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Increased quasi-resonant amplification and persistent summer weather extremes in multimodel climate projections with high emissions and aerosol forcing

Authors

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BACKGROUND AND CONCEPTS

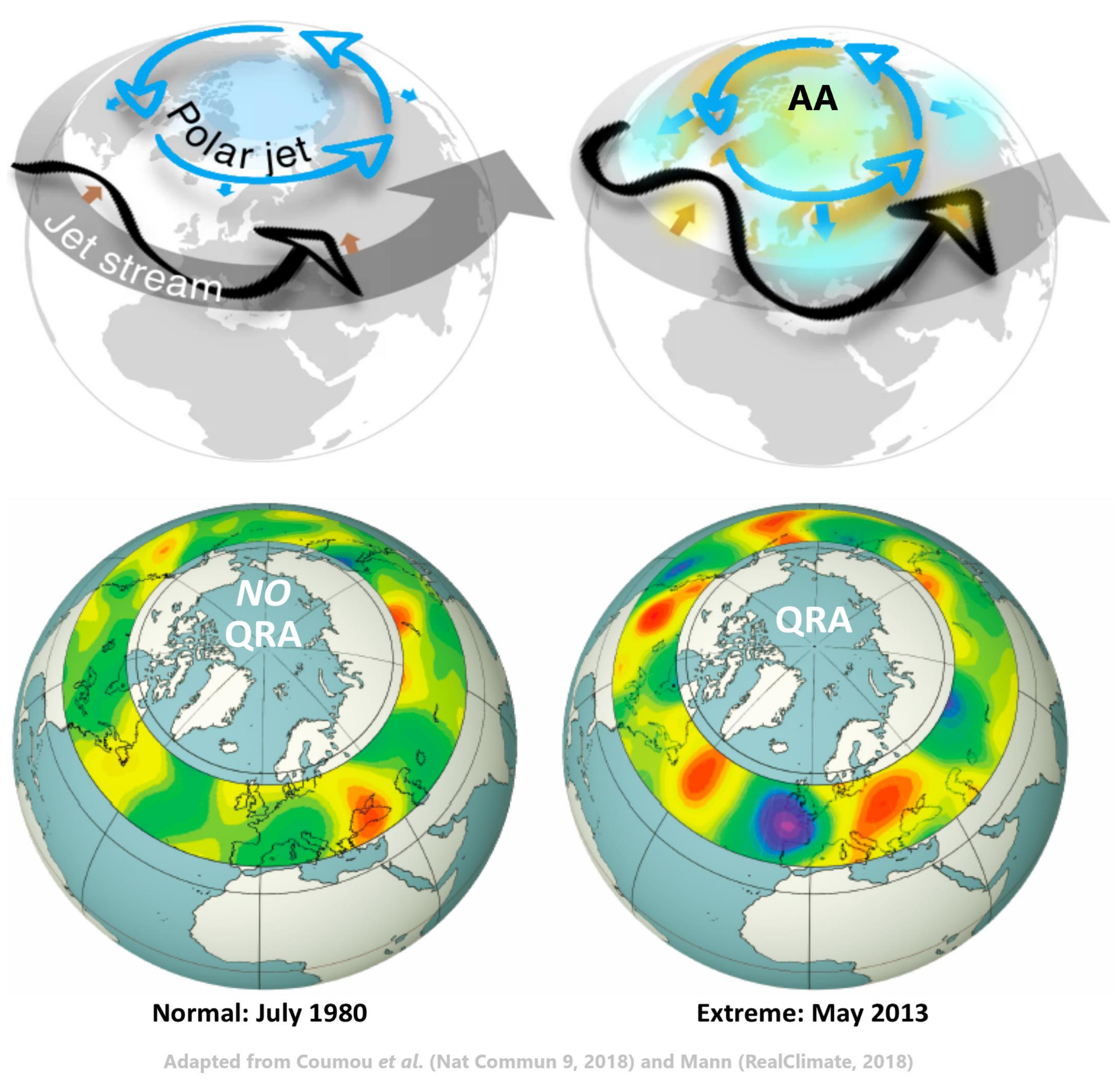
High-amplitude quasi-stationary atmospheric Rossby waves with zonal wave numbers 6 to 8 associated with the phenomenon of ***quasi-resonant amplification (QRA)*** have been linked to ***persistent summer extreme weather events*** in the Northern Hemisphere.

We project future occurrence of **QRA events** based on an index derived from the **zonally averaged surface temperature** field 25N-75N, **JJA** seasonal mean, comparing results from **CMIP5** and **CMIP6** climate projections.

RESEARCH GOALS

Temperature anomaly signatures of **observed** QRA events are used to **generate** a composite **fingerprint** for **model simulations**, and then access outcomes of future changes in climate **extreme trends**.

Fig. 1 *– QRA and Arctic amplification (AA) representation*



RESULTS AND DISCUSSION

Under the scenarios analyzed, there is a general **agreement among models**, with most simulations projecting **increase in QRA index**, see **Fig. 2**. Larger increases are found among **CMIP6-SSP5-8.5** (42 models, 46 realizations, **Fig. 4-C**) models with **85%** of models displaying a **positive trend**, as compared with **60%** of **CMIP5-RCP8.5** (33 models, 75 realizations, **Fig. 4-A**), and a **reduced spread** among **CMIP6-SSP5-8.5** models for the first half of 21 century.

Fig. 2 *– QRA fingerprint series according to CMIP models*

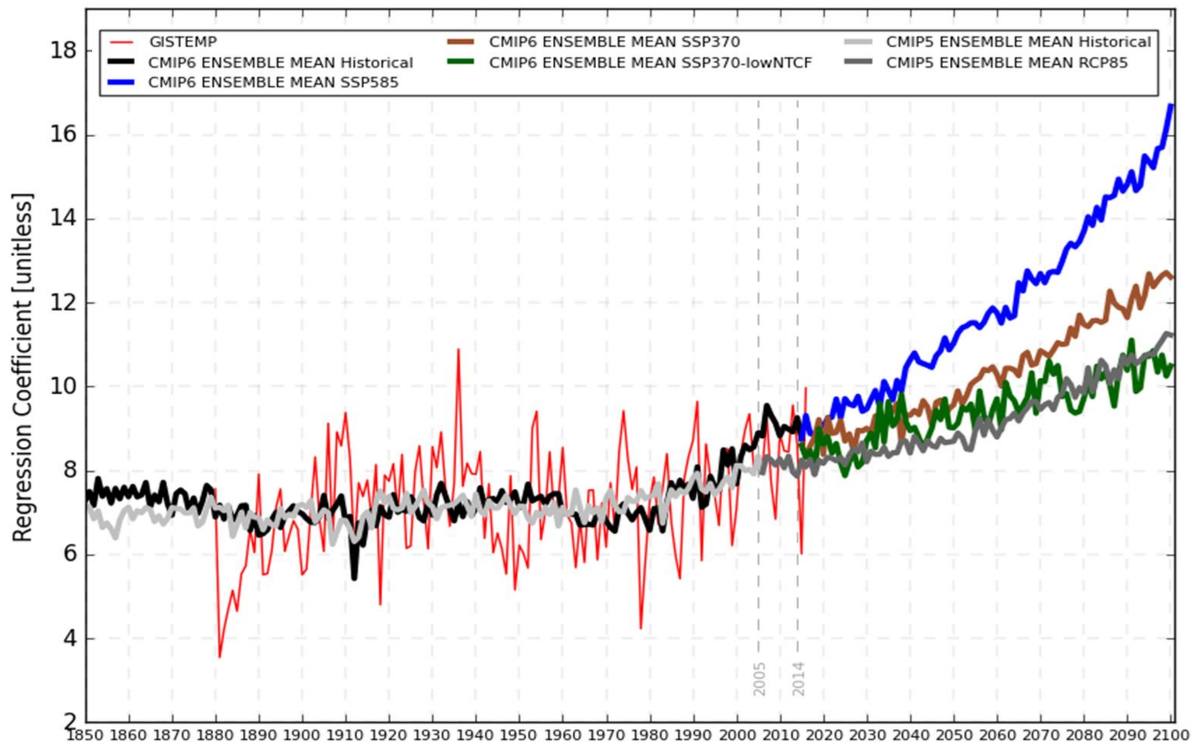
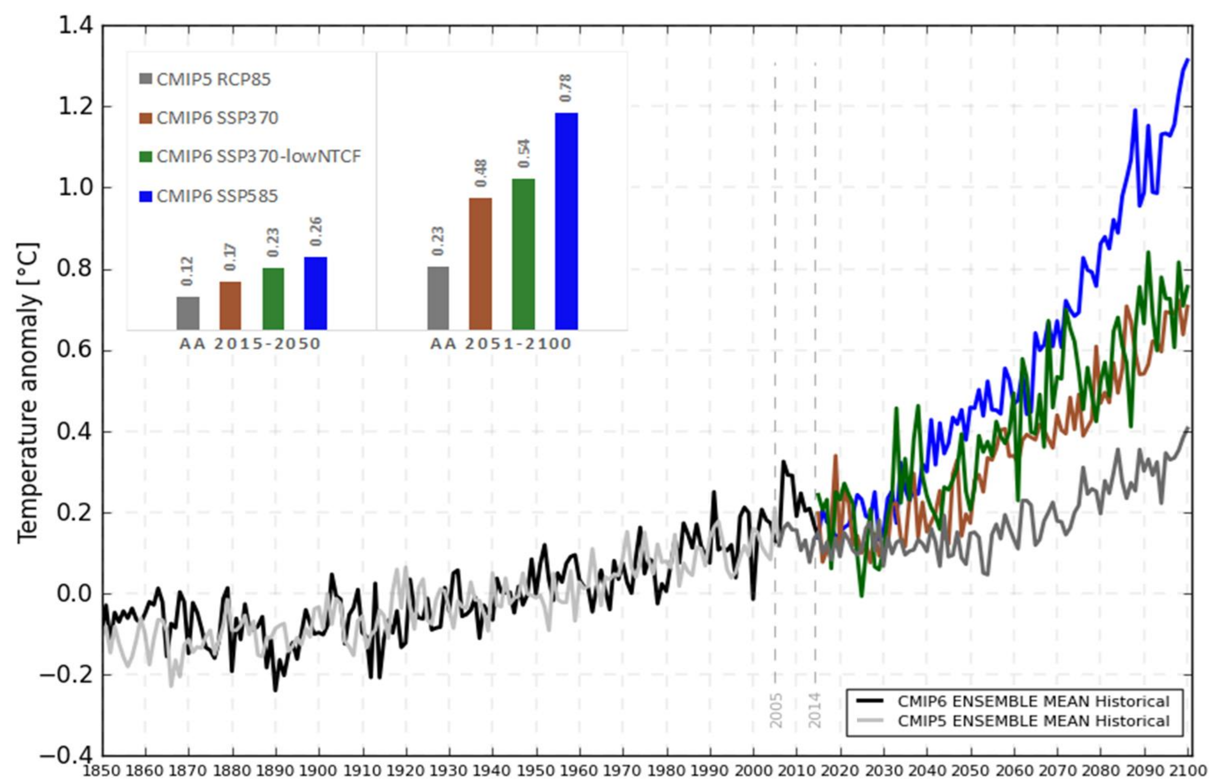
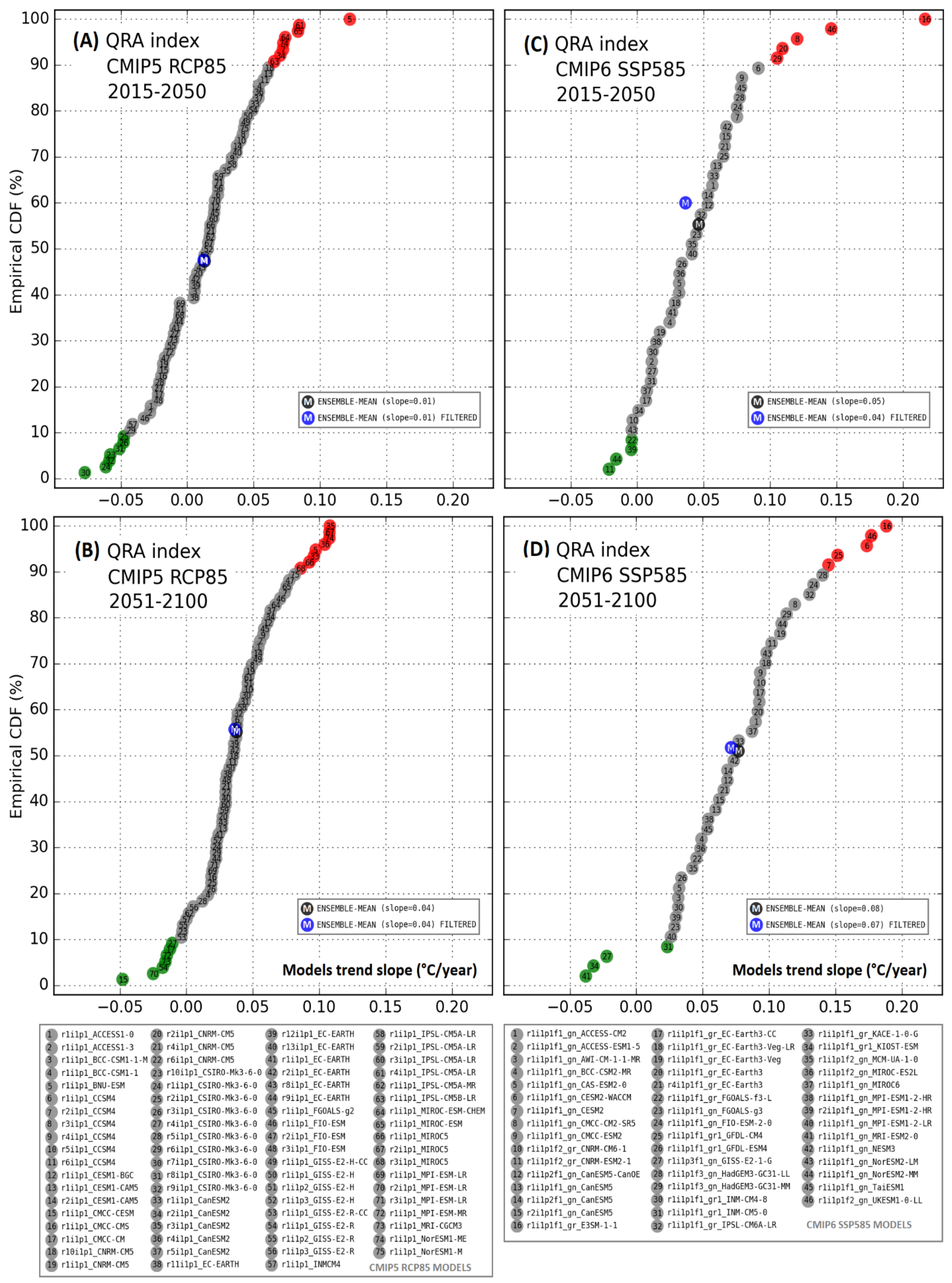


Fig. 3 *– Arctic amplification (High "65-75N" minus Mid "25-60N")*



CMIP6-SSP3-7.0 (25 models, 28 realizations) display qualitatively similar behavior to **CMIP6-SSP5-8.5**, and the results **hold regardless** of the **increase in climate sensitivity** in **CMIP6**. Also, the **aerosol forcing** plays a **substantial role** in CMIP5 and CMIP6 models; a **reduction in aerosol loading** (CMIP6-SSP3-7.0-**lowNTCF**) reduces **AA**, and mitigates potential increases in QRA-related persistent weather events - **Fig. 2** and **3**.

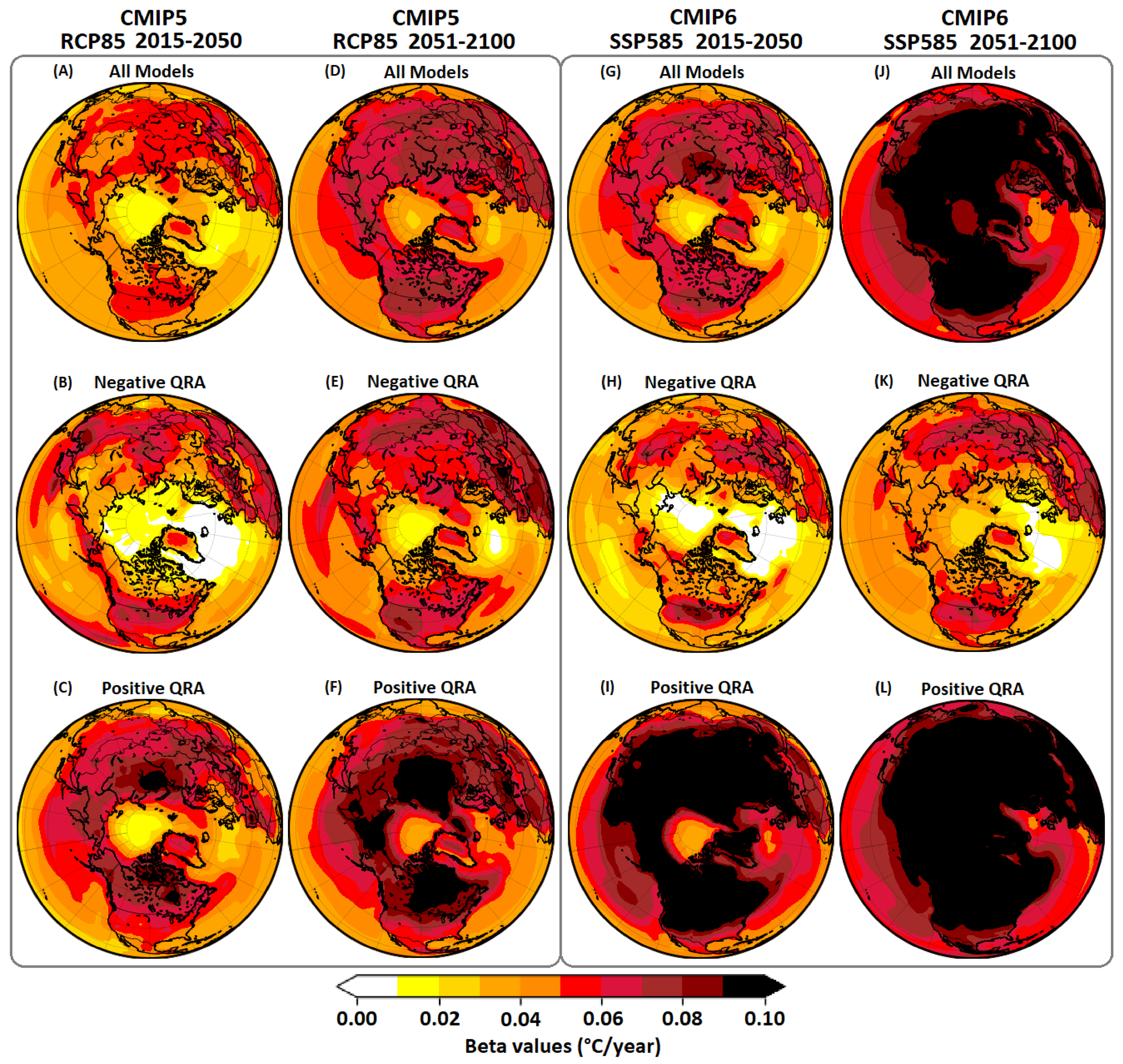
Fig. 4 *– CDF of QRA fingerprint's mean future projection*



CONCLUSIONS

Our analysis suggests that **anthropogenic warming** will **likely lead** to an even more **substantial increase** in **QRA events** (and associated **summer weather extremes**) for CMIP6 than our previous analysis of CMIP5 simulations, align with **warming patterns** indicating greater **AA**, with the largest QRA-trending models showing the most **significant polar amplification**.

Fig. 5 *– CMIP mean surface temperature trend patterns (JJA mean)*



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Kornhuber, K., Petoukhov, V., Petri, S., Rahmstorf, S., Coumou, D. **Evidence for wave resonance as a key mechanism for generating high-amplitude quasi-stationary waves in boreal summer**. Climate Dynamics, 2017.

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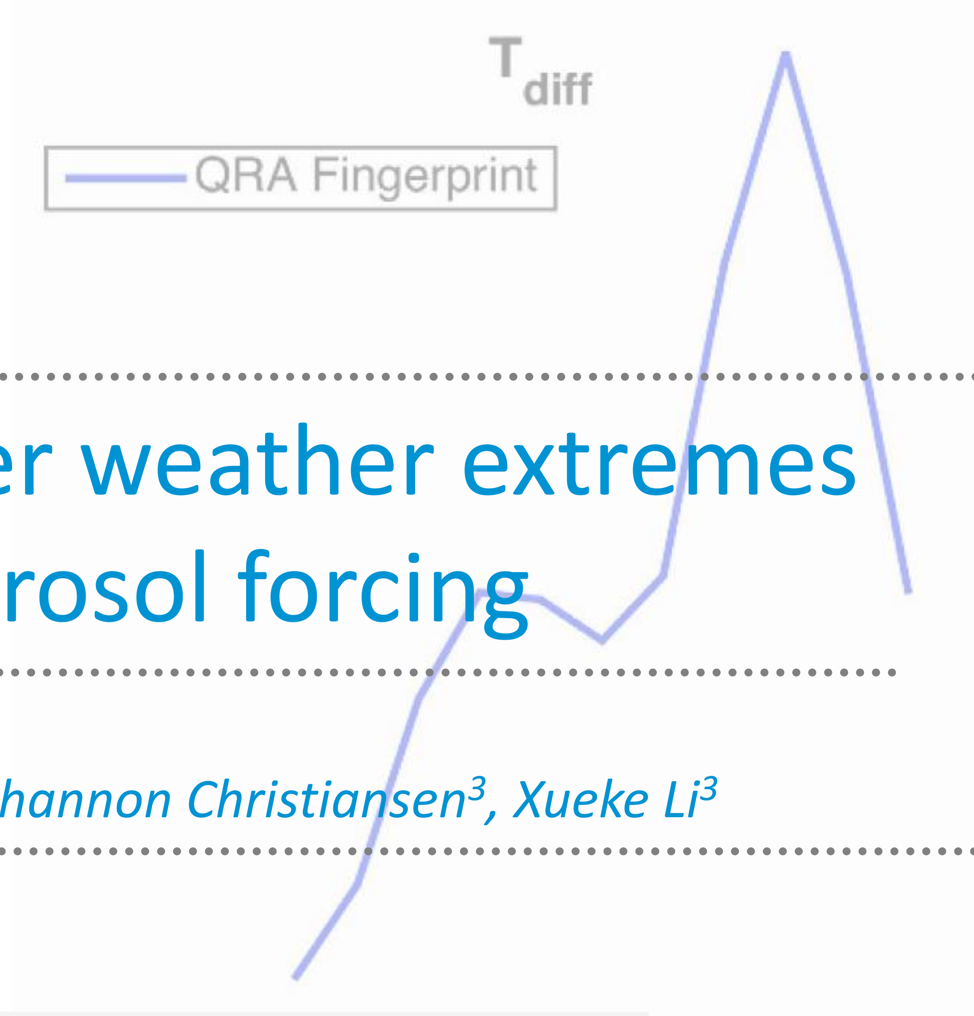

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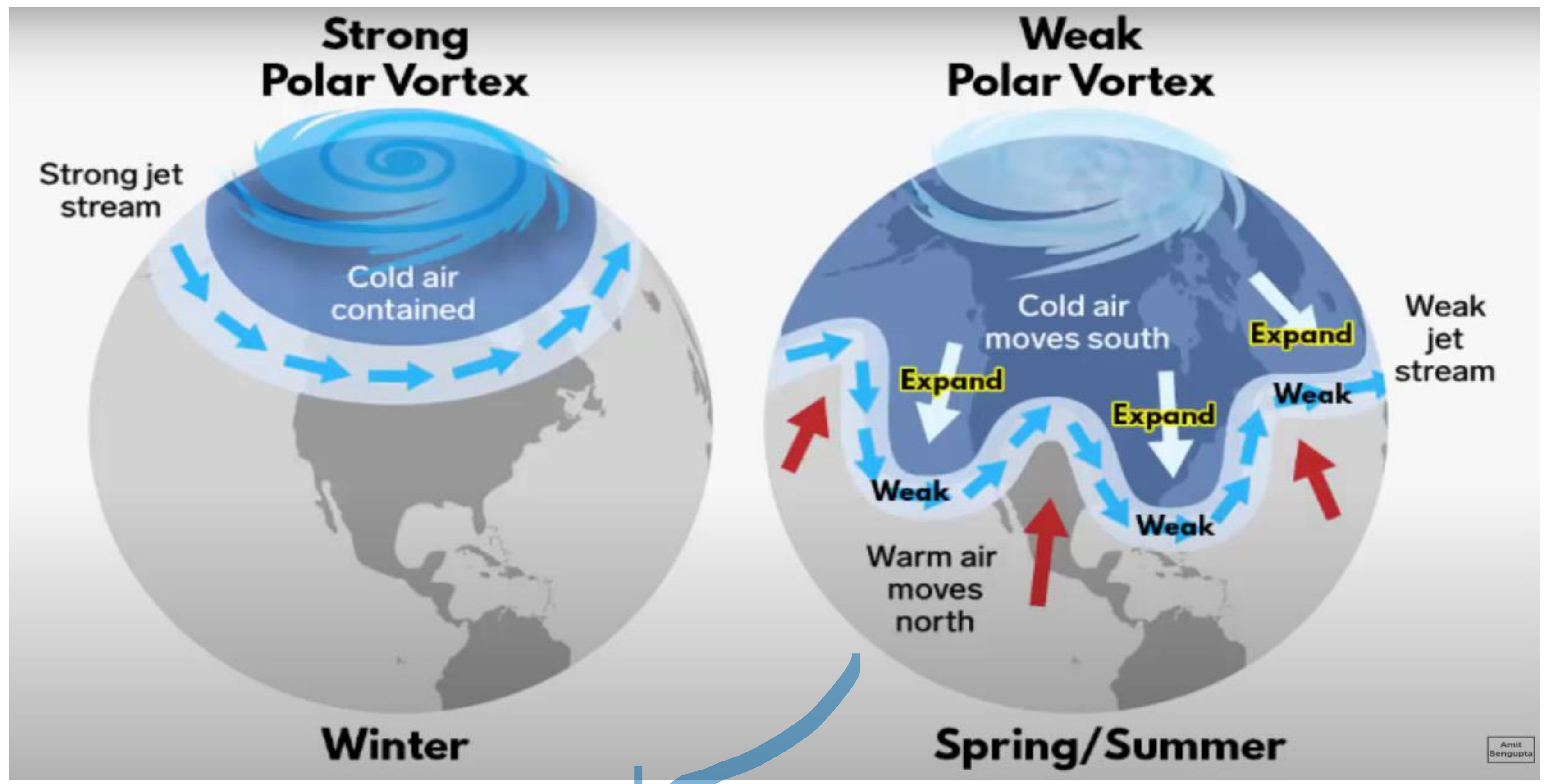
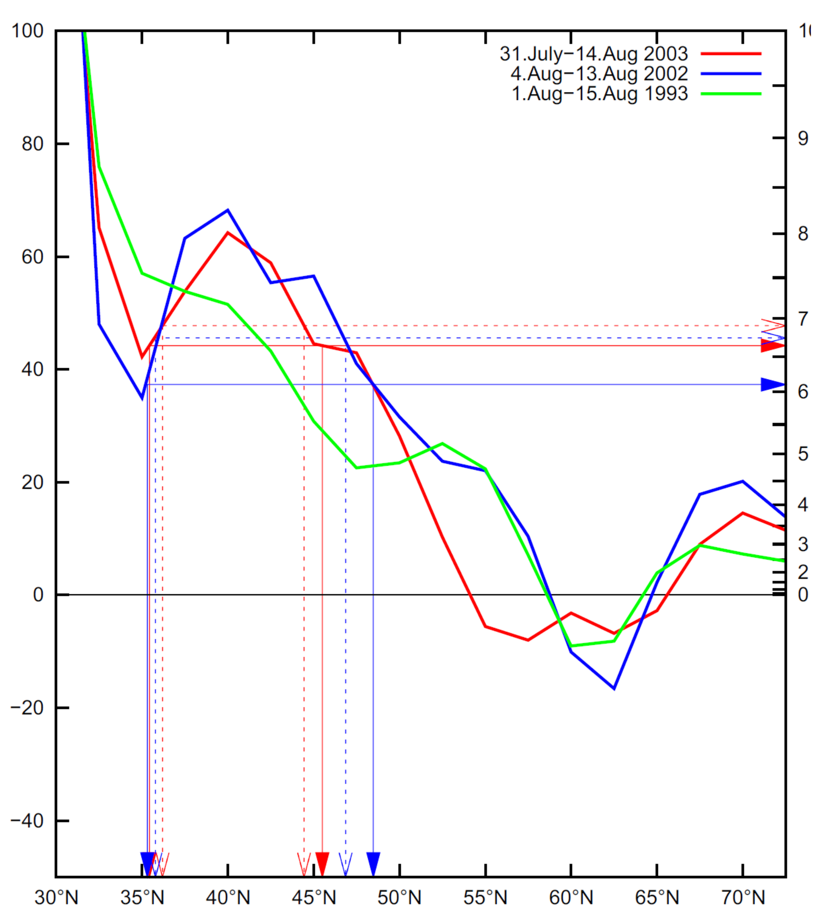
BACKGROUND AND CONCEPTS

With the high-amplitude quasi-stationary atmospheric Rossby waves with zonal wave numbers **6** to **8** associated with the phenomenon of ***quasi-resonant amplification (QRA),*** *the* **QRA events** are identified using **ERA5 daily Summer data** (NH temperature and wind).

The **QRA Fingerprint** of the daily **QRA events,** derived from **zonally averaged surface temperature** field 25N-75N for **JJA** seasonal mean, was used to standardize (mean/std adjustment) **CMIP5** and **CMIP6** climate projections.



Petoukhov et al. 2013 PNAS Waveguides 6-8 study



Kornhuber et al. 2017 Clim Dyn Waveguides 6-8 Detection scheme

Table 1 Overview of applied QRA detection conditions i–ii

i. Waveguide for synoptic scale free wave k
1. Two turning points (TPs, change of sign) in l^2
2. $l^2 > 0$ between the turning points (TP)
3. $U > 0$ in between and in the vicinity of the TPs
4. The highest value of l^2 between the TPs is in the range of l^2_{min} and l^2_{max}
5. The TPs lie within a region of 30°N and 70°N
6. The TPs have a minimum distance of W_k
7. In case of two waveguides their distance has to exceed at least 5°

ii. Effective Forcing Amplitude for forced wave $m \approx k$
8. The effective forcing Amplitude A_{eff} for a respective wave number m has to exceed a certain threshold q_k

ERA5 and ERA-Interim Daily Temp and Wind

QRA Fingerprint from ERA5 JJA daily

QRA index from ERA5 Monthly by Standardization

T_ERA_CLIM --> Climatology avg [1979-2015 2.5dg]

T_ERA_QRA --> QRA fingerprint ERA5 [1979-2015 JJA 0-90N 2.5dg]

T_ERA_QRA_ANOM = (T_ERA_QRA - T_ERA_CLIM) - mean(T_ERA_QRA - T_ERA_CLIM)

T_ERA_QRA_ANOM_SMOOTH --> smooth T_ERA_QRA_ANOM [1979-2015 JJA 25N-75N 5dg]

QRA index from GISSTEMP by Standardization

T_GISS_CLIM --> Climatology avg [1979-2015 5dg]

T_GISS --> Temperature series [1880-2016 5dg]

T_GISS_ANOM = (T_GISS - T_GISS_CLIM) - mean(T_GISS - T_GISS_CLIM)

QRA_index_GISS_step_1 = sum_over_lats(T_GISS_ANOM[t,lats] * T_ERA_QRA_ANOM_SMOOTH[lats])

QRA_index_GISS_step_2 = standard_deviation(QRA_index_GISS_step_1[t])

QRA index from CMIP models by Standardization

T_MOD_1_CLIM --> Climatology avg [1979-2005 5dg]

T_MOD_1 --> Temperature series [1861-2005 5dg]

T_MOD_1_ANOM = (T_MOD_1 - T_MOD_1_CLIM) - mean(T_MOD_1 - T_MOD_1_CLIM)

T_MOD_MEAN_ANOM = mean(T_MOD_1_ANOM; T_MOD_2_ANOM; ... ; T_MOD_N_ANOM)

OFFSET = mean(T_GISS_ANOM[1880:2005,lats]) - mean(T_MOD_MEAN_ANOM[1880:2005,lats])

T_MOD_MEAN_ANOM_offset = T_MOD_MEAN_ANOM[t,lat] + OFFSET[lat]

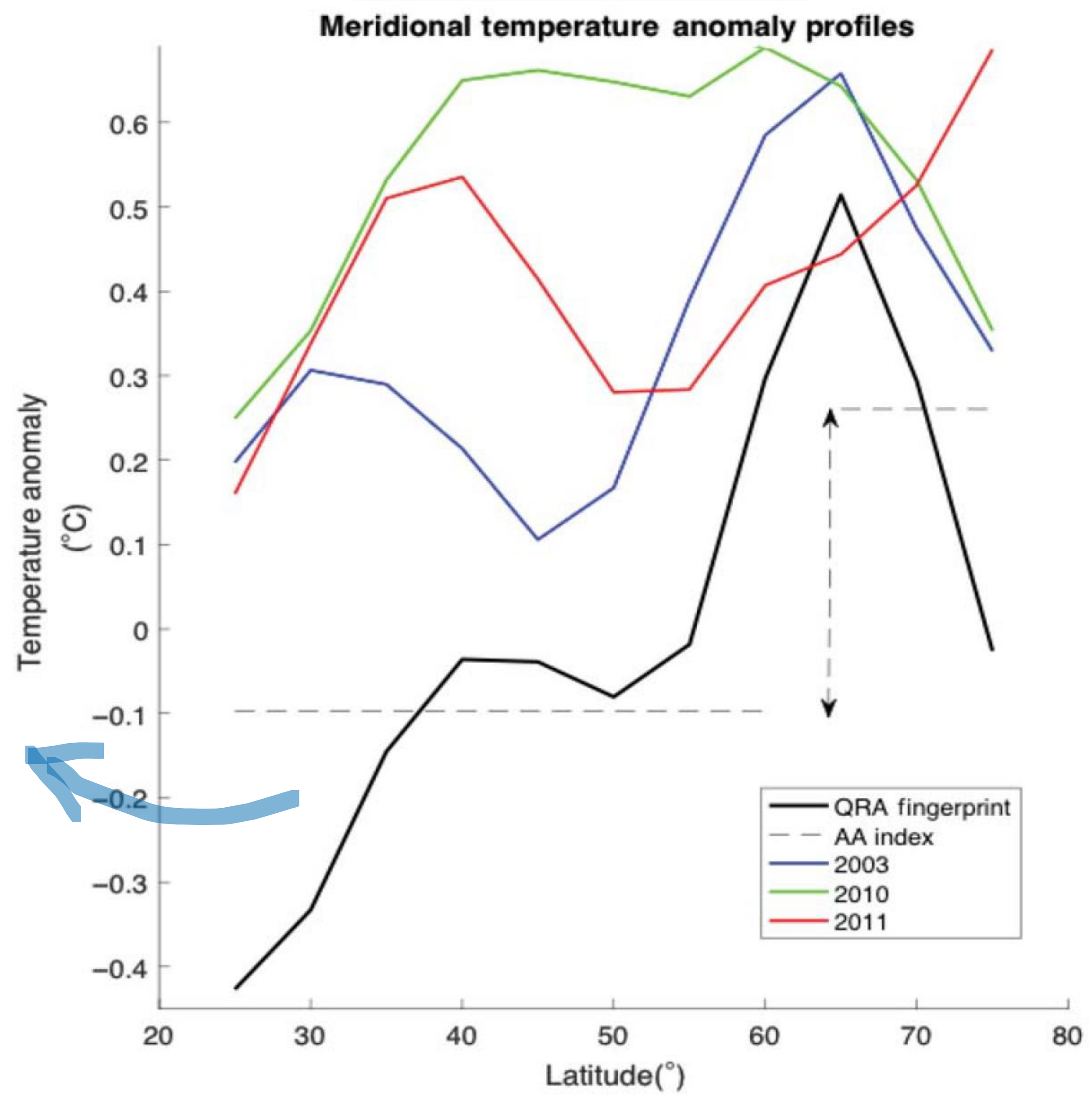
T_MOD_1_ANOM_offset = T_MOD_1_ANOM[t,lat] + OFFSET[lat]

QRA_index_MOD_1_step_1 = sum_over_lats(T_MOD_1_ANOM_offset[t,lats] * T_ERA_QRA_ANOM_SMOOTH[lats

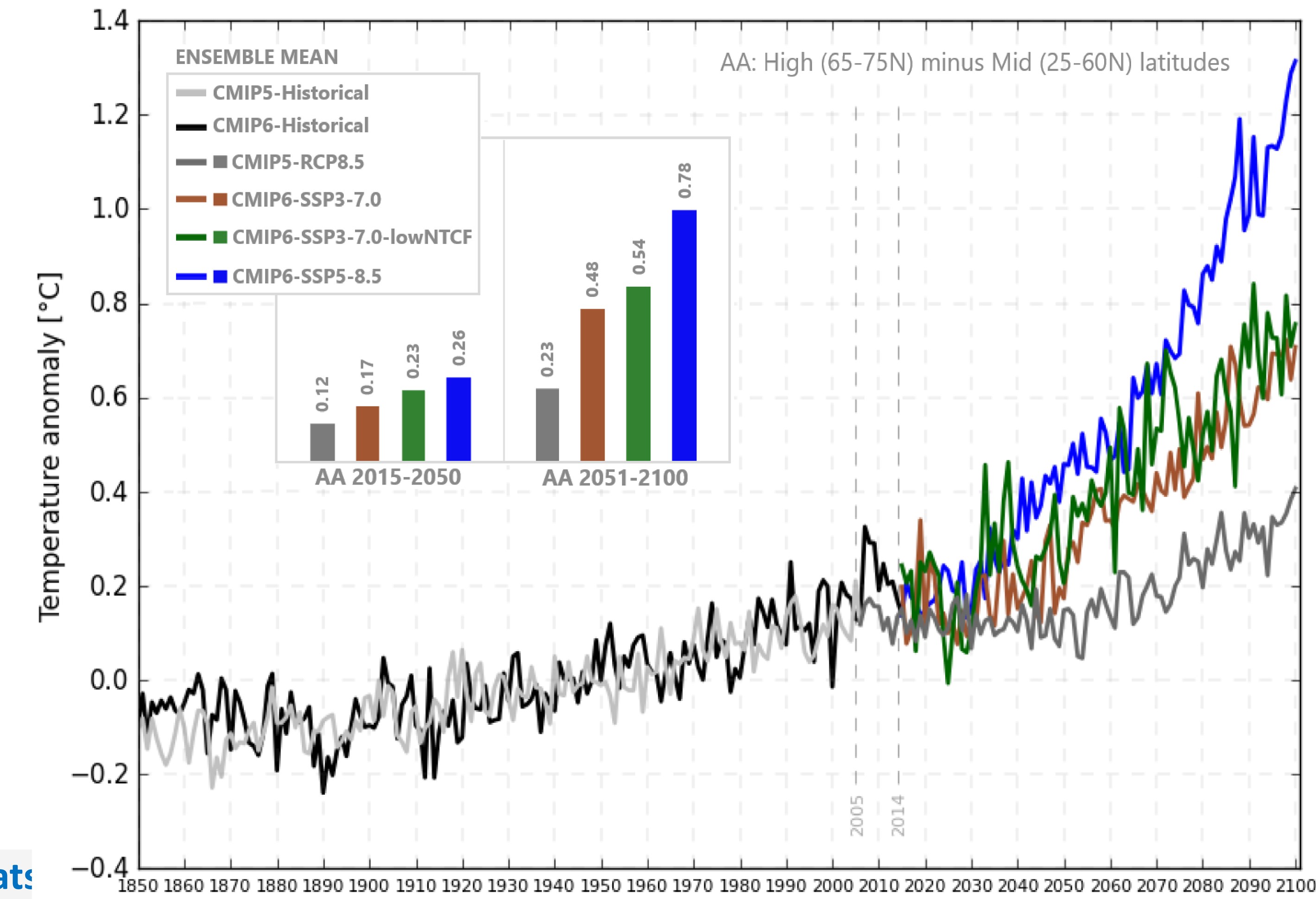
QRA_index_MOD_1 = QRA_index_MOD_1_step_1[t] / QRA_index_GISS_step_2

QRA_index_MOD_MEAN = mean(QRA_index_MOD_1; QRA_index_MOD_2; ... ; QRA_index_MOD_N)

Michael Mann et al. 2017 and 2018 Sci. Adv. QRA index Analysis



Guimaraes et al. 2024 EGU QRA index Analysis



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