What is the single biggest environmental issue facing society today?
What is the single biggest environmental issue in the Earth sciences today?
Is the Earth warming?

How do we know?
150 yrs of thermometer measurements
150 yrs of thermometer measurements

and the rate of warming is increasing
Global warming is an overwhelmingly robust observation (as we shall see), but how much of recent global warming is “man made”?
global temperature change since 1860

climate model “hindcast”: natural causative factors ("forcings") only

IPCC TAR (2001)
global temperature change since 1860

climate model "hindcast"
man-made causative factors ("forcings") only

IPCC TAR (2001)
global temperature change since 1860

(note strong resemblance of model and obs)

climate model “hindcast”: natural and man-made causative factors (“forcings”)

IPCC TAR (2001)
temperature change since 1900

**model** “hindcasts” considering all factors (incl. GHG’s), natural factors only, **black is observed temperatures**

source: IPCC ‘07
The question is no longer “whether” there is man-made warming or whether it will continue, but “by how much and how fast”, and “what are the risks”, and “what can or should we do about them”…. 
The problem of “man-made” warming and what to do about it is one of the most complex and serious issues facing society.

This course attempts to provide a analytical understanding of the changing Earth based on a systems approach for use in deciphering the complex and uncertain forecast...
some examples…

**NOTE** (added to lecture for download): The following examples are for illustrative purposes and will be covered in later lectures. You are not (yet) responsible for the concepts and terms that follow….
end-of-summer sea ice extent
1981 v. 2007

cryosphere today
July Arctic Sea Ice Extent ‘79 - ‘07

Extent (millions of square kilometers)

11.5
11.0
10.5
10.0
10.5
9.5
9.0
8.5
8.0

Year

trend = -6.2%/decade

but, is the trend long enough to make a prediction?
What is the interaction shown here?

Think about this: sea ice is bright and reflects ~90% of the sun’s rays, sea water is dark and absorbs ~90% of the sun’s rays.

source: A. Gore’s “AIT”
a feedback involving sea ice

temperature

sea ice cover

“reflectivity”

what is the “sign” of the one way interaction?
a feedback involving sea ice

temperature

sea ice cover

"reflectivity"

positive

negative

+, which is destabilizing (we’ll formalize this concept next class)
July Arctic Sea Ice Extent ‘79 - ‘07

does understanding a key interaction assist in making a prediction?

Extent (millions of square kilometers)

Year


11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0

trend = -6.2%/decade
• we need more than factual knowledge or observations

• we need a theoretical or conceptual framework in which to place and make sense of observations (facts we can always look up)

source: CU-SEI
sea level change
the last century......

during the last century sea level rose ~ 2mm/yr
during the last decade sea level rose ~3.1 mm/yr
warm water expands!

• sea water expands by, roughly, ~0.33% for every K (or °C) of warming

• so for every K of warming in upper 1 km of ocean, level would rise ~3.3 m due to thermal expansion

• precise measurements of ocean temperature change indicate ~0.05K warming of upper few km over last ~50 yr due to global warming

• this would explain much of sea rise of ~20 cm observed fr. tide gauges
anomalous melting

~30% increase in melt area since 1979
Warm water expands and ice melts.

If that were the whole picture, the forecast would be relatively straightforward...
stable Greenland ice sheet

at steady state ice gain is matched by ice loss from melting and ice berg calving at ice streams

melting is a slow process

friction limits flow through ice streams

heat diffuses slowly thru ice
melt water reaches the ice sheet bed, greatly reducing friction and permitting accelerated sliding and flow through ice streams, increased ice berg calving and ice sheet thinning
what if gradual melting triggers fast sliding?
Ice sheet quakes!

Lurching of Greenland ice streams creates tremors that are recorded worldwide. They occur more frequently in warm months (due to melt lubrication). Their annual occurrence has doubled in the last 5 years!

Ekstrom et al., ‘06
consider impact of small (but uncertain) fractional loss of Greenland or West Antarctic Ice Sheets

1 meter SL rise would submerge:

- 18% of Bangladesh
- 6% of The Netherlands
- ~960 of the 1200 Maldive Islands

*2 meters looks like this....*
the global water cycle
signature of the global water cycle

evaporation minus precipitation (cm/yr)

(“Inter-Tropical Convergence Zone”)
heating and the "ITCZ"

heating = expansion = buoyancy = uplift
rising air replaced by moist air converging from below
sinking air is dry
a simple mechanistic forecast
(in response to heating due to greenhouse warming)

more intense heating, more convection, rainfall and flooding
more descending dry air, more & longer drought
warmer, wetter, more snowfall

Archer
“Results averaged across 19 different models. P-E is net flux of water at surface that, over land, sustains soil moisture, ground water, and river runoff”

Seager et al., Science in press
widespread drought

American SW and other subtropical regions will become increasingly arid

transition to drier climate already underway and will become well established in coming decades with “permanent drought”

a robust finding across 19 IPCC model projections- assoc. with amplification and poleward displacement of the hydrologic cycle

Aridity levels of The Dust Bowl & 1950’s droughts will become the new climatology of the American SW by mid-century

Seager et al., 2007
amplification of the hydrologic cycle......

“Results averaged across 19 different models. P-E is net flux of water at surface that, over land, sustains soil moisture, ground water, and river runoff”

Seager et al., Science in press
projected crop yield (as % of 1990), A2

w/ “CO₂ fertilization” effect

climate only

projected deficits are primarily in developing countries
(CO₂ fertilization effect is uncertain)  

Parry et al. 2004
Projected crop yield (as % of 1990), A2

with "CO₂ fertilization" effect

Projected deficits are greatest in areas of greatest expected population growth.
projected crop yield (as % of 1990), A2

these areas are seriously vulnerable to food shortages already!
Hurricane Isabel as seen from the International Space Station
Tuesday, 16 September 2003
hurricanes

• large topical storm systems that form and develop over warm waters near equator from small tropical depressions
• brought westward by gentle steering winds (trades)
• fueled by heating over warm ocean and moisture convergence
• generally require waters warmer than 26 °C to form and develop
The frequency of the most powerful (category 5) hurricanes has doubled in the last 30 years.....

Webster et al. ‘05
global economic losses from weather disasters

losses primarily from storms and floods

Georisk Research, Munich Re (2006)
powering the planet

following slides drawn from
Prof. Dan Nocera, MIT
global energy use by source (and projected)

this is simply a global “burn rate” expressed in quadrillions of Watts

14.9 TW

- renewable (0.13)
- nuclear (0.92)
- hydro (0.92)
- coal (3.8)
- gas (3.5)
- oil (5.6)

2004
global energy use by source (and projected)

E = N \times \frac{GDP}{N} - \frac{E}{GDP}

E = world energy consumption (TW)
N is population

N growth = +0.9%/yr
i.e. from 6 to 9.4 billion

GDP/N is per capita GDP

GDP/N growth = +1.4%/yr
i.e. from $7500 to $15000

E/GDP is energy intensity
(energy consumed per unit of GDP)

0.294 W/($/yr) > 0.20 W/($/yr)
E/GDP decrease = 0.8 %/yr

therefore E will grow at:
2.3%/yr - 0.8%/yr = 1.5%/yr
(i.e. doubling by 2050)
energy use per person in different countries

energy demand and GDP per capita (1980-2004)

what is dominant trajectory in this graph? why? is this a problem?
energy use per person in different countries

energy demand and GDP per capita (1980-2004)

population: 3.2 B of current 6.2 B
Meeting the global energy demand while reducing carbon emissions and addressing climate change is the challenge of the century...
overview of class topics
(download at http://instaar.colorado.edu/lehman/env-issues/)

• Earth System interactions
• radiation, energy and the Greenhouse Effect
• composition and structure of the atmosphere
• heat, winds and currents (I-III)
• water in the climate system
• case study: Lessons from the ice age
• fossil fuels and the carbon cycle
• case study: natural CO$_2$, climate and sea level change
• recent warming, evidence and attribution
• commitment warming & sea level rise
• case study: sea-ice, glacier and ice-sheet melting
• projected impacts of warming
• powering the planet
• decisions, decisions
• carbon policy
requirements and resources:

• **required text:**
  “Global Warming: Understanding the Forecast”

• **supplemental text:**
  “Dire Predictions: Understanding Global Warming”
  M. Mann & L. Kump (U. Penn.), DK Publ., 2009

• **grading:**
  Two 1-Hour Exams (30%)
  Final Exam (30%)
  Homework and in-class exercises (30%)
  iClicker participation (10%)

• **exams will be based on learning goals & key concepts and terms identified in lectures and assigned readings** (called “take home points” in the required text).

• **Class web site:** [http://instaar.colorado.edu/lehman/env-issues/](http://instaar.colorado.edu/lehman/env-issues/)
  will be your most up-to-date resource for lecture notes, reading and homework assignments.

• **Remember to get an iClicker and register it (at CuConnect)**
offices hours & syllabus

Offices
• BESC, Room 246F, ph. 492-5478
  Office Hours: 10:00 – 11:00 A.M., TR, or by e-mail (best) or phone appointment

• East Campus, RL-1 (INSTAAR), Room 157, ph. 492-8980

Syllabus
we all have responsibilities- be sure to read and understand them at:
http://instaar.colorado.edu/lehman/env-issues/
semester goals....

make use of a single, big problem, namely, assessing the risk of global warming.....

• to develop an analytical understanding of interactions within the Earth System

• as an opportunity to learn how scientists think about complex issues
  ("Do I understand this? How can I check?")

• to evaluate possible mitigation and adaptation strategies
next class:

- Earth system components and interactions (coupling, feedback and equilibrium)
- assigned reading: Archer Ch.1
- bring your clicker!