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CHANGES IN EARTH'S CLIMATE IN THE 18TH THROUGH 21ST CENTURIES AND THEIR REASONS

The paper proves that the planets of the Solar System, by their gravitational impact on the Sun, change its activity and indirectly influence the climate on the Earth. There is also a forecast of climate in Poland in the 21st century with due consideration of the anthropogenic element.

Studies were made on the basis of data from Warsaw (made available by the Institute of Meteorology and Water Economy): air temperature (1779—1984), precipitation (1813—1980), and on the basis of astronomical data: Wolf number (1779—1978), heliocentric ecliptic coordinates of planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto — in the period 1779—2135. The location of planets was determined from the empirical formulas, as given in A. P. Reznikow's (1982) publication for geophysical purposes.

THE METHOD OF STUDIES

Assuming that planets interact gravitationally with the Sun (changing its activity — the number of spots) and indirectly cause changes in climate on Earth, four astronomical parameters were defined to characterize the Solar System:

L — distance of geometrical centre of the Solar System from the ecliptic ($L = r_z$, $\vec{r} = [r_x, r_y, r_z] = \frac{1}{n}\sum_i \vec{R}_i$ — in astronomic units AU)

F — resultant gravity force ($\vec{F} = \sum_i \frac{m_i}{R_i^3}\vec{R}_i$, $F = \vec{F}\frac{\vec{r}}{|\vec{r}|}$ — in $m_3 AU^{-2}$)

M — total moment of inertia of 9 planets relative to the centre of mass of the Solar System

$$\left(M = \frac{1}{n} \sum_i m_i \left(X + Y_i^2 + Z_i^2 \right),\ \vec{X} \parallel \vec{R} \text{ — in } 10^3 m_3 AU^2 \right)$$

R — distance of the centre of mass of the Solar System from the Sun

$$\left(\vec{R} = \frac{1}{m} \sum_i m_i \vec{R}_i,\ \vec{R} = |\vec{R}|\ , \text{ in } AU \right)$$

where: m_i, R_i — mass, radius vector of an i-th planet, m_3 — mass of the Earth, m — mass of all planets.

The effect of Sun's activity and Earth's climate on the movement of planets was studied by developing Wolf numbers, air temperature and precipitation into Taylor series

$$y = a_o + \sum_{\alpha=1}^{\xi} \sum_{\beta=1}^{\alpha+1} \sum_{\gamma=1}^{\beta} \sum_{\delta=1}^{\alpha-\beta+2} a_{\alpha\beta\gamma\delta}\, L^{\alpha-\beta-\delta+2}\, F^{\delta-1}\, M^{\beta-\gamma}\, R^{\gamma-1} \tag{1}$$

relative to parameters $L(t)$, $F(t)$, $M(t)$, $R(t)$ changing in time t. The equations of hypersurface regression (1) were verified by the Fisher-Snedecor test.

DEPENDENCE OF SOLAR ACTIVITY ON PLANETS' GRAVITY FORCE AND DISPERSION OF THEIR MASS

A dependence of the number of spots on the Sun on the locarion of planets relative to the Sun was determined. The largest impact is caused by the resultant gravity force F and the moment of inertia M (dispersion of mass of planets in the Solar System). Correlation coefficients 0.41 and 0.20 are significant at the level of confidence of 99%.

The dependence of Solar activity on parameters of the Solar System is well described by the first term of Taylor series ($\xi = 1$) — equation of regression hyperplane

$$W = 102.7 - 1.577\ L + 2.835\ F - 8.942\ M - 2.842\ R \tag{2}$$

with a coefficient of multiple correlation $\varrho = 0.552$ — significant at the level of confidence 99% (Fisher characteristics: $F_o = 21.3$, $F_{tab} = 3.4$, $F_o > F_{tab}$).

With a larger dynamic impact of planets on the Sun, i.e. with larger gravity force F, smaller dispersion of mass of planets M and less distance of geometric centre from the ecliptic plane L, there are more spots on the sun and it shows a higher activity. The dependence of Solar activity on parameters of the Solar System is best expressed by three

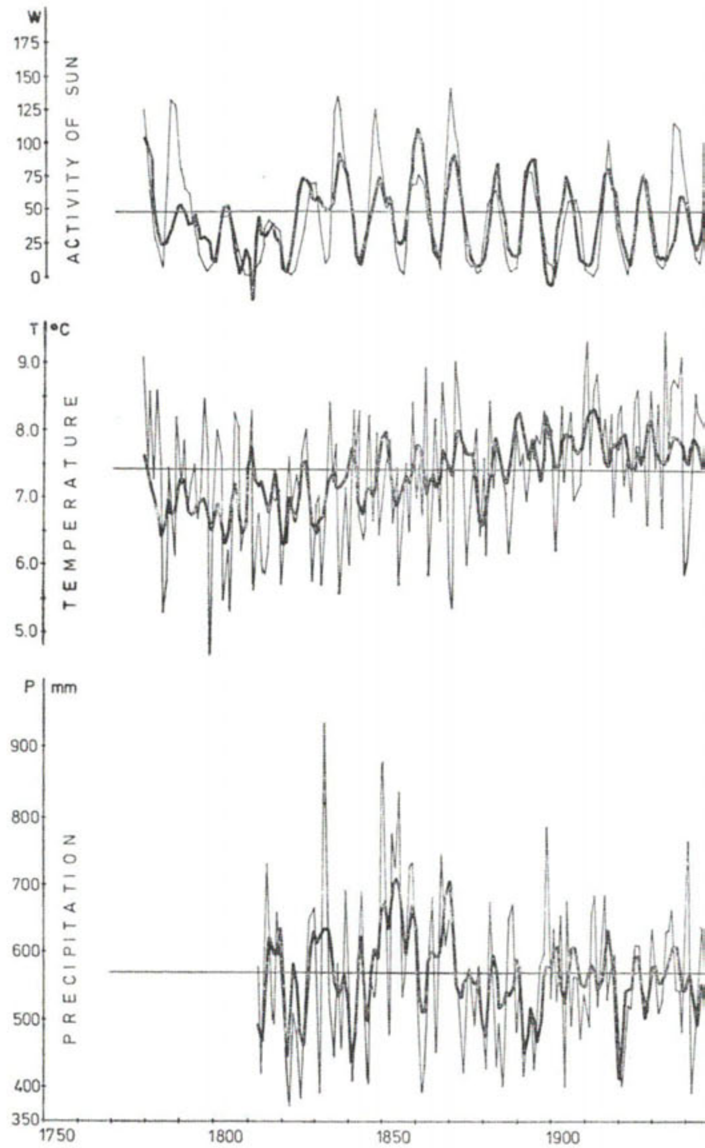
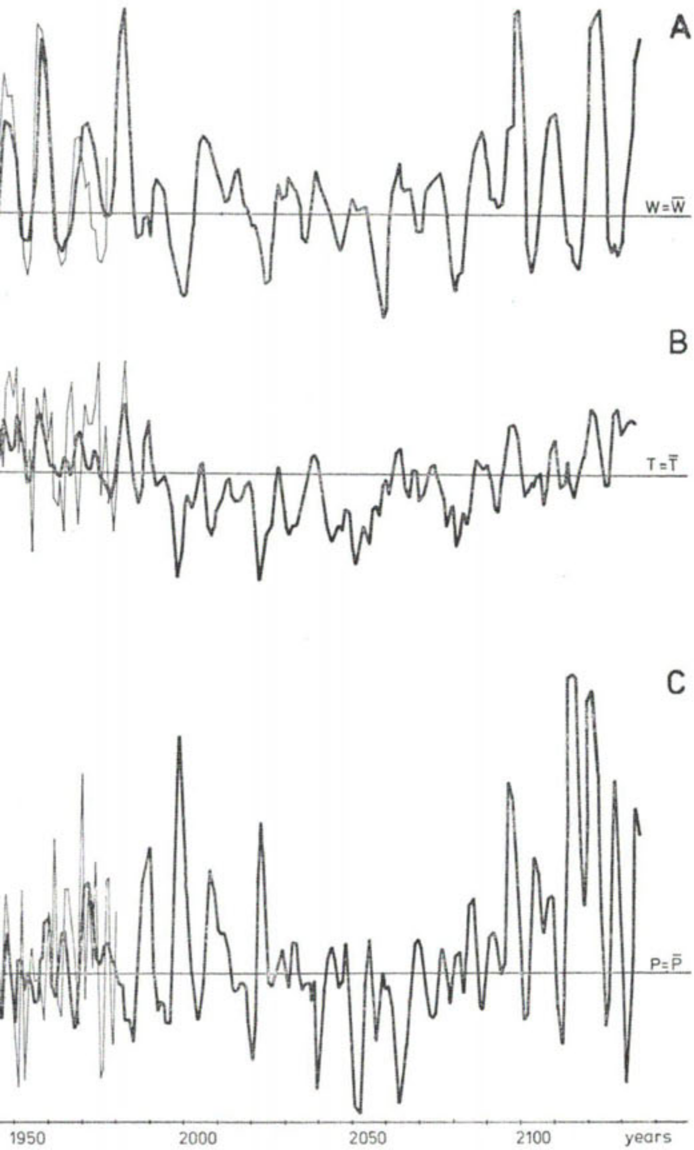


Fig. 1. Time trend of solar activity (
(C) in Warsaw — graphs of polynomials



A), air. temperature (B) and precipitation
(3), (5), (6) in time range 1779—2135.

terms in Taylor series ($\xi = 3$) — polynomial of regression, third degree in relation to F, M, R, L:

W = 407.2

+48.84	L	+3.937	F	−98.79	M	−38.68	R	
−87.62	L^2	−5.359	LF	−0.1279	F^2	−3.741	LM	
+0.8456	FM	+0.9085	LR	−1.352	FR	+4.169	M^2	
+16.08	MR	−0.2686	R^2	−18.20	L^3	−1.1113	L^2F	
−0.09977	LF^2	−0.006183	F^3	+11.05	L^2M	+0.8153	LFM	
+0.01987	F^2M	+3.406	F^2R	+0.03687	LFR	+0.02231	F^2R	
−0.8539	LM^2	−0.1049	FM^2	+2.582	LMR	−0.06017	FMR	
−1.980	LR^2	+0.3275	FR^2	+0.2148	M^3	−0.6079	M^2R	
−1.476	MR^2	+0.4857	R^3					(3)

with a coefficient of multiple correlation $\varrho = 0.803$ which is significant at the level of significance 1% ($F_o = 8.808$, $F_{tab} = 1.8$).

It simulates well the 11-year and centennial activity of the Sun in the period 1779—1978 (diagram Fig. 1A). Dates of absolute extremes of the polynomial (minimum 1810, maximum 1958) are in the years of the lowest (1810) and highest (1957) number of spots on the Sun. The consistence of dates occurs both in the previous and present century:

W_{min}	1900	1911	1923	1934	1943	1954	1964	1977
Data	1901	1913	1923	1933	1944	1954	1964	1976
W_{max}	1904	1917	1927	1939	1947	1958	1971	1982
Data	1905	1917	1928	1937	1947	1957	1968	

Solar activity for the 21st century was forecast by extrapolating the values of the polynomial (3), i.e. by inserting the values of parameters *L, F, M, R* forecast for the period 1979—2135 (Fig. 2). It is interesting to compare the minima (W_{min}) and maxima (W_{max}) of the polynomial with extremes of the time trend $w = w(t)$ of Wolf number (w_{min}, w_{max}) resulting only from their periodicity (Boryczka 1984):

W_{min}	1986	2000	2012	2024	2036
w_{min}	1985	1999	2011	2022	2032
W_{max}	1982	1992	2005	2016	2028
w_{min}	1979	1990	2005	2016	2027

According to the two types of forecasts of Solar activity, the next minimum of the number of Solar spots will occur around the year 2000. A. N. Afanasiev (1967) in astronomical forecasts till the end of the 20th century expects a minimum of the century to be in 2001.

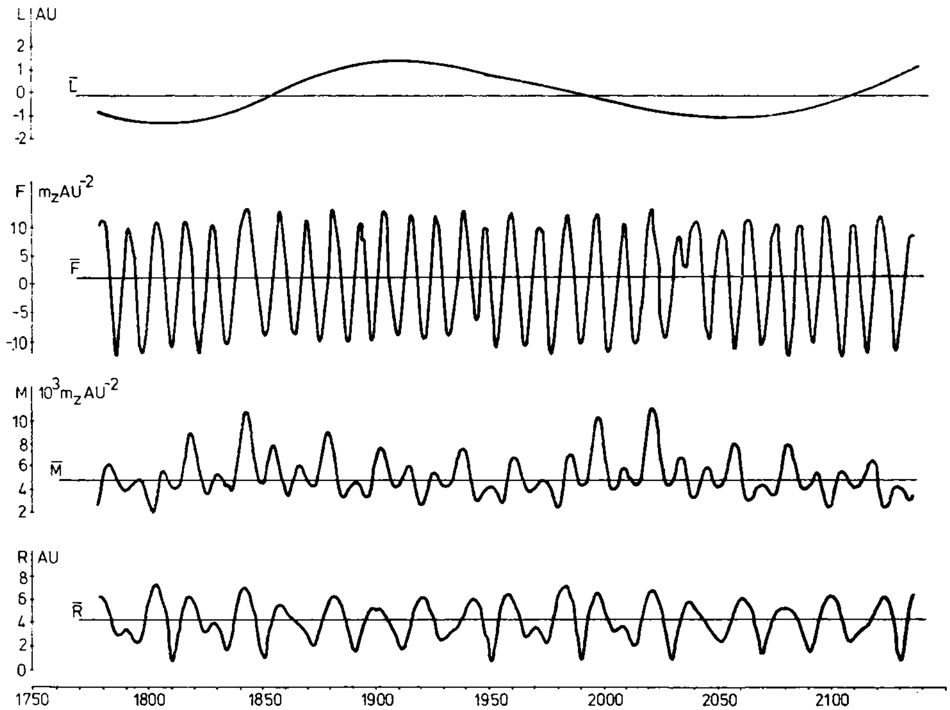


Fig. 2. Time changes of parameters of the Solar System L, F, M, R in the period 1779—2135.

INDIRECT IMPACT OF PLANETS ON EARTH'S CLIMATE

Solar activity (influenced by the movement of planets) conditions the contemporary anomalies of the Earth's climate. This is proven by equations of regression hyperplane of air temperature (T) and precipitation (P) relative to parameters of the Solar System:

$$T = 7.992 - 0.3359\ L + 0.0141\ F - 0.0725\ M - 0.0499\ R$$
$$P = 621.4 - 55.14\ l + 0.5786\ F + 6.450\ M - 10.24\ R$$

where $l = |L|$.

Despite an indirect (secondary) dependence, the coefficients of multiple correlation (0.378, 0.243) are significant at the level of confidence 99% ($F_o = 8.43$, $F_o = 2.42$). There is a significant consistence of signs of coefficients of partial regression of air temperature and Solar activity relative to parameters of the Solar System — gradients

$$\frac{\partial W}{\partial L}, \frac{\partial W}{\partial F}, \frac{\partial W}{\partial M}, \frac{\partial W}{\partial R}, \text{ and } \frac{\partial T}{\partial L}, \frac{\partial T}{\partial F}, \frac{\partial T}{\partial M}, \frac{\partial T}{\partial R}.$$

Air temperature (similarly as Solar activity) grows along with a growth of the resultant gravity force (F) and diminishes along with a greater dispersion of mass of 9 planets (M), larger distance of the centre of mass from the Sun (R) and larger distance of the geometrical centre from the ecliptic plane (L).

Precipitation (similarly as Solar activity) grows along with a growth of gravity force F and diminishes with larger distance of the geometrical centre from ecliptic (L) and larger distance of the centre of mass from the Sun (R). It also diminishes with a greater dispersion of mass (M).

Air temperature depends most on parameter L, and precipitation — on $l = (L)$. Correlation coefficients −0.35 and −0.20 are significant at the level of confidence 99% and 95%. The dependence of air temperature and precipitation on parameters of the Solar System is better expressed by three terms in Taylor series — polynomials of regression, third degree:

$T = 15.84$

+2.309	L	+0.1678	F	−3.769	M	−0.1358	R	
−0.4019	L^2	−0.02943	LF	−0.01258	F^2	−0.8385	LM	
−0.1083	FM	−0.1990	LR	+0.09977	FR	+0.4577	M^2	
+0.4441	MR	−0.3602	R^2	+0.02961	L^3	−0.01995	L^2F	
−0.001976	LF^2	−0.0004981	F^3	+0.06773	L^2M	−0.003312	LFM	
+0.0006682	F^2M	−0.003877	F^2R	+0.01093	LFR	+0.002225	F^2F	
+0.02482	LM^2	+0.009142	FM^2	+0.1060	LMR	−0.0001576	FMR	
−0.02996	LR^2	−0.01167	FR^2	−0.005066	M^3	−0.07442	M^2R	
+0.03562	MR^2	+0.02338	R^3					(5)

$P = -1781$

+304.6	l	−16.71	F	+702.9	M	+613.1	R	+	
−505.1	l^2	−44.51	lF	+1.507	F^2	+118.4	lM	+	
+7.086	FM	−111.3	lR	+9.784	FR	−46.13	M^2	+	
−198.1	MR	−3.599	R^2	−75.62	l^3	−12.32	l^2F	+	
−1.521	lF^2	+0.02268	F^3	+118.2	l^2M	+9.823	lFM	+	
−0.2214	F^2M	+16.36	F^2R	+2.112	lFR	+0.2978	F^2R	+	
−40.64	lM^2	−1.480	FM^2	+30.71	lMR	−0.04244	FMR	+	
−4.306	lR^2	−1.184	FR^2	+3.076	M^3	+5.307	M^2R	+	
+11.02	MR^2	−4.298	R^3						(6)

with coefficients of multiple correlation $\varrho = 0.500$ and $\varrho = 0.499$ significant at the level of confidence 95% ($F_O = 1.671$, $F_O = 1.299$); they are presented by curves in Figs. 1B and 1C.

There is a large similarity between curves of trend of polynomial $T = f(L, F, M, R)$ and trigonometric trend $T = f(t)$, resulting from an overlay of natural temperature cycles (Boryczka, Stopa-Boryczka, 1984). Both curves (just like Wolf numbers) are characterized by: upward trend in 1779—1984, deep minimum at the beginning of the 19th century (at absolute minimum of solar activity) and a vast maximum in mid-20th century (at absolute maximum of Solar activity). There is also a convergence of the two types of air temperature forecasts — extrapolated parts of the curves $T = f(L, F, M, R)$ and $T = f(t)$, in the period 1980—2100 are below the average two-century value $T = \bar{T}$.

The most significant cooling and warming of the climate in Poland (main extremes of the trend $T = f(L, F, M, R)$ are expected in the following years:

	Cool weather					Warm weather				
Year	1999	2023	2052	2082	Year	1990	2006	2040	2065	2095
T_{min}	5.9	5.9	6.2	6.4°C	T_{max}	8.5	7.6	7.8	7.9	8.2°C

At the end of the 20th century (at the centennial minimum of Solar activity in the year 2000) one may expect cool years — temperature drops on the average by 1.6°C below the average from the two last centuries.

Basing on the polynomial (6) it is expected that the following years will by "dry" and "humid" years (with lowest P_{min} and highest P_{max} of total precipitation):

	Dry years					Humid years				
Year	2020	2040	2052	2064	Year	1990	1999	2008	2023	2097
P_{min}	447	401	364	382mm	P_{max}	756	807	719	795	853mm

The extremes vary significantly from the annual average precipitation $P = 568$ mm in the period 1813—1980. At the end of the 20th century — about 1999 — one may expect exceptionally high precipitation — 238 mm higher than normal.

ANTHROPOGENIC CHANGES OF THE CLIMATE

The measure of anthropogenic changes of the climate is linear component $\Delta T = at$ of air temperature time trend (or precipitation):

$$T = a_o + at + \sum_j b_j \sin\left(\frac{2\pi}{\Theta_j} t + c_j\right) \quad (7)$$

resulting from overlaying of natural cycles — sinusoids with period Θ_j and phase shifts c_j were determined by selecting sinusoid of regression equations:

$$T = a_o + b \; sin\left(\frac{2\pi}{\Theta} t + c\right) \tag{8}$$

from among $\Theta = 1, 2, ..., n$ years — proposed by the author (Boryczka 1984). It is a selection of sinusoids of regression with largest amplitudes b_j, verified with the Fisher-Snedecor test.
It should be stressed that the equation of regresion line

$$T = Ao + At \tag{9}$$

i.e. coefficient A is not a measure of anthropogenic changes of the climate. For instance, an upward trend $A = 0.6°C/100$ years of average annual air temperature in the last two centuries (1779—1979):

$$T = 6.881 - 0.005784 \; t \tag{10}$$

is a resultant of overlayng of two natural cycles 89 and 217 years (Fig. 3).

The anthropogenic element $\Delta T = at$ of average monthly values of air temperature in Warsaw (1779—1979) ranges within a year and this is described with a sinusoid equation

$$a = 0.083 + 0.226 \; sin \; (2\pi t + 1.494), \quad \text{in °C/100 years} \tag{11}$$

Its annual variability in the years of 1900, 2000, 2100 is illustrated by curves in Fig. 4.

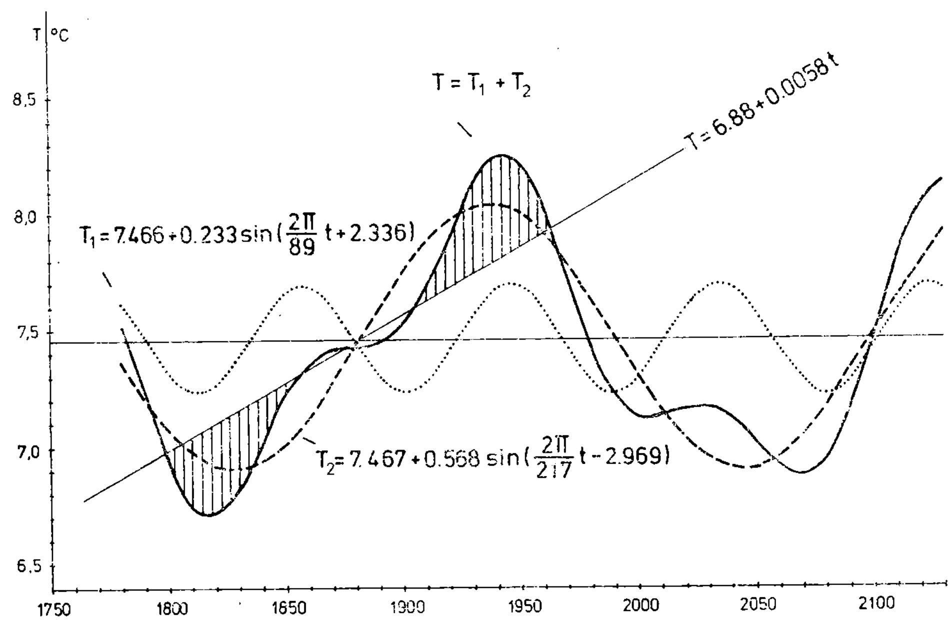


Fig. 3. Upward trend 0.6°C/100 years of air temperature in Warsaw in the period 1779—1979 as resultant from its natural cycles: 89 years and 217 years.

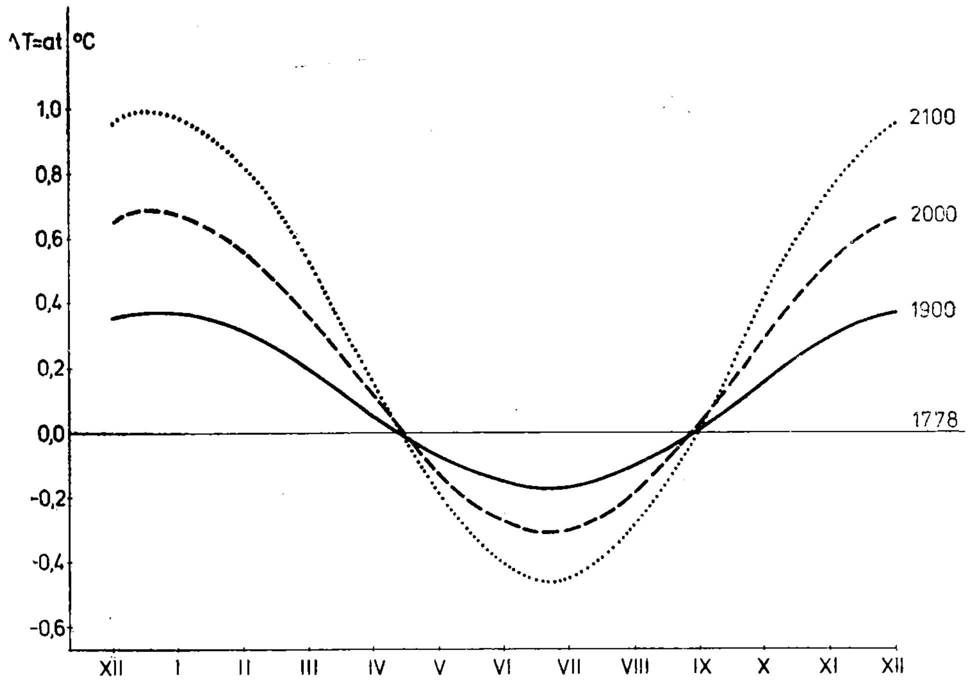


Fig. 4. Anthropogenic element of air temperature trend in the years: **1900, 2000, 2100.**

Here is a forecast of changes of the anthropogenic element in relation to 1778 ($\Delta T = 0$):

	1779	1900	2000	2100
January	0	0.4	0.7	1.0
July	0	−0.2	−0.3	−0.5
Year	0	0.1	0.2	0.3

In winter ($\Delta T > 0$) probably the hothouse effect is dominating and it is iausen by the inireased CO_2 content in the atmosphere, in summer ($\Delta T < 0$) — absorption of solar radiation by natural dusts and dusts from secondary emission. The contrary operation of CO_2 and dusts on the climate causes that anthropogenic growth of the annual average air temperature ΔT and annual volume of precipitation ΔP is small.

REFERENCES

Reznikov A. P., (1982), Predskazanie estestvennykh procesov obuchaynskchejsya sistemoj, Novosybirsk.