Impact of Climate Change on New England

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Charter of the VERMONT ACADEMY OF SCIENCE AND ENGINEERING

Purposes of the Academy

- to recognize outstanding achievement and contribution in the broadly defined areas of science and/or engineering
- **to foster a deeper understanding and promote discourse on scientific and technical matters among the citizens of the State of Vermont**
- to provide expert and impartial technical advice to the people and the government of the State of Vermont

Climate Change

- **One of the great challenges for this century**
- Complex: energy, water and biosphere
- What is known? What might we face?

My background:

Nottingham High School

- Founded 1513 by Dame Agnes Mellors
- Superb education in science, classics & languages
- *1550 heading into ‘little ice-age’*
- *1620 Pilgrim fathers*

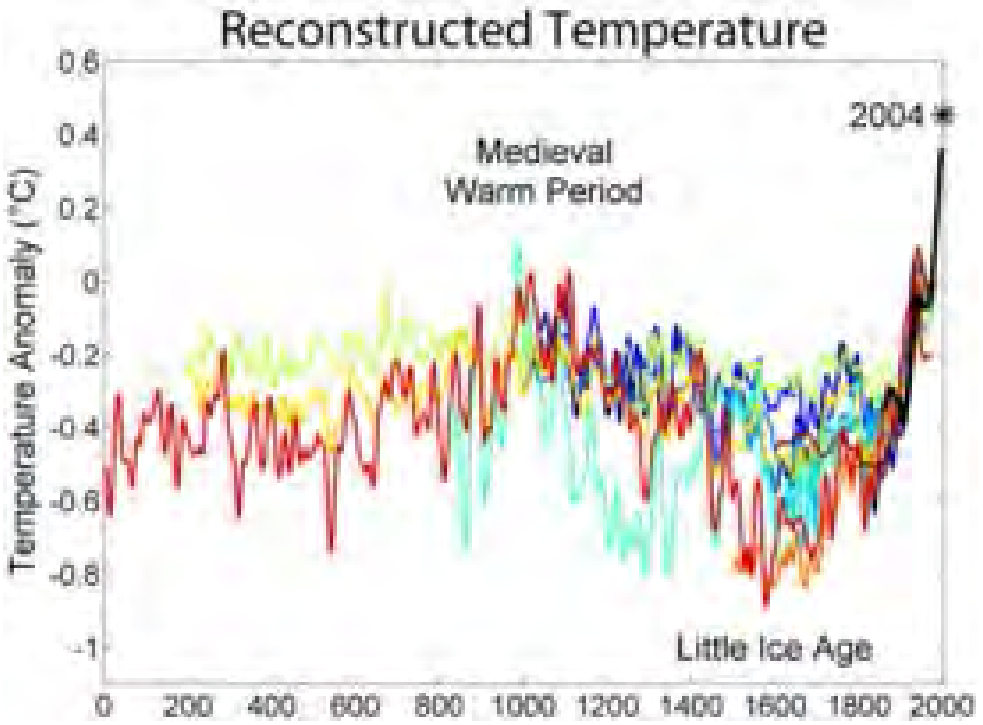
Peterhouse, Cambridge

- Peterhouse, Cambridge: founded 1284 by the Bishop of Ely.

- *Medieval warm period; Vinland colony*

The last thousand years…

- Before thermometers, estimates have large uncertainty
- *[realclimate.org]*



I started research on clouds in London in 1968

Dissertation on
‘Cumulus Convection’

Puffy clouds that don’t rain

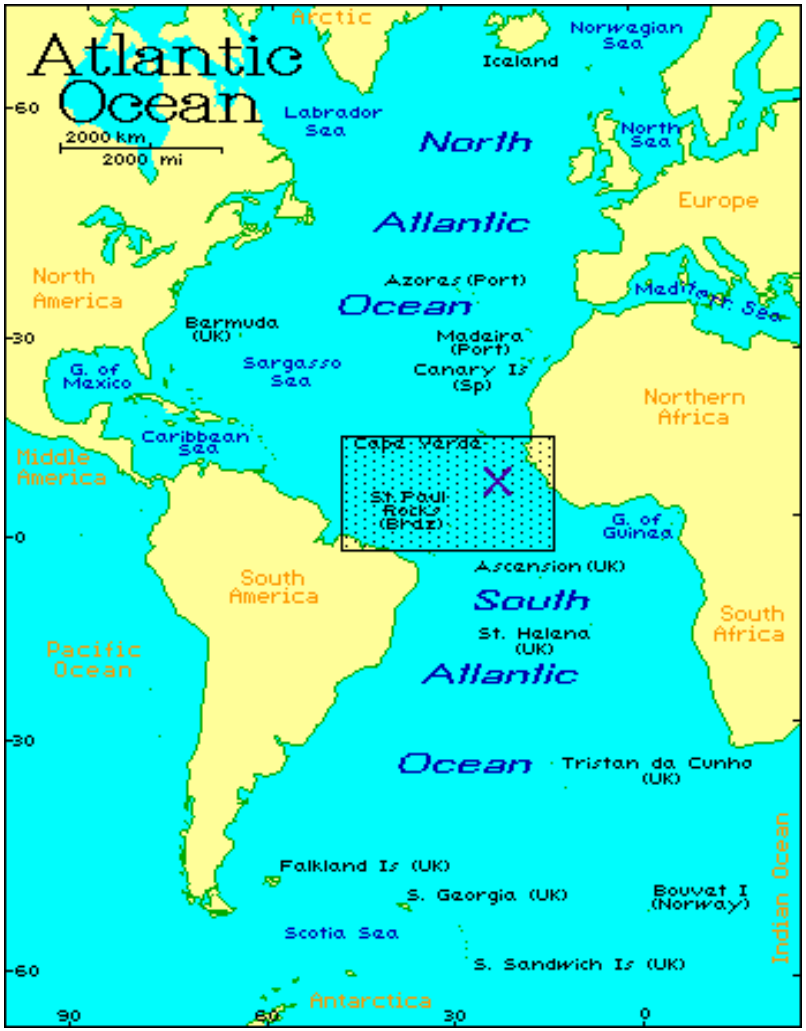
Condense, transport and evaporate water

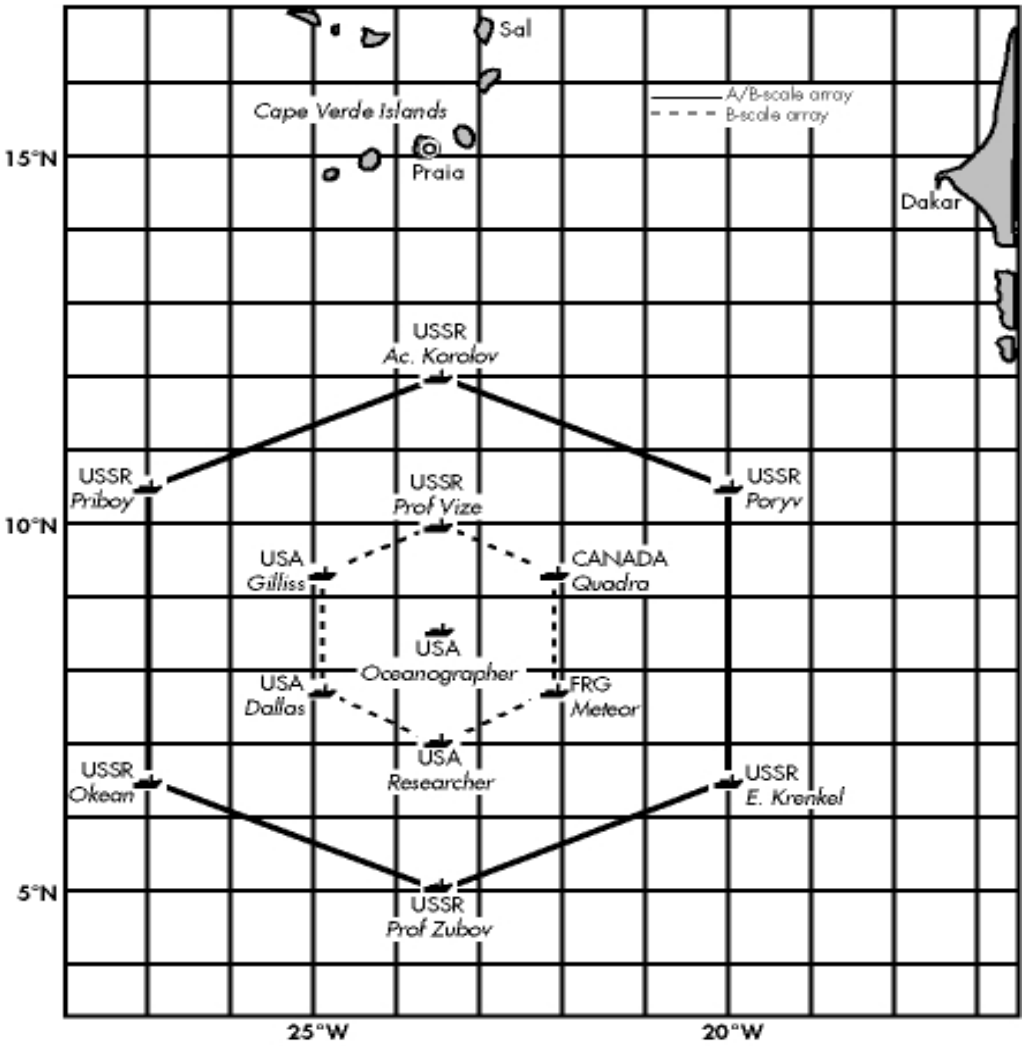
Reflect sunlight, absorb ‘infrared’ radiation

Huge climate impact

Anaco, Venezuela, 1969

Moved to Colorado State in 1970, researching tropical weather





Global Atmospheric Research Program
Atlantic Tropical Experiment, 1974

15 research ships

Vanguard [NASA], Quadra [Canada], Dallas [US Coastguard]

7 research aircraft

'Electra' from National Center for Atmospheric Research

Moved to Vermont in 1978 as ‘independent scientist’

- Built solar home in West Pawlet with photovoltaic electricity
- Analyze data and improve weather forecast and climate models
- Funded by National Science Foundation, NASA

"Flux towers" in Rondonia, Brazil

Can we understand the climate system?

- Energy (sunlight and heat radiation)
- Water (clouds, rain, rivers and oceans; snow and ice)
- **You understand most of the parts (especially living with seasons in Vermont)**

- So let us put it all together!

Oceans and clouds

Sunlight heats the ocean, evaporation cools it

Clouds form, reflecting some sunlight

Northern winter when sun in south!

- Cold, not much sun
- Grey, under clouds
- Precipitation falls as snow
- Snow reflects, but trees are dark

Winter in Vermont!

- Sun is low; and snow reflects sunlight, except where trees!
- It stays cold

And why is the grass green?

- Leaves use red light to convert CO_2 and H_2O to carbohydrates

We understand what we can see: the sun, clouds, snow and trees

- Sun heats the earth; clouds and snow reflect it back
- Evaporation from oceans and trees and grass cools the earth

One key element we cannot see, but you can feel it!

- ‘Infrared’ or ‘heat’ radiation

Atmosphere is transparent to ‘light’ but not to ‘infrared’ radiation

- The earth emits infrared radiation but molecules H_2O, **CO_2**, CH_4 vibrate and absorb it
- So the atmosphere blankets the earth and keeps it warm [60^oF warmer!]

- So oceans do not freeze and life is possible

The earth's climate depends on these balances

- Sun shines through the atmosphere and heats the earth
- But it is reflected by clouds, ice and snow
- Earth and oceans cool by evaporating water, by warm air rising and by radiating heat
- Earth's atmosphere traps heat [infrared] radiation like a blanket or a greenhouse, because clouds and gases [H_2O, $\mathbf{CO_2}$ ..] absorb infrared radiation

We measure and model global weather and climate

- Many measurement methods
  - weather stations, buoys, balloons, satellites

- Model the whole globe [supercomputers]
  - oceans, land [forests, crops, grasslands]
  - atmosphere and clouds

What can we predict?

- Predict global weather for 5-10 days
  [in winter better than summer]
- But predict climate with little certainty
- WHY?
- Unstable complex system with many processes and timescales
- We humans are involved on global scale!

Many time-scales!

- Clouds last hours
- Storms last days
- Water in soil stored for months
- Oceans turn over in years to centuries
- Ice-sheets melt in decades to centuries
- Forests grow until fire [or we cut them!]

Primary driver of climate change

- Greenhouse gases from fossil fuel burning (CO_2) and other industrial sources
- ‘blanket earth’ by trapping of infrared radiation; driving up mean temperature
- Water vapor and snow/ice amplify effects
- Clouds add complex ‘fast’ feedbacks:
  oceans and ice-sheets react more slowly
- Biosphere controls our long-term fate

Climate is also unstable

- Ice and snow reflect sunlight: earth cools and drifts into ice-age; ‘sudden’ collapse
- Unstable currents in the oceans driven at the surface with return flow in the depths: even the Gulf stream has stopped in the past

  [*Movie: Day after tomorrow!!]*

- Forests soak up sunlight, bind soil and store water – deforest and soil may wash away

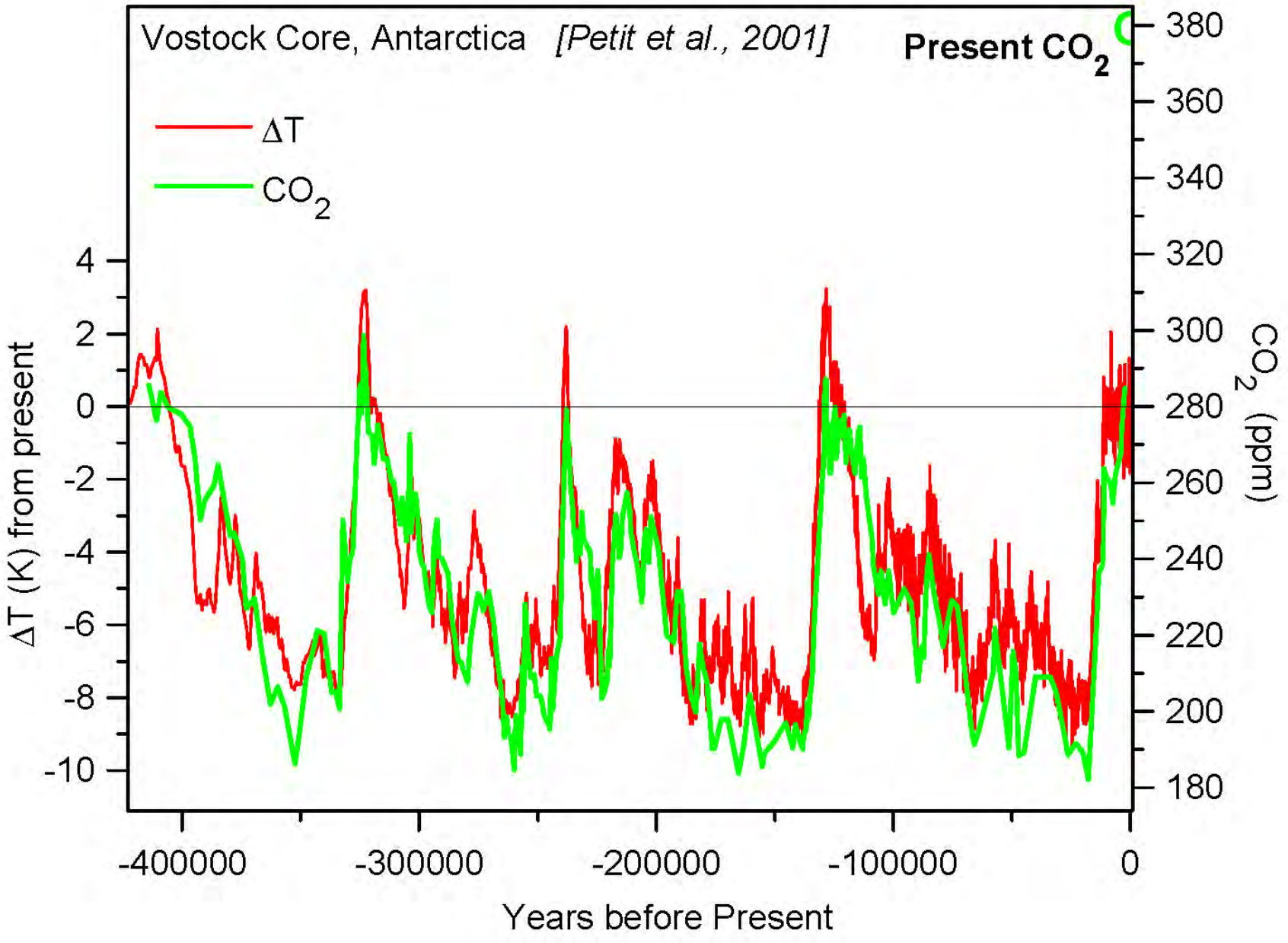
What do we know from past?

- **Reconstruct past climate**

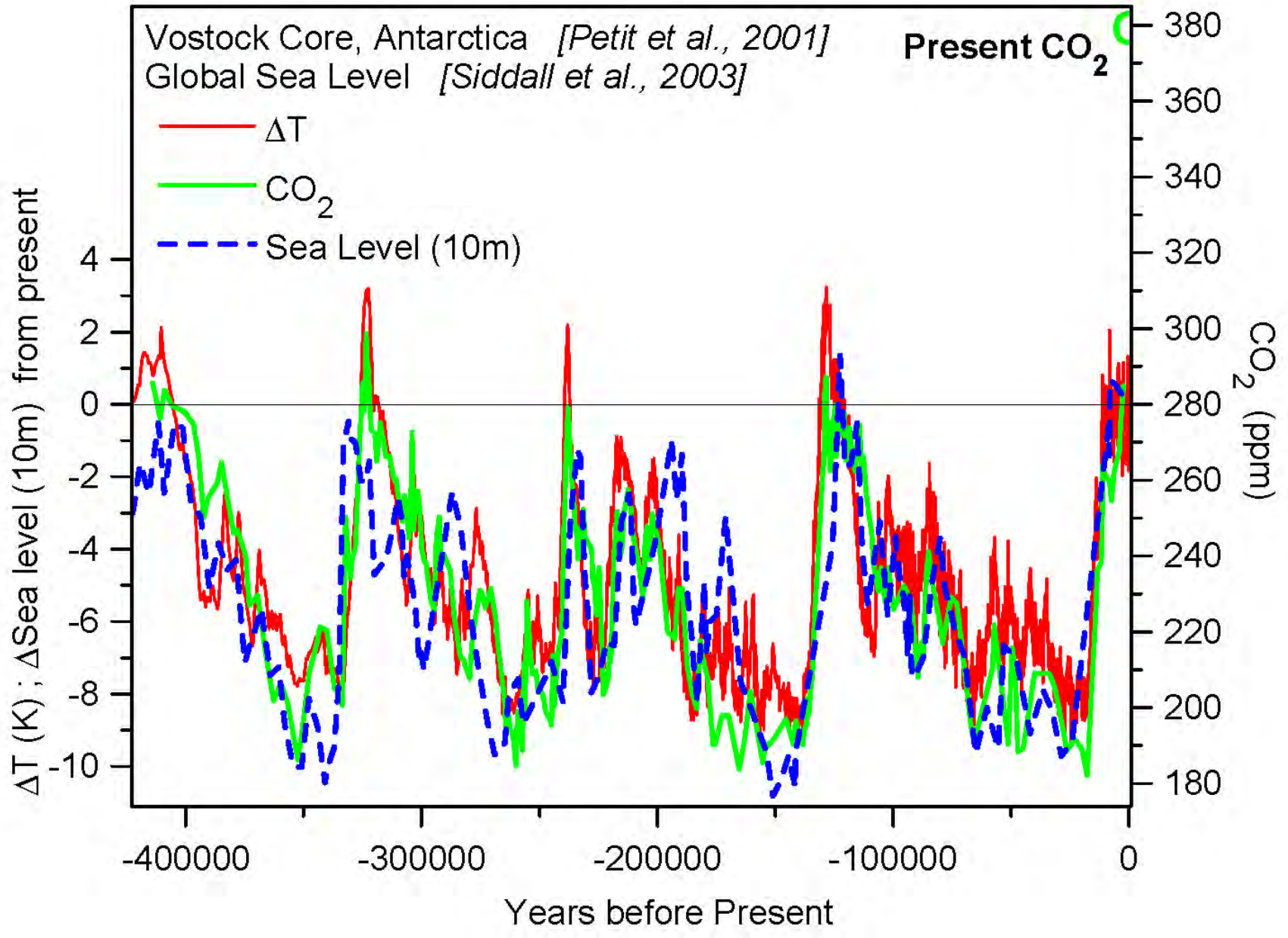
- Ice core history: T, CO_2, CH_4 through many ice-ages - nearly a million years
- Ocean sediments
- Tree rings – a few thousand years

Ice-core history!

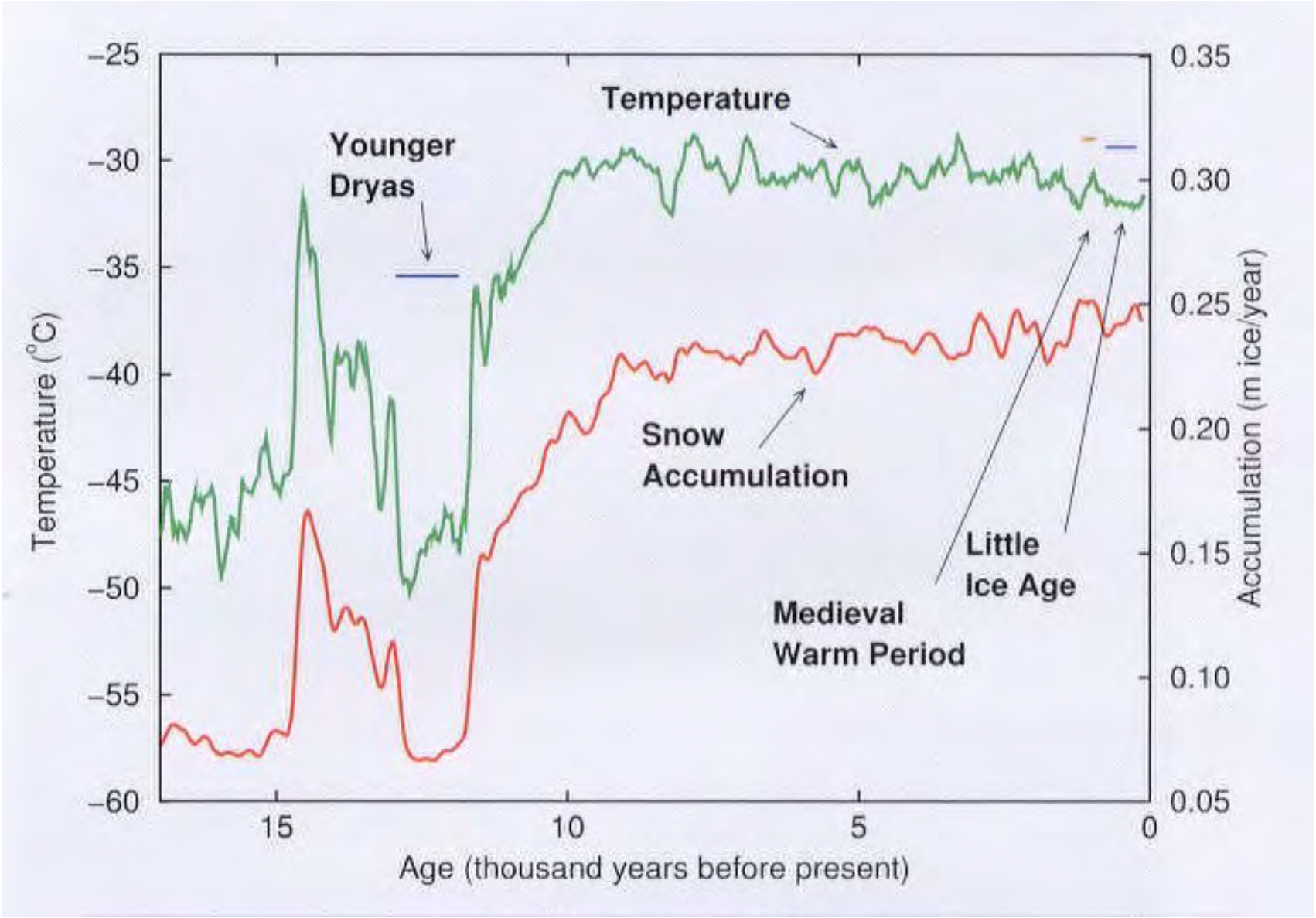
Four ice-age cycles



Four ice-age cycles



Sudden changes in Greenland!



Melting water cascades down a ‘moulin’ to the base of the Greenland ice sheet in summer

- when will the ice-sheet become unstable?

J. Hansen, Scientific American, March, 2004

Icebergs

- With break-up of large ice-sheets, sea level has risen in the past as fast as 5m (16ft) in 100 years

J. Hansen, Scientific American, March, 2004

Current sea level rise only 2.8mm/yr [1ft/100 years]

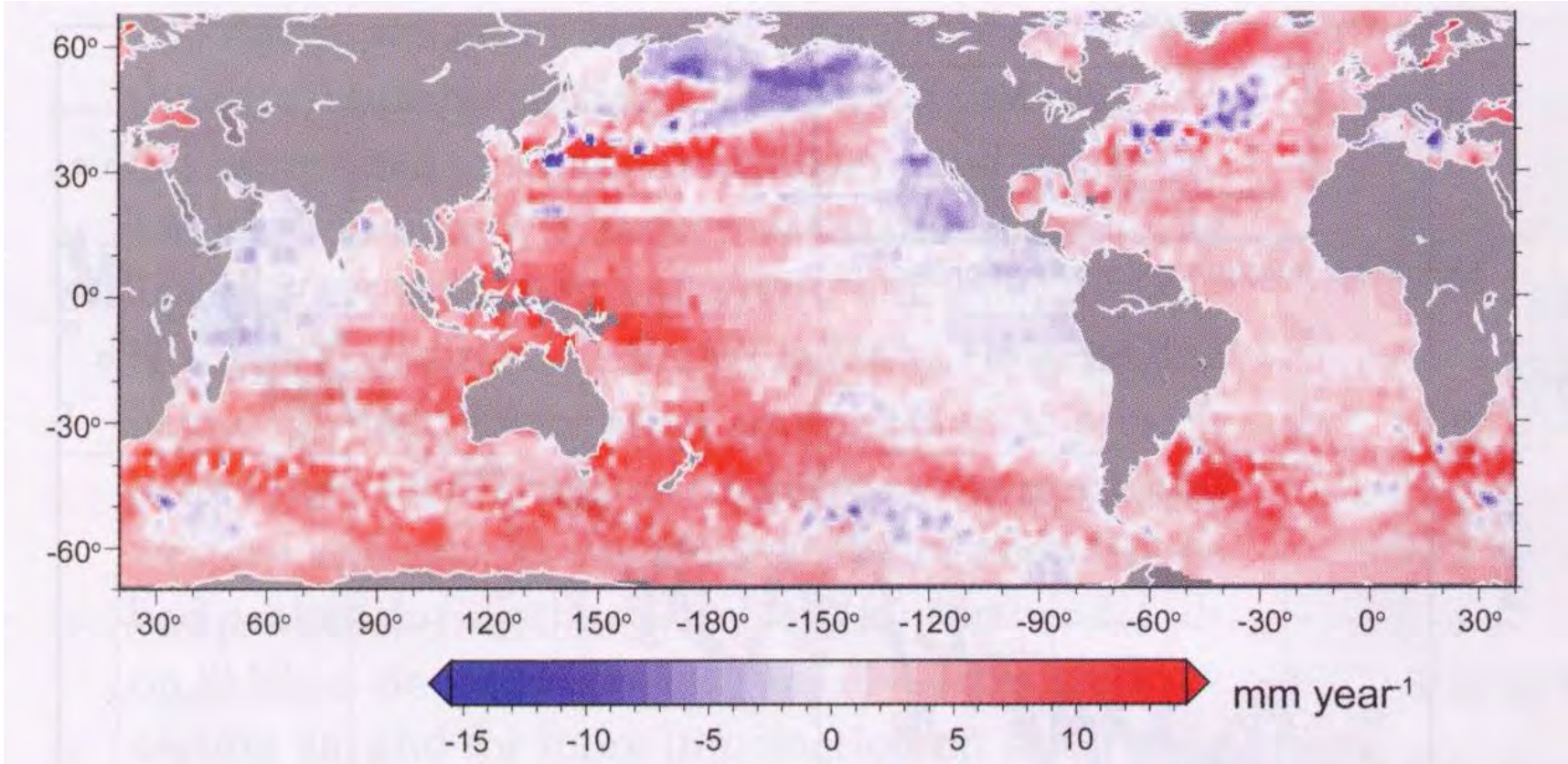


FIG. 2.11. Sea level trends over the period 1993–2004 determined from TOPEX and *Jason-1* satellite altimeter observations. The global mean of this map gives the 2.8 mm yr^{-1} value shown in Fig. 2.10.

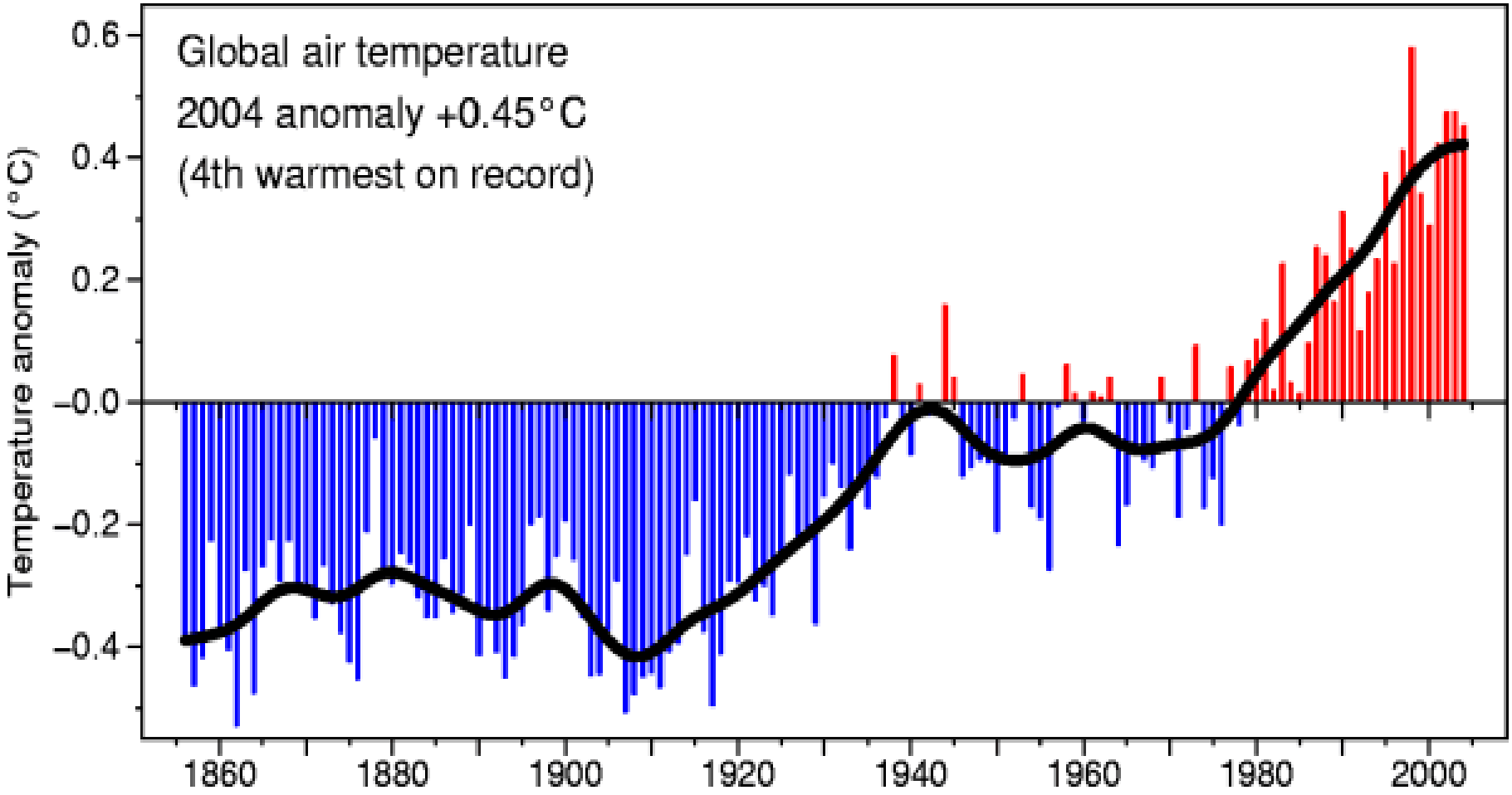
What are we now in 2005?

- **CO_2 up from 280 to 380ppm; 560ppm 'inevitable'**
- **Far beyond range of 'recent' climate record**
- 34MY ago at 1000ppm, earth had no Antarctic ice-sheet
- Mean temperature risen about 1^{o}F:

  predicted rise 3-8^{o}F this century
- 1990's, 2000's warmest on record
- Intense hurricanes are increasing
- Permafrost melting; tundra greening; ice shelves melting; frost-free season longer

Last 150 years temperature record

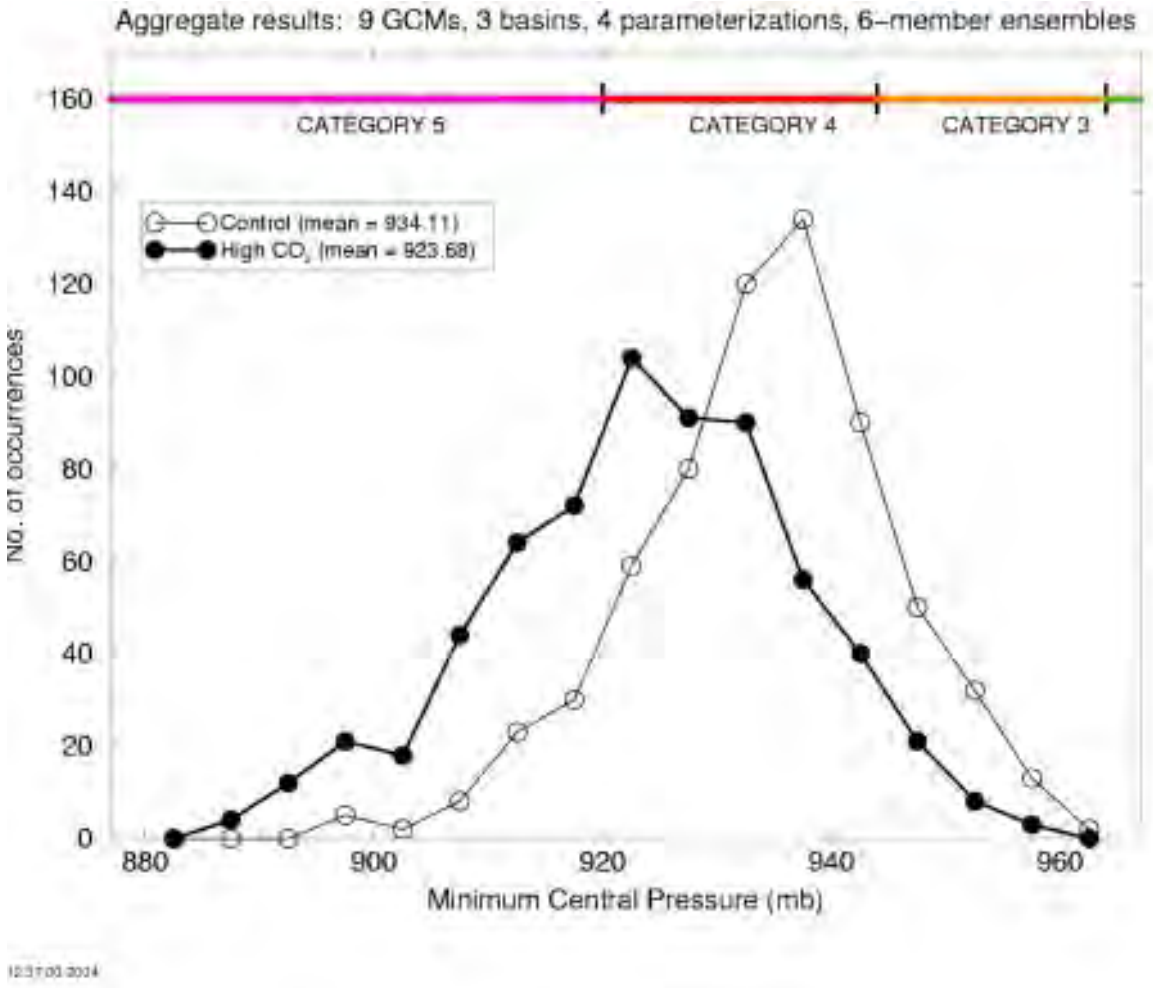
- *Jones, 2005*



Hurricane intensity changes with doubled CO_2
[Knutson and Tuleya, J. Climate, 2004]

- Warmer oceans
- Frequency of Category 5 hurricanes triples

[1300 simulations for 3 basins]



Climate, energy, water and carbon dioxide linked

- CO_2 is low in atmosphere because of *Photosynthesis by plants*
- $CO_2 + H_2O +$ sunlight (1%) **Y** Carbohydrates + O_2
- *Respiration/metabolism*
- Carbohydrates + O_2 **Y** $CO_2 + H_2O +$ energy
- almost in balance – over millions of years, small conversion to fossil fuels: *Coal, oil, gas*:
- *Stored sunlight, concentrated energy*

Humanity needed concentrated energy.

- Discovered coal, oil and gas **Y** industrial revolution

  Burning fossil fuels is putting stored CO_2 back into atmosphere *in a hurry*

- **Trees, plants and oceans are taking up about half**, but rest is accumulating, and CO_2 is rising faster than biosphere can adapt

- Centuries to burn all stored carbon, millennia for earth to equilibrate,

  [especially the oceans and ice]

What will it mean for New England?

- **Next few decades**
- Vermont: climate zone shift from 4 to 6 (Connecticut)
- Ice-water boundary will shift north and 1000ft upward

  - more wet snow; more winter thaws, more winter rain and freezing rain
- Warmer winters, longer growing season

  - good for summer agriculture, but maple syrup industry may shift to Quebec

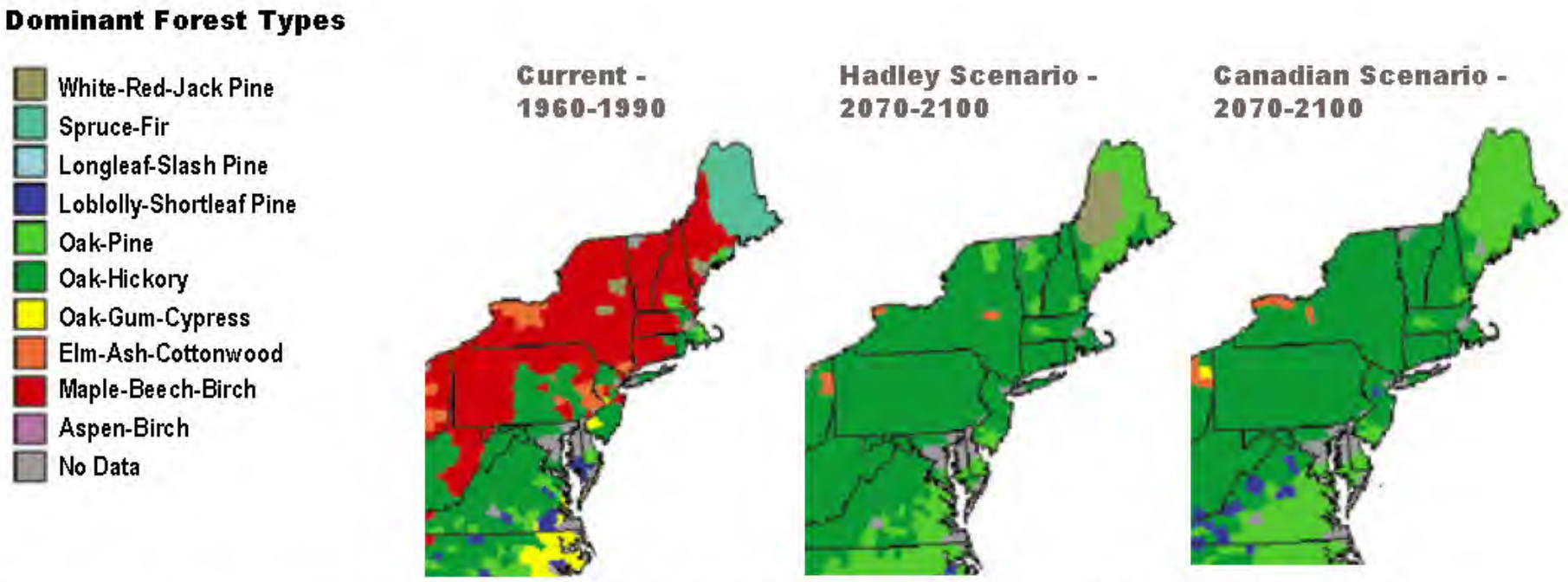
Snow-rain boundary shifts 1000ft upward

More wet snow, more winter rain and freezing rain

Will sugaring move north?

-

Will we lose the maple forests?



The maps above show current and projected forest types for the Northeast, based on the DISTRIBmodel (see Forest sector). Note that Maple-Beech-Birch, currently a dominant forest type in the region, is completely displaced by other forest types in both the Hadley and Canadian climate scenarios.

What will it mean for ecosystems?

- Birds and (ocean) fish can move north with habitat, if available
- Forests will struggle to adapt; damage from pests and disease are likely
- Farmers can adapt more readily (but poorer regions of world will need assistance)

Jokers in the pack!

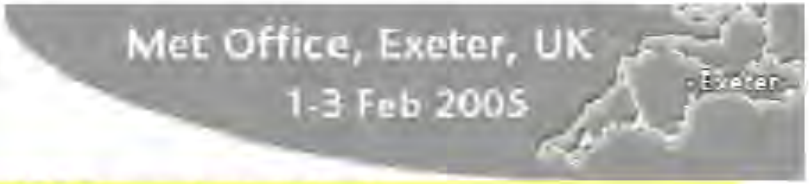
- **Extreme weather events**
- Heavier rain, more flooding
- Jan 1998 VT, Quebec ice-storm in warmest winter
- Other possible examples

  - 2003 heat wave in Europe [deaths from O_3]

  - 2004 hurricane season in Florida

  - more powerful hurricanes [Katrina, Rita 2005]

Avoiding Dangerous Climate Change



http://www.stabilisation2005.com/aim.html

Event sponsored by UK Department for Environment, Food and Rural Affairs

defra

Aim

In a speech on 14 September 2004, the British Prime Minister Tony Blair announced the conference by saying:

"... we propose first to host an international scientific meeting at the Hadley Centre for Climate Prediction and Research in Exeter in February. More than just another scientific conference, this gathering will address the big questions on which we need to pool the answers available from the science:

"What level of greenhouse gases in the atmosphere is self-evidently too much?

"What options do we have to avoid such levels?"

The UK Department of Environment, Food and Rural Affairs has been tasked to organise this event. The aim of the symposium is to advance scientific understanding of and encourage an international scientific debate on the long term implications of climate change, the relevance of stabilisation goals, and options to reach such goals; and to encourage research on these issues.

1. For different levels of climate change what are the key impacts, for different regions and sectors, and for the world as a whole?

2. What would such levels of climate change imply in terms of greenhouse gas stabilisation concentrations and emission pathways required to achieve such levels?

3. What technological options are there for achieving stabilisation of greenhouse gases at different stabilisation concentrations in the atmosphere, taking into account costs and uncertainties?

Avoiding Dangerous Climate Change

Stabilising climate to avoid dangerous climate change — a summary of relevant research at the Hadley Centre

- ***UK Met Office and Dept for Environment, Food and Rural Affairs, 2005***

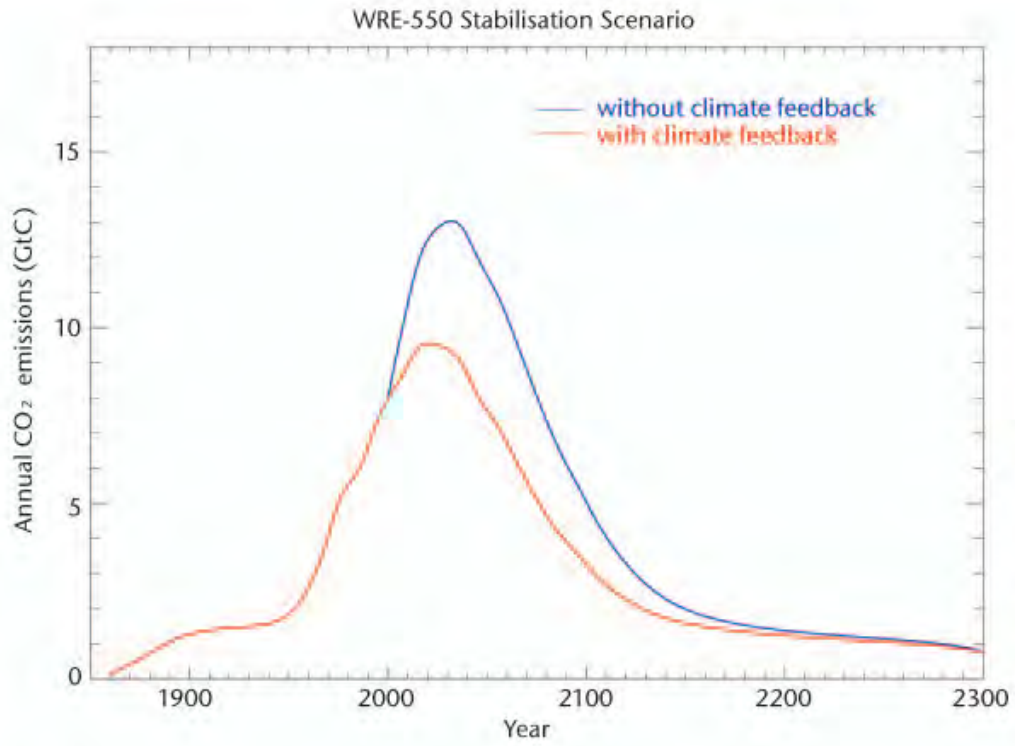
To limit global temperature rise to 2ºC (3.6ºF) above present day

- CO_2 in the atmosphere (now 380ppm) would need to be stabilized in the range of about **490ppm to 670ppm**

(5% and 95% confidence levels)

[Avoiding dangerous climate change
http://www.stabilisation2005.com/
Hadley Centre, 2005]

Meaning for CO_2 emissions …



Emissions of CO_2 which would be consistent with the WRE550 stabilisation scenario, estimated by the Hadley Centre climate model with and without the inclusion of carbon cycle feedback

- Global emissions permitted in order to stabilize CO_2 concentration at 550ppm — as predicted by the Hadley Centre coupled climate-carbon model.

In other words..

- Avoiding dangerous climate change means a radical shift in our industrial society away from dependence on fossil fuels in just one generation
- A huge task

Scientific, social, political and moral issues

- Science can give us good estimates, but not exact answers, because the earth's climate system is very complex
- Do we need more science to start the process of adaptation?
- What are our responsibilities to the earth and to our children?

Why is it difficult?

- Natural world is very complex and also alive

  we can't predict very well: many surprises
- Unlike the world of machines & computers, which are man-made and predictable
- ***Current problem arises because our technology is having a global impact on the natural world***
- **Climate change is not fully predictable**
- ***We are already decades late in taking action***
- *[UN Framework Convention on Climate Change,*

  Rio de Janeiro, 1992]

Is our democracy well-informed?

- You would think from the media that
  climate change was in doubt!
  we live in a sea of disinformation!
- Yes, it is complex
  Yes, ‘predictions’ are not precise..
  but the direction and its cause is clear
- ‘Truth’ may seem elusive in the face of uncertainty and complexity
  but honesty is not

Fifteen years ago…

- ***Science, like any field of endeavor, relies on freedom of inquiry; and one of the hallmarks of that freedom is objectivity. Now more than ever, on issues ranging from climate change to AIDS research to genetic engineering to food additives, government relies on the impartial perspective of science for guidance.***

— PRESIDENT GEORGE H. W. BUSH, 1990

[Remarks to the National Academy of Sciences, April 23, 1990. Online at bushlibrary.tamu.edu/papers/1990/90042301.html]

In weather and climate science…

- Weather forecasting is ‘protected’ by short-term reality: its credibility is seen tomorrow

- Climate science is more vulnerable because its predictions are viewed as a threat

What could we do?

- Admit fossil fuel economy is now driving climate change [despite ‘deep uncertainty’]
- Creatively start the adaptation towards a more efficient renewable energy path
- And save a lot of money as fossils fuels get more expensive!

Resources

For science:

US Global Change Research Program

- www.usgcrp.gov for vast overview
- www.realclimate.org for discussion/debate

For policy:

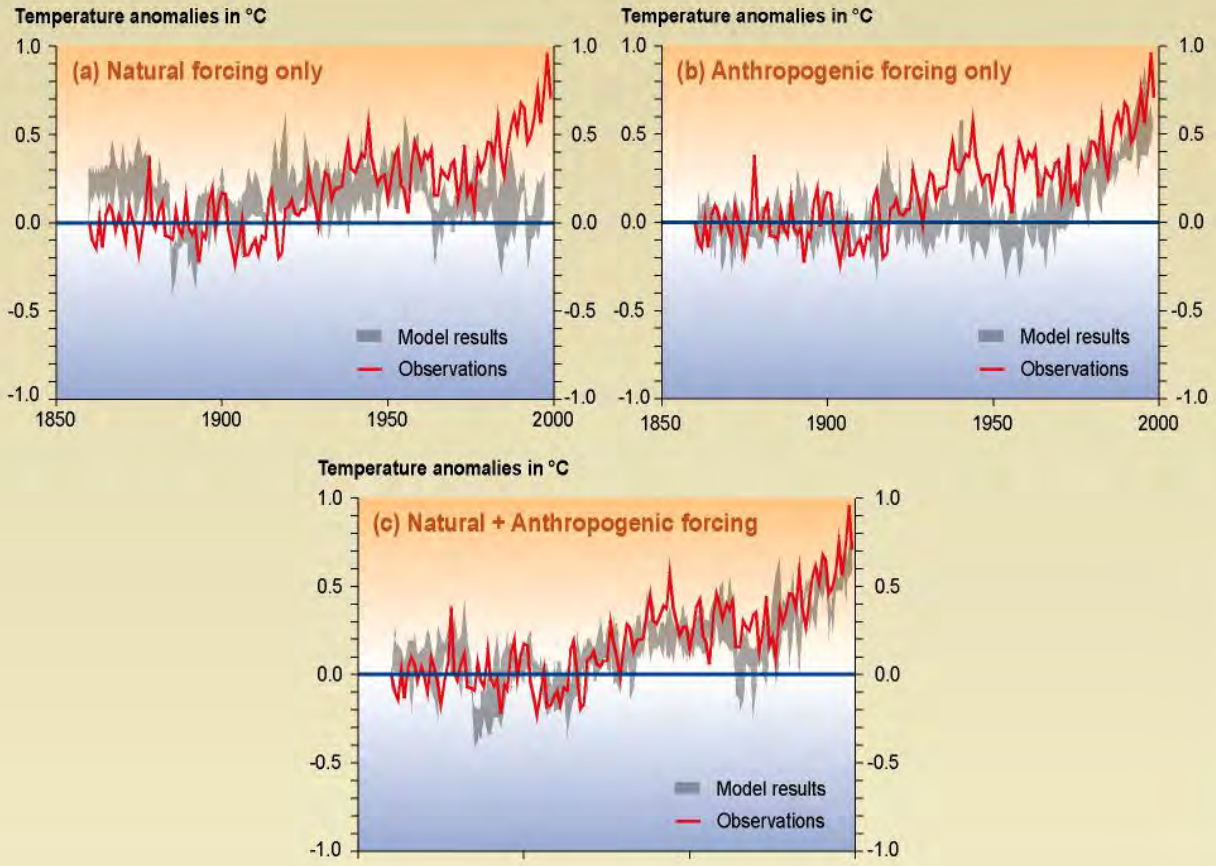
- *"Red Sky at Morning" James Gus Speth*
- www.redskyatmorning.com
- Download the afterward: *"Climate Change.. what we can do in America"*

International policy:

http://unfccc.int/2860.php

http://www.ipcc.ch/

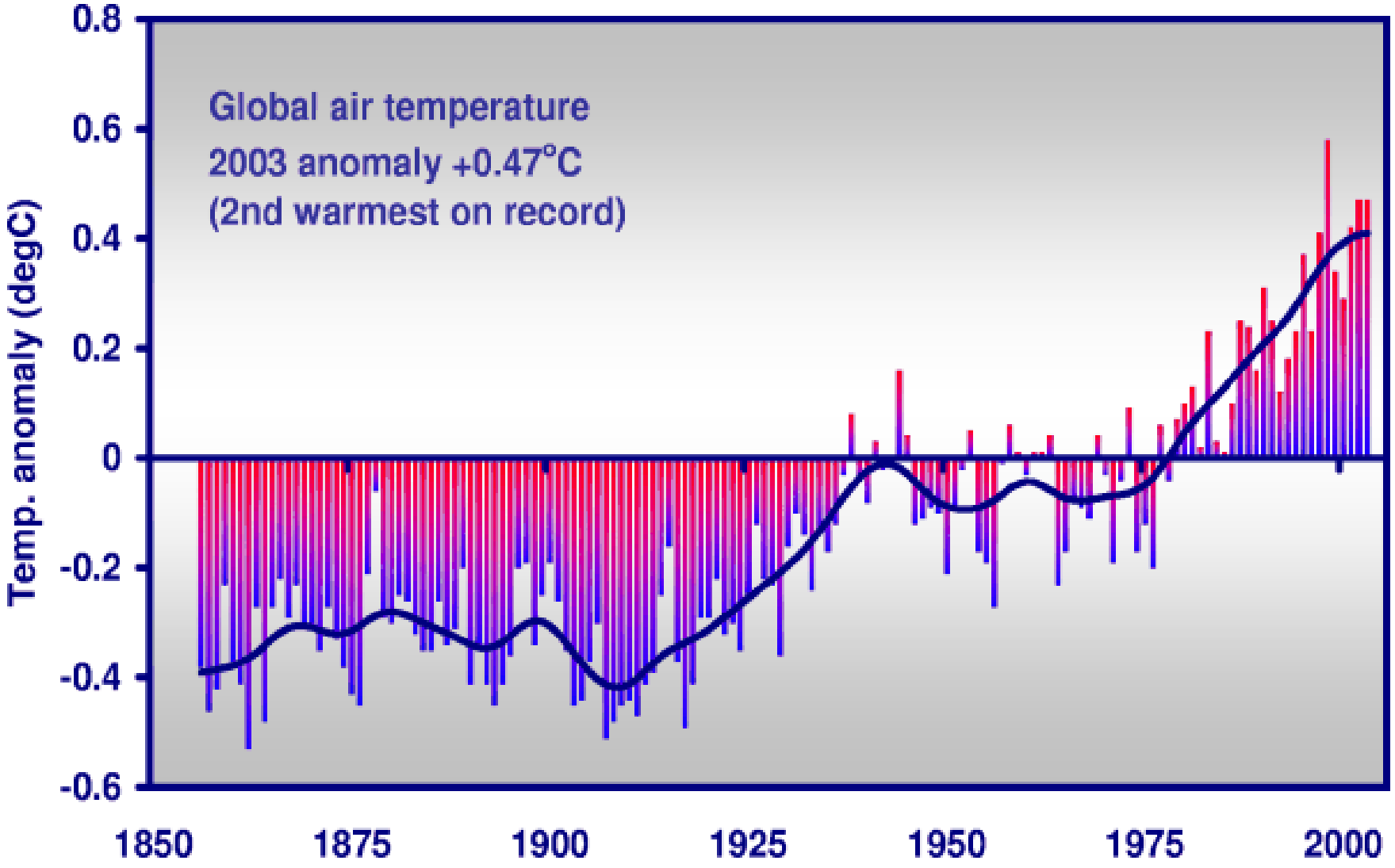
Comparison between modeled and observations of temperature rise since the year 1860



SYR - FIGURE 2-4

Last 150 years temperature record

- *Jones and Moberg, 2003*



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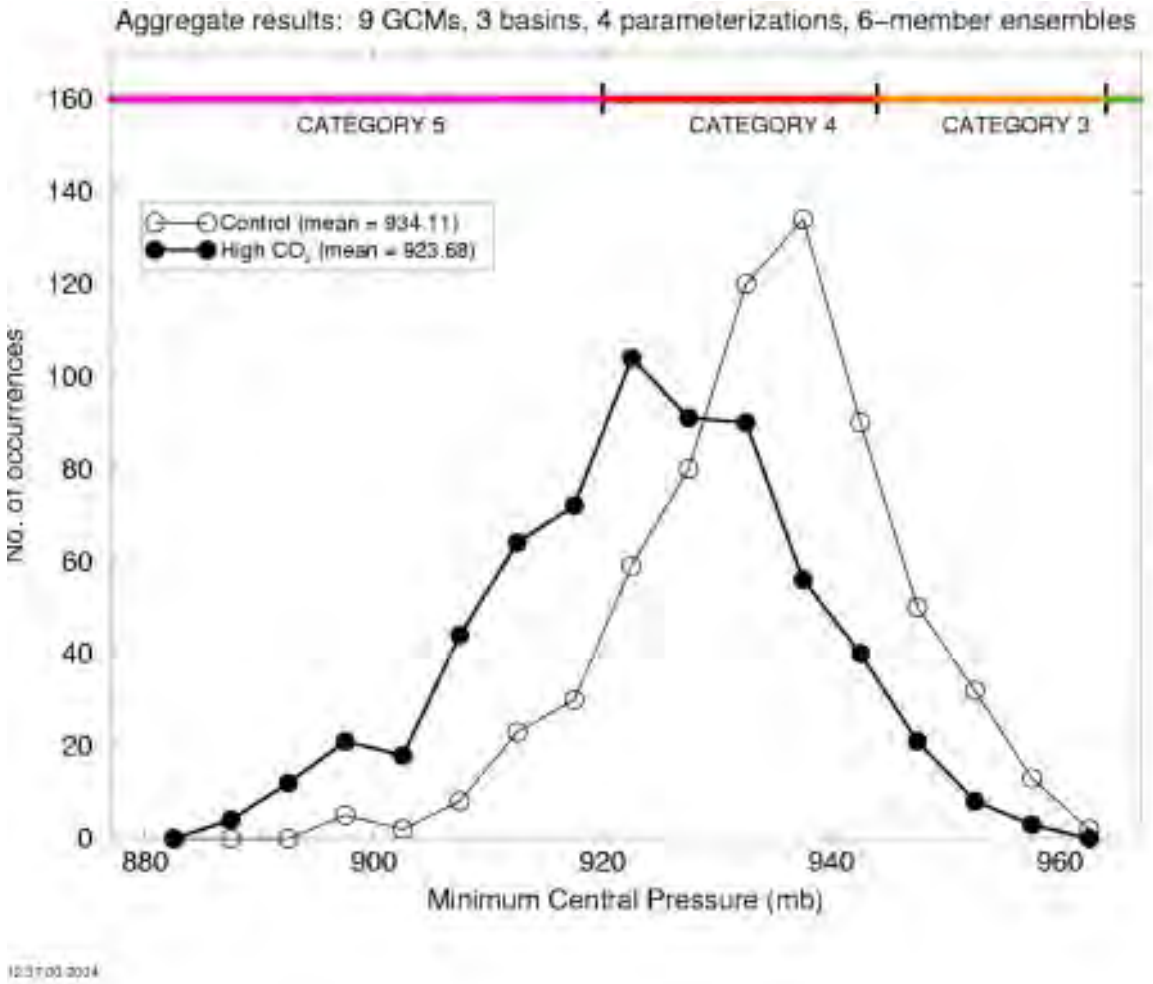
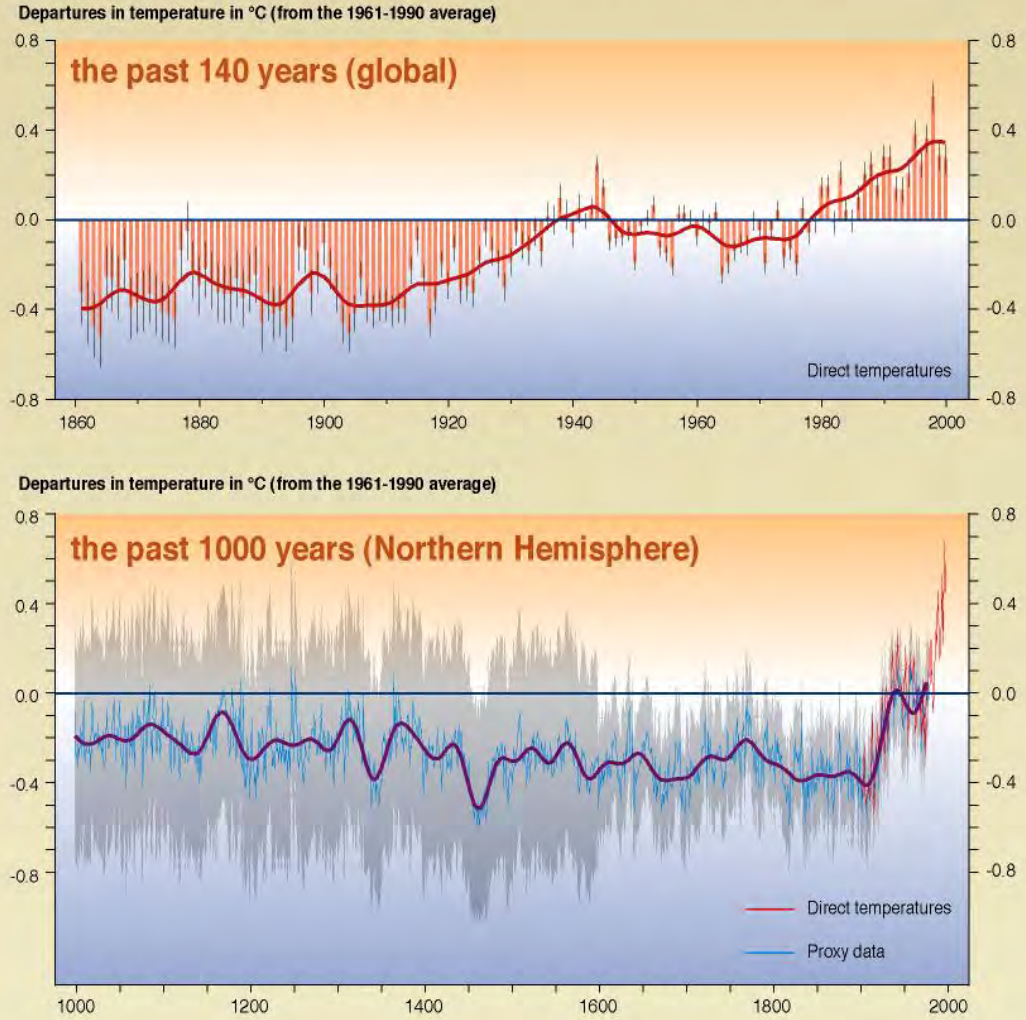


Variations of the Earth's surface temperature for...



SYR - FIGURE 2-3

1000-yr temperature reconstruction