

RESEARCH ARTICLE

Maximum and minimum temperatures in the United States: Time trends and persistence

Luis A. Gil-Alana

Economics and I.C.S., Universidad de Navarra
Facultad de Economicas, Pamplona, Spain

Correspondence

L. A. Gil-Alana, Department of Economics,
Universidad de Navarra Facultad de Economicas,
Pamplona, Spain.
Email: alana@unav.es

Funding information

Ministerio de Economía y Competitividad, Grant/
Award number: ECO2014-55236

We investigate the time trends in the maximum and minimum temperatures in the United States from 1895 to 2017 using techniques that allow for fractional integration in the detrended series. In doing so we get more accurate estimates of the trends than those obtained using standard methods that impose either stationarity $I(0)$ or nonstationarity $I(1)$. Our results reveal evidence of significant positive trends in both maximum and minimum temperatures, while the difference between them show a significant negative trend as a consequence of the higher increase in the minimum temperatures. Evidence of stationary long memory behavior is also found in the three series examined.

KEYWORDS

fractional integration, maximum and minimum temperatures, temperatures, time trends

1 | INTRODUCTION

In spite of the overwhelming evidence of increasing temperatures all over the world, accurate estimation of the time trends is still an open issue. Bloomfield and Nychka (1992) found a significant trend in the Hansen and Lebedeff (1987, 1988) temperatures though Woodward and Gray (1995) suggested that the trend may abate in the future. Both papers deal with the choice between deterministic (linear) trends or ARIMA (or stochastic trend) models. Later on, a vast number of papers have examined the trends in global and regional mean temperatures over time finding support for global warming in practically all cases. In recent years there has been an increasing interest in how global and local temperatures have evolved over time, both in the scientific community and the general public (Boykoff, 2014, Lewandowsky, Oreskes, Risbey, Newell, & Smithson, 2015; Rahmstorf, Foster, & Cahill, 2017; etc.). Most of this literature focuses on standard linear regression models on time, testing if the time trend coefficient is significantly positive in a regression where the errors follow a short memory process. This paper focuses on the case of the United States and examines the time trends in the

maximum and minimum temperatures since 1895 allowing for a plausible degree of persistence in the data that is modeled through a long memory process.

Long memory (and more specifically, fractional integration) is a technique that has been widely employed in the analysis of temperature time series data. Examples are the paper of Stephenson, Pavan, and Bojariu (2000); Gil-Alana (2005, 2006, 2008a, 2017), Vyushin and Kushner (2009), Zhu, Fraedrich, Liu, and Blender (2010), Lennartz and Bunde (2009), Rea, Reale, and Brown (2011), Franzke (2011), Yuan, Fu, and Liu (2013), etc. This technique is useful in the sense that it generalizes the standard models that employ $I(0)$ or $I(1)$ behavior to the $I(d)$ case where d can be a fractional value constrained between 0 and 1.¹

We examine linear trends in the model given by:

$$y_t = \beta_0 + \beta_1 t + x_t; \quad (1 - B)^d x_t = u_t, \quad t = 0, 1, \dots, \quad (1)$$

where y_t is the temperature data (maximum, minimum and the difference between the two in the United States); β_0 and β_1 are unknown coefficients referring respectively to the intercept and the time trend and B is the backshift operator

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2018 The Authors. *Atmospheric Science Letters* published by John Wiley & Sons Ltd on behalf of the Royal Meteorological Society.

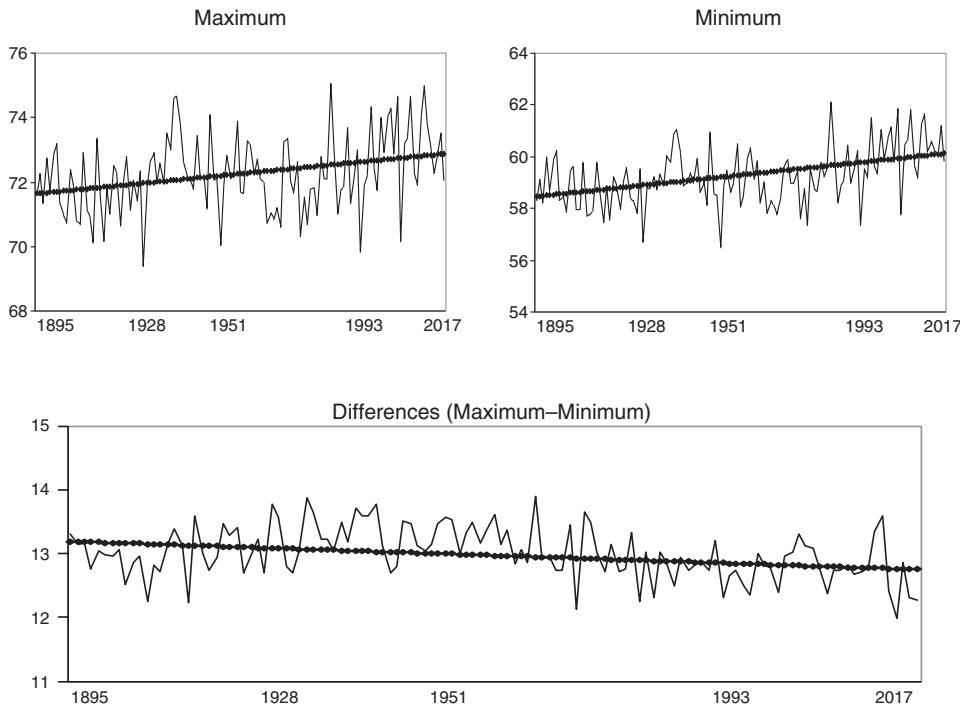


FIGURE 1 Time series plots and estimated time trends

(i.e., $Bx_t = x_{t-1}$). In the context of global warming we should expect β_1 to be positive in the two series, but we also want to look at the difference between the two, in order to check if there is a significant trend in this respect.

2 | DATA AND EMPIRICAL RESULTS

We use annual data of the maximum and minimum temperatures in the (contiguous) United States including 48 states, from 1895 to 2017 obtained from a monthly basis (first month of the year) at the NOAA National Centers for Environmental Information (<https://www.ncdc.noaa.gov>) as well as the differences between the two (see Figure 1). We preferred to work with annual rather than with monthly data to avoid seasonal anomalies. Nevertheless, the results using that frequency were very similar to those reported in this letter.

Table 1 displays the estimated value of d for each series using the model given by Equation (1) under the assumption that u_t is firstly a white noise process, and then allowing for weak autocorrelation throughout the exponential spectral model of Bloomfield (1973). Along with the estimates of d , we also report the values for the intercept and the linear time trend (with their corresponding t -values). Finally, in the last two columns of the table we also report the estimated trends under the assumptions that x_t in (1) is $I(0)$ and $I(1)$, respectively.

Starting with the case of uncorrelated errors, we notice that the order of integration is significantly positive in the three series (0.135 for the maximum; 0.124 for the minimum and 0.191 for the difference between them) and the time trend coefficients are 0.01011, 0.01369 and 0.00357, respectively for the three series. Very similar results are obtained under autocorrelation in the error term though the order of integration is slightly smaller for the maximum temperatures (0.121)

TABLE 1 Estimation of d and the time trend coefficients

(i) Uncorrelated errors					
Series	d (95% interval)	Intercept	Time trend	I(0)	I(1)
				Time trend	Time trend
Maximum	0.135 (0.036, 0.273)	71.63577 (231.33)	0.01011 (2.41)	0.01006 (3.56)	0.00336 (0.02)
Minimum	0.124 (0.037, 0.244)	58.42111 (216.38)	0.01369 (3.74)	0.01368 (5.38)	0.01188 (0.09)
Differences	0.191 (0.111, 0.305)	13.20324 (106.02)	0.00357 (2.14)	-0.00361 (-3.70)	0.00852 (0.19)
(ii) autocorrelated errors					
Series	d (95% interval)	Intercept	Time trend	I(0)	I(1)
				Time trend	Time trend
Maximum	0.121 (-0.049, 0.348)	71.63383 (236.49)	0.01011 (2.46)	0.01006 (3.48)	0.00336 (0.03)
Minimum	0.210 (0.047, 0.434)	58.44975 (160.19)	0.01362 (2.78)	0.01368 (4.99)	0.01188 (0.12)
Differences	0.268 (0.133, 0.451)	13.19216 (83.70)	0.00360 (1.96)	-0.00361 (-3.62)	0.00852 (0.23)

Note. The values in parenthesis in the second column refer to the 95% confidence bands for the values of d . For the rest of the cases, they are t -values.

and a bit higher in the other two cases (0.210 for the minimum temperatures and 0.268 for the difference between them). As expected the time trend coefficients are significantly positive in the two series (maximum and minimum temperatures), the estimated coefficient being higher in the minimum temperatures, but it is also worth noticing that the difference between them display a significant negative coefficient implying that the gap between the temperature recordings has decreased across time. These coefficients are slightly different if we (wrongly) impose a priori $d = 0$ or $d = 1$, especially in the latter case, where the coefficients are found to be insignificant. (See Figure 1 for the estimated time trends on the series). The possibility of structural breaks was also taken into account. Performing Bai and Perron (2003) and Gil-Alana's (2008b) tests, the results indicate the presence of a single break in the maximum and minimum temperatures at 1995, and two breaks (at 1917 and 1972) for the differenced data. However, some of the subsamples were then too small to estimate the differencing parameters. Alternatively, nonlinear deterministic trends of the form advocated in Cuestas and Gil-Alana (2016) were also examined and the results support this specification in a number of cases. These are issues that will be examined in future papers.

3 | CONCLUSIONS

We have examined the time trends of the maximum and minimum temperatures in the United States, annually, from 1895 until 2017 using I(d) techniques. In doing so we allow more flexibility than the classical methods based on stationarity I(0) and nonstationarity I(1). The results indicate that both series, along with the differences between them, display long memory behavior, with orders of integration significantly above 0. This implies that shocks will have long lasting effects. Moreover, the time trends are also positive, supporting the hypothesis of global warming, with the values increasing over time. Finally, the time trend coefficient is higher in the minimum temperatures, with the difference between them presenting a significant negative trend, implying that the difference between the two series is decreasing over time, which is a consequence of the increase in the minimum temperatures.

ACKNOWLEDGEMENTS

Comments from the Editor and two anonymous reviewers are gratefully acknowledged.

NOTE

¹Applications using I(0) models in temperature data are among others Bloomfield and Nychka (1992) and Woodward and Gray (1993), while unit roots or I(1) models have been employed in Woodward and Gray (1995), Stern and Kaufmann (2000), Kaufmann and Stern (2002), and Kaufmann, Kauppi, and Stock (2006).

REFERENCES

- Bai, J., & Perron, P. (2003). Computation and analysis of multiple structural change models. *Journal of Applied Econometrics*, 18, 1–22.
- Bloomfield, P. (1973). An exponential model in the spectrum of a scalar time series. *Biometrika*, 60, 217–226.
- Bloomfield, P., & Nychka, D. (1992). Selecting a model for detecting the presence of a trend. *Journal of Climate*, 8, 1929–1937.
- Boykoff, M. T. (2014). Media discourse on the climate slowdown. *Nature Climate Change*, 4, 156–158.
- Franzke, C. (2011). Nonlinear trends, long-range dependence, and climate noise properties of surface temperature. *Journal of Climate*, 25(41), 72–83.
- Gil-Alana, L. A. (2005). Statistical modeling of the temperatures in the northern hemisphere using fractional integration techniques. *Journal of Climate*, 18(24), 5357–5369.
- Gil-Alana, L. A. (2006). Nonstationarity, long memory and anti-persistence in several climatological time series. *Environmental Modelling and Assessment*, 11(1), 19–29.
- Gil-Alana, L. A. (2008a). Time trend estimation with breaks in temperature time series. *Climatic Change*, 89(3–4), 325–337.
- Gil-Alana, L. A. (2008b). Fractional integration and structural breaks at unknown periods of time. *Journal of Time Series Analysis*, 29, 163–185.
- Gil-Alana, L. A. (2017). Alternative modelling approaches for the ENSO time series. Persistence and seasonality. *International Journal of Climatology*, 37(5), 2354–2363.
- Hansen, J., & Lebedeff, S. (1987). Global trends and measured surface air temperature. *Journal of Geophysical Research*, 92(13), 345–372.
- Hansen, J., & Lebedeff, S. (1988). Global surface air temperatures. Update through 1987. *Geophysical Research Letters*, 15, 323–326.
- Kaufmann, R. K., Kauppi, H., & Stock, J. H. (2006). The relationship between radiative forcing and temperature: What do statistical analyses of the instrumental temperature record measure? *Climatic Change*, 77(3–4), 279–289.
- Kaufmann, R. K., & Stern, D. I. (2002). Cointegration analysis of hemispheric temperature relations. *Journal of Geophysical Research*, 107(D2), 10–18.
- Lennartz, S., & Bunde, A. (2009). Trend evaluation in records with long-term memory: Application to global warming. *Geophysical Research Letters*, 36, L16706.
- Lewandowsky, S., Oreskes, N., Risbey, J. S., Newell, B. R., & Smithson, M. (2015). Climate change denial and its effect on the scientific community. *Global Environmental Change*, 33, 1–13.
- Rahmstorf, S., Foster, G., & Cahill, N. (2017). Global temperature evolution: Recent trends and some pitfalls. *Environmental Research Letters*, 12, 54–70.
- Rea, W., Reale, M., & Brown, J. (2011). Long memory in temperature reconstruction. *Climate Change*, 107(3–4), 247–265.
- Stephenson, D. B., Pavan, V., & Bojariu, R. (2000). Is the North Atlantic oscillation a random walk? *International Journal of Climatology*, 20, 1–18.
- Stern, D. I., & Kaufmann, R. K. (2000). Detecting a global warming signal in hemispheric temperature series: A structural time series analysis. *Climatic Change*, 47(4), 411–438.
- Vyushin, D. I., & Kushner, P. J. (2009). Power law and long memory characteristics of the atmospheric general circulation. *Journal of Climate*, 22, 2890–2904.
- Woodward, W. A., & Gray, H. L. (1995). Selecting a model for detecting the presence of a trend. *Journal of Climate*, 8, 1929–1937.
- Yuan, N., Fu, Z., & Liu, S. (2013). Long-term memory in climate variability: A new look based on fractional integral techniques. *Journal of Geophysical Research: Atmospheres*, 118(12), 962–969.
- Zhu, X., Fraedrich, K., Liu, Z., & Blender, R. (2010). A demonstration of long-term memory and climate predictability. *Journal of Climate*, 23(50), 21–29.

How to cite this article: Gil-Alana LA. Maximum and minimum temperatures in the United States: Time trends and persistence. *Atmos Sci Lett*. 2018;19:e810. <https://doi.org/10.1002/asl.810>