

# Who am I

- Name:** Ron Smernik
- Born:** 1969, Griffith, NSW
- Moved:** 1970 to Sydney
- Undergrad:** 1988-1991 B.Sc. University of Sydney
- Postgrad:** 1992-1996 PhD University of Sydney (organic chemistry)
- Postdoc:** 1997-current Research Fellow, University of Adelaide Soil Science
- 2007-current Lecturer (3-month contract), University of Adelaide Soil Science
- Summary:** Science (chemistry) training
- Research experience (soil carbon)
- This guy knows what he's talking about (CC believer)
- This guy is part of the establishment (CC sceptic)

# Where to start – The carbon cycle

**Not a good place to start!**

# Where to start – The Greenhouse Effect

**A better place to start!**

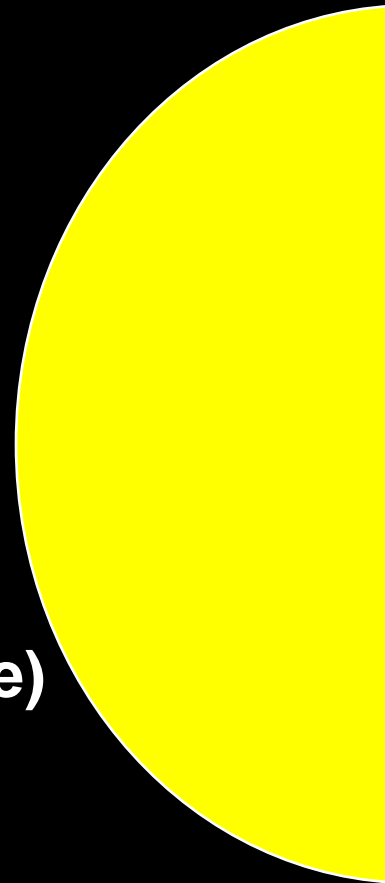
# The Greenhouse Effect

1. The sun delivers energy to the earth



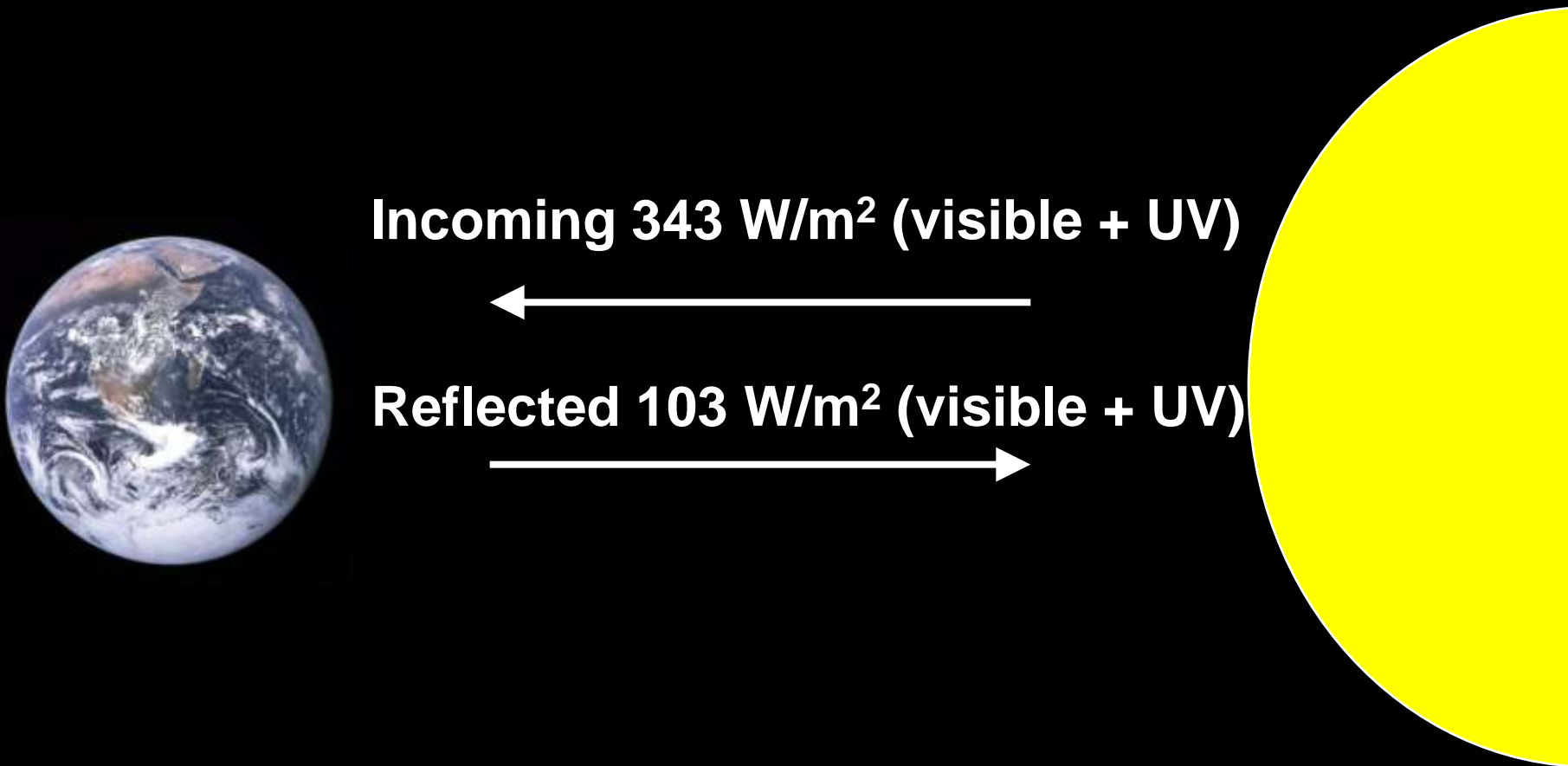
**343 W/m<sup>2</sup> (watts per square metre)**

**- mostly visible + UV**



# The Greenhouse Effect

2. ~30% is reflected, ~70% is absorbed



# The Greenhouse Effect

3. There has to be net energy balance – the absorbed energy is re-irradiated as “longwave radiation” (IR or “irradiated heat”)



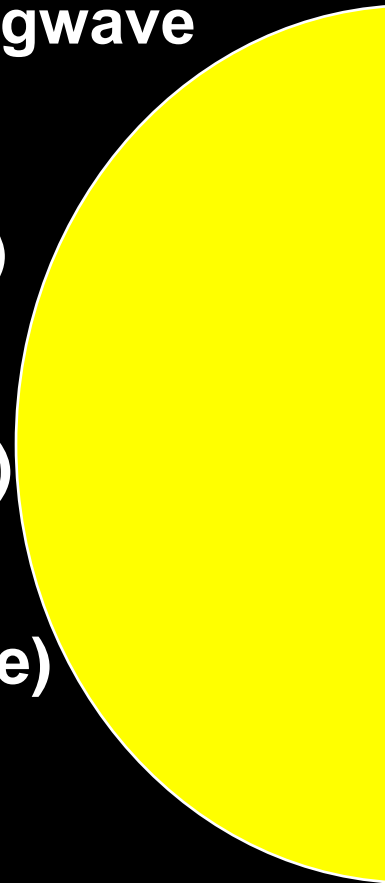
Incoming  $343 \text{ W/m}^2$  (visible + UV)



Reflected  $103 \text{ W/m}^2$  (visible + UV)

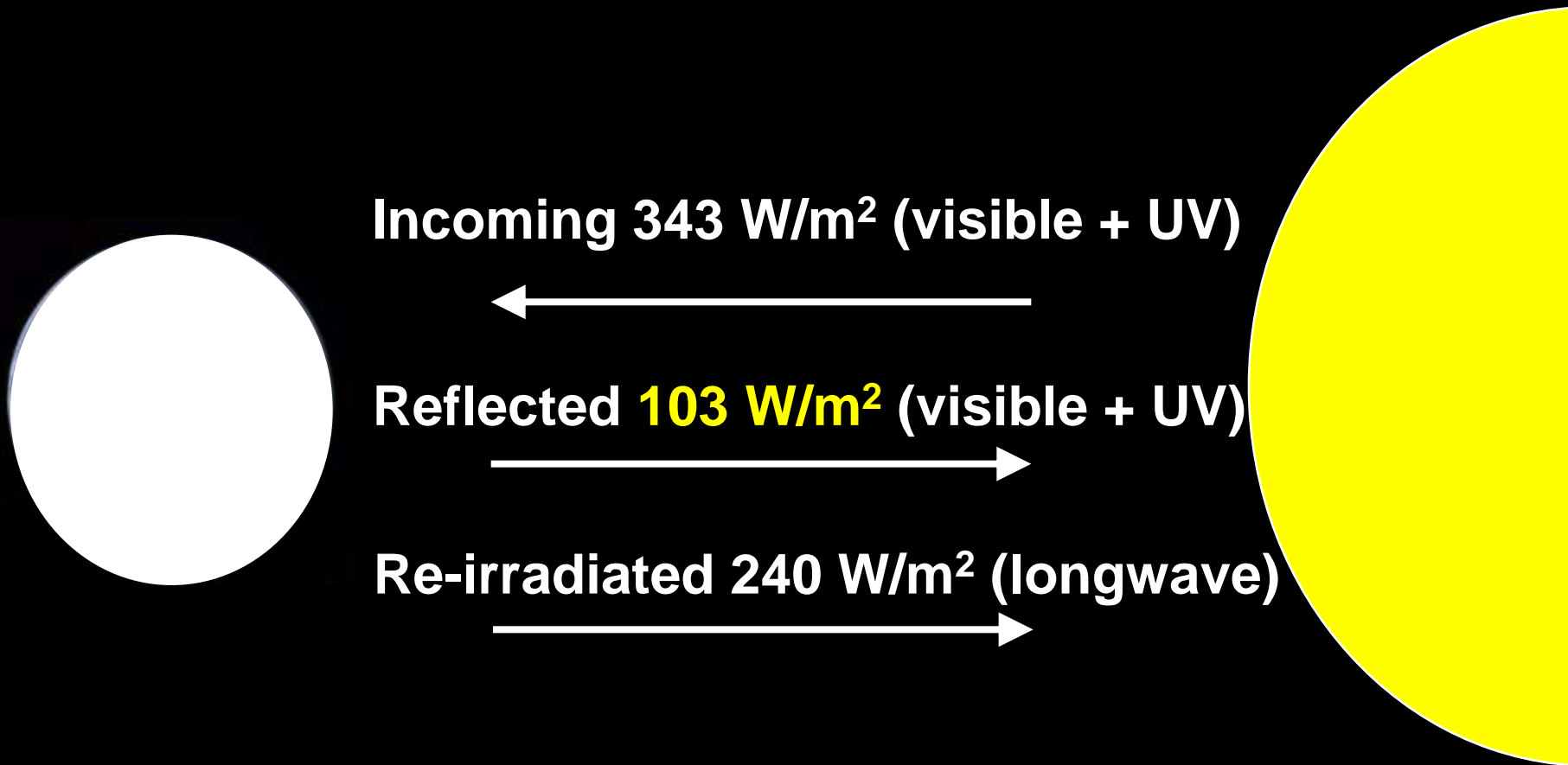


Re-irradiated  $240 \text{ W/m}^2$  (longwave)



# The Greenhouse Effect

4. If there was no atmosphere, the average temperature of the Earth would be  $-19^{\circ}\text{C}$ .



# The Greenhouse Effect

4. If there was no atmosphere, the average temperature of the Earth would be  $-19^{\circ}\text{C}$ .

The Earth is on average  $14^{\circ}\text{C}$  because of the “natural” Greenhouse Effect.



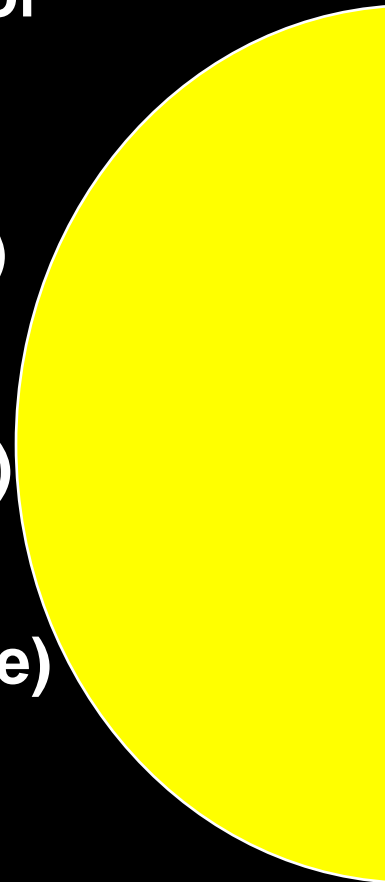
Incoming  $343 \text{ W/m}^2$  (visible + UV)



Reflected  $103 \text{ W/m}^2$  (visible + UV)

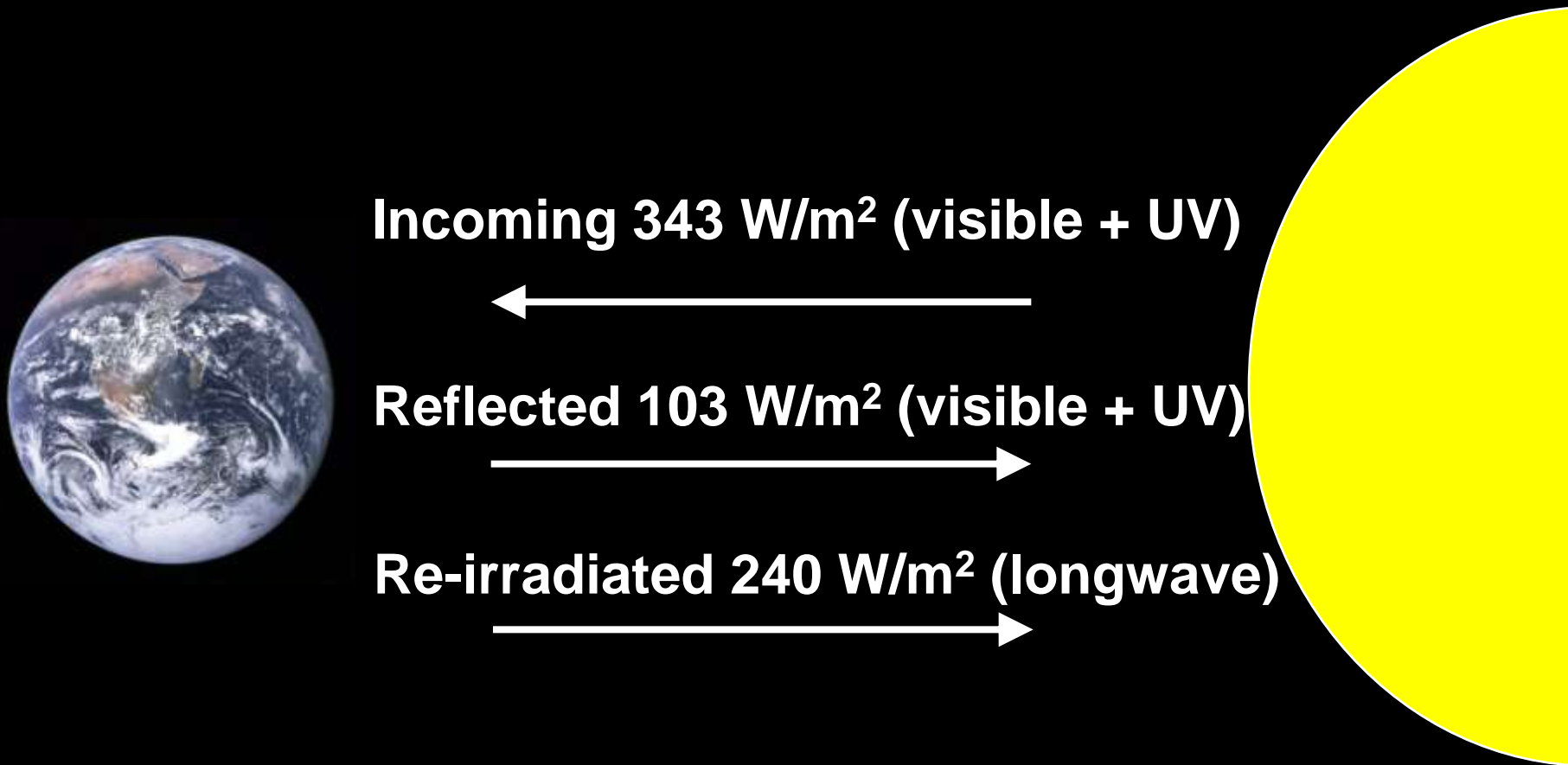


Re-irradiated  $240 \text{ W/m}^2$  (longwave)

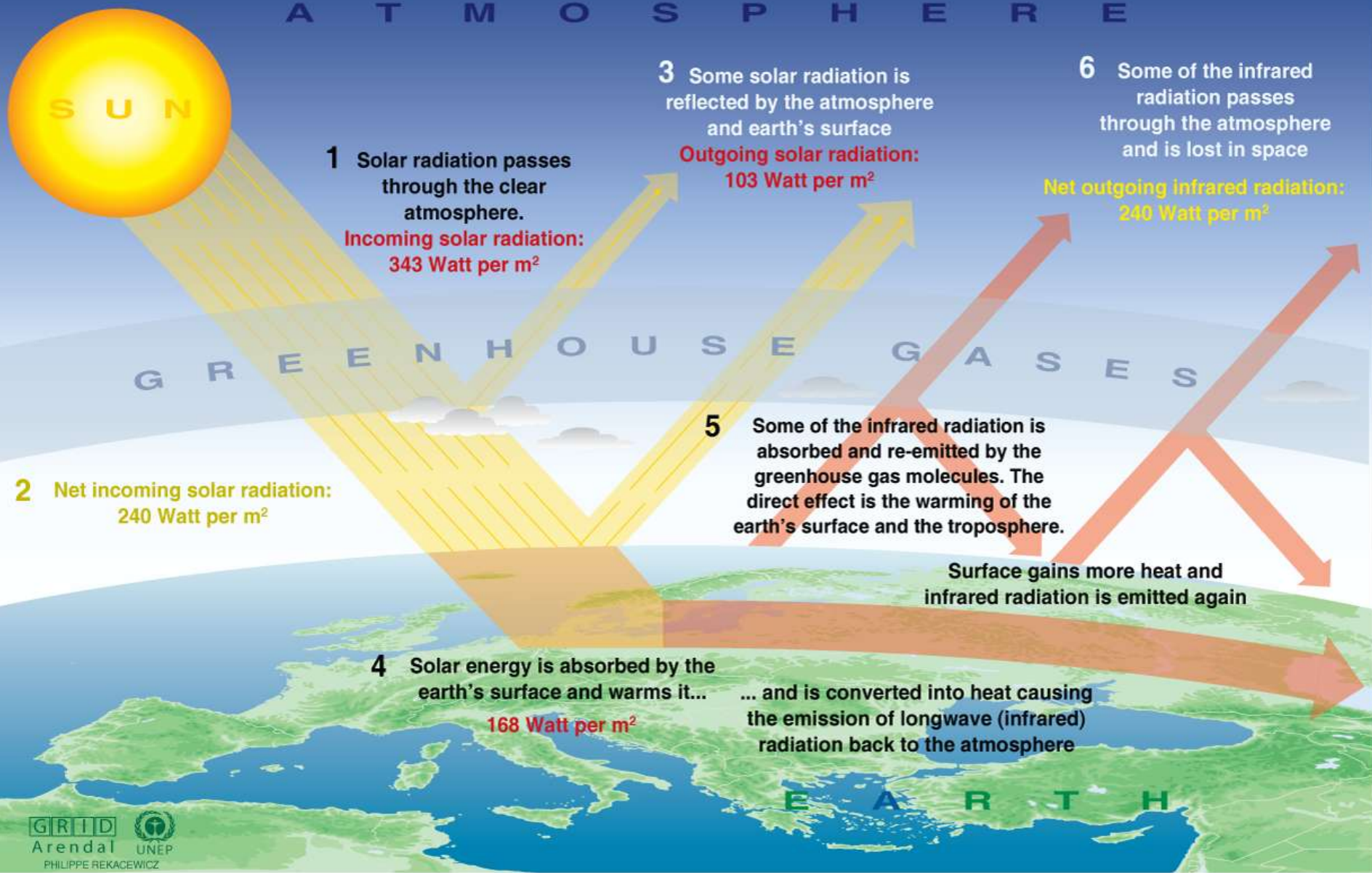


# The Greenhouse Effect

5. “Greenhouse gases” restrict the direct re-irradiation of longwave radiation, directing some back to the surface.



# The Greenhouse effect



# What are greenhouse gases?

**Greenhouse gases are those which absorb longwave radiation**

**The two most abundant gases in the atmosphere, nitrogen ( $N_2$ ) and oxygen ( $O_2$ ), are not greenhouse gases**

**The most “important” greenhouse gases are:**

- 1. Water ( $H_2O$ ) ~60%**
- 2. Carbon dioxide ( $CO_2$ ) ~20%**
- 3. Methane ( $CH_4$ ), ozone ( $O_3$ ), nitrous oxide ( $N_2O$ ), CFCs etc.**

**“Importance” depends on concentrations, how much radiation they absorb and their lifetime in the atmosphere**

# Why pick on CO<sub>2</sub>?

**Human activity has relatively little direct\* influence on water vapour concentrations in the atmosphere**

**Human activity has a large influence on atmospheric CO<sub>2</sub> concentrations**

**Human activity has a large influence on other greenhouse gases (GHGs), but the overall effect is less than for CO<sub>2</sub> (and I still haven't got to the C cycle yet!)**

# How much should “anthropogenic CO<sub>2</sub>” increase temperature?

**Depends on:**

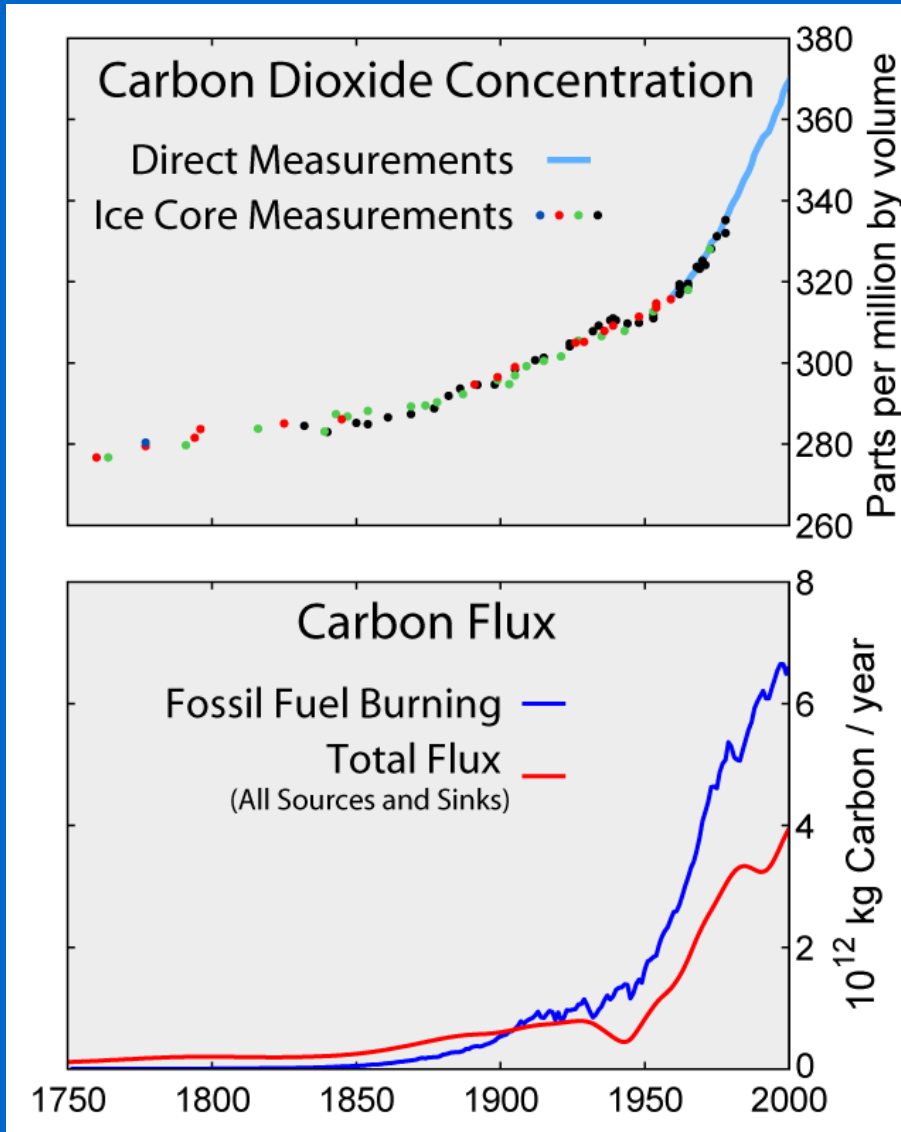
- **The increase in atmospheric CO<sub>2</sub> due to human activity**
- **The relative effect of CO<sub>2</sub> on longwave radiation**

# How much should “anthropogenic CO<sub>2</sub>” increase temperature?

**Depends on:**

- **The increase in atmospheric CO<sub>2</sub> due to human activity**
- **The relative effect of CO<sub>2</sub> on longwave radiation**
- **Whether other stuff is happening as a result or coincidentally at the same time**

# Anthropogenic increase in CO<sub>2</sub>



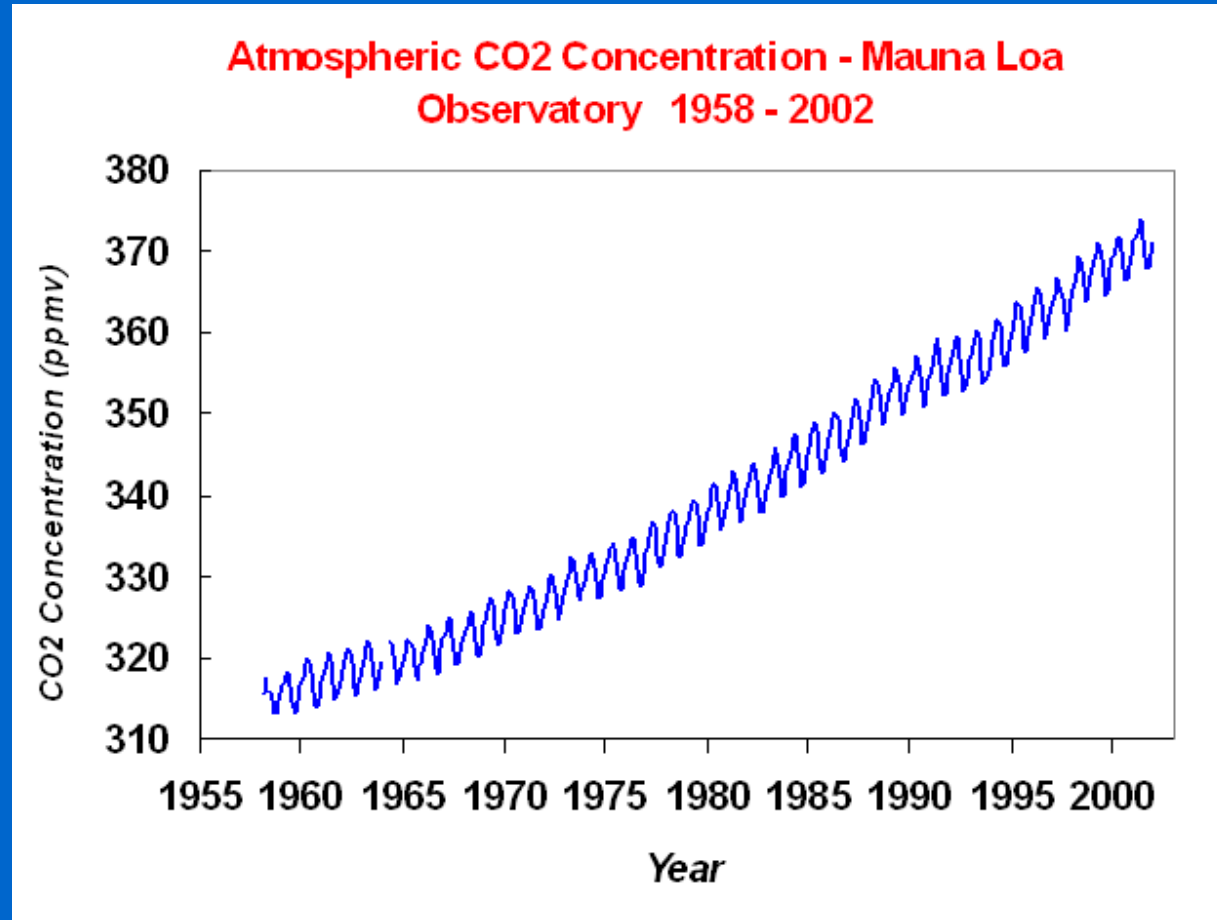
**Atmospheric CO<sub>2</sub> has increased by ~100 ppm since 1750.**

**Over half of this increase (~55 ppm) has been in the time since direct measurements were begun in 1958.**

**Earlier measurements are from air trapped in ice.**

**Until ~1900 most of the increase in CO<sub>2</sub> was due to land-use change.**

# Anthropogenic increase in CO<sub>2</sub>



Direct measurements show annual variation due to plant growth and decay.

# The predicted effect of increasing CO<sub>2</sub> on temperature

More CO<sub>2</sub> in the atmosphere means longwave radiation is less efficiently re-irradiated to space

As a consequence the surface of the Earth warms until incoming and outgoing irradiation are again in balance (note: warmer objects irradiate more energy)

The physics is pretty straightforward – the 100 ppm increase in atmospheric CO<sub>2</sub> decreases the re-irradiation by  $1.66 \pm 0.17$  W/m<sup>2</sup>

In the absence of any other effect, this would result in an average warming of  $\sim 1.3^\circ\text{C}$

# The Greenhouse Effect

Atmospheric CO<sub>2</sub> at 280 ppm



Incoming 343 W/m<sup>2</sup> (visible + UV)



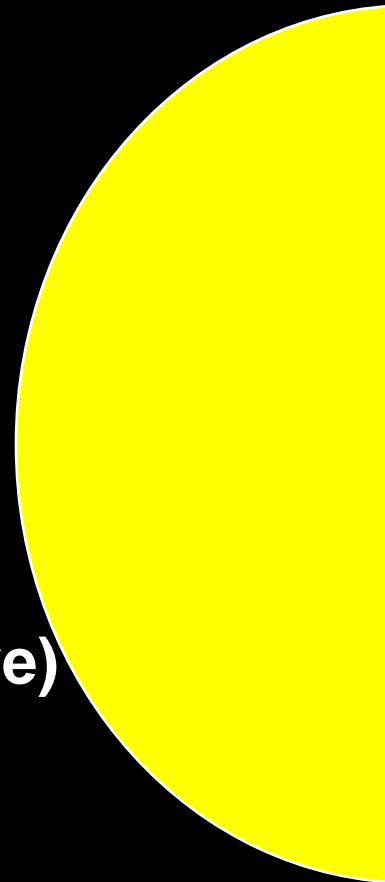
Reflected 103 W/m<sup>2</sup> (visible + UV)



Re-irradiated 240.0 W/m<sup>2</sup> (longwave)



Balanced



Earth at 14.0°C

# The Greenhouse Effect

Increase atmospheric CO<sub>2</sub> from 280 ppm to 380 ppm



Incoming 343 W/m<sup>2</sup> (visible + UV)



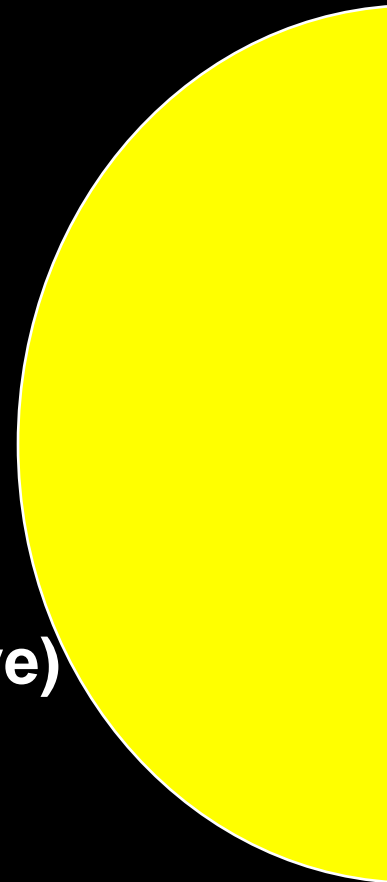
Reflected 103 W/m<sup>2</sup> (visible + UV)



Re-irradiated 238.4 W/m<sup>2</sup> (longwave)



Not balanced



Earth at 14.0°C

# The Greenhouse Effect

Increase atmospheric CO<sub>2</sub> from 280 ppm to 380 ppm



Incoming 343 W/m<sup>2</sup> (visible + UV)



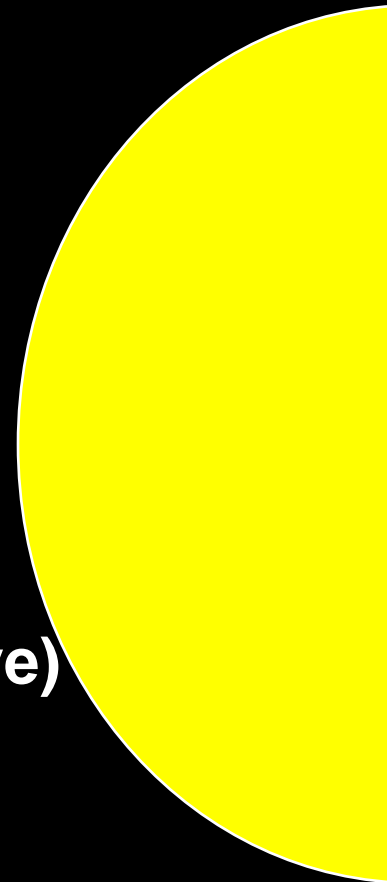
Reflected 103 W/m<sup>2</sup> (visible + UV)



Re-irradiated 240.0 W/m<sup>2</sup> (longwave)



Balanced



Earth at 15.3°C

# How much should “anthropogenic CO<sub>2</sub>” increase temperature?

Depends on:

- The increase in atmospheric CO<sub>2</sub> due to human activity
- The relative effect of CO<sub>2</sub> on longwave radiation
- Whether other stuff is happening as a result or coincidentally at the same time

# Other changes

## Resulting changes - feedbacks

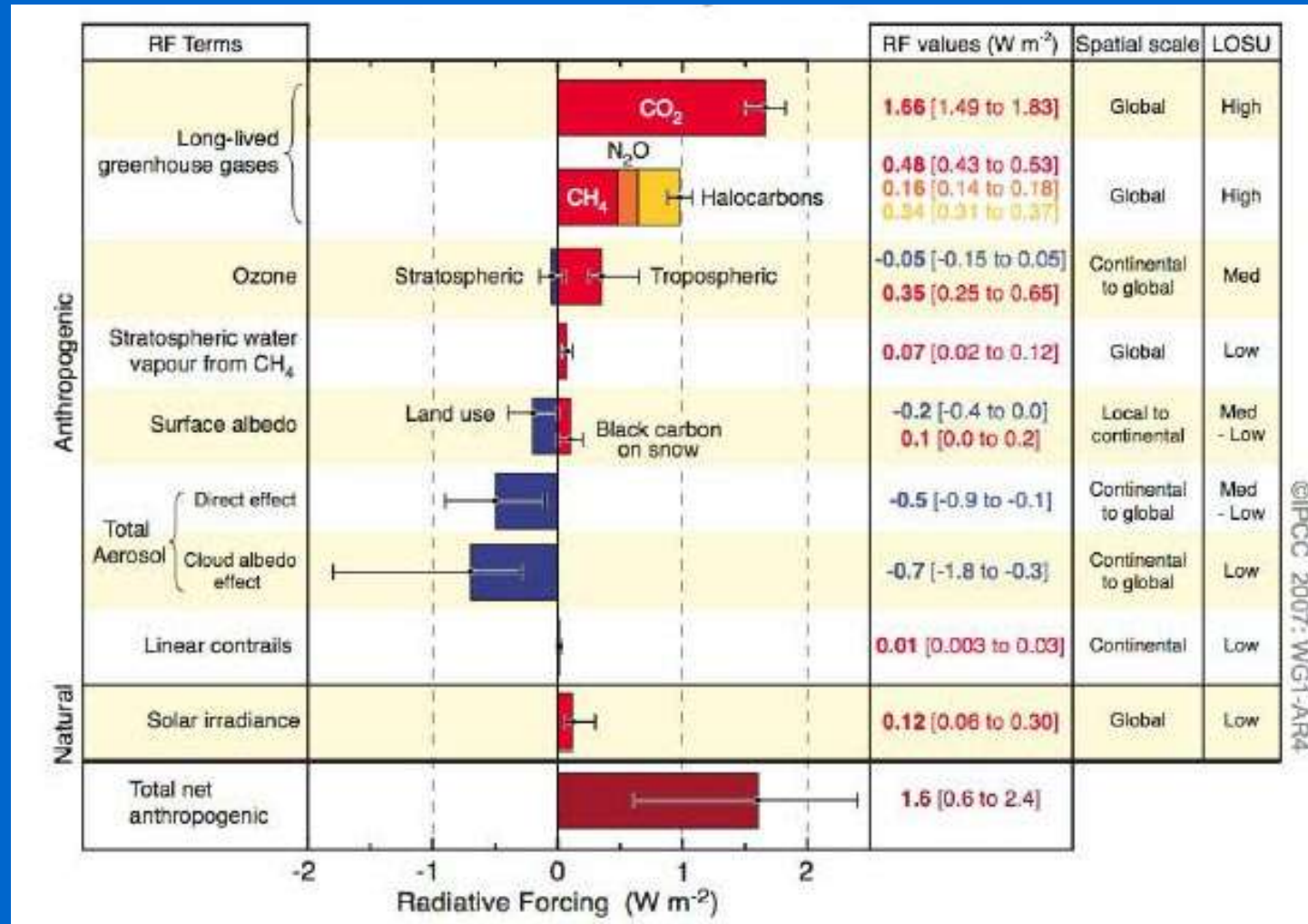
- **Positive feedbacks**
  - **Increase in water vapour with incr. temp**
  - **Increased natural CO<sub>2</sub> release (soils, sediment methane)**
  - **Decreasing ice-caps**
- **Negative feedbacks**
  - **Increased cloudiness**
  - **Increased snowfall**

# Other changes

## Coincidental changes

- **Changing solar irradiance**
- **Other anthropogenic gases (methane, nitrous oxides, CFCs)**
- **Aerosols (volcanoes, fossil fuel burning, biomass burning)**
- **Surface albedo (deserts reflect more light than forests)**

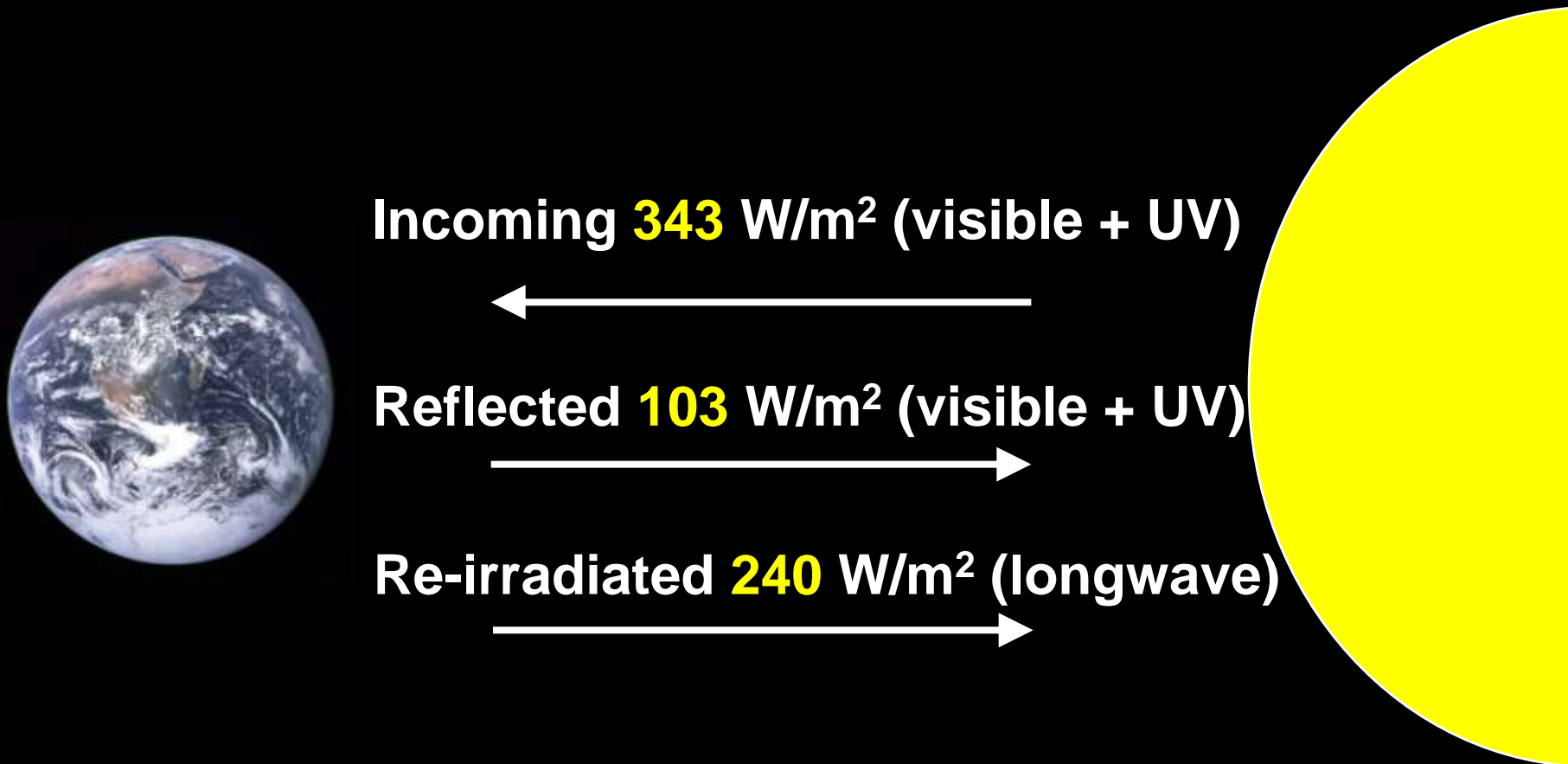
# Other changes



Increase in CO<sub>2</sub> is the biggest driver, other factors cancel each other out

# The Greenhouse Effect

Over time, all three of these values can vary, both independently and in response to each other



# The Greenhouse effect - summary

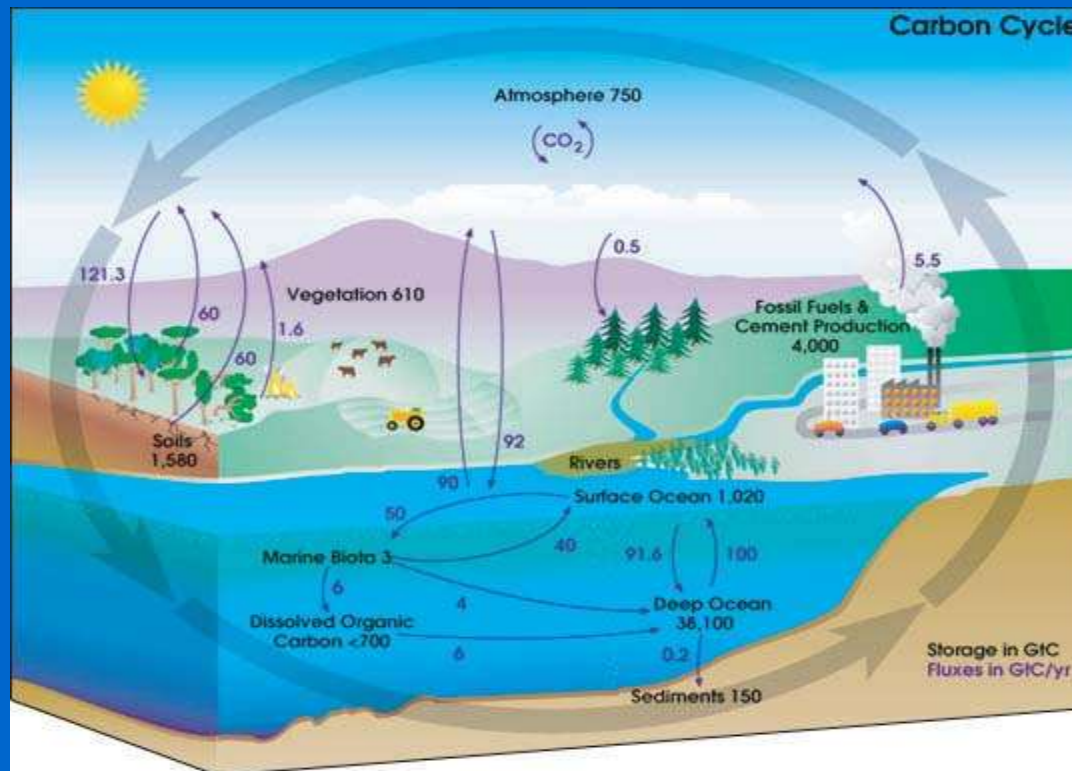
**Atmospheric CO<sub>2</sub> has increased by ~35% due to human activity since 1750**

**This is likely to increase the average global temperature due to the “Greenhouse Effect”**

# Where to start – The carbon cycle

Atmospheric CO<sub>2</sub> is only one component of the carbon cycle, and it is linked to other carbon “pools” through a variety of processes

For climate change, what matters is both the **size** of the pool and the **flux** (rate of change) to and from that pool



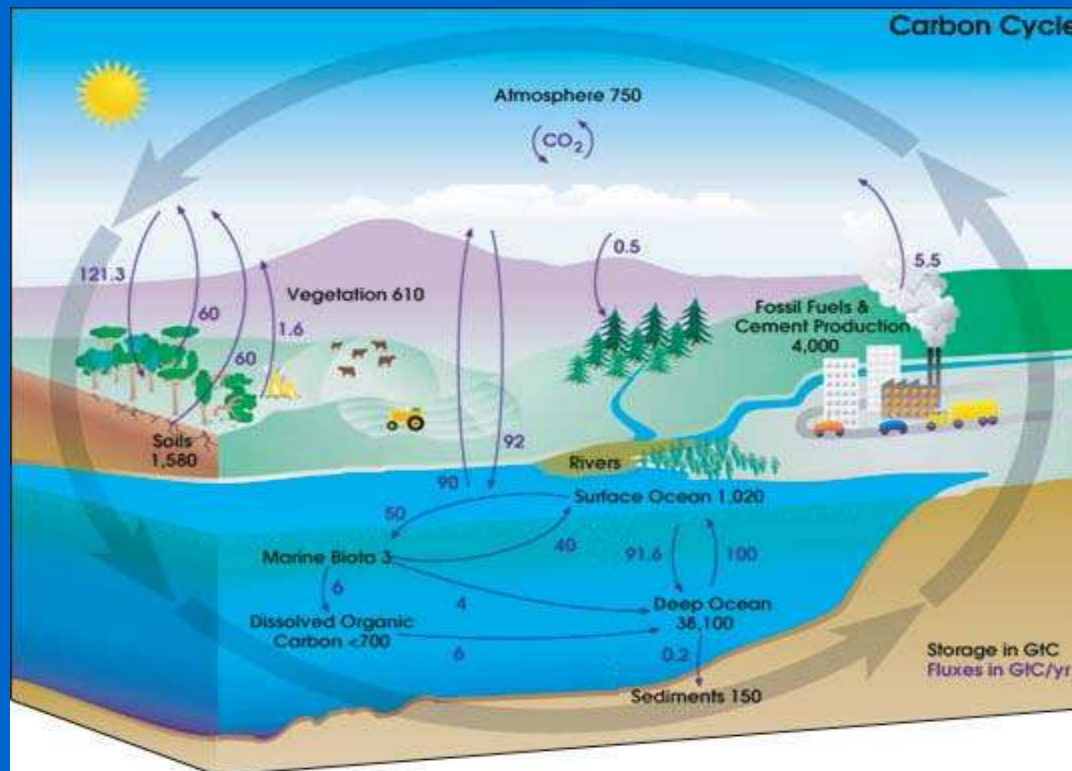
# Key carbon pools

Atmospheric CO<sub>2</sub>

Marine carbon pools

Terrestrial carbon pools

Fossil carbon pools

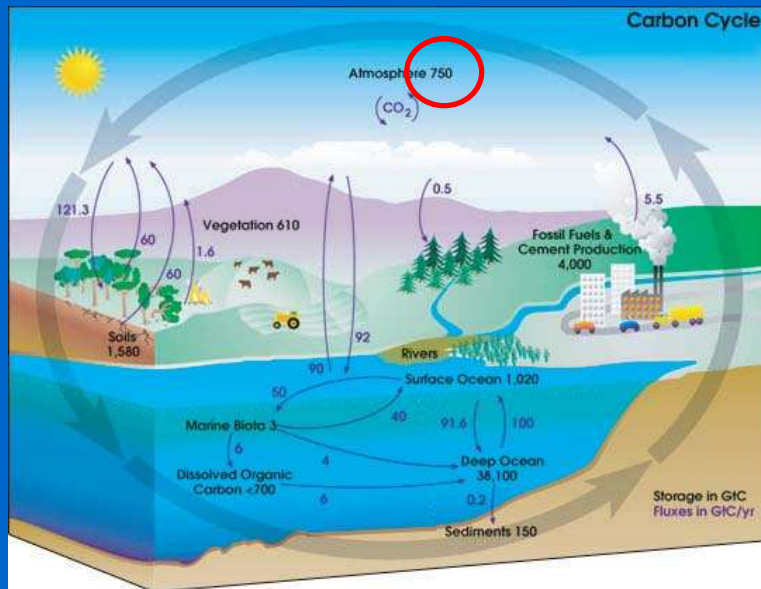


# Atmospheric CO<sub>2</sub> – pool size

750 GtC (Gigatons of carbon = billion tons of carbon)

- Roughly equivalent to a cube of diamond with 6 km sides

This is ~35% more than in 1750 (380 ppm now, 280 ppm then)

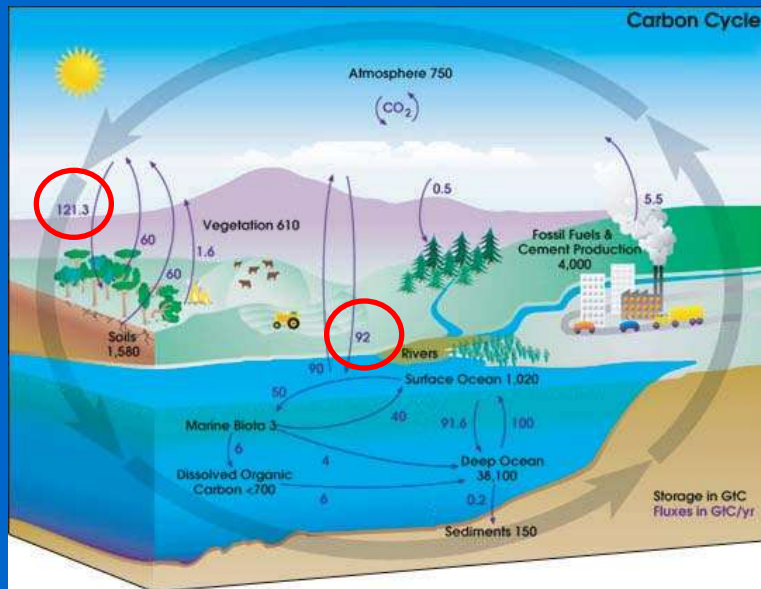


There is only 1.5 kg of C (5.5 kg of CO<sub>2</sub>) per square metre of earth's surface, i.e. only ~400g of "excess" (anthropogenic) atmospheric C

# Atmospheric CO<sub>2</sub> – fluxes out

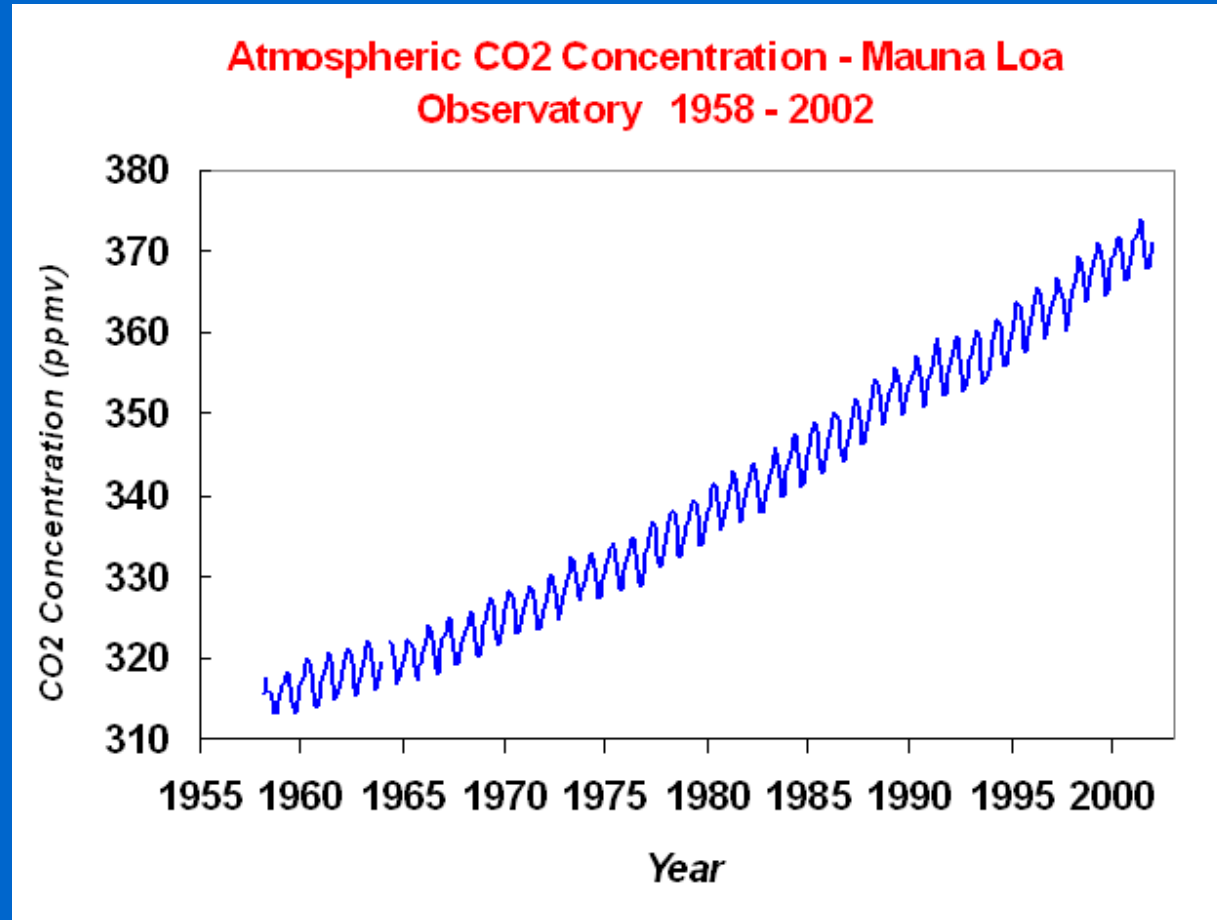
121.3 GtC per year taken up by photosynthesis (16% of total C in atmosphere)

92 GtC per year dissolved in the world's oceans (12% of total C in atmosphere)



Total uptake of atmospheric CO<sub>2</sub> equates to around 30% of the total.

# Anthropogenic increase in CO<sub>2</sub>



Direct measurements show annual variation due to plant growth and decay.

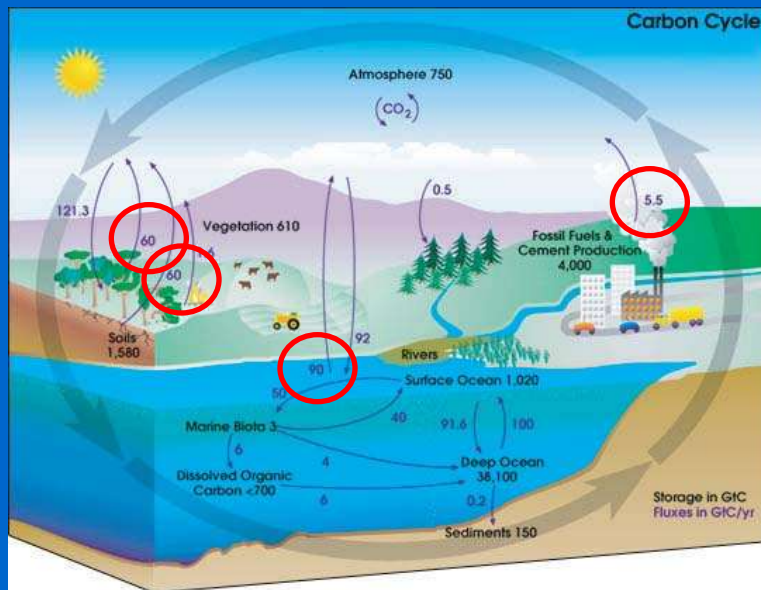
# Atmospheric CO<sub>2</sub> – fluxes in

121.3 GtC per year taken up by photosynthesis (16% of total C in atmosphere)

**120 GtC per year respired by plants (60) and soil biota (60)**

92 GtC per year dissolved in the world's oceans (12% of total C in atmosphere)

**90 GtC per year released from the world's oceans**



**The largest fluxes nearly cancel each other out**

**This leaves anthropogenic sources as the largest unbalanced flux**

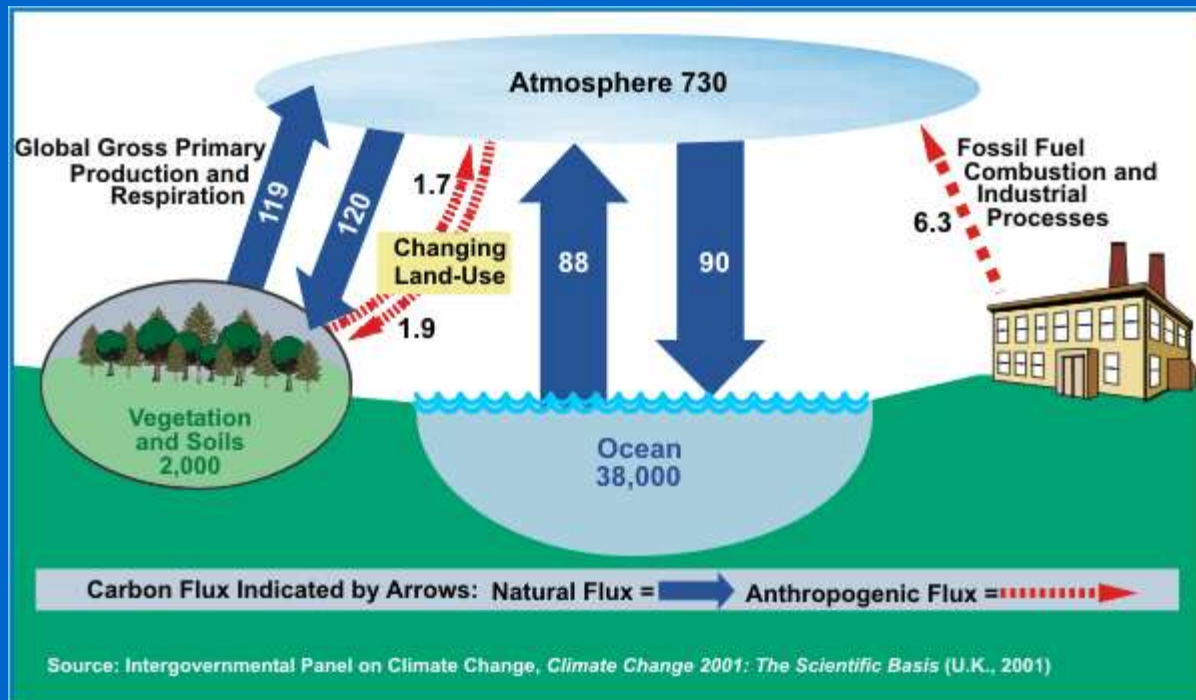
# Atmospheric CO<sub>2</sub> – sources & sinks

Changes to atmospheric CO<sub>2</sub> levels are often presented in terms of sources and sinks

Currently, the main source is fossil fuel combustion (now 7.2 GtC per year)

The oceans provide a ~2 GtC per year “discount” (at cost of acidification)

Land-use change currently appears to provide a net sink



# Marine C – pool sizes

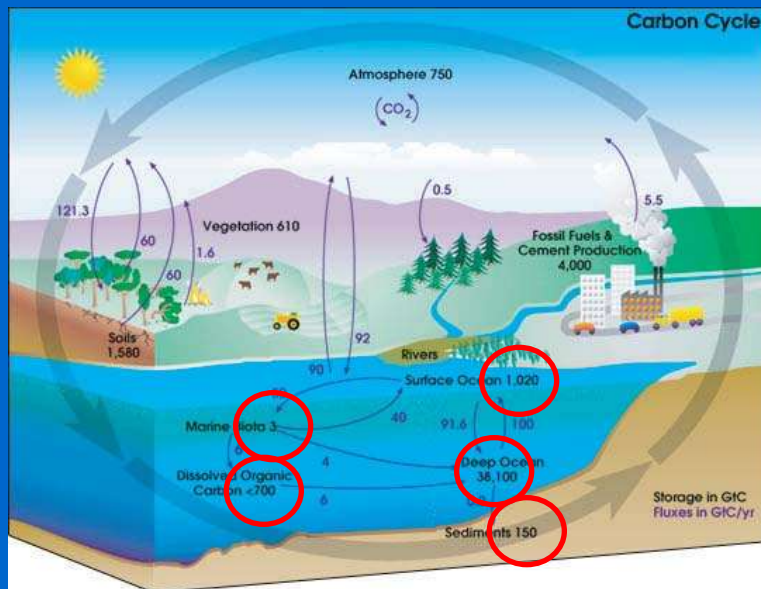
Surface ocean carbonate ~1020 GtC

Deep ocean carbonate ~38100 GtC

Marine sediments ~150 GtC

Dissolved organic C ~100 GtC

Marine biota ~3 GtC



There is much more C (50x) stored in the ocean than in the atmosphere

In terms of climate change, the key is rates of exchange with atmospheric CO<sub>2</sub> and between pools

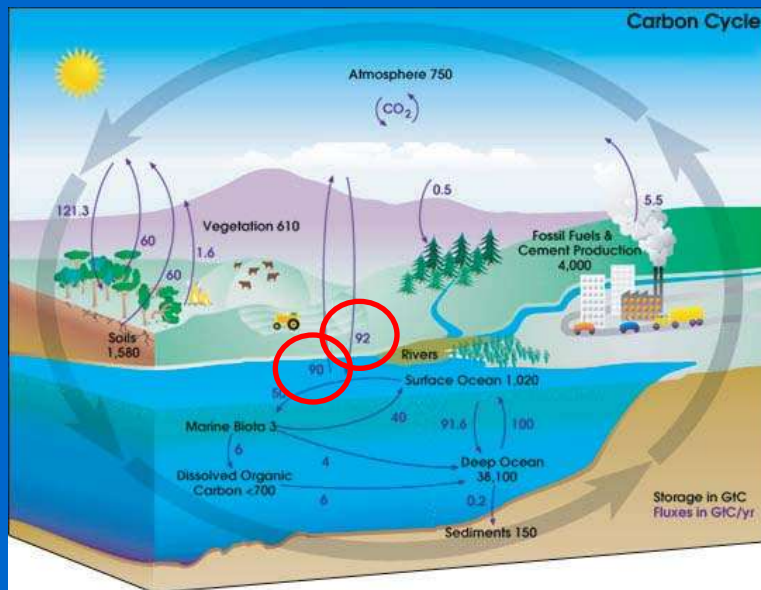
# Marine C – fluxes

Dominant connection to atmospheric CO<sub>2</sub> is through exchange with dissolved carbonate

Responsible for ~2 GtC per year sink

Main driver is increased atmospheric CO<sub>2</sub> concentration

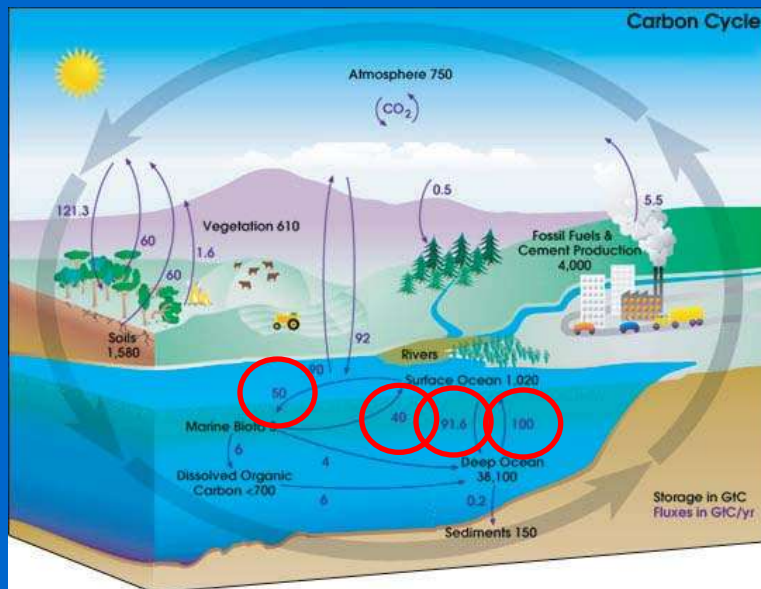
Classic buffering effect



# Marine C – fluxes

Once carbon is dissolved in the ocean, there are a number of possible fates (other than being released back to the atmosphere)

- It can be transported to the deep ocean (91.6 GtC/yr)
- It can be taken up by photosynthesis and converted to organic C (50 GtC/yr)



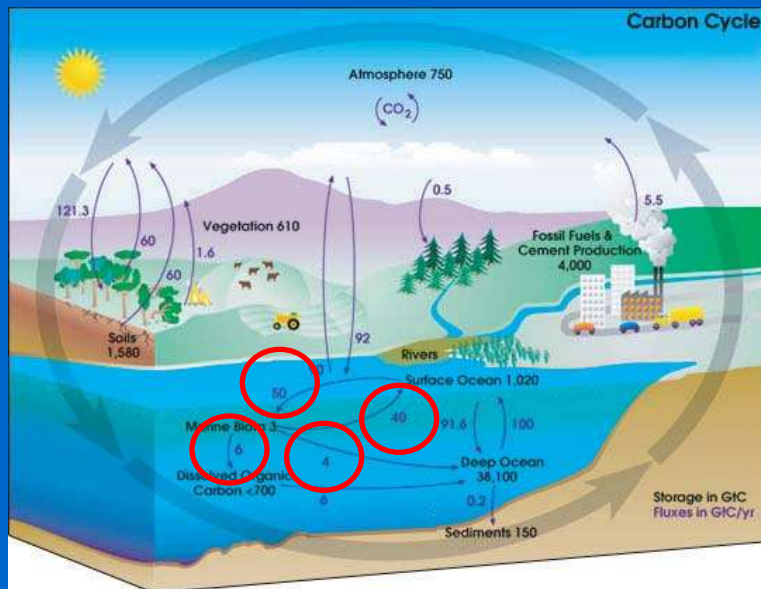
Although these are large fluxes, they are almost negated by balancing fluxes in the opposite direction

Nonetheless, these are important to the long-term fate of anthropogenic C

# Marine C – fluxes

Although marine biota represent a small pool of C, they are responsible for some large fluxes

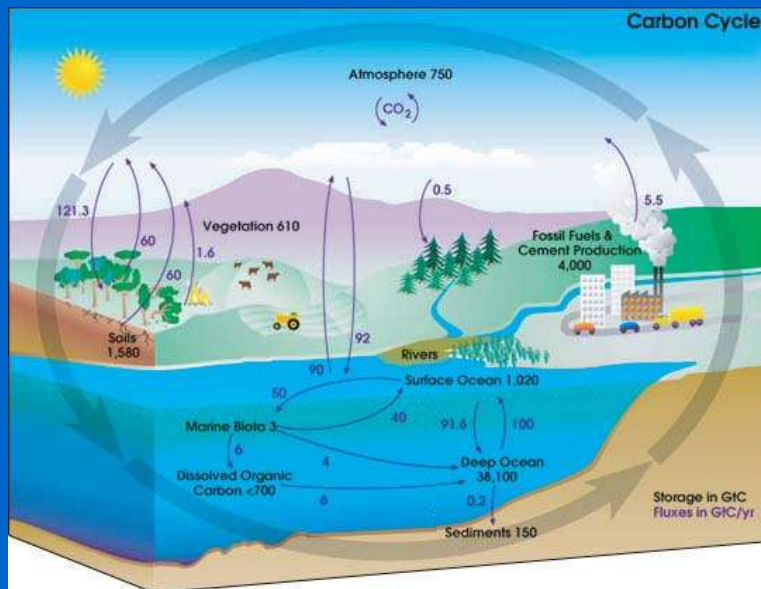
- Photosynthesis (50 GtC/yr)
- Respiration (40 GtC/yr)
- Dissolved organic C production (6 GtC/yr)
- Sinking particles (4 GtC/yr)



# Marine C – climate feedbacks

Many of the marine C fluxes are subject to potential climate feedbacks, both positive and negative

- Ocean warming decreases  $\text{CO}_2$  solubility (+)
- Warming increases stratification, decreasing exchange between surface and deep ocean (+)
- Increased desertification and wind may fertilize deep oceans, increasing sinking particles (-)



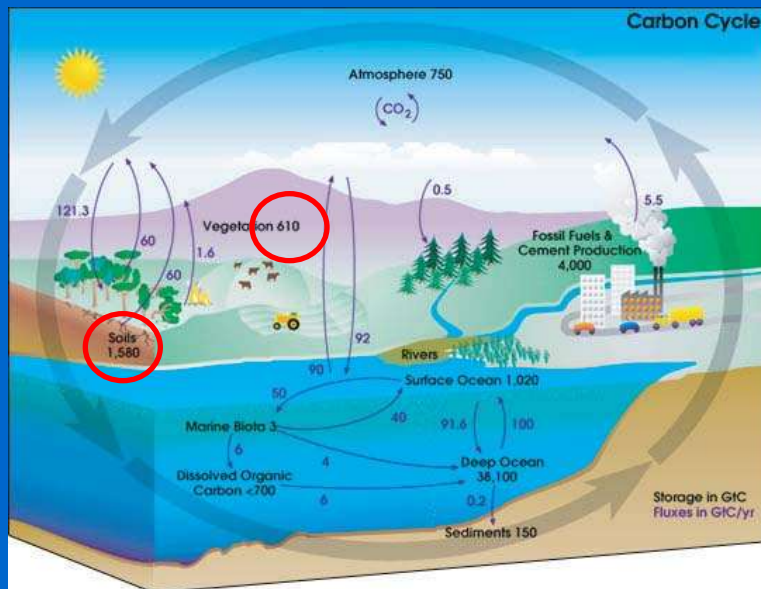
# Terrestrial C – pool sizes

## Vegetation ~610 GtC

- heterogeneous pool (lots of different types of vegetation e.g. above-ground, underground; annual, perennial; deciduous, evergreen). Reasonably easy to quantify.

## Soil ~1580 GtC

- Even more heterogeneous pool. Difficult to quantify.



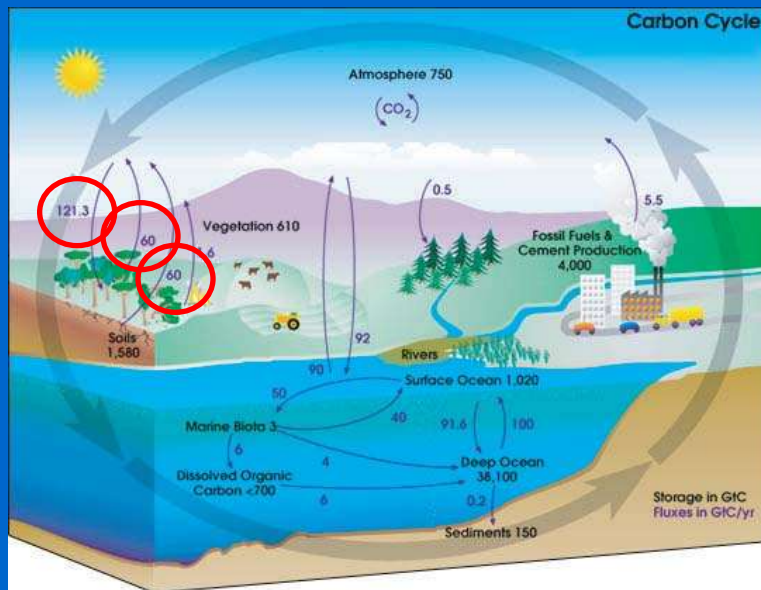
**There is more C (3x) stored in vegetation + soils than in the atmosphere**

**In terms of climate change, the key is rates of exchange with atmospheric  $\text{CO}_2$  and between pools**

# Terrestrial C – fluxes

Driven by photosynthesis (121.3 GtC/yr)

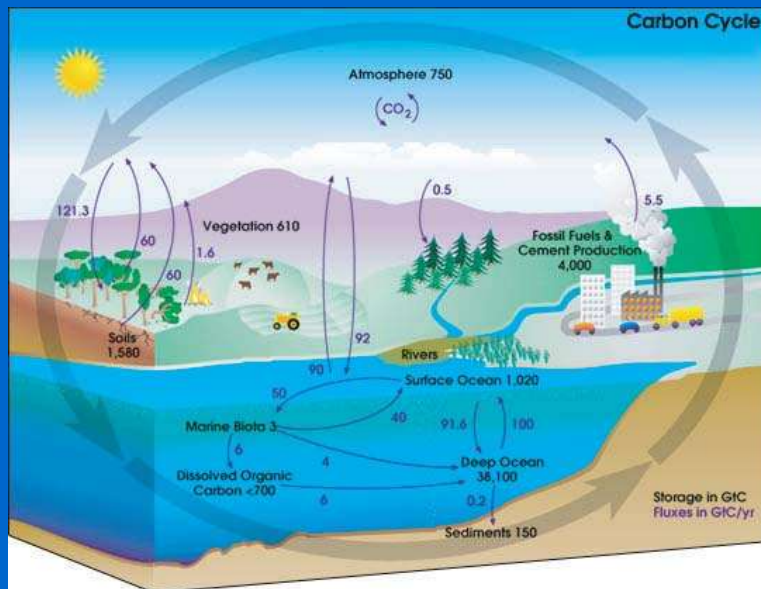
Not quite balanced by respiration, both direct (60 GtC/yr) and via soil (60 GtC/yr)



# Terrestrial C – climate feedbacks

Terrestrial C fluxes are more sensitive than marine C fluxes to potential climate feedbacks

- Changes in net primary productivity with changes in temperature and rainfall (+/-)
- Changes in soil C degradation with increasing temperature (+)
- CO<sub>2</sub> fertilization (-)
- Changed fire regimes (+/-)



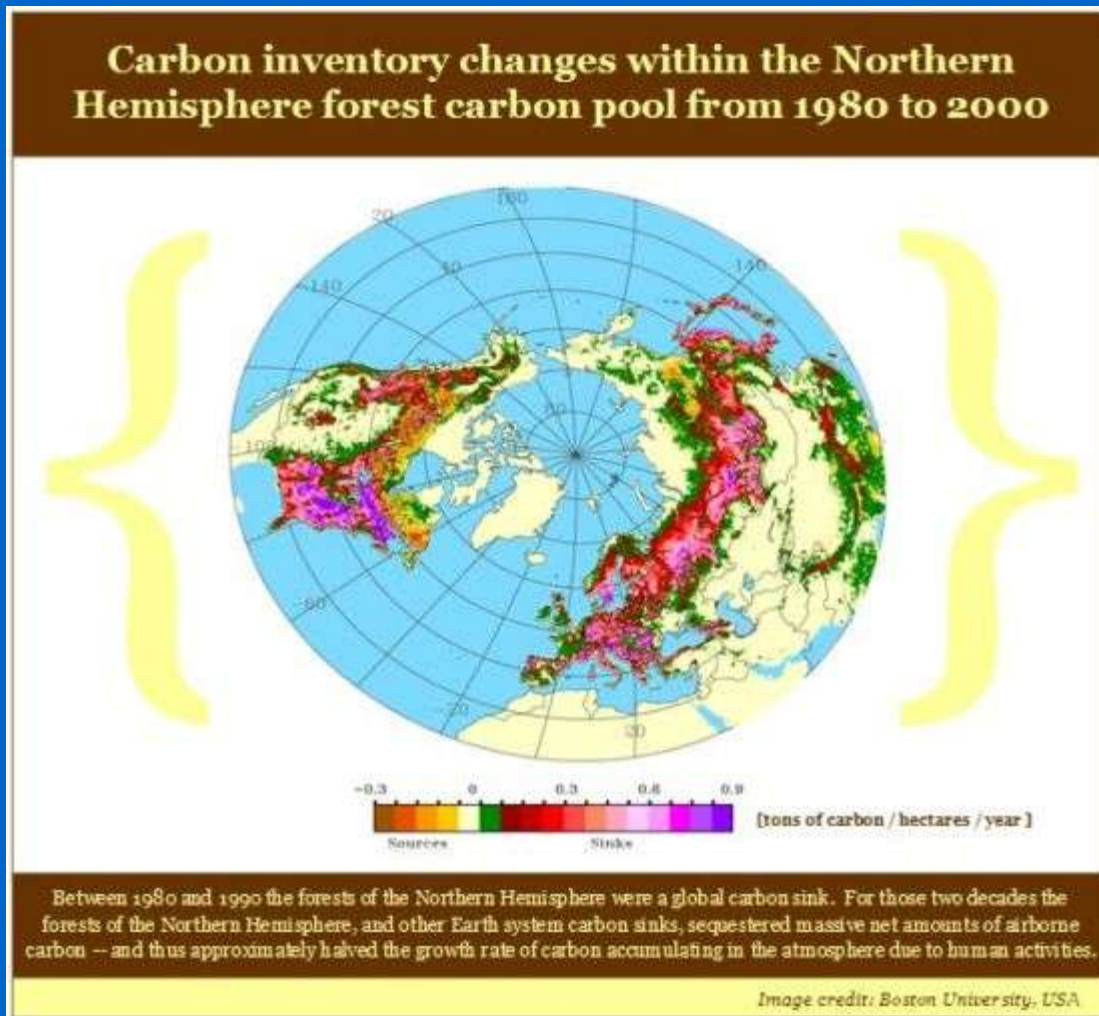
# Terrestrial feedbacks – vegetation changes

The quantity of C stored in northern hemisphere forests increased in recent decades.

This may be due to increased temperatures or CO<sub>2</sub> fertilization although recovery from previous degradation also contributes

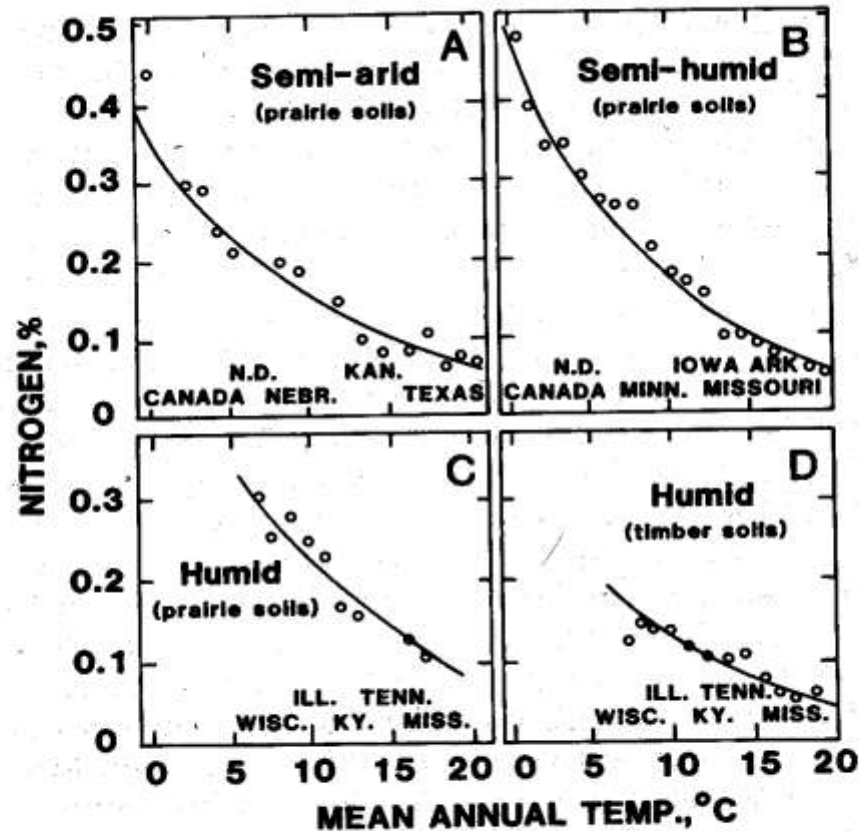
Max 1 tonne C/ha/yr = 0.1 kg C/m<sup>2</sup>/yr

(cf 0.4 kgC/m<sup>2</sup> anthropogenic CO<sub>2</sub>)



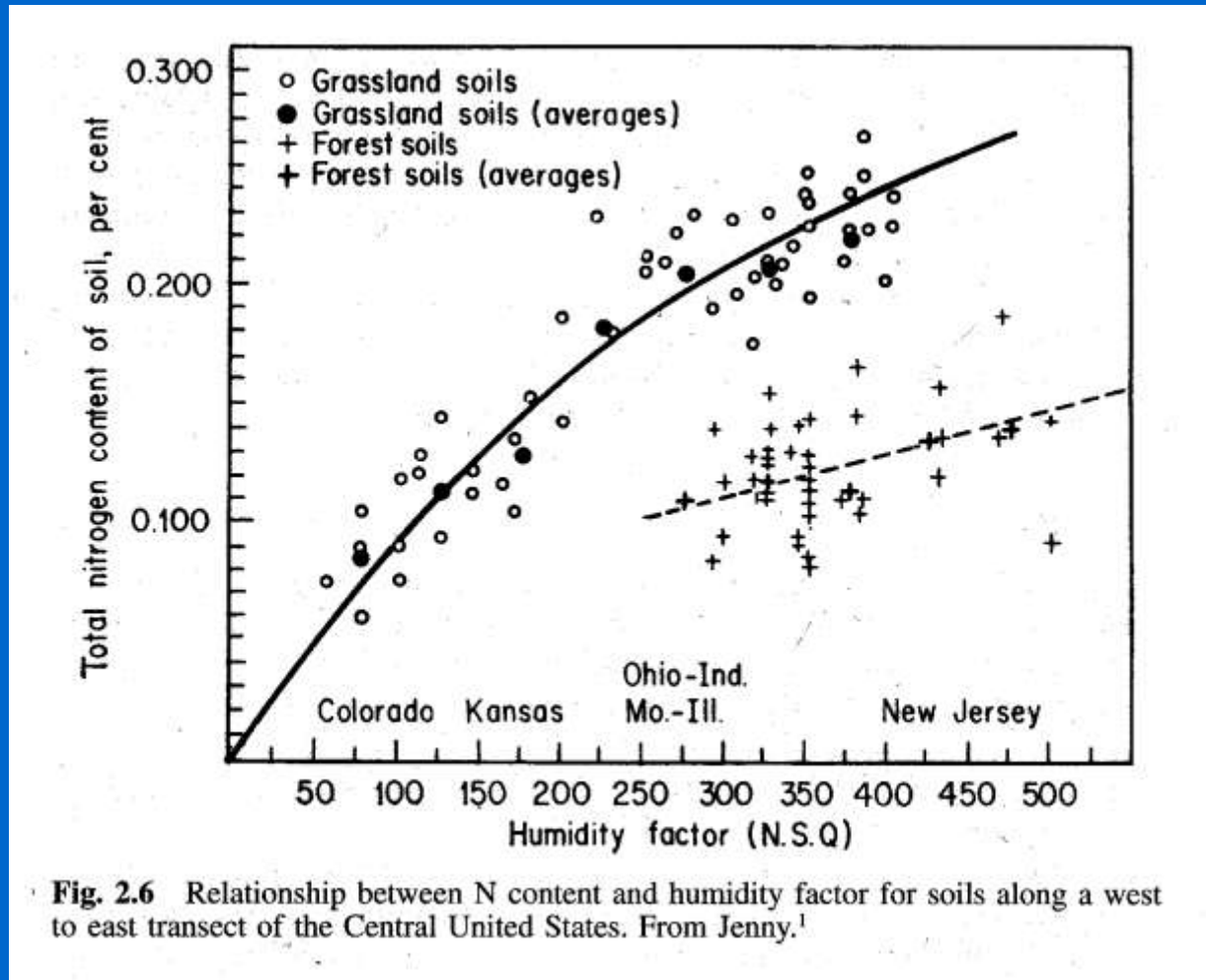
# Terrestrial feedbacks – soil C changes with temperature

(Proxy for C content!)



**Fig. 2.4** Average total N content as related to mean annual temperature for soils along north to south transects of the semiarid, semihumid, and humid regions of the central United States,<sup>6</sup> reproduced by permission of the American Society of Agronomy.

# Terrestrial feedbacks – soil C changes with rainfall



# Terrestrial feedbacks – permafrost and peat soil carbon



Of particular concern are the world's cold soils (e.g. permafrost) and wet soils (e.g. peats), which store large amounts of C that will be released if they are warmed and dried

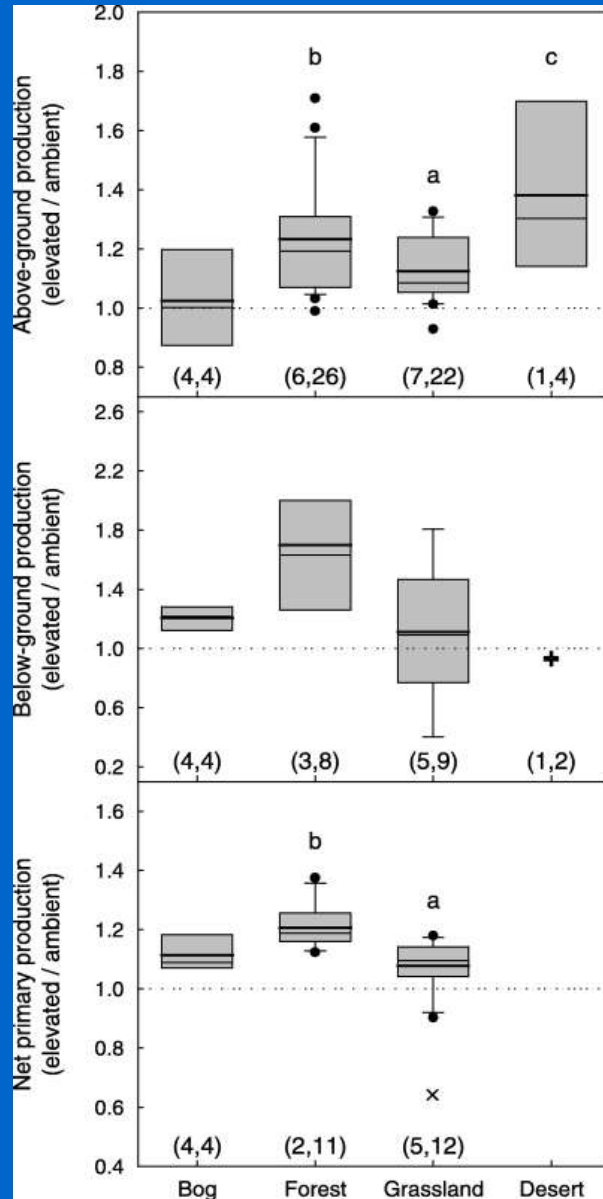
# Terrestrial feedbacks - CO<sub>2</sub> fertilization

Increased atmospheric CO<sub>2</sub> concentrations are predicted to increase plant growth, representing a negative feedback

However, there are many complications and the best way to test “real world” CO<sub>2</sub> enrichment is free-air CO<sub>2</sub> enrichment (FACE)



# Terrestrial feedbacks - CO<sub>2</sub> fertilization



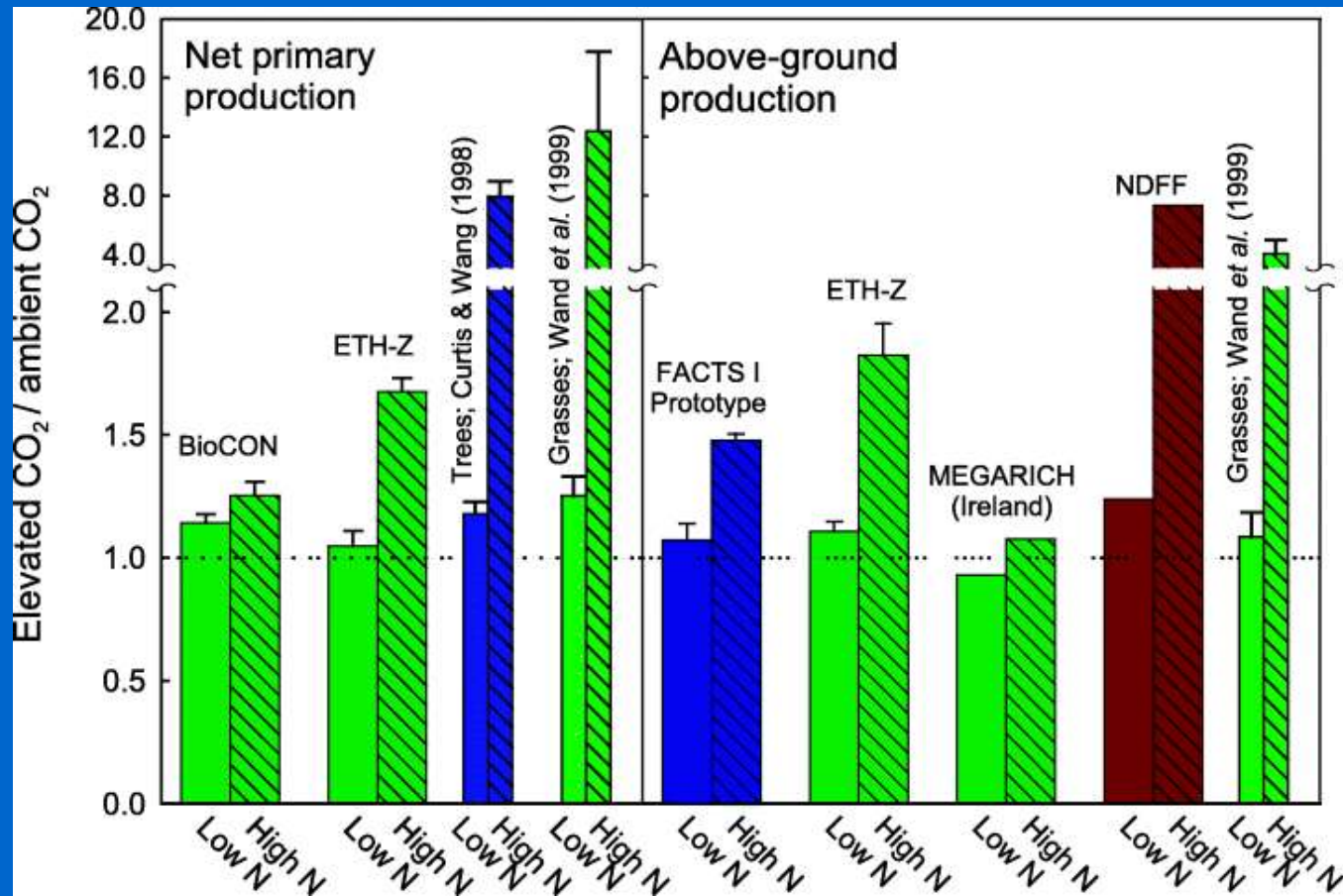
On the whole, FACE experiments confirm increased CO<sub>2</sub> levels increase net primary production (average ~10-20%)

However, there is considerable variability – the effect appears greater for woody plants and is greater in desert environments

It can influence the ratio of above-ground to below-ground allocation (important for rate of decomposition)

May also affect “quality” of organic matter and its decomposability

# Terrestrial feedbacks - CO<sub>2</sub> fertilization



There is a strong coupling between CO<sub>2</sub> enhancement and N availability – NPP under increased CO<sub>2</sub> is increased much more when N availability is high

# Terrestrial feedbacks - fire



**3-8% of global NPP is converted to CO<sub>2</sub> by fire (short-term source)**

**However, with stable fire regimes, there is no net effect on C pools (vegetation grows back)**

**Changing fire regimes do effect C pools – generally a source of CO<sub>2</sub> (less vegetation on average)**

# Terrestrial feedbacks - fire



## More indirect feed-backs:

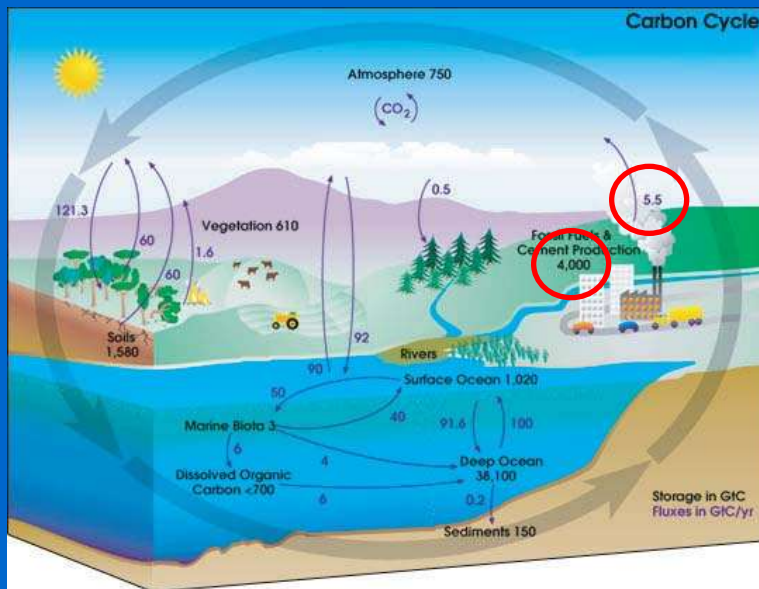
- Forest to savannah conversion – impact on soil C
- Smoke increases albedo (reflects more light - cooling)
- Fall-out of soot on snow and ice increases albedo (warming)
- Char and soot is less decomposable than plant residues (produces a stable C pool - decreases CO<sub>2</sub> in long-term)

# Fossil C – pool sizes

Estimated fossil fuel reserves are 4000 GtC

Actually much more (~40000x) fossil C (kerogen) present in low concentrations in sedimentary rocks

- Not viable as an energy source
- Fluxes to and from this pool are balanced except on geological timescales.



Even bigger pool of carbonate rocks (3x kerogen). Not strongly coupled to other pools, except for cement production

It is very hard to compensate for the 5.5 GtC/yr flux from the fossil C pool!

# Greenhouse Mitigation

To curtail, limit, prevent or reverse the Greenhouse Effect, we will need to influence at least one of the factors involved.



Incoming  $343 \text{ W/m}^2$  (visible + UV)



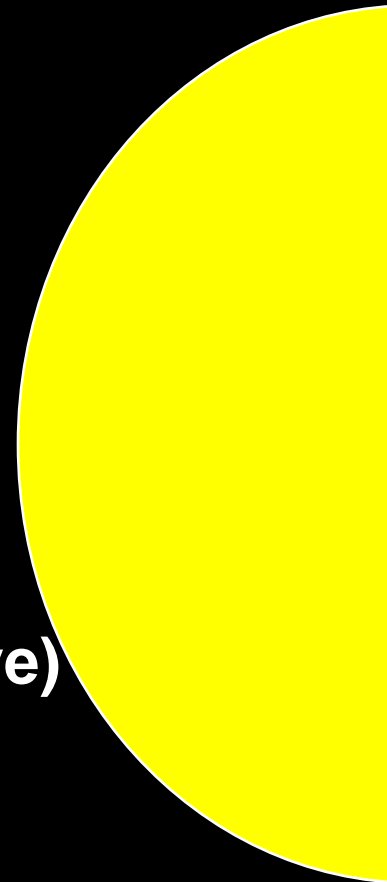
Reflected  $103 \text{ W/m}^2$  (visible + UV)



Re-irradiated  $240.0 \text{ W/m}^2$  (longwave)



Balanced



Earth at  $15.3^\circ\text{C}$

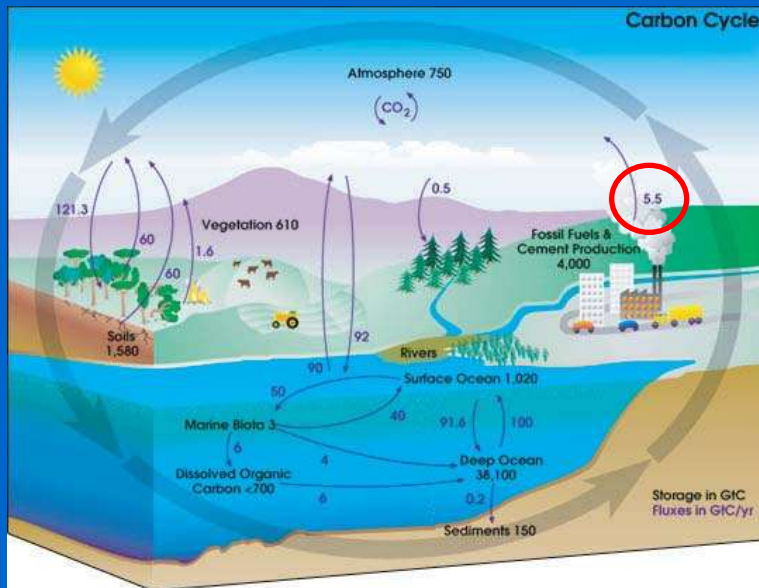
# Mitigation strategies

Reflect away irradiation

Use less energy

Switch to alternative energy sources

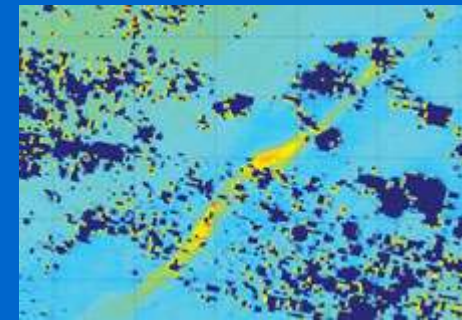
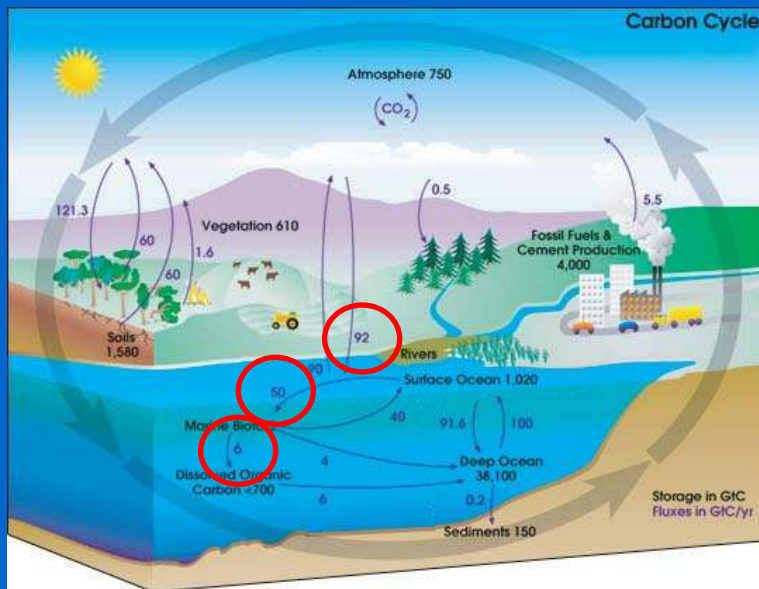
Carbon capture and storage



# Mitigation strategies

## Ocean fertilization

- Productivity in much of the deep ocean is nutrient limited, especially in iron
- Adding iron to these waters promotes algal growth
- This is not enough – need the fixed carbon to sink

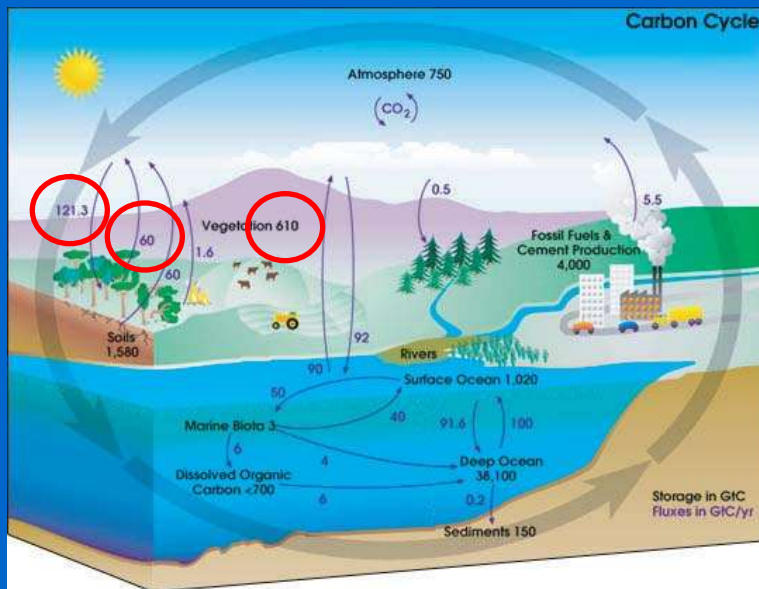


*Nature* 420, 722 (19 December 2002)

# Mitigation strategies

## Vegetation as a carbon sink

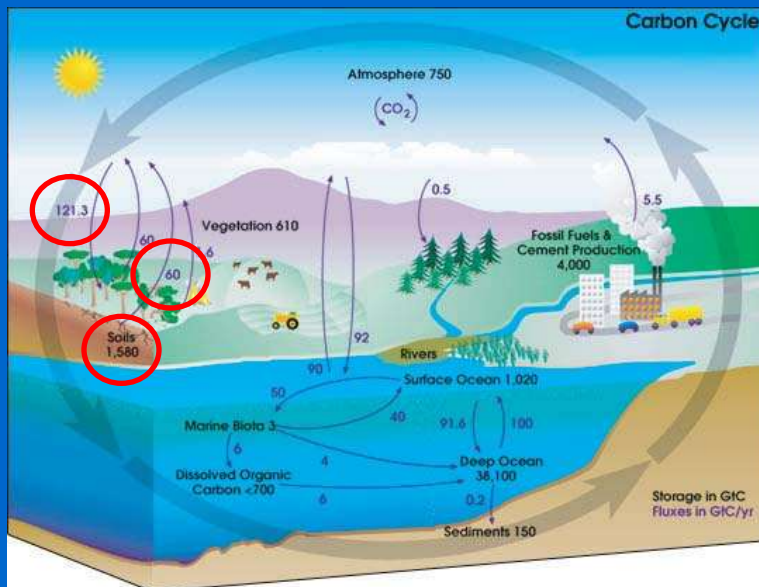
- Simple concept, already commercially implemented, relatively easy to calculate
- Requires **additional** vegetation
- Makes sense on degraded land, concerns over converting productive land to forest
- Water balance, biodiversity issues, susceptible to fire



# Mitigation strategies

## Soil as a carbon sink

- Larger pool than vegetation
- Not so susceptible to fire
- May be beneficial to productivity
- Difficult to calculate and audit



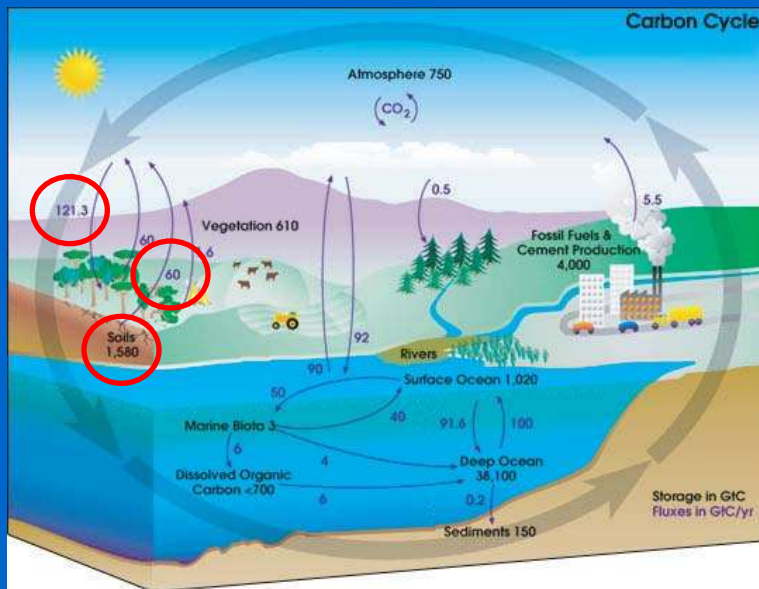
# Soil carbon mitigation -1. tillage

One way to increase soil C storage is to reduce tillage

This is already being done – but for another reason

Increasing soil carbon improves productivity through

- improved physical conditions (water holding, strength, aggregation, water holding capacity)
- improved nutrition (slow release N, P, retention of other nutrients)



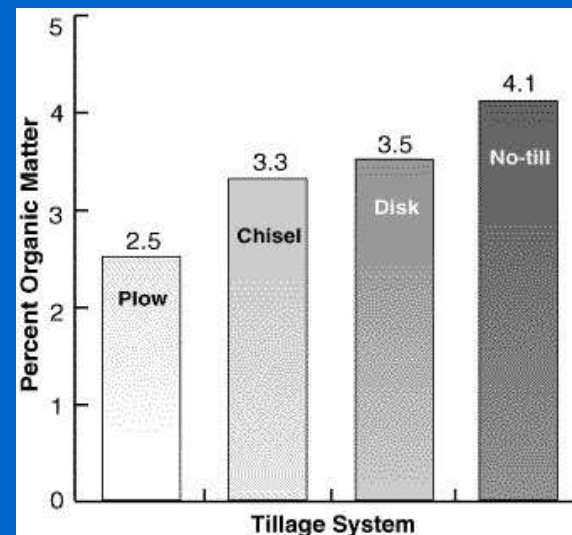
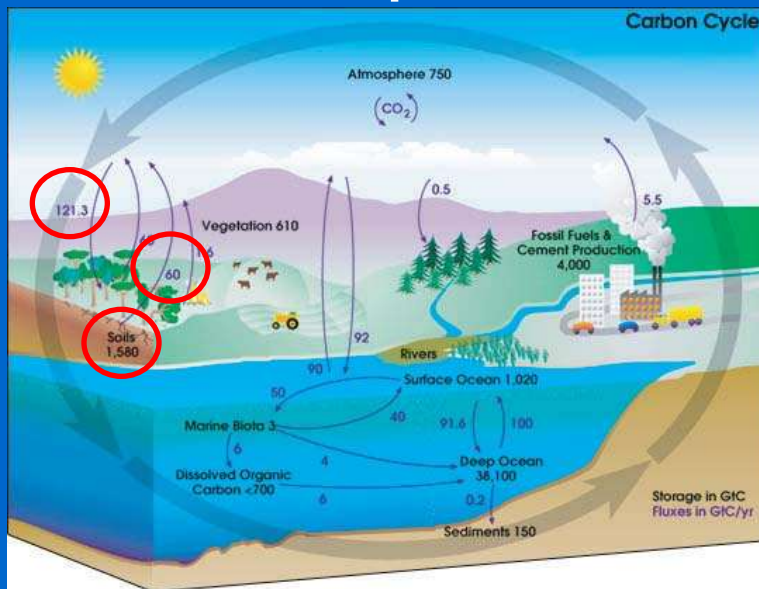
# Soil carbon mitigation -1. tillage

Tillage (ploughing) increases breakdown of soil carbon (through mechanisms not completely understood)

New machinery and use of herbicides requires less (reduced-till) or no (no-till) tillage for cropping

Conservation tillage can increase soil C content by ~1% (e.g. 2% to 3%) in top 10 cm. This equates to 1.5 kg per square metre.

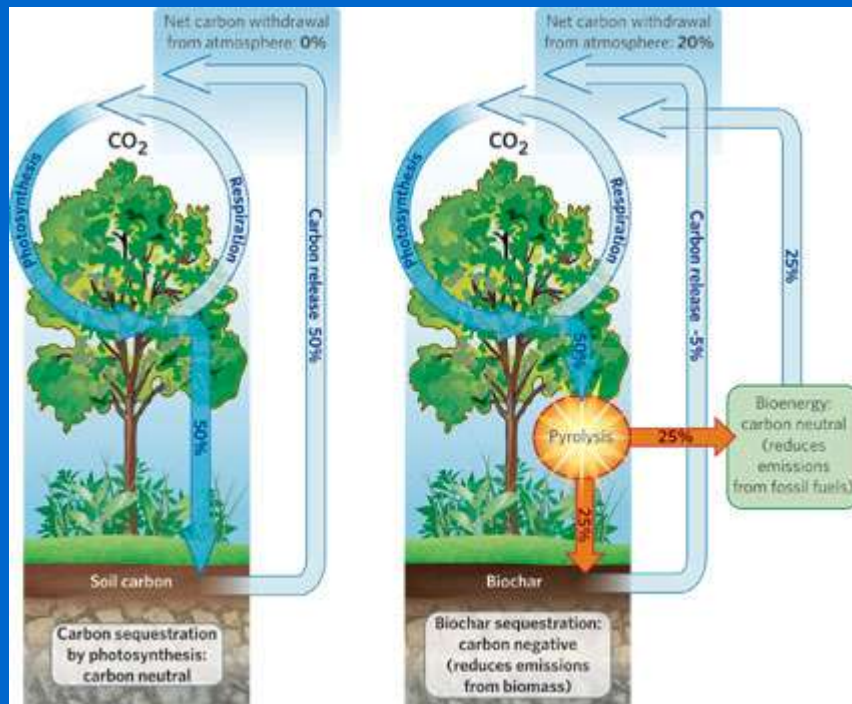
Increasing soil C by this much in the 6% of the earth's surface that is arable land, represents ~25% of the 100 ppm excess CO<sub>2</sub>



# Soil carbon mitigation - 2. Biochar

The biochar concept is to tap into and enhance the natural C-fixing ability of the plant/soil system

In steady-state systems, there is no net flux of C between the atmospheric and terrestrial pools, but a large gross flux



If plant residues are collected and pyrolysed (heated in the absence of oxygen) rather than left to decompose, **carbon neutral** energy can be produced

During pyrolysis, only ~50% of C is converted to CO<sub>2</sub>, the rest is converted to char

Char is then returned to the soil, where it decomposes very slowly. The overall effect is **carbon negative**

*Nature* 447, 143-144 (10 May 2007)

# Soil carbon mitigation - 2. Biochar

Biochar is also reported to increase the fertility and productivity of the soil

The strongest evidence comes from the “terra preta” soils of the Amazon – fertile patches of dark soil containing signs of human occupation that contain a lot of old charcoal

Recent biochar trials also show fertility benefits



[http://jardinons.files.wordpress.com/2008/01/terra\\_preta.jpg](http://jardinons.files.wordpress.com/2008/01/terra_preta.jpg)

<http://www.biochar-international.org/>

# Soil carbon mitigation - 2. Biochar

Lots more research is required:

- Old vs recent char
- Identify most effective chars
- Cause(s) of fertility benefit
- Lifetime of char in soil
- Biochar has benefits in easy auditing and 3-pronged advantages



[http://jardinons.files.wordpress.com/2008/01/terra\\_preta.jpg](http://jardinons.files.wordpress.com/2008/01/terra_preta.jpg)

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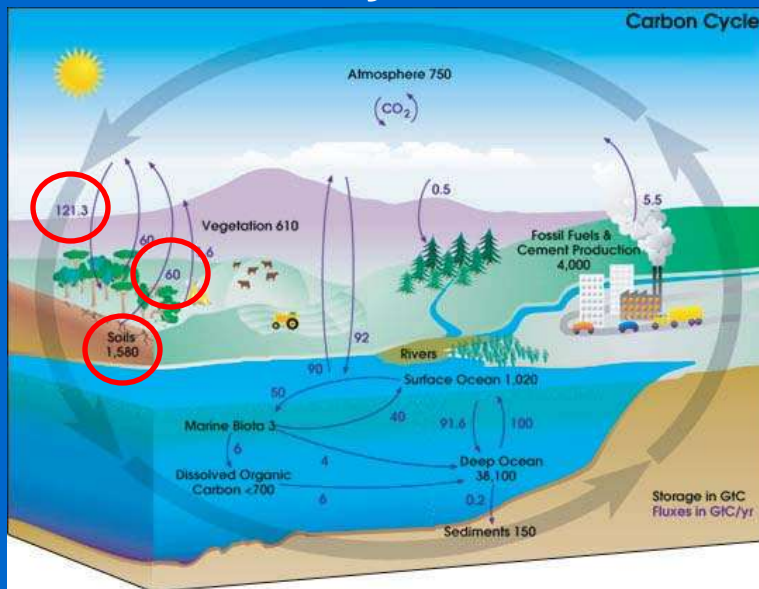
# The carbon cycle summary

- ❖ Human activity, especially use of fossil fuels, has increased the concentration of CO<sub>2</sub> in the atmosphere
- ❖ CO<sub>2</sub> is a “Greenhouse gas” – it “traps” heat within earth’s atmosphere
- ❖ Carbon is present in many other forms and there are inter-conversions between these types at various rates
- ❖ The carbon cycle is central to climate change due to:
  - feedbacks which can diminish or enhance atmospheric CO<sub>2</sub> increases
  - the potential for mitigation – manipulating fluxes in order to reduce atmospheric CO<sub>2</sub>

# A plug for soil carbon research

(In my opinion) soil carbon has huge potential for carbon capture and storage

- it is a large C pool and it strongly coupled (through vegetation) by a large flux
- soil C is very useful – it increases soil productivity and in many cases this benefit is economic on its own
- our current understanding of soil carbon processes is very rudimentary – better knowledge should further increase its potential



**Soil C research – please give generously!**