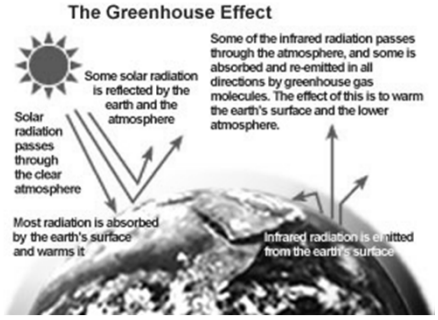
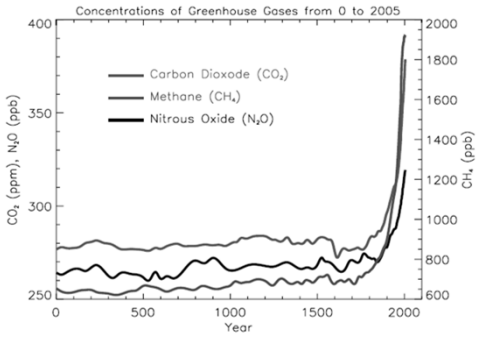
The Greenhouse Effect is Real & Real Important



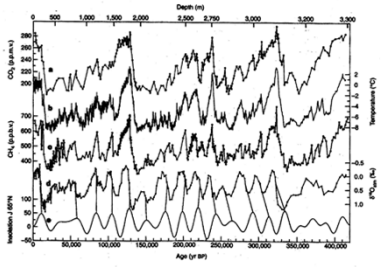


The past 420,000 years from the Vostok ice core.

CH_4 →

CO_2 →

Current levels of GH gases are abnormally high



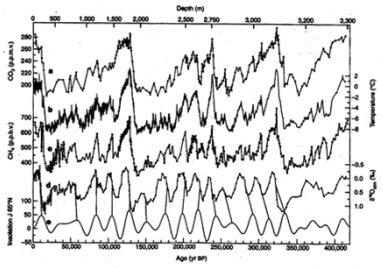
Past changes in GH gases correspond to past changes in temperature

The past 420,000 years from the Vostok ice core.

CH_4 →

CO_2 →

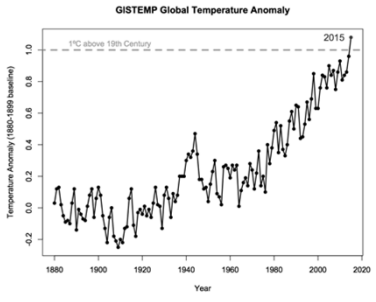
Current levels of GH gases are abnormally high



The Earth's Climate is Changing

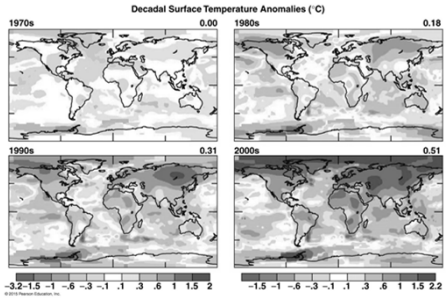
Many changes over the last century are consistent with an enhanced greenhouse effect.

GLOBAL SURFACE TEMPERATURES HAVE INCREASED

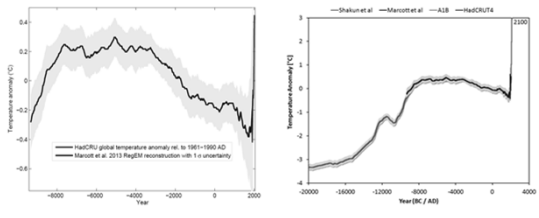


2015 was the warmest year since record keeping began.

Strings of warm temperatures are unlikely to be due to chance



Temperatures Have Become Unusually Warm



And may be outside the range experienced during the last 5 million years

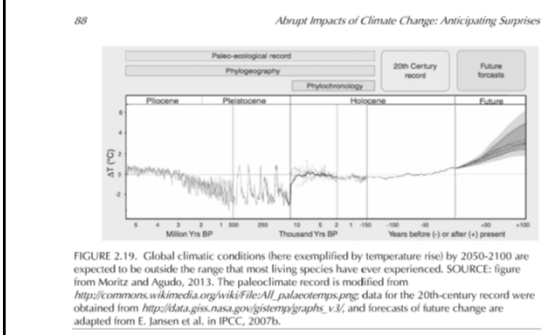
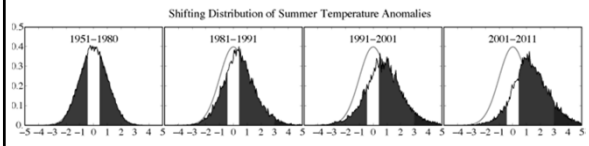
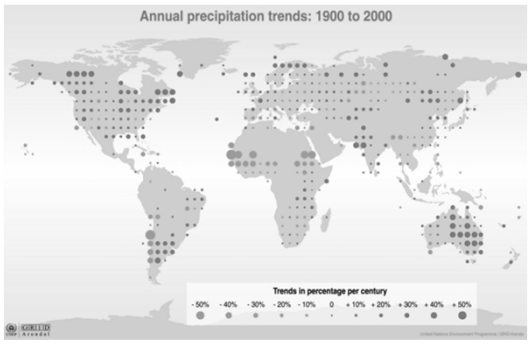


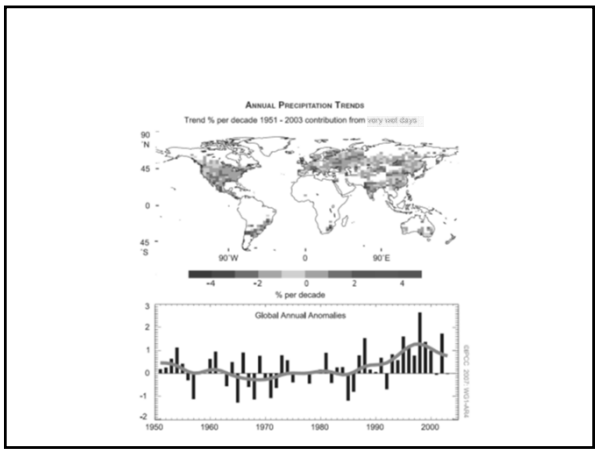
FIGURE 2.19. Global climatic conditions (here exemplified by temperature rise) by 2050-2100 are expected to be outside the range that most living species have ever experienced. SOURCE: figure from Moritz and Agudo, 2013. The paleoclimate record is modified from *http://commons.wikimedia.org/wiki/File:All_palaeotemps.png*; data for the 20th-century record were obtained from *http://data.giss.nasa.gov/gistemp/graphs_v3/*; and forecasts of future change are adapted from E. Jansen et al. in IPCC, 2007b.

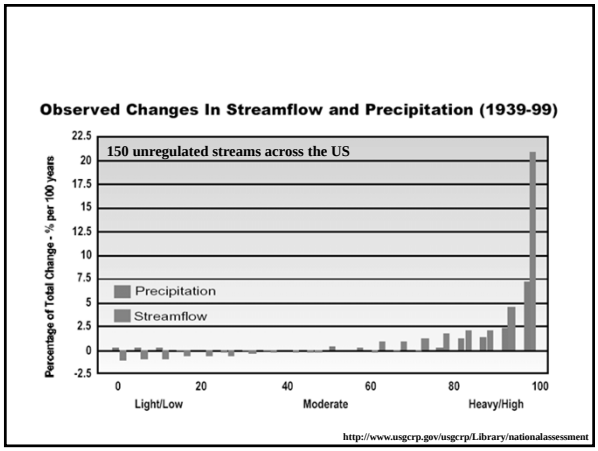
The distribution of summer temperatures has shifted

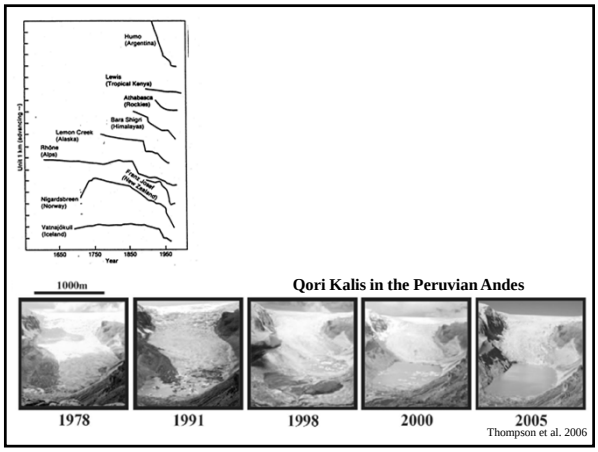
We are loading the climate dice.

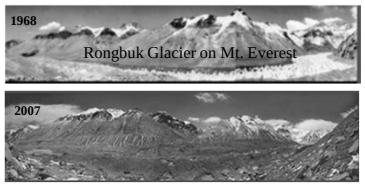





Annual Precipitation Trends
Trend % per decade 1951 - 2003 contribution from very wet days
90 N
45
0
45 S
90°W
0
90°E
-4
-2
0
2
4
% per decade
Global Annual Anomalies
3
2
1
0
-1
-2
1950
1960
1970
1980
1990
2000


Observed Changes In Streamflow and Precipitation (1939-99)
150 unregulated streams across the US
Percentage of Total Change - % per 100 years
22.5
20
17.5
15
12.5
10
7.5
5
2.5
0
-2.5
Precipitation
Streamflow
0
20
40
60
80
100
Light/Low
Moderate
Heavy/High
http://www.usgcrp.gov/usgcrp/Library/nationalassessment


Humo (Argentina)
Lewis (Tropical Kenya)
Athabasca (Rockies)
Bara Shigri (Himalayas)
Lemon Creek (Alaska)
Rhône (Alps)
Nigardsbreen (Norway)
Vatnajökull (Iceland)
1650
1750
1850
1950
Year
1000m
Qori Kalis in the Peruvian Andes
1978
1991
1998
2000
2005
Thompson et al. 2006



Sea Level is Rising

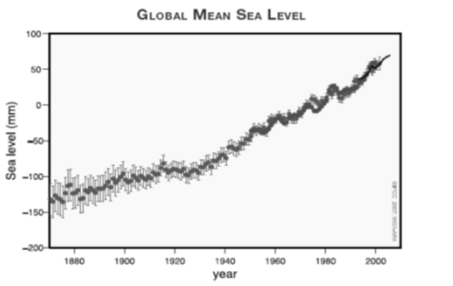
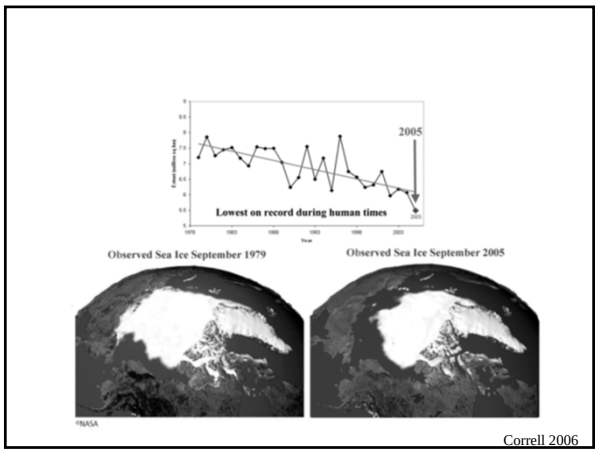


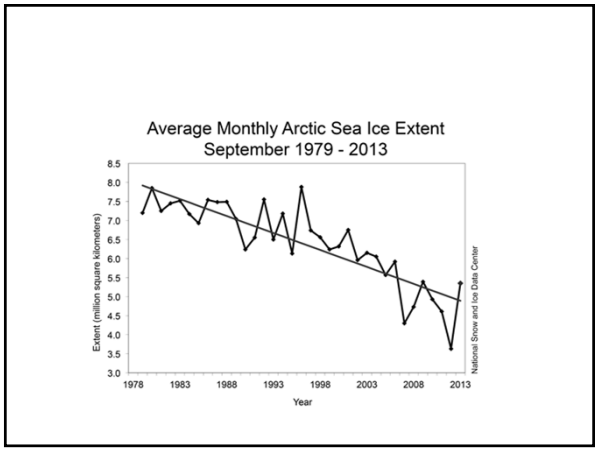
Table TS.3. *Contributions to sea level rise based upon observations (left columns) compared to models used in this assessment (right columns; see Section 9.5 and Appendix 10.A for details). Values are presented for 1993 to 2003 and for the last four decades, including observed totals. [Adapted from Tables 5.3 and 9.2]*

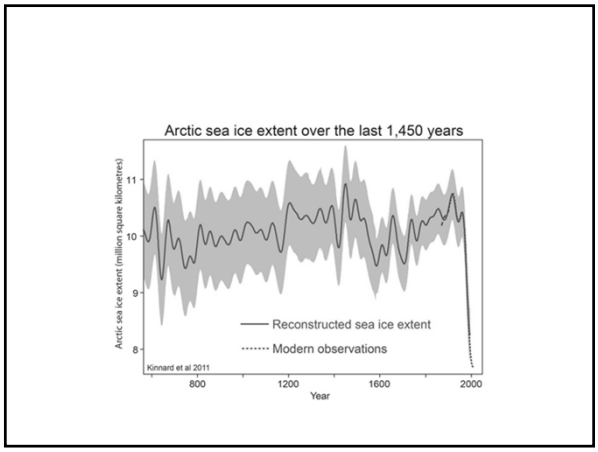
	Sea Level Rise (mm yr⁻¹)			
	1961–2003		1993–2003	
Sources of Sea Level Rise	Observed	Modelled	Observed	Modelled
Thermal expansion	0.42 ± 0.12	0.5 ± 0.2	1.6 ± 0.5	1.5 ± 0.7
Glaciers and ice caps	0.50 ± 0.18	0.5 ± 0.2	0.77 ± 0.22	0.7 ± 0.3
Greenland Ice Sheet	0.05 ± 0.12[a]		0.21 ± 0.07[a]	
Antarctic Ice Sheet	0.14 ± 0.41[a]		0.21 ± 0.35[a]	
Sum of individual climate contributions to sea level rise	1.1 ± 0.5	1.2 ± 0.5	2.8 ± 0.7	2.6 ± 0.8
Observed total sea level rise	1.8 ± 0.5		3.1 ± 0.7	
Difference (Observed total minus the sum of observed climate contributions)	0.7 ± 0.7		0.3 ± 1.0	

Notes:
[a] prescribed based upon observations (see Section 9.5)



Correll 2006





Ice Albedo Feedback Loop

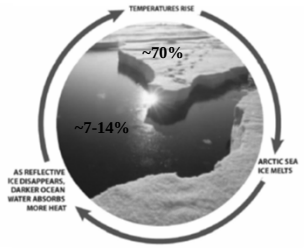


FIGURE 2.15 Climate Feedback Loop: The melting of Arctic sea ice is an example of a positive feedback loop. As the ice melts, less sunlight is reflected back to space and more is absorbed into the dark ocean, causing further warming and further melting of ice. Source: NRC, 2010b.

The Biosphere Is Not Waiting to be Told That It's Warmer

Plants are on the move too.

Elevational change in plant species from 1997-2007 in Southern California's Santa Rosa Mountains.

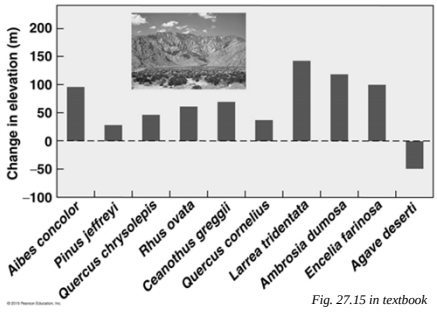
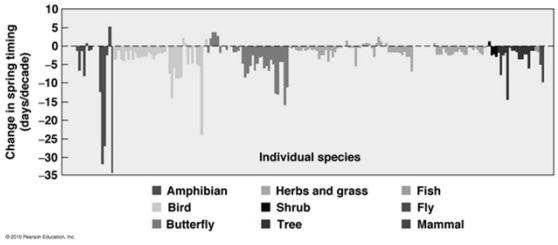


Fig. 27.15 in textbook



"The Natural Cycles of Interdependent Creatures May Fall Out of Sync"

In 7 of 11 studies with sufficient data, the temporal asynchrony increased between interacting species in response to climate warming.

Montaigne 2004
National Geographic

9 predator-prey relationships
2 insect-host plant interactions

Parmesan 2006

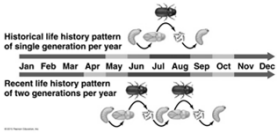
Some may fall out of sync with changes in the environment

Camouflage mismatch in seasonal coat color due to decreased snow duration L. Scott et al. 2013 PNAS

More destructive bark beetles survive the warmer winters and are moving to higher elevations in the Rocky Mountains

Photo from my vacation in RMNP summer 2011

And produce more generations per year.

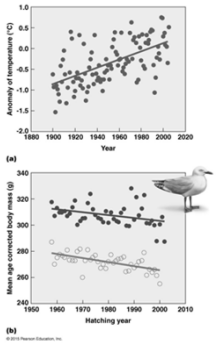


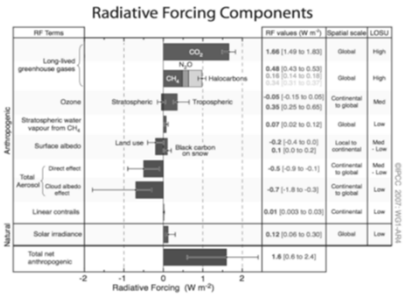
The Body Size of Some Species is Changing

Bergmann's Rule – *For endotherms, when all else is equal, body size tends to increase with decreasing mean annual temperature.*

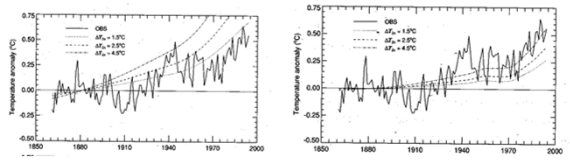
Several studies document changes in animal body size for local populations that correlate with changes in temperature.

Read pages 146-147



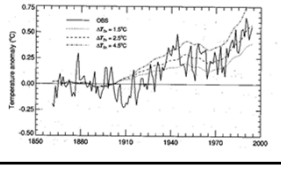


We must rely on computer models to forecast future changes



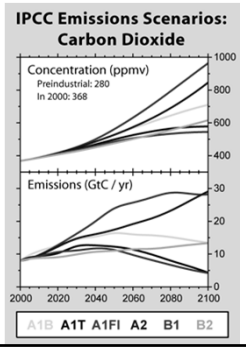
GH gases only

GH gases + aerosols



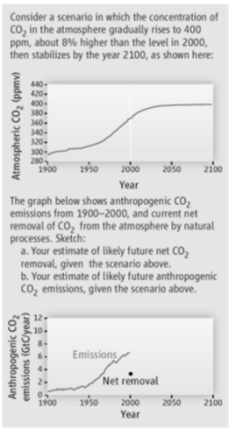
GH gases + aerosols + changes in solar output

The future depends on our behavior

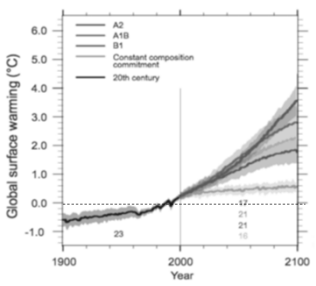


"Images created by Robert A. Rohde / Global Warming Art"

Why do concentrations continue to rise if emissions slow or even decline?



Are you smarter than graduate students at MIT?



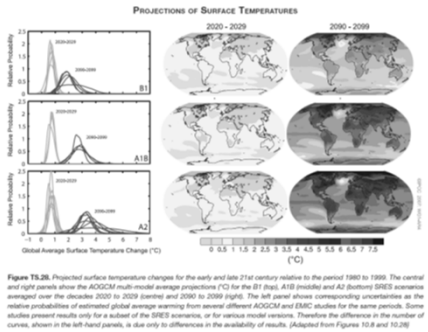
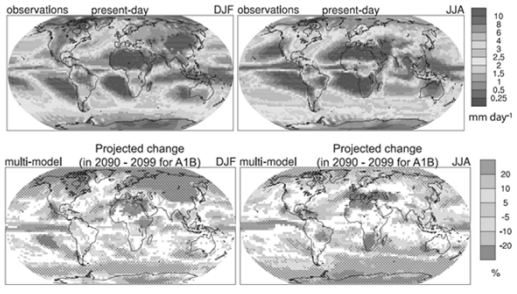
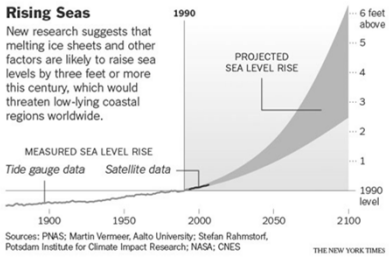


Figure TS.28. *Projected surface temperature changes for the early and late 21st century relative to the period 1980 to 1999. The central and right panels show the AOGCM multi-model average projections (°C) for the B1 (top), A1B (middle) and A2 (bottom) SRES scenarios averaged over the decades 2020 to 2029 (centre) and 2090 to 2099 (right). The left panel shows corresponding uncertainties as the relative probabilities of estimated global average warming from several different AOGCM and EMIC studies for the same periods. Some studies present results only for a subset of the SRES scenarios, or for various model versions. Therefore the difference in the number of curves, shown in the left-hand panels, is due only to differences in the availability of results. [Adapted from Figures 10.8 and 10.28]*

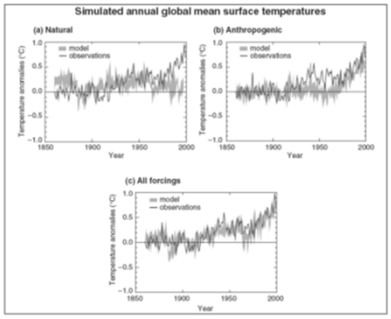
Other Model Predictions

Increased subpolar precipitation in NH and decreased subtropical precipitation over North America and Europe





Most of the warming since ~ 1950 appears to be due to human activities



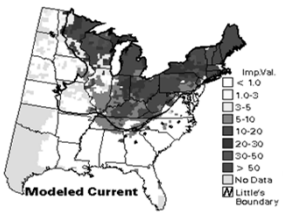
IPCC 2001

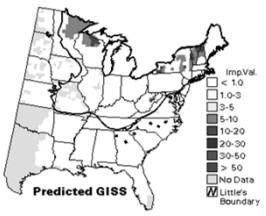
Impacts on Species

Good & poor places exist for every species

Loss of Brown Trout Habitat from Doubling of CO_2

Forecast Change in Sugar Maple Importance





Direct Impacts on Humans

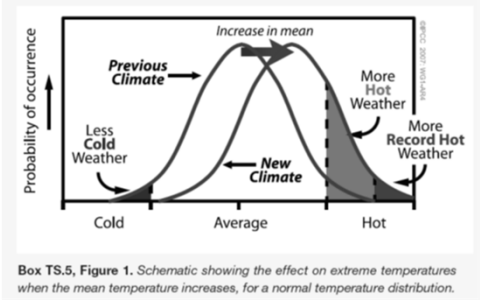
An increase in average temperature should increase the frequency of very hot days.

- **For Chicago, 5.4ºF increase in July temp. should increase probability of heat index > 120ºF during the month from 1 in 20 to 1 in 4.**

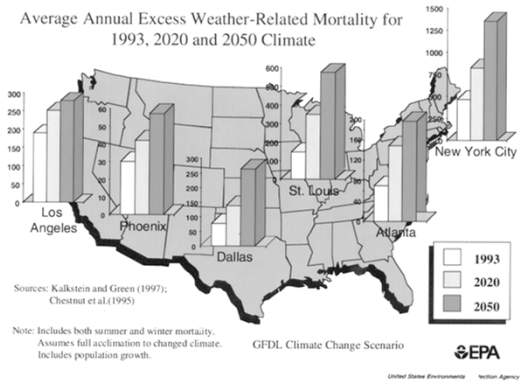
During heat waves, deaths from cardiovascular & respiratory illnesses increases.

Reductions in winter mortality are not expected to offset increased summer mortality.

The elderly (esp. those alone) & children are the most affected during heat waves.



Box TS.5, Figure 1. *Schematic showing the effect on extreme temperatures when the mean temperature increases, for a normal temperature distribution.*



Indirect Effect on Humans

Threat to food production

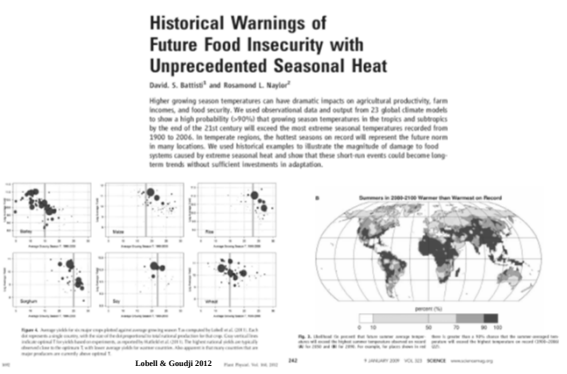
Range & life-cycles of pathogens & vectors which transmit disease are affected by climate.

Climate change should increase the potential transmission of many vector-borne diseases.

Outbreaks of infectious diseases have been associated with specific weather patterns:

- **Malaria**
- **Hantavirus**
- **St. Louis Encephalitis**

Threat to food production

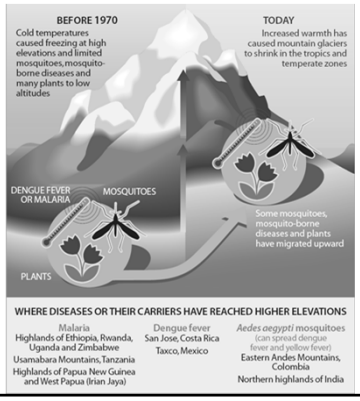

Historical Warnings of Future Food Insecurity with Unprecedented Seasonal Heat

David. S. Battisti[1] and Rosamond L. Naylor[2]

Higher growing season temperatures can have dramatic impacts on agricultural productivity, farm incomes, and food security. We used observational data and output from 23 global climate models to show a high probability (>90%) that growing season temperatures in the tropics and subtropics by the end of the 21st century will exceed the most extreme seasonal temperatures recorded from 1900 to 2006. In temperate regions, the hottest seasons on record will represent the future norm in many locations. We used historical examples to illustrate the magnitude of damage to food systems caused by extreme seasonal heat and show that these short-run events could become long-term trends without sufficient investments in adaptation.

Lobell & Goudji 2012

Diseases & Their Vectors May Spread



Epstein 2000

Climate change appears to already be a killer.


REVIEWS

Impact of regional climate change on human health

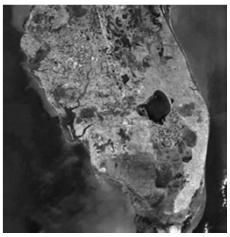
Mortality per million people
0 – 2
2 – 4
4 – 70
70 – 120
No data

In recent years, properties in low-lying coastal states have experienced increasing damage from storms and severe flooding. Almost three million people—and their homes—reside within three feet of mean sea level. With rising seas projected to exceed the three-foot mark within this century, a great many homes are clearly at risk.

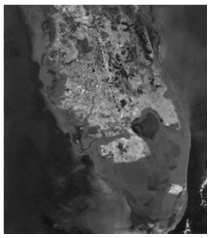
Map based on data from Strauss et al. 2012.

If half of Greenland and West Antarctica melted

Southern Florida
Present Sea Level

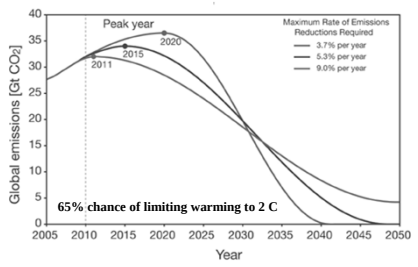


Southern Florida
20 Foot Sea-Level Rise



Gore 2006

Where should we be heading?



Recommended web sites dealing with climate change

http://dotearth.blogs.nytimes.com/
interesting blog

http://www.skepticalscience.com/
devoted to addressing issues raised by skeptics w/ lots of links to primary literature

http://www.realclimate.org/
a climate science blog by real climate scientists