4. Forecasting Global Warming

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Based on the book: "Fundamentals of Global Warming"

Presentations about Global Warming

- I. Global Warming 1901-2018
- 2. Influence of the Sun
- 3. CO2 Emissions and Concentration
- 4. Forecasting Global Warming
- 5. Seawater and Ice Conditions
- 6. Milankovich Cycles
- 7. Action Plans
- 8. Target Scenario 2050

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- 3. Model of warming using TSI, CO2 and SO2
- 4. Forecasting Future Warming
- 5. Comparision with IPCC estimates
- 6. Summary

1. INTRODUCTION

Svante Arrhenius (1859-1927)

Developed 1896 a formula for global warming:

 $\Delta F = \alpha \times \ln (C/C_0)$

 Δ F= forcing (W/m2) C = CO2 concentration Co = CO2 in the beginning

If CO2 concentration will be double, temperature would rise 5 – 6 deg. C



GREENHOUSE GAS EFFECT

0.2

Downgoing Solar Radiation Upgoing Thermal Radiation Spectral Intensity 70-75% Transmitted 15-30% Transmitted Infrared UV Visible 100 -Percent 75 -**Total Absorption** 50 and Scattering 25 -Water Vapor Major Components Carbon Dioxide Oxygen and Ozone Methane Nitrous Oxide Rayleigh Scattering 0.2 10 70

Wavelength (µm)

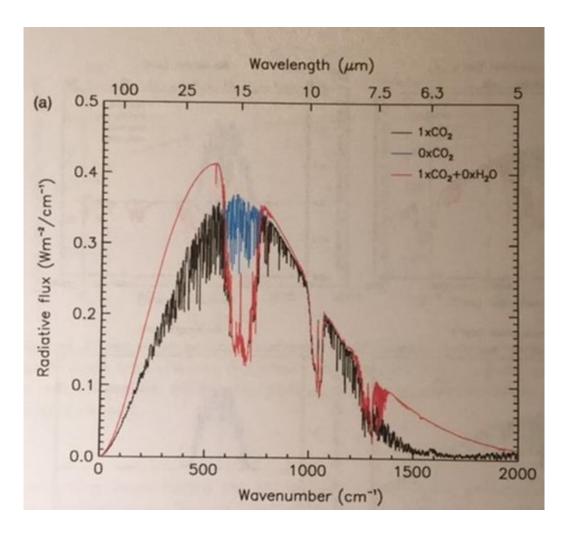
Radiation Transmitted by the Atmosphere

Absorption of infrared radiation by CO2



70

GREENHOUSE GAS EFFECT



CO2 absorbs Radiative flux at 15 um waves. Blue curve. If CO2 = 0, black curve, if CO2= at todays level. Red curve H2O=0

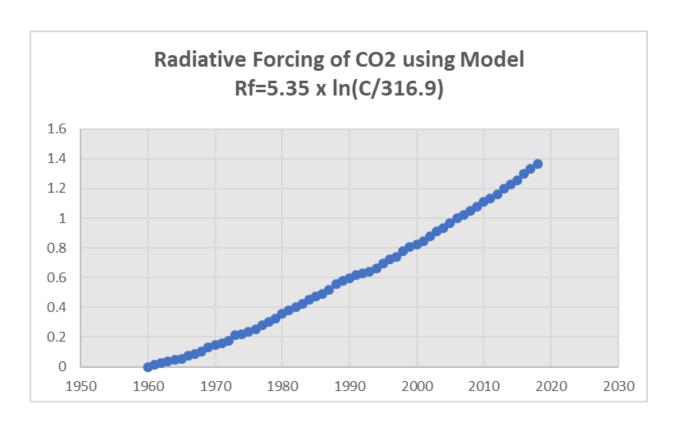
2. RADIATIVE FORCINGOF CO2

Arrhenius Formula for Radiative Forcing of CO2 (W/m2)

 $Rf = 5.35 \times ln (C/Co)$

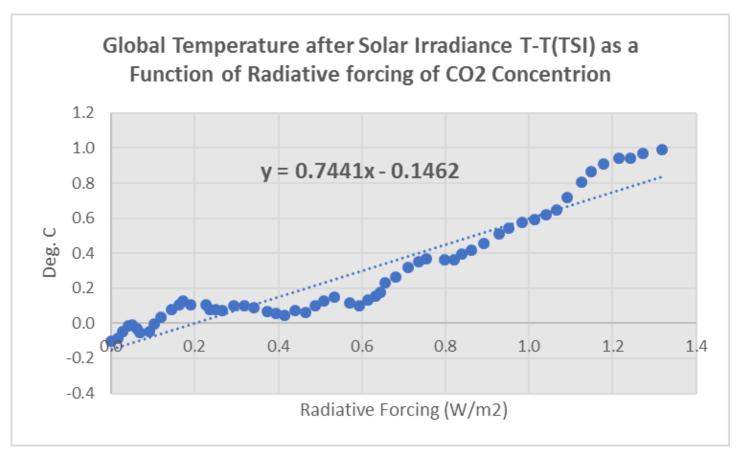
Where 5.35 = IPCC given value Co(1959) = 315.97

Radiative Forcing Starting from Year 1959 was 1.4 W/m2 in 2018



IPCC formula Rf = $5.35 \times \ln (C/316.9)$

Temperature after Solar Irradiance as a Function of Radiative Forcing



Linear fit is not accurate in the whole range

Formulas for temperature rise after solar irradiance, T – T(TSI)

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dT = 0.744 x dRf

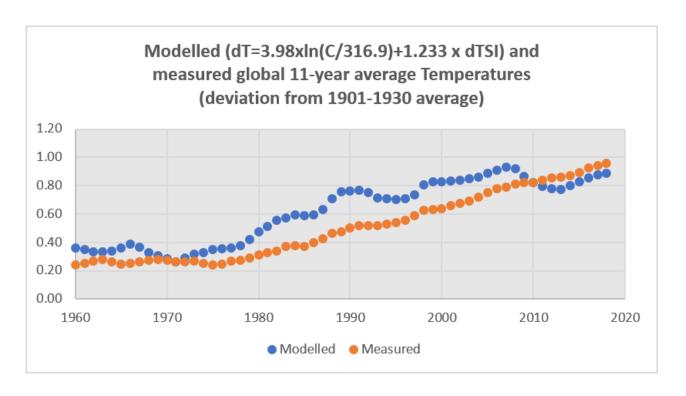
where dRf = 5.35 x ln (C/316)

dT = 0.744 x 5.35 x ln (C/316)

= 3.98 x ln (C/316)

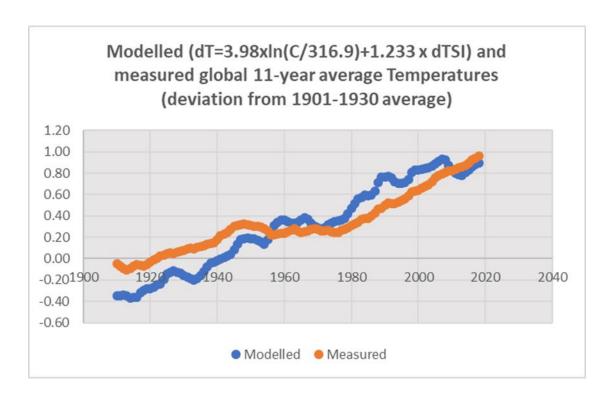
If C = 450, then dT = 1.4 deg. C if C= 520, then dT = 2.0 deg. C
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Measured and modelled temperatures using CO2 and TSI



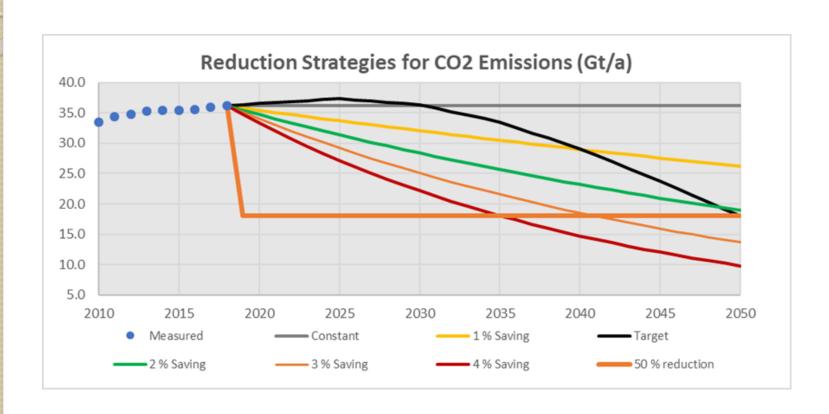
 $dT = 3.98 \times ln(C/316.9) + 1.233 \times dTSI$ Standard deviation between modelled and measured values is 0.096 deg. C, during years 1960-2018

Measured and modelled temperatures using CO2 and TSI

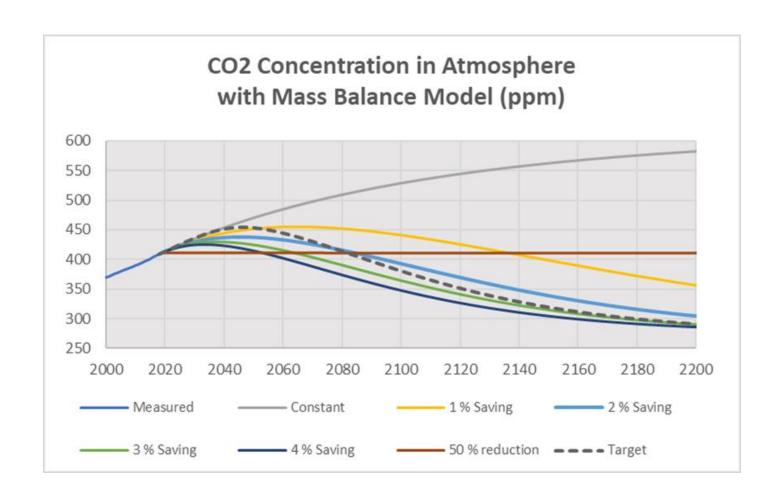


 $dT = 3.98 \times ln(C/316.9) + 1.233 \times dTSI$ Standard deviation is 0.18 deg. C in the whole range 1911-2018

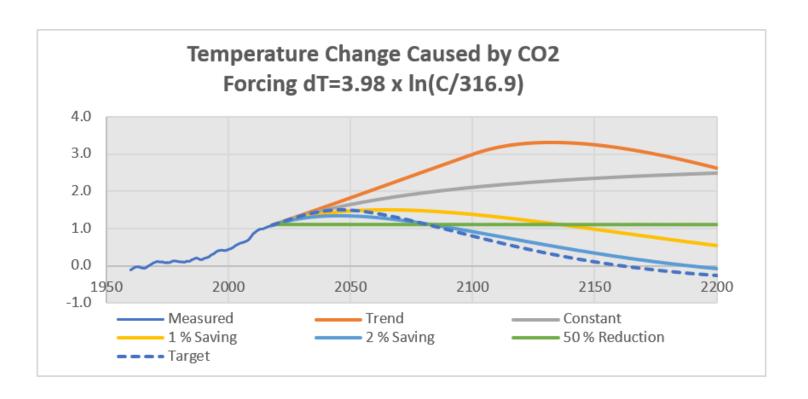
Reduction of CO2 Emissions



CO₂ Concentration



Global Warming until 2200

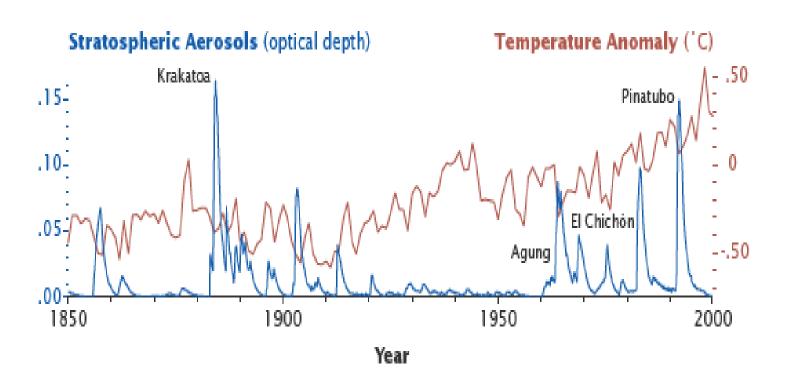


Global warming scenarios using CO2 concentration as a variable

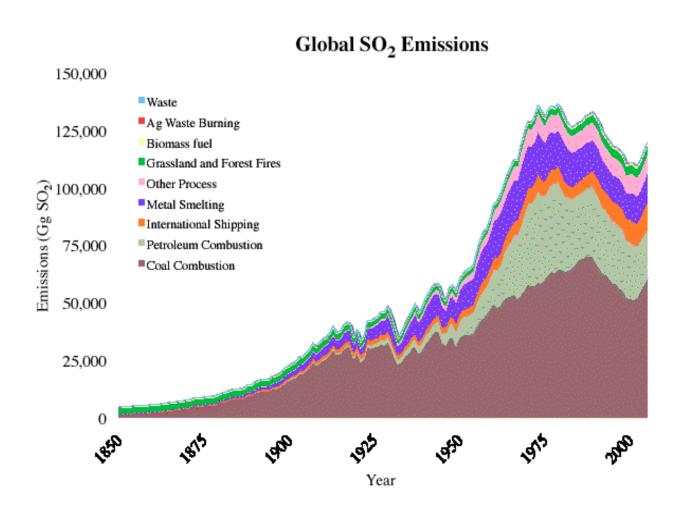
Year	Trend	Constant	1 % Saving	2 % Saving	50 % Saving	Target
2018	1.08	1.08	1.08	1.08	1.08	1.08
2030	1.35	1.33	1.30	1.28	1.11	1.34
2040	1.59	1.50	1.42	1.34	1.11	1.47
2050	1.82	1.64	1.48	1.35	1.10	1.49
2100	3.00	2.10	1.39	0.92	1.10	0.80
2200	2.63	2.49	0.53	-0.08	1.10	-0.26
Maximum	3.32	2.49	1.51	1.35	1.11	1.50

3. MODEL OF GLOBAL WARMING USING TSI, CO2 AND SO2 AS VARIABLES

Global SO2 emissions cool the climate



Global SO2 emissions caused by man



Global Warming Model using TSI, CO2 and SO2 as variables

$$dT = 1.23 \times dTSI + 4.61 \times ln(C/292) + 0.30 \times ln(E/22.57)$$

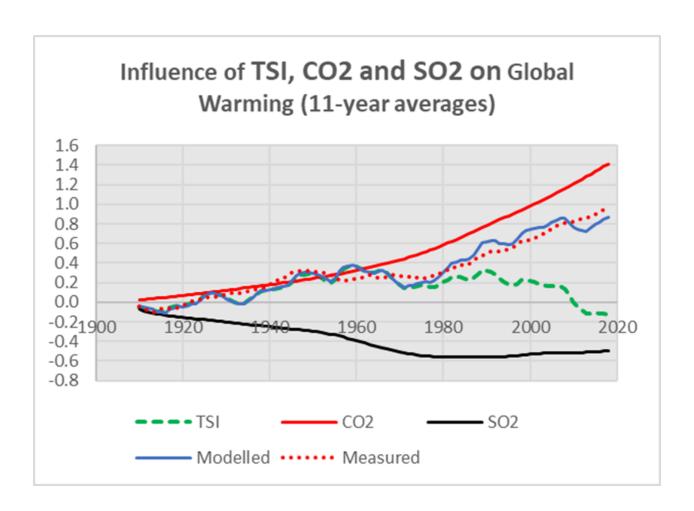
Where

dTSI = Change in Total Solar Irradiance

C= CO₂ concentration in the Atmosphere

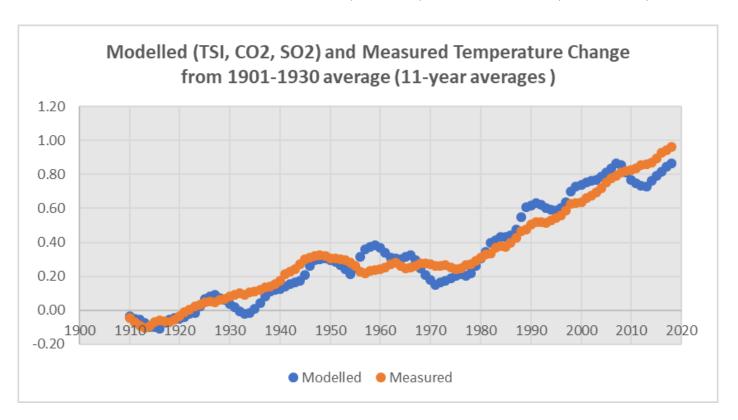
 $E = SO_2$ emissions (1000 tons)

Modelling Global Warming by TSI, CO2 and SO2



I.4 deg.C(CO2) - 0.4 deg.C (SO2) - 0.1 deg. C(TSI) = + 0.9 deg. C

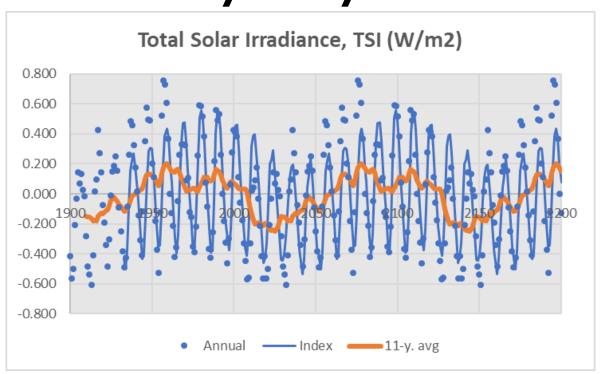
Modelling Global Warming by TSI, CO2 and SO2 $dT = 1.23 \times dTSI + 4.61 \times ln(C/292) + 0.30 \times ln(E/22.57)$



Standard deviation of the model temperatures from measured temperatures = 0.07 deg. C in the whole range 1911 - 2018

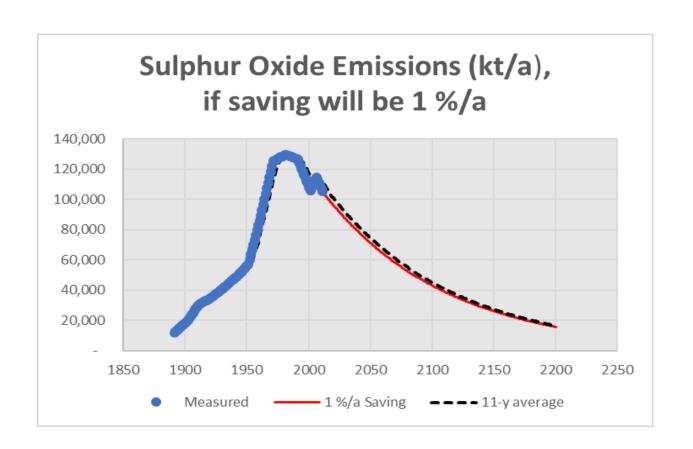
4. FORECASTING FUTURE GLOBAL WARMING

Assumption: Future Total Solar Irradiance will Follow the 99-year cycle

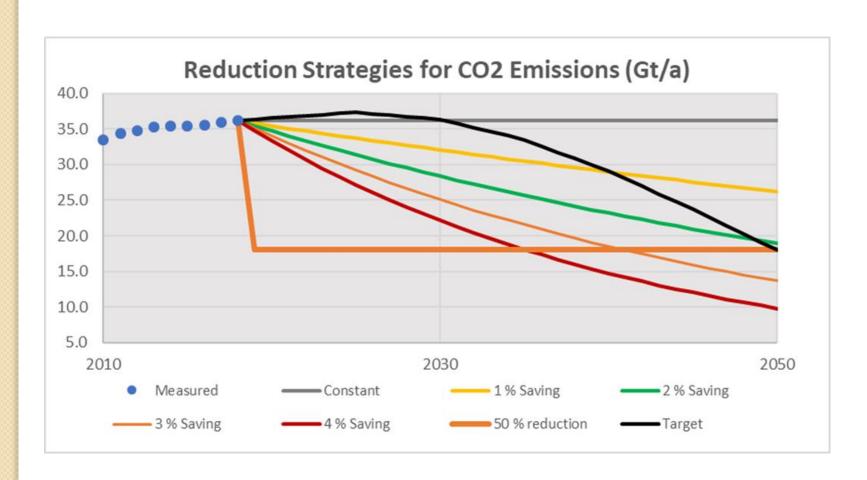


TSI(2019) = TSI(1920) etc.

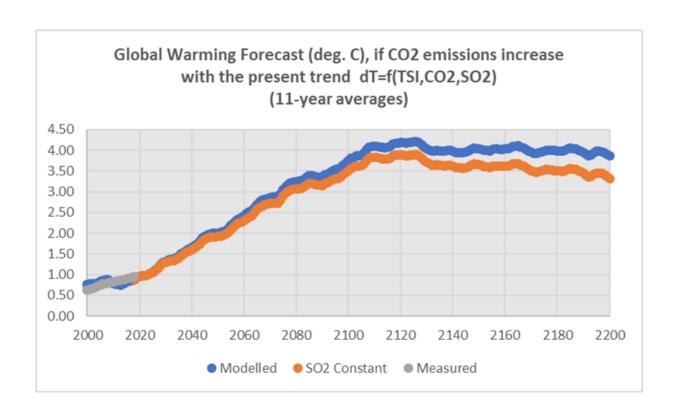
Assumption: SO2 emissions will decrease I %/a



Assumption: CO2 Emissions will be Reduced 0 – 4 %/a or with Target Plan

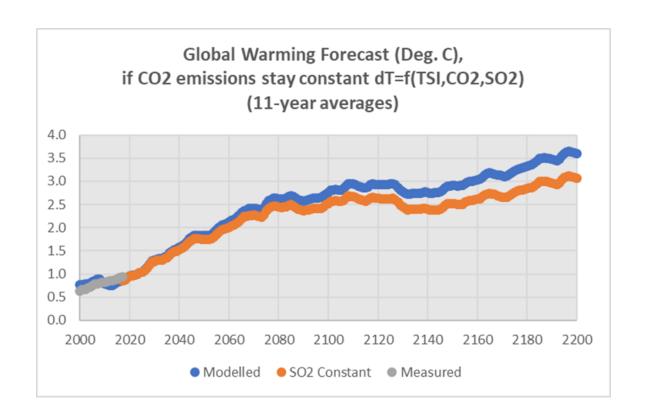


Global warming, if CO2 emissions increase with the present trend and TSI changes as during years 1920-2018



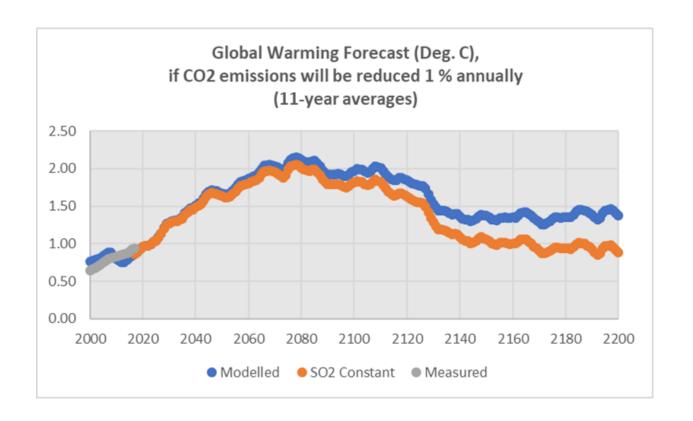
2.0 deg. limit will be achieved by 2050 and 3.0 deg. limit by 2080

Global warming, if CO2 emissions will stay constant and TSI changes as during years 1920-2018



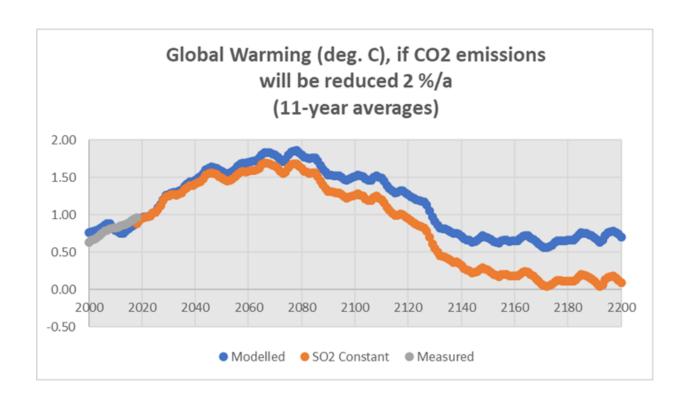
2.0 deg. limit will be achieved by 2060 and 3.0 deg. limit by 2110

Global warming, if CO2 emissions will decrease 1 %/a and TSI will change as in years 1920-2018



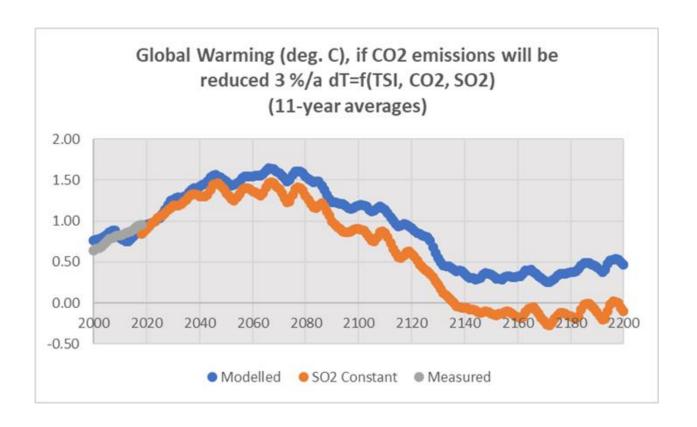
2.0 deg. C limit will be achieved by 2070. Peak will be 2.2 deg. C.

Global warming, if CO2 emissions will decrease 2 %/a and TSI will change as in years 1920-2018



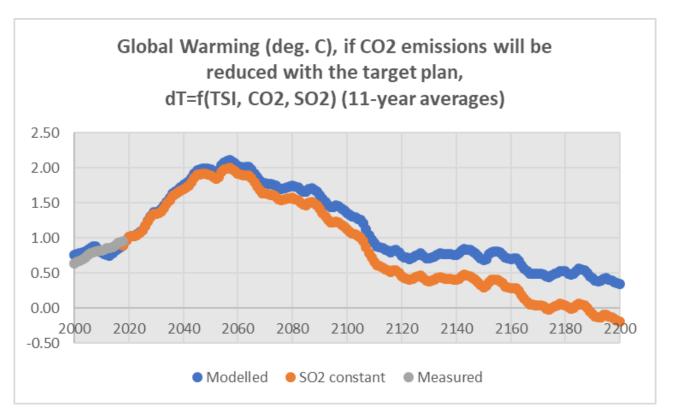
1.5 deg. Limit will be exceeded by 2040. Peak will be at 1.9 deg. C.

Global warming, if CO2 emissions will decrease 3 %/a and TSI will change as in years 1920-2018



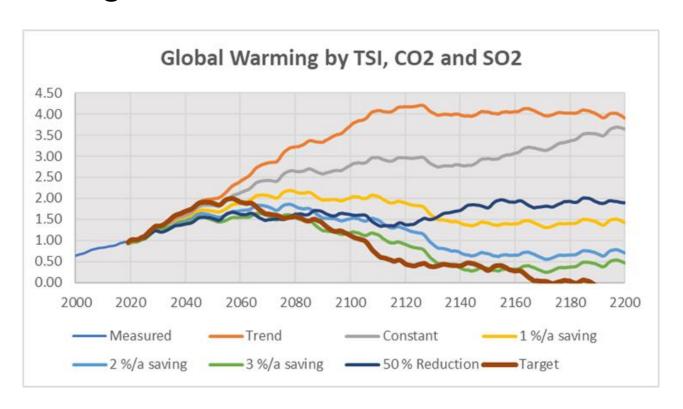
1.5 deg. C limit will be achieved by 2045. Peak at 1.7 deg. C.

Global warming, if CO2 emissions will decrease with target plan and TSI will change as in years 1920-2018



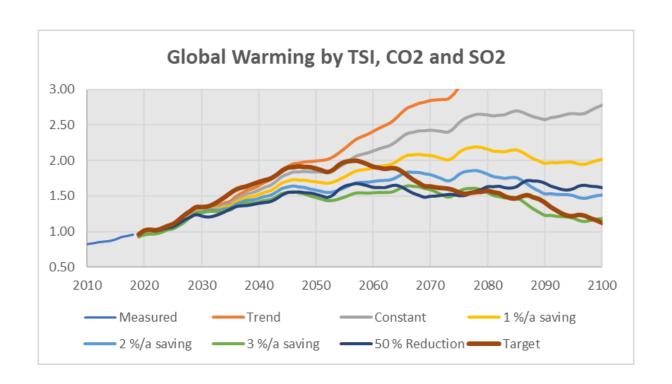
Temperature peak at 2.0 deg. C by 2045-2050.

Global warming depending on CO2 saving strategies



Peak at 4 deg. C with present trend, at 3.5 deg. C with constant emissions

Global warming depending on CO2 saving strategies



dT = 2.0 deg. C, if CO2 emissions will be reduced with the target plan dT = 1.9 deg. C, if CO2 emissions are reduced 2 % annually (Blue)

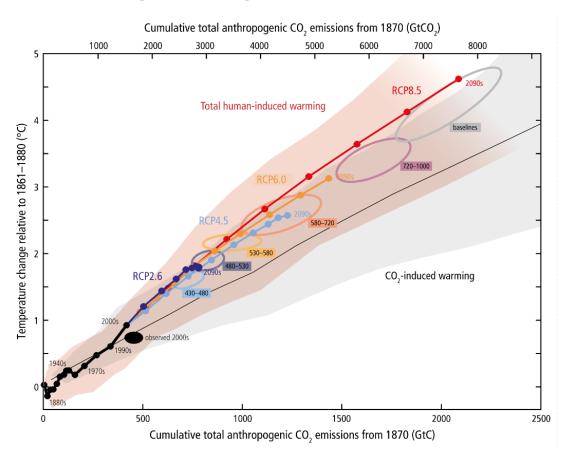
Global warming depending on CO2 saving strategies

		Global wa					
Year	Trend	Constant	1 %/a	2%/a	3 %/a	-50%	Target
2018	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2030	1.3	1.3	1.3	1.3	1.3	1.2	1.3
2040	1.6	1.6	1.5	1.5	1.4	1.4	1.7
2050	2.0	1.8	1.7	1.6	1.5	1.5	1.9
2100	3.7	2.8	2.0	1.5	1.2	1.6	1.1
2200	3.9	3.6	1.4	0.7	0.5	1.9	-0.2
Max	4.2	3.7	2.2	1.9	1.6	2.0	2.0

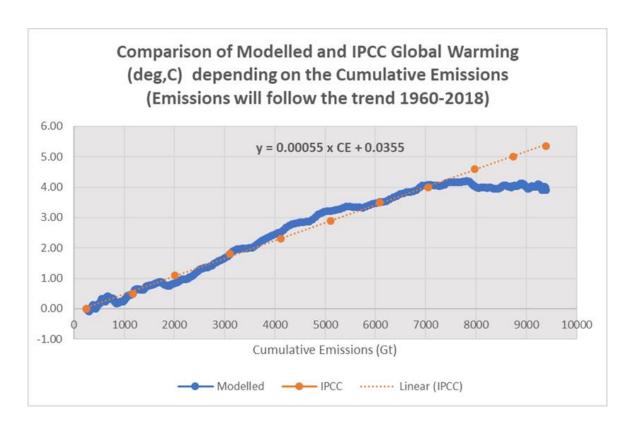
The 2.0-degree limit will not be exceeded, if CO2 emissions will be reduced 50 % today, 2 % annually or with the target plan.

The 1.5-degree limit will need 4 % reduction annually

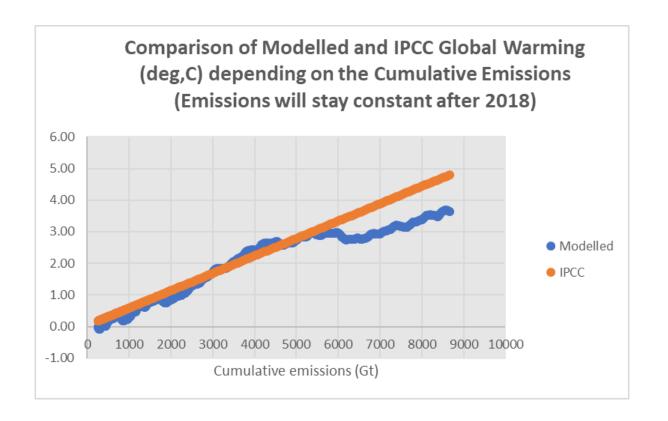




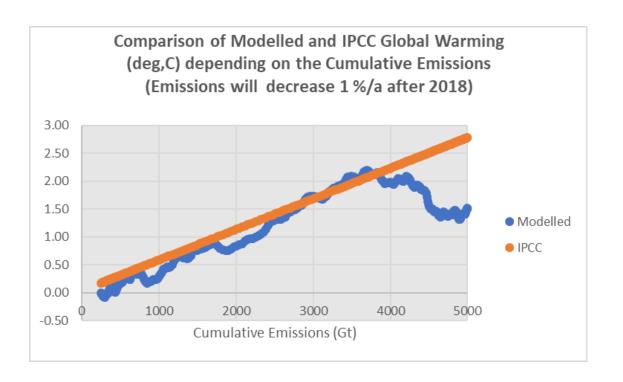
4 deg. C limit will be achived at 1900 Gt C emissions (7000 GtCO2)



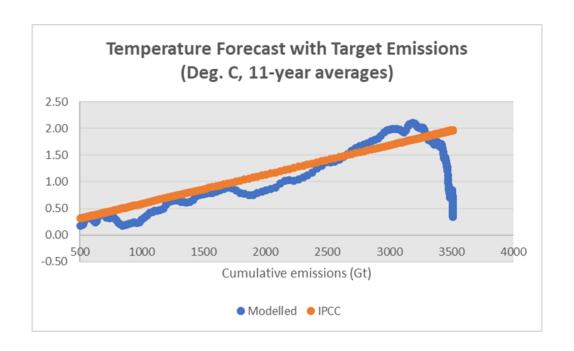
If CO2 emissions increase with the present trend, the both IPCC and mass balance model gives 4.0 deg. C warming at 7000 Gt. The 2 deg. C limit will be achived at 3500 Gt CO2 emissions



If CO2 emissions will stay constant IPCC and our model gives 3.0 warming at 5500 Gt cumulative emissions



If emissions will be reduced 1 % annually the both models give 2 deg. C warming at 3500 Gt emissions



If emissions will be reduced with the target plan, our model will give 2.0 deg. C warming at 3000 Gt emissions and IPCC curve at 3500 Gt emissions

6. Summary

Global warming can be limited to 2.0 deg. C, if CO2 emissions will be reduced 2 % annually or with the target plan

Our model gives the 2 deg. C warming at 3000 Gt cumulative emissions. IPCC curve at 3500 Gt.

About 2080 Gt CO2 have been already emitted, there are only 900 Gt remaining to avoid 2 deg. C warming

Reference

The book "Fundamentals of Global Warming" can be downloaded from

www.ekoenergo.fi