Air Temperature Changes in Jerusalem

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Abstract

Two completely different monitoring systems were applied to analyze annual air temperature differences.
The first monitoring system for analysis of changes in air temperature in Jerusalem is a meteorological station at Jerusalem University.
The second monitoring system for analysis of surface temperature changes globally and locally in Israel is applied by NASA and further analyzed and detailed by FAOSTAT.
Both monitoring systems indicate an average temperature increase since the starting year of the Jerusalem database, 1993.
The temperature difference between the year 1993 and 2021 in Jerusalem is 1.44°C, in Israel 1.52°C and global 1.09°C.
Application of 30 years linear trendlines in various periods shows a constant increase in the slope of the trendlines from 0.0209°C/y in years 1962-1991 to 0.0357°C/y in years 1992-2021 for the global change of surface temperature.
According to the most recent trendline, the temperature increase in the year 2035 compared to the 1951-1980 baseline will be 2.20°C in Jerusalem, 2.28°C in Israel, and global 1.96°C.

Source of Data

Air Temperature in Jerusalem

Temperature data for Jerusalem are available on the Israeli Meteorological Service Internet site [1].

The records are for every 10 minutes. The number of records for one year is 52,560.

The parameter selected is "temperature", which is "dry temperature".

There are a few meteorological stations in Jerusalem. Among the all Jerusalem stations, Jerusalem University Givat Ram station number 7020 has the longest records, reaching the year 1993, therefore it was selected for this work. Givat Ram is in the center of Jerusalem, the site of Jerusalem University, the government campus, the parliament, and the Israel Museum. The station is located at the Institute of Earth Science at Jerusalem University, N31.7704° E35.1973°, elevation 770 m. This station may be regarded as "open-air", surrounded by a relatively green area.

All data are in degrees Celsius according to winter time – LST, GMT-2.

Global Surface Temperature Changes

NASA database [3] [4] [5] distinguish between 3 sets of data:

- annual mean surface temperature change over land
- annual mean surface temperature change over the ocean
- annual mean surface temperature change over land and over the ocean

Surface temperature change over land is selected.

Changes in Surface Temperature in Israel

FAOSTAT Temperature Change Internet site includes data of surface temperature changes in all countries [6].

The database includes monthly data. Annual January-December averages were calculated in this work.

Missing Records in Jerusalem Database

Table 1 - Missing records in Jerusalem database

year	missing	missing, %
1993	530	1.0%
1994	3,809	7.2%
1995	1,928	3.7%
1996	730	1.4%
1997	541	1.0%
1998	54	0.1%
1999	237	0.5%
2000	83	0.2%
2001	38,138	72.6%
2002	ALL	100.0%
2003	8,726	16.6%
2004	606	1.2%
2005	11	0.0%
2006	1,121	2.1%
2007	4	0.0%
2008	4	0.0%
2009	3	0.0%
2010	4	0.0%
2011	16	0.0%
2012	11	0.0%
2013	4,134	7.9%
2014	15	0.0%
2015	6	0.0%
2016	13	0.0%
2017	38	0.1%
2018	16	0.0%
2019	31	0.1%
2020	45	0.1%
2021	143	0.3%

Considering the number of missing records, the years 2001-2003 were removed from the analysis.

Adding Missing Records

The following procedure is applied to estimate values of the missing records:

- Up to 11 missing records, the estimation is done by linear interpolation between the neighboring records.
- For up to 24 continuous missing records the average of the neighboring days was applied

- For longer periods of continuous missing records, data were copied from other station in Jerusalem with correction of difference between the stations as on the neighboring days.

29 February

Years having 366 days have colder average temperatures than 365 days' years because the additional day is in the middle of winter.
Therefore 29 February was removed from the calculations of the average temperature.

Applied Jerusalem Database

Table 2 - Database applied

start year	1993	
end year	2021	
years not included	2001, 2002, 2003	
years included	26	Years
Existing	1,352,427	Records
Existing	99.0%	Records
Missing	14,133	Records
Missing	1.0%	Records
full set	1,366,560	Records

This work applies a database of air temperature monitored at one station between the years 1993-2021. 3 years (2011-2013) were excluded from the analysis because of the large number of missing records. Finely the database applied includes 10 minutes records for 26 years. The number of available records is 1,352,427 (99.0%). The number of missing records in years applied is 14,133 (1.0%). After adding alternative replacements for missing records the corrected database includes 1,366,560 records.

Air Temperature and Surface Temperature

The difference between the air temperature and surface temperature is explained in [2].
Air temperature is measured at a standard height of 1.2 m above the ground surface. Air temperature can be quite different from surface temperature. In general, air temperatures above a surface reflect the same trends as ground surface temperatures, but ground temperatures are likely to be more extreme [2].
The Jerusalem University data are for air temperature and not surface temperature.
Global data and data for Israel are for surface temperature.

Baseline Temperature

The next parts of this analysis will be related to changes in global (world) surface temperature as recorded by NASA [3] [4] [5].
NASA presents the temperature changes as the difference to the average temperature between the years 1951 – 1980.
UN-FAO-Stat applies the same baseline [6].
As this work does not include records for years 1951-1992 for Jerusalem, the following formula will be applied for the determination of baseline for the temperature changes in Jerusalem:

Formula 1 - Jerusalem air temperature baseline

$$BL = DB1993 - NASA1993$$

BL Jerusalem air temperature baseline [°C]
DB1993 average air temperature in Jerusalem in the year 1993 according to the applied database [°C]
NASA1993 surface temperature change over land, year 1993 average [°C] [5]
NASA1993 = 0.23°C
DB1993 = 16.76°C
BL = 16.53°C

Trendline Type

This work applies 29-30 annual records linear trendlines.

The attempt to apply 30 annual records parabolic trendlines caused errors.

The trendlines formulas are displayed on charts.

Air Temperature in Jerusalem

Table 3 - Annual changes in air temperature in Jerusalem [°C]

	Jm Ave °C	Δ to BL °C	mAve °C
1993	16.76	0.23	0.23
1994	16.78	0.26	0.24
1995	16.96	0.43	0.31
1996	17.28	0.75	0.42
1997	16.40	-0.12	0.31
1998	17.63	1.10	0.44
1999	17.60	1.07	0.53
2000	16.76	0.23	0.49
2001			0.49
2002			0.49
2003			0.53
2004	17.20	0.68	0.59
2005	17.10	0.57	0.61
2006	16.81	0.28	0.54
2007	17.03	0.50	0.63
2008	17.66	1.13	0.64
2009	17.67	1.14	0.65
2010	19.38	2.85	1.02
2011	16.82	0.29	0.93
2012	17.84	1.31	0.97
2013	17.69	1.17	0.99
2014	17.87	1.34	1.06
2015	17.80	1.27	1.13
2016	18.17	1.65	1.27
2017	17.74	1.21	1.34
2018	18.25	1.72	1.40
2019	17.55	1.02	1.38
2020	17.81	1.29	1.23
2021	18.20	1.67	1.36

Jm Ave annual averages of air temperature in Jerusalem [°C]
Δ to BL difference of average year air temperature in Jerusalem to Jerusalem baseline temperature [°C]
BL Jerusalem baseline temperature = 16.53°C
mAve moving average (10 years) of "Δ to BL" [°C]

Chart 1 - Changes in air temperatures in Jerusalem [°C]

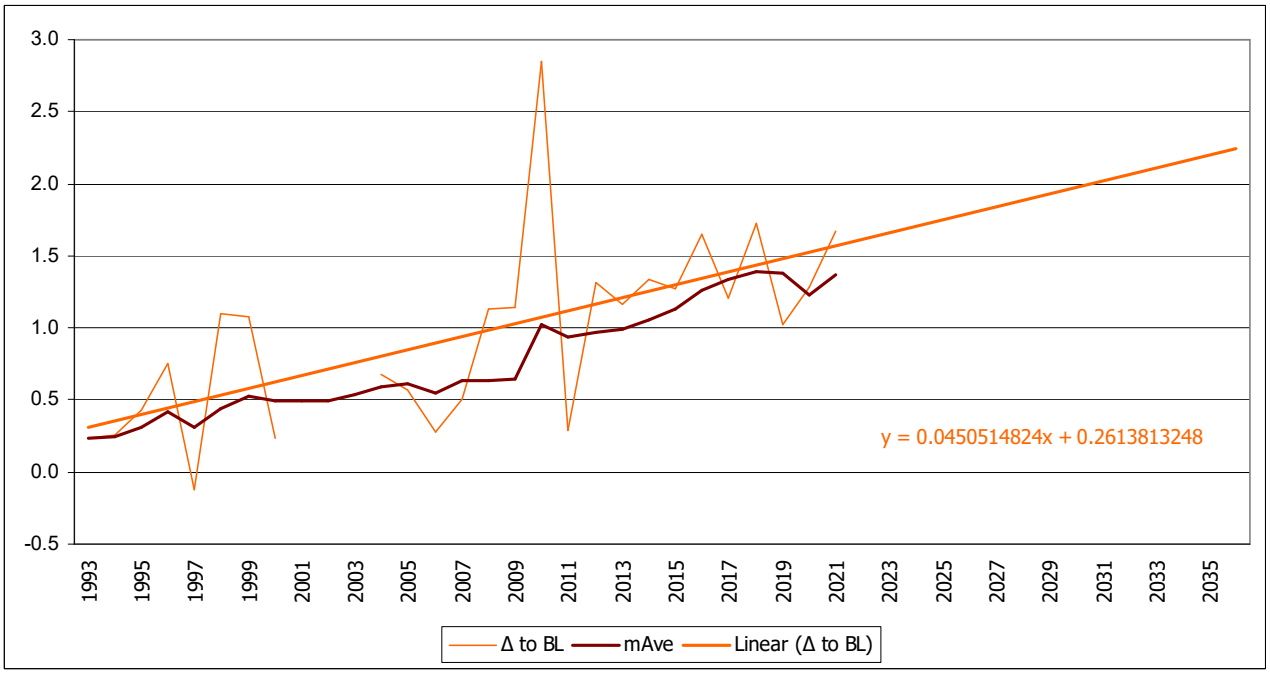


Table 4 - Trendline of air temperature in Jerusalem [°C]

	TL °C	Actual °C
2015	1.30	1.27
2016	1.34	1.65
2017	1.39	1.21
2018	1.43	1.72
2019	1.48	1.02
2020	1.52	1.29
2021	1.57	1.67
2022	1.61	
2023	1.66	
2024	1.70	
2025	1.75	
2026	1.79	
2027	1.84	
2028	1.88	
2029	1.93	
2030	1.97	
2031	2.02	
2032	2.06	
2033	2.11	
2034	2.15	
2035	2.20	

TL linear trendline of (Δ to BL) [°C]

Changes in Surface Temperature in Israel

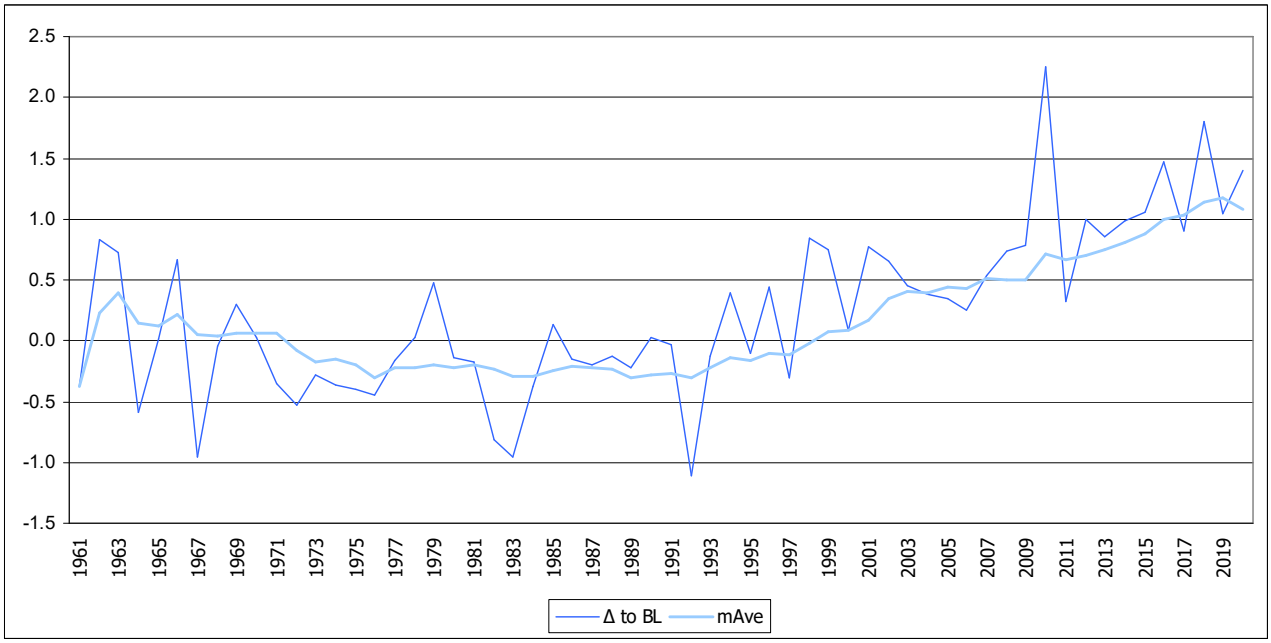
The data are from FAOSTAT [6]. The baseline is an average in the years 1951-1980, as NASA [3] [4] [5].
The database includes monthly data. Annual January-December averages are applied.
The database starts at the beginning of the year 1961.

Table 5 - Changes in surface temperature in Israel [°C] [6]

	Δ to BL °C	mAve °C
1961	-0.38	-0.38
1962	0.83	0.22
1963	0.73	0.39
1964	-0.59	0.15
1965	0.02	0.12
1966	0.67	0.21
1967	-0.95	0.05
1968	-0.05	0.03
1969	0.30	0.06
1970	0.02	0.06
1971	-0.36	0.06
1972	-0.53	-0.07
1973	-0.28	-0.17
1974	-0.36	-0.15
1975	-0.40	-0.19
1976	-0.45	-0.31
1977	-0.17	-0.23
1978	0.02	-0.22
1979	0.47	-0.20
1980	-0.14	-0.22
1981	-0.17	-0.20
1982	-0.82	-0.23
1983	-0.95	-0.30
1984	-0.37	-0.30
1985	0.13	-0.24
1986	-0.15	-0.21
1987	-0.20	-0.22
1988	-0.12	-0.23
1989	-0.23	-0.30
1990	0.03	-0.29
1991	-0.03	-0.27
1992	-1.11	-0.30
1993	-0.12	-0.22
1994	0.40	-0.14
1995	-0.10	-0.16
1996	0.44	-0.11
1997	-0.30	-0.12
1998	0.85	-0.02
1999	0.75	0.08
2000	0.09	0.09
2001	0.77	0.17
2002	0.65	0.34
2003	0.45	0.40
2004	0.38	0.40
2005	0.35	0.44
2006	0.25	0.42
2007	0.54	0.51
2008	0.74	0.50
2009	0.78	0.50
2010	2.25	0.72
2011	0.32	0.67
2012	1.00	0.71
2013	0.86	0.75
2014	0.99	0.81
2015	1.06	0.88
2016	1.48	1.00
2017	0.90	1.04
2018	1.80	1.14
2019	1.05	1.17
2020	1.40	1.09

Δ to BL difference of change of surface temperature in Israel to baseline [°C]
BL baseline change of surface temperature in Israel, average in years 1951-1980 [°C]
mAve moving average (10 years) of "Δ to BL" [°C]

Chart 2 - Changes in surface temperature in Israel [°C] [6]



Global Surface Temperature

Input Data

The data are from NASA[3] [4] [5]. The baseline is an average in the years 1951-1980.

Starting Year for Analysis

Starting year for the analysis will be the same as the available data for Israel – 1961.

Table 6 - Global surface temperature change over land [°C] [3] [4] [5]

	Δ to BL °C	mAve °C
1961	0.14	0.14
1962	0.08	0.11
1963	0.17	0.13
1964	-0.27	0.03
1965	-0.14	0.00
1966	-0.05	-0.01
1967	0.02	-0.01
1968	-0.14	-0.02
1969	-0.13	-0.04
1970	0.03	-0.03
1971	-0.03	-0.05
1972	-0.15	-0.07
1973	0.31	-0.06
1974	-0.13	-0.04
1975	0.13	-0.01
1976	-0.25	-0.03
1977	0.23	-0.01
1978	0.06	0.01
1979	0.12	0.03
1980	0.34	0.06
1981	0.53	0.12
1982	0.07	0.14
1983	0.42	0.15
1984	0.08	0.17
1985	0.05	0.17
1986	0.25	0.22
1987	0.39	0.23
1988	0.61	0.29
1989	0.33	0.31
1990	0.66	0.34

	Δ to BL °C	mAve °C
1991	0.58	0.34
1992	0.25	0.36
1993	0.23	0.34
1994	0.47	0.38
1995	0.74	0.45
1996	0.40	0.47
1997	0.58	0.49
1998	0.92	0.52
1999	0.69	0.55
2000	0.61	0.55
2001	0.81	0.57
2002	0.99	0.64
2003	0.92	0.71
2004	0.76	0.74
2005	1.10	0.78
2006	0.94	0.83
2007	1.18	0.89
2008	0.87	0.89
2009	0.94	0.91
2010	1.11	0.96
2011	0.96	0.98
2012	0.96	0.97
2013	1.05	0.99
2014	1.02	1.01
2015	1.31	1.03
2016	1.48	1.09
2017	1.37	1.11
2018	1.22	1.14
2019	1.42	1.19
2020	1.59	1.24
2021	1.32	1.27

Δ to BL difference of change of global surface temperature to baseline change of global surface temperature [°C]

BL baseline change of global surface temperature, average in years 1951-1980 [°C]

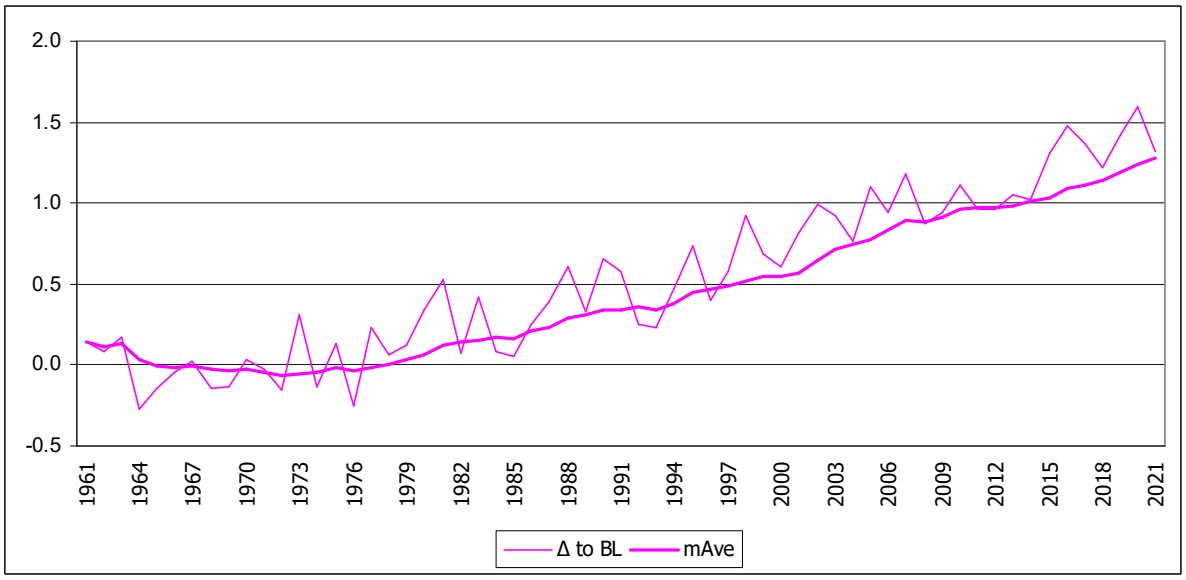
mAve moving average (10 years) of "Δ to BL" [°C]

Source:

GISTEMP Team, 2022: GISS Surface Temperature Analysis (GISTEMP), version 4. NASA Goddard Institute for Space Studies. Dataset accessed 2022-02-05 at https://data.giss.nasa.gov/gistemp

Lenssen, N., G. Schmidt, J. Hansen, M. Menne, A. Persin, R. Ruedy, and D. Zyss, 2019: Improvements in the GISTEMP uncertainty model. J. Geophys. Res. Atmos., 124, no. 12, 6307-6326, doi:10.1029/2018JD029522.

Chart 3 - Global surface temperature change over land [°C] [3] [4] [5]



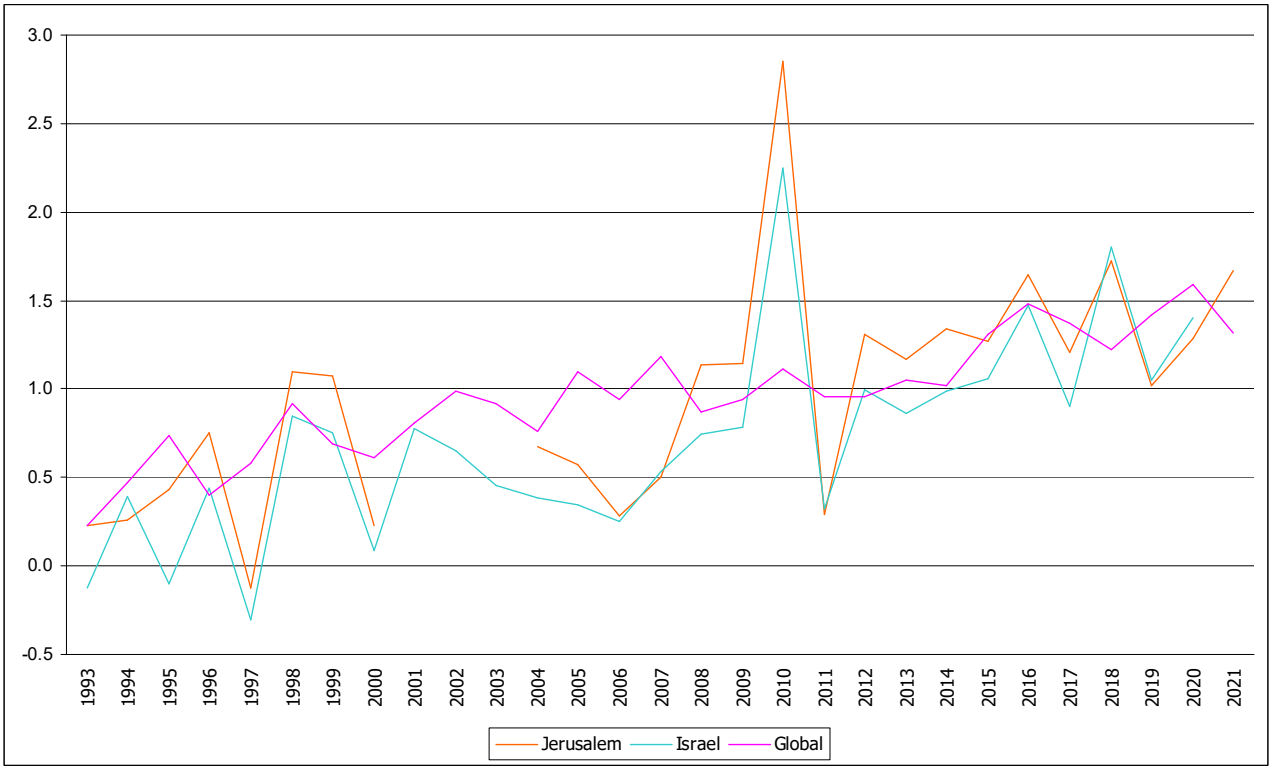
Changes in Air Temperature in Jerusalem, Surface Temperature in Israel and Global Surface Temperature

Table 7 - Changes in air temperature in Jerusalem, the surface temperature in Israel, and global surface temperature [°C]

	Jerusalem °C	Israel °C	Global °C	Δmax °C
1993	0.23	-0.12	0.23	0.35
1994	0.26	0.40	0.47	0.21
1995	0.43	-0.10	0.74	0.84
1996	0.75	0.44	0.40	0.35
1997	-0.12	-0.30	0.58	0.88
1998	1.10	0.85	0.92	0.25
1999	1.07	0.75	0.69	0.38
2000	0.23	0.09	0.61	0.52
2001		0.77	0.81	0.04
2002		0.65	0.99	0.34
2003		0.45	0.92	0.47
2004	0.68	0.38	0.76	0.38
2005	0.57	0.35	1.10	0.75
2006	0.28	0.25	0.94	0.69
2007	0.50	0.54	1.18	0.68
2008	1.13	0.74	0.87	0.39
2009	1.14	0.78	0.94	0.36
2010	2.85	2.25	1.11	1.74
2011	0.29	0.32	0.96	0.67
2012	1.31	1.00	0.96	0.35
2013	1.17	0.86	1.05	0.31
2014	1.34	0.99	1.02	0.35
2015	1.27	1.06	1.31	0.25
2016	1.65	1.48	1.48	0.17
2017	1.21	0.90	1.37	0.47
2018	1.72	1.80	1.22	0.58
2019	1.02	1.05	1.42	0.40
2020	1.29	1.40	1.59	0.30
2021	1.67		1.32	0.35
Ave				0.48
Max				1.74

Δmax maximum absolute difference between each column [°C]

Chart 4 - Changes in air temperature in Jerusalem, the surface temperature in Israel, and global surface temperature 1993-2021 [°C]



Temperature increase in Israel is much faster than the global change and the change in air temperature in Jerusalem.

Temperature Difference between 1993 and 2021

Table 8 - Temperature difference between 1993 and 2021 [°C]

	Jerusalem	Israel *	Global
	°C	°C	°C
1993	0.23	-0.12	0.23
2021	1.67	1.40	1.32
Δ to 1993	1.44	1.52	1.09

* 1993-2000

Change of Trendline of Surface Temperature in Israel with Years

Trendline based on period 1962-1991 resulted in -0.03°C estimated change of surface temperature in Israel in the year 2035 compared to baseline.
Trendline based on the period 1992-2020 gives different results.
Trendlines formulas are displayed on charts.

Chart 5 - Estimation of surface temperature change in Israel in the year 2035 based on 1962-1991 data [°C]

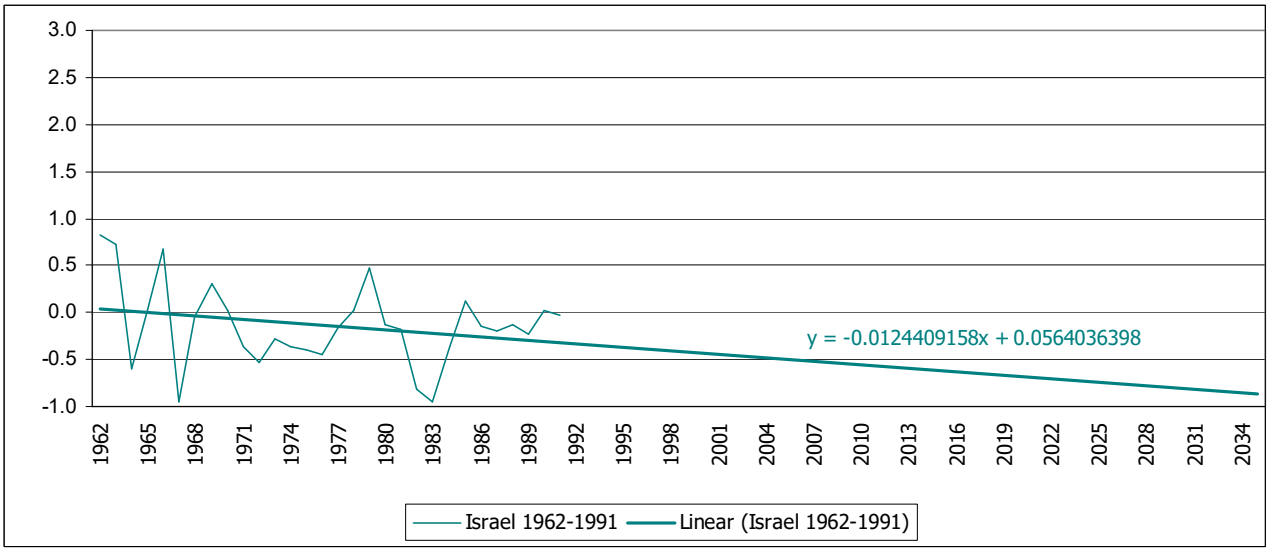


Chart 6 - Estimation of surface temperature change in Israel in the year 2035 based on 1972-2001 data [°C]

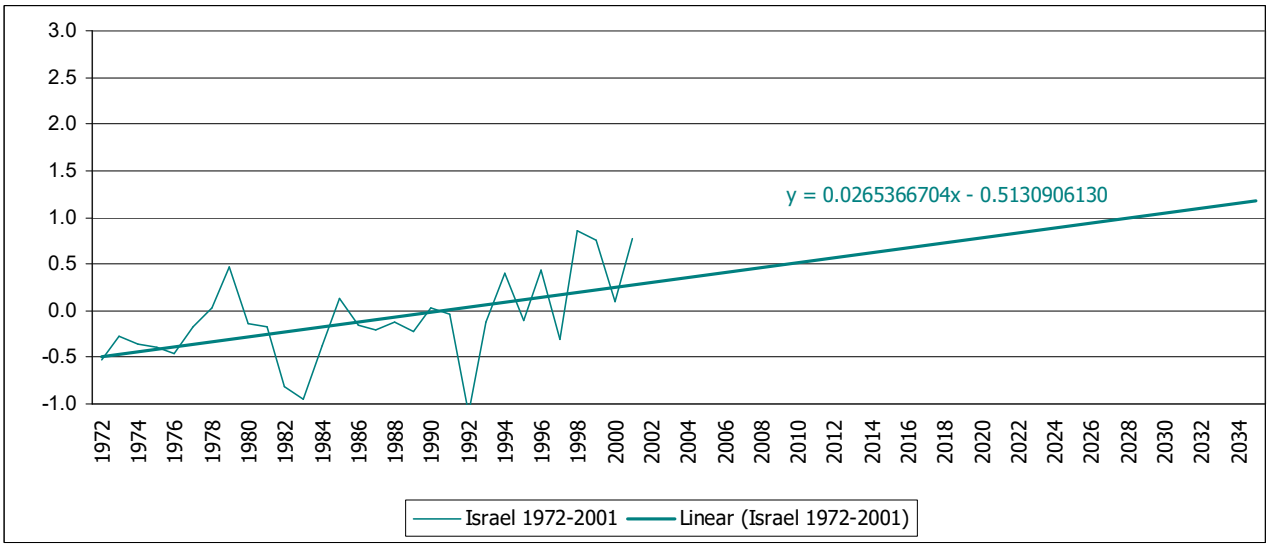


Chart 7 - Estimation of surface temperature change in Israel in the year 2035 based on 1982-2011 data [°C]

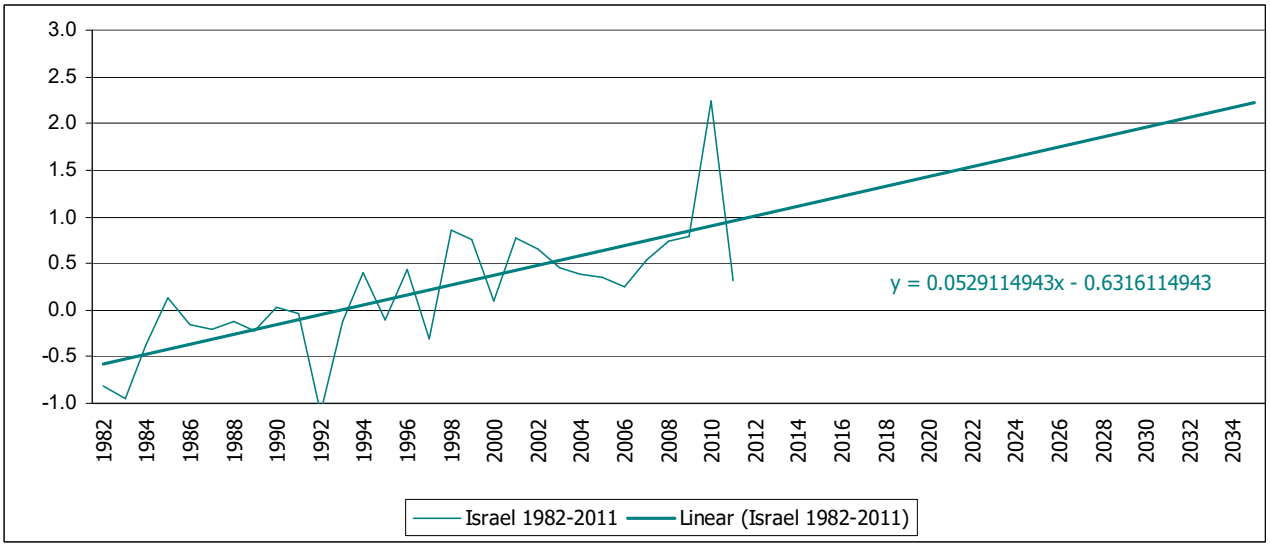


Chart 8 - Estimation of surface temperature change in Israel in the year 2035 based on 1992-2020 data [°C]

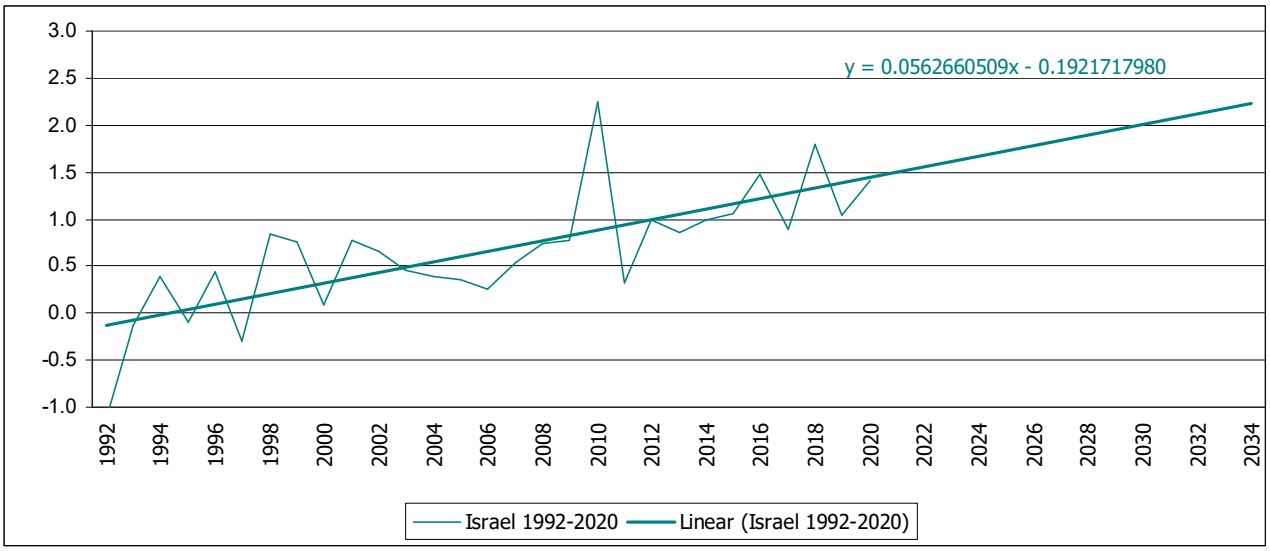


Chart 9 - Change of trendlines of surface temperature in Israel with years [°C]

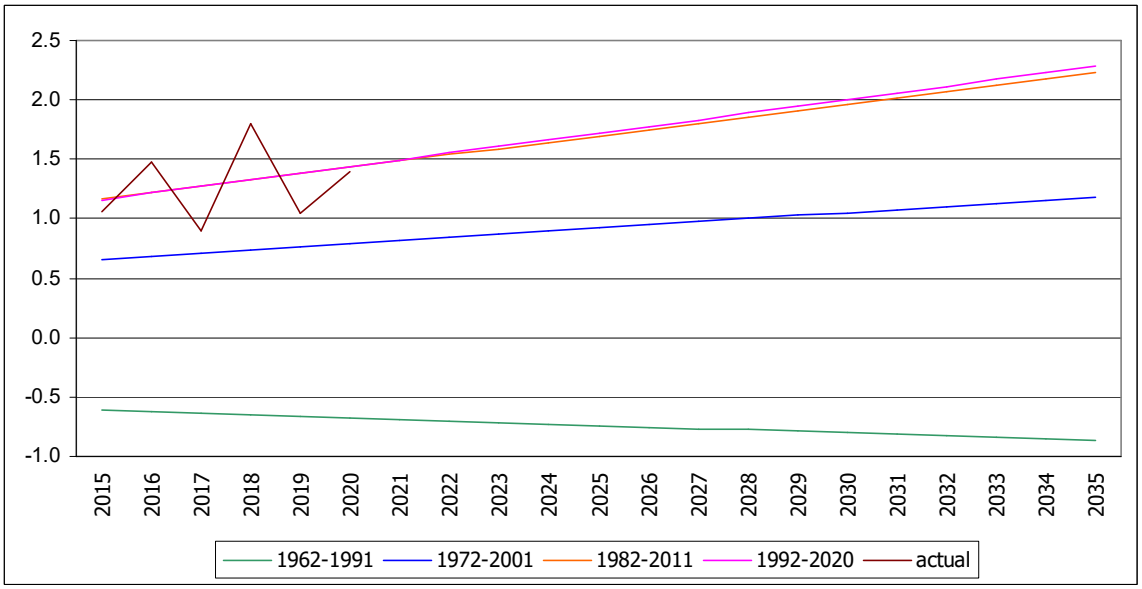


Table 9 - Change of trendlines of surface temperature in Israel with years

	1962-1991 °C	1972-2001 °C	1982-2011 °C	1992-2020 °C	actual °C
2015	-0.62	0.65	1.17	1.16	1.06
2016	-0.63	0.68	1.22	1.21	1.48
2017	-0.64	0.71	1.27	1.27	0.90
2018	-0.65	0.73	1.33	1.33	1.80
2019	-0.67	0.76	1.38	1.38	1.05
2020	-0.68	0.79	1.43	1.44	1.40
2021	-0.69	0.81	1.48	1.50	
2022	-0.70	0.84	1.54	1.55	
2023	-0.71	0.87	1.59	1.61	
2024	-0.73	0.89	1.64	1.66	
2025	-0.74	0.92	1.70	1.72	
2026	-0.75	0.95	1.75	1.78	
2027	-0.76	0.97	1.80	1.83	
2028	-0.78	1.00	1.86	1.89	
2029	-0.79	1.03	1.91	1.95	
2030	-0.80	1.05	1.96	2.00	
2031	-0.81	1.08	2.01	2.06	
2032	-0.83	1.11	2.07	2.11	
2033	-0.84	1.13	2.12	2.17	
2034	-0.85	1.16	2.17	2.23	
2035	-0.86	1.19	2.23	2.28	

Table 10 - Estimation of surface temperature change in Israel in the year 2035

	1962-1991 °C	1972-2001 °C	1982-2011 °C	1992-2020 °C
2035	-0.86	1.19	2.23	2.28
Δ		2.05	1.04	0.06

Change of Global Temperature Trendline with Years

Trendline based on period 1962-1991 resulted in 1.36°C estimated global surface temperature increase in the year 2035 compared to baseline.

Trendline based on the period 1992-2021 gives different results.

Trendlines formulas are displayed on charts.

Chart 10 - Estimation of global temperature change in the year 2035 based on 1962-1991 data [°C]

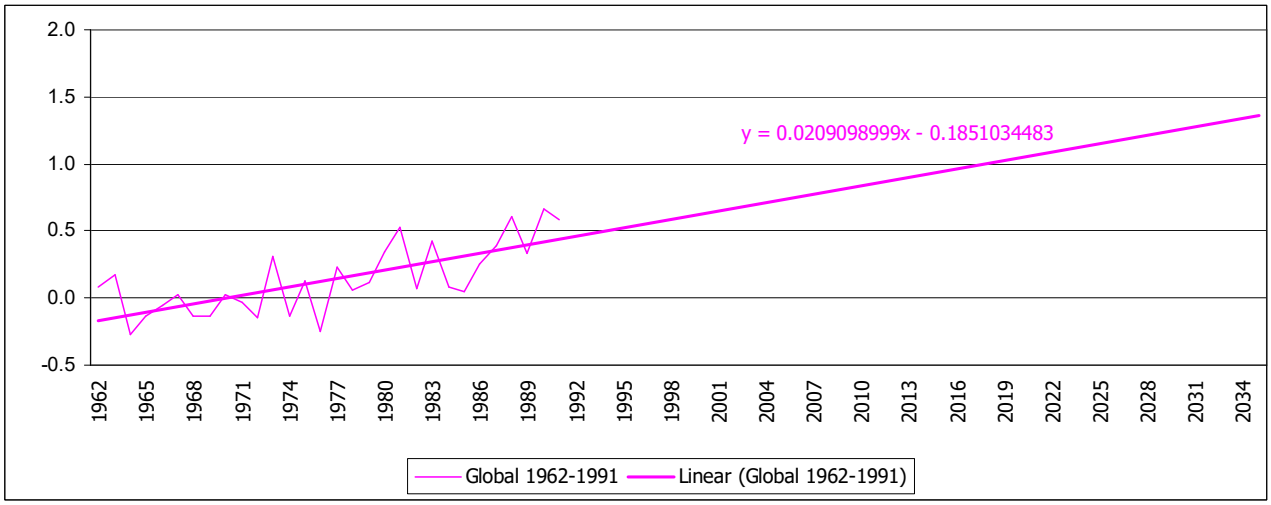


Chart 11 - Estimation of global temperature change in the year 2035 based on 1972-2001 data [°C]

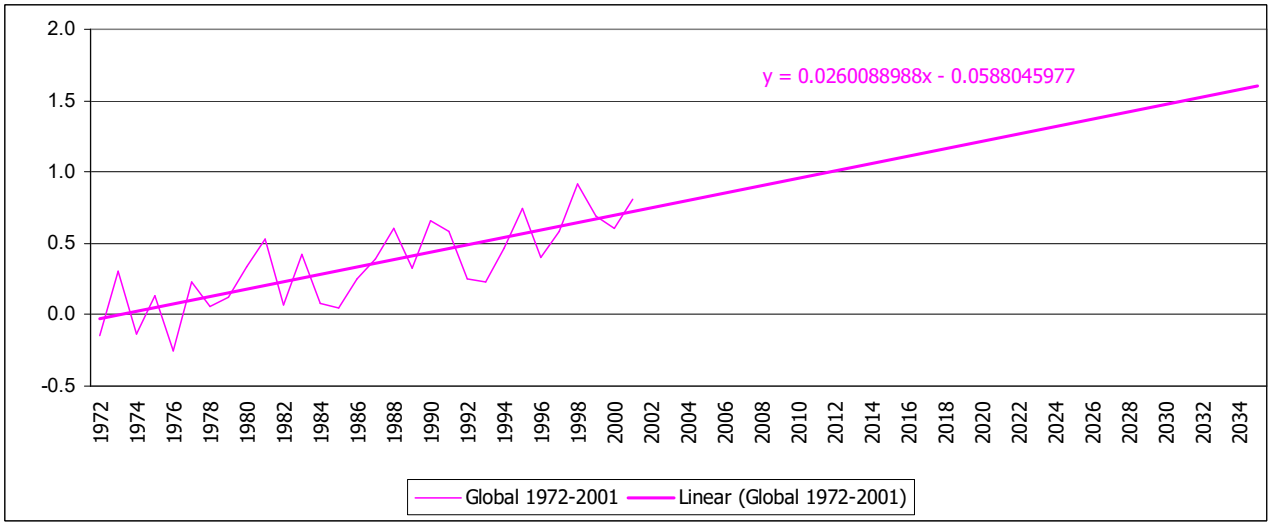


Chart 12 - Estimation of global temperature change in the year 2035 based on 1982-2011 data [°C]

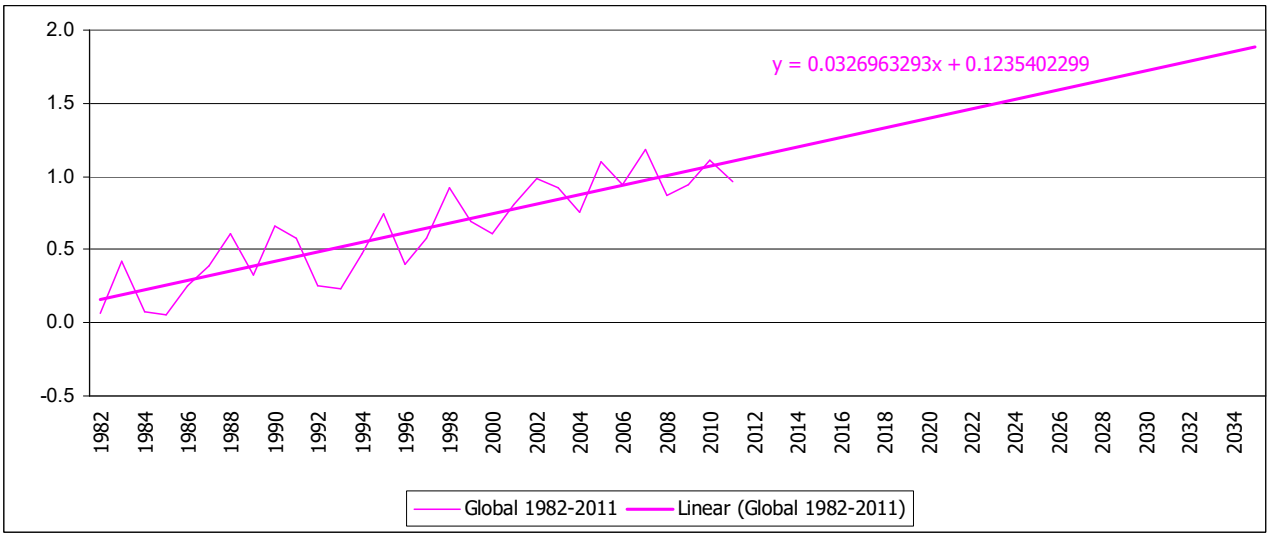


Chart 13 - Estimation of global temperature change in the year 2035 based on 1992-2021 data [°C]

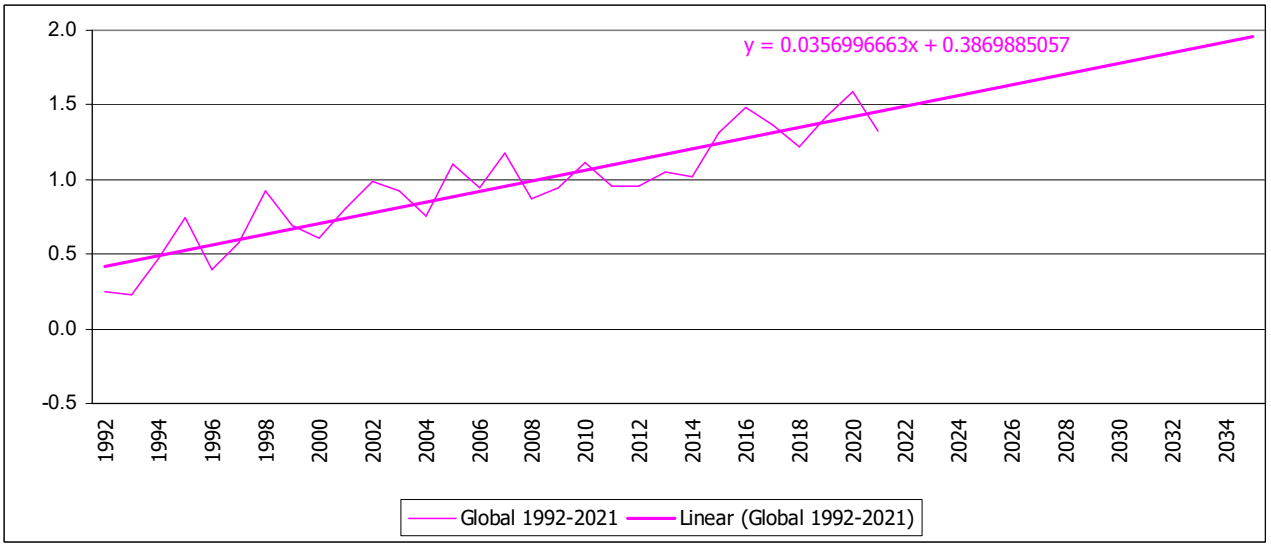


Chart 14 - Change of global temperature trendlines with years [°C]

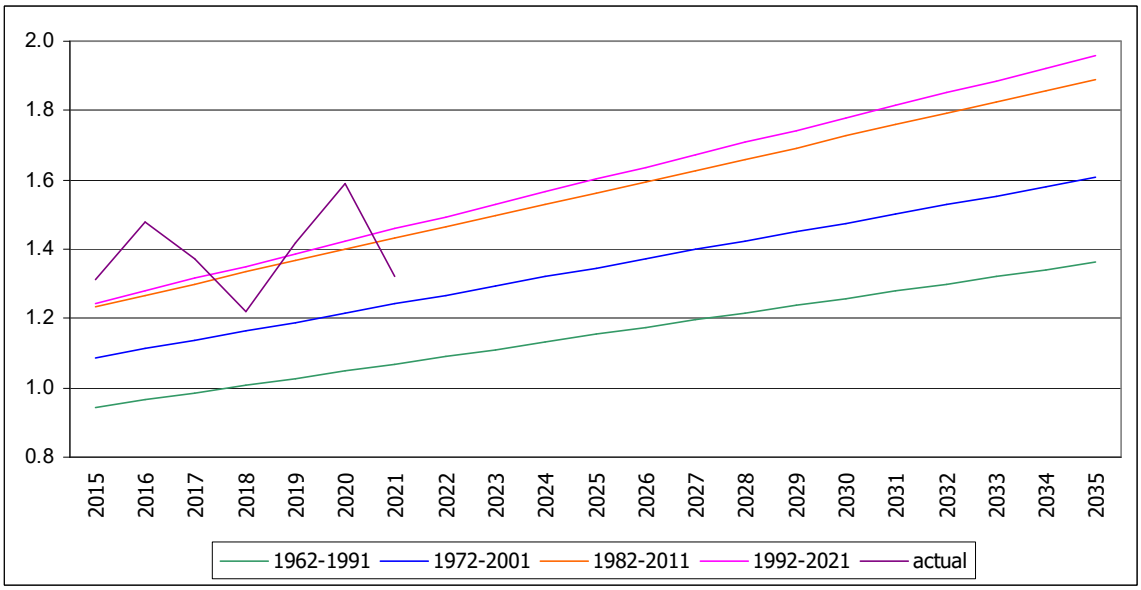


Table 11 - Change of global temperature trendlines with years

	1962-1991 °C	1972-2001 °C	1982-2011 °C	1992-2021 °C	actual °C
2015	0.94	1.09	1.24	1.24	1.31
2016	0.96	1.11	1.27	1.28	1.48
2017	0.99	1.14	1.30	1.32	1.37
2018	1.01	1.16	1.33	1.35	1.22
2019	1.03	1.19	1.37	1.39	1.42
2020	1.05	1.22	1.40	1.42	1.59
2021	1.07	1.24	1.43	1.46	1.32
2022	1.09	1.27	1.46	1.49	
2023	1.11	1.29	1.50	1.53	
2024	1.13	1.32	1.53	1.57	
2025	1.15	1.35	1.56	1.60	
2026	1.17	1.37	1.59	1.64	
2027	1.19	1.40	1.63	1.67	
2028	1.22	1.42	1.66	1.71	
2029	1.24	1.45	1.69	1.74	
2030	1.26	1.48	1.73	1.78	
2031	1.28	1.50	1.76	1.81	
2032	1.30	1.53	1.79	1.85	
2033	1.32	1.55	1.82	1.89	
2034	1.34	1.58	1.86	1.92	
2035	1.36	1.61	1.89	1.96	

Table 12 - Estimation of global temperature change in the year 2035

	1962-1991 °C	1972-2001 °C	1982-2011 °C	1992-2021 °C
2035	1.36	1.61	1.89	1.96
Δ		0.24	0.28	0.07

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