Paleoclimatology
And climate change

Summer School: "Environmental studies in the boreal forest zone: Contribution to the International Polar Year and the Northern Eurasia Earth Science Partnership Initiative, Fedorovskoe, July 17, 2007."

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What can we learn from the past?

• We can learn about how the Earth System works.
• We can see how the present compares with the past, and how the near future might differ.

You can find a useful introduction to the state-of-the-art on this topic in Chapter 6 of the report of Working Group 1 of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), which can be downloaded from www.ipcc.ch
A changed, and changing world

IGBP, 2001
A changed, and changing world

- Paul Crutzen, Nobel laureate in Chemistry has suggested that the time since the industrial revolution be designated as a new geological period – the “Anthropocene”, so great and pervasive is the human influence on the Earth.
- Formerly, the Sun, the Earth’s orbit, the tilt of its axis, the influence of the Biosphere and Geosphere, and geography, controlled climate variability.
- Now, we “mark the Earth” – with ruin?
Climate is about the range of possibilities that can be expected at a place. Climate change is about a shift in that range.
Incoming solar radiation

Outgoing thermal radiation

Energy deficit

Energy surplus

Energy deficit

Flux (W m$^{-2}$)

Pole

Equator

Pole

Transport

Redrawn from Taylor (2006)

The Natural Greenhouse Effect

- Solar radiation

Long-wave radiation

Greenhouse gases

Enhanced greenhouse effect
Double* CO₂ direct effect
+ 1.2°C
Double CO₂ plus feedbacks
+ 2.5°C +/-???

*Double the pre-industrial level, likely to be reached by 2050

Modified from Houghton, 2004
Feedbacks*

• Water-vapor feedback
  – Warmer atmosphere is wetter, water vapor is a greenhouse gas (+)

• Cloud-radiation feedback
  – Can reflect solar radiation (-), or absorb heat (+)

• Ocean-circulation feedback (+/-)
  – Complex, e.g. warm sea surface, more water vapor, more active atmosphere, more wind, stronger ocean circulation

• Ice-albedo feedback
  – As ice melts, less light reflected to space, more absorbed and so more ice melted (+)

+ or - sign of feedback to greenhouse effect

* some of the toughest challenges for climate modelers
Climate Models

• These are mathematical summaries of what we know about the mechanisms of the climate system.

• One of the major tests of these models is to reproduce the main features of modern climate.

• Another is to capture the dynamic changes of the recent Ice Ages, in time and geographically.

√ - not perfect, but very informative.
How was climate before us?

Photos: Mark Twickler; NOAA Paleoclimatology Program

Raynaud et al, 2003; PAGES
Our time in the context of recent Earth History

Ice ages have waxed and waned over the last 800,000 years with linked changes in:

- global climate (including temperature)
- the volume of land ice
- the living world and
- sea level and the area of coastal land
- the concentrations of some gases in the atmosphere (especially carbon dioxide and methane),

These fluctuations have limits, and they have some regularity.
Our time in the context of recent Earth History

• The pacemaker of the ice ages has been driven by regular changes in the Earth’s orbit and the tilt of its axis

Approximate primary periods:
- Eccentricity 100,000 years
- Precession 23,000/18,000 years
- Tilt 41,000 years

Hence a rich pattern of changing seasonality at different latitudes over time, which affects the growth and retreat of the great ice sheets.

Diagram Courtesy of Windows to the Universe, http://www.windows.ucar.edu
What happens if we push a forcing factor outside its normal range?

Alverson et al., 2003.
Checking the models – what actually happened?

Global land-ocean temperature relative to 1951-1980, °C

Comparison between modeled and observations of temperature rise since the year 1860

(a) Natural forcing only
Mainly solar and volcanic

(b) Anthropogenic forcing only
Mainly GH gases + sulfate aerosol

(c) Natural + Anthropogenic forcing

3.6°F

IPCC TAR Summary for Policymakers (2001)
http://www.grida.no/climate/ipcc_tar/wg1/figspm-4.htm
Human-induced Ocean Warming since 1960

- Observed signal
- Due to solar and volcanic effects
- Range of “free behavior”

Signal strength in °C

Barnet et al. 2005
Human-induced Ocean Warming since 1960

The picture is similar in all the oceans.

Barnet et al. 2005
The verdict based on the last 150 years?

- The observed patterns cannot be explained without a major role for increased greenhouse gases, especially carbon dioxide, and for sulfate aerosols.
- The increases in greenhouse gases and sulfate aerosols overwhelmingly result from human activities.
- Therefore human activities can change the global climate and already have.
What about the centuries just before the “Anthropocene”?
Can’t use thermometer records.....

Land based temperature stations in Global Historical Climate Network

Maps prepared by Dr. Fenbiao Ni
> 400 original records used, condensed to 112

Can’t use thermometers, ..but we did use these..

Trained on main patterns in annual surface temperature record, 1902-1980; checked on 1854-1901

Mann
Bradley,
Hughes,
1998
Maps are very testable

To calculate yearly maps of temperature...
..from which we got this...

2.9°F
...and this....

Mann, Bradley, Hughes, 1999

Northern Hemisphere mean temperature since AD 1000

TEMPERATURE ANOMALY (°C)

YEAR

1998
And others get similar results independently…

From historical documents and early meteorological instruments…

Luterbacher et al., 2004
…with completely independent data and methods – glaciers...

1928
South Cascade Glacier
Washington State

2000

Pictures courtesy of USGS
..borehole temperatures...

Huang, Pollack, and Shen, 2000
The picture is less firm before ~AD 1600 (as we showed in ‘99).
IPCC AR4* took all available reconstructions and plotted their overlap:

* Intergovernmental Panel on Climate Change, 4th Assessment Report, 2007
Compare this with climate model runs:

With greenhouse gases

Without greenhouse gases
Can draw reasonable conclusions:

• The common pattern of variability seen in many kinds of records, and many analyses for the last several centuries shows the late 20\textsuperscript{th}/ early 21\textsuperscript{st} century as the warmest period for several hundred years.

• Until the 20\textsuperscript{th} century the general patterns can be accounted for by solar and volcanic forcing.

• It is not possible to reasonably explain the course of change from the 19\textsuperscript{th} to late 20\textsuperscript{th} century without greenhouse gases and sulfate aerosols.
Describing AND understanding the history of climate shows:

• There have been large, unprecedented, increases in carbon dioxide and other human-produced greenhouse gases (GHG) over last 150 years.
• Temperature has increased at a rate, in places and at times distant and recent, consistent with model projections including major GHG effects.
• Many other climate data also consistent.
• The basic physics of the greenhouse effect support this.
Thanks for your attention!