# The IPCC Working Group I Assessment of Physical Climate Change

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The Working Group I Report

• Started 2003
• Completed February 2007
• 152 Authors
• ~450 contributors
• ~600 expert reviewers
• 30,000+ review comments

Contents

• Summary for policymakers
• Technical summary
• 11 Chapters
• Frequently asked questions
• ~5000 literature references
• ~1000 pages

You can get it at:

http://ipcc-wg1.ucar.edu/

Includes supplementary material.
All figures available in PowerPoint format.
Book now published by Cambridge University Press.

• ~1000 pages
Observed Climate Change

Warming of the climate system is unequivocal

Numerous long-term changes in climate observed at continental, regional and ocean basin scales

Some aspects of climate have not been observed to change
Global average temperature

![Graph showing global temperature changes over time](chart)

- **Annual mean**
- **Smoothed series**
- **5-95% decadal error bars**

<table>
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<tr>
<th>Period</th>
<th>Rate (°C per decade)</th>
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<tr>
<td>25</td>
<td>0.177±0.052</td>
</tr>
<tr>
<td>50</td>
<td>0.128±0.026</td>
</tr>
<tr>
<td>100</td>
<td>0.074±0.018</td>
</tr>
<tr>
<td>150</td>
<td>0.045±0.012</td>
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</tbody>
</table>
Warming is truly global

Warming trends since 1979 (when satellite measurements started) show:

- Warming everywhere at surface except in eastern Pacific, Southern Ocean and parts of Antarctica;
- Land warming significantly faster than ocean over last 20 years;
- Mid-troposphere warming consistent with that at surface.
Consistent pattern across climate system

- Surface temperatures increasing
- Tropospheric temperatures increasing
- Atmospheric water vapour content increasing
- Ocean heat content increasing
- ... now directly linked to sea level rise
- Greenland and Antarctic Ice Sheets losing mass
- Glaciers and snow cover decreasing
- Arctic sea ice extent decreasing
- Area of seasonally frozen ground decreasing
- Mid-latitude wind patterns/storm tracks shifting poleward
- More intense and longer droughts
- Frequency of heavy precipitation events increasing
- Extreme temperatures increasing
- Tropical cyclone intensity increasing

Unequivocal
The Greeks knew a lot about geophysics;
And that the sun heated the planet;
But not how the greenhouse effect worked!

The Fall of Icarus
Jacobi Gowi
The natural greenhouse effect increases surface temperatures by about 30°C.

Increasing greenhouse gas concentrations tends to increase surface temperatures.
Drivers of Climate Change

Concentrations of CO₂, methane and nitrous oxide have increased markedly as a result of human activities and now far exceed pre-industrial values.

Net effect of human activities since 1750 has been one of warming.
Industrial revolution and the atmosphere

The current concentrations of greenhouse gases and their rates of change are unprecedented.
Radiative forcing: measures the change in the Earth’s energy balance due to different causes of climate change.

Increased by 20% over 1995 - 2005
Identifying cause and effect

“Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.”

*Very likely means an assessed likelihood of being correct greater than 90%
Climate models explain observed global mean temperatures with greenhouse gases and aerosols included.

No model can explain observed global mean temperatures without including increased greenhouse gases.

Note – transient coolings due to volcanic eruptions
Can not explain spatial pattern of warming without this component.
Projections of climate change

Svante Arrhenius, “Verldamas Utveckling”, 1906

... any doubling of the percentage of carbon dioxide in the air would raise the temperature of the Earth’s surface by 4°C.

... the percentage of carbonic acid in the atmosphere may, by the advances of industry, be changed to a noticeable degree in the course of centuries.

Intergovernmental Panel on Climate Change 2007

... the best estimate of climate sensitivity to a CO₂ doubling is a warming of 3°C, with a likely range of 2 to 4.5°C.

... “business as usual” scenarios lead to CO₂ doubling over pre-industrial levels between 2050 and 2100.
Projected global average warming

- **Low scenario**
  - Warming of about 0.2°C per decade for next two decades for a range of scenarios

- **Medium scenario**
  - Further warming of ~0.6°C after concentrations stabilized
  - 1.8°C = 3.2°F

- **High scenario**
  - Higher emissions lead to more warming later in century.
  - 3.4°C = 6.1°F
  - 2.8°C = 5.0°F

Higher emissions lead to more warming later in century.
No one lives at the global average

Medium (A1B) scenario (2090-2099): Global mean warming 2.8°C; Much of land area warms by ~3.5°C Arctic warms by ~6°C. A 550 ppm CO2-eq world would more likely than not be warmer.
Projected precipitation change

Underlying physics of precipitation change is better understood.

Pattern is: increases in tropics and high latitudes; decreases in sub-tropics.

Consistent with observed trends.

Multi-model mean change shown where >66% of models agree in sign; >90% of models agree in stippled areas.
Calculus of extremes

The distribution of weather events around the climatic average follows a ‘bell-shaped’ curve.

Climate change can involve change in the average, or the spread around the average (standard deviation), or both.

A shift in the distribution of temperatures has a much larger relative effect at the extremes than near the mean.
Projected changes in extremes

**Precipitation intensity**

a) A2
b) Precipitation intensity

-1.25 -1 -0.75 -0.5 -0.25 0 0.25 0.5 0.75 1 1.25 (std. dev.)

**Heat waves**

c) A2
d) Heat waves

-3.75 -3 -2.25 -1.5 -0.75 0 0.75 1.5 2.25 3 3.75 (std. dev.)
Extremes will increase

- Projected increases in heavy precipitation and drought are linked to physical processes – principally increased absolute humidity and patterns of convergence and divergence in atmospheric transport.

- Precipitation intensity increases - even where total precipitation decreases.

- Risk of 2003 type heat wave doubled in Europe due to current level of greenhouse gases (single study).

- Extreme summer temperatures become at least 20 times more frequent by end of century (average for 3 scenarios and for multiple models).
Wide area average temperature anomaly
~3°C

Soil moisture feedback, i.e. less moisture means more sensible heating

Tens of thousands of premature deaths

Loss of about 500 Mt carbon from soils

Unprecedented drop in crop yields

Europe – July 2003
Number of deaths in Paris in summer 2003 (Ch 8)
Summary

Confidence in climate change science has increased significantly.

Evidence for warming of the climate system is unequivocal.

We are changing the geography of the planet.

Reducing greenhouse gas emissions can reduce the magnitude of change in the longer term.
Glacier mass balance

Cumulative loss of glacier mass in many regions

During the 20th century, glaciers and ice caps have experienced widespread mass losses and have contributed to sea level rise.
Changes in ice sheets

Surface elevation changes shown as red hues where rising and blue where falling.

Evidence for rapid changes in ice flow in some regions.

Very likely that Greenland Ice Sheet shrunk from 1993 to 2003. Thickening in central regions more than offset by increased melting in coastal regions.

Antarctic ice sheet also estimated to have lost mass, but uncertainties are larger.
Tide gauge and satellite data on sea level

Average rate of sea level rise:
1961 – 2003: 1.8 mm /yr
1993 – 2003: 3.1 mm /yr
Sea level trends - satellite altimetry

Since 1993 satellite techniques have provided a much more detailed picture of sea level changes.

Over 1993 – 2003 trends vary significantly from place to place.

The pattern of sea level trends is very similar to that of the underlying change in ocean heat content.
**Carbon Dioxide**

**Fossil fuel emissions:**
- 1980s: 19.8 GtCO₂ /yr
- 1990s: 23.5 GtCO₂ /yr
- 2000-2005: 26.4 GtCO₂ /yr

**Land Use Change flux:**
- 1980s: 5.1 GtCO₂ /yr
- 1990s: 5.9 GtCO₂ /yr

**Atmospheric CO₂ growth rate:**
- 1960 – 2005: 1.4 ppm /yr
- 1995 – 2005: 1.9 ppm /yr
Radiative forcing: CO₂ equivalents

Used to compare different drivers of climate change

<table>
<thead>
<tr>
<th>RF Terms</th>
<th>CO₂-eq of 455 ppm for long lived greenhouse gases</th>
<th>Offset cooling by Aerosols removed within weeks of emission</th>
<th>CO₂-eq of 375 ppm for net human activities</th>
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<tbody>
<tr>
<td>Long-lived greenhouse gases</td>
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<td>Ozone</td>
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<td>Stratospheric water vapour from CH₄</td>
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<td>Surface albedo</td>
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<td>Land use</td>
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<td>Black carbon on snow</td>
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<td>Direct effect</td>
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<td>Cloud albedo effect</td>
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<td>Linear contrails</td>
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<td>Solar irradiance</td>
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<td>Total net anthropogenic</td>
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RF values (W m⁻²) | Spatial scale | LOSU
-0.05 [-0.15 to 0.05] | Continental to global | Med
0.35 [0.25 to 0.65] | Global | Low
0.07 [0.02 to 0.12] | Global | Low
-0.2 [-0.4 to 0.0] | Local to continental | Med - Low
0.1 [0.0 to 0.2] | Local to continental | Med - Low
0.01 [0.003 to 0.03] | Continental | Low
0.12 [0.06 to 0.30] | Global | Low
Anthropogenic climate change signals

**Attribution** – is based on a large number of climate models and simulations with and without greenhouse gases and aerosols.

Observed patterns can only be explained **with** greenhouse gases and aerosols.
Based on pre-2000 literature

No additional climate change policy (no mitigation)

Low, Medium, and High emission scenarios.

“Physics tests” kept atmospheric composition constant.

Compare doing so in 2100 vs doing so in 2000.

Results from
- 14 modelling groups
- 23 models
Near term climate change

For SRES scenarios average warming in all continents will exceed range of natural variability in next few decades.
Sea level rise has 3 main components:

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<th>Component</th>
<th>Description</th>
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<tr>
<td>Thermal expansion</td>
<td>New estimates use much more detailed models and give results slightly less than in TAR. Causes 70 – 75% of projected sea level rise.</td>
</tr>
<tr>
<td>Glaciers and small ice caps</td>
<td>Uncertainties reduced using new data.</td>
</tr>
<tr>
<td>Ice Sheets</td>
<td>Processes that are simulated in ice dynamics models with confidence remain much as in TAR.</td>
</tr>
<tr>
<td>(Total)</td>
<td>New projections are within 10% of those in the TAR but have smaller uncertainties.</td>
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For the parts of sea level rise explained by models, projections for 2100 range from 0.28 to 0.43 m (9 to 16 in).
Sea level rise – limits to knowledge

Accelerated ice sheet discharge observed in recent years implies ice processes that are not in current models.

We can not provide a best estimate or upper bound for sea level rise by 2100

Surface melt on Greenland ice sheet descending into moulin, a vertical shaft carrying the water to base of ice sheet. Photo credit: Roger Braithwaite