The Seasonality of Surface Temperature Warming: A Global Comparison of Climate Model Ensembles and Observations

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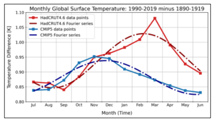
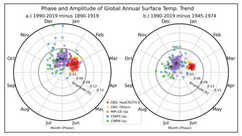
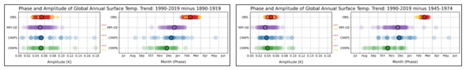






INTRODUCTION

Observations and climate models agree that global warming has larger amplitude in boreal winter than boreal summer. However, this apparent agreement masks a clear disagreement: observed warming rates are largest in early boreal spring, while simulated warming rates are largest in early boreal winter – a 90° phase difference. We analyze this using a sinusoidal fit to global, local and zonally-averaged monthly temperature differences.

The figures above show three ways of depicting the differences. Upper left is the monthly temperature differences in HadCRUT observations and CMIP5 simulations, along with the sinusoidal fit. Upper right is the amplitude and phase of the seasonal warming variations in individual ensemble members, with the ensemble means shown by black outlines. Bottom is the amplitude and phase plotted separately, for two different time intervals.

DATA

Analyses

- HadCRUT 4.6.0.0 100-member ensemble
- HadCRUT 4.6.0.0 median
- HadCRUT 4.6.0.0 Cowtan and Way
- HadCRUT 5.1.0.0 median
- GISTEMP v4 1200 km
- GISTEMP v4 250 km
- NOAAGloalTemp v5
- HadSST 3.1.1.0 (sea)
- CRUTEM 4.6.0.0 (land)

Simulations

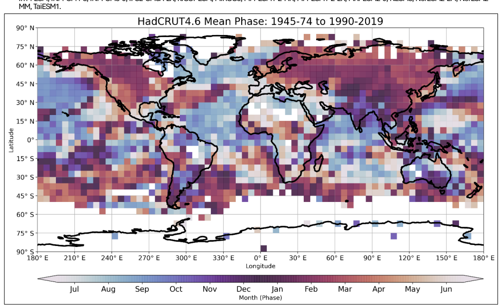
- Max Planck Institute for Meteorology Grand Ensemble (MPI-GE), 100-member ensemble
- CMIP5 one member per model, historical extended with RCP8.5, equal weights
- CMIP6 one member per model, historical extended with ssp585 , equal weights

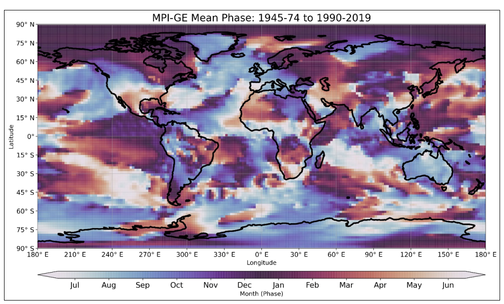
Model variables

tas (land), ts (ocean), tas (globe)

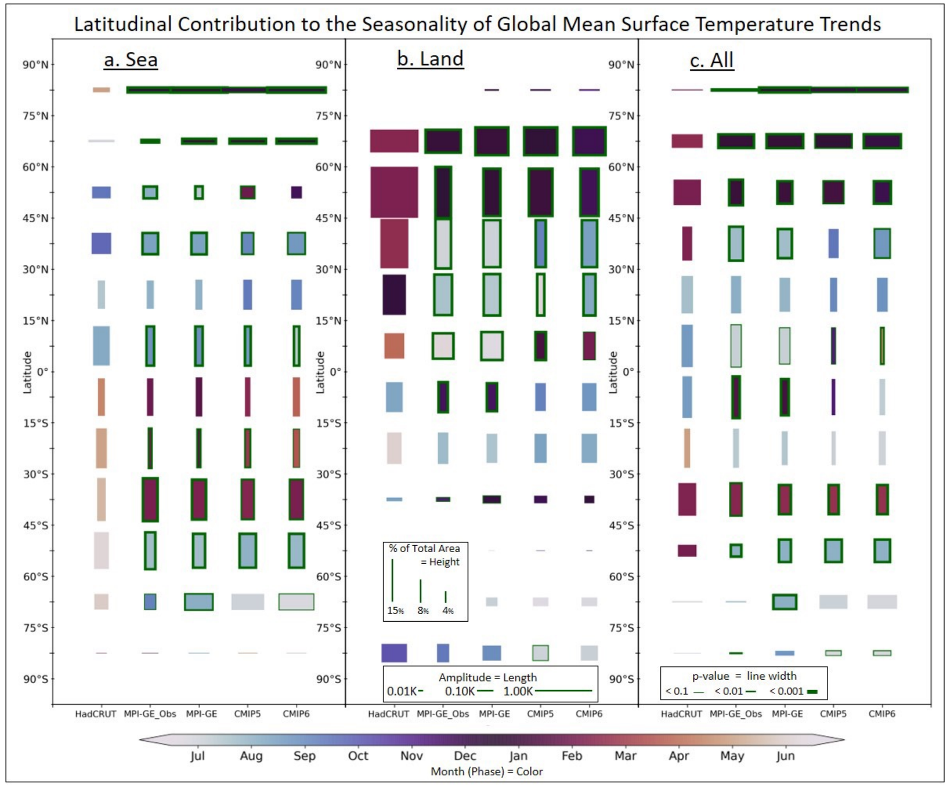
CMIP5 models: ACCESS-0, ACCESS1-3, bcc-csm1-1, BNU-ESM, CanESM2, CCSM4, CESM1-CAM5, CMCC-CM, CMCC-CMS, CMCC-CESM, CNRM-CM5, CSIRO-Mk3.6.0, EC-EARTH, FGOALS_g2, FGOALS_s2, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-H-CC, GISS-E2-R, GISS-E2-R-CC, HadGEM2-AO, HadGEM2-CC, HadGEM2-ES, inmcm4, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR, MIROC5, MIROC-ESM, MIROC-ESM-CHEM, MPI-ESM-LR, MPI-ESM-MR, MRI-CGCM3, NorESM1-M, NorESM1-ME.

CMIP6 models: ACCESS-CM2, ACCESS-ESM1-5, AWI-CM-1-1-MR, BCC-CSM2-MR, CAMS-CSM1-0, CAS-ESM2-0, CESM-WACCM, CIESM, CMCC-CM2-SR5, CMCC-ESM2, CanESM5, E3SM-1-1, EC-Earth3, EC-Earth3-CC, EC-Earth3-Veg, EC-Earth3-Veg-LR, FGOALS-f3-L, FGOALS-g3, FIO-ESM-2-0, GFDL-ESM4, IITM-ESM, INM-CM4-8, INM-CM5-0, IPSL-CM6A-LR, KIOST-ESM, MIROC6, MPI-ESM1-2-HR, MPI-ESM1-2-LR, MRI-ESM2-0, NESM3, NorESM2-LM, NorESM2-MM, TaiESM1.





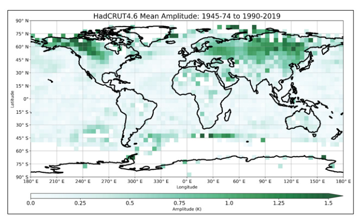
The figure below summarizes the results of this investigation. Temperature variations are aggregated into 15-degree latitude bands and subdivided into sea and land portions. (Grid cells containing coasts are not included in either sea or land categories but are included in the overall averages.) The height of each rectangle corresponds to the percent of global area in each category included in the latitude band, while the width of the band indicates the amplitude of the seasonal warming difference. Thus, the area of each rectangle represents the contribution of each area to the global warming difference. The presence and thickness of green outlines around each rectangle (scale at bottom right) indicate the statistical significance of the difference between the modeled seasonal warming (amplitude and phase) and observed seasonal warming, given the ensemble spreads in both models and observations. The color of each rectangle (legend at bottom) represents the seasonal peak of warming. The five columns within each category are: HadCRUT4.6, MPI-GE masked to HadCRUT4.6 data points, unmasked MPI-GE, unmasked CMIP5, and unmasked CMIP6. Results are not sensitive to masking.

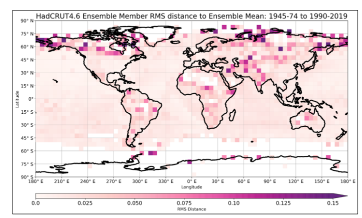


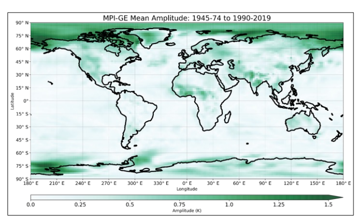
Left: The season in which the first harmonic of the difference between the thirty-year monthly temperature averages in 1945-1974 and 1990-2019 reaches its maximum value, for observations (top) and the MPI grand ensemble (bottom).

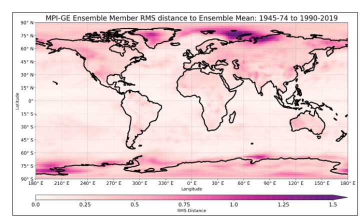
Right: The amplitude of the first harmonic of the temperature difference. The observed seasonality of warming has its largest amplitude over middle and high latitude land surfaces, while the modeled seasonality of warming has its largest amplitude over areas with frequent sea ice.

Far Right: The within-ensemble variability of the first harmonic of the temperature difference. The observation ensemble has largest variability over data-sparse continental areas, while the model ensemble has largest variability along sea ice margins.







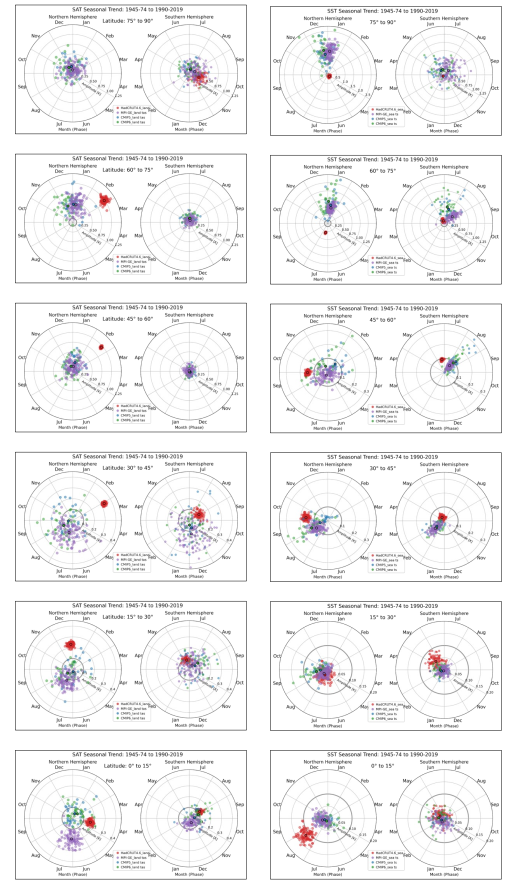


RESULTS

The largest seasonality in surface temperature trends is located from 30°N to 90°N. For SAT trends over land, and SST trends over ocean, all of the GCM ensembles are significantly different from observations to a p-value of < 0.001. Within this broad region, the observed seasonal SAT trends over land regions peak in March, with a maximum seasonal amplitude of about 1.0 K. North of 45°N, the modeled SAT trends lead observations by a few months, peaking in January, and between 45°N and 30°N their phase lags behind observations, and modeled amplitudes are too weak.

The second largest seasonal temperature trends arise from SSTs in 30°S to 60°S. The observed SST trend peaks in late austral fall, and the combined land-sea mean phase is in March (early austral fall). This is the same phase (March) as the warming over NH land. The mismatched seasonal SST trends from the GCMs tend to peak a few months later than observations from 60°S to 45°S, and northward to 30°S they peak earlier than observation seasonal SST trends.

A small but distinct annual phase and amplitude of seasonal surface temperature trends is observed in NH tropical regions from the equator to 30°N. This annual warming trend is mostly absent from models. Modeled SST trends are also significantly different from observations from the equator to 15°N. The phase of observed warming is roughly consistent with the expected effects of orbital precession, which would induce a maximum warming trend in October in both hemispheres. Orbital precession cannot explain the other discrepancies noted above.



The diagram in the center is a statistical aggregation of information such as is depicted in the polar diagrams above. Each colored circle represents the amplitude (indicated by distance from center) and phase of the seasonal warming difference of a model ensemble member (green, blue, and purple) or an analysis ensemble member (red). Ensemble means are indicated by circles with black outlines. The left column is for temperatures over land; the right column is for temperatures over water. The Southern Hemisphere phase is rotated 180° to facilitate identification of common physical behavior. The amplitude scale is variable. The 0.1 °C amplitude value is indicated by a thick ring in all plots; a larger thick ring corresponds to generally smaller amplitudes. Notice the lack of overlap between model and observation ensembles in many latitude bands.