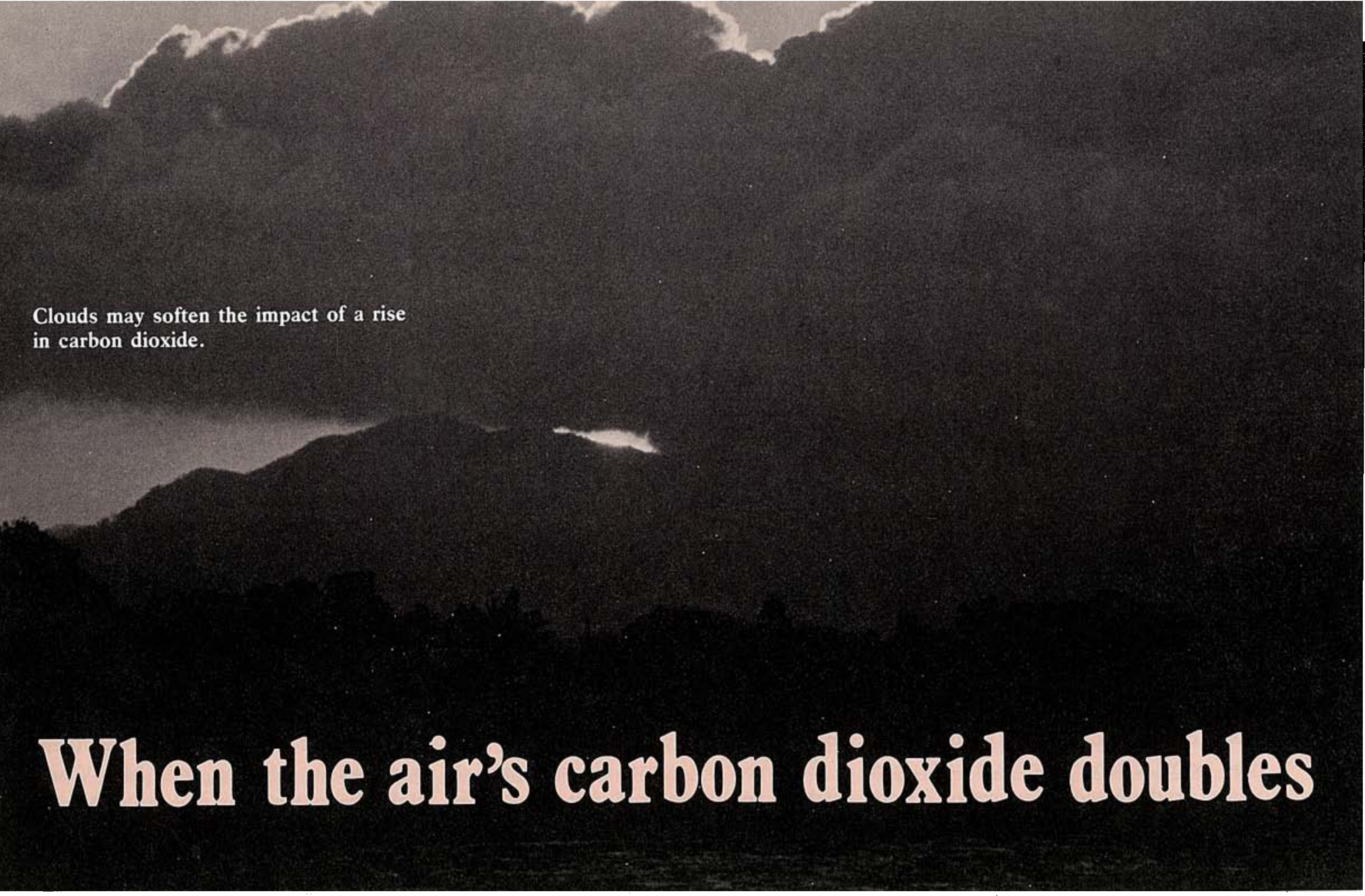


Clouds may soften the impact of a rise in carbon dioxide.

When the air's carbon dioxide doubles

Inhale. Some ten thousand million more molecules of carbon dioxide entered your lungs than did so in your previous breath.

And so it will go, day after month after year, with every successive lungful containing its supernumerary molecules. It's probably not doing you any harm (cross your fingers), but it has climatologists worried.

Scientists who measure the atmosphere's carbon dioxide concentration find it increasing at a rate of about 1 part per million every year. Today the air contains 335 p.p.m. (by volume) of the gas; the figure last century was only about 290 p.p.m. Some time in the next century scientists are virtually certain the level will rise to 600 p.p.m. — double the pre-industrial value — and keep rising.

Although 335 p.p.m. (0·03%) doesn't seem like much, that's what all the earth's plants survive on as they extract the gas from the air in the process of photosynthesis. Our lives depend on (and are part of) the ceaseless activity of the carbon cycle. A doubling of carbon dioxide, perhaps within 50 years, may therefore be expected to have far-reaching consequences. A beneficial effect will be enhanced growth of plants, but there are many possible drawbacks.

Atmospheric scientists are predicting that, because of the heat-absorbing properties of carbon dioxide, the earth's average temperature will rise, the most commonly mentioned figure being 2–3°C. Consequences of a warmer earth would include disturbed climate patterns, slow melting of Polar ice, and altered growing conditions and yields for much of our agriculture.

In the main, those extra molecules come from chimney stacks and exhaust pipes, as they pour forth the products of burning coal, oil, and gas.

Clearing of forests also contributes, freeing carbon (as carbon dioxide) from the standing mass of wood to join the 700-billion-tonne atmospheric pool of carbon dioxide.

The 'carbon dioxide–climate' problem, as outlined above, brought more than 100 Australian scientists to the Academy of Science in Canberra at the end of last year to share their expertise.

Something that emerged from the symposium was that many aspects of the problem are still far from being understood. Many more measurements and experiments are needed before we can say whether the roughly based predictions of climate change will come to pass.

The dilemma is that when — perhaps in 20 years — we have the facility to predict with confidence the climate changes that may occur, it will be impossible to stop them occurring. In fact it is highly unlikely that policies aimed at phasing out fossil fuel use, even if they were adopted around the world now, could be implemented quickly enough to prevent the expected doubling of carbon dioxide levels. It would take at least 15–20 years to fully replace coal, oil, and gas with alternative energy sources — probably much longer.

Sources and sinks

Since 1958, when accurate measurements of the carbon dioxide concentration in the air began, the level has risen from 314 p.p.m. to today's 335 p.p.m., an increase of 21 p.p.m. or 44 billion tonnes of carbon. During this same period, more than 80 billion tonnes of carbon in the form of fossil fuel have been burnt. In other words, only about half of the carbon dioxide released appears to have remained in the atmosphere.

Some of the gas has dissolved in the oceans; some has been taken up by plants, because the more abundant is carbon dioxide the more prolifically

Polar temperatures are predicted to rise 7°C or more when carbon dioxide doubles. Sea ice would probably disappear.

plants can grow. However, we cannot say how carbon dioxide liberated today and not retained in the atmosphere would be shared between these two 'sinks', because there are a number of unknown factors in the global carbon cycle.

For example, we don't know how much carbon dioxide has been, and is now being, liberated because of human impact on the world's plant cover. We are removing forest in some areas and planting it in others (presently forests cover about 30% of the land surface) and we are increasing the area of farmland (currently about 10% of the land).

Even if we knew the area affected by each activity and could estimate the quantities of wood and crops involved, we still couldn't work out the effect on atmospheric carbon dioxide because of the unknown impact the changes have on the organic matter in the disturbed soil. This organic matter breaks down, releasing carbon dioxide, and is normally replenished by leaf or root litter. Forest scientists have only tentative ideas of how much carbon dioxide results. Rough estimates suggest that 40–200 billion tonnes of carbon (out of the soil's 2000 billion tonnes) have been liberated to the air since early last century.

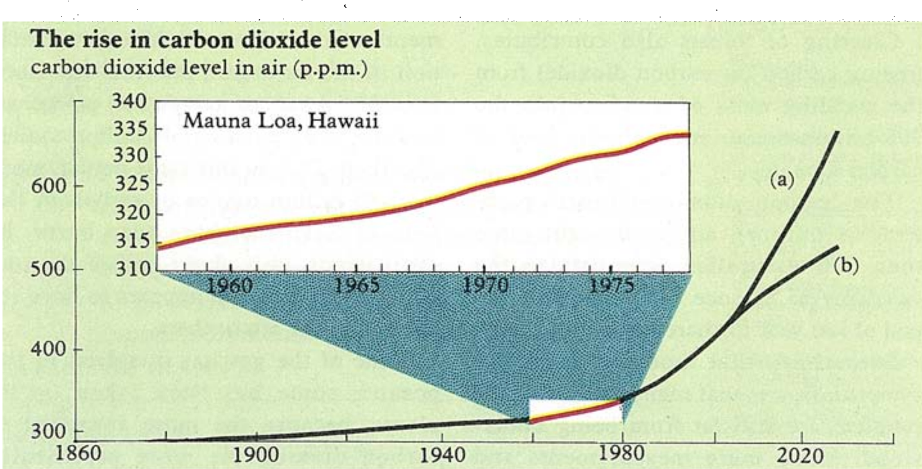
Clues given by isotope compositions of sinks in the carbon cycle (see the box on page 6) tend to point to a figure of about 50% as the fraction of carbon remaining in the air after the burning of the last several years' worth of fossil fuels. This matches the figure derived by comparing the amount of fuel burnt with the rate of increase of carbon dioxide in the atmosphere.

The conclusion is that, in recent years, the effects of forest clearing and farming have been generally balanced by growth in tree plantations and increased growth elsewhere due to higher levels of carbon dioxide.

Each year we burn 5 billion tonnes of carbon, mostly in coal, but about one-third in petroleum. As a comparison, the earth's plants turn over 10 times as much and the oceans 20 times more. The important difference is that the natural processes are cyclic; human effects are cumulative.

Despite uncertainties, the presently accepted figure of 50% for the amount of carbon dioxide remaining airborne after combustion gives us a basis for some calculations.

Accurate measurements of carbon dioxide have only been made from 1958 to the present (inset shows Mauna Loa, Hawaii, figures). However, estimates of fossil fuel usage, past and future, allow extension of the graph. Curve (a) assumes that 100% of an estimated energy requirement of 33 billion kilowatts in 2020 will come from fossil fuels; curve (b) assumes 53%.



The future

From a survey of current literature, Dr Graeme Pearman of the CSIRO Division of Atmospheric Physics has concluded that global energy requirements are likely to grow from the present 8 billion kilowatts to about 30 billion kW in 50 years' time. If this power demand is to be met primarily from coal, then we will need to burn about 35 billion tonnes of it a year by the end of that period. (The total amount of coal burnt since the Industrial Revolution began has been 150 billion tonnes.)

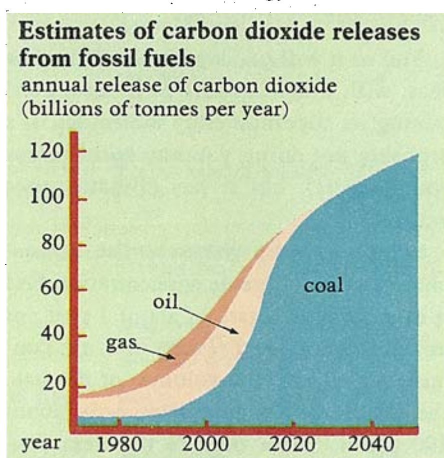
At this rate, calculations show that, if 50% of carbon remains airborne, the carbon dioxide concentration will then have doubled. If all the globe's recoverable fossil fuel reserves of 7000 billion tonnes, or more, were burnt in the next few centuries, the carbon dioxide level could be increased to 6–8 times the present level.

Those extra molecules come from chimney stacks and exhaust pipes.

But to restrict ourselves to the immediate future, just about every student of the subject considers that, unless there is a massive change away from fossil fuels, the carbon dioxide level will inevitably double within 80 years, if not 50. What then is the likely effect?

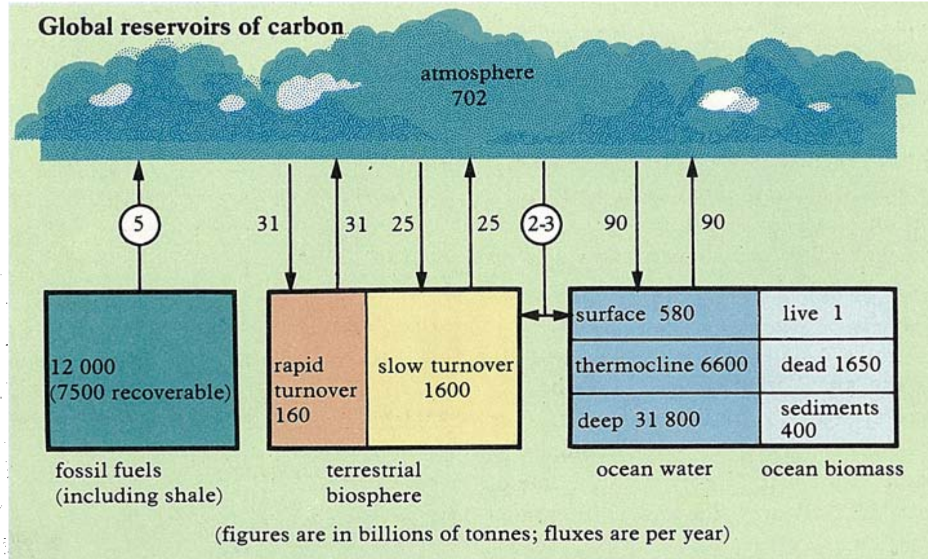
Scientists have built up a number of computer models that try as far as possible to reflect in a mathematical way the intricate physical processes that go on in the atmosphere. The models encompass the driving force of solar radiation entering at the top of the atmosphere and filtering down to the surface; the end-point of the models sees heat radiation diving off into space after its upward travel. In between is a lot of interaction between the air, clouds, ground, and ocean.

The graph assumes we will require 33 billion kilowatts of energy in 2020.



Most of the models consolidate around a value of 2–3°C rise in temperature at low latitudes, increasing to 7–10°C at the Poles.

In 1979, the United States National Academy of Sciences reviewed the car-

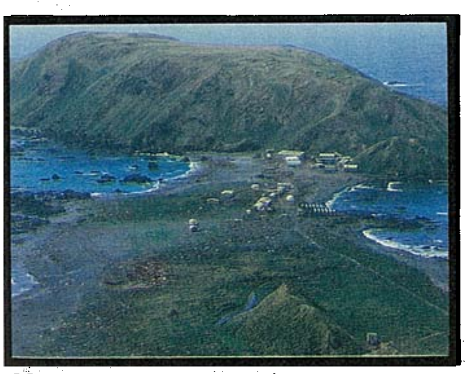


The reservoirs are very large when compared with the yearly flux. The outpouring of carbon dioxide from fossil-fuel combustion is beginning to alter the balance between the atmosphere and the other reservoirs.

bon dioxide–climate question and concluded: 'we estimate the most probable global warming for a doubling of CO_2 to be near 3°C with a probable error of ±1·5°C'.

While this temperature change may seem rather small in relation to day-to-day changes, consider that the 'Little Ice Age' from 1350 to 1850 was associated with a global temperature drop of only about 1°C. The River Thames froze repeatedly, and settlements in Greenland had to be abandoned.

A rise in temperature of 10°C at the Poles could readily melt the Arctic sea ice, which is only 2–3 metres thick, within a decade. As a consequence of the melting of glaciers and other thin ice covers, the sea level would be expected to rise by about half a metre. The Antarctic ice cover is much thicker and would require tens of thousands of years to melt completely. However, if it did, the sea would have risen by some 70 m!



Macquarie Island is remote from civilization — all the better to interpret the carbon dioxide measurements constantly made there.

Any temperature change should have a large impact on agriculture. A 1°C rise is roughly equal to a 10-day increase in the growing season in mid to high latitudes. This would aid the Canadian and northern Russian grain belts — if other factors remained unchanged.

Unfortunately, the predicted warming — greatest at the Poles — would tend to flatten out the temperature differences between the equator and the Poles. Since this temperature gradient is effectively the driving force for the whole atmospheric circulation, climate would alter in many ways.

Winds would be reduced slightly in strength and the movement of high and low pressure systems would probably alter. Some regions would benefit from the change; others would suffer.

The frequency of drought might increase in some areas and decrease in others, while a region ideal for growing one crop might become more suitable for another. A region's water storages might become abundant or inadequate, depending on how rainfall was affected.

A warming of oceans could affect their currents and biology, and, through greater acidity due to carbon dioxide, their chemistry. Thus, the rate of growth of plankton could alter and fish populations change.

A warmer Australia

Dr Barrie Pittock of the Division of Atmospheric Physics has looked into what climatic changes Australia might experience as a result of a warming.

Computer models are at present too crude to give results on a regional scale with much credibility. (For what it is worth, the most widely quoted models, by S. Manabe and R.T. Wetherald in America, suggest increases in rainfall of up to 500 mm per year in latitudes 0°–40° and a decrease at 40°–50°). So Dr Pittock resorted to three alternative methods of prediction. None by itself is very convincing, but together they seem to point in one direction.

The first method involves picking out the warmer years from a collection of weather records and looking to see how the weather patterns then differed from the ones in the colder years.

The second method is to look at the type of weather experienced during particularly warm periods in past millennia. The 'Climatic Optimum' (about 7500 B.C.) is a prime candidate for study. Fossil and sediment records are the key to finding out the weather pattern then.

The third approach draws on knowledge of what affects what, in a climatic sense (for example, a warmer climate will mean that weather systems will, in all seasons, tend to become more like those normally found in summer).

All approaches point to increased summer monsoon rainfall, possibly by up to 75% in some areas of northern Australia. Rainfall may be reduced in southern Australia, but this is less certain.

More rain will benefit those areas with good soils, but in many regions increased evaporation (due to the warmer temperatures) may nullify this advantage. In any case, more flooding may be expected and, in some areas, soil erosion.

Similar sorts of analyses have been done, by other workers, for the Northern Hemisphere. Their results suggest the possibility that the major grain-growing regions across Europe, Asia, and North America could be adversely affected.

Dr Pittock believes that the social, economic, and political consequences of changes in other parts of the world may well be more important to Australia than the local gains or losses due to changes in Australia's climate.

Effects already?

The atmosphere's carbon dioxide level has so far increased by about 10%. If the predictions for a 100% increase are correct, then a fraction of the predicted effect should have already occurred.

Dr Brian Tucker, Chief of the Division, has been examining Australian weather records of the past 30 years to see what shows up. The problem, of course, is that the effect he is looking for is pretty small compared with the unceasing short- and long-term fluctuations in climate that occur naturally.

What carbon isotopes tell us

The most abundant form of carbon is carbon-12. However, small quantities of the isotopes carbon-13 and carbon-14 also exist, and they can help us understand the workings of the carbon cycle.

Carbon-14 is formed by the action of cosmic rays on the atmosphere. It is radioactive, with a half-life of 5700 years.

Since fossil fuels have lain buried for millions of years, all the carbon-14 incorporated into them when their progenitors — living plants — were photosynthesizing has decayed.

Burning fossil fuels therefore dilutes the proportion of carbon-14-type carbon dioxide in the air. From the amount of coal, oil, and natural gas burnt each year, and the observed dilution of carbon-14, we can calculate the size of the atmospheric carbon pool.

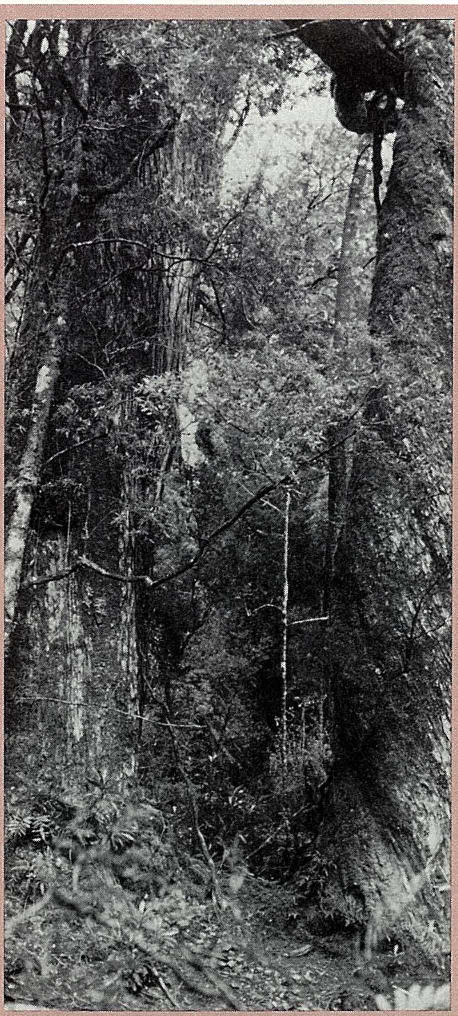
Unfortunately, carbon-14 is also produced by nuclear explosions, so during the fifties and early sixties a large but unknown amount was added to the atmosphere. This has upset measurements of the atmospheric carbon pool, but it has created a pulse of tracer (or radioactive marker) that can be followed down to the ocean depths. In this way, the turnover of ocean carbon can be determined.

Carbon-13 is not radioactive. And, during photosynthesis, plants tend to discriminate against it when taking carbon dioxide from the air. Scientists hope that measurements of the carbon-13 depletion in tree rings will give us a clue to how carbon dioxide levels have fluctuated in times and climes long past.

However, recent work by Dr Graham Farquhar of the Department of Environmental Biology at the Australian National University suggests they may tell us more about plant physiology. It seems that carbon-13 discrimination is affected not only by the atmospheric concentration of carbon dioxide, but also by the inter-cellular concentration in the leaf — which in turn is affected by temperature, humidity, light intensity, and nutrient supply. Scientists studying tree rings face a big task trying to sort out those factors one from another.

Nevertheless, Dr Roger Francey of the CSIRO Division of Atmospheric Physics is attempting to do so. He is analysing growth rings of softwoods from Tasmania's western coast. Here growing conditions have been unusually stable, with prevailing winds off the ocean minimizing local effects. By taking three or four species over a number of regions, he hopes that physiological variations may average out, leaving variations due to past carbon dioxide levels.

Ms Helen Goodman of the Division has for the past 3 years been measuring the relative abundance of carbon-13 in the air at Cape Grim, Tasmania. Her measurements are the first made of this quantity in the Southern Hemisphere. As expected from the increasing amount of fossil-fuel carbon in the air, evidence is emerging of a gradual decrease in the proportion of carbon-13, in agreement with Northern Hemisphere measurements.



Large Tasmanian Huon pines, estimated to be about 800 years old. Cores taken from them will, scientists hope, allow carbon dioxide levels in the past to be determined.

Furthermore, we don't know whether an average rise in temperature of, say, 3°C will manifest as a 3°C rise in all temperatures or as a larger rise in minimum (or maximum) temperatures only. Again, maybe only winter (or summer) temperatures will be affected. Nevertheless, Dr Tucker thought the exercise was worth trying.

The Manabe and Wetherald models suggest that rainfall in the north of Australia should have increased by possibly 80 mm per year, and that in the south temperatures may have risen by 0·4°C.

Dr Tucker first looked at temperatures for stations in the wheat belt for the period 1950–1979. Four stations in South Australia, out of many studied, showed an increase of about 0·8°C in the daily minimum temperature (although not in the maximum). Next, he examined rainfall data covering the same period for areas over the whole of Australia. Four areas in the north-west of the continent show substantial increases (of between 150 and 300 mm per year).

All approaches point to increased summer monsoon rainfall, possibly by up to 75% in some areas of northern Australia.

Dr Tucker is quick to point out that his results in no way confirm the model predictions. The results are strongly influenced by the very wet years 1973 and 1974, and are not statistically significant — that is, they are within the bounds of the natural variability of climate. What can be said is that they are consistent with predictions, and they will certainly prompt scientists to keep a close watch on the situation.

Sans souci

At this point, having given the main thrust of the ideas of those who hold that we are heading towards a warmer, but probably less cosy, world, it is time to explain why others feel much more complacent about the situation.

A number of feedback mechanisms have been identified in the carbon dioxide–climate question. Some are positive, amplifying the warming effect of carbon dioxide, but it is the negative ones with their stabilizing influence that a

Clearing of forest causes the carbon accumulated in the trees to be lost to the air

number of scientists believe will be strong enough to stop the predicted climate changes occurring.

The point they emphasize is that the models used for predicting climate change are simplifications of the real world. In making a model manageable, scientists consider only the basic processes. A number of effects that could be vital are ignored.

The major positive feedback factor is water vapour, which any model worth its salt will take into account. By itself a doubled carbon dioxide level might increase the earth's temperature by only 1°C. But this higher temperature would increase the amount of water vapour in the atmosphere, and water vapour is an even more powerful absorber of heat radiation than carbon dioxide. The net result is that the temperature would increase not by 1°C but by 2°C.

Another widely discussed positive feedback mechanism is the one due to ice and snow. These reflect much of the sun's energy back to space, but if the temperature should rise, some will melt. As a result, more energy will be absorbed by the earth, raising temperatures further still. Models indicate that this factor would add another 0·4°C (globally averaged) to the predicted temperature rise.

. . . on the other hand, plantations of trees capture additional carbon dioxide.

The really interesting — or contentious — aspects of the problem arise when we start to examine negative feedbacks (and buffering effects), largely because they are very difficult to quantify.

Take oceans, for a start. Models involving both oceans and carbon dioxide levels have to date treated the ocean as having no ability to transport heat from latitude to latitude. Yet at some places the ocean carries as much as 50% of the known polewards heat flux.

We saw that one consequence of a carbon dioxide increase was a lessened temperature gradient between the equator and Poles, leading to gentler winds. Ocean currents would then be weakened, too. A possible result of both weakened winds and weakened currents is a slower movement of heat from the equator to the Poles. Hence, the temperature gradient might be steepened to some degree and the predicted polar warming ameliorated.

Not only may the oceans have a feedback effect to the atmosphere, but by themselves they are certain to have a buffering effect. Their enormous mass allows them to soak up great amounts of heat and carbon dioxide. A model run by Mr Barrie Hunt of the Australian Numerical Meteorology Research Centre indicates that the oceans would slow down the expected global warming by 8 years.

The models used for predicting climate change are simplifications of the real world.

However, models to date, if they have considered the oceans, have only taken into account the upper well-mixed layer down to about 80 m depth. The rationale for this has been that only this layer reacts to the atmosphere, exchanging heat and carbon dioxide.

The mixed layer contains about the same amount of carbon as the atmosphere, but because of a chemical buffering effect the ocean water requires a 10% increase in carbon dioxide in the air to increase its carbon dioxide level by 1%.

But the oceans may help us more than we imagine. It has generally been believed that the cold deep ocean, cut off from the surface by stable layers, takes perhaps a thousand years to respond to any change above — too long to affect, except in the very long term, any atmospheric warming.

Recently, however, scientists have observed large tropical 'gyres', covering in total more than half the ocean surface area, which appear to pump water down below the mixed layer at a rate of 10–20 cm a day. The phenomenon does not take water to the deepest levels, but it appears to provide a sink for water and carbon dioxide much larger than previously recognized.

This, if borne out, makes the effective heat capacity of the ocean nearly ten times greater than that of the mixed layer alone. Thus, atmospheric warming could be slowed down by several decades, at least. Since carbon dioxide could be absorbed in this sink too, we may be granted extra breathing space.

Clouding the issue

Clouds are the day-dreamer's most popular subject, but hardly the scientist's. Their delicacy, grace, and fluidity may be fine for fantasy, but it's little wonder that scientific analysis hasn't made much headway in understanding their dynamics.

Yet clouds are conceivably the most vital factor in regulating the earth's climate. They are efficient reflectors of solar radiation and at the same time absorbers (and emitters) of heat radiation from the earth. When they form they virtually cut the atmosphere in two. The difference cloud cover makes to the temperatures of our surroundings is marked. It is no accident that cloudy days tend to be cool, and cloudy nights warm.

We can therefore imagine that warming due to carbon dioxide might produce more water vapour, leading to increased cloudiness. The cloud might reflect more sunlight, partially cancelling the warming (a negative feedback effect).

On the other hand, clouds might give rise to positive feedback. Their influence as absorbers of heat might dominate, so a 'blanket' of clouds would help heat up the earth.

Apparently, the height of a cloud is the key to determining whether it warms or cools the earth. The net effect of low cloud (below 1500 m altitude) is to cool, whereas that of high cloud, although not certain, appears to be to warm.

Unfortunately, scientists are not able to say at present if a warming will lead to more (or less) cloud, let alone whether the cloud would be high or low.

Clouds are the ultimate subtlety in the entire climate system, and to predict their occurrence and effects we would need to know and understand virtually every other climatic factor. We don't, so we are forced to deal with clouds with the tools we have — basic mathematical models. In the same way as a painter can with broad brush capture wisps in a skyscape, so we hope our models are suggestive of the real thing.

However, current weather models, when they do consider cloud, use no less than a house-painting brush. Individual clouds are below the grid scale of the models, and so cloudiness, derived from observations, is given as the average over an entire zone.

Several models have generated cloud cover using the following simple procedure. No cloud exists in a zone until the relative humidity exceeds a pre-set value, at which time full cloud cover is assigned to that zone. These models do not show much change in cloud amount with increasing carbon dioxide.

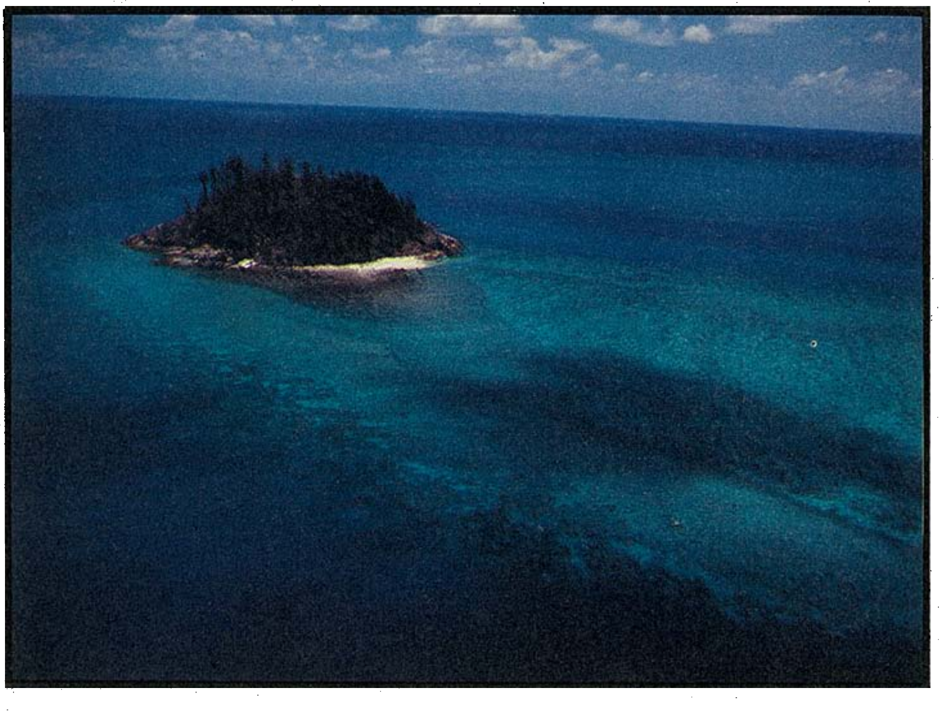
However, the current limitations of the models restrict the credence that can be given to the results obtained with them. According to Dr Garth Paltridge, also of the Division of Atmospheric Physics, feedback due to cloud can potentially make nonsense of a model's predictions of warming due to carbon dioxide. He says that, by invoking assumptions no less questionable than those used in any current model, he can calculate a global temperature rise due to a doubling of atmospheric carbon dioxide that is at least a degree less than most climatologists are predicting.

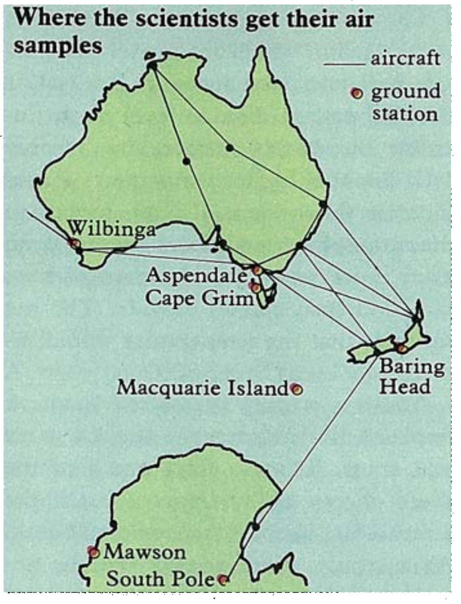
His paper to the symposium, 'Clouds — one (of the many) good reasons not to

continued on page 10

Due to rising carbon dioxide levels, the world's vegetation is storing more carbon than it used to.

The oceans absorb heat and carbon dioxide.





Continual analysis is carried out at Cape Grim, Aspendale, Macquarie Island, Baring Head and the South Pole. Sampling flasks are used on aircraft and at the other sites.

Measuring and modelling carbon dioxide movements

The rise in the atmosphere's carbon dioxide level is not steady — there are fluctuations superimposed upon the upward trend. Plots of the level look like charts of (bullish) stock-market prices and differ according to place and time.

The fluctuations are mainly due to seasonal changes in the activity of natural sources and sinks, notably land vegetation, sea plants, and the oceans. Changes in carbon dioxide output from man-made sources, and changes in wind direction, also cause fluctuations in the concentration recorded at individual measuring stations.

The seasons see leaves sprouting and dying, oceans warming up and cooling down, and weather patterns dancing to and fro. The result is an unceasing rising and falling in the level of carbon dioxide. The graph of it (for samples taken by aircraft over Australia) on this page shows the annual variation; short irregularities appear too.

Scientists around the world are following the tortuous run of the graph as closely as any stockbroker looks at his stock-market charts. They know that each movement of the graph can be traced back to a physical cause, so, if enough data are studied closely, it should be possible to work out what is going on in the world's carbon cycle.

If you want to predict market movements, it helps to know the market forces. The scientists want to know the size of sources and sinks, and their rate of turnover.

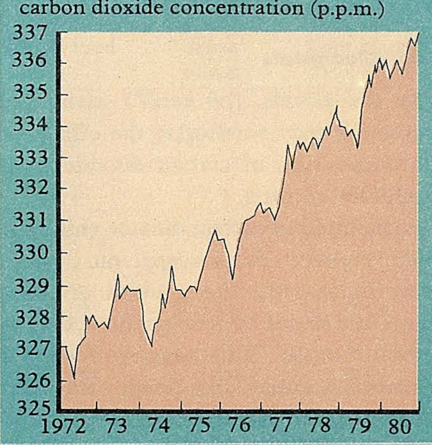
At the Division of Atmospheric Physics, Mr David Beardsmore is measuring the concentration of carbon dioxide in air samples collected from Australia, the Tasman Sea, the Southern Ocean, and Antarctica. The map shows where the samples come from.

Some of the samples are taken from aircraft. Qantas and TAA planes take regular samples at altitudes up to 12 km over Australia and the Tasman Sea. Military aircraft flying to Antarctica from Australia and New Zealand also carry sampling flasks.

However, most samples are collected on the ground. The air at the Division's headquarters at Aspendale, Vic., is analysed weekly, and monthly samples come from Wilbinga, W.A., on the coast 75 km north of Perth.

The Antarctic station of Mawson collects monthly samples, and at Macquarie

The dips and rises in carbon dioxide level



Scientists analysed samples taken by aircraft over Australia to get this graph.

Island in the Southern Ocean semi-automatic analysing equipment has been at work for the last 2 years.

The most important data come from the Australian Baseline Air Pollution Station at Cape Grim on Tasmania's north-western corner. Air analysed at the station has crossed thousands of kilometres of ocean, so it is free of local influences — hence the term 'baseline' (see *Ecos* 25).

Dr Graeme Pearman, Dr Paul Fraser, and Mr Peter Hyson, of the Division, have been analysing the information collected and using it to form models of the carbon cycle. Their work is leading to a better understanding of carbon dioxide movements.

They have found that the background level of carbon dioxide is 3–4 p.p.m. less in the Southern Hemisphere than in the Northern. This is because most of the world's combustion of fuel takes place in the Northern Hemisphere. The concentration figures indicate that 10 billion tonnes of carbon dioxide (about half of that released) travels southwards across the equator each year.

As we saw above, carbon dioxide levels show an annual fluctuation due to the seasonal activity of plants and oceans. Plants take up much more carbon dioxide in the warm months than in winter. Oceans take up the gas as they cool in autumn and winter and release some of it as they warm up again. The combined effect is an annual cycle, shown in the graphs for Cape Grim and Mauna Loa, Hawaii.

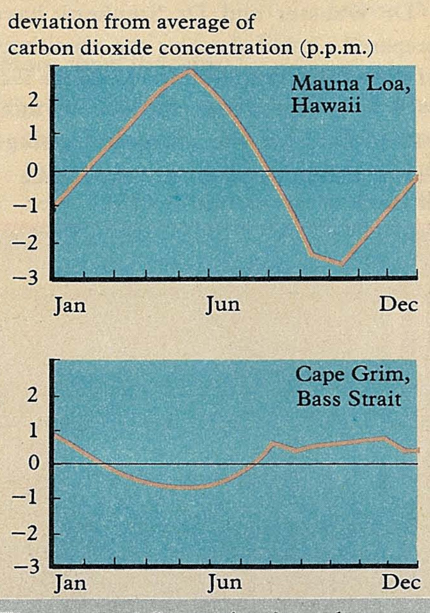
The seasonal fluctuation is greater at Hawaii because there is much more land, and hence much more vegetation, north of the equator than in the south. The fact that most Northern Hemisphere trees are deciduous, and don't take up any carbon dioxide after their leaves have fallen, also contributes.

The flow of carbon dioxide across the equator also affects the size of the fluctuations in the Southern Hemisphere. The scientists estimate that the amplitude at Cape Grim might be one-third greater were it not diminished by the intrusion from the north.

Northern Hemisphere stations have been showing a gradual increase in the amplitude of the annual variation, and this could be attributed to an increasing biomass. The effect has not been noted in the Southern Hemisphere, perhaps because data have not been collected for as long and because the smaller annual fluctuation makes changes harder to detect.

The CSIRO scientists have also found that the carbon dioxide concentration varies with altitude. In springtime at mid-southern latitudes, it is about 1 p.p.m. greater at sea level than at a height of 10 km. In autumn, there is no difference. The explanation is the extra carbon dioxide given off by the sea as it warms up. The models suggest the southern oceans give off 6 billion tonnes of carbon dioxide before they begin cooling down and starting to absorb it again.

Annual cycles in the Northern and Southern Hemispheres



The seasonal fluctuation in carbon dioxide level is greatest in the Northern Hemisphere.

believe everything you hear about the CO_2 doomsday', makes clear that the modelling of clouds is one of the weakest links in predicting the effect of carbon dioxide.

It is possible, of course, that the omissions and simplifications in models may lead to under-estimates of the effects of carbon dioxide rather than over-estimates.

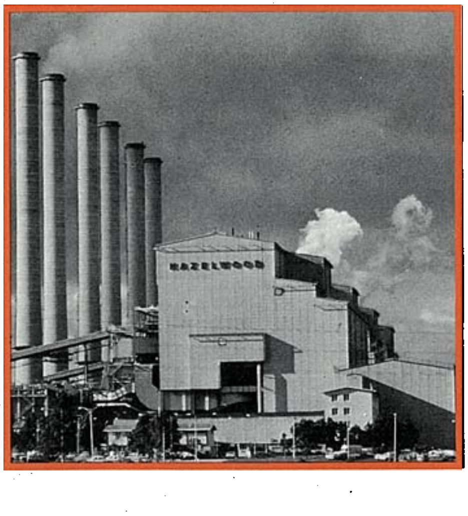
The 10% effect

At the Division of Atmospheric Physics, Dr Peter Webster and Dr Graeme Stephens have been studying the effect of clouds on atmospheric temperature. Their work is a first step towards more accurate modelling of cloud. They have shown that it is possible to represent the various radiative properties of a cloud through one variable — the number of centimetres of water (or ice) through which a light beam would travel in traversing it.

In results presented to the symposium, the two scientists calculated that a 10% change in cloud amount would compensate for a warming of 2·6°C. Either an increase in low cloud or a decrease in high cloud would do. Work with a simple one-dimensional model by Mr Barrie Hunt has confirmed this assessment. But it should be noted that a change in surface temperature cannot be simply compensated for by cloud or any other factor without some change in the climate. Mr Hunt's model suggests that temperature changes due to carbon dioxide would still occur in the stratosphere (about 10 km altitude), which might then induce changes in weather patterns.

Dr Webster and Dr Stephens have prepared a table showing the sensitivity of the earth's temperature to various factors. It is reproduced opposite. It indicates that, for the same percentage change in each factor, the temperature is most sensitive to a change in the sun's output, followed by cloud amount, reflectivity of the earth's surface, ozone concentration in the atmosphere, and, finally, carbon dioxide level.

Power station chimneys are the source of much of the carbon dioxide.



Stimulated plants

Like the clouds, the earth's mantle of vegetation may ameliorate the effects of the outpouring of carbon dioxide from fossil-fuel burning.

A doubling of carbon dioxide shifts the photosynthetic mechanism into higher gear, increasing the growth of most plants and hence increasing the uptake of carbon dioxide. This negative feedback mechanism could slow down somewhat the increase in atmospheric carbon dioxide.

Stimulated plant response to carbon dioxide has been made use of for many years by horticulturists, who raise the level of carbon dioxide in glasshouses to speed up the growth and increase production of crops such as tomatoes, lettuce, and cucumber.

Only recently, however, have measurements been made of this accelerated growth over extended periods. Two papers presented at the symposium gave results of studies where carbon dioxide levels in glasshouses had been doubled. Dr Chin Wong of the Department of Environmental Biology at the Australian National University studied the response of snow gum, cotton, and corn, while Dr John Downton of the CSIRO Division of Horticultural Research, together with American colleagues, investigated some desert shrubs.

Clouds are conceivably the most vital factor in regulating the earth's climate.

Each recorded a significant enhancement in the rate of photosynthesis, as expected, ranging from 40% to 100% for plants with a C_3 photosynthetic pathway (most of the world's plants). Plants with the C_4 pathway, notably corn, were much less affected. However, important subsidiary effects also occurred. Among them was a marked reduction in the amount of water lost through transpiration, in this case showing up most strongly in corn.

With extra carbon dioxide, the abundance of plants in arid areas may increase.

The net result is that all plants displayed greater efficiency in water use, typically a halving in the amount needed for a given amount of growth. One implication is that, with elevated carbon dioxide levels, plants may begin to grow in arid areas where they are unable to grow at the moment. The increased water-use efficiency of plants may also counter one predicted effect of higher carbon dioxide levels — namely, reduced rainfall in some important agricultural areas.

However, there is not enough evidence yet to show definitely that the world's biomass will increase. Dr Roger Gifford of the CSIRO Division of Plant Industry has grown wheat in a controlled environment charged with extra carbon dioxide. The plants grew more quickly and were larger. But in the real world, will the rich diversity of plants all behave similarly or will many just reach the same size faster and crowd out the slower-growing ones?

Dr Gifford believes the question is a tough one, but that indications are that land plants will indeed grow bigger (marine plants are not considered because of lack of knowledge about them).

Scientists talk of the 'biotic growth factor' — the proportion of extra carbon that plants store, over their whole life, per unit increase in carbon dioxide. Values of 0·5 to 0·8 have been derived from experiments with individual plants and small canopies. That is, the plants store 0·5–0·8% more carbon when carbon dioxide is increased by 1%.

Some scientists hesitate to apply those figures to plant communities, believing limiting factors such as competition for light, water, and nutrients will come into play and lower the figure considerably. However, Dr Gifford's experiments, with annual plants, lead him to think that extra carbon dioxide tends to make plants use all scarce resources more efficiently (albeit with some difference between the growth response of individual plants and that of plant communities).

Cause and effect

for a 10% change in:	surface temperature will change by this number of degrees Celsius				
	given: clear sky	low-level cloud	medium-level cloud	high-level dense cloud	high-level light cloud
sun's output	12·6	12·0	12·0	12·5	12·7
amount of cloud		−2·8	−2·2	0·4	2·6
reflectivity of earth's surface	−8 to −9	−1·3 to −1·4	−1·7 to −1·8	−3 to −4	−4·6 to −12
carbon dioxide level	0·26	0·06	0·05	0·04	0·04
amount of ozone	0·23	0·16	0·18	0·04	0·04

The table, prepared by Dr Webster and Dr Stephens, shows the sensitivity of the earth's surface temperature to various factors.

Dr Roger Gifford has found that extra carbon dioxide makes plants use scarce resources more efficiently.

Dr Gifford believes biotic growth factors in the real world should remain high, even over the life of long-lived perennials, and on present knowledge he selects a value of 0·6 as a best estimate of the average figure. All ecosystems, whether they are limited by light and nitrogen (as in the humid tropical forests) or by low water supply (as in the semi-arid regions) or by low temperatures (as in temperate forests), should benefit.

Most of the world's biomass is in forests; so — over the time scale of decades, in which we are interested — trees are the most significant absorbers of carbon dioxide, storing the carbon in wood. Annuals will simply cause a year-to-year oscillation in the amount in store. Of course, over a time scale of centuries, trees will die and we need to consider the build-up of long-lasting soil organic matter.

Tropical rainforests are being cleared rapidly in many parts of the world — a matter of concern from many viewpoints. Fortunately, however, it seems that temperate forests, after facing their greatest onslaught earlier in the century, are now increasing due to reafforestation.

Despite the lushness of tropical forests, temperate forests are just as good at laying down carbon where it matters — in long-lasting wood. Indeed, because of the fast decomposition of leaf litter in the tropics, the floor of temperate forests actually holds ten times as much organic carbon (40 billion tonnes over 24 million square km) as the tropical forest floor (4 billion tonnes over a similar area).

Plants may begin to grow in arid areas where they are unable to grow at the moment.

Dr Gifford estimates that the world's vegetation is storing more than 1 billion tonnes more carbon each year than it would if carbon dioxide levels had remained at 1958 values (when monitoring began). He derived this figure from estimates of biotic growth factors and of rates of growth and decay in each of nine broad vegetation categories (tropical forest, temperate forest, woodland, tropical grassland, and so on).

Evidence that the biosphere has in fact increased in size comes from seasonal measurements of global carbon dioxide concentration. These show an annual fluctuation related to summer growth and winter decay of vegetation, and the size of this annual fluctuation has steadily increased over the past 20 years (see the box on page 9).

All this suggests that the biosphere may already be having an appreciable effect on carbon dioxide level, and that its flourishing will increase as carbon dioxide levels become higher.

A tentative estimate by Dr Gifford is that the world's tropical grasslands store in total at least as much carbon in response to elevated carbon dioxide as do the tropical forests. Apparently the grasslands can store long-lasting soil organic carbon whereas wetter tropical forests cannot. This is not an argument for clearing tropical forests, but it does show that effects are often unpredictable.

Disruptive changes

Taken together, the oceans, clouds, and plants may soften the impact of a rise in carbon dioxide. But then again, they may not.

If the carbon dioxide level does rise to the expected levels and the climate changes, not all the changes need be deleterious, as we have seen. However, on the social and political levels, any major change is likely to be disruptive. One country's increased rainfall does not simply make up for the decrease in another's.

A crucial point is the speed at which changes occur. The longer the time span, the more likely it becomes that we will cope satisfactorily. To buy time we could conserve energy, swing over as quickly as possible to renewable energy sources (or nuclear power), and plant more trees.

Andrew Bell

More about the topic

'Carbon Dioxide and Climate: Australian Research.' Ed. G.I. Pearman. (Australian Academy of Science: Canberra 1981.) (This volume contains all the papers delivered to the symposium.)

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