Climate Change: The Move to Action
(AOSS 605 (480) // NRE 501.076)

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LECTURE NUMBER 7
February 1, 2007

Class News

- February 2, 2007, the official summary for IPCC should be released. The rest of the report will follow over the year.

- THURSDAY: A week from today. We will discuss projects. If you have a specific topic you want to study, then come with the idea of a proposal.
  - I think they are more reflective of the real world if they are team projects where you are forced to balance contradictory requirements.

Speakers subject to scheduling

- Maria Carmen Lemos
- Andy Hoffman
- Barry Rabe
- Nina Mendelson
- Justin Felt
- Meredith Fowlie
- Marie O’Neill
- Phil Rasch (3/22)
- Sabrina McCormick
- Henry Pollack
- Rosina Bierbaum (3/29)
- Others

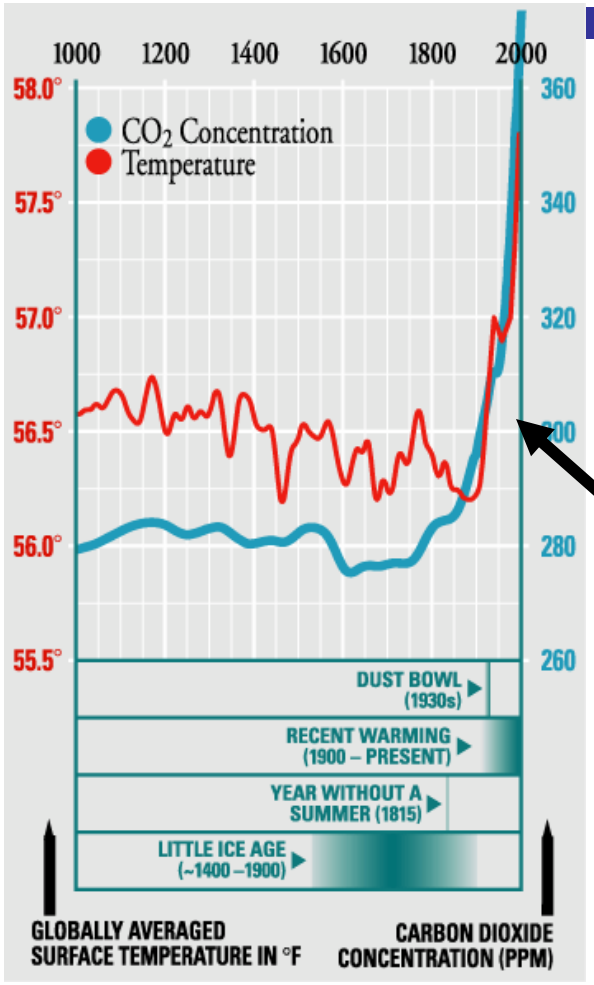
Ideas and Things

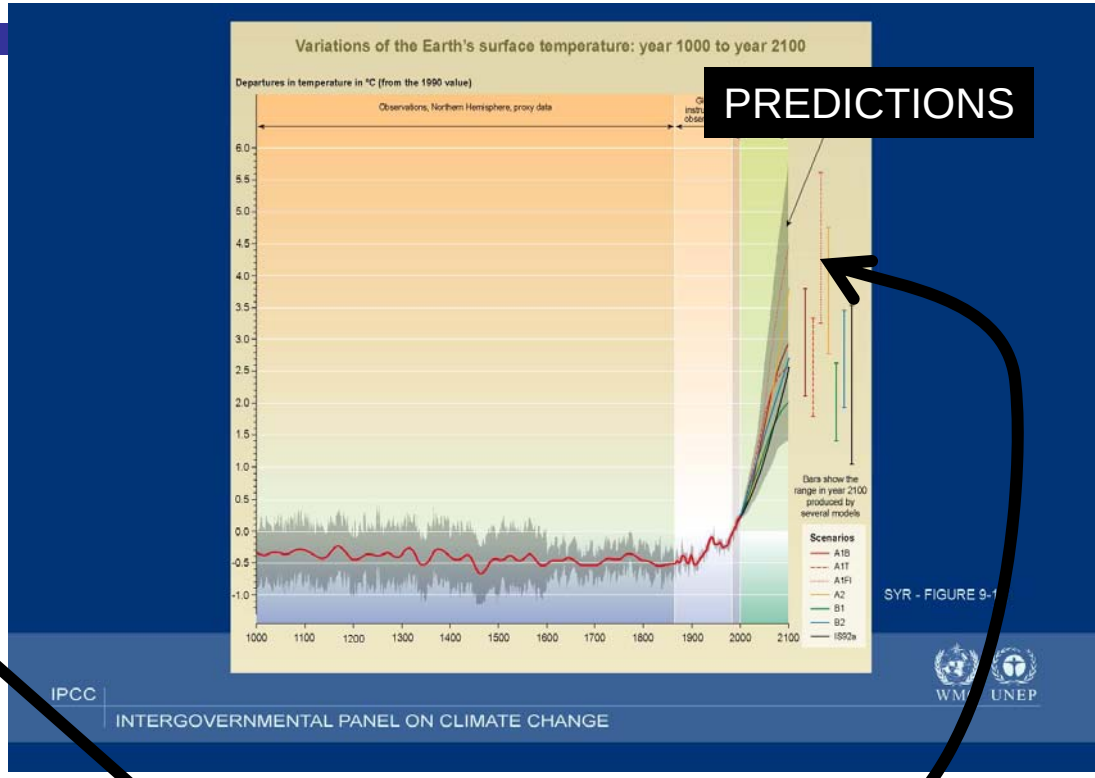
- NEWS: Anyone hear or read any news they want to discuss.
  - Any one have information from the Senate and House Hearings?
  - Criticism / Discussion of IPCC
    - USA Today Yesterday

Science Basis of Climate Change (4)

- Last time we went through the Earth system at the level of Atmosphere-Cloud-Land-Ocean-Ice.
  - Role of each in the energy balance
  - Introduced the idea of the atmosphere and ocean transporting energy around
  - Paid most attention to ice – the cryosphere
  - Introduced the idea of feedbacks
    - Damp warming
    - Accelerate warming

Schematic Summary



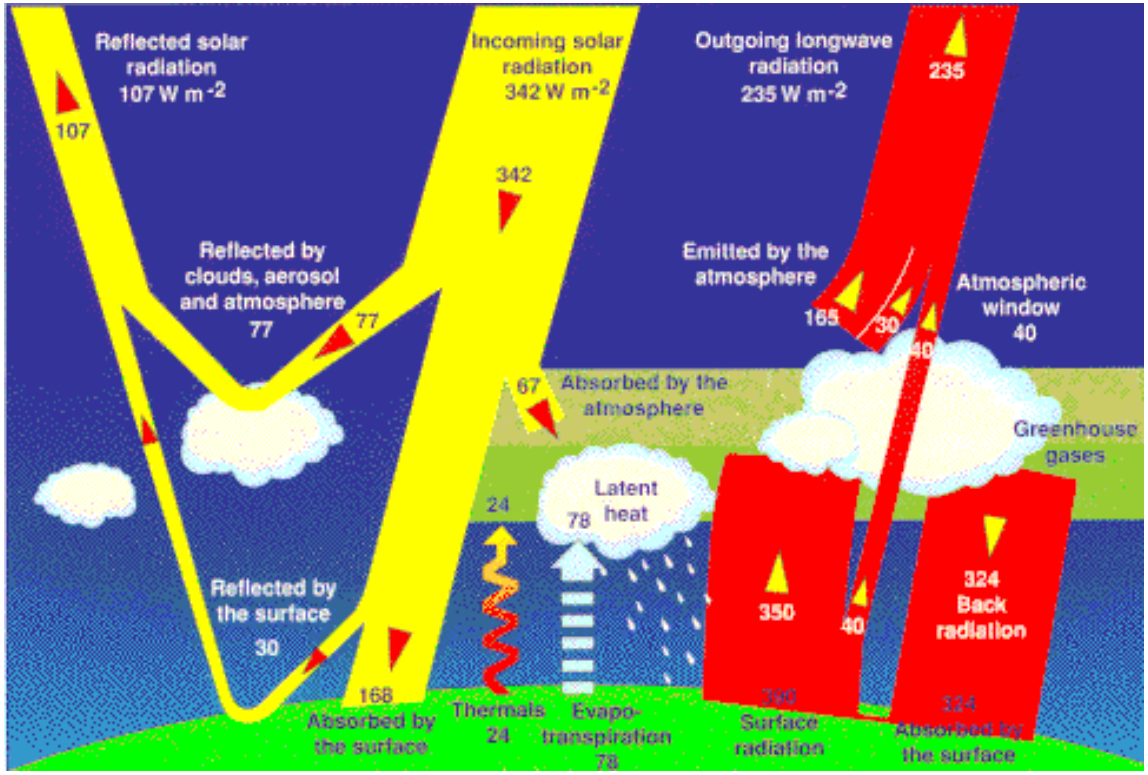


PREDICTIONS

INCREASING CARBON DIOXIDE
INCREASING TEMPERATURE

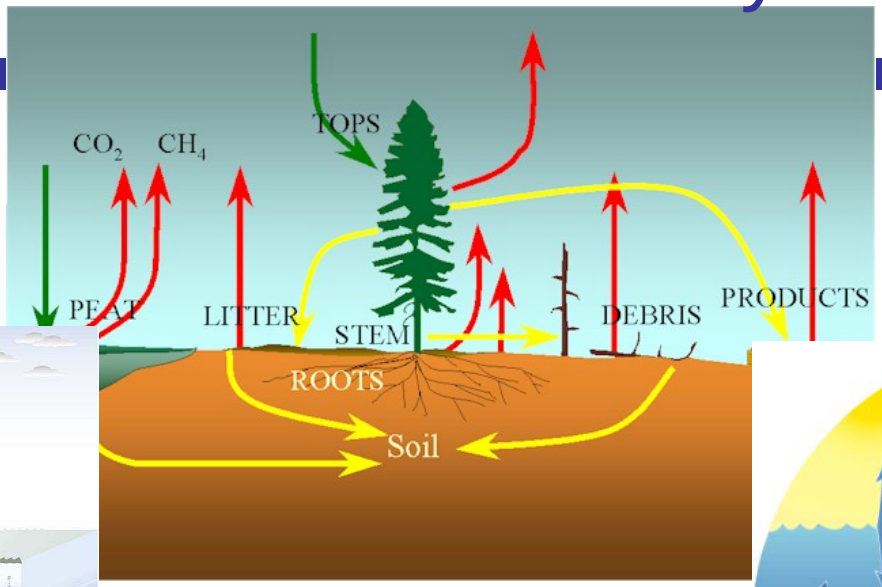
OBSERVATIONS

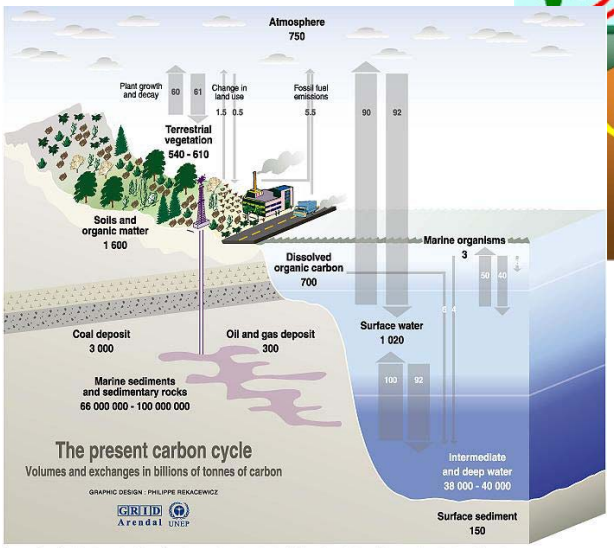
Schematic Summary



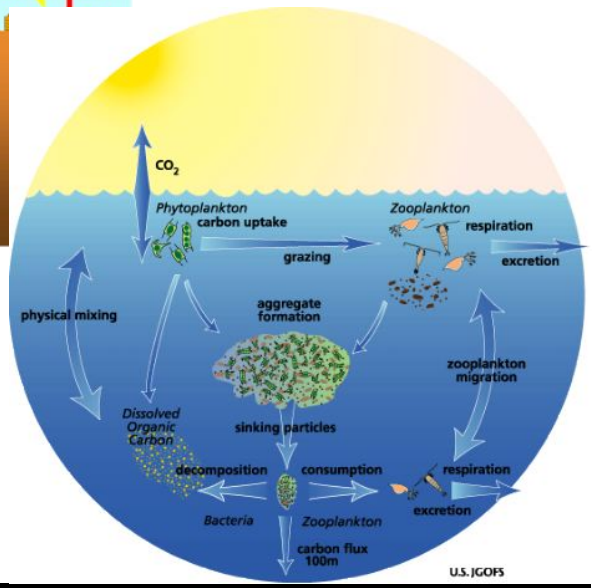
IF WE CHOOSE TO DO SOMETHING ABOUT THIS, THEN
CHANGE ENERGY BALANCE
CHANGE ABSORPTION OF RADIATIVE ENERGY
CHANGE REFLECTION OF RADIATIVE ENERGY

Schematic Summary





Sources: Center for climatic research, Institute for environmental studies, university of Wisconsin at Madison; Okanagan university college in Canada, Department of geography; World Watch, November-December 1998; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.



IF WE CHOOSE TO DO SOMETHING ABOUT THIS, THEN

CHANGE CARBON DIOXIDE BALANCE

CHANGE SOURCE OF CARBON DIOXIDE

CHANGE SINK OF CARBON DIOXIDE

A QUESTION OF BALANCE

- Is the ocean a safe and reliable sink for energy (heat) and carbon dioxide?

- Do ecosystems take off in any safe and reliable way to use the extra carbon dioxide?

Schematic Review go?

CHANGES IN DYNAMICS?
(HEAT / WATER VAPOR TRANSPORT)

CLOUD-RADIATIVE FEEDBACK

ICE-ALBEDO FEEDBACK

WATER VAPOR FEEDBACK

TEMPERATURE FEEDBACK

THE EARTH IS EXPECTED TO RESPOND TO THESE CHANGES
FEEDBACKS
POSITIVE: ACCELERATE WARMING
NEGATIVE: DAMP WARMING

The Question of Feedbacks

- Is there some sort of balance in the system that work to keep the equilibrium temperature of the Earth the same?
  - Why would this be the case?

Water, Water, Water

- We talk about global warming, but what's really important is water.
  - Water in the physical climate system
    - Ice-Liquid-Vapor Balance
  - Water supply for humans and ecosystems
  - Water in the ocean

Abrupt Climate Change

- We have introduced the idea of abrupt climate change.
  - And perhaps we have evidence of it having occurred.

We need to introduce aerosols

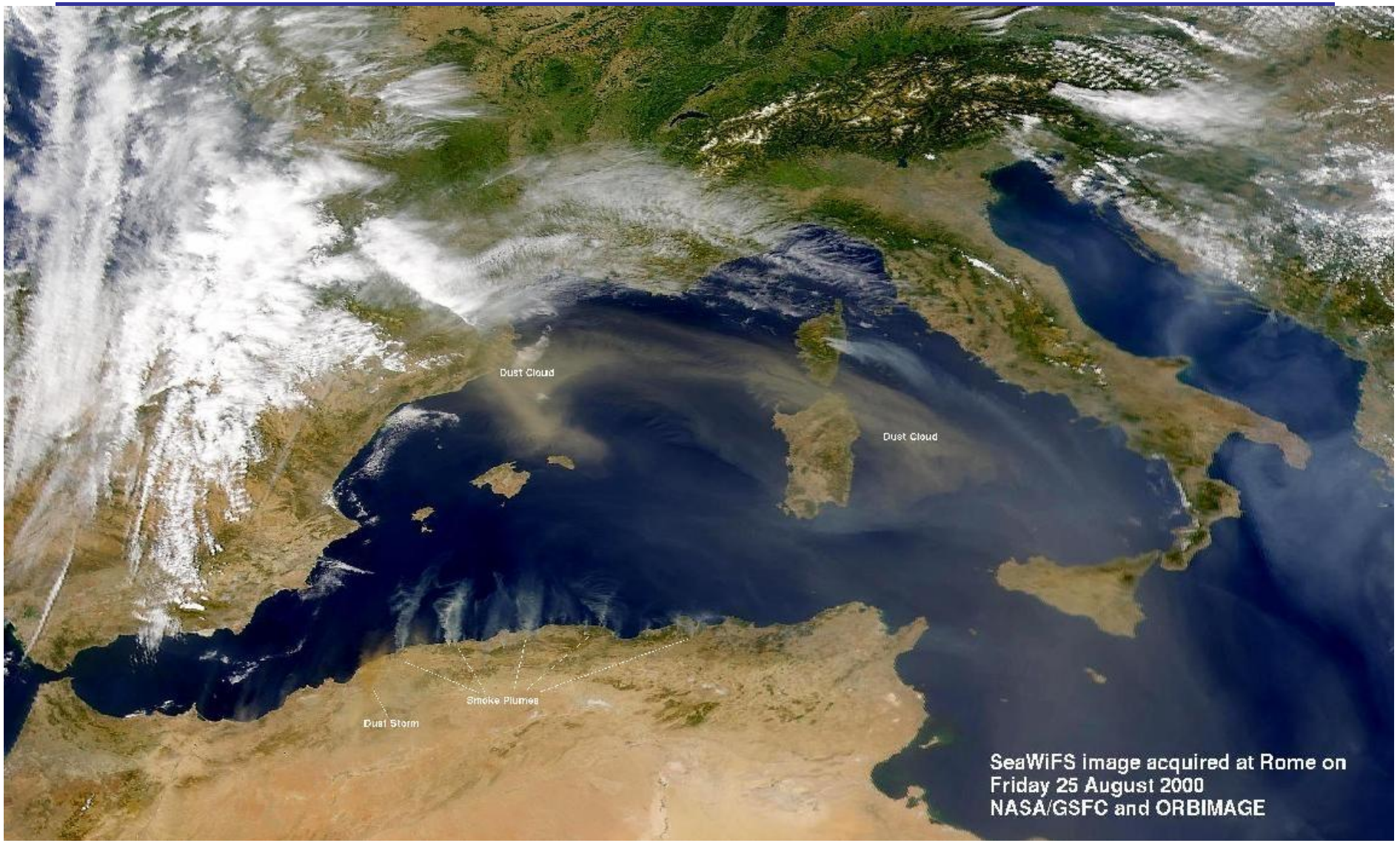
Aerosols: Particles in the Atmosphere

Aerosols: Particles in the atmosphere.

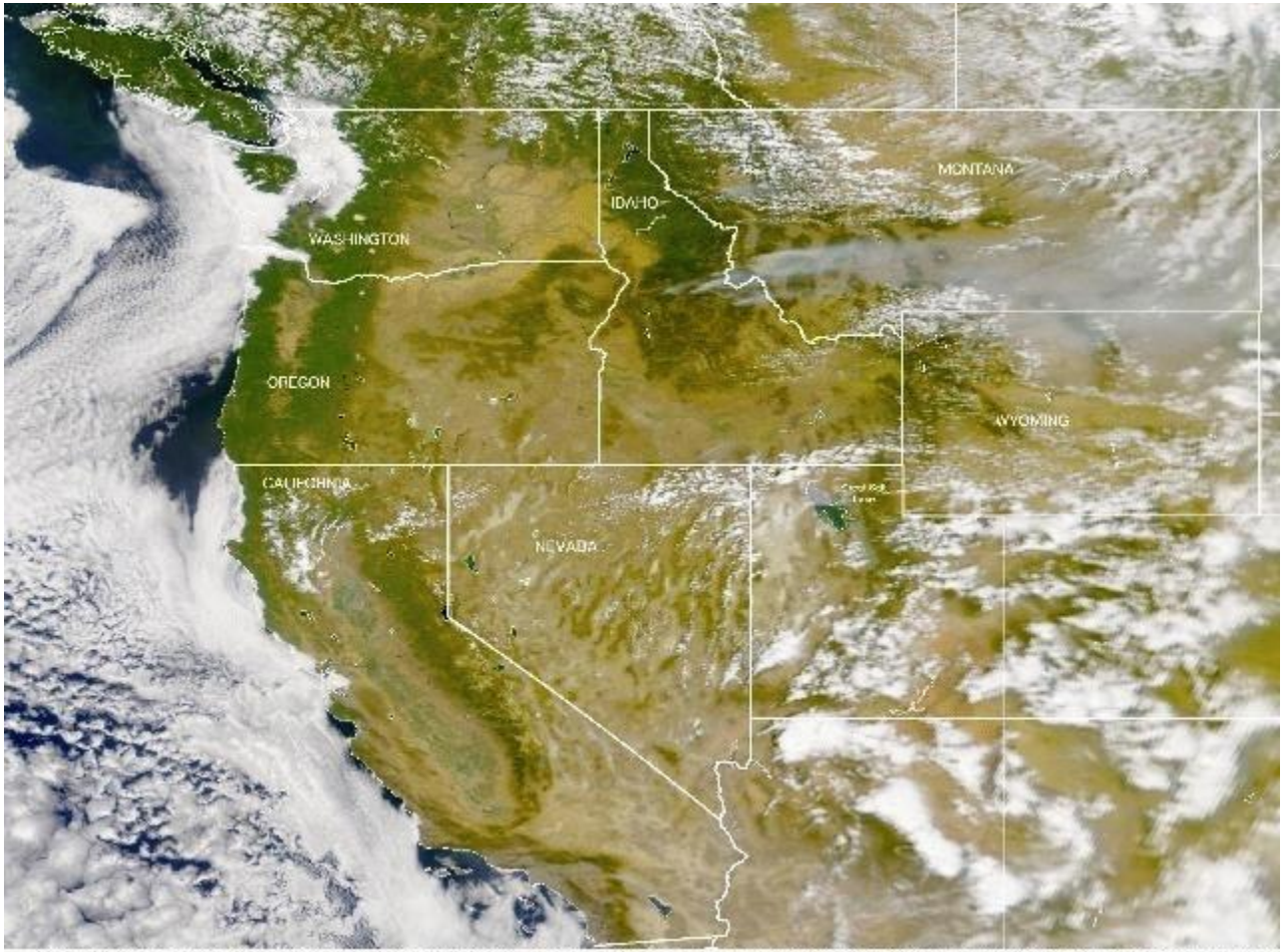
- Water droplets – (CLOUDS)
  - “Pure” water
  - Sulfuric acid
  - Nitric acid
  - Smog
  - …
- Ice
- Dust
- Soot
- Salt
- Organic hazes

AEROSOLS CAN:
REFLECT RADIATION
ABSORB RADIATION
CHANGE CLOUD DROPLETS

Dust and fires in Mediterranean



Forest Fires in US



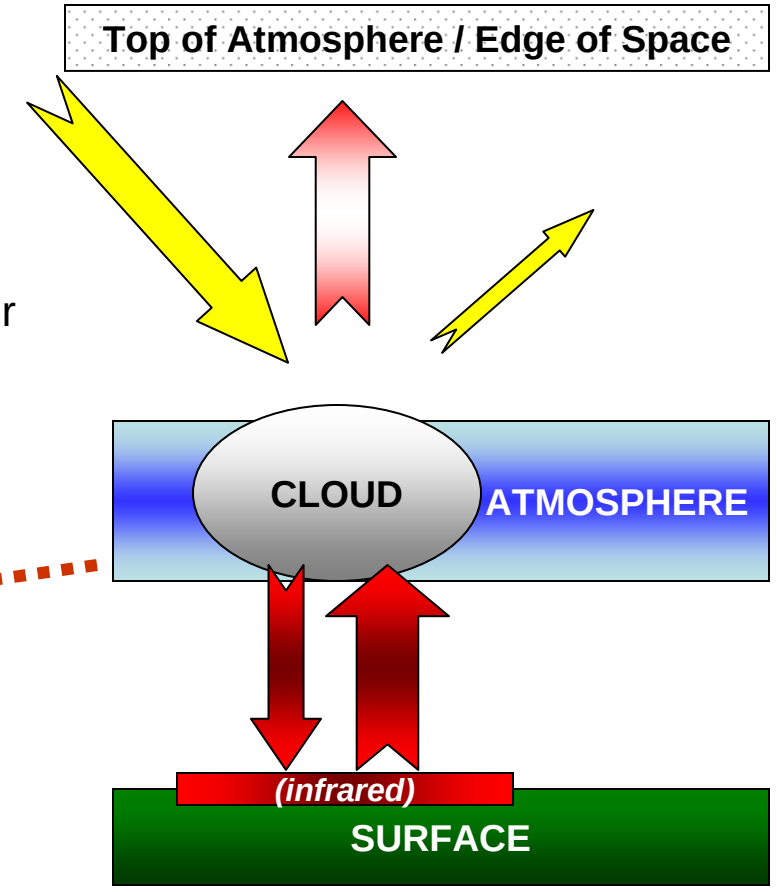
SeaWiFS view of the fires in the Western United States Monday 7 Aug 2000 NASA/GSFC and ORBIMAGE

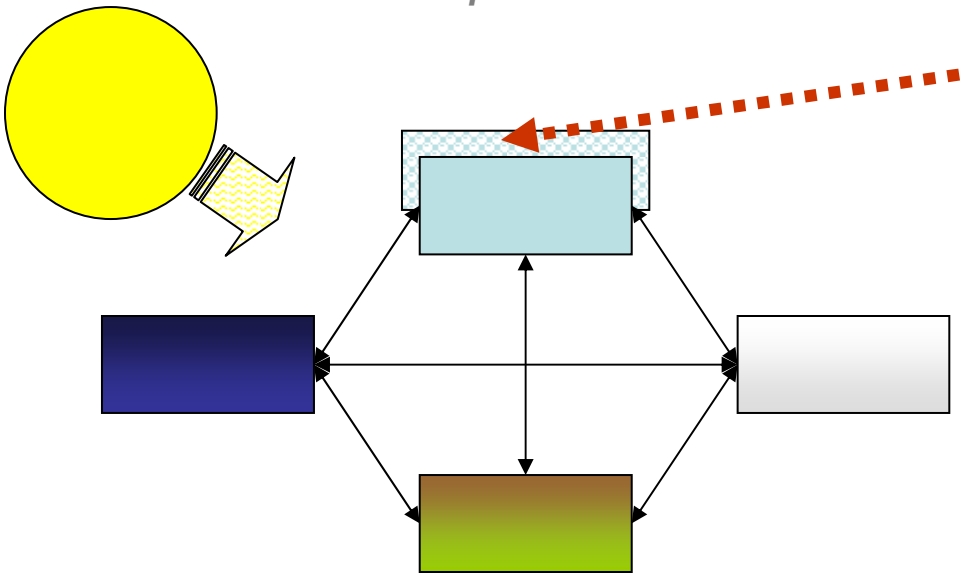
The Earth System
Aerosols (and clouds)

Clouds are difficult to predict or to figure out the sign of their impact

- Warmer → more water → more clouds
- More clouds mean more reflection of solar → cooler
- More clouds mean more infrared to surface → warmer
- More or less clouds?

  - *Does this stabilize?*
  - *Water in all three phases essential to stable climate*



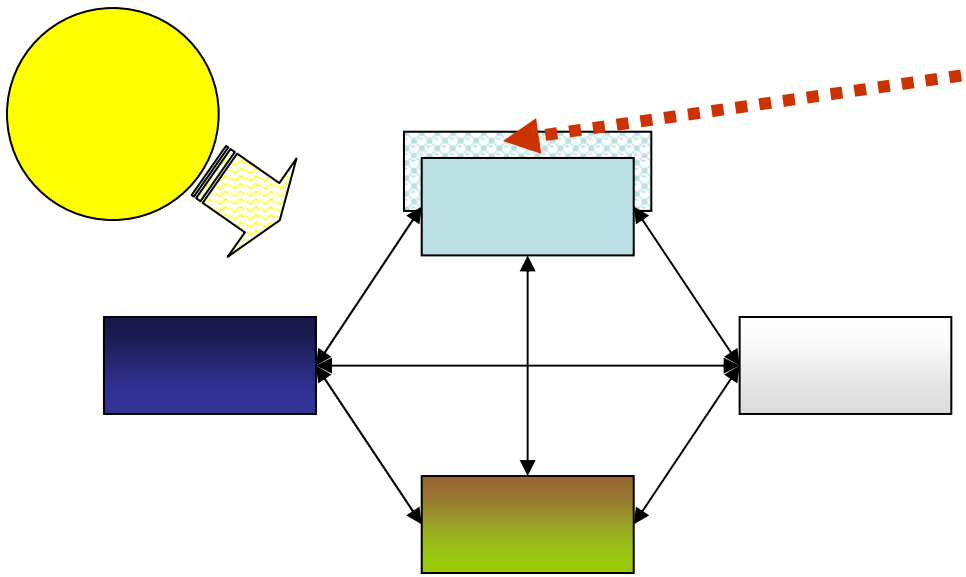


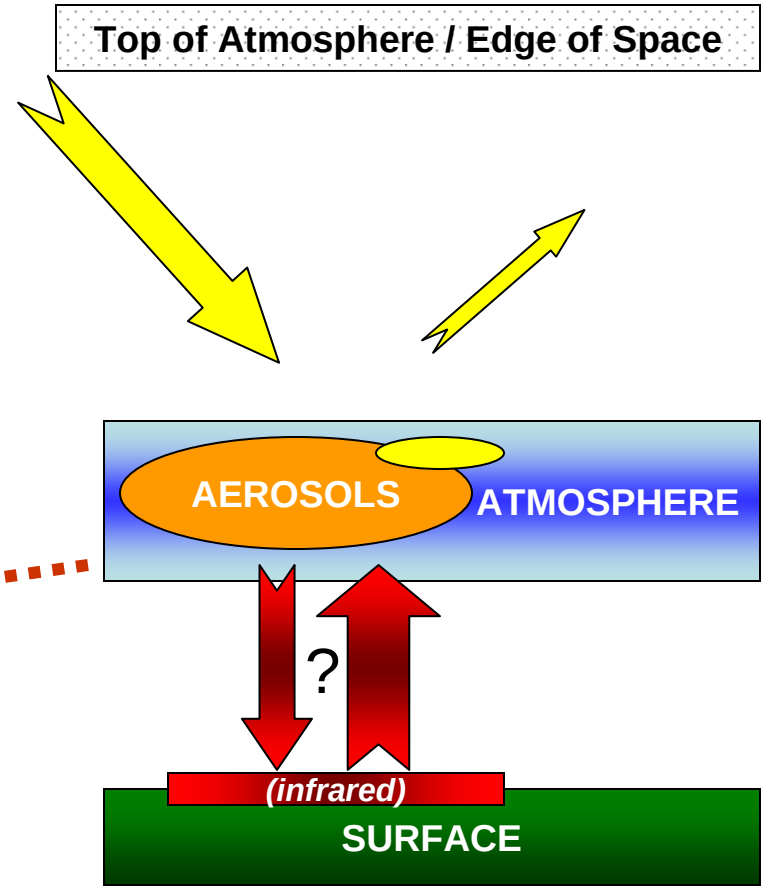
The Earth System: Aerosols

Aerosols directly impact radiative balance

- Aerosols can mean more reflection of solar → cooler
- Aerosols can absorb more solar radiation in the atmosphere → heat the atmosphere

- In very polluted air they almost act like a "second" surface. They warm the atmosphere, cool the earth's surface.



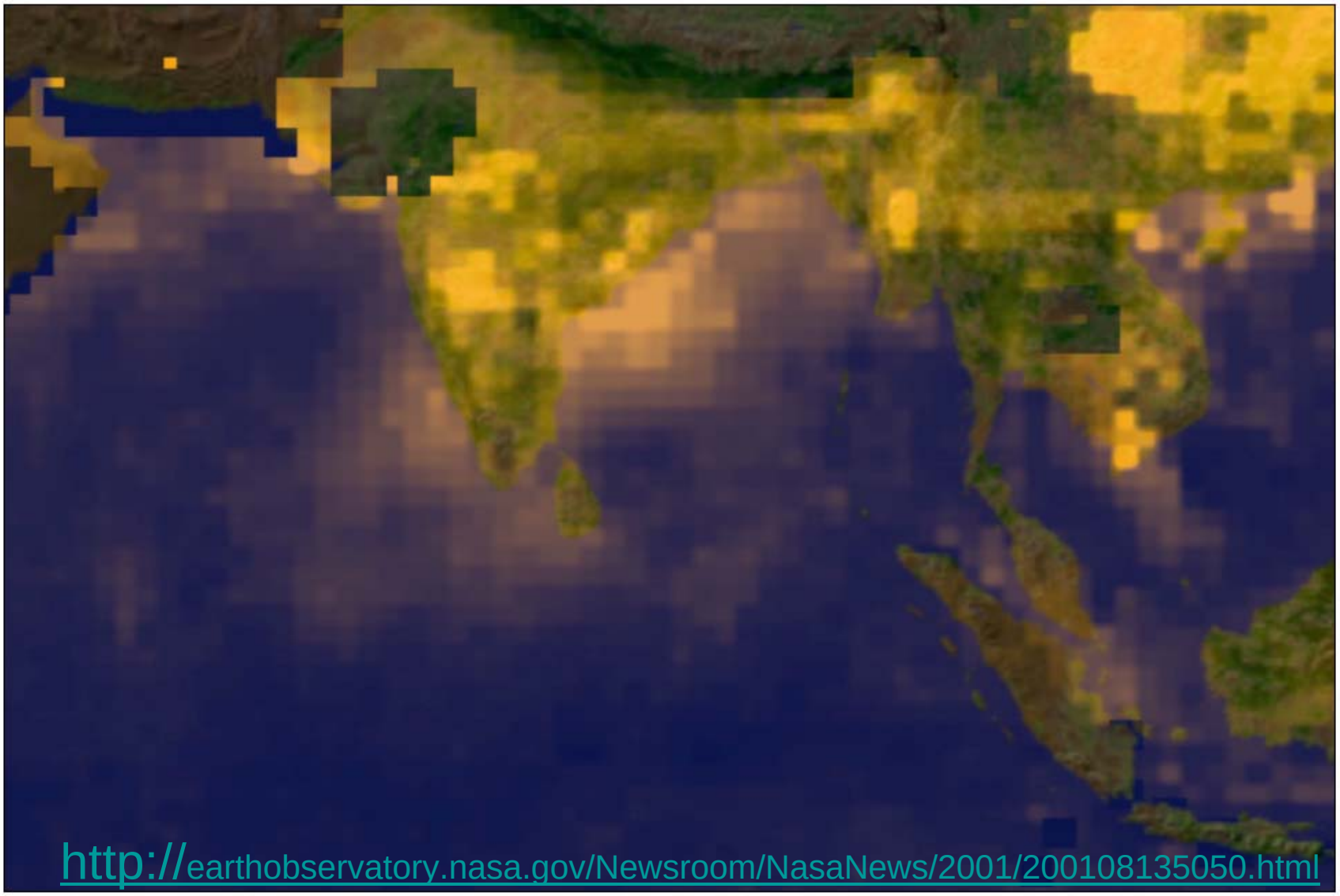


Composition of aerosols matters.

- This figure is simplified.
- Infrared effects are not well quantified

Aerosol

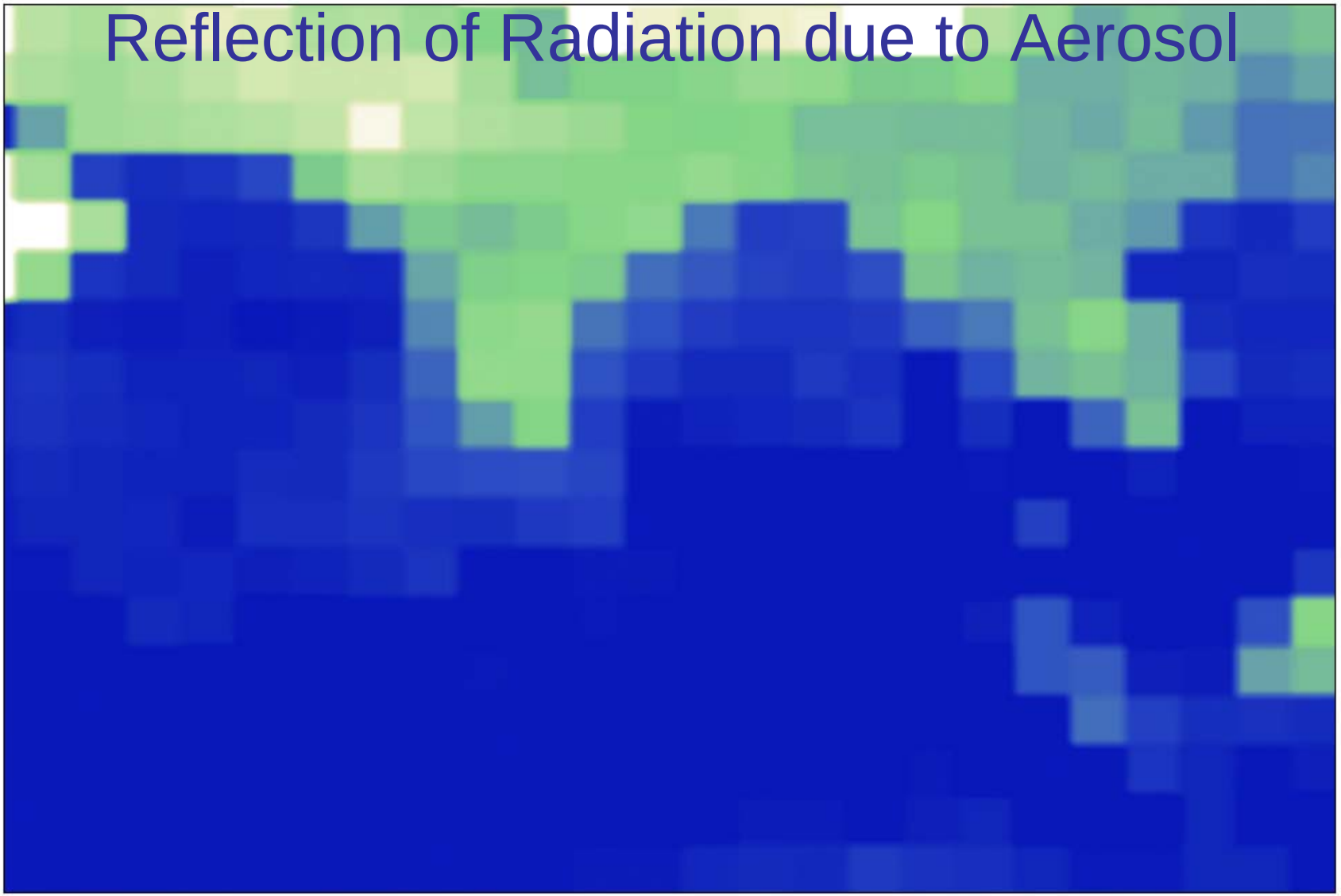
Aerosol: South & East Asia



low high

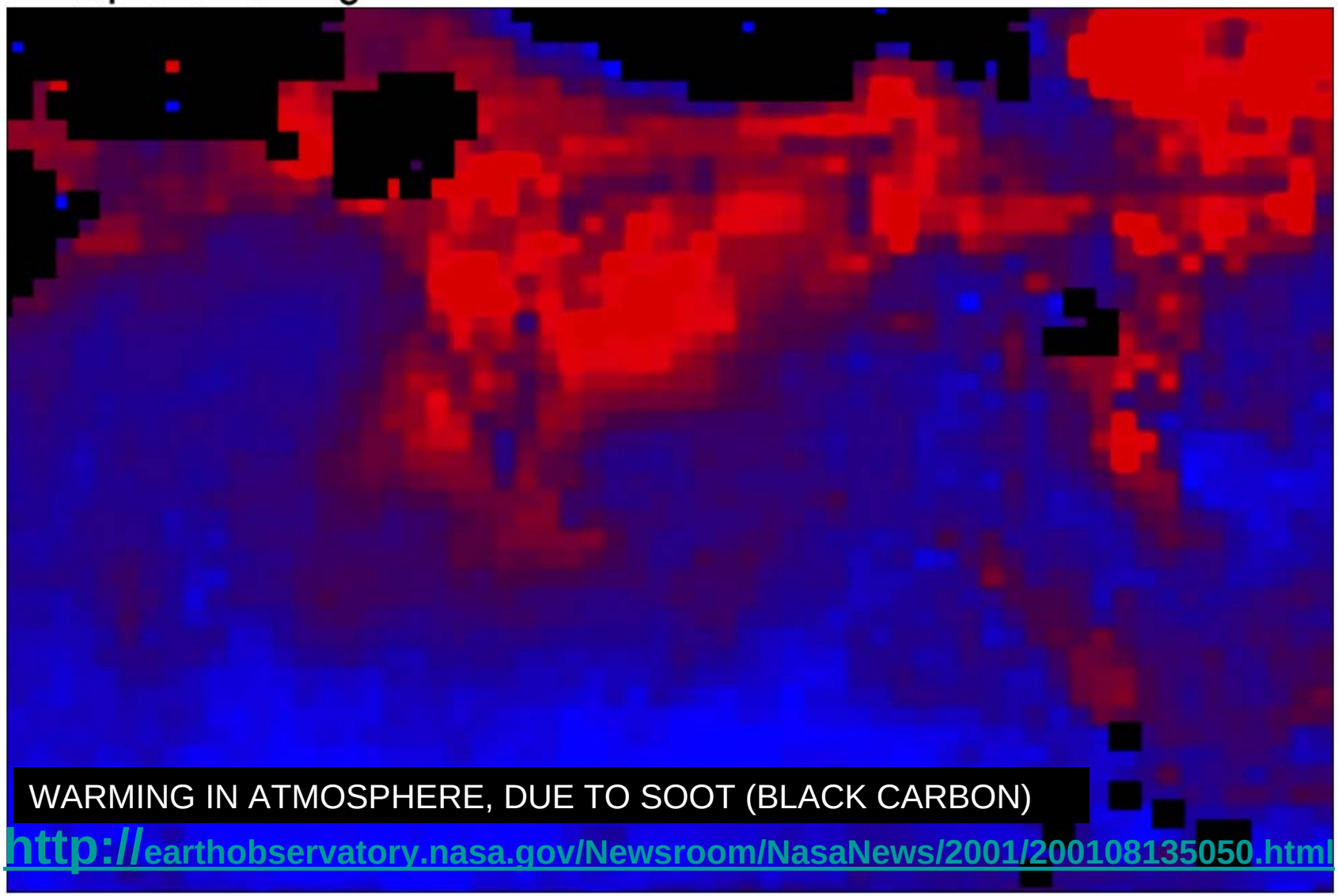
Albedo

Reflection of Radiation due to Aerosol



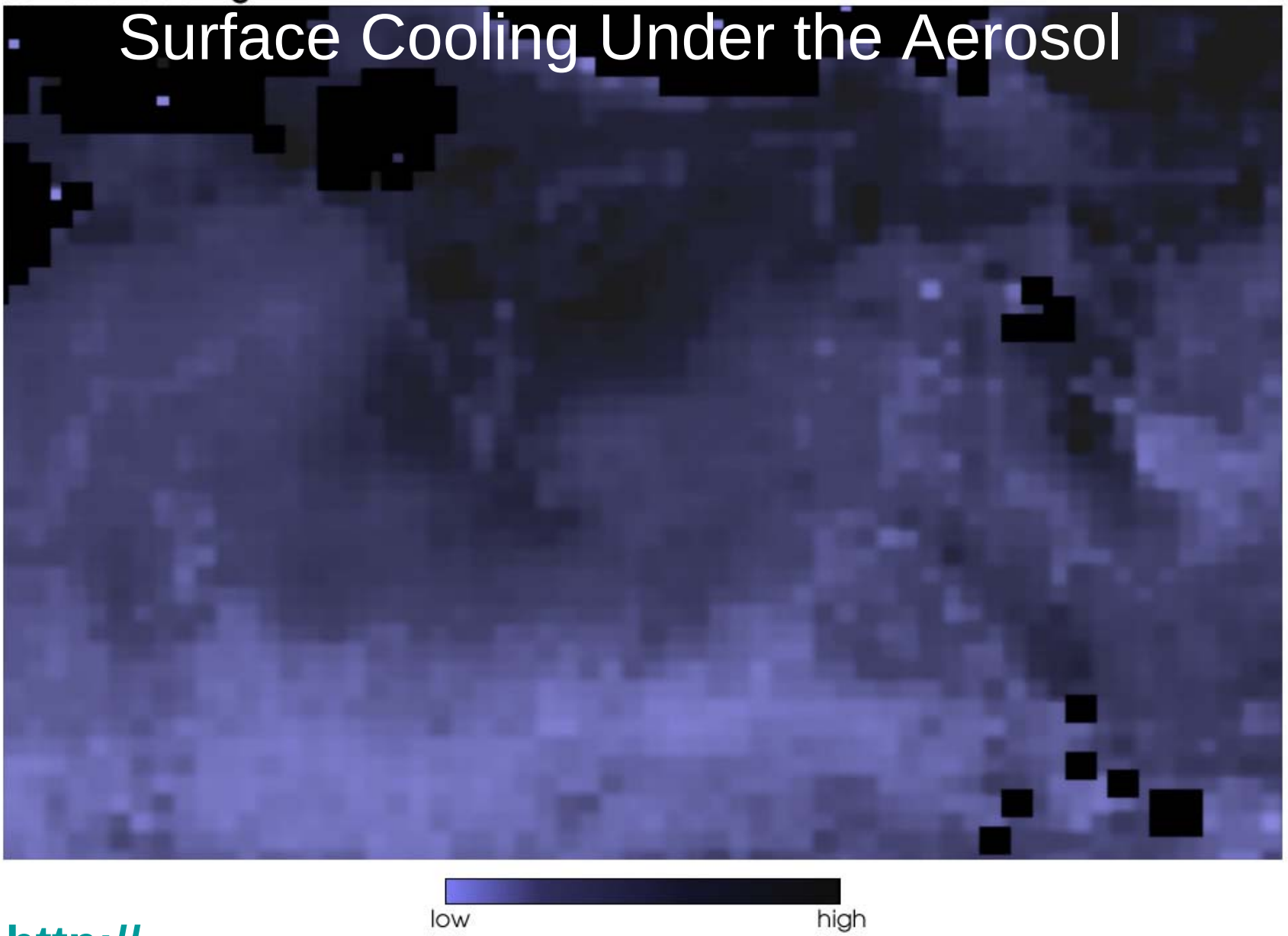
http://earthobservatory.nasa.gov/Newsroom/NasaNews/2001/200108135050.html

Atmospheric Warming: South & East Asia



Surface Cooling

Surface Cooling Under the Aerosol

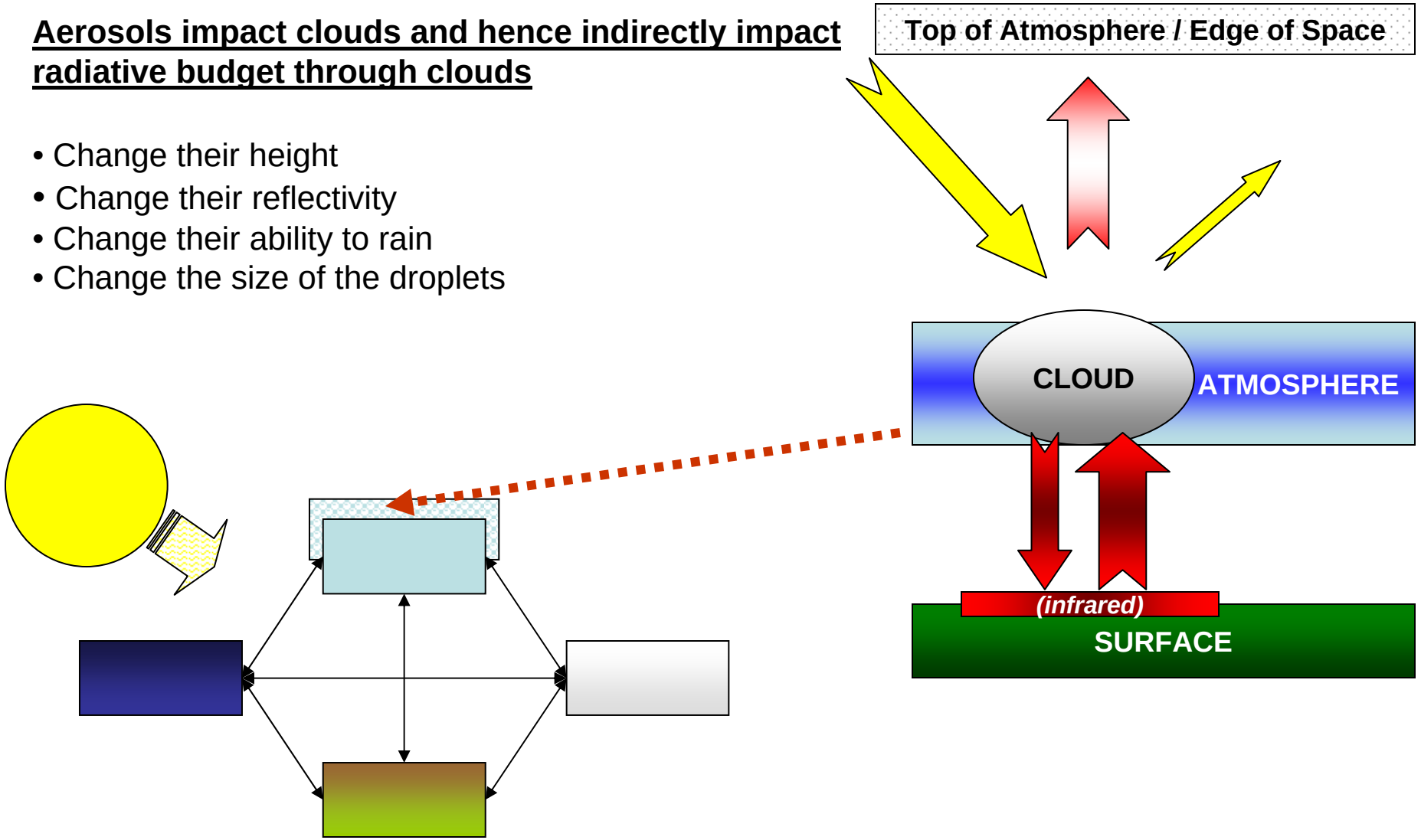


http://earthobservatory.nasa.gov/Newsroom/NasaNews/2001/200108135050.html

The Earth System
Aerosols (and clouds)

Aerosols impact clouds and hence indirectly impact radiative budget through clouds

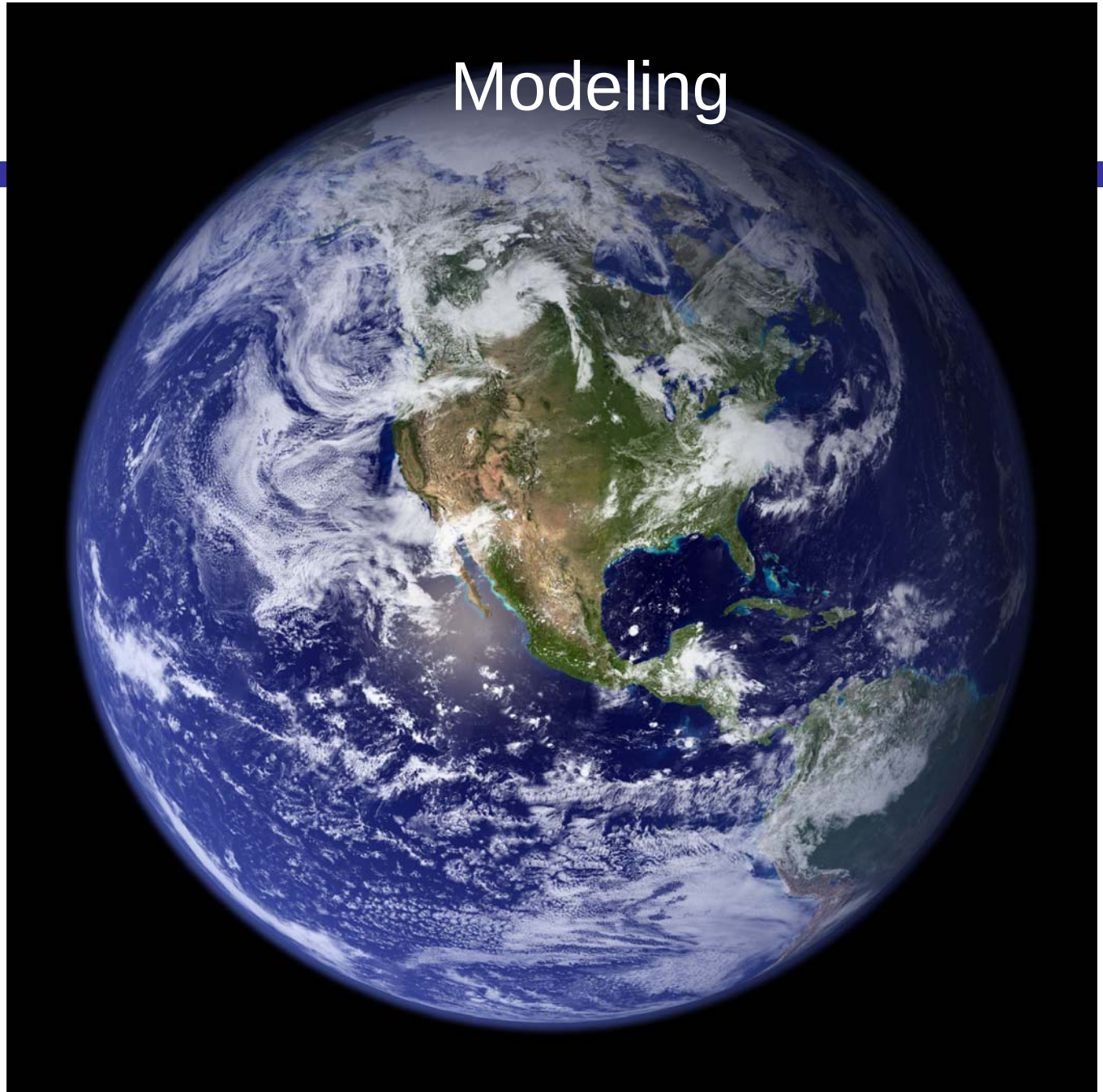
- Change their height
- Change their reflectivity
- Change their ability to rain
- Change the size of the droplets



Some important things to remember about aerosols

- They can directly impact radiative budget through both reflection and absorption.
- They can indirectly impact radiative budget through their effects on clouds → both reflection and absorption.
- They have many different compositions, and the composition matters to what they do.
- They have many different, often episodic sources.
- They generally fall out or rainout of the atmosphere; they don’t stay there very long compared with greenhouse gases.
- They often have large regional effects.
- They are an indicator of dirty air, which brings its own set of problems.

Modeling



Now Let's Go To Models

- We have used heuristic models to develop some conceptual understanding of the greenhouse effect.
- We have posed that the conservation equation is the foundation of a physical model.
- There are also statistical models
- Some modeling subsets
  - Mechanistic models
  - Component models
  - Coupled models
  - .....

What is a Model?

- Model
  - A work or construction used in testing or perfecting a final product.
  - A schematic description of a system, theory, or phenomenon that accounts for its known or inferred properties and may be used for further studies of its characteristics.
- Numerical Experimentation
  - Given what we know, can we predict what will happen, and verify that what we predicted would happen, happened?

What do we do?

- We develop models based on the conservation of energy and mass and momentum, the fundamental ideas of classical physics. (Budget equations)

For exampled, we considered the conservation of energy and CO_2 in the ice core data

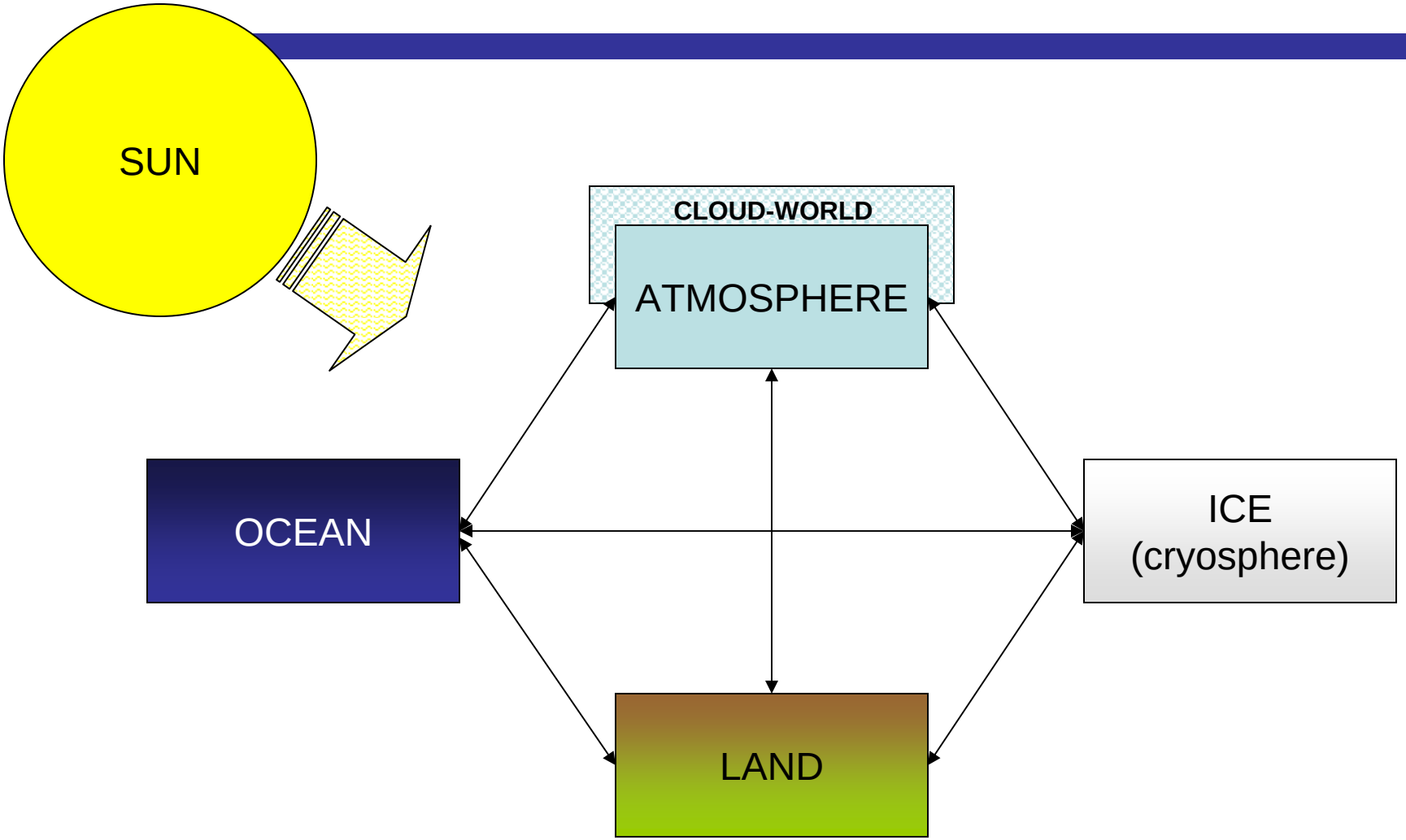
CHANGES IN SOLAR HEATING

$$\frac{\Delta T}{\Delta t} = Heating - Cooling = H - \lambda T$$

CHANGES IN CO_2, WHICH CHANGE THE RATE OF COOLING

$$\frac{\Delta CO_2}{\Delta t} = P_{CO_2} - L_{CO_2}$$

The Earth System



Symbolic Energy Balance Equation

Atmosphere:

$$\mathbf{E}^{\mathbf{a}}_{t+\Delta t} = \mathbf{E}^{\mathbf{a}}_{t} + \Delta t\left(\left(\boldsymbol{P}^{a} - L^{a}\mathbf{E}^{a}\right) + \left(\mathbf{Tr}^{a\leftrightarrow oil} + \boldsymbol{M}^{a}\right)\right)$$

Symbols

E = "**E**nergy"
P = **P**roduction
L = **L**oss rate
Tr = **T**ransfer
M = ***M***otion

Superscripts

a is for atmosphere
o is for ocean
i is for ice
l is for land

Variables

t = time
Δt = time increment

Symbolic Energy Balance Equation (Earth System)

Atmosphere:

$$\mathbf{E}^{\mathbf{a}}_{t+\Delta t} = \mathbf{E}^{\mathbf{a}}_{t} + \Delta t\left(\left(\boldsymbol{P}^{a} - L^{a}\mathbf{E}^{a}\right) + \left(\mathbf{Tr}^{a\leftrightarrow oil} + \boldsymbol{M}^{a}\right)\right)$$

Ocean:

$$\mathbf{E}^{\mathbf{o}}_{t+\Delta t} = \mathbf{E}^{\mathbf{o}}_{t} + \Delta t\left(\left(\boldsymbol{P}^{o} - L^{o}\mathbf{E}^{o}\right) + \left(\mathbf{Tr}^{o\leftrightarrow ail} + \boldsymbol{M}^{o}\right)\right)$$

Ice:

$$\mathbf{E}^{\mathbf{i}}_{t+\Delta t} = \mathbf{E}^{\mathbf{i}}_{t} + \Delta t\left(\left(\boldsymbol{P}^{i} - L^{i}\mathbf{E}^{i}\right) + \left(\mathbf{Tr}^{i\leftrightarrow oal} + \boldsymbol{M}^{i}\right)\right)$$

Land:

$$\mathbf{E}^{\mathbf{l}}_{t+\Delta t} = \mathbf{E}^{\mathbf{l}}_{t} + \Delta t\left(\left(\boldsymbol{P}^{l} - L^{l}\mathbf{E}^{l}\right) + \left(\mathbf{Tr}^{l\leftrightarrow oia} + \boldsymbol{M}^{l}\right)\right)$$

What do we do?

- We develop models based on the conservation of energy and mass and momentum, the fundamental ideas of classical physics. (Budget equations)
- We determine the characteristics of production and loss from theory and observations of, for instance, the eruption of a major volcano and the temperature response as measured by the global observing system.

Consider just the Production and Loss Rate (We call this forcing.)

$$\boldsymbol{P}^{a} - \boldsymbol{L}^{a}\mathbf{E}^{a}$$

We can divide this, conceptually, into two:

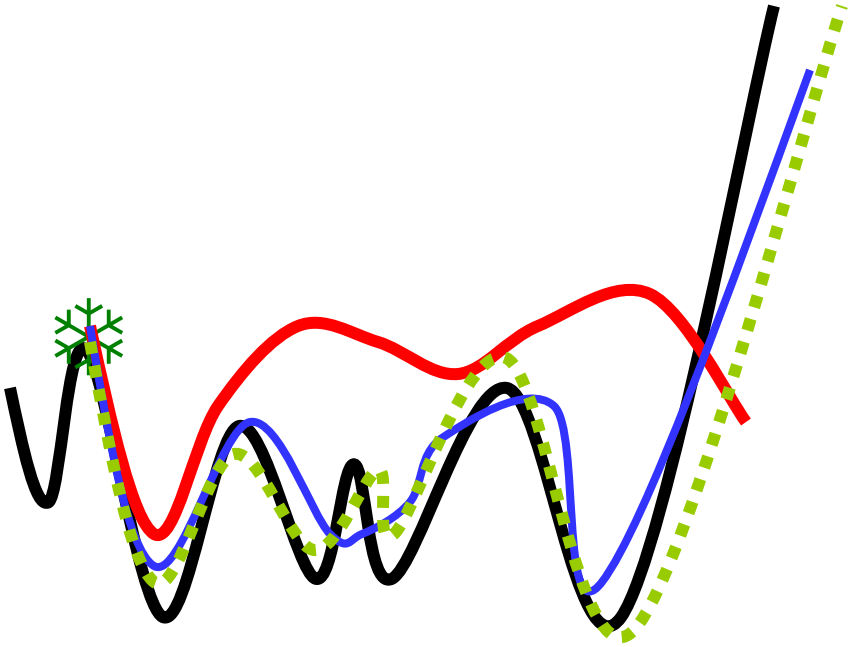
- That in absence of the influence of the "industry" of humans
  - Variability of the sun
  - What volcanoes put in the atmosphere
  - Greenhouse gases prior to industrial revolution
  - Aerosols from, for instance, sea salt and desert dust

- That which includes the influence of the "industry" of humans
  - Changes in greenhouse gases due to burning of fuel
  - Aerosols from "industrial" emissions
  - Changes in gases due to changes in what is growing
  - Change in absorption and reflection due to land use change
  - More?

What do we do?

- We develop models based on the conservation of energy and mass and momentum, the fundamental ideas of classical physics. (Budget equations)
- We determine the characteristics of production and loss from theory and observations of, for instance, the eruption of a major volcano and the temperature response as measured by the global observing system.
- We attempt to predict the temperature (“Energy”) response.
- We evaluate (validate) how well we did, characterize the quality of the prediction relative to the observations, and determine, sometimes with liberal interpretation, whether or not we can establish cause and effect.

Schematic of a model experiment.



Start model prediction

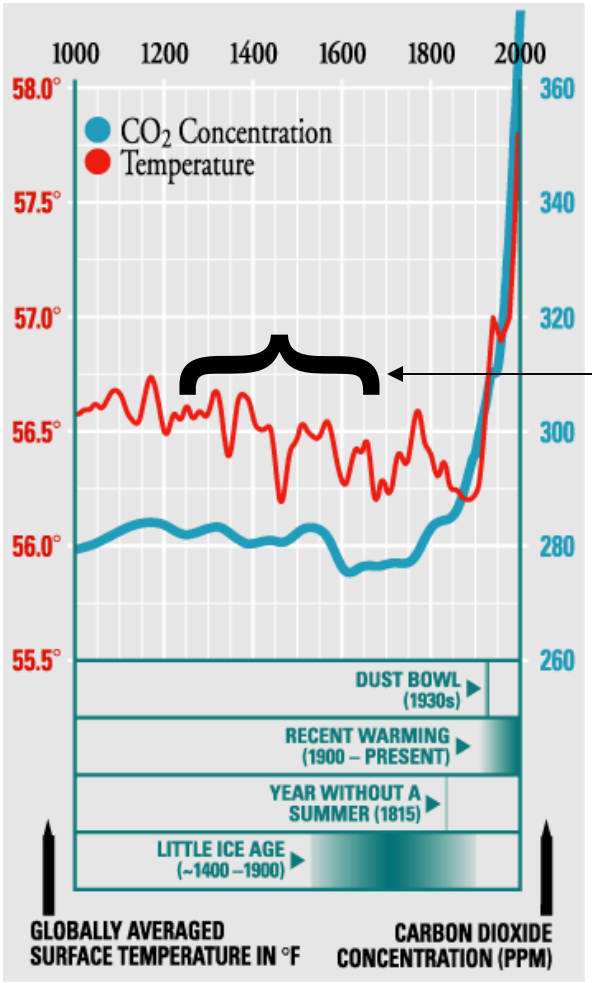
Model prediction without forcing

Model prediction with forcing

Model prediction with forcing and source of internal variability

Observations or “truth”

CO_2 and Temperature for Last 100 years



Surface temperature and CO_2 data from the past 1000 years. Temperature is a northern hemisphere average. Temperature from several types of measurements are consistent in temporal behavior.

Note that on this scale, with more time resolution, that the fluctuations in temperature and the fluctuations in CO_2 do not match as obviously as in the long, 350,000 year, record.

What is the cause of the temperature variability? Can we identify mechanisms, cause and effect? How?

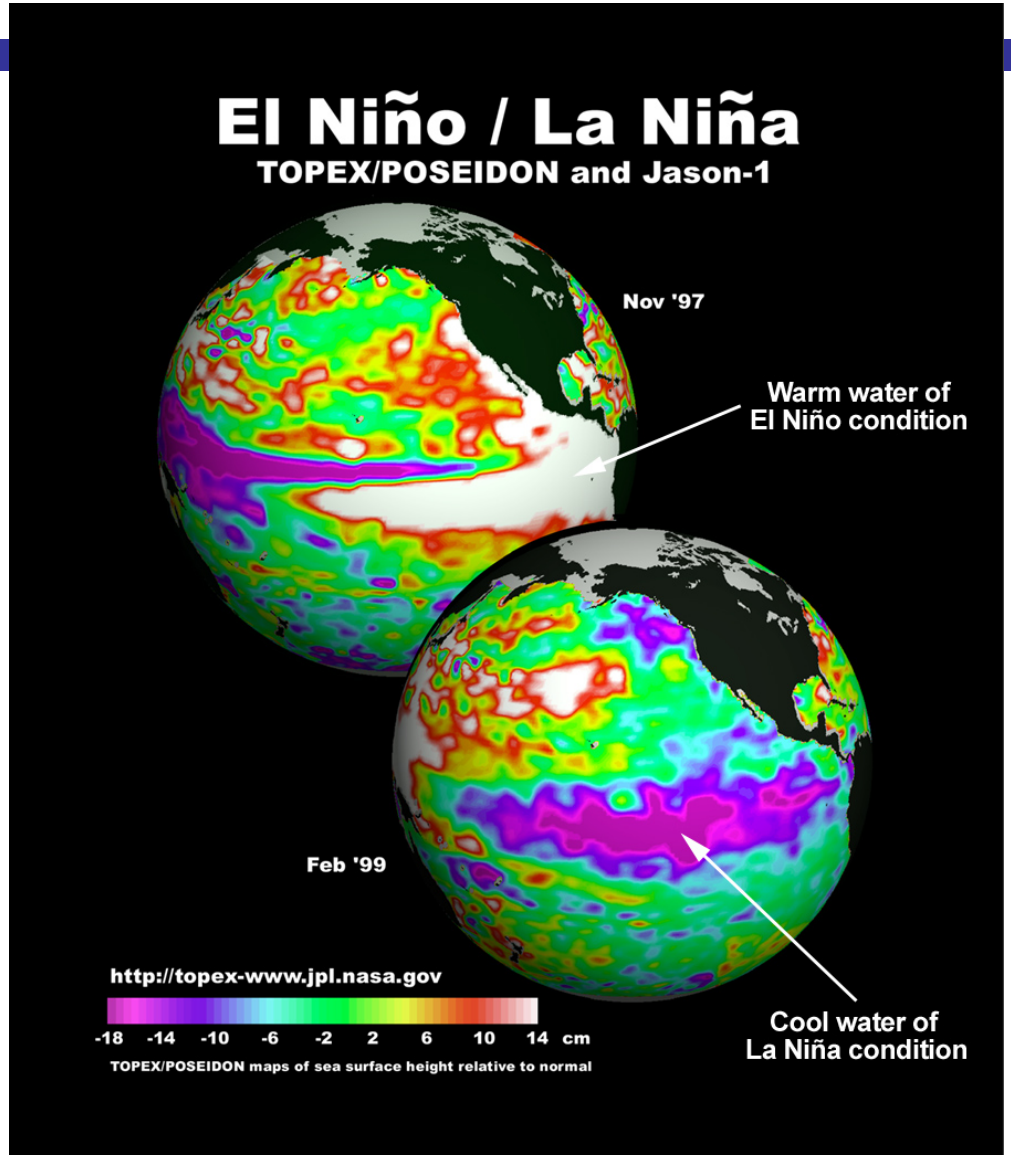
What do we know from model experiments and evaluation (validation) with observations

- With consideration of solar variability and volcanic activity, the variability in the temperature record prior to 1800 can be approximated.
- After 1800 need to consider the impact of man
  - Deforestation of North America
  - Fossil fuel emission
  - Change from coal to oil economy
  - Clean air act
- Only with consideration of CO_2, increase in the greenhouse effect, can the temperature increase of the last 100 years be modeled.

Internal Variability?

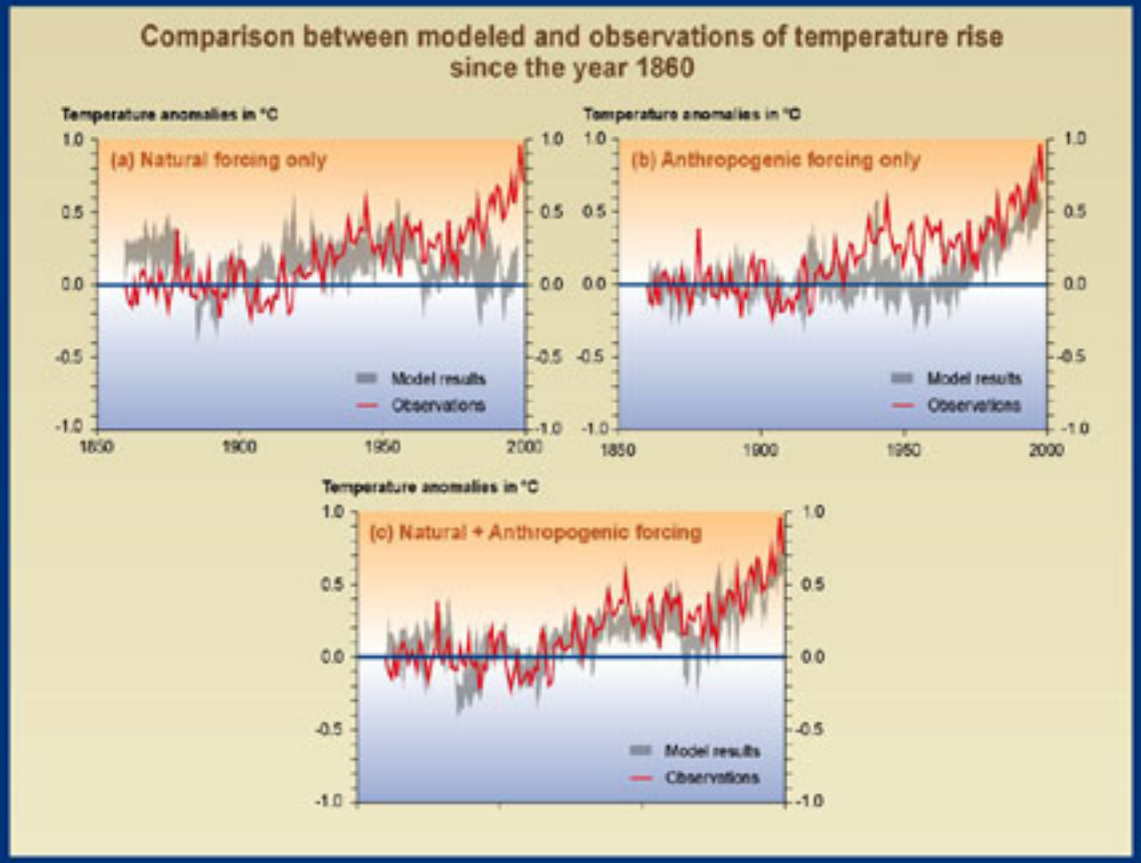
- There are modes of internal variability in the climate system which cause global changes.
  - El Nino – La Nina
  - North Atlantic Oscillation
  - Annular Oscillation
  - Inter-decadal Tropical Atlantic
  - Things we have not observed
  - We (might) return to this.

Changes during El Nino



Back to the Predictions

Model determination of impact of fossil fuels



SYR - FIGURE 2-4

IPCC
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

WMO UNEP

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