

Suicide seasonality: Evidence of 11-year cyclic oscillations in Brazilian suicide rates

Sazonalidade do suicídio: Índícios de oscilações cíclicas de 11 anos nas taxas de suicídio brasileiras

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Abstract

Several researchers have studied suicide seasonality through different statistical approaches. In the present research, we performed a detailed statistical study of Brazilian suicide data registered from 1980 to 2010 using a new approach known as Threshold Bias Model (TBM). Eleven-year cyclic oscillations were observed in suicide rates that, at first sight, appear as being negatively correlated with the cycles of solar activity. Such oscillations are more noticeable for males although they also have been observed in the female rates.

Keywords: suicide; seasonal variations; solar activity.

Resumo

Vários pesquisadores têm estudado a sazonalidade do suicídio utilizando diversas abordagens estatísticas. Na presente pesquisa, realizamos um estudo estatístico dos dados de suicídio brasileiros registrados entre 1980 e 2010 utilizando uma nova abordagem conhecida como Modelo da Tendência Limiar (TBM). Foram observadas oscilações com período de 11 anos nas taxas de suicídio que, à primeira vista, parecem ser negativamente correlacionadas com os ciclos de atividade solar. Essas oscilações foram mais notáveis nas taxas masculinas, ainda que também tenham sido observadas nas taxas femininas.

Palavras-chave: suicídio; variações sazonais; atividade solar.

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INTRODUCTION

Suicide seasonality is a multifactorial phenomenon that is often associated with the increased winter-summer variation in the number of sunlight hours that occurs in temperate and polar zones of the globe^{1,2}. Consequently, its occurrence has been little studied in the tropics.

In Brazil, a previous study conducted between 1996 and 2004 in the city of São Paulo (located on the Tropic of Capricorn) did not reveal significant correlation between suicides and the number of sunlight hours³. However, beyond the hypothetical influence of the daily duration of sunlight on suicide rates, several authors have reported that long-term seasonal patterns in such rates may be correlated with solar and geomagnetic activities⁴⁻⁷.

Since seasonal oscillations in suicide rates may be small in comparison with data fluctuations due to death undercounting and/or cause of death misclassification, researchers are using several statistical methods in order to quantify this phenomenon^{8,9}. Considering this, we performed a preliminary study of suicide seasonality in Brazil employing the recently proposed Threshold Bias Model (TBM)¹⁰ — a model that provides useful comparison parameters to help us identify seasonality patterns.

METHOD

The present research considers male and female suicide rates structured by age that were recorded in Brazil from 1980 to 2010. Such data are openly available from the website of DATASUS¹¹. In the same way, the average sunspot numbers considered here (relating to solar cycles 21, 22 and 23) can be freely obtained from the website of the Solar Influences Data Analysis Center (SIDC)¹².

All analyses were made using the software Microcal Origin version 5.0¹³. In this software, suicide rates were edited in proper worksheets and plotted as functions of age. Then, we employed the Levenberg-Marquardt method to fit Equation 1 (TBM distribution) to these datasets considering $\beta=11$ as discussed in Folly¹⁰. The meanings of all TBM parameters were explained in this reference.

$$SR(t) = \begin{cases} 0 & \text{if } (t < t_c) \\ \left[a \cdot \left(\frac{\beta + 1}{\tau_{1/2}} \right) \cdot \left(\frac{t - \tau_{1/2}}{\tau_{1/2}} \right)^\beta + b - V_0 \right] \cdot C_{ap} & \\ \exp \left[-a \left(\frac{t - \tau_{1/2}}{\tau_{1/2}} \right)^{\beta + 1} + V_0 \cdot (t - \tau_{1/2}) \right] & \text{if } (t \geq t_c) \end{cases} \quad (1)$$

After all the distributions were fitted, we used the values of the parameters b , V_0 and C_{ap} to calculate the middle-age suicide rates $SR(\tau_{1/2})$ for each year from 1980 to 2010 using the expression $SR(\tau_{1/2}) = (b - V_0) \cdot C_{ap}$. Such distributions were numerically integrated (using Origin's integration tool) from the critical age t_c to infinity in order to determine the areas under the curves. The values of t_c can be calculated using Equation 2.

$$t_c = \tau_{1/2} - \tau_{1/2} \left[\frac{1}{a} \left(\frac{\tau_{1/2}}{\beta + 1} \right) (b - V_0) \right]^{\frac{1}{\beta}} \quad (2)$$

The areas under the TBM distributions and the calculated values of $SR(\tau_{1/2})$ were plotted together with sunspot numbers in a same time scale to facilitate comparisons. In order to quantify the period and amplitude of seasonal oscillations of these data, they were fitted by the function $f(T)$ defined by the Equation 3, in which T is the time in years. The year 1980 was considered as the zero on the time scale.

The Equation 3 defines $f(T)$ as being the sum of a third order polynomial (necessary to fit the secular trend) and a sinusoidal term in which the parameters P_5 , P_6 and P_7 are the amplitude, period in years and initial phase respectively.

$$f(T) = P_1 + P_2 \cdot T + P_3 \cdot T^2 + P_4 \cdot T^3 + P_5 \cdot \sin \left(\frac{2\pi T}{P_6} + P_7 \right) \quad (3)$$

RESULTS

The TBM distributions were fitted to yearly suicide rates by age from 1980 to 2010 (Figure 1). The obtained parameter values with standard errors, chi-squares, degrees of freedom and p-values are shown in the Table 1. Despite the distributions fitted better the female data, even for males, the differences between fitting curves and statistical data were not significant (all $p > 0.05$), with the worst fit observed for the year 1987 ($p = 0.975$).

We organized the curves for the male datasets in a 3D graph in order to depict their annual evolution over the studied period (Figure 2). By performing numerical integrations, we determined the areas under the fitted distributions for males and females. Such areas are shown in the Figure 3a with the sunspot numbers for solar cycles 21, 22 and 23 on the same time scale. In the same way, the calculated middle-age suicide rates $SR(\tau_{1/2})$ are shown together with sunspot data in Figure 3B.

As previously explained, the values of $SR(\tau_{1/2})$ and the areas under the TBM distributions were fitted by the

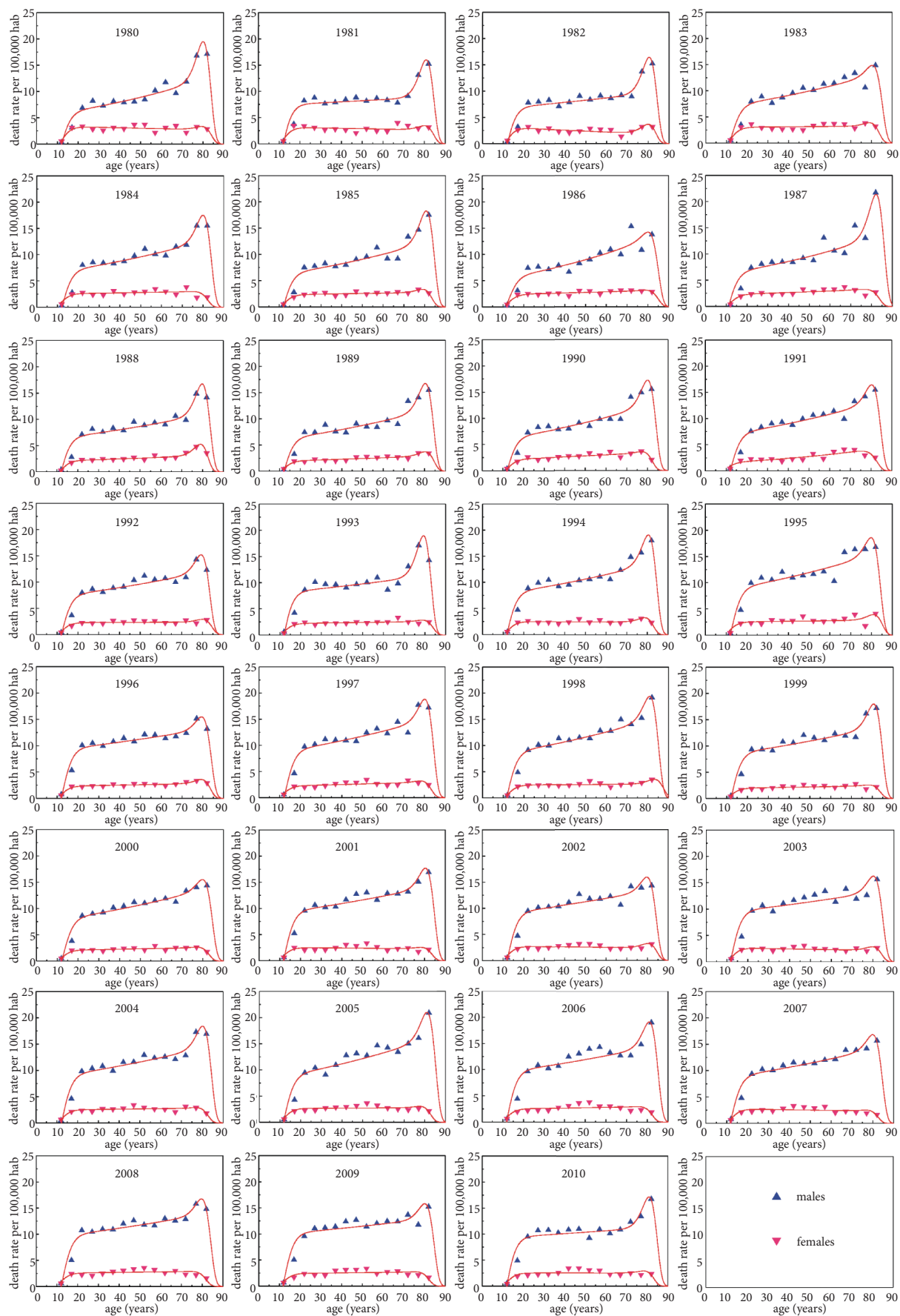


Figure 1. Annual suicide rates by age and gender in Brazil from 1980 to 2010. The continuous curves shown in red are the Threshold Bias Model (TBM) distributions fitted to each statistical dataset

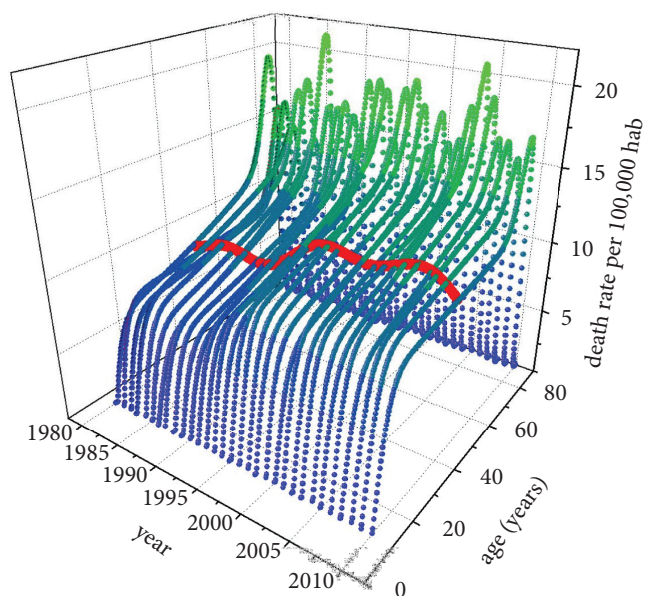
Table 1. Threshold Bias Model parameter values

Year	Gender	C_{ap}	a	b (year ⁻¹)	$\tau_{1/2}$ (year)	V_0 (year ⁻¹)	χ^2	df	p-value
1980	M	77.0 (9.1)	12.8 (1.4)	0.120 (0.014)	45	0.0108 (0.0020)	1.498	10	0.998
	F	17.4 (9.3)	14.3 (6.2)	0.172 (0.099)	45.5 (2.0)	-0.0030 (0.0033)	1.104	10	0.999
1981	M	90.9 (9.3)	10.4 (1.3)	0.092 (0.011)	45	0.0026 (0.0018)	1.287	10	0.999
	F	19.2 (10)	11.7 (5.1)	0.149 (0.085)	45.3 (2.1)	-0.0027 (0.0039)	1.476	10	0.999
1982	M	82.9 (9.3)	11.3 (1.4)	0.102 (0.012)	45	0.0051 (0.0019)	1.589	10	0.998
	F	30.8 (7.8)	7.6 (2.0)	0.073 (0.024)	44.1 (0.8)	-0.0073 (0.0033)	0.827	10	0.999
1983	M	47.8 (10.4)	17.7 (5.1)	0.211 (0.045)	46.5	0.0089 (0.0024)	2.249	11	0.997
	F	17.4 (7.8)	13.5 (5.2)	0.181 (0.086)	45.2 (1.4)	0.0010 (0.0030)	0.889	10	0.999
1984	M	67.5 (8.3)	16.0 (2.1)	0.145 (0.018)	45.5	0.0091 (0.0019)	1.808	10	0.997
	F	7.9 (4.2)	16.7 (5.2)	0.352 (0.19)	45	0.0022 (0.0036)	1.374	11	0.999
1985	M	72.1 (10.4)	13.2 (2.5)	0.130 (0.019)	45.5	0.0100 (0.0023)	2.133	10	0.995
	F	14.5 (3.4)	13.8 (3.0)	0.176 (0.044)	45.0 (0.7)	0.0026 (0.0018)	0.231	10	0.999
1986	M	37.8 (11.2)	19.0 (7.2)	0.240 (0.068)	46.5	0.0124 (0.0031)	2.979	11	0.991
	F	9.5 (2.3)	17.7 (4.0)	0.290 (0.070)	46.5	0.0038 (0.0019)	0.405	11	0.999
1987	M	88.6 (19.5)	8.6 (3.5)	0.113 (0.024)	45.5	0.0104 (0.0032)	3.799	11	0.975
	F	7.8 (3.4)	18.8 (5.9)	0.36 (0.15)	46	0.0053 (0.0031)	0.947	11	0.999
1988	M	72.1 (8.9)	13.4 (1.6)	0.123 (0.015)	45	0.0078 (0.0020)	1.722	10	0.998
	F	25.7 (3.0)	10.2 (1.6)	0.105 (0.013)	43.99 (0.34)	0.0057 (0.0017)	0.186	10	0.999
1989	M	66.1 (9.4)	14.7 (2.4)	0.136 (0.019)	45.5	0.0094 (0.0023)	1.825	10	0.998
	F	15.4 (3.6)	11.5 (2.9)	0.159 (0.039)	45.3 (0.98)	0.0058 (0.0021)	0.308	10	0.999
1990	M	63.7 (8.4)	15.4 (2.2)	0.147 (0.019)	45.5	0.0104 (0.0020)	1.483	10	0.999
	F	10.7 (2.4)	20.4 (3.1)	0.259 (0.057)	45.3	0.0067 (0.0021)	0.427	11	0.999
1991	M	59.0 (7.2)	17.2 (2.6)	0.171 (0.021)	46	0.0091 (0.0017)	1.294	10	0.999
	F	5.4 (5.2)	12.7 (6.5)	0.49 (0.46)	45	0.0135 (0.0038)	1.307	11	0.999
1992	M	58.3 (7.3)	18.0 (2.1)	0.167 (0.021)	45.5	0.0071 (0.0018)	1.381	10	0.999
	F	13.8 (2.6)	12.7 (2.6)	0.169 (0.034)	45.5	0.0005 (0.0022)	0.431	11	0.999
1993	M	94.4 (11)	12.2 (1.1)	0.106 (0.013)	44.5	0.0049 (0.0020)	1.757	10	0.998
	F	10.8 (2.7)	14.5 (3.4)	0.222 (0.058)	45.5	0.0022 (0.0025)	0.637	11	0.999
1994	M	78.8 (8.4)	13.5 (1.8)	0.138 (0.015)	45.5	0.0078 (0.0016)	1.339	11	0.999
	F	16.9 (2.4)	11.9 (1.4)	0.145 (0.022)	44.5	-0.0004 (0.0019)	0.336	11	0.999
1995	M	65.4 (10.8)	18.8 (3.6)	0.185 (0.030)	46	0.0083 (0.0022)	2.229	10	0.994
	F	19.8 (7.5)	7.8 (4.1)	0.137 (0.055)	45	0.0020 (0.0045)	2.058	11	0.998
1996	M	58.4 (5.8)	20.1 (2.1)	0.194 (0.019)	46	0.0052 (0.0012)	0.802	10	0.999
	F	15.9 (2.7)	11.7 (2.0)	0.163 (0.029)	44.83 (0.53)	0.0031 (0.0014)	0.149	10	0.999
1997	M	70.8 (8.5)	18.2 (2.6)	0.169 (0.020)	46	0.0077 (0.0017)	1.418	10	0.999
	F	11.1 (3.3)	13.5 (3.1)	0.236 (0.069)	45	0.0041 (0.0027)	0.693	11	0.999
1998	M	74.6 (8.6)	14.5 (2.3)	0.159 (0.018)	46	0.0081 (0.0015)	1.226	11	0.999
	F	18.7 (5.3)	9.9 (3.3)	0.138 (0.041)	46.66	0.0012 (0.0012)	0.334	11	0.999
1999	M	73.4 (8.0)	16.0 (2.3)	0.152 (0.017)	46	0.0068 (0.0015)	1.192	10	0.999
	F	8.9 (2.6)	14.8 (3.8)	0.249 (0.074)	45.5	0.0032 (0.0027)	0.596	11	0.999
2000	M	51.1 (6.0)	22.0 (3.2)	0.211 (0.025)	46.5	0.0080 (0.0014)	1.108	10	0.999
	F	8.3 (1.9)	17.4 (2.8)	0.279 (0.063)	45.35	0.0031 (0.0019)	0.324	11	0.999
2001	M	70.7 (7.7)	16.2 (2.2)	0.166 (0.018)	46	0.0061 (0.0039)	1.409	11	0.999
	F	10.9 (4.5)	12.3 (4.2)	0.219 (0.095)	45	-0.0015 (0.0039)	1.414	11	0.999
2002	M	60.4 (8.3)	18.8 (2.9)	0.187 (0.026)	46	0.0057 (0.0017)	2.745	11	0.994
	F	18.6 (4.1)	9.8 (2.4)	0.136 (0.033)	45	-0.0021 (0.0027)	0.754	11	0.999
2003	M	65.7 (11.6)	16.3 (3.5)	0.175 (0.031)	46	0.0049 (0.0022)	2.381	11	0.997
	F	16.4 (3.4)	10.9 (2.3)	0.144 (0.033)	45	-0.0030 (0.0026)	0.640	11	0.999
2004	M	72.4 (7.9)	18.1 (2.4)	0.163 (0.018)	46	0.0069 (0.0015)	1.291	10	0.999
	F	9.6 (2.6)	18.1 (3.4)	0.276 (0.074)	45.33	0.0016 (0.0023)	0.522	11	0.999

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Table 1. Continuation

Year	Gender	C_{ap}	a	b (year ⁻¹)	$\tau_{1/2}$ (year)	V_0 (year ⁻¹)	χ^2	df	p-value
2005	M	80.4 (12)	14.2 (3.1)	0.155 (0.023)	46	0.0086 (0.0020)	2.300	11	0.997
	F	11.7 (3.4)	15.3 (3.3)	0.233 (0.069)	45	0.0007 (0.0028)	0.814	11	0.999
2006	M	81.3 (13.5)	14.4 (3.3)	0.149 (0.025)	46	0.0059 (0.0022)	2.840	11	0.993
	F	8.3 (4.5)	16.7 (5.4)	0.327 (0.176)	45	0.0024 (0.0039)	1.507	11	0.999
2007	M	61.0 (7.2)	17.2 (2.4)	0.189 (0.022)	46	0.0070 (0.0014)	1.170	11	0.999
	F	9.8 (3.6)	16.7 (4.3)	0.256 (0.098)	45	-0.0024 (0.0033)	1.062	11	0.999
2008	M	65.3 (6.9)	19.4 (2.3)	0.182 (0.020)	46	0.0053 (0.0014)	1.154	10	0.999
	F	7.4 (3.6)	18.5 (5.0)	0.369 (0.180)	45	0.0017 (0.0033)	1.113	11	0.999
2009	M	66.4 (11.1)	16.5 (3.3)	0.174 (0.030)	46	0.0037 (0.0021)	2.142	11	0.998
	F	7.8 (3.7)	17.7 (5.0)	0.33 (0.16)	45	0.0018 (0.0035)	1.141	11	0.999
2010	M	89.6 (10.5)	12.2 (1.8)	0.117 (0.015)	45.5	0.0027 (0.0017)	2.102	11	0.998
	F	12.7 (4.4)	13.8 (4.0)	0.200 (0.073)	45	-0.0001 (0.0037)	1.352	11	0.999

**Figure 2.** 3D representation of male Threshold Bias Model distributions plotted as functions of age and year. The continuous curve shown in red represents the annual evolution of middle-age death rates by suicide

function $f(T)$ defined by the Equation 3. The obtained parameter values with respective standard errors, chi-squares, degrees of freedom and p-values are shown in Table 2. It was observed that the amplitude (modulus of parameter P_5 shown in Table 2) of the sinusoidal part of $f(T)$ fitted to $SR(\tau_{1/2})$ is about 6% of the average value of this quantity for males and 3% for females. In addition, it was found that the periods of the sinusoidal part of $f(T)$ (values in years of P_6 shown in Table 2) are closely compatible with the 11-year sunspot cycles. The Figures 3a and b show that the areas under the TBM distributions and the values of $SR(\tau_{1/2})$ present three events of minima in the studied time range: the first in 1979–1980, the second in 1989–1990 and the

third in 2001–2002. Such events occurred at approximately the same years of maxima of the sunspot cycles 21, 22 and 23 (Figures 3A and B).

DISCUSSION

Albeit some researchers have reported positive correlations between suicide rates and sunspot numbers⁴, our preliminary results are in agreement with the findings of several other authors who have reported negative correlations between these phenomena⁵⁻⁷.

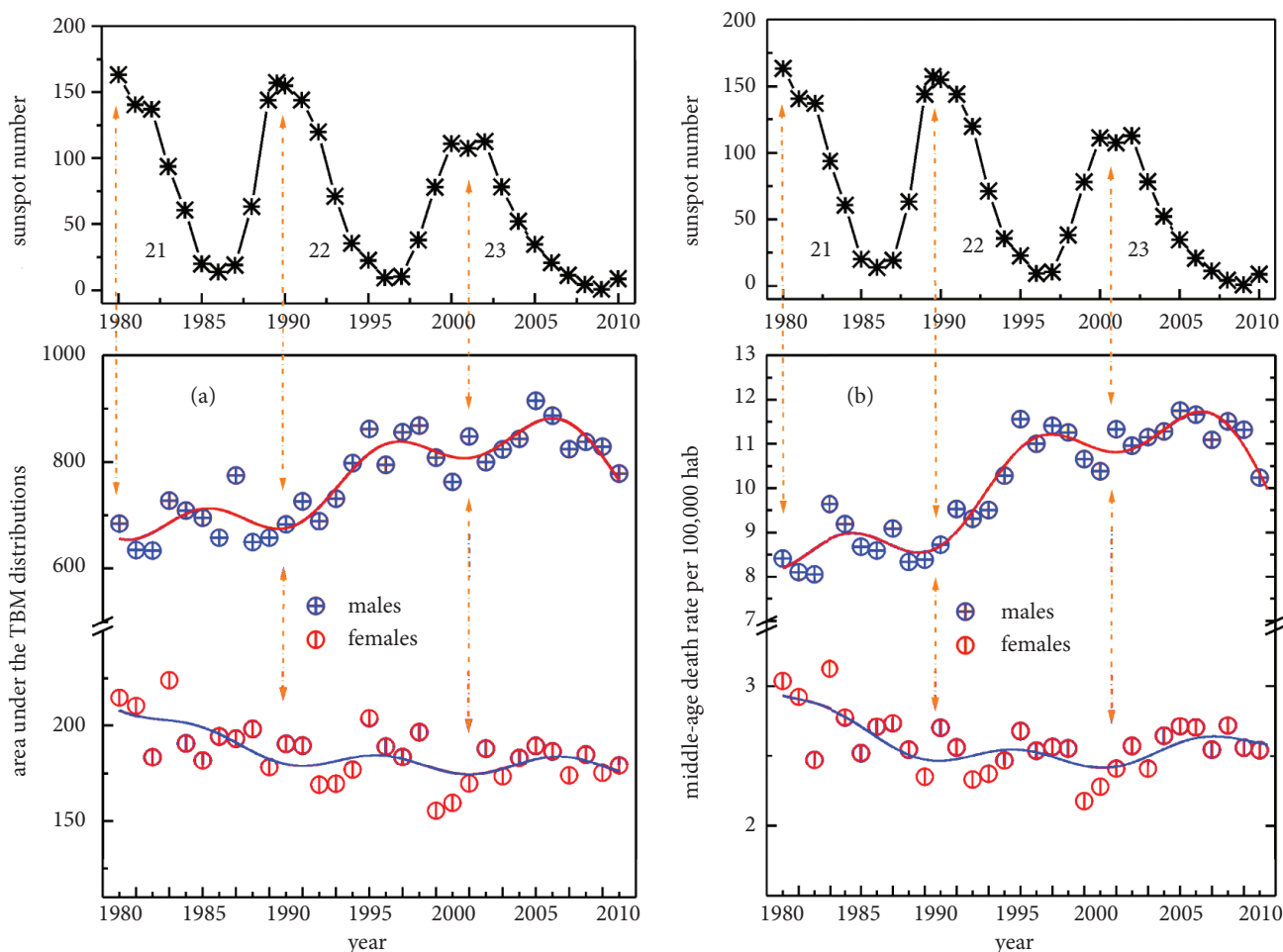
Since the middle-age suicide rates $SR(\tau_{1/2})$ and the areas under the TBM distributions are relatively immune to data fluctuations over the studied age groups, the results of present research can be considered as relatively robust.

Despite the observed oscillations in suicide rates be more prominent for males, they were also noticeable for females. For males, these oscillations are observed over all age groups, but become more intense with increasing ages (Figure 2). Such a progression with age was not clearly observed in the female rates. In Brazil, due to occupational factors, men are more likely to be exposed to sunlight than women¹⁴. This fact may hypothetically explain the greater amplitude of oscillations observed in the male suicide rates although this hypothesis has not been tested in the present study. The reader should also be aware that the present results (obtained from nationwide population data) might not be valid at regional level. Interpretations of such results as being valid for small cohorts can lead to ecological fallacy¹⁵.

The neurobiological mechanism linking suicide with solar activity remains unknown. Recent studies have positively correlated suicide occurrence with low levels of melatonin¹⁶ in populations exposed to increased number of sunlight hours. As such correlation was not investigated in the present work, further researches are required in order to clarify this point.

Table 2. Parameter values of $f(T)$ obtained for $SR(\tau_{1/2})$ and for integrated $SR(t)$

$f(T)$	G	P_1	P_2	P_3	P_4	P_5	P_6	P_7	χ^2	df	p-value
$SR(\tau_{1/2})$	M	8.67 (0.35)	-0.186 (0.093)	0.0296 (0.0067)	-0.00071 (0.00014)	-0.57 (0.11)	11.7	8.29 (0.19)	0.39	25	0.999
	F	3.01 (0.15)	-0.072 (0.039)	0.0029 (0.0028)	-0.00003 (0.00006)	-0.072 (0.044)	11.7	8.81 (0.63)	0.25	25	0.999
Integral of $SR(t)$	M	709.6 (34)	-17.14 (8.72)	2.12 (0.63)	-0.048 (0.013)	-39.14 (9.78)	10.8 (0.6)	1.17 (0.58)	34.2	23	0.062
	F	217.2 (11)	-4.95 (2.96)	0.21 (0.21)	-0.0030 (0.0044)	4.61 (3.25)	10.8	-1.86 (0.8)	20.4	24	0.726

**Figure 3.** Sunspot numbers during solar cycles 21, 22 and 23 plotted together with (A) the areas under Threshold Bias Model (TBM) distributions and (B) the middle-age death rates by suicide. The continuous curves shown in red and blue were obtained by fitting the function defined by the Equation 3 to these data for males and females respectively

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