Our Changing Planetary Environment and Impacts for Hawaii

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Outline of Presentation

I. Introductory comments: environmental change issues

II. The most discussed contemporary environmental issue: global warming
   A. Consequences
   B. Some surprises

III. Conclusions
The Two Major Agents of Human-Induced Global Environmental Change

1. The distribution and rates of growth of the human population

2. Demand for economic growth with the concomitant utilization of natural resources, e.g., fossil fuels of coal, oil and gas
Human Activities Stemming from Population Growth and the Demand for Economic Growth

1. Fossil fuel and biomass combustion

2. Deforestation and other land-use changes

3. Agricultural practices

4. Resource consumption

5. Halocarbon, pesticide, and other synthetic chemical production and release
Some Major Global (Worldwide) Environmental Change Issues

1. Climatic changes from anthropogenic inputs to the atmosphere of carbon dioxide ($CO_2$), methane ($CH_4$), and other greenhouse gases, and sulfur dioxide ($SO_2$)

2. Human interference and disruptions in the manner in which carbon, nitrogen, phosphorus, sulfur, trace metals, and other substances circulate about the Earth (the biogeochemical cycles of the elements)

3. Emissions of nitrogen and sulfur oxide gases and volatile organic compounds to the atmosphere and the issues of acid deposition and photochemical smog

4. Depletion of the stratospheric ozone layer and associated increase in the flux of ultraviolet radiation to the Earth’s surface

5. Increasing rates of tropical deforestation and other large scale land-use change destruction of habitat, with potential effects on climate and the hydrologic and nutrient cycles

6. Disappearance of biotic diversity through explosive rates of species extinction

7. Global consequences of the application of xenobiotic (foreign and generally harmful to organisms) chemicals--DDT, dieldrin, etc

8. Cultural eutrophication

9. Other water and air quality issues

10. Waste disposal: municipal, toxic chemical, radioactive, and that resulting from natural resource exploitation
Global Warming
THE GLOBAL WARMING ISSUE

Planet has always had a natural greenhouse effect in which outgoing long-wave, infrared radiation from the planetary surface is absorbed by the greenhouse gases in the atmosphere of CO₂, CH₄, N₂O, and tropospheric O₃ warming the Earth’s surface. Today it is a matter of an enhancement of the greenhouse effect developed from emissions of these same gases, plus the industrially made chlorofluorocarbons (CFCs), to the atmosphere because of human activities, e.g., fossil fuel combustion.
Science Has Spoken: Global Warming Is a Myth

BY MARKETING THE WALL STREET JOURNAL, DECEMBER 3, 1997

The other side of the coin

500 million years of long-term changes in atmospheric CO$_2$, ocean pH and dissolved inorganic carbon, and climate driven by plate tectonics (balance of uptake of CO$_2$ in weathering vs volcanic release of CO$_2$) and plant evolution

Adapted from Mackenzie, Arvidson and Guidry interactive cycles model, 2007
European Project for Ice Coring in Antarctica, Dome Concordia Ice Core. Changes in atmospheric gas concentrations and hence temperature caused by variations in orbital parameters, ocean circulation, Sun’s energy emission, and natural feedbacks like sea ice coverage, ice sheet extent, wetland distribution, etc.

Out of the environmental window of the past >600 ky!

Siegenthaler et al., 2005
Growth of industrial emissions of CO$_2$ to the atmosphere (80% of total emissions). With only 4.5% of the world population, the United States has accounted for 33% of these emissions since 1950.

Data from Carbon Dioxide Information Analysis Center (CDIAC), 2004
Historical and projected land-use (mainly deforestation) change CO₂ emissions

Houghton, et al., 1998
World Population and Fossil Fuel and Land Use Emissions Time Trend

Demand for economic growth was driven by the use of fossil fuels especially for the past 150 years leading to many of our environmental ills.

In addition, national energy consumption/capita, mainly as fossil fuels, and GDP/capita were linearly correlated until the early 1970s when the relationship broke down and globally energy intensity decreased (efficiency increased)--a result of the Arab embargoes. Mackenzie and Lerman, 2006.
A reminder!

Hawaii’s Petroleum Imports 2005

Movement of Petroleum to Hawaii - 2005
Barrels per Day - Average (Pt)

CRUDE OIL
- Saudi Arabia 17.6%
- China 16.4%
- Vietnam 14.1%
- Indonesia 13.4%
- USA - Alaska 11.4%
- Brunei 8.1%
- Malaysia 5.9%
- Australia 3.7%
- Yemen 2.0%
- U.A.E 2.0%
- Others 7.5%

REFINED PRODUCT
- S. Korea 51.6%
- USA 28.6%
- Kuwait 7.3%
- Taiwan 6.5%
- Malaysia 2.6%
- Canada 1.5%
- Others 1.9%

NOTE: Arrows’ width are roughly proportionate to percentages of oil imports from sources.

Source of strategic and environmental problems
Without doubt human activities have changed atmospheric chemistry.

- **Carbon Dioxide**
  - 280 ppmv in 1850

- **Nitrous Oxide**
  - 275 ppbv in 1850

- **Methane**
  - 730 ppbv in 1850

1987 Montreal Protocol

0 pptv in 1850

CDIAC, 2006
Atmospheric carbon dioxide (CO$_2$) increase at the Mauna Loa Observatory from 1958 to 2007. Notice the seasonal pattern of variation due to the “breathing” of Northern Hemisphere temperate and boreal forests.
SOME CONSEQUENCES OF GLOBAL WARMING FOR THE WORLD AND HAWAII
Northern Hemisphere temperature record

The “Hockey Stick” of Global Mean Surface Temperature

Other studies have confirmed this general trend but debate still ensues.

Mann et al., 1999
Global land-ocean temperature anomaly (°C) 2001-2005 mean surface temperature anomaly (°C)

Fig. 1. Surface temperature anomalies relative to 1951-1980 from surface air measurements at meteorological stations and ship and satellite SST measurements. (A) Global annual mean anomalies. (B) Temperature anomaly for the first half decade of the 21st century.

Hansen et al., 2006
Regional and global temperature trends for most of the 20th century. Black lines are from observations and red shaded areas are for a composite of models using both natural and anthropogenic forcings. Blue shaded areas are for natural forcings of only solar activity and volcanic emissions (IPCC, 2007).
Some Hawaii surface temperature records: care must be taken in interpretation because of urban heat effect; in general high elevation temperature stations like Mauna Loa show small but significant warming trends (Giambelluca, 2007)
Pacific region surface temperature changes between the end of the 20th century and the end of the 21st century: Hawaii 2-3 °C warmer

Shea et al., in Guidry and Mackenzie, 2006: Hadley HADCM2 model
Spatial patterns of percent precipitation changes for the end of the 21st century
Hawaii Rainfall Index (HRI): Index is the winter mean of the standardized rainfall amounts for 27 stations on three islands during a given year.

Becoming drier?

Blue dots: winter means

Chu and Chen, 2005; Giambelluca, 2007
Pacific region precipitation changes between the end of the 20th century and the end of the 21st century: Hawaii perhaps wetter, perhaps drier (mainly a function of elevation of trade wind inversion above which rainfall decreases sharply)

Shea et al., in Guidry and Mackenzie, 2006: Hadley HDCM2 model
Annual averages in millimeters from reconstructions (red), tide gauges (blue) and satellite altimetry (black) relative to the average for 1961-1990

1870-2003: ~20 cm (7.9 inches)
Contributions to sea level rise in mm/yr for more recent periods based on observations compared to models: thermal expansion of the oceans, valley glacier and mountain ice cap melting account for most of the past and present rise (IPCC, 2007)

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<tbody>
<tr>
<td>Thermal expansion</td>
<td>0.42 ± 0.12</td>
<td>0.5 ± 0.2</td>
<td>1.6 ± 0.5</td>
<td>1.5 ± 0.7</td>
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<tr>
<td>Glaciers and ice caps</td>
<td>0.50 ± 0.18</td>
<td>0.5 ± 0.2</td>
<td>0.77 ± 0.22</td>
<td>0.7 ± 0.3</td>
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<tr>
<td>Greenland Ice Sheet</td>
<td>0.05 ± 0.12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.21 ± 0.07&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.21 ± 0.35&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.21 ± 0.35&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>Antarctic Ice Sheet</td>
<td>0.14 ± 0.41&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
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<td>Sum of individual climate contributions to sea level rise</td>
<td>1.1 ± 0.5</td>
<td>1.2 ± 0.5</td>
<td>2.8 ± 0.7</td>
<td>2.6 ± 0.8</td>
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<tr>
<td>Observed total sea level rise</td>
<td>1.8 ± 0.5</td>
<td></td>
<td>3.1 ± 0.7</td>
<td></td>
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<td>(tide gauges)</td>
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<td>(satellite altimeter)</td>
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<tr>
<td>Difference (Observed total minus the sum of observed climate contributions)</td>
<td>0.7 ± 0.7</td>
<td>0.3 ± 1.0</td>
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Notes:
<sup>a</sup> prescribed based upon observations (see Section 9.5)
Years ago, says a veteran skier, “conditions were fantastic” at the world’s highest ski area, on 17,250-foot Chacaltaya Glacier near La Paz, Bolivia. Today, few attempt the run, even after a snowfall. The glacier has shriveled in the past decade, turning much of the slope into a boulder field.
Ice mass loss trends Greenland ice sheet, equivalent to 248 +/- 36 km³/yr or a global sea level rise of 0.5 +/- 0.1 mm/yr from April, 2002 to April, 2006.

GRACE: satellite gravity survey

Velicogna and Wahr, 2006
Enhanced summer melt water entering a moulin, central Greenland ice cap, probably lubricating base of glacier and increasing flow toward ocean.
Examples of some flooding scenarios leading to accelerated beach erosion, wetland development, salting out of fresh water lenses, and increased damage from storm surges and waves and heavy rain events.

Galveston, TX

Atlantic City, NJ

Newport Beach, CA

Honolulu, HI

[one meter (39 inches) a possibility for Hawaii in the year 2100; Chip Fletcher and others]
Pacific Region Projections of Sea Level Rise in Meters

Late 20th to mid-21st century

Shea et al., in Guidry and Mackenzie, 2006: Hadley HDCM2 model
Arctic Sea Ice Area (see recent Time magazine discussing the issue in the context of who has rights to the opening waters of the Arctic)

Figure 3. Areas of perennial sea ice extent in all Arctic, East Arctic (0–180°E) and West Arctic (0–180°W) Ocean from 1 October 2005 to 15 April 2006 as observed by QSCAT. Each color scale on the vertical axis applies to the plot with the same color.

The global climate of the 21st century

(a) CO₂ emissions
(b) CO₂ concentrations
(c) SO₂ emissions
(d) Temperature change
(e) Sea level rise

IPCC, 2001; 2007 similar
SRES--Special Report on Emissions Scenarios
Emission scenarios for different final stabilization CO$_2$ levels
Trends in atmospheric CO\textsubscript{2} levels for different final stabilization levels of CO\textsubscript{2}.
Global geographic temperature change predictions

Note warmer Northern Hemisphere and warmer continents and CO₂ stabilization values

Increasing temperature ⇒
Global average radiative forcing estimates (RF) and ranges in 2005 since 1750 for greenhouse gases and other agents and mechanisms (IPCC, 2007)

REMINDER: THE STORY IS COMPLEX.
SOME SURPRISES
New research indicates there may be thresholds at which rapid changes in the intensity of the conveyor belt circulation may be triggered.
Meridional ("conveyor belt") circulation intensity

1 Sv = $1 \times 10^6$ cubic meters per second

Decreasing intensity
CH₄ clathrate (frozen H₂O-CH₄ ice compound) locations
Distribution of major biomes today
Distribution of major biomes in a 2X CO$_2$ world
Land sink will weaken

$C_3$: most plants; trees, shrubs and cool-climate grasses

$C_4$: tropical and subtropical grasses, productive crops

Modified from Woodwell and Mackenzie, 1995
Documented changes in surface ocean water inorganic carbon chemistry in the North Pacific and North Atlantic

**HOT**

- **pH**
- **$\text{CO}_3^{2-}$ (µmol kg$^{-1}$)**
- **$p\text{CO}_2$ (µatm)**

**BATS**

- **pH**
- **$\text{CO}_3^{2-}$ (µmol kg$^{-1}$)**
- **$p\text{CO}_2$ (µatm)**

Graphs show trends over time from 1990 to 2002.
Grossman, Mackenzie and Andersson, 2007

pH down
downarrow
Mid 19th century: higher pH, lower temperature

Evolution of development of Pacific surface ocean water conditions marginal for reef growth due to changes in Pacific surface seawater saturation state and temperature

Mid 21st century: lower pH, higher temperature

Guinotte et al., 2003
So where do we stand with respect to the environmental ills of the planet?

- Fossil fuel burning is responsible for many of our environmental ills, not just global warming of the planet.
- Without doubt the greenhouse effect exists and has influenced climatic change in the past.
- Without doubt human activities are increasing levels of greenhouse gases in the atmosphere.
- General consensus is that global warming due to human activities is occurring. The major problems lie in the rate and magnitude of the warming in the future and effects on precipitation, the cryosphere, sea level, ecosystems, etc.
- Hawaii is particularly vulnerable as an island ecosystem: dependence on foreign oil and the internal combustion engine, sea level rise, water resources, ocean acidification, already endangered terrestrial ecosystems.
- Regardless of the amount of warming, the oceans will continue to acidify arguing that anthropogenic CO$_2$ emissions to the atmosphere must be abated.
Our Changing Planet
An Introduction to Earth System Science and Global Environmental Change
Third Edition

Fred T. Mackenzie

Prentice Hall, 1993
Carbon in the Geobiosphere
– Earth’s Outer Shell –

by
Fred T. Mackenzie and Abraham Lerman

Carbon and carbon dioxide always played an important role in the geobiophere that is part of the Earth’s outer shell and surface environment. This book’s eleven chapters cover the fundamentals of the biogeochemical behavior of carbon near the Earth’s surface, in the atmosphere, in the hydrosphere, in the biosphere, in sediments, and in the atmosphere. The coupling of the carbon cycle to nutrient nitrogen and phosphorus cycles, and the future of the carbon cycle in the Anthropocene.

This book is mainly a reference text for Earth and environmental scientists; it presents an overview of the origins and behavior of the carbon cycle and atmospheric carbon dioxide, and the human effects on them. The book can also be used for a one-semester course on an intermediate level addressing the behavior of the carbon and related cycles.

Mackenzie and Lerman’s book is the culmination of two splendid careers dedicated to understanding the carbon cycle. It’s everything you always wanted to know about carbon biogeochemistry past, present, and future.

Lee R. Kump, Department of Geosciences, Pennsylvania State University, USA

Majestic in scope, this text builds from fundamentals to state-of-the-art research, showing the pivotal role of the carbon cycle in Earth system science.

Rob Buswell, University of Leeds, UK

Using skills honed from decades of leadership in the field, Mackenzie and Lerman ably guide us along the pathways of carbon cycling in Earth’s outer layers. This is an essential journey for anyone interested in the origin and evolution of life and its fate under human influence.

Tim Lyons, University of California, Riverside, USA
SO THESE SCIENTISTS DID THIS EXPERIMENT THAT IF YOU DROP A FROG INTO BOILING WATER HE JUMPS OUT.

BUT IF YOU PUT HIM IN WARM WATER AND HEAT IT SLOWLY, HE JUST SWIMS AROUND UNTIL HE'S COOKED.

WHAT'S THE POINT OF THAT EXPERIMENT?

BEATS ME.

SCIENTISTS. GO FIGURE.

PROBABLY THE SAME ONES STUDYING GLOBAL WARMING.

HEY, LET'S SWIM AROUND SOME MORE!
FINI
Mahalo for coming and your attention
Net reaction of increasing CO$_2$:  

\[ \text{CO}_2 + \text{H}_2\text{O} + \text{CO}_3^{2-} = 2\text{HCO}_3^- \]

\[ \Rightarrow \downarrow \text{pH – “ocean acidification”} \]
\[ \Rightarrow \downarrow [\text{CO}_3^{2-}] \]
\[ \Rightarrow \downarrow \text{carbonate saturation state (Ω)} \]
85% of world’s commercial energy today from coal, oil and gas.
Distribution of organic carbon in Earth reservoirs (excluding dispersed carbon in rocks and sediments, which equals nearly 1,000 times this total amount). Numbers in gigatons ($10^{15}$ tons) of carbon.

Mackenzie and Lerman, 2006
Ice mass loss for entire Greenland ice sheet, equivalent to $248 \pm 36$ km$^3$/yr or a global sea level rise of $0.5 \pm 0.1$ mm/yr from April, 2002 to April, 2006

Velicogna and Wahr, 2006

GRACE: satellite gravity survey: deviation from mean

Monthly averages
The Peak in Oil

Duncan, 2001
Global warming

Climate sensitivity
0.3°C/doubling CH₄
18% greenhouse

Methane

4850 MTC
1.75 ppmv
R.T. = ~8 years
Accumulation:
14 MTC/yr
8 ppbv/yr

Waste treatment
Energy
Biomass burning
Termites
Landfills
Rice paddies
CH₄ hydrate
Soil uptake
Ruminants
Natural wetlands

Ocean
Land

CO

METHANE
(Fluxes = MTC/yr)

OH, O(D), NO₃ depletion
450 – 510

To stratosphere
40 – 46

Component of photochemical smog
Component of photochemical smog

Contributes to atmospheric CO₂ burden

Component of photochemical smog

Mackenzie, 2003
Claude Monet, “London Houses of Parliament, 1904”, showing smog conditions developed from coal burning
Eutrophication

Global warming

Acid deposition

Haber-Bosch process
Component of photochemical smog

Acid deposition

Global warming

Mackenzie, 2003
The last 10,000 years of greenhouse gas concentrations

- Carbon dioxide, $\text{CO}_2$
- Methane, $\text{CH}_4$
- Nitrous oxide, $\text{N}_2\text{O}$
Temperature

AOGCM Projections of Surface Temperatures

Global Average Surface Temperature Change (°C)

Relative Probability

- 2020-2029
- 2090-2099

B1: 2020-2029
B1: 2090-2099

A1B: 2020-2029
A1B: 2090-2099

A2: 2020-2029
A2: 2090-2099

Color Scale:
0 0.5 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5
Surface warming using different economic scenarios
-162±22 km³/yr
~0.4 ±0.1 mm/yr sea level rise

Velicogna and Wahr, 2005
Changes in Temperature, Sea Level, and Northern Hemisphere Snow Cover

(a) Global mean temperature

(b) Global average sea level

(c) Northern hemisphere snow cover

Temperature

Sea level

N.H. snow cover

IPCC, 2007
COMMENT ON SUSTAINABILITY: Sustainable development meets the needs of the present without compromising the ability of future generations to meet their needs—*economically, socially and environmentally* (1987 Brundtland Report of the World Commission of Environment and Development)
To achieve sustainable development with minimum impact on the environment, there is a need to satisfy these conditions:

**EQUITY CONDITION**

- Must bring a substantially better life for the poor who make up 75% of humankind.
- Will require a redistribution of power and wealth among nations, or development of dependencies.
This reflects the link between our interests and those of our descendants.

Important consideration in terms of continuous economic growth and use of nonrenewable resources.
CONTINUITY CONDITION

• Path to sustainability must begin from the present, inequitable, and unsustainable world

• Relies on support of rich nations

• Relies on cooperation of poor nations, even though in many cases they still will not receive an equitable share

• Form of insurance against war and political instabilities
SOME COMMENTS ON ENVIRONMENTAL CHANGES AND CAUSES
Does not show land-use change emissions that are less well known but the initial rise in atmospheric CO$_2$ levels from Late Holocene levels in the late 1700s reflects this agent of change.

Today: 7.4 Gt/yr and close to 385 ppmv
Where has all the anthropogenic CO$_2$ gone?

Mackenzie, Lerman and Ver, 2001