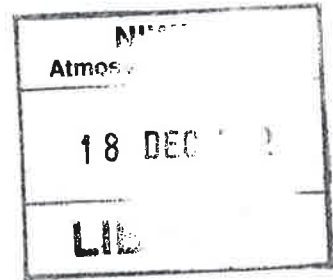


TUVALU
AND
CLIMATE CHANGE



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*PROJECT 3 OF A PROJECT-BASED TRAINING COURSE AT THE NATIONAL INSTITUTE OF WATER
AND ATMOSPHERIC RESEARCH*

Wellington

August 1992

SUMMARY

The purpose of the report is to provide the latest information on climate change and the possible impacts it would have on the country of Tuvalu. The report has two main parts. The first part focuses mainly on Tuvalu, describing the geographical nature of the country, the economy and the climate. The second main part discusses in detail the climate change and the possible impacts it might have on the country. This section firstly differentiates between the natural climate change and human-induced climate change, then moves on to describe the sources and sinks of greenhouse gases; how the scientists predict future climate change, and lastly the social and economic impacts of climate change on Tuvalu. Recommendations are stated at the end of the report.

This report was made possible by a training secondment of the author with the National Institute of Water and Atmospheric Research, Wellington. Acknowledgement is made of the project supervision by Dr. Reid Basher, Manager Climate analysis and Applications, and of the funding support of the New Zealand aid programme to Tuvalu.

CONTENTS

	Page
1 TUVALU, THE COUNTRY AND ITS PEOPLE	1
1.1 Location	1
1.2 Land	1
1.3 Population	2
1.4 Economy	3
1.5 The Weather and Climate of Tuvalu	3
1.5.1 Semi-Permanent Anticyclone or South Pacific Anticyclone	4
1.5.2 Convergence Zones: The ITCZ and SPCZ	4
1.5.3 Tropical Cyclones	5
1.5.4 El Nino/Southern Oscillation Phenomenon	5
1.5.5 Other Facts About The Weather and Climate of Tuvalu	5
2 NATURAL CLIMATE CHANGE AND MAN-INDUCED CLIMATE CHANGE	
2.1 Introduction	8
2.2 Natural Climate Change	
2.2.1 Historical Natural Changes in Climate	8
2.2.1 The Natural Greenhouse Effect	10
2.2.2 Other Natural Climate Events	10
2.3 Human-Induced Climate Change	
2.3.1 Enhanced Greenhouse Effect	11
2.4 Greenhouse Gases Sources and Sinks	11
2.5 Predicting Future Climate Change	
2.5.1 The Intergovernmental Panel on Climate Change	13
2.5.2 General Circulation Models	13
3 IMPACTS OF CLIMATE CHANGE ON TUVALU	
3.1 Impacts of Sea Level Rise	
3.1.1 Coastal Flooding	15
3.2 Coral Reefs	16
3.3 Salt Water Intrusion	16
3.4 Waste Disposal	17
3.5 Tropical Cyclone	17
3.6 Rainfall in Tuvalu	18
3.7 Health	19
3.8 Transportation and Communication	20
3.9 Exclusive Economic Zone	20
4 RECOMMENDATIONS	21
5 CONCLUSION	21
REFERENCES	22

TUVALU, THE COUNTRY AND ITS PEOPLE

1.1 Location

Tuvalu is a nation that was born on the first of October, 1978. It was formerly known as the Ellice islands part of the British Gilbert and Ellice Islands protectorate. The nation consists of nine atolls positioned just south of the Equator and west of the International Dateline. In a chain-like formation the islands are spread over 670 km with a general northwest-southeast orientation between 5 and 10 degrees South latitude and 176 and 179 degrees East longitude. The orientation and positioning of the atolls provides Tuvalu with an Exclusive Economic Zone of 1.3 million square kilometres. The country's nearest neighbours are Kiribati to the north, Tokelau to the east, Fiji and Tonga to the south and Solomon Islands and Vanuatu to the west. The capital island, Funafuti is in the southern group of islands, and is 900 km west of Tokelau, and 1000 km north of Fiji. This is the port of entry and the only air link to overseas countries.

1.2 Land

The nine atolls are mainly made up of corals, sand and gravels. Out of the nine atolls, five are classified as true atolls (Nanumea, Nui, Nukufetau, Funafuti and Nukulaelae), i.e., having more or less continuous rim of reef, at or near the surface of the sea and surrounding a distinct and deeper lagoon (McLean and Hosking, 1991a). The other three islands (Nanumaga, Niutao and Niulakita) occupy flat tops of table reefs and there are no surface draining lagoons. Rather they have a continuous land margin that completely encircles a shallow mangrove-fringed and enclosed lagoon or pond. Vaitupu, the largest island at 530 hectares, has the composite characteristics of the atoll and table reef forms. Its two small lagoons are almost occluded by land and reef flat, filling through shallow channels at only the higher stages of the tide (McLean and Hosking, 1991a).

The total land area of Tuvalu is 24.4 square kilometres. Table 1 shows the nine islands of Tuvalu with their land areas. All the islands barely rise five metres above mean sea level, and the average height above mean sea level is three metres. The islands' motu type nature where the land is all coastal and low lying, makes Tuvalu one of the most vulnerable nation in the world to climate change and rising sea level.

Table 1. Tuvalu nine islands with their land areas.

Name of island	Area (ha)
Vaiutpu	530
Nanumea	366
Nui	352
Nukufetau	331
Nanumaga	272
Funafuti	271
Niutao	225
Nukulaelae	183
Niulakita	40
Total	2570

1.3 Population

Ethnically 96% of Tuvaluans are Polynesians, 2% are Micronesian and the last 2% belongs to other. Table 2 shows the figures of the population for Tuvalu in the year 1991. Tuvalu has a very high average population density of 372 per square kilometre, which is one of the highest in the world and it is growing.

Table 2 Population figures of Tuvalu 1991 census.

Island	Population		Population density/sq. km	Increase % from 1987
	Number	% Total		
Funafuti	3837	42	1626	41
Vaitupu	1205	13	246	-16
Nanumea	825	9	231	-15
Nukufetau	756	8	247	5
Niutao	749	8	353	-14
Nanumaga	644	7	225	-10
Nui	608	7	185	-2
Nukulaelae	370	4	218	10
Niulakita	75	1	183	0
TOTAL	9069	100	372	7

The island of Funafuti is the worst considering its population density of 1626 people per square kilometre, and 41% increase in population from 1987. Funafuti is the capital, where the main administration centre for the government is located, since the separation from the

Gilbert Islands (Kiribati) in 1976. This is one of the main factors that has contributed to the sudden boom in population in Funafuti.

1.4 Economy

Tuvalu's economy is small and very fragile, not only in relation to the global economy but also because of its vulnerability to natural disasters such as tropical cyclones. The country has a very small land area, very poor soil and limited land-based natural resources. The economy of the country is mainly dependent on fishery, agriculture, philatelic bureau sales, copra, remittance from people working overseas, and most of all foreign aid. Tourism is the other sector which is a growing contributor to the economy of the country.

Table 3 provides a breakdown of the national accounts of Tuvalu for 1990. The Gross Domestic Product at current market prices was AUS9.20 million. The average per capita income for Tuvaluans is \$917.00. The majority of the population, specially those living in outer islands have incomes far less than the average per capita of \$917.00. (Note, the Tuvalu's national currency is the Australian dollar.)

Table 3 The National Account of Tuvalu for 1990.

Total Gross Domestic Product(GDP) of Tuvalu

Sector	Amount \$AUS	%
Agriculture	1,096,100	12.4
Fisheries	556,900	6.3
Construction	1,529,300	17.3
Trade, Hotels and Restaurant	1,105,000	12.5
Real Estate and Housing	618,000	7.0
Government Services	3,067,480	34.7
Other	866,320	9.8
Total	8,840,000	100.0
GDP at Market Prices	9,290,000	
GDP - Expatriates' Compensation	8,290,000	
GDP Per Capita	917	

GDP are based on preliminary estimates for 1990. Sector data for 1989
 * Source: Government of Tuvalu, 1991 1b)

The people of Tuvalu mostly live a very subsistence and sustainable way of life. Cash activities are mostly carried out on Funafuti and Vaitupu.

1.5 The Weather and Climate of Tuvalu

Tuvalu lies within the trade wind belt, generally its climate is hot

and humid with only two seasonal variations through the year, namely wet and dry seasons. The weather and climate of Tuvalu is determined by certain atmospheric circulation features in the South Pacific, principally the easterly trade winds, the semi-permanent anticyclone in the eastern Pacific, convergence zones, i.e., the Intertropical Convergence Zone (ITCZ) and South Pacific Convergence Zone (SPCZ), and tropical cyclones. The El Nino/Southern Oscillation (ENSO) phenomenon is the other major factor that has a dramatic effect on the weather and climate of the country. How each of the above atmospheric circulation features affect the weather and climate of Tuvalu is explained below.

1.5.1 Semi-Permanent Anticyclone or The South Pacific Anticyclone

The semi-permanent anticyclone that is centred far to the East between 90-100 degrees west is the source of the north-easterly and south easterly trades. The strength of these trades depends on the intensity of the semi-permanent anticyclone. In Tuvalu this occurs mainly around the months of May to October, where the pressure within the semi-permanent anticyclone are highest and the trades could reach 25 knots in speed. According to Thompson (1987), north and northwest winds mostly occur between the months of January to April and November to December. East to south east winds are most frequent between June and August.

1.5.2 Convergence Zones: The ITCZ and The SPCZ

On the northern edge of the South Pacific anticyclone, north easterly and south easterly winds converge to form the Intertropical Convergence Zone (ITCZ), which lies between latitude 5 degrees North and 10 degrees North. The ITCZ varies in its intensity from day to day and shifts its position to north and south with the seasons, lagging the movement of the sun by two or three months. Rainfall is relatively high for islands underneath this convergence zone. The weather and climate of Tuvalu is affected most by the ITCZ during the Southern Hemisphere summer, when the convergence zone is at its southern most position.

A second convergence zone lies to the south of Tuvalu. In the western South Pacific the easterly trades have a more southerly component due to the passage of migratory anticyclones across the Australian Bight and New Zealand. The convergence between the trades from the semi-permanent anticyclone and the those from the migratory anticyclones is called the South Pacific Convergence Zone (SPCZ). The SPCZ is a semi-permanent cloud feature of the Southern Hemisphere. The intensity of the SPCZ varies considerably from day to day. Heavy rainfall and deterioration of the weather is expected for islands underneath this convergence zone. As with the ITCZ the location of the SPCZ varies with season. During the Southern Hemisphere summer (December-January-February) the SPCZ is most active and lies between Fiji and Samoa and extends through to the Southern Cook Islands, and it is well south of Tuvalu. In winter, the SPCZ is fairly weak and it lies from near Niulakita (the southern most island of Tuvalu), to between the Southern Cook Islands and Society Islands. Rainfall in

Tuvalu depends on the positioning of the SPCZ.

1.5.3 Tropical Cyclones

Tropical cyclones have major impacts on the weather of the country, specially strong winds and heavy rainfalls. These are low pressure synoptic systems that have wind speed greater than 34knots. They form over warm tropical oceans (with temperature greater than 26 degrees Celsius), usually within a region of low pressure on the northern side of the SPCZ, and confine to at least 5 degrees or more from the equator. In Tuvalu, low pressure systems could develop all year round, but those with wind speeds greater than 34knots usually develop around the months of November to April, about south of latitude 9 degrees, and they rarely develop into major hurricanes while in the Tuvalu area. There have been four known tropical cyclones to result in severe damage to Tuvalu. These occurred on 18 February 1891, 2 January 1958, 19 October 1972 and 2 February 1990. Tropical depressions that develop within Tuvalu account for sixty percent of annual rainfall around the country, where the heaviest downpours occur in the wet season (November to April).

1.5.4 El Nino/Southern Oscillation Phenomenon

The El Nino/Southern Oscillation (ENSO) phenomenon is strongly associated with the well known year to year variation in rainfall pattern in Tuvalu and the rest of the South Pacific countries. The Southern Oscillation (SO) is a "sea saw" of atmospheric mass between the Eastern Pacific and the northwest of Australia region. Extreme phases of the pressure swing can persist for up to a year at a time. The SO behaviour can be monitored from pressure changes at Tahiti and Darwin, which are combined to produce the Southern Oscillation Index (SOI).

El Nino is the name given to conditions where unusual warm water appears in the coast of South America and extending to the eastern and central Pacific. It is accompanied by high surface pressure over western and low surface pressure over the south eastern tropical Pacific, coinciding with heavy rainfall, unusually warm surface waters, and relaxed trade winds in the central and eastern tropical Pacific. This is often referred to as one of the extreme phases of the Southern Oscillation (Philander, 1990).

The two parts of ENSO (El Nino and the Southern Oscillation) occur in association and are accompanied by major shifts in the region's winds and locations of convergence zones. It is these changes which lead to the abnormal rainfall patterns and drought throughout the Pacific during the negative phase of this phenomenon, i.e. when the Southern Oscillation Index is negative. The eastern Pacific anticyclone is weaker, and both the Intertropical and South Pacific Convergence Zones shift eastward, with weakening of the equatorial easterlies (Basher et al., 1992). The SPCZ will be closer or over Tuvalu as it shifts eastward, increasing seasonal and annual rainfall, and also an increase

in the frequency of tropical cyclones (Hay and Aalbersberg, 1992; Thompson, 1987).

The following description illustrates the general patterns of the 1982/83 ENSO event. In the 1960's it became apparent that the year-to-year variations in Sea Surface Temperatures (SSTs) and consequently El Nino events were closely linked to the Southern Oscillation. Generally before an ENSO event, equatorial easterlies are quite stronger than normal in the western equatorial Pacific, causing unusual high sea levels in the west. The sea surface temperatures are warmer in the west and colder in the east, and the pressure are below normal around Indonesia and above average in the eastern Pacific.

During an onset of an ENSO event, generally around December, the equatorial easterlies weaken dramatically and a sudden shift to westerlies around the region between Indonesia and the International Dateline. The sea surface temperatures become warmer in the central Pacific and the precipitation increases in the unusually low rainfall area in the central Pacific. SSTs along the coast of South America are normal but increasing. Around the February-March of the following year the SSTs on the coast of Peru are above average, the rainfall in the equatorial Pacific, especially in Kiribati is higher than normal, the sea levels are above average and the SSTs are above normal in the central equatorial Pacific. The westerlies have shifted to be centred at the International Dateline. In the Africa, Indonesia and Australia region, rainfall is well below normal in contrast with very heavy rainfall in the equatorial and eastern Pacific. The atmospheric pressure in Tahiti is well below normal while in Darwin, the pressure is well above normal. The changes in anomalies grow towards the end of the calendar year.

At the decaying stage of the ENSO event, i.e. around December, the westerlies weakens and easterlies start to strengthen, the SSTs in the west start to increase while along the coast of South America, the SSTs start to decrease and the cold current from the South Pole starts to spread towards the central equatorial Pacific. Approximately 18 months after the onset, the pressures in Darwin and Tahiti return to normal and also the rainfall. This is a general picture, but each ENSO event is unique and there are wide variations from event to event.

Tuvalu's rainfall is highly influenced by an ENSO event (SOI is negative). The northern islands of Tuvalu have their rainfall highly correlated with negative SOI, but this correlation weakens towards the southern islands. From the years 1951 to 1985, 9 of the 10 dry years occurred when the SOI was positive, while five of the six wet years occurred when the SOI was negative (Thompson, 1987). However the strength of the correlation varies from month to month and from island to island.

1.5.5 Other Facts About The Weather and Climate of Tuvalu

- a) Tuvalu tends to have considerably more rainfall than island groups to the north (e.g. Kiribati) and south (e.g. Fiji and Tonga). The

average annual rainfall for Tuvalu's southern islands is over 3000mm, but decreasing moving towards the more northern atolls with average annual rainfall around 2800mm (Thompson, 1987).

- b) Dry spells could occur on average between one and ten in every decade and are more likely to occur in the northern islands of Tuvalu (Thompson, 1987).
- c) Air temperatures are uniformly high all year around, average 28 degrees Celsius, with mean maximum and minimum temperatures of 31 degrees Celsius and 25 degrees Celsius respectively. Temperatures over 34 degrees Celsius occur about once every two years, and below 21 degrees Celsius once every three or four years for the southern islands, but once every ten to fifteen years for the northern atolls.
- d) The mean annual sea temperature is 29 degrees Celsius with very small year to year variation.

2 NATURAL CLIMATE CHANGE AND HUMAN-INDUCED CLIMATE CHANGE

2.1 Introduction

Differentiation between natural climate change and human-induced climate change is discussed in this part of the report. The first section focuses only on natural climate change and covers topics such as historical natural climate change, natural greenhouse effect and El Nino. The last section (Section 2.2) deals exclusively with human-induced climate change, enhanced greenhouse effect and current knowledge of how to predict future climate change.

2.2 NATURAL CLIMATE CHANGE

2.2.1 Historical Natural Changes in Climate

We tend to take for granted the moderate nature and relative stability of the Earth's climate. Modern human societies have experienced little else, because of the prevailing "interglacial" period. But the Earth's climate has changed dramatically in the past. Early human societies experienced a colder climate, a glacial period or ice age, extending until about 10,000 years ago. In still earlier periods, the Earth was ice free and far warmer than today.

The long term climate record derived from "paleological" records provides clear evidence of fluctuations in temperature and precipitation on all time scales. Swings in broad-scale average temperatures of around 4-5 degrees Celsius in amplitude reflect the onset and retreat of ice ages, periods lasting thousand of years when large tracts of North America and Northern Europe were covered by year-round ice and snow. Data from Antarctica confirm that such fluctuations were indeed global. There were alternating periods of peak warmings, lasting for several thousand of years, where temperatures were about 2-5 degrees Celsius higher than today's global average, and periods of ice age also lasting from several hundreds to several thousands of years, where temperature were 2-5 degrees below today's global average.

The period of peak warming was about 5000BC-2000BC. During this period the average temperature was about 2 degree Celsius warmer than today. Also sea level was higher by about 1.2 metres. Beaches were formed during this period have provided much of the flat land now used for farming in the Pacific islands.

Coming out of the ice-age, the sea level rise was very rapid, as much as 1 or 2 metres every 100 years. Hence during such events, like when there is a spring high tide and a storm with gale force winds or stronger blowing from the sea to the land, the strong winds caused large waves which break on the shore. Before water from one wave can

drain back to the sea the next wave arrives. This causes the water to rise up by several metres and pile up on the shore.

Where the ice was thick the land was forced down under the weight of ice. When the ice melted the land was able to gradually rise up. Scandinavia is thought to have risen by 250-300 metres since the end of the ice age and still rising at about 1 metre every 100 years. This makes measuring the sea level rise over recent times very difficult. As one area rises the other will sink. For example as Scotland and Scandinavia are rising the south of England and Ireland are sinking.

Another warm period occurred about the time of the Roman Empire (0 AD) and came to an end about 300-400 AD. Also the area between Russia and China became much drier. This contributed to the migration of people out of this area to Europe. These are the Goths and the Huns in particular and their invasion of Europe caused the fall of the Western Roman Empire.

After this there was another warming (warm period) from about 900 AD. During this period the Vikings from Scandinavia, especially Norway, explored the North Atlantic and made settlements first in Iceland, second in Greenland and third in North America.

After 1300 AD the weather cooled again. This period is known as "the little Ice Age", and lasted to the middle of the last century. About 1850 temperatures are thought to have been about 1 degree Celsius colder than today for the global average but in the tropics the temperature was about what it is today. This covers the beginning of the meteorological records such as thermometer readings.

Because the poles were much colder than today and the tropics hardly changed at all, the temperature difference between the poles and the Equator were much greater than today. This caused more frequent severe storms in Europe, even though sea level may have been lower. The severe storms caused extreme storm surge on the coast of Europe on a number of occasions. As many as one million people are thought to have been killed in Holland and Germany over a period of 100 years. The worst event may have killed about 300,000 people in one day.

A flood in China in 1332 caused an estimated 7 million deaths, and conditions following the flood caused an explosion of the rat population. This contributed to the spread of the bubonic plague out of Asia into Europe. The plague killed about one third of the people living between India and Iceland in the space of 18 months.

An interesting example of evidence of the cooling comes from records of the Cod fishery in the area around the Faeroe Islands west of Norway. There were no fish caught at all for a period of about 80 years. Cod are unable to live in sea at 2 degree Celsius or colder. Therefore the disappearance of these fish from the Faeroe Islands is taken as evidence that the sea was about 6 degree Celsius colder in this area than it is today. Also on several occasions Eskimos were sighted off the coast of Scotland.

One of the worst periods during the little Ice Age came after a major volcanic eruption in Laki, Iceland in 1783. This threw a cloud of dust and ash into the atmosphere. This blocked some of the sunlight reaching the earth, much as sun-glasses block some of the sunlight. This lowered temperatures and caused the European harvest to fail in two years. The Mount Pinatubo in the Philippines last year is having a similar effect on the world now. This should last for a period of about two and a half years.

Volcanic eruptions may have helped start the ice-ages. The largest volcanic eruption in historical times (since written records exist) was Lake Taupo in New Zealand in 180 AD. Although there were no people living here, the effects were felt in the Northern Hemisphere. Both the Roman and Chinese have left written accounts of the effect of the Taupo eruption. These include the moon having a red appearance for about 3 months and the sun not being visible until it was 17 degrees above the horizon.

The occurrences of volcanoes over the last 200,000 years can be studied using the ice-cores from Greenland and the Antarctic. A large volcanic eruption throws sulphur dioxide into the high atmosphere. This combines with water to form sulphuric acid which causes the hazes and eventually falls with the rain and snow. The acidity of the ice in the ice-cores can be measured for each year. This gives some idea of how much volcanic activity there has been at different times in the past.

Natural climate change is going on all the time both on the large scale of changes into and out of the ice ages and also smaller changes such as the warming around 400 BC and 100 AD and the cooler period known as the little ice age from 1300-1850 AD. Now consider the possibility that human race activities, which have changed the composition of the atmosphere, will cause significant warming in the new future.

2.2.1 The Natural Greenhouse Effect

The Earth's temperature is determined by the balance between the rate at which sunlight is received by the Earth's surface, and the rate at which the warmed Earth sends longwave radiation back into space. The Earth absorbs solar radiation (short-wave) from the sun, mainly at the surface. This radiation is then redistributed by the atmosphere and ocean and re-radiated back to space in the form of infrared radiation (longwave). In the atmosphere, water vapour and other natural greenhouse gases, such as carbon dioxide, methane, nitrous oxide and ozone absorb this infrared radiation and re-radiate it into all directions (i.e. back to the lower atmosphere, Earth's surface and to space) in the form of longwave radiation or heat energy. Hence naturally keeping the Earth warm enough to be habitable. This phenomenon is known as the natural greenhouse effect.

2.2.2 Other Natural Climate Events

The El Nino/Southern Oscillation phenomenon which has fully described

in section 1.5.5 is a natural climatic event, and it is not related to climate change. Volcanoes are natural events and have a great impact on the climate.

2.3 HUMAN INDUCED CLIMATE CHANGE

2.3.1 Enhanced Greenhouse Effect

It is well established that the warm temperatures (which make life on Earth possible) are the direct result of the trapping of part of the Earth's radiant heat by natural greenhouse gases. Now, however, as the world's population increased, as the world became more industrialised and as agriculture developed, the abundances of greenhouse gases increased markedly, with additions of new and very powerful infrared-absorbing gases, such as the industrial chemicals known as chlorofluorocarbons (CFCs).

Any increase in the greenhouse gases will cause a parallel increase in the Greenhouse Effect, i.e. the global-average annual-mean surface-air temperature (simply known as "global temperature") will increase, although there are uncertainties about the rate at which this will occur. Strictly, this is enhanced greenhouse effect - above that occurring due to natural greenhouse effect. Scientists believed this could lead to thermal expansion of the sea surface and melting of land ice, which could result in the rising of sea level. Hence threatening the existence of low lying atolls like Tuvalu and Tokelau.

2.3.2 Other Human Activities that have the potential to affect Climate

A change in the albedo (reflectivity) of the land, brought about by desertification or deforestation affects the amount of solar energy absorbed at the Earth's surface. Human-made aerosols, from sulphur emitted largely in fossil fuel combustion, can modify clouds and this may act to lower temperatures. Lastly, changes in the ozone in the stratosphere due to CFCs may also influence climate.

2.4 GREENHOUSE GASES SOURCES AND SINKS

As already noted, the radiatively active trace gases, namely carbon dioxide, methane, nitrous oxide, CFCs and particularly in the lower atmosphere, ozone as well as water vapour, heat up the atmosphere by allowing solar radiation to pass the atmosphere almost unhindered, while absorbing a large portion of the heat radiating from the Earth's surface and emitting this radiation back to the surface. Table 4 shows the greenhouse gases with their sources and sinks.

Table 4 Sources and Sinks of Greenhouse gases.

Gas	Source	Sink
Carbon Dioxide	Burning of fossil fuel Deforestation Human being land use Forest fires	Ocean Plants
Methane	Natural sources: Wetlands Termites + other insects Oceans Fermentation by ruminants (cows) Human sources: Landfills Burning of Biomass Cultivation of rice paddies Natural gas leakage during production & distribution Coal mining	Chemical deposition by OH- radicals Stratospheric decomposition
Nitrous Oxide	Natural sources: Microbiological denitrification and nitrification in soil Human sources: Fertilisers Fossil fuel and biomass burning Land conservation for agriculture	Stratospheric decomposition
CFCs	No natural source Human sources only: Manufactured for solvents; aerosol spray propellants; foam packaging and refrigerants	Topospheric partial decomposition
Ozone	Natural sources: Naturally produced in the troposphere and stratosphere Human sources: Product of sunshine and pollutants (carbon monoxide; methane; other hydrocarbon)	Atmospheric reactions Reaction on plants and other surfaces
Water vapour	Natural sources only, highly variable: clouds; evaporation.	

The greenhouse gases will keep on increasing if the industrialised countries do not stop greenhouse gas emissions, or stabilised their emissions to 1990 levels by the year 2000. Therefore leading to increase temperature on the Earth's surface, hence drastic sea level rise due to thermal expansion of the sea surface and melting of ice in the poles. The enhanced greenhouse effect results from past years' emissions of greenhouse gases and cannot be stopped overnight.

2.5 PREDICTING FUTURE CLIMATE

2.5.1 The Intergovernmental Panel on Climate Change (IPCC)

This section describes the work of the Intergovernmental Panel on Climate Change (IPCC) and their latest conclusions on climate change.

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988. The panel is made up of scientists from all over the world and its purpose is to:

- a. Assess the scientific information that is related to the various components of climate change issue, such as emissions of major greenhouse gases and modification of the Earth's radiation balance resulting therefrom, and that is needed to enable the environmental and socio-economic consequences of climate change to be evaluated; and
- b. Formulate realistic response strategies for the management of the climate change issue.

The work of the IPCC is delegated amongst three established Working Groups and they are:

- i. Working Group I: This group is responsible for assessing available scientific information on climate change;
- ii. Working Group II: Their responsibility is to assess environmental and socio-economic impacts of climate change; and
- iii. Working Group III: They formulate response strategies.

2.5.2 General Circulation Models

The IPCC uses computer based models for predicting future climate and modelling the climate. These highly developed tools are called general circulation models or GCMs, and are based on the laws of physics and use descriptions in simplified physical terms (called parametrizations) of the smaller scale processes such as those due to clouds and deep mixing in the ocean. Coupled general circulation models have the atmospheric components linked to an oceanic component of comparable complexity. (IPCC, 1992).

The major Conclusions of IPCC Working Group I (IPCC supplement, 1992) are:

- (a) Emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons, and nitrous oxide.
- (b) The evidence from the modelling studies, from observations and sensitivity analyses indicate that the sensitivity of global mean surface temperature to a doubling of carbon dioxide is likely to lie within the range of 1.5 degrees Celsius to 4.5 degrees Celsius.
- (c) Global mean surface temperature has increased by 0.3 degree Celsius to 0.6 degree Celsius over the last hundred years.
- (d) The size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability. Thus the observed increase could be largely due to natural variability; alternatively this variability and other human factors could have offset a still larger human-induced greenhouse warming.
- (e) There are many uncertainties in the predictions particularly with regard to the timing, magnitude and regional patterns of climate change due to our incomplete understanding.
- (f) The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more.

Recent simulations using coupled ocean-atmosphere GCM, generally confirm the IPCC 1990 estimates of future warming at rates of about 0.3 degree Celsius/decade (range 0.2 to 0.5 degree/decade) over the next century for IPCC 1990 scenario A.

The simulated rate of change of sea level due to oceanic thermal expansion only ranges from 2 to 4cm per decade, again consistent with the previous report.

In summary the best estimate: temperature will rise by 0.2 degree Celsius per decade, where by the year 2025, the global mean temperatures would likely to be 1 degree Celsius above present value and the sea will rise by 30cm above present levels by the year 2030.

We need to note that so far there are many uncertainties in the predictions made by scientists, particularly with regard to the timing, magnitude and regional patterns of climate change. For example, the scientists are unable to predict what weather changes might occur to individual countries, whether the number of tropical cyclones will increase or not. So we do not know whether conditions in Tuvalu will become more rainy, cloudy or drier.

3 IMPACTS OF CLIMATE CHANGE ON TUVALU

The likely impacts of climate change on Tuvalu are fully discussed in this section. The focus is mainly on rising sea level, coastal flooding, tropical cyclones, rise in temperature and their effects on agriculture, health, the economy of the country and the people of Tuvalu.

3.1 Impacts of Sea Level Rise

The IPCC Working Group II Impacts Assessment estimated a sea level rise of about 0.3-0.5 m by 2050 and about 1m by 2100, together with a rise in the temperature of the surface ocean layer between 0.2-0.5 degree Celsius.

The atolls of Tuvalu rarely rise three metres above sea level. A rise in sea level would affect the nation socially, economically, and culturally. The people of Tuvalu live on Mother Nature; Mother Nature provides the people with fish, taro, drinks and other life necessities.

3.1.1 Coastal Flooding

This would bring a lot of stress to the land and to the people. The land area of the nine atolls ranges only from 2.9-4.5 square kilometres and most of them are very narrow. There will be rapid loss of land to the sea due to coastal erosion, and there are few, if any, possibilities of retreating to new lands. Coastal erosion will have many effects, specially on:

(a) Buildings: Most of the houses in Tuvalu are build along the coast or very close to the coast. If the sea walls (sea defences) could not prevent erosion and battering of storm surges during tropical cyclone all of the houses would surely be washed away and the area would not be suitable for building houses again. Hotels and sea wharfs are also threatened by this phenomenon, and the government would have to pour in a lot of funds to maintain the standard of these structures.

(b) Roads: The roads in Tuvalu mainly run along the coast, and they are vulnerable to coastal erosion. Presently in the northern end of Funafuti near the causeway, already a quarter of the road has been eaten or eroded away by the sea. The roads would be completely washed away if sea level rises to 30cm by 2030, and in some of the islands like Funafuti there are no spaces available to build another road.

(c) Plants: The coconut trees and other plants that grow along the

coast, help in preventing severe damages from erosion and also act as windbreaks during strong winds. Coconut trees, pandanus, breadfruit trees are relatively salt-resistant, but a further rise in sea level will increase the salinity of the soil and water which could result in declination of productivity and death of trees. If this happens, the rate of coastal erosion would increase, more loss of land, some roads would cease to exist and more severe damages from cyclone would be expected.

3.2 Coral Reefs

All of Tuvalu is protected by coral reefs. Coral reefs are found in areas where mean annual water temperatures do not fall below 24 degrees Celsius; where oxygen levels are high and where light penetration is sufficient for algal growth. The most critical factor to coral communities in terms of combined reef growth is water temperature. This limits the growth of coral and also affects the health of coral communities. Sea water temperatures in Tuvalu average approximately 29 degree Celsius which is considered to be within a degree of the upper level for coral growth (Hay and Aalbersberg, 1992). A rise in temperature due to greenhouse effect beyond the thermal limits of coral growth, would slow or stop the coral from growing any further, i.e., tropical reefs would no longer reach an upper limit determined by tidal exposure but rather an upper limit determined by temperature. Moreover, relatively rapid elevation of sea temperatures has been associated with most episodes of coral bleaching, but not enough is known about the process to determine whether a slow warming of the sea will have a similar effect (Hay & Aalbersberg, 1992).

3.3 Salt Water Intrusion

Any intrusion of salt-water into the groundwater lenses will have a direct effect on agriculture and on the supply of potable water. The most obvious effect on agriculture would be the increased salinity in taro and pulaka pits, and lower productivity in taro and pulaka would result. Other plants like coconut trees, pandanus, breadfruit trees would certainly decrease in their productivity. The people of Tuvalu mostly rely on these plants for food, drink and building materials. These plants could cease to exist if the sea keeps on rising and this could make the land uninhabitable.

Underground water or well water is mainly used by people on outer islands, for washing, bathing, drinking and poultry farming. This resource is threatened by the rising sea level, specially the intrusion of salty water, the decreasing amount of underground water lenses due to the lost of land and ever increasing consumption by the community as stated previously. The rise in sea level would likely to increase the concentration of salt in the groundwater, eventually making it impossible for human consumption. The people would have to shift to places where they could find a good supply of rain-water and underground water, which will be hard to find since all of the islands

are similar and very small in land area.

3.4 Waste Disposal

Waste disposal would be one of the biggest problem if sea level rises, specially in relation to health. The waste, for example in septic tanks would rise slowly as sea level rises, and could create greater chances for disease-causing bacteria and viruses to invade and contaminate the population, increasing the number of different diseases and the number of people suffering from these diseases. In addition, land areas available for waste disposal are already small and are likely to decrease owing to population pressure and coastal erosion. There is likely to be degradation of underwater lenses due to contamination from waste disposal.

3.5 Tropical Cyclones

In the southwest Pacific, a tropical cyclone is classified as having wind speeds of at least 34 knots. They form over warm tropical waters (i.e. temperature above 28 degrees Celsius) at an area between 5S and 20S in a band covering the Coral Sea through to Tuvalu and Fiji, on the northern side of the South Pacific Convergence Zone. The cyclone season generally falls in the months of November to April.

Two factors may cause more cyclone damage. Firstly, the warming of the earth's surface due to climate change may cause an increase in the number or the strength of cyclones occurring, i.e. the tropical waters could more easily reach temperatures above 28 degrees Celsius. Secondly, with higher sea levels the storm surges would be much bigger and could reach further inland causing a lot damages to plants and mostly the coastal area.

Tuvaluans rely on fish for their cheapest and most abundant source of protein and for a source of income too. An increase in the number of cyclones and bad weather will not only prevent fisherman from going out to the sea to catch fish, but also cutting the means of obtaining a major source of protein and income. In addition, large number of fishing boats could be destroyed, and it would cost a fortune for a Tuvaluan to buy a new fishing boat.

Agriculture would be badly affected by any increase in cyclones occurrences. The past cyclones that struck Tuvalu (including strong wind events, <034 knots) have always destroyed about more than 60% of crops. For example, cyclone Bebe, in 1972, destroyed more than 80% of the crops in Funafuti, and cyclone Ofa, in 1989, destroyed more than 60% of the crops in the island of Vaitupu (Tuvalu Met. Service, 1991). This indicates that with any increase in cyclones, there may not be enough time for the crops to recover before another hurricane strikes.

This would have a drastic impact on the diet of the majority of the population. The people rely mainly on root crops like pulaka and taro; breadfruit trees and coconut as their major and cheapest source of starch. These sources may already be under threat from sea level rise.

Most of the houses in the outer islands are build using local materials and they are easily blown down by strong winds. In Funafuti the majority of the houses are build using cement blocks and corrugated iron roofing, but still they are vulnerable to tropical cyclones. The people rely mainly on iron roof for catching rain-water. This resource could be limited if the houses are being blown down by cyclones, even the water tanks could be damaged from flying debris, leading to shortage of water. Also seawater from storm may intrude into well water. Overall it may be that the worst effect of climate change are those felt from tropical cyclones.

3.6 Rainfall in Tuvalu

As already stated in Section 1.5.4, Tuvalu rainfall is highly influenced by the negative Southern Oscillation Index (SOI) i.e. the correlation between rainfall and SOI is negative. The northern islands have above average rainfall as shown in table 5, specially at Nanumea. The correlation weakens towards the southern islands, where at the most southern island, Niulakita, the weakest correlation exists. These above normal rainfall occur, about 3-6 months, after the first observed negative SOI.

Table 5 Rainfall anomalies, expressed in % values, for composites of years in which the SOI was in the upper quartile (high), and in the lower quartile (low). (Basher et al., 1992).

Station	LAT.	LONG.	Annual		December-January-February	
			SOI Low	SOI High	SOI Low	SOI High
Nanumea	05 40 S	176 07 E	123	71	145	73
Nui	07 15 S	177 09 E	121	80	119	97
Funafuti	08 31 S	179 02 E	112	83	94	106
Niulakita	10 47 S	179 28 E	103	89	82	118

The correlation shows clearly or significantly when considering monthly intervals. For the above table, the three monthly interval used (December to February), showed clearly the correlation between rainfall and SOI, i.e. above average rainfall for Nanumea and Nui (northern islands) and below average rainfall for Funafuti and Niulakita (southern islands).

For the estimating possible impacts of potential changes in climate in the South Pacific; Basher et al., 1992, developed draft scenarios to represent conditions in about 40 years time, i.e. about 2030. Two scenarios were developed, one based on El Nino conditions, the other on

La Nina conditions. For the El Nino scenario, the southern Tuvalu would have 10-20% increase in annual rainfall, and of about 20-40% for the northern Tuvalu. For wet season rainfalls, northern Tuvalu would have a 50-100% increase and 10% decrease in the southern Tuvalu. For the La Nina scenario, annual rainfall would decrease by 5-10% in Tuvalu. The wet season rainfall shows a different pattern, a 10-30% increase in southern Tuvalu. These scenarios are not predictions, but only tools to explore possible future changes of climate.

3.7 Health

Human health is likely to be affected by changes in climate and the rising of sea level. The climate of Tuvalu is hot and humid, which are suitable conditions for spreading diseases. The rising sea level would force underground water to rise, creating longer periods of standing water and exposing the surface and ground water to a greater degree of contamination from human and domestic wastes. This would also provide more breeding grounds for mosquitoes and the chance for spreading vector borne diseases, for example, dengue fever (yellow fever) and elephantiasis. These viral and parasitic diseases have the potential for increase and reintroduction in the Tuvalu group and neighbouring countries, if global warming creates more favourable conditions for these diseases, with increasing precipitation in tropical and subtropical areas. Table 6 contains the most common diseases found in Tuvalu.

Table 6 Some of the common diseases found in Tuvalu.

Disease type	Name of Disease
Viral diseases	Dengue fever
	Measles
	German measles (Rubella)
	Chicken pox
	Small pox
	Mumps
Bacterial diseases	Cholera
	Tuberculosis
	Cerbrospiral meningitis
	Scabies
	Bacillary dysentery
	Whooping cough
	Tetanus
Trachoma	

(Source: Mamaha Lameko, 1992).

The people of Tuvalu may increasingly become exposed to these viruses and bacteria, and a rise in incidences of the above diseases would be expected.

The other factor that contributes to the deterioration of health is the rise in population. Tuvalu has one of the highest population density per square kilometre in the Pacific, this would certainly rise to higher figures due to increase in population, and loss of island size from rising sea level. With no land to retreat to, some places would be overcrowded, leading to very poor living conditions where diseases would be easily and quickly spread.

The increase in temperature and the likely high humidity result from climate change would increase discomfort amongst the population, specially outdoors workers and inside a concrete house. In addition there would be an increase in cardiovascular diseases due to heat stress, for example, heart attack (Weihe, 1985). The life expectancy of various drugs would decrease.

We need to note that so far scientists are unable to predict what weather changes might occur to individual countries, so we do not know whether Tuvalu conditions will become more humid or more sunny or more rainy etc. This means we cannot be sure what health effects will actually occur.

3.8 Transportation and Communication

Tuvalu has only one cargo and passenger ship, which operates within the group and provides services to Fiji, Nauru, Tokelau, American Samoa and Western Samoa. The two fishing vessels are occasionally used in emergency cases (medical purposes). The ship usually does not sail during bad weather conditions. Any increase in the number of cyclones in the group would certainly disrupt this service. The people of outer islands rely on the ship for imported goods, petrol and medical supplies, therefore any increasing storminess would prevent the ship from delivering goods and medical supplies, giving rise to shortage of food and petrol, and possibly deaths amongst the most sick persons.

Communication may also be threatened by climate change, specially sea level rise. Telephone cables in Funafuti are underground, and this could be affected by intrusion of underground water which is forced to rise by rising sea level. The satellite dish in the main telecommunication centre in Funafuti is also vulnerable to tropical cyclones. This satellite dish provides telecommunication links with other countries, and has to be dismantled during very strong winds, shutting down Tuvalu from the rest of the world. This might occur more frequently in the future, if there is a rise in frequency of cyclones in the Pacific region.

3.9 Exclusive Economic Zone

Tuvalu has an Exclusive Economic Zone of approximately 1.3 million square kilometres. This is one of the major aspects which contributes to the economy of the country. Foreign fishing vessels are licensed by the Tuvalu government to fish in this EEZ. Under current laws, the

size of this EEZ would be threatened by any disappearance of islands due to sea level rise.

4 RECOMMENDATIONS

- (a) Prepare a report describing past measurements of climate of Tuvalu, what changes have occurred and what needs to be measured to detect future changes.
- (b) Development environment and climate education for introduction in school curriculum.
- (c) Require every project to undergo environment impact assessment first before proceeding on.
- (d) Co-operate with other Pacific island countries and with international and regional agencies such as the South Pacific Regional Environment Programme.
- (e) The people of Tuvalu should have a general understanding of this controversial topic of Climate Change and Sea Level Rise. Public talks and open forum should be encouraged and more radio programmes on the topic should be made available for the public to hear and comment on. A trip around the outer islands to give lectures, in order to make the locals understand fully the nature of the topic.

5 CONCLUSION

Tuvalu, with very low lying atolls, rising only three metres above sea level and having a very small land area, is one of the most vulnerable countries to the effects climate change and sea level rise. The country has already experienced the effects of coastal erosion, for example, in the island of Funafuti the lagoon coastal side is eroding away very fast.

The people should be educated to better understand their climate and to have a feel for their environment, they should have the idea of conserving, recycling and taking care of their own environment. For example, not destroying the ocean side hurricane bank, by using the stones for constructing roads, buildings, etc. It is important to maintain good quality climate monitoring in Tuvalu.

It is hoped that industrialised countries will take into consideration the plea by low lying states to stabilise their emissions of greenhouse gases, and will respond and assist the poor countries with the development of plans and activities which will, to the greatest extent

possible, alleviate adverse environmental impacts associated with climate change and sea level rise.

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