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Large-amplitude quasi-stationary waves in ERA5 and CESM2: trends and decadal variability in NH winter

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Background

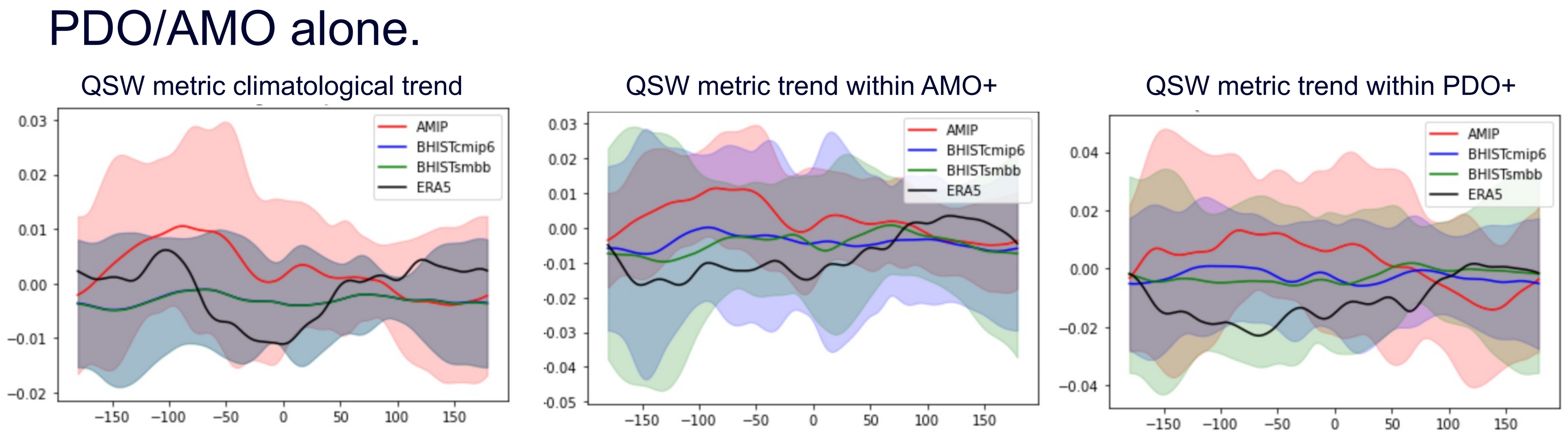
- Quasi-stationary Rossby waves (QSWs) are linked with persistent extreme events.
- **QSWs exhibit preferred phases, resulting in an uneven distribution of heatwaves (cold spells) in summer (winter) across different regions.**
- Since the preferred phase remains consistent across most decades, it must be associated with stationary forcing, such as diabatic heating.
- However, the diabatic heating pattern is expected to change with global warming and internal variability

Data and Methods

- Reanalysis data: u and v (ERA5), diabatic heating (JRA55)
- Experiments: 10 CESM2 AMIP ensemble, 14 CESM2 LENS CMIP6 ensemble and 14-member CESM2 LENS SMBB ensemble
- PDO and AMO indices are calculated and available across all datasets spanning from 1950 to 2014 (2012 for ERA5).
- The QSWs metric is the same as the metric described in Rothlisberger (2019), which is based on the Fourier transform of the 15-day running mean of meridional wind averaged between 35N and 65N.

Trends of QSWs

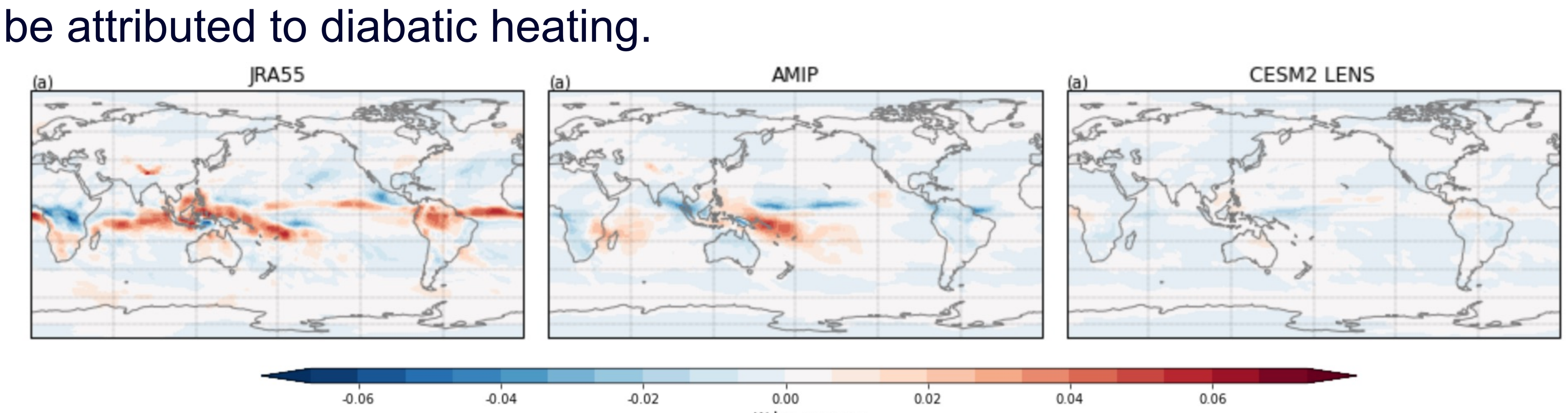
- The climatological QSW metric trend falls within the range of 2 standard deviation QSW metric trends observed in CESM2 AMIP/LENS during the period 1940-2014, or during positive/negative (not shown) phases of PDO/AMO alone.



- Although the entire range is encompassed by the 2 standard deviation ranges, **both the ERA5 and the climate model mean trend are consistent throughout the entire period or within the AMO/PDO positive/negative phases**.
- In ERA5 data, QSWs amplitude exhibit an increasing trend around the Pacific and a decreasing trend around the Atlantic, and an increasing trend around the globe in AMIP experiments. There is little trend of QSWs in CESM2 LENS
- The effect of internal variability with historical SSTs in AMIP seems to be greater than in the full-coupled CESM2 LENS, indicating the importance of coupling processes

Diabatic heating trends

Since SSTs in AMIP experiments and ERA5 reanalysis should be similar, the different forcing leading to different trends in the climate model and ERA5 can be attributed to diabatic heating.



The linear trends of diabatic heating in 1940-2014 winter

- The correlation between the diabatic heating trends from 1940 to 2014 and within decadal variability varies from 0.45 to 0.98 in ERA5. However, the correlation are all above 0.83 in AMIP and varies from 0.22 to 0.8 in CESM2 LENS
- **The different trends in AMIP and CESM2 LENS indicates the effect of underestimation of internal variability in AMIP and trends in LENS**

The frequency of QSWs with decadal variability

Europe QSWs

variability	ENSO	decadal NAO	PDO	AMO
ERA5	0.76	0.77	0.71	1.00
CESM2 AMIP	0.51(+/-0.10)	1.41(+/-0.48)	0.87(+/-0.13)	1.16(+/-0.33)
CESM2 LENS	0.72(+/-0.10)	0.97(+/-0.22)	0.88(+/-0.13)	0.95(+/-0.15)

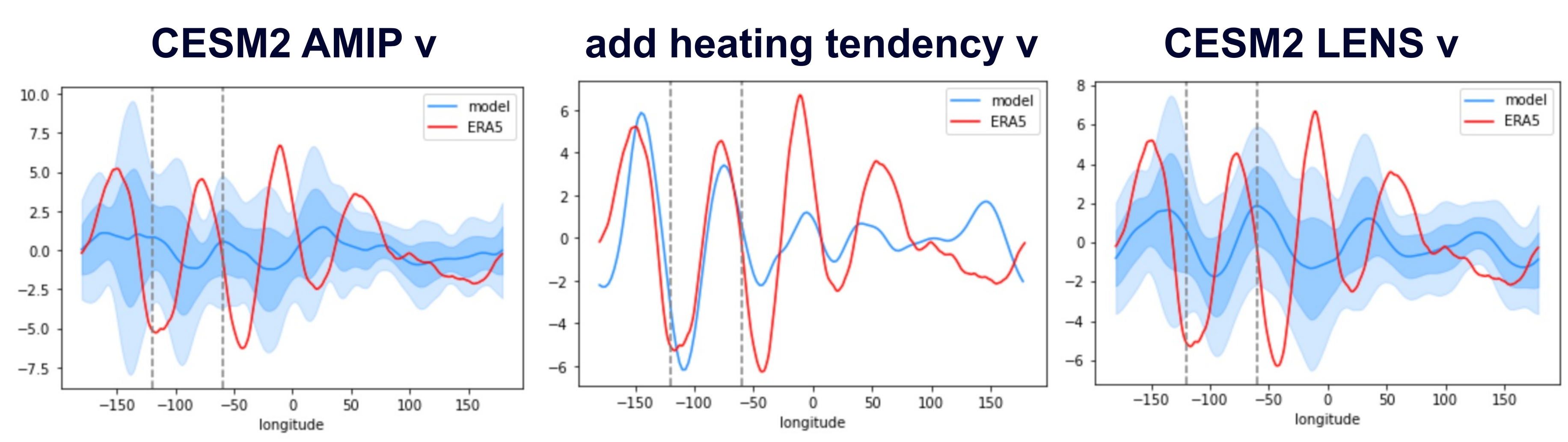
NAmerican QSWs

variability	ENSO	decadal NAO	PDO	AMO
ERA5	0.33	0.85	0.71	1.15
CESM2 AMIP	0.45(+/-0.10)	1.22(+/-0.45)	0.76(+/-0.11)	1.14(+/-0.31)
CESM2 LENS	0.48(+/-0.12)	0.87(+/-0.13)	0.83(+/-0.10)	1.02(+/-0.14)

The table show normalized QSWs frequencies in different regions: freq>1 means more QSWs occur during the positive phase of internal variability; freq<1 indicates the opposite

Significant change of QSWs frequency can be found during PDO and ENSO, and the latter one is studied in Wolf (2022).

North American QSW events pattern during PDO

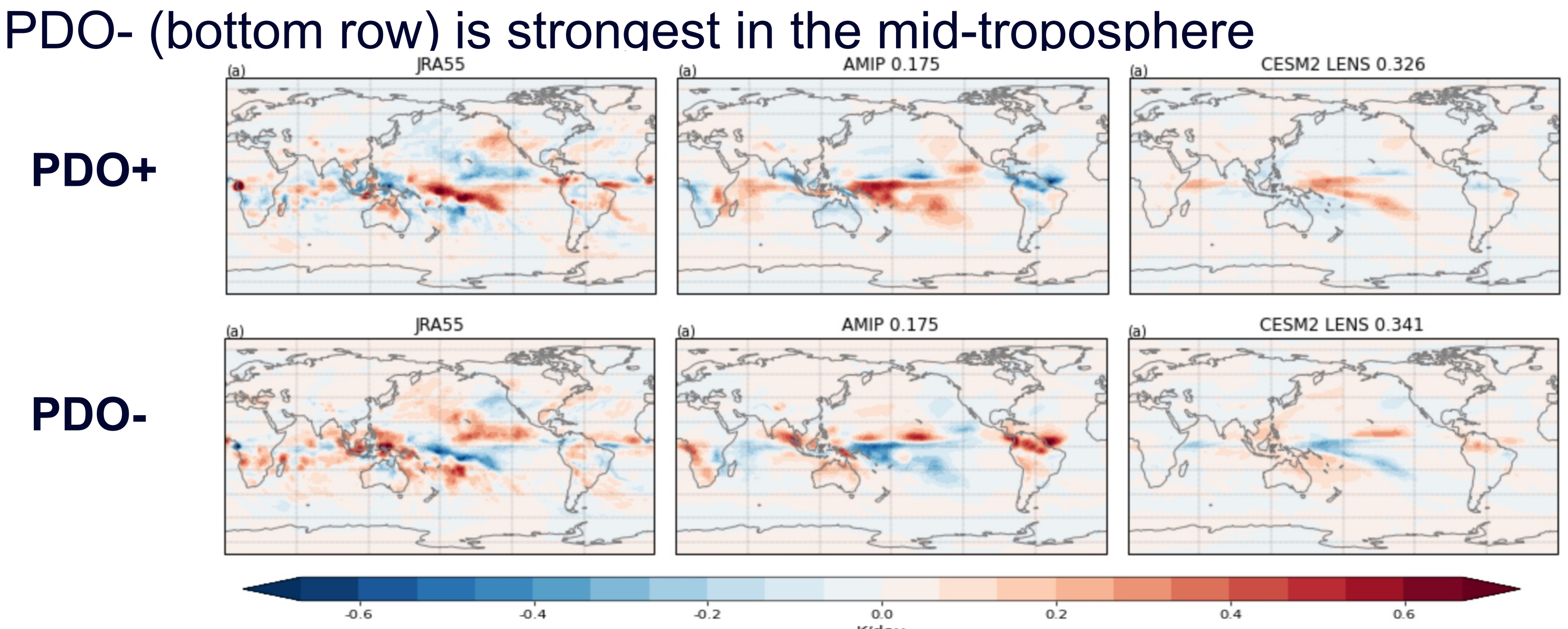


The lines show the difference in meridional wind anomaly composites between PDO+ and PDO-. The shading represents the 2 standard deviation range among model ensembles.

- If we add anomalous diabatic heating tendency from JRA55 into the AMIP experiment in CESM2, it can reproduce a meridional wind pattern even more accurately than CESM2 LENS. **Climatological diabatic heating plays a crucial role in shaping the phase preference pattern of QSWs.**
- The coupling processes may contribute to establishing a more accurate diabatic heating climatology.
- Nonetheless, the representation of diabatic heating in climate models may differ from that in reanalysis data, necessitating a comparison of diabatic heating patterns in CESM2 ensembles and reanalysis.

Diabatic heating within PDO

The difference in diabatic heating climatology between PDO+ (top row) and PDO- (bottom row) is strongest in the mid-troposphere



The first (second) row represents the diabatic heating anomaly at 500 hPa during PDO+(-) in JRA55, CESM2 AMIP experiments, and CESM2 LENS, respectively. The numbers in the last two rows show the correlation coefficients between the climate model mean and reanalysis data.

- The magnitude of the diabatic heating anomaly during PDO+/- in CESM2 is weaker than in JRA55.
- The diabatic heating pattern in CESM2 LENS is much more similar to ERA5 than in AMIP experiments

Summary

- QSWs appear to exhibit a decreasing trend over the Atlantic and an increasing trend over the Pacific in ERA5, although these trends are not statistically significant.
- The trends of QSWs and diabatic heating differ between reanalysis and climate models. QSWs are strongly influenced by internal variability
- Accurate representation of diabatic heating is crucial for capturing the correct pattern of QSWs and estimating the strength of QSWs and consequently, the distribution of extreme events in the future.