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The persistence of the hemispheric averages of mean monthly surface temperature anomalies

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RESUMEN

Los promedios hemisféricos de las anomalías medias mensuales de la temperatura en superficie, corregidas por tendencia, son altamente más persistentes en verano que en invierno. Esta propiedad estacional es asombrosamente evidente en el Hemisferio Norte, donde los meses estivales guardan una altísima correlación entre ellos y positivamente con los mismos meses veraniegos en el siguiente año; mientras que los meses invernales tienen bajos coeficientes de correlación con todos los meses, cayendo hasta cero para los mismos meses en el año subsiguiente. La variabilidad de un mes a otro en la persistencia de la temperatura se presenta como evidencia para sugerir que los veranos del Hemisferio Septentrional es probable que exhiban propiedades estables; mientras que los inviernos del propio Hemisferio pueden ocasionalmente mostrar un comportamiento de flujo caótico. La persistencia a largo plazo de las anomalías veraniegas de temperatura de un verano al verano siguiente pueden explicarse por el hecho de que los veranos retienen su memoria por varios años, debido a la capacidad térmica de los océanos, pero esta memoria es temporalmente destruída en invierno por el caos inducido por la inestabilidad baroclínica del flujo superior del oeste.

ABSTRACT

The hemispheric averages of detrended mean monthly surface temperature anomalies are more highly persistent in summer than in winter. This property of the season is strikingly evident in the Northern Hemisphere, where summer months correlate highly with each other, and positively with the same summer months in the following year, while winter months have low correlations with all months, falling to zero, for the same months in the following year. The month to month variability in the persistence of temperature is presented as evidence to suggest that Northern Hemisphere summers are likely to exhibit stable properties while Northern Hemisphere winters may occasionally exhibit chaotic flow behaviour. The longer term persistence of summer temperature anomalies from one summer to the following summer may be explained by the fact that summers retain their memory for several years due to the heat capacity of the oceans, but this memory is temporarily destroyed in winter by the chaos induced by baroclinic instability of the upper level westerly flow.

1. Introduction

A meticulous analysis and study of inter-monthly and inter-annual climate variability provides a first step forward to the elusive goal pursued by many climatologists, the ability to make successful forecasts of the climate on a time scale of a few months, or even a few years into the future. Here we use mean surface temperature anomalies as a very elementary surrogate of climate.

Evidence will be presented which suggests that patterns of persistence of hemispherically averaged mean surface temperature anomalies represented by serial auto-correlation coefficients for different months for different lag periods, indicate that summers are more constant in their statistical composition, and therefore in their dynamic nature, that is, they have less variability from month to month, than other seasons. A synoptician might infer that this property extends to weather changes from week to week, and possibly even from day to day. In contrast the persistence of temperature anomalies in winter months is short, giving rise to the hypothesis that the weather in those months is influenced by chaotic behaviour of weather systems. This behaviour is particularly evident in the Northern Hemisphere. Dynamicists would explain the differing structures of the summer and winter statistics in terms of the properties of the westerly planetary flow. In summer the meridional thermal gradients are sufficiently weak to allow stable Rossby waves to propagate from west to east. In winter, however, occasionally very steep thermal gradients cause the Rossby waves to become unstable through the process of baroclinic instability. Lorenz (1990) constructed a theoretical numerical model and showed that in summer the westerly flow was stable (he termed the flow oscillatory in the sense of Rossby wave propagation). The model also showed that the steeper meridional thermal gradients in winter caused chaotic flow to develop.

2. The time constant

A useful statistic to complement the auto-correlation coefficient is the time constant, which we will define by τ. If a system is instantaneously perturbed from some mean state $u(0)$ to some new state $u(1) = u(0) + u'(0)$, τ may be defined as the e-folding time taken by the system to relax by Newtonian cooling to the state $u(0) + u'(0)/e$. It can be easily shown that $\tau = [\log \frac{1}{\alpha_1}]^{-1}$, where α_1 is an auto-correlation in a first order auto-regressive process. Supposing we express a historical time serie of hemispheric mean temperature anomalies in the form

$$x(t) = \alpha_1 x(t-1) + \nu$$

where $x(t)$ represents the temperature anomaly at time t and ν represents white noise of mean zero and known standard deviation, then if α_1 is unity the relation above describes a random walk and if α_1 is zero the equation describes the white noise. Normally the value of α_1 lies between these extremes. The time constant therefore expresses the e-folding time for the system to decay from $x(t-1)$ to $x(t)$

The decay persistence may be measured by the function e^{-x} where $x = t/\tau$. Thus, the e-square folding period gets rid at about 90% of the persistence, while the e-cube folding period gets rid of about 95%. This time constant is a useful parameter against which Newtonian decay may be visualized.

3. The Hadley Centre data set of hemispheric surface temperature anomalies (1859-1995)[1]

The historical hemispheric mean monthly surface temperature anomalies for land and sea (Parker-Jones Hadley Centre data set (1856-1995)) were detrended and normalized about a zero mean for each month of the year. The raw data series contain long term trends which increases the peristence as indicated by correlation coefficients. We are not concerned here with possible long term climate change, but only with changes from one month to the next month or following months up to about a year in the future. The detrended series will serve this purpose better than series containing long term trends, which could be due to anthropogenic activities, or could be purely stochastic. (Woodward and Gray, 1993; Gordon, 1991-a,b).

Figure 1 shows a plot of the 12 months running average of the detrended mean surface temperature anomalies for the NH Parker/Jones data set (1856-1995). It is evident that there is a long wave periodicity. The only full cycle which can be identified is about 60 years and this has an amplitude of about 0.8°C.

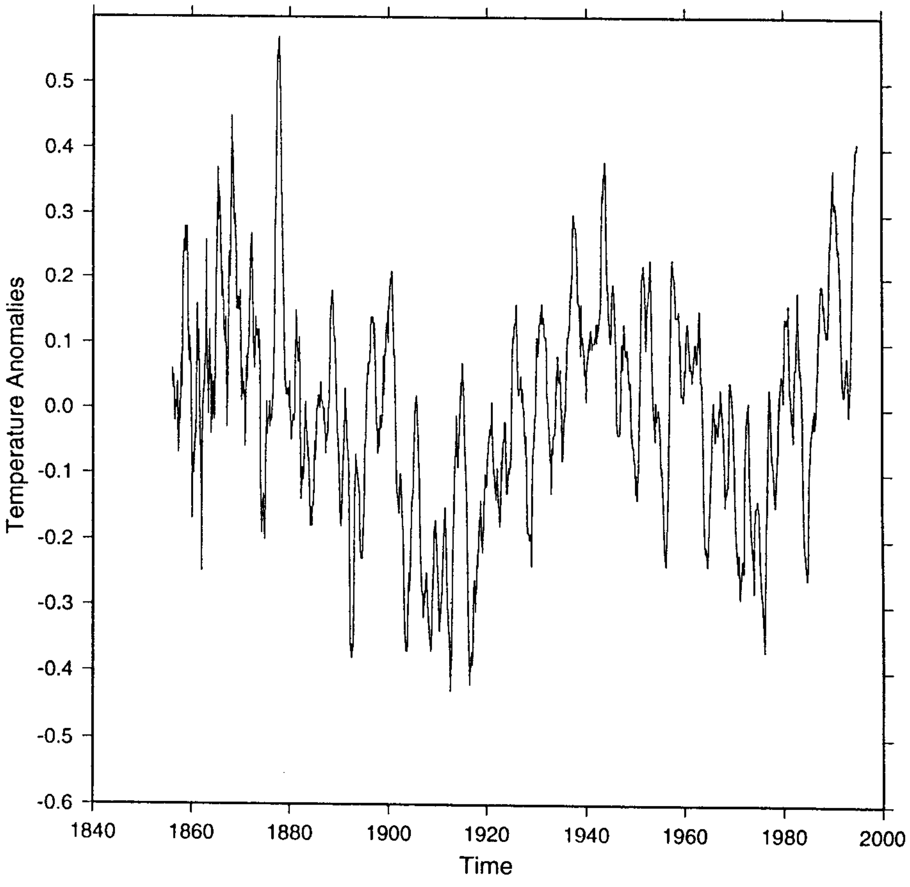

Fig. 1. The decadal variability of the Northern Hemisphere surface mean temperature anomalies.

Table 1 shows the correlation coefficients for lag 1 (month to month) for each month of the year for the detrended monthly series for the two hemispheres. In the NH maximum persitence

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[1] The anomalies for this set are differences from the 1961-1990 mean.

occurs from July to August with a time constant of 5 1/2 months. Minimum persistence occurs from December to January with a time constant of less than a month. In the SH the persistence is more uniform throughout the year with a maximum from February to March and a minimum from June to July. The peaks and troughs of persistence from one month to the next month occur at the same seasonal time of the year in both hemispheres. The SH may be less representative of true temperatures than the NH because of a scarcity of observations over the higher proportion of the surface covered by the ocean. On the other hand oceans impart more persitence to the SH than to the NH, which gives credence to the results.

	N.H.		S.H.	
	auto-correlation lag 1	time constant months	auto-correlation lag 1	time constant months
Jan-Feb	0.564	1.74	0.773	3.38
Feb-March	0.464	1.30	0.795	4.35
March-April	0.598	1.94	0.767	3.76
April-May	0.618	2.07	0.735	3.24
May-June	0.580	1.83	0.708	2.89
June-July	0.770	3.82	0.635	2.20
July-August	0.835	5.54	0.643	2.26
August-Sept	0.671	2.50	0.738	3.29
Sept-Oct	0.658	2.38	0.698	2.78
Oct-Nov	0.473	1.33	0.709	2.90
Nov-Dec	0.396	1.07	0.722	3.07
Dec-Jan	0.270	0.76	0.768	3.78

Table 1. Lag 1 auto-correlations and time constants for each moth for the two hemispheres for the detrended series (1856-1995).

The results shown in Table 1 for the NH do suggest that climate is more consistent in summer than in winter. This might be interpreted to support a conclusion that the atmospheric flow in summer is baroclinically stable because of weak meridional temperature gradients, while in winter the flow breaks down, because of intense meridional temperature gradients, becoming chaotic due to the occurrence of baroclinic instability. Gordon *et al.*, (1998). An argument based on synoptic grounds may be presented that the latter mechanism produces intense and deep low pressure systems in the westerlies, which develop rapidly, accompanied by huge cloud shields. A complimentary effect is the production of anticyclonic blocks, creating clear skies over large snow covered continental snow covered areas. The exact timing and location of the synoptic results of intense baroclinic activity is unpredictable, so that the effect on climate may be judged chaotic (Lorenz, 1994) in the mathematical sense on a month to month time scale. These conditions are certainly present in the NH. In the SH baroclinic instability does not have as great a seasonal variability as in the NH and its effect is less pronounced on climate because of the large proportion of ocean and because the continents have a less important role in the perturbation of the midlatitude westerlies and consequent meridional exchange of polar and tropical air masses.

Tables 2 and 3 show the lag auto-correlations between the months from lags 1 to 12 inclusive, that is, the correlations between each month and every other month following up to a year ahead, for both hemispheres. An interesting feature in Table 2 is the band of relatively low correlations, along the diagonal extending from the bottom left to the top right of the diagram. This diagonal represents the correlations of each month with January, suggesting that in the Northern Hemisphere January retains little memory of its previous state. The effect is that summers correlate more strongly with the following spring and summer than with the intervening autumn and winter. The behaviour of the SH is more like that to be expected for a region with a large proportion of ocean. There is an irregular but gradual decay from lag 1 to lag 12 months. The Southern Hemisphere data set contributes little to the conclusions reached about the Northern Hemisphere. The main forcing contributing to the interesting pattern displayed in Figure 2 is the effect on the temperature of the circulation of the middle latitude westerlies. The ocean-atmosphere system in the tropics behaves quite differently (Webster, 1995) and contributes little to the effect produced by the whole. Nevertheless the combined effect of the land and ocean in the NH shown by the land-marine temperature anomaly mix yields clues to the hemispheric climate not shown by the individual components of the system taken alone. Although the SH data set contributes little to the discussion of the NH behaviour the SH correlations are presented in Table 2 for comparison, while a possible reason for their difference from the NH is proposed in the discussion in the preceding paragraph.

Figure 2 shows Table 2 in graphical form quite clearly. Note the blue colour diagonal extending from the bottom left to the top right of the figure. The colour scale may be judged by comparing the figure with the numerical values in Table 2.

Table 2. Auto-correlations for lag 1-12 inclusive for each month of the year for the land marine mix series of mean surface temperature anomalies (detrended) for the Northern Hemisphere.

lag	1	2	3	4	5	6	7	8	9	10	11	12	mean
January	.564	.260	.378	.335	.296	.114	.225	.359	.166	.172	.090	.019	
February	.464	.436	.313	.336	.275	.402	.302	.226	.795	.172	.075	.070	
March	.598	.401	.364	.412	.450	.217	.308	.157	.213	.164	.176	.119	
April	.618	.597	.550	.584	.504	.417	.267	.231	.335	.365	.315	.366	
May	.580	.538	.550	.496	.446	.204	.341	.305	.318	.307	.399	.327	
June	.770	.676	.615	.393	.229	.353	.306	.456	.335	.472	.330	.360	
July	.835	.620	.480	.345	.366	.303	.324	.285	.496	.458	.464	.487	
August	.671	.580	.456	.391	.352	.336	.313	.473	.453	.487	.522	.448	
September	.658	.456	.393	.188	.388	.357	.501	.457	.514	.490	.530	.410	
October	.473	.395	.252	.308	.293	.431	.397	.404	.398	.458	.326	.398	
November	.396	.217	.157	.181	.242	.208	.223	.273	.277	.165	.281	.090	
December	.270	.378	.211	.322	.304	.307	.202	.194	.262	.215	.030	.003	

Table 3. Auto-correlations for lag 1-12 inclusive for each month of the year for the historical series of mean surface temperature anomalies for the Southern Hemisphere.

lag	1	2	3	4	5	6	7	8	9	10	11	12	mean
January	.773	.735	.732	.619	.553	.490	.532	.469	.402	.314	.237	.258	
February	.795	.727	.591	.460	.462	.464	.467	.440	.312	.244	.275	.183	
March	.767	.729	.560	.539	.593	.547	.515	.403	.357	.335	.316	.293	
April	.735	.663	.554	.575	.586	.592	.446	.410	.384	.269	.308	.295	
May	.708	.630	.530	.584	.550	.417	.327	.347	.274	.300	.306	.316	
June	.635	.592	.507	.418	.425	.457	.428	.328	.344	.398	.373	.356	
July	.643	.618	.562	.437	.427	.470	.401	.446	.470	.415	.429	.422	
August	.738	.650	.486	.489	.485	.428	.411	.424	.429	.314	.419	.351	
September	.698	.512	.441	.417	.414	.398	.429	.351	.245	.331	.338	.430	
October	.709	.608	.597	.588	.542	.505	.398	.374	.383	.381	.455	.319	
November	.722	.665	.650	.624	.517	.500	.350	.303	.416	.379	.284	.222	
December	.768	.706	.673	.709	.545	.431	.322	.443	.397	.386	.270	.245	

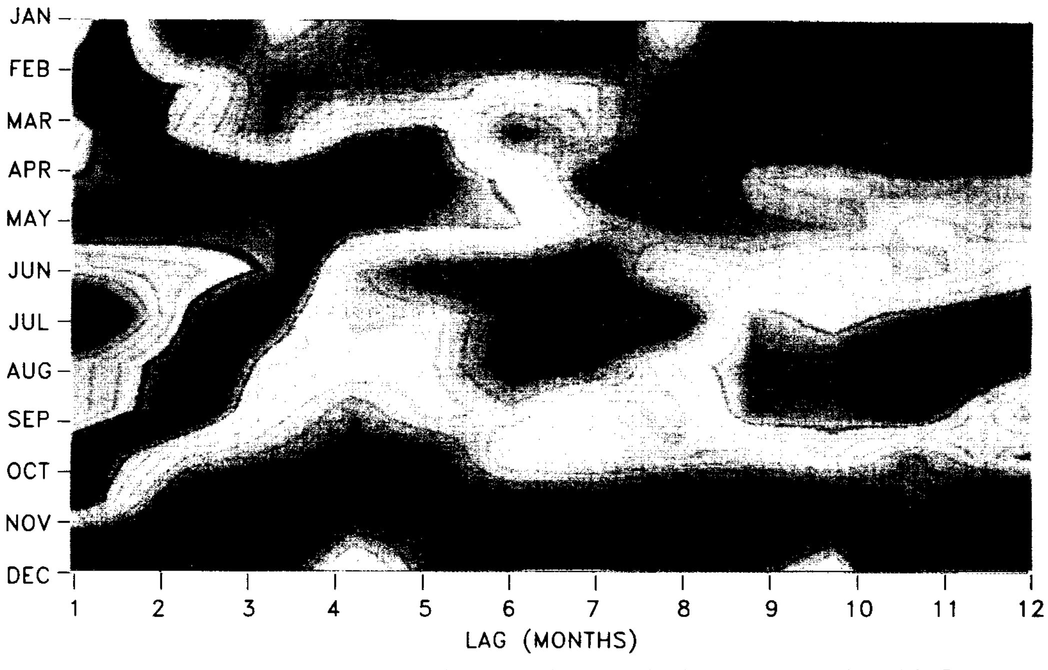

Fig. 2. The tortoise and the rabbit graphic of Table 3. The y-axis shows the months with January at the top and December at the bottom and July half way down. The x-axis represents lags from lag 1 (month to month) correlation at extreme left and lag 12 (year to year correlation) for each month at extreme right. Red is high correlation, blue low, and purple near zero or negative. Note the diagonal of blue (low correlation) from the bottom left to top right of the figure. With perception one might imagine a tortoise and the left chasing a rabbit on the right, summer chasing its shadow summer a year ahead.

The intra-annual patterns of persistence of the two hemispheres are projected into the inter-annual scale. Thus some positive persistence of summer temperature anomalies persists for up to 12 years. Winters decay after about 10 months. On the other hand in the SH persistence in July, August and September decays in about 8 years while January, February and March decay in about 5 years. The months of greatest persistence are the same in the SH as in the NH although the season is the opposite. This may be due to ENSO (Allan *et al.*, 1996), which is known to have its greatest persistence in the SH winter (Fig. 3). Gordon (1991b) reported that the temperature anomalies for the Northern Hemisphere as a whole showed positive persistence for 12 years and for the Southern Hemisphere for 8 years.

It is noted that the predictability barrier in the boreal spring for the southern oscillation lag correlation coefficients (Fig. 3) does not show up in the temperature anomaly pattern in Figure 2.

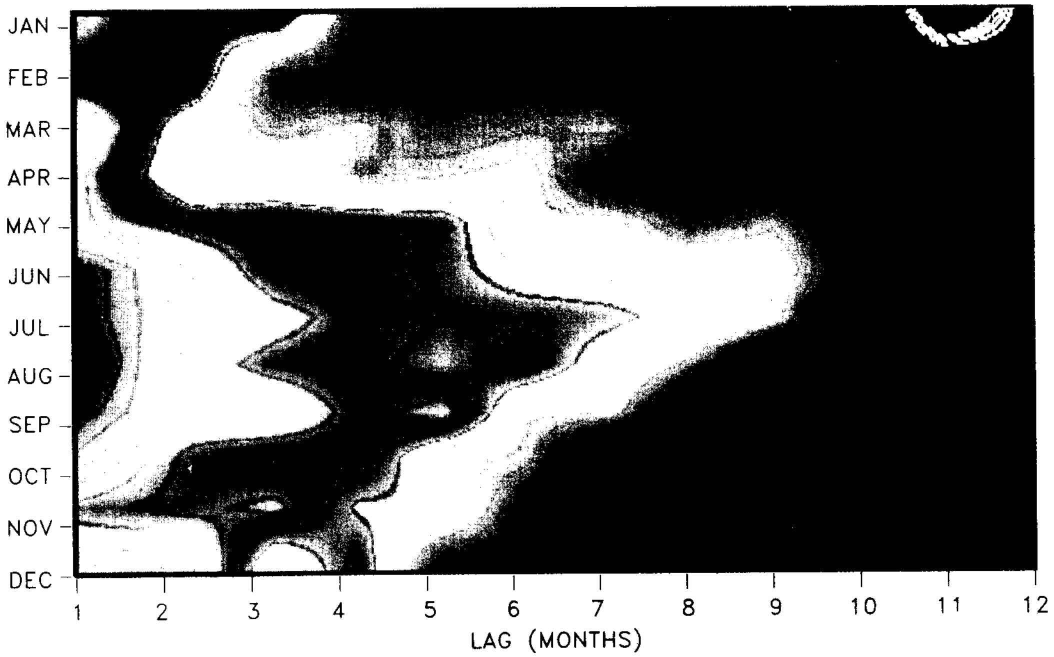

Fig. 3. The Southern Oscillation matrix of correlation coefficients shows strong persistence in the Northern Hemisphere summer months and a pronounced predictability barrier in the boreal spring. The diagram is constructed in an identical fashion to Figure 2. The x and y labels are identical in both Figures 2 and 3.

4. Runs of mean monthly anomalies

Table 4 shows a greater frequency of both positive and negative anomalies for lag 12, one year ahead, for July than for January, clearly illustrating the greater persistence to be expected in this Northern Hemisphere summer month than in the winter month.

Table 5 lists the counts of positive and negative correlations from one year to the next, that is, the summer of ++ and - - sequences and of the + - and - + sequences, for each month of the year, together with the significance of the numbers counted.

The counts of the positive transitions (+ +, - -) and the negative transitions (+ -, - +) clearly show the high statistical significance of the summer months (April through October) year to year persistence.

Table 4. Runs of successive sign of anomaly from one year to the next for January and July for the Northern Hemisphere (Hadley Centre series). The anomalies are relative to zero mean for the detrended series.

January			July		
Runs of	positive	negative	Runs of	positive	negative
1	16	16	1	8	10
2	9	9	2	5	4
3	7	2	3	5	2
4	0	1	4	0	1
5	1	3	5	1	3
6	1	0	6	0	0
7	1	0	7	2	0
8	0	1	8	1	1
			13	0	1
			16	1	0

Table 5. Counts of the positive and negative transitions from one month to the corresponding month one year ahead, for each month of the year (Hadley Centre data set, 1856-1995). The set is detrended and normalized about a zero mean.

Month	transition positive	transition negative	Chi-square significance
January	79	60	n.s.
February	84	55	5
March	70	67	n.s.
April	83	56	5
May	81	58	10
June	85	54	1
July	100	39	<0.1
August	96	43	<0.1
September	88	51	1
October	92	47	<0.1
November	76	63	n.s.
December	69	70	n.s.

5. Conclusion

Analysis of the matrix of persistence correlation from lag 1 - 12 for each month of the year suggests that Northern Hemisphere temperatures are more persistent in summer than winter. The result suggests that the summer circulation is characterized by stable flow. Winters, on the other hand, show small persistence from one month to the next. Perhaps an indication that the flow is baroclinically unstable and thus chaotic (Lorenz, 1994). Strinking evidence of this conclusion is shown by the band of low correlation between each month and the winter months centred on January in Figure 2.

The summer months in the NH correlate moderately well with summer months one year ahead, and positively with summer months many years in the future. This somewhat remarkable property of the NH summer climate is believed to result from the fact that summers retain their memory for several years but that memory is temporarily lost by the volatility of the winter baroclinic instability induced surface temperature perturbations.

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