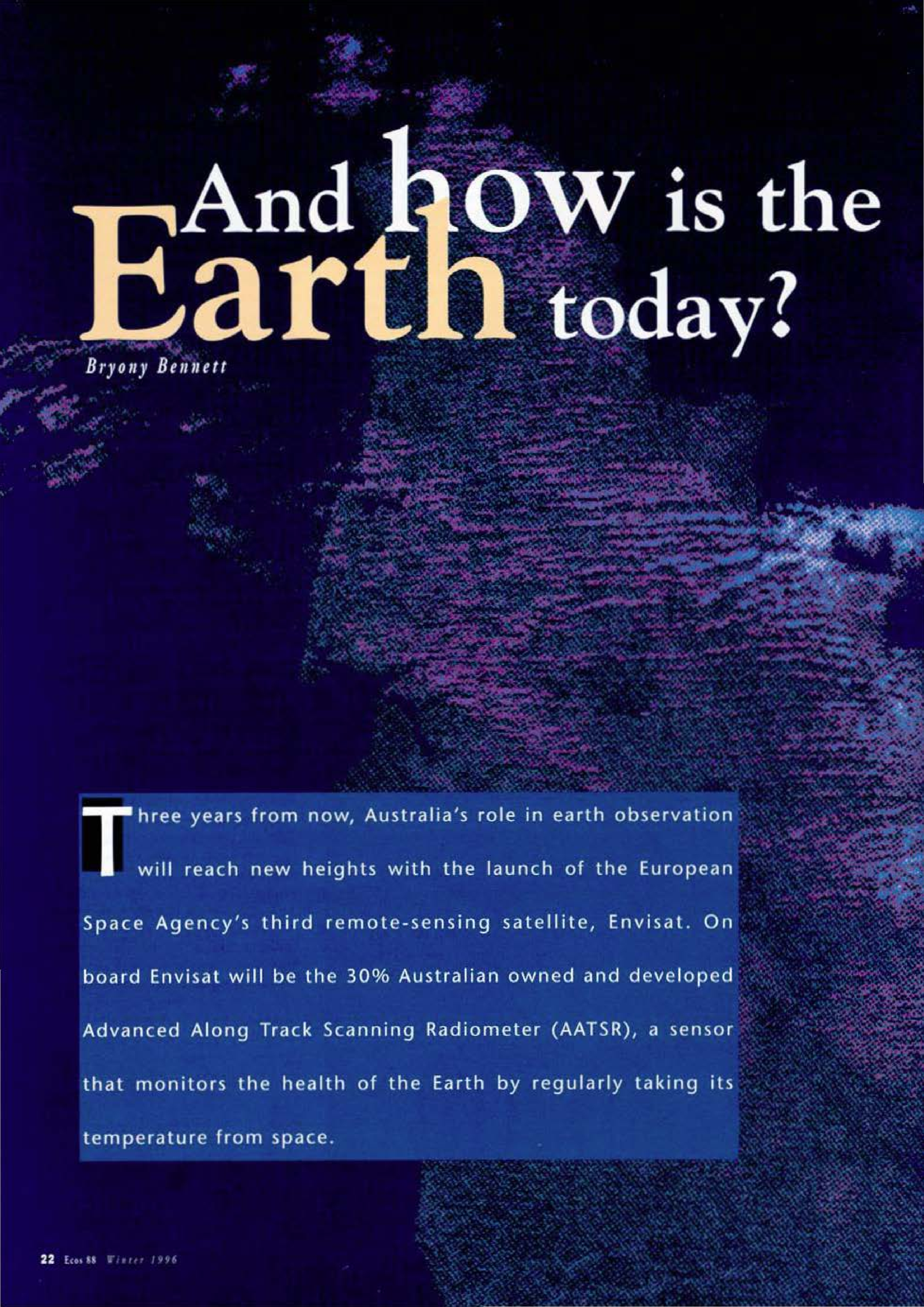


And how is the Earth today?

Bryony Bennett

Three years from now, Australia's role in earth observation will reach new heights with the launch of the European Space Agency's third remote-sensing satellite, Envisat. On board Envisat will be the 30% Australian owned and developed Advanced Along Track Scanning Radiometer (AATSR), a sensor that monitors the health of the Earth by regularly taking its temperature from space.

The radiometer is the third of its kind to be carried aboard a European Space Agency satellite. The first version, ATSR-1, was launched in 1991, and the second, ATSR-2, has been in orbit for just over a year. Measurements taken by the ATSRs are unique because the sensor scans the Earth from two angles. When the different views are matched, distortion caused by the atmosphere (such as water vapour and dust) can be eliminated, yielding precise data that can be applied in climate research and resource management.

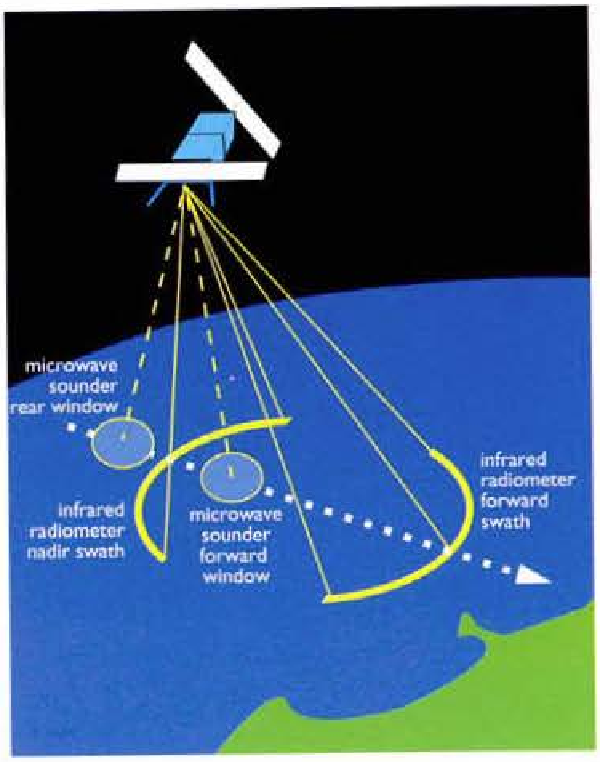
Australia's link with the ATSR program was established through Dr Ian Barton, a CSIRO scientist who has been involved with the sensor's development from its conception. Barton put forward the idea of a dual-scanning radiometer in 1980, when he was part of a UK team invited to design a remote-sensing instrument for a French satellite. At the time he was working on the analysis of data from NASA's Nimbus 5 satellite at Oxford University's Department of Atmospheric Physics.

'The only way to understand how the global climate system works is by using comprehensive models of the Earth's atmosphere and ocean systems,' Barton says. 'It was recognised 15 years ago that to see these models work correctly, global sea-surface temperatures to 0.25°C accuracy would be needed.

'I had found large errors in sea-surface temperatures derived from data collected by the Selective Chopper Radiometer on Nimbus 5. The errors were caused mainly by absorption of the signal by water vapour and aerosols as it travels from the Earth's surface to the satellite. As a result, the temperatures were accurate to only 0.6°C in the mid-latitudes and 1°C or worse in the tropics. (Interference is greater in the tropics because water vapour is more plentiful and variable.) My theoretical analyses at Oxford University had shown that two angles could be used to give an improved measurement.'

Although the French satellite opportunity slipped by, Barton's idea was embraced by his colleagues. The design work began, and in 1982 the ATSR was proposed as the UK's instrument on board ERS-1, the European Space Agency's first remote-sensing satellite. Barton returned to Australia soon after, but has remained on the ATSR science team. He works for CSIRO's Division of Atmospheric Research, and is based at the Hobart Marine Laboratories.

Australia officially joined the ATSR program in 1984, with the Federal Government funding a locally-built digital electronics unit, and CSIRO's Office of Space Science Applications (COSSA) contributing to the mission's science plan. The Australian Space Office spent $4 million on the development of ATSR-2, and companies in Adelaide and Canberra built the sensor's electronic ground support system and main optical system. Australia's contribution to the Advanced ATSR will total some $12 million.



The ATSR's infrared radiometer scans the Earth from two different angles (0° and 52°) in curved swaths 500 km wide and separated, along track, by about 800 km at ground level. When the different views are matched, distortion caused by the atmosphere can be eliminated, yielding precise data that can be applied in climate research and resource management. To account for the influence of water vapour, a common source of 'noise' in the measurement of sea-surface temperatures, the ATSR's microwave radiometer monitors the total water vapour content of the atmosphere. This information is used to improve the 'atmospheric correction' of sea-surface temperatures.

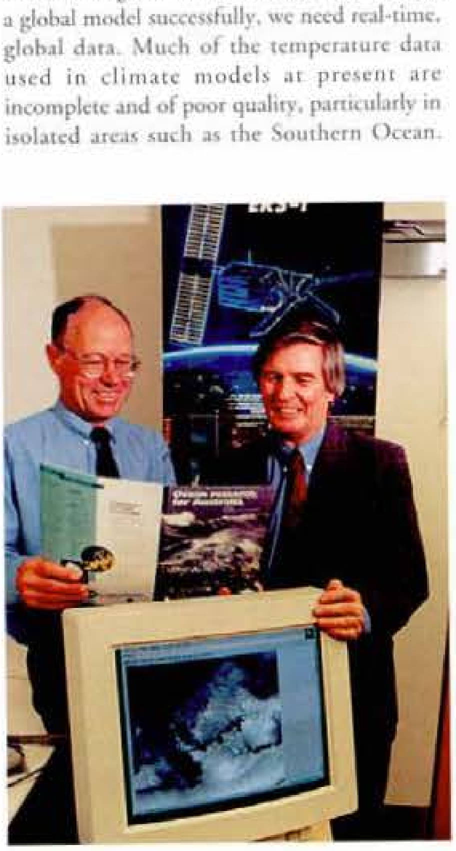
In addition to expanding its role in instrument development, Australia has been a major participant in the ATSR program's validation campaign. Between September and December of 1991, Barton and his CSIRO colleagues completed four cruises in the Coral Sea, taking ship measurements to compare with those from ATSR-1. The Coral Sea provided perfect conditions in which to test the sensor's abilities: warm sea, a suitable amount of water vapour, and at that time of year, few clouds.

What was the result? ATSR-1 passed the test with flying colours. The sensor was measuring sea-surface temperatures to an accuracy of 0.25°C. Good enough in Barton's view to satisfy the driving force behind the ATSR program: the need for economic, accurate measurements of land and sea-surface temperatures worldwide.

In return for its significant contribution to the ATSR program, Australia has priority access to information collected by the ERS satellites. This is made available on tapes, on CD-ROM, or on the Internet, depending on the size of the data-set required. The challenge now for Australian scientists is to make the best use of this new stream of high-definition data. At CSIRO, an important application will be climate research.

Making better models

'To understand climate variability and possible climate changes due to human activities, we have to model how climate works on a global scale,' Barton says. 'To run a global model successfully, we need real-time, global data. Much of the temperature data used in climate models at present are incomplete and of poor quality, particularly in isolated areas such as the Southern Ocean.



CSIRO's Dr Ian Barton and head of the European Space Agency's Earth Observation Mission Management Office, Dr Guy Duchossois. Australia's scientific and industrial expertise have contributed to the agency's ERS satellite program in the areas of equipment supply, experimentation, and in validating the data received for climate change and land use programs.

The only way to gather data on sufficient time and space scales is from satellites.'

Barton says although satellites are expensive to build and launch, the cost per measurement is low compared with sending out aircraft or ships. 'Also, the measurements are self consistent because with one instrument you get repeated coverage of the globe,' he says.

Accurate measurements of sea-surface temperature from the ATSR can be applied in various ways to validate and improve the performance of models that simulate climate variability (such as the occurrence of droughts and floods), and possible global warming. Temperatures at the sea surface, which are influenced by ocean currents, govern the direction and rate of heat and energy exchange between the atmosphere and ocean. The inability of climate models to characterise these complex processes is a major factor limiting their capacity to yield reliable predictions.

By studying the long-term records of sea-surface temperatures, scientists can learn more about the apportionment of heat and energy over the sea: how much water is evaporated, how much energy is radiated, how much goes into direct heating of the atmosphere and how these processes are affected by humidity and clouds. The equations developed to represent these processes in climate models (their parameterisation), can now be improved by using satellite data in experimental studies.

Understanding the dynamics of the sea surface is important, because small anomalies in sea-surface temperature can have massive effects on climate by controlling where large scale convection and rainfall develop. When heat is released from the ocean to the atmosphere as water vapour (in much the same way that steam rises from a boiling kettle), energy is transferred away from the sea surface, often resulting in clouds which release heat by warming the atmosphere when they condense and rain.

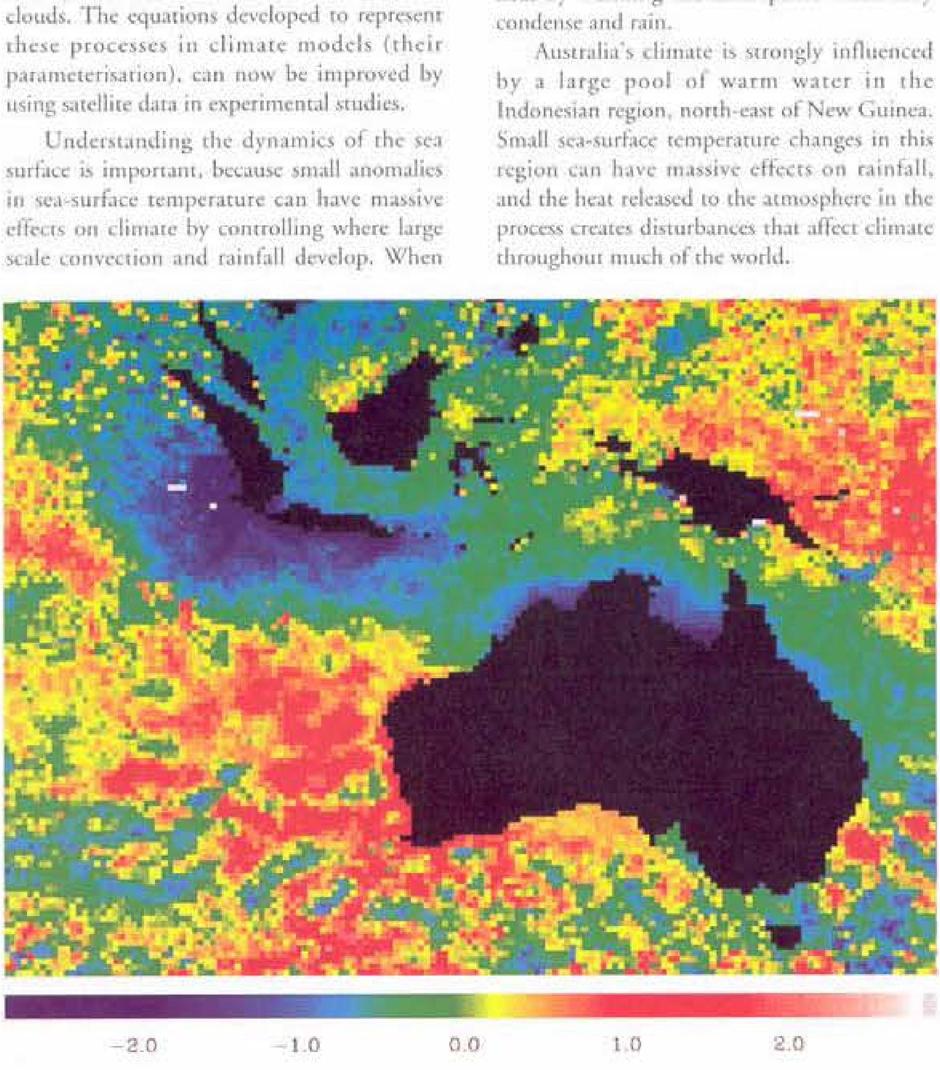
Australia's climate is strongly influenced by a large pool of warm water in the Indonesian region, north-east of New Guinea. Small sea-surface temperature changes in this region can have massive effects on rainfall, and the heat released to the atmosphere in the process creates disturbances that affect climate throughout much of the world.

During an El Niño event, for example, the shift of this warm pool from west to east across the Pacific causes flooding over the normally arid coast of South America, while the colder water in its wake curbs rainfall in the western Pacific, often causing the eastern two-thirds of Australia to enter drought. Long-range forecasting of climate variability across Australia depends on simulating events such as these changes in temperature of tropical waters to the continent's north.

Scientists from CSIRO and the Australian Bureau of Meteorology have been working together on this conundrum. The potential benefits of the research for primary producers and natural resource managers is recognised by the Land and Water Resources Research and Development Corporation. Earlier this year, the corporation funded a three-year project to develop a prototype system for providing a 12-month forecast of significant variations in Australia's climate.

Research leading up to the prototype has concentrated on the Indonesian region, to understand the mechanisms responsible for climatic patterns such as El Niño. At CSIRO Oceanography, this work is led by Dr Gary Meyers, a scientist whose knowledge of ocean

Knowledge of the ocean/atmosphere interactions that shape Australia's long-term climate variability is drawn from thousands of sea-temperature measurements gathered by CSIRO's Ocean Observing Network. The network involves volunteers aboard merchant vessels deploying instruments called expendable bathythermographs (XBTs). The data are transmitted by satellite to research and climate prediction centres worldwide. Scientists can now use measurements taken by the Along Track Scanning Radiometer to confirm and enhance their understanding of climate processes exposed by the XBTs.



This image created from ATSR data shows the difference in winter sea-surface temperatures between 1993 and 1994 in a region now known to have a significant influence on Australia's climate. It shows a 'cold spot' in the Indian Ocean which was first exposed by CSIRO's Ocean Observing Network in the winter of 1994. The cold spot exacerbated existing El Niño conditions by preventing the formation of rain clouds which normally blow across the continent to eastern Australia.

Playing with spectral bands

MOVING AT six kilometres a second, at a mean height of 780 km, the ERS-1 satellite orbits the Earth 14 times a day. On board, the Along Track Scanning Radiometer (ATSR-1) scans the Earth in 500 km swaths, covering the globe twice every three days. It's a terrific vantage point, but what is the ATSR looking at and how does it see?

The ATSR responds to electromagnetic radiation: the energy emitted by all objects warmer than absolute zero (-273°C). Although we can't see it happening, we can imagine this radiation as moving like an ocean wave. The distance between two adjacent wave crests is called a wavelength. Visible wavelengths are less than one micrometre (one millionth of a metre, or 1 µm) and heat wavelengths are nearer 10 µm.

Hotter objects radiate more energy at shorter wavelengths and colder objects radiate more energy at longer wavelengths. For example, the sun at 6000°C has maximum energy at visible wavelengths (0.5 µm), but the Earth's surface at 20°C has maximum energy at thermal infrared wavelengths (10 µm). The range of wavelengths over which electromagnetic radiation extends is called the electromagnetic spectrum and regions within it are called spectral bands (see diagram).

Only a small part of the spectrum – visible light – can be seen by the human eye. The eye identifies objects by noting variations in reflected light in the visible region. This variation, which we recognise as colour, stems from the different absorption and emission properties of the surface materials. But heated objects emit radiation in other parts of the electromagnetic spectrum too, particularly the thermal (infrared) and microwave bands. Remote-sensing instruments can also detect variations in these parts of the spectrum.

To gather detailed information about the ocean and the atmosphere, or particular kinds of objects on the Earth's surface (such as minerals or vegetation), remote-sensing instruments are tuned to channels within the spectral bands that offer the best view. For example, shorter bands, which penetrate furthest into water, are useful for assessing water quality and watching algae; visible-light bands are used to monitor land; and the near infrared region (1-3 µm) is used in geological mapping and determining vegetation health.

This system would work perfectly given a clear sky, but matters are complicated by the atmosphere. Radiation reflected and emitted from the Earth is absorbed by the atmosphere in many parts of the electromagnetic spectrum. Gases such as carbon dioxide absorb and radiate differently at different wavelengths, and aerosols and water droplets can absorb, scatter and emit radiation, reducing the accuracy of satellite measurements of surface features. According to Dr Ian Barton, a founder of the ATSR program, this absorption must be accounted for when viewing the Earth's surface, but alternatively it can be used to deduce properties of the atmosphere. For example, the atmosphere is opaque in the 13 to 15 µm band, because this is a spectral region in which carbon dioxide absorbs radiation strongly. This band, which offers no view of the Earth's surface, can be used to measure the temperature of the upper atmosphere. But when a clear view of the Earth's surface is required, sensors must operate in 'atmospheric windows' or spectral regions where there is the least interference with the radiation signal.

The ATSR is comprised of two radiometers: one infrared and one microwave. The infrared radiometer on ATSR-1 has four 'channels', three of which are used to measure sea-surface temperatures. The fourth channel measures radiation in the near-infrared region, and is used to detect clouds, ice and snow in daytime. Version two of the instrument, ATSR-2 has three additional channels in the visible light region. These are used for viewing land surfaces and vegetation colour. Information such as the health and moisture content of vegetation can be inferred from these measurements.

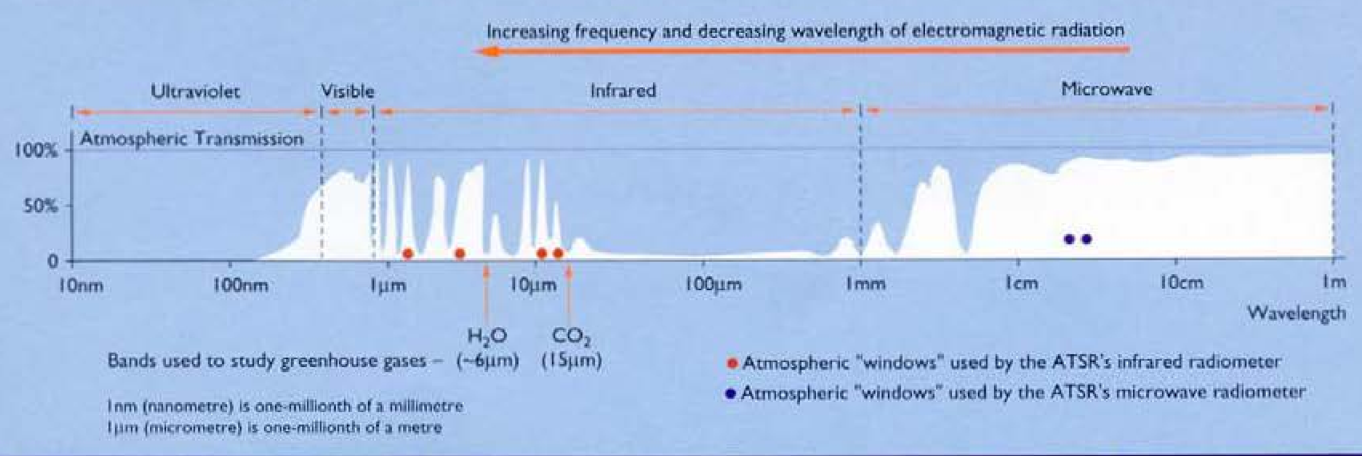
Cleaning the windows

Even in the 'window' regions, atmospheric effects – such as cloud, dust and water vapour – interfere with remotely-sensed measurements. As a result, temperatures measured from space are often several degrees lower than their true value at the Earth's surface. Corrections must be made to account for these atmospheric effects. This is where the ATSR is particularly clever.

The ATSR's infrared radiometer involves a rotating mirror which scans the Earth's surface from two different angles (0° and 52°) in curved swaths 500 km wide and separated, along track, by about 800 km at ground level. From the two measurements, information is obtained about the effect of the intervening atmosphere, allowing the atmospheric influence to be eliminated. 'The stereoscopic view also tells us something about the height and structure of clouds,' Barton says. 'Because the radiometer senses in the infrared band, measurements cannot be made when it's cloudy. While areas of heavy cloud are obvious, it has previously been difficult to detect temperature distortions caused by sparse cloud.'

A further technique is used to account for water vapour, a source of 'noise' in the measurement of sea-surface temperatures. The ATSR's microwave radiometer monitors the total water vapour content of the atmosphere. With this extra information, the atmospheric correction of sea-surface temperatures can be improved.

The electromagnetic spectrum extending from the ultraviolet to the microwave region



physics in this region is fed by an 'intelligence' network operating in the Southern, Indian and Pacific oceans.

CSIRO's Ocean Observing Network is run by Rick Bailey, from the office next door to Meyers. It involves volunteers (usually ships' officers) aboard merchant vessels deploying instruments called expendable bathythermographs (XBTs) at preset intervals as the ships traverse areas of scientific interest. The XBTs carry thermometers which transmit water temperatures back to the ship every 60 centimetres to a depth of about 760 metres. The data are stored on a shipboard microcomputer, and a condensed version transmitted by satellite to research and climate prediction centres worldwide. Bailey says more than 33 000 XBTs have been launched since the program began in 1983.

Validating the cold spot

In the winter of 1994, data from the XBTs alerted scientists to a zone of colder than usual sea-surface temperatures in the Indian Ocean. According to Meyers, the 'cold spot' was the product of a complex interaction between winds, ocean currents and El Niño. It exacerbated the existing El Ni§o conditions by preventing the formation of rain clouds which normally blow across the continent to eastern Australia.

In late 1995, the cold spot first exposed by the XBTs was confirmed from space by the ATSR. When Meyers and Barton studied the remotely-sensed sea-surface temperatures taken for the same period, they found a large cold spot covering an area extending along Sumatra and Java and the Indonesian Archipelago and into the Indian Ocean from the Indonesian coast (see image). The spatial pattern of the temperatures validated Meyers' original interpretation of the mechanisms causing the cold spot. It also reaffirmed the need for scientists to consider the influence of the Indian Ocean, as well as the Pacific, in developing systems to predict Australia's climate.

'For me it was remarkable that the patterns we had observed from our XBT data could be seen from satellite data in much greater detail than we could hope to observe from ships,' Meyers says. 'We're beginning to understand how the ocean's internal structure and currents affect climate, but the data we collect are limited to the routes taken by merchant vessels and on research cruises. With satellites, we can get a broad view in the form of an ocean map.'

Meyers has also made use of ocean measurements taken by two other sensors on the ERS-1 satellite. These are a wind scatterometer which measures the speed and direction of wind near the surface of the sea, and a radar altimeter which measures wave height and sea-surface elevation. Measurements of sea level reveal much about the internal temperatures of the ocean, which in turn are representative of ocean currents. This is because columns of warmer water, which are less dense than cold water, produce higher sea levels.

With data from the XBTs, the ATSR, the wind scatterometer and the radar altimeter, Meyers and his team have been able to develop a fairly complete dynamical description of the Indian Ocean 'cold spot' phenomenon. 'The satellite data revealed a

With double vision, little escapes from view

AS WELL as providing accurate ocean temperatures for climate studies, the ATSR is keeping a watchful eye on other features of the atmosphere, land and sea that influence the state of our environment.

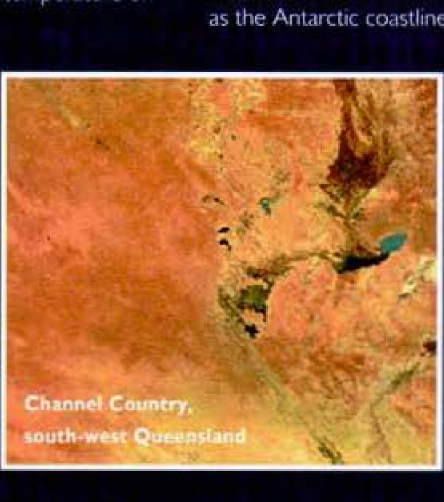
Land temperature: Field work conducted by Dr Fred Prata from the Division of Atmospheric Research has shown that the ATSR's dual view capability gives improved readings of land-surface temperature. When Prata compared ATSR measurements with those taken on the ground at a uniform land site near Hay in New South Wales, they were accurate to 1°C, an improvement on previous instruments.

Clouds and ash: Conventional techniques for determining cloud height rely on a coarse relationship between the cloud temperature and its height. The ATSR's stereoscopic view enables cloud height to be measured through simple geometry. This has been useful in monitoring the height of ash clouds from explosive volcanic eruptions. In these extreme cases the usual dependence of cloud temperature on height does not apply.

Vegetation health: The first ATSR only viewed the Earth's surface at infrared (heat) wavelengths, but the successive two instruments also use the visible part of the spectrum, the part seen by the human eye (see story on page 25). The ATSR-2 and the Advanced ATSR see the surface in yellow, green and red. By observing the colour of the surface much can be learnt about the health of the underlying vegetation and its moisture content. This latter parameter is used by several Australian state fire authorities to assess the distribution of fire-prone area, in their agricultural zones.

Antarctic sea ice: ATSR data have proved a boon for Antarctic research. When the data from several instruments on the ERS satellites are combined, the distribution of sea ice and the temperature of the Antarctic ice sheet can be determined. This knowledge assists with weather forecasting, not only in polar regions, but also in southern Australia as scientists start to realise that weather patterns as far south as the Antarctic coastline can influence our weather.

Lake Eyre, South Australia



Channel Country, south-west Queensland

Aerosol: The new visible channels on the ATSR-2 are able to track the passage of aerosols in the atmosphere. Aerosols can be generated through industrial activities, or by natural events such as dust storms in central Australia. They can have a significant role in determining local climate by absorbing and scattering the sun's energy before it reaches the surface.

This snapshot of the applications of ATSR shows that Australia will gain significant benefits from the use of these new satellite measurements, not only in climate applications, but also in the monitoring of the state of our extensive land and ocean environments.

more complete description of the spatial extent and better understanding of mechanisms that made the cold spot happen,' Meyers says.

Setting the models in motion

Thanks to the data provided by the ATSR and the XBTs, Meyers and his team now have two sources of sea-surface temperature measurements in the regions that influence Australia's climate. These will be combined during the development of the climate forecasting system to improve its representation of the mechanisms of climate variability.

The ATSR data will also be used to specify the initial or start-up conditions for the climate prediction model. Values typically used for this purpose in global climate modelling are long-term averages, ignoring yearly or monthly variations. And in the case of the Indian and Pacific oceans, ATSR data will expand the spread of temperature measurements.

'The climate prediction model being developed will use satellite data to help specify the state of the ocean at a particular time to initialise a forecast,' Meyers says. 'It's important to get the sea-surface temperature correct because that's the feature in direct contact with the atmosphere.'

Once the model has been set in motion, its progress can be checked against the remotely-sensed data and, if necessary, fine tuned. The model's final outcome can also be verified in this way.

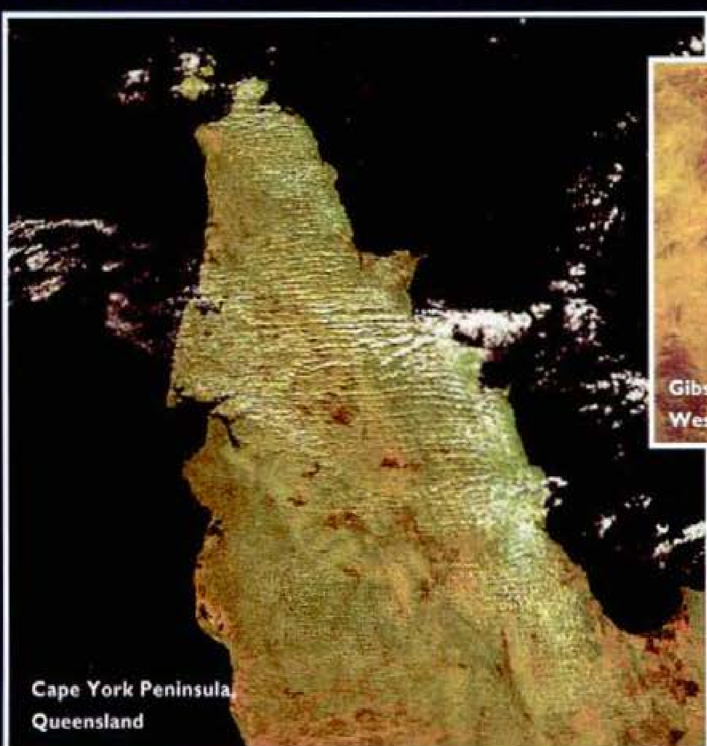
Quality control

Although Barton and his colleagues are well pleased with the ATSRs' performance, the challenge to improve the accuracy of their data products is ongoing. A focus of this work is the interpretation of water vapour measurements taken by the instrument's microwave radiometer (see story on page 25). Barton is working to improve the equations used to derive sea-surface temperatures from these raw data.

'Errors in temperatures seem to be linked to abnormal distributions of water vapour,' Barton says. 'If there is a lot of water vapour at the surface with a dry layer above (or vice versa), we appear to get an error. This is because the equations used to derive sea-surface temperatures from infrared data assume that the atmosphere has a fixed distribution of water vapour with height.

'The secret is to try to use all the remotely-sensed data to get a feel for how the water vapour is distributed in the atmosphere. These studies require a combination of many simultaneous satellite and ground-based measurements, along with a theoretical model of the effect of atmospheric absorption on the infrared radiation.

'Eventually it will be possible to just feed all satellite and ground-based measurements into numerical models of the weather. The model will then determine the best equation to use, not only to calculate sea-surface temperature, but for all other weather parameters as well. This scenario may be some years away, but Australian scientists are part of a large international community working in this direction.'


Cape York Peninsula, Queensland


Gibson Desert, Western Australia


MacDonnell Ranges, Northern Territory

Information extracted from the dual angle multispectral ATSR-2 can be used to study changes in vegetation, surface radiation budget parameters such as albedo, temperature, longwave emissivity and shortwave fluxes (see story on page 29). ATSR-2 also provides atmospheric information on aerosols and clouds over land. These ATSR images show the surface features of a range of Australian landscapes.