Climate Change

Overall Picture

- Increasing body of evidence for warmer world and other climate changes
  - Surface temperature has increased over 20th century by about 0.8 C
  - Temperature has risen during last four decades in lowest 8 km of atmosphere (troposphere)
  - Snow cover has decreased
  - Global sea level has risen

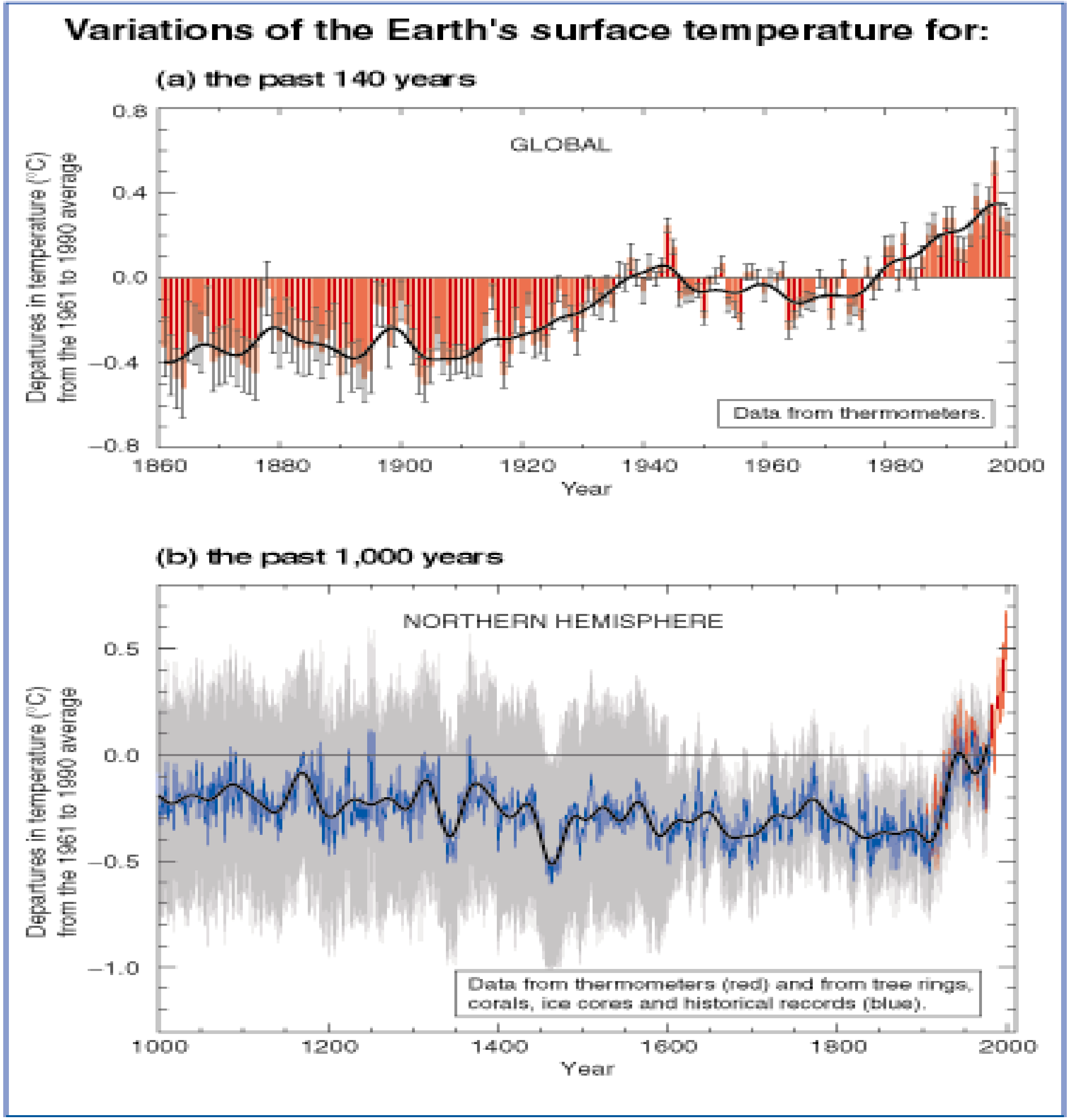

Figure 1: Variations of the Earth's surface temperature over the last 140 years and the last millennium.

(a) The Earth's surface temperature is shown year by year (red bars) and approximately decade by decade (black line, a filtered annual curve suppressing fluctuations below near decadal time-scales). There are uncertainties in the annual data (thin black whisker bars represent the 95% confidence range) due to data gaps, random instrumental errors and uncertainties, uncertainties in bias corrections in the ocean surface temperature data and also in adjustments for urbanisation over the land. Over both the last 140 years and 100 years, the best estimate is that the global average surface temperature has increased by 0.6 ± 0.2°C.

(b) Additionally, the year by year (blue curve) and 50 year average (black curve) variations of the average surface temperature of the Northern Hemisphere for the past 1000 years have been reconstructed from "proxy" data calibrated against thermometer data (see list of the main proxy data in the diagram). The 95% confidence range in the annual data is represented by the grey region. These uncertainties increase in more distant times and are always much larger than in the instrumental record due to the use of relatively sparse proxy data. Nevertheless the rate and duration of warming of the 20th century has been much greater than in any of the previous nine centuries. Similarly, it is likely[7] that the 1990s have been the warmest decade and 1998 the warmest year of the millennium.

[Based upon (a) Chapter 2, Figure 2.7c and (b) Chapter 2, Figure 2.20]

Other changes

- Precipitation likely to have increase 0.5 – 1% per decade in 20th century
- Likely increase over 20th century in mid-latitude of frequency of heavy precipitation
- Likely increase 25% in cloud cover over 20th century over land areas
- Since 1950 very likely reduction in frequency of extreme low temperatures

Other changes

- Warm El Nino have been more frequent and persistent
- Small increase in more areas experiencing more severe draught or severe wetness
- Increase in frequency of draughts

No change in some climate aspects

- Few areas have not warmed (Southern oceans and part of Antarctica)
- NO significant trend in Antarctic sea ice?
- Changes in tropical and extra-tropical storm intensity and frequency dominated by inter-decadal to multi-decadal variability
- No systematic change in tornadoes, thunder days or hail

Emission of greenhouse gases and aerosol due to human activities continue to alter the atmosphere in ways that are expected to affect climate

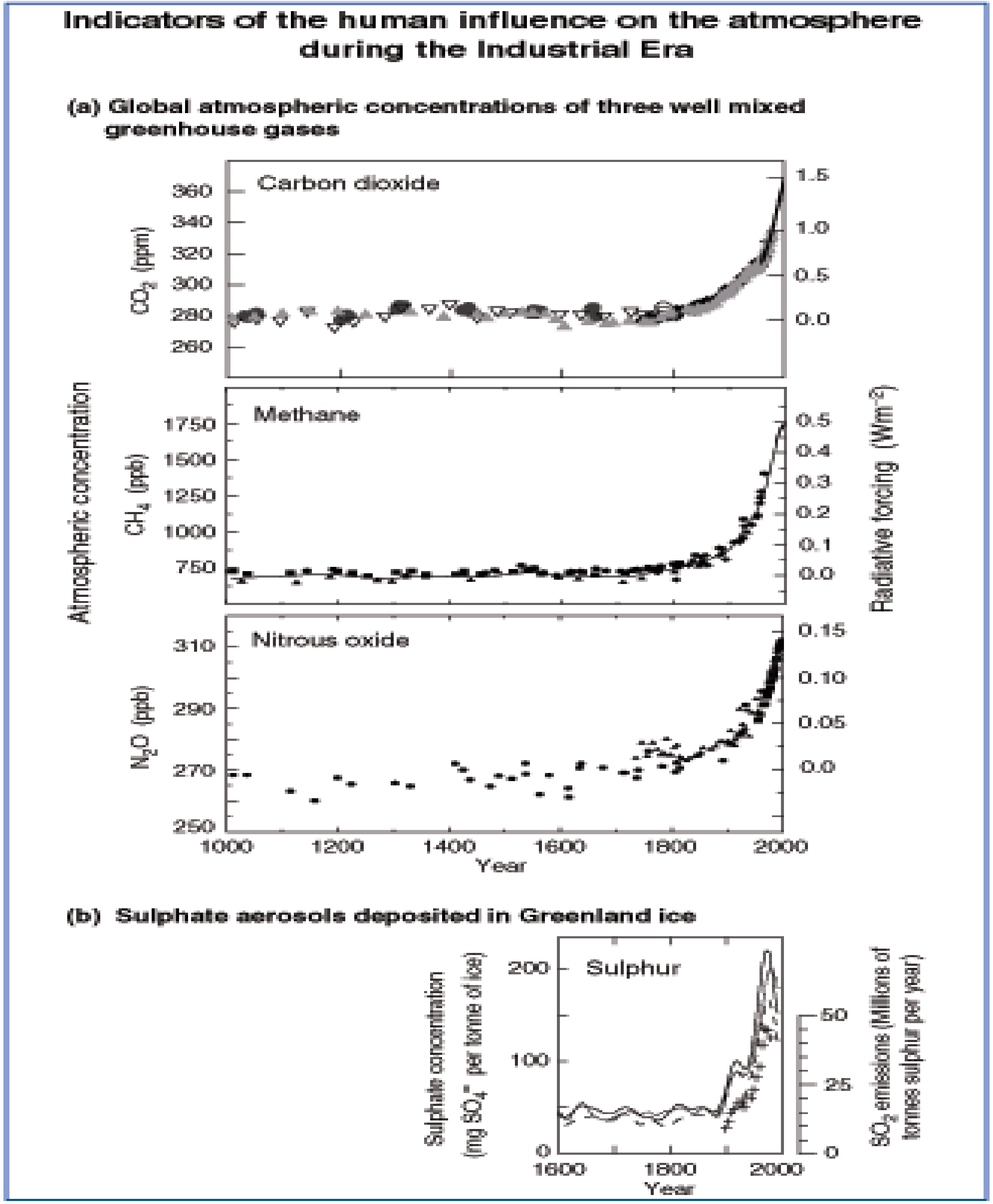

Figure 2: Long records of past changes in atmospheric composition provide the context for the influence of anthropogenic emissions.

(a) shows changes in the atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) over the past 1000 years. The ice core and firn data for several sites in Antarctica and Greenland (shown by different symbols) are supplemented with the data from direct atmospheric samples over the past few decades (shown by the line for CO_2 and incorporated in the curve representing the global average of CH_4). The estimated positive radiative forcing of the climate system from these gases is indicated on the right-hand scale. Since these gases have atmospheric lifetimes of a decade or more, they are well mixed, and their concentrations reflect emissions from sources throughout the globe. All three records show effects of the large and increasing growth in anthropogenic emissions during the Industrial Era.

(b) illustrates the influence of industrial emissions on atmospheric sulphate concentrations, which produce negative radiative forcing. Shown is the time history of the concentrations of sulphate, not in the atmosphere but in ice cores in Greenland (shown by lines; from which the episodic effects of volcanic eruptions have been removed). Such data indicate the local deposition of sulphate aerosols at the site, reflecting sulphur dioxide (SO_2) emissions at mid-latitudes in the Northern Hemisphere. This record, albeit more regional than that of the globally-mixed greenhouse gases, demonstrates the large growth in anthropogenic SO_2 emissions during the Industrial Era. The pluses denote the relevant regional estimated SO_2 emissions (right-hand scale).

[Based upon (a) Chapter 3, Figure 3.2b (CO_2); Chapter 4, Figure 4.1a and b (CH_4) and Chapter 4, Figure 4.2 (N_2O) and (b) Chapter 5, Figure 5.4a]

Concentration of atmospheric greenhouse gases and radiative forcing

- CO_2
  - concentration has increased 31% since 1750 (exceeded past 420,000y and likely past 20 my), unprecedented increase over past 20,000
  - _ of CO_2 emission is anthropogenic due to fossil fuel burning
  - Rate of increase 1.5 ppm per y over past 2 decades but variable (0.9 –2.8) over 20th century

Greenhouse gases

- CH_4
  - Concentration has increased by 1060 ppb
  - Present concentration not been exceeded over past 420,000 y
  - Annual growth slowed down
  - Slightly more than _ emissions are anthropogenic (fossil fuel use, cattle, rice agriculture and land fills)

Greenhouse gases

- N2O
  - Concentration has increased 46 ppb since 1750
  - Present concentration not been exceeded during at least past thousand years
  - 1/3 emissions are anthropogenic
- Halocarbon gases (CFCs) – ozone depleting and Greenhouse gases
  - Increasing more slowly or decreasing (Montreal protocol)
  - Concentration of substitutes that are also Greenhouse gases are increasing

Greenhouse Radiative Forcing

- Radiative Forcing = Imposed perturbation to energy balance – expressed in Wm^{-2}
- Allows to compare effect of different gases
- Total forcing = 2. 5 Wm^{-2}
  - CO_2 forcing = 1.5 Wm^{-2}
  - CH4 forcing = 0.48 Wm^{-2}
  - Halocarbons forcing = 0.34 Wm^{-2}
  - N_2O forcing = 0.15 Wm^{-2}

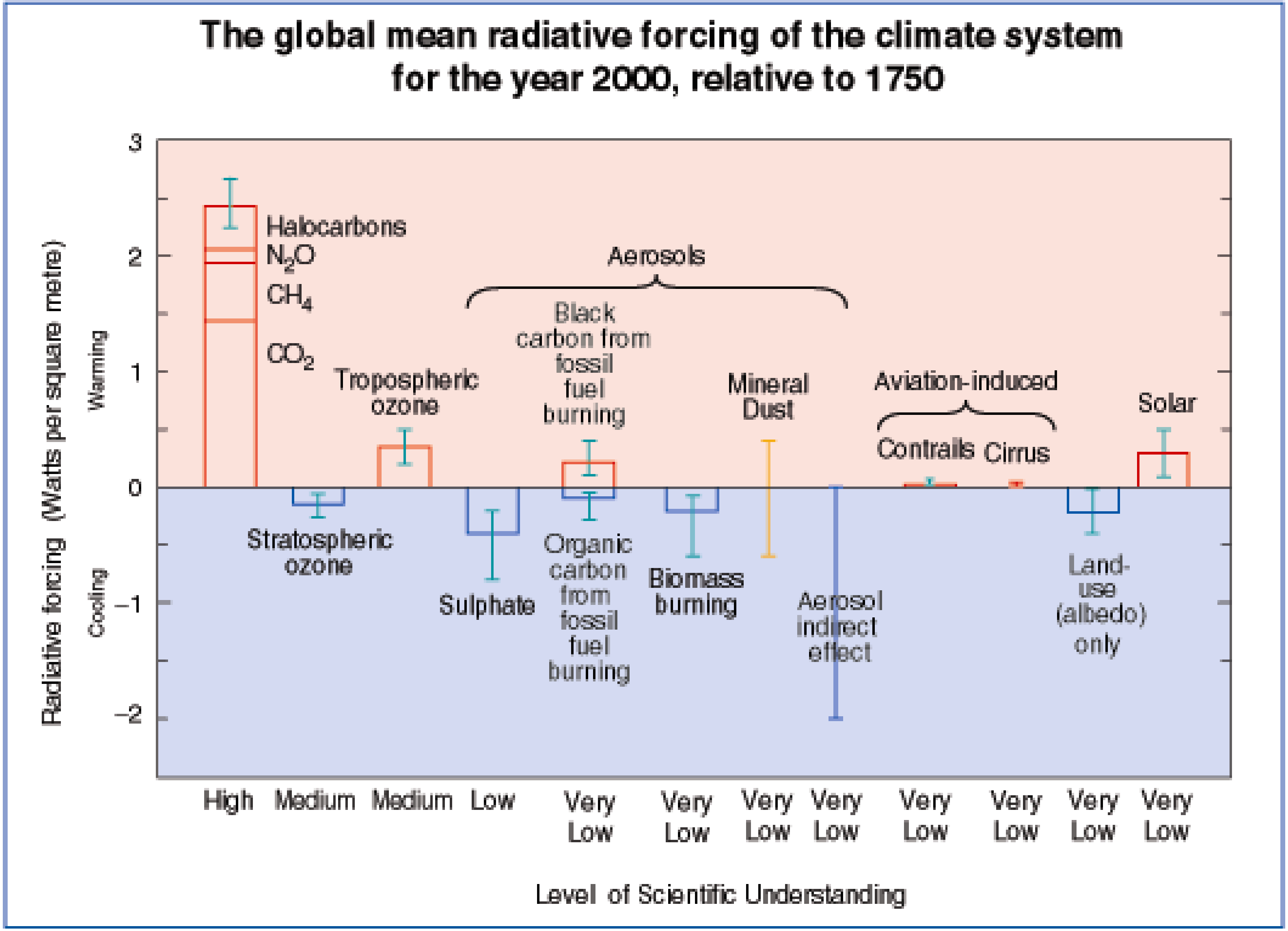

Figure 3: Many external factors force climate change.

Ozone (O_3) Radiative Forcing

- Observed ozone depletion in stratosphere 1979 –2000 => negative radiative forcing
- Total O_3 in troposphere has increased by 36% since 1750 due to anthropogenic emission of several 03-forming gases => positive forcing

Anthropogenic aerosol

- Short lived
- Mostly producing negative forcing
- Major source anthropogenic aerosol = fossil fuel and biomass burning
- Better characterization of direct radiative role

  -0.4 Wm_{-2} for sulphate

  -0.2 for biomass burning

  -0.1 for fossil fuel organic carbon

  +0.2 for black carbon
- Much less confidence for quantifying total direct effect
- Indirect effect ???

Natural Factors have made small contribution

- Radiative effect due to solar irradiance change since 1750 ~ 1.3 Wm-2 mostly during first half of 20th century
- Stratospheric aerosol from volcanoes lead to negative forcing that lasts for a few years
- Combine effect probably negative for the past two may be four decades

Confidence in models to predict

- Has increased but still uncertain
- Water vapor, sea ice dynamics and ocean heat transport representation better
- Estimates of natural and anthropogenic effects on changes of temperature closer to observations
- Some aspects of model simulations of El Nino, monsoon, NAO have improved

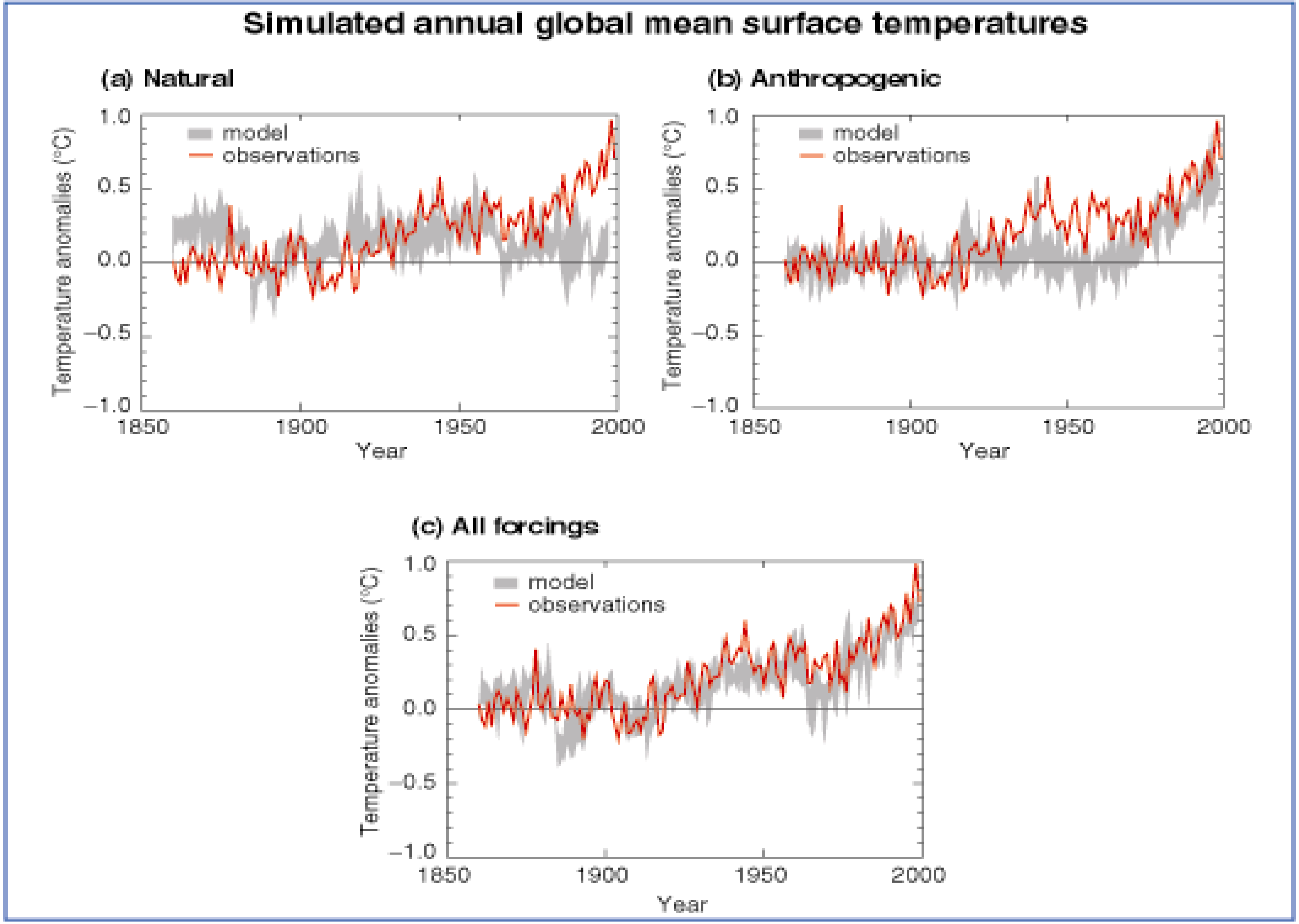

Figure 4: Simulating the Earth's temperature variations, and comparing the results to measured changes, can provide insight into the underlying causes of the major changes.

Strong evidence that most of warming observed over last 50 y is anthropogenic

- Longer and better temperature records
- Warming over past 100 y very unlikely due to internal variability alone
- New estimates of climate response and new detection techniques
- Simulation of natural forcing alone cannot explain warming
- Uncertainties due to climate sensitivity are now included
- Estimated rate similar to that observed
- Best comparisons between model simulations and observations when natural and anthropogenic effects are taken into account