

Global Warming Acceleration

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Abstract

This publication analyzes changes in global warming rates (GWR) expressed in Centigrade per year ($^{\circ}\text{C}/\text{y}$) and introduces a parameter “*global warming acceleration*” (GWA) expressed in Centigrade per year per year ($^{\circ}\text{C}/\text{y}^2$). GWA may be applied to forecast the GWR for the next decade. If the current decrease of GWA will continue for the next 11 years, Global Warming Rate will increase from the current $+0.017^{\circ}\text{C}/\text{y}$ to $+0.019^{\circ}\text{C}/\text{y}$, for land+ocean.

Glossary

Ave	average
BL	Global Warming baseline 1850-1900
dGWA	annual change in Global Warming Acceleration, GWA, in the trendline period, $^{\circ}\text{C}/\text{y}^3$ ($^{\circ}\text{C}/\text{y}^2$ per year) ($^{\circ}\text{C} \text{ y}^{-3}$)

GW	Global Warming, global surface temperature above the 1850-1900 baseline, °C
GWA	Global Warming Acceleration, change of the velocity of the Global Warming in time, the annual change in Global Warming Rate in the trendline period, °C/y ² (Centigrade per year per year) (°C y ⁻²)
GWR	Global Warming Rate, the velocity of the Global Warming, change of Global Warming in time, annual change in global surface temperature in the trendline period, °C/y ([8] Formula 1)
Ref	reference
TL	trendline

Units

The temperature change is in °C above the 1850-1900 baseline.

Global Warming Rate, GWR, annual change in the global surface temperature in the trendline period, is in °C/y.

Global Warming Acceleration, GWA, annual change in the global warming rate in the trendline period, is in °C/y² (Centigrade per year per year).

The annual change in the global warming acceleration in the trendline period, dGWA, is in °C/y³ (°C/y² per year).

Trendlines

Global surface temperature 61 years linear trendlines are applied every 10 years starting from 1850 (1880 for ocean only).

Table 1 - Trendlines

i	Trendline ID	Trendline period			Trendline Center	
		from	to	years		
Symbol	TL(i)				CenterTL	Δy
Formula					Formula 6	Formula 5
Units		year	year	years	year	years
1	TL1	1850	1910	61	1880	
2	TL2	1860	1920	61	1890	10
3	TL3	1870	1930	61	1900	10
4	TL4	1880	1940	61	1910	10
5	TL5	1890	1950	61	1920	10
6	TL6	1900	1960	61	1930	10
7	TL7	1910	1970	61	1940	10
8	TL8	1920	1980	61	1950	10
9	TL9	1930	1990	61	1960	10
10	TL10	1940	2000	61	1970	10
11	TL11	1950	2010	61	1980	10
12	TL12	1960	2020	61	1990	10
13	TL13	1961	2021	61	1991	1

Formulas

Formula 1 - Linear trendline

$$T(y) = (y-n) * a + b$$

$T(y)$ global surface temperature above 1850-1900 baseline in year y , °C
 n the year before the trendline start point, i.e., for trendline in period 1961-2021 $n=1960$
 a, b parameters related to the linear function displayed on the Excel trendline chart

Formula 2 - Global Warming Rate, GWR

$$GWR = a \text{ [}^\circ\text{C/y]}$$

Formula 3 - Global Warming Acceleration, GWA

$$GWA = \Delta a / \Delta y \text{ [}^\circ\text{C/y}^2\text{]}$$

Formula 4 - Δa

$$\Delta a = a(i) - a(i-1)$$

$a(i)$	annual change in global surface temperature in trendline period “i”, equals to parameter “a” of trendline “i” (from Excel chart formula), °C/y
$a(i-1)$	annual change in global surface temperature in trendline period “i-1”, equals to parameter “a” of trendline “i-1” (from Excel chart formula), °C/y

Formula 5 - Δy

$$\Delta y = \text{CenterTL}(i) - \text{CenterTL}(i-1)$$

$\text{CenterTL}(i)$	center of trendline “i”, year
$\text{CenterTL}(i-1)$	center of trendline “i-1”, year

Formula 6 - CenterTL

$\text{CenterTL}(i)$ = average year between start year and end year of trendline TL(i))

Formula 7 - $dGWA$ – annual change in Global Warming Acceleration

$$dGWA = a(GWA) / \Delta y \text{ [}^\circ\text{C/y}^3\text{]}$$

$dGWA$	annual change in Global Warming Acceleration, °C/y ³
$a(GWA)$	parameter “a” in the Global Warming Acceleration linear trendline, °C/y ²
Δy	time difference between trendlines on the chart = 10 years

Databases Applied

- NASA [1] [2]
- NOAA [3]
- Berkeley Earth (LBL) [4] [5] [6] [7]

Global Warming

Global Warming, GW, is defined in this work as the global surface temperature above the 1850-1900 baseline, °C.

Global Warming Rate

According to IPCC [9] *“Since 1970 the global average temperature has been rising at a rate of 1.7°C per century”*.

According to NASA [10] *“The majority of the warming has occurred since 1975, at a rate of roughly 0.15 to 0.20°C per decade”*.

According to NOAA 2020 Annual Climate Report [11] *“the combined land and ocean temperature has increased at an average rate of 0.13 degrees Fahrenheit (0.08 degrees Celsius) per decade since 1880; however, the average rate of increase since 1981 (0.18°C / 0.32°F) has been more than twice that rate”*.

Global Warming Rate, GWR, is defined in this work as the velocity of the Global Warming, GW, change of Global Warming in time, annual change in the global surface temperature in the trendline period, °C/y ([8] Formula 1)

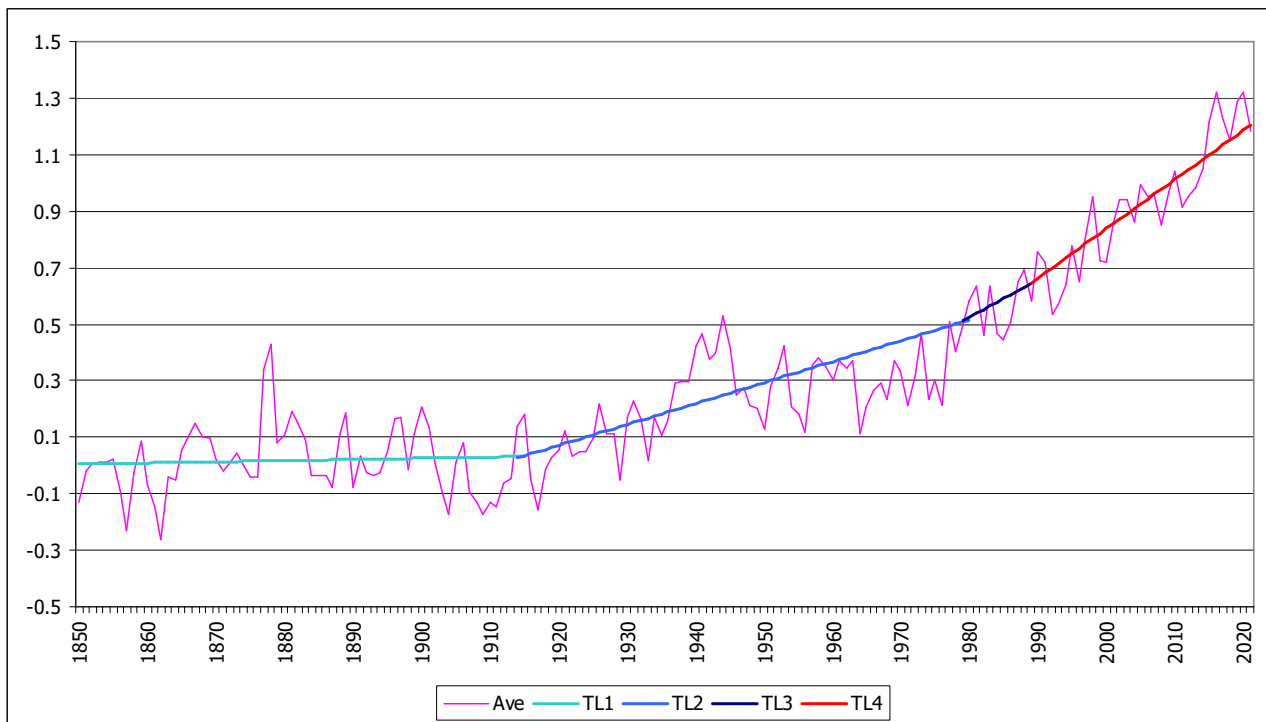
Publication [8] includes 61 years trendlines and the Global Warming Rate values in each trendline period.

Global Warming Acceleration

Global Warming Acceleration, GWA, is the change in the velocity of the Global Warming in time. The velocity of the Global Warming is in this work Global Warming Rate, GWR, and is determined for each trendline. As the trendlines are for every 10 years, the GWA is calculated as the difference between the current GWR and the GWR in the previous trendline, divided by 10 years.

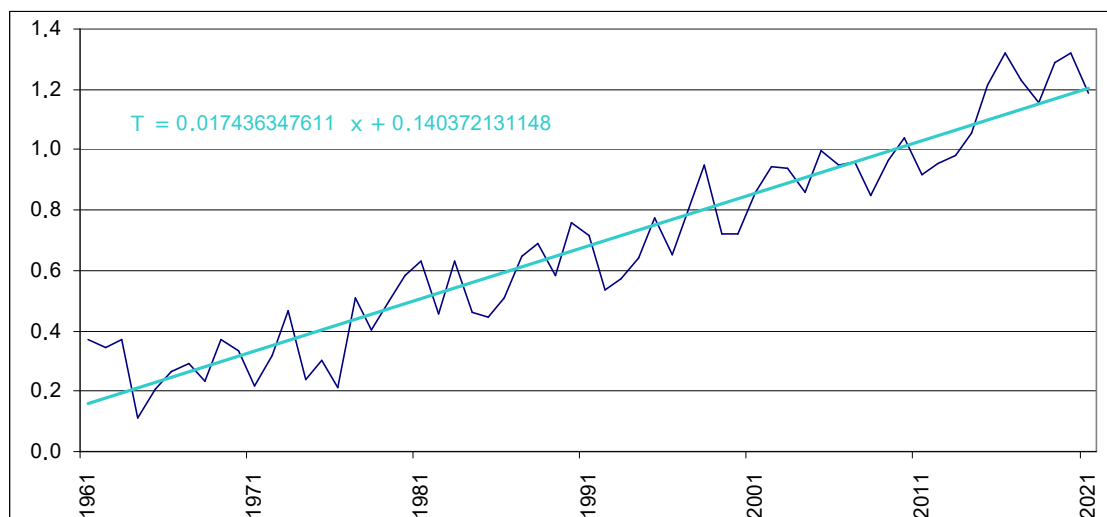
Global Surface Temperature Changes over Land and Ocean

Chart 1 - Trendlines, land+ocean, 1850-1900 baseline [8] [°C]



Ave average of all databases [°C]

Chart 2 - Last trendline TL13 (1961-2021), land+ocean, 1850-1900 baseline [8] [°C]



The above trendline (TL13) is from 1961 to 2021, having a center in the year 1991.

The formula of this trendline is:

$$T = 0.017436347611x + 0.140372131148$$

$$a = +0.017436347611$$

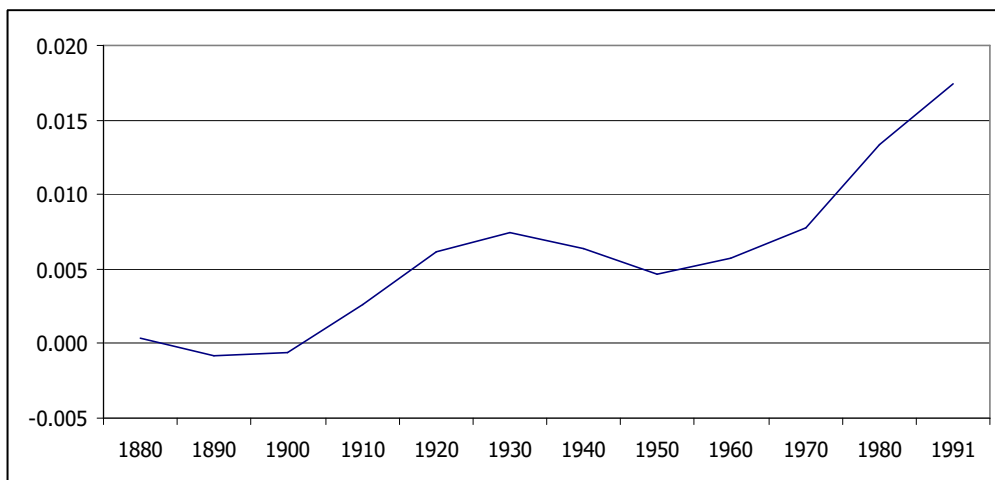
$$b = +0.140372131148$$

The slope of the above trendline is parameter "a" in the trendline formula displayed on the chart. The trendline slope (parameter "a") is the Global Warming Rate in the period of the trendline and equals +0.017 °C/y.

Table 2 - Global Warming Rate (GWR) and Global Warming Acceleration (GWA), land+ocean

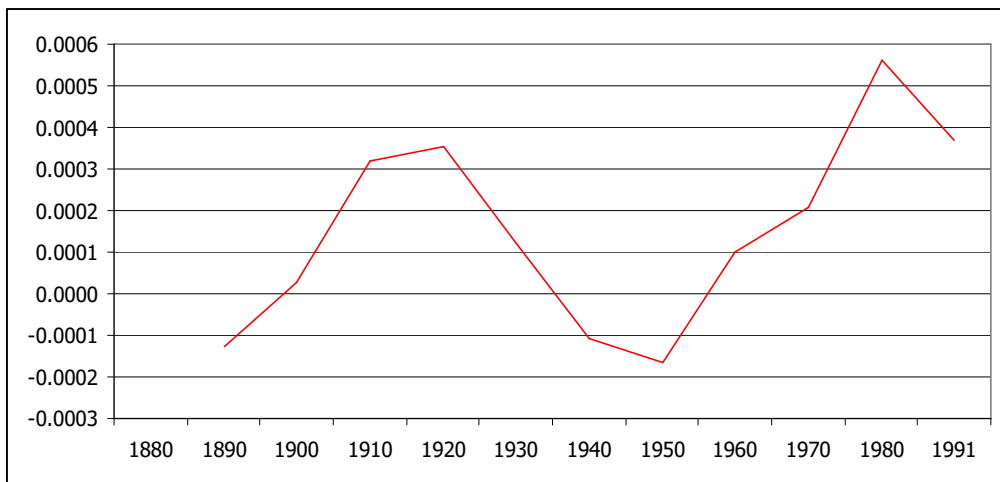
i	Trendline ID	Trendline period			Trendline Center	Δy	Global Warming Rate	GWR Change per Δy	Global Warming Acceleration
	TL(i)	from	to	years	CenterTL		GWR	ΔGWR	GWA
Formula					Formula 6	Formula 5	Formula 1	Formula 4	ΔGWR/Δy
Units		year	year	years	year	years	°C/y	°C/y	°C/y ²
1	TL1	1850	1910	61	1880		+0.000417		
2	TL2	1860	1920	61	1890	10	-0.000865	-0.001282	-0.000128
3	TL3	1870	1930	61	1900	10	-0.000578	+0.000287	+0.000029
4	TL4	1880	1940	61	1910	10	+0.002629	+0.003207	+0.000321
5	TL5	1890	1950	61	1920	10	+0.006173	+0.003544	+0.000354
6	TL6	1900	1960	61	1930	10	+0.007406	+0.001233	+0.000123
7	TL7	1910	1970	61	1940	10	+0.006335	-0.001071	-0.000107
8	TL8	1920	1980	61	1950	10	+0.004676	-0.001659	-0.000166
9	TL9	1930	1990	61	1960	10	+0.005681	+0.001005	+0.000101
10	TL10	1940	2000	61	1970	10	+0.007744	+0.002063	+0.000206
11	TL11	1950	2010	61	1980	10	+0.013362	+0.005618	+0.000562
12	TL12	1960	2020	61	1990	10	+0.017213	+0.003851	+0.000385
13	TL13	1961	2021	61	1991	1	+0.017436	+0.000223	+0.000223

Chart 3 - GWR – Global Warming Rate, land+ocean [°C/y]



Axis x is the center of the 61 years trendline period

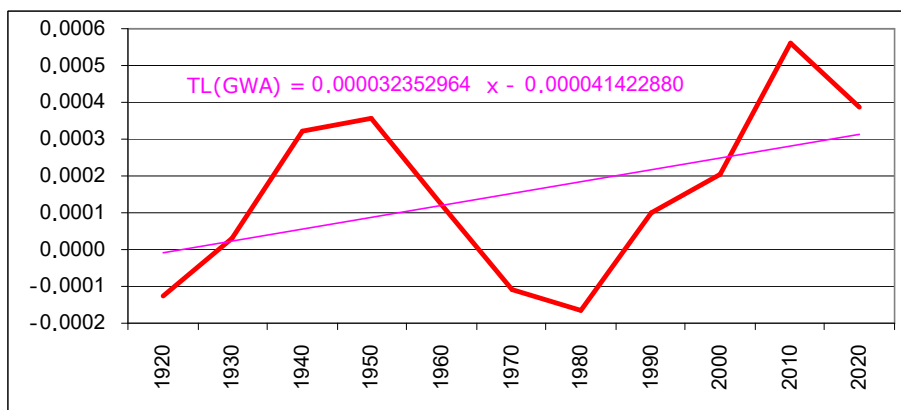
Chart 4 - GWA - Global Warming Acceleration, land+ocean [°C/y²]



Axis x is the center of the 61 years trendline period

Since 1960 the GWA is above zero, which means the Global Warming Rate (GWR) [°C/y] is increasing. The negative slope of GWA between 1980 and 1991 means a slower increase in GWR.

Chart 5 - Trendline of Global Warming Acceleration, land+ocean [°C/y³/10years]



Axis x is the **end** of the 61 years trendline period

Table 3 - dGWA, change in Global Warming Acceleration

Global Warming Acceleration	GWA Trendline formula:	TL(GWA) = 0.000032352964x - 0.000041422880	
Parameter "a" in GWA trendline formula	a(GWA)	+0.000032352964	°C/y ² /10y
Parameter "b" in GWA trendline formula	b(GWA)	-0.000041422880	°C/y ² /10y
Time difference between trendlines on the chart	Δy	10	years
Annual Change in Global Warming Acceleration	dGWA	Formula 7: a(GWA)/Δy	°C/y ³
Change in Global Warming Acceleration	dGWA	+0.000003235296	°C/y ³

Change in Global Warming Acceleration (dGWA) is determined in this work as a slope of the Global Warming Acceleration trendline. The slope is indicated in the chart trendline formula as parameter "a".

The value of the chart slope is per 10 years, therefore the "a" parameter is divided by 10 to receive the dGWA.

Table 4 - Starting values for the forecast

Starting year	TL a	TL b	GW(BL) TL	GWR	GWA	dGWA
			°C	°C/y	°C/y ²	°C/y ³
2020	+0.017213	+0.132767	+1.183	+0.017213	+0.000385	+0.0000032

Global Surface Temperature Changes over Land

Chart 6 - Trendlines, land only, 1850-1900 baseline [8] [°C]

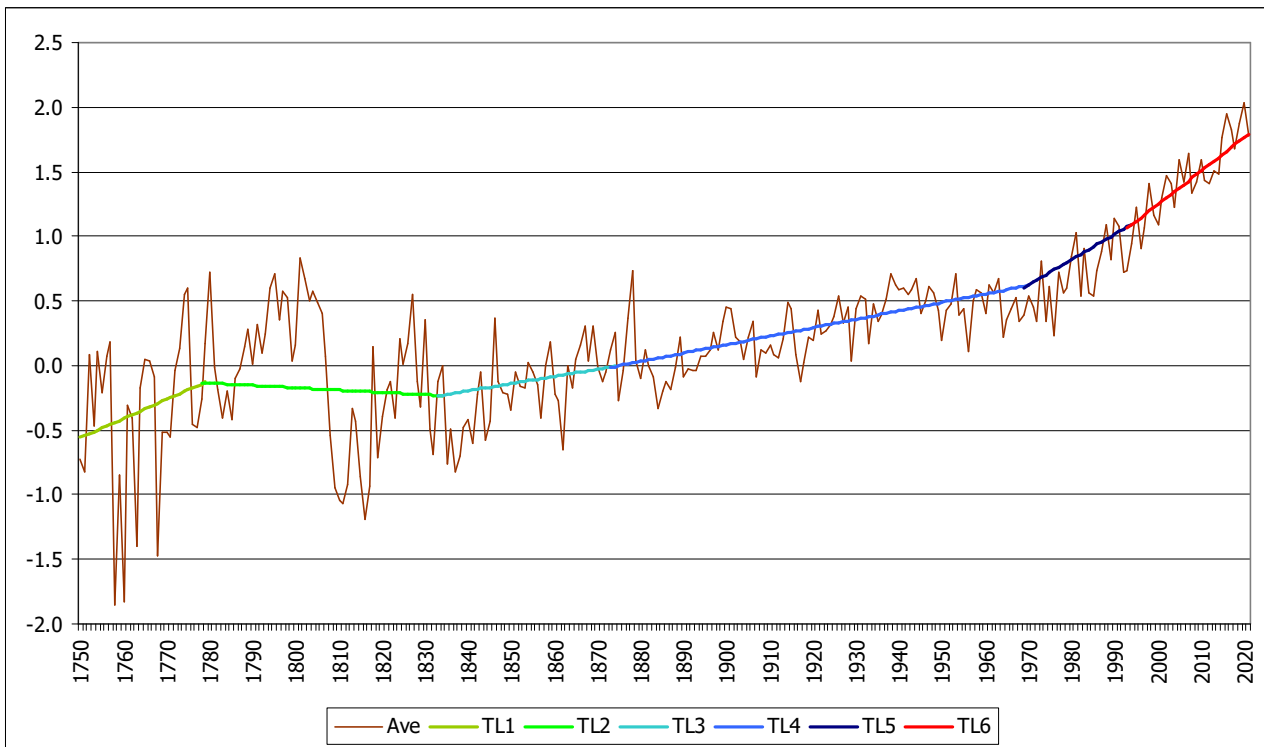
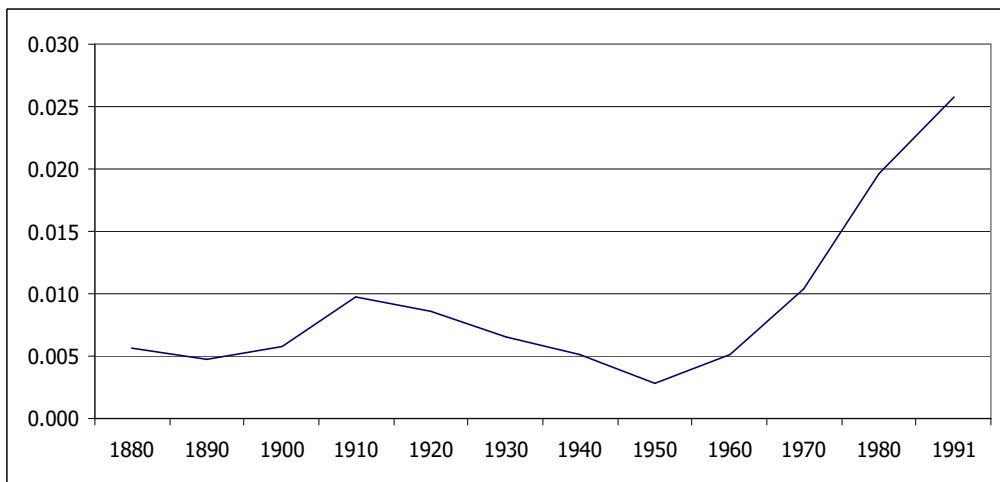


Table 5 - Global Warming Rate (GWR), land only

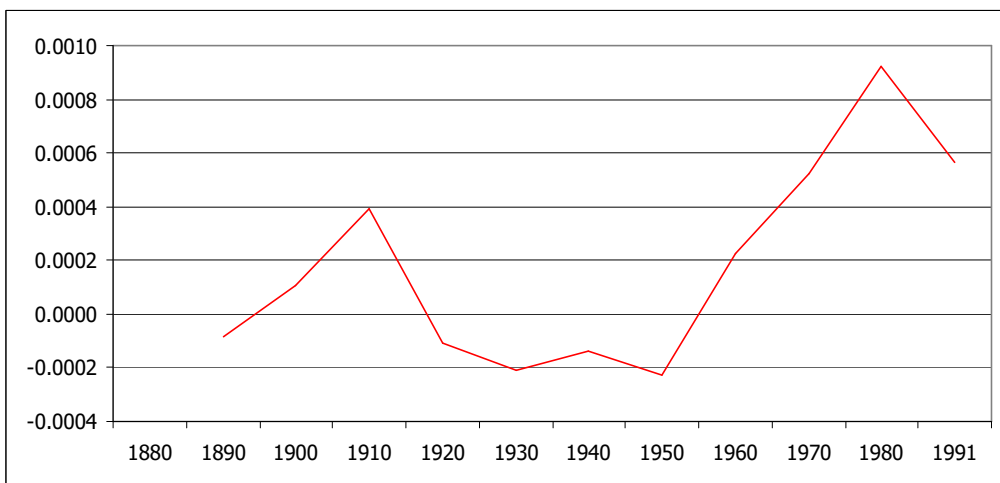
i	Trendline ID	Trendline period			Trendline Center	GWR			Global Warming Acceleration
	TL(i)	from	to	years	CenterTL Formula 6	Δy Formula 5	a Formula 1	Δa Formula 4	GWA Formula 3
Units		year	year	years	year	years	°C/y	°C/y	°C/y ²
1	TL1	1850	1910	61	1880		+0.005583		
2	TL2	1860	1920	61	1890	10	+0.004718	-0.000865	-0.000087
3	TL3	1870	1930	61	1900	10	+0.005764	+0.001046	+0.000105
4	TL4	1880	1940	61	1910	10	+0.009694	+0.003930	+0.000393
5	TL5	1890	1950	61	1920	10	+0.008613	-0.001081	-0.000108
6	TL6	1900	1960	61	1930	10	+0.006541	-0.002072	-0.000207
7	TL7	1910	1970	61	1940	10	+0.005145	-0.001396	-0.000140
8	TL8	1920	1980	61	1950	10	+0.002857	-0.002288	-0.000229
9	TL9	1930	1990	61	1960	10	+0.005129	+0.002272	+0.000227
10	TL10	1940	2000	61	1970	10	+0.010380	+0.005251	+0.000525
11	TL11	1950	2010	61	1980	10	+0.019618	+0.009238	+0.000924
12	TL12	1961	2021	61	1991	11	+0.025828	+0.006210	+0.000565

Chart 7 - GWR – Global Warming Rate, land only [°C/y]



Axis x is the center of the 61 years trendline period

Chart 8 - GWA - Global Warming Acceleration, land only [°C/y²]



Axis x is the center of the 61 years trendline period

Global Surface Temperature Changes over the Ocean

Chart 9 - Trendlines, ocean only, 1850-1900 baseline [8] [°C]

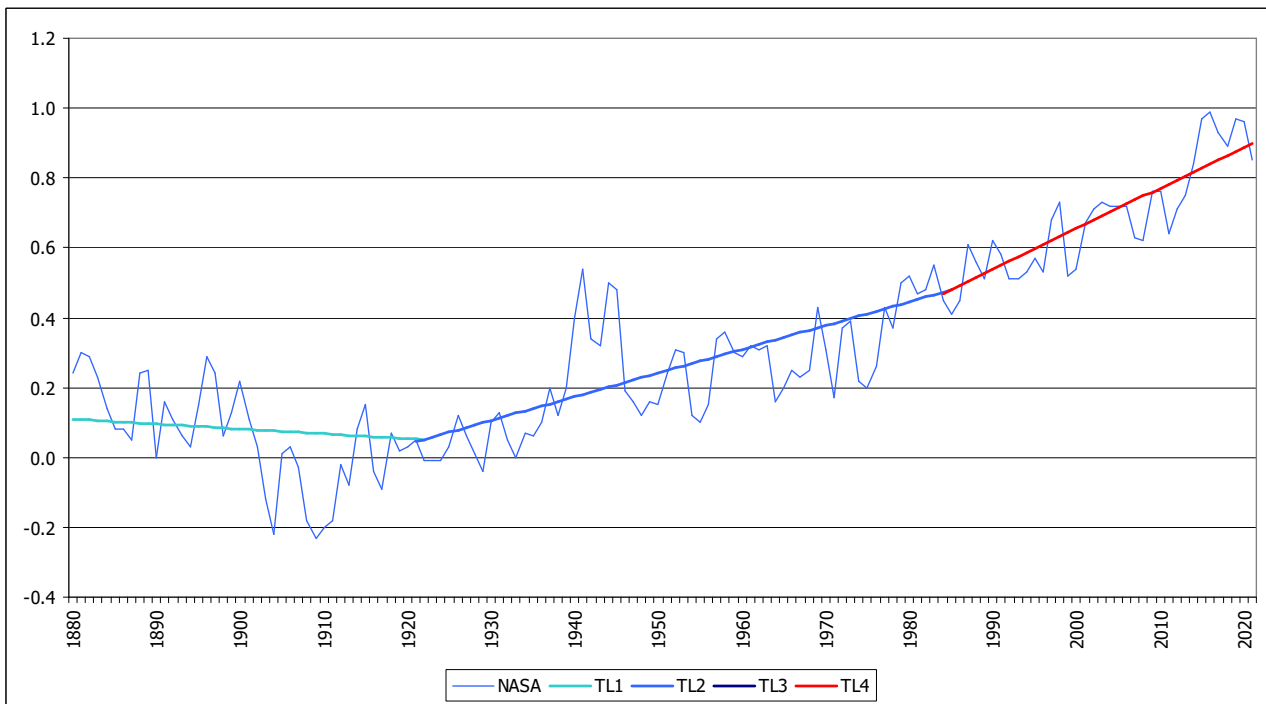
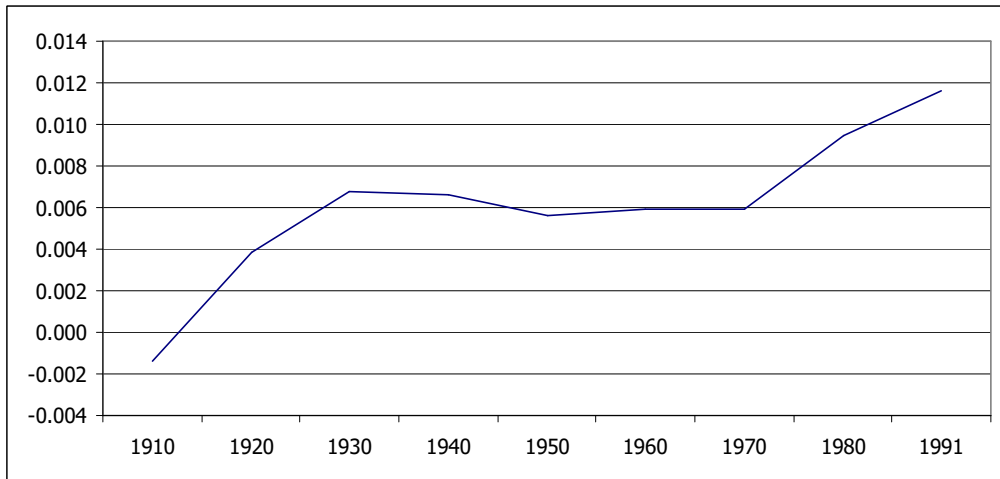


Table 6 - Global Warming Rate (GWR), ocean only

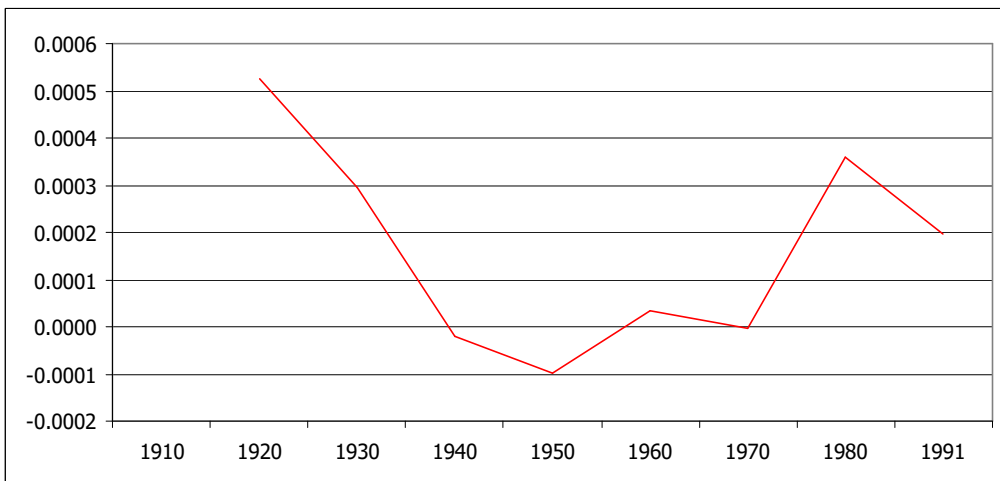
i	Trendline ID	Trendline period			Trendline Center	GWR				Global Warming Acceleration
		from	to	years		Δy	a	Δa	GWA	
Symbol Formula	TL(i)				CenterTL Formula 6	Formula 5	Formula 1	Formula 4	Formula 3	
Units		year	year	years	year	years	°C/y	°C/y	°C/y ²	
1	TL1	1880	1940	61	1910		-0.001397			
2	TL2	1890	1950	61	1920	10	+0.003850	+0.005246	+0.000525	
3	TL3	1900	1960	61	1930	10	+0.006790	+0.002940	+0.000294	
4	TL4	1910	1970	61	1940	10	+0.006577	-0.000213	-0.000021	
5	TL5	1920	1980	61	1950	10	+0.005600	-0.000978	-0.000098	
6	TL6	1930	1990	61	1960	10	+0.005928	+0.000328	+0.000033	
7	TL7	1940	2000	61	1970	10	+0.005895	-0.000032	-0.000003	
8	TL8	1950	2010	61	1980	10	+0.009489	+0.003593	+0.000359	
9	TL9	1961	2021	61	1991	11	+0.011652	+0.002163	+0.000197	

Chart 10 - GWR – Global Warming Rate, ocean only [°C/y]



Axis x is the center of the 61 years trendline period

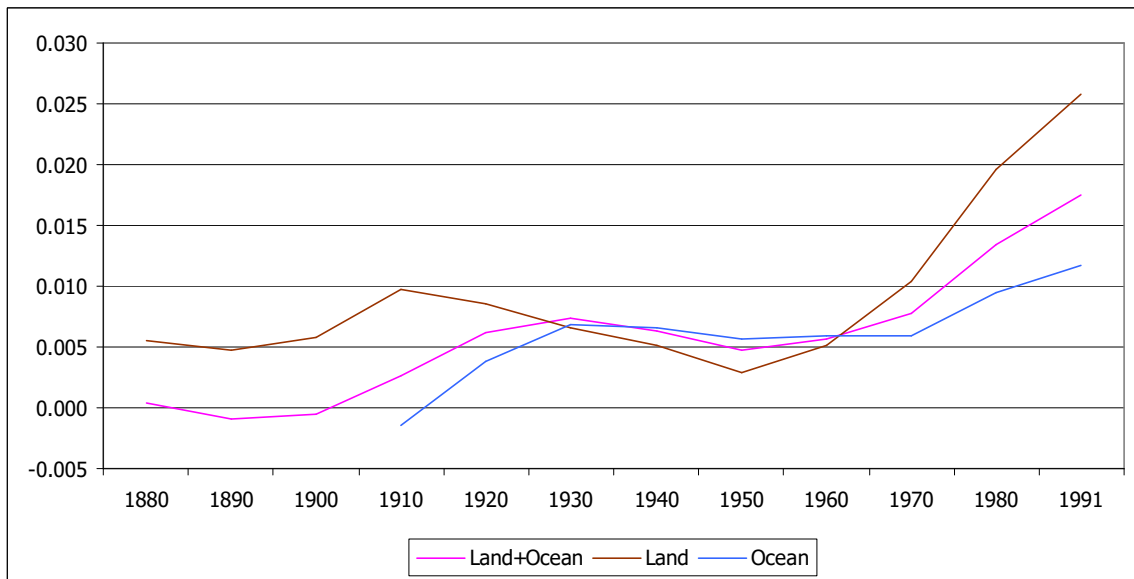
Chart 11 - GWA - Global Warming Acceleration, ocean only [°C/y²]



Axis x is the center of the 61 years trendline period

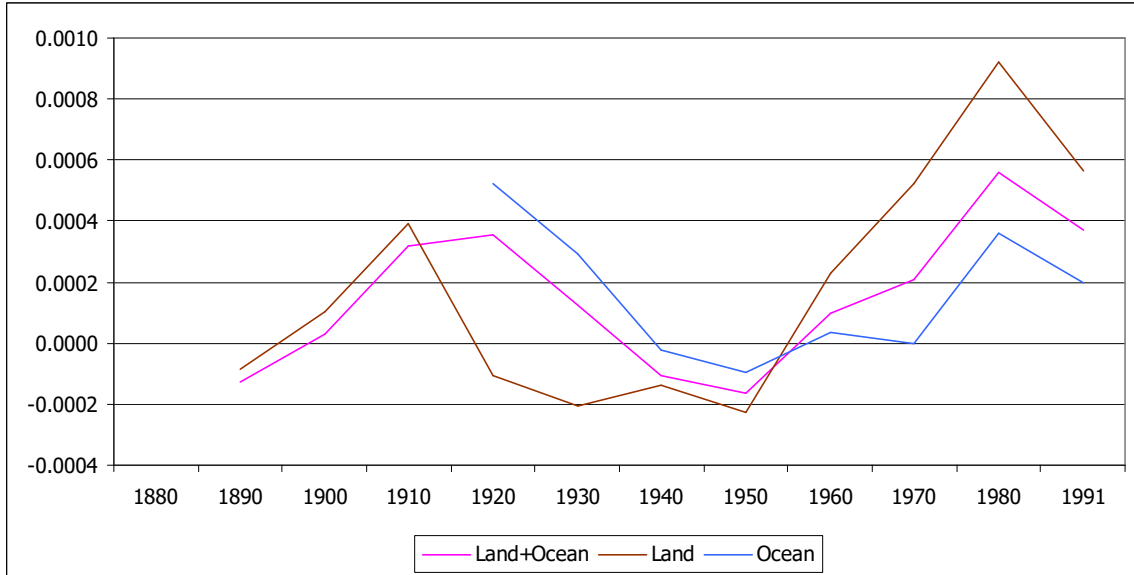
All Global Warming Rates and Acceleration

Chart 12 - All GWR – Global Warming Rate [°C/y]



Axis x is the center of the 61 years trendline period

Chart 13 - All GWA - Global Warming Acceleration [°C/y²]



Axis x is the center of the 61 years trendline period

Application of Global Warming Acceleration for Forecast of Global Warming

In the following example it is assumed that the current year is 2010, attempting to estimate global warming for land+ocean for the 2010-2020 decade.

The calculations are based on TL11 (1950-2010).

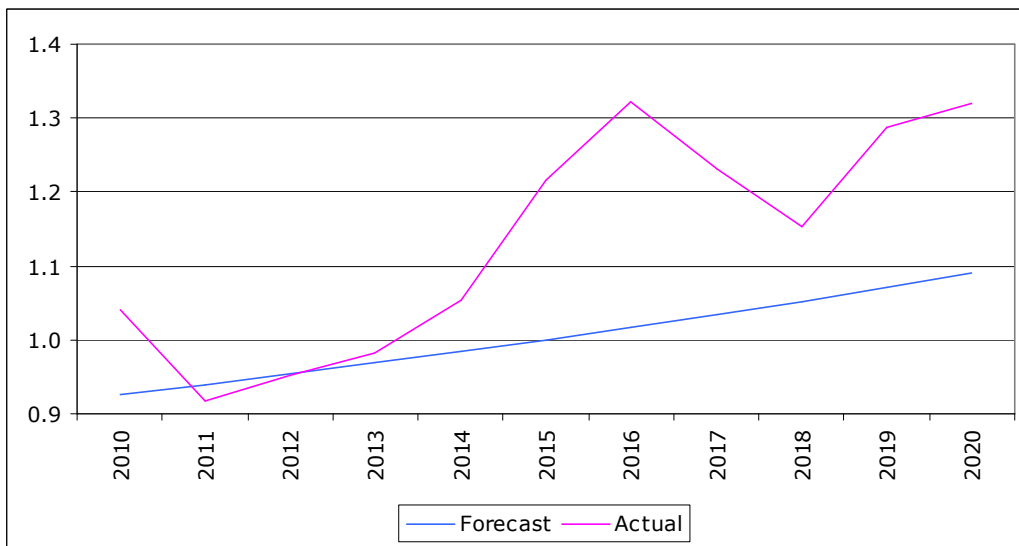
Table 7 - Starting point for the forecast

from	to	Trendline		Starting year	GW	GWR	GWA	dGWA
		a	b		TL	$^{\circ}\text{C}/\text{y}$	$^{\circ}\text{C}/\text{y}^2$	$^{\circ}\text{C}/\text{y}^3$
1950	2010	+0.013362	+0.109975	2010	+0.925	+0.013362	+0.000562	+0.0000032

Table 8 - Forecast of next decade Global Warming Rate using GWA for land+ocean

	dGWA	GWA	GWR	GW TL	GW actual	Δ	Δ
	$^{\circ}\text{C}/\text{y}^3$	$^{\circ}\text{C}/\text{y}^2$	$^{\circ}\text{C}/\text{y}$	$^{\circ}\text{C}$	$^{\circ}\text{C}$	$^{\circ}\text{C}$	%
2010	+0.0000032	+0.000562	+0.013362	+0.925	+1.040	+0.115	
2011	+0.0000032	+0.000565	+0.013927	+0.939	+0.916	-0.023	
2012	+0.0000032	+0.000568	+0.014495	+0.953	+0.953	-0.000	
2013	+0.0000032	+0.000572	+0.015067	+0.969	+0.982	+0.014	
2014	+0.0000032	+0.000575	+0.015642	+0.984	+1.053	+0.069	
2015	+0.0000032	+0.000578	+0.016220	+1.000	+1.217	+0.217	
2016	+0.0000032	+0.000581	+0.016801	+1.017	+1.323	+0.306	
2017	+0.0000032	+0.000584	+0.017385	+1.035	+1.232	+0.197	
2018	+0.0000032	+0.000588	+0.017973	+1.053	+1.154	+0.101	
2019	+0.0000032	+0.000591	+0.018564	+1.071	+1.287	+0.216	
2020	+0.0000032	+0.000594	+0.019158	+1.090	+1.319	+0.229	
			Ave	+1.003	+1.134	+0.131	11.5%

The procedure recommended in this work results in an underestimation of the actual Global Warming by 11.5%, which means that the actual Global Warming exceeded the estimation based on previous decade data by 11.5%.

Chart 14 - Forecast and actual Global Warming 2010-2020 [°C]

Changes in this Version

- addition of parameter “*Annual Change in Global Warming Acceleration*” (dGWA) based on GWA trendline slope
- replacement of the 1961-2021 trendline by the 1960-2020 trendline for some calculations
- editorial changes

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