Greenhouse gases, emissions, and the carbon balance

How fast will CO₂ reach dangerous levels?

Wouter Peters
Energydays 2013
Mauna Loa CO$_2$ record
Mauna Loa CO$_2$ record

Carbon dioxide passes symbolic mark
What 400PPM CO2 looks like

What data says it looks like

What skeptics say it looks like

What Al Gore says it looks like

What plants say it looks like

What Alarmists say it looks like

What it really looks like - just a number
X00 ppm CO$_2$: So what?
X00 ppm CO₂: So what?

CO₂ in ppm
T in degC

Modern Man
LGM
X00 ppm CO$_2$: So what?

- Climate forcing ($\neq$ climate change!)

“if the quantity of carbonic acid [$H_2CO_3$] increases in geometric progression, the augmentation of the temperature will increase nearly in arithmetic progression.”
X00 ppm CO$_2$: So what?

• Climate forcing (≠ climate change!)

“if the quantity of carbonic acid [H$_2$CO$_3$] increases in geometric progression, the augmentation of the temperature will increase nearly in arithmetic progression.”
Surface ocean acidification

$\text{CO}_2(g)$

$\text{CO}_2 \cdot \text{H}_2\text{O}$

$\text{HCO}_3^-$

$\text{HCO}_3^-$

$\Delta \text{sea-surface pH} [-]$
X00 ppm CO₂: So what?

- Surface ocean acidification

  \[
  \begin{align*}
  \text{CO}_2(g) & \leftrightharpoons \text{CO}_2 \cdot \text{H}_2\text{O} \\
  \text{CO}_2 \cdot \text{H}_2\text{O} & \leftrightharpoons \text{HCO}_3^- + \text{H}^+ \\
  \text{HCO}_3^- & \leftrightharpoons \text{CO}_3^{2-} + \text{H}^+
  \end{align*}
  \]

  \[\text{pH} = - \log(\text{H}^+)\]
CaCO$_3$: Calcite
Aragonite

X00 ppm CO$_2$: So what?
Contents

• Why do we care about X00 pm CO$_2$?
• What do we know about the carbon balance, and the contributors to CO$_2$ increase?
• The virtues of integrated greenhouse gas monitoring
• How fast are we approaching dangerous levels?
Mauna Loa CO$_2$ record
PARTS PER MILLION


YEAR

30 years

50 ppm
The carbon cycle

\[ \frac{\Delta [\text{CO}_2]}{\Delta t} = F_{\text{fossil}} + F_{\text{fire}} + F_{\text{ocean}} + F_{\text{biosphere}} \]
The carbon cycle

\[
\frac{\Delta [\text{CO}_2]}{\Delta t} = F_{\text{fossil}} + F_{\text{fire}} + F_{\text{ocean}} + F_{\text{biosphere}}
\]

- CO₂ is nearly inert
- 1 PgC = \(10^{15}\) g = billion tons
- 1 PgC = 0.47 ppm
- 1 ppm = 2.123 PgC
The carbon cycle

\[
\frac{\Delta [\text{CO}_2]}{\Delta t} = F_{\text{fossil}} + F_{\text{fire}} + F_{\text{ocean}} + F_{\text{biosphere}}
\]

\[
\left( \frac{395 - 342}{30} \cdot \frac{1}{0.47} \right) = 6 + 2 + F_{\text{ocean}} + F_{\text{biosphere}}
\]

\[
3.8 = 6 + 2 + F_{\text{ocean}} + F_{\text{biosphere}}
\]

\[
-4.2 = F_{\text{ocean}} + F_{\text{biosphere}}
\]
The carbon cycle

\[
\frac{\Delta [\text{CO}_2]}{\Delta t} = F_{\text{fossil}} + F_{\text{fire}} + F_{\text{ocean}} + F_{\text{biosphere}}
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3.8 = 6 + 2 + F_{\text{ocean}} + F_{\text{biosphere}}

-4.2 = F_{\text{ocean}} + F_{\text{biosphere}}

The global ocean and biosphere are a net sink of carbon dioxide
Saturation of the Southern Ocean CO₂ Sink Due to Recent Climate Change
Corinne Le Quéré, Christian Rödenbeck, Erik T. Buitenhuis, Thomas J. Conway, Ray Langenfelds, Anthony Gomez, Casper Labuschagne, Michel Ramonet, Takakiyo Nakazawa, Nicolas Metzl, Nathan Gillett, Martin Heimann

CLIMATE CHANGE
Illuminating the Modern Dance of Climate and CO₂
Peter Cox and Chris Jones

LETTERS
Searching out the sinks
Martin Heimann

ATMOSPHERIC SCIENCE
Himalaya—Carbon Sink or Source?
Jerome Gaillardet and Albert Galy

Global nitrogen deposition and carbon sinks

The carbon balance of terrestrial ecosystems in China
Shilong Piao, Jingyun Fang, Philippe Ciais, Philippe Peylin, Yao Huang, Stephen Sitch & Tao Wang

REVIEW ARTICLE
Net carbon dioxide losses of northern ecosystems in response to autumn warming

High sensitivity of peat decomposition to climate change through water-table feedback
Takeshi Ise, Allison L. Dunn, Steven C. Wofsy and Paul R. Moorcroft

PROGRESS ARTICLE
Carbon accumulation in European forests

The effect of permafrost thaw on old carbon release and net carbon exchange from tundra
Mauna Loa CO$_2$ record
O$_2$/N$_2$ ratio drawdown

Needs large source of carbon

$\text{CH}_{1.4} + 1.35 \text{ O}_2 \rightarrow \text{CO}_2 + 0.7 \text{ H}_2\text{O}$

courtesy of Scripps, LaJolla, USA
$^{13}$C isotope in CO$_2$

Needs strong source of ‘light’ carbon
$^{14}$C isotope in CO$_2$

Radiocarbon ($^{14}$CO$_2$) dating

$\leq 60,000$ yrs
$^{14}$C isotope in CO$_2$

Needs strong source of ‘old’ carbon
## Multi-tracer monitoring

<table>
<thead>
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<th>CO\textsubscript{2}:CO</th>
<th>O\textsubscript{2}/N\textsubscript{2}</th>
<th>\textsuperscript{14}C/\textsuperscript{12}C</th>
<th>\textsuperscript{13}C/\textsuperscript{12}C</th>
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<td>↓</td>
<td>↓</td>
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<td>↓</td>
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Integrated Monitoring

\[
\frac{d[CO_2](x, y, z, t)}{dt} = F_{\text{traffic}}(x, y, z, t) + F_{\text{powerplants}}(x, y, t) + F_{\text{heating}}(x, y, t) + F_{\text{northsea}}(x, y, t) + F_{\text{rivers}}(x, y, t) + F_{\text{ocean}}(x, y, t) + F_{\text{photosynthesis}}(x, y, t) + F_{\text{respiration}}(x, y, t) + F_{\text{soil}}(x, y, t) + P_{\text{chemistry}}(x, y, z, t) + A(x, y, z, t) + D(x, y, z, t)
\]

\[
dt = \text{hours to years}
\]

\[
x, y, z = 1 \text{ to } 100 \text{ kilometers}
\]

\[
A, D = \text{Atmospheric Transport}
\]
Example 1: CarbonTracker

www.carbontracker.eu
Example 1: CarbonTracker