## The Moscow Warming Hole

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- Climate Science

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This week, PNAS published our paper Increase of Extreme Events in a Warming World, which analyses how many new record events you expect to see in a time series with a trend. It does that with analytical solutions for linear trends and Monte Carlo simulations for nonlinear trends.

A key result is that the number of record-breaking events increases depending on the ratio of trend to variability. Large variability reduces the number of new records – which is why the satellite series of global mean temperature have fewer expected records than the surface data, despite showing practically the same global warming trend: they have more short-term variability.

Another application shown in our paper is to the series of July temperatures in Moscow. We conclude that the 2010 Moscow heat record is, with 80% probability, due to the long-term climatic warming trend.

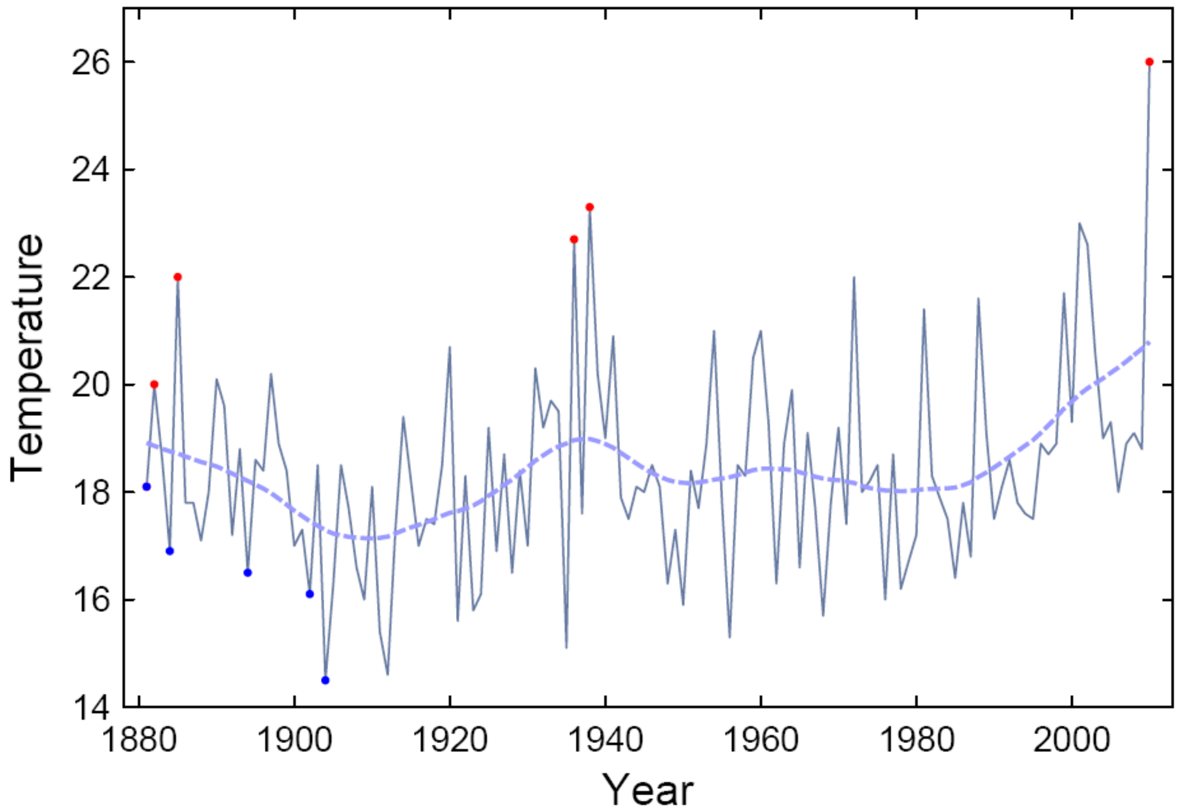


**Figure 1:** Moscow July temperatures 1880-2010. New records (hottest or coldest months until then) are marked with red and blue dots. Dashed is a non-linear trend line.

With this conclusion we contradict an earlier paper by Dole et al. (2011), who put the Moscow heat record down to natural variability (see their press release). Here we would like to briefly explain where this difference in conclusion comes from, since we did not have space to cover this in our paper.

The main argument why Dole et al. conclude that climatic warming played no role in the Moscow heat record is because they found that there *is no* warming trend in July in Moscow. They speak of a "warming hole" in that region, and show this in Fig. 1 of their paper. Indeed, the linear July trend since 1880 in the Moscow area in their Figure is even slightly negative. In contrast, we find a strong warming trend. How come?

The difference, we think, boils down to two factors: the urban heat island correction and the time interval considered. Dole et al. relied on linear trends since 1880 from standard gridded data products. The figure below shows these linear trends for the GISS data for each calendar month, for two data versions provided by GISS: unadjusted and 'homogenised'. The latter involves an automatic correction for the urban heat island effect. We immediately see that the trend for July is negative in the homogenised data, just as shown by Dole et al. (Randall Dole has confirmed to us that they used data adjusted for the urban heat island effect in their study.)

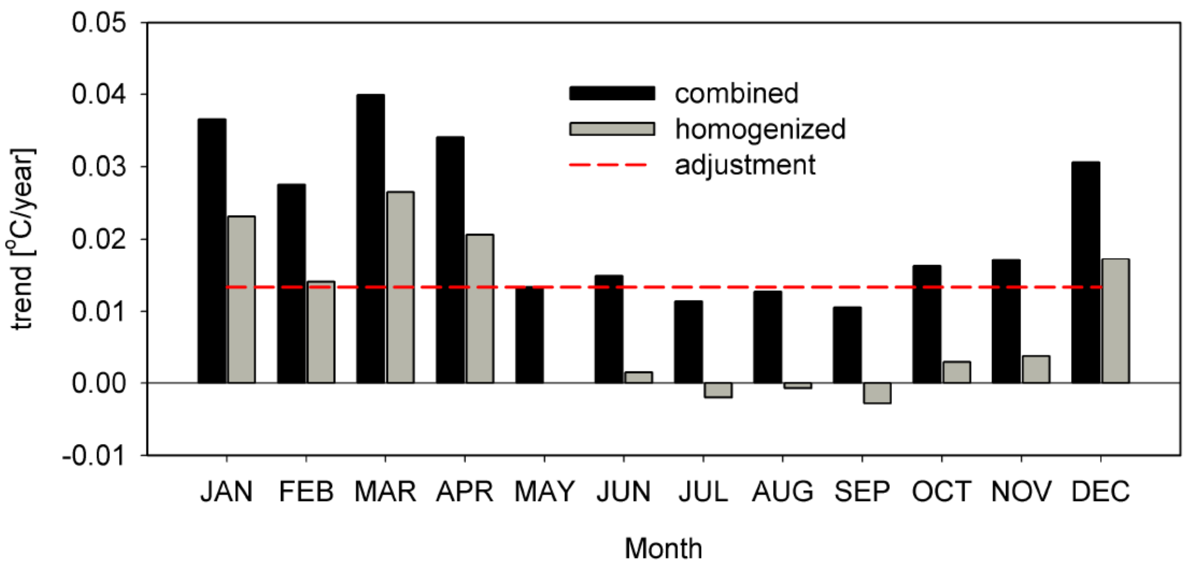


**Figure 2:** Linear trends since 1880 in the NASA GISS data in the Moscow area, for each calendar month.

But the graph shows some further interesting things. Winter warming in the unadjusted data is as large as 4.1ºC over the past 130 years, summer warming about 1.7ºC – both much larger than global mean warming. Now look at the difference between adjusted and unadjusted data (shown by the red line): it is exactly the same for every month! That means: the urban heat island adjustment is not computed for each month separately but just applied in annual average, and it is a whopping 1.8ºC downward adjustment. This leads to a massive over-adjustment for urban heat island in summer, because the urban heat island in Moscow is mostly a winter phenomenon (see e.g. Lokoshchenko and Isaev). This unrealistic adjustment turns a strong July warming into a slight cooling. The automatic adjustments used in global gridded data probably do a good job for what they were designed to do (remove spurious trends from global or hemispheric temperature series), but they should not be relied upon for more detailed local analysis, as Hansen et al. (1999) warned: "We recommend that the adjusted data be used with great caution, especially for local studies." Urban adjustment in the Moscow region would be on especially shaky ground given the lack of coverage in rural areas. For example, in the region investigated by Dole et al (50N-60N/35E-55E) no single (or combined) rural GISS station (with a population less than 10,000) covers the post-Soviet era, a period when Moscow expanded rapidly.

For this reason we used unadjusted station data (i.e. the “GISS combined Moskva” data) and also looked at various surrounding stations, as well as talking to scientists from Moscow. In our study we were first interested in how the observed local warming trend *in Moscow* would have increased the number of expected heat records – regardless of what caused this warming trend. What contribution the urban heat island might have made to it was only considered subsequently.

We found that the observed temperature evolution since 1880 is only very poorly characterized by a linear trend, so we used a non-linear trend line (see Fig. 1 above) together with Monte Carlo simulations. What we found, as shown in Fig. 4 of our paper, is that up to the 1980s, the expected number of records does not deviate much from that of a stationary climate, except for the 1930s. But the warming since about 1980 has increased the expected number of records in the last decade by a factor of five. (That gives the 80% probability mentioned at the outset: out of five expected records, one would have occurred also without this warming.)

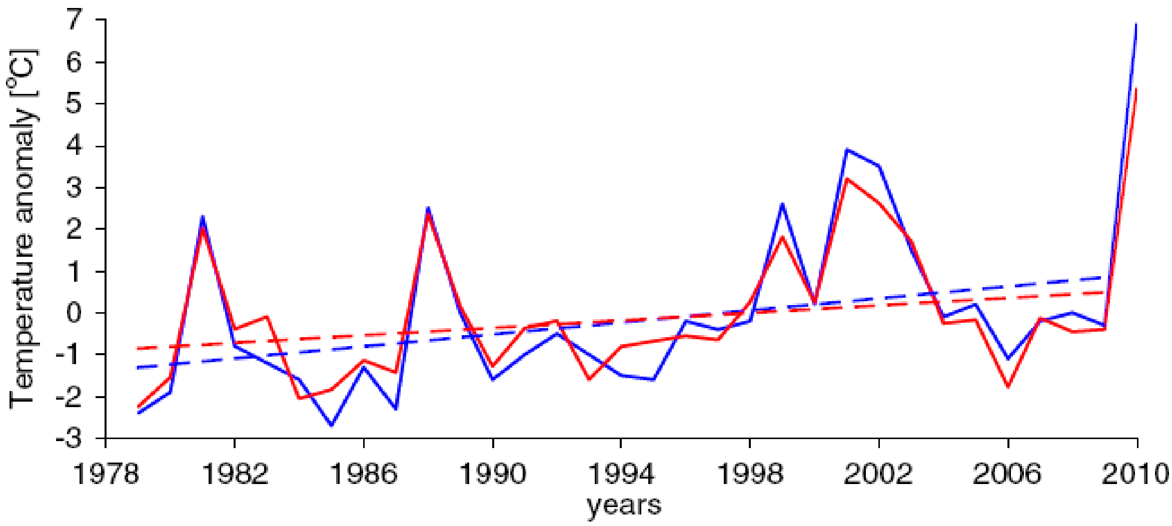


**Figure 3:** Comparison of temperature anomalies from RSS satellite data (red) over the Moscow region (35ºE–40ºE, 54ºN–58ºN) versus Moscow station data (blue). The solid lines show the average July value for each year, whereas the dashed lines show the linear trend of these data for 1979–2009 (i.e., excluding the record 2010 value).

So is this local July warming in Moscow *since 1980* just due to the urban heat island effect? That question is relatively easy to answer, since for this time interval we have satellite data. These show for a large region around Moscow a linear warming of 1.4 ºC over the period 1979-2009. That is (even without the high 2010 value) a warming three times larger than the global mean!

So much for the “Moscow warming hole”.

Stefan Rahmstorf and Dim Coumou

**Related paper:** Barriopedro et al. have recently shown in *Science* that the 2010 summer heat wave set a new record Europe-wide, breaking the previous record heat of summer 2003.

**PS (27 October):** Since at least one of our readers failed to understand the description in our paper, here we give an explanation of our approach in layman's terms.

The basic idea is that a time series (global or Moscow temperature or whatever) can be split into a deterministic climate component and a random weather component. This separation into a slowly-varying 'trend process' (the dashed line in Fig. 1 above) and a superimposed 'noise process' (the wiggles around that dashed line) is textbook statistics. The trend process could be climatic changes due to greenhouse gases or the urban heat island effect, whilst the noise process is just random variability.

To understand the probabilities of hitting a new record that result from this combination of deterministic change and random variations, we perform Monte Carlo simulations, so we can run this situation not just once (as the real Earth did) but many times. Just like rolling dice many times to see what the odds are to get a six. This is extremely simple: for one shot of this we take the trend line and add random 'noise', i.e. random numbers with suitable statistical properties (Gaussian white noise with the same variance as the noise in the data). See Fig. 1 ABC of our paper for three examples of time series generated in this way. We do that 100,000 times to get reliable statistics.

There is a scientific choice to be made on how to determine the trend process, i.e. the deterministic climate change component. One could use a linear trend – not a bad assumption for the last 30 years, but not very smart for the period 1880-2009, say. For a start, based on what we know about the forcings and the observed evolution of global mean temperature, why would one expect climate change to be a linear warming since 1880 in Moscow? Hence we use something more flexible to filter out the slow-changing component, in our case the SSAtrend filter of Moore et al, but one could also use e.g. a LOESS or LOWESS smooth (as preferred by Tamino) or something else. That is the dashed line in Fig. 1 (except that in Fig. 1 it was computed including the 2010 data point; in the paper we excluded that to be extra conservative, so the warming trend we used in the analysis is a bit smaller near the end).

After making such a choice for determining the climate trend, one then needs to check whether this was a good choice, i.e. whether the residual (the data after subtracting this trend) is indeed just random noise (see Fig. 3 and Methods section of our paper).

One thing worth mentioning: whether a new heat record is hit in the last ten years *only depends on the temperature of the last ten years and on the value of the previous record*. Whether one includes the pre-1910 data or not *only* matters if the previous record dates back to 1910 or earlier. That has nothing to do with our choice of analysis technique but is simply a logical fact. In the real data the previous record was from 1938 (see Fig. 1) and in the Monte Carlo simulations we find that only rarely does the previous record date back to before 1910, hence it makes just a small difference whether one includes those earlier data or not. The main effect of a longer timeseries is that the expected number of recent new records in a *stationary* climate gets smaller. So the ratio of extremes expected with climate change to that without climate change gets larger if we have more data. I.e., the probability that the 2010 record was due to climate change is a bit larger if it was a 130-year heat record than if it was only a 100-year heat record. But this is anyhow a non-issue, since for the final result we did the analysis for the full available data series starting from 1880.