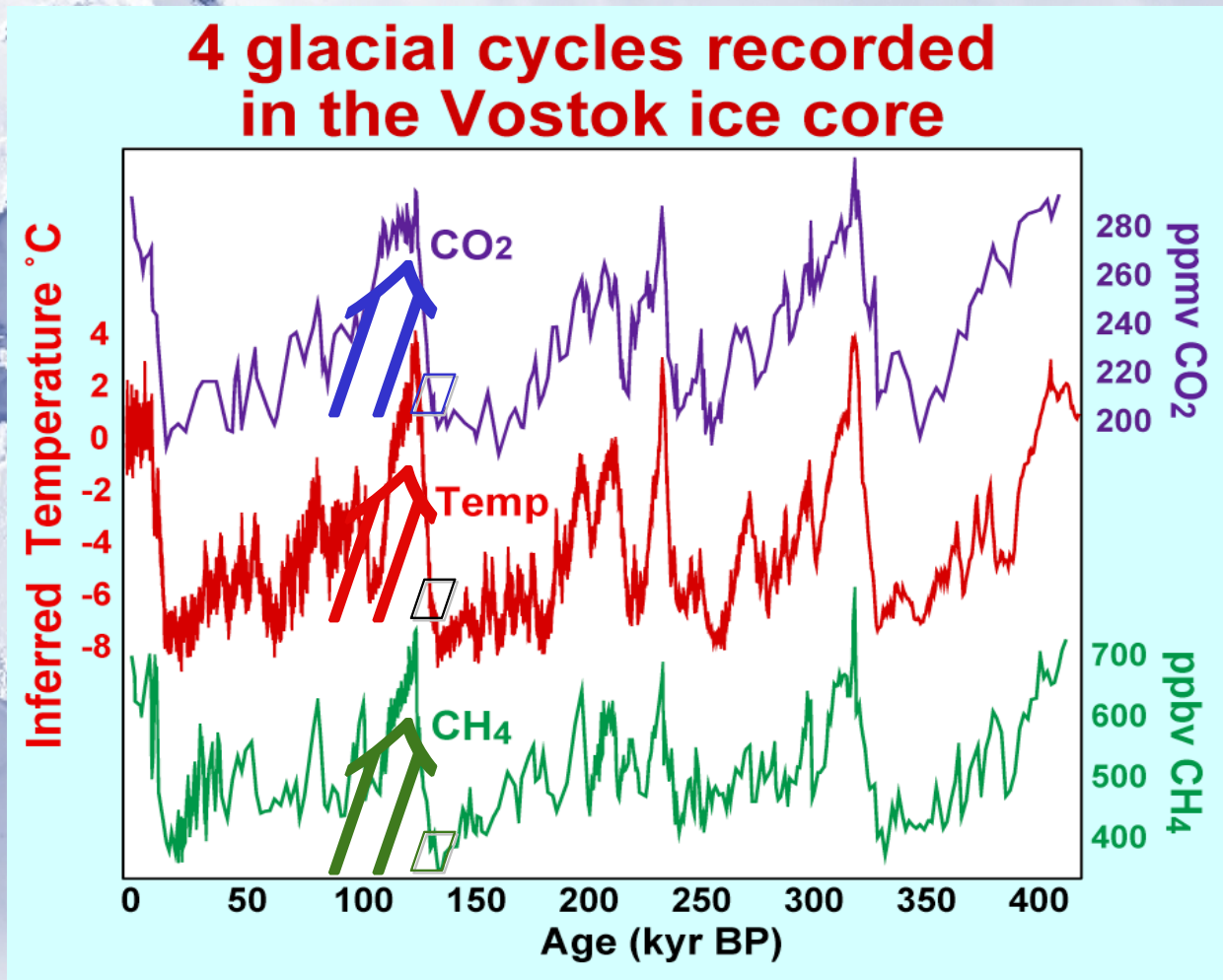
15.023J / 12.848J / ESD.128J Global Climate Change: Economics, Science, and Policy
Spring 2008

THE CLIMATE MACHINE I
Past Climate, and Gases, Aerosols and Radiation

R. PRINN, FEBRUARY 19, 2008

1. Past Climate Trends
2. The Climate System
3. Energy Balance in the Climate System
4. Radiative Forcing of Climate
5. Carbon Dioxide and the Carbon Cycle
6. Other Greenhouse Gases & Aerosols

HOW HAVE TEMPERATURE & GREENHOUSE GASES CHANGED OVER THE PAST 400,000 YEARS?



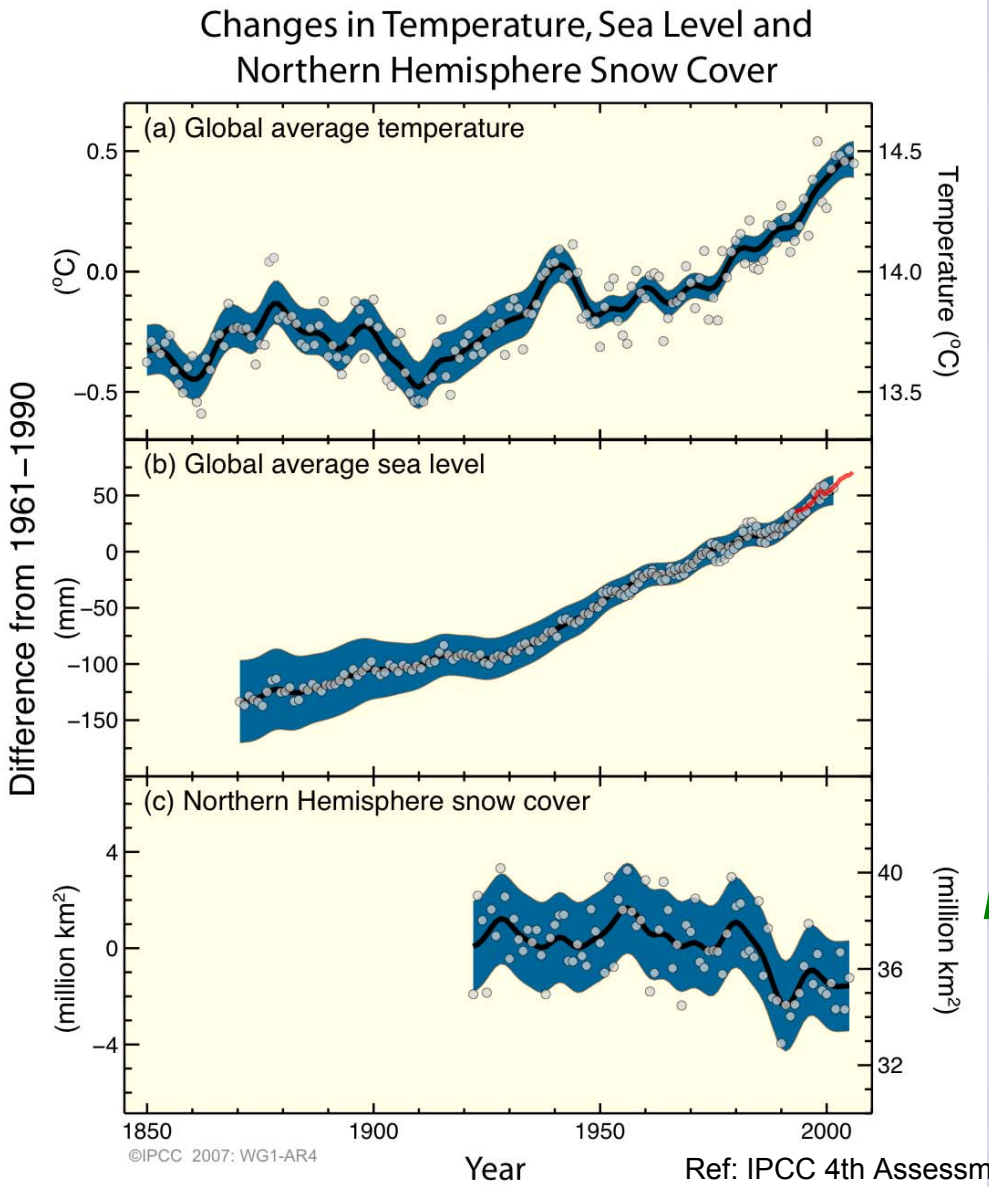
From: Petit *et al.*, ***NATURE***, **399: 429-436 (1999)**

HOW HAS TEMPERATURE CHANGED OVER THE PAST 1200 YEARS?

Figure and text removed due to copyright restrictions. See figure entitled "Records of past climate" in:

Briffa, Keith, and Timothy Osborn. "Blowing Hot and Cold." *Science* 295 (2002): 2227-2228.

HOW HAVE GLOBAL TEMPERATURE & SEA LEVEL, & N.H.SNOW COVER CHANGED OVER THE PAST 150 YEARS?



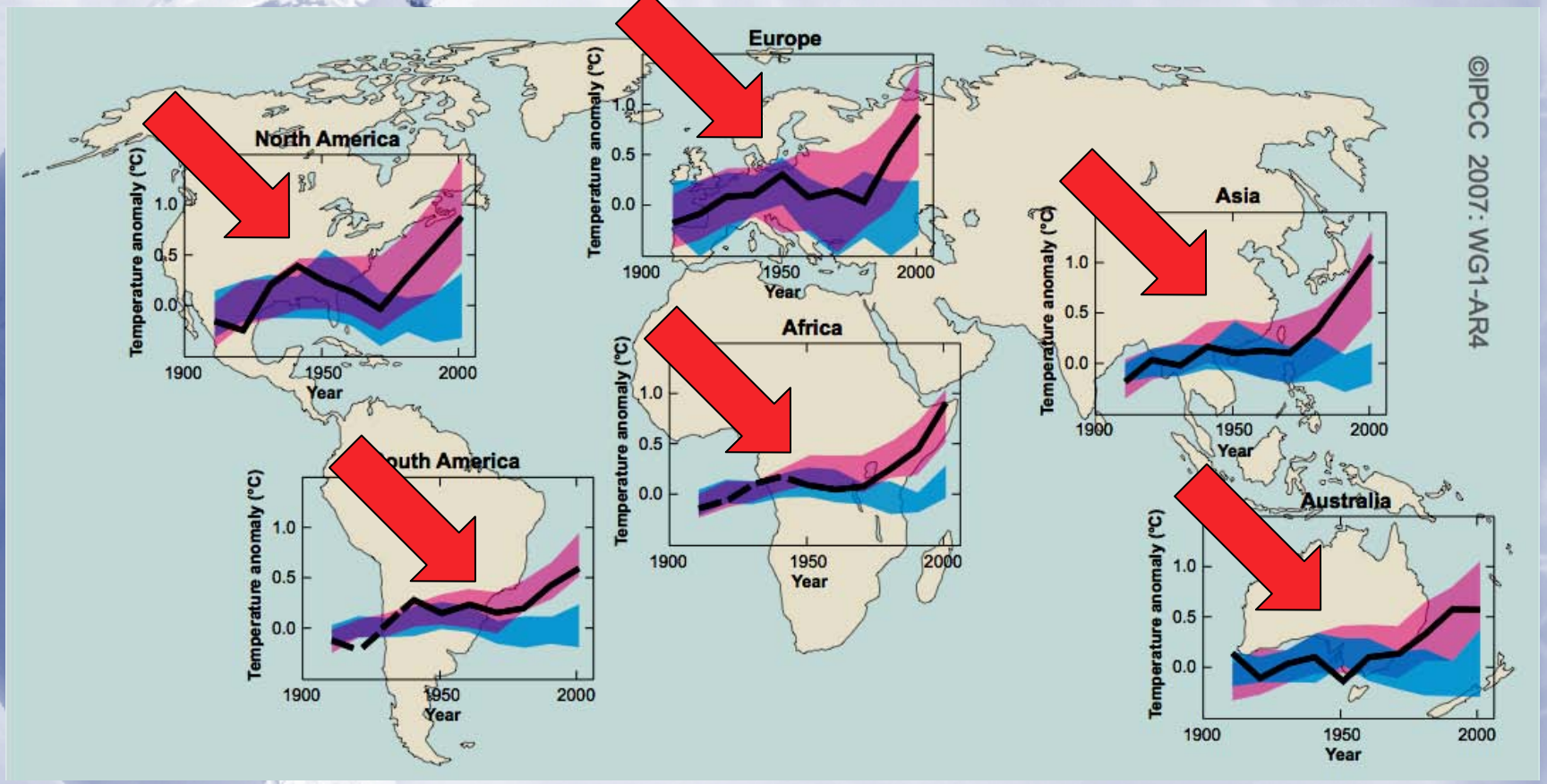
1998 and 2005 had the highest temperatures ever recorded

Sea level rise driven by expanding ocean water and melting glaciers

Less snow cover means more sunlight absorbed & increased warming

Ref: IPCC 4th Assessment, Summary for Policymakers, Feb. 2, 2007

HOW HAVE CONTINENTAL TEMPERATURES CHANGED OVER THE PAST CENTURY (1906-2005), AND WHY?

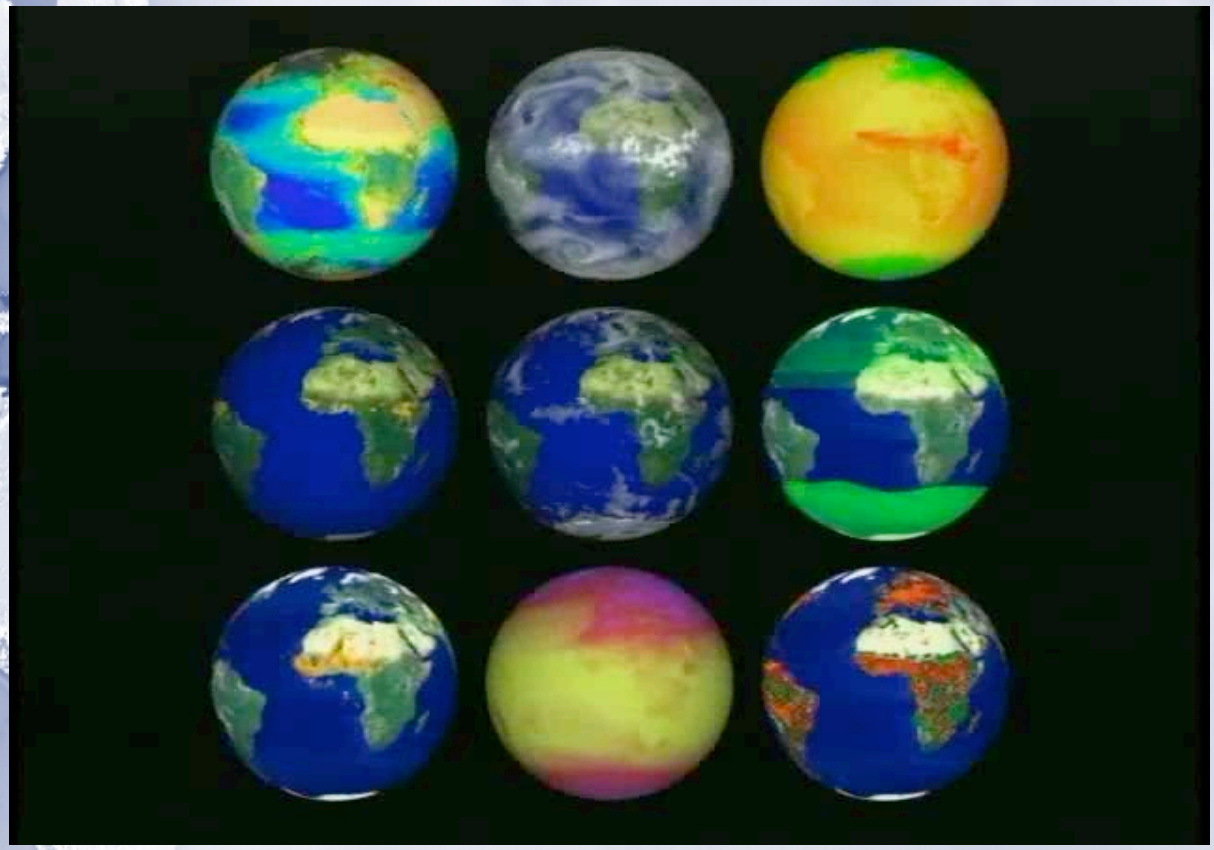


Courtesy of the Intergovernmental Panel on Climate Change. Used with permission.

Black lines:observed changes. **Blue bands: range for 19 model simulations using natural forcings.**
Red bands: range for 51 model simulations using natural and human forcings.

Ref: IPCC 4th Assessment, Summary for Policymakers, Feb. 2, 2007

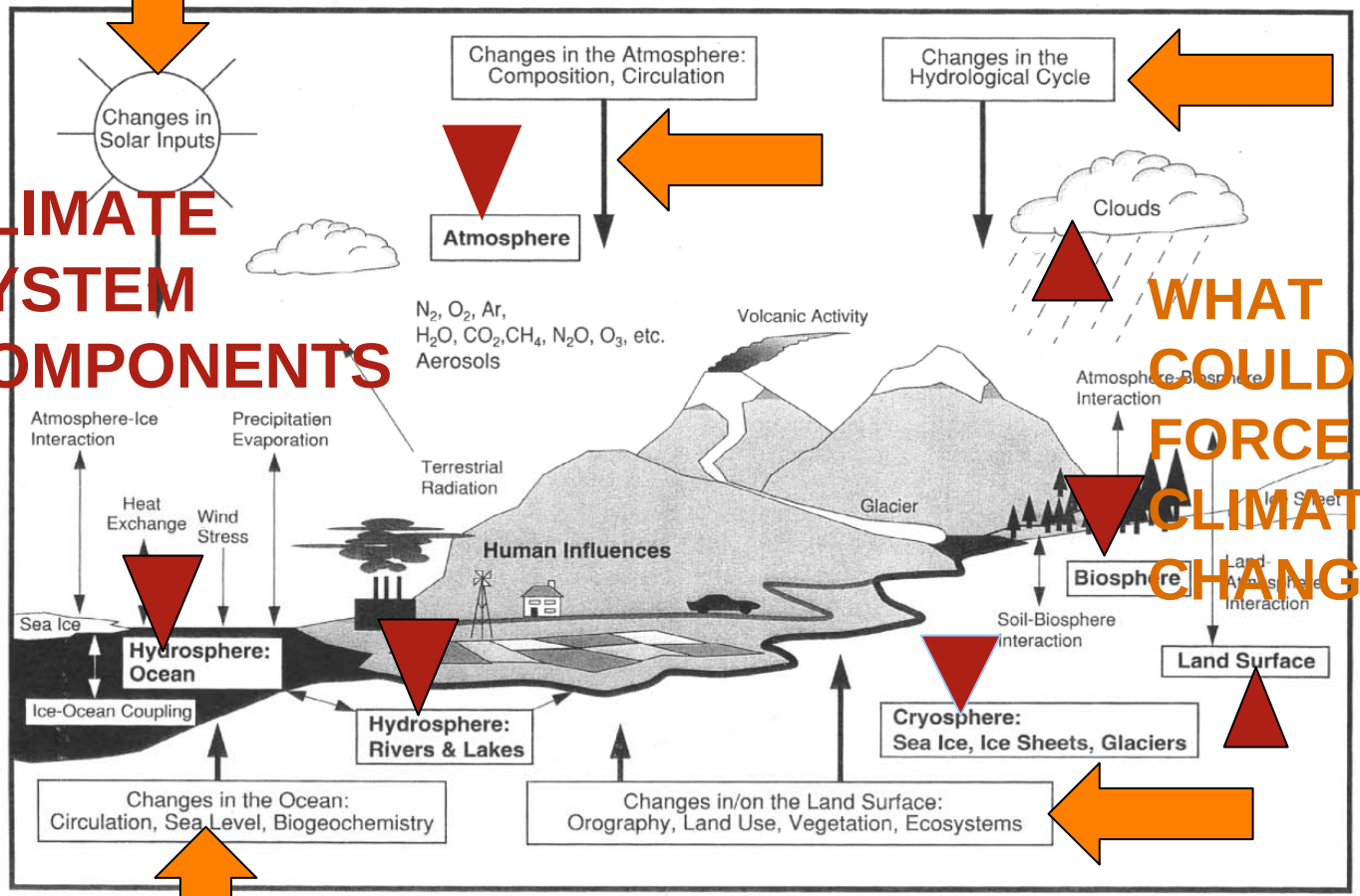
WHAT IS THE NATURE OF THE SYSTEM THAT DETERMINES CLIMATE?



IMAGES From NASA's TERRA satellite

Investigation of this complex system requires an integrated approach

THE CLIMATE SYSTEM: AN OVERVIEW



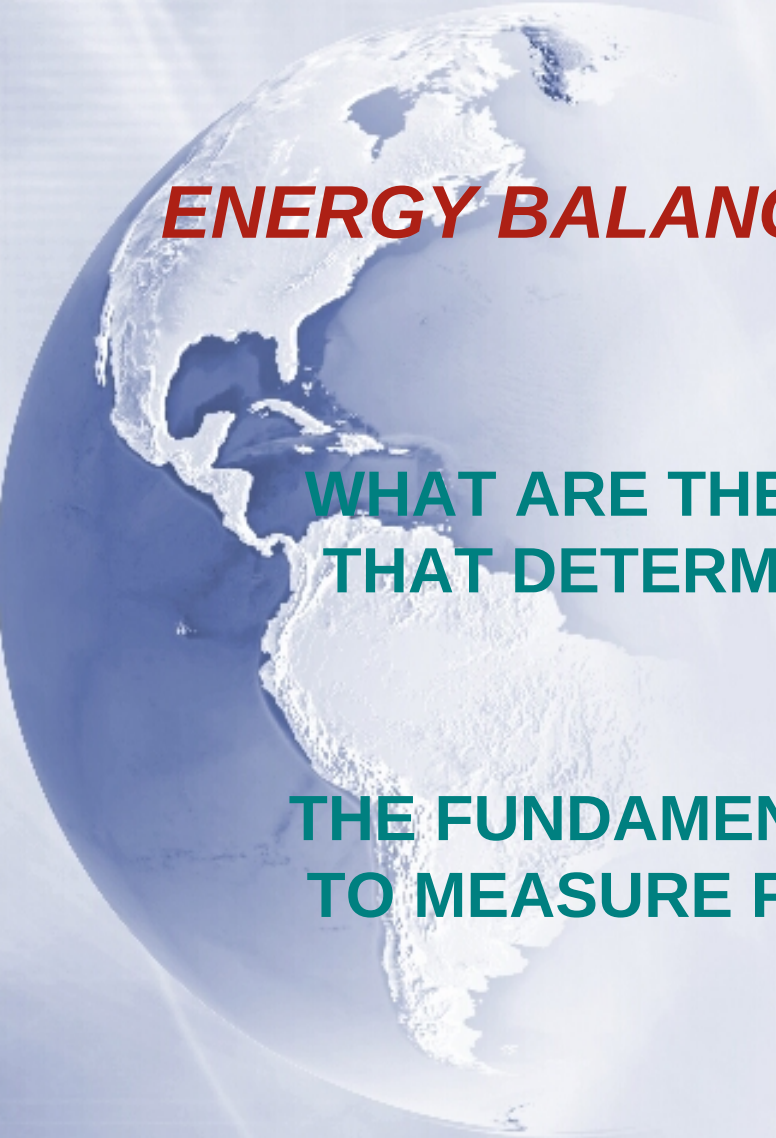
CLIMATE SYSTEM COMPONENTS

WHAT COULD FORCE CLIMATE CHANGE?

FIGURE 1.1 Schematic view of the components of the global system (bold), their processes and interactions (thin arrows) and some aspects that may change (bold arrows).

http://www.ipcc.com//pub/tar/wg1/040.htm#fig11

Courtesy of the Intergovernmental Panel on Climate Change. Used with permission.

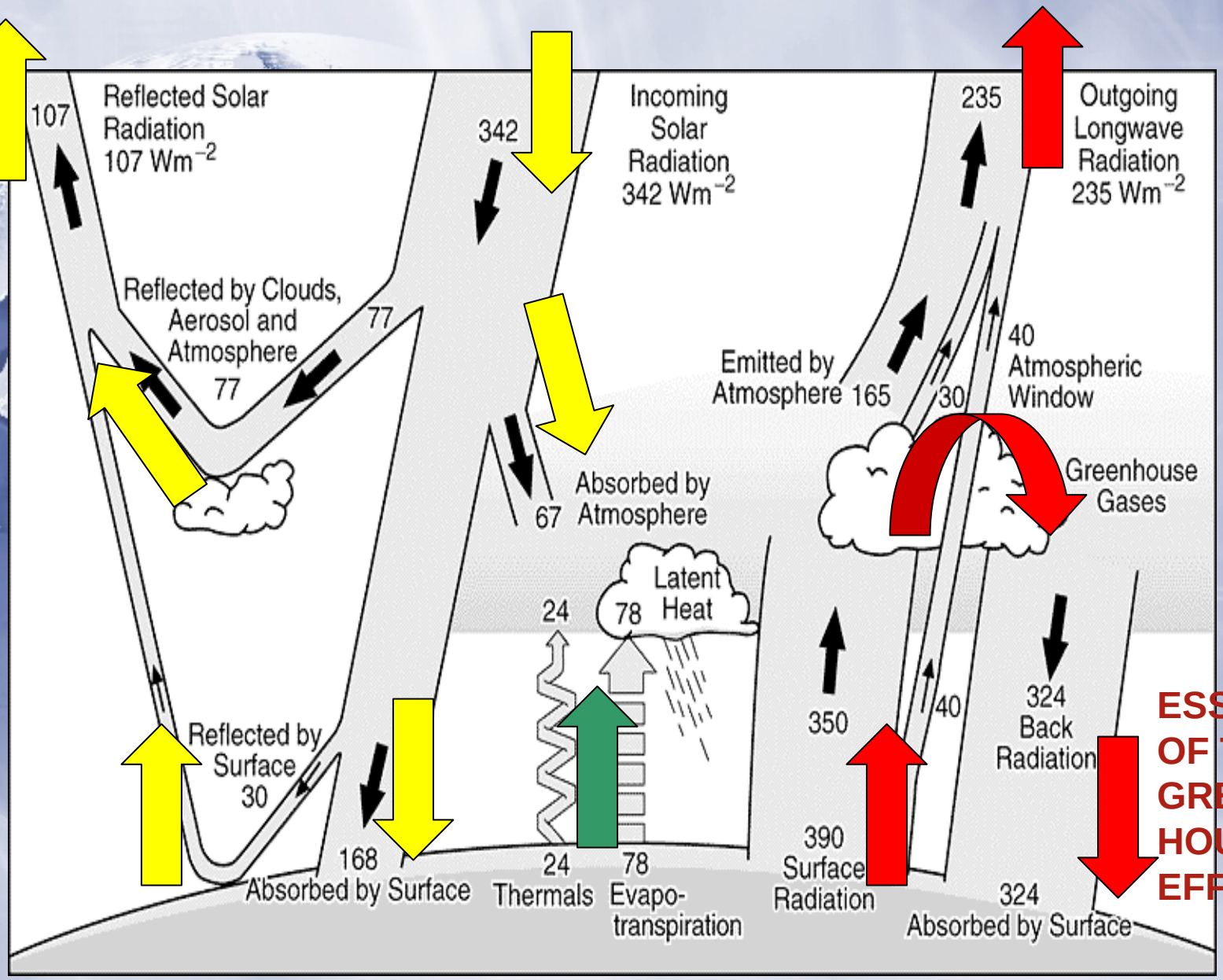


ENERGY BALANCE IN THE CLIMATE SYSTEM

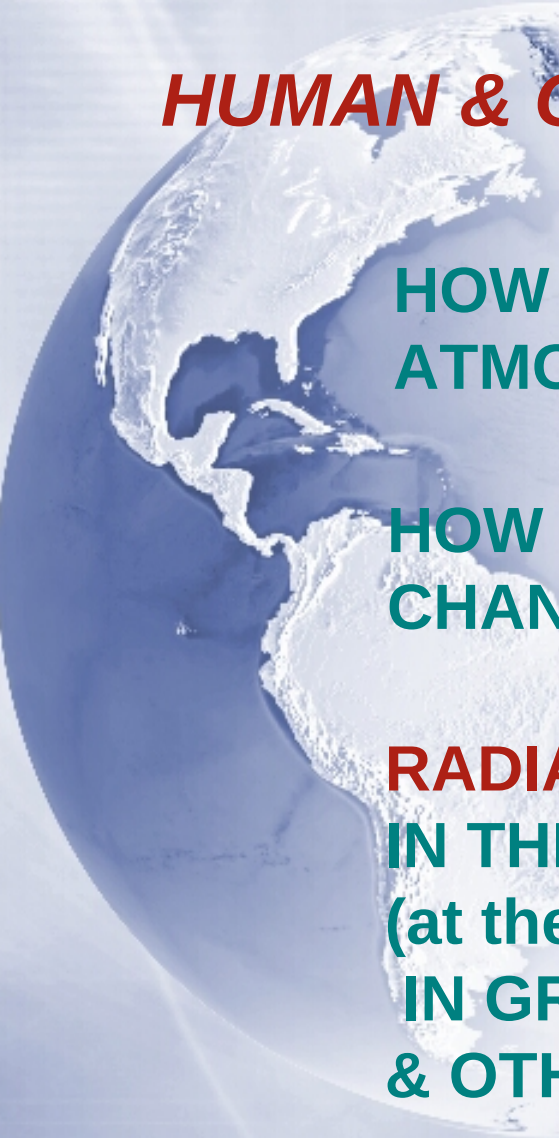
WHAT ARE THE VERTICAL FLOWS OF ENERGY THAT DETERMINE GLOBAL TEMPERATURES?

THE FUNDAMENTAL UNITS WE WILL USE TO MEASURE FLOWS ARE WATTS/(METER)^2

ENERGY BALANCE IN THE CLIMATE SYSTEM



Courtesy of the Intergovernmental Panel on Climate Change. Used with permission.



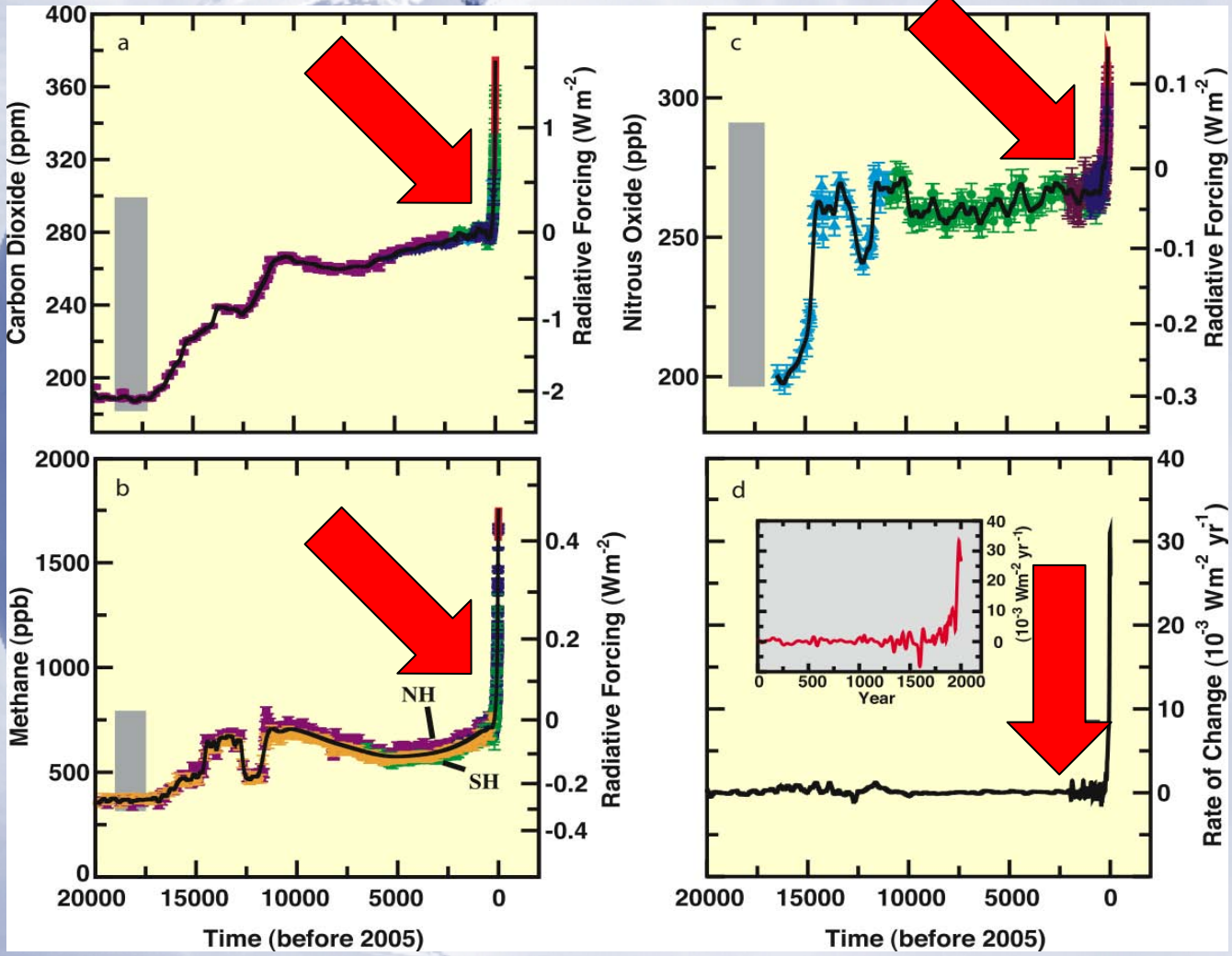
HUMAN & OTHER INFLUENCES ON CLIMATE

HOW IS THE COMPOSITION OF THE ATMOSPHERE CHANGING?

HOW HAVE THE ENERGY FLOWS CHANGED SINCE PRE-INDUSTRIAL TIMES?

RADIATIVE FORCING (watt/m^2) IS THE CHANGE IN THE VERTICAL ENERGY FLOW (at the tropopause) INDUCED BY CHANGES IN GREENHOUSE GASES, AEROSOLS, & OTHER CLIMATE FORCING PROCESSES

ATMOSPHERIC COMPOSITION & RADIATIVE FORCING: TRENDS OVER THE LAST 20,000 YEARS

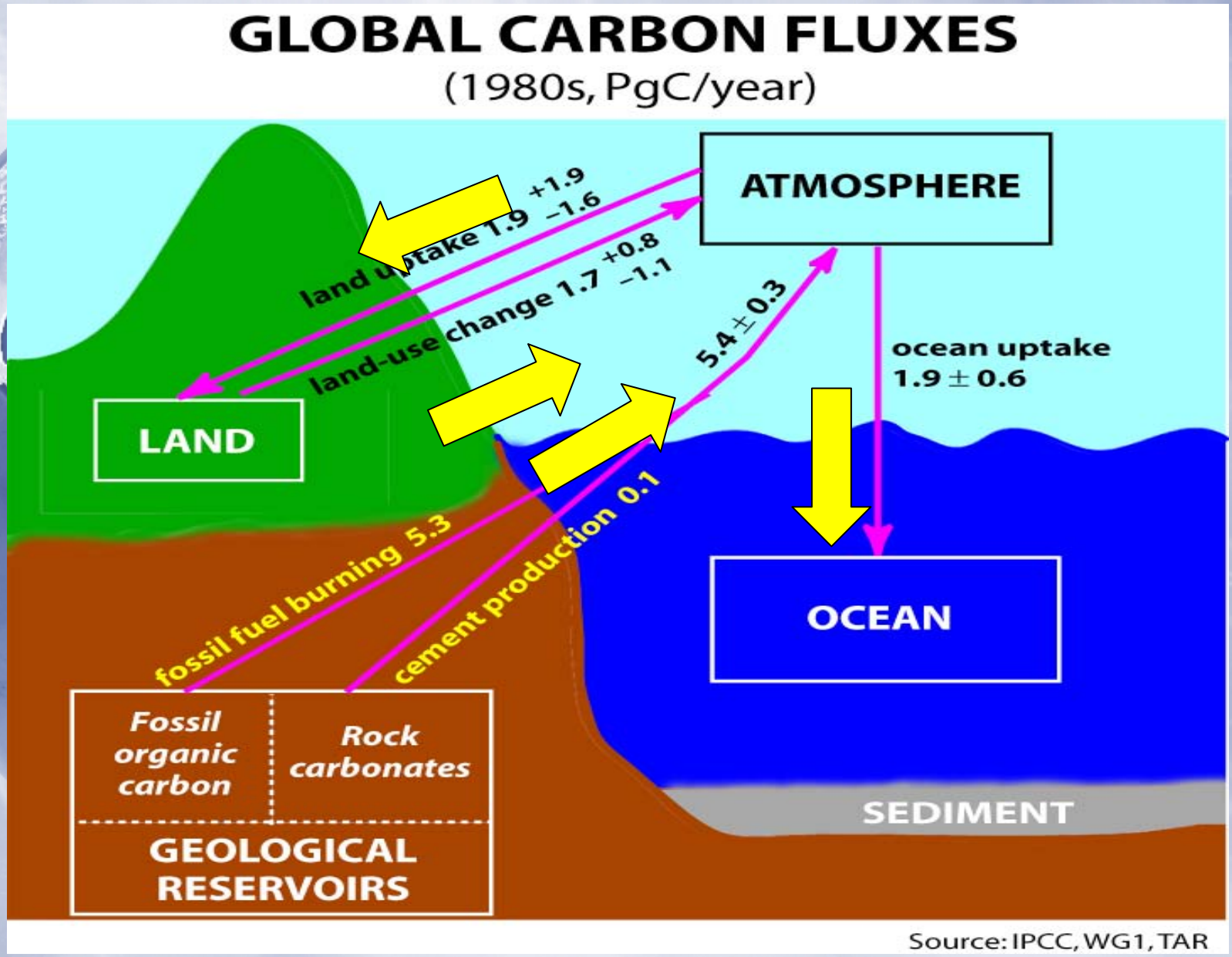


The concentrations and radiative forcing by (a) carbon dioxide (CO_2), (b) methane (CH_4), (c) nitrous oxide (N_2O) and (d) the rate of change in their combined radiative forcing over the last 20,000 years reconstructed from Antarctic and Greenland ice and firn data (symbols) and direct atmospheric measurements (panels a,b,c, red lines). The grey bars show the reconstructed ranges of natural variability for the past 650,000 years. The rate of change in radiative forcing (panel d, black line) has been computed from spline fits to the concentration data. The negative rate of change in forcing around 1600 shown in the higher-resolution inset in panel d results from a CO_2 decrease of about 10 ppm in the ice core record.

Courtesy of the Intergovernmental Panel on Climate Change. Used with permission.

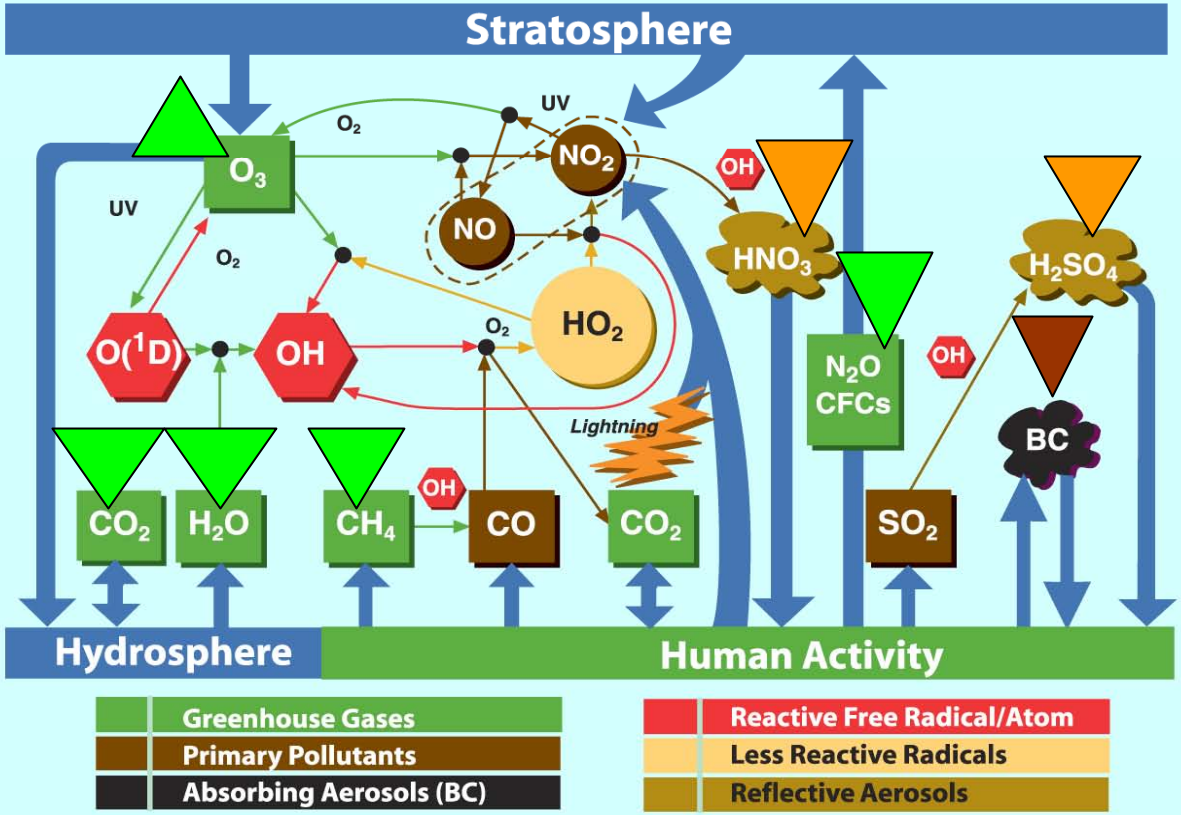
Ref: IPCC 4th Assessment, Summary for Policymakers, Feb. 2, 2007

WHAT CONTROLS GREENHOUSE GAS AND AEROSOL LEVELS?



Courtesy of the Intergovernmental Panel on Climate Change. Used with permission.

Life Cycles of Substances Important in Climate



WATER VAPOR IS THE MOST POWERFUL GREEN-HOUSE GAS!

WHAT ARE THE EFFECTS OF AEROSOLS ON CLIMATE?

Direct Effect: aerosols reflect or absorb sunlight leading to warming or cooling

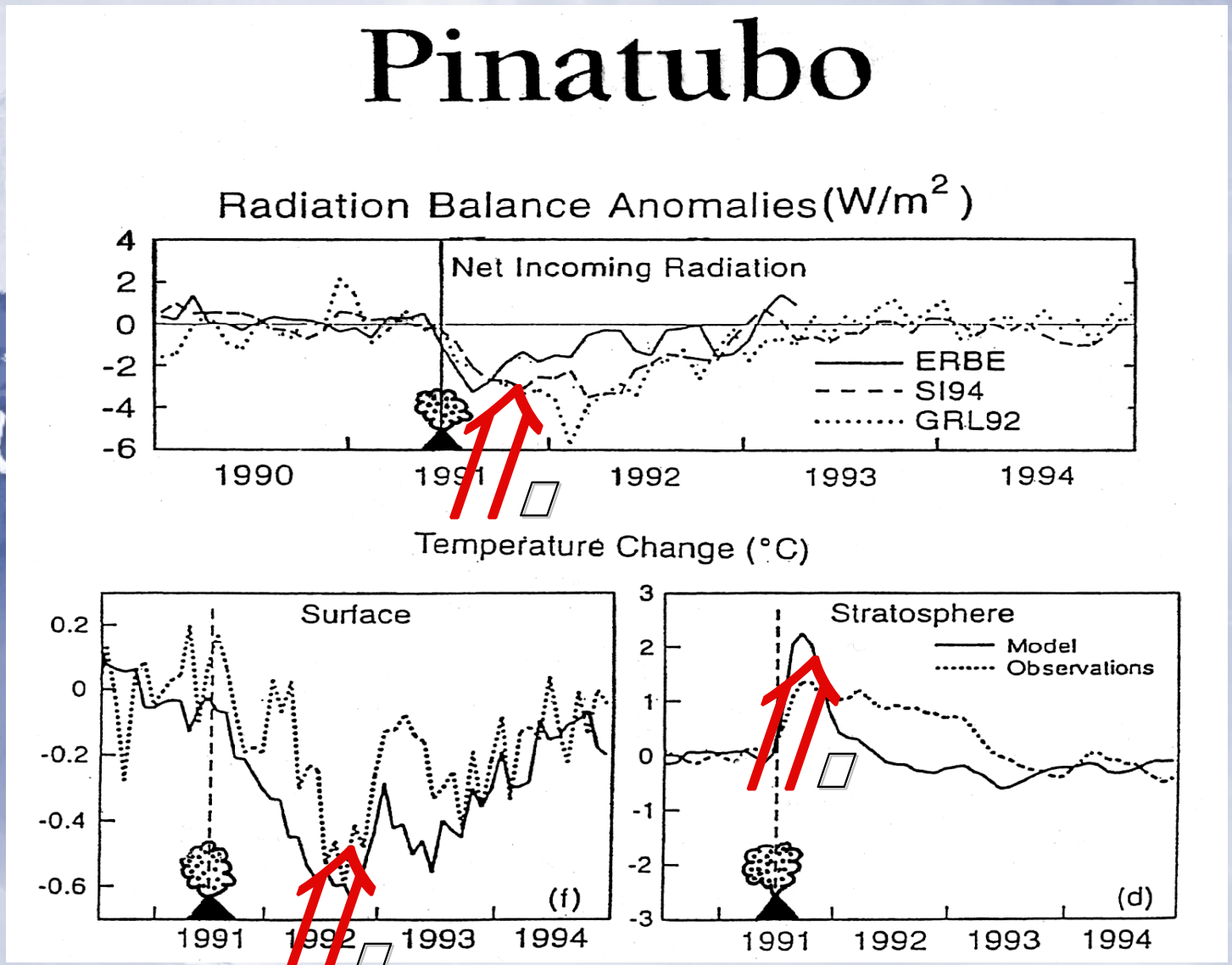
Indirect Effects: aerosols create more and smaller cloud droplets which:

(1) increases reflection, and

(2) suppresses rainfall

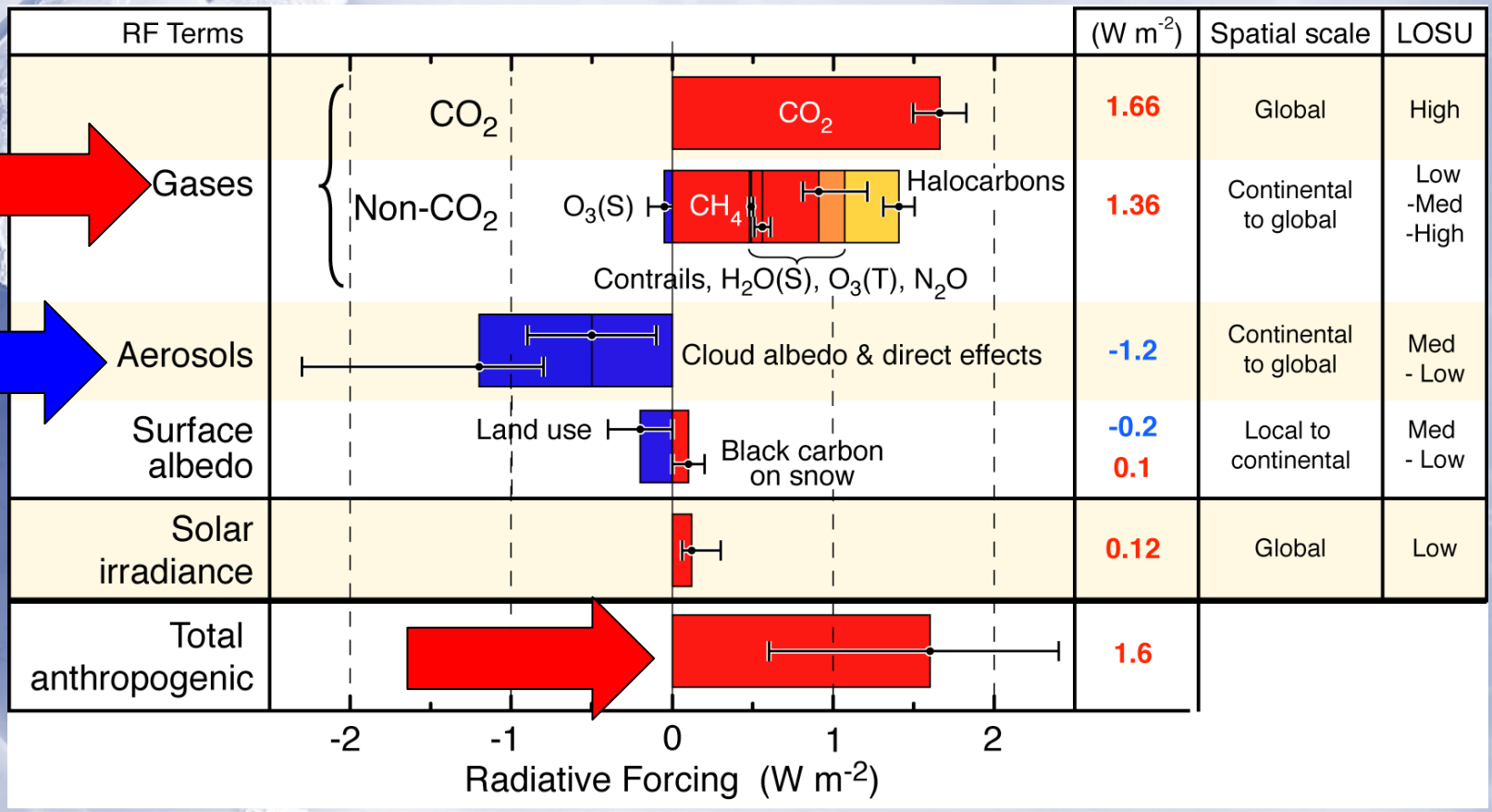
Semi-direct effects: absorbing aerosols heat air and cool surface suppressing convection and condensation

DO WE HAVE EVIDENCE FOR GLOBAL COOLING BY SULFATE AEROSOLS?



Hansen, J., R. Ruedy, M. Sato, R. Reynolds, "Global Surface Air Temperature in 1995: Return to Pre-Pinatubo Level." *Geophys Res Lett* 23, no. 13 (1665-1668, 1996). Copyright [1996] American Geophysical Union. Reproduced/modified by permission of American Geophysical Union.

WHAT ARE THE MAJOR HUMAN & NATURAL ACTIVITIES FORCING CLIMATE CHANGE IN THE INDUSTRIAL ERA (1750-2005)?



Ref: adapted from IPCC 4th Assessment, Summary for Policymakers, Feb. 2, 2007