Adaptation to Sea Level Rise: Protecting the Coastal Zone Against, or Preparing it for, Inundation?
Adaptation to Sea Level Rise: Protecting the Coastal Zone Against, or Preparing it for, Inundation?

Hans-Peter Plag
October 19, 2015
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1 or 2 meters of sea level rise in a century ...

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The Baseline: Past Climate and Sea Level Changes

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The Syndrome: Recent Climate and Global Changes

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The Diagnosis: Leaving the “safe operating space”

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The Diagnosis: Leaving the “safe operating space”
The Prognosis: Anticipating Surprises
The Therapy: “Lifestyle” changes

Hans-Peter Plag
October 19, 2015
The Baseline: Past Climate Variability
Climate Change is a long-term shift in the statistics of weather - averages, frequency and magnitude of extremes.
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Climate is determined by:

- incoming radiation (sun)
- reflected radiation (albedo)
- retained heat (Greenhouse gases)
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Climate can change from local to global scales.
Climate Change is a long-term shift in the statistics of weather - averages, frequency and magnitude of extremes.

Climate is determined by:
- incoming radiation (sun)
- reflected radiation (albedo)
- retained heat (Greenhouse gases)

Climate can change from local to global scales.

Climate can change a lot over time.
The Baseline: Past Climate Variability

INTERNATIONAL CHRONOSTRATIGRAPHIC CHART

Series/Epoch  Stage /Age  Numerical age (Ma)  Environm. / Clim  Eleutheria / Era  Cyrenium / Period  Numerical age (Ma)

Holoceane  Upper  Tihonian  152.4 ± 0.9  Neoproterozoic  Cryogenian  568 ± 0.5
  Middle  Kimeridgian  157.3 ± 1.0  Frasnian  367 ± 0.5
  Lower  Pliensbachian  192.7 ± 0.7  Emian  458 ± 0.5
  Jurassic  Lower  Kimmeridgian  192.6 ± 0.5  Pragian  458 ± 0.5
  Middle  Oxfordian  178.6 ± 0.5  Lovanium  486 ± 0.5
  Upper  Kimmeridgian  157.3 ± 1.0  Trosselian  507 ± 0.5
  Carnian  193.9 ± 0.5  Pragian  507 ± 0.5
  Lower  Ladinian  242 ± 0.5  Cisuralian  526 ± 0.5
  Upper  Norian  257 ± 0.5  Tiahsian  546 ± 0.5
  Lower  Callovian  247 ± 0.5  Tiahsian  546 ± 0.5
  Upper  Oxfordian  252.1 ± 0.5  Maastrichtian  566 ± 0.5
  Lower  Kimmeridgian  252.1 ± 0.5  Maastrichtian  566 ± 0.5

Cretaceous

Upper  Cenomanian  80.5 ± 0.5  Maastrichtian  566 ± 0.5
  Turonian  80.5 ± 0.5  Maastrichtian  566 ± 0.5
  Santonian  80.5 ± 0.5  Maastrichtian  566 ± 0.5
  Campanian  80.5 ± 0.5  Maastrichtian  566 ± 0.5
  Maestrichtian  80.5 ± 0.5  Maastrichtian  566 ± 0.5

Cenozoic

Upper  Miocene  15.9 ± 0.5  Pliocene  5.0 ± 0.5
  Pliocene  15.9 ± 0.5  Pliocene  5.0 ± 0.5
  Pleistocene  1.8 ± 0.5  Holocene  0.0 ± 0.5
  Holocene  1.8 ± 0.5  Holocene  0.0 ± 0.5

Unit of all eras and in the sequence of time defined by Global Boundary Stratigraphic Section and Points (GSSP) for their lower boundaries, including those of the Andean and Australian, long defined by Global Boundary Stratigraphic Ages (GCSA) (1996) and International Commission on Stratigraphy (ICS) for the upper boundary. Numerical ages are subject to revision and do not define units in the Phanerzoic and the Paleozoic for which the U.S. Geological Survey provided web or in the Paleozoic for which the ICS published 12520003.01.07.01.png.
The Baseline: Past Climate Variability

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<td>Pliocene</td>
<td>Piscocian</td>
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INTERNATIONAL CHRONOSTRATIGRAPHIC CHART

International Commission on Stratigraphy

v 2014/02

[Image of the International Chronostratigraphic Chart]
The Baseline: Past Climate Variability

<table>
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<tr>
<th>Subdivisions of the Quaternary System</th>
<th>System/Period</th>
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<td>Gelasian</td>
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Neogene
Pliocene
Pleistocene
older

INTERNATIONAL CHRONOSTRATIGRAPHIC CHART
www.stratigraphy.org
International Commission on Stratigraphy
v 2014/02
# The Baseline: Past Climate Variability

## Subdivisions of the Quaternary System

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<th>Stage/Age</th>
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<td>Miocene</td>
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## Pliocene

- **PlIOCEN***
  - **PlIOCEN***
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                                                                                     **INTERNATIONAL CHRONOSTRATIGRAPHIC CHART**
                                                                                     **INTERNATIONAL COMMISSION ON STRATIGRAPHY**
                                                                                     **www.stratigraphy.org**
                                                                                     **v 2014/02**
                                                                                     **Chart drafted by J. C. Cohen & S. G. P. Fominykh; International Commission on Stratigraphy, 2014.**
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The Baseline: Past Climate Variability
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Rockstrom and Klum, 2015
The Baseline: Past Climate Variability

Rockström and Klum, 2015
The Baseline: Past Climate Variability

Marcott et al., 2013

Rockstrom and Klum, 2015
The Baseline: Past Climate Variability

(a) CO₂, CH₄ and Sea Level

(b) Climate Forcing

(c) Temperature Change
The Baseline: Past Climate Variability

The “Safe Operating Space”

Marcott et al., 2013

Marcott et al. reconstruction
Mann et al. reconstruction

Years (BP)

Temperature Anomaly (°C)

(AD 1961-1990)

CH₄ and Sea Level

Climate Forcing

Temperature Change
The Baseline: Past Climate Variability

The “Safe Operating Space”

Marcott et al., 2013

Marcott et al., 2013

Holocene
The Baseline: Past Climate Variability

Global and Local Sea Level Changes

![Graph showing global and local sea level changes over time. The graph plots sea level change in meters against thousands of years ago.]
20,000 years ago, sea level in Northern America and Scandinavia was up to 600 m higher than today, and in some other location 200 m lower.
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Local Sea Level changes can be much larger than the global average changes.
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During the last 7,000 years, global (and local) sea level was exceptionally stable.

Sea Level changes can be much larger than what we know from our history.
The Baseline: Past Climate Variability

(a) CO₂, CH₄ and Sea Level

(b) Climate Forcing

(c) Temperature Change
The Baseline: Past Climate Variability

Normal Range up to 1900
The Baseline: Past Climate Variability

Long-term (centuries to millennia) correlations:
• 130 ppm CO
• 130 ppm CO

Normal Range up to 1900
The Baseline: Past Climate Variability

Long-term (centuries to millennia) correlations:

- 130 ppm CO
- 130 ppm CO

Normal Range up to 1900

Holocene
The Baseline: Past Climate Variability

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The Baseline: Past Climate Variability
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Global Temperature Changes

Global Sea Level Changes

Marcott et al., 2013

---Holocene---

Temperature Anomaly (°C)

Years (BP)

Marcott et al. reconstruction

Mann et al. reconstruction

---Holocene---

Marcott et al., 2013
During the Holocene, climate, global temperature, and sea level were exceptionally stable; a perfect condition for the development of civilization.

Marcott et al., 2013

The Baseline for Civilization: During the Holocene, climate, global temperature, and sea level were exceptionally stable; a perfect condition for the development of civilization.
The Baseline: Past Climate Variability

Global Temperature Changes

Global Sea Level Changes

The Holocene was a “safe operating space for humanity”
The Baseline: Past Climate Variability

Global Temperature Changes

Global Sea Level Changes

The Holocene was a "safe operating space for humanity"
The Baseline: Past Climate Variability

Global Temperature Changes

The Holocene was a “safe operating space for humanity”

Global Sea Level Changes

Marcott et al., 2013
Key Points
Key Points

During the Holocene, climate and sea level were exceptionally stable

The Holocene was a “safe operating space for humanity”
The Syndrome: Recent Climate and Global Change
The Syndrome: Recent Climate and Global Change

Temperature 2008-2012 compared to 1900
Heat storage:

**Where heat is stored**

Scientists say much of the excess carbon dioxide given off by fossil-fuel burning is absorbed by the oceans, which also take up most of the excess heat energy that would otherwise be going into the atmosphere. As a result, the oceans are becoming warmer and more acidic, and sea levels are rising.
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Heat storage:
The Syndrome: Recent Climate and Global Change

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The Syndrome: Recent Climate and Global Change
The Syndrome: Recent Climate and Global Change

(a) Observed globally averaged combined land and ocean surface temperature anomaly 1850–2012

- Annual average Temperature
- Decadal average

Year: 1850, 1900, 1950, 2000
The Syndrome: Recent Climate and Global Change

(a) Observed globally averaged combined land and ocean surface temperature anomaly 1850–2012

- Annual average Temperature
- Decadal average

(b) Northern Hemisphere spring snow cover

(c) Arctic summer sea ice extent

(d) Change in global average upper ocean heat content

(e) Global average sea level change

IPCC, 2013
The Syndrome: Recent Climate and Global Change

(a) Observed globally averaged combined land and ocean surface temperature anomaly 1850–2012

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- Decadal average Temperature

(b) Sea Ice

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(d) Global average sea level change

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(c) Atmospheric CO₂

(d) Surface Ocean CO₂ and pH

IPCC, 2013
The Syndrome: Recent Climate and Global Change

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(c) Arctic summer sea ice extent

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(e) Surface Ocean CO2 and pH

(f) Global sea level change

IPCC, 2013
The Syndrome: Recent Climate and Global Change
The Syndrome: Recent Climate and Global Change

Population | GDP | CO2 | CH4

1750 - 2000

Temperature | Floods

McDonald’s | Cars | Deforestation | Extinction

Figure 1. An enterprise to reckon with. Human manipulation of their environment began in earnest during the Industrial Revolution and accelerated markedly after the 1950s, as IGBP’s Great Acceleration graphs show. Modified after Steffen W et al. (2004).
The Syndrome: Recent Climate and Global Change

We are Reengineering the Planet ...

Population GDP CO2 CH4
1750 2000 Temperature Floods

McDonald’s Cars Deforestation Extinction

Figure 1. An enterprise to reckon with. Human manipulation of their environment began in earnest during the Industrial Revolution and accelerated markedly after the 1950s, as IGBP’s Great Acceleration graphs show. Modified after Steffen W et al. (2004).
The Syndrome: Recent Climate and Global Change
We are moving out of the Holocene and the “safe operating space for humanity” (Rockstroem et al., 2009):

- Climate Change (***)
- Ocean acidification (**) 
- Stratospheric ozone depletion (*)
- Nitrogen (******) and Phosphorous cycles (**) 
- Global freshwater (*)
- Change in land use (*)
- Biodiversity loss (*******)
- Atmospheric aerosols (?)
- Chemical pollution (?)

**Figure 1 | Beyond the boundary.** The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded.
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- Change in land use (*)
- Biodiversity loss (******)
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- Chemical pollution (?)

Climate change and sea level rise are symptoms, not the cause, the “sickness.”

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Chemical pollution (?)

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Key Points

During the Holocene, climate and sea level were exceptionally stable.
The Holocene was a “safe operating space for humanity”
Key Points

During the Holocene, climate and sea level were exceptionally stable.
The Holocene was a “safe operating space for humanity”

During the last hundred years, we have introduced rapid and large changes.
The Diagnosis: Leaving the “Safe Operating Space”
The Diagnosis: Leaving the “Safe Operating Space”

“Normal Range” (800,000 years)
The Diagnosis: Leaving the “Safe Operating Space”

“Current State”

“Normal Range” (800,000 years)
HUMANITY’S JOURNEY
The Evolution of Key Environmental Factors

10,000 YRS

AIR TEMPERATURE
0.01°C/century

CO₂
0.2 ppm/century

SEA LEVEL
0.05 m/century

POPULATION
16 M/century

ENERGY CONSUMPTION
0.01 TW/century

GINI COEFFICIENT
0.003/century

Stability
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Humanity's Journey
The Evolution of Key Environmental Factors

- Air Temperature: 0.01°C/century
- CO₂: 0.2 ppm/century
- Sea Level: 0.05 m/century
- Population: 16 M/century
- Energy Consumption: 0.01 TW/century
- Gini Coefficient: 0.003/century

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Humanity's Journey
The Evolution of Key Environmental Factors

<table>
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<td>Carbon Dioxide ppm/century</td>
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<td>120</td>
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<tr>
<td>Sea Level metres/century</td>
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<td>Population million/century</td>
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<td>5500</td>
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<td>Energy Consumption TW/century</td>
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<tr>
<td>Gini Coefficient /century</td>
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ichen: 100X Faster
600X Faster
4X Faster
350X Faster
1600X Faster
100X Faster

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<th>Factor</th>
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<td>0.003</td>
<td>0.3</td>
<td>100X Faster</td>
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**Holocene: Stability**
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<th>20th and 21st Century</th>
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<tr>
<td>Air Temperature °C/century</td>
<td>0.01</td>
<td>1.0</td>
</tr>
<tr>
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</tr>
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**Humanity’s Journey: The Evolution of Key Environmental Factors**

- **Holocene: Stability**
- **20th and 21st Century: Change, imbalance**

© 2015 Tivah
Key Points

During the Holocene, climate and sea level were exceptionally stable.
The Holocene was a “safe operating space for humanity.”

During the last hundred years, we have introduced rapid and large changes.
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The Prognosis: Anticipating Surprises
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Global average surface temperature change

(a)
The Prognosis: Anticipating Surprises

IPCC Assessment: Very Likely by 2100

Marcott et al., 2013
The Prognosis: Anticipating Surprises

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---Holocene---

---Post-Holocene---

Marcott et al., 2013
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Global mean sea level rise

Mean over 2081–2100

Year

(m)

IPCC, 2013
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Note: No accelerated contribution from Greenland and Antarctic ice sheets considered

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Gravity Recovery and Climate Experiment (GRACE)
The Prognosis: Anticipating Surprises

Greenland and Antarctica

During the period of April 2002 to February 2009, the mass loss of the polar ice sheets was not constant but increased with time, implying that the ice sheets’ contribution to sea level rise was increasing.

Greenland:
- mass loss increased from 137 Gt/yr in 2002–2003 to 286 Gt/yr in 2007–2009
- acceleration of \(-30 \pm 11\) Gt/yr\(^2\) in 2002–2009.

Antarctica:
- mass loss increased from 104 Gt/yr in 2002–2006 to 246 Gt/yr in 2006–2009
- acceleration of \(-26 \pm 14\) Gt/yr\(^2\) in 2002–2009.
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The last 12 years of observing the ice sheets have revealed many surprises …
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There is the potential for surprises and new extremes …
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Already happening: Disappearance of late-summer Arctic sea ice

Arctic ice extent melt, 1979 - 2014

Elliott, 2015
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Rossman & Marash (2014)
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August 29, 2015: “The critical question thus becomes: Is Greenland likely to lose even more ice than it’s currently losing per year — and could Antarctica do the same?”

Why NASA’s so worried that Greenland’s melting could speed up
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800 Years?
100 Years?
How worried should we be?
The Prognosis: Anticipating Surprises
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Understanding thresholds
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The threshold is not where the boat goes over the edge, it is far up the river, when the people in the boat lose the option to get to the shore.
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On a big, unknown river, don’t go into the middle, stay close to the shore.

*Jim White*
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Lenton & Schellnhuber (2007) *Nature Reports Climate Change*
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*Francis and Vavrus, 2015*
The Prognosis: Anticipating Surprises

“Current State”

“Normal Range” (800,000 years)
The Prognosis: Anticipating Surprises

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Our Commitment: The “~400 ppm CO₂ World”:
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Hansen et al., 2015: “… Evidence … that 2°C global warming is highly dangerous.”
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How likely is it that LSL might by far outside the limited range considered? **WE CANNOT EXCLUDE THIS TO HAPPEN IN THE “Post-Holocene”**

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Necessary:
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*Rockstrom and Klum, 2015*
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- making room for the water
- a built environment for extreme floods (buildings and services)
- preparing the coastal zone for future inundation
- making room for ecosystem migration

Rockstrom and Klum, 2015
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- making room for ecosystem migration

Living where it is safe, working where it is needed

*Rockstrom and Klum, 2015*
## Key Points

During the Holocene, climate and sea level were exceptionally stable

The Holocene was a “safe operating space for humanity”

During the last hundred years, we have introduced rapid and large changes

The system is already now outside the “normal range” and in the transition to the Post-Holocene

Our knowledge is changing very fast and we may not know all thresholds

There is a potential for surprises and we need to be prepared
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Paradigm shifts may be required; for example: instead of “Sea level does not change very and changes in the coastal zone are gradual” assume “Sea level can change fast and coastal zones can migrate rapidly.”
The Therapy: “Lifestyle” Changes
Sustainable Development is a development that meets the needs of the present while safeguarding Earth’s life support systems, on which the welfare of current and future generations depends.” (Griggs et al., 2013)
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Economy against humanity:
An economy that meets our needs by burning fossil fuels and destroying Earth’s life-support system is like a doctor who practices medicine by killing the patients.
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“What is good for Earth’s life support system is good for humanity”
“No problem can be solved with the same consciousness that created it.”

*Albert Einstein*

“It is difficult to get a man to understand something when his job depends on not understanding it”

*Upton Sinclair*