Changes in mid-latitude atmospheric dynamics in the CESM Large Ensemble

What role AA compared to other processes in a warming climate?

Gudrun Magnusdottir and Yannick Peings
Department of Earth System Science
University of California Irvine
and Julien Cattiaux
CNRS/Meteo-France, Toulouse, France
1. AA has been suggested as a driver of recent cooling trend in mid-latitudes, as well as responsible for increased jet stream meandering, blockings and associated extreme events (e.g., Cohen et al. 2014, Francis and Vavrus 2012, 2015). However, in observations, attribution of the recent trends to AA is debated and hampered by large internal variability (Barnes 2013, Screen and Simmonds 2013, Barnes and Screen 2015, Overland et al. 2015).

Cohen et al. (2014)
1. AA has been suggested as a driver of recent cooling trend in mid-latitudes, as well as responsible for increased jet stream meandering, blockings and associated extreme events (e.g., Cohen et al. 2014, Francis and Vavrus 2012, 2015). However, in observations, attribution of the recent trends to AA is debated and hampered by large internal variability (Barnes 2013, Screen and Simmonds 2013, Barnes and Screen 2015, Overland et al. 2015).

Caution: large internal variability in the extratropical atmosphere (e.g., Wallace et al 2014)
It is therefore attractive to use a large ensemble of simulations to increase the signal to noise ratio

CESM large ensemble (CESM-LENS) from NCAR

40 members of fully coupled simulations

Run over 1920-2100

Historical forcing to 2005 thereafter following RCP8.5 anthropogenic emissions

**An opportunity to investigate robustly how the mid-latitude climate responds to a strong Arctic sea ice decline**

From Francis & Vavrus (2012): “Evidence linking Arctic amplification to extreme weather in mid-latitudes”
Evolution of zonal mean of $\Delta$SIC and $\Delta T_{sfc}$ in LENS ensemble mean

40-member ensemble mean, anomalies relative to 1981-2010
Ensemble mean changes in winter (JFM) between 2071-2100 and 1981-2010

SIC (%)

T2m (K)

Z500 (m)

U_10hPa (m/s)

Subtract the global mean
Changes in zonal mean flow at 50N

Zonal Index: ZON

\[ ZON = Z_{500_{\text{mid}}} - Z_{500_{\text{pol}}} \]
Changes in zonal mean flow at 50N

Zonal Index: ZON

\[ ZON = Z_{500}^{mid} - Z_{500}^{pol} \]

Change in zonal index at 50N in CESM-LENS

Peings et al (2017)
Change in waviness at 50N

Sinuosity: SIN
length of the average Z500 isopleth within 30-70N

Similar to river sinuosity used in geomorphology

A straightforward metric to measure the waviness of the atmospheric circulation, or meanders in the mid-latitude jet stream, and how it responds to climate change
Change in waviness at 50N

Sinuosity: SIN

Length of the average Z500 isopleth within 30-70N

Peings et al (2017)
Change in waviness at 50N

Does not support the “Francis & Vavrus hypothesis” except over AM

SINUOSITY
Changes in the eddy-driven jet stream

2071-2100 vs 1981-2010 pressure/latitude change in zonal mean zonal wind (m/s) in CESM-LENS. Gray contours represent climatology.
Changes in the eddy-driven jet stream

2071-2100 vs 1981-2010 pressure/latitude change in zonal mean zonal wind (m/s) in CESM-LENS. Gray contours represent climatology.
Changes in the eddy-driven jet stream (JFM)

Latitude-time Hovmoller plots of anomalies in JFM zonal mean U700 (m/s) (relative to 1981-2010 climatology, shown in the right panel) in the NH. The 40-member ensemble mean is shown, with shading indicating anomalies that are significant at the 95% confidence level.
Changes in the eddy-driven jet stream (JFM)

Latitude-time Hovmoller plots of anomalies in JFM zonal mean U700 (m/s) (relative to 1981-2010 climatology, shown in the right panels) for the different longitudinal sectors.

Narrowing and reinforcement of the Atlantic and Pacific jets at the end of the 21st century in CESM-LENS
Changes in the eddy-driven jet stream

"Tug-of-war" between the Arctic warming and the tropical warming in the upper-troposphere, with opposite effects on each side of the jet.

Arctic Amplifications contributes to the asymmetry between the Northern Hemisphere and the Southern Hemisphere, where polar warming near the surface is missing.

Peings et al (2017)
What happens in the CMIP5 ensemble mean?

Examine 36 ensemble members from 36 different models with different climate sensitivity etc.
Changes in the eddy-driven jet stream from CMIP5

Still have the tug-of-war between the Arctic warming and the tropical upper-tropospheric warming.

No significant signal in PST

The narrowing and reinforcement of the zonal mean jet still occurs, but it is earlier or in fall to early winter in the CMIP5 ensemble.
Changes in the eddy-driven jet stream from CMIP5

Sector mean over North Atlantic

2065-2095 vs 1981-2010 pressure/latitude change in sector mean (Atlantic) zonal wind (m/s) in CMIP5. Gray contours represent climatology.
Changes in the eddy-driven jet stream from CMIP5

Sector mean over North Atlantic

2065-2095 vs 1981-2010 pressure/latitude change in sector mean (Atlantic) zonal wind (m/s) in CMIP5. Gray contours represent climatology.
Changes in the eddy-driven jet stream from CMIP5

Zonal mean over NH in winter (JFM)

2065-2095 vs 1981-2010 pressure/latitude change in NH zonal-mean zonal wind (m/s) in winter (JFM) in CMIP5. Gray contours represent climatology.
Results from CMIP5 models

Ensemble mean of 36 CMIP5 models: latitude-time Hovmöller plots of anomalies in JFM zonal mean U700 (m/s) (relative to the 1981-2010 climatology, shown in the right panels), over the NH (left) and AT sector (right).

CMIP5 models also project a narrowing of the Atlantic eddy-driven jet in winter
Results from CMIP5 models

Change in zonal mean westerly winds at 700hPa as a function of month and latitude

NH

Atlantic sector
Conclusions

• CESM large ensemble has no significant change in NH Zonal Index at the end of the century. The response is sector dependent. Only the American sector shows a negative ZON response.

• SIN (sinuosity) is decreased over the NH in winter. Only over the American continent does SIN increase in winter.

• The response in the eddy driven jet is one of a narrowing and reinforcement of the zonal mean jet, primarily contributed to by the Atlantic and the Pacific sectors.

• Examined a 36 member ensemble of CMIP5 simulations. Also see the reinforcement and narrowing in the zonal mean jet, but it occurs earlier, or in late fall to early winter. Work in progress.
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• Interested in hi-top forced experiments nudging to AA, UTW, PST one by one and in combination
CMIP5
Changes in the eddy-driven jet stream from CMIP5

Sector mean over N America

2065-2095 vs 1981-2010 pressure/latitude change in zonal mean zonal wind (m/s) in CMIP5. Gray contours represent climatology.