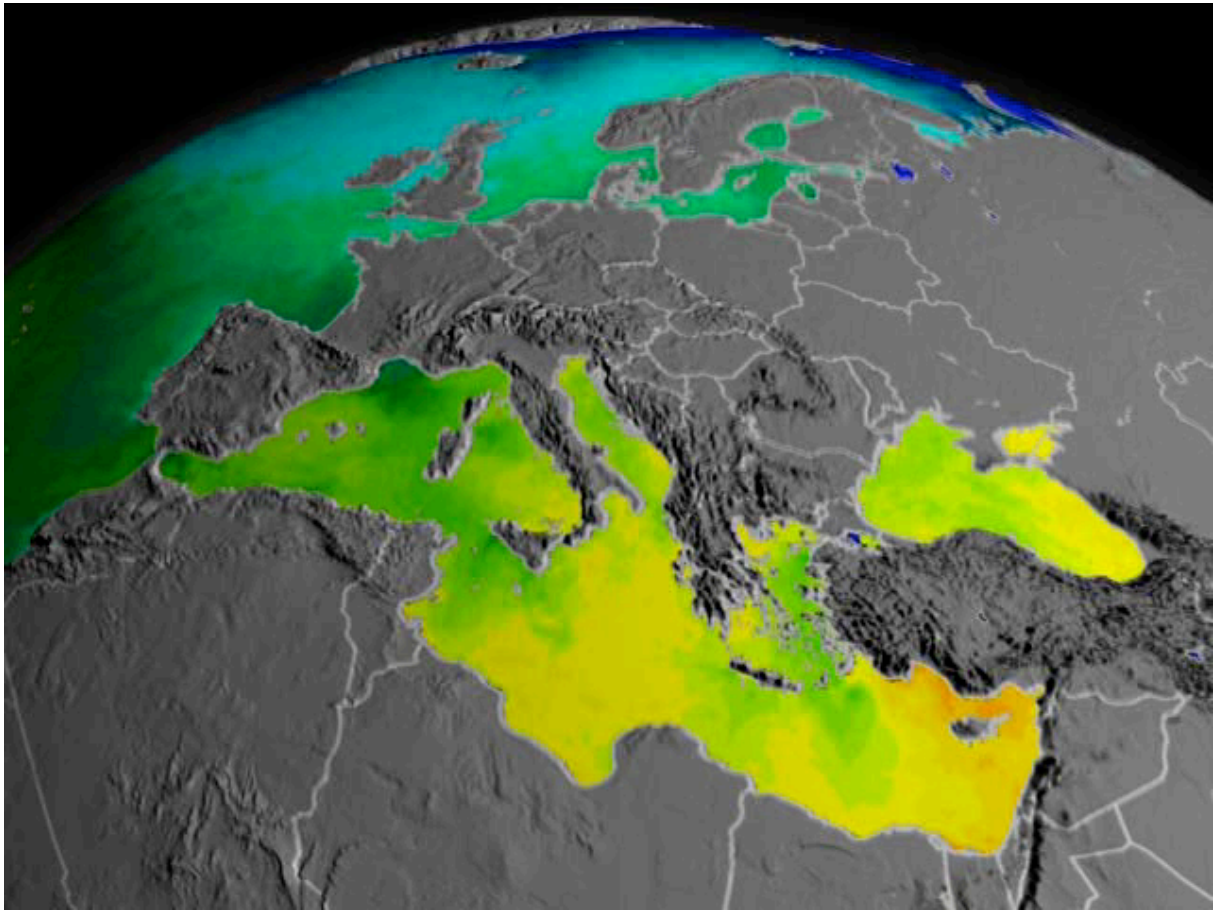
Climate change and the ocean

Ric Williams

1. Climate forcing from CO_2

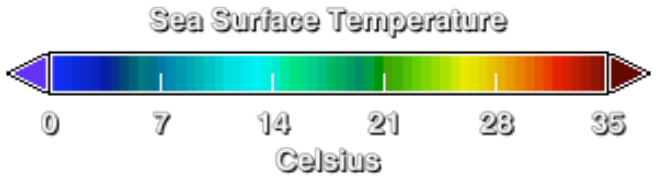
2. Warming of the ocean

3. Ocean CO_2 cycle

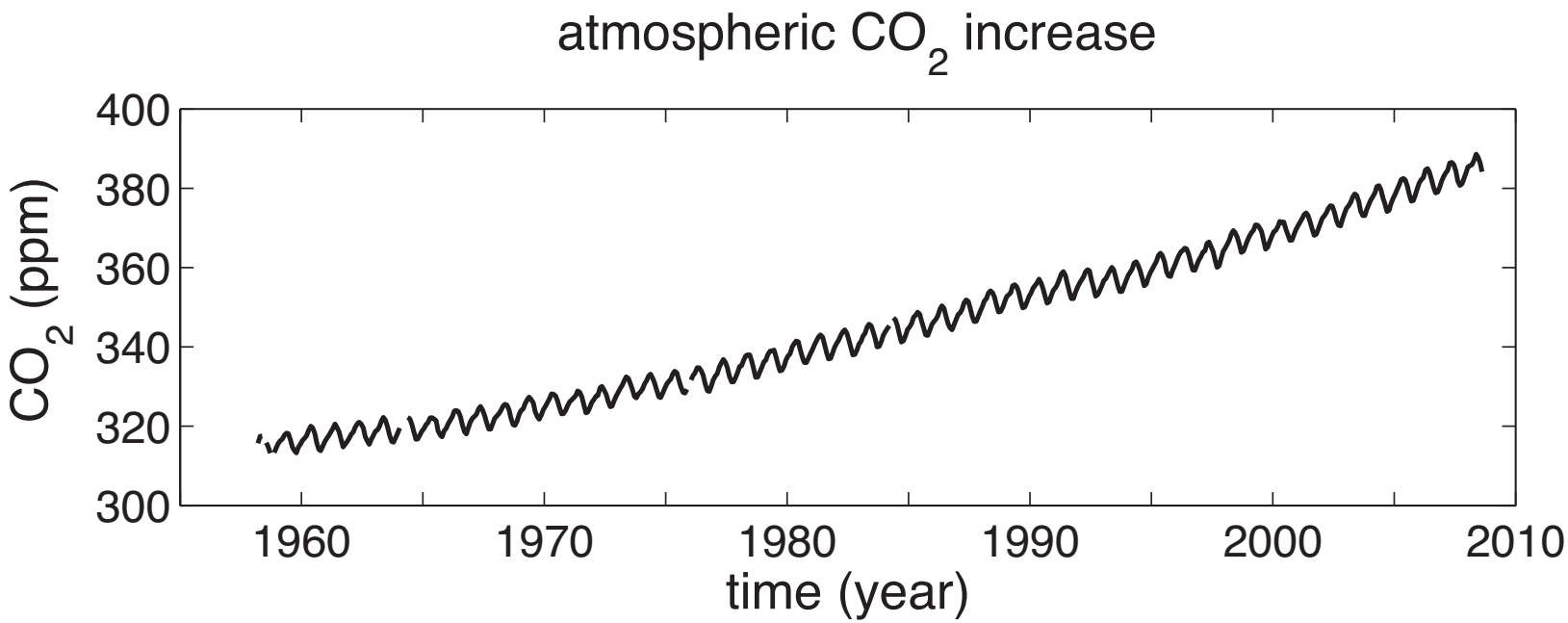


MODIS Sea Surface Temperature (2002 to 2006)

This animation shows a 32-day moving average of SST data spanning July 4, 2002 to October 23, 2006. The animation starts over Europe, pans across the Atlantic, and settles in over the Gulf Stream. (Courtesy of NASA)



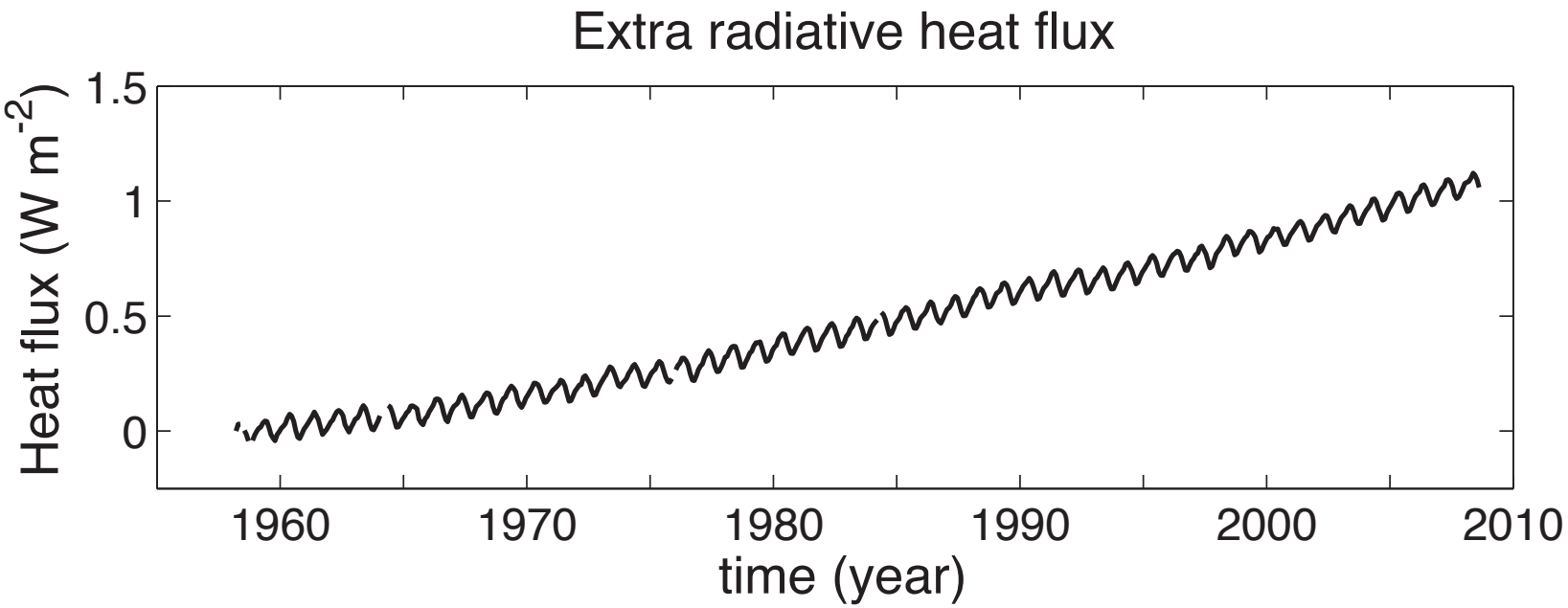
1. Climate forcing from CO_2



Hawaii atmospheric time series, started by Keeling in March 1958, continued by Scripps & NOAA

radiative heating varies with log of atmospheric CO_2

$$\Delta F = \alpha \log\left(\frac{CO_2(t)}{CO_2(t_o)}\right)$$



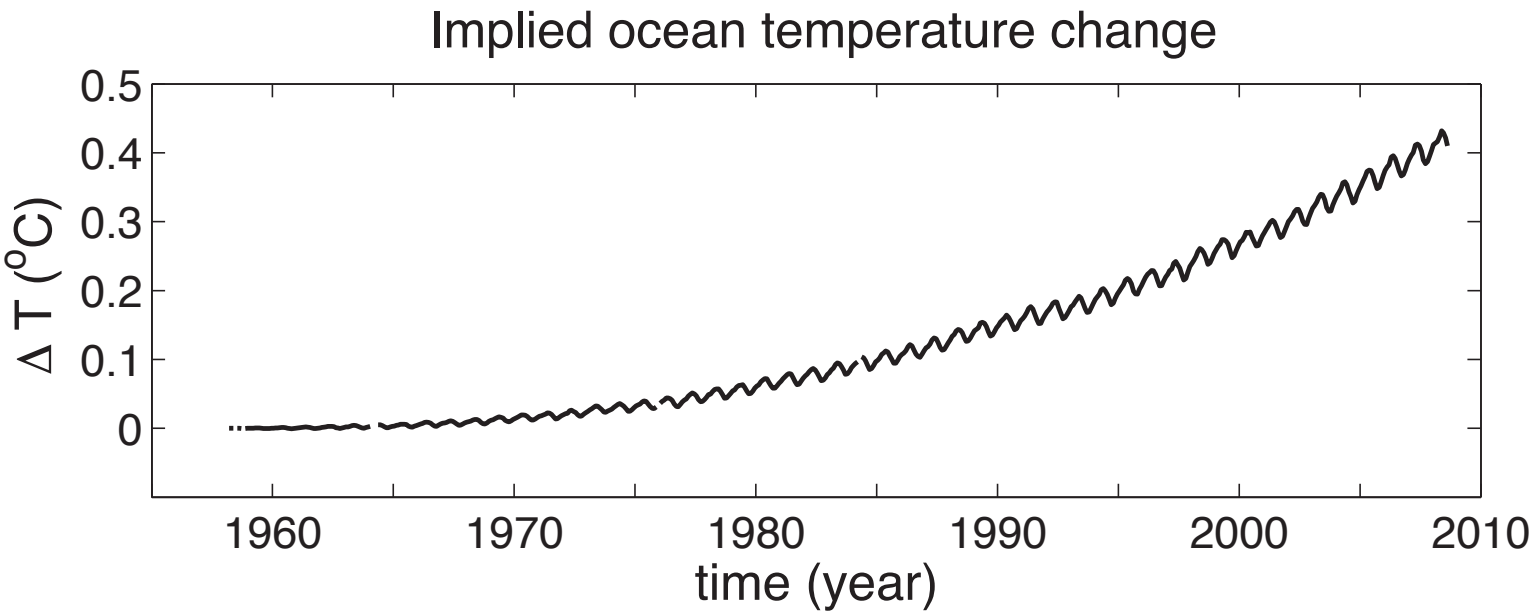
Extra radiative heating from CO_2 of ~1 Wm^{-2}

Since pre-industrial period,

implied radiative heating of 1.67 Wm^{-2} (0.6 to 2.6 Wm^{-2})

IPCC report

How much might the upper 1 km of ocean warm?

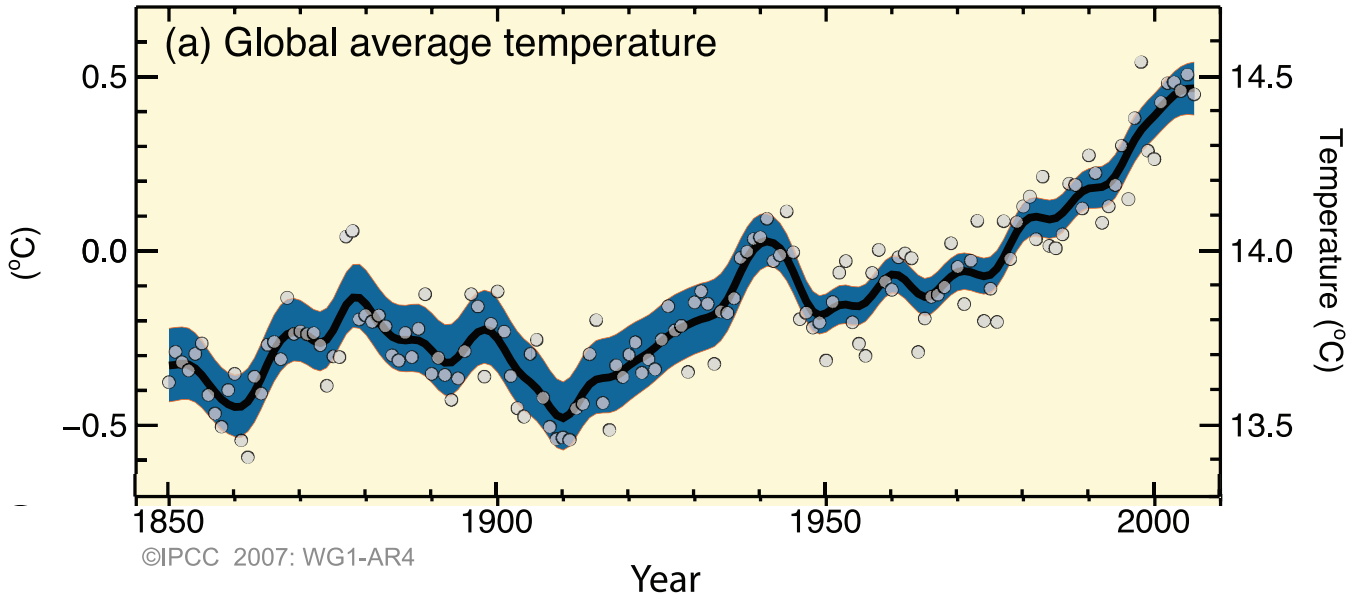


expect

global rise in surface temperature ~ 0.4°C

(change in ocean heat storage ~ 10^{20}J over 1° square)

Global warming signal (from IPCC, 2007)



from 1950,
see global warming of 0.6°C from surface temperature record

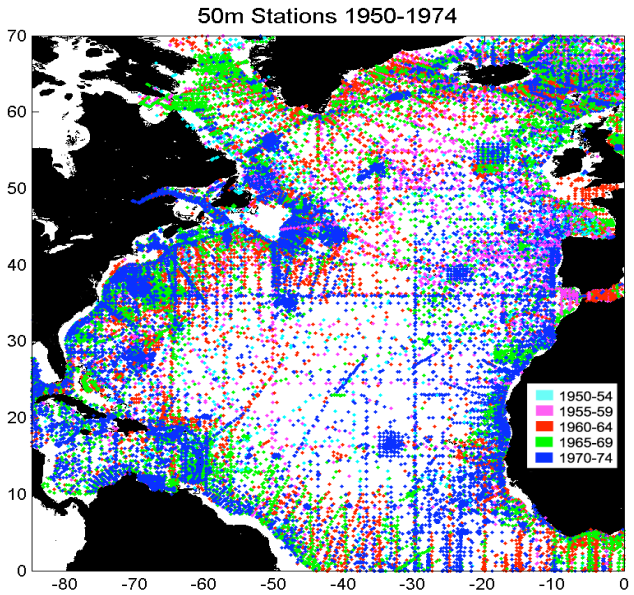
comparable with simple calculation

2. What is the response over the North Atlantic Ocean?

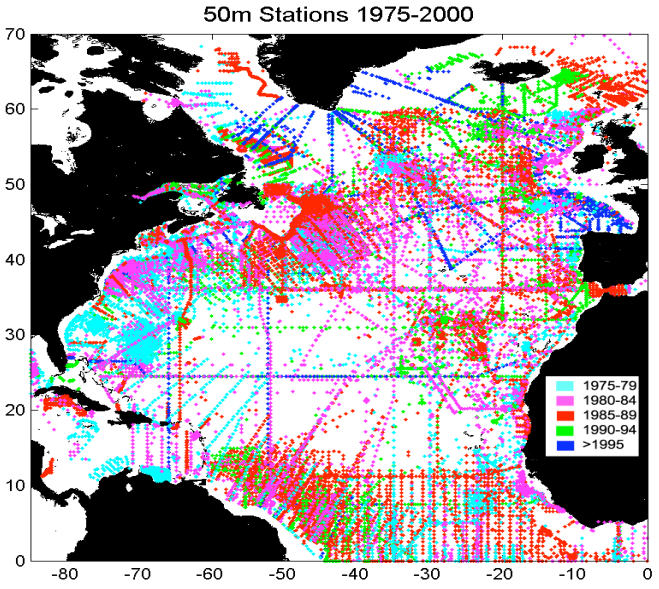
Our analysis for North Atlantic

Lozier, Leadbetter, Williams et al. (2008) Science

1950-1974



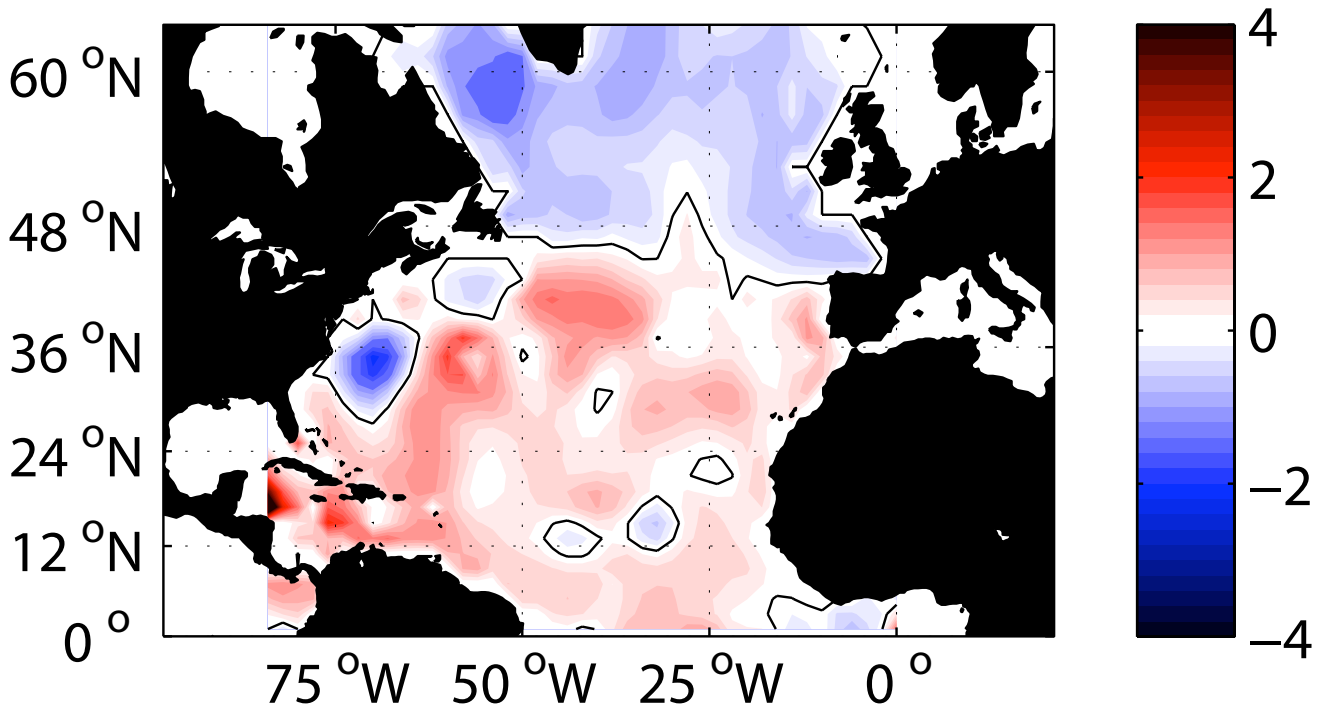
1975-2000



data from NODC World Ocean Atlas (2001) and WOCE programme

Data

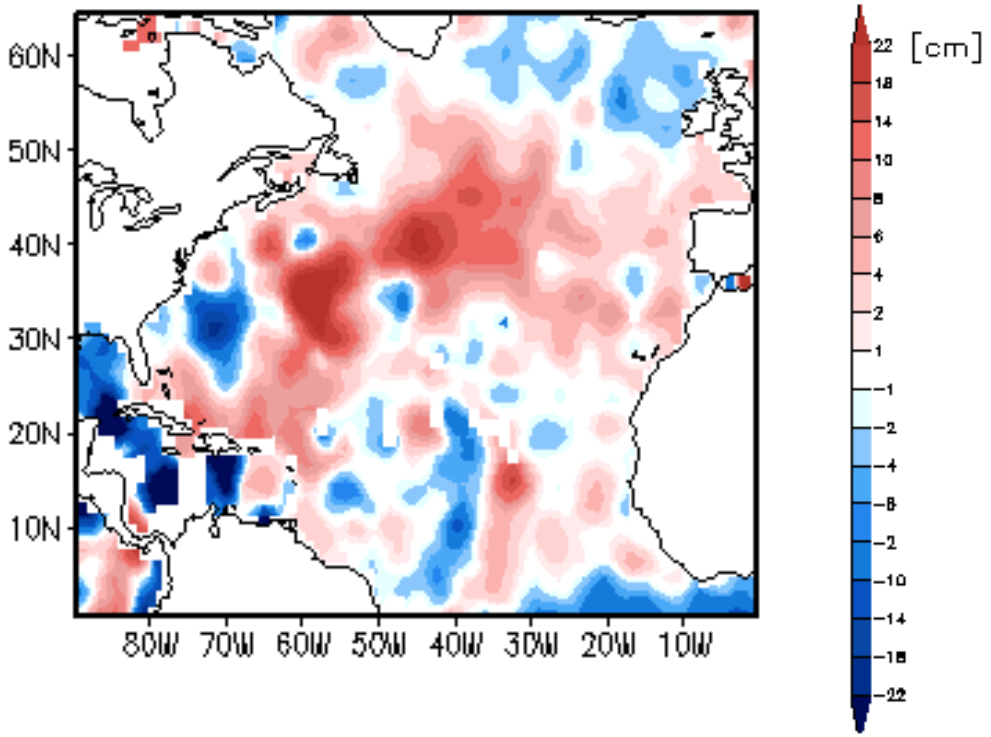
Ocean heat content change



Change in ocean heat content (10^{20}J) between 1980-2000 and 1950-1970

- Overall heat gain is significant (0.4±0.05 W m^{-2})
- Larger regional changes (±4 W m^{-2})

implied change in sea surface height from ocean warming between 1980-2000 and 1950-1970



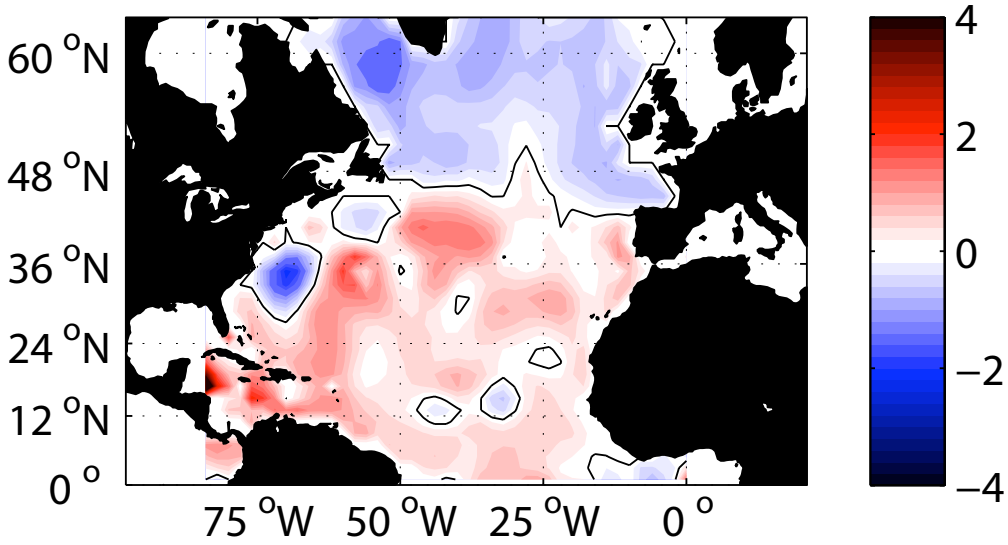
generally rise, some localised fall

~10 - 20 cm over 30 years ~ 3- 6 mm y^{-1}

cf global average rise of 2 mm y^{-1}

Speculations

Change in ocean heat content (10^{20}J) between 1980-2000 and 1950-1970



- Regional pattern of ocean change can be explained by atmospheric forcing linked to the North Atlantic Oscillation

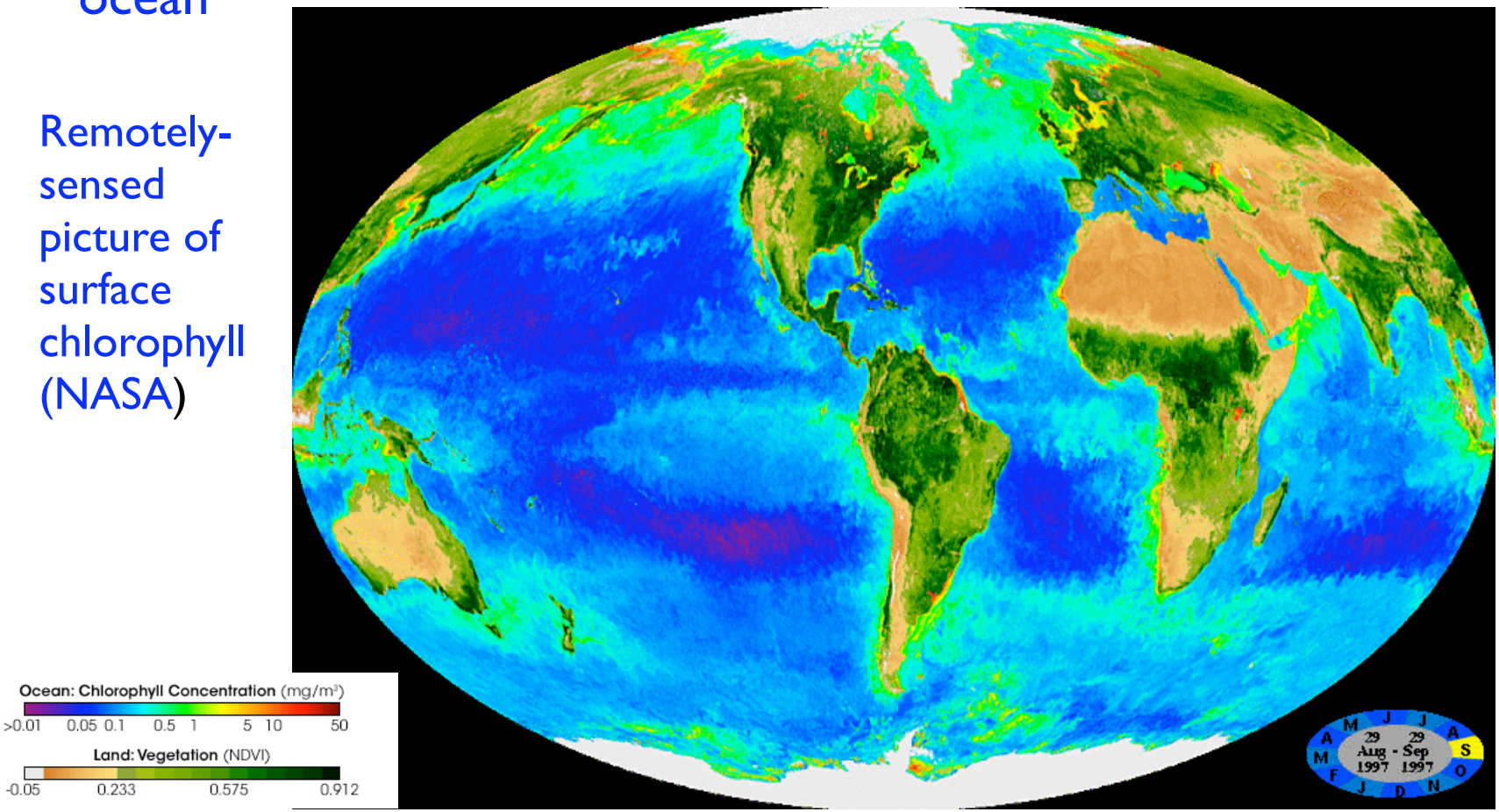
- On regional scale, decadal, natural variability might mask any **local** signal of greenhouse forcing

- Or any anthropogenic change is being imprinted on the ocean with the *same pattern* as that of the North Atlantic Oscillation

3. How is the ocean taking up CO_2?

- Ocean holds ~ 50 as much carbon as in the atmosphere
- 1/3 the recent industrial emissions of carbon has gone into ocean

Remotely-sensed picture of surface chlorophyll (NASA)



Why does the ocean take up so much carbon dioxide?

Ocean holds ~ 50 times as much carbon as in the atmosphere

CO_2 reacts in seawater

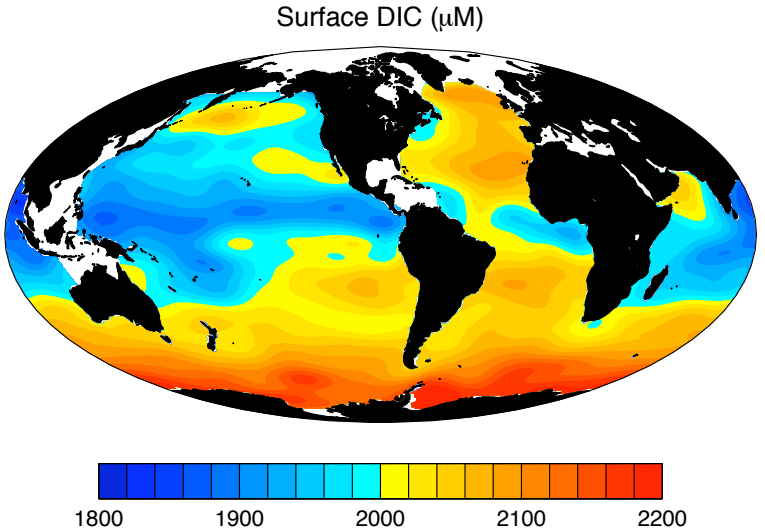
$$DIC = CO_2^* + HCO_3^- + CO_3^{2-}$$

Dissolved inorganic carbon

aqueous carbon dioxide (1%)

bicarbonate (90%)

carbonate (9%)



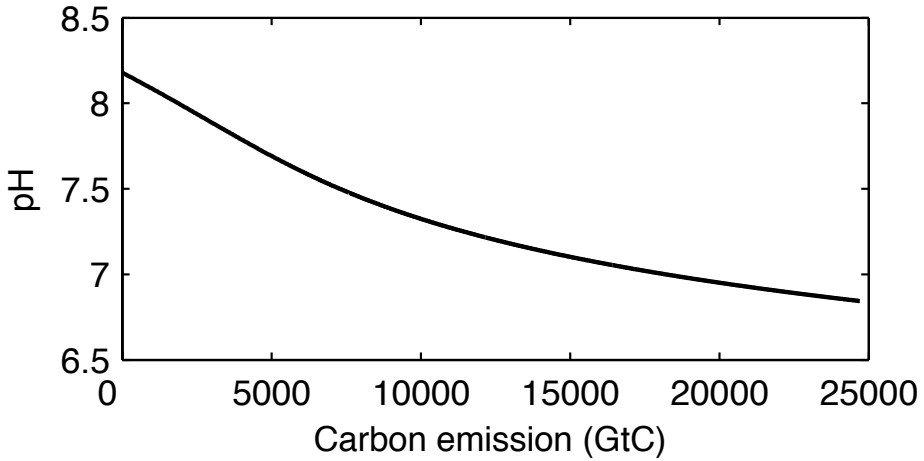
How does an addition of CO_2 alter the carbon chemistry?

add more CO_2

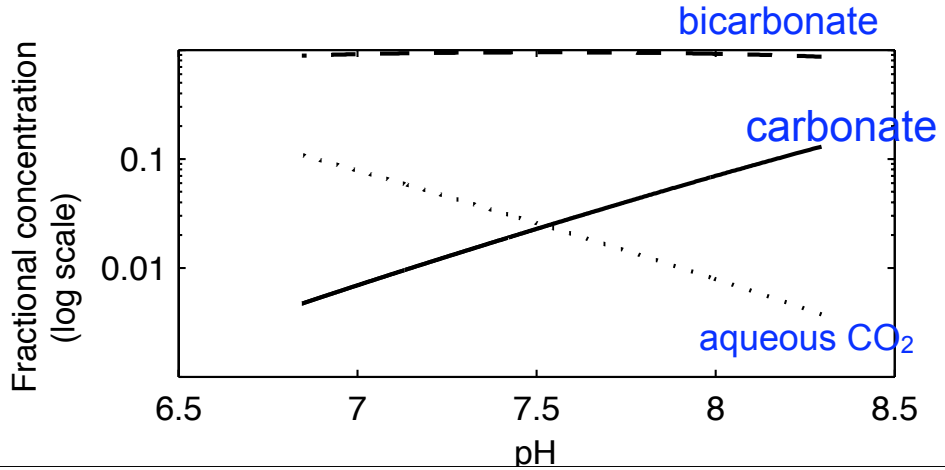
$$CO_2 + 2H_2O \leftrightharpoons CO_3^{2-} + 2H^+$$

increase in H^+ ions

increase in acidity
(a decrease in pH)

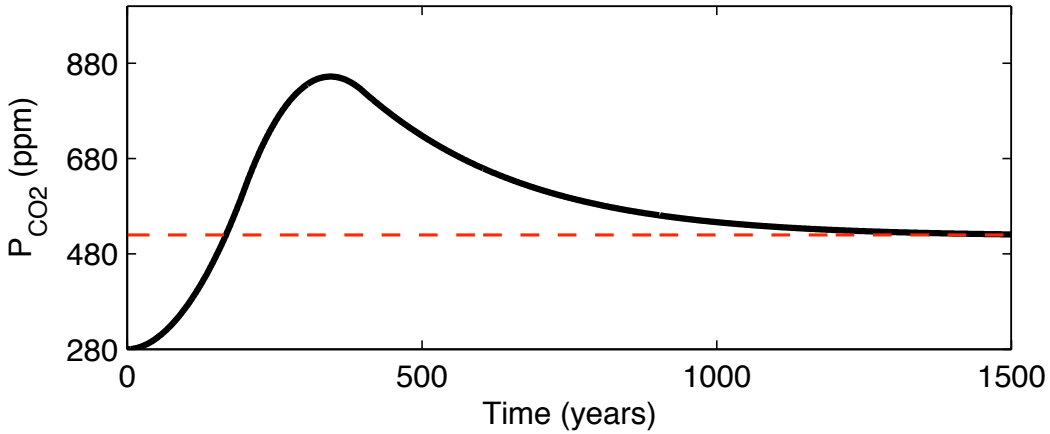


shift in partitioning,
- more CO_2 ends up in dissolved CO_2 pool
- **inhibits** further ocean uptake



What happens if we burn all our fossil fuels?

atmospheric CO_2



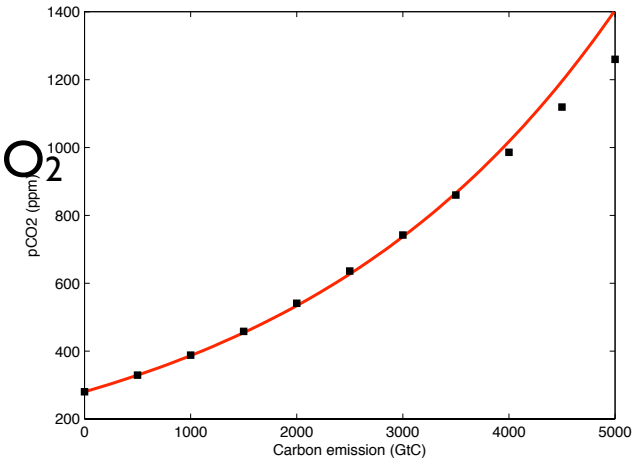
- Initial fast rise in atmospheric CO_2
- Ocean (& terrestrial) uptake
- Eventually approach a steady state

  steady state set by the total amount of carbon emitted

Goodwin et al. (2007, 2008) Global Biogeochemical Cycles

For a **long term** steady state:

final CO_2



Carbon emissions

atmospheric CO_2 varies *exponentially* with carbon emissions

radiative forcing ΔF varies *linearly* with carbon emissions ΔI

$$\Delta F = \left(\frac{\alpha}{I_B} \right) \Delta I$$

α =5.35 Wm^{-2}

I_B ~3000 GtC

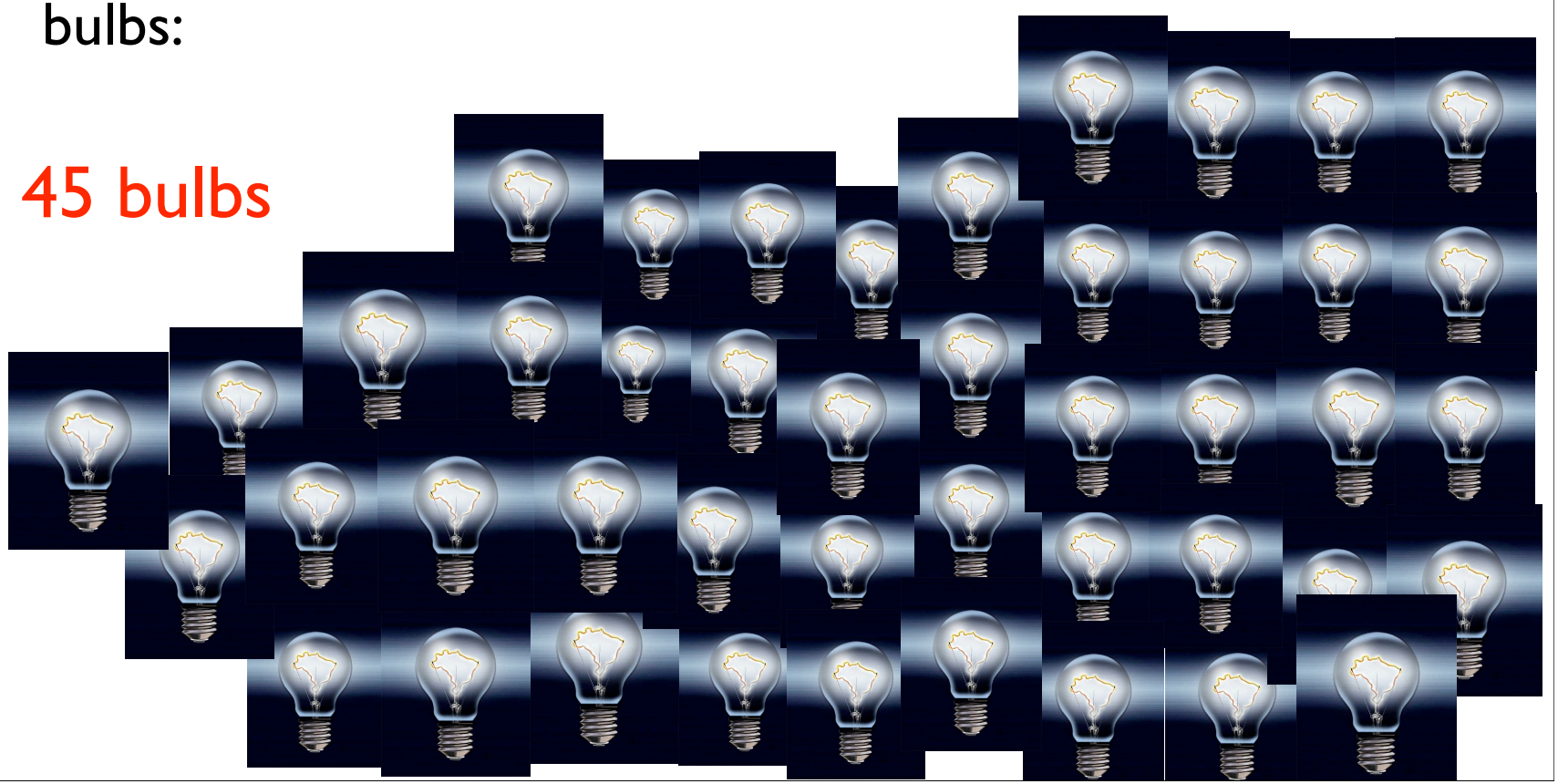
emit 1000 PgC implies extra heating of 1.5 Wm^{-2} lasting for millennia

Goodwin, Williams, Ridgwell and Follows (2009) Nature Geoscience

If burn all of conventional fossil fuels, 5000 PgC without carbon capture, then extra heating of $7.5\,Wm^{-2}$

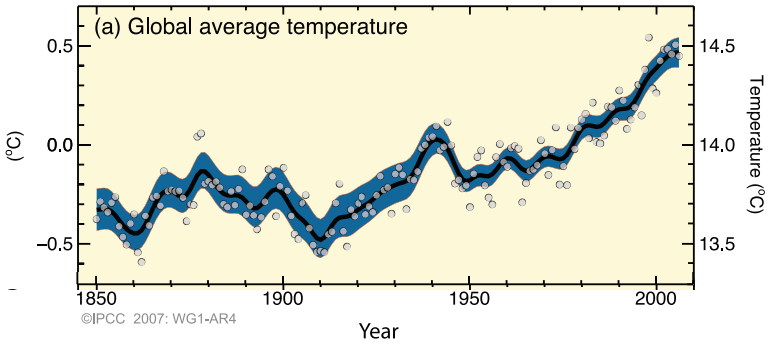
same amount of heating given in this room (20m x 30m) by these 100 W light bulbs:

45 bulbs

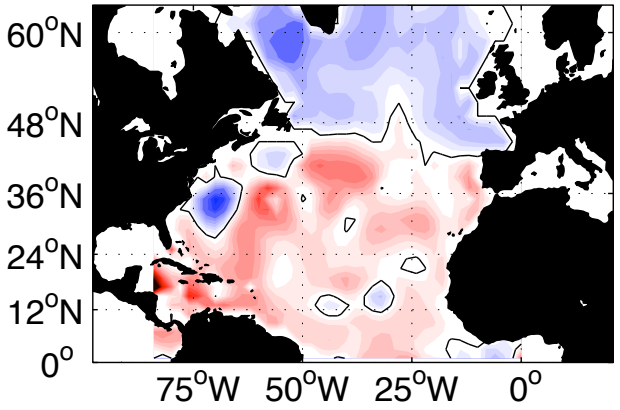


Summary

- Ocean is warming on global scale



- Regional pattern is more complex
  - large decadal variability
  - warming signal might be *imprinted* via the pattern of NAO induced forcing



heat content change 1990 - 1960 (red, gain)

- Ocean uptake ~1/3 of emitted CO_2, but long term uptake inhibited by rising acidity

If release all fossil fuels,
implies ~ 7.5 W m^{-2} extra heating
lasting for millennia,
~ 5 x present anthropogenic heating