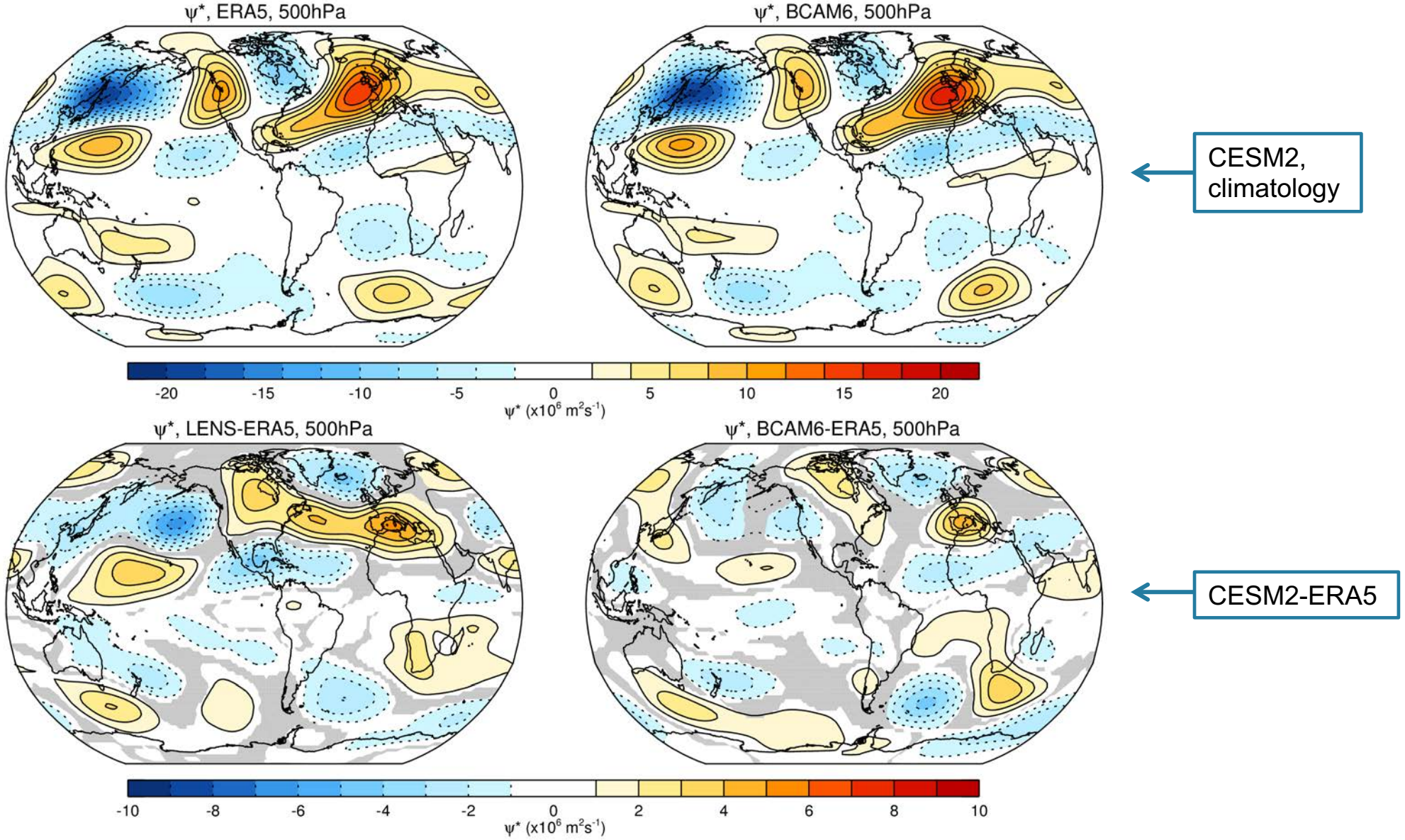
Stationary waves, 500hPa eddy streamfunction (DJF)

ERA5, climatology

CESM2, climatology

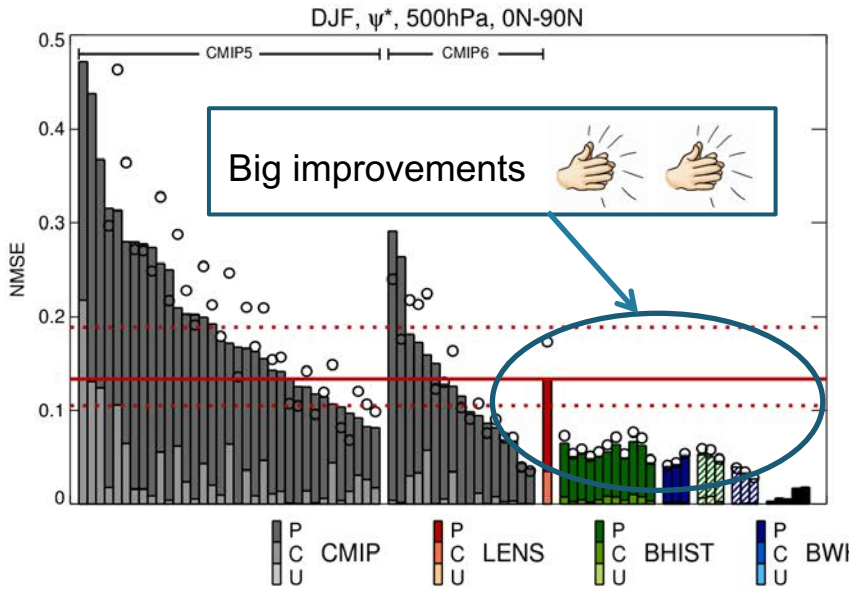
CESM1-ERA5

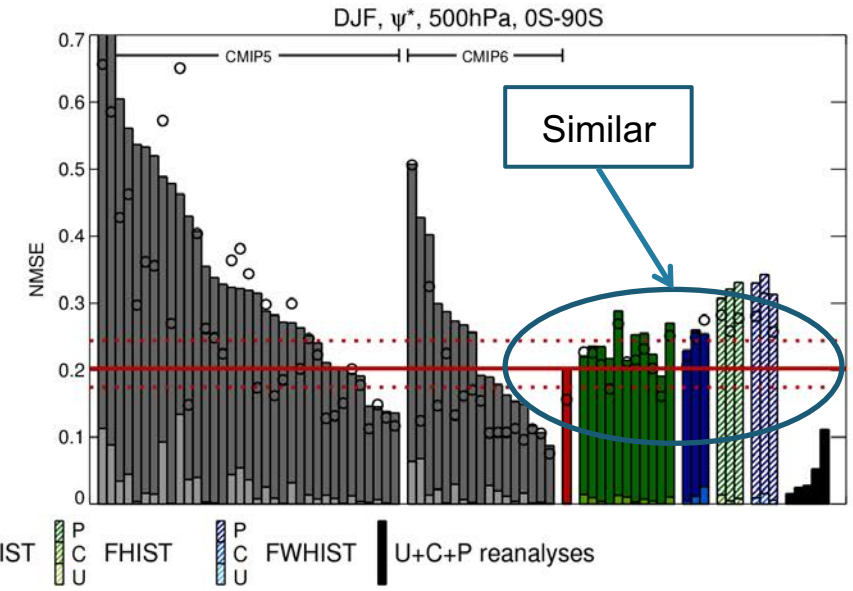
CESM2-ERA5



Stationary waves, 500hPa eddy streamfunction (DJF)

NH

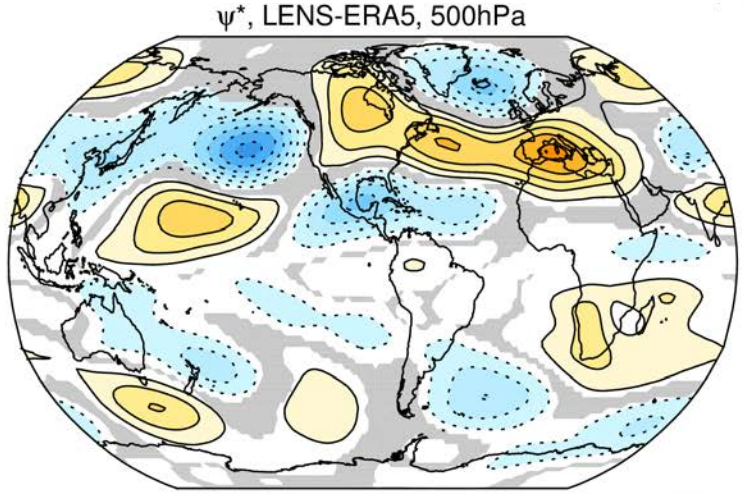


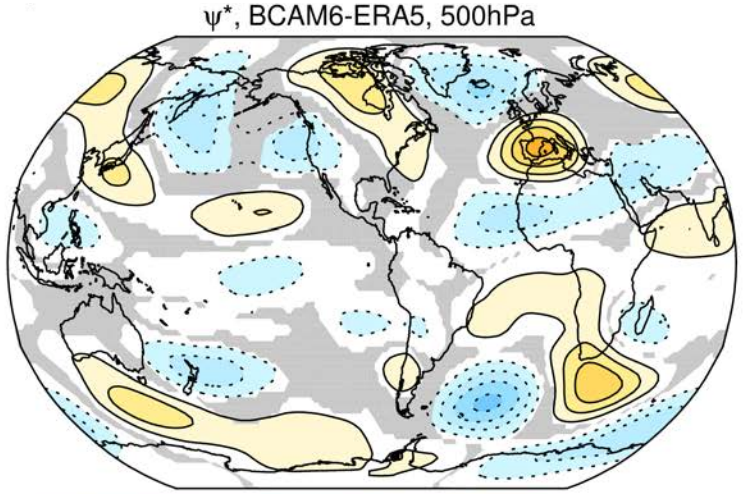


SH

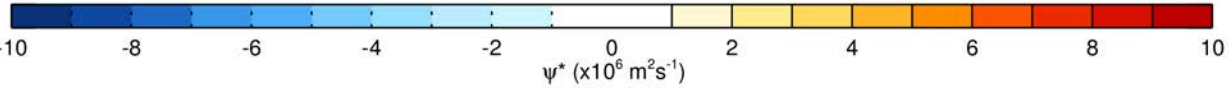
P C U CMIP | P C U LENS | P C U BHIST | P C U BWHIST | P C U FHIST | P C U FWHIST | U+C+P reanalyses

CESM1-ERA5





CESM2-ERA5



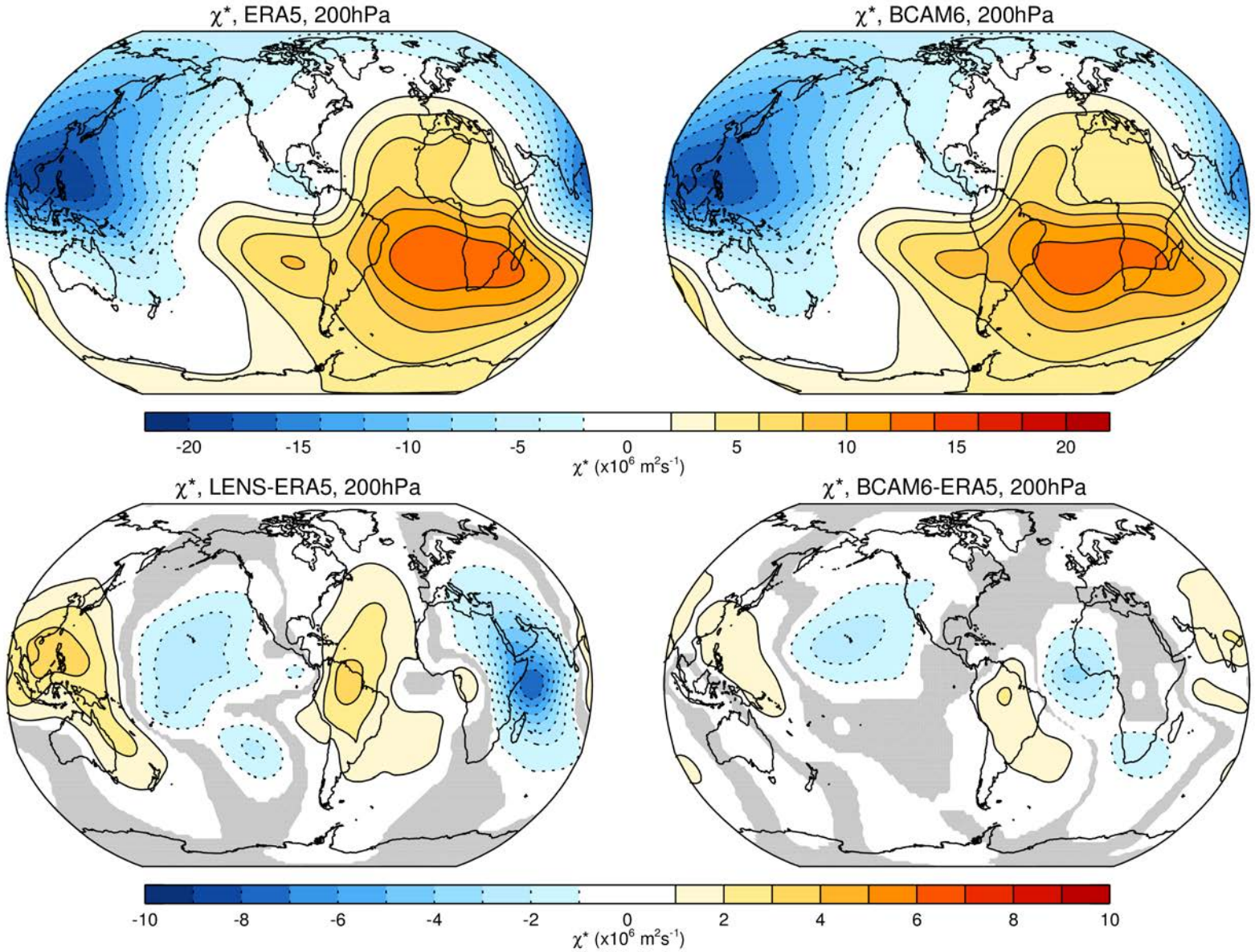
200hPa velocity potential (JJA)

ERA5, climatology

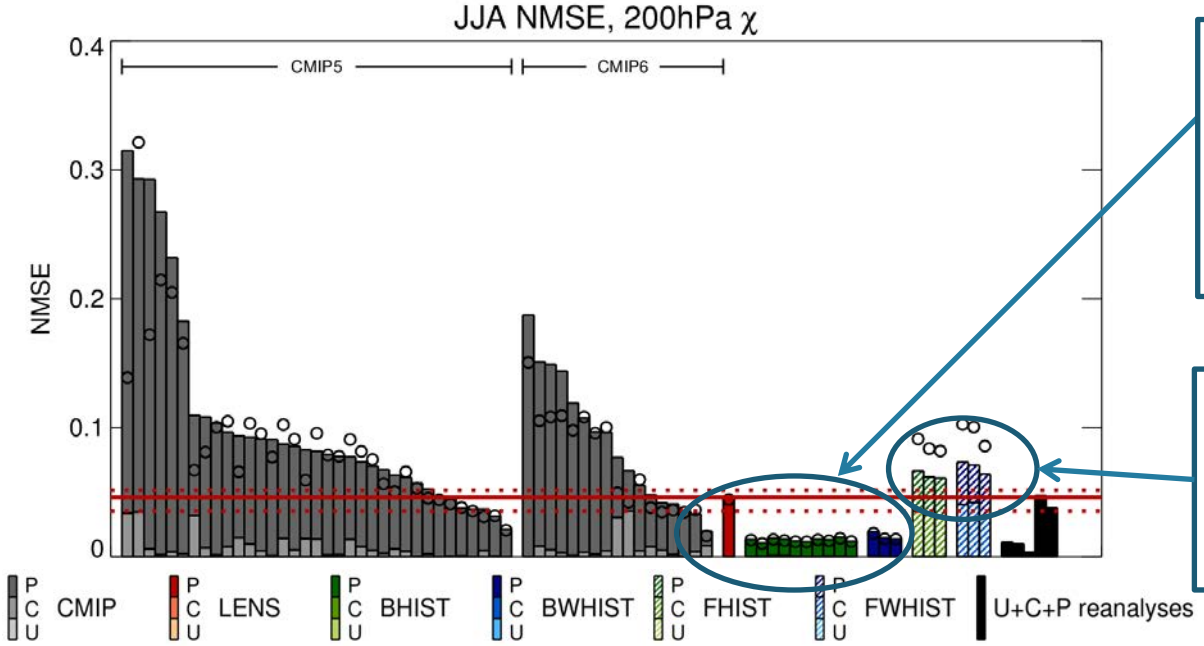
CESM2, climatology

CESM1-ERA5

CESM2-ERA5



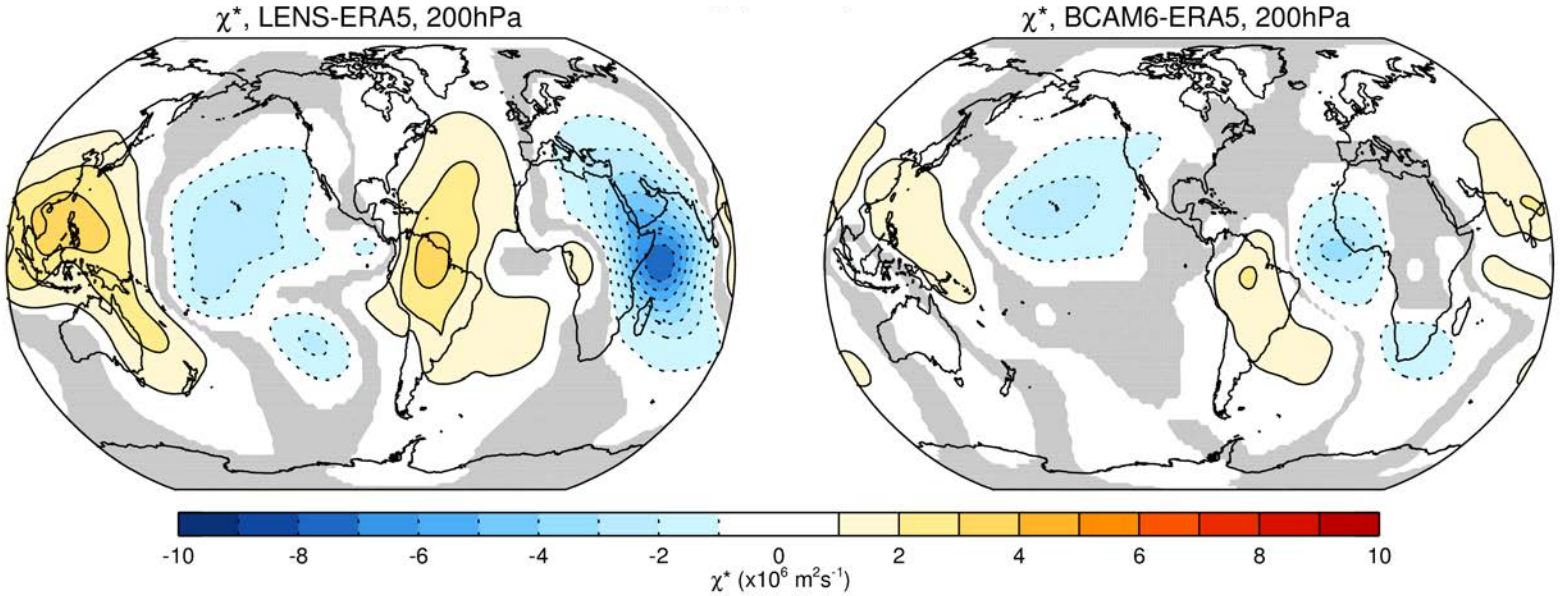
200hPa velocity potential (JJA)



CESM2 is excellent. Agrees with ERA5 to a similar extent as ERA-Interim agrees with ERA5!

But we have some compensating errors. Looks worse with prescribed observed SSTs and it's not due to the lack of coupling

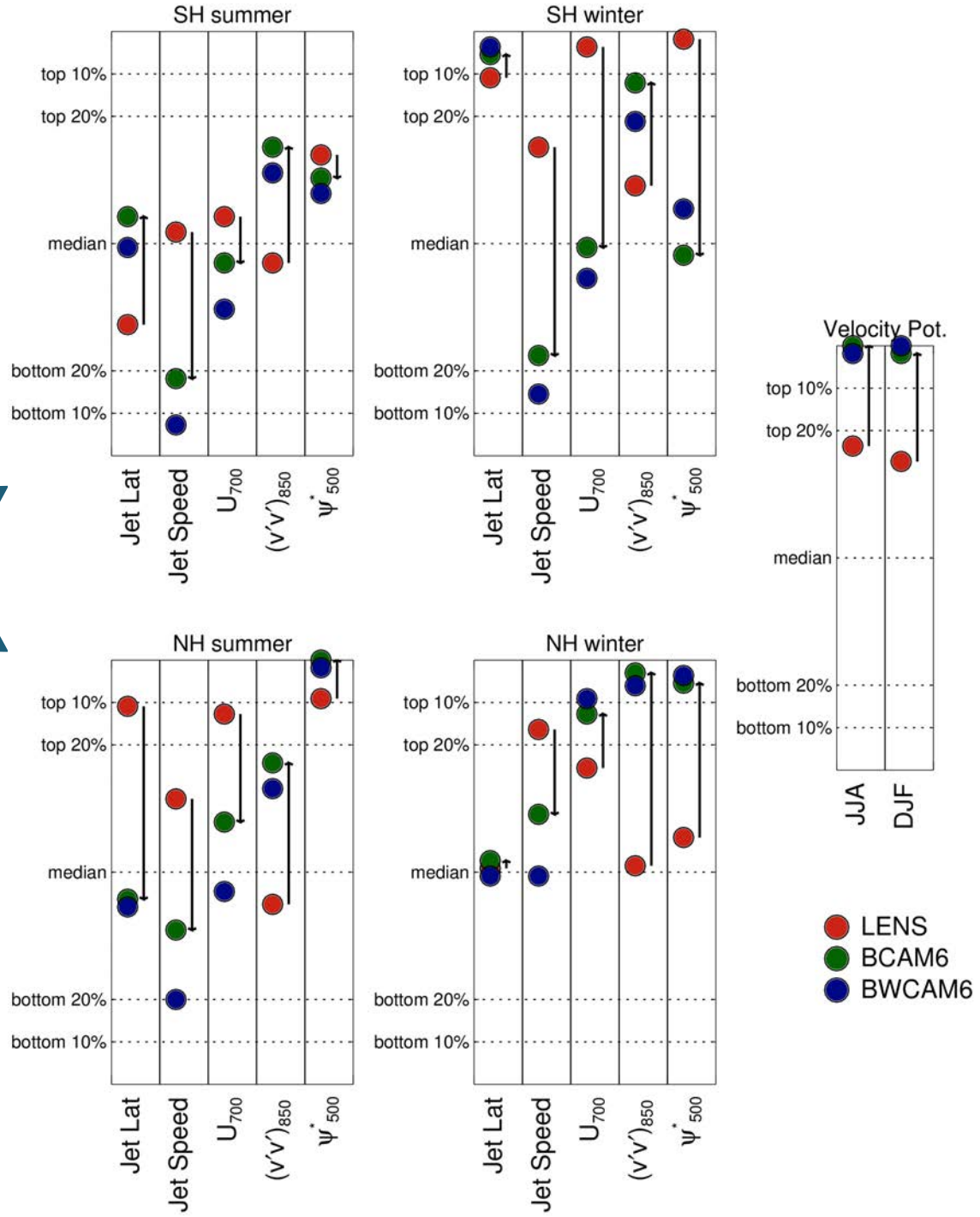
CESM1-ERA5



CESM2-ERA5

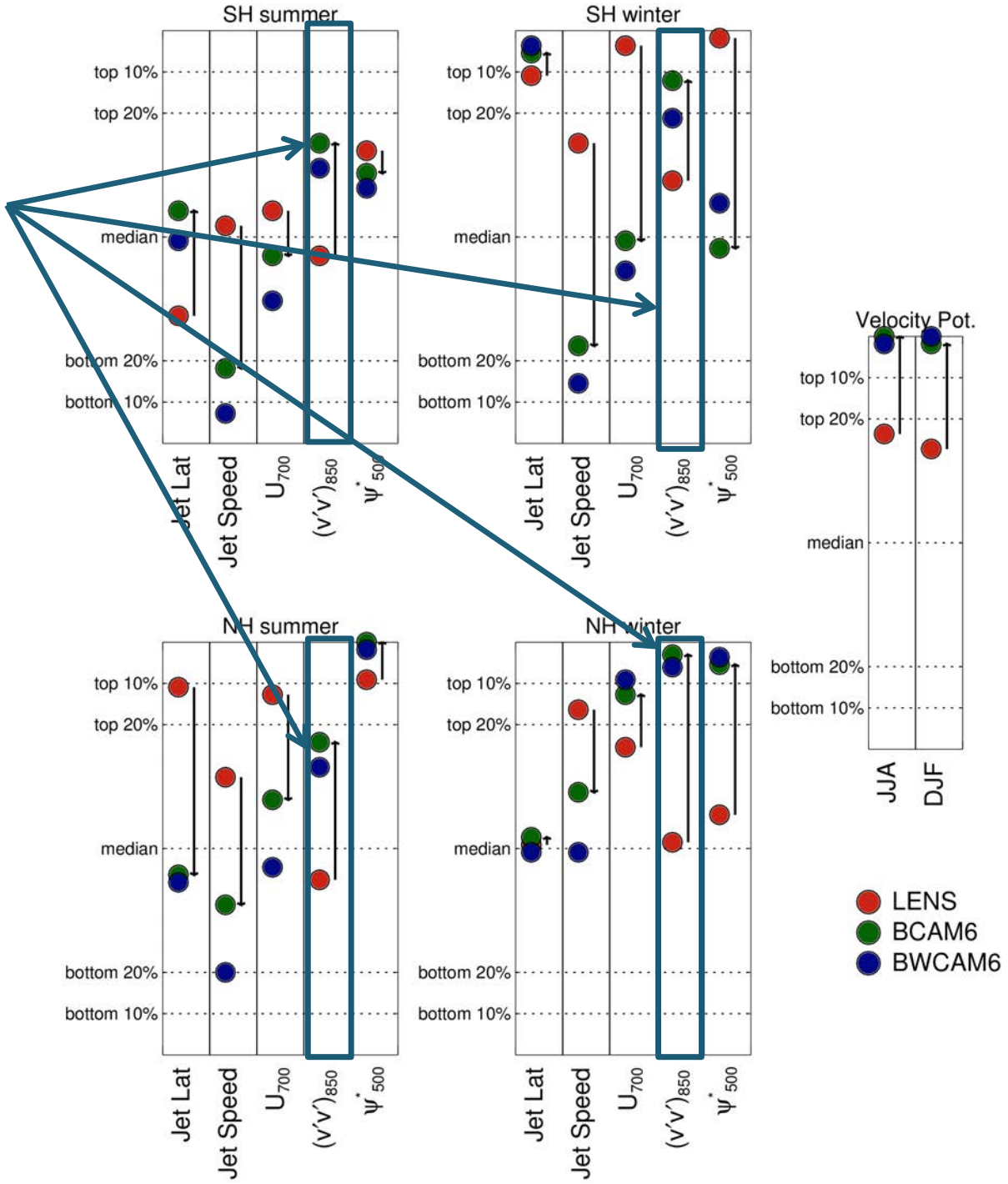
Summary

Pooling all CMIP5 and CMIP6 models together and ranking CESM2 (CAM6 and WACCM6) and CESM1 relative to those other models



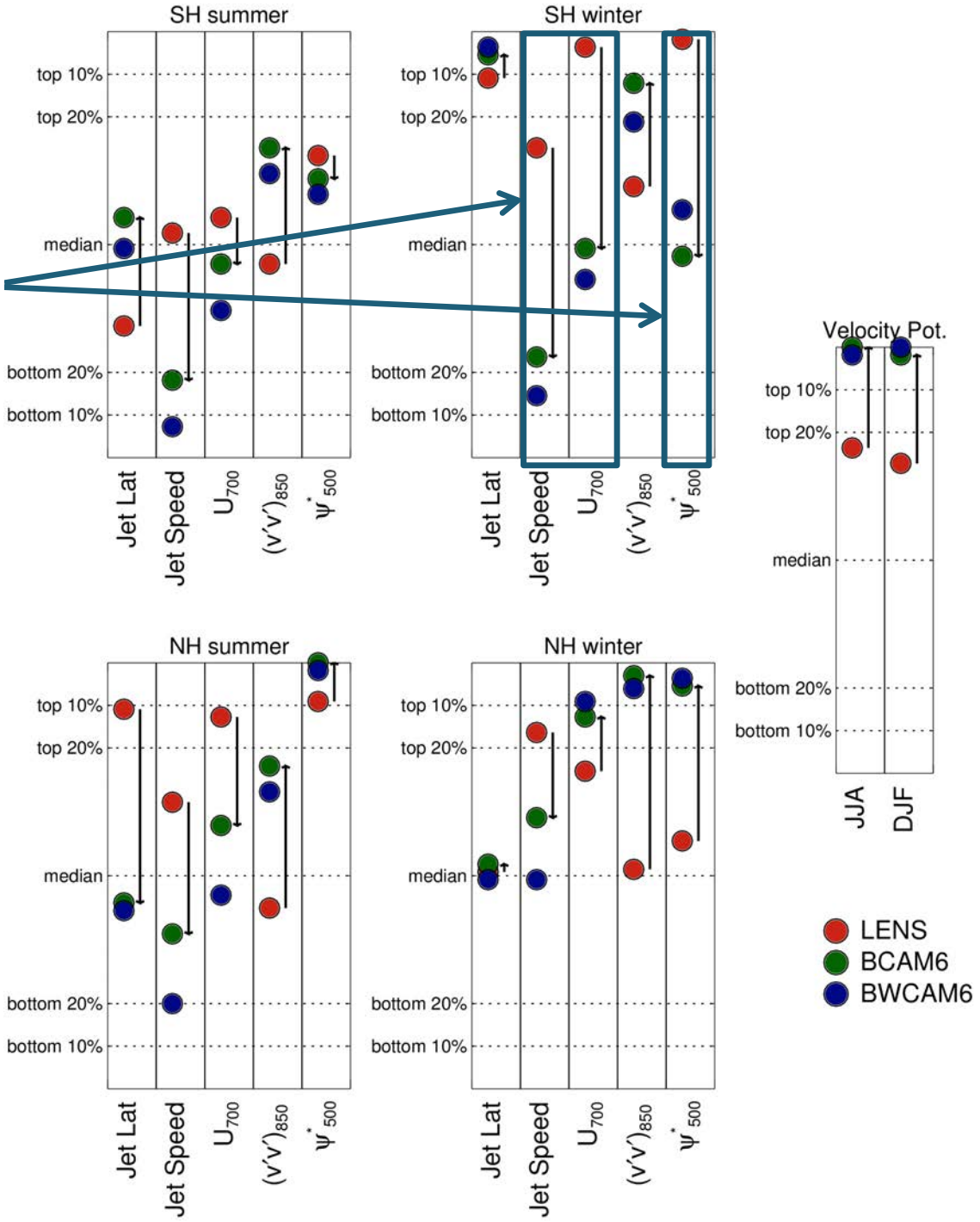
Summary

- Improved representation of the storm tracks in summer and winter in each hemisphere



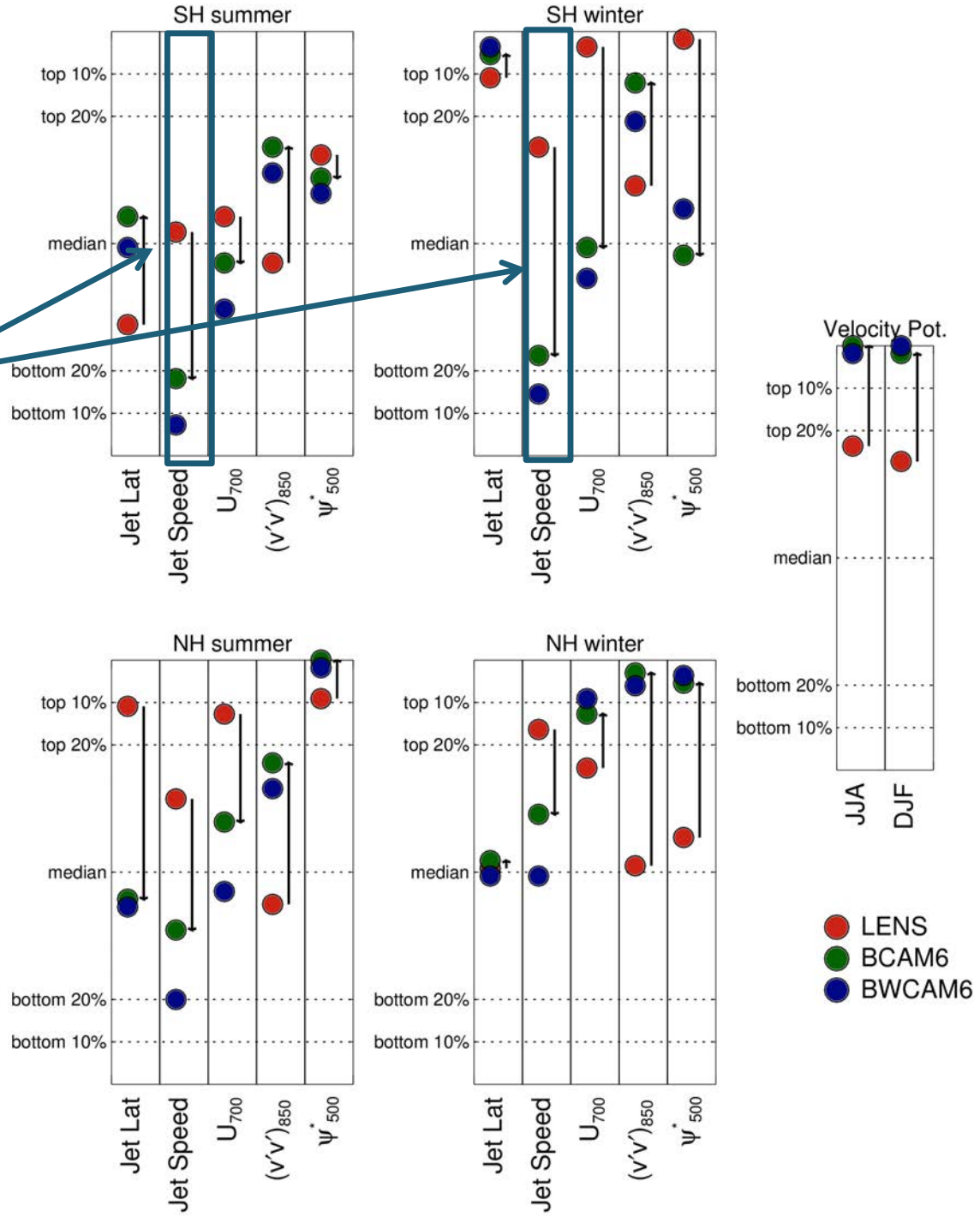
Summary

- Improved representation of the storm tracks in summer and winter in each hemisphere
- Degradation of other aspects of the SH winter circulation



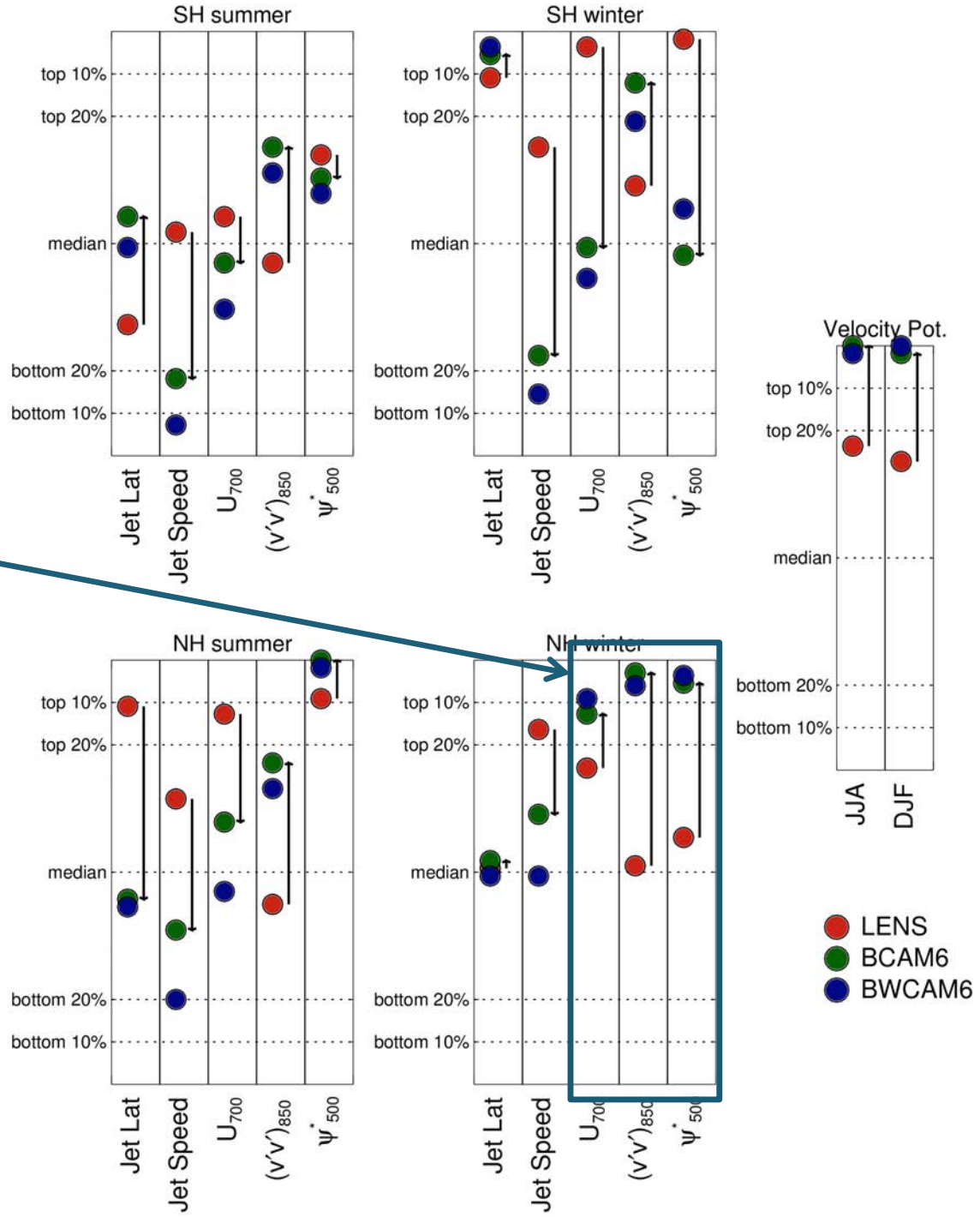
Summary

- Improved representation of the storm tracks in summer and winter in each hemisphere
- Degradation of other aspects of the SH winter circulation
- SH westerlies have become stronger (ranking pretty low in jet speed)



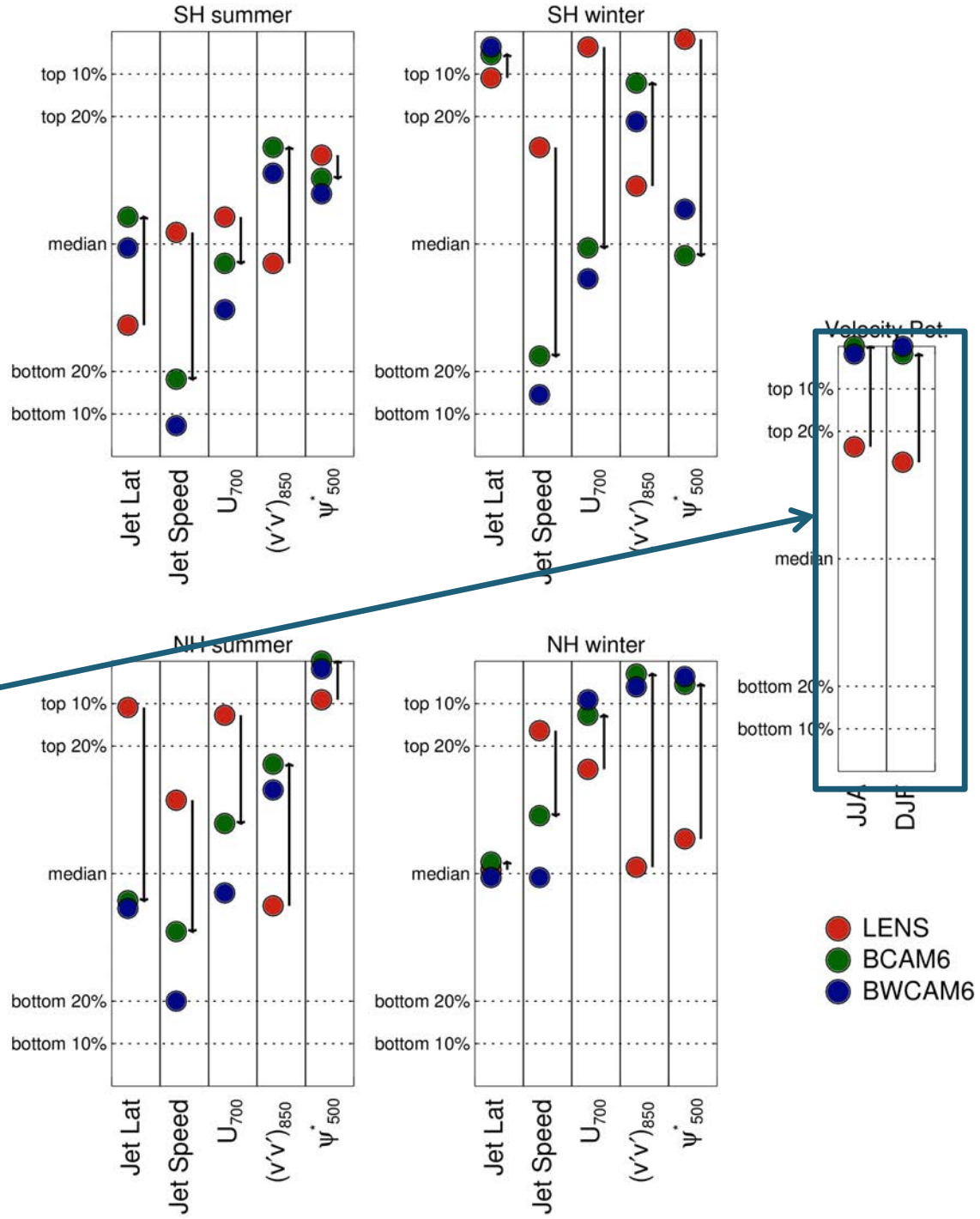
Summary

- Improved representation of the storm tracks in summer and winter in each hemisphere
- Degradation of other aspects of the SH winter circulation
- SH westerlies have become stronger (ranking pretty low in jet speed)
- Really excellent representation of the NH winter jet streams, storm tracks and stationary waves



Summary

- Improved representation of the storm tracks in summer and winter in each hemisphere
- Degradation of other aspects of the SH winter circulation
- SH westerlies have become stronger (ranking pretty low in jet speed)
- Really excellent representation of the NH winter jet streams, storm tracks and stationary waves
- Remarkable representation of the global divergent circulation. (caveat = probably have some compensating errors, looks worse in AMIP mode and that's not due to the lack of coupling)



Summary

- Improved representation of the storm tracks in summer and winter in each hemisphere
- Degradation of other aspects of the SH winter circulation
- SH westerlies have become stronger (ranking pretty low in jet speed)
- Really excellent representation of the NH winter jet streams, storm tracks and stationary waves
- Remarkable representation of the global divergent circulation. (caveat = probably have some compensating errors, looks worse in AMIP mode and that's not due to the lack of coupling)

Process oriented studies

- Investigation into the role of new orographic schemes in CESM2 in storm track improvements.

- Investigation of nudging tendencies in nudged to reanalysis simulations may provide indications of fast, parameterized process contributing to biases. Would be nice to look at this in a multi-model context.