National Tidal Facility

South Pacific Regional Environment Programme

The South Pacific Sea Level and Climate Change Newsletter

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During this period, our *Quarterly Newsletter* will report on activities and programmes related to the Project, especially during the May 97 Modular Training Attachment for Forum Island Governments at the National Tidal Facility, Flinders University in South Australia. The Modular Training Attachment Programme was planned for 5–23 May 1997. Thirteen participants from the Forum countries attended this attachment, which focused mainly on surveying. The composition of the group included nine surveyors, two meteorologists and two environ–mental scientists. Other courses including analyses of tides, data interpretation and management, information systems and coastal management, and planning were also presented. Practical field trips were organised to visit the South Australian Lands Department, Bureau of Meteorology, Laser Airborne Depth Sounding Research Institute (LADS), Department of Coastal Protection, Airborne Meteorology Group in the School of Earth Science, Marion Council Area and the Greater Southern Ocean Beach. Nine resource people were involved in the training attachment programme from NTF, SPREP, National Oceanic Atmospheric Agency (NOAA, USA) and the School of Earth Sciences at the Flinders University of South Australia. The training programme was opened by the State Director of AusAID and closed by Bill Mitchell, Acting Director of NTF. The feedback from participants on the training attachment, in addition to the overall smooth organisation and planning of the programme, indicated that this was another training success story.

The Delegate from Kiribati saying a few words of appreciation and thanks to AusAID and NTF during the course dinner

Other activities that are currently planned and on-going for the project include:

- completion of eight draft modules of the curriculum on Climate Change and Sea Level Rise,

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AusAID

Adelaide Director of AusAID delivering the opening address for the Training Course at NTF

targetting secondary schools in the Pacific Islands. Dr Than Aung (NTF), Dr Chalapan Kaluwin (SPREP) and Mr Darrell Strauss (NTF) are currently working on this activity. The product is expected to be circulated by early 1998.

- The Project was represented at the 8th Pacific Science Inter-Congress ("Islands in the Pacific Century") held in Suva, Fiji, from 14 to 18 July 1997. Dr Kaluwin (SPREP's Climate Change Officer) and Dr Aung (Training Coordinator) presented technical papers, providing excellent promotion of the Project.
- Bill Mitchell, Greg Musiela and Dr Aung (all from NTF) also represented the Project and made technical presentations in the Third SPREP Climate Change and Sea Level Rise conference in Noumea, New Caledonia, on 18 to 22 August 1997. This conference invited all Forum governments to participate. Science, impacts and response options to climate change and sea level rise were addressed at the regional and national levels.
- During October 1997, another Modular Training Attachment was conducted at NTF. Once again, SPREP coordinated the government nominees attending this training. The training emphasised the treatment of tide signals, usage of information and data interpretation, numerical modelling, and Integrated Coastal Management (ICM). The training was made possible through funding from the Australian Government (AusAID).

This issue contains articles on signal interpretation with respect to the oceans, atmosphere, sea level rise, earthquakes and environmental changes in the region, as well as understanding mean sea level and tides. There is also reporting and updated information on the Southern Oscillation Index and forecasting El Niño signals in the Pacific Region. Discover how satellites can be used to measure sea level changes in the region in order to validate or check the modern tide gauge station measurements in the Pacific Islands. Finally, in the Children's Education segment, we look at past clues–or fossils–and link these to current sea-level changes.

Your Opinion

We are anxious to have feedback from readers on the content and presentation of the South Pacific Sea Level and Climate Change Newsletter.

Is it too technical? Or too banal? What can we do to make it more appealing without increasing production cost? Please spare a few minutes to let us know your constructive opinion.

Some features of Project data during this quarter

Dr T. H. Aung, the Training Coordinator for the Project, reports on the developing El Niño event, tsunamis and other features of the Project data.

Before looking through the Project data, it may be worthwhile to mention the news about the infamous El Niño in the Pacific Ocean. According to the Seasonal Climate Outlook Bulletin, Australia, Issue No. 98, July 1997 (Bureau of Meteorology, Melbourne, Australia), the value of the Southern Oscillation Index (SOI) continued its rapid fall during June 1997 and the latest value was -24.1. The resulting SOI value of -24.1 was a further drop from May (-22.4), April (-16.2) and March (-8.5). It is the lowest monthly value since April 1994. The trend of significant negative values in recent months is consistent with the development of an El Niño type scenario (Note: SOI is negative in El Niño period). Sea surface temperatures in the equatorial Pacific Ocean displayed further warming in the central and eastern Pacific and cooling in the far west reinforced the typical El Niño pattern. Strong westerly wind anomalies remained over the western tropical Pacific during April and May, consistent with the low value of the SOI and the development of an El Niño type scenario. (See further discussions in the next section.) Since the South Pacific Sea Level and Climate Monitoring Project began, we have been measuring oceanographic and meteorological parameters such as sea level, water temperature, atmospheric pressure, wind speed, direction and gust, and water temperature. Sea level is a measurable quantity and is the result of all influences which affect the height of the sea surface (moon and sun for daily tides, atmospheric pressure, winds, seismic activity, some oceanographic effects such as El Niño and so on). Tides are only part of the sea

Although very often mistakenly referred to as "tidal waves", tsunamis are not caused by tidal influences at all. Out in the ocean where the water is deep, far from land, the tsunami is not dangerous. This changes as the tsunami approaches land.

Having realised that the Southern Oceans hold the key to climate, Pacific delegates were eager to see the Southern Ocean and find out the differences to their native water, the Pacific Ocean. This photo shows delegates and some of the resource team at the Great Southern Ocean beach facing the ocean (across the Coorong) level and tide is related in frequency, amplitude and phase to astronomical forcing. The common terminology, residual, is equal to "sea level - tides". The residual is the observed change in the sea level which is not due to tides. It is due to meteorological effects, seismic activity and many other influences, generated locally or perhaps many thousands of kilometres away (i.e. tsunamis). One of the most spectacular and devastating long gravity waves, tsunami (or seismic sea wave) is a Japanese word meaning harbour wave of great wavelength, caused by the seismic disturbance or by the slumping of submarine sediment masses due to gravitational instability (i.e. sudden movement of the ocean bottom resulting from earthquakes or volcanic eruptions). Human-made disturbances such as underwater nuclear explosions can also set off the powerful waves. However, the most frequent cause, by far, is the earthquake. Although very often mistakenly referred to as "tidal waves", tsunamis are not caused by tidal influences at all. Accordingly, whenever we find unusual sea level residuals in our monthly data, we need to look at the cause and scientific reasons to justify why it happens. Strong winds, high or low atmospheric pressure and water temperature are the usual causes in this respect. Detailed treatment on this matter is presented in the Monthly Data Report. In this quarter, we would like to highlight another phenomena which may affect sea level-earthquakes. There was only one significant earthquake in the Pacific Ocean in April 1997

Table 1

Date	Time (UTC)	Latitutde	Longitude	Strength	Vicinity
21 April	1202	12.2°S	166.3°E	7.7	Santa Cruz Island

and details are given in Table 1, the magnitude is measured on the Richter Scale.

Based upon location and magnitude, this earthquake was not strong enough to generate a very significant tsunami. The nearest SEAFRAME station of the Project, in Vanuatu, felt the effect of the tsunami and registered significant signals of tsunami waves on that date (see Figure 1, note the vertical scale is given in metres and the horizontal scale is given in hours for 21–22 April 1997).

A tsunami is made up of a series of very long waves and each wave can be separated by tens of kilometres apart from the successive wave. The speed of tsunamis depends on the depth of water. In very deep oceans, the waves travel as fast as a jet plane. In this particular case, it took about one hour to reach the SEAFRAME station at Port Vila, Vanuatu. Peak-to-trough heights between

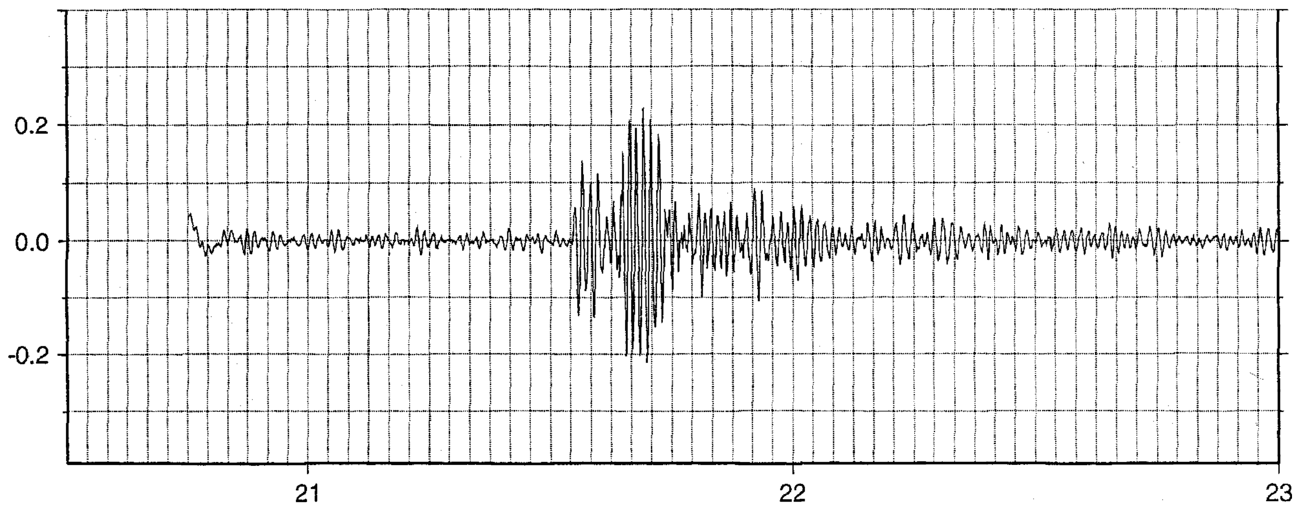

Figure 1: Tsunami waves registered at the SEAFRAME gauge in Port Vila, Vanuatu.

13:00 hours and 18:00 hours on 21 April 1997 were sometimes over 40 centimetres. Tsunamis are collectively unique in the amount of energy they contain, even when compared to the most powerful wind-driven waves. But at sea, tsunami waves cannot be felt or seen by ships. Nobody on the ship can feel the waves as they pass under the ship. Nor can the tsunami be seen by planes from the air. Out in the ocean where the water is deep, far from land, the tsunami is not dangerous. This changes as the tsunami approaches land, as the speed of the waves slows down in shallow waters. In 20 metres of water a tsunami travels at ~50 kilometres per hour, the speed of a slow car. The problem is that, although the first wave slows down in shallow water, the second wave is tens of kilometres behind and it is travelling faster. The result is that the distance between the waves does not remain at tens of kilometres. It grows smaller. The waves are "squashed" together, making the waves taller. This is when the tsunami waves can become dangerous, so that a small wave of half-a-metre high in the deep ocean may grow into a monster wave of tens of metres high as it sweeps over the shore. According to our personal communication with the Vanuatu Meteorological Service, damage caused by the above tsunami in April 1997 was considerable in the coastal areas of many islands in Vanuatu even though, in statistical terms, it was not a large tsunami.

In search of the mean sea level

Calculating mean sea levels is a complicated process. But without accurate calculations, how can we grasp what is happening in our oceans? In the following article, Emeritus Professor G. W. Lennon explains some of the complexities—and provides some solutions.

The harmonic model of the tide is very complex, just like the astronomical motions it follows. As a consequence, there is no identifiable time span within which all harmonic constituents complete an integral number of oscillations. In fact, the tide-generating circumstances which are responsible for the tide occurring at a particular port on a particular day, will never again be repeated for that port. Consequently any simple arithmetic mean of, say hourly observations of sea level, calculated over a discrete period, may well be biased by the fact that one–and commonly more–of the constituents will not have completed an integral number of oscillations. This affects the accuracy of such a calculation of mean sea level. The longer the period selected, the more reliable will be the estimate. However when, for example, mean sea level is calculated for the purpose of determining the secular trend of sea levels over many years, as in studies of the impacts of climate change where the trend signal may be as small as 1 millimetre per year, the simple arithmetical mean is inadequate for the purpose.

Given the above problem, it is much more satisfactory if a preliminary stage is introduced to the calculation which removes the tidal oscillations. This can be achieved in a number of ways:

- One course of action would be to subject the data set to harmonic analysis, so as to identify the tidal constituents and to use these to predict the time series for the same period and for the same sampling interval. The predicted values should then be subtracted from the observed values, and an arithmetic mean of the residual series obtained.
- Another method in common use is to apply a numerical "LOW PASS" filter designed to remove all frequencies higher than a defined threshold, and to allow only frequencies lower than the threshold to remain in the series. This would then be subjected to the calculation of a mean value. In this way, one may set the threshold, for example, so that only frequencies less than diurnal remain in the series.

One needs to think carefully about what is required in a particular case, since the two procedures outlined above have different implications. Consider the following.

The harmonic model of the tides contains long period terms of annual, semi-annual, monthly and fortnightly periods. (Sa, Ssa, Mm, Msf and so on). It is not advised that these terms are removed in the above procedures. In the filter option it is suggested that the threshold is set just below the frequency of the diurnal tide. In the "prediction" option, these terms are omitted from the harmonic model. The reason is that, at these frequencies, there are many non-gravitational sources of energy (mainly from radiational or meteorological sources) where the character of the contribution is not truly periodic and is not continuous in the same manner as a tidal constituent.

For example, Sa, the solar annual term, although existing in the astronomical tide-generating potential, derives much of its energy from the atmosphere (from temperature, water density, land-water run-off, wind stress and so on, which occurred in the particular year). Consequently there is strong variance from year to year, and the mean sea level is affected so that it tends to fluctuate from year to year over a range of several centimetres. This obscures the secular trend of sea level, of the order of one millimetre, in the same period.

Similarly periods of weather–perhaps storm and high winds–may bring excessive precipitation, lowering density in the vicinity of the observing tide gauge, or alternatively, through wind stress, generating what is known as a storm surge whereby water may be transported so as to build-up along a coastline which faces the oncoming wind.

Again we need to keep in mind that the ocean acts as an inverted barometer, and consequently its surface rises as barometric pressure drops and vice versa. In fact, a one millibar (one hecto-Pascal) reduction of barometric pressure will cause sea level to rise by approximately one centimetre. A tropical cyclone combines wind stress and pressure effects very effectively. There are other problems, for example if the observing tide gauge was of the bottom-mounted barometric type, it would not “see” the inverted pressure effect since it would be concerned only with the combined pressure of ocean and atmosphere. The effect would be automatically compensated in the signal which the gauge would receive.

In the above and many other ways, the mean sea level is affected by a complex package of radiational effects, and some of these can be of exceptionally long period or indeed may represent the coastal signature of an effect which may have been generated quite remotely. In the latter category, one would place the coastally-trapped long waves which dominate many continental coastlines such as the Australian South Coast. These can be in excess of one metre from crest to trough, travelling slowly along the coast so that several days may be taken for a single wave to pass a specific coastal station.

Other features fall into the steric category, by which is meant that the elevation of the sea surface depends upon density anomalies. For example again, it is known that possibly the warmest area of ocean water lies in the western Pacific to the north of Papua New Guinea. This area is also notable for its heavy precipitation which further contributes to a low density anomaly, causing the area to stand high by as much as 0.5 metres for several years at a time. But then we are aware that at times of El Niño, which is thought to occur in time scales of two to seven years, this warm patch migrates eastwards to the Central Pacific, so that the sea surface topography is changed for many months.

Inter-annual variance is not restricted to such mechanisms. Again, as an extreme case, consider that theories have been established to explain why the major ocean currents may be subject to cyclical change in periods of many years, perhaps of one thousand years, and this brings us to the geological evidence that sea levels have been fluctuating throughout time and through several hundred metres.

We are left with the reality that sea level is a transitory feature, subject to variations of many kinds, some cyclical, and over an enormous range of time scales. As we concern ourselves with the threat of sea-level rise as a result of climate change, we are presented with a major difficulty—we do not know where we stand at this moment of the Earth’s history, in this complex array of sea level oscillations. If we find that sea level is currently rising, ever so slightly as it is, and if our records show (as they do) that through a long period this has been the case, we may nevertheless pose the question as to how long this trend may persist. Are we, for example nearing the crest of an oscillation after which sea levels will begin to fall?

Just as in the case of the tidal constituents where we could not define a period wherein the constituents all complete an integral number of cycles, the same also is true for these non-gravitational features. There is no ideal period on which to base a determination of sea level trends, except to state that the longer the period of observation, the better. In the projects here, we are simply stating that any period short of 20 years of observations is likely to provide very deceptive results. If we take as long a period of observation as possible, remove the tidal contribution (since this is a major factor with which we can deal effectively), if we work in periods of 20 years (since there is a tidal signal of such a period associated with the Moon’s orbit), then we are doing as best we can in a system attuned to the practicalities of a social structure which needs to plan in such time scales. Nature operates in a different time scale.

Emeritus Professor G W Lennon is the founding father of National Tidal Facility and a former Director of the South Pacific Sea Level and Climate Monitoring Project.

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Measuring sea level changes from the sky?

A single measurement of the distance between a satellite and the ocean surface by a radar altimeter is now so accurate that variations of a few centimetres can be detected. This accuracy is now being put to use in determining global mean sea level change. Greg J. Musiela reports on developments in this area.

The exciting new era for oceanographic and climate research began in August 1992 with the launch of a joint CNES/NASA satellite devoted to ocean topography measurements with two altimeters (TOPEX and POSEIDON). As a result, data on sea level variability over a large ocean area became available in unprecedented detail.

At the same time, the South Pacific Sea Level and Climate Monitoring Project has been established by setting up high resolution land-based monitoring stations in eleven Pacific island countries. Supplementary survey and geodetic programmes are also being carried out to help identify the vertical land movements in the area. In order to achieve a better accuracy and more reliable sea level data sets, an attempt has been made to compare the Project data with the sea surface elevation data observed from the satellites. Although the data sets from the Project may only indicate the regional sea level changes, the results may help to estimate the global sea level variations.

If another five-year phase is granted by the Australian Government in due course, the future prospect of sea level observations in the Pacific region will be very much secured.

According to the report from World Climate News (No. 10, January 1997), so far the results from satellites can be summarised as follows. The yearly amplitude variation in sea level for the northern hemisphere is 25.6 millimetres and the value for the southern hemisphere is 18.3 millimetres. The maximum sea level occurs at the end of September and the end of March for respective hemispheres.

The global mean sea level trend during 810 days (December 92 to Feb/Mar 95) has been estimated to be 4.0±2.5 millimetres per year. The value is above the long-term trend of 2±0.5 millimetres per year, which is derived from land-based tide observations. A noteworthy point here is that this particular time period experienced a strong global warming of the sea surface.

It was just after the temporary cooling period caused by the eruption of the Philippine's Mt. Pinatubo volcano in June 1991. This warming may have caused a sea level rise of about three millimetres per year due to the thermal expansion of sea water. This time was partly coincident with the last El Niño period as well.

Determining a sea level rise rate due to secular global warming requires a far longer time series. On one hand, the prospects of acquiring this time series from the satellites are good, since TOPEX/POSEIDON should acquire data until the year 2000 and the space agencies involved plan to launch the first altimeter of a series called JASON-1, with TOPEX/POSEIDON quality, at the end of the century. On the other hand, the present phase of the South Pacific Sea Level and Climate Monitoring Project is until the year 2000 and, if another five-year phase is granted by the Australian Government (AusAID) in due course, the future prospect of sea level observations in the Pacific region will be very much secured. Accordingly, the concerns raised by the South Pacific Forum countries over the potential impacts of the greenhouse effect on climate and sea levels in the Pacific region may be resolved.

Mr Greg J. Musiela is a Computing Systems Officer of the South Pacific Sea Level and Climate Monitoring Project.

El Niño forecast for the region

The Bureau of Meteorology has developed a computer model to forecast the temperature anomaly (i.e. the difference from normal) for the central/eastern equatorial Pacific Ocean. The temperature anomaly is averaged over an expanse of ocean from 150°W to 90°W between 5°N and 5°S, known as Niño3 (see Figure 2 below). This ocean region is important in controlling Australia's and Pacific island countries' seasonal rainfall and can be indicative of an El Niño.

The model output is best expressed as the percentage likelihood that the temperature anomaly in the Niño3 region will fall within a certain range. The percentage chance of temperatures being "near normal" (neutral) for December 1997 in the Niño3 region is 22 percent, with 78 percent chance that the temperature anomaly will be more than +1°C (El Niño). The model also calculates a "best estimate" of what the actual temperature anomaly in Niño3 will be. For December 1997, the predicted anomaly is +1.5°C (currently 2.1°C).

This outlook is updated every month as the computer model is run again. The model continues to predict a warming trend in the Nino3 region, peaking in about October but then cooling somewhat towards the end of the year. This is why the probability of El Niño is not even higher than 78 percent.

Table 2: Likely temperature ranges in Niño3 for December 1997

	La Niña	**Neutral**	**El Niño**
Probability		22%	78%
Temperature Anomaly in Niño3	-1°C		-1°C

Explanation of El Niño and La Niña

El Niño: a sustained warming in excess of 1°C above normal, of the central and eastern tropical Paific Ocean which is typically centred around the Niño3 region. This warming is usually accompanied by negative values of the SOI; a decrease in the strength of the Pacific Trade Winds; and a reduction in rainfall over eastern and northern Australia which often results in drought. The most recent El Niño was in 1994 and early 1995.

La Niña: a sustained cooling, in excess of 1°C below normal, of the central and eastern tropical Pacific Ocean, typically centred around the Niño3 region. This cooling is usually accompanied by positive values of the SOI; an increase in the strength of the Pacific Trade Winds; and higher than normal rainfall over 1988/89 which was a fairly weak event that occurred in late 1995 and through much of 1996.

Figure 2: The Niño3 region

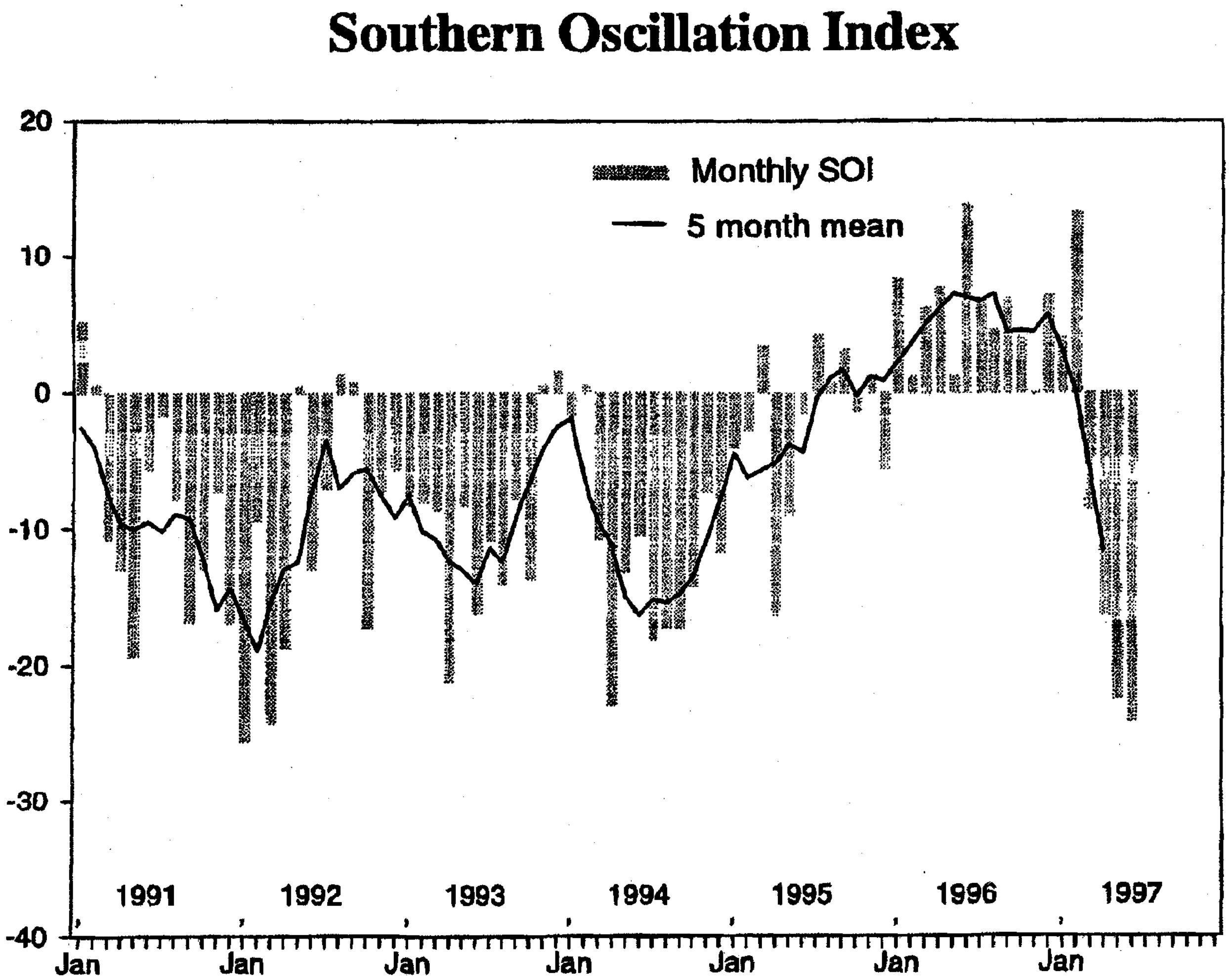

Figure 3: Plot of Southern Oscillation Index for the period January 1991 to June 1997

The Southern Oscillation Index (SOI) for June 1997 was -24.1, a further drop from the May value of -22.4. Note the original value of -24.1 for May was corrected due to erroneous data from Tahiti. In June, the mean sea level pressure at Darwin was 1014.7hPa, 2.2hPa **above** the long-term average for the month, whilst at Tahiti, the mean sea level pressure was 1012.9hPa, 0.8hPa **below** average. For comparison:

- During the El Niño of 1982/83, the June 1982 SOI was -20.1
- During the La Niña of 1988/89, the June 1989 SOI was +7.4

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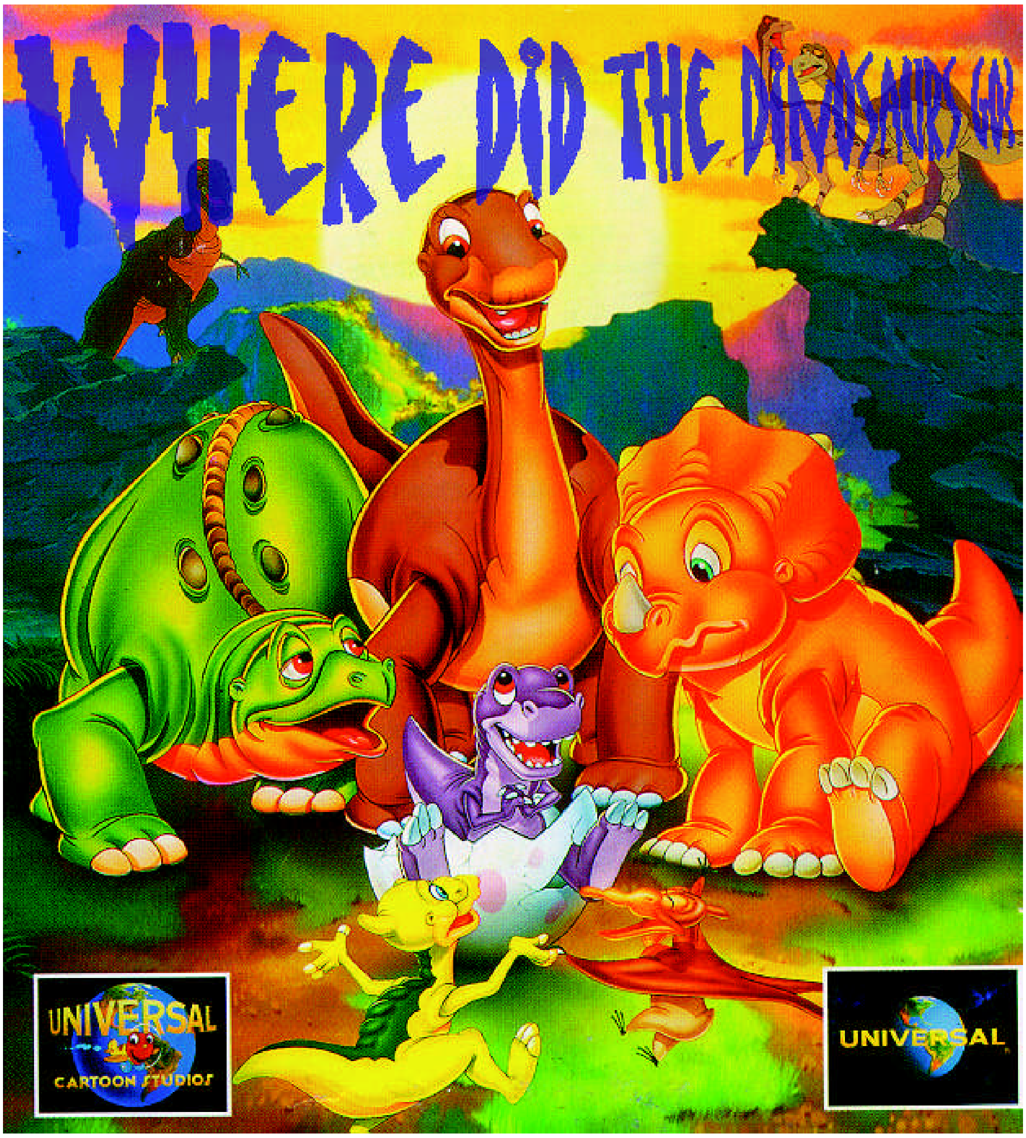
Seasonal Climate Outlook (No. 95), National Climate Centre, Australian Bureau of Meteorology, 1997.



The very popular characters (l-r: Spike, Littlefoot, Sarah, Petrie, Ducky and Chomper) from Universal Studio's ***Land Before Time*** *series.*

Many scientists believe that changes in the earthly environment may have played a bigger part in killing off the dinosaurs 65 million years ago than exotic visitors such as asteroids. But have they really been killed off? Heather G. Westrup of NTF doesn't think so.

According to the report from *New Scientist* (No. 2076, 5 April 1997), British researchers are studying the fossil record of extinctions at the end of the Cretaceous period when the dinosaurs and many other species disappeared. It is now suggested that most died out gradually as falling sea levels and volcanic eruptions took their toll. Their results show that the species died out due to several environmental changes. Most extinctions were caused by a drop of 100 metres in sea level, and when volcanic eruptions in India threw debris into the atmosphere. Most palaeontologists also believe that the mass extinction was the result of a dramatic change in climate.

Although the dinosaurs disappeared 65 million years ago, they are still very popular in our daily life. About two years ago, the movie Jurassic Park hit the box office record. In fact, the word "Jurassic" is a geological term and it indicates the middle period of the Mesozoic era covering an approximate time-span from 215-145 million years ago. It was named after the type area, the Jura mountains, and the corresponding system of rocks. The Jurassic system is subdivided into many stages. On land, dinosaurs continued to flourish and diversify. Due to the unprecedented popularity of the dinosaurs' story and Jurassic Park, another dinosaur movie called *The Lost World* (Jurassic Park) was recently produced and hit the box office record again. The latter seems to be more popular than the former one and a huge amount of support has come from both children and adults. Due to the extremely high interest of children in the life of dinosaurs enhanced by movies such as Universal Studio's *Land Before Time* series, it may be worth mentioning about another new theory that tries to explain the mass extinction of the dinosaurs 65 million years ago.

Some scientists believe that the culprit was the deadly radiation caused by the collision of two stars. According to the report from *Current Science* (Vol. 82, No. 13, 21 March 1997), physicists say that stars collide every day somewhere in the universe. These collisions produce radiation called gamma and cosmic rays with the potential to destroy the protective layers of the Earth's atmosphere and kill most animal and plant life. Usually, the collisions are too distant to do any damage to life on Earth. But, once every 100 million years or so, stars collide relatively close to Earth. A nearby collision could have emitted enough gamma and cosmic rays to bump off the dinosaurs. To support this idea, scientists are now looking through layers of ancient rock for minerals that show evidence of being bombarded by cosmic radiation 65 million years ago. Whatever caused the extinction of our beloved dinosaurs, we still miss them, don't we?

Ms Heather G. Westrup is the Office Manager of the National Tidal Facility and is believed to be one of the many active dinosaur fans.

Clues to past climate changes

Fossil evidence show that the Northern Hemisphere once had a much warmer climate than today. Dr T. H. Aung explores how ancient dinosaurs and alligators can tell us about our past . . . and our present.

Seventy-five million years ago, the country we now know as Canada was considerably warmer. The climate across the entire Northern Hemisphere was at least ~5.5°C warmer and a good deal more humid. How do we know that? Fossils show it. Fossils found in Canada, Asia, and the northern United States; in mud and rocks; on and in oceans; and in many kilometres deep, pitch-dark caves. For instance, fossils from Canada, Utah, Montana and Michigan show that palm trees once grew much farther north than they do now. These warm-climate plant fossils give evidence that the Northern Hemisphere once had a much warmer climate than today. Although the intensity of warming probably varied from region to region, the climate was warmer and more humid almost everywhere in the world.

Fossils of Tyrannosaurus Rex have also been found in both North America and Asia. These two continents are now separated by the Bering Strait. To travel from one to the other, dinosaurs must have used a strand of land that is now underwater. How could warm-climate dinosaurs survive so far north? For Tyrannosaurus Rex to have ranged over North America and Asia for millions of years, winters must have been much milder than they are now. Today's reptiles-alligators, for example—cannot live in cold climates. In the United States, the alligators' range extends only a little north of the Gulf Coast. But fossils of alligators from five million years ago have been found as far north as Canada, another indication of a once-warmer climate.

Now extinct, ammonites were shelled animals that lived in the sea. Surprisingly, their shells have been found in the centre of the American continent, far from present coasts. This suggests that seawater once extended across North America, and that this water was warm enough for the ammonites to survive. Some scientists think that a huge sea once covered a large part of today's continents, and that this sea helped to keep the Earth's climate mild. Why do they think so? How could more extensive oceans affect climate change? What other factors might also have warmed the planet? Scientists have developed at least two prevailing theories.

First, the Earth may have had more extensive oceans, and the atmosphere may have contained more of the gases (water vapour and carbon dioxide) that trap heat. Volcanoes also contributed these gases, along with sulfur-rich gases (e.g. SO_2) that form heat-trapping particles. Second, the Earth might have been warmed by the Sun more than it is today.

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Forecasting the Future: Exploring Evidence for Global Climate Change, National Science Teachers Association, 1840 Wilson Boulevard, Arlington, VA 22201-3000, USA. 149 pp.

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