UPDATE OF SURFACE AIR TEMPERATURE TRENDS IN ALMERIA GREENHOUSES FLATLAND (SPAIN) IN THE CONTEXT OF PRESENT GLOBAL WARMING PAUSE

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ABSTRACT

Changes in land surface albedo may cause dramatic alterations of surface radiation budgets and drive local surface air trends in directions opposite to regional and global trends. One such unique case is the offset of global warming at the greenhouses of Campo de Dalias flatland in the Province of Almeria. Here, a cooling trend has been associated through observational and simulation studies to a strong local forcing due to land use change towards reflective greenhouses horticulture from the early 1980s to date. In contrast with this local trend, over the Iberian Peninsula significant high rates of air temperature increases have been recorded by the Spanish Meteorological Network (AEMET) since early 1970s, in accordance with the last period of accelerated global warming.

However, in recent years new forcings of global reach might be impacting the temperatures at the region and at the study area. Despite the maintenance of a sustained rising of greenhouse gases in the atmosphere, a recent slow-down or pause in air surface temperature warming has been registered in most field stations throughout the globe from 1998 to date. The statistical significance of this pause is under growing debate, and this phenomenon offers a good opportunity to improve projection skills of climate models through the assessment of new parameterizations of the forcings and feedbacks needed to reproduce it in simulation experiments as it can affect future proyections of climate change. Warming is in general expressed as the slope of linear trends obtained by least squares method, as IPCC usually reports. However, just fitting a straight line may be misleading, as does not describe the patterns of variability in the series, and can hide present changes in trends. Long-term fitting also ignores the existence of breakpoints in the series that might be signals of changes in key forcings of the climate system.

Here, an alternative statistical approach, piecewise regression fit, has been applied to historic observations, determining the continuous set of straight lines, separated by trend changing points in trends, that best fits every time series. The goal is to determine whether present slow-down is or not statistically significant, or “normal” in terms of historic internal variability. We have updated with new meteorological records collected from 2005 to 2013 the temperature series from agroclimatic stations in Campo de Dalias, along with data from the main surrounding first order AEMET stations in SE Spain. Regional data are compared to Land-Ocean NASA-GISS series, used here as a reference for present global warming slow-down. Piecewise regression, along with other types of fit, has been applied to all time series, and statistical significance of these tests is discussed.

Piecewise regression fit model showed a better representation of the data than just linear regression fits. The absence of long-term warming signals is maintained in the greenhouses area series, and all stations showed lower updated warming trends than those previously reported, or the absence of significative trends in the majority of the time series in recent years, in accordance with global warming pause. Main breakpoints were identified in every series.

Keywords. Piecewise regression, local climate change, temperature trends, global warming pause, Almeria, greenhouse farming

RESUMEN

Los cambios en el albedo de la superficie terrestre pueden causar drásticas alteraciones de los balances de radiación a nivel de superficie y orientar las tendencias locales de las temperaturas en direcciones opuestas a las temperaturas regionales y globales. Un caso único es la compensación del calentamiento global en el área de invernaderos del Campo de Dalias, en la provincia de Almería. Aquí, mediante estudios observacionales y de simulación, ha podido asociarse el establecimiento de una tendencia al enfriamiento de la temperatura al intenso forzamiento local debido al cambio de uso del suelo hacia la horticultura de invernaderos reflectantes desde el comienzo de los años 80 hasta hoy. En contraste con esta tendencia local, sobre la Península Ibérica, se han registrado por la red meteorológica de AEMET elevadas tasas significativas de incremento de la temperatura desde los primeros años 1970s, coincidiendo con el último periodo de calentamiento global acelerado.

Sin embargo, en años recientes nuevos forzamientos de alcance global podrían estar afectando a las temperaturas en el área de estudio. A pesar del aumento sostenido de los gases de efecto invernadero en la atmósfera, en la mayoría de estaciones del globo se viene registrando una reciente ralentización o pausa en el calentamiento desde 1998 hasta la fecha por todo el globo. La significación estadística de esta pausa está siendo foco de creciente debate y este fenómeno ofrece una buena oportunidad para mejorar la capacidad de predicción de los modelos climáticos, mediante la evaluación de nuevas parametrizaciones de los forzamientos y “feedbacks” precisos para reproducirla. El calentamiento se expresa en general como la pendiente de tendencias lineares obtenidas por el método de mínimos cuadrados, tal y como habitualmente reflejan los informes del IPCC. Sin embargo, este ajuste linear simple puede llevar a conclusiones erróneas, ya que no permite describir los patrones de variabilidad en las series y puede enmascarar cambios presentes en la tendencia. Estos ajustes lineales de largo plazo ignoran la existencia de puntos de inflexión en las series que podrían ser indicadores de cambios en forzamientos clave del sistema climático.

Aquí hemos aplicado una aproximación estadística alternativa a los datos locales, el ajuste de regresión linear segmentada, mediante el cual se determina el conjunto continuo de líneas rectas, separadas por puntos de cambio de tendencia, que mejor se ajustan a cada serie temporal. El objetivo es determinar si la presente pausa es estadísticamente significativa y “normal” en términos de la variabilidad interna histórica en la región. Hemos actualizado con nuevos datos meteorológicos las series de temperatura de las estaciones agroclimáticas del Campo de Dalias, así como las series de las estaciones de primer orden de AEMET del SE de España que rodean el sitio (aeropuertos). Los datos regionales se comparan con la serie global tierra-océanos de la NASA-GISS, como término de referencia de la presente ralentización del calentamiento global. La regresión segmentada, junto con otros tipos de ajustes, se han aplicado a todas las series, y se discute la significación estadística de estos ajustes.

El modelo de ajuste de regresión segmentada mostró en todos los casos una mejor representatividad de los datos que el ajuste de regresión linear simple. En el área de invernaderos se mantiene la ausencia de signos de calentamiento a largo plazo, y todas las estaciones mostraron reducciones en las tendencias de calentamiento respecto a las publicadas con anterioridad o la ausencia de tendencias en los últimos años, en concordancia con la pausa global. En cada serie se identificaron los principales puntos de inflexión.

Palabras clave. Regresión segmentada, cambio climático local, tendencias de temperatura, pausa en el calentamiento global, Almería, agricultura de invernaderos.

1. INTRODUCTION

Local records usually show differential trends compared to global and regional average series, and are frequently driven by local forcings of higher intensity than global agents of change. Land use changes are likely to be among the first drivers of climate change at meso- and local scales (Mahmood *et al.*, 2013; Pielke *et al.*, 2011). One such unique study case is Campo de Dalias, coastal flatland located on the Mediterranean coast at the Province of Almeria (SE Spain), that holds the widest concentration of highly reflective greenhouses in the world (27,000 ha) (San Juan, 2007). Here, changes in surface energy balance by land use change towards a higher albedo surface have very likely been responsible for the offset of global warming signals in the local air surface temperature records, as recent observational and simulation studies have strongly suggested. Since the beginning of reliable records from two independent field stations in the area in the early 1980s, a cooling trend of historic temperatures of -0.3 ºC per decade was detected by simple linear regression of field data (Campra *et al.*, 2008). However no update of temperature series in the area later than 2005 has been reported. Running meso-scale simulation experiments, Campra and Millstein (2013) obtained a reduction of 0.5 ºC of mean summer months temperatures, and more than 1 ºC reduction on mean daily temperature in summer days, showing the potential impact of historic changes in albedo at the area on the annual cycle of temperatures..

Over the Iberian Peninsula, significant high rates of air temperature increases have been recorded by the Spanish Meteorological Network (AEMET) since the early 1970s, in accordance with the last period of accelerated global warming. Last update of Spanish temperature series dates from 2006 (Brunet *et al.*, 2006; Del Rio, 2012). Since then, temperature series representing air surface temperatures of different sub-regions or localities across the Iberian Peninsula have been reported, but none of them has reported updates of long-term trends in temperature series for SE Spain or Almeria Province.

Global warming is generally expressed as the slope of long term linear trends obtained by standard ordinary least squares method, as IPCC usually reports (IPCC, 2013). However, just fitting a straight line may be misleading, as does not describe the patterns of variability in the series. Long-term linear fitting lacks physical realism and ignores the existence of breakpoints in the series that might be signals of unusual changes in key forcings of the climate system. There is no physical reason why trends should be linear, especially over long periods. Moreover, temperature series are often extrapolated to make projections into the future based on simple linear trends, with no physical basis to do so, as the climatic system exhibits highly nonlinear behavior. At present, we have to deal with the issue of a decreasing rate of warming over the past 15 years, smaller than the rate from 1951.Despite the maintenance of a sustained rising of greenhouse gases (GHGs) (the increase in globally averaged well-mixed GHGs was 11.6 ppm from 2005 to 2011 (IPCC, 2013), global temperatures seem to have stabilized since 1998 to date (though still maintaining the highest values of the historic registry) and warming trends throughout the planet have either decreased or lost statistical significance at most field stations (Easterling, 2009; Kaufmann *et al.*, 2011, Happer, 2014.). Global warming shows a present slow-down with a decrease in the trend from 0.12 °C per decade in the period 1951-2012 to 0.05 °C per decade in 1998-2012 (IPCC, 2013).

An alternative fitting approach for long term climatic series is piecewise or segmented regression. Karl *et al.*, (2000) used this approach to obtain a better fit of global temperatures than simple linear regression, partitioning the historic series into the best combination of four line segments where the minimum sum of squares can be obtained. In this method, the boundaries between the segments, called breakpoints, can be located in different points, depending on previously defined constraints, such as number of segments, minimum time interval or simple eye inspection of clear changes in trends. Tomé and Miranda (2004) further developed an algorithm to identify best location for breakpoints in climatic series, with the constraints of a minimum of 15 years between them, and different signs between consecutive trends.

The objectives of this work are first to update the records of air surface temperatures in Campo de Dalias and Almeria AEMET airport station up to year 2013; and second, to test the statistical significance of piecewise regression fit of the series, compared to conventional simple linear regression. As a reference for comparison, linear and segment regressions are also applied to surrounding series of Almeria (AL), Malaga (MA), Murcia (MU) and Granada (GR) AEMET first order airport stations, as well as NASA-GISS Global Land-Ocean Series (Hansen *et al.*, 2010).

2. DATA AND METHODS

1.1. Area of study and data

The study area is known as Campo de Dalias, a coastal plain with a relatively gentle relief, limited by the Mediterranean at the south and the Sierra de Gador range (above 2000 m high) at the north, and it occupies a surface area of around 33,000 ha. The climate is Mediterranean, with mild winters and low annual precipitation: average annual temperature and rainfall are 18.8 ºC and 220 mm, respectively. Detailed description of the study area is provided elsewhere [Castilla and Hernandez, 2005; Pulido-Bosch *et al.*, 2000; Fernandez *et al.*, 2007].

Two independent agroclimatic meteorological stations inside this flatland have been registering reliable 2-m temperatures from the early 1980s: La Mojonera (MOJ) at 36º 47'N, 2º 42'W (Institute for Research and Training in Agriculture and Fisheries IFAPA, Junta de Andalucia), and Las Palmerillas (PAL) at 36º 48'N, 2º 43'W (Las Palmerillas-Cajamar Research Station). Both stations lie at 2 km distance from each other, so both series can be considered as a field duplicate that accurately reflects the historic evolution of air surface temperatures the area, so we decide to take MOJ data as representative of the study area. We have tested this null hypothesis applying some statistical tests to both historic series of annual means of 2-m air surface temperature anomalies, all showing that both series can be considered as equally distributed (Kolmogorov-Smirnov goodness of fit test of normality, *P*-values of 0.862 and 0.909 for MOJ and PAL, respectively; Student's *t*-test for the difference between the two series means, *P*-value= 0.70; Levene's test for variances, *P*-value = 0.578; Kendall's coefficient of concordance, *P*-value = 0.44).

Almeria airport station (AL) is located 20 Km east from Campo de Dalias, and greenhouse facilities have more recently developed around the station, but it is not completely surrounded by them as MOJ and PAL. Granada (GR), Malaga (MA) and Murcia (MU) airports stations are located 120 km, 180 km and 170 km away from AL station, respectively. All stations selected are outside urban locations, whether in airports or rural experimental stations, so urban heat island effects can be neglected (except maybe MA). Every time series has undergone different quality controls, such as removal of outliers.

Annual trends in the raw data are derived using annual means based on daily maximum and minimum surface temperatures. Records for 1950-2013 were supplied by AEMET (Spanish Meteorological Agency) for AL, MA, MU and GR first order weather stations. Data are available from 1972 in GR and AL, and from 1950 in MA and MU, but only from 1983 in the study site stations MOJ and PAL. MOJ time series was obtained from IFAPA (Junta de Andalucia), and PAL series from Cajamar Foundation. All stations have automatic equipment and the data are widely held to be homogeneous and quality-controlled. Combined Land-Surface Air and Sea-Surface Water Temperature Anomalies (Land-Ocean

Temperature Index, LOTI) were obtained from NASA GISS website, and were used as global warming reference http://data.giss.nasa.gov/gistemp/tabledata_v3/GLB.Ts+dSST.txt) (Hansen *et al.* 2006).

1.2.Statistical analyses

Piecewise regression, also known as segmented, broken-line or multi-phase regression, is a method in regression analysis where the response variable is cut off in two or more intervals and a line segment is fitted in each interval, with the constraint that the regression function will be continuous. Each line is connected at an unknown value called break-point, change-point or transition-point. Segmented regression is suitable for situations when the response variable shows abrupt changes in a few values of the explanatory variable. So, a segmented model between the mean response E[Y] and the explanatory variable Z is modeled by adding in the linear predictor the terms (Muggeo, 2008):

$$\beta_1 z_i + \beta_2 (z_i - \psi)_+$$

where $(z_i - \psi)_+ = (z_i - \psi) \times I(z_i > \psi)$ being I (A) =1 if A is true. According to such parameterization, β1 is the slope of the left line segmented, β2 is the 'difference-in-slopes' and ψ is the break-point. In order to estimate break-points and slopes, we used the Muggeo's approach (Muggeo, 2003), and the R package "segmented" (Muggeo, 2008). This approach consist of, given a starting values for the break-points, $\tilde{\psi}$, estimating the model by fitting iteratively the model

$$\beta_1 z_i + \beta_2 (z_i - \tilde{\psi})_+ + \gamma \; I(z_i > \tilde{\psi})^-$$

Where I(·)- = -I(·) and γ a re-parameterization of ψ. The convergence of the algorithm implies that significant break-points are believed to exist.

We use smoothed scatter plots to provide the starting values for break-points and check that estimates and t value of difference-in-slope and the 'gap' are, large and small respectively, as conditions required to exist a break-point. Before estimating the linear models with segmented relationships, we have tested the residuals for normality, independence, homogeneous variability and linearity In order to check for correlation we have used both a graph of the residuals over time and an autoregressive AR (Muggeo, 2003) variance structure to model the residuals. Both graphs, residuals over time and partial autocorrelation function showed that there were not any correlations. Ljung-Box test supported the hypothesis that all the data analyzed were independently distributed. We used Wald's parametric test to check the significance of the slopes (Wald, 1940). We consider significant (very likely) our estimations of trends those with a 90-100% probability (p<0.1) (IPCC, 2013).

As a reference for piecewise regression fit assessment, conventional simple linear regression, by least squares method and quadratic (2^{nd} order polynomial) regressions were applied to every series. Linear trends are the values of the slopes of the simple linear regression or segmented regression lines. R software, version 0.98.501 (RStudio, Boston, MA, USA) and IBM SPSS Statistics 20 (IBM Corporation, NY, USA) where used for statistical analyses.

3. RESULTS AND DISCUSSION

The historic annual mean temperature anomalies record from MOJ station is represented in Fig. 1. Simple linear regression fit shows a cooling trend of -0.22 [-0.39 to -0.01] ºC per decade ($p < 0.01$) (Fig 2A, Table 1) for the period 1983-2013. However, the goodness of this fit is low (R^2=0.20) and an eye inspection reveals that the decrease in temperatures is by no means constant. Two periods can be observed: warming from the beginning of data collection in 1983 until the maximum value in 1990, and cooling since then, with a drop in temperatures in the period 1999-2005. Since 2005, temperature seems to have stabilized, but keeping values well below the historic average of the series, with an average anomaly of -0.43 ºC for the last decade (2003-2013). Fitting a piecewise regression model with one breakpoint, the R pakage *segmented* fixes it in 1989 (Fig. 2B). Alternatively, two breakpoints can be obtained, in 1999 and 2002 (Fig. 2C), obtaining the best fit of the four models tested (Table 1), but still indicating a weak correspondence between the data and the estimated model. However, and even though the fitted piecewise regression model is not accurate, it shows a superior behavior compared to conventional simple linear regression model. Only negative slopes were significant ($p<0.10$), (A, B2, and C2) suggesting a very likely cooling long term trend of temperatures in Campo de Dalias Area.

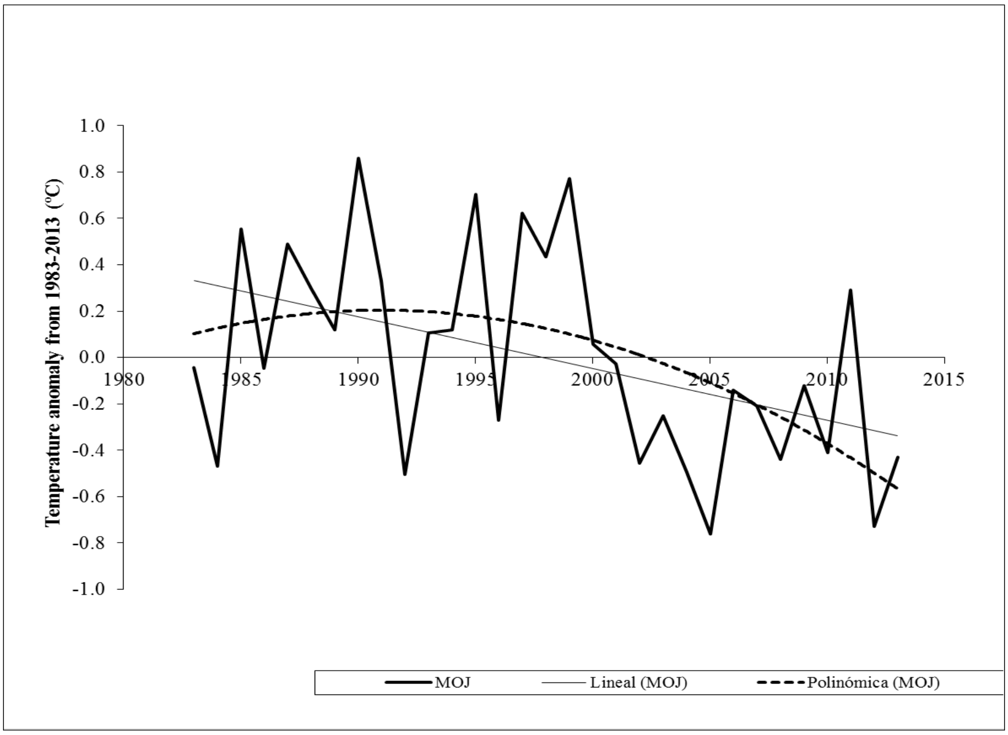

Figura 1. Campo de Dalías historic records of temperature (MOJ). Linear and quadratic regression fit lines.

Segment	Estimate	95% Confidence Interval		p-value	R^2
A (Linear) (1983-2013)	**-0.02**	-0.01	-0.04	**0.01**	0.20
B1 (1983-1989)	0.15	-0.11	0.40	0.22	0.32
B2 (1989-2013)	**-0.03**	-0.05	-0.01	**0.00**	
C1 (1983-1999)	0.03	-0.01	0.07	0.19	0.45
C2 (1999-2002)	**-0.27**	-0.61	0.06	**0.10**	
C3 (2002-2013)	0.01	-0.06	0.08	0.75	

Table 1. SLOPES OF REGRESSION FIT (IN ºC PER YEAR) FOR MOJ SERIES FOR LINEAR AND PIECEWISE REGRESSION MODEL WITH 1 BREAKPOINT (B) OR 2 (C). SLOPES OF LINEAR SEGMENTS NUMBERED IN FIGURE 2. SIGNIFICATIVE VALUES IN BOLD ($P<0.1$).

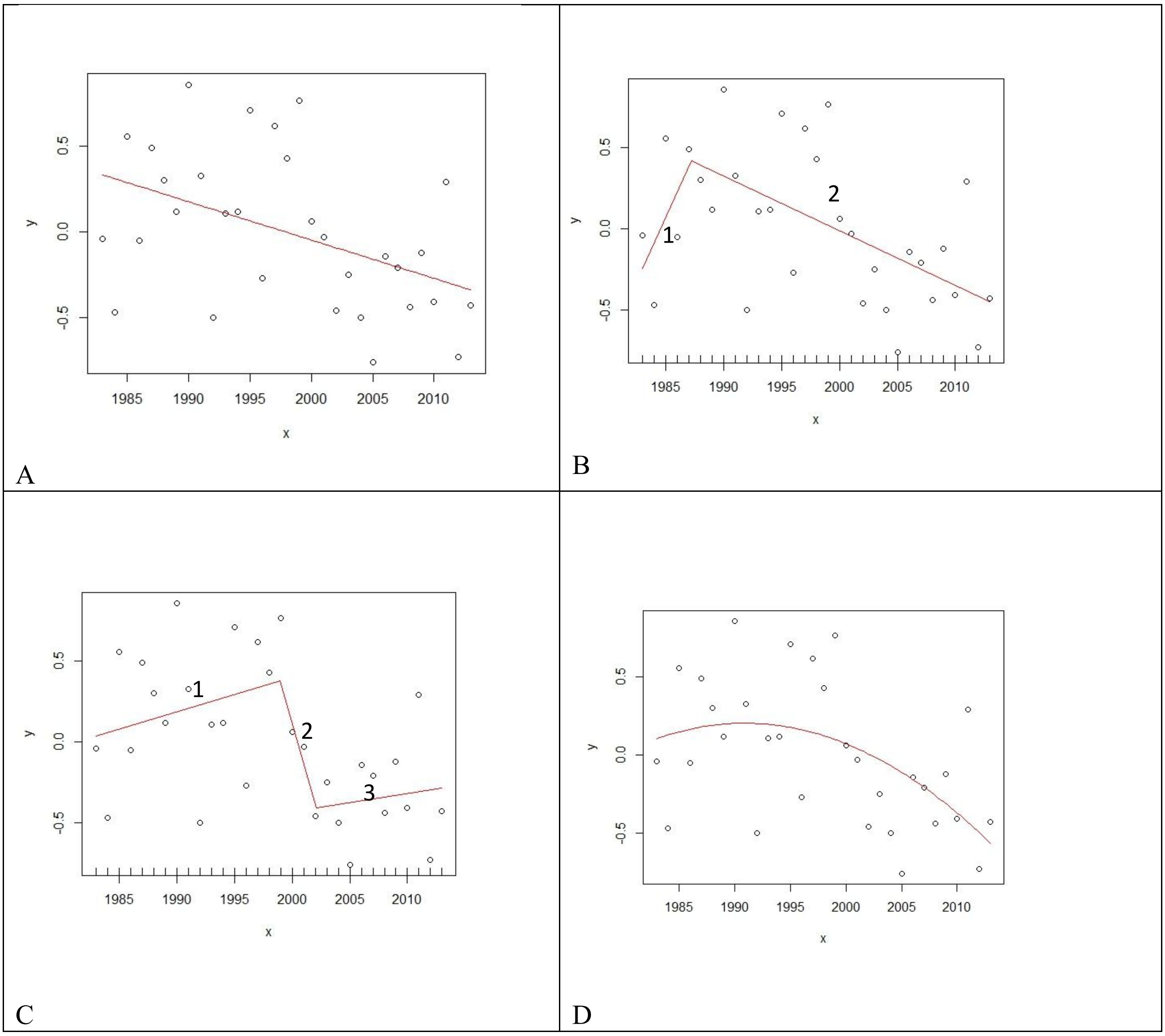

Figure 2. Regression models of Campo de Dalias temperature series (MOJ). A: Simple Lineal. B: Piecewise (1 breakpoint). C: Piecewise (2 breakpoints). D: Quadratic.

A casual eye inspection of SE Spain temperature series on the period 1972-2013 shows two clear periods in all of them (Fig. 3): a remarcable intense warming period, from 1972 until 1989/1990, and since then, a recent period of lower rates of temperatures increase up to 2013. The sharp drop in 1991 was transient in all global series, and was due to Mt. Pinatubo eruption. Simple linear regression slopes from 1972-2013 shows average warming trends in the region around 0.3-0.4 ºC per decade, in accordance with the last period of global warming from the early 1970s (+0.17 ºC per decade for GISS), but in contrast with the local cooling in Campo de Dalias MOJ series (Table 3).

Alternatively, piecewise regression models offer a better fitting in all series (Table 2), showing that this model represents the observations more accurately than the linear regression model generally used to describe climatic warming trends. In global series the goodness of fit (R^2) for all models tested is much better than regional Spanish observational series, due in great part to averaging and smoothing processes in the elaboration of the GISS global series.

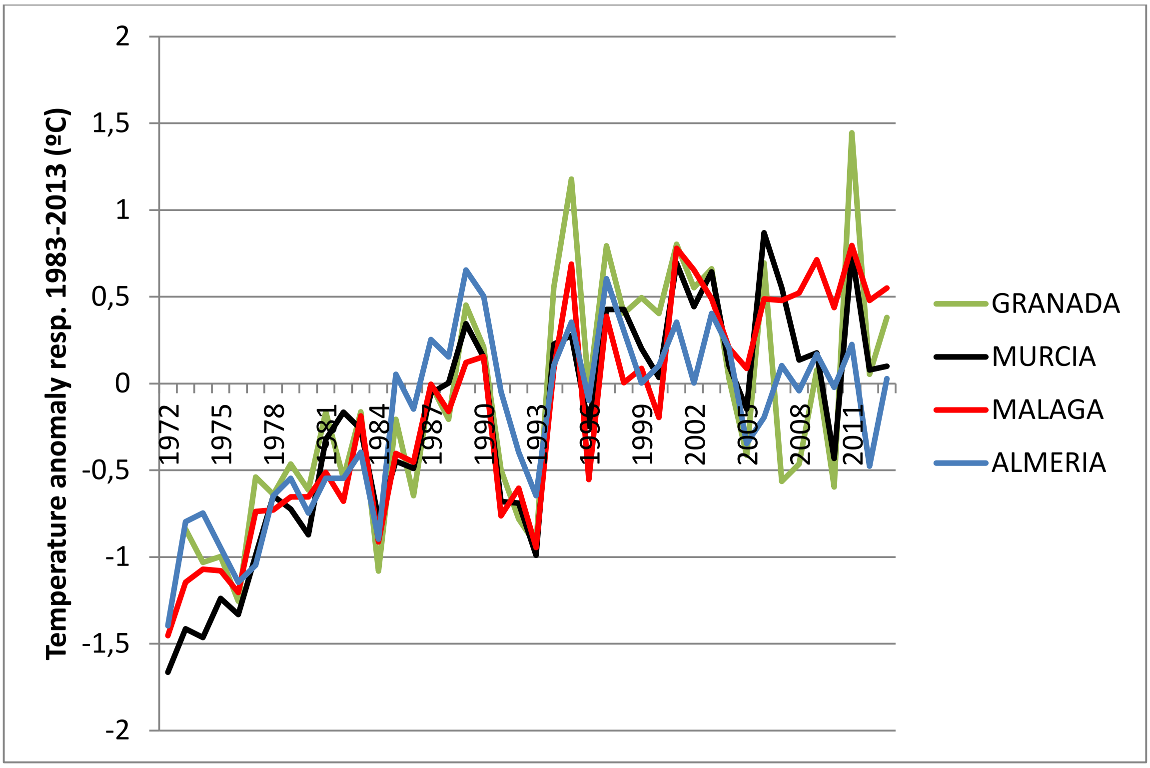

Figure 3. Mean annual temperature anomaly series from SE Spain.

Different points of changing trends and decreased warming were obtained after 1972 in every series: 1989 for AL (fixed by eye inspection), 2002 for MU, and 1999 for GR. In global GISS breakpoints were estimated by R *segmented* in 1971 and 2006, with a high goodness of fit ($R^2 = 0.922$). No significative trend was detected for the most recent period (2006-2013) ($p = 0.77$). Alternatively, we tested piecewise regression of GISS series, selecting by eye inspection commonly cited years (1910, 1944, 1976 and 1998) as fixed breakpoints, obtaining a similar goodness of fit ($R^2 = 0.916$), suggesting a global warming slowdown from a significative trend of +0.22 ºC per decade in the period 1976-1998 to a no significative trend for 1998-2013.

The absence of significative trends from the last breakpoints in SE Spain series (Table 2), except MA, is a regional sign of the recent slow-down in warming trends that characterizes present global pause. However, differences in breakpoint location and trends are due to undetermined differences in local forcings that still need to be characterized. For instance, the absence of a significative trend from 2003-2013 in MOJ might be related to the stop in the growth of surface covered by greenhouses, around the year 2000 (San Juan, 2007). In MA no more breakpoints were obtained later than 1972 for the historic series, but local recent heat island effects around the airport station should be investigated.

	MOJ	AL	GR	MA	MU	GISS
Simple Linear (1972-2013)	-0.22 (from 1983)	+0.26	+0.32	+0.45	+0.41	+0.17
R-squared	0.20	0.40	0.33	0.75	0.60	0.83
Piecewise (1breakpoint)	-0.33 *1989*	-0.07 *1989*	-0.25 *1999*	+0.44 *1972*	_	_
R-squared	0.32	0.67	0.44	0.64		
Piecewise (2 breakpoints)	+0.11 *2002*	---	----	---	-0.28 *2002*	+0.10 *1998*
R-squared	0.45				0.58	0.92

Table 2. RECENT TRENDS ESTIMATIONS, IN ºC PER DECADE, MOJ, SE SPAIN AND GLOBAL (GISS) SERIES, EXPRESSED EITHER AS THE SLOPE SIMPLE LINEAR REGRESSION FROM 1972, OR FROM THE LATEST BREAKPOINT OF PIECEWISE REGRESSION MODEL (YEAR IN ITALICS) TO 2013. SIGNIFICATIVE TRENDS IN BOLD ($p<0.1$).

5. CONCLUSIONS

In conclusion, our results show that the generalized use of simple linear regression fits for the estimation of long term trends might not be sufficiently accurate in many cases, while piecewise regression models provide better fits. Moreover, suggesting extrapolations into the future based exclusively on regression fittings, as usual in mass media, should be considered as a mathematically inconsistent misuse of the model, as it is constructed with the only aim of minimizing de errors with respect to the observed data, and not taking into account generalization issues. Trends estimated by these techniques can just help explain the behaviour of the observed data, but proper climate modeling experiments must be used to support future projections of climate change. The 1998 global breakpoint in not significant in SE Spain, but breakpoints and recent slow-down in long term warming appear in some stations 10-20 years before that. However, and given the limited length of the series, we cannot suggest by our statistical analysis that present decreased rates of warming are inconsistent with historic variability of the series studied.

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