Random walk lengths of about 30 years in global climate

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[1] We have applied the relation for the mean of the expected values of the maximum excursion in a bounded random walk to estimate the random walk length from time series of eight independent global mean quantities (temperature maximum, summer lag, temperature minimum and winter lag in land and over the ocean) derived from the NOAA-CIRES twentieth century reanalysis (V2) for 1871–2008 and the ECHAM5 IPCC AR4 twentieth century run for 1860–2100, and also the Millenium 3100 yr control run mil01, which was segmented into records of specified period. The results for NOAA-CIRES, ECHAM5, and mil01 (mean of thirty 100 yr segments) are very similar and indicate a random walk length on land of 24 yr and over the ocean of 20 yr. Using three 1000 yr segments from mil01, the random walk lengths increased to 37 yr on land and 33 yr over the ocean. This result indicates that the shorter records may not totally capture the random variability of climate relevant on the time scale of civilizations, for which the random walk length is likely to be about 30 years. For this random walk length, the observed standard deviations of maximum temperature and minimum temperature yield respective expected maximum excursions on land of 1.4 and 2.3°C and over the ocean of 0.5 and 0.7°C, which are substantial fractions of the global warming signal. **Citation:** Bye, J., K. Fraedrich, E. Kirk, S. Schubert, and X. Zhu (2011), Random walk lengths of about 30 years in global climate, *Geophys. Res. Lett.*, *38*, L05806, doi:10.1029/2010GL046333.

1. Introduction

[2] The annual cycle is the largest climate signal, however its variability has often been overlooked as a climate diagnostic, even though global climate has received intensive study in recent times [e.g., *Intergovernmental Panel on Climate Change* (*IPCC*), 2007], with a primary aim of accurate prediction under global warming. The approach has been to use ensemble averages of coupled climate models as a guide, the differences between the results form the individual runs being consigned to natural variability. In this study we evaluate the lengths of random walks, which occur in the global annual surface temperature cycle by identifying the time of occurrence and magnitude of temperature maxima and minima over the ocean and on land. For temperature cycles with a single maximum and minimum, this gives rise to eight weakly correlated time series for processing. The aim of the analysis is to find out whether the effect of random walks is significant for global mean temperatures over the time scales of interest in anthropogenic climate change.

[3] The regions of one maximum temperature and one minimum temperature are identified by searching for extrema using Lagrangian interpolation from monthly data over three consecutive months with the requirement that the extremum occurs in the three month period. This procedure is more suitable for our purpose than the Fourier method, which resolves the annual and higher harmonics of the temperature cycle [e.g., *Prescott and Collins*, 1951; *Alexander et al.*, 2005; *Yashayaev and Zveryaev*, 2001; *Stine et al.*, 2009].

2. Data Sources and Methodology

[4] We use (i) the twentieth century NOAA-CIRES reanalysis data (http://www.esrl.noaa.gov/psd/data/gridded/data.20thC_ReanV2.monolevel.mm.html) for 1871–2008 [*Compo et al.*, 2011], which has a T62 resolution of surface air temperature (the air temperature on the lowest sigma level), (ii) the T63 run of the ECHAM5 model for the IPCC AR4 20C (run1) for 1860–2100 [*Roeckner*, 2005; *Giorgetta et al.*, 2006; *Hagemann et al.*, 2006; data: *Uppala*, 2003] from which the fields of the globally defined surface temperature (TS), which is the skin temperature at the interface, and in ice covered regions of the ocean is measured just above the ice (http://cf-pcmdi.llnl.gov) have been extracted, and (iii) the Millennium control run of 3100 years (mil01) from the MPI-M Earth System Model on a T31 resolution [*Jungclaus*, 2007] from which fields of TS have also been obtained as for (ii).

[5] These temperature fields were processed to obtain the time (t_{max}) of maximum temperature (T_{max}), and the time (t_{min}) of minimum temperature (T_{min}). In the following discussions we exclude grid points which occur in the tropics.

[6] In the subtropics, the solar radiation input has an annual cycle with a single peak in insolation so that the summer lag (SL) of the temperature relative to the peak in daily insolation in the subtropics (June 21 in the northern hemisphere and December 22 in the southern hemisphere) and the winter lag (WL) relative to December 22 in the northern hemisphere and June 21 in the southern hemisphere (in days) can be obtained from the times of maximum temperature (t_{max}) and minimum temperature (t_{min}) by a change in reference time (northern hemisphere: SL = t_{max} − 172, WL = t_{min} + 9, southern hemisphere: SL = t_{max} + 9, WL = t_{min} − 172) from which the global means and standard deviations of WL and SL and T_{min} and T_{max} on land and over the ocean have been derived (Table 1).

3. Random Walk Lengths

[7] The random walk lengths are estimated from the statistical data for the time series using the relation for the mean of the expected values of the maximum excursion of the random walk, $E|M_T| = \sqrt{(2T/\pi)}\ \sigma$; where M_T is the

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Table 1. Statistics of the NOAA-CIRES 1871–2008, ECHAM5 1860–2100, and mil101 3100 Year Time Series

	NOAA-CIRES 1871–2008		ECHAM5 1860–2100		mil101			
					100 yr[a]		1000 yr[b]	
	Land	Ocean	Land	Ocean	Land	Ocean	Land	Ocean
				Global Mean (Excluding the Tropics)				
SL d	27	61	26	65	29	65	29	65
T_{max}°C	19.2	15.4	15.2	14.4	16.2	13.9	16.2	13.9
WL d	24	69	26	77	25	77	25	77
T_{min}°C	−10.0	8.4	−13.7	6.1	−14.0	6.3	−14.0	6.3
				Maximum Excursion (M_T)				
SL d	5.77	4.08	6.37	3.43	5.65	3.24	7.06	3.84
T_{max}°C	0.95	0.38	1.17	0.25	1.17	0.31	1.56	0.44
WL d	11.03	6.45	11.23	5.36	12.24	5.83	15.53	7.18
T_{min}°C	1.86	0.40	2.05	0.57	2.02	0.61	2.52	0.76
				Standard Deviation (σ)				
SL d	1.30	1.25	1.49	0.86	1.44	0.81	1.44	0.81
T_{max}°C	0.33	0.12	0.27	0.09	0.32	0.10	0.32	0.10
WL d	2.55	1.57	3.03	1.25	3.07	1.45	3.08	1.45
T_{min}°C	0.53	0.15	0.55	0.19	0.55	0.19	0.55	0.19
				Estimate of Random Walk Length (E |T|)				
SL yr	31	17	29	25	24	25	38 ± 1	36 ± 5
T_{max} yr	13	17	29	12	22	16	38 ± 4	31 ± 6
WL yr	29	26	22	29	25	26	40 ± 9	38 ± 5
T_{min} yr	19	12	22	14	21	18	33 ± 7	26 ± 7

[a]Mean of 30 consecutive 100 yr segments.
[b]Mean of 31 consecutive 1000 yr segments and the standard deviation of the random walk length estimates.

maximum excursion, T is the length of the walk and σ is the standard deviation [*Feller*, 1962]. We invert this relation to yield an estimate of the random walk length,

$$E|T| = \pi/2(M_T/\sigma)^2 \qquad (1)$$

The results for ECHAM5 and NOAA-CIRES were obtained from the linearly de-trended data, and those for the mil01 run are averages over consecutive segments of data (thirty-one 100 year periods and three 1000 year periods). It is clear for each of the shorter periods (Table 1) that the mean random walk lengths are similar (NOAA-CIRES 21 yr, ECHAM5 23 yr and mil01 22 yr), and also that the mean random walk on land (24 yr) is greater than that over the ocean (20 yr). The mean random walk for SL and WL (26 yr) also is greater than that for T_{max} and T_{min} (18 yr). The mean random walk length for all three shorter record lengths (22 yr) is shorter than the record lengths (NOAA-CIRES 137 yr, ECHAM5 240 yr and mil01 100 yr). There is still the possibility however that the record lengths have influenced the mean random walk length.

[8] This was tested using mil01 run segments of 1000 yr (Table 1). These results indicated that the random walk length increased to 37 yr on the land and 33 yr over the ocean, with a mean standard deviation of 6 yr (the mean random walk lengths for record lengths between 100 and 1000 years showed a gradual increase from 22 to 35 yr). On this basis we argue that a reasonable estimate for the random walk length for the global climate on the time scale of civilisations is about 30 years.

[9] The simplest way to interpret this result is through the Langevin equation,

$$dT/dt + B\ T = q \qquad (2)$$

where T is temperature, q is a random heat input and B is a heat exchange coefficient. The solution of (2) for the component exp(iωt) where ω is the angular frequency yields a response function, $R(\omega) = 1/(\omega^2 + B^2)^{1/2}$ which for $\omega \to \infty$ is the red noise spectrum $R^2(\omega) \approx \omega^{-2}$, and for $\omega \approx 0$ is the white noise spectrum, $R^2(\omega) \approx$ const. The maximum gradient in slope occurs at a period, $T_0 = 2\pi/B$, which identifies the transition from red noise to white noise, and hence defines the random walk length. Thus for a random walk length of 30 yr, the heat exchange coefficient is B = 0.21 $year^{-1}$. For a cycle of angular frequency (ω_0), the phase lag is $\tan^{-1}$ (ω_0/B), which for the annual cycle yields 88°. This phase corresponds with a lag of 89 days which is clearly much closer to the observed mean oceanic lag than the mean terrestrial lag (Table 1) indicating that the random walks arise primarily from oceanic processes, associated with the exchange of heat with the deeper layers. This conclusion is supported by the energy spectra for T_{max} and T_{min} over the ocean from the mil01 run.

[10] The standard deviations of the time series which give rise to the random walks are greater in winter than in summer, and also greater on land than over the ocean (Table 1). In particular, the observed standard deviation in T_{max} (NOAA-CIRES: land 0.33, ocean 0.12°C) and in T_{min} (NOAA-CIRES: land 0.53, ocean 0.15°C) impose an irreducible uncertainty on the global temperature series, which applies on time scales of 30 years and upwards. On assuming the mean value (30 yr) of the random walk length for T_{max} and T_{min}, the mean of the expected maximum excursions on land and over the ocean are respectively, T_{max}: 1.4 and 0.5°C; T_{min}: 2.3 and 0.7°C, which are significant fractions of the global warming signal.

4. Conclusion

[11] In 1935, the International Meteorological Organisation confirmed that 'climate is the average weather' and adopted the years 1901–1930 as the 'climate normal period'.

Subsequently a period of thirty years has been retained as the classical period of averaging [*IPCC*, 2007]. Our analysis suggests that this administrative decision was an inspired guess. Random walks of length about 30 years within natural variability are an 'inconvenient truth' which must be taken into account in the global warming debate. This is particularly true when the causes of trends in the temperature record are under consideration.

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