Use of the TREND RUN model to deduce trends in South African Weather Service (SAWS) atmospheric data: Case study over Addo (33.568°S, 25.692°E) Eastern Cape, South Africa

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Abstract

This paper reports on the use of a multi-regression model adapted at the University of Reunion Island, that was formulated for surface temperature trend estimates in South Africa. Depending on the location of the observing site, the selected geophysical signal is expressed in the form of a sum of forcings, which account for most of its variability. The trend values are then derived from the residual terms as a linear function. The atmospheric forcings included in the model are: Annual, Semi-annual, Quasi-Biennial Oscillation, El-Nino Southern Oscillation (ENSO), the 11-year solar cycle (SSN) and Indian Ocean Dipole (IOD). Long-term data-bases of more than 20 years are typically considered for the measurement of decadal trends and to determine the contribution of different atmospheric forcings. In this study, the surface minimum and maximum temperature datasets collected from 1980 to 2004 (25 years) at the South African Weather Service (SAWS) Addo station (33.568°S; 25.692°E), located in the Eastern Cape, South Africa are employed. The first results obtained for this station are presented and illustrate the validity of the model to account for observed trends.

Keywords:

Decadal trends, Atmospheric measurements, Model simulation, Atmospheric forces and Linear statistics

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1. Introduction

Long-term climate trends and cycles have recently become the focus of many studies in the field of atmospheric research. However, the physical mechanisms responsible for these cycles are not understood and are therefore not included in current climate models. The increase in anthropogenic greenhouse gas emissions is known to result in temperature changes and can influence rainfall pattern and sea surface temperature change. The Intergovernmental Panel on Climate Change (IPCC) has shown that global temperatures increased at a rate of 0.13°C per decade (IPCC, 2007).

There are few previous studies that have investigated temperature trends over South Africa (Hugues and Balling 1995; Kruger and Shongue 2004; Engelbrecht 2005; and Tshiala et al., 2011). Hugues and Balling (1995) reported temperature trends for both a non-urban and urban station in South Africa. These results indicated a maximum increase of 0.11°C per decade over the period 1960 to 1990. Furthermore, using data from 1960 to 2003, Kruger and Shongue (2004) found a significant increase in temperature for three stations in Limpopo Province, South Africa, namely Bela Bela, Polokwane and Musina. The model simulation of Engelbrecht (2005) indicated that South Africa experienced a temperature increase of 1 to 3° C in summer and 1 to 2°C in winter. A more recent study by Tshiala et al. (2011) showed that temperature trends for Limpopo province, South Africa corresponded to an increase of 0.12°C per decade. However, all the above studies have not addressed any quantitative contribution of the various atmospheric forcings to the temperature trend values.

In this paper, trends and variability in surface temperature are investigated using historical data sets from the South African Weather Service (SAWS) station at Addo (33.568°S; 25.692°E) in the Eastern Cape of South Africa, for the period January 1980 to December 2004. The trend is calculated by applying the linear-regression fitting model, hereafter referred as Trend-Run. Trend-Run is a statistical model adapted at the University of Reunion Island for temperature trend estimates in the southern subtropical upper troposphere lower stratosphere (UT-LS) region (Bencherif et al., 2006).

In the present study, the model was adapted for SAWS data and regional oceanic forcings such as the Indian Ocean Dipole (IOD), taken into account. The impact of IOD in trend estimation was performed by considering results with or without the inclusion of IOD in the model. The IOD corresponds to the inter-variability present in the Indian Ocean, with an east-west dipole in the SST anomalies of the basin. The mechanisms responsible for the IOD are not well known, however, two mechanisms have been suggested for this phenomenon. The first mechanism is based on the fact that the IOD is generated by a feedback coupled with ocean-atmosphere monsoon and tropical circulation (Saji et al., 1999). The second mechanism considers IOD as part of an Indo-Pacific ENSO (Behera et al., 2002). A recent study by Morioka et al. (2010) concluded that the IOD is now an accepted major climate parameter and must be considered in any studies taking place in the southern Indian Ocean.

2. Data

Data was recorded by the SAWS for the period January 1980 to December 2006. The data was collected by a ground based Automatic Weather Service (AWS) and contained information on the parameters: minimum and maximum surface temperature, rainfall, wind-speed and wind-direction. Daily data-sets were averaged over each month and employed in the present study. Any unusual peaks or outlying values were discarded prior to calculation of the monthly mean.

3. Trend-Run Model

Trend-Run model is based on a linear regression and is adapted from the AMOUNTS (Adaptive MOdel UNambiguous Trend Survey) and AMOUNTSO3 models, previously developed for ozone and temperature trend assessments (Hauchecorne et al., 1991; Keckhut et al., 1995; Guirlet et al., 2000). Trend-Run is therefore a statistical model that has been adapted and employed at Reunion University for temperature trend estimates in the southern subtropical UTLS (Bencherif et al., 2006). The model is based on the principle that variations in a time series signal (in this case, temperature) Y (t) can be expressed as the sum of individual parameters that describe the variations in Y(t):

$$Y(t) = c_1.SAO(t) + c_2\,AO(t) + c_3\,QBO(t) + c_4\,ENSO(t) + c_5\,SSN(t) + \varepsilon, \qquad (1)$$

where ε is the residual term and $c_{i,\ i=1\ \text{to}\ 5}$ represents the considered atmospheric forcing coefficients. When the coefficients $c_{i,\ i=1\ \text{to}\ 5}$ are calculated, the corresponding parameters are removed from the model and the least-square method applied in order to minimize the sum of the residual squares and determine the parameter coefficients c_i. The trend is parameterised as linear and regarded as $Trend(t) = \alpha_0 + \alpha_1.t$. In this expression, t denotes the time series, α_0 is a constant and α_1 is the slope of Trend(t) line that estimates the trend over the period of study.

The previous version of the model used only the principle forcings: annual and semi-annual oscillations (AO, SAO), QBO (Quasi-Biennial Oscillation), ENSO (El-Nino Southern Oscillation, based on multivariate ENSO index) and the 11-year solar cycle (SSN). Annual and Semi-Annual oscillations are considered to be mean seasonal cycles. This model also used monthly mean zonal wind speed at Singapore (equatorial zone, near to 0°) at 30-hPa level, South Oscillation Index to parameterize the QBO (Randel et al., 1994; Li et al., 2008) and the ENSO cycles respectively. The 11-year solar cycle was defined as a linear function correlated with the solar flux at 10.7 cm.

The model has recently been modified through the introduction of a parameter called IOD. The impact of IOD was addressed in recently published research (Begue et al., 2010 and Sivakumar et al., 2011). In order to study the influence of IOD on the variation in temperature trend, the signal variations can be represented as:

$$Y(t) = c_1.SAO(t) + c_2\,AO(t) + c_3\,QBO(t) + c_4\,ENSO(t) + c_5\,SSN(t) + c_6\,IOD(t) + \varepsilon \qquad (2)$$

IOD is characterized by a positive phase when SST (Sea Surface Temperature) is abnormally cool in the eastern equatorial Indian Ocean and abnormally warm in the western equatorial Indian Ocean. A negative phase corresponds to a reversal of these conditions (Behera et al., 2002). The IOD is commonly measured by an index known as the Dipole Mode Index (DMI). This is defined as the SST anomaly difference between the western (50°E-70°E, 10°S-10°N) and eastern (90°E-110°E, 10°S-Equator) tropical Indian Ocean. In order to consider IOD in the Trend-Run model, DMI was obtained from www.jamstec.go.jp/frsgc/research/d1/iod.

4. Results and Discussion

The time series of monthly mean surface minimum temperature for the period January 1980 – December 2004, is shown Figures 1(a) and 1(b) (blue line). This data has been analyzed by the Trend-Run model and simulated data is indicated by the red line in the above figures. The minimum temperature variations fluctuate between 5°C and 15°C and a distinct increasing trend is seen over the period of study. A maximum temperature of approximately 17°C is seen during January to February while a minimum is noted during the period June to July. This behavior represents the summer/winter seasonal cycle. This temperature data clearly indicates the contribution of the annual oscillation. Simulations were performed with and without considering the contribution of the IOD and are shown Figure 1(a) (with IOD) and Figure 1(b) (without IOD), respectively. It is seen that actual and simulated data are in good agreement. It is also seen that the simulated signal does not vary much from the actual data, irrespective of the inclusion of IOD in the simulations. A statistical parameter or regression coefficient, R^2, is used to quantify the agreement between Trend-Run simulated data and actual data. In general, if R^2 is closer to unity (one or 100 %), this implies that the model reproduces the actual data accurately and that considered atmospheric forcings included in the model play a significant role in the variability of actual data (Pastel et al., 2007). However, if R^2 is less than one, indicates that the model have not able to reproduce the actual data or the considered atmospheric forcings do not account for the observed variability. The regression coefficient obtained for the simulated and observed data-sets, is found to be 94%. A very small difference of 0.1 % is noticed with the introduction of IOD in the trend model.

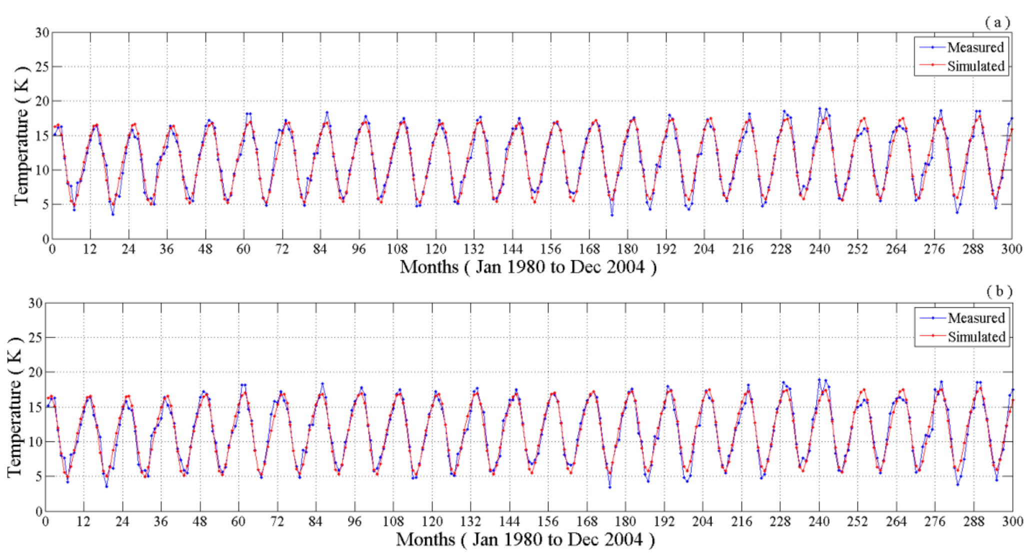

Fig. 1. Temporal evolution of monthly minimum surface temperature values as observed over Addo (33.568° S; 25.692° E), Eastern Cape, for the period January 1980 to December 2004 (blue line). Simulated data from the Trend-Run model is indicated by the red line. Figure 1(a) Simulation with the inclusion of contribution from Indian Ocean Dipole and Figure 1(b) Simulation without the inclusion of contribution from Indian Ocean Dipole.

Through the application of the Trend-Run model, it is possible to estimate the contribution of different atmospheric forcing included in the model. The contribution of each atmospheric forcing is tabulated in Table 1. Results indicate that the contribution due to the annual oscillation component is a dominant, followed by that of the semi-annual oscillation, ENSO, and other forces included in the calculation. It is interesting to note that SSN shows a negative contribution. This indicates that this parameter does not contribute to temperature variability. Overall trend values show an increase in temperature of 0.37°C per decade and show minimal difference with or without the inclusion of IOD in simulations.

Table 1: Contribution (in percentages) obtained by the linear regression Trend-Run model of SAC, AC, QBO, IOD, ENSO and 11-year solar cycle. The last line in the table gives the corresponding values for the coefficient of determination, R^2

Parameters	Minimum Temperature		Maximum Temperature	
	With IOD	Without IOD	With IOD	Without IOD
SAO (%)	10.73	10.28	8.28	8.3
AO (%)	71.35	75.01	66.41	66.54
QBO (%)	0.697	0.484	2.52	2.54
IOD (%)	2.77		-0.124	
ENSO (%)	4.91	3.70	-4.484	-4.43
SSN (%)	-3.95	-3.922	-2.507	-2.52
Trend (°C/decade)	0.37	0.38	0.1266	0.1264
R^2 (%)	94.41	94.39	84.34	84.33

Furthermore, the above results show little difference in terms of the regression or trend values with the removal of the IOD contribution. This difference corresponds to less than 0.1% and may be ignored (taking into account the values for standard deviations and errors).

Figure 2 shows the temporal evolution of maximum surface temperature values obtained from the same station and for the same time period described above. Temperature values are approximately 15°C higher than those for minimum temperature. A similar trend is observed and is characterized by an annual oscillation pattern with maximum temperature of ~30°C and minimum temperature of ~22°C during summer and winter, respectively. Both simulated and actual data are found to be in good agreement. Analysis using the Trend-Run model was completed and contributions of the atmospheric forcings determined. The contributions in percentages are tabulated and given in Table 1. The contribution of AO, SAO, ENSO, IOD is shown to be less, while that due to QBO is more significant compared to the analysis carried out on minimum temperature data.

Furthermore, regression values are found to be 84 % compared to 94 % obtained for minimum temperature. It is therefore seen that there is an additional contributing factor in the maximum temperature data which has to be further investigated. The QBO contribution is found to be dominant for maximum temperature variations and this may be due to changes in the wind speed and direction during the day. The minimum temperature is expected at night and it is therefore expected that few atmospheric forcings are significant at this time due to the absence of solar inputs. The contribution and trend values do not vary much with or without the inclusion of the IOD.

The obtained temperature trend value of 0.126°C per decade is in agreement with earlier results over South Africa (Hugues and Balling 1995; Tshiala et al., 2011). Kruger and Shongwe (2004) reported a positive temperature trend for most South African stations based on SAWS data from 1991 to 2003. Their results for the same station indicated trend values of 0.15°C per decade for maximum temperature variation and the trend value is about twice (0.22°C per decade) for the case of minimum temperature.

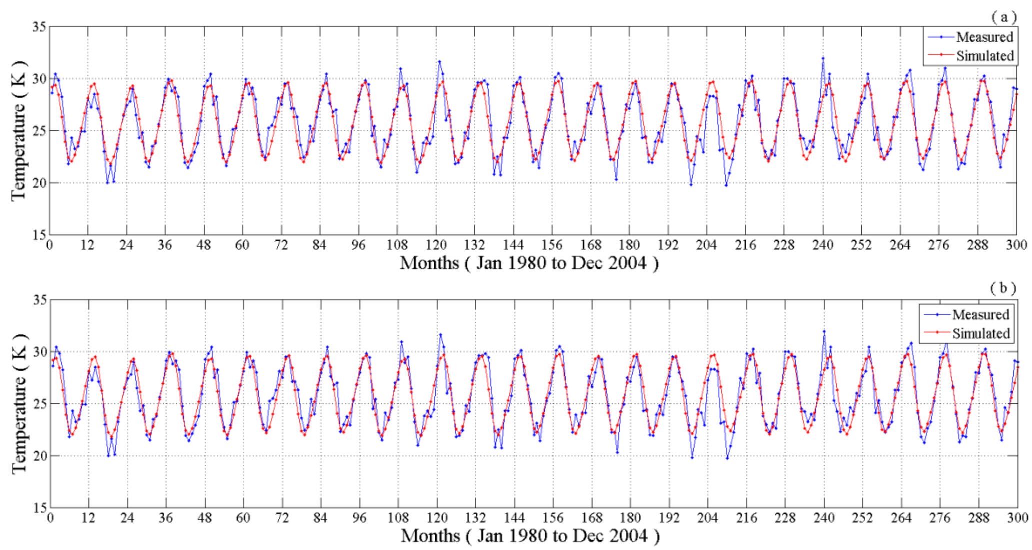

Fig. 2. Temporal evolution of monthly maximum surface temperature values as recorded at Addo (33.568°S; 25.692°E), Eastern Cape, for the period January 1980 to December 2004 (blue line), superimposed with the simulated data from Trend-Run model (red line), a) With inclusion of Indian Ocean Dipole and b) Without inclusion of Indian Ocean Dipole.

4. Summary

In this investigation, the validity of the Trend Run model for the analysis of temperature trends obtained from SAWS data, was determined. The model was tested on data (surface minimum and maximum temperature datasets collected from 1980 to 2004) recorded at Addo (33.568°S; 25.692°E), Eastern Cape, and was able to convincingly reproduce the observed trend seen in recorded data. The aim of using the multi-parameter regression analysis was to examine the impact of various geophysical cycles and forcings on the variability of thermal structure. The Annual Oscillation was found to be the dominant contributor to the variability seen in both minimum and maximum temperature datasets. Results presented here also suggest that the underlying Indian Ocean Dipole (IOD) may have little influence on the variability of thermal structures and trend calculation. Future work is planned to extend the analysis to include data from other South Africa Weather Service stations as well as the inclusion of additional parameters such as ozone and rainfall.

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Conflict of Interest

The authors hereby confirm that the results presented here are not subject to conflict of interest of others. The signed conflict of interest has been sent to the journal for their record.

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