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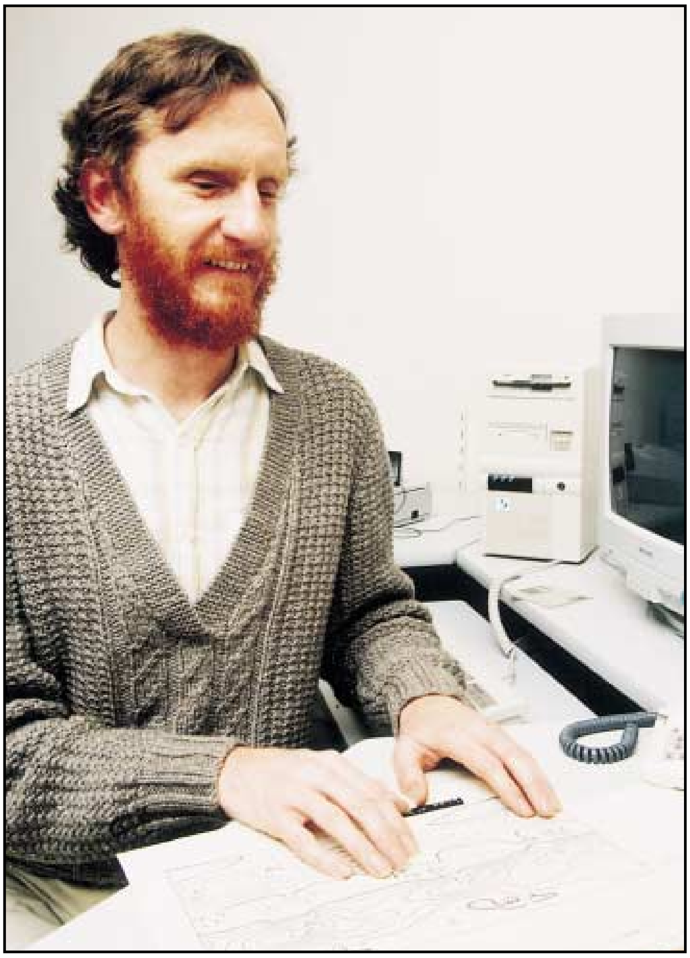
Deconstructing ENSO

Researchers first noted a connection between CO_2 and ENSO events in 1976. Analysis of 40 years of data has since revealed a complex but consistent relationship between ENSO events and atmospheric CO_2 anomalies, in particular, a sharp decline in atmospheric CO_2 just before the onset of ENSO events, followed by a 'rebound' effect.

Dr Peter Rayner of the Cooperative Research Centre for Southern Hemisphere Meteorology says the initial, rapid response appears to be driven by the oceans, while the 'rebound' effect reflects the delayed response of terrestrial ecosystems to changes in temperature and precipitation.

In El Niño years the trace dips sharply downwards, then rebounds, while in La Niña years it swings violently upwards, before subsiding again. Both trends reflect the movement of several gigatonnes of carbon between sources and sinks in the oceans and on land (one gigatonne = one billion tonnes).



Dr Peter Rayner is studying the seasonality, timing and duration of ENSO events in order to model their influence on the global carbon budget.

Between the extreme low of the 1982–83 ENSO event, regarded as one of the most severe this century, and the high of the La Niña event of 1988–89, the difference was equivalent to four billion tonnes of CO_2. Clearly, any model of the global carbon budget must factor in El Niño as a major player.

'We need to stress just how big these inter-annual variations in atmospheric CO_2 are,' Rayner says. 'There is recent data suggesting that the 1996–97 ENSO event produced an even more dramatic swing than those of the 1980s and early 1990s.

'The interannual swings are equivalent to four gigatonnes of CO_2, or two thirds of the emissions from fossil fuel burning.'

Currently, about half of the nearly six billion tonnes of CO_2 emitted by fossil fuel burning are removed from the atmosphere each year. Of this amount, about two billion tonnes is taken up by the oceans. On average, a somewhat smaller amount is stored in terrestrial ecosystems, as the difference between photosynthesis and respiration.

'Our quantitative understanding of this is severely limited by the much larger year-to-year variations associated with ENSO,' Rayner says.

At first glance the CO_2–ENSO relation defies common sense: during ENSO events, the average global temperature increases slightly, so it might be expected that globally averaged heat transfer to the surface layers of the oceans would release more dissolved carbon dioxide into the atmosphere.

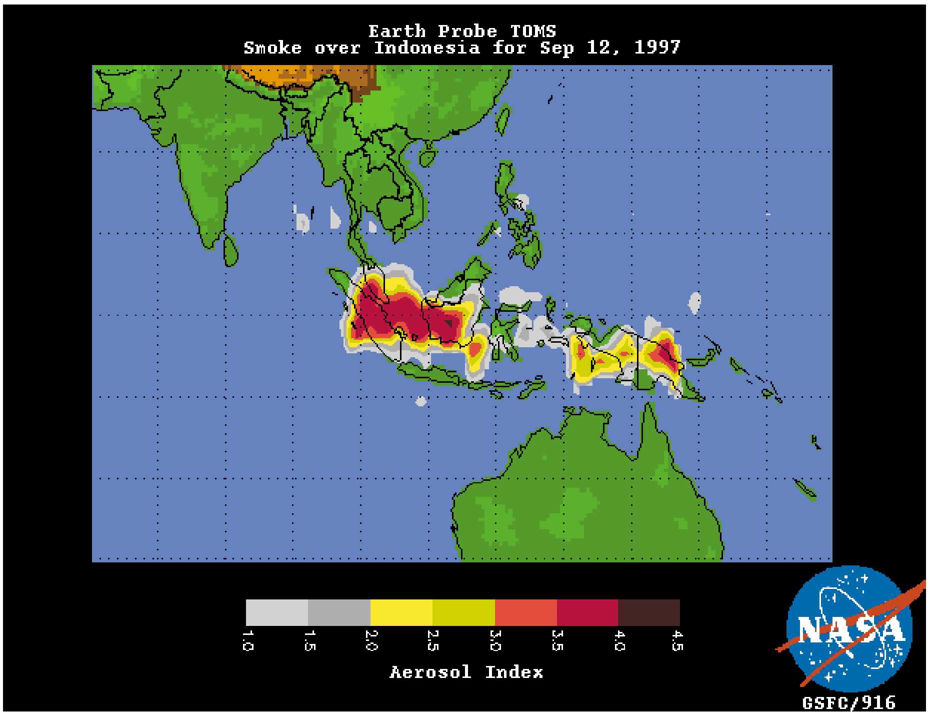
In fact, the reverse happens. During ENSO events, atmospheric CO_2 levels initially fall steeply, with the pattern reversing in La Niña years. Then a 'rebound effect' kicks in, partially correcting these sudden excursions from the norm.

'We have learned that the interactions are rather more subtle and complex than we thought,' Enting says. 'We have to think carefully about the seasonality, timing and duration of ENSO events.'

Rayner says the first and most immediate effect of an ENSO event is a change in the pattern of upwelling deep oceanic water in the eastern tropical Pacific Ocean. A huge pool of warm, low-salinity tropical water, usually centred in the equatorial Pacific north-east of New Guinea, flows eastwards towards the Pacific coast of South America.

The warm layer overrides the frigid, CO_2-charged waters that normally upwell in the oceans west of South America, throttling off the large amounts of CO_2 that normally diffuse into atmosphere in the region. In consequence, atmospheric CO_2 levels fall sharply over the eastern Pacific.

But this is not the only effect of an ENSO event, Rayner says. ENSO also has dramatic impacts on land, through its effect on precipitation and temperature.



Major fires in parched forests, such as those in Indonesia during the severe 1997–98 ENSO event, release large quantities of CO_2. (Source: NASA)

'It's difficult to know what the aggregate effect is, but it probably tends to drive increases in CO_2 and temperature over land, particularly in the western Pacific region,' he says.

ENSO events cause lower sea-surface temperatures in the western Pacific, resulting in reduced evaporation and precipitation.

The drier atmosphere leads to higher temperatures in Indonesia, accelerating decomposition of the litter layer of the region's tropical rainforest. At the same time, the plants become water-stressed and their growth slows.

Accelerated decomposition and reduced CO_2 intake for photosynthesis both tend to increase CO_2 in the atmosphere, and major forest fires in the parched forests, like those in Indonesia during the severe 1997–98 ENSO event, release even larger quantities of CO_2.

'Indonesia seems to start burning earlier in the ENSO cycle than one might expect, because the ocean starts to cool, and evaporation from the sea surface decreases, reducing precipitation and drying the land,' Rayner says.

'Rainfall and temperature changes have integrated effects. They take time to bite, because the land takes time to get hotter and dry out.

'There is also the effect of the underlying seasonal cycle: if the monsoonal rains come late, wildfires can suddenly become much more severe.

'Modellers have no trouble making the terrestrial biosphere the big player, but the problem is that the atmospheric signal is not compatible with the timing and duration of ENSO events.'

Southern picture obscured by ice and algae

Rayner says it is not yet clear how ENSO or other climatic cycles affect CO_2 sources and sinks in the Southern Ocean.

'We do know that the Southern Ocean is very active, and that it is probably a huge sink for CO_2, particularly between 20 to 50°South,' he says.

'But that's a major point of controversy, because while local measurements suggest it should be a strong sink, the atmospheric data don't confirm it.'

The frigid water and large algal biomass of the Southern Ocean should draw down large amounts of CO_2, but the picture is complicated by the presence of vast expanses of sea ice that develop in the zone between 55°South and the Antarctic coast each winter. The sea ice seals off the cold water, preventing CO_2 uptake, and shutting down algal photosynthesis: the ice blocks what little sunlight is available during the southern winter.

Rayner says in the past the ocean was thought to be the major player in the large interannual fluctuations in atmospheric CO_2 concentrations. But the recent studies do not support this belief. Despite the dramatic changes that occur in the tropical oceans west of Peru, the atmosphere is seeing much more CO_2 than the oceans can generate, which implicates terrestrial processes.

Graeme O'Neill

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