Temperature Trends and the Diurnal Cycle in ERA5

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Abstract

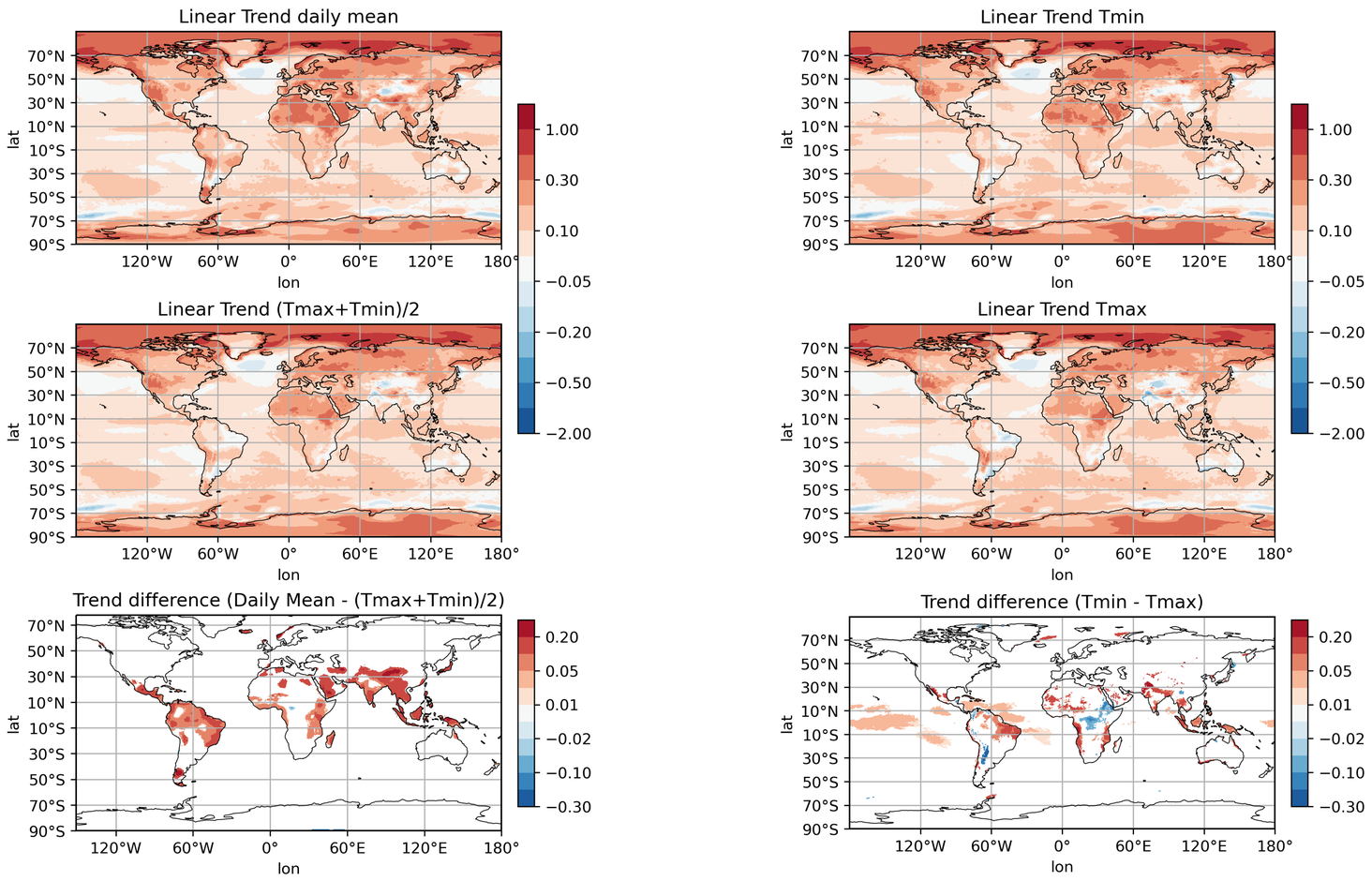
Daily mean temperatures are typically computed using the average (T_{mm}) of the daily minimum (T_{min}) and maximum (T_{max}) temperature. It is well known that there are differences between that approach and computing the daily mean of hourly or 3 hourly (T_{mean}) temperature observations.

$$T_{\mathrm{mm}} = (T_{\mathrm{min}} + T_{\mathrm{max}})/2,$$

$$T_{\mathrm{mean}} = 1/8 \sum_{i=0}^{7} T_{2\mathrm{m}}(3\mathrm{i})$$

- Here we show that **the different approaches also lead to differences in estimates of the long term trends** (1940-2019) of global and regional temperature, using ERA5 reanalysis 2-m temperature.
- The **differences in trends are largest over land areas in the Tropics**, where the trend from T_{mean} is larger than the trend in T_{mm}. Tropical regions are also where trends in T_{min} and T_{max} differ the most. In the global mean the trend from T_{mean} also outpaces the trend using the average of T_{min} and T_{max}.
- **This study indicates that using the approach of averaging T_{min} and T_{max} to estimate daily temperatures may be systematically underestimating the rate of global temperature increase** in ERA5 reanalysis due to changes in the diurnal cycle. We reproduce this behavior in the trends using a synthetic time series with non-sinusoidal diurnal cycle.

Trends



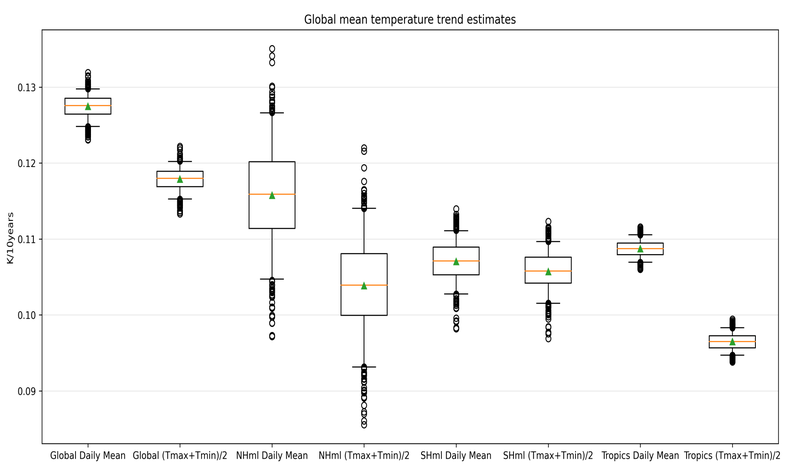
Linear Trends estimated from 1940-2019 in ERA5 for T_{mean}(top), T_{mm}(middle), and difference in trends between T_{mean} and T_{mm}. Units are K/10y. Only significant differences are shown in the bottom panel.

Linear Trends estimated from 1940-2019 in ERA5 for T_{min}(top), T_{max}(middle), and difference in trends between T_{min} and T_{max}. Units are K/10y.

ERA5 trends in 2m temperature differ significantly depending on whether a daily average of 8 measurements (T_{mean}) or the mean of minimum (T_{min}) and maximum (T_{max}) daily temperatures (T_{mm}) are used to compute the daily mean temperature.

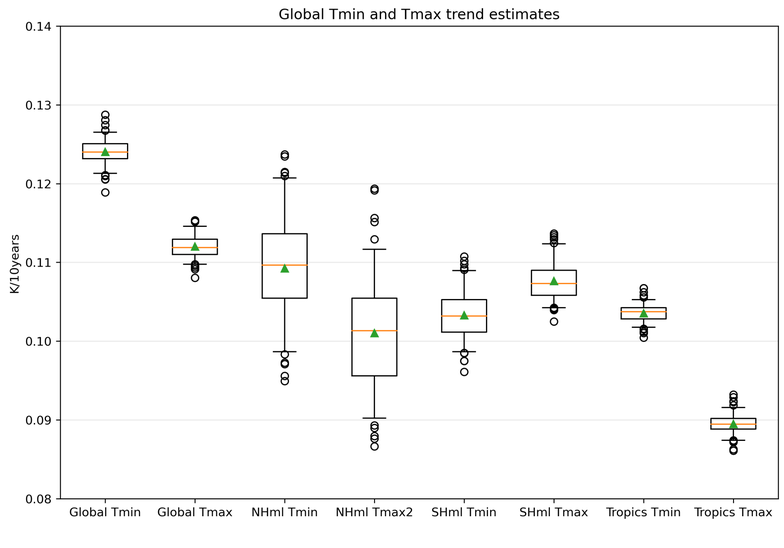
Regional Trend Distributions

$\mathbf{T_{mean}}$ and $\mathbf{T_{mm}}$



On the global mean scale the trends estimated from T_{mean} and T_{mm} are significanty different. The difference in global mean temperature trends estimated from T_{mean} and T_{mm} is about than 0.07K over the 80 years from 1940 - 2019. In South-East Asia this difference comes to 0.8K.

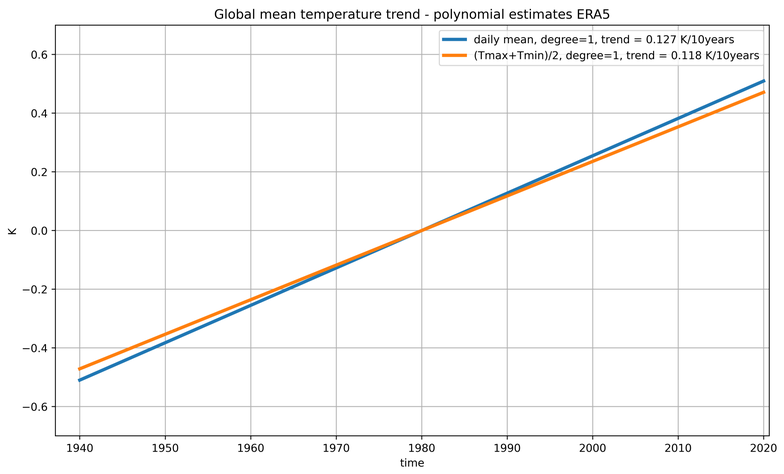
$\mathbf{T_{min}}$ and $\mathbf{T_{max}}$



Similarly, global mean trends of T_{min} and T_{max} are significanty different. As has been previously observed, **trends in T_{min} tend to be larger than trends in T_{max}.** This difference is largest in the Tropics, although the spread in trends is largest in the Northern Hemisphere mid-latitudes.

Synthetic Time Series

Can we generate a synthetic time series where the diurnal cycle changes in a similar manner to what is observed and the trends in T_{mean} and T_{mm} differ as well?



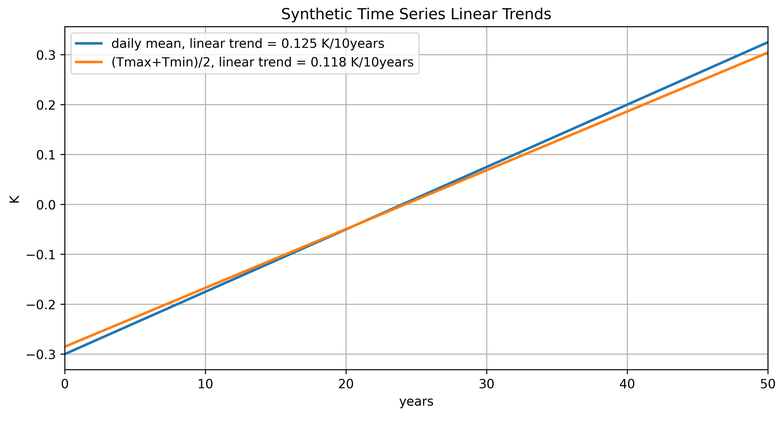
$$T(t) = a * t + c + D(t, P, A_{\mathrm{min}}(t), A_{\mathrm{max}}(t)) + G(t, 0, \sigma^2)$$

$$D(t, P, A_{\mathrm{min}}(t), A_{\mathrm{max}}(t)) =$$

$$= \begin{cases} A_{\mathrm{max}}(t)\sin(\frac{4}{3}tP) \; for \quad \mathrm{mod}\ (t, 2\pi/P) < \frac{4}{3}\pi/P \\ A_{\mathrm{min}}(t)\sin(\frac{2}{3}tP) \; for \quad \mathrm{mod}\ (t, 2\pi/P) >= \frac{4}{3}\pi/P \end{cases}$$

$$A_{\mathrm{max}}(t) = 0.3 - a_{\mathrm{max}}t, A_{\mathrm{min}}(t) = 0.4 - a_{\mathrm{min}}t$$

Here $a = 0.125\mathrm{K/10y}$, the constant offset is $c = -0.3$, the diurnal cycle period is $P = 2\pi/8$, and the noise variance $\sigma^2 = 0.01$. The amplitude trends are $a_{\mathrm{max}} = 0.06\mathrm{K/10y}$ and $a_{\mathrm{min}} = 0.002\mathrm{K/10y}$.



From 50 years of this time series we can estimate the trends: $T_{\mathrm{min}}$is $0.146\mathrm{K/10y}$, $T_{\mathrm{max}}$is $0.09\mathrm{K/10y}$, $T_{\mathrm{mean}}$is $0.125\mathrm{K/10y}$ and the trend in $T_{\mathrm{mm}}$is $0.118\mathrm{K/10y}$.

Summary and Next Steps

Differences in global and regional trends estimated from daily mean temperature time series based on ERA5 $T_{2\mathrm{m}}$and two different methods of computing the daily mean temperature are presented.

We find that **trends in T_{mean} exceed T_{mm}** for global averages by 0.07K over 80 years. In the Tropics that difference is 0.11K over the same time period.

While this difference is likely not large enough to affect global warming impacts, **locally these differences can be much larger**. This has potential implications on local and regional scales on temperature change impacts on agriculture and human health.

We generate a synthetic time series to illustrate the impact of changes in the diurnal cycle in the trend estimates. By having a **non-sinusoidal diurnal cycle with different trends in the minimum and maximum, we are able to show similar trend differences as are observed**.

Next Steps

Compute local solar time (LST) daily means and minimum and maximum values. In regions with daily minimum and maximum values near the beginning or end of the day using UTC could double count maxima from adjacent days in the presence of a trend. Using LST should ameliorate this issue.

Compute Automated Surface Observing System (ASOS) station data diurnal cyles and trends to verify the ERA5 results. There are several locations in the Tropics that have recorded data in the early and late period of the 1940-2019 time frame (although not necessarily continuously).

Acknowledgements

European Centre for Medium-Range Weather Forecasts. 2019, updated monthly. ERA5 Reanalysis (0.25 Degree Latitude-Longitude Grid). Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. https://doi.org/10.5065/BH6N-5N20. Accessed 12 Mar 2024.