Climate change: recent changes in sea level and the ocean

UNIVERSITY OF LIVERPOOL

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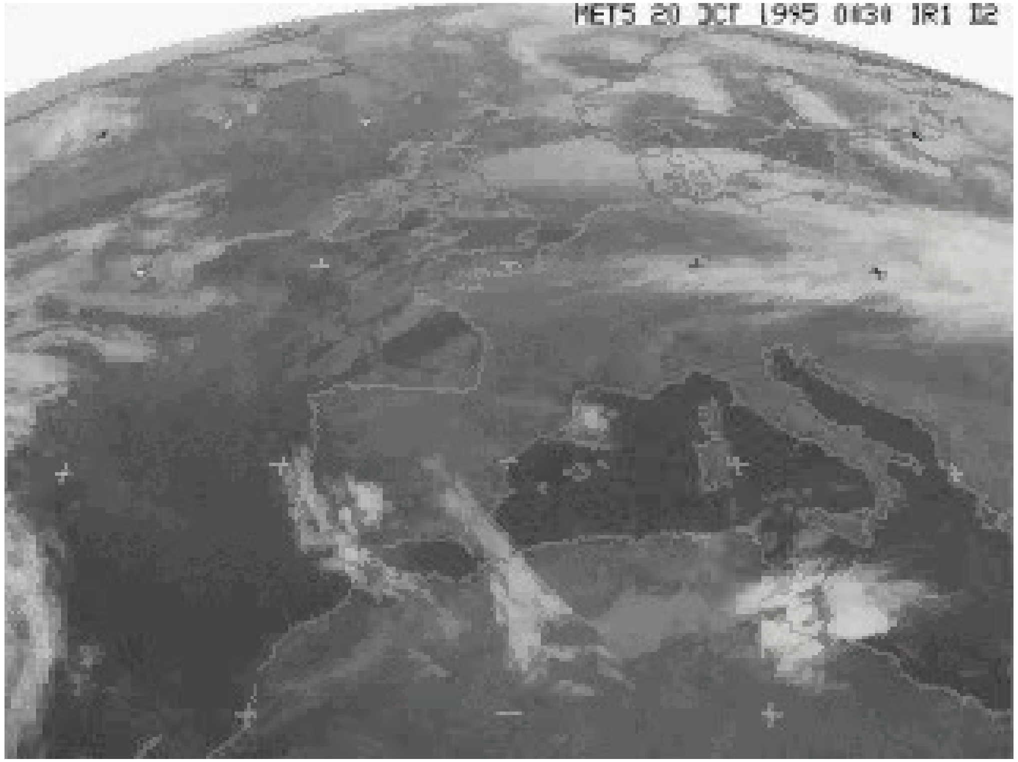
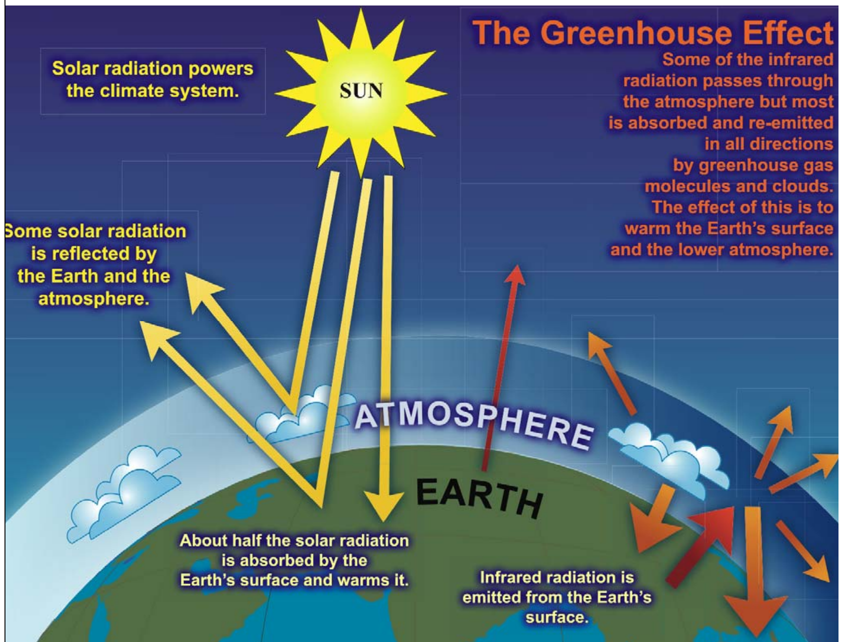


1. Is climate change happening?
2. Why care about the ocean?
3. What might happen in the future?

Prof. Phil Woodworth,
Proudman Oceanography Laboratory

1. Is climate change happening?

- Atmospheric change



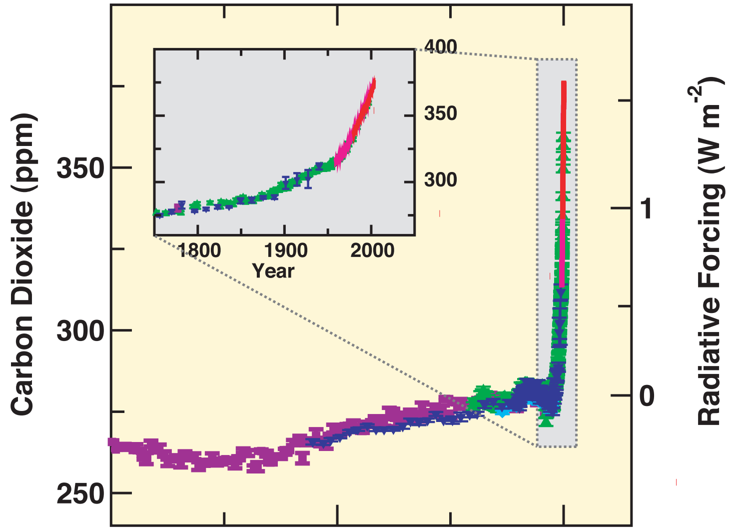


Figure SPM.1. *Atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). The corresponding radiative forcings are shown on the right hand axes of the large panels. {Figure 6.4}*

Implied radiative heating of 1.67 Wm^{-2}

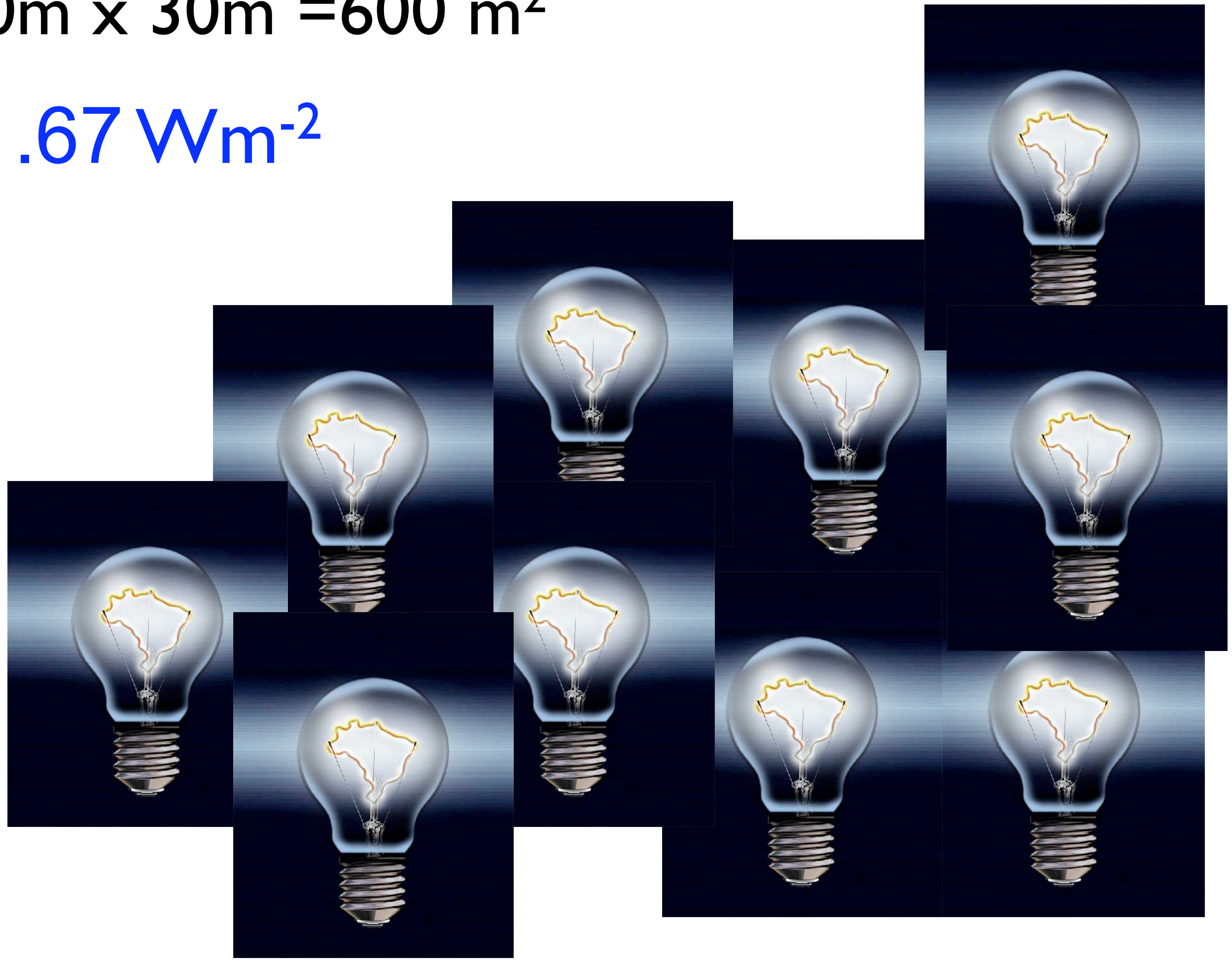
range: 0.6 to 2.6 Wm^{-2}

How many light bulbs would be lit in this room by this energy input?

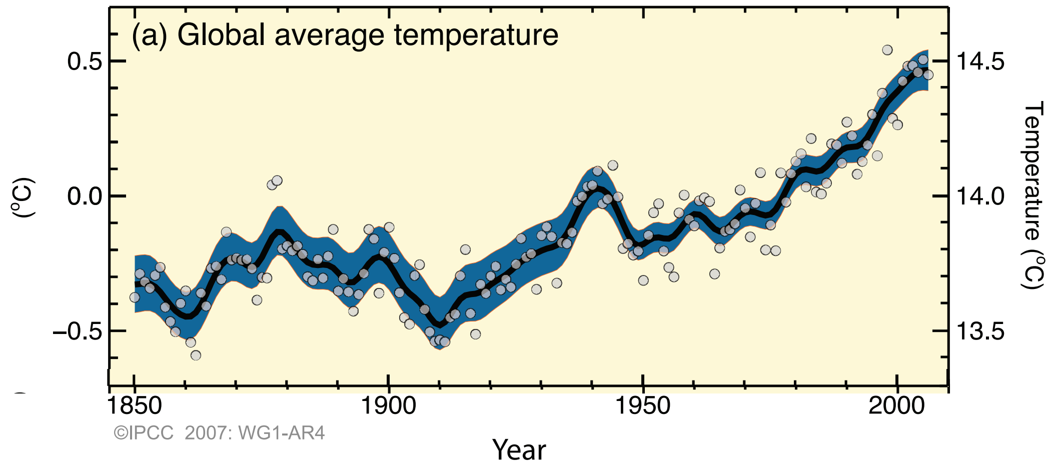
If room is 20m x 30m =600 m^2

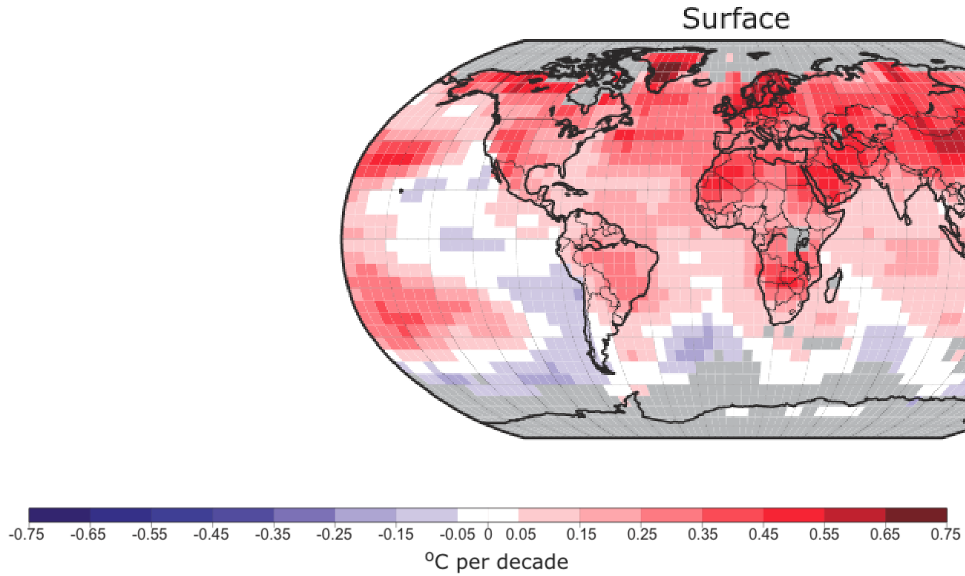
warming of 1.67 Wm^{-2}
equivalent to

10 bulbs



Warming signal

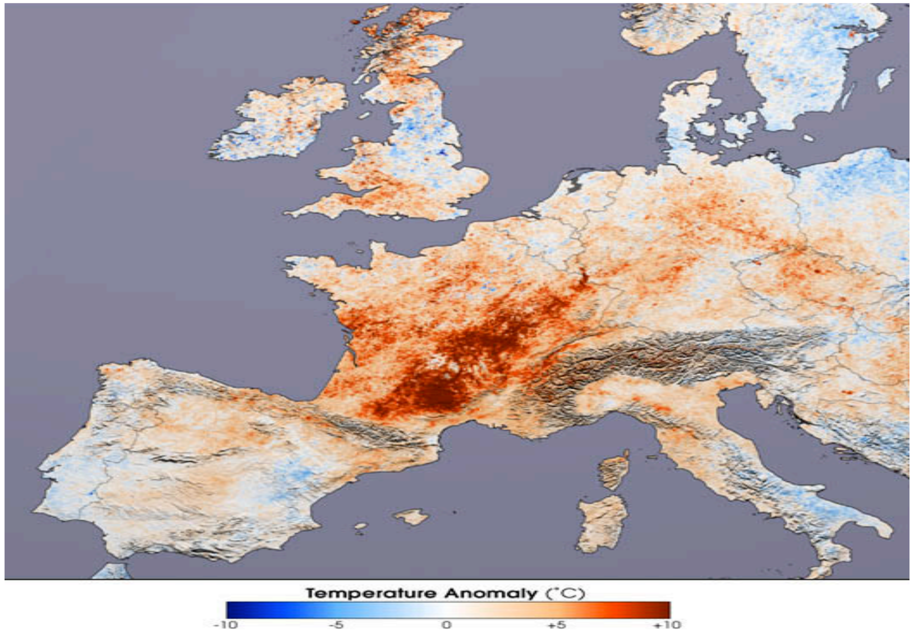


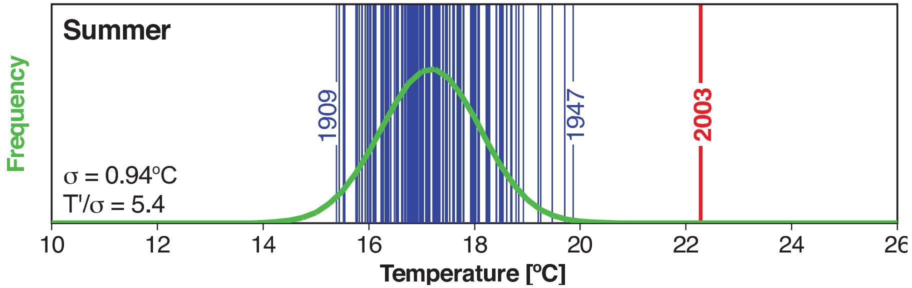


Warming trends since 1979 (when satellite measurements started) show:

- Warming everywhere at surface except in eastern Pacific, Southern Ocean and parts of Antarctica;
- Land warming significantly faster than ocean over last 20 years;

Extreme events: Heat wave in summer 2003





FAQ 9.1, Figure 1. *Summer temperatures in Switzerland from 1864 to 2003 are, on average, about 17°C, as shown by the green curve. During the extremely hot summer of 2003, average temperatures exceeded 22°C, as indicated by the red bar (a vertical line is shown for each year in the 137-year record). The fitted Gaussian distribution is indicated in green. The years 1909, 1947 and 2003 are labelled because they represent extreme years in the record. The values in the lower left corner indicate the standard deviation (σ) and the 2003 anomaly normalised by the 1864 to 2000 standard deviation (T'/σ). From Schär et al. (2004).*

Modeled variability with & without anthropogenic forcing

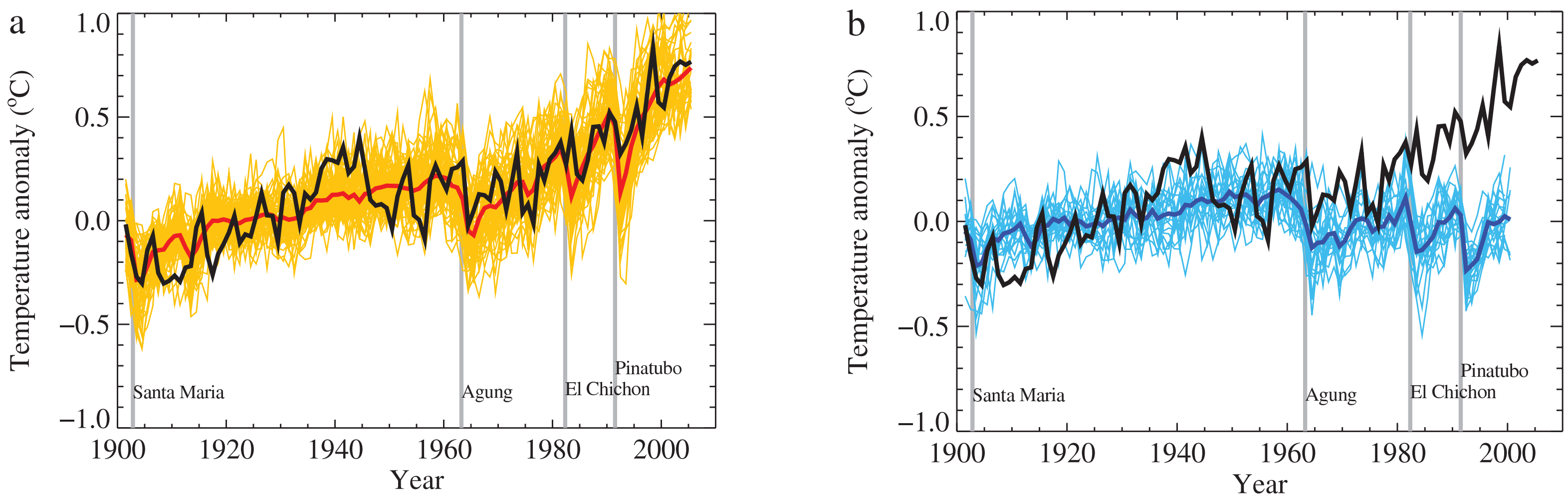
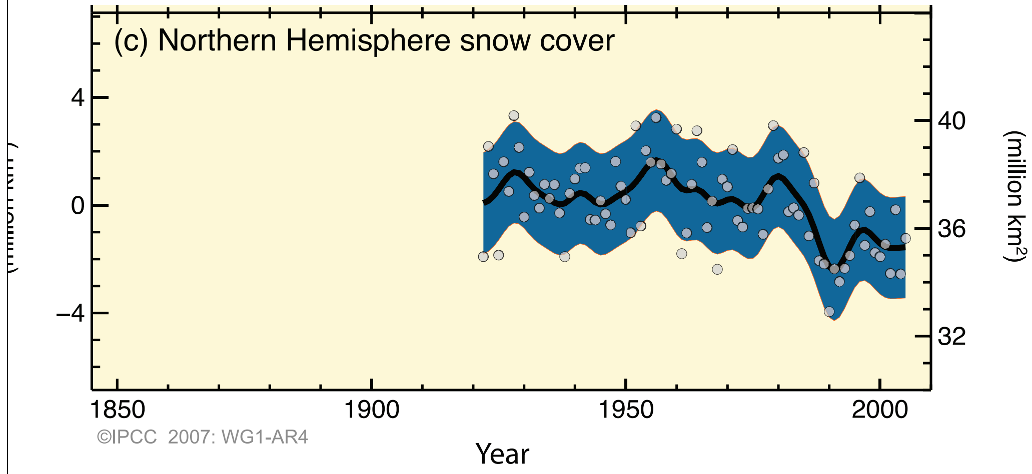
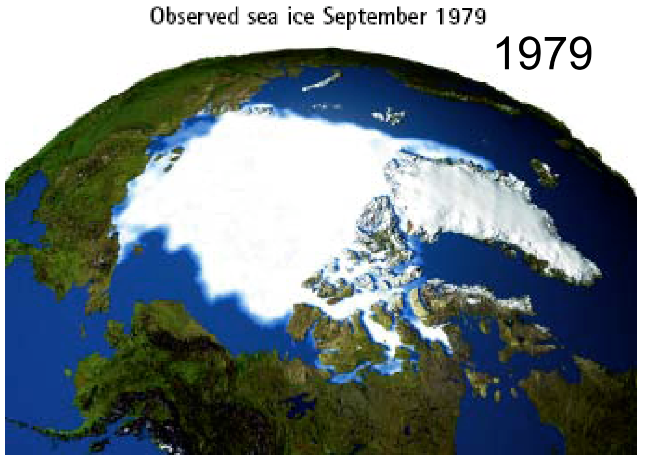
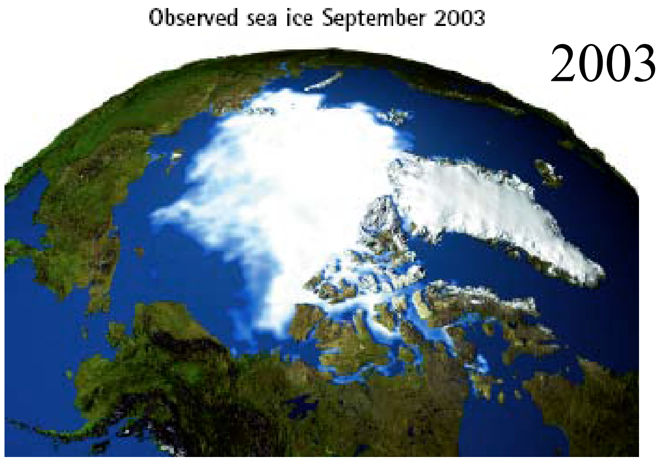


Figure 9.5. *Comparison between global mean surface temperature anomalies (°C) from observations (black) and AOGCM simulations forced with (a) both anthropogenic and natural forcings and (b) natural forcings only. All data are shown as global mean temperature anomalies relative to the period 1901 to 1950, as observed (black, Hadley Centre/Climatic Research Unit gridded surface temperature data set (HadCRUT3); Brohan et al., 2006) and, in (a) as obtained from 58 simulations produced by 14 models with both anthropogenic and natural forcings. The multi-*

Reduction in snow cover and Arctic sea ice in summer







2. Why care about the ocean?

- upper 2.5 m of ocean holds as much heat as overlying atmosphere

- 80% of anthropogenic extra heating has gone into the ocean

Oceans have been absorbing more than 80% of heat added to the climate system.

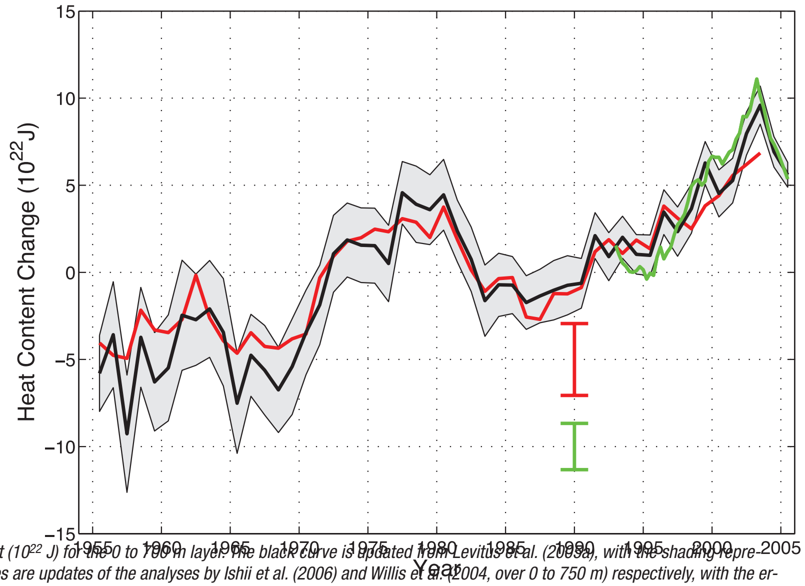
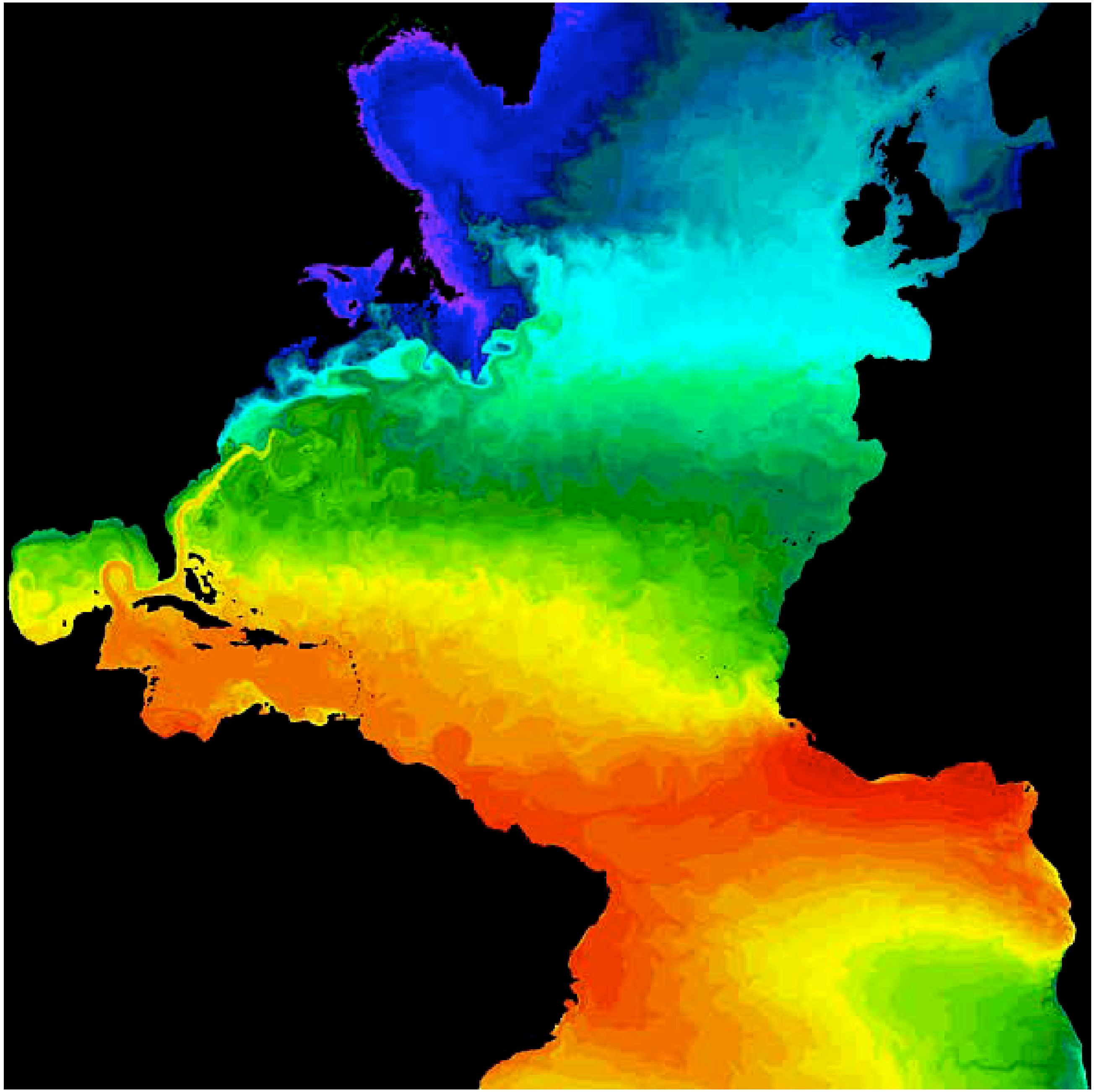


Figure 5.1. *Time series of global annual ocean heat content (10^{22} J) for the 0 to 700 m layer. The black curve is updated from Levitus et al. (2005a), with the shading representing the 90% confidence interval. The red and green curves are updates of the analyses by Ishii et al. (2006) and Willis et al. (2004, over 0 to 750 m) respectively, with the error bars denoting the 90% confidence interval. The black and red curves denote the deviation from the 1961 to 1990 average and the shorter green curve denotes the deviation from the average of the black curve for the period 1993 to 2003.*



Ocean heat content change

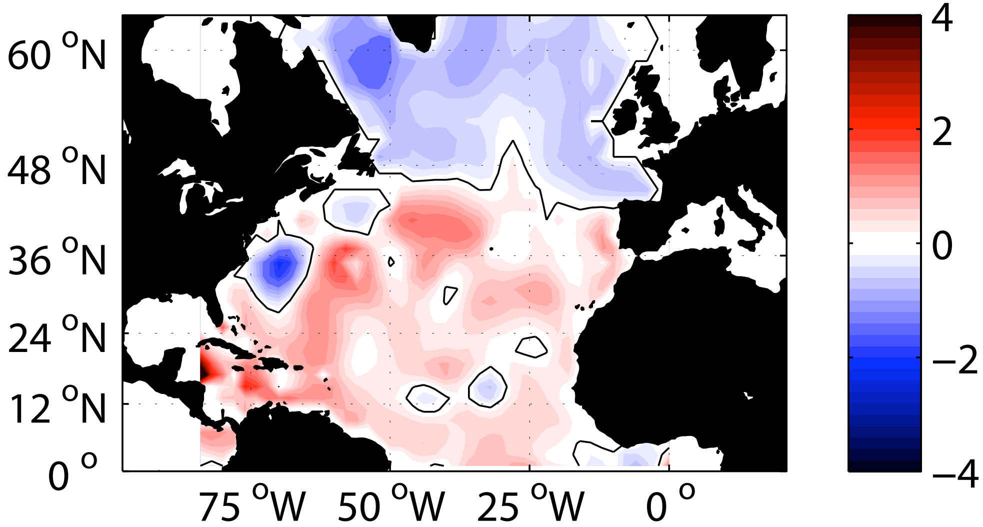
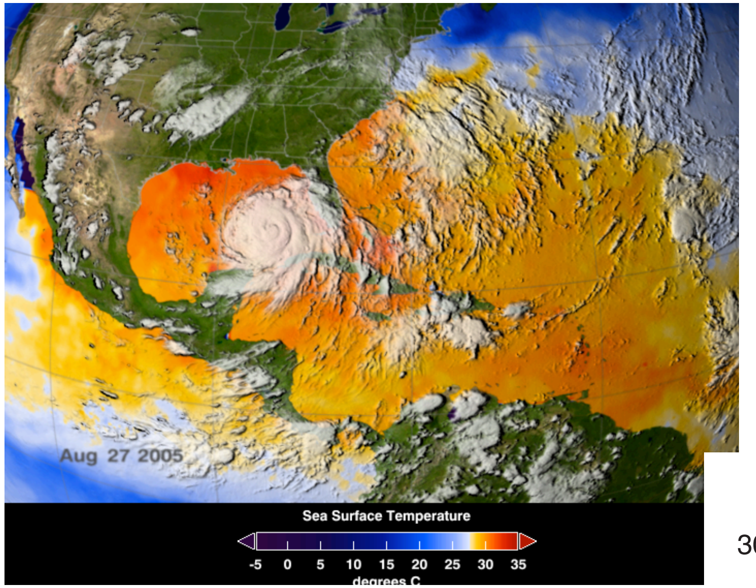


Figure 1. Change in ocean heat content (10^{20}J; red represents a gain in heat for the later period) between the twenty-year periods 1980-2000 and 1950-1970 diagnosed from (a) historical data integrated over the water column and (b) 1.4° ocean model output using realistic ECMWF wind

Intensification of Hurricane Katrina



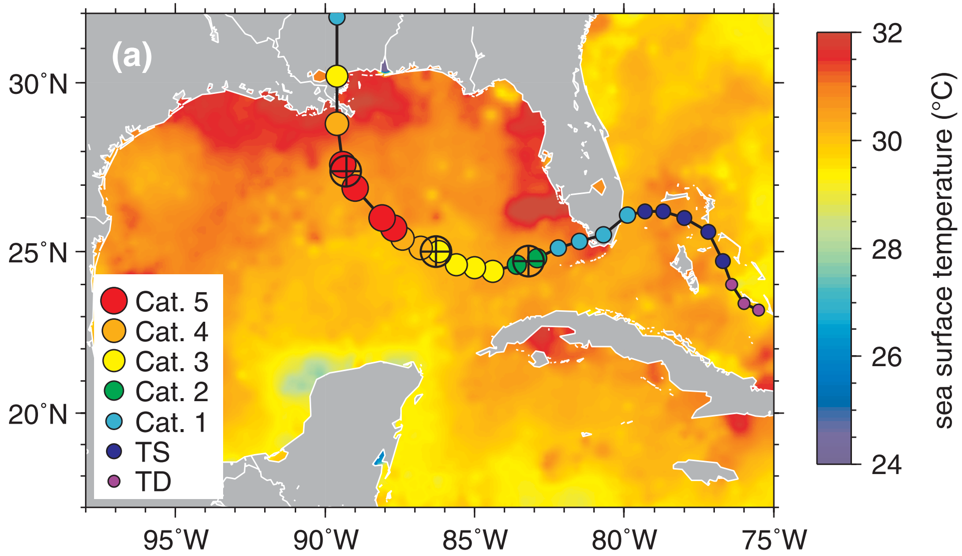


Fig. 2. The location and intensity of Katrina at intervals of six hours (circles indicate data from National Hurricane Center advisories) show two intensification events. (a) Intensification is not correlated with sea surface temperature (from POES high-resolution infrared data). (b) In contrast, the intensifications correlate well with highs in the ocean dynamic topography (from Jason 1, TOPEX, Envisat, and GFO sea surface height data). The Loop Current can be seen entering the Gulf south of Cuba and exiting south of Florida; the warm-core ring (WCR) is the prominent high shedding from the Loop Current in the center of the Gulf. The crosshair symbols on the storm tracks show the storm position at the times of the three rows of panels in Figure 1.

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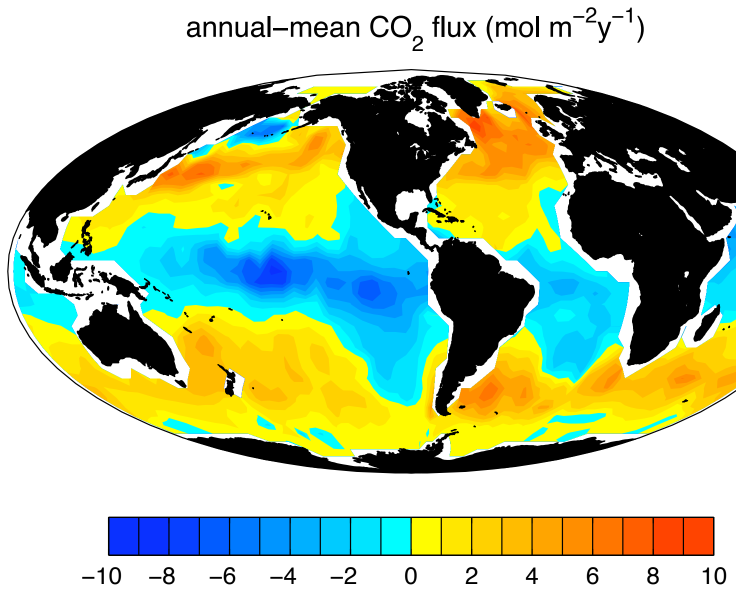
Ocean uptake of carbon

- 50 - 70 times as much carbon in the oceans as in the atmosphere

air-sea flux of CO_2 into the ocean
(Takahashi et al., 2002)



Pattern reflects combination of physics & biology

- 1/2 the recent industrial emissions of carbon has gone into ocean

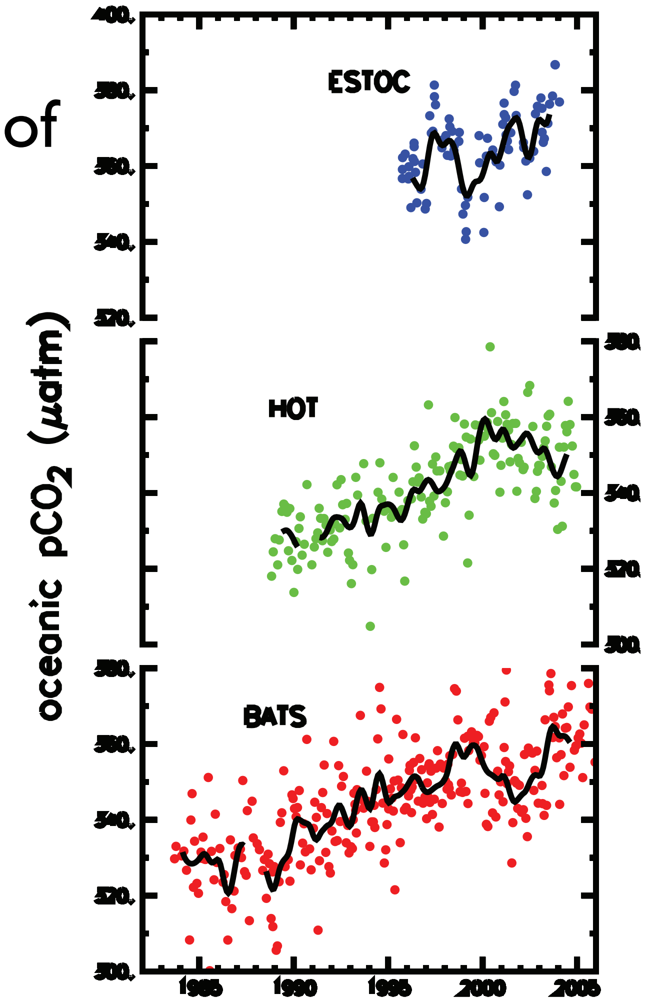
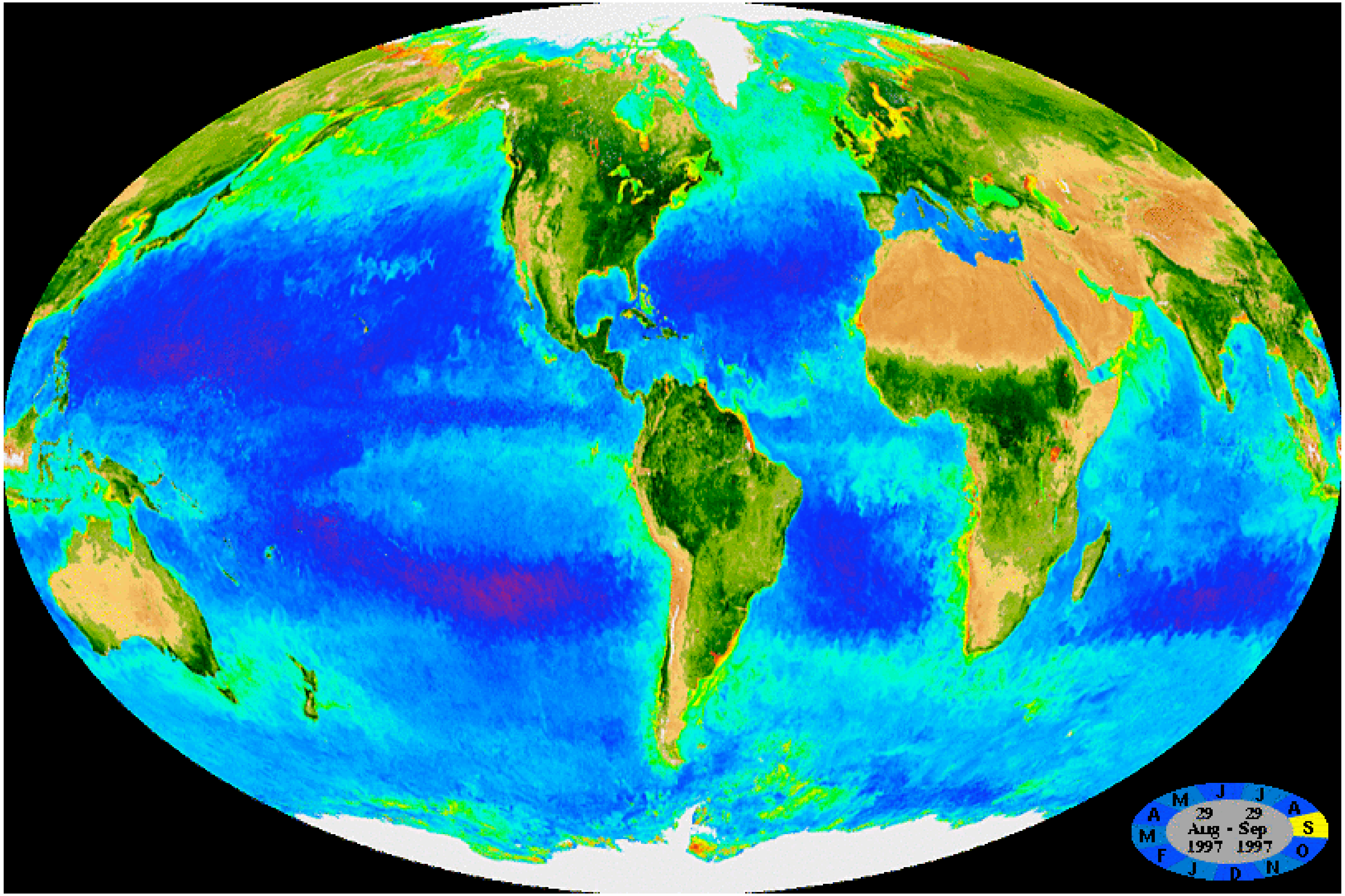


Figure 5.9. *Changes in surface oceanic pCO_2 (left; in µatm) and pH (right) from three time series stations: Blue: European Station for Time-series in the Ocean (ESTOC, 29°N, 15°W; Gonzalez-Dávila et al., 2003); green: Hawaii Ocean Time-Series (HOT, 23°N, 158°W; Dore et al., 2003); red: Bermuda Atlantic Time-series Study (BATS, 31/32°N, 64°W; Bates et al., 2002; Gruber et al., 2002). Values of pCO_2 and pH were calculated from DIC and alkalinity at HOT and BATS; pH was directly measured at ESTOC and pCO_2 was calculated from pH and alkalinity. The mean seasonal cycle was removed from all data. The thick black line is smoothed and does not contain variability less than 0.5 years period.*



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3. What might happen in the future?

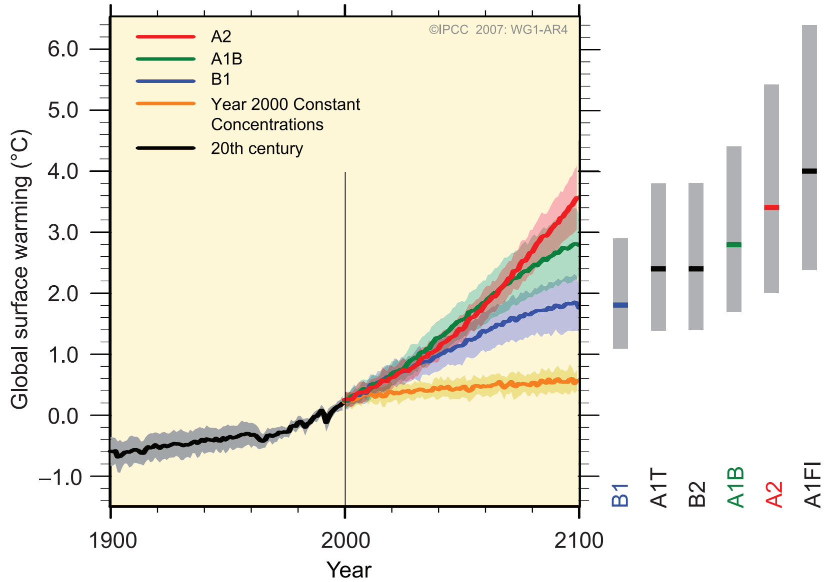
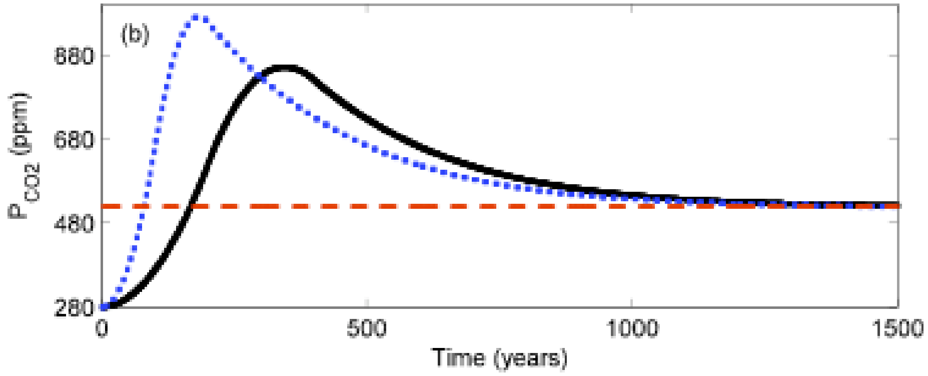


Figure SPM.5. *Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the* ***likely*** *range assessed for the six SRES marker scenarios. The assessment of the best estimate and* ***likely*** *ranges in the grey bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. {Figures 10.4 and 10.29}*

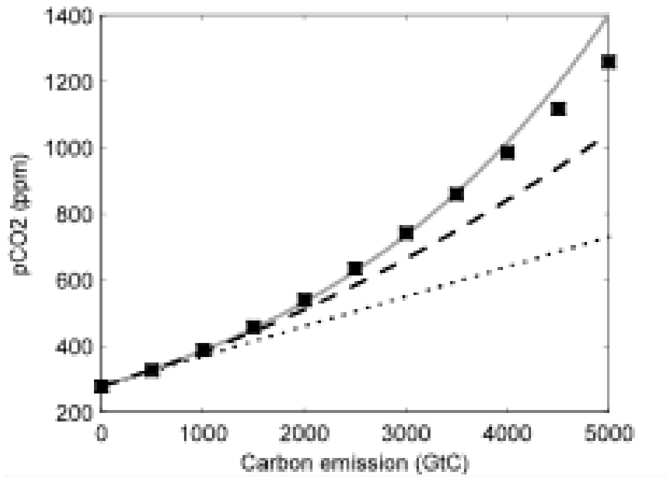
What happens if we burn all our fossil fuels?



- Initial fast rise in atmospheric CO_2
- Ocean (& terrestrial) uptake
- Eventually approach a steady state

steady state set by the total amount of carbon emitted

For a long term steady state:



partial pressure of CO_2 varies *exponentially* with C emissions

$$P_{CO2} = 280 \exp\left(\frac{\Delta C}{I_B}\right)$$

I_B ~3000 GtC

radiative forcing varies *logarithmically* with partial pressure of CO_2

$$\Delta F_{CO2} = \alpha \ln\left|\frac{P_{CO2}}{280}\right|$$

α =5.35 Wm^{-2}

radiative forcing varies *linearly* with C emissions

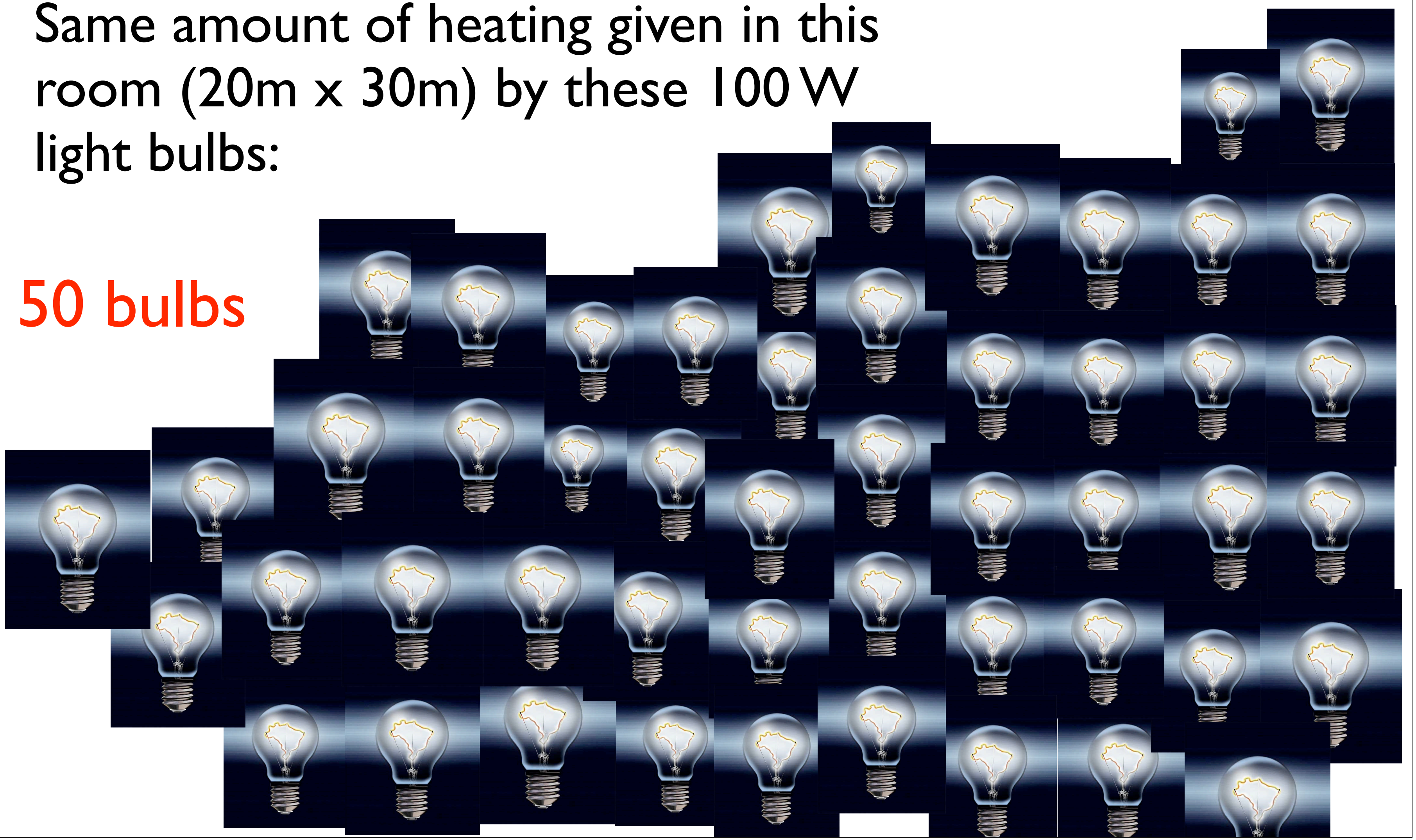
$$\Delta F_{CO2} \approx \frac{\alpha}{I_B} \Delta C$$

PhD thesis of Phil. Goodwin (Liverpool)

If burn all of the conventional fossil fuels, 5000GtC, then extra heating of 8.5 Wm^{-2}

Same amount of heating given in this room (20m x 30m) by these 100 W light bulbs:

50 bulbs



Summary

Evidence for warming of the climate system is unequivocal.

We are seeing coherent changes in many aspects of the climate system other than temperature.

The role of greenhouse gases is well understood and their increases are clearly identified.

The net effect of human activities is now quantified and known to cause a warming at the Earth's surface.

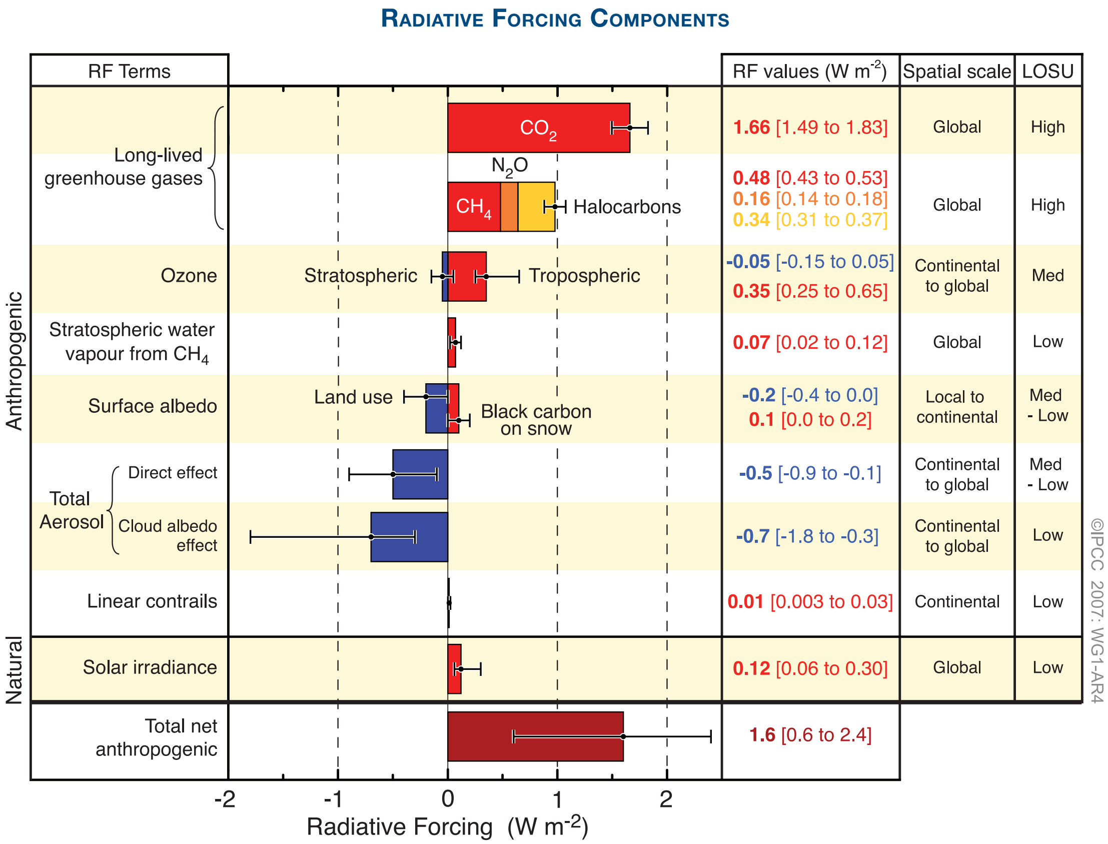
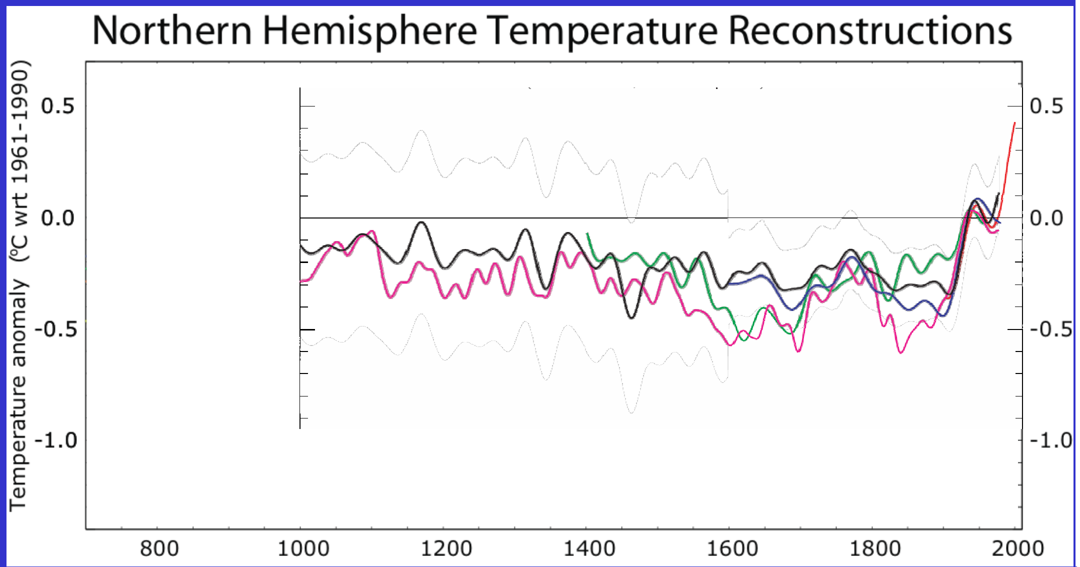


Figure SPM.2. *Global average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). The net anthropogenic radiative forcing and its range are also shown. These require summing asymmetric uncertainty estimates from the component terms, and cannot be obtained by simple addition. Additional forcing factors not included here are considered to have a very low LOSU. Volcanic aerosols contribute an additional natural forcing but are not included in this figure due to their episodic nature. The range for linear contrails does not include other possible effects of aviation on cloudiness. {2.9, Figure 2.20}*

TAR

Four long term proxy records for temperature. One uncertainty analysis.



AR4

Warmth of the last half century is unusual in at least the previous 1300 years.