Abstract

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Quantifying changes in seasonal temperature variations using a functional data analysis approach

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1. Research goal and Functional data approach

- The increase of temperature is not uniform throughout the year, resulting in changes in the mean annual cycle.
- The shape of the annual cycle and its changes vary considerably around the globe. Therefore, we use a diagnostic that can be evaluated for different annual cycle shapes (e.g., single/double waves, different timing of seasons, etc.).
- We introduce an innovative approach based on **functional data analysis (FDA)** which converts the daily annual cycle of temperature to functional form.

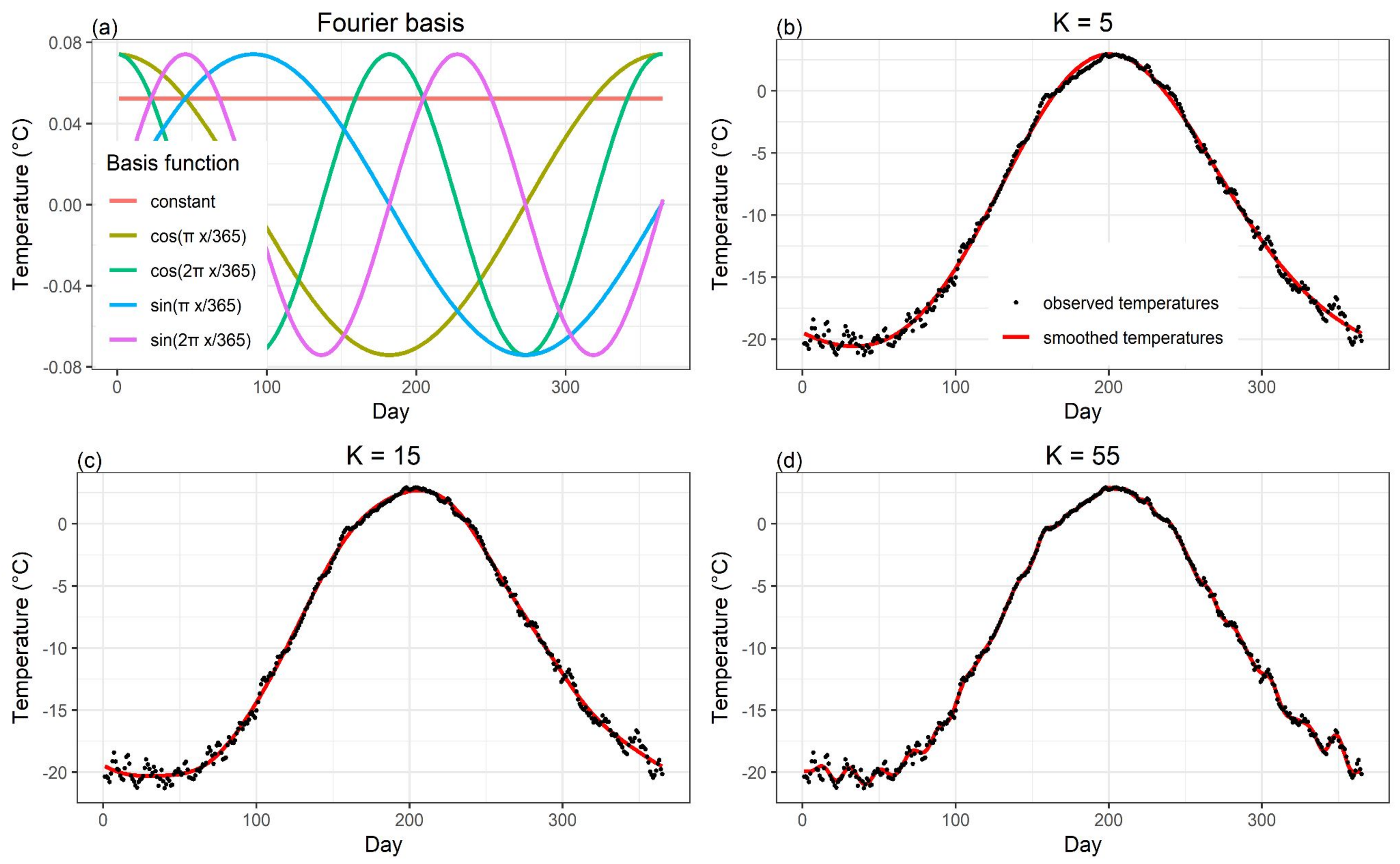

Figure 1: *(a) Basis functions for the case K=5; (b, c, d) smoothed temperature with respect to K = 5, 15, 55. As the number of coefficients grows more and more variability beyond the mean seasonal cycle is captured by the FDA. We choose K=15.*

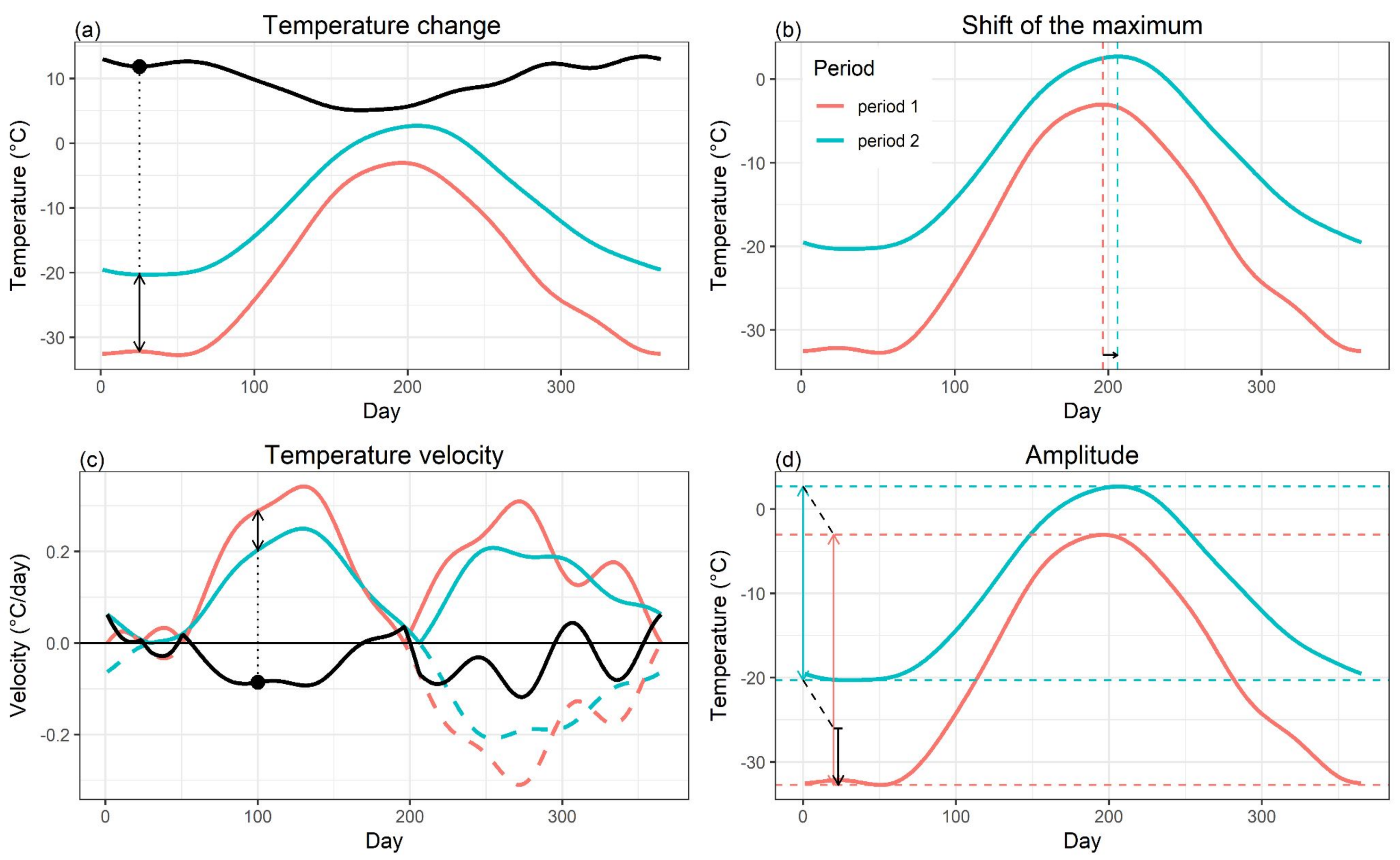

Figure 2: *The FDA diagnostics interpretation framework. Black arrows illustrate the FDA diagnostics. For temperature change and temperature velocity, we evaluate the Euclidean distance of the curves between two time periods and the 10th and 90th percentiles of the changes to investigate different patterns of change throughout the year.*

2. Data

- **2 reanalyses (ERA5 and CERA20C, both created by ECMWF)**
- **5 CMIP6 ESMs: CanESM5, CNRM-ESM2-1, EC-Earth3, MPI-ESM1-2-HR, NorESM2-MM), historical and SSP3-7.0**
- Historical time periods: 1951-1980, 1981-2010
- Future time period 2071-2100 vs. reference 1961-1990 (not shown)

➔Annual cycle changes can be very heterogeneous through the year, in particular (but not only) at high latitudes.

➔FDA enables evaluation of annual cycle properties such as the slope ("temperature velocity") but also more standard metrics such as location of the maximum and amplitude.

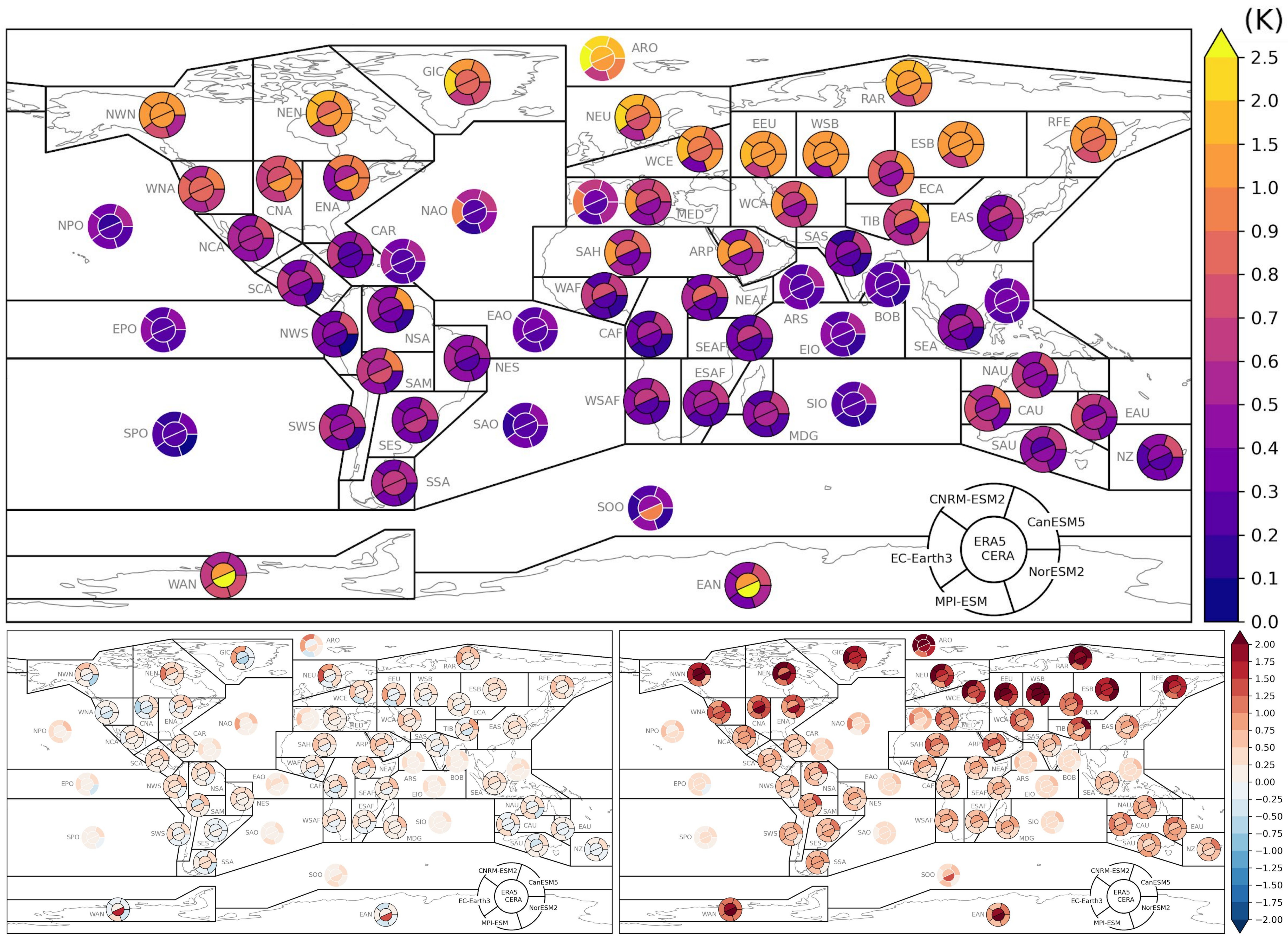

Figure 3: Top: *Euclidean distance of the whole FDA mean annual cycle curves.*
Bottom: *10th percentile (left) and 90th percentile (right) of daily euclidean distances.*

All plots are the change 1981-2010 minus 1951-1980.

5. Selected results

- Temperature increase is evident across regions, with varying magnitudes (Fig. 3 top); large disagreements between datasets occur over southern ocean and Antarctica, but partly also near the equator.
- Temperature decreases in a part of the year in Greenland, WNA and CNA regions; otherwise, we find distinct differences in the 10th percentile of changes between the reanalyses, especially near the equator and in the Arctic and Antarctic regions (Fig. 3 bottom left).
- Reanalyses agree on a decrease in amplitude, while models show diverging results. For the future, the projections anticipate substantial amplitude increase in the Mediterranean and decrease in the Arctic.
- Maximum shift does not show any distinct pattern, but the reanalysis and models disagree mainly over southern America and southern Africa (Fig. 4). Projections (not shown) expect delayed maximum near the poles and earlier maximum in many tropical continental regions.
- Higher magnitude of temperature velocity change is detected in higher latitudes, mainly in the northern hemisphere. All regions experienced both decrease and increase of slope of the annual cycle. The pattern remains the same in the projections.

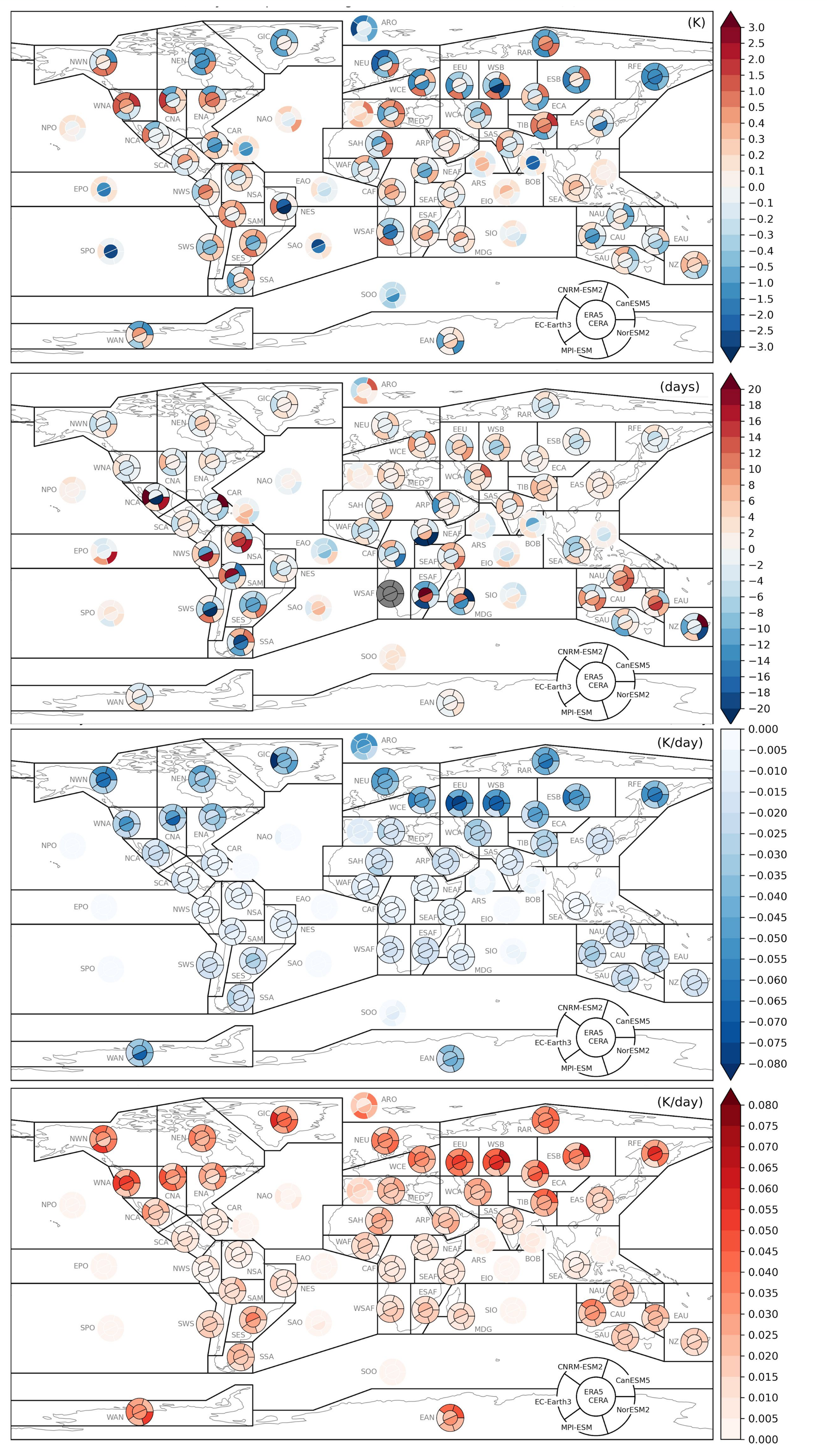

Figure 4: 1st: *Annual cycle amplitude change.* ***2nd:*** *Annual cycle maximum shift.* **3rd & 4th:** *10th and 90th of changes in the FDA mean annual cycle slope (temperature velocity).*

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