Monday PM, Explain: Basic Climate Change

Slide 1

MONDAY PM
Basic Climate Change

Basic Climate Change: Enhanced Atmospheric Greenhouse Effect
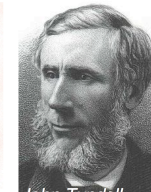
- 19th century physics

- What is a (computer) climate model?

- Water vapor feedback

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Slide 2

Basic Physics & Common Sense
Why it's simpler than you think
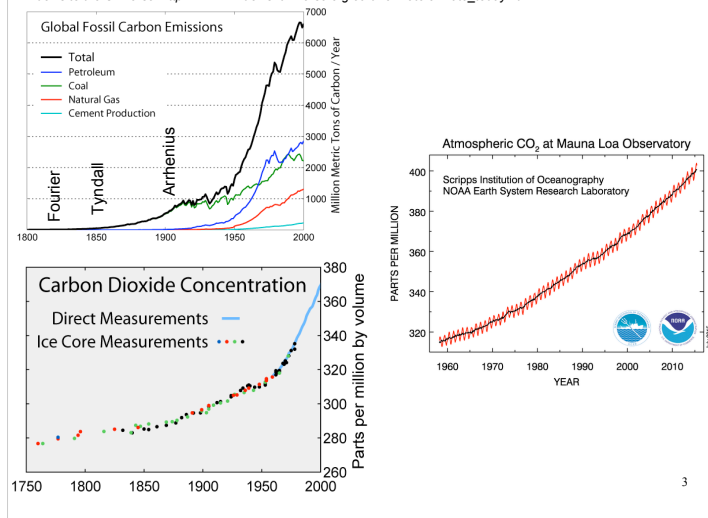
Joseph Fourier   *John Tyndall*

- Fourier in the 1820's first describes the atmospheric greenhouse effect
- Tyndall in the 1850's first measures the radiative properties of atmospheric greenhouse gases (H_2O, CO_2, ...)
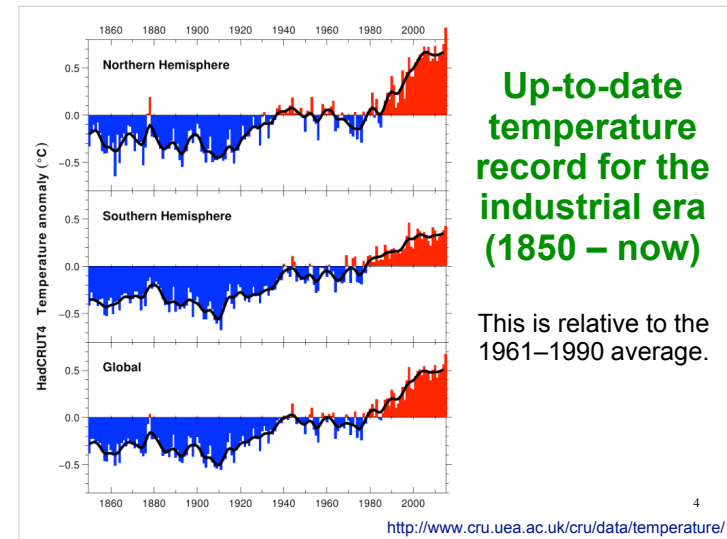
Svante Arrhenius

- Arrhenius in 1896: doubling CO_2 enhances atmospheric greenhouse effect, surface warming of ~6 C = 11 F
- Arrhenius adjusted number in 1906:
  2 x CO_2 → 2.1 C = 3.8 F warming
- his calculation included two largely compensating errors

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Windows to the Universe: http://www.windows2universe.org/earth/climate/climate_today.html

Global Fossil Carbon Emissions
- Total
- Petroleum
- Coal
- Natural Gas
- Cement Production

Fourier Tyndall Arrhenius

Atmospheric CO_2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory

Carbon Dioxide Concentration
- Direct Measurements
- Ice Core Measurements

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Slide 4

Up-to-date temperature record for the industrial era (1850 – now)

This is relative to the 1961–1990 average.

Northern Hemisphere
Southern Hemisphere
Global

HadCRUT4 Temperature anomaly (°C)

http://www.cru.uea.ac.uk/cru/data/temperature/

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Slide 1

What is a Model?

- Wikipedia: "Scientific modeling is a scientific activity, the aim of which is to make a particular part or feature of the world easier to understand, define, quantify, visualize, or simulate."
- Our simple atmospheric greenhouse calculations were done using a model (assumptions: treat atmosphere as blackbody, no circulations/winds)
- Quantitative models for weather and climate quickly become so complex that they require the use of computers ("number crunchers")

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Slide 2

What is a Computer Climate Model?

Basically, a set of equations that represent the atmosphere, ocean, sea ice, land surface, and land ice. E.g. for the atmospheric component:

Wind
$$\frac{\partial \mathbf{v}}{\partial t} = -\mathbf{v} \cdot \nabla \mathbf{v} - \omega \frac{\partial \mathbf{v}}{\partial p} + f\mathbf{k} \times \mathbf{v} - \nabla \Phi + \mathbf{D}_M$$

Temperature
$$\frac{\partial T}{\partial t} = -\mathbf{v} \cdot \nabla T + \omega \left(\frac{\kappa T}{p} - \frac{\partial T}{\partial p} \right) + \frac{Q_{rad}}{c_p} + \frac{Q_{con}}{c_p} + D_H$$

Water Vapor
$$\frac{\partial q}{\partial t} = -\mathbf{v} \cdot \nabla q - \omega \frac{\partial q}{\partial p} + E - C + D_q$$

Mass Conservation
$$\frac{\partial \omega}{\partial p} = -\nabla \cdot \mathbf{v}$$

Hydrostatic Balance
$$\frac{\partial \Phi}{\partial p} = -\frac{RT}{p},$$

These quantities represent the effects of clouds, radiation, evaporation, friction on the atmosphere. They cannot be calculated directly (below model scale) and need to be estimated/parametrized.

from Trenberth (1992)

Slide 3

Different CO_2 concentrations in Radiative-Convective Equilibrium Model: Change in surface temperature when going from 300 to 600 ppmv CO_2 is ≈ 2.4 C ≈ 4.3 F.
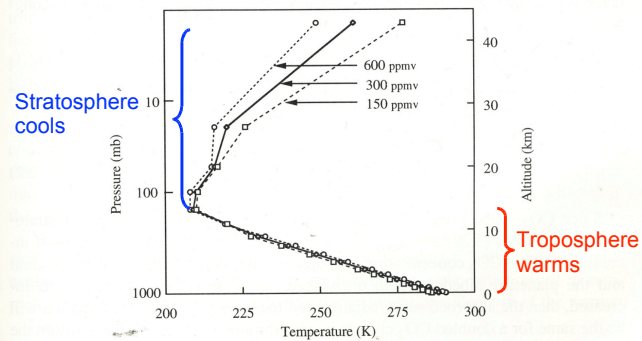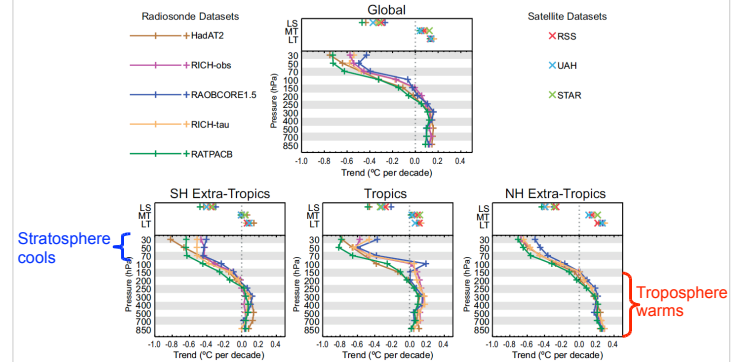
Stratosphere cools

Troposphere warms

Fig. 12.7 Temperature profiles calculated with a one-dimensional radiative-convective equilibrium model for CO_2 at 150, 300, and 600 ppmv. [Data from Manabe and Wetherald (1967). Reprinted with permission from the American Meteorological Society.]
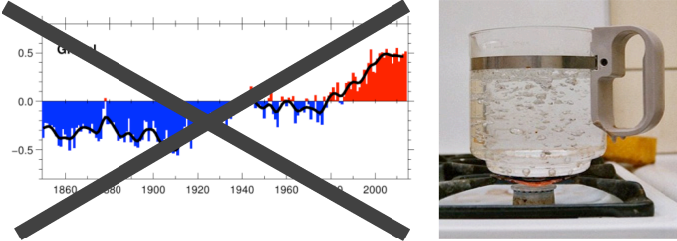
Slide 4

Observed Vertical Trend Structure

Radiosonde Datasets: HadAT2, RICH-obs, RAOBCORE1.5, RICH-tau, RATPACB

Satellite Datasets: RSS, UAH, STAR

Global / SH Extra-Tropics / Tropics / NH Extra-Tropics

Stratosphere cools

Troposphere warms

IPCC, 2013

These temperature trends are consistent with what one would expect due to greenhouse gas forcing.

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A Common Myth

"People are worried about climate change because it's been getting warmer lately"

WRONG! We're concerned because we know that when we add energy to things, they warm up!

Feedbacks

- *A process that changes the sensitivity of the climate response to an external forcing*
- **Positive feedback:** increase the magnitude of the response to the forcing
  - Ice/albedo feedback
  - Water vapor feedback
  - Ocean carbon cycle feedbacks
- **Negative feedback:** decrease the magnitude of the response to the forcing
  - Stefan-Boltzmann feedback (i.e. warmer Earth emits more radiation out to space)

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Water Vapor Feedback (Positive)

- Most important feedback in the climate system
- (recall that water vapor is a powerful greenhouse gas)
- As climate warms saturation vapor pressure increases – warm air tends to contain more water vapor
- As water vapor increases its radiative effects warm the climate more
- As the climate warms further air tends to contain even more water vapor, and so on ...
- This feedback loop is true as long as relative humidity is roughly constant (which seems to be roughly the case in observations and climate models)

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Stefan-Boltzmann Feedback (Negative)

- Recall the total possible rate of radiation emission by an object is given by: $E = \sigma T^4$
- Hence, a warmer earth will emit more radiation to space, eventually stabilizing the climate system and capping the rise in temperature
- Likewise, a cooler earth will emit less radiation to space

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