Global, and Local, Climate Change

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"The balance of evidence suggests that there is a discernible human influence on global climate"

UN's *Intergovernmental Panel on Climate Change* Second Assessment Report, 1996
"There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activity"

UN's *Intergovernmental Panel on Climate Change* Third Assessment Report, 2001
"Warming of the climate system is unequivocal, as is now evident from observations…"

"Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases."

"Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations. It is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica)."

UN's *Intergovernmental Panel on Climate Change* Fourth Assessment Report, 2007
at the center of the debate is the (natural and anthropogenic) greenhouse effect

the Earth's surface
incoming solar shortwave radiation
atmosphere
 LWRadiation
atmospheric radiation
the Earth's surface
or, with two atmospheric layers

the Earth's surface
observed "facts" about the Earth's radiative budget

Incoming Solar Radiation

Space 100

Atmosphere 100

16 Absorbed by H₂O, Dust, O₃

16 BackScattered by Air

6 Reflected by Clouds

20 Reflected by Surface

4 Absorbed in Clouds

15 Absorbed by H₂O, CO₂

40 Reflected by Clouds

Outgoing Infrared Radiation

Net Emission by H₂O, CO₂

38 Emission by Clouds

26 Net Emission of Infrared Radiation from Surface

21 Sensible Heat Flux

7 Latent Heat Flux

23
"observed" radiative balance

\( SW_{\text{top}} \)

\( LW_{\text{top}} \)

DJF

JJA

DJF

JJA

W m\(^{-2}\)
"observed" radiative balance II

SW$^\text{surf.}$

LW$^\text{surf.}$

W m$^{-2}$
"observed" annual means

SW↑surf.  LW↑surf.  SW↓surf.  LW↓surf.

W m⁻²
radiative equilibrium: incoming = outgoing

1) no atmosphere:

\[ S_o (1 - \alpha) = 4\sigma T_g^4 \]

\[ T_g = \sqrt[4]{\frac{S_o (1 - \alpha)}{4\sigma}} \]

where

\( \sigma \approx 5.7 \cdot 10^{-8} \text{ W m}^{-2} \text{ K}^{-4} \)

is the Boltzmann constant, and

\( S_o \approx 1380 \text{ W m}^{-2} \)

is the solar "constant"
Dec. '06: notice the difference!

available

actually absorbed
with planetary $\alpha \approx 0.3$

$$T_g = \sqrt[4]{\frac{0.7 \cdot 1380 \, \text{W m}^{-2}}{4 \cdot 5.7 \cdot 10^{-8} \, \text{W m}^{-2} \text{K}^{-4}}} \approx 255 \, \text{K}$$

and, for other values of $\alpha$,

the ground temperature in a 1D, no-atmosphere planet
introduce an idealized atmosphere

\[ S_o \]

- top of atmosphere downward shortwave radiation (SW ↓)

\[ \alpha = 0.3 \]

\[ T_a = \text{atmospheric temperature} \]

\[ T_g = \text{ground temperature} \]

\[ S_o (1 - \alpha) \]

- SW ↓ absorbed by ground

\[ 4\sigma T_g^4 = S_o (1 - \alpha) + 4\sigma T_a^4 \]

- ground heat balance

\[ 2\sigma T_a^4 = \sigma T_g^4 \]

- atmosphere heat balance
using the two equations,

\[ 4\sigma T_g^4 = S_o (1 - \alpha) + 4\sigma T_a^4 \]

\[ 2\sigma T_g^4 = S_o (1 - \alpha) \]

\[ T_g = 4 \sqrt[4]{\frac{S_o (1 - \alpha)}{2\sigma}} \]

\[ T_g = 4 \sqrt[4]{\frac{1380 \cdot 0.7}{2 \cdot 5.7 \cdot 10^{-8}}} \approx 303 \text{ K} \]
so the "greenhouse effect" of our "atmosphere" switches

\[ T_g \approx 255 \text{ K} \quad \rightarrow \quad T_g \approx 303 \text{ K} \]

\[ \Delta T_g^{GH} \approx 48 \text{ K} \approx 87^\circ \text{F} \]

or, for other values of \( \alpha \), the greenhouse effect, defined as the ground minus air temperature difference, is
the sensitivity to atmospheric opacity

suppose (as is indeed the case), that the atmosphere absorbs only a fraction \((1-\beta)\) of the upwelling longwave radiation, letting a fraction of it, \(\beta\), to pass through. Then the configuration is

and the atmosphere's heat balance is

\[
(1 - \beta)\sigma T_g^4 = 2\sigma T_a^4
\]

\[
T_a = \sqrt[4]{\frac{1}{2} (1 - \beta) T_g^4}
\]

\[
\frac{1}{4} S_o (1 - \alpha)
\]

\[
\frac{1}{4} S_o
\]

\[
\beta \sigma T_g^4
\]

\[
\alpha \frac{S_o}{4}
\]

\[
\sigma T_g^4
\]

\[
\sigma T_a^4
\]

\[
\frac{1}{4} S_o
\]
The ground heat balance is

\[ \frac{1}{4} S_o (1 - \alpha) + \sigma T_a^4 = \sigma T_g^4 \]

yielding

\[ T_g = \sqrt[4]{\frac{S_o (1 - \alpha)}{2 \sigma (1 + \beta)}} \]

\[ \alpha, \text{ albedo} \]
\[ \beta, \text{ the George W. Bush parameter} \]

← more CO₂ and water vapor
The ground heat balance is yielding more CO$_2$ and water vapor.
which is not all that unrealistic
zonal- and annual-mean climatological ratio of $\uparrow LW, 100 \times (\text{top/surface})$
the moral of our brief intro to radiation transfer:

1. the natural greenhouse effect is a crucial element of life on earth
2. the more opaque the atmosphere - the warmer the ground
The Observed Record: it's getting hot

$\Delta T'$ from '61-'90 mean, K

annual mean $T'$ extremes, K; $\Delta$ from '61-'90 mean; 71% of land area
spatial-mean temperature anomalies

(a) Globe
- SST
- NMAT

(b) Globe
- HadSST2
- COBE-SST (JMA)
- NCDC

(c) Northern Hemisphere
- HadSST2
- HadMAT

(d) Southern Hemisphere
- HadSST2
- HadMAT
zonal-mean 1900-2005 surface temps. departures from '61-'90 mean
linear temp. trends, 1901-2005, K century$^{-1}$
linear temp. trends, 1979-2005, K decade$^{-1}$
Annual-Mean Surface Temperature Changes
1901-2000

IPCC 2001
Annual-Mean Surface Temperature Changes 1976-2000
and seasonally

DJF

JJA
global mean $T$

Estimated actual global mean temperatures (°C)

Difference (°C) from 1961 - 1990

Global mean temperature trends
final year = 2005

trend, 0.1 K decade$^{-1}$

number of years used to calculate trend

25 50 100 150
extremes cold events

days per decade with
$T< (1961-1990$ PDF's 10th percentile)
extremes warm events

days per decade with $T > (1961-1990$ PDF's 90th percentile)
not surprisingly, ice responds

tongue length of major global glaciers

tropics, New Zealand, Patagonia, mainly Canadian Rockies, South Greenland, Iceland, Jan Mayen, Svalbard, Scandinavia, European Alps, Caucasus and central Asia
in all latitudes
global glacier mass balance, 1988-1998

Area of circle is proportional to the log of the rate of mass loss or gain. Largest circles: 2-3m/yr

mass balance:
negative
positive

global glacier mass balance

Kilimanjaro
Mt. Kenya
Uganda

NY Times, 3/5/06
Glacier National Park, Montana

two glaciers that represent the all others in the park

average summer temperature

Glacier size, hectares
Grinnell glacier, GNP, Montana

1910                                          1998
Boulder glacier, GNP, Montana

1932

1988
raising sea level

Annual, global mean sea level (mm).

TOPEX/Poseidon

Jason

Tide gauges
Satellite altimetry
global ocean, upper 300 m

heat content, $10^{22}$ J

volume mean T anomaly, °C

calendar year

Southern hemisphere

Northern hemisphere
five-year running composites of heat content in the upper 3 km of the major ocean basins (Levitus)
seawater thermal expansion
warming has been going on for a while
compilation of millennium-long reconstructions
even on really long timescales

$10^3$ years before the present
at the same time, atmospheric concentrations of greenhouse gases are rising
$\text{CO}_2$

Mauna Loa CO$_2$

PPM


NOAA  SIO
pre-industrial CO$_2$: $\sim 275$ ppm
and for a while now current CO$_2$: $\sim 375$ ppm

$\sim 2,000$ yr history of the three main non-H$_2$O GHGs
even for a **LONG** while!
with the radiative effect (over 1750-2005) of
water vapor feedback

$2\times\text{CO}_2 + \text{H}_2\text{O} + \text{clouds}$

the consequences of CO$_2$ doubling
while models are not perfect
they seem not entirely useless either (remember: climate, not weather)
So:

It's getting hot most everywhere, but especially over land.
if it's so compelling, why is anthropogenic climate change so *hotly* contested?!

part of the problem is distinguishing a low-frequency cycle from a secular trend

A single frequency

Multiple frequencies
slow drift of PDFs
another issue: imperfectly known PDFs

daily temperature in Podunk, TX

temperature range, °F

frequency of occurrence or likelihood of realizing

5-10 11-15 16-20 21-25 26-30 31-35 36-40 41-45 46-50 51-60 61-65 66-70 71-75 76-80 81-85 86-90 91-100 101-105
now when you get a freaky event…

and those questions are as likely to be answered to your fullest satisfaction as is the Gore-v.-Bush saga…

temperature range, °F

you naturally ask - how likely is that event?
So:

- Recent global surface temperatures are unprecedented this century, and likely *at least* the past millennium
- It is difficult to explain the recent surface warming by invoking natural climate variability
- Recent surface warming is largely consistent with simulations of the effects of anthropogenic influence on climate
Millbrook, NY

position: 41.785°N, 73.694°W
elevation: ~570 ft
population ('03): ~1,500

- **sampling rate:** a measurement every 15 seconds
- **reported values:** hourly min./ave./max.
- **variables:** wind (speed, direction, rms) relative humidity, air temperature, near-full radiation set.
- **transform to:** hour-mean deviations from the diurnal and seasonal cycles by subtracting, such climatologies as, e.g.,
for each time series, compute linear trend, and perform a 500-member, 10% data withheld, Monte Carlo validation
normalized linear trends over 1988-'08

relative humidity

air temperature
the basics:

- $T\uparrow$ actually significant except in spring
- summer $T\uparrow$ is highest during the warmest hours and for $T_{\text{max}}$; fall $T\uparrow$ is also highest during the warmest hours
- summer AM $r$'s also rise, with $r_{\text{max}}$ rising most
- PM $r$'s drop significantly, in accordance with CCE
winds shift
$T_{\text{max}}, \text{DJF}$

$T_{\text{min}}, \text{DJF}$

$T_{\text{max}}, \text{JJA}$

$T_{\text{min}}, \text{JJA}$
and curiously,
**SO:**

- the earth is most definitely getting warmer
- there is a very strong and well-developed theory connecting greenhouse gases and surface temperatures
- many independent lines of evidence are consistent with the notion that the observed warming does result from elevated GHG concentrations in the atmosphere
- uncertainty remains, but keeps getting smaller
- puzzles abound…