Is global climate change tracking the worst-case scenario?

The world economy has the world fixed on the worst-case climate change scenario (RCP8.5) - for almost all drivers and indicators

All indicators are increasing faster than ever, most accelerating

Peter Carter
4 May 2020

*See defined slide 7
Global temperature increase for April 2010: +1.3°C

Record high non El Nino April

Acceleration from 2010

Virtually as high as the big El Nino record of 2016

The last 12 months - May 2019 to April 2020

12-months global surface air temperature anomalies (°C) relative to 1981-2010

Alaska, Greenland, Siberia, West Antarctic

April 2020 1.29°C from pre-industrial
Global temperature increase for April 2020: +1.3°C
Record high non El Nino April
Accelerating fast

°C Relative to 1981-2010

°C Relative to pre-industrial
Add 0.63°C for pre-industrial conversion

Climate Emergency Institute
1st. quarter of 2020 (Jan-March) global surface temperature increase: + 1.5°C !!!

Global average temperature change from preindustrial (1881-1920)

https://data.giss.nasa.gov/gistemp/maps/

NASA GISS Surface Temperature Analysis (v4) Global Maps

Accessed 29 April 2020

Climate Emergency Institute
60-year trend of accelerating atmospheric CO2 increase
Faster for the past decade

Mauna Loa Monthly Averages  NOAA, Trends in Atmospheric Carbon Dioxide

Monthly Average Mauna Loa CO2

April 2020: 416.21 ppm
April 2019: 413.33 ppm

April 2020: 2.88 ppm growth rate !!
44% increase over last decade average

1 million-year ice core limit (300 ppm)

Latest data 3
NOAA, May 2020

Seasonally adjusted mean
→ trend  April 2020
   413.38

→ co2 monthly average

Climate Emergency Institute
National Oceanic & Atmospheric Administration
ACCELERATING ATMOSPHERIC CONCENTRATION from 1740 to April 2020

Increased acceleration rate from 1960
Explosive increase from 2000 to April 2020

Seasonally adjusted mean CO2

Monthly CO2 rises and falls with the seasons annually, as CO2 is absorbed and released by green vegetation each year.

NOAA Atmospheric CO2, 26 April 2020: 413.3 ppm
No change from pandemic emissions reduction

Pre-industrial CO2
278 ppm

1 million-year atmospheric CO2 ice core limit (300 ppm)

Scripps Institute of oceanography
Merged Ice-Core Record
From 1740 updated to April 2020

NOAA, Mauna Loa
Mauna Loa, Hawaii, United States (MLO)

National Oceanic & Atmospheric Administration

https://www.esrl.noaa.gov/gmd/dv/iadv/
Data Trends
(30 years or more)

The IPCC

We have data trends to today for all indicators, but not for all RCP8.5 scenarios, because the deviation of worst-case and best-case for most indicators is only just starting. Yet, never has been is been more vital that we know which direction global climate change is going.

**ACCELERATING TRENDS** In many cases the trends to today are extremely rapid and accelerating, from which we may be able to infer worst-case scenario to come.

- Emissions of CO2, methane, nitrous oxide, CO2 equivalent (PBL)
- Fossil fuel CO2 emissions (GCP)
- Atmospheric GHG concentrations (IPCC AR5)
- Atmospheric CO2 (NOAA)
- Atmospheric methane (NOAA)
- Atmospheric nitrous oxide (NOAA 20 year but accelerating)
- Atmospheric CO2 equivalent (NOAA)
- Global average surface temperature increase (NASA GISS)
- Sea level rise (NOAA)
- Ocean heat (NOAA)
- Sea surface temperature (Japan Met)
- Ocean acidification (Japan Met)
- Ocean deoxygenation (IPCC)
- Arctic sea ice (IPCC, NOAA)
- Arctic snow cover (IPCC, NOAA)
130 years of increasing to accelerating atmospheric CO2 concentration

May 02, 2020

130 years of increasing to accelerating global average surface warming

Land-Ocean: Global Means (J-D)

(NASA GISS reference smoothing period)

base-line 1881-1920

NASA/GISS/GIstemP v4
Accelerating Global surface heating
1st quarter of 2020 + 1.5°C

NASA GISS Surface Temperature Analysis
Additional Analysis Plots

Land-Ocean: Global Means (DJF)

Lowess Smoothing 5 years

NASA/GISS/GISTEMP v4

Note permafrost

Arctic polar view

Siberia +4-8.9°C

Permafrost distribution

NASA GISS Surface Temperature Analysis (v4)
Global Maps

Climate Emergency Institute
Permafrost is warming at a global scale, Boris K. Biskaborn et al., Jan 2019
Worst-case scenario methodology

As used here means clear or early divergence of the median observed parameter towards the worst-case scenario RCP 8.5.

For all the indicators we have established trends (>30 years)

The solid line is the median projection used which is the projection using the single climate sensitivity of 3°C. (for 2X CO2 ppm). The shading above and below the solid line are probability ranges. Recent research indicates the sensitivity is not below 3°C and may be above 3°C. This does not affect this presentation.

Current energy and climate policies and plans are drivers that will keep global climate and ocean changes on the worst cease scenario. There is no international policy agreement to limit atmospheric greenhouse concentrations (as the 1992 UNFCCC UN climate convention) nor to limit emissions. There is no agreement or discussion of ending fossil fuel energy. In fact the highest emitters are pursuing a policy of maximizing fossil fuel production, and practically all countries are still subsidizing fossil fuels.

It is the hope of this paper that if policy makers are advised of this situation, they will take immediate measures to ensure the immediate rapid reduction of global emissions.
GLOBAL AVERAGE TEMPERATURE INCREASE
With worst-case scenario methodology

Example for methodology
In this presentation the comparison of the latest data to worst-case scenario (RCP 8.5) cases are shown, with the RCP8.5 year in question by the maroon dotted line. The plot of projections to 2100 is zoomed in / cut down to focus on the present. Closer grids are added for comparison accuracy. At this time the deviation of the scenarios is just discernable. The RCP85 result is written in maroon and the current data result in black., as for the 2019 global average temperature increase example below. All projections are median (most likely) but are based on a single static climate sensitivity of 3°C (2XCO2ppm), which may be higher making these results conservative.

Present day focus

2019 GLOBAL SURFACE TEMPERATURE INCREASE 1.2°C is tracking the worst-case
RADIATIVE (HEAT) FORCING (2018) is tracking the worst-case scenario RCP8.5 on an accelerating trajectory. Radiative (heat) forcing increased 43% from 1990 to 2019.


The RCP scenarios (IPCC 2014 5th assessment) were set by pre-determined radiative forcing up to 2100.

The NOAA ANNUAL GREENHOUSE GAS INDEX (AGGI) NOAA Earth System Research Laboratory
GLOBAL SURFACE TEMPERATURE INCREASE (2019) is tracking the worst-case

Abstract ... The 2019 global temperature was +1.2°C (~2.2°F).

Present day focus

Higher warming with higher climate sensitivity

Lower climate sensitivity can be excluded by observations to date

RCP2.6
T°+ 2019:1.2°C

2019 RCP 8.5: 1.1°C
Worst-case IPCC Emissions Scenarios

**Worst case IPCC 2007 4th Assessment**
- SRES A1FI (fossil fuel intensive)
- By 2100: +4.5°C up to a possible 7.5°C
- The SRES scenarios are derived from socio-economic projections

**Worst case IPCC 2014 5th Assessment**
- RCP 8.5 (high radiative heat forcing)
- By 2100: +4.3°C up to a possible 7.2°C
- The RCP scenarios start with potential radiative heat forcings and backtrack to see if and how they are feasible
- It is important to this project that the worst-case SRES and RCP scenarios are almost identical.

Note all these projections assume a single fixed climate sensitivity of 3°C and no amplifying feedback emissions. Many models (past & present) arrive at a higher sensitivity. This does affect the trends to date.
GLOBAL FOSSIL FUEL CO2 EMISSIONS (2019) are tracking close to the worst-case scenario (RCP 8.5)

2019 CO2 emissions: 36.8 Gt

Projection 2019: 36.8 Gt CO2

2019 RCP8.5: 41 Gt

RCP8.5 3.2–5.4°C relative to 1860–1900

RCP6 2.0–3.7°C

RCP2.6 Best case IPCC 5th assessment Global emissions decline from 2020

New SSP emissions decline from 2020 for 1.5°C and 2°C

Global Carbon Project 2019

Global Carbon Project 2015 (for RCP emissions scenarios)
GLOBAL CO2 EQUIVALENT EMISSIONS (2018) are tracking above the worst-case scenario (RCP 8.5) with increasing divergence since 2010

(CO2 equivalent includes the other greenhouse gases, along with CO2)

"The 2018 global greenhouse gas emissions amounted to 55.6 GtCO2 eq when also including those from land-use change"

We are looking at data sets of indicators from 2000.

It is important to be aware that around 2000 there was a large increase in the increase rate of global greenhouse gas emissions, and therefore a large increase in the forcing of climate from 2000.
2020 ATMOSPHERIC CO2 CONCENTRATION is tracking the worst-case scenario (RCP 8.5) (1st example)

Actual present

NOAA Trends in atmospheric CO2, April update
Monthly Average Mauna Loa CO2

March 2020: 414.50 ppm
March 2019: 411.97 ppm

Note high annual growth rate and accelerating trend

Original for RCP 8.5

Australian Climate Change Science Program Information Paper

Representative Concentration Pathways (RCPs) Authors: Imogen Jubb, Pep Canadel, and Martin Dix

Climate Emergency institute
2020 ATMOSPHERIC CO2 CONCENTRATION is tracking the worst-case scenario (RCP 8.5) (2nd example)

March 2020 atmospheric CO2 : 414.50 ppm
March 2019: 411.97 ppm

Focused RCP8.5 with present day

The representative concentration pathways: an overview, Detlef P. van Vuuren, 2011
(The 2014 IPCC 5th assessment RCP scenarios reference paper)
ATMOSPHERIC METHANE CONCENTRATION is tracking towards the worst-case scenario RCP 8.5

The figure is updated from that in Nisbet et al. (2019) using NOAA mole fraction data to June 2019.

ATMOSPHERIC CO2 CONCENTRATION is tracking above the worst-case scenario RCP 8.5

The CO2 equivalent includes the other greenhouse gases, so it is higher than CO2 alone. It is the metric used by the IPCC in mitigation calculations.

In terms of CO2 equivalents, the atmosphere in 2018 contained 496 ppm, of which 407.4 is CO2 alone. The rest comes from other gases.

The CO2 equivalent includes the other greenhouse gases, so it is higher than CO2 alone. It is the metric used by the IPCC in mitigation calculations.

NOAA’s Annual Greenhouse Gas Index, 2019

Source: EPA Climate change science

Future of climate change 2017

Global CO2 Emissions and Atmospheric CO2 Concentrations are Tracking the Worst-Case Scenario
1750-2019

CO2 in the atmosphere and annual emissions (1750-2019)
GLOBAL AVERAGE SURFACE TEMPERATURE INCREASE is tracking the worst-case scenario (RCP 8.5)
2019 increase from pre-industrial is 1.2°C*

*Global Temperature in 2019, 15 January 2020
NASA expert team, James Hansen, M. Sato, R. Ruedy, G. Schmidt, K.Lob, M. Hendrickson
Abstract ... “The 2019 global temperature was +1.2°C (~2.2°F)”
GLOBAL AVERAGE SURFACE TEMPERATURE INCREASE is tracking the worst-case scenario (RCP 8.5)

2019 increase from pre-industrial is *1.2°C*

Note: “Global temperature increase has accelerated over the past decade” (15 Jan 2020, NASA expert team Climate Awareness Science and Solutions)

*Global Temperature in 2019, 15 January 2020
NASA climate expert team, James Hansen, M. Sato, R. Ruedy, G. Schmidt, K.Lob, , M. Hendrickson
Abstract ... “The 2019 global temperature was +1.2°C (~2.2°F)“

Present day focus showing RCP8.5 with upper range and 2019 temperature increase
The RATE OF ACCELERATION has increased over the past 10 years
2019 global average surface temperature increase +1.2°C

Global average temperature change from preindustrial (1881-1920)

2019 no big El Nino
Annual J-D 2019 L-OT (°C) Anomaly vs 1881-1920 1.23

2019: 1.23°C

2016 big El Nino
Annual J-D 2016 L-OT (°C) Anomaly vs 1881-1920 1.28

The 2016 record 1.28°C
2019 is a RECORD NON-EL NINO YEAR & ACCELERATING FAST

Reversal of cooling trend from 1920

Annual global temperature increase from pre-industrial (1881-1920)

Land-Ocean: Global Means (J-D)

5-year Loess smoothing

Removal of big 2015-2016 El Nino
Ist. quarter of 2020 (Jan-March) global surface temperature increase: +1.5°C !!!

Global land temperature increase: +1.95°C

Global average temperature change from preindustrial (1881-1920)

Global average (land-ocean) temperature increase

Jan-Mar 2020  L-OTI(°C) Anomaly vs 1881-1920  1.51

Global average LAND temperature increase

Jan-Mar 2020  Tsurf(°C) Anomaly vs 1880-1920  1.95

There is no El Nino in 2020

Siberia +4.8°C

NASA GISS
EXTREME ACCELERATED WINTER TEMPERATURE INCREASE (Dec-Jan-Feb) +1.38°C
Past and future changes in the ocean

IPCC, 2019, Special Report on the Ocean and Cryosphere in a Changing Climate

Figure SPM.1 |
SEA LEVEL RISE

is tracking above the worst-case scenario (RCP8.5)

Change in sea level since 1993 as observed by satellites.
LATEST MEASUREMENT: December 2019: 95 mm

Source: NASA Climate Change Vital Signs

Original for RCP8.5

Global mean sea level rise (relative to 1986–2005)

Mean over 2081–2100

Source: climate.nasa.gov

Supporting data set
Accelerating sea level rise

IPCC 2014 5th assessment Figure SPM.6 | Global average surface temperature change (a) and global mean sea level rise (b) from 2006 to 2100 as determined by multi-model simulations. All changes are relative to 1986–2005.

NOAA, Climate Change: Global Sea Level Author: Rebecca Lindsey November 19, 2019
The IPCC 2019 Report shows historic sea level rise to 2016

A.3.2 “Sea level rise has accelerated due to the combined increased ice loss from the Greenland and Antarctic ice sheets (very high confidence). Mass loss from the Antarctic ice sheet over the period 2007–2016 tripled relative to 1997–2006. For Greenland, mass loss doubled over the same period “

A.3.3 “Acceleration of ice flow and retreat in Antarctica, which has the potential to lead to sea level rise of several metres within a few centuries, is observed in the Amundsen Sea Embayment of West Antarctica and in Wilkes Land, East Antarctica (very high confidence). These changes may be the onset of an irreversible ice sheet instability.”

The impression is that sea level rise is tracking towards the worst-case

Original for RCP8.5

Focus to present day
GLOBAL SEA LEVEL RISE is tracking above the worst-case scenario RCP 8.5

APRIL 9, 2018
Early climate action has big effect on rising sea levels by Larry O’hanlon, American Geophysical Union

OCEAN ACIDIFICATION
is tracking the worst-case scenario (RCP8.5)

IPCC 2019 Ocean & Cryosphere Report
The Lower the pH- the Higher the acidity

IPCC 2019 Ocean & Cryosphere Report Figure SPM.1 | Observed and modelled historical changes in the ocean and cryosphere since 1950, and projected future changes under low (RCP2.6) and high (RCP8.5) greenhouse gas emissions scenarios.

The Lower the pH- the Higher the Acidity

Present day focus

https://www.ipcc.ch/srocc/chapter/summary-for-policymakers/
Ocean acidity is accelerating

Ocean acidity (inverse of pH)
(1860-2016, around Australia)

From Australia’s changing climate, Dec 2018,
The Commonwealth Scientific and Industrial Research Organisation (CSIRO)
Supporting recent research

**Kuroshio Recirculation**
(26°N – 30°N)

**Subtropical Frontal Zone**
(20°N – 22°N)

**Tropical Zone**
(5°N – 10°N)

*Acceleration of Ocean Acidification in the Western North Pacific*
Hisashi Ono, et al, GRL, Nov 2019
Though it is not possible to discern a deviation of the scenarios from the latest IPCC report data illustration, ocean heat is accelerating (Figure 5.1, see also next) which would be towards the worst-case.

The rate of heat uptake in the upper ocean (0–700 m) is very likely higher in the 1993–2017 (or 2005–2017) period compared with the 1969–1993 period (see Table 5.1). The deeper layer (700–2000 m) heat uptake rate is likely to be higher in the 1993–2017 period compared with the 1969–1993 period. (IPCC 2019 Oceans and Cryosphere Report 11.142)

Figure 5.1

Table 5.1

<table>
<thead>
<tr>
<th>Period</th>
<th>Ocean Heat Uptake Rate, ZJ yr⁻¹</th>
<th>Ocean Heat Uptake as Average Fluxes, W m⁻²</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–700 m</td>
<td>3.22 ± 1.01</td>
<td>6.28 ± 0.48</td>
</tr>
<tr>
<td>700–2000 m</td>
<td>0.97 ± 0.64</td>
<td>3.86 ± 2.09</td>
</tr>
<tr>
<td>CMIP5 ESM Ensemble-mean Ocean Heat Uptake with 90% Certainty Range from Ensemble Spread:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–700 m</td>
<td>3.60 ± 1.92</td>
<td>7.37 ± 2.09</td>
</tr>
<tr>
<td>700–2000 m</td>
<td>1.32 ± 1.49</td>
<td>2.72 ± 1.41</td>
</tr>
</tbody>
</table>
How fast are the oceans warming?
Lijing Cheng et al, Science 11 Jan 2019

ADVANCES IN ATMOSPHERIC SCIENCES, VOL. 37, FEBRUARY 2020, 137–142

Record-Setting Ocean Warmth Continued in 2019 Lijing CHENG

Fig. 1. (a) Upper 2000 m OHC from 1958 through 2019.
OCEAN HEAT (2020)
from this projection is tracking the worst-case scenario (RCP 8.5)
It is accelerating (NOAA)

NOAA, Global Ocean Heat and Salt Content

Church et al. 2013, IPCC WGI AR5 Ch13

10 to power 22 joules

10 to power 24 joules

Original

Church et al. 2013, IPCC WGI AR5 Ch13
Accelerating Ocean Heating Causes Ocean De-oxygenation

Trend: $2.35 \pm 0.30 \times 10^{22}$ J/decade

Normal: 1981–2010 average

Japan Meteorological Agency
OCEAN DEOXGENATION is tracking above the worst-case scenario

IPCC, 2019, Special Report on the Ocean and Cryosphere in a Changing Climate
According to the IPCC, by 2005 a distinction between the scenarios is not established. However, as there is a big jump in SST from 2010, SST is assumed to be tracking the worst-case as is the global average surface temperature, and SST is accelerating.

**SEA SURFACE TEMPERATURE INCREASE**

?tracking the worst-case

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**Sea surface temperature rise is accelerating**

Is the global sea surface temperature rise accelerating? I.H. Bâki Iz, 2018

https://doi.org/10.1016/j.geog.2018.04.002
Supporting sea surface temperature data

![Graph showing sea surface temperature anomaly over time with a trend line indicating a warming trend.]

Trend = 0.55°C/Century
Base Line: 1981-2010 Average

Japan Meteorological Agency

Updated on 17 Feb. 2020 Global Environment and Marine Department, Japan Met
SEA SURFACE TEMPERATURE INCREASE
and the worst-case scenario RCP 8.5

All of the simulations used the observed greenhouse gas concentrations for 1976–2005 and the RCP8.5 “business as usual” scenario.

The anomalies are relative to the historical period (1976–2005). They were obtained from the individual CMIP5 (red) and CESM-LENS (blue) simulations.

The box boundaries are the inter-quartile range (25%–75%) and the median is the central line.

Hadley SST observations are shown with black dots for the 1980s, 1990s, 2000s and the period 2006–2016.

Source: Projected sea surface temperatures over the 21st century, Michael A. Alexander et al., 2028
The final data is the record of declining Arctic summer sea ice extent and Arctic snow cover, which requires explanation because of the effect on the global climate.

The vast area of white through the Arctic summer reflects in coming solar energy away from the Arctic surface back out to space. This property is called Arctic albedo. It is a key component of the stable climate.

There has been Arctic sea ice to some extent for the past 13-14 million years, with the largest sea ice extent for the past 2-3 million years.

The climate change issue here is Arctic albedo, which is a powerful cooling influence maintaining the cold climate of the Arctic, the year-round frozen Arctic regions, and the temperate climate regions of the northern hemisphere.

The current rapid decline of Arctic albedo has a global impact.

It boosts the rate of melting of the Greenland ice sheet and the rate of sea level rise.
It boosts the thawing of Arctic permafrost, which is already releasing all three major greenhouse gases from the Arctic soils: methane, CO2 and nitrous oxide.
This will turbo-charge the rate of global surface heating.

It will inevitably have a large effect on the northern hemisphere temperate climate, where the world’s top agricultural food producing regions are located.
A.3.3 Acceleration of ice flow and retreat in Antarctica, which has the potential to lead to sea level rise of several metres within a few centuries, is observed in the Amundsen Sea Embayment of West Antarctica and in Wilkes Land, East Antarctica (very high confidence). These changes may be the onset of an irreversible ice sheet instability.
GREENLAND ICE SHEET mass loss is tracking the worst-case scenario RCP 8.5

Past and future changes in the ocean and cryosphere
Historical changes (observed and modelled) and projections under RCP2.6 and RCP8.5 for key indicators
- Historical (observed)
- Historical (modelled)
- Projected (RCP2.6)
- Projected (RCP8.5)

Original for RCP8.5
(e) Greenland ice sheet mass loss as sea level equivalent, change relative to 1986–2005

Present day focus to show historic change to 2016 and RCP 8.5

https://www.ipcc.ch/srocc/chapter/summary-for-policymakers/

IPCC 2019 Special Report Oceans & Cryosphere, Figure SPM.1 | Observed and modelled historical changes in the ocean and cryosphere since 1950, and projected future changes under low (RCP2.6) and high (RCP8.5) greenhouse gas emissions scenarios.
60 years trend (from 1960) of Arctic sea ice and snow decline

**Arctic Ocean Sea Ice extent**
- 2018 = 25% loss
- Linear decline from 2000
- Little difference between best and worst case till after 2040
- Committed to a 50% loss by 2040
- 2030 = average 40% loss
- 2040 = average 50% loss

**Arctic snow cover**
- 2018 = 8% loss
- Linear decline from 2000
- Little difference between best and worst case till after 2040
- Committed to a 14% loss by 2040
- 2030 average = 10% loss
- 2040 average = 16% loss
40-year trend of precipitous Arctic albedo (cooling) decline, to 2019

We have no RCPs projections for Arctic albedo, but there is a 40 trend of rapid decline.

NOAA, Climate Monitoring
Snow and Ice
Sea Ice and Snow Cover Extent
Accessed May 2020

Climate Emergency Institute
Though in some cases only just discernable, all indicators show that global climate change is tracking the worst-case scenario (RCP 8.5) or closest to the worst-case scenario, with a reasonable degree of certainty.

Trends of rapid increase and acceleration will predictably keep global climate change on the worst-case scenario, until Parties to the 1992 Framework Convention on Climate Change, cooperate to put global emissions into rapid decline.

Atmospheric greenhouse gas concentrations and trends are far above dangerous (dangerous interference with the climate system as defined by the 1992 Framework Convention on Climate Change, or any definition).