The Westminster Briefing

Presentation 1:
An Introduction to Climate Dynamics

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This opening presentation provides a generalised introduction to climate dynamics and to the system of feedback mechanisms within it.

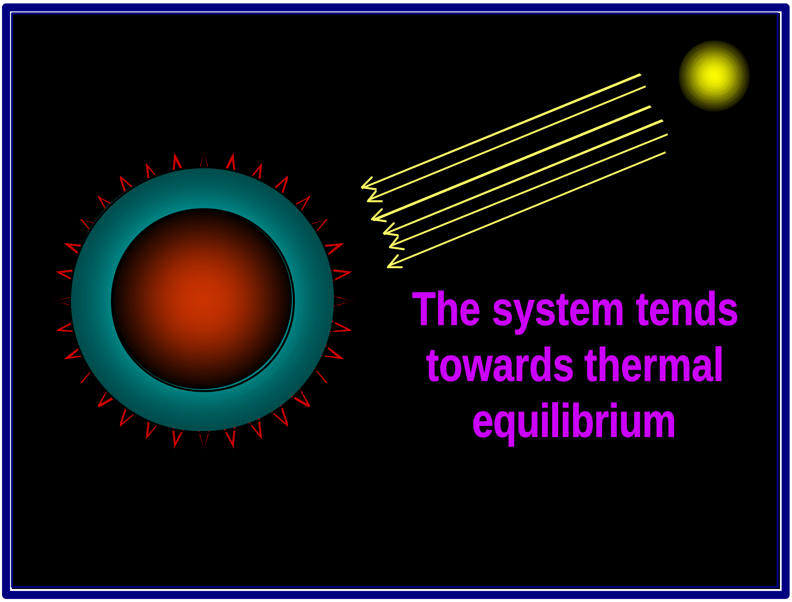

Figure 1.1

We begin by viewing the earth hanging in space as a "hot black body" giving out infra-red radiation through its mantle of the atmosphere, and receiving energy from solar input.

It achieves a stable surface temperature with radiation just balancing inputs of energy from outside the system. That is what we would call climate in an equilibrium state.

To be sure, over the last one million years, temperatures have varied from ice-ages to warm inter-glacial periods, but the climate has stayed roughly in equilibrium during those transitions.

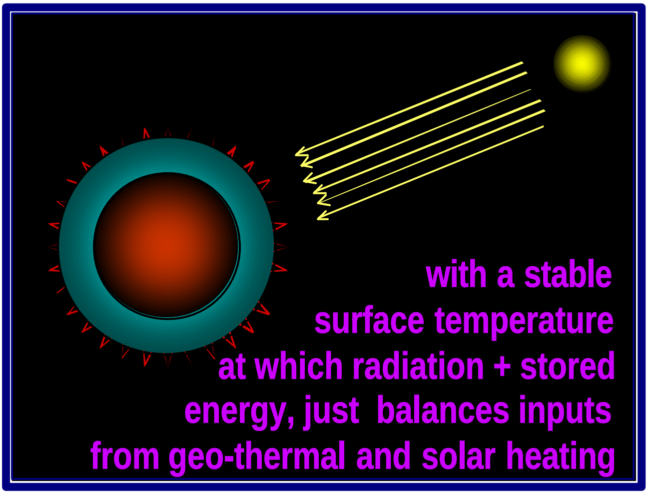

Figure 1.2

Until homo so-called sapiens arrived on the scene and decided that instead of just working with what we could harvest from solar inputs year by year,

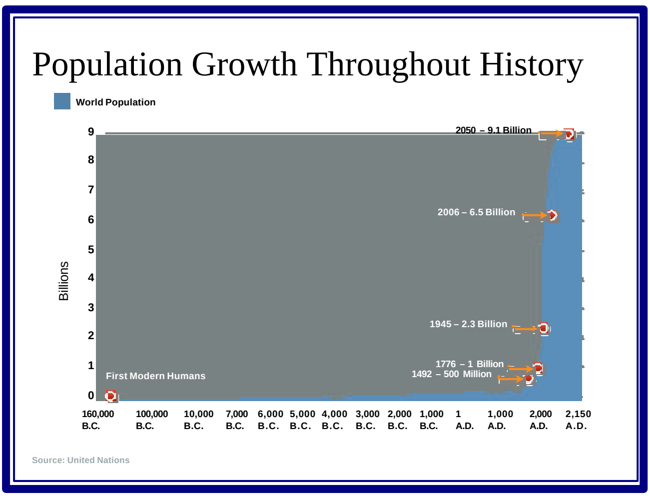

Figure 1.3

we would dig up the remnants of solar energy from millions of years ago and use that as well. In so doing we set off a population explosion which reached about 2.3 billion by the middle of the twentieth century, and now stands at 6.5 billion. It is likely to peak at between 9.5 and 10 billion by 2050, though any such prediction is subject to a wide range of contingencies.

Figure 1.4

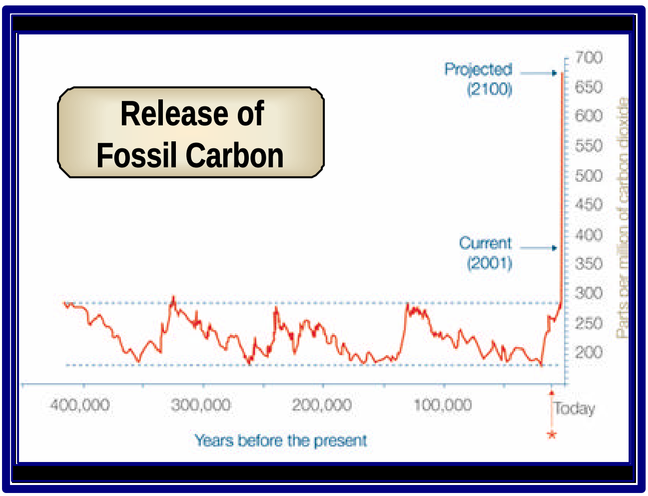

Figure 1.5

As one of the inadvertent polluting by-products, we released back into the atmosphere the carbon that had been biologically sequestrated to cool the earth in the natural process of things over many millions of years. This has pushed the concentration of atmospheric carbon dioxide way outside the pattern of variation over the last 400,000, to 1 million years.

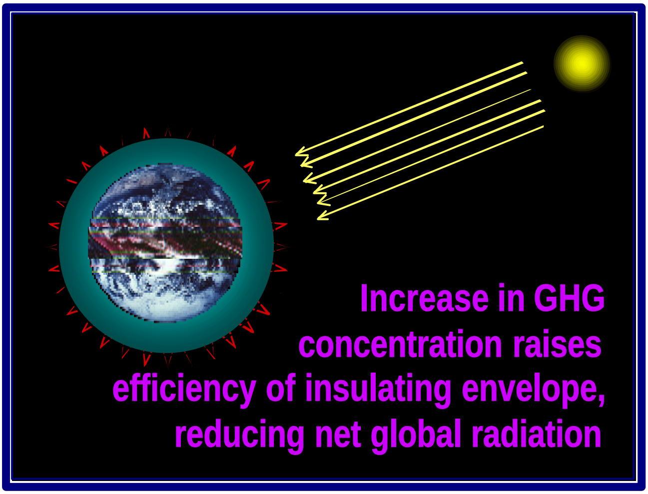

Figure 1.6

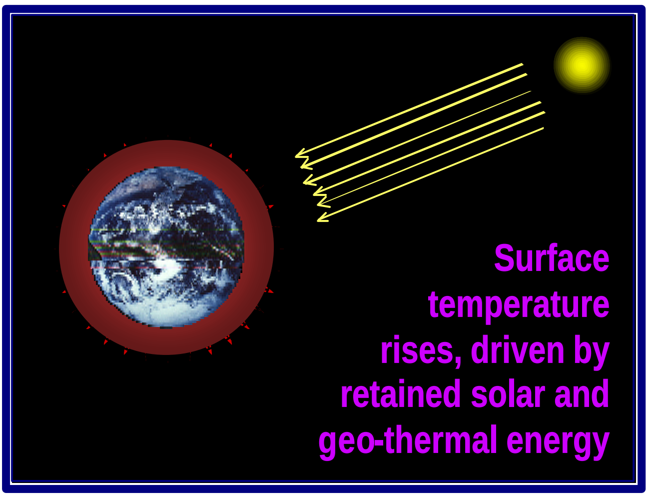

Figure 1.7

It currently stands at around 384 parts per million (ppm), and it is projected (under the "business as usual" scenario) to go up towards the 650 ppm by the year 2100.

Increasing the concentration of greenhouse gasses raises the efficiency of the "duvet", the insulating atmospheric mantle. It reduces the outgoing radiation. That in turn begins to drive up the temperature of the surface.

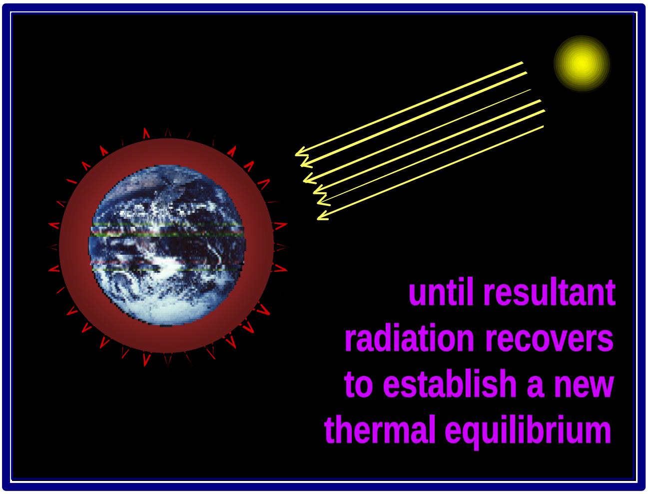

Figure 1.8

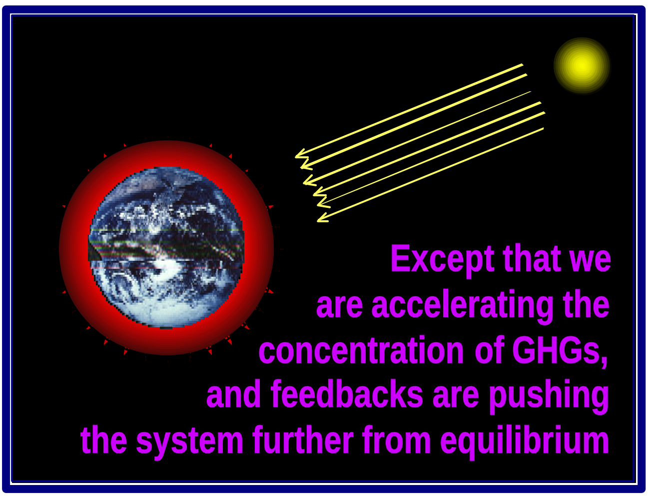

Figure 1.9

The temperature goes on going up until thermal equilibrium is re-established, at which outgoing radiation from a hotter surface just balances input of energy from the sun. Or at least that is the theory.

In practice the increase in concentration of greenhouse gasses is not a single "step" change. It is a continuous and accelerating process. We are continuously improving the tog of the duvet, so it gets hotter and hotter in bed, and cooler in the room outside. The temperature goes on increasing, accelerated by the effects of positive feedback. The time-lag between the current surface temperature and the attainment of eventual equilibrium becomes bigger and bigger.

At this point we move on from the initial presentation of the thermodynamics of the whole earth in its spatial context. In the next section, we begin to explore the set of factors that drive climate change and the system of positive feedback mechanisms that threaten to push it into uncontrollable behaviour.

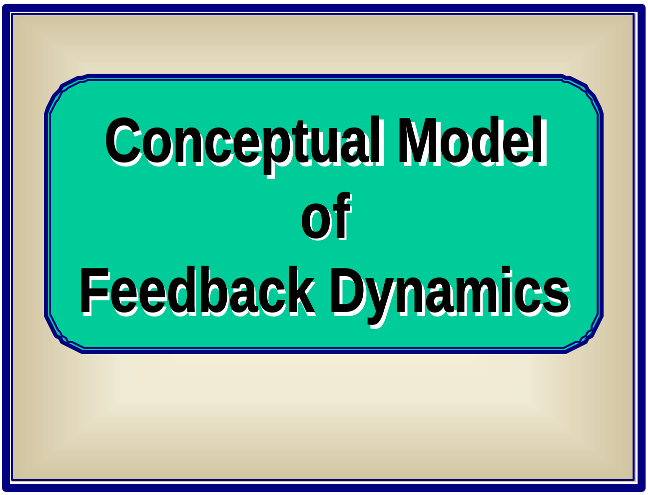

Figure 1.10

The system that governs the behaviour of the climate is made up of many elements and they are also subject to feedbacks which accelerate their effect on the problem. We will now develop a conceptual model of feedback dynamics and start with the very basic drivers of the climate system.

Geo-thermal energy is pretty stable. It is comparatively small, and changes over very long time-scales, so for our purposes we are going to ignore it. Solar energy obviously is the main heater. The elements that drive change in global heating are represented by the green boxes in the lower part of the slide.

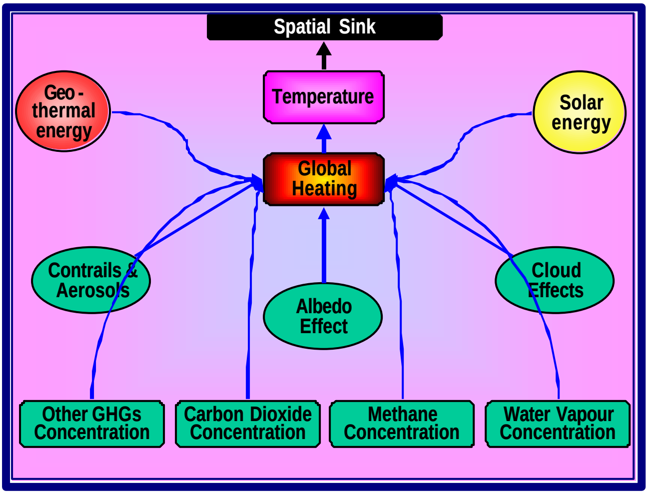

Figure 1.11

Increase in carbon dioxide concentration drives the greenhouse effect, as does methane release. Other greenhouse gasses, the nitrous oxides, the CFCs, and ozone also contribute to global heating. Contrails and aerosols, aircraft trails and particles in the atmosphere, also make a difference, as do water vapour concentration and cloud effects. Albedo, the reflection of solar radiation from land surface, vegetation, oceans and ice, completes the set of elements in the overall climate system. They drive global heating – technically radiative forcing – and slowly that pushes the temperature up, and that eventually enables more energy to radiate out to the spatial sink.

Now we can introduce the feedback system. (See *Figure 1.12*) We have identified 8 categories of feedback here and there is still one in hiding which I will introduce in a moment. Feedback categories may each contain many feedback mechanisms and I am going to give you a brief introduction to that system before handing on to Peter Cox to look in detail at what is going on in the carbon cycle.

The feedback Category **F1**, is driven by rising carbon dioxide concentration. It effects and accelerates change in carbon dioxide concentration. It also has some minor effects on the albedo. All other categories are driven by rising temperature. The hotter it gets, the faster it gets hotter!

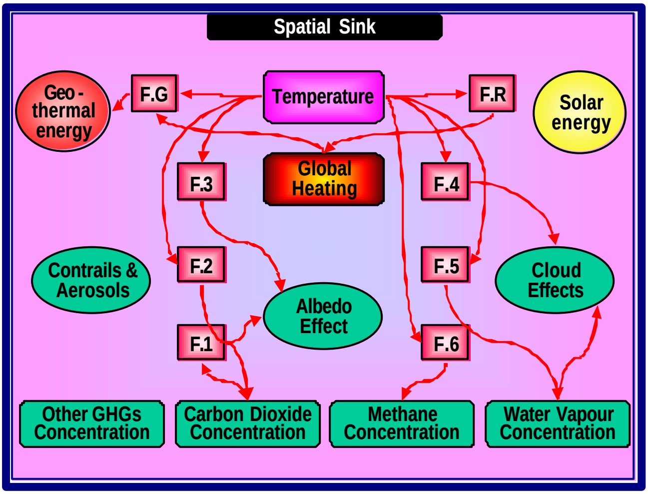

Figure 1.12

F2 is temperature driven and affects carbon dioxide concentration. **F3**, also temperature driven, changes the albedo effect. **F4**, temperature-driven, works on clouds. **F5**, changes water-vapour concentration, and finally, **F6** is temperature driven and works on the methane cycle. The feedback category relating to solar radiation is also important, and I will speak about that in a moment.

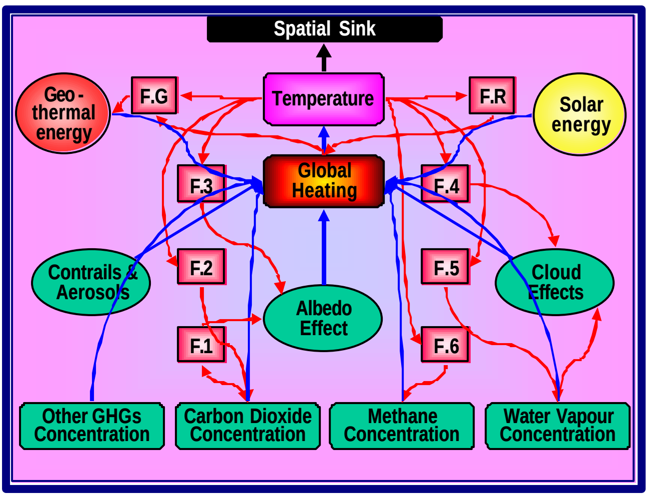

Figure 1.13

Now we can combine feedbacks and the standard drivers. And this slide has many active links. If I click on “Solar Energy”, it opens up the radiation cycle.

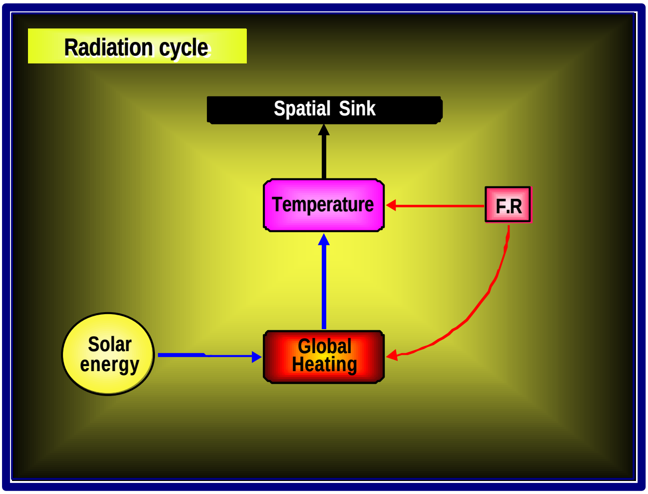

Figure 1.14

Solar energy, trapped by the greenhouse effect, drives global heating. Slowly (because the thermal inertia of the earth is so massive) temperature goes up. More energy is eventually radiated back out to the spatial sink.

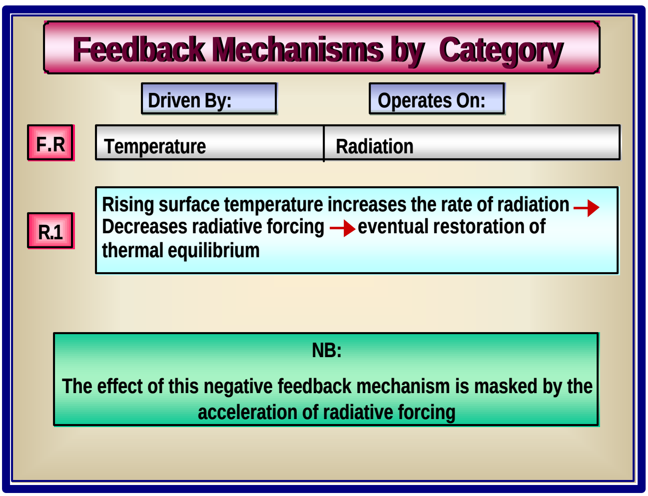

Figure 1.15

There is a feedback category in this cycle that we can explore. It is driven by rising temperature and effects the rate of radiation.

Rising temperature of the surface of the earth increases the rate of radiation into space, so that discharges the tension between inputs and outputs and would eventually restore thermal equilibrium. Except of course that we are making it worse all the time, so the effect of that feedback mechanism is masked by our acceleration of radiative forcing.

Next we can explore the carbon cycle. I will give a brief summary before the detail is covered by Peter Cox.

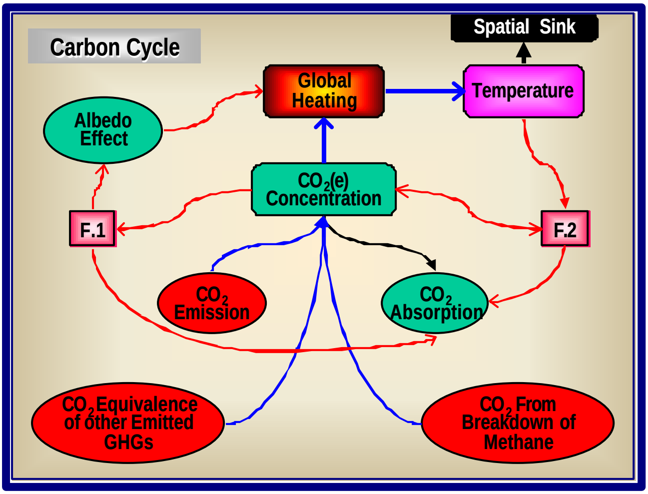

Figure 1.16

CO_2 emissions from all sources, other greenhouse gasses put here as CO_2 equivalents, and CO_2 from the breakdown of methane in the atmosphere – all contribute to the CO_2 equivalent concentration. There is a sink that absorbs some of that back into the land and the ocean and the vegetation. The rest of it contributes to radiative forcing – global heating.

Let us now turn to the feedback categories in the carbon cycle, **F1**, **F2**. For instance, in Feedback **1.1**, rising CO_2 concentration leads to acidification of the ocean water and highly acidic water does not take up so much CO_2, so that is a positive (amplifying) feedback. No.**1.2** – plankton do not thrive in acid water, so we get an increasing destruction of plankton and therefore the sink that they represent also starts to degrade.

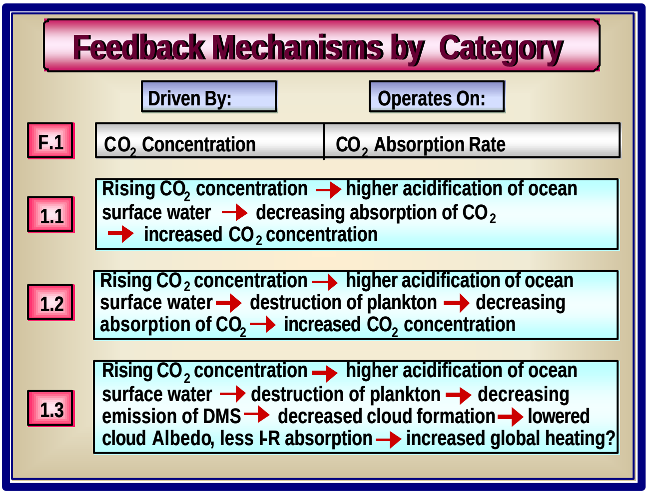

Figure 1.17

1.3 is a technical one. As the plankton population goes down they give out less dimethyl sulphide. It is a gas which breaks down in the atmosphere to create tiny crystals of sulphur around which droplets of water form. As a consequence the cloud does not form as well over the derelict seas that have become too hot for plankton to operate. That feedback is an ambiguous one, with lowered albedo compensated by lowered absorption of infra -red radiation.

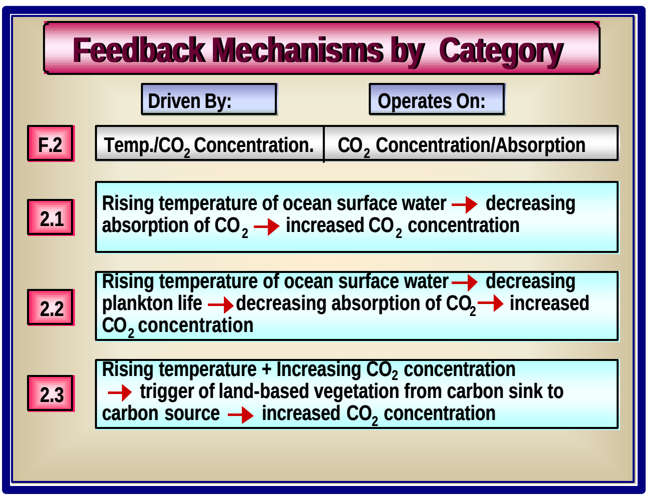

Figure 1.18

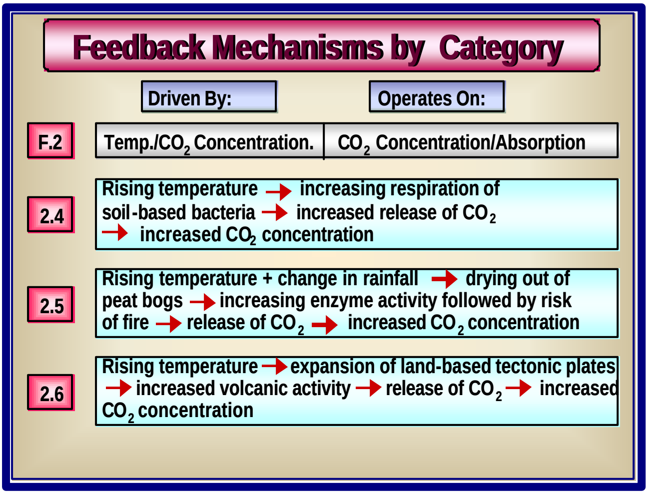

Figure 1.19

Figures 1.18 and *1.19* outline six feedback mechanisms in the carbon cycle that are driven by rising temperature, and Peter Cox will address these in detail.

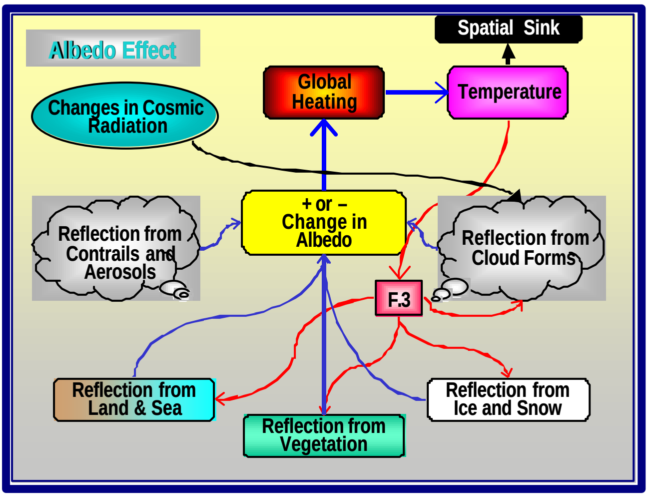

Figure 1.20

Next we take a look at the albedo cycle. Reflections from all surfaces, land and sea, vegetation, and ice and snow, change the albedo effect positively or negatively, so changing the reflection of energy back out into space.

There is reflection from aircraft trails and aerosols in the atmosphere and from natural cloud formations. There is also a small input from changes in cosmic radiation, which over a 22 year cycle of sunspot activity, changes the way clouds form. We can ignore that unless it happens at a very sensitive point in the system's behaviour.

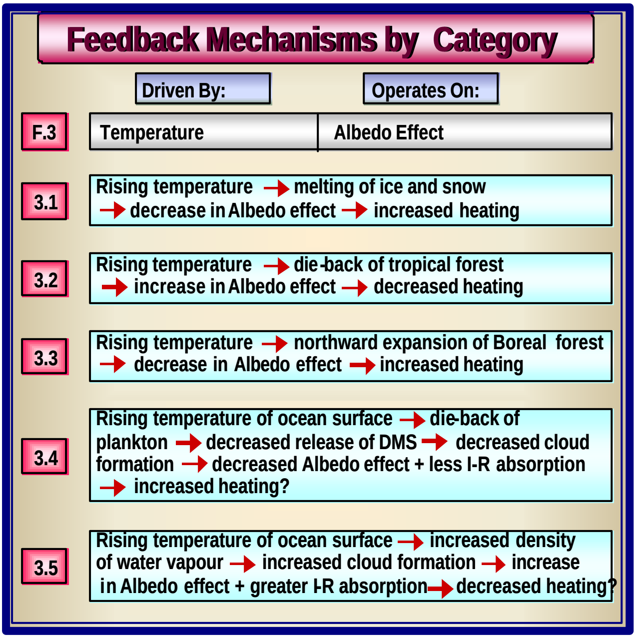

Figure 1.21

Figure 1.21 outlines the various feedback mechanisms in the category **F3**. Some of this will be Peter Wadham's domain. Temperatures go up, melting ice and snow, less reflection, more absorption, increased heating. Dieback of tropical forest, increased albedo effect – because savannah reflects more than forest does – decreased heating, that is a negative feedback. (But by the way, as Deepak Rughani will be noting, a massive amount of carbon is released into the atmosphere as the forests die back. The vegetation also ceases to act as a carbon sink, which is something that Peter Cox will be looking at.) Rising temperatures lead to northward expansion of the northern forests. The tundra reflects a lot of light, particularly with snow on it, but forests do not. So we get a decreased albedo and that is a positive feedback. Then there is the die back of plankton with reduction of cloud albedo, but increase of cloud albedo because higher temperatures lead to more water vapour and more clouds.

We will look briefly at two more cycles. First, the methane cycle, with methane generated by human, plant, animal, and bacterial activity.

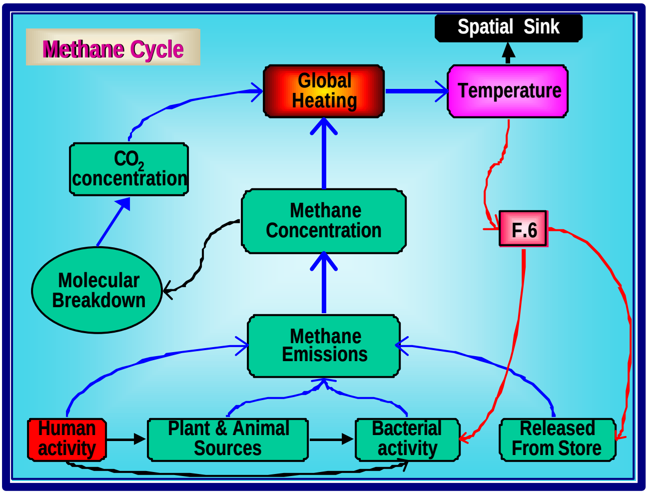

Figure 1.22

Of course human activity not only leads to methane emission in its own right, but also affects the outputs from animals, plants and bacteria. The methane output from the cows in India is significant. Somebody is trying to work on genetic modification to prevent cows emitting so much methane. Bacteria have outputs in their own right, but bacterial activity in landfill sites also creates methane some of which discharges into the atmosphere.

Then there is methane stored in frozen conditions in the tundra and also in the clathrates – the concentrations of methane in the rotted vegetation held frozen in crystalline form on the ocean floor by a combination of temperature and pressure. So that completes the set of methane emissions which drives up the concentration. Chemically, methane does break down in the atmosphere eventually into water vapour and CO_2, so that inputs to the carbon cycle. As a greenhouse gas methane is some 23 times more powerful than Carbon dioxide. It drives global heating and contributes to the rising temperature.

Feedbacks in this zone are temperature driven: So, the hotter the temperature, the more bacterial activity, more methane is emitted. Thawing of tundra permafrost releases methane, increases greenhouse gas and increases global heating. Finally, the well known one, the warming of the shallow seas could start to release the methane held in frozen crystal form in the sea bed and that would be a long term but potentially very powerful dynamic feedback.

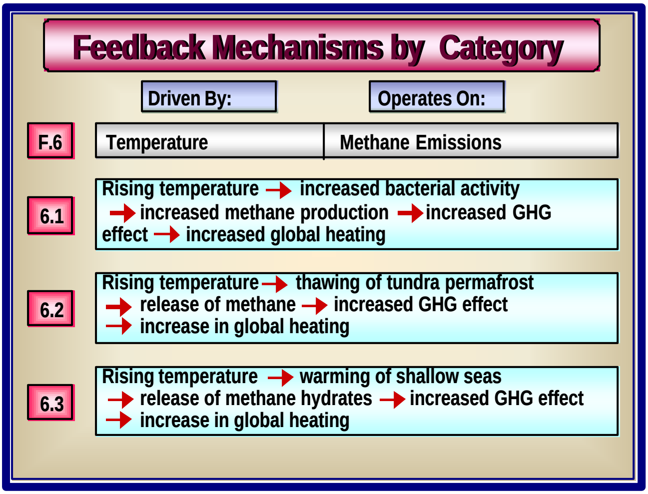

Figure 1.23

The final cycle concerns water vapour.

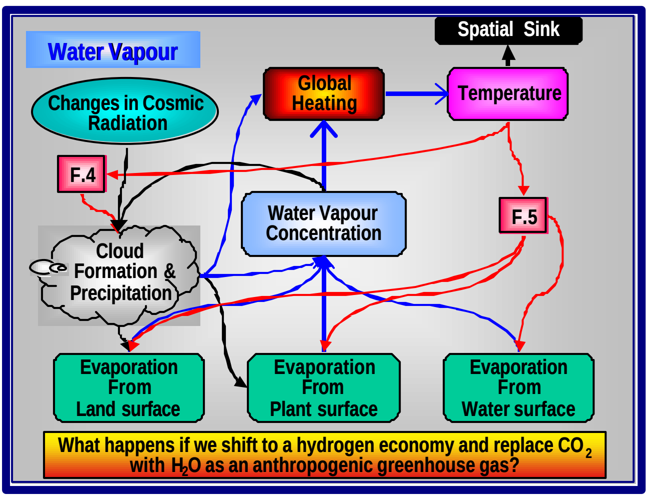

Figure 1.24

Evaporation from all surfaces increases the concentration of water vapour, some of it then condenses to form clouds and rains back to earth. I didn't bother to put rain onto the sea because it is as wet as it is, whether it has rain falling on it or not, and it does not change the evaporation rate!

F4 changes what is going on in the clouds, it is pretty small as a feedback source and I am ignoring it today.

The feedback category **F5** is temperature driven and affects what is happening in the water vapour cycle. Meanwhile small changes in cosmic radiation affect cloud formation. Lastly, the question is often raised: "What happens if we all go to a hydrogen economy? Doesn't that put out water vapour? Isn't that a green house gas? Wouldn't that change the situation?" The answer to that is that the amount of CO_2 we have put out is significant compared to what is up there already. If we put out water vapour the amount is absolutely minuscule compared to the amount of water vapour already in the atmosphere. Forget it, we can safely have a hydrogen economy.

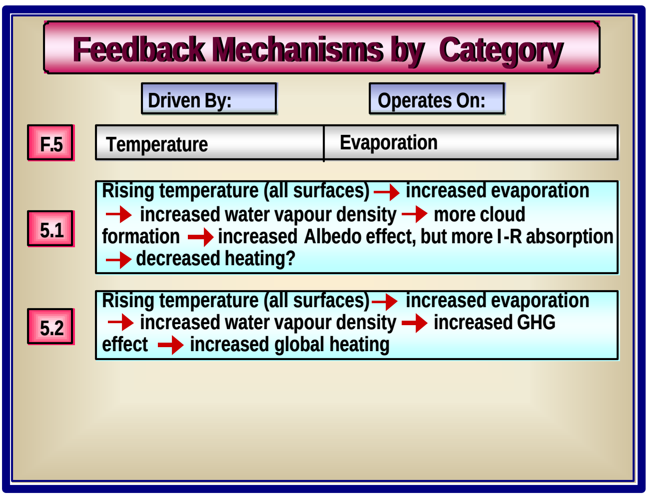

Figure 1.25

Feedback **5.1**, rising temperature, increased evaporation, increased water vapour density and its effect on clouds, is an ambiguous mechanism: – more clouds, more reflection of sunlight, but more blocking of infrared heating and radiation. So not quite sure how that one goes.

5.2: Rising temperature at all surfaces leads to increased evaporation, increased water vapour density, increased green house gas effect from the (uncondensed) water vapour. Water vapour constitutes the most profoundly dominant greenhouse gas. There are massive amounts in the atmosphere. What we are looking at are the slight changes in that amount caused by rising temperature. This fast-acting feedback mechanism becomes more and more significant as the temperature starts to rise.

In the final section I want to pay attention to the **"Thermal Inertia"** of the earth. There is a long time lag between the heat engine turning up the power and temperature following suit. Thermal inertia of the earth is massive.

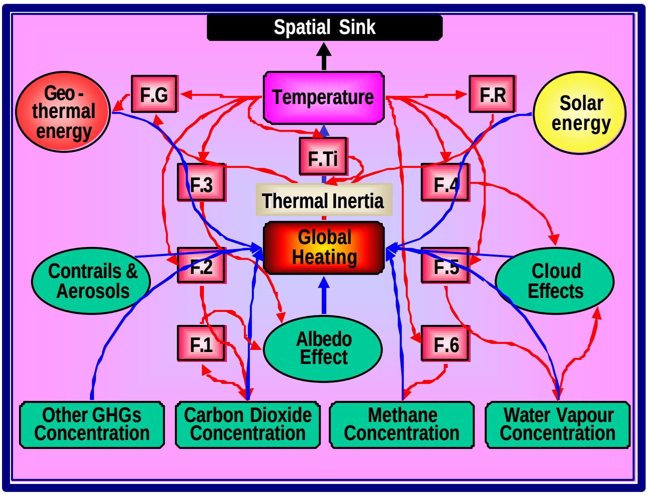

Figure 1.26

There is another feedback category (**F.Ti**) that is driven by rising temperature and changes the thermal inertia, so altering the rate at which temperature rises. That in turn affects the behaviour of all the other temperature-driven feedback mechanisms.

Radiative forcing, drives up the rate of heating, leading eventually to change in temperature. In *Figure 1.27*, I am going to explore all the various mechanisms that take up the heat energy and moderate the change in global temperature.

Global heating slowly warms the ocean surface. That takes a lot of energy, and the mixing takes the heat down into the deeper water. Heating of ice. That is by conduction and takes up much less energy.

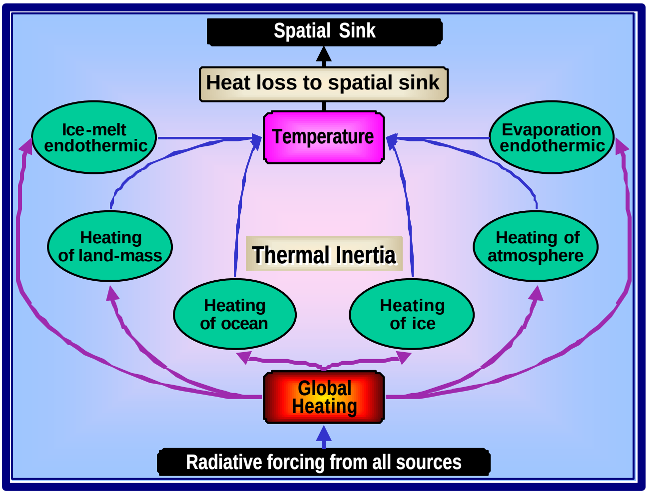

Figure 1.27

Heating of land mass is quite quick as also is the warming of the atmosphere. Melting of ice takes up energy. You have to input energy to melt ice in water. So that keeps temperatures down while the energy is being taken up in the volume of melted ice. Finally we have the evaporation of water – change of phase from liquid to gas also absorbs energy. It is "endothermic". So there is a cooling effect there. The temperature rise is damped by these last two endothermic mechanisms.

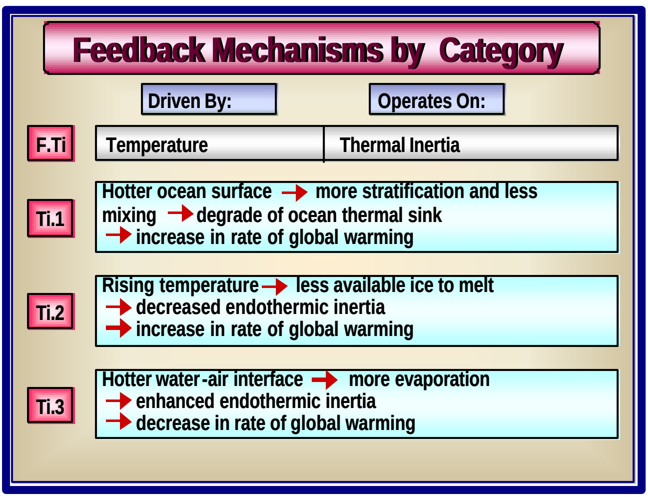

Figure 1.28

There is a feedback loop between the rising temperature and thermal inertia.

In **Ti.1**, the hotter the surface water of the sea becomes, the more stratification occurs in the upper layers of the ocean. Warmer water is less dense and stays at the top. There is less mixing, and that decreases the efficiency of the oceanic thermal sink. That is a positive feedback that increases the rate of global warming.

Secondly, in **Ti.2**, as the ice melts there is less volume of ice available to melt. At the higher latitudes the area of ice shrinks as the ice retracts. Similarly, as you go up mountains the areas of snow and ice shrink the higher you go. So the thermal inertia due to ice-melt decreases with rising temperature (another positive feedback that increases the rate of temperature increase). However, this feedback decreases in power as areas become ice-free.

And finally a damper (or negative feedback). The hotter the water/air interface, the more evaporation, and so more cooling. The more sea levels rise and the less the area of sea-ice, the greater the area of water available for evaporation. That slightly slows the rate of temperature increase.

So that completes the set of feedback categories with their various mechanisms and effects that, taken all together, drive climate dynamics.

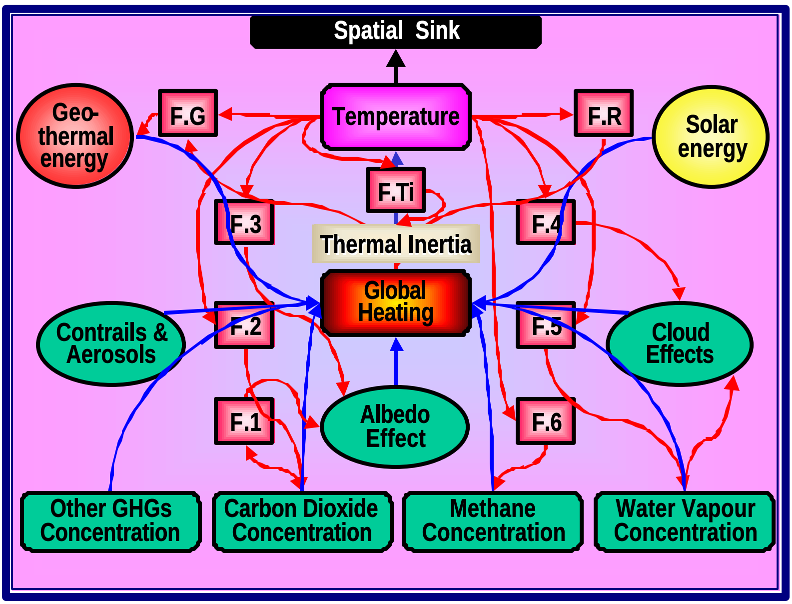

Figure 1.29