THE UNIVERSITY OF BIRMINGHAM

Caves, Climate, CO_2 and Civilization

Inaugural lecture, May 18th 2004

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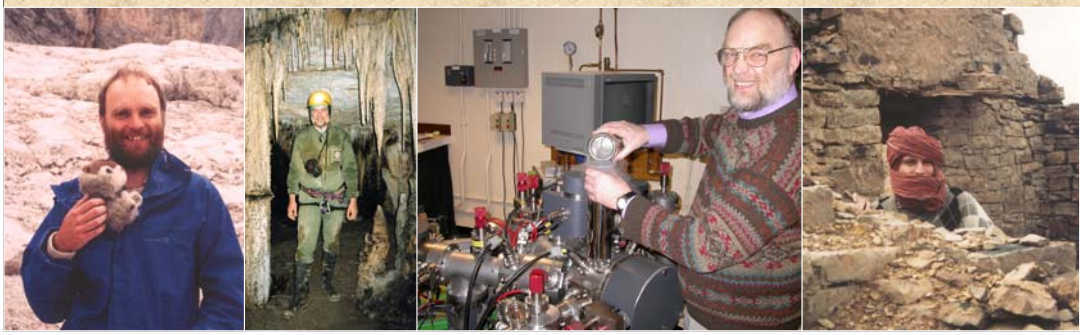


Those who know me well know that I seem to end up mixing seriousness with levity and today is no exception. The opportunity to give such a lecture is a highlight of one's career, not least because of the pleasure in bringing together family, friends and colleagues, but also to discuss the wider implications of one's research. Research, as in life, carries with it joy and despair, but also requires serendipity – the ability to make delightful discoveries by accident, as we will see.

Whereas at the beginning of my career it was a lonely path, guided largely by my supervisor Tony Dickson, the subsequent *cooperative* activities have provided a number of life's highlights. Here are just a few of my mentors, colleagues and students and you can sense some of their qualities, the grace, the energy, the wisdom, but most of all two things: the dress-sense and the shared sense of fun that helps provide the essential creative spark.

In this lecture, I am going to dwell on scientific and geographical truth and in particular truths that flow from our knowledge of the world that are vital for the future well-being of our civilization and our species. There is an alarming tendency these days for truth to be the slave of expediency and of entertainment, and this poses us moral dilemmas.

Evidence?

Truth: I had lots of hair once!

But how do you know for sure? Can you trust photographic evidence?

Evidence

??

Albula railway, Switzerland, 2002

Can you really trust photographic evidence?

Evidence???

Sue Fairchild on *Max*, Alsager

This one is really fun!

……but whether or not the images we see in the media are genuine is an issue of serious concern.

"Isn't global warming just one of those natural changes in climate?" he enquired mildly.

Did I really eat with the Royals? This cartoon appeared around the time the Royal couple visited Keele for its 50th anniversary celebrations and Prince Philip visited my poster about climate change.

"Isn't global warming just one of those natural changes in climate?" he enquired mildly.

Well no, it *isn't* natural and yes it *is* dangerous. It's the sort of incident that brings home the importance to communicate the wider implications of our scientific knowledge as I will do today.

Common facts

Uncertain = contentious:
Bush will be/not be re-elected

Reasonable certainty or consensus:
Arsenal will not be relegated from the Premier league next season.

Certain = I'd stake my life on it:
We will all die

Let's consider how likely some things are to be true – first some common facts.

Scientific facts

Uncertain = contentious:
It will rain on June 30th in Birmingham

Reasonable certainty or consensus:
The amount of carbon dioxide in the atmosphere will rise in 2005

Certain = I'd stake my life on it:
1) Species will become extinct in 2005
2) The Earth is immensely old

Now some scientific contentions and facts.

Value judgements

Uncertain = contentious:
Global warming can be blamed for the greater incidence of river flooding in recent years

Reasonable certainty or consensus:
Human activity is causing current global warming (IPCC – Intergovernmental Panel on Climate Change provides a scientific consensus view)

Certain = I'd stake my life on it:
It would be morally wrong for politicians to ignore the scientific evidence of climatic change

Global warming is now a more serious threat to the world than terrorism Sir David King, Chief Scientist HM Government, *Science, Jan 9th 2004*

But scientists can never deal only with simple facts – they have to produce models of the world and these give rise to value judgements…..

Sir David King has made headlines with this value judgement – global warming is now a more serious threat to the world than terrorism

Occurrences in the new film: *The Day After Tomorrow*

Impossible
Temperatures fall so quickly (10 degrees a second) that people outside are frozen solid

Uncertain = contentious:
The Gulf Stream circulation shuts down because of increased freshwater input to the North Atlantic related to global warming

Reasonable certainty or consensus:
The US Government is depicted as trying to protect economic interests over a possible climatic change

Certain = I'd stake my life on it:
(nothing)

The latest Hollywood blockbuster provides a dilemma for climate scientists…….

Verdicts on: *The Day After Tomorrow*

Sir David King reported as saying (Guardian, 13.5.04) that *the film is welcome as raising public awareness and debate about a vital issues.….the beginning of the film is particularly realistic scientifically and politically*

Dr. Meric Srokocz (coordinator of NERC's RAPID Climate Change programme which is funding a collaborative project led from Birmingham) *"any publicity is good publicity for the climate cause" (*mainly because there had not been enough)

Professor Mike Hulme -(Tyndall Centre for Climate Research, UEA) "*It breaks the laws of physics……it's a parable that doesn't do anything for me"*

These value judgements tend to be messy, but increasingly rational voices need to be heard – and in particular the voices of geographers, with their interest and understanding of both the physical and the human worlds.

Three-by-three

A. Three sources of geographical knowledge

B. Three sources of fascination for me: CO_2, speleothems and systems

C. Three comparable physiologies: person, cave and planet

This talk is in threes -

So I'll talk next about what makes geographers wise, and you'll see that we all have some of this wisdom.

Then I'll explain a little about my interests and how they bear on issues of carbon dioxide and climate change

And finally I'll enlarge on the concept of comparative physiologies - which I hope will bring home the need to take care with our Planet

Three sources of geographical knowledge

1. Indigenous peoples

2. Explorers

3. Intellectuals

Icelandic harvest – must have been a good year, then!

http://egla.bok.hi.is/

Indigenous peoples are those who are native to a place or a region and who come to know it well, both through the wisdom passed down from their ancestors and their community, and from their own direct observation, often through the necessity of survival. Local people in the Alps knew there had been ice ages before scientists "discovered" the concept.

1. Indigenous peoples

River Frome, Frampton Cotterell, winter 1968

River Frome, April 1969

These photos reflect my interest in geographical phenomena in the area in which I grew up. In our society, this knowledge is diluted by lack of contact with the land and social mobility.

1. Indigenous peoples

The Khushman of the Eastern desert of Egypt

(Hobbs, 1992)

For other images see Hobbs, J.J. 1992 *Bedouin Life in the Egyptian Wilderness*

University of Texas Press, Austin

I am grateful to Judith Bunbury for drawing my attention to a wonderful geographical thesis by Hobbs on the Khushman people of the eastern desert of Egypt whom I can use as an example. The Khushman in the 1980s were still largely a pastoral nomadic people. They have only been native there for 200 years, but they have built up a deep understanding of their environment – for example they have names for 155 plant species and an encyclopaedic knowledge of plant and animal ecology and the distribution of water. There are no simple words for places: each also has another meaning (perhaps the time when flowers bloom or the name of the person who cared for that place). But if we go beyond the realm of their direct experience, we find some more disconcerting aspects of their knowledge system.

1. Indigenous peoples

Musallim Suliman felt, as all nomads do, that it was the sun that turned around the earth…..
"If the world turned, the waters of the Nile and the seas would spill over or run uphill"

Those who say the earth rotates are crazy. If it did, you would be praying toward Mecca to the east in the morning, to the south at midday, to the west in the afternoon. This is impossible. If the earth turned the other way (flipped over), all would be chaos. Polaris (al-Jadi) remains in place, and the other stars move. If the world turned, all the stars would rotate together. The world does not turn. If it did, all the stars would appear or disappear together. The sun rises to move and set on opposite sides of the earth. *In the very center of the earth is Mecca, like the centrepole of a tent. God separated the earth from the heavens, and made the earth to stand in place, and the sun and stars to revolve around the earth.*

1. Indigenous peoples

The Khushman refer to a flat earth... although one had a model like a hubcap to account for low countries, being colder (e.g. US, UK)) receiving less heat. Their country was undoubtedly the best!

A recent survey by Scientific American revealed that... 45% of Americans... believe God created life some time in the past 10,000 years……
From the Observer, March 17 2002
http://www.guardian.co.uk/religion/Story/0,2763,954018,00.html

We can laugh at how the limited geographic experience of the Khushman leads them to accept such beliefs. Who would put a Khushman tribesman in charge of a space mission?

But what about these views? A recent survey by Scientific American revealed that... 45% of Americans... believe God created life some time in the past 10,000 years. The 45%They are views that provide a very distorted lens for understanding what we are doing to the Planet.

They stem from a particular take on Biblical teaching, but they are also reflect what has become an indigenous, cultural tradition in the USA, because Christians in other parts of the world predominantly do not accept these views. These " 45%" also strongly overlap with the natural democratic constituency of the current American President, a man with unique responsibilities for the future development of our planet.

Three sources of geographical knowledge

1. Indigenous peoples
2. **Explorers**
3. Intellectuals

Illustration:

Three Princes going Hunting, Mughal painting by Balchand (ca. 1635) reproduced in Science 304, 213 (2004)

The three Princes of Serendip, by accident and through wisdom, were always making discoveries of things for which they were not searching

Now for explorers – with mention of the Princes of Serendip, who will return at the end of the lecture

Illustrations from Times History of the World (an annotated atlas)

Explorers have many different motives for exploring, but inevitably their knowledge is extensive and comparative, typically eclectic, sometimes prejudiced, but often explorers would learn much from indigenous peoples too. All the ancient civilizations engaged in exploration to some extent.

From IJF's first field report aged 13 (c. 1966) on the geography of Westbury-sub-Mendip, Somerset

Through exploration in fieldwork, and in particular through mapping, I have come to know a few places as only few of the indigenous peoples do.

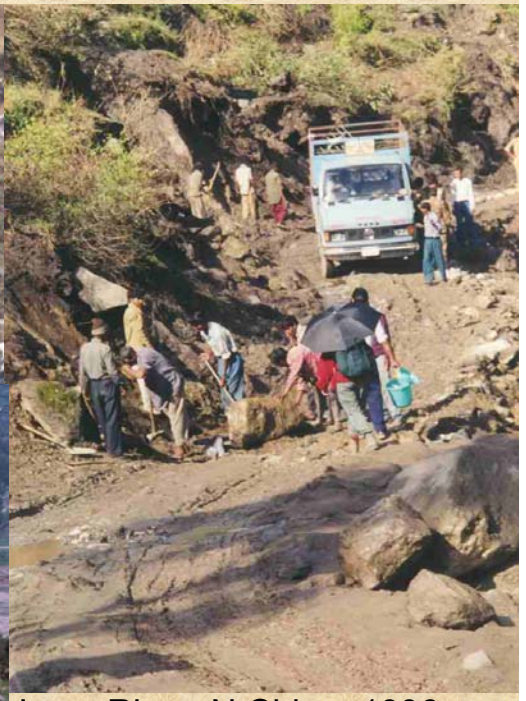
Ny Friesland ice cap, Svalbard 1982

I have been privileged to see with my own eyes much evidence for the immensely long history of the Earth, and for evolution. But also fieldwork in uninhabited environments brings home the dangers of climate change (the whole Earth was like this at certain times early in our history) and our interference with the climate system.

Western Sahara, Mauritania, 1988

Much of the Earth was like this at other times in its history.

Garhwal, India, 1998



Juma River, N China, 1996

Fieldwork in inhabited areas can show the dignity and struggles of the poor, and the impact that we have on the environment.

Three sources of geographical knowledge

1. Indigenous peoples
2. Explorers
3. **Intellectuals**

"Beethoven", limestone landform, Liaoning province, China, 1993

The third source of knowledge is from the intellectuals: the people who think, who innovate and who put things together.

I was asked to translate the Chinese names for different rock formations along this coast into English to assist tourist development. The Chinese name for *this* rock was Beethoven.

1569 Mercator's *'New and more complete representation of the terrestrial globe properly adapted for navigation'* using what became known as Mercator's projection

Illustrations used from Crane, N. 2002 Mercator

Weidenfeld and Nicolson, London

(Crane, 2002)

The map-maker Mercator is a marvellous example of an intellectual, although he was also an artisan making scientific instruments for much of his living– from a poor family, he trained in Euclidean geometry, mastered the new art of triangulation – and developed a "*New and more complete representation of the terrestrial globe properly adapted for navigation"* using what became known as Mercator's projection, so that mariners could follow a bearing on a straight line on their charts. Here is the great power of the intellect from someone who mostly sat at home compiling the information of others.

One of Mercator's six regional maps of England & Wales (1595)

Crane, 1992 p. 278
quote from Mercator:

In Britain…the days are very long, and no night is without a little light, since the extreme flatness of her shores do not draw down shadows, and the face of heaven and of the stars passes the finish-line of night like the sun itself… Indeed, Britain is the work of joyous nature; nature seems to have created here like another world outside the world, for the pleasure of the human race, and to have limned her singularly like a shape of utmost beauty and a universal ornament, with such gemlike quality and pleasant painting that the eye of whosoever falls on her is refreshed.

But Mercator also produced a florid description of Britain: *Indeed, Britain is the work of joyous nature; nature seems to have created here like another world outside the world, for the pleasure of the human race, and to have limned her singularly like a shape of utmost beauty and a universal ornament, with such gemlike quality and pleasant painting that the eye of whosoever falls on her is refreshed.* Mercator had never been to Britain…….whilst environmental research without intellect is pedestrian, environmental work without a field understanding is dangerous.

Garvellachs, NW Scotland, 1979. Deposits of a Precambrian Ice Age

I was accused of being an intellectual once – by a hermit on the Garvellach Islands in Scotland. We each thought that we were the only person staying there. He dismissed my account of ancient ice ages millions of years ago – *intellectuals; always theorizing – I just enjoy the island as it is,* he proclaimed. Hmm, but by living there, exploring and comparing with other places, and thinking about that place, I think I succeeded in having a deeper appreciation of the nature and value of that place.

Three-by-three

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B. Three sources of fascination for me: CO_2, speleothems and systems

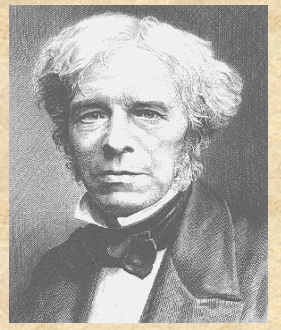
C. Three comparable physiologies: person, cave and planet

Now we come to some of my fascinations – starting with carbon dioxide – CO_2

Three sources of fascination 1: CO_2

Michael Faraday - *so vast an achievement as to lead his successor, Tyndall, to say, "Taking him for all and all, I think it will be conceded that Michael Faraday was the greatest* ***experimental*** *philosopher the world has ever seen."*

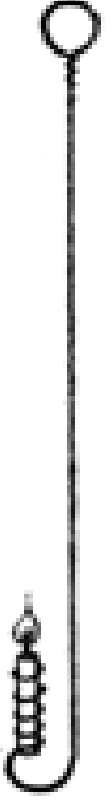
http://www.fordham.edu/halsall/mod/1860Faraday-candle.html



The Chemical History of A Candle, (5 lectures) 1860

Organic matter (e.g. candle) + Oxygen --> carbon dioxide and water

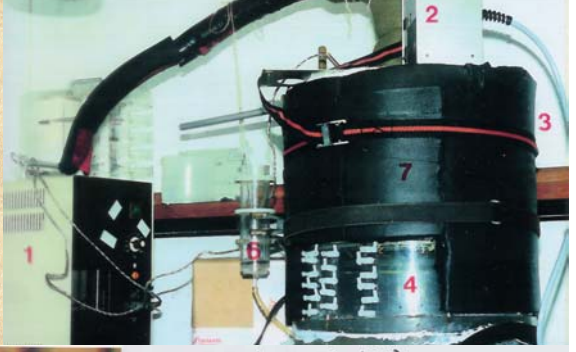
CH_2O + O_2 ---> CO_2 + H_2O

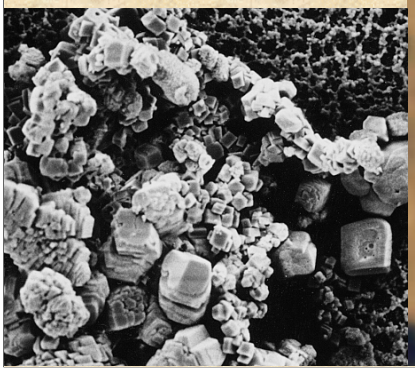


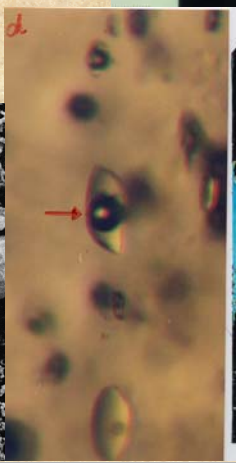
Thanks to David Richards for drawing my attention to these lectures. In 1860, Michael Faraday based a series of lectures around vivid practical demonstrations connected with the gases and the chemistry associated with the burning of a candle. Even this afternoon in a chemistry department, Health and Safety legislation these days makes it much more difficult to show these practical wonders, although I do remember Professor Chaloner, giving a visiting lecture here a few years ago putting his cigarette in an oxygen cylinder to show us that fire limits the amount of oxygen in the atmosphere. In this lecture series of Faraday's he had much to say about carbon dioxide, the product both of combustion and the decay of organic matter in the presence of oxygen, and his scientific fervour was bound up with the power of experiments – something that certainly influenced me to study chemistry and physics at advanced level.

Experiments:

Precipitation of calcium carbonate and production of CO_2-enriched gas bubbles during freezing



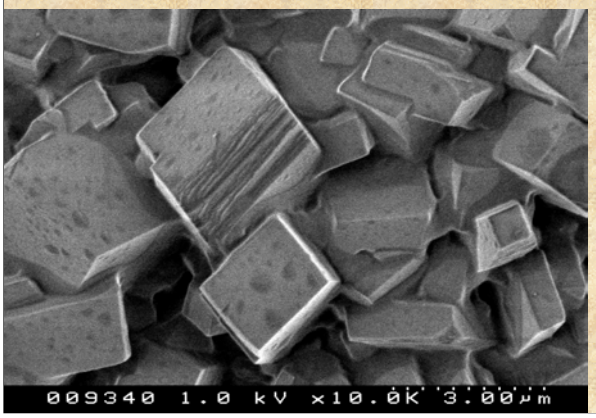




For example, in the mid 1990s we did the most chemically comprehensive experiments to date on controlled freezing of waters such as we might find under glaciers and here we see how the ice contains bubbles contain three phases: brine, crystals of calcium carbonate and gas rich in carbon dioxide.

Experiments 2:

Leaching experiments to simulate dissolution of limestone in soils - the limestone reacts with the CO_2



Precipitation of calcium carbonate crystals to simulate cave environments where CO_2 is given off into the cave as the crystals precipitate

Experimental crystals (Huang and Fairchild, 2001)

We've also carried out experiments to understand limestone and cave environments. Carbon dioxide from the atmosphere, or the much larger quantities in soils is used up in immense quantities when most rocks are weathered, but is given out when calcareous crystals form. So this is one powerful approach and source of scientific truth - experiments to understand our natural environments.

Short Term

photosynthesis

$CO_2 + H_2O$ decomposition $CH_2O + O_2$

carbon dioxide water organic matter oxygen

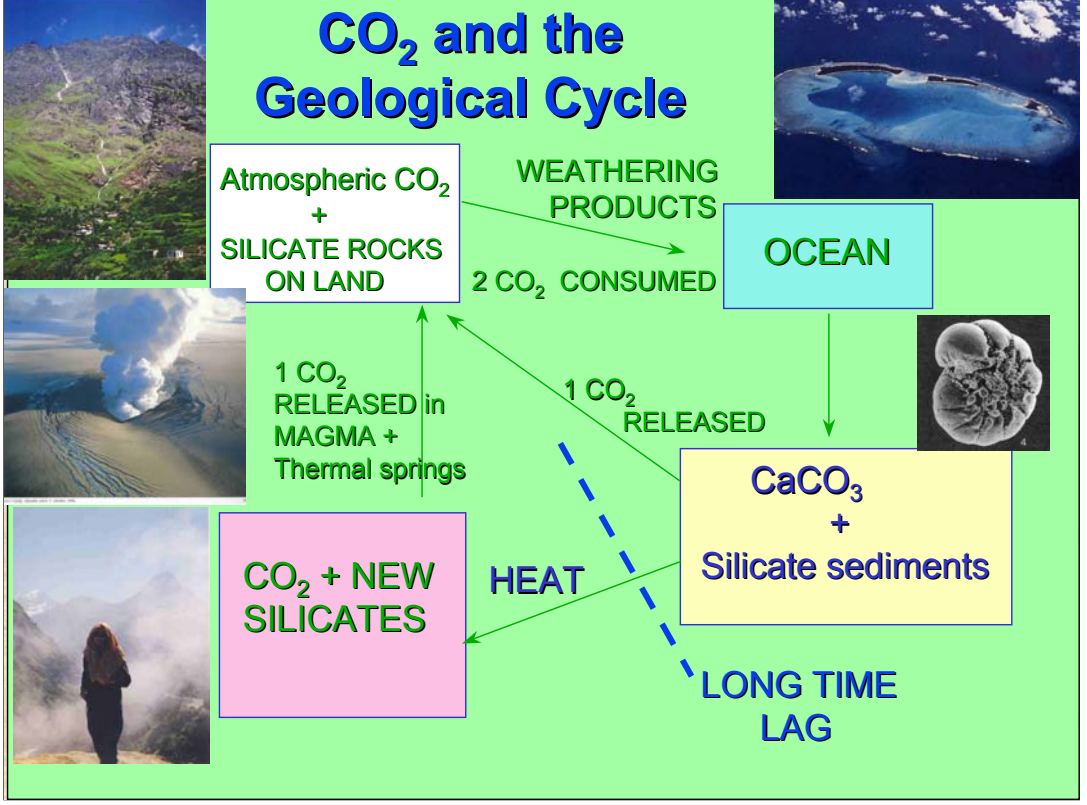
burial

erosion of organic matter

burial of organic matter (peat --> coal) lowers CO_2 in atmosphere

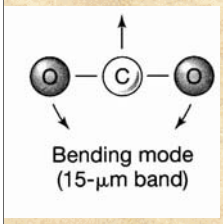
Long Term

When we put these various processes in a global context, we see that the decomposition-combustion reaction, producing CO2 is enhanced when we cut down rainforests, but is reversed if extra plant growth occurs. On the geological timescale, changes in the proportion of rock types being eroded or deposited caused changes in the composition of carbon dioxide in the Earth's atmosphere and changed its climate



One strand of my research with Cambridge colleagues in India, and with Keele colleagues in Iceland involves studying the consumption of CO2 by rock weathering as part of the geological cycle of removal and generation of CO2 over immensely long timescales

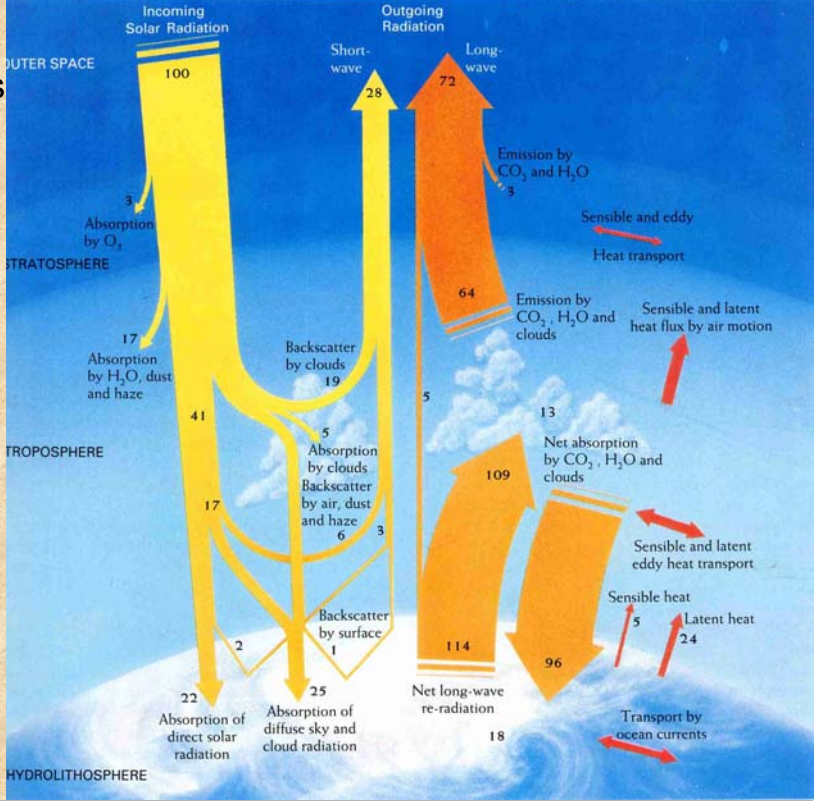
CO_2 - greenhouse gas



Atmospheric energy budget

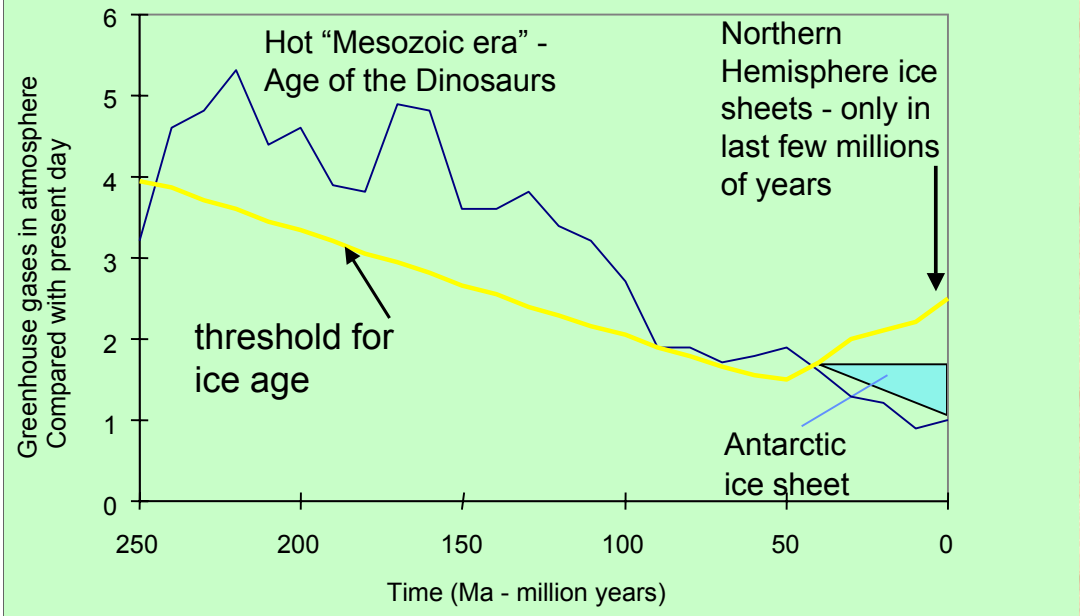
Units are % of total incoming radiation per unit area

Graedel & Crutzen 1993



Now why does CO2 relate to climate – well because it's perhaps the most crucial greenhouse gas. When sunlight strikes the Earth's surface it is absorbed and re-reradiated as infrared radiation, or heat. In the atmosphere, CO2 has the crucial role of absorbing significant amounts of this heat – without such greenhouse gases our planet would be uninhabitable (like Mars would be even if it were as close to the Sun as we are), but given too much greenhouse gas, the Planet would still be uninhabitable (like Venus).

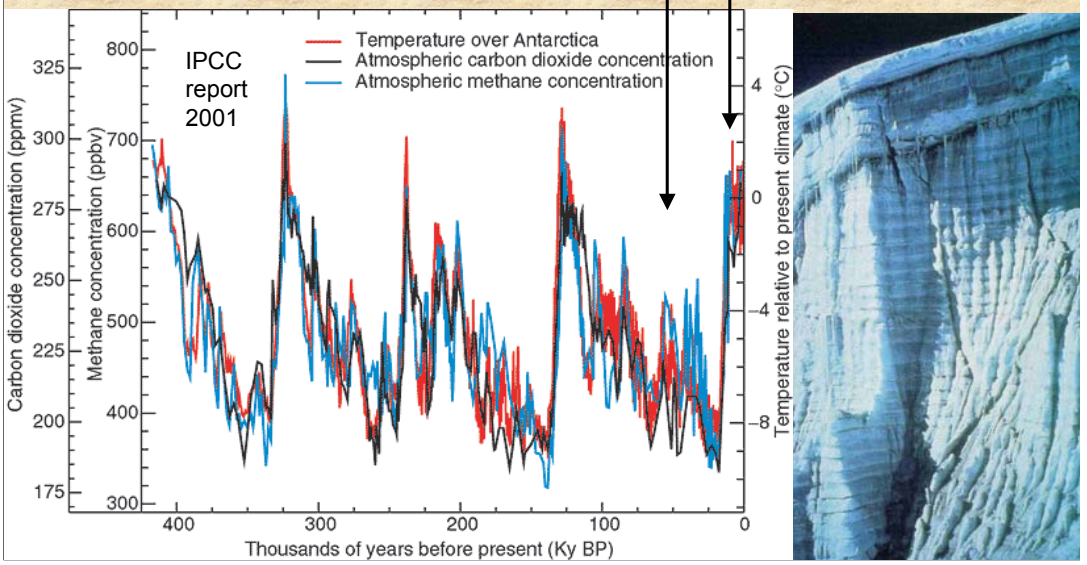
History of CO_2 in the atmosphere



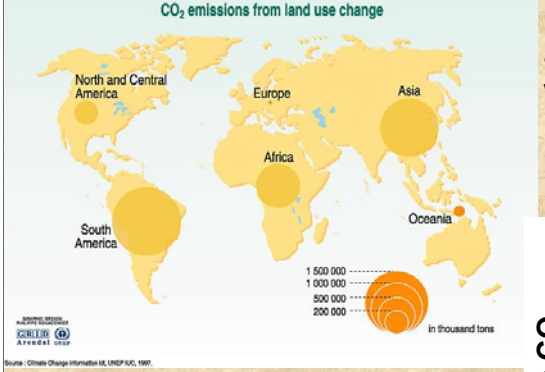
In the Age of the Dinosaurs, there was much more CO2 in the atmosphere, it was much hotter and sea level was 200 m higher. Later the amounts of CO2 fell significantly, partly related to increased weathering in new mountain belts and together with other palaeogeographic changes made our Planet susceptible to glaciation.

History of CO_2 in the atmosphere

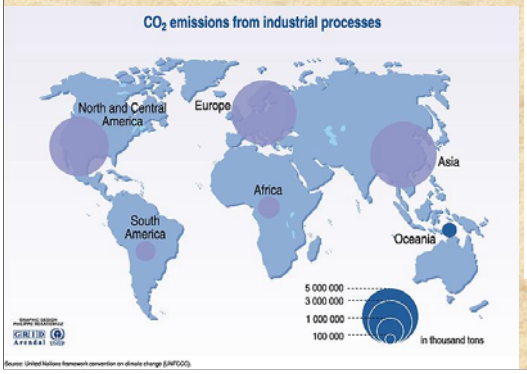
records from ice cores show that the values fluctuated between ice ages and intervening warmer periods like the present day

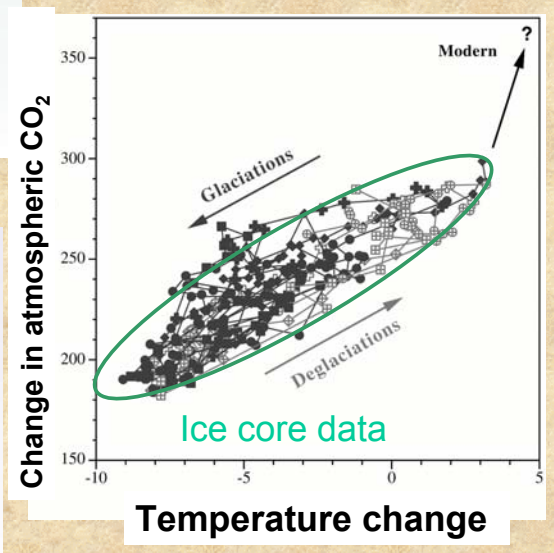


A beautifully clear knowledge of the climate atmospheric history over the last half-million years has come from studying cores drilled through major glaciers. We can count down the years of snowfall, one-by-one, as they gradually change to ice and go back, tens, hundreds, thousands and hundreds of thousands of years. By analyzing the bubbles of air and the composition of the ice we can learn about the atmosphere and climates of the past. The picture that emerges, as corroborated by evidence from on land and under the sea is a series of great ice ages in which the composition of the atmosphere changed synchronously with temperaure change – our sub-species Homo sapiens sapiens first appeared during the last one. The cold was partly caused by changes in ocean circulation and reflectivity of the planet, but also by the reduced amount of greenhouse gas during ice ages. And so our civilizations did not start to develop until after the beginning of the current warm interglacial 11 thousand years ago. The CO2 content of the atmosphere stayed roughly constant until the industrial revolution.



CO_2 emissions from land use change and fossil fuel burning have taken us well outside the natural climatic frame





Falkowski et al (2000)

CO_2 emissions from land use change and fossil fuel burning have taken us well outside the natural climatic frame (of 180-280 ppm CO2) – the temperature anomaly is not yet strong, but there is already much more CO2 in the atmosphere than there has been for the last 0.5 Million years and this is propelling us into territory that is new since the origin of our species (or even our genus).

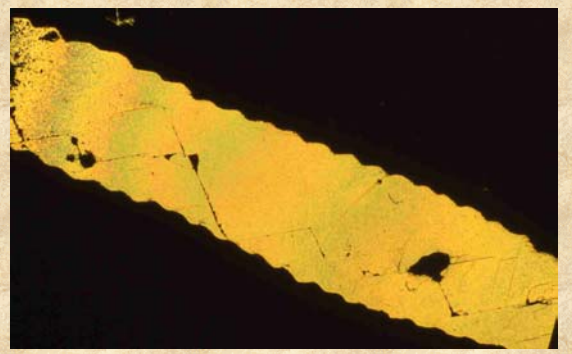
Three sources of fascination 2: speleothems

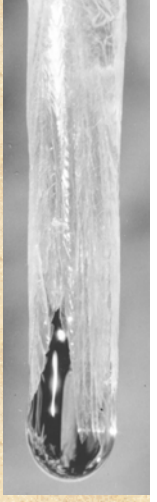
Speleothems (cave precipitates like stalagmites) can grow semi-continuously for up to tens of thousands of years

Stalagmite from Refugio cave, SE Spain and Bartolomé Andreo

Now for my second source of fascination: speleothems. In my research in collaboration with colleagues, some of whom are here together, we are using speleothems, cave deposits, similarly to give us detailed climate records of inhabitable regions.

Soda straw stalactites grow downwards as a ring with an extension rate normally several times faster than associated stalagmites. Annual layers are shown



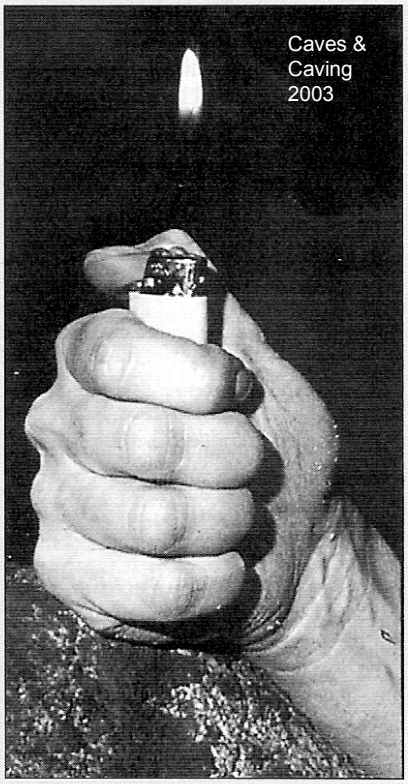


With these deposits too we can count back in time year by year for thousands to tens of thousands of years. I have a sample of one of these beautiful soda straw stalactites here today.

Ernesto Cave: cave bear skull incorporated into speleothem (flowstone) with a charcoal coating from humans' fires:

Age around 9000 years - around the time of earliest human civilizations

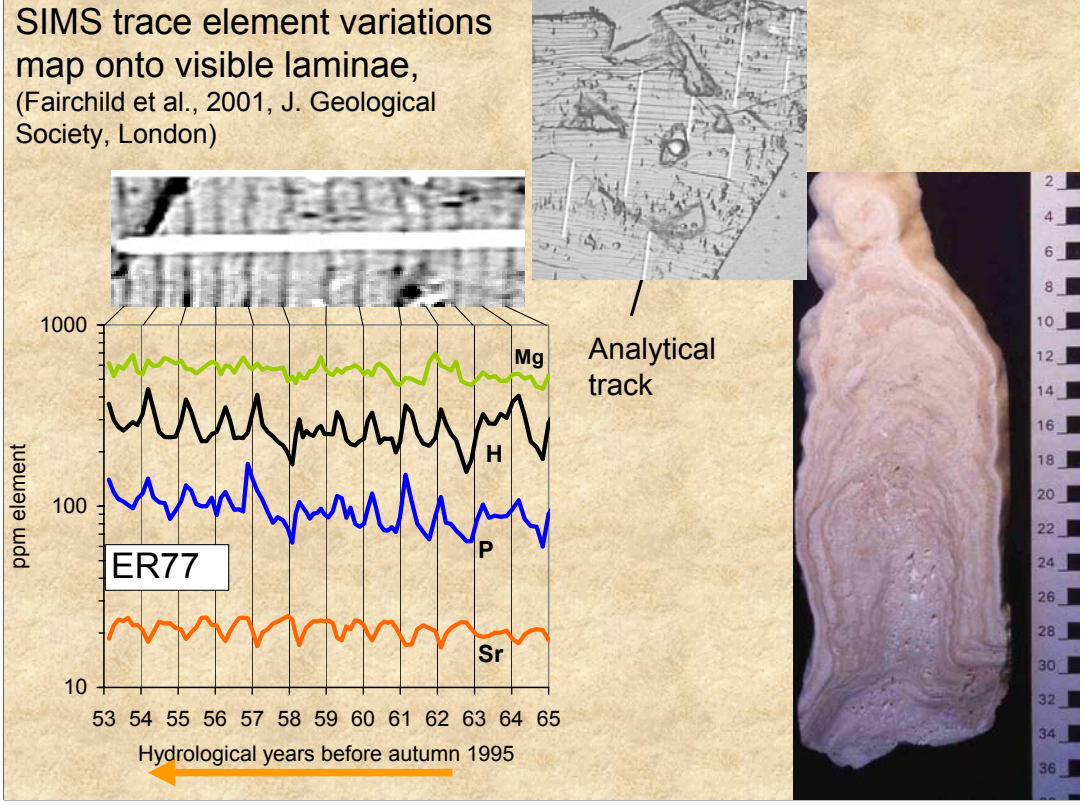
Caves were important shelters and even religious sites for our ancestors, and here a speleothem 9000 years old from one of our study sites in Italy contains a cave bear skull partly covered with charcoal from a fire in the cave.



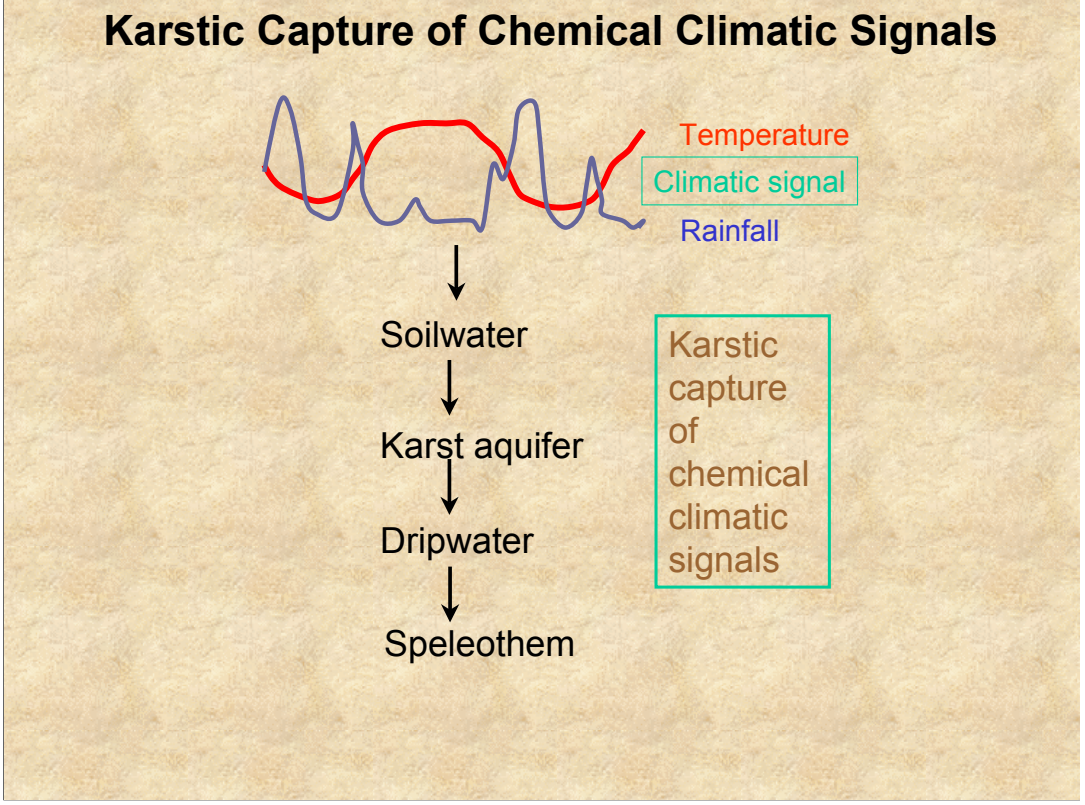
This photo was taken in Grill Cave at Bungonia, NSW, Australia, where the interface of high CO_2 concentration is encountered and O_2 is close to 15%. A butane lighter was lit in good air and gradually lowered into the foul air. The 25mm flame stayed burning just above the oxygen-deficient interface. The photo shows that within the foul air there was insufficient O_2 to support the combustion of butane but, at 75mm higher, there *was* sufficient oxygen.

This phenomenon can not occur with solid fuels, such as matches and candles, as the heat from the flame is required to vaporise the volatile compounds.

Caves can often contain more carbon dioxide than the external atmosphere and this photo shows an unusual case where a layer of rich in CO2 and poor in oxygen is at the level of the lighter and the flame only burns slightly higher up where the air is better.



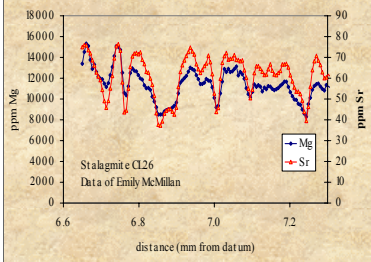
In our work on stalagmites, like this example from the same Italian cave we can sometimes count years by visible layers caused by autumnal rains, but we can also see an annual rhythm of the chemical elements seeking the origin of which has been a major preoccupation of mine for several years.

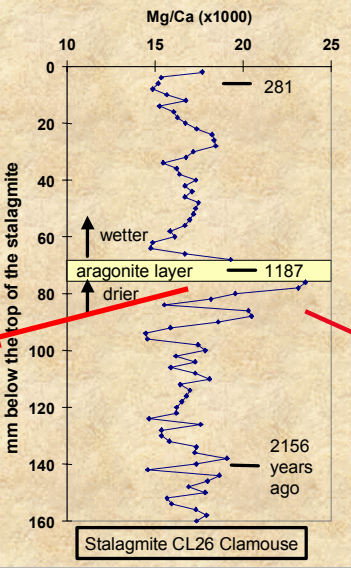


The holy grail is to understand how the climate factors can get entombed inside a stalagmite or other speleothem.

Drought period nearly 1200 years ago shown by chemical changes in stalagmite

Peaks and troughs in chemical elements in the detailed plot of a small thickness (below) show the annual rhythm with prolonged summer drought





This is a nice example being worked on by my student Emily McMillan where the stalagmite from Clamouse in southern France shows annual chemical variations that we can interpret as reflecting a dry summer. These become very intense and even trigger a change in the mineral form around 1200 years ago. It looks as though we may find something similar too in southern Spain.

The Mayans

http://www.civilization.ca/civil/maya/images

Over in central America 1200 years ago, the Mayan civilization showed signs of collapse as the southern Mayans abandoned their cities – and there is evidence of multidecadal droughts at this time. We need to be sure about our data to know if we are recognizing the same event in Europe. And as we'll see later, we need to wonder about if such an event is likely to recur.

Three sources of fascination 3: Systems

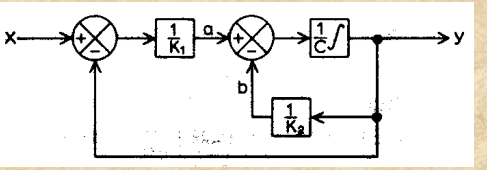
- ……. *a meaningful arrangement of things*

(Schumm, 1977 quoted by Huggett, 1985)

My third technical theme is that of systems – and this beautifully composed photograph of my wife's parents taken by her in France illustrates my favourite definition of a system as a meaningful arrangement of things – something that has resonance in the arts as well as the sciences.

Three sources of fascination 3: Systems

…transfers of matter and energy from place to place...



Bennett & Chorley (1978)

Dick Chorley
(from Gregory, 2000)

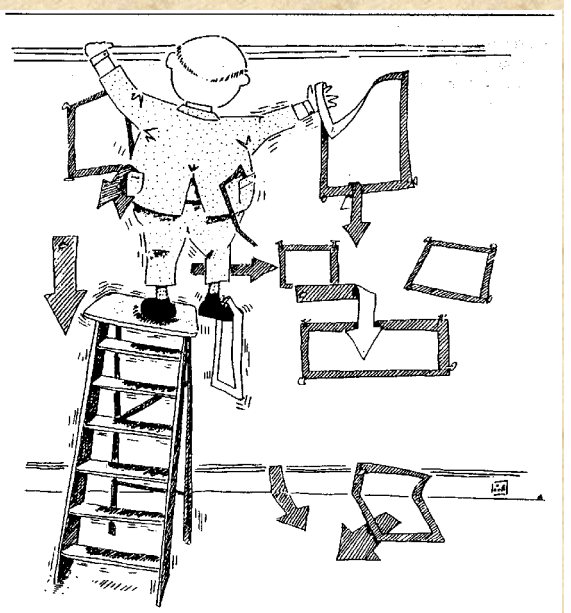
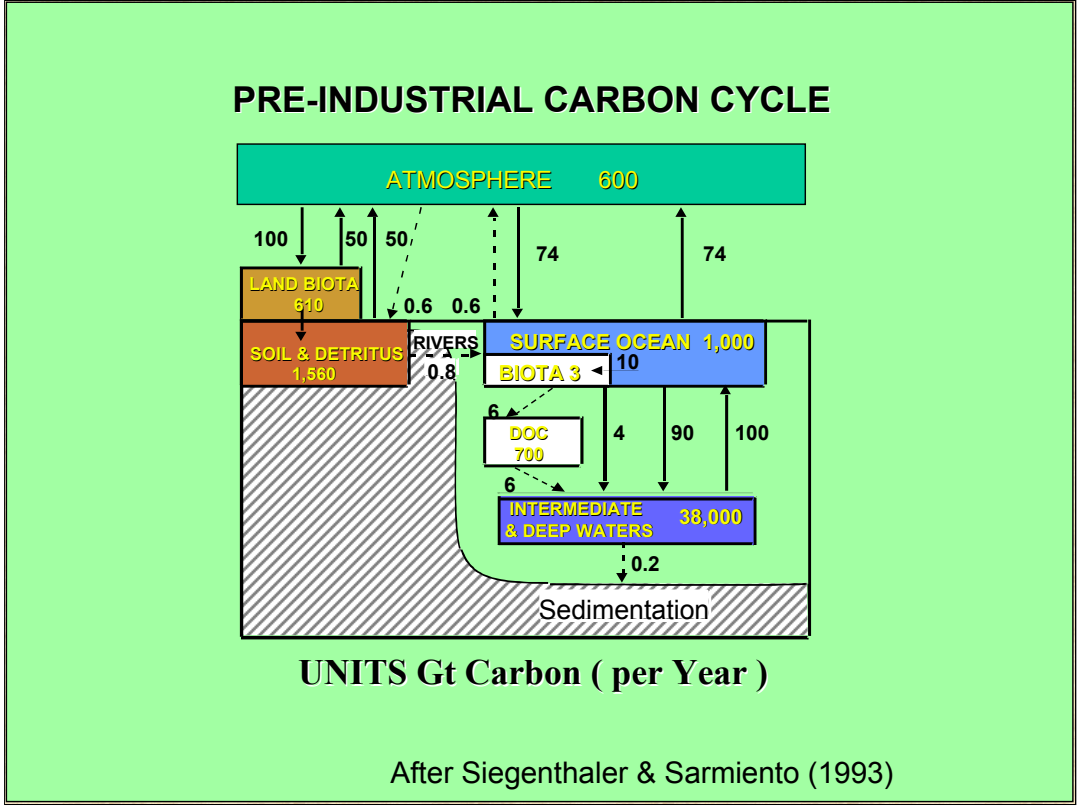
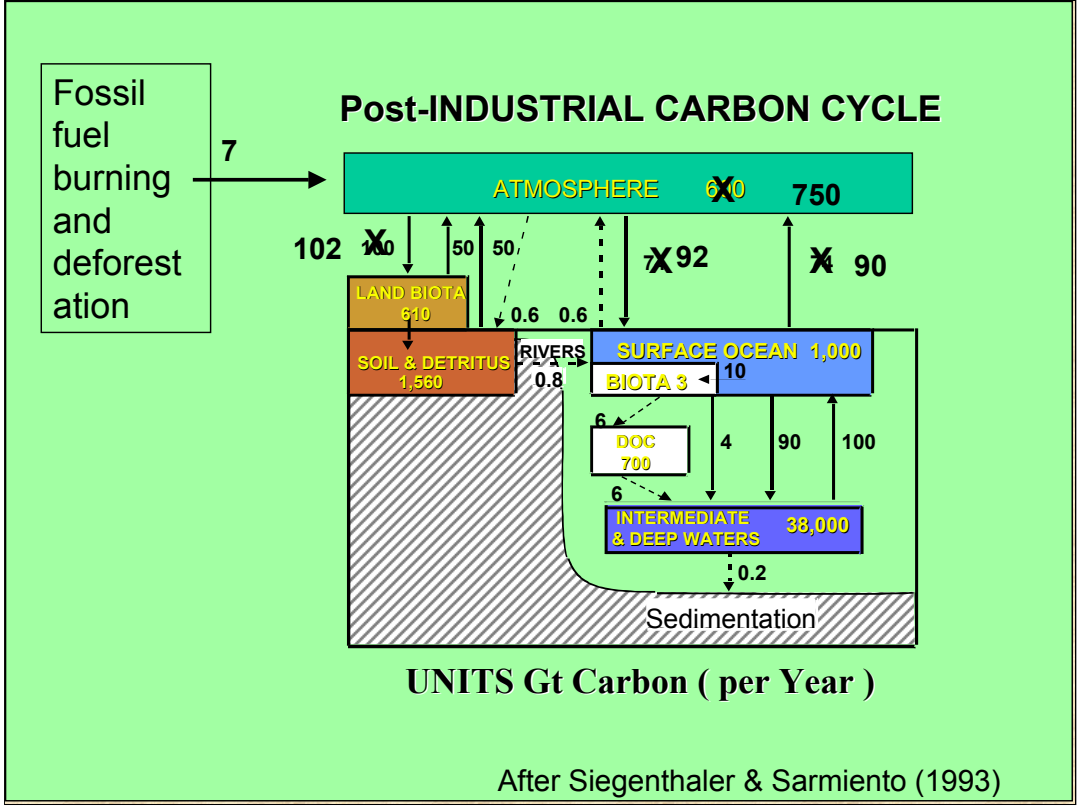


Figure 3.4 A representation of Professor Richard Chorley in the early 1960s (from Stoddart, 1997b, with permission from Routledge publishers). This was described as the way 'a local wag' viewed Dick Chorley constructing one of his many works from that time.

Geographers went mad on systems in the quantitative revolution in the 1960s and 1970s. Subsequently system ideas have become central to all the sciences of our environment - ideas such as Gaia – that life on Earth (perhaps unconsciously) acts to ensure its survival, e.g. by helping to regulate planetary temperature and the broader idea of Earth System Science, that the Earth consists of interconnected parts.



Here is the C cycle on Earth depicted as a system using the convention of boxes showing the amoung of C in a given reservoir and arrows showing the annual fluxes, i.e. the amounts of matter moved from one box to another. sSo when we think of carbon dioxide in the atmosphere, it is connected by flows of matter to lakes and oceans, to land and aquatic plants.

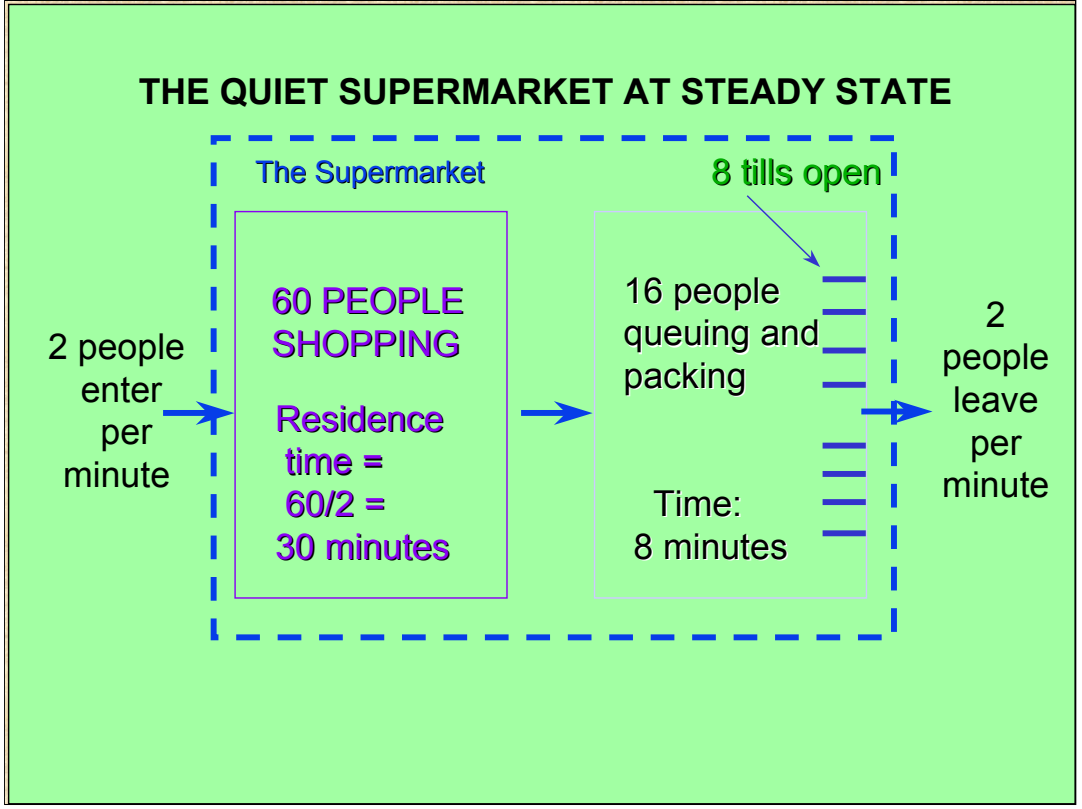


The result of human activities is to increase supply to the atmosphere. This has also stimulated increased take up by plants and the oceans, but the atmosphere is still changing its composition rapidly.

The quiet supermarket

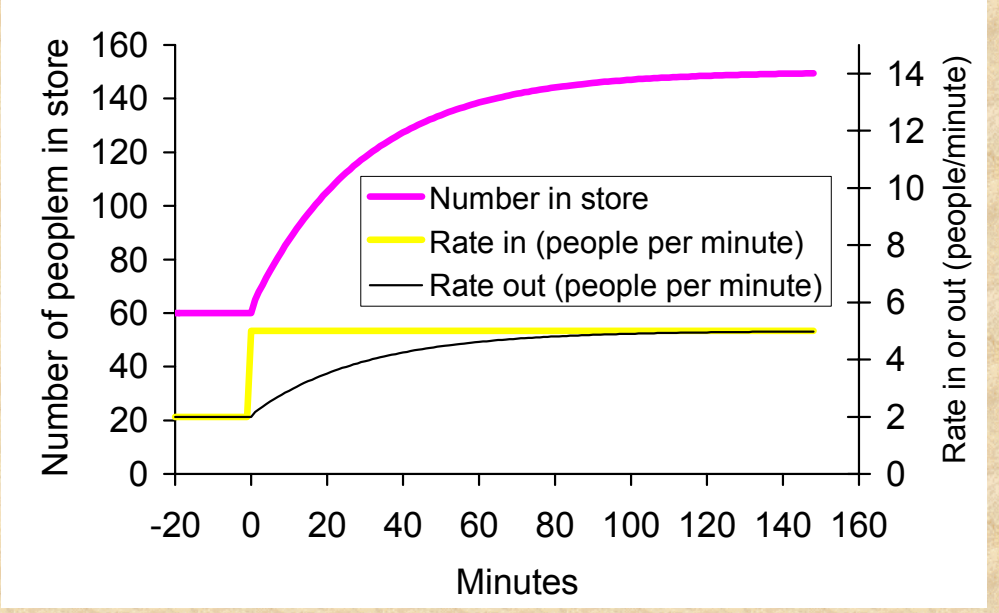
Systems

Let's use an analogy, that I developed originally for my first inaugural lecture at Keele. The people shopping in a supermarket are used to represent the amount of carbon in the atmosphere. Take a quiet supermarket: just two people enter it per minute....



...they spend 30 minutes shopping and 8 minutes at the till. The supermarket is well run and 2 people leave per minute so everything is in balance, or steady-state as we say. This is like the atmosphere before the industrial revolution where a relatively low amount of CO2 was present, corresponding to a relatively empty store.

Quantifying systems



If the supermarket gets busier, the manager has to respond by opening more tills. If they do this at the right time they can keep the numbers going out of the store the same as the numbers coming in. We reach a new steady state, but the number of people in the store is much greater than before. That's what we're doing to our atmosphere now.

Now I want to introduce you to my CO2 probe that has been quietly logging the amount of carbon dioxide in this room whilst I have been speaking. The results are displayed on this screen and you can see the effects as people have entered the lecture room. The CO2 changes because we exhale CO2 in our breath. Let's find out how much by asking someone to blow into this bag....

Composition of atmospheric air and expired air in a typical subject.
Note that only a fraction of the oxygen inhaled is taken up by the lungs.

Component	Atmospheric Air (%)	Expired Air (%)
N_2 (plus inert gases)	78.62	74.9
O_2	20.85	15.3
CO_2	0.03	3.6
H_2O	0.5	6.2
	100.0%	100.0%

http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/P/Pulmonary.html (J.Kimball of Harvard's on-line biology text)

This chart shows us the typical CO2 content of breath. Oxygen goes down and CO2 goes up. High CO2 levels are an indication of bad air and don't half make it more difficult to concentrate in lectures!

The Office Experiment

CO_2 content of my exhaled breath: 3.6% (36000 parts per million)

At rest – breaths per minute: 15-18

Air exchanged per breath: 0.5 litres

http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/P/Physiology.html (J.Kimball of Harvard's on-line biology text)

Volume of CO_2-rich air exhaled per minute: 8 litres

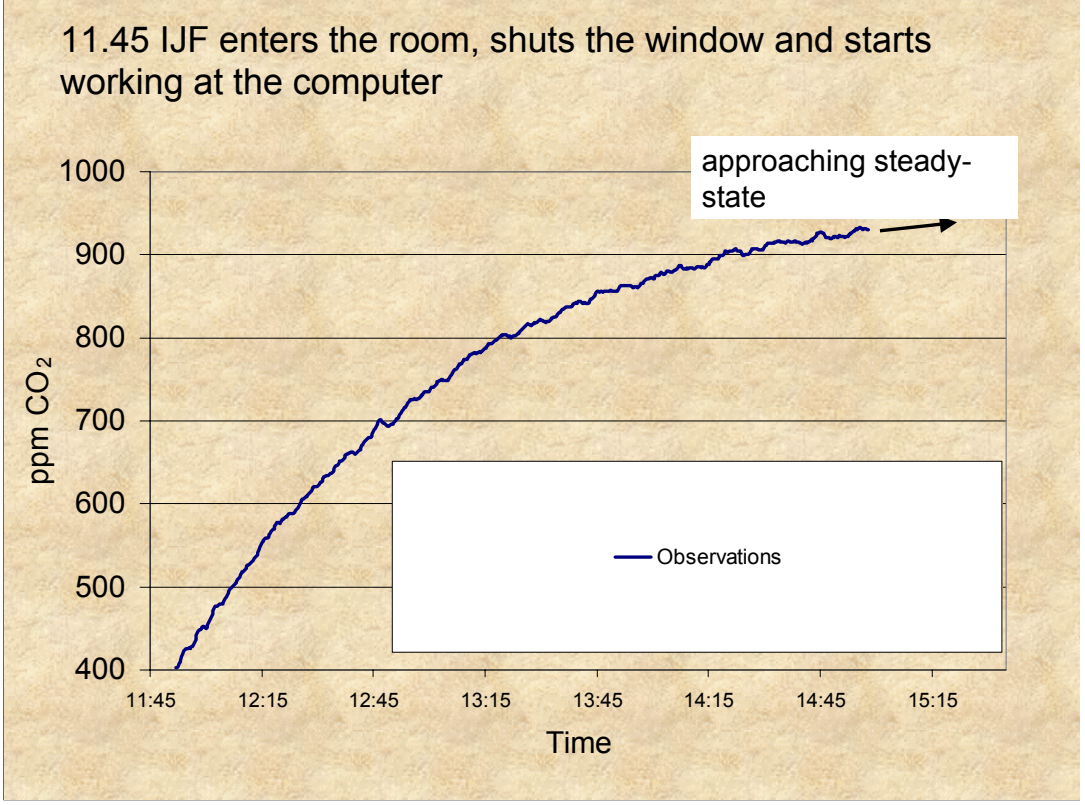
Volume of my office: 32 m^3 = 32,000 litres

Time to exhale the volume of my office = 4,000 minutes

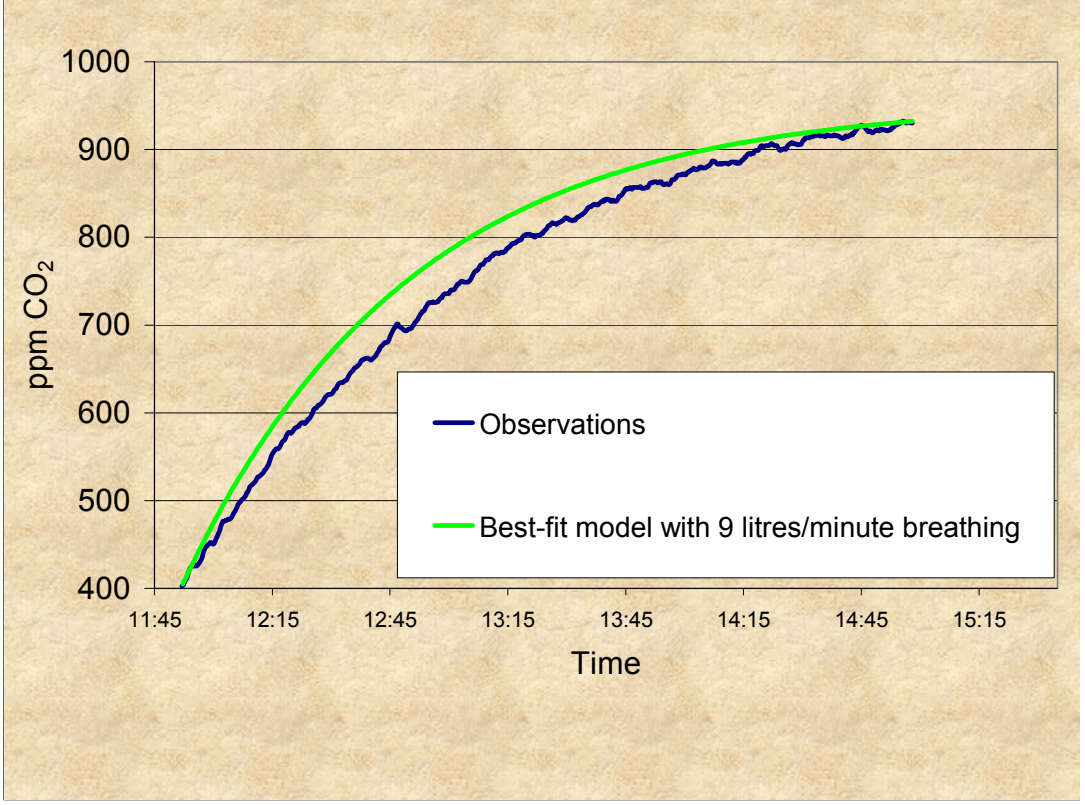
Rate of addition of CO_2 = 36000/4000 = 9 ppm per minute

20th April 2004,11.44 a.m., Room GES421: window open;
CO_2 in air just above outside atmospheric value of 380 ppm

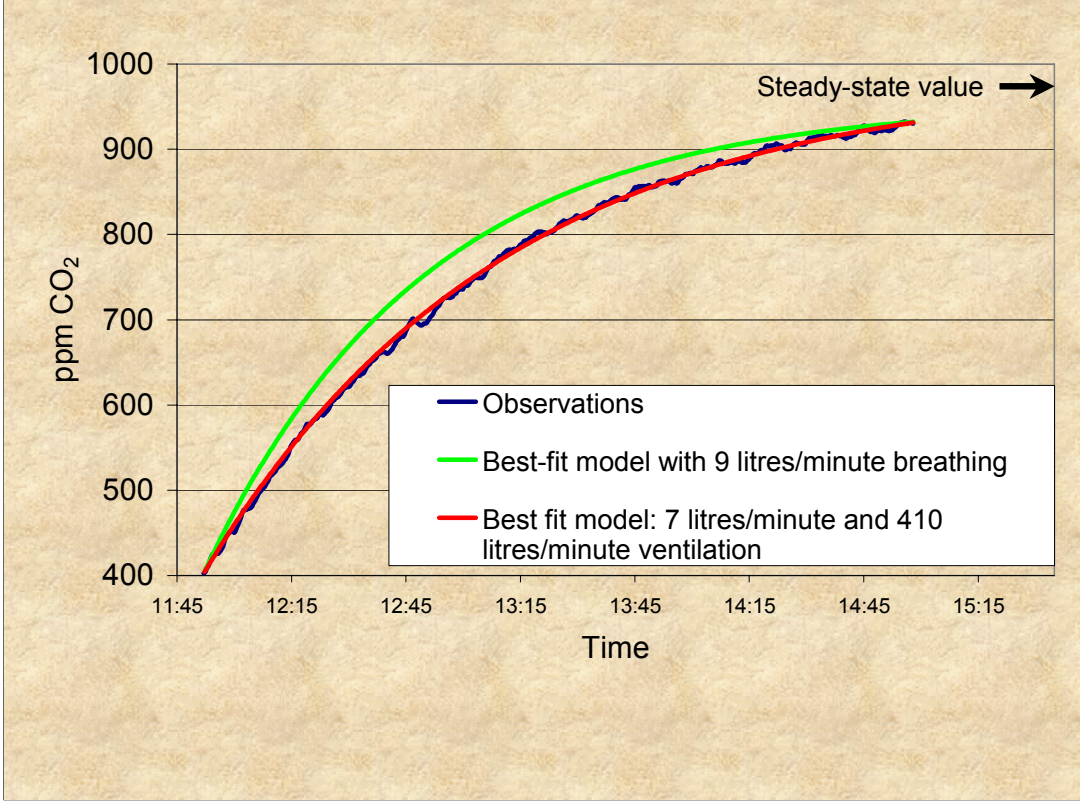
I did an experiment on this in my office last month. I found these facts on respiration and used them as parameters in a simple system model. The model assumes that I breathe at a constant rate and that there is steady exchange of air between the office and the external atmosphere.



I started the experiment and sat quietly at my desk as it proceeded. You can see that after 3 hours we are approaching a new steady state because the ventilation process becomes progressively more efficient at removing CO2 as the gas builds up in my office.



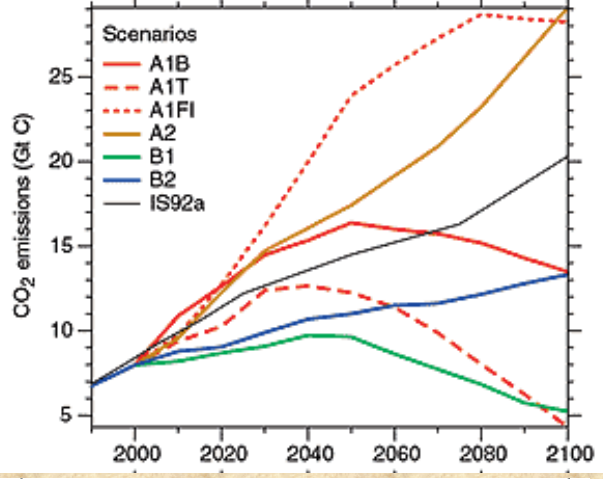
Comparing these data with a model calculated assuming that I breathed at 9 litres/minute doesn't quite fit.



But if I change to 7 litres a minute, the fit is excellent. From this I can estimate that even though the window is closed, 410 litres of air is exchanged across the ventilation grill per minute and so the air in the room is changed about once an hour.

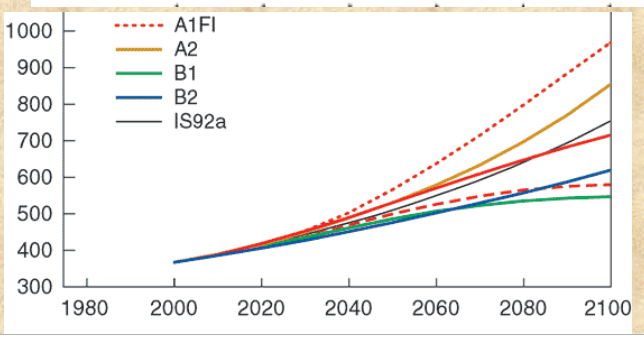
What happened in my room during those hours is what could happen to the atmosphere depending on our emissions:

If we emit this much CO_2:



This will be the atmospheric concentration of CO_2:

(GCM models, IPCC Houghton et al., 2001)



The middle of this range is thought to lead to a global temperature rise of about 3 degrees C

What happened in my room during those hours is what could happen to the atmosphere depending on our emissions:

(The Kyoto protocol targets would involve reduction of the total greenhouse gas load between 2000 and 2010)

Three-by-three

A. Three sources of geographical knowledge

B. Three sources of fascination for me: CO_2, speleothems and systems

C. Three comparable physiologies: person, cave and planet

Now to the comparative physiologies: person, cave and planet (building on the exising concept of planetary physiology developed by James Lovelock)

A person

Has a history

Has a physiology acting as a system

e.g. by maintaining a constant temperature (homeostasis)……

e.g by breathing – exhaling excess CO_2

but any body will suffer if abused, and for any body there are dangerous thresholds

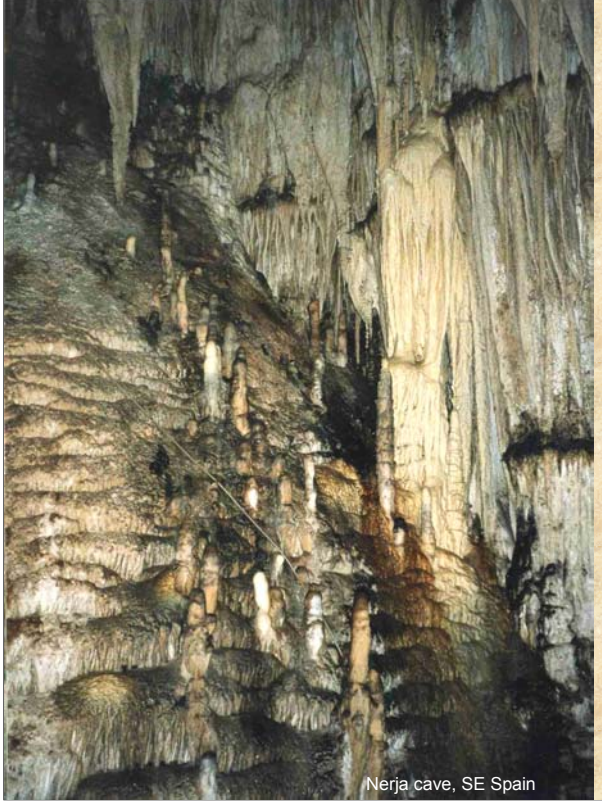
A cave


Brenta Dolomites, Italy

Has a long history, mostly of gradual growth over perhaps millions of years


Brefugio cave, SE Spain

Speleothems only form towards the end of its life

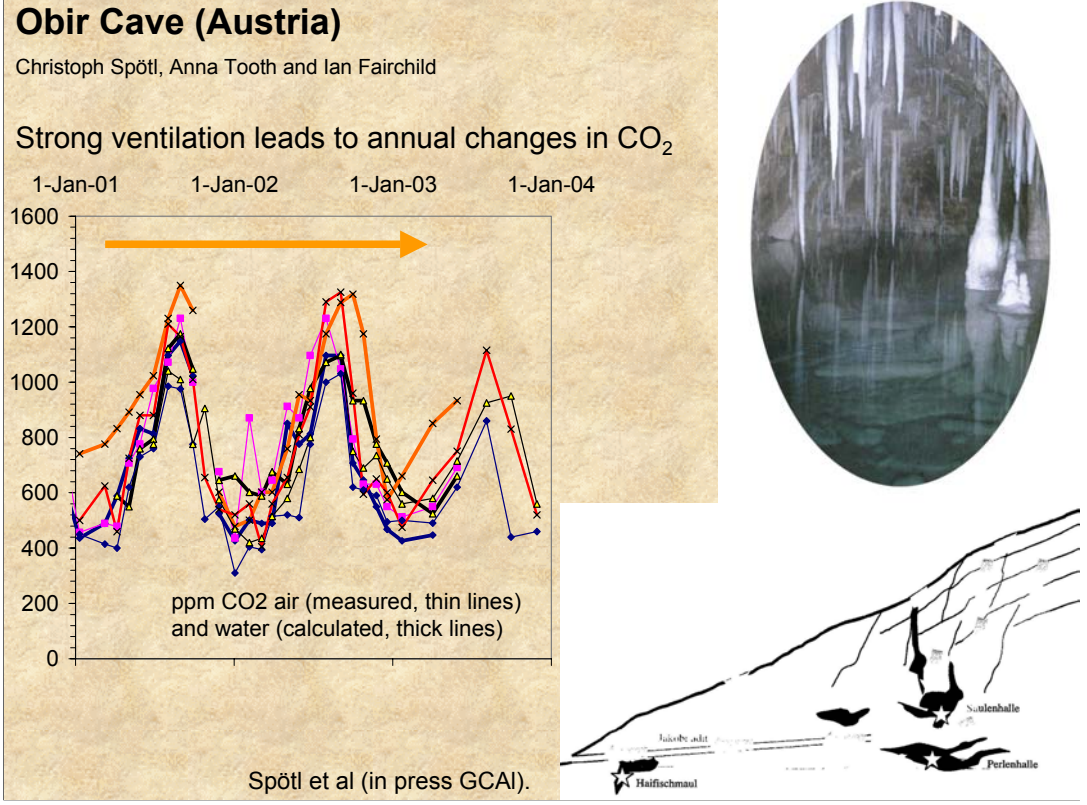

Nerja cave, SE Spain

A cave

Has a physiology acting as a system

e.g. by maintaining a constant temperature (homeostasis)……

e.g. by exhaling CO_2 and exchanging it with the outside atmosphere



We have a beautiful example now from Austria of a cave system showing annual variations in CO2. This one is strongly dynamically ventilated, whereas other caves show much more muted "breathing". We are just beginning to get an understanding of what controls these effects and are having to discard some long-cherished ideas; this effect is probably responsible for most examples of annual changes in trace elements in speleothems. So to understand the cave records of climate we need to think of the cave more in terms of its physiology – a relatively neglected field to date.

Cave paintings, Chauvet, c. 35 ka old

A cave

Can suffer from abuse (excess visitors – CO_2 damage, vandalism, excessive water loss etc….

And will ultimately be filled or collapse as thresholds of change are crossed

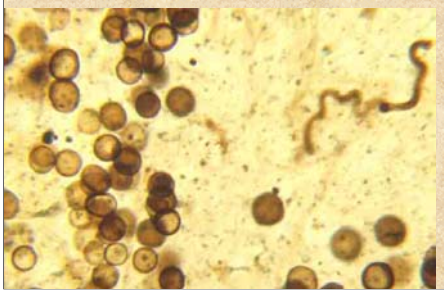
Fallen stalactite – the Lance, Nerja cave

This planet

Has a long and interesting history

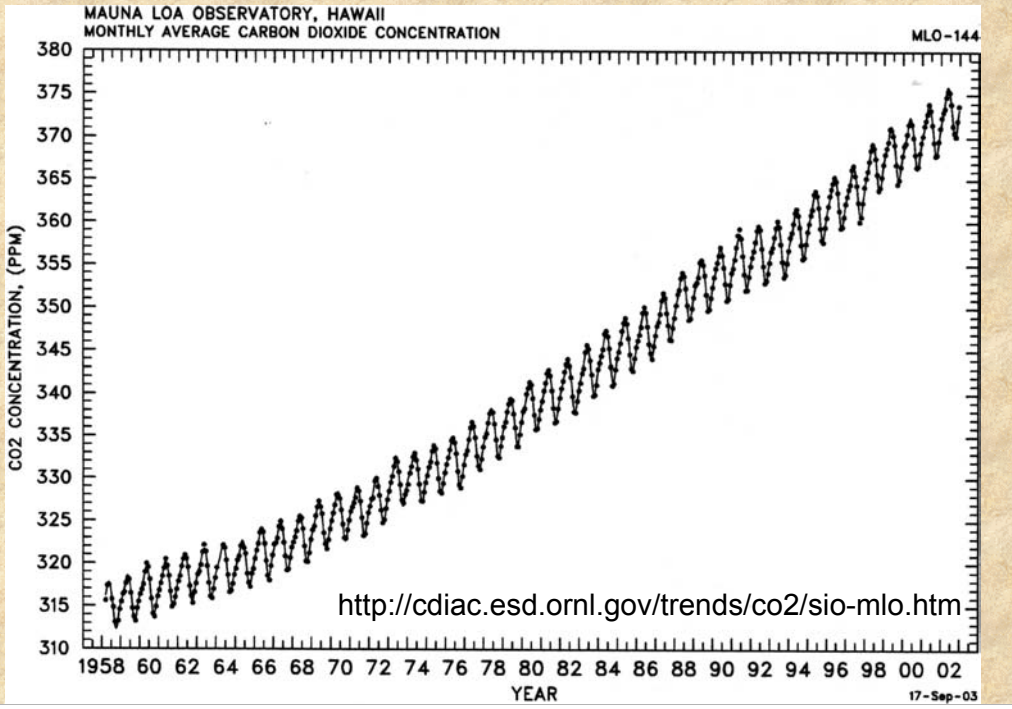
NASA

Has a physiology acting as a system (Gaia)
e.g. by maintaining a relatively constant temperature for 4 billion years whilst the sun has warmed by 40%



Precambrian photosynthetic organisms (Svalbard)

This planet – exchanges CO_2 as part of its core business

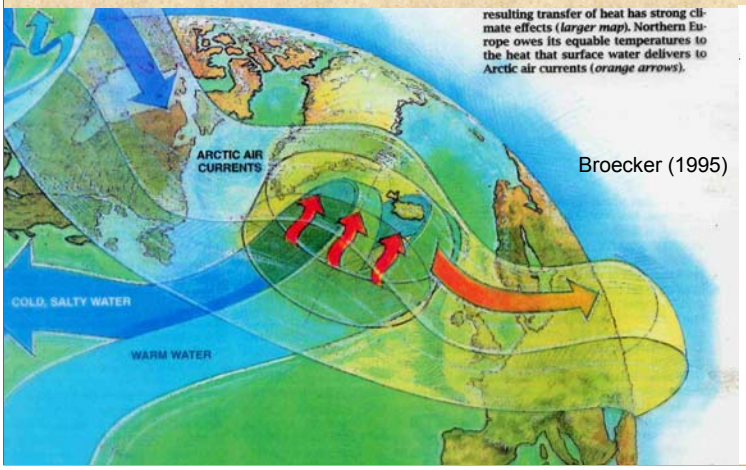


The annual rhythm of CO_2 change recorded at Hawaii superimposed on its inexorable rise has been likened to the Planet breathing

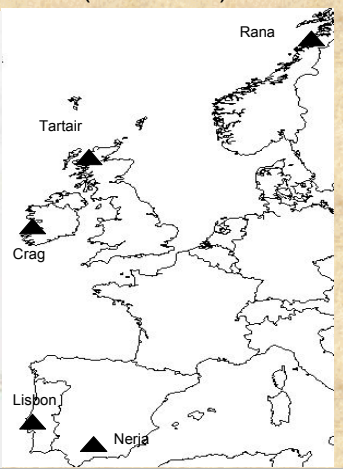
But the Planet can have dangerous thresholds…….

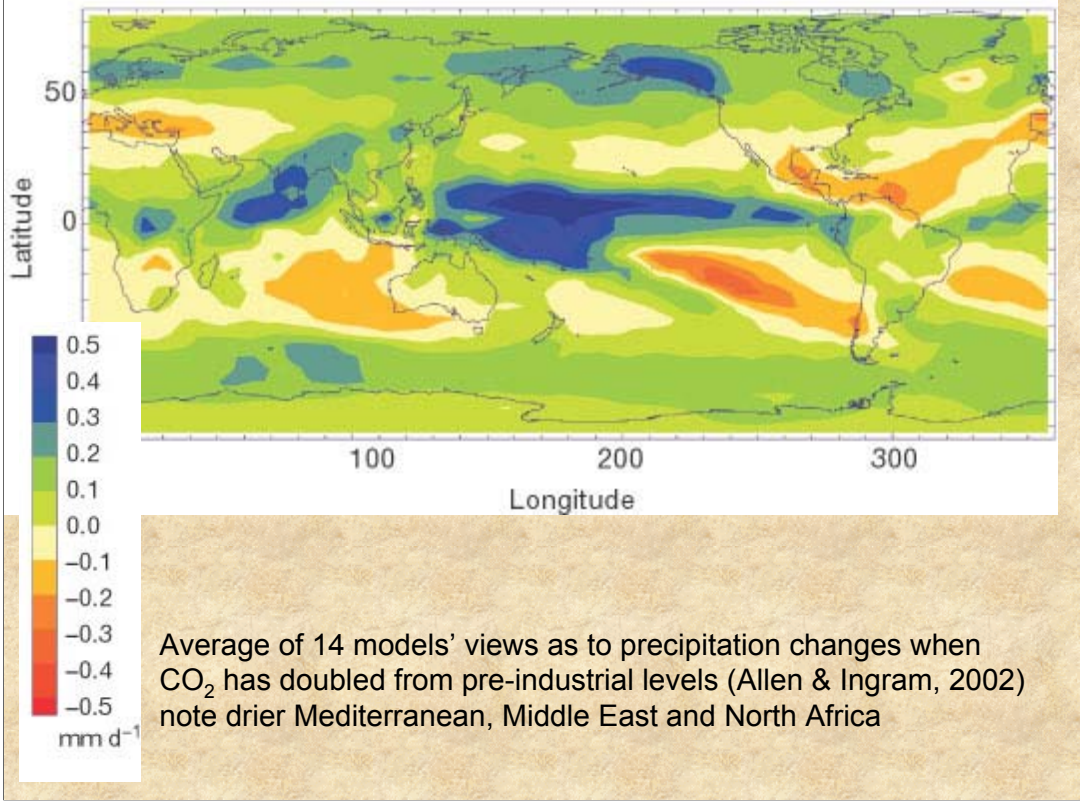
Will our Gulf stream be destabilized by freshwater input in the coming decades? (We know it will be slower than in *The Day after Tomorrow*!)

Focus of Birmingham-led research programme called ASCRIBE (Atlantic Seaboard Climatic Reconstruction Including Bounding Errors) funded by the Natural Environment Research Council under their RAPID climate change programme (2003-2006)



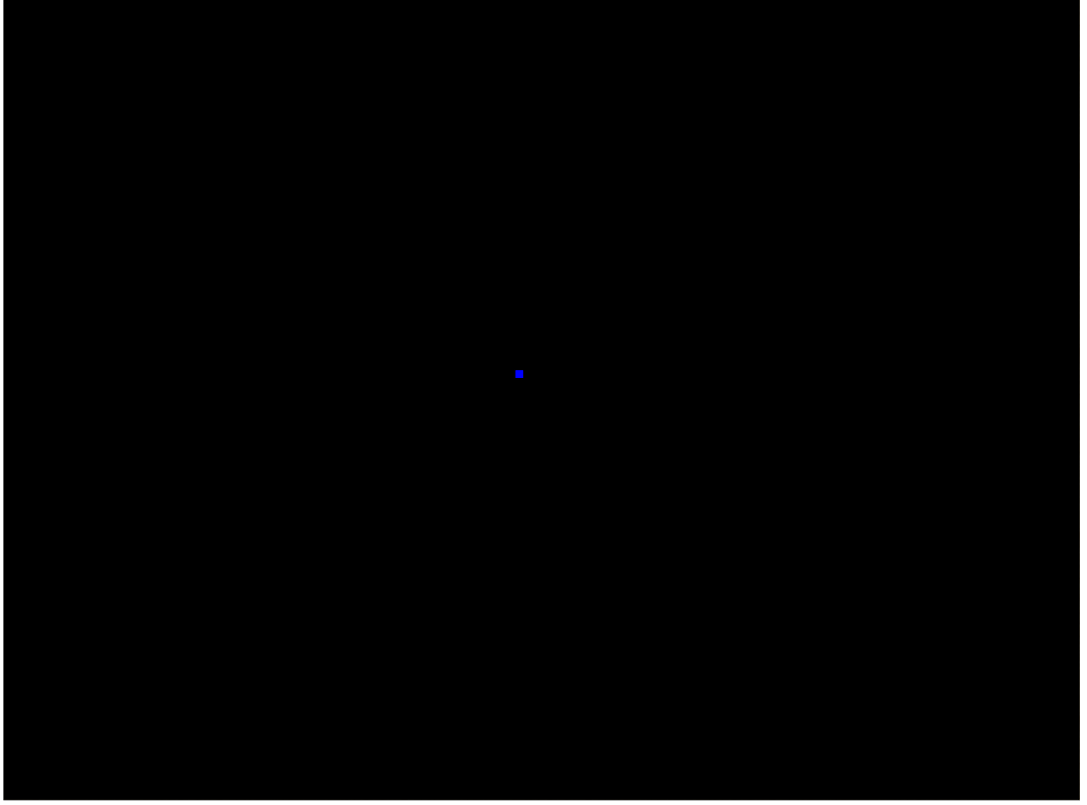
Broecker (1995)





Average of 14 models' views as to precipitation changes when CO_2 has doubled from pre-industrial levels (Allen & Ingram, 2002) note drier Mediterranean, Middle East and North Africa

Here is the long-range annual rainfall forecast for later this century when CO2 has reached 560 ppm: its only a model, but doesn't it look like our possible 1200 year old drought in France, Spain and central America? What price world stability when the water dries up in the Middle East? So when Sir David King says that climate change is an even bigger threat than terrorism – actually it's a problem that is intertwined not just with terrorism but more generally with the aspirations of peoples in poorer, dry countries who could be driven from their lands by climate change. The smallest likely price to pay for our oil, coal and gas-burning lifestyles now is that of dealing with mass migration later.



And so as we near the end of this lecture, I put aside my gown. It, like this experience, is ephermeral, just 50 minutes of my 50 years, that's around one 500,000th of my life. And this small soda straw – so fragile – it took a few years to grow – around one 500,000th the life of its cave (crushes straw). And our civilizations - they've been coming and going for 9 or 10 thousand years now – just one 500,000th of the history of our planet (Lights off)

The dinosaur's advice

The Princes of Serendip

Music purchasable at *http://www.princesofserendip.info/*

Lyrics by T. G. Vanini include the words –

“This is the dinosaur's advice..
And since you've nowhere else to go
Might as well take good care of your home

Once in a million years I awake and look at the Earth…
And next time I look, you won't be there”

Music plays

http://www.princesofserendip.info/

Adapt or die!

A Charley Parker cartoon

http://www.dinosaurcartoons.com/