Atmos. Chem. Phys. Discuss., 12, 14727–14746, 2012
www.atmos-chem-phys-discuss.net/12/14727/2012/
doi:10.5194/acpd-12-14727-2012
© Author(s) 2012. CC Attribution 3.0 License.

Atmospheric
Chemistry
and Physics
Discussions

This discussion paper is/has been under review for the journal Atmospheric Chemistry and Physics (ACP). Please refer to the corresponding final paper in ACP if available.

# On the scaling effect in global surface air temperature anomalies

**C. A. Varotsos and M. N. Efstathiou**

Climate Research Group, Division of Environmental Physics and Meteorology, Faculty of Physics, University of Athens, University Campus Bldg. Phys. V, Athens 15784, Greece

Received: 8 April 2012 – Accepted: 31 May 2012 – Published: 8 June 2012

Correspondence to: C. A. Varotsos (covar@phys.uoa.gr)

Published by Copernicus Publications on behalf of the European Geosciences Union.

## Abstract

The annual and the monthly mean values of the land-surface air temperature anomalies during 1880–2011, over both hemispheres, are used to investigate the existence of long-range correlations in their temporal march. The analytical tool employed is the detrended fluctuation analysis which eliminates the noise of the non-stationarities that characterize the land-surface air temperature anomalies in both hemispheres. The main result obtained is that deviations of one sign of the land-surface air temperature anomalies in both hemispheres are generally followed by deviations with the same sign at different time intervals. In other words the land-surface air temperature anomalies exhibit persistent behaviour i.e., deviations tend to keep the same sign. Specifically, the scaling exponents of the annual (monthly) mean land-surface air temperature anomalies, $\alpha = 0.65$ (0.73–0.75), are roughly equal in both hemispheres approaching to that of the global annual (monthly) mean land-surface air temperature anomalies, $\alpha = 0.68$ (0.80). Taking into account our earlier study according to which the land and sea surface temperature anomalies obey scaling exponents $\alpha = 0.78$ and $\alpha = 0.89$ in the Northern and Southern Hemisphere, respectively, we conclude that the difference between the scaling exponents in both sea and land contributions to the surface air temperature stems mainly from the sea surface temperature, which exhibits stronger memory in the Southern than in the Northern Hemisphere. This conclusion may be attributed to the fact that oceans have the greatest capacity to store heat, being thus able to regulate the temperature on land with less pronounced persistence. Moreover, the variability of the scaling-exponents of the annual mean values of the land-surface air temperature anomalies versus latitude shows an increasing trend from the low to polar regions starting from the classical random walk (white noise) over tropics. The gradual increase of the scaling exponent from the low to high latitudes (which is stronger over the Southern Hemisphere) could be associated with the poleward increase in climate sensitivity predicted by the global climate models. In this context, the persistence in the

land-surface air temperature enhances the feasibility of its reliable long-term forecast, which is very important for various climate applications.

## 1 Introduction

The land-surface air temperature (LSAT) is a crucial thermodynamic parameter of the earth's climate driving among others the atmospheric greenhouse effect. According to the current scientific understanding the spatial and temporal fluctuations of LSAT are generated by natural and anthropogenically-induced mechanisms. The prediction of these mechanisms is of great importance for the description of the temporal evolution of the other sub-systems of the climatic system, given that they interact between them via non-linear processes (Anthis and Cracknell, 2005; Alexandris et al., 1999; Katsambas et al., 1997; Kondratyev and Varotsos, 1996; Melnikova, 2009; Xue et al., 2011). In other words, the temporal fluctuations of LSAT are of composite nature, consisting of periodic and non-periodic components (Chattopadhyay and Chattopadhyay, 2010; Efstathiou and Varotsos, 2010).

It has been stated by Koscielny-Bunde et al. (1998), that the deviations of the daily maximum temperatures from their average values follow a universal scaling law (or persistence law) with roughly the same exponent 0.7. This behavior was said to be found in the atmospheric variability by 14 meteorological stations around the globe, but in a later study Weber and Talkner (2001) found differences between these exponent values, depending on the altitude of the meteorological station.

In this regard, Eichner et al. (2003) studied the appearance of long-term persistence in surface air temperature records, obtained at 95 stations all over the globe using several variants of the detrended fluctuation analysis (DFA). They obtained correlation exponent values in the range 0.55–0.9 centered strongly at around 0.65 over continents, but systematically higher values for islands.

The DFA tool was also used by Maraun et al. (2004) in order to study the existence of long-range correlations, which mathematically denote that the correlation sum is divergent (Varotsos, 2005; Varotsos and Kirk-Davidoff, 2006). They argued that power-law scaling of the fluctuation function (and thus long-memory) may not be assumed a priori but have to be established by the investigation of the local slopes. They suggested that comparing a long-memory with a short-memory model the inference of long-range correlations from a finite amount of data by means of DFA is not specific. They also remarked that scaling cannot be concluded from a straight line fit to the fluctuation function in a log-log representation.

Recently, six reconstructed records of the Northern Hemisphere temperatures, analyzed by Rybski et al. (2006), revealed long-term persistence. Due to the long-term persistent correlations, the mean temperature variations $\sigma(m,L)$ between $L$ yr, obtained from moving averages over $m$ yr, are considerably larger than for uncorrelated or short-term correlated records. Rybski et al. (2006) also compared the values for $\sigma(m,L)$ with the most recent temperature changes $\Delta T_i(m,L)$ in the corresponding instrumental record and determined the year $i_\mathrm{c}$ where $\Delta T_i(m,L)/\sigma(m,L)$ exceeds a certain threshold and the first year $i_\mathrm{d}$ when this could be detected.

In a previous study, Varotsos et al. (2009) studied the scaling behavior of the time-series of the hemispheric mean monthly land and sea surface temperature (LSST) anomalies during the period January 1850–August 2008. The datasets employed were obtained from the Climatic Research Unit (School of Environmental Sciences of University of East Anglia; http://www.cru.uea.ac.uk/cru/data/temperature/). They showed that there are persistent long-range power-law correlations in the time series of the LSST anomalies, which stem from their time evolution and not from their values distribution. This persistency was found stronger at the Southern Hemisphere.

In this paper, we substantially extend the above-mentioned analysis by considering the LSAT anomalies for various latitudinal zones of each hemisphere separately and globally by employing another dataset of observations. Our principal aim is to investigate the intrinsic scaling properties of the LSAT anomalies and to compare them with those of LSST anomalies. In other words, we examine whether the fluctuations of the LSAT anomalies in small time intervals are correlated to those in longer time intervals and to identify the type of this correlation. Finally, the comparison of the scaling lows of LSST and LSAT anomalies will probably reveal the percentage contribution of the lithosphere and hydrosphere to the scaling behaviour.

## 2 Data and analysis

For the above mentioned purposes we employed annual and monthly mean values of LSAT anomalies (in 0.01 °C) obtained from the National Aeronautics and Space Administration Goddard Institute for Space Studies, covering the period 1880–2011 (http://data.giss.nasa.gov/gistemp/). As it is clearly stated in this web site the analysis is limited to the period since 1880 because of poor spatial coverage of stations and decreasing data quality prior to that time.

The main aim of this paper was to search efficiently for time scaling in the LSAT anomalies time-series, by using a data analysis technique that would not be affected by the nonstationarity of the data comparing with the classical methods like the autocorrelation function, Fourier analysis, Hurst analysis, etc. The technique that has been proved to satisfy this criterion is the well-established DFA, which stems from random walk theory and permits the detection of intrinsic self-similarity in non-stationary time series (Peng et al., 1994; Weber and Talkner, 2001; Varotsos et al., 2002, 2003, 2005, 2006, 2007).

The sequential steps of DFA may be briefly described as follows: firstly, the $y(i)$ = LSAT anomalies time-series is integrated and it is divided into a series of non-overlapping boxes of equal length, $\tau$. Then in each box a polynomial local trend is fitted, in order to detrend the integrated profile by subtracting the locally fitted trend. Secondly, the root-mean-square fluctuations $F_d(\tau)$ of this integrated and detrended profile is calculated over all scales (box sizes). More specifically, the detrended fluctuation function

cc BY

$F$ is defined by (Kantelhardt et al., 2002):

$$F^2(\tau) = \frac{1}{\tau}\sum_{i=k\tau+1}^{(k+1)\tau}[y(i)-z(i)]^2, \quad k = 0,1,2,\ldots,\left(\frac{N}{\tau-1}\right) \tag{1}$$

where $z(i)$ is the polynomial of order $l$ least-square fit to the $\tau$ data points contained into a box.

It is worth to be noted that averaging $F(\tau)$ over the $N/\tau$ intervals gives the fluctuation $\langle F(\tau)\rangle$ as a function of $\tau$. For scaling dynamics, the averaged $F^2(\tau)$ over the $N/\tau$ intervals with length $\tau$ is expected to obey a power law, notably:

$$\langle F^2(\tau)\rangle \sim \tau^{2\alpha} \tag{2}$$

and the power spectrum function scales with $1/f^{\beta}$, with $\beta = 2\alpha - 1$ (Ausloos and Ivanova, 2001).

A derived DFA-exponent $\alpha \neq 1/2$ in a certain range of $\tau$ values denotes the existence of long-range correlations in that interval, while $\alpha = 1/2$ reveals the classical random walk (white noise). If $0 < \alpha < 0.5$, power-law anticorrelations are present (antipersistence). If $0.5 < \alpha < 1.0$, then persistent power-law correlations prevail. The case $\alpha = 1$ corresponds to the so-called $1/f$ noise. In addition, when $1 < \alpha < 1.5$, then long-range correlations are again present (Weber and Talkner, 2001). A more detailed description of the DFA tool is presented in Varotsos et al. (2009).

The reason we have used both annual mean and monthly mean temperature anomalies is that there is a debate on the minimum allowable number of data to employ reliably the DFA methodology (Bryce and Sprague, 2012). Some of the earlier studies claim that DFA requires a large sample size-most packages available to download recommend 1000+ data points. Other papers suggest a definitive minimum sample size (e.g. 600 by Ludecke et al., 2011). Thus, someone could argue that annual temperature anomalies should not be used for DFA for exactly this reason and suggest that monthly temperature anomalies should be used instead.

The data analyzed here refer to annual mean values of LSAT anomalies of 131 data points and 1572 data points for the monthly values of LSAT anomalies. It should be emphasized that Audit et al. (2002) demonstrated that the wavelet transform modulus maxima estimator leads to larger mean squared errors (compared to those obtained by DFA) when analyzing short time series of length $10^2$ data points. That is why it was preferred to use DFA and not, for example, wavelet based estimators of self-similarity.

## 3 Results and discussion

### 3.1 DFA-exponent in the time-series of the annual mean LSAT anomalies

The annual means used in the present study were based on LSAT anomalies covering the global earth and both hemispheres (Fig. 1). The principal feature shown in Fig. 1 is the existence of non-stationarities into the LSAT anomalies spectral distribution and the strong upward trend which both can mask correlations and in particular long-term correlations. For instance, uncorrelated data with long-term trend may look like correlated. Also long-term correlated data may look like uncorrelated data due to a trend. Thus the long-term trend was filtered out by calculating the departures of the LSAT anomalies values from the polynomial best fit to the whole LSAT anomalies time-series, over the global earth and both hemispheres, separately (Fig. 2).

In the following, the results obtained from the application of DFA to the LSAT anomalies time-series are presented and interpreted. The DFA-value for the detrended LSAT anomalies time-series over the global earth and both hemispheres ranges between (0.65, 0.68) with standard deviation 0.03. Therefore, the fluctuations of the studied parameter exhibit long-range persistence. The long-range correlations found signify that the fluctuations of the LSAT anomalies, from small time intervals (4 yr) to larger ones (up to 32 yr) are positively correlated in a power-law fashion. In other words, persistence refers to the "long memory" or internal correlation within the LSAT anomalies time-series (Fig. 3).

In order to examine whether the afore-mentioned value of the $\alpha$-exponent is attributed to the LSAT anomalies evolution versus time period and not to the values of the LSAT anomalies, the investigated time-series was randomly shuffled. If the shuffled LSAT anomalies values followed the random (white) noise, then the persistence found above would not come from the data, but from their time evolution (e.g., Varotsos et al., 2006, 2007). Indeed the application of the DFA to the shuffled data, over the global earth and both hemispheres, gave $a$-exponent between (0.51, 0.52) with standard deviation 0.03, pointing towards an uncorrelated shuffled LSAT anomalies data (Fig. 4).

The long-range persistence found above in the structural profile of LSAT anomalies signifies its impacts to climate system. We emphasize that the reliably modelled values of LSAT anomalies versus time period (i.e. past and future simulations) must exhibit the same scaling properties with that possibly existing in the real observations of the LSAT anomalies during the covered period (1880–2012).

As mentioned in the section of Introduction Varotsos et al. (2009) suggested that the LSST anomalies data of the Climatic Research Unit (School of Environmental Sciences of University of East Anglia; (http://www.cru.uea.ac.uk/cru/data/temperature/) during the period January 1850–August 2008 obey persistent long-range power-law correlations which are stronger at the Southern Hemisphere for all time lags between 4 months and 39 yr. In more detail Varotsos et al. (2009) have found that the LSST anomalies scaling exponents are $\alpha = 0.78$ and $\alpha = 0.89$ in the Northern and Southern Hemisphere, respectively. This is a composite outcome of the air temperature persistence over both land and sea, suggesting that the air temperature of the Southern Hemisphere behaves more persistently. The reason, however, has not been explained so far.

The analysis presented here stresses that the scaling exponents of LSAT anomalies for both hemispheres are equal ($\alpha = 0.65$) approaching to that of the global LSAT anomalies ($\alpha = 0.68$). It clearly suggests that the land contributes equally to the scaling of the surface air temperature of both hemispheres, independently of their peculiarities.

cc BY

Thus, the net result drawn is that the difference between the scaling exponents in both sea and land contributions to the surface air temperature stems mainly from the sea surface temperature, which exhibits stronger memory in the Southern than in the Northern Hemisphere. This finding is in line with that of Monetti et al. (2003) according to which a stronger persistence is observed over the oceans (Atlantic and Pacifc Oceans) than over the continents. From physical point of view the strong tendency of the air temperature over ocean at a particular period to remain the same the next period (strong persistence) is expected, because the oceans have the greatest capacity to store heat (covering almost three quarters of the earth's surface), being thus able to regulate the temperature on land. The latter may probably be the reason for the less pronounced persistence of temperature over land.

It is worth to be noted that the scaling property may serve as a unique criterion of the reliability of a proposed climate model. In this regard, Govindan et al. (2002) carried out a test for the scaling performance of seven leading global climate models by analyzing the temperature records of six representative sites around the globe simulated by the models. The test showed that the simulated records fail to reproduce the scaling behavior of the observed records.

Therefore, the afore-mentioned scaling found for the temporal evolution of the surface air temperature over land of both hemispheres or globally must not be violated by the global climate models.

### 3.2 DFA-exponent in the time-series of the monthly mean LSAT anomalies

In order to confirm the above mentioned result we also used monthly mean values of LSAT anomalies covering the global earth and both hemispheres, during the same period 1880–2011. The long-term trend was filtered out, by calculating the departures of the monthly mean values of LSAT anomalies from the polynomial best fit to the whole LSAT anomalies time-series, over the global earth and both hemispheres, separately.

The obtained DFA-exponents for the detrended time-series of the monthly mean LSAT anomalies over both hemispheres are almost equal (0.75 and 0.73 for the

Northern and the Southern Hemisphere, respectively) approaching to that of the global LSAT anomalies ($\alpha = 0.80$) (Fig. 5). That result supports the equal contribution of the land to the scaling of the surface air temperature of both hemispheres. Moreover, the fluctuations of the monthly means reveal stronger persistent long-range correlations than the annual means for the interval time ranging from 4 months to 32 yr.

### 3.3 DFA-exponent in the time-series of the annual mean LSAT anomalies versus latitude

In the following, we studied the annual mean values of LSAT anomalies over selected latitude zones, during the period 1880–2011. Table 1 depicts the DFA-value for the polynomially detrended time-series of the annual mean LSAT anomalies versus latitude. The obtained $a$-exponent ranges between (0.51, 0.79) with standard deviation 0.03 and indicates long-range persistence over the latitude zones 24° N–44° N, 24° S–44° S, 44° N–64° N, 44° S–64° S, 24° N–90° N, 24° S–90° S and the classical random walk (white noise) over the zones Equator–24° N and Equator–24° S.

The poleward increase of the power-law exponents of the annual mean values of the LSAT anomalies in both hemispheres could be associated with the poleward increase in climate sensitivity predicted by the global climate models. In contrast, the plausible reasons for the classical random walk over tropics need further elaboration.

## 4 Conclusions

The detrended fluctuation analysis curried out to the annual and the monthly mean values of the LSAT anomalies over both hemispheres during 1880–2011 in order to search for LSAT anomalies intrinsic dynamical properties such as distributions, scaling and long-range correlations very often masked by non-stationarities. This analytical tool has the advantage over standard variance analysis of being able to detect long-term dependence in non-stationary time series. The main conclusion drawn from this

CC BY

analysis is that there is a “long memory” within both annual and monthly mean LSAT anomalies time-series, all over the globe and both hemispheres. More precisely, the application of the DFA method to the detrended values of the LSAT anomalies versus time period, revealed persistent long-range power-law correlations. The analysis of the shuffled data showed that this scaling comes from the time evolution and not from the values of the temperature anomalies.

Additionally, the scaling exponents of the annual (monthly) mean LSAT anomalies, $\alpha = 0.65$ (0.73–0.75), are roughly equal in both hemispheres approaching to that of the global annual (monthly) mean LSAT anomalies, $\alpha = 0.68$ (0.80). Keeping in mind our earlier result (Varotsos et al., 2009) that the LSST anomalies obey stronger scaling exponent ($\alpha = 0.89$) in the Southern Hemisphere than in the Northern Hemisphere ($\alpha = 0.78$) we reach to the conclusion that the difference between the scaling exponents in both sea and land contributions to the surface air temperature stems mainly from the sea surface temperature, which exhibits stronger memory in the Southern than in the Northern Hemisphere. This conclusion is in accordance to the fact that oceans have the greatest capacity to store heat, being thus able to regulate the temperature on land with less pronounced persistence. Moreover, studying the annual mean values of LSAT anomalies over selected latitude zones, it was derived that the scaling-exponents reveal long-range persistence over the latitude zones 24° N–44° N, 24° S–44° S, 44° N–64° N, 44° S–64° S, 24° N–90° N, 24° S–90° S and the classical random walk (white noise) over the zones Equator–24° N and Equator–24° S. The observed poleward greater persistence in LSAT could be in general a result of either stronger positive feedbacks or larger inertia.

Finally, the scaling property detected in the in-field observations of the LSAT anomalies could serve as test for the state-of-the-art and the scaling performance of the global climate models.

CC BY

## References

Alexandris, D., Varotsos, C., Kondratyev, K. Y. and Chronopoulos, G.: On the altitude dependence of solar effective UV, Phys. Chem. Earth Pt. C, 24, 515–517, 1999.

Anthis, A. I. and Cracknell, A. P.: A method for classification accuracy evaluation for a precipitation-oriented classifier, Int. J. Remote Sens., 26, 4785–4800, 2005.

Audit, B., Bacry, E., Muzy, J. F., and Arneodo, A.: Wavelets based estimators of scaling behavior, IEEE T. Inform. Theory, 48, 2938–2954, 2002.

Ausloos, M. and Ivanova, K.: Power-law correlations in the southern-oscillation – index fluctuations characterizing El Nino, Phys. Rev. E, 63, 047201, doi:10.1103/PhysRevE.63.047201, 2001.

Bryce, R. M. and Sprague, K. B.: Revisiting detrended fluctuation analysis, Sci. Rep., 2, 1–6, doi:10.1038/srep00315, 2012.

Chattopadhyay, S. and Chattopadhyay, G.: Univariate modelling of summer-monsoon rainfall time series: comparison between ARIMA and ARNN, CR Geosci., 342, 100–107, 2010.

Govindan, R. B., Vyushin, D., Bunde, A., Brenner, S., Havlin, S., and Schellnhuber, H. J.: Global climate models violate scaling of the observed atmospheric variability, Phys. Rev. Lett., 89, 028501, doi:10.1103/PhysRevLett.89.028501, 2002.

Efstathiou, M. N. and Varotsos, C.: On the altitude dependence of the temperature scaling behavior at the global troposphere, Int. J. Remote Sens., 31, 343–349, 2010.

Eichner, J. F., Koscielny-Bunde, E., Bunde, A., Havlin, S., and Schellnhuber, H. J.: Power-law persistence and trends in the atmosphere: a detailed study of long temperature records, Phys. Rev. E, 68, 046133, doi:10.1103/PhysRevE.68.046133, 2003.

Kantelhardt, J. W., Zschiegner, S. A., Koscielny-Bunde, E., Havlin, S., Bunde, A., and Stanley, H. E.: Multifractal detrended fluctuation analysis of nonstationary time series, Physica A, 316, 87–114, 2002.

Katsambas, A., Varotsos, C. A., Veziryianni, G., and Antoniou, C.: Surface solar ultraviolet radiation: a theoretical approach of the SUVR reaching the ground in Athens, Greece, Environ. Sci. Pollut. R., 4, 69–73, 1997.

Kondratyev, K. Y. and Varotsos, C. A.: Global total ozone dynamics – impact on surface solar ultraviolet radiation variability and ecosystems, Environ. Sci. Pollut. R., 3, 205–209, 1996.

Koscielny-Bunde, E., Bunde, A., Havlin, S., Roman, H. R., Goldreich, Y., and Schellnhuber, H. J.: Indication of a universal persistence law governing atmospheric variability, Phys. Rev. Lett., 81, 729–732, 1998.

Maraun, D., Rust, H. W., and Timmer, J.: Tempting long-memory – on the interpretation of DFA results, Nonlinear Proc. Geoph., 11, 495–503, 2004.

Melnikova, I.: Comparative assessment of the impact of molecular scattering and total ozone content on the characteristics of UV radiation in the atmosphere, Int. J. Remote Sens., 30, 6141–6150, 2009.

Monetti, R. A., Havlin, S., and Bunde, A.: Long-term persistence in the sea surface temperature fluctuations, Physica A, 320, 581–589, 2003.

Rybski, D., Bunde, A., Havlin, S., and von Storch, H.: Long-term persistence in climate and the detection problem, Geophys. Res. Lett., 33, l06718, doi:10.1029/2005gl025591, 2006.

Varotsos, C.: Power-law correlations in column ozone over Antarctica, Int. J. Remote Sens., 26, 3333–3342, 2005.

Varotsos, P. A., Sarlis, N. V., and Skordas, E. S.: Long-range correlations in the electric signals that precede rupture, Phys. Rev. E, 66, 011902, doi:10.1103/PhysRevE.66.011902, 2002.

Varotsos, P. A., Sarlis, N. V., and Skordas, E. S.: Long-range correlations in the electric signals that precede rupture: Further investigations, Phys. Rev. E, 67, 021109, doi:10.1103/PhysRevE.67.021109, 2003.

Varotsos, C. and Kirk-Davidoff, D.: Long-memory processes in ozone and temperature variations at the region 60° S–60° N, Atmos. Chem. Phys., 6, 4093–4100, doi:10.5194/acp-6-4093-2006, 2006.

Varotsos, C., Ondov, J., and Efstathiou, M.: Scaling properties of air pollution in Athens, Greece and Baltimore, Maryland, Atmos. Environ., 39, 4041–4047, 2005.

Varotsos, C. A., Ondov, J. M., Cracknell, A. P., Efstathiou, M. N., and Assimakopoulos, M. N.: Long-range persistence in global aerosol index dynamics, Int. J. Remote Sens., 27, 3593–3603, 2006.

Varotsos, C., Assimakopoulos, M.-N., and Efstathiou, M.: Technical Note: Long-term memory effect in the atmospheric $CO_2$ concentration at Mauna Loa, Atmos. Chem. Phys., 7, 629–634, doi:10.5194/acp-7-629-2007, 2007.

Varotsos, C., Efstathiou, M., and Tzanis, C.: Scaling behaviour of the global tropopause, Atmos. Chem. Phys., 9, 677–683, doi:10.5194/acp-9-677-2009, 2009.

Weber, R. O. and Talkner, P.: Spectra and correlations of climate data from days to decades, J. Geophys. Res., 106, 20131–20144, 2001.

Xue, Y., Ai, J., Wan, W., Guo, H., Li, Y., Wang, Y., Guang, J., Mei, L., and Xu, H.: Grid-enabled high-performance quantitative aerosol retrieval from remotely sensed data, Comput. Geosci., 37, 202–206, 2011.

**Table 1.** DFA-exponent for the annual mean LSAT anomalies versus latitude.

| NH Latitude | Equator–24° N | 24° N–44° N | 44° N–64° N | 24° N–90° N |
|---|---|---|---|---|
| $\alpha$-value | 0.52 | 0.55 | 0.6 | 0.63 |
| SH Latitude | Equator–24° S | 24° S–44° S | 44° S–64° S | 24° S–90° S |
| $\alpha$-value | 0.51 | 0.74 | 0.76 | 0.79 |

CC BY

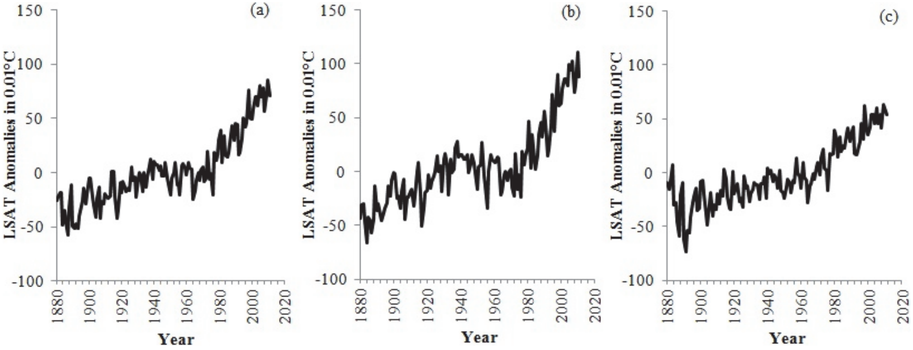

**Fig. 1.** Annual LSAT anomalies in 0.01 °C, during the period 1880–2011, **(a)** globally, **(b)** over the NH and **(c)** over the SH.

Title Page
Abstract
Introduction
Conclusions
References
Tables
Figures
◀▮ ▶▮
◀ ▶
Back
Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

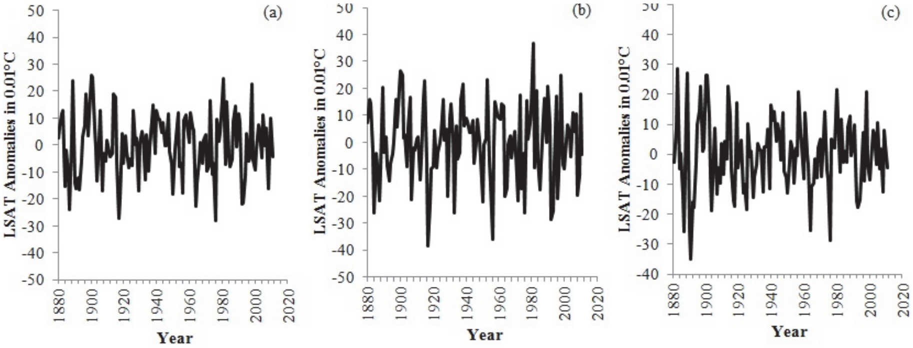

**Fig. 2.** Detrended annual mean LSAT anomalies in 0.01 °C, during the period 1880–2011, **(a)** globally, **(b)** over the NH and **(c)** over the SH.

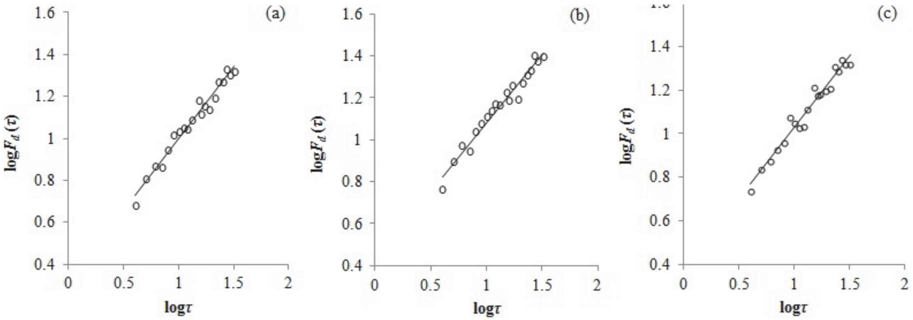

**Fig. 3.** Log-log plot of the root-mean-square fluctuation function ($F_d(\tau)$) versus time interval $\tau$ (in yr) for the detrended annual mean LSAT anomalies set **(a)** globally with the best fit equation ($y = 0.68x + 0.32$ with $R^2 = 0.97$), **(b)** over the NH with the best fit equation ($y = 0.65x + 0.43$ with $R^2 = 0.97$), **(c)** over the SH with the best fit equation ($y = 0.65x + 0.38$ with $R^2 = 0.97$).

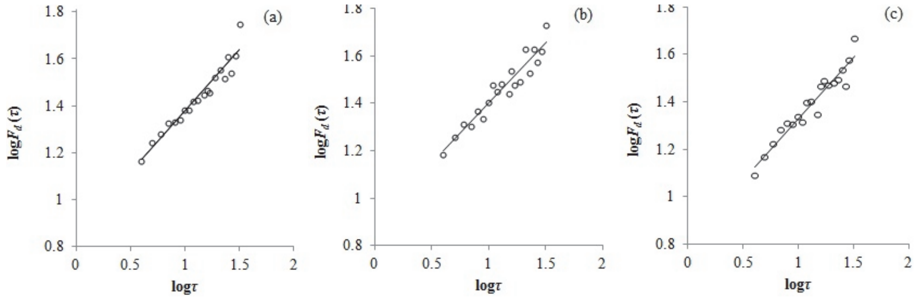

**Fig. 4.** Log-log plot of the root-mean-square fluctuation function ($F_d(\tau)$) versus time interval $\tau$ (in yr) for the shuffled annual mean LSAT anomalies data set **(a)** globally with the best fit equation ($y = 0.51x + 0.86$ with $R^2 = 0.94$), **(b)** over the NH with the best fit equation ($y = 0.51x + 0.89$ with $R^2 = 0.92$), **(c)** over the SH with the best fit equation ($y = 0.52x + 0.81$ with $R^2 = 0.93$).

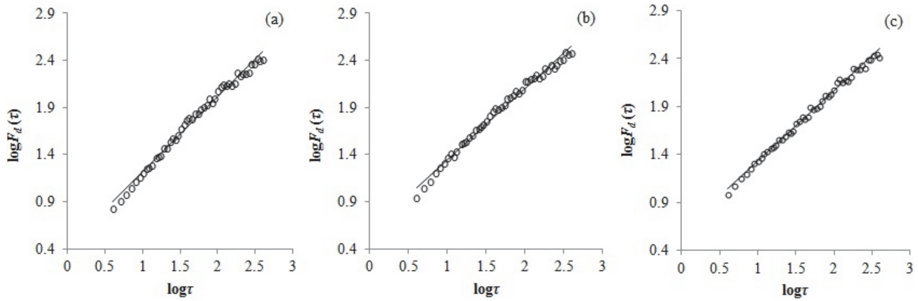

**Fig. 5.** Log-log plot of the root-mean-square fluctuation function ($F_d(\tau)$) versus time interval $\tau$ (in month) for the detrended monthly mean LSAT anomalies data set **(a)** globally with the best fit equation ($y = 0.80x + 0.41$ with $R^2 = 0.99$), **(b)** over the NH with the best fit equation ($y = 0.75x + 0.60$ with $R^2 = 0.99$), **(c)** over the SH with thebest fit equation ($y = 0.73x + 0.60$ with $R^2 = 0.99$).