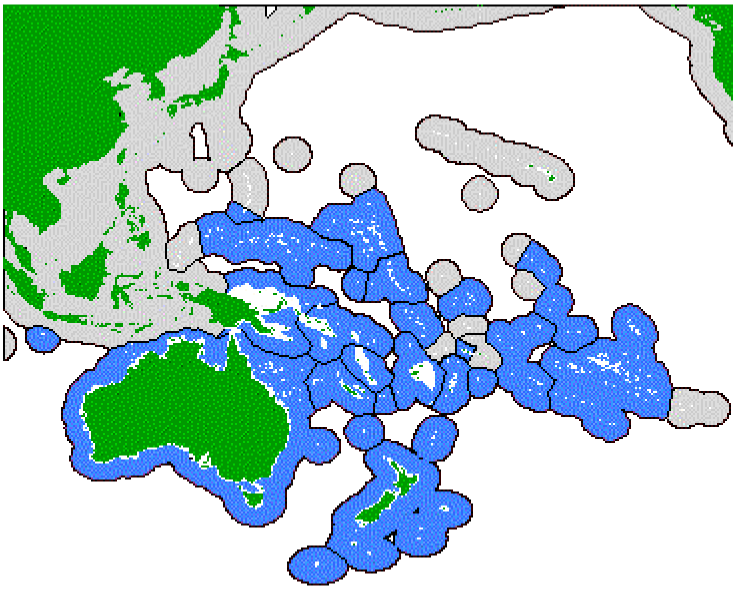
CLIMATE TRENDS AND VARIABILITY IN OCEANIA

2nd APN Workshop on Climate Variability and Trends in Oceania

5 - 9 November 2001

Auckland, New Zealand

WORKSHOP REPORT



Organised by the National Institute of Water and Atmospheric Research
Funded by the Asia-Pacific Network for Global Change Research

P O Box 109-695, Auckland
Tel + 64 9 375 2050 Fax + 64 9 375 2051

CLIMATE TRENDS AND VARIABILITY IN OCEANIA

2nd APN Workshop on Climate Variability and Trends in Oceania

5 – 9 November 2001

Auckland, New Zealand

Organised by the National Institute of Water and Atmospheric Research (NIWA)
Funded by the Asia-Pacific Network for Global Change Research

NIWA, P O Box 109-695, Auckland, New Zealand
Tel + 64 9 375 2050 Fax + 64 9 375 2051

WORKSHOP REPORT

AK02009

Climate Variability and Trends in Oceania

NIWA Report AK02009

The 2nd workshop on *Climate Variability and Trends in Oceania* was organised by the National Institute of Water and Atmospheric Research, Auckland, New Zealand from funding provided by the Asia-Pacific Network for Global Change Research.

Workshop Report:
Edited by Dr Jim Salinger
Contributors: Dr Brett Mullan, Ashmita Gosai, Dr Blair Trewin, Hilia Vavae

Climate Variability and Trends in Oceania

SUMMARY

Oceania occupies a large portion of the Pacific Basin, and climate and ocean/atmosphere interactions of global significance occur here on annual to decadal time-scales. These include the El Niño-Southern Oscillation (ENSO), and the Interdecadal Pacific Oscillation (IPO), an ENSO-like variation which modulates climate on time scales of two to three decades, which cause significant climate change in parts of Oceania and beyond.

The APN workshops on climate variability and trends in Oceania are contributing to increased understanding by searching and extending historical climate data back over long periods, and refining these for changes in site, exposure and instrumentation. The description of climate variability and trends provides answers that IPCC assessments will address, and extends previous knowledge on regional climate variability. The compilation of high-quality series of climate data will allow the detection and attribution of climate change, particularly in Oceania. The first workshop from 13 – 15 September 2000 had wide involvement of Pacific Island Countries and national meteorological services in the region. Fiji, Tuvalu and Tonga are key collaborators with New Zealand and Australia, with involvement from nine other Pacific Island Countries, in collaboration with the South Pacific Regional Environment Programme (SPREP) and the WMO Sub-Regional Office in Apia. This second workshop had participants from eleven Pacific island countries, Australia, New Zealand, and the WMO Sub-Regional Office.

The aims of the workshop are to develop contacts and networks, and to assess climate change and variability in Oceania. Specific goals included preparation of a draft paper on country and regional climate trends and variability for publication, and provide material to enable Pacific Island countries to prepare reports on climate trends and variability for Oceania country state of the environment reports.

The workshop made a very significant step towards enhancing both regional and national capacity for Oceania countries to determine and understand their own climate variability and trends, and for regional participation in studies to monitor and detect trends and variability in climate.

The first session of the Auckland workshop provided background on the draft paper to be prepared which was followed by two presentations on homogenizing climate data and metadata assessment, as well as a tutorial on the Monthly Data Analyser software for the removal of data biases through homogeneity analyses.

Workshop participants then presented reports on historical and observed data resources, as well as the data brought for analysis. They then checked their data for quality and homogeneity for assessment of trends and variability. There was a large variation in the range of data resources available, with some countries having a high quality reference climate station network, and quite a few others with a very sparse climate network and major problems in retaining long-term climate sites and records.

On the second day the latest information on global and regional climate trends from the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report was presented, along with 21st century temperature and rainfall projections from climate models based on various scenarios. The impacts of such trends were also discussed. Workshop participants then considered

methods of time series analysis for trends before then analysing their country data. This was followed on the next day by consideration of regional climate variability in the region, driven by ENSO and IPO. Palaeoclimate evidence demonstrates that these features have been a dominant cause of variability in the region for several centuries. After methods for quantifying variability were shown, attendees then analysed country data to ascertain climate teleconnections with ENSO and the IPO.

On the fourth day the World Meteorological Organisation (WMO) Sub-Regional office presented the programme thrusts of its climate work, including moves to improve regional observations to meet Global Climate Observing System (GCOS) initiatives. Participants discussed the restoration of the sub-regional climate data archive, including access and operation. It was agreed that Island data providers should receive a share of the costs in return if charges for their data procurement are made. At the moment some data series in the sub-regional climate data archive are incomplete and NIWA will commence a programme of data rescue. As well, some media training was given. Participants then commenced preparation of the scientific paper.

On the final day a review of the 3rd APN Workshop on Climate Extremes, held in Melbourne in April 2001, was presented. Workshop participants then reviewed the results of analysis of trends and variability and the draft paper was prepared. In the final session a CD-RoM was distributed of all presentations, data and other resource material. Workshop participants addressed issues, and reported their conclusions to the final plenary session where recommendations were formed.

The participants noted that another workshop in 2003 would be extremely desirable to continue the work, networking and capacity building from the first two workshops in the region. The recommendations for action are that:

1. The protection for critical observation sites should occur by means of World Heritage listing or a similar mechanism. Sites identified as being especially critical are Apia, Papeete and Rapa. It was also considered important not to lessen the perceived importance of the remainder of the observation network. Accurate daily measurements of temperature and rainfall in different parts of the Pacific enable accurate climate monitoring to detect trends and predict variability.

2. It is desirable that the developed countries in the region should consider providing advice and technical support to less developed countries on equipment maintenance and servicing, and station inspection and documentation. It is recommended that specific training programmes in statistical data analysis be introduced. On-site training for capacity building is highly desirable.

3. Databases, (specifically the one currently maintained by NIWA, but also potentially others) should be supplied with data as a means of providing offsite backup to national databases (with requests for the data being referred back to the originating country, as per current practice with the NIWA database). NIWA will identify missing post-1992 data and contact the countries concerned.

4. Reporting on a national scale should, at this stage, concentrate on observed climate trends and SOI/ENSO-climate variability relationships. It was agreed that an improved understanding of the IPO is required before information based on this phenomenon was suitable for use in national-scale reporting.

5. It is recommended that funding be sought to stage an APN workshop in 2003 centred on metadata documentation and storage. The objectives of next workshop would focus on

techniques, and on metadata compilation and interpretation, with presenters to come from Australia, New Zealand and French Territories as available. Any software will be developed in Excel. The proposed workshop would be preceded by communication by e-mail, to clarify key questions, identify techniques, and to define key data sets for analysis.

6. Participating countries should complete their GCOS reports for SPREP (with a copy to WMO RA V). Preparation of individual reports of national requirements and priorities for improving observing systems by SPREP member countries is required by February 2002.

7. The draft paper and necessary reports from the workshop should be completed and submitted to a scientific journal for publication in due course during 2002.

8. Collaboration between countries participating in APN should be continued. In particular, to enhance communication, it is recommended that the APN web pages should be further developed and an e-mail alias (along the lines of apn@…) be established.

The workshop *Climate Variability and Trends in Oceania* was organised by the National Institute of Water and Atmospheric Research (NIWA) with funding from the Asia-Pacific Network for Global Change Research to assist Oceania countries monitor and detect climate change and variability.

Contents

Background to Workshop

The behaviour of the El Niño-Southern Oscillation (ENSO), which causes droughts or floods in many parts of the world, has been unusual since the mid-1970s (Trenberth, 1997). The ENSO is the major cause of global climate variability, after global warming, and is primarily driven out of Pacific basin ocean/atmosphere interactions. Recent analysis has uncovered that ENSO variations are modulated on timescales of two or three decades by the Interdecadal Pacific Oscillation (IPO). This variation is also centred on the Pacific basin, and causes significant shifts in climate on interdecadal time scales (Power et al. 1999, Salinger et al. 2002).

Oceania occupies a large portion of the Pacific Basin, and climate and ocean/atmosphere interactions here of global significance occur on annual to decadal time-scales. The behaviour of El Nino-Southern Oscillation (ENSO), a major cause of both Oceania and global climate variability, has been unusual since the mid-1970s. The IPO and ENSO, both centred in the tropical Pacific, cause significant climate change in parts of Oceania and beyond.

Both the Intergovernmental Panel on Climate Change (IPCC) and the Global Climate Observing system (GCOS) have noted the paucity of data over the Southern Hemisphere, making it crucial to improve databases for monitoring climate trends and variability, and to develop a network of long-term climate monitoring sites in the region (IPCC, 2001). These APN workshops are contributing by searching and extending historical climate data back over long periods, and refining these for changes in site, exposure and instrumentation. The description of climate variability and trends provides answers that current and future IPCC assessments will address, and extend previous knowledge on regional climate variability. The compilation of high-quality series of climate data will allow the detection and attribution of climate change, particularly in Oceania.

The first workshop from 13 – 15 September 2000 had wide involvement of Pacific Island Countries and national meteorological services in the region. Fiji, Tuvalu and Tonga are key collaborators with New Zealand and Australia, with involvement from nine other Pacific Island Countries, in collaboration with the South Pacific Regional Environment Programme (SPREP) and the WMO Sub-Regional Office in Apia. Workshop participants presented overviews of historical and observed climate data resources available in their own countries to study climate trends and variability, along with indications of analyses that had already been undertaken. There was a large variation in the range of data resources available, with some countries having a high quality reference climate station network, and data stored on relational databases with metadata, to those with a very sparse climate network and information stored on personal computers. Many countries have a significant paper archive of data requiring digitisation. Methods of analysis of data for climate trends and variability were discussed, in particular selection of climate indices for analysis, time series analysis and establishment of significance of any trends. It established contacts within Oceania to progress research on climate change and variability.

The participants of the 1st workshop noted that a follow-on APN workshop in 2001 would be extremely desirable to progress the worked commenced. For the region, real-time data quality guidelines be developed so that all data being used is of similar standard. The purpose of the second workshop is to continue the capacity building begun in the first meeting, and prepare a paper on country and regional climate trends and variability. Other goals would include provision of assessments of regional climate change and prepare reports on climate trends and variability for Oceania country state of the environment reports. This workshop would continue collaboration on climate change and variability work across Oceania, and improve capacity building for analysis of observed climate data**.**

1 Introduction

The meeting began with opening remarks from Dr Rick Pridmore (Deputy Chief Executive, NIWA)

Dr Jim Salinger outlined the goals of the workshop, which is to provide a focus on the mix of science and policy, with emphasis on inter-country participation and collaboration. The purpose of the workshop is to develop contacts and networks, and to assess climate change and variability in Oceania. Specific goals include:

- Prepare a paper on country and regional climate trends and variability for publication, and input into future IPCC assessments of regional climate change
- Prepare reports on climate trends and variability for Oceania country state of the environment reports
- Continue collaboration on climate change and variability work across Oceania
- Improve capacity building for analysis of observed climate data
- Contribute to CLIVAR and IGBP-START programmes on global change
- Provide direct input into the proposed APN human dimensions programme “Ethnographic perspectives on resilience to climate variability in the Pacific Island Countries”
- Prepare a report on the workshop for the Asia Pacific Network and the Global Climate Observing System (GCOS).

Dr Jim Salinger (New Zealand) presented material on previous work on climate change and variability in the South Pacific. This shows that surface temperatures have warmed by 0.5 - 0.8 C during the 20th century. The IPO causes climate shifts in the south west Pacific every 20-30 years and this results in changes in the mean values of temperature and rainfall. The IPO modulates the response to ENSO between phases and the South Pacific Convergence Zone moves its location on average. Understanding of observed climate change and variability in the region is essential for understanding global climate and provides critical information so as to improve climate modelling of climate on all time scales.

2 Historical Data Resources and Removing Data Biases

Climate station histories or metadata are essential in providing base information for removal of data biases. Dr Malcolm Haylock (Australia) provided a brief tutorial on the Monthly Data Analyser. The Monthly Data Analyser (Version 1.03), developed by Byron Gleason (NOAA, USA) and Janet Petersen (NIWA) is a Microsoft Excel (Version 97 or higher) program designed to assist researchers in the analysis of monthly data for climate change and detection. More specifically, Monthly Data Analyser takes monthly data for temperature and rainfall and undertakes the quality control, homogeneity testing, and calculation of indices and plots these and other graphs.

Dr Blair Trewin discussed the use of metadata knowledge of the instrument, station history and exposure that is essential for data interpretation and use. These allow correction for non-climatic influences and utilisation of quality control procedures and performance monitoring. This information is especially important where there are no neighbouring data to identify potential inhomogeneities. Metadata types include station identification, location and elevation, observational history and practices, instrumentation, information on the site and instrument condition.

3 Historical and Observed Data Resources in Oceania

Many detailed country reports were received on historical and observed data resources. These are contained in Appendix JJ. Participants discussed the data brought for analysis, and then the data was checked using the Monthly Data Analyser.

Australia

Data for analysis was brought for 68 stations. Over half of these are composite records due to station changes.

Cook Islands

Only one manual station exists in the Cook Islands, as the remainder have been automated; these have broken records because of instrument and communication problems. One station brought for analysis.

Fiji

Although data for 23 stations was available for analysis, only 12 stations were actually analysed. All were climate stations. There are long datasets available for Fiji, some extend as back as late 1880s.

Recently there has been an increasing trend to replace outer manual stations with AWSs (Automatic Weather Stations) which has led to data gaps since its inception (1999). Most of the AWSs are on outlying islands, therefore transportation becomes a problem in instances of breakdowns. There is limitation in terms of transports availability. There is also cost and capabilities limitations.

Climate data is quality controlled (manually and automatic) and stored in CLICOM. There is a offsite backup system where the data is backed up on CD-ROM and stored off site.

French Polynesia

The available network consists of 8 Météo-France manual stations, these cover the 5 archipelagoes: Atuona (Marquesas); Bora-bora, Tahiti-Faaa, Hereheretue (Societe); Tubuai, Rapa (Australes); Takaroa, Rikitea (Tuamoto-Gambier). All records begin 1961 (rainfall) and 1951 (temp) or later for this study.

Kiribati

One station (Tarawa) was brought for analysis, which has records dating back to the 1940s.

New Caledonia

There are a total of 99 stations currently available for climatological analysis, consisting of 6 synoptic stations with Météo-France staff, 27 automatic weather stations, 51 raingauge sites and 15 climate stations with automatic data loggers. However there are only 20 stations with at least 40 years and less than 4% of missing data. Data used for workshop are from 11 stations. Noumea records date back to 1864 but much pre-1900 data missing. Good metadata post-1950 but limited information prior to this (especially with respect to instrument shelters).

New Zealand

New Zealand has made considerable progress in the establishment of high-quality historical and operational networks for climate change purposes. Presently, there is a network of 21 reference climate sites with historical documentation and homogenisation completed. Data for 10 sites were used for analysis (Chatham, Raoul and Campbell Islands; Auckland, Kelburn, Dunedin, Masterton, Hokitika, Lincoln, Appleby), with the earliest sites commencing prior to 1900.

Niue

The current observation network consists of 3 stations, with 1 rainfall site, 1 climate site and 1 synoptic site. The data start in 1905, but have considerable inhomogeneities due to five site changes. Only one site was analysed.

Papua-New Guinea

There are currently 14 major observing stations run by the Papua-New Guinea National Weather Service, most with records starting from the 1960s. Two stations were selected (Port Moresby and Madang) for workshop analysis. Little metadata exists, and like many other countries, there is difficulty servicing and maintaining the climate network.

.

Samoa

Samoa has the longest observation series in the Pacific Island (from 1830s). Apia also has a relatively long record, having been run by German meteorologists during the period 1890 to 1920. There are currently two manual surface stations in the observation network with a further 12 AWSs located in Tuvulu, Samoa and American Samoa. There are problems with AWS. Data was brought for 2 stations: Apia (1890-present), Afiamalu (1966-). Apia has a reasonably complete record since 1902, except for civil service strike (1981) and tropical cyclone Ofa (1990). Problems include: records lost during extremes (TCs Ofa, Val); digitised data lost due to CliCom and PC crashes; lack of operational funding for instruments/observers; more training of observers needed. The data are scattered around PCs.

Solomon Islands

The Solomon Islands has five stations suitable for record analysis. Station records generally commence in the 1950s and 1960s, and equipment support is from Australia.

Tonga

The total available climate network consists of 13 stations, including 7 synoptic, 3 climate, 1 automatic weather station and 2 rainfall-only stations. The longest series commences in 1945. For Tonga, there are some metadata available, and there have been few site changes. Three the three climate stations were used for further analysis.

Tuvula

Four stations are available for climate work: Funafuti (1933), Nanumea (1941), Nuilakita (1957), Nui (1947). All stations are less than 3 metres above mean sea level, so problems occur because of tidal flooding, rising sea level, and effect of salt on instruments. Extra personnel are required to assist, as there is no expertise to carry out calibration of instruments. Also recorded sea level data (since 1993), and which is available for analysis. Station quality reasonable at present but there is a significant risk of instrument failure in the future.

Vanuatu

Vanuatu has seven synoptic stations and data from two were brought for workshop analysis: Lamap on Malekula Is. in central Vanuatu, and Aneityum in the far south of the island group. These have respectively about 40 and 50 years of record. Funding difficulties means that if instruments are broken, there can be considerable time before they are replaced. Assistance in collecting metadata about the station is also needed. Little information on station and instrument history exists.

4 Analyses for Trends

4.1 OBSERVED AND PREDICTED TRENDS

Dr Jim Salinger (New Zealand) presented the latest information from the IPCC Third Assessment Report on observed climate change and variability. Twentieth century warming has occurred in two periods: 1910-1945, mainly in North America and Europe, and 1976-1999 with warming almost everywhere but particularly in high latitudes of the Northern Hemisphere. Some cooling occurred in the intermediate period of 1946-75, but particularly for North America-Europe. Overall temperature increases with a trend of about 0.1°C/decade has occurred since the early 1960s. There are many other indicators of climate warming including retreat of mountain glaciers, and thinning of Arctic sea ice.

Pene Lefale (New Zealand) summarized global average temperature and sea level rise projections under all IPCC Special Report on Emission Scenarios (SRES) illustrative greenhouse gas emission scenarios. Projected increases in global mean temperatures from 1990 to 2100 for a range of plausible greenhouse gas emission scenarios lie between 1.4°C and 5.8°C. Global mean sea level changes for the same range of emission scenarios lie between 9 and 88 cm. Changes are expected in some extreme weather and climate events, including higher maximum temperatures and more hot days, more intense (heavy) rainfall events, and (over some areas) an increase in peak wind intensities and mean and peak rainfall intensities in tropical cyclones. Current projections show little change or a small increase in amplitude for El Niño events over the next 100 years. However, even with little or no change in El Niño amplitude, global warming is likely to lead to greater extremes of drying and heavy rainfall, and to increase the risk of droughts and floods that occur with El Niño events in many different regions including small Pacific Island states. Best current future projections of climate change for Pacific Islands indicates the region is likely to warm at a slightly slower rate than the global average, but at a rate that is still substantial and likely to have significant impacts. Confidence in rainfall changes is lower because of the strong difficulty of simulating these with low-resolution models. However, the coupled models suggest increased precipitation along the equatorial belt from the dateline_eastwards, and a likelihood of decreases in the southwest Pacific. Dr Brett Mullan provided two overheads of GCM changes projected for next fifty years, showing a general pattern of more El Nino-like conditions.

Implications of these findings are addressed in the report of IPCC Working Group II (IPCC, 2001b). Pene Lefale outlined the WGII Summary for Policymakers identifies coral reefs and atolls, and mangroves amongst natural systems which are vulnerable to (and will possibly be irreversibly damaged by) climate change. It states that small island states and low-lying coastal areas are particularly vulnerable to increases in sea level and storms, and notes that most of them have limited capabilities for adaptation.

4.2 TIME SERIES ANALYSIS

Paul Della-Marta outlined analysis methods for trends. Care is required in computing a linear trend and estimates of slope and its error. Assumptions: normality of data, trend is linear, independence (seasonality, serial correlation). Allowance is required of all these things in order to obtain a reliable estimate of the significance of our linear trend. For the global temperature curve, the linear trend over last 100 years is 0.0042 +/- 0.0012°C/yr, when serial correlation has been taken into account. Serial correlation doubles the standard error.

Time series analysis includes the determination of which timescales of variation are important using techniques such as harmonic analysis, which involves fitting a series with a smooth curve. Fourier analysis is a common method for this purpose.

The degree of persistence within a time series can be investigated using autocorrelation techniques. Strong positive autocorrelation is associated with “smooth” time series with low frequency (red noise), while strong negative autocorrelation is associated with “spiky” time series with high frequency (blue noise). Time series with autocorrelation close to zero are more random in nature (white noise).

Participants in this session analysed country data for trends, which are contained in the draft paper (Appendix ccc).

5 Analysis for Variability

Dr David Stephens (Australia) discussed the important role of the southern mid-latitudes in forcing extreme ENSO events. Rapa Island (south of Tahiti) is a key site for monitoring pressure changes in South Pacific. A strong trough in central Pacific is associated with El Niño. Pressure increases here lead the Niño 3 changes and decay of El Niño event. A stronger, more consistent trough in South Pacific has occurred since the mid-1970s. The trough drives the strength of the trade winds. An El Niño Prediction Index (EPI) was described, derived from southeast Australian pressures that lead Nino3 SST changes. These Australian pressures form the western part of a mid-latitude index of the Southern Oscillation (Rapa Is being the east end). There is a suggested tendency for a long-wave trough over southeast Australia in winter of year prior to El Niño events.

Dr Jim Renwick (New Zealand) discussed the Interdecadal Pacific Oscillation (IPO) as a long-period variation in Pacific SST patterns. The impacts of the IPO on SOI, location of SPCZ, and on SOI correlation fields with pressure, temperature, and precipitation were described. Whether the IPO could merely be a low-pass filtered version of Niño 3.4 was discussed.

Dr Brad Linsley (United States) showed that coral cores from the Rarotonga area are used as a paleoclimate record. Isotope ratios (O, Ca/Sr) can be used to infer SSTs for last 271 years. Results obtained correlate very well with Rarotonga SST, which in turn correlates well with IPO-like pattern when filtered, so that the coral results may be IPO indicator. These show very warm conditions pre-1760.

Information on ENSO in context of decadal variation and trends was described by Dr Brett Mullan (New Zealand). Considerable variations in climate impacts from one ENSO event have been noted. These are based on subtle differences in SST anomalies and random variation. Recent work suggests the latter is more important. ENSO pressure, rainfall and wind anomalies in Pacific vary under different ENSO/IPO conditions. In the negative IPO phase, the very strong SOI/temperature correlations in the equatorial zone extends much further west. However climate trends can be obscured by ENSO-related interannual variations. Models suggest ENSO-like precipitation changes in Pacific over next 50 years. A very useful website for analysis of data series online can be found at:http://climexp.knmi.nl . Georgina Griffiths (New Zealand) demonstrated its use.

6 Regional Perspectives

6.1 WORLD METEOROLOGICAL ORGANISATION

Henry Taiki (WMO) described WMO RA-V efforts in the climate variability and change area. WMO has an emphasis on capacity building, to meet Global Climate Observing System (GCOS), UN Framework Climate Change Convention (UNFCCC) and other requirements. It has four climate programs in the region (data management and monitoring, applications and services, impacts and response strategies, research). Each regional association meets formally once every four years with working groups operating in between. RA V (South West Pacific) next meets in May 2002.

6.2 SUB-REGIONAL CLIMATE DATABASE

NIWA holds a sub-regional climate database for parts of Oceania, with data from many Pacific Island climate stations. Stuart Burgess (New Zealand) outlined the South West Pacific data in the NIWA Climate Database. There are gaps in the NIWA database after 1992. NIWA can secure the data (if requested) so it is not available to others. If data is stored in at least two locations, this protects against accidental loss. NIWA database uses Oracle 8.1.6 (since September 2001). Web-based retrieval system expected to be ready by early 2002. Planned access arrangements are at no cost for contributors for their own data and a modest amount of other data.

6.3 ETHNOGRAPHIC PERSPECTIVES

Dr Mark Busse (New Zealand) is organising another APN workshop on ethnographic perspectives on climate change and variability on the region at Apia, December 2002 at which the results from this workshop will be present.

6.4 MEDIA

Jan Sinclair (New Zealand) outlined the communication of science to the media. Media often do not know the issues to follow on scientific issues and require good guidance. It is critical to decide prior to the interview, which are the two or three most important points to communicate.

7 Outputs and Products

Outputs and products from this second workshop:

- Continued regional participation in global studies to monitor and detect trends and variability in climate and improve capacity building;
- Identified the status and availability of relevant historical climate data in the region;
- Trained participants in appropriate methods for analysis of climate trends and variability;
- Continued a collaborative project to analyse the national climate records for trends and variability across Oceania;
- Prepared a draft paper for submission to a scientific journal in 2002;
- Provided information for preparation of national reports on climate change and variability;
- Enhanced regional and national capacity for Oceania countries to determine and understand their climate variability and trends;
- Provided participants with a CD-RoM containing all workshop presentations, data resources, analysis software and draft paper;
- Prepared a report on the workshop for the Asia Pacific Network, the World Meteorological Organization (WMO) and the Global Climate Observing System (GCOS).

8 Summary, Recommendations and Future Directions

Summary

A compilation of Pacific Island national climate measurements produces regional trends of Pacific climate from 1950 – 2000. New figures compiled from detailed Pacific island climate records show that over the last fifty years, many parts of the Pacific warmed much faster than the global average warming. This amount of detail had not been available before. The resulting pattern of the Pacific's climate over the second half of the 20th century was viewed with interest by climate scientists at the workshop.

For the twentieth century, the global average temperature rise was 0.6°C, but in the Pacific, temperatures rose more than that in parts of the region during the second half of the century.

The daily temperature records show that in Australia, the Cook Islands, Fiji, French Polynesia, New Caledonia, the Solomon Islands and Vanuatu, temperatures rose by 0.5 to 1°C in the second half of the twentieth century. Elsewhere in the Pacific, the warming was similar to the global average warming. This would have been accentuated by the greater number of El Niños, which developed in the last quarter of the 20th century, between 1976 and 1998. By contrast, in New Zealand where El Niño brings cooler temperatures, the unusual number of El Niños slowed the warming to below the global average.

The compilation of detailed national weather records also revealed a significant reduction in rainfall in many parts of the Pacific. While this was not as widespread as the unusual warming, it is also evidence of long-term changes in climate.

For variability, the ENSO and IPO are shown to be associated with interannual to decadal climate variability over parts of the Pacific Basin. The IPO modulates interannual ENSO-related climate variability over Australia. Three phases of the IPO have been identified during the 20th century: a positive phase (1922 – 1944), a negative phase (1946 – 1977) and another positive phase (1978 –

1998). With the change to the negative phase after 1946, annual surface temperature increased significantly southwest of the South Pacific Convergence Zone (SPCZ) at a rate similar to the average Southern Hemisphere warming. Northwest of the SPCZ temperature increases were less than, and northeast of the SPCZ more than, the hemispheric warming in surface temperature. Increases of annual precipitation of 30 percent or more occurred northeast of the SPCZ, with smaller decreases to the southwest, associated with a movement in the mean location of the SPCZ northeastwards. The IPO modulates teleconnections with ENSO in a complex way, strengthening relationships in some areas and weakening them in others. Only for New Zealand is there a consistent bias towards stronger teleconnections for the positive IPO period.

These compilations demonstrate that the IPO is a significant source of climate variation on decadal time scales throughout the South West Pacific region, on a background which includes global mean surface temperature increases. The IPO also modulates interannual ENSO climate variability over the region

Recommendations

1. World Heritage listing of climate sites. The group recommended the protection for critical observation sites by means of World Heritage listing or a similar mechanism. These are Apia, Papeete and Rapa. But it was also considered important not to lessen the perceived importance of the remainder of the observation network. Accurate daily measurements of temperature and rainfall in different parts of the Pacific let them to warn Governments of potentially devastating droughts, cyclones and heavy rain months or even years beforehand. But these warnings rely on weather monitoring stations remaining in the same location. Apia has the best records in the whole of the Pacific, and has been in the same place since 1902 with an unbroken record.

2. Advice and Technical Support. It is desirable that the developed countries in the region should consider providing advice and technical support to less developed countries on equipment maintenance and servicing, and station inspection and documentation. It is recommended that specific training programmes in statistical data analysis be introduced. Many Oceania states require specific training in statistical data analysis, commencing from very basic principles and progressing to sophisticated time series techniques, to describe trends and variability in their data. It was agreed that training in the use of Excel would also be useful. On-site training for capacity building is highly desirable.

3. Sub-regional databases. Databases, (specifically the one currently maintained by NIWA, but also potentially others) should be supplied with data as a means of providing offsite backup to national databases (with requests for the data being referred back to the originating country, as per current practice with the NIWA database). In the specific case of those countries currently supplying data to the NIWA database, NIWA (Stuart Burgess) will identify missing post-1992 data and contact the countries concerned.

4. National climate reports. Reporting on a national scale should, at this stage, concentrate on observed climate trends and SOI/ENSO-climate variability relationships. It was agreed that an improved understanding of the IPO is required before information based on this phenomenon was suitable for use in national-scale reporting.

5. APN Workshop. It is recommended that funding be sought to stage an APN workshop in 2003 centred on metadata documentation and storage. The objectives of this workshop would be to:

- Prepare country and regional metadata documentation;
- Update information on climate trends and variability for Oceania on a national basis;
- Continue collaboration on climate change and variability work across Oceania;
- Improve capacity building on metadata compilation;
- Contribute to CLIVAR and IGBP-START programmes on global change
- Provide direct input into human dimensions climate change and variability programme.

This next workshop would focus on techniques, and on metadata compilation and interpretation, with presenters to come from Australia, New Zealand and French Territories as available. Any software will be developed in Excel. The proposed workshop would be preceded by communication by e-mail, to clarify key questions, identify techniques, and to define key data sets for analysis. This preparatory work would include the identification of appropriate metadata records in the region, digitisation of metadata and development of a standard set of standard analysis routines and macros for Excel spreadsheets for analysis use. It was recognised that the establishment of a standard metadata database with minimum requirements is very important. The metadata will include details on site locations, exposures, instrumentation and instrumentation types. Metadata-bases should, where possible, utilise common software such as Microsoft Access. NIWA will establish a 'blank' metadata-base for common use.

6. GCOS Reports. Participating countries should complete their GCOS reports for SPREP (with a copy to WMO RA V). Preparation of individual reports of national requirements and priorities for improving observing systems by SPREP member countries is required by February 2002. This is so that the development of a Pacific GCOS Action Plan can be achieved to serve as the basis for proposals to fund improvements in observing systems for climate. This plan would be facilitated by SPREP in cooperation with the Council of Regional Organizations in the Pacific (CROP) and the co-sponsors of GCOS. The targeted completion date is June 2001 in order to be able to present the Plan to the COP7 deliberations in July.

7. Paper. The draft paper and necessary reports from the workshop should be completed and submitted to a scientific journal for publication in due course during 2002.

8. Collaboration and capacity building. Collaboration between countries participating in APN should be continued. In particular, to enhance communication, it is recommended that the APN web pages should be further developed and an e-mail alias (along the lines of apn@…) be established.

References

IPCC, 2001: *Climate Change 2001. The scientific basis*. Eds. J. T. Houghton, Y. Ding, D. Griggs, M. Noguer, P. Van der Linden, X. Dai, K. Maskell, C.A. Johnson. Cambridge Univ. Press. Cambridge, U.K., 2001.

Peterson, T.C., Easterling, D.R., Karl, T.R., Grosiman, P., Nicholls, N., Plummer, N., Torok, S., Auer, I., Boehm, R., Gullett, D., Vincent, L., Heino, R., Tuomenvirta, H., Mestre, O., Szentimrey, T., Salinger, J., Førland, E., Hanssen–Bauer, I., Alexandersson, H., Jones, P., and Parker, D. 1998. 'Homogeneity adjustments of in situ atmospheric climate data: A review'. *Int. J. Climatol.*, 18: 1493–1517.

Power, S., T. Casey, C. Folland, A. Colman, and Mehta, V. 1999. 'Inter-decadal modulation of the impact of ENSO on Australia'. *Climate Dynamics*, **15,** 319-324.

Salinger, M.J., Renwick, J.R, and Mullan, A.B. 2002. 'Interdecadal Pacific Oscillation and South Pacific Climate', *Int. J. Climatol*. (in press).

Trenberth, K.E., and Hoar, T.J. 1997. 'El Niño and climate change'. *Geophys. Res. Letts.*, **24**, 3057-3060.

APPENDIX 1: AGENGA

Agenda

Monday 5 November

Introductory Session

0830-0900	Welcome – Dr. Rick Pridmore, Deputy Chief Executive Officer,
0900-0920	Introduction and Confirmation of the Programme – Dr. Jim Salinger, NIWA.
0920-0950	Overview of previous work on Climate Change and Variability in Oceania – Dr. Jim Salinger, NIWA.
0950-1010	Coffee Break
1010-1030	Paper to be prepared during Workshop – Dr. Jim Salinger, NIWA.
1030-1150	Discussion of climate elements for the paper – Dr. Jim Salinger, NIWA.

Session One: Historical Data Resources and Removing Data Biases

Participants describe their data resources

1150-1210	ClimDex – Homogenising climate data – Mr. Malcolm Haylock, Bureau of Meteorology, Australia.
1210-1230	Metadata Assessment – Data about data – Dr. Blair Trewin, Bureau of Meteorology, Australia.
1230-1330	Lunch break
1330-1500	Participants discuss country data for homogeneity
1500-1520	Afternoon Tea
1520-1700	Country data check for homogeneity

Tuesday 6 November

0830-0900	Climate Diagnostics and Prediction – Dr. David Stephens, Australia
0900-1000	Continuation of Data Checks
1000-1015	Morning Tea break

Session Two: Climate data analysis for trends

1015-1035	IPCC Third Assessment Report – Global Observed Climate Change – Dr. J. Salinger, NIWA.
1035-1055	IPCC Third Assessment Report - Impacts on Oceania – Mr. P. Lefale/Dr. Jim Renwick. NIWA.
1055-1115	Analysis methods for trends - Mr. Paul Della-Marta, Bureau of Meteorology, Australia.
1115-1200	Participants analyse country data for trends

1200-1230	Lunch Break
1230-1500	Participants analyse country data for trends (cont'd)
1500-1515	Afternoon Tea break
1515-1700	Participants analyse country data for trends (cont'd)

(*Parallel Event: 1230-1515 The Island Climate Update (ICU) November Conference*)

Wednesday 7 November

Session Three: Climate data analysis for variability

0830-0850	The regional view – Mr. Henry Taiki, World Meteorological Organization (WMO) Sub-regional office for the South West Pacific
0850-0910	Climate databases – Mr. Stuart Burgess, NIWA
0910-0930	Climate and the Media – Ms Jan Sinclair, University of Auckland
0930-0950	The Interdecadal Pacific Oscillation (IPO) – Dr. Jim Renwick, NIWA
0950-1010	Morning Tea break
1030-1200	Participants analyse country data for variability
1200-1300	Lunch break
1300-1700	Participants analyse country data for variability

Thursday 8 November

Session Four: Synthesis of Trends and Variability

0830-0850	El Nino/Southern Oscillation (ENSO) – Dr. Brett Mullan, NIWA
0850-0910	Analysis methods for variability – Ms Georgina Griffiths, NIWA
0910-1000	Participants describe trends and variability in their country paper Country by country examination of trends and variability
1000-1020	Morning Tea break
1020-1200	Participants describe trends and variability in their country paper (cont'd)
1200-1300	Lunch
1300-1500	Participants describe trends and variability in their country for paper Discussion on regional averaging
1500-1515	Afternoon Tea
1515-1700	Draft paper plan and preparation

Friday 9 November

Session Five: Climate change and variability in Oceania – The Review

0830 – 0910	3rd APN Workshop on Climate Extremes – A Review
0910-1000	Draft paper discussion
1000 - 1030	Morning Tea break
1030-1200	Presentation on paper figures
1200-1300	Lunch break
1300-1445	Discussion on changes to draft paper

	Final workshop draft distributed to participants along with software and a copy of regional data (if agreed) on a CD
1445-1500	Afternoon Tea Break
1500-1600	Discussion on changes to draft paper (cont’d) Future steps Close of Workshop

APPENDIX 2. LIST OF PARTICIPANTS

Mark Busse Department of Anthropology University of Auckland Private Bag 92 019 Auckland NEW ZEALAND TEL: +64 9 373 7599 FAX: EMAIL: m.busse@auckland.ac.nz	David Wratt NIWA P O Box 14 901 Kilbirnie Wellington NEW ZEALAND TEL: +64 4 386 0588 FAX: +64 4 386 0574 EMAIL: d.wratt@niwa.cri.nz
Stuart Burgess NIWA P O Box 14 901 Kilbirnie Wellington NEW ZEALAND TEL: +64 4 386 0569 FAX: +64 4 386 0574 EMAIL: s.burgess@niwa.cri.nz	Seluvaia Finaulahi Tonga Met Service P O Box 845 Nuku Alofa TONGA TEL: +676 23 401 FAX: +676 24 145 EMAIL: sfinaulahi@mca.gov.to
Paul Della-Marta Bureau of Meteorology GPO Box 1289k Melbourne 3001 AUSTRALIA TEL: +61 3 9669 4780 FAX: +61 3 9669 4678 EMAIL: p.della-marta@bom.gov.au	Georgina Griffiths NIWA P O Box 109 695 Newmarket Auckland NEW ZEALAND TEL: +64 9 375 2055 FAX: +64 9 375 2051 EMAIL: g.griffiths@niwa.cri.nz
Tekena Teitiba Kiribati Meteorological Service Tarawa KIRIBATI TEL: +686 26511 FAX: +686 26089 EMAIL: kirimet@tskl.net.ki	Victoire Laurant Meteo France BP 6005 Faaa TAHITI TEL: +689 803367 FAX: +689 803309 EMAIL: victoire.laurent@meteo.fr
Justina Kameata PNG National Weather Service	Ashmita Gosai Fiji Meteorological Service

P O Box 1240 Boroko PAPUA NEW GUINEA TEL: +675 325 2788 FAX: +675 325 2740 EMAIL: jkameata@pngmet.gov.pg	Private Mail Bag NAP 0351 Nadi Airport FIJI TEL: +679 724 888 FAX: +679 736 047 EMAIL: ashmita.gosai@met.gov.fj
Malcolm Haylock Bureau of Meteorology Research Centre GPO Box 1289K Melbourne 3001 AUSTRALIA TEL: +61 3 9669 4269 FAX: +61 3 9669 4660 EMAIL: m.haylock@bom.gov.au	Blair Trewin National Climate Centre Bureau of Meteorology GPO Box 1289K AUSTRALIA TEL: +61 3 9669 4061 FAX: +61 3 9669 4760 EMAIL: b.trewin@bom.gov.au
Penehuro Lefale NIWA P O Box 109 695 Newmarket Auckland NEW ZEALAND TEL: +64 9 375 2050 FAX: +64 9 375 2051 EMAIL: p.lefale@niwa.cri.nz	Lloyd Tahini Solomon Islands Meteorological Service P O Box 21 Honiara SOLOMON ISLANDS TEL: +677 21757 FAX: +677 20046 EMAIL: L_tahina@hotmail.com
Luc Maitrepierre Meteo – France BP 151 Noumea NEW CALEDONIA TEL: +687 27 9300 FAX: +687 27 9327 EMAIL: luc.maitrepierre@meteo.fr	Dean Solofa Samoa Meteorological Services Ministry of Agriculture, Forest Fishery & Met P O Box 3020 Apia SAMOA TEL: +685 20855 FAX: +685 20857 EMAIL: dsolafa@meteorology.gov.ws
Mercy Nalawas Vanuatu Met Service PMB 054, Port Vila VANUATU TEL: +678 23866 FAX: +678 22310 EMAIL: climate@meteo.vu	Nga Rauraa Cook Islands Met Service Box 127 Rarotonga COOK ISLANDS TEL: +682 20603 FAX: +682 21603 EMAIL: nrauraa@attglobal.net
Brett Mullan NIWA P O Box 14 901	Darren King NIWA P O Box 109 695

Kilbirnie Wellington NEW ZEALAND TEL: +64 4 386 0343 FAX: +64 4 386 2153 EMAIL: j.mullan@niwa.cri.nz	Newmarket Auckland NEW ZEALAND TEL: +64 9 375 2050 FAX: +64 9 375 2051 EMAIL: d.king@niwa.cri.nz
Jim Renwick NIWA P O Box 14 901 Kilbirnie Wellington NEW ZEALAND TEL: +64 4 386 0343 FAX: +64 4 386 2153 EMAIL: j.renwick@niwa.cri.nz	Jim Salinger NIWA P O Box 109 695 Newmarket Auckland NEW ZEALAND TEL: +64 9 375 2053 FAX: +64 9 375 2051 EMAIL: j.salinger@niwa.cri.nz
Henry K Taiki World Meteorological Organization (WMO) WMO Subregional Office for SW Pacific P O Box 240 Apia SAMOA TEL: +685 25706 FAX: +685 25706 EMAIL: wmo.srop@sprep.org.ws	Hilia Vavae Tuvalu Meteorological Service Private Bag Funafuti TUVALU TEL: +688 20736 FAX: +688 20090 EMAIL: hiliavavae@yahoo.com
David Stephens Agriculture Western Australia Locked Mail Bag No 4 Western Australia 6983 AUSTRALIA TEL: +61 8 9368 3346 FAX: +61 8 9368 3939 EMAIL: dstephens@agric.wa.gov.au	Janet Petersen NIWA P O Box 109 695 Newmarket Auckland NEW ZEALAND TEL: +64 9 375 2058 FAX: +64 9 375 2051 EMAIL: j.petersen@niwa.cri.nz

APPENDIX 3. LIST OF ACRONYMS

ADAM	Australian Data Archive for Meteorology
APN	Asia-Pacific Network for Global Change Research
AWS	Automatic weather station
CDMS	Climate Data Management System
CLICOM	WMO system for inputting climate data
CLIPS	Climate Information and Prediction Systems
CLIVAR	Climate Varaibility and Predictability
ENSO	El Niño-Southern Oscillation
GCOS	Global Climate Observing System
IGBP	International Geosphere Biosphere Program
IPCC	Intergovernmental Panel on Climate Change
IPO	Interdecadal Pacific Oscillation
NIWA	National Institute of Water and Atmospheric Research
SPCCD	Subregional Pacific Community Climate Database
SPCZ	South Pacific Convergence Zone
SPREP	South Pacific Regional Environment Programme
START	System for analysis, Research and Training
UNFCCC	United Nations Framework Convention on Climate Change
WCDMP	World Climate Data and Monitoring Programme
WCRP	World Climate Research Programme
WMO	World Meteorological Organisation

APPENDIX 4. LIST OF HIGH QUALITY STATIONS

List of high–quality stations, their location and period of record. Absence of a period of record for a specific variable indicates that the station was not used to analyse that variable.

Country	Station	Latitude	Longitude	Rainfall	Temperature
Australia	Kalumburu Mission	14.30 S	126.64 E	1941-2001	1957-2001
	Darwin Airport	12.42 S	130.89 E	1869-2001	1941-2001
	Weipa Aero	12.68 S	141.92 E	1914-2001	1959-2001
	Tennant Creek Airport	19.64 S	134.18 E	1874-2001	1957-2001
	Burketown Post Office	17.74 S	139.55 E	1886-2001	1957-2001
	Cairns Aero	16.87 S	145.75 E	1882-2001	1942-2001
	Willis Island	16.30 S	149.98 E	1921-2001	1939-2001
	Carnarvon Airport	24.88 S	113.67 E	1899-2001	1945-2001
	Port Hedland Airport	20.37 S	118.63 E	1897-2001	1948-2001
	Alice Springs Airport	23.80 S	133.89 E	1873-2001	1941-2001
	Giles Meteorological Office	25.04 S	128.29 E	1956-2001	1956-2001
	Marree	29.65 S	138.06 E	1885-2000	1957-2001
	Tibooburra Post Office	29.44 S	142.01 E	1892-2001	1921-2001
	Charleville Aero	26.41 S	146.26 E	1874-2001	1942-2001
	Yamba Pilot Station	29.43 S	153.36 E	1882-2001	1921-2001
	Cape Leeuwin	34.37 S	115.13 E	1897-2001	1957-2001
	Cunderdin	31.66 S	117.25 E	1914-2001	1957-2001
	Kalgoorlie-Boulder Airport	30.79 S	121.45 E	1896-2001	1939-2001
	Ceduna AMO	32.13 S	133.71 E	1939-2001	1939-2001
	Mildura Airport	34.23 S	142.08 E	1908-2001	1946-2001
	Mount Gambier Aero	37.75 S	140.79 E	1860-2001	1942-2001
	Deniliquin Post Office	35.55 S	144.95 E	1870-2001	1957-2001
	East Sale Airport	38.11 S	147.13 E	1870-2001	1945-2001
	Moruya Heads Pilot Station	35.91 S	150.15 E	1875-2001	1921-2001
	Cape Bruny Lighthouse	43.49 S	147.14 E	1871-2001	1957-2001
	Lord Howe Island Aero	31.54 S	159.08 E	1886-2001	1912-2001
	Norfolk Island Aero	29.04 S	167.94 E	1890-2001	1939-2001
	Macquarie Island	54.50 S	158.95 E	1948-2001	1948-2000
	Forrest	30.84 S	128.11 E	1930-2001	1946-2001
Cook Islands	Rarotonga	09.00 S	158.05 W	1929-2000	1930-2000
	Penrhyn	21.20 S	159.80 W	1937-1995	1937-1995
Fiji	Rotuma	12.50 S	177.05 E	1912-2000	1933-2000
	Suva	18 15 S	178.45 E	1942-2000	1942–2000
	Rarawai Mill	17.55 S	177.73 E	1910-2000	1925-2000
Country	Station	Latitude	Longitude	Rainfall	Temperature
Fiji	Labasa Mill	16.45 S	179.35 E	1891-2000	1930-2000
	Savusavu	16.48 S	179.21 E	1956-2000	1956-2000

	Nadi	17.45 S	177.27 E	1942-2000	1942-2000
French Polynesia	Rapa	27.62 S	144.33 W	1953–2000	1953–2000
	Tubuai	23.20 S	149.28 W	1964–2000	1964–2000
	Faaa	17.55 S	149.60 W	1957–2000	1957–2000
	Atuona	9.80 S	139.03 W	1960–2000	1961–2000
	Takaroa	14.28 S	145.02 W	1952–2000	1952–2000
	Hereheretue	19.54 S	144.57 W	1960–2000	1960–2000
	Rikitea	23.07 S	134.57 W	1980–2000	1980–2000
Niue	Alofi	19.05 S	169.92 W	1930-2000	1930-2000
New Caledonia	Koumac	20.56 S	164.28 E	1951–2000	1954–2000
	Nouméa	22.28 S	166.45 E	1901–2000	1951–2000
	Ouanaham	20.78 S	167.24 E		1960–2000
	Chepenehe	20.79 S	167.15 E	1951-2000	
	Gomen	20.67 S	164.40 E	1909-2000	
	Toutouta	22.01 S	166.22 E	1949–2000	
	Païta	22.14 S	166.37 E	1936–2000	
	Touho	20.78 S	165.22 E	1952–2000	
	Ponérihouen	21.08 S	165.40 E	1952–2000	
	Yaté	22.15 S	166.91 E	1930–2000	
New Zealand	Appleby	41.28 S	173.10 E	1884-2000	1908-2000
	Campbell Is.	52.55 S	169.15 E	1941-2000	1941-2000
	Hokitika	42.72 S	170.99 E	1895-2000	1894-2000
	Kelburn	41.28 S	174.77 E	1864-2000	1863-2000
	Dunedin	45.90 S	170.52 E	1852-2000	1853-2000
	Lincoln	43.63 S	172.47 E	1865-2000	1864-2000
	Masterton	40.97 S	175.65 E	1884-2000	1906-2000
	Mangere, Auckland	36.97 S	174.78 E	1853-2000	1853-2000
	Chatham Is.	43.95 S	176.57 E	1878-2000	1878-2000
	Raoul Is.	29.25 S	177.92 E	1937-2000	1940-2000
Papua New Guinea	Port Moresby	9.60 S	147.21 E	1950–1999	1950-1999
	Madang	5.21 S	145.78 E	1972 –1998	1950 –1999
Samoa	Apia	13.80 S	171.77 W	1902–1998	1902–1998
Solomon Islands	Taro Island	6.70 S	156.40 E	1975–2000	1975–2000
	Munda	8.33 S	157.26 E	1962–2000	1962–2000
	Honiara	9.41 S	159.97 E	1951–2000	1951–2000
	Henderson	9.42 S	160.05 E	1974–2000	1974–2000
	Auki	8.14 S	160.73 E	1962–2000	1962–2000
	Kira Kira	10.42 S	161.92 E	1965–2000	1965–2000
	Lata	10.70 S	165.80 E	1970–2000	1970–2000
Tonga	Nuku’alofa	21 08.2S	175 11.5W	1945-2000	1949-2000
	Lupepau’u	18 35 16S	173 58.8W	1947-2000	1950-2000
	Keppel	15 57.2S	173 45.6W	1949-2000	1947-2000
Country	Station	Latitude	Longitude	Rainfall	Temperature
Tuvalu	Funafuti	8 31’S	179 12’E	1933-1998	1927-2000
	Nanumea	5 40’S	176 7’E	1941-1996	1941-1999
	Nui	7 15’S	177 9’E	1947-1995	1941-1996
	Niulakita	10 47’S	179 28’E	1957-1995	1941-1996

Vanuatu	Aneityum	20 14’S	169 47’E	1948-2000	1948-2000
	Lamap	16 25	167 48’E	1961-2000	1961-2000

APPENDIX 5. CD ROM CONTENTS

1. APN workshop scientific presentations
2. Monthly climate data
3. Monthly Data Analyzer Software and Manual
4. Regional Sea Surface Temperature Data
5. Draft paper

APPENDIX 6 DRAFT PAPER

Trends and variability in temperature and rainfall in Oceania: 19XX–2000

Salinger, M.J. [1], Akapo, A. [2], Burgess, S.M. [3], Busse, M. [4], Della-Marta. P. [5],
Finaulahi, S. [6], Gosai, A. [7], Griffiths, G. [1], Haylock, M.R.[5], Kameata, J. [8],
Laurent, V. [9], Lefale, P. [1], Maitrepierre, L. [10], Mullan, A.B. [3], Nalawas, M. [11],
Petersen, J. [1], Rauraa, N.[12], Renwick, J.A. [3], Solofa, D. [13],
Tahani, L. [14], Taiki, H. [15], Teitiba, T. [16], Trewin, B. [5], Tualevao, N. [13], Vavae, H. [17]

To be submitted to International Journal of Climatology

Contact: Dr Jim Salinger
NIWA
P O Nox 109 695, Newmarket
Auckland
New Zealand
email: j.salinger@niwa.com

1 National Institute for Water and Atmospheric Research (NIWA), Auckland, New Zealand
2 National Atmospheric and Aeronautic Administration (NOAA), American Samoa
3 National Institute for Water and Atmospheric Research (NIWA), Wellington, New Zealand
4 University of Auckland, Auckland, New Zealand
5 Bureau of Meteorology, Melbourne, Australia
6 Tonga Meteorological Service, Tonga
7 Fiji Meteorological Service, Nadi, Fiji
8 National Weather Service, Papua New Guinea
9 Météo–France, Papeete, French Polynesia
10 Météo–France, Noumea, New Caledonia
11 Vanuatu Meteorological Service, Port Vila, Vanuatu
12 Cook Islands Meteorological Service, Rarotonga, Cook Islands
13 Samoa Meteorological Service, Apia, Samoa
14 Solomon Islands Meteorological Service, Solomon Islands
15 World Meteorological Organisation Subregional Office, Apia, Samoa
16 Kiribati Meteorological Service, Tarawa, Kiribati
17 Tuvalu Meteorological Service, Funafuti, Tuvalu

Abstract

Trends and variability in annual and seasonal surface air temperature and rainfall have been analysed from the commencement of observations to 2000 for Oceania (Australia, New Zealand and the South Pacific islands). Observations from the 20th century were chosen to highlight significant decadal to century scale variability in this large region. The results are derived from high quality, long-term climate data. Using records from 78 stations in 15 countries, significant increases in annual temperatures were detected over the entire region. Annual maximum temperatures showed a different pattern of temperature increase to minimum temperatures, with concomitant changes in the diurnal temperature range. Trends in rainfall trends generally showed increases in the south Pacific to the north-east of the South Pacific Convergence Zone (SPCZ), whilst decreases occurred to the southwest of the SPCZ. Interannual variability in temperature and rainfall is very much driven by the Southern Oscillation (SO) throughout Oceania, with decadal trends by the Interdecadal Pacific Oscillation(IPO). The seasonal response to SO and IPO varies throughout the region. The Oceania region is one that demonstrates the interaction between the century scale trend of global warming, decadal shifts of the IPO and interannual variability of the SO.

1 Introduction

Oceania occupies a large portion of the Pacific Basin, and climate and ocean/atmosphere interactions of global significance occur here on annual, decadal and centennial time-scales. These include the El Niño-Southern Oscillation (ENSO), and the Interdecadal Pacific Oscillation (IPO), an ENSO-like variation which modulate climate on time scales of two to three decades, which cause significant climate change in parts of Oceania and beyond.

Global mean surface temperatures have increased by 0.6°C during the 19th century, with the ten globally averaged warmest years all occurring since 1983 (IPCC., 2001). The 1990s was the warmest decade, and 1998 the single warmest year on record. New analyses of proxy data for the Northern Hemisphere indicate that the increase in temperature in the 20th century is likely to have been the largest of any century during the past 1000 years. Temperatures have risen during the past four decades in the lowest 8 kilometres of the atmosphere. Snow cover has decreased, and global average sea level has risen and ocean heat content increased.

Observed trends and variability in climate and sea level for Oceania (Australia, New Zealand and the South Pacific) derived from high quality, long-term climate data found that annual surface air temperatures increased between 0.4-0.8°C throughout most of the region in the period 1951-1993 (Salinger, et al., 1996). Precipitation showed increases in the South Pacific to the northeast of the South Pacific Convergence Zone (SPCZ), whilst decreases occurred to the southwest of the SPCZ.

Beyond the long-term trends in climate, interannual climate variability over the Pacific is dominated by the El Niño/Southern Oscillation (ENSO) phenomenon (Salinger et al., 1995). This has the strongest sea surface temperature (SST) signals of one sign along the equator over the central and eastern Pacific and a boomerang-shaped pattern of weaker SST signals of opposite sign extending over the middle latitudes of both hemispheres in the North and South Pacific. Interannual variability in the Pacific is dominated by ENSO, which is driven out of the Pacific Basin. It has the strongest SST signals of one sign along the equator over the central and eastern Pacific and a boomerang-shaped pattern of weaker SST signals of opposite sign extending over the middle latitudes of both hemispheres in the North and South Pacific. At the same time there is an exchange of atmospheric mass between the western and eastern equatorial Pacific, with mean sea level pressure anomalies of one sign over the Indo-Australian region, and of the opposite sign over the central and eastern tropical Pacific.

Recently shifts in climate have been detected in the Pacific basin, driven by a newly described feature of the atmospheric feature, the Interdecadal Pacific Oscillation (IPO), which modulates climate on time scales of one to three decades (Power et al. 1999). The IPO causes significant shifts in climate which result in changes in average climate. Folland and Salinger (1995) described temperature variability in the New Zealand region and its surrounds, a prominent mode of which has a time scale of about 13-18 years and Folland et al (1997) extended the analysis to the south Pacific. The evidence indicates that the decadal variations have origins in both the Pacific and the Southern Oceans (Folland et al.,1999; Mantua et al.,1997; Salinger et al., 2001).

The recently described IPO is a major source of climate variability in the south Pacific. The IPO, a coupled atmosphere/ocean process operates on time scales of several decades. In the positive phase sea level pressure (SLP) is lower in north Pacific, and east Pacific, and higher in the south west Pacific. This is coupled with a trend of cooler than normal SSTs in the north Pacific, and the south west Pacific centred on the Cook Islands, and warmer than normal SSTs in the tropical south east Pacific. More southerly airflow is prevalent in the south west Pacific, and south westerly flow over the New Zealand area. In the negative phase the described anomalies are reversed. Climate shifts occur in the south Pacific when the IPO changes its phase.

In 2000, the Asia Pacific Network for Global Change funded a workshop on climate trends and variability in Oceania, hosted by the National Institute of Water and Atmospheric Research. A major aim of this workshop was to encourage regional participation in the global studies to monitor and detect trends and variability in climate (Salinger et al. 2000). The meeting included representatives from 12 countries: Australia, Cook Islands, Fiji, French Polynesia, New Caledonia, New Zealand, Niue, Papua New Guinea, Samoa, Tonga, Tuvalu and Vanuatu. A significant outcome of the workshop was the desire of all participants to contribute to an analysis of country and regional trends and variability in observed climate towards future global assessments on climate change. It was intended that this analysis should be consistent across the region, simple to calculate and relevant across the region.

This led to a second workshop in November 2001, attended by representatives from the same 12 countries plus American Samoa, Kiribati and the Solomon Islands. At this workshop, trends and variability in temperature and rainfall were analysed by applying common quality control and analysis techniques across the region. While other variables could have been considered, temperature and rainfall were judged in the 2000 workshop as being the variables with the longest and most reliable records, and the most relevant for comparison with other international studies. This paper reviews longer-term climate trends in Oceania, then identifies interannual and decadal patterns of climate variation throughout the region responsible for fluctuations on annual to decade time scales. Quality control and analysis techniques are described in the next section, followed by trend results in section 3, and a discussion of the results in section 4.

2 Data analysis methods

Climate station selection

Representatives from the national weather service of each country participating in the workshop provided monthly rainfall and maximum and minimum temperature data for a small number of stations in their country. The stations satisfied the following criteria:

- The records were as long as possible, and included the standard reference period of 1961–1990
- Less than 3 of the monthly values were missing in each year
- The stations were of high–quality, preferably non–urban and well maintained
- The station, in most cases, had a documented history of changes such as those involving instrumentation, observation practices and the station’s immediate environment (metadata)
- In most cases the station had been located at a single site during the period of record.

Whilst participants were free to choose the stations that they felt best met these criteria, obvious candidates were those stations already selected for inclusion in the country's Reference Climate Station (RCS) network or the Global Climate Observing System (GCOS) Surface Network (GSN) (Peterson et al. 1997). The primary purpose of such stations is to identify long–term climate trends and consequently these stations will have been chosen for having long, continuous and homogeneous records; for having minimal influence from urbanisation; and for generally being high–quality stations.

Quality control

Inhomogeneities or discontinuities in a climate record can be caused by any change to the station or its operation, including site location, exposure, instrumentation or observational practice. These discontinuities will not only affect mean climatic values but also the extremes of the climatic distribution. Numerous studies have used procedures such as visual examination of data, neighbouring station checks and statistical tests to identify and adjust for inhomogeneities in seasonal or annual mean temperature and total rainfall (eg. Rhoades and Salinger, 1993; Torok and Nicholls 1996; Lavery et al. 1992, 1997; Peterson et al., 1998).

The monthly and annual time series from each station were first examined visually to identify any obvious outliers, trends and potential discontinuities. Annual mean series (annual total for rainfall) were then produced from the monthly rainfall and maximum and minimum temperature time–series and examined for discontinuities using a software package known as Monthly Data Analyser (MDA) (Gleason and Petersen, 2001). The MDA performs routine quality control procedures, then homogeniety testing through visual inspection of the time series and statistical test of the difference between two adjacent period mean values. Potential break points were identified using MDAand compared with available metadata.

If no major discontinuities were detected for a station then it was accepted for analysis. If a discontinuity could be related to some change suggested by the station metadata then the station was rejected. If a discontinuity could not be related to metadata, it was assumed that the climatic shift was real. The results presented here are derived from the most homogeneous data identified at the workshop.

Based on the homogeneity testing and quality control, data for a set of XX high–quality stations (Appendix 1) were prepared for analysis. Most of these have data for the period 1961–1998, so that was the period examined for trends in extremes. A small proportion of stations did not have data for the complete period (see Appendix 1). These are the best possible data series for us. However, many of the stations are on isolated Pacific islands which do not permit neighbour station or other forms of homogeniety testing. Therefore other unidentified inhomogeneities could exist in these data.

Analysis methods

Time series analysis and correlation analysis between SOI and IPO were analysed using the MDA.

3 Annual and seasonal rainfall and temperature trends

Regional patterns of trends

Before describing the direction and magnitude of trends at each station for each country, an overview of the geographical pattern of trends is given. This provides a clear picture of the spatial variation in the direction of trends and their statistical significance for Oceania. The regression coefficient was used to test significance of the trends. All trends noted as significant were significant at the 95% level.

Rainfall

Annual total rainfall in the region has generally decreased (not shown). This decrease is associated with the predominance of El Niño events since the mid–1970s (Trenberth and Hoar, 1997). Total rainfall has increased significantly in etc etc (Figure 1).

Trends in seasonal rainfall were etc etc (Figure 2) (Figure 3) (Figure 4).

Temperature

Trends in mean annual surface temperature show a general increase over the region (Figure 5). However, there is a differential rate of temperature rise between annual maximum (Figure 6) and minimum (Figure 7) temperatures, leading to a change in the diurnal temperature range (figure 8). Table Y enumerates the rates of temperature increase.

Seasonal, mean, maximum and minimum surface air temperatures…….(Figure 10)

Trends for each country

The maps and charts presented above summarise some interesting trends across the region. In this section, we briefly discuss the changes that have occurred in each country.

Australia

Over the 1950-2000 period almost all the Australian stations studied experienced a warming trend, with the trend exceeding 0.01°C/year at 20 of 28 stations studied. The trend was somewhat stronger for minimum temperatures than for maxima, and was at its weakest north of 20°S. Over the shorter periods 1951-75 and 1976-2000 results were more mixed, although most stations experienced warming in both periods. Some stations in central and north-western Australia experienced cooling in 1951-75 and very strong warming (0.04-0.06°C/year) in 1976-2000, principally as a result of a succession of very cool years in the mid-1970's.

A decrease in rainfall was observed over the 1950-2000 period over areas of south-western and south-eastern Australia. Over much of the rest of the country rainfall increased, with particularly strong increases at a number of tropical stations. Many of these stations observed particularly rapid increases in rainfall (over 10 mm/year) in the post-1975 period. Most south-eastern stations showed a decreasing trend in rainfall between 1951 and 1975, with mixed trends since 1975. Over the full period of record, most stations showed increases in rainfall, the exceptions being the stations in south-eastern Australia, and Norfolk and Lord Howe Islands.

Cook Islands

Rarotonga in the Southern Cooks shows a slight warming for the 1950-2000 period and below average rainfall. Penrhyn in the Northern Cooks shows a slight cooling with above average rainfall during this period.

Fiji

Seven stations were analysed for climate trends in Fiji. These stations represented various climatological regimes of the country. These were Nadi, Rarawai, Suva, Rotuma, Ono-I-Lau, Labasa and Savusavu, which stretches from north to south and east to west.

From the beginning of the record till 2000, temperature trend for all sites is increasing with rainfall increasing in Rotuma, Ono-I-Lau, Savusavu, Rarawai and Suva, while decreasing rainfall trend in Nadi and Labasa.

There is increasing temperature trends during the period 1976 to 2000 for all sites. Except for Suva, Ono-I-Lau and Savusavu, all sites show increasing rainfall trend. The positive rainfall trends are significant.

For the period 1950 till 1975, there is no clear trend for temperature and rainfall for the country as some sites have increasing trend and some have decreasing trend.

Overall, there seems to be increasing temperature trends for the country, while variability in trends for rainfall. Rainfall is a variable element especially in the tropical regions, which is driven by other factors like SPCZ and ENSO. Therefore, there will be more inter-annual variability in rainfall while temperatures show clearer trend for Fiji.

French Polynesia

In Atuona, in the Marquesas Islands and in Hereheretue, in the Tuamotu Islands, there has been a significant increase in total rainfall. Monthly total rainfall increased clearly after 1976. Elsewhere in French Polynesia, no monthly rainfall trends were significant.

Monthly mean temperature in French Polynesia has generally increased. In Rapa and in Tubuai, in the Australes Islands extreme monthly temperature trends were not significant.

Kiribati

In the long term there is an increase in the amount of rainfall that has fallen during the period of record. There is a slight warming of the temperatures but at the same time abnormal minimum temperatures have occurred in the long term.

However, over the shorter time scales during the periods 1950-1975 a general cooling of temperatures and decline in rainfall occurred. As the small islands are surrounded by a vast cool ocean during the period the predominant onshore easterlies have significantly affected the climate .

During the last 15 years (1976-2000) warming followed with a very dramatic decline in the amount of rainfall that had fallen.

New Caledonia

There is no significant trend in New Caledonia for rainfall witch are well ENSO related (dry in El Nino, wet in La Nina). For the period 1950-2000 there is a significant warming (+0.7°C to +0.9°C) particularly for the 1976-2000 period. 1976 is the start of this strong warming (+0.3°C or more per decade). It is difficult to distinguish if the minimum temperatures are rising faster than the maximum temperature as one out of the 3 stations show the opposite pattern.

New Zealand

Trends are generally statistically insignificant at New Zealand stations because of large ENSO-related interannual variability. Nevertheless, there is a fairly coherent pattern in the trends. Over 1950-2000, Tmin displays the largest temperature trends of generally near 0.010ºC/year. The Tmax trend is smaller, although still positive at all stations except Lincoln and Dunedin. The largest rainfall trends over 1950-2000 are Hokitika (positive) and Lincoln, Masterton and Raoul (all negative).

Niue

Overall there is no large trend in any variable at Niue for the long-term record (1930-2000). In the second half of the century (1950-2000) all temperatures experienced small-scale increases while rainfall shows a small decrease. Between 1950-1975 temperatures trend cooler with an associated large decrease in rainfall. The latter period 1976-2000 returns to warming temperatures with a high increase in rainfall (14mm/yr).

Papua New Guinea

For the long term period there is a slight warming in the mean temperature and the minimum temperature. The amount of warming increases from the long term to the last twenty five years. On the other hand there is a slight cooling in the maximum temperature. The cooling amount in the maximum temperature does not seem to have any pattern between the long term and the last twenty five years. There is also decreasing trend in the rainfall for the stated periods. The amount of rainfall decrease increases from the long term to the last twenty five years.

Samoa

Trends observed for temperatures for the analysed periods show an overall slight warming. There is also a noticeable increases in both maximum and minimum temperature extremes. Overall trend for rainfall show a significant decrease in annual amounts

For the period 1950 – 1975 mean, maximum and minimum temperatures shows almost a neutral trend relative to the long term trend. Rainfall trend shows a significant increase in annual amounts. For the1976 - 2000 period mean temperatures show a a relatively sharp increase relative to the long term value, with maximum temperatures showing a relatively neutral trend and minimum temperatures a strong increase during this period. Rainfall shows a decrease for this period

Solomon Islands

Overall, there is a significant negative trend in Solomon Islands for rainfall for the long-term record (1962-2000). In decadal analysis there is no obvious change in the trend. Kirakira station is very obvious while Honiara is the least obvious in the rainfall trend.

Unlike the rainfall trend there is a general increase in temperature in Solomon Islands for the long-term period (1962-2000). It is also obvious in the decadal analysis. The mean temperature analysis shows that the trend is steadily increasing.

Tonga

The trend shows that there is a decrease in rainfall throughout the Tonga group, from Northern to Southern part of the group. Also the temperature trend shows that it is warming.

For the period 1976 2000, rainfall increased in Southern and Northern Tonga with an increase in temperature while in central parts of the group experienced decrease in rainfall.

Tuvalu

Three stations were analysed for climate trends in Tuvalu. From the beginning of the record until the end, temperature and rainfall both increase in Nanumea and Niulakita, and both show a slight decrease for Funafuti.

There is increasing temperature trend during the period 1976 to 2000 for all sites. Except for Funafuti, the other two sites show decreasing rainfall trends. Positive rainfall trends occur for Funafuti.

For the period 1950 till 1975, Nanumea and Niulakita temperature increases and rainfall decreases, with opposite trends for Funafuti.

Vanuatu

Overall view analyses indicates that there is a slight trend. There is an increase in temperature and decrease in rainfall. Analyses was done using two climate stations namely Lamap representing the central north and Aneityum representing the southern part of the country.

4 Annual and seasonal rainfall and temperature variability

For the IPO, between the most recent negative and positive phases little warming is seen in western parts of Kiribati and Banaba, where southerly airflow changes are greatest, and temperature increases are in excess of 0.6 °C in northern French Polynesia, where airflow changes are smallest. Annual rainfall increases by 50 percent or more in the north east of the south west Pacific region, whilst small decreases (~5 percent) occur in New Caledonia, Vanuatu, much of Fiji, Tonga, Nuie and in the southern Cooks. The IPO also alters teleconnections with the SOI. The climate shifts in the south Pacific caused by the IPO operate on a background of global warming. FOR REVISION

Major climatic anomalies occur both globally and regionally during El Niño and La Niña events. In the tropical South Pacific the southwest Pacific becomes drier, whilst the central and eastern Pacific wetter. La Niña events tend to bring opposite climate anomalies in the Pacific and some regions of the globe. FOR REVISION

IPO and ENSO climate impacts for each country

The maps and charts presented above summarise the variability associated with the IPO and ENSO across the region. In this section, we briefly discuss the interannual to decadal changes that occur in each country.

Australia

In Australia, at the annual timescale the SOI generally shows a positive correlation with precipitation. These correlations are generally quite weak, reaching 0.3 only in parts of eastern Australia. They are strongest during the negative IPO phase (1946-76), widely reaching 0.4, and are weak and of mixed signs during the positive IPO phase from 1977-98, except in the south-east and on Australia's Pacific Ocean islands.

Over the record as a whole, correlations between annual SOI and annual mean temperatures are generally quite weak in mainland Australia, with negative correlations observed in parts of the inland. Strong positive correlations occur at Norfolk and Willis Islands. Both IPO sub-phases show widespread positive correlations between temperature and the SOI. Northern Australia shows widespread positive correlations during the positive IPO phase, and parts of the south during the negative IPO phase, but only in isolated cases do these correlations exceed 0.3.

Cook Islands

A moderate correlation with the Rarotonga data with the exception of a weak one during the late period. Penrhyn on the other hand had a stronger correlation with odd one during the start of the late period.

Fiji

Apart from Rotuma, all correlations between the SOI and temperature and rainfall are positive. For Rotuma annual correlations are negative with both temperature and rainfall. In the positive phase of the IPO rainfall is generally lower, except at Rotuma. Strong correlations exist between temperature at Rotuma (negative) to the north and Ono-I-Lau (positive) to the south with the IPO.

French Polynesia

Temperature variability in Atuona, in northern French Polynesia shows a strong correlation between mean annual temperature and variations ENSO and IPO. This correlation becomes weak in centre French Polynesia and no exits in southern French Polynesia. The correlation between SOI and temperature varies between -0.76 in Marquesas Islands and +0.25 in Rikitea, in southeastern French Polynesia. There is a see-saw between north Polynesia and south Polynesia.

Between the IPO and temperature the correlation coefficient is between +0.81 and +0.25 for the entire period but higher for the 1977-1998 period.

For rainfall, the correlation coefficient between total annual rainfall and variations ENSO and IPO is weak. There is a very low correlation in southern French Polynesia. Between SOI and rainfall: the correlation coefficient varies between 0.15 and -0.4 for the entire period but higher for the 1977-1998 period above all in Faa'a. For IPO and rainfall: consistently the correlation coefficient is between +0.57 in Atuona and +0.18 in Hereheretue. There is a negative correlation coefficient in Takaroa , located between Marquesas Islands and Tahiti, with –0.40.

Kiribati

Two stations, Tarawa and Butaritari according to the above tables generally indicate the very strong relationship in rainfalls with the SOI .Butaritari Island further north and closer to the ITCZ and wetter than Tarawa is even affected during EL NINO by recording comparatively very high rainfall amounts exceeding the monthly normals.

Generally during EL NINO years all islands in Kiribati experience very wet conditions ,intensified and prolonged rainfalls . Rainfall records dated back to the 1940s provide reliable information for further rainfall studies .

New Caledonia

Relation between SOI and Rainfall : the correlation coefficient is between 0.4 and 0.6 for the entire period but higher for the 1977-1998 period with $0.4<r<0.7$, except for the North West of the country were Koumac and Gomen got it inversed.

Relation between IPO and Rainfall : consistently the correlation coefficient is negative and from –0.3 to –0.3 for the entire period but lower for the 1977-1998 period with $0.4<r<0.6$, except for the East part of the country and Loyalty Island were Touho, Ponerihouen, Yate and Chepenehe got it inversed.

Relation between SOI and Temperature: the correlation coefficient is between 0.25 and 0.4 for the entire period but seems higher for the negative phase of IPO (from beginning of the data (1951 to 1961) to 1976) with values going up to 0.58.

Relation between IPO and Temperature: the correlation coefficient is quite small (<0.1) for the entire period but shift to higher and negative values for the negative phase of IPO (from beginning of the data (1951 to 1961) to 1976) with values going up to –0.45. For the positive phase of the IPO, correlation coefficients are back to very small values.

New Zealand

In New Zealand, at the annual timescale the SOI generally shows a positive correlation with temperature. These correlations range from 0.1 to 0.7, and are stronger during the negative IPO phase. For precipitation there is a northeast southwest gradient ranging from positive values in the northeast to negative values in the southwest. The gradient is stronger during the positive phase of the IPO.

Niue

Overall, there is a positive relationship between P and SOI values across all time periods, with moderately strong correlation demonstrated. The relationship between P and IPO is similar (showing a negative relationship). Incidentally, the period between 1946-76 shows the least strong correlation between P and SOI and IPO.

Regarding the relationship between mean T and SOI a strong negative correlation is shown (e.g. –7293 between 1930-2000). The relationship between mean T and IPO is weak positive correlation. Lastly, during the period 1977-98 the weakest correlation coefficients are shown between SOI and IPO (e.g. –0.2474 and 0.2531 respectively).

Papua New Guinea

For the long term record the precipitation is positively correlated with the SOI and negatively correlated with IPO. Mean temperature for the station of Port Moresby is negatively correlated with SOI and visversa for IPO. For the long term IPO is correlated positively with mean temperature.

During the negative phase of IPO, there is a positive correlation of precipitation with SOI at Port Moresby and also the same with mean temperature in Madang. The mean temperature in Port Moresby is negatively correlated with the SOI .

On the other hand during the positive phase of IPO, there is positive correlation of precipitation both in Port Moresby and Madang. Also the mean temperature in Madang is positively correlated with SOI. The only negative correlation during the positive phase of IPO is with the mean temperature in Port Moresby.

Samoa

Precipitation shows a strong negative correlation with SOI while a strong positive correlation with IPO occurs across all time periods. Mean temperature has the inverse correlation relationship for both SOI and IPO across the same period.

During the negative IPO Phase (1946-1976) precipitation shows strong negative correlation with SOI while a strong positive correlation occurs with IPO. Mean temperature for this negative phase has moderate positive correlation with the SOI while a negative correlation exists with the IPO

During the positive IPO Phase (1977-1998) the negative and positive correlation for precipitation and mean temperature continues though both are reduced particularly mean temperature values with SOI and IPO.

Solomon Islands

Rainfall and SOI trend is positive for Auki, Kirakira, Honiara and negative for Munda. The correlation between rainfall and SOI is stronger for Honiara and Kirakira compared to Auki and Munda.

Rainfall and IPO trend is negative for Auki, Kirakira, Honiara and zero trend for Munda. The correlation between rainfall and IPO is stronger for Honiara and Kirakira compared to Auki and Munda.

Mean Temperature and SOI trend is positive for Auki, negative for Kirakira and Honiara and zero trend for Munda. The correlation between Mean Temperature and SOI is weak for Munda and Auki compared to Kirakira and Honiara.

Mean Temperature and IPO is positive trend at all stations with very strong correlation.

Tonga

Out of the relationship between rainfall with the SOI and IPO there is correlation between SOI and rainfall as the SOI is positive and increasing with rainfall. There is a very weak correlation between the IPO and rainfall as shown by the negative slope. With temperature there is correlation between SOI and temperature but this varies. In the Northern most part of the group the SOI was found to be negative in Keppel while the IPO value was found to be positive. Lupepau'u and Keppel have a +ve correlation with the IPO value.

Tuvalu

Negative correlations exist between Funafuit annual rainfall and tempature with the SOI, and positive relationships between rainfall and temperature with the IPO.

Vanuatu

The brief findings of the two stations resulted in that there is a strong correlation between the rainfall and SOI. When the rainfall / IPO is negative there is slight negative trend. When there is a positive or negative SOI/IPO with temperature there is no correlation.

5 Discussion

Acknowledgements
The Asia-Pacific Network for Global Change Research (APN) generously funded the two workshops that led to the production of this paper. The National Institute of Water and Atmospheric Research (NIWA), Auckland, New Zealand, hosted both workshops. Byron Gleason developed the monthly data analyzer. The research was funded under New Zealand Foundation for Research Contract No. C01X0030.

References

Folland, C. K., D. E. Parker, A.W. Colman, and R.Washington, 1999. 'Large scale modes of ocean surface temperature since the late nineteenth century'. In*: Beyond El Niño: Decadal and Interdecadal Climate Variability*, pp. 73-102. A. Navarra, Ed. Springer-Verlag, Berlin, 374 p.

Folland, C.K. and Salinger, M.J. 1995. 'Surface temperature trends in New Zealand and the surrounding ocean, 1871 – 1993', *Int. J. Climatol.*, **15**, 1195 - 1218.

Folland, C. K., Salinger, M. J. and Rayner, N. 1997. 'A comparison of annual South Pacific island and ocean surface temperatures'. *Weather and Climate*, **17(1),** 23-42.

Gleason, B., Petersen, J. 2001. Monthly Data Analyser 1.03 – Users Guide.

IPCC, 2001: *Climate Change 2001. The scientific basis*. Eds. J. T. Houghton, Y. Ding, D. Griggs, M. Noguer, P. Van der Linden, X. Dai, K. Maskell, C.A. Johnson. Cambridge Univ. Press. Cambridge, U.K., 2001.

Lavery, B., Kariko, A. and Nicholls, N. 1992. 'A historical rainfall data set for Australia'. *Aust. Met. Mag.*, **40**, 33–39.

Lavery, B., Joung, G. and Nicholls, N. 1997. 'An extended high–quality historical rainfall dataset for Australia'. *Aust. Met. Mag.*, **46**, 27–38.

Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and Francis, R.C. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. *Bull. Amer. Meteor. Soc.,* **78,** 1069-1079.

Nicholls, N. 1995. 'Long–term climate monitoring and extreme events'. *Climatic Change*, **31**, 231-245.

Power, S., T. Casey, C. Folland, A. Colman, and Mehta, V. 1999. 'Inter-decadal modulation of the impact of ENSO on Australia'. *Climate Dynamics*, **15,** 319-324.

Rhoades, D.A. and M.J. Salinger, 1993. 'Adjustment of temperature and rainfall records for site changes'. *Int. J. Climatol.*, **13**, 899 - 913.

Nicholls, N., and Kariko, A., 1993. 'East Australian rainfall events: Interannual variations, trends, and relationships with the Southern Oscillation'. *J. Climate*, **6**, 1141-1152.

Petersen, T.C., Harald, D. and Jones, P. 1997. 'Initial selection of a GCOS surface network'. *Bull. Am. Met. Soc.,* **78,** 2145-2152.

Peterson, T.C., Easterling, D.R., Karl, T.R., Grosiman, P., Nicholls, N., Plummer, N., Torok, S., Auer, I., Boehm, R., Gullett, D., Vincent, L., Heino, R., Tuomenvirta, H., Mestre, O., Szentimrey, T., Salinger, J., Førland, E., Hanssen–Bauer, I., Alexandersson, H., Jones, P., and Parker, D. 1998. 'Homogeneity adjustments of in situ atmospheric climate data: A review'. *Int. J. Climatol.*, **18**, 1493–1517.

Salinger, M.J., Allan, R., Bindoff, N., Hannah, J., Lavery, B., Lin, Z., Lindesay, J., Nicholls, N., Plummer, N., and Torok, S. 1996. ‘Observed variability and change in climate and sea level in Australia, New Zealand and the South Pacific’, In: *“Greenhouse: Coping with Climate Change”* Eds: G.I. Pearman and M. Manning. CSIRO Publishing, Melbourne, p.100-126.

Salinger, M.J., Renwick, J.R, and Mullan, A.B. 2002. ‘Interdecadal Pacific Oscillation and South Pacific Climate’, *Int. J. Climatol*. (in press).

Salinger, M.J., Fitzharris, B.B., Hay, J.E., Jones, P.D., MacVeigh, J.P. and Schmidely-Leleu, I. 1995. ‘Climate trends in the South-West Pacific’, *Int. J. Climatol.*, **15**, 285-302.

Szentimrey, T. 1996. ‘Statistical procedure for joint homogenization of climatic time series’. *Proceedings of the Seminar for Homogenization of Surface Climatological Data*, Budapest, Hungary, pp. 47–62.

Torok, S.J. and Nicholls, N. 1996. ‘A historical annual temperature dataset for Australia’. *Aust. Met. Mag*., **45**, 251–260.

Trenberth, K.E., and Hoar, T.J. 1997. ‘El Niño and climate change’. *Geophys. Res. Letts.*, **24**, 3057-3060.

Figures proposed

Figure 1. Map of the Oceania region showing all station locations used (dots) and place names referred to in the text. The heavy dashed line indicates the approximate mean position of the South Pacific Convergence Zone.

Figure 2. Trends in annual rainfall. The diameter of the circle indicates the rate of change per decade, open circles represented increases and closed circles decreases. Sites with significant trends (95%) are underlined. Data from 19XX–2000.

Figure 3. Trends in (a) DJF and (b) MAM rainfall. As for Figure 2.

Figure 4. Trends in (a) JJA and (b) SON rainfall. As for Figure 2. in the percentage of annual total rainfall from the 4 highest events (*extreme proportion*). The sign of the linear trend is indicated by +/– symbols at each site; bold indicates significant trends (95%). Data from 1961–1998.

Figure 5. Trends in annual surface mean air temperature. The diameter of the circle indicates the rate of change per decade, open circles represented increases and closed circles decreases. Sites with significant trends (95%) are underlined. Data from 19XX–2000.

Figure 6. Trends in annual surface maximum air temperature. The diameter of the circle indicates the rate of change per decade, open circles represented increases and closed circles decreases. Sites with significant trends (95%) are underlined. Data from 19XX–2000.

Figure 7. Trends in annual surface minimum air temperature. The diameter of the circle indicates the rate of change per decade, open circles represented increases and closed circles decreases. Sites with significant trends (95%) are underlined. Data from 19XX–2000.

Figure 8. Trends in annual diurnal temperature range. The diameter of the circle indicates the rate of change per decade, open circles represented increases and closed circles decreases. Sites with significant trends (95%) are underlined. Data from 19XX–2000.

Figure 9. Trends in seasonal surface mean air temperature. The diameter of the circle indicates the rate of change per decade, open circles represented increases and closed circles decreases. Sites with significant trends (95%) are underlined. Data from 19XX–2000.

Figure 10. Annual and seasonal correlations between the Southern Oscillation Index and temperature.

Figure 11. Annual and seasonal correlations between the Southern Oscillation Index and rainfall.

Figure 12. Annual and seasonal correlations between the Interdecadal Pacific Oscillation and temperature.

Figure 13. Annual and seasonal correlations between the Interdecadal Pacific Oscillation and rainfall.

Table 1: Climate Trends 1950 – 2000

Country	Station	TMEAN	TMAX	TMIN	Rainfall
Australia	Willis Island	+0.001	-0.005	+0.005	+3.16
	Darwin Airport	+0.007	+0.007	+0.007	+9.26
	Weipa	-0.002	+0.001	-0.002	+6.17
	Tennant Creek	+0.007	+0.004	+0.011	+3.26
	Burketown	Too many	Missing	years	+2.73
	Cairns	+0.015	+0.003	+0.025	+3.50
	Carnarvon	+0.014	+0.009	+0.019	+0.02
	Port Hedland	+0.013	+0.008	+0.020	+0.62
	Alice Springs	+0.017	+0.023	+0.014	+2.09
	Giles	+0.002	+0.012	+0.001	+3.20
	Marree	+0.020	+0.010	+0.027	+0.49
	Tibooburra	+0.019	+0.017	+0.023	+0.96
	Charleville	+0.025	+0.012	+0.038	-0.69
	Yamba	+0.014	+0.014	+0.013	-1.47
	Cape Leeuwin	+0.008	+0.001	+0.013	-1.22
	Cunderdin	+0.011	+0.022	+0.010	-0.23
	Kalgoorlie	+0.017	+0.008	+0.029	+1.29
	Ceduna	+0.018	+0.010	+0.023	-1.59
	Mildura	+0.011	+0.004	+0.018	-0.18
	Mount Gambier	+0.023	+0.016	+0.028	-0.48
	Deniliquin	+0.006	+0.006	+0.010	-1.35
	East Sale	+0.014	+0.030	-0.001	-2.06
	Moruya Heads	+0.004	+0.003	+0.005	-2.58
	Cape Bruny	+0.013	+0.009	+0.018	+0.79
	Forrest	+0.017	+0.014	+0.014	+1.48
	Lord Howe Island	+0.010	+0.006	+0.017	-1.24
	Norfolk Island	+0.010	+0.006	+0.013	-4.32
	Macquarie Island	+0.014	+0.015	+0.013	+3.46
	Kalumburu	+0.019	+0.006	+0.033	+3.95
Cook Islands	Rarotonga J84300	+0.0203	+0.0121	+0.0268	-5.7002
	Penrhyn J80000	+0.0121	+0.0098	+0.0082	+38.586
Fiji	Nadi	+0.006	+0.007	+0.004	+1.068
	Suva	+0.021	+0.025	+0.016	-5.33
	Rarawai	+0.004	-0.003	+0.005	-0.503
	Labasa	+0.0141	+0.011	+0.022	+3.221
	Rotuma	+0.011	+0.006	+0.014	-1.582
	Ono-I-lau	+0.011	+0.013	+0.008	-8.863
	Savusavu	+0.013	+0.020	-0.0012	-2.96
French Polynesia	Atuona	+0.020849	+0.0214	+0.0201	+25.5054
	Rapa	+0.0113	+0.0001	+0.0211	-6.397
	Faaa	+0.0348	+0.0350	+0.0345	-0.9618
	Hereheretue	+0.0090	-0.0051	+0.0231	+11.8540
	Takaroa	+0.0279	+0.0349	+0.0193	+1.4116
	Tubuai	+0.0184	+0.0094	+0.0274	+1.0986
	Rikitea	+0.0351	+0.0143	+0.0529	-2.7571
Kiribati	Tarawa	+0.0002	+0.0025	-0.0018	+5.2855

New Caledonia	Noumea	+0.01297	+0.02257	+0.00914	-1.268
	Koumac	+0.01911	+0.01487	+0.02339	-1.150
	Ouanaham (1960-)	+0.02144	+0.01172	+0.03094	
	Gomen				-5.652
	Tontouta				-5.309
	Paita				-2.643
	Touho				+3.745
	Ponerihouen				+0.246
	Yate				+2.729
	Chepenehe				+2.886
New Zealand	Appleby	+0.007	+0.001	+0.011	+0.54
	Campbell Is	+0.007	+0.002	+0.011	-0.21
	Hokitika	+0.007	+0.001	+0.010	+6.97
	Kelburn	+0.010	+0.006	+0.013	-1.70
	Dunedin	+0.005	-0.005	+0.012	+1.01
	Lincoln	+0.003	-0.010	+0.013	-4.09
	Masterton	+0.007	+0.010	+0.003	-2.35
	Mangere, Auckland	+0.010	+0.006	+0.014	-0.52
	Chatham Islands	+0.012	+0.009	+0.010	-0.10
	Raoul Island	+0.008	+0.010	+0.004	-3.06
Niue	Alofi	0.0076	0.0077	0.0063	-3.1921
Papua New Guinea	Port Moresby	+0.002	-0.016	+0.023	-2.67
	Madang	+0.003	+0.018	+0.012	----
Samoa	Apia	+ 0.0319	+ 0.0088	+ 0.00168	-0.6411
Solomon Islands	Auki	0.0248	0.0278	0.0209	-18.1775
	Kirakira	0.0372	0.0491	0.0209	-35.6808
	Munda	0.0137	0.0040	0.0228	-11.444
	Honiara	0.0230	0.0201	0.0259	-7.9908
Tonga	Keppel	+0.028	+0.0305	+0.011	+2.00
	Lupepau’u	+0.0062	+0.006	+0.0035	-6.4244
	Nuku’alofa	+0.0193	+0.0188	+0.0139	-7.1830
Tuvalu	Funafuti	0.0059	0.0396	0.0870	-0.4158
	Nanumea	+0.0141	+0.016	+0.005	+11.1026
	Nui				
	Niulakita	+0.0146	-0.0101	-0.0169	-17.9241
Vanuatu	Aneityum	0.0022	0.0101	0.0073	-5.4642
	Lamap				

Table 2: Climate Trends 1976 – 2000

Country	Station	TMEAN	TMAX	TMIN	Rainfall
Australia	Willis Island	+0.012	-0.005	+0.013	+22.14
	Darwin Airport	+0.001	+0.003	+0.001	+16.24
	Weipa	+0.007	+0.012	+0.001	+11.49
	Tennant Creek	+0.055	+0.048	+0.051	+0.09
	Burketown	Too many	Missing	years	+40.42
	Cairns	+0.021	+0.014	+0.019	+4.42
	Carnarvon	0.000	+0.003	0.000	+5.82
	Port Hedland	+0.017	+0.020	+0.031	+3.17
	Alice Springs	+0.036	+0.018	+0.065	-3.42
	Giles	+0.012	+0.019	+0.039	+6.87
	Marree	+0.032	+0.015	+0.054	-2.46
	Tibooburra	+0.020	-0.007	+0.056	-2.28
	Charleville	+0.028	+0.014	+0.043	+5.14
	Yamba	+0.016	+0.019	+0.010	-3.41
	Cape Leeuwin	+0.018	-0.002	+0.029	-5.91
	Cunderdin	+0.008	+0.029	-0.004	+3.23
	Kalgoorlie	-0.009	-0.022	+0.006	+7.12
	Ceduna	+0.011	+0.008	+0.018	+0.19
	Mildura	+0.012	+0.007	+0.027	+0.95
	Mount Gambier	+0.009	+0.008	+0.004	+1.78
	Deniliquin	0.000	-0.002	+0.010	+3.02
	East Sale	-0.014	-0.001	-0.022	+0.15
	Moruya Heads	+0.018	+0.003	+0.030	-6.87
	Cape Bruny	+0.015	+0.006	+0.023	-7.00
	Forrest	+0.027	+0.009	+0.025	+5.20
	Lord Howe Island	-0.001	+0.010	-0.007	+3.29
	Norfolk Island	+0.028	+0.012	+0.035	+4.29
	Macquarie Island	-0.011	-0.015	-0.009	+7.15
	Kalumburu	+0.039	+0.011	+0.069	+14.48
Cook Islands	Rarotonga J84300	+0.0254	+0.0121	+0.0360	-9.6277
	Penrhyn J80000	+0.0122	+0.0117	-0.0005	+48.4155
Fiji	Nadi	+0.012	-0.012	+0.037	+27.81
	Suva	+0.036	+0.033	+0.039	-15.95
	Rarawai	+0.064	+0.029	+0.087	+37.941
	Labasa	+0.029	+0.036	+0.0272	+13.806
	Rotuma	+0.028	+0.035	+0.016	12.107
	Ono-I-lau	+0.026	+0.030	+0.021	-7.723
	Savusavu	+0.022	+0.0084	+0.038	-0.415
French Polynesia	Atuona	-0.00152	-0.01624	+0.013628	+8.9338
	Rapa	+0.03598	+0.03955	+0.032923	-13.52
	Faaa	+0.0435	+0.0444	+0.0424	-2.6854
	Hereheretue	+0.0121	-0.0008	+0.0250	+29.0096
	Takaroa	-0.0173	+0.0393	+0.0268	+18.5290
	Tubuai	+0.0359	+0.0125	+0.0592	+8.6238
	Rikitea	+0.0351	+0.0143	+0.0529	-2.7571

Kiribati	Tarawa	+0.0087	+0.0104	+0.0212	-37.4223
New Caledonia	Noumea	+0.02983	+0.03940	+0.03835	+3.664
	Koumac	+0.03191	+0.03360	+0.02997	+8.151
	Ouanaham	+0.03599	+0.01989	+0.05146	
	Gomen				+6.615
	Tontouta				+2.102
	Paita				+9.992
	Touho				+21.490
	Ponerihouen				+16.827
	Yate				+25.085
	Chepenehe				+2.886
New Zealand	Appleby	+0.024	+0.022	+0.030	+1.58
	Campbell Is	-0.007	-0.006	-0.004	+7.77
	Hokitika	+0.013	+0.012	+0.017	+11.71
	Kelburn	+0.026	+0.023	+0.031	-10.51
	Dunedin	-0.001	-0.004	+0.002	-3.38
	Lincoln	+0.021	+0.003	+0.041	-8.83
	Masterton	+0.007	+0.039	-0.024	-12.43
	Mangere, Auckland	+0.030	+0.037	+0.023	+0.21
	Chatham Islands	+0.013	+0.006	+0.023	1.98
	Raoul Island	+0.013	+0.020	+0.007	-9.38
Niue	Alofi	-0.0080	-0.0037	-0.0134	-11.4506
Papua New Guinea	Port Moresby	+0.006	-0.0108	+0.049	-5.54
	Madang	+0.008	-0.053	+0.040	-14.52
Samoa	Apia	+ 0.0572	- 0.0055	+ 0.0417	-0.2859
Solomon Islands	Auki	0.0239	0.0240	0.0204	-5.320
	Kirakira	0.0359	0.0552	0.0077	-11.3527
	Munda	0.0060	0.0117	0.0035	-21.6257
	Honiara	0.0363	0.0388	0.0337	4.8707
Tonga	Keppel	+0.0366	+0.0219	+0.0262	+19.96
	Lupepau’u	-0.0398	-0.0582	+0.0170	+3.5838
	Nuku’alofa	+0.0474	+0.0514	+0.0440	+10.0362
Tuvalu	Funafuti	0.0135	0.0985	0.0891	18.5105
	Nanumea	+0.0061	+0.039	+0.011	-15.2274
	Nui				
	Niulakita	+0.0085	-0.0230	-0.0173	-41.1170
Vanuatu	Aneityum	0.0037	0.0549	-0.0548	-14.5008
	Lamap				3.7112

Table 3: Climate Trends 1950 – 1975

Country	Station	TMEAN	TMAX	TMIN	Rainfall
Australia	Willis Island	+0.004	+0.010	-0.001	-6.30
	Darwin Airport	+0.004	+0.017	-0.008	+17.00
	Weipa	+0.034	+0.005	+0.013	+3.52
	Tennant Creek	-0.040	-0.061	-0.048	+5.49
	Burketown	Too many	Missing	years	+12.21
	Cairns	+0.014	-0.005	+0.032	+25.48
	Carnarvon	+0.013	+0.010	+0.019	+2.67
	Port Hedland	+0.010	+0.007	+0.006	+1.27
	Alice Springs	+0.004	+0.007	+0.018	+10.38
	Giles	-0.065	-0.036	-0.068	+15.10
	Marree	-0.001	-0.009	+0.016	+3.13
	Tibooburra	+0.018	+0.007	+0.026	+3.44
	Charleville	+0.040	+0.010	+0.077	-4.45
	Yamba	-0.004	-0.007	+0.005	+5.69
	Cape Leeuwin	+0.017	+0.023	+0.001	+2.75
	Cunderdin	-0.024	-0.027	-0.025	+0.51
	Kalgoorlie	+0.007	-0.008	+0.021	+2.79
	Ceduna	+0.040	+0.025	+0.048	-2.29
	Mildura	+0.012	+0.003	+0.025	+2.44
	Mount Gambier	+0.044	+0.043	+0.050	-1.15
	Deniliquin	+0.006	+0.010	+0.006	-1.35
	East Sale	+0.036	+0.039	+0.021	-2.22
	Moruya Heads	-0.003	+0.015	-0.017	-0.48
	Cape Bruny	+0.021	+0.019	+0.042	+8.61
	Forrest	+0.021	+0.021	+0.013	+4.18
	Lord Howe Island	+0.020	-0.004	+0.043	+3.72
	Norfolk Island	+0.014	+0.010	+0.022	-4.03
	Macquarie Island	+0.019	+0.019	+0.022	-7.74
Cook Islands	Rarotonga J84300	+0.0256	+0.0296	+0.0250	-3.4017
	Penrhyn J80000	-0.0233	-0.0346	+0.0009	-14.7528
Fiji	Nadi	+0.009	+0.018	-0.0008	-4.231
	Suva	+0.021	+0.036	+0.005	+18.71
	Rarawai	-0.0002	-0.025	+0.016	+20.392
	Labasa	-0.007	-0.05	+0.022	-11.77
	Rotuma	+0.013	-0.004	+0.029	-3.335
	Ono-I-lau	+0.0087	-0.0004	+0.018	-2.87
	Savusavu	-0.005	+0.006	-0.02	+32.73
French Polynesia	Atuona	+0.016577	+0.0472	-0.01539	-4.2500
	Rapa	+0.018882	+0.01546	+0.028767	-5.675
	Faaa	-0.0041	+0.0122	+0.0210	-22.0361
	Hereheretue	-0.0031	-0.0337	+0.0288	-46.2622
	Takaroa	+0.0330	+0.0135	-0.0496	-12.4138
	Tubuai	+0.0783	+0.1095	+0.0455	-23.0308
	Rikitea				
Kiribati	Tarawa	-0.0291	-0.0241	-0.0267	-5.8879

New Caledonia	Noumea	+0.00776	-0.00192	+0.01841	-9.879
	Koumac (1954-	+0.01392	+0.00054	+0.02911	+4.805
	Ouanaham				
	Gomen				-0.745
	Tontouta				-5.444
	Paita				-9.100
	Touho				-0.756
	Ponerihouen				+14.720
	Yate				-32.780
	Chepenehe				+13.574
New Zealand	Appleby	+0.010	+0.004	+0.014	-0.84
	Campbell Is	+0.000	-0.005	+0.006	-1.08
	Hokitika	+0.017	+0.013	+0.013	+4.42
	Kelburn	+0.015	+0.017	+0.014	+0.49
	Dunedin	+0.021	+0.012	+0.023	+2.24
	Lincoln	+0.019	+0.010	+0.021	-5.07
	Masterton	+0.019	+0.013	+0.024	-7.19
	Mangere, Auckland	+0.021	+0.012	+0.028	-3.05
	Chatham Islands	+0.001	+0.008	-0.014	-4.72
	Raoul Island	+0.015	+0.011	+0.017	2.19
Niue	Alofi	0.0245	0.0100	0.0470	14.4831
Papua New Guinea	Port Moresby	+0.006	-0.055	+0.039	-7.39
	Madang	+0.001	+0.026	+0.023	-------
Samoa	Apia	- 0.0086	- 0.0089	- 0.0050	+ 21.4359
Solomon Islands	Auki	0.0231	0.0345	0.0097	17.2747
	Kirakira	0.0155	0.0236	0.0119	-76.8727
	Munda	0.0080	0.0171	0.0026	-22.9868
	Honiara	0.0058	-0.0044	0.0159	15.7842
Tonga	Keppel	+0.0252	+0.0293	+0.0174	+7.18
	Lupepau'u	+0.0381	+0.0454	+0.0090	+8.1887
	Nuku'alofa	+0.0260	+0.0092	+0.0188	+4.0150
Tuvalu	Funafuti	-0.0226	0.1570	-0.1390	46.5346
	Nanumea	+0.0048	-0.034	+0.019	-15.8563
	Nui				
	Niulakita	+0.0053	-0.0176	-0.0389	-11.5840
Vanuatu	Aneityum	-0.0100	-0.0079	0.0057	-8.0258
	Lamap				

Table 4: Climate Trends: Beginning of record - 2000

Country	Station	TMEAN	TMAX	TMIN	Rainfall
Australia	Willis Island				+1.99

	Darwin Airport				+2.32
	Weipa				+6.53
	Tennant Creek				+0.43
	Burketown				+1.61
	Cairns				-3.05
	Carnarvon				+0.13
	Port Hedland				+0.01
	Alice Springs				+0.14
	Giles				
	Marree				+0.37
	Tibooburra	+0.009	+0.004	+0.018	+0.82
	Charleville				-0.30
	Yamba	+0.008	+0.008	+0.010	+0.88
	Cape Leeuwin				+0.49
	Cunderdin				-0.09
	Kalgoorlie				+0.69
	Ceduna				
	Mildura				+0.29
	Mount Gambier				-1.16
	Deniliquin				-0.16
	East Sale				-0.17
	Moruya Heads	-0.001	+0.005	-0.006	+1.68
	Cape Bruny				+0.22
	Forrest				
	Lord Howe Island	+0.004	-0.006	+0.016	-2.77
	Norfolk Island				-1.31
	Macquarie Island				
	Kalumburu				
Cook Islands					
Fiji	Nadi	+0.009	+0.018	-0.0008	-4.231
	Suva	+0.021	+0.036	+0.005	+18.71
	Rarawai	-0.0002	-0.025	+0.016	+20.392
	Labasa	-0.007	-0.05	+0.022	-11.77
	Rotuma	+0.013	-0.004	+0.029	-3.335
	Ono-I-lau	+0.0087	-0.0004	+0.018	-2.87
	Savusavu	-0.005	+0.006	-0.02	+32.73
French Polynesia	Atuona	+0.020849	+0.0214	+0.0201	+25.5054
	Rapa	+0.0113	+0.0001	+0.0211	-6.397
	Faaa	+0.0348	+0.0350	+0.0345	-0.9618
	Hereheretue	+0.0090	-0.0051	+0.0231	+11.8540
	Takaroa	+0.0279	+0.0349	+0.0193	+1.4116
	Tubuai	+0.0184	+0.0094	+0.0274	+1.0986
	Rikitea	+0.0351	+0.0143	+0.0529	-2.7571
Kiribati	Tarawa	-0.0002	0.0027	-0.0034	+2.3395
New Caledonia	Noumea (1901-				+0.932
	Koumac				
	Ouanaham				
	Gomen (1909-				-2.046

	Tontouta				
	Paita (1936-				-1.931
	Touho				
	Ponerihouen				
	Yate (1930-				+0.630
	Chepenehe				
New Zealand	Appleby 1884-2000				+0.28
	Appleby 1908-2000	+0.006	+0.006	+0.007	
	Campbell Is 1941-2000	+0.005	+0.000	+0.010	-0.77
	Hokitika 1895-2000				+0.48
	Hokitika 1894-2000	+0.009	+0.001	+0.011	
	Kelburn 1864-2000				+1.25
	Kelburn 1863-2000	+0.000	+0.003	+0.002	
	Dunedin 1852-2000				+0.35
	Dunedin 1853-2000	+0.005	+0.006	+0.005	
	Lincoln 1865-2000				+0.35
	Lincoln 1864-2000	+0.008	+0.013	+0.003	
	Masterton 1884-2000				-1.14
	Masterton 1906-2000	+0.009	+0.004	+0.013	
	Mangere, Auckland 1853-2000	+0.004	+0.003	+0.007	+0.86
	Chatham Is 1878 - 2000	+0.008	+0.012	+0.000	+0.92
	Raoul Is 1937 - 2000				+2.19
	Raoul Is 1940 - 2000	+0.015	+0.011	+0.017	
Niue	Alofi 1930-2000	0.0033	-0.0077	0.0099	-0.8225
Samoa	Apia	+ 0.0178	+ 0.0095	+ 0.0025	-0.6411
Solomon Islands	Auki	0.0248	0.0278	0.0209	-18.1775
	Kirakira	0.0372	0.0491	0.0209	-35.6808
	Munda	0.0137	0.0040	0.0228	-11.444
	Honiara	0.0230	0.0201	0.0259	-7.9908
Tuvalu	Funafuti	-0.0028	+0.0013	+0.0024	-1.4762
	Nanumea	+0.0094	+0.014	+0.004	+5.8256
	Nui				
	Niulakita	+0.0146	-0.0101	-0.0169	-8.7623

Table 5: Climate Relationships: Beginning of record – 2000

Country	Station	R(Prcp,SOI)	R(Prcp,IPO)	R(Tmean,SOI)	R(Tmean,IPO)
Australia	Kalumburu	0.22	0.00	-0.21	0.37
	Darwin	0.17	-0.19	-0.18	0.45
	Weipa*	0.18	-0.23	0.30	0.02
	Tennant Creek	-0.03	-0.01	-0.08	0.31
	Burketown*	0.25	-0.32	-0.43	0.72
	Cairns	0.19	-0.23	0.06	0.35
	Willis Island	0.20	-0.10	0.40	-0.14
	Carnarvon	0.18	-0.19	-0.02	0.22
	Port Hedland	0.19	-0.10	-0.22	0.46
	Alice Springs	0.18	-0.18	-0.12	0.37
	Giles	0.32	-0.21	-0.38	0.43
	Marree	0.23	-0.23	-0.06	0.20
	Tibooburra	0.39	-0.36	-0.28	0.29
	Charleville	0.32	-0.33	-0.29	0.50
	Yamba	0.35	-0.36	-0.26	0.32
	Cape Leeuwin	0.24	-0.13	0.07	-0.20
	Cunderdin	0.14	-0.06	-0.32	0.33
	Kalgoorlie	0.12	0.02	-0.38	0.45
	Ceduna	0.17	-0.20	-0.03	0.17
	Mildura	0.31	-0.27	-0.02	0.17
	Mount Gambier	0.25	-0.31	0.04	0.15
	Deniliquin	0.35	-0.23	0.17	-0.15
	East Sale	0.18	-0.17	0.00	0.18
	Moruya Heads	0.31	-0.38	0.11	0.08
	Cape Bruny	0.08	-0.19	0.43	-0.34
	Lord Howe Island	0.33	-0.16	0.04	0.04
	Norfolk Island	0.51	-0.40	0.51	-0.28
	Macquarie Island	-0.16	0.18	0.13	-0.04
	Forrest	0.16	0.01	-0.23	0.29
Cook Islands	Rarotonga	+0.425441	+0.331361	+0.292233	+0.10247
	Penrhyn	+0.559375	+0.674685	+0.780449	+0.833007
Fiji	Suva	0.38	-0.52	0.20	0.09
	Nadi	0.53	-0.57	0.20	0.002
	Rarawai	0.50	-0.61	0.26	-0.36
	Labasa	0.53	-0.66	-0.06	0.20
	Savusavu	0.36	-0.49	0.33	-0.09
	Rotuma	-0.07	-0.13	-0.15	0.16
	Ono-I-Lau	0.49	-0.64	0.41	-0.14
French Polynesia	Atuona	-0.38	+0.57	-0.76	+0.81
	Takaroa	+0.34	-0.40	-0.13	+0.25
	Faaa	-0.18	+0.28	-0.46	+0.53
	Hereheretue	-0.30	+0.18	+0.04	+0.08
	Tubuai	+0.14	-0.22	-0.06	+0.13
	Rapa	+0.01	-0.08	+0.14	-0.03
	Rikitea	-0.13	+0.05	+0.25	-0.05

Kiribati	Tarawa	-0.80	0.58	0.35	0.42
	Butaritari	-0.64			
New Caledonia	Noumea	0.4527	-0.5144	0.2497	0.0673
	Koumac	0.4621	-0.4615	0.2685	0.0814
	Ouanaham (1960-			0.3800	-0.0341
	Gomen	0.5406	-0.4795		
	Tontouta	0.5766	-0.5682		
	Paita	0.5119	-0.4313		
	Touho	0.3723	-0.2933		
	Ponerihouen	0.5254	-0.3419		
	Yate	0.4072	-0.2593		
	Chepenehe (1951-	0.5359	-0.4264		
New Zealand	Chatham Is	-0.148	0.054	0.233	-0.191
	Campbell Is	-0.257	0.127	0.079	0.168
	Kelburn	0.088	-0.137	0.386	-0.345
	Masterton	0.044	-0.063	0.486	-0.304
	Hokitika	-0.263	0.032	-0.037	-0.376
	Raoul Is	0.049	-0.076	-0.181	0.248
	Appleby	-0.055	-0.305	0.081	-0.350
	Mangere	0.289	-0.108	0.390	-0.380
	Dunedin	-0.291	0.160	0.396	-0.213
	Lincoln	0.051	-0.035	0.339	-0.313
Niue	Alofi	0.4538	-0.4411	-0.7293	0.3575
Papua New Guinea	Port Moresby	+0.3767	-0.3429	-0.1691	+0.1136
	Madang	--------	--------	+0.0529	-0.1127
Samoa	Apia	-0.5349	+0.4795	+0.4583	-0.4902
Solomon Islands	Auki	+0.039	-0.01	+0.03	+0.38
	Kirakira	+0.542	-0.613	-0.256	+0.489
	Honiara	+0.374	-0.520	-0.228	+0.468
	Munda	-0.149	0.049	0.03	+0.379
Tonga	Nuku'alofa	+0.5419	-0.6211	+0.263	-0.49
	Keppel	+0.28	-0.362	-0.444	+0.449
	Lupepau'u	+0.656	-0.641	+0.04	+0.02
Tuvalu	Funafuti	-0.1470	+0.2337	-0.4967	+0.6188
Vanuatu	Aneityum	+0.52	-0.48	+0.32	-0.79

Table 6: Climate Relationships: Negative IPO Phase (1946-1976)

Country	Station	R(Prcp,SOI)	R(Prcp,IPO)	R(Tmean,SOI)	R(Tmean,IPO)
Australia	Kalumburu	0.32		-0.05	
	Darwin	0.56		0.05	
	Weipa*	0.51		0.17	
	Tennant Creek	0.17		-0.21	
	Burketown*	0.40		-0.91	
	Cairns	0.18		0.48	
	Willis Island	0.19		-0.15	
	Carnarvon	-0.04		0.02	
	Port Hedland	0.15		-0.11	
	Alice Springs	0.29		0.01	
	Giles	0.41		-0.47	
	Marree	0.41		-0.05	
	Tibooburra	0.47		-0.43	
	Charleville	0.43		-0.21	
	Yamba	0.37		0.02	
	Cape Leeuwin	0.29		0.00	
	Cunderdin	0.01		-0.30	
	Kalgoorlie	0.10		-0.29	
	Ceduna	0.20		0.14	
	Mildura	0.31		0.05	
	Mount Gambier	0.22		0.34	
	Deniliquin	0.52		0.22	
	East Sale	0.16		0.29	
	Moruya Heads	0.46		0.06	
	Cape Bruny	0.28		0.49	
	Lord Howe Island	0.24		0.35	
	Norfolk Island	0.43		0.73	
	Macquarie Island	0.10		0.43	
	Forrest	0.29		-0.20	
Cook Islands	Rarotonga	+0.169411	+0.091104	+0.567715	+0.515461
	Penrhyn	+0.422137	+0.62426	+0.738444	+0.80666
Fiji	Suva	0.39	-0.47	0.61	-0.40
	Nadi	0.55	-0.56	0.28	-0.12
	Rarawai	0.58	-0.68	0.09	0.004
	Labasa	0.54	-0.69	0.33	-0.33
	Savusavu	0.25	-0.40	0.05	0.01
	Rotuma	-0.14	0.04	-0.33	0.53
	Ono-I-Lau	0.56	-0.65	0.63	-0.56
French Polynesia	Atuona	-0.32	+0.32	-0.70	+0.71
	Takaroa	+0.43	-0.53	+0.32	-0.34
	Faaa	+0.08	+0.09	-0.08	+0.08
	Hereheretue	-0.18	+0.39	+0.60	-0.66
	Tubuai	+0.33	-0.34	-0.09	-0.06
	Rapa	-0.14	+0.05	+0.19	-0.18
	Rikitea				

Kiribati	Tarawa	-0.88		0.35	
	Butaritari	-0.81			
New Caledonia	Noumea	0.4413	-0.5690	0.5001	-0.3881
	Koumac (1954-	0.3357	-0.3193	0.5804	-0.3863
	Ouanaham (1960-			0.5717	-0.4562
	Gomen	0.4582	-0.4893		
	Tontouta	0.4025	-0.5446		
	Paita	0.4022	-0.4837		
	Touho	0.2131	-0.2114		
	Ponerihouen	0.3955	-0.2845		
	Yate	0.1937	-0.1699		
	Chepenehe (1951-	0.3607	-0.2343		
New Zealand	Chatham Is	-0.014	0.097	0.097	-0.203
	Campbell Is	-0.257	0.208	0.117	-0.176
	Kelburn	0.275	-0.349	0.532	-0.399
	Masterton	-0.486	-0.196	0.241	0.319
	Hokitika	0.228	0.075	0.374	-0.448
	Raoul Is	0.618	-0.605	0.735	-0.669
	Appleby	0.057	-0.112	0.601	-0.450
	Mangere	0.322	-0.134	0.206	-0.625
	Dunedin	-0.164	0.028	0.563	-.517
	Lincoln	0.000	-0.024	0.464	-0.401
Niue	Alofi	0.3711	-0.3338	-0.5313	0.3892
Papua New Guinea	Port Moresby	+0.1192	---------	-0.1327	-------
	Madang	---------	---------	+0.1349	-------
Samoa	Apia	-0.7080	+0.6710	+0.4836	-0.5805
Solomon Islands	Auki	+0.235		-0.553	
	Kirakira	+0.051		+0.176	
	Honiara	-0.022		-0.203	
	Munda	-0.645		+0.446	
Tonga	Nuku’alofa	.425	0.423	0.662	0.663
	Keppel	+0.293	-0.383	+0.263	-0.248
	Lupepeu’u				
Tuvalu	Funafuti	-0.1715	+0.1277	+0.0316	-0.1277
Vanuatu	Aneityum	+0.51	-0.59	+0.32	-0.08

Table 7: Climate Relationships: Positive IPO Phase (1977-1998)

Country	Station	R(Prcp,SOI)	R(Prcp,IPO)		R(Tmean,IPO)
Australia	Kalumburu	-0.05		0.29	
	Darwin	0.00		0.27	
	Weipa	0.01		0.38	
	Tennant Creek	-0.31		0.27	
	Burketown	0.03		0.22	
	Cairns	0.24		0.28	
	Willis Island	0.30		0.36	
	Carnarvon	0.14		0.29	
	Port Hedland	0.27		0.08	
	Alice Springs	-0.07		0.08	
	Giles	-0.02		0.05	
	Marree	-0.01		0.13	
	Tibooburra	0.39		-0.08	
	Charleville	-0.08		0.06	
	Yamba	0.32		-0.07	
	Cape Leeuwin	0.11		-0.30	
	Cunderdin	0.09		-0.12	
	Kalgoorlie	-0.11		-0.04	
	Ceduna	-0.04		0.09	
	Mildura	0.19		0.16	
	Mount Gambier	0.37		0.33	
	Deniliquin	0.26		0.15	
	East Sale	0.37		0.15	
	Moruya Heads	0.30		0.17	
	Cape Bruny	-0.09		0.52	
	Lord Howe Island	0.53		0.28	
	Norfolk Island	0.62		0.60	
	Macquarie Island	-0.32		0.34	
	Forrest	-0.02		-0.16	
Cook Islands	Rarotonga	+0.541479	+0.490714	+0.476445	-0.2946
	Penrhyn	+0.282489	+0.340441	+0.749066	+0.698212
Fiji	Suva	0.21	-0.50	0.46	-0.12
	Nadi	0.30	-0.42	0.29	0.002
	Rarawai	0.27	-0.52	0.21	0.05
	Labasa	0.28	-0.45	0.26	0.11
	Savusavu	0.14	-0.21	0.79	-0.56
	Rotuma	-0.23	-0.24	0.06	0.04
	Ono-I-Lau	0.07	-0.23	0.66	-0.36
French Polynesia	Atuona	-0.28	+0.52	-0.78	+0.76
	Takaroa	+0.34	-0.40	-0.13	+0.25
	Faaa	+0.39	+0.46	-0.40	+0.40
	Hereheretue	-0.29	+0.37	-0.18	+0.35
	Tubuai	+0.07	-0.21	-0.06	+0.12
	Rapa	+0.07	-0.09	+0.18	-0.04
Kiribati	Tarawa	-0.74		-0.06	
	Butaritari	-0.48			

New Caledonia	Noumea	0.4767	-0.3778	0.3801	0.1338
	Koumac	0.4032	-0.3852	0.5078	0.0373
	Ouanaham			0.2176	0.0052
	Gomen	0.4156	-0.3930		
	Tontouta	0.7103	-0.4587		
	Paita	0.5597	-0.3380		
	Touho	0.5759	-0.4757		
	Ponerihouen	0.6634	-0.4015		
	Yate	0.5288	-0.3813		
	Chepenehe	0.6517	-0.6442		
New Zealand	Chatham Is	0.111	-0.166	0.213	-0.540
	Campbell Is	-0.310	0.452	0.419	-0.469
	Kelburn	0.059	-0.040	0.588	-0.355
	Masterton	0.163	-0.145	-0.304	-0.089
	Hokitika	-0.427	0.169	0.246	-0.505
	Raoul Is	0.546	-0.306	0.635	-0.204
	Appleby	0.447	-0.187	0.533	-0.370
	Mangere	-0.209	-0.300	-0.162	-0.208
	Dunedin	-0.422	0.400	0.438	-0.323
	Lincoln	0.092	0.000	0.611	-0.289
Niue	Alofi	0.4860	-0.5316	-0.2474	0.2531
Papua New Guinea	Port Moresby	+0.5866	-------	-0.2988	--------
	Madang	+0.5999	-------	+0.0100	-------
Samoa	Apia	-0.3260	+0.4283	+0.1786	-0.2678
Solomon Islands	Auki	+0.33		+0.469	
	Kirakira	+0.57		+0.400	
	Honiara	+0.524		+0.234	
	Munda	0.00		+0.418	
Tuvalu	Funafuti	+0.0400	0.0000	+0.1900	-0.2881
Tonga	Nuku'alofa	0.424	0.569	0.455	0.130
	Keppel				
	Lupepau'u				
Vanuatu	Aneityum	+0.51	-0.43	0.32	-0.08
	Lamap	+0.50	-0.42		

* denotes station with limited temperature data for analysis in the period concerned

Monthly Data Analyser - Version 1.03

User's Guide

Byron Gleason and Janet Petersen

November, 2001

TABLE OF CONTENTS

Appendix A: Frequently Asked Questions

Appendix B: Input Data Format

Appendix C: Software Development

Introduction

Monthly Data Analyser (Version 1.03) is a Microsoft Excel (Version 97 or higher) program designed to assist researchers in the analysis of monthly climate change and detection. More specifically, Monthly Data Analyser takes monthly data for temperature and rainfall and undertakes the following steps:

1. Quality Control
2. Homogeneity Testing
3. Calculation of indices
4. Plot annual data, indices and other graphs

The following sections discuss in more detail what the software does.

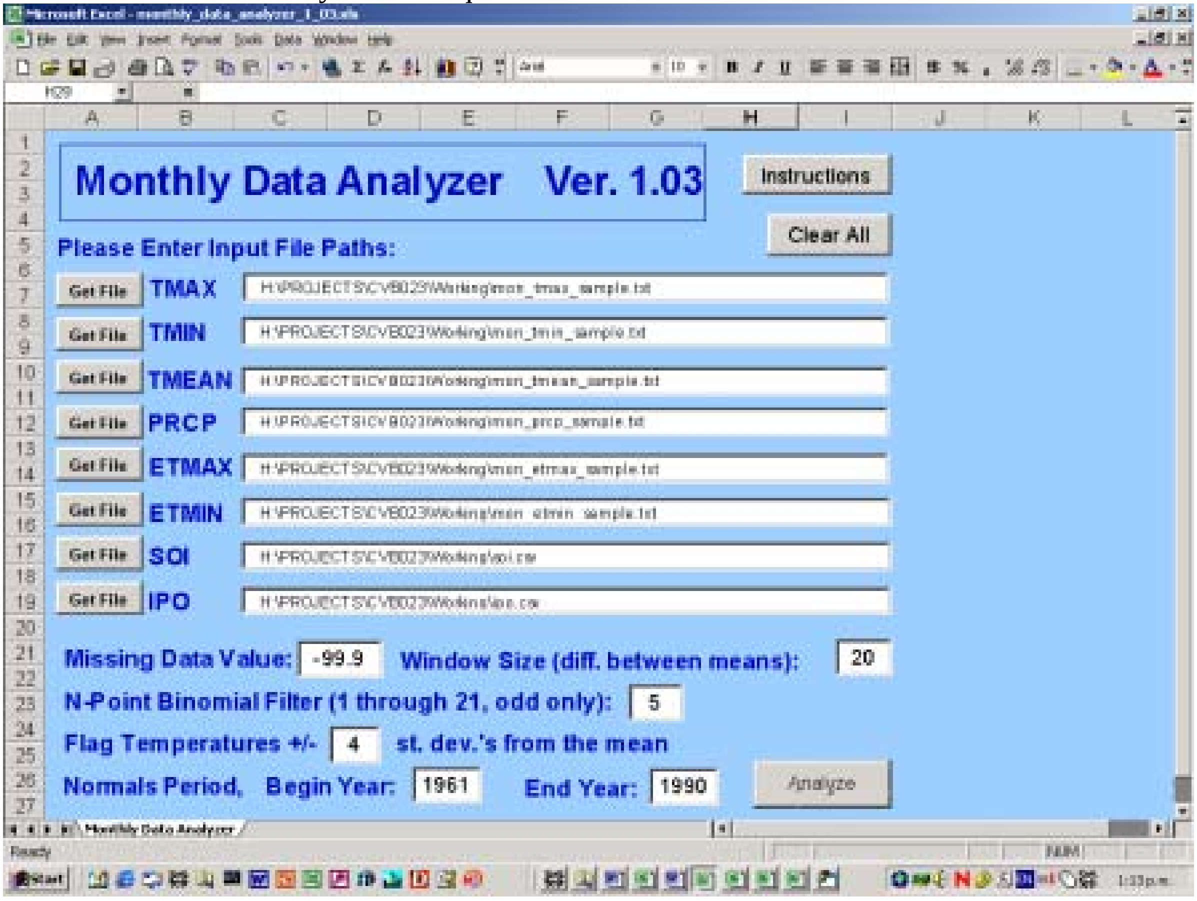
Running the Software

To start, open up the excel file monthly_data_analyzer_1_03.xls and fill in the appropriate

information in the text boxes. The information required is as follows:

Input data files	You can either type the file names in or use the "Get File" button to browse the list of files. See appendix B for the list of input files required and their format.
Missing data value	This will be set to –99.9 in most instances. Another value can be used but it must apply to all of the files used as input.
Window size	This is the window size for the t-test and represents a number of years (see section on homogeneity testing).
N-Point binomial filter	This is the number of coefficients used in the binomial filter. Choose an odd number between 1 and 21.
Std Dev. from mean	This is the number of standard deviations from the mean, outside which the data will be removed.
Normals period	These are the representative years that will be used for comparison to calculate the anomalies.

Note that when you first open the monthly data analyser you may be asked whether you want to enable macros. Answer yes to this question.



Please Enter Input File Paths:

TMAX H:\PROJECTS\CVB023\Working\mon_tmax_sample.txt
TMIN H:\PROJECTS\CVB023\Working\mon_tmin_sample.txt
TMEAN H:\PROJECTS\CVB023\Working\mon_tmean_sample.txt
PRCP H:\PROJECTS\CVB023\Working\mon_prcp_sample.txt
ETMAX H:\PROJECTS\CVB023\Working\mon_etmax_sample.txt
ETMIN H:\PROJECTS\CVB023\Working\mon_etmin_sample.txt
SOI H:\PROJECTS\CVB023\Working\soi.csv
IPO H:\PROJECTS\CVB023\Working\ipo.csv

Missing Data Value: -99.9 Window Size (diff. between means): 20
N-Point Binomial Filter (1 through 21, odd only): 5
Flag Temperatures +/- 4 st. dev.'s from the mean
Normals Period, Begin Year: 1961 End Year: 1990

Figure 1 Example of input used in the monthly data analyser

When you are satisfied that all the input data has been entered then select the “Analyse” box to run the software. The program will then carry out the steps listed in the introduction (more information can be found in the following sections). While the program is running it will ask you whether you want to calculate seasonal data – if you answer no then the program will stop, otherwise the seasonal data will be calculated (this is the default). When activated, the “Clear All” button will clear all of the input boxes and the “Instructions” button will give brief summary information about the software. By selecting the “Get File” button you will be able to browse directories to find the input file you are looking for. If you choose cancel then the associated box will be cleared and no file will be used.

The output created by running the software will be three spreadsheets. The first contains all of the input data and graphical information in individual worksheets (i.e. Tmax, Tmin, Tmean, Precip, ETmax, Etmin, SOI and IPO-SST), an extreme temperature range data (ETR) worksheet and a “QC” worksheet, which has a list of data that was removed during the quality control checks. The second contains all of the seasonal data, with anomalies and the binomial filter calculated for each season and annually and the third spreadsheet has the seasonal averages and graphical comparisons and correlations with IPO/SOI data. These spreadsheets can be saved to file with user-selected names. If you stopped running the program before the seasonal data was calculated then only the first spreadsheet will be created.

Quality Control

The first step in the analysis process consists of the application of routine quality control procedures to a user's station data. The quality control checks performed on the monthly data are as follows:

1. Tmin > Tmax
2. Precipitation < 0.0 mm
3. Identifying extreme values > or < a specified number of standard deviations

4. ETmax < Tmax
5. ETmin > Tmin

Taking the example shown in Figure 1, a user is analysing a station with 30 years of monthly data (1961 to 1990). The user selects +/- 3 standard deviations from the mean for the extreme values. A standard deviation is calculated for each month for all 12 of the same month values. Thus, for a particular month, January for example, a standard deviation is calculated for all 30 January values (excluding missing values). Then each January value is compared to the standard deviation for that month and if it is > or < 3 standard deviations, then it is set equal to the missing value designated by the user. In addition, values that meet the criteria within the other quality control steps (e.g. TMIN > TMAX, PRCP < 0.0, ETmax < Tmax, ETmin > Tmin) are also set to missing. Users who desire to preserve as much of their original data as possible should consider using a large number of standard deviations from the mean (perhaps 5 or greater). The quality control procedure within Monthly Data Analyser is not meant to be comprehensive but rather to assist a user in identifying common gross errors that may exist within monthly station data.

Homogeneity Testing

Monthly Data Analyser provides users with a way to detect temperature (TMAX and TMIN) and precipitation inhomogeneities. These values can be thought of as discontinuities or shifts in the data record or time series of maximum or minimum temperature. These abrupt or sometimes gradual changes can be traced to both natural and artificial (human induced) changes. User's are generally more interested in eliminating or mitigating the effects of the latter (artificial) and trying to detect and/or explain the former (natural). The scientific literature has many articles devoted to various philosophies and techniques for identifying inhomogeneities. The number of articles is too numerous to list in this guide. Monthly Data Analyser's homogeneity testing procedure is fairly simple compared to many of these articles in print and therefore a user may want to supplement their data with further testing from these additional techniques. It utilizes the following techniques to examine a temperature and precipitation time series for inhomogeneities:

1. Visual inspection of a temperature and precipitation time series
2. Statistical test (t-test) to test the difference between two adjacent period mean values

Monthly Data Analyser provides the user with a time series of annual mean (temperature) and accumulated values (precipitation). These time series can then be examined in conjunction with any existing metadata to identify potential inhomogeneities.

The second part involves the user defined "window" size in years (must be an even number). This window is split into two adjacent periods and a 2 sided (Beta not equal to 0) t-test is performed to examine the difference between means for the first (window/2) years and the remaining years. The result of this test is always listed for the year that represents the start of the second 'mean' period. For example: 10 yr Window, 1900 through 1909, (mean of 1900 to 1904 vs. mean of 1905 to 1909) the result would be listed during 1905. The resultant probabilities from this statistical test are plotted with the annual data in the worksheet where the data is being tested.

Calculation of Indices

Once the data has been checked, as described in the section on quality control, the extreme temperature range (ETR) for a year is calculated from the difference between the highest ETmax and the lowest Etmin for that year. The results are displayed in both tabular and graphical form (Figure 2).

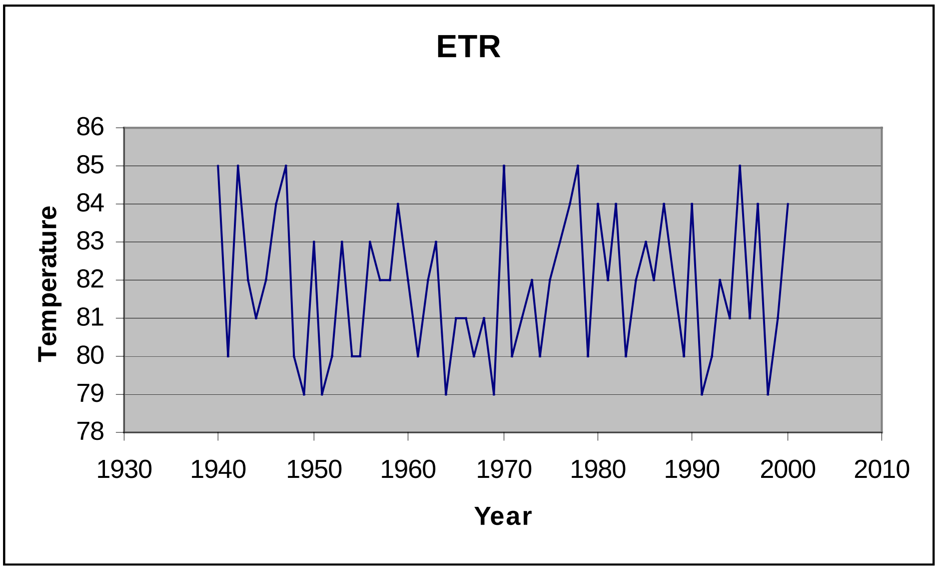


Figure 2 Graphical results showing extreme temperature range.

Plotting SOI and IPO-SST

The Monthly Data Analyser also plots data for the mean temperatures and precipitation versus the southern oscillation index (SOI) and the Inter-decadal Pacific Oscillation sea surface temperatures (IPO-SST). These graphs can be found in the results spreadsheet in the Tmean and Precipitation worksheets. An example is shown below (Figure 3):

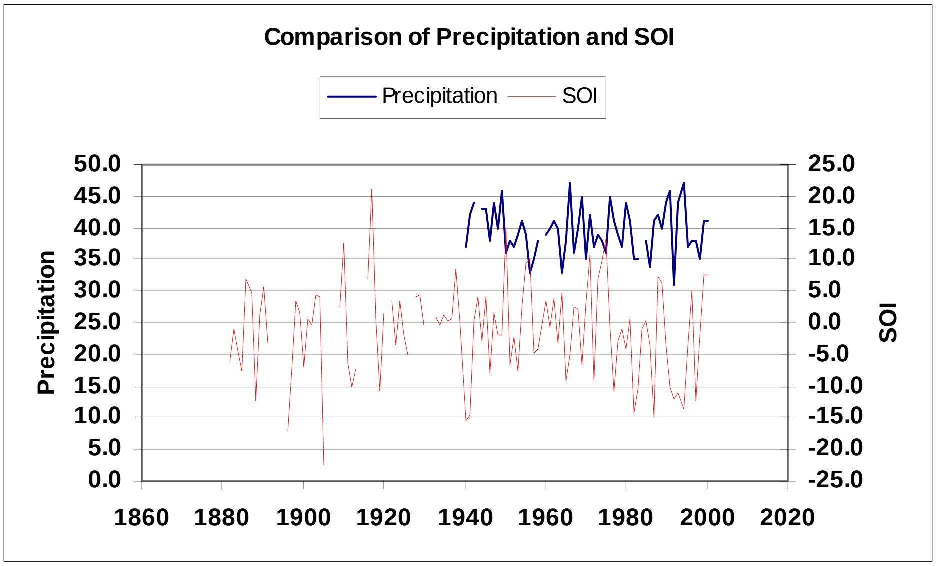


Figure 3 Output showing comparison of precipitation versus SOI

Calculating and Displaying Seasonal Data

As well as calculating monthly and annual data there is the option to calculate seasonal data within the monthly data analyser. The seasons are defined as DJF (December, January, February), MAM (March, April, May), JJA (June, July, August) and SON (September, October, November). The averages are calculated for all of the temperature data, precipitation, SOI and IPO. Annual averages are also calculated using seasonal averages.

In addition, for each set of seasonal and annual data the anomalies and N-Pt Binomial filter are calculated and plotted and the precipitation and mean temperatures are graphed (and correlated) against the SOI and IPO.

APPENDIX A: Frequently Asked Questions

General

1. Why was Monthly Data Analyser created?

Monthly Data Analyser software was created to assist users at the APN meeting in the rapid analysis of their monthly data. The majority of scientific conferences range in length from a few days to a week. This is generally not enough time for participants of these conferences to develop programs that can analyze their own data. Therefore, Monthly Data Analyser can fulfill this need by greatly reducing the programming that is usually necessary to conduct such analyses.

2. Why was Monthly Data Analyser created using Microsoft Excel (version 97)?

The decision to use Microsoft Excel was based on several different factors. First, Microsoft Excel is used globally and has extensive scientific analysis and graphing capabilities. Second, Microsoft Excel has its own built in programming language (Visual Basic for Applications) that will allow users to customize and/or expand the existing Monthly Data Analyser software. Third, Microsoft Excel has graphical user interface (GUI) programming capabilities. The GUI allows users to quickly get started using Monthly Data Analyser and not have to worry about learning a complicated programming language in a short period.

3. Where can I learn more about Microsoft Excel (version 97 or higher) and Visual Basic for Applications (Microsoft Excel's programming language)?

Several internet search engines can provide multiple sources of information and web-sites on the above topics.

4. What about developing a version of Monthly Data Analyser in the most widely used scientific programming language - FORTRAN 77 or FORTRAN 90?

Although future versions of Monthly Data Analyser could and may be developed using FORTRAN, this language was not desirable for at least two reasons. First, FORTRAN compilers are often very expensive and can very significantly from system to system. In most cases the commercial version of Microsoft Excel is already available within most institutions and if not can generally be purchased for less than the cost of a new compiler. Second, FORTRAN does not contain built in graphical capabilities for creating maps, graphs, and/or graphical user interfaces. There are of course many third party software packages which can interface with the FORTRAN programming language and provide users with the above mentioned graphical capabilities. However, this would add yet another software package that users would have to obtain, install, and learn to use.

Using Monthly Data Analyser

1. Monthly Data Analyser does not appear to be reading in my input data file correctly when I run the "Quality Control" step. What could be the problem?

The format of the input data file for this step must be in a specific format. Please refer to APPENDIX B in this manual. In addition, if you are sure you have followed the appropriate format, check to make sure each line of data concludes with a carriage return. If the carriage return does not exist, Monthly Data Analyser will attempt to read in all your data as if it were one single line of data. This generally results in a memory error as Monthly Data Analyser can only read in a specific number of characters per line.

2. Can I alter the source code within Monthly Data Analyser?

Yes, you may change some or all of the source code within Monthly Data Analyser. If you would like to view and/or change the source code, you will need to use the Visual Basic Editor that is included in Microsoft Excel.

APPENDIX B: Input Data Format

Several input files are required for the software to run. They include data for temperature, rainfall, SOI and IPO - SST. The input data files have several requirements:

1. ASCII text file (***no*** header)
2. Carriage Return at the end of each line
3. Format:

   Year Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
   This data can be comma, tab or space delimited. Do not put a comma or a space before the year. The year should be the first four digits in each line. Use –99.9 for missing values (but not for the year).
4. Precipitation units are in millimetres and temperature units are in degrees Celsius.

Examples of how the input data could look like are shown below.

Temperature example:

```
1935 -99.9 -99.9 -99.9 10.5 9.8  6.5  6.7  9.8  10.3  14.8  19.7  22.5

1936  24.5 21.0 18.0 10.5 9.8  6.5  6.7  9.8  10.3  14.8  19.7  22.5
```

Rainfall example:

```
1935 -99.9 -99.9 -99.9 100 358 645 385 25 10 5 78 957

1936 145 363 200 100 358 645 385 25 77 75 78 957
```

Each monthly climate element should be in a separate file. The files expected by the software are as follows:

- Average maximum temperature
- Average minimum temperature
- Mean monthly temperature
- Monthly rainfall total
- Extreme maximum temperature (optional)

- Extreme minimum temperature (optional)
- SOI (optional)
- IPO-SST (optional)

Make sure you know how your system handles the insertion of carriage returns at the end of each data line. Often carriage returns cannot be seen unless you are using a special editor that can show the existence using a special code (e.g. in unix = "^M").

All of the data files that are created by the program are in Microsoft Excel format.

APPENDIX C: Software Development

This software was initially developed by Byron Gleason (NCDC/NOAA, USA) and further modified by Janet Petersen (NIWA, Auckland, NZ). The original software by Byron Gleason had the following features:

Read in temperature and precipitation data and put it into a new spreadsheet.

1. Undertake quality control checks to ensure that Tmin < Tmax, precipitation > 0 and that extreme values do not fall outside a specified number of standard deviations.
2. Carry out statistical test on data to check whether there are any shifts in the mean.
3. Plot time series data, P value, anomalies and N-Pt binomial filter for temperature and precipitation data.
4. Calculate and display extreme temperature range (for each year).

The changes made by Janet Petersen were as follows:

1. Add test to check that ETmax ≥ Tmax and ETmin ≤ Tmin for each month.
2. Add worksheets that contain SOI and IPO data and graph these in comparison with precipitation and mean temperature.
3. Calculate and graph seasonal and annual seasonal averages for all temperature and precipitation data.
4. Plot seasonal SOI and IPO in comparison to seasonal mean temperature and precipitation.
5. Calculate and plot seasonal anomalies and N-Pt binomial filter for all temperature and precipitation data.