PROJECT 1.4: REGIONALLY SPECIFIC CLIMATE DATA AND MONITORING FOR THE NORTH-WEST AND SOUTH-WEST TO SUPPORT THE UNDERSTANDING OF PAST, PRESENT AND FUTURE CLIMATE

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Objectives

- To apply rigorous scientific methods to the development and extension of climate change datasets for WA.
- To enhance the range of datasets used within IOCI 3.
- To increase the accessibility and usability of the datasets.

Key Research Findings

- The high quality daily rainfall network has been expanded from 40 stations to a potential 228 daily reporting stations. There has been a particular increase in the north-west of the state, where previously there were very few high-quality stations.
- This improvement in the network is essential for properly characterising climate change at fine spatial and temporal scales. Such observations are also an important input of downscaling techniques aimed at predicting future rainfall changes. This information will be essential for the planning and management of existing and future agricultural areas, mining industry activities and ecological and environmental studies.
- The previously existing Australian high-quality daily station temperature dataset of 103 stations over Australia, including 19 in Western Australia, has been extended to 112 stations, with six new stations in Western Australia, making a total of 25. This will improve the spatial resolution of long-term

temperature analyses, particularly in the south-west. Four new stations have been added in this area (Morawa, Merredin, Bridgetown and Katanning).

- In addition, records from Albany were severely affected by a 1965 move, with no overlap period, from the town centre to the airport 10 km inland, but the re-opening in 2002 of a site near the pre-1965 location has greatly improved the confidence with which adjustments for that area can be made. A specific goal which the updated dataset will fulfil is to allow the apparent summer cooling since 1950 to be resolved more precisely; in the previous, relatively coarse, network, analyses "projected" anomalies at Albany a substantial distance inland, an effect which will be reduced by the new network.
- The new dataset extends the record back to 1910 and up to 2009. It includes a large quantity of recently digitised data which were not available for use in previous studies, as well as fully incorporating more recent data.
- The new dataset allow century-scale analyses of changes in temperature extremes, both in Western Australia and elsewhere, and will also allow monthly data from the 1910-1949 period to be included in the Bureau's real-time monitoring products.
- A purpose built web area attached to the Bureau of Meteorology's website is being built to make available the new rainfall and temperature high-quality datasets to State stakeholders. This web area will use the OpenLayers platform, which allows innovative site navigation and provides users with other relevant information, such as roads, rivers, elevation and place names.
- Dr Marco Marinelli has been recruited to provide an enhanced local capacity in climate analysis and monitoring and to liaise with State stakeholders.

MILESTONE 1.4.1: HIGH-QUALITY AND SCIENTIFICALLY DOCUMENTED DAILY RAINFALL DATASET EXTENDED BACK TO 1900.

Senior Investigator

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Background

Introduction

High-quality daily rainfall observations are essential for properly characterising climate change at fine spatial and temporal scales. Such observations are also an important input of downscaling techniques (that have been developed as part of IOCI Stages 1 and 2) aimed at predicting future rainfall changes. The climate predictions of an area can be significantly improved if more high quality stations can be added to an existing network. Furthermore, additional application of high quality precipitation (and temperature) datasets include the planning and management of existing and future agricultural areas (such as the wheat belt region in the south west and the proposed expansion of agricultural in the Kimberley), ecological/environmental studies and in the mining/oil industries. In all, a good understanding of the climate of an area is important if not essential. As such, there is scope for the inclusion of more high quality stations, and for further improvement of existing quality controlled data for IOCI, especially in the data sparse areas of Western Australia.

For Western Australia, and particularly in the north-west region, the observational network is sparse due to the large distances between stations. Also, the operational period of a station and/or frequency of measurements, may have been subject to change over the last 100 years. As discussed in Lavery *et al.,* (1992), the rationale is that "if an observer was diligent then the reliability of his reports may be less open to question". However, in some cases the error may be due to other factors such as instrumentation error, instrumentation exposure changes, site moves or a range of other possible factors. Therefore, if a station is to be classified as high quality it must pass a higher level of quality control tests.

The earlier work by Lavery *et al.*, (1991) identified 191 high-quality long-term rainfall records in Australia. This was later increased to 379 stations (Lavery *et al.*, 1997). The rainfall data from each of these stations at the monthly time scale was considered high-quality, with a subset of these stations also having high-quality daily data available. There are 40 Lavery daily high-qulaity stations in Western Australia, most of which are in the south of the state (see Figure 1.4.1). Project 1.4.1 aims to significantly increase this network of stations, especially in the north of the state. It will also asses the quality of the Lavery stations to ensure that they still pass the high quality criteria.

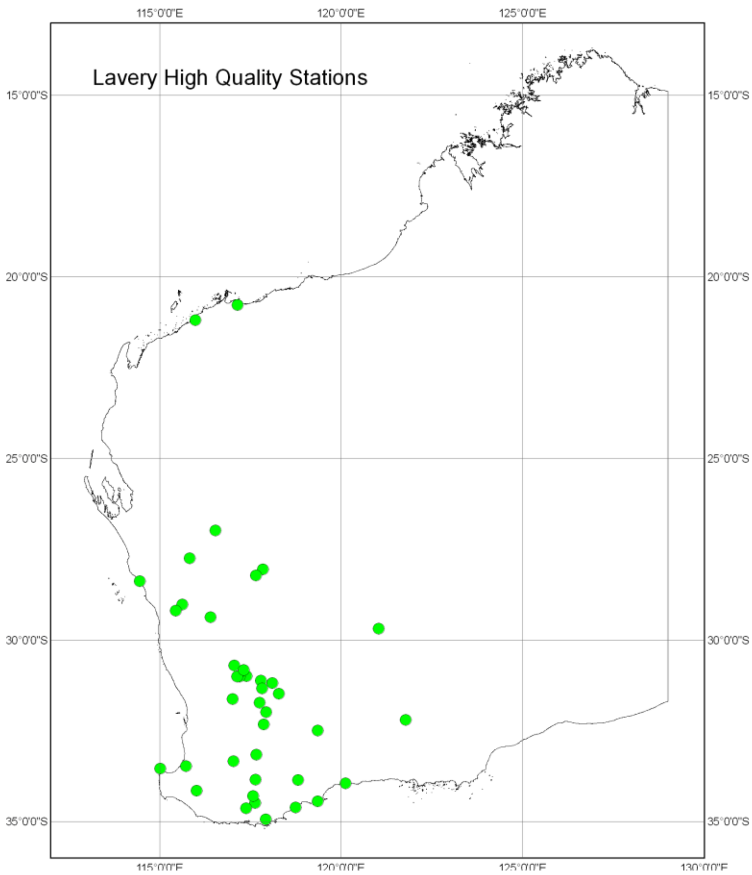

Figure 1.4.1: The Lavery *et al.*, 1997 Daily High-quality Stations

Technical Details

Methods and Results

For IOCI 3, enhancing the high-quality rainfall network has been done in two steps. Firstly the completeness of the rainfall data for Western Australian stations was assessed to compile a list of candidate high-quality rainfall stations with long and largely complete records. The second step was to identify those stations of the highest quality through the application of a range of statistical test. The new high-quality rainfall dataset covers those stations with long and complete records and recording assessed as being reliable.

Analysis of Data Completeness

The data completeness tests for possible new high-quality rainfall candidate stations were carried out in two steps to identify candidates for the two periods 1950-2008 and 1900-2008.

In the first case, stations must have been open in 1950, still be open at the end of 2008, and be at least 95% complete (of possible daily observations) in the 1950-2008 period. An exception was made for the Bureau of Meteorology station of Giles (near the WA/NT/SA border intersection), which is an automatic inclusion due to its location in a data sparse region of the interior. Giles opened in 1957, is a Bureau meteorological office and is expected high-quality.

In the second case, candidate stations covering the period 1900 to 2008 were determined. By default, all of the stations in the 1950-2008 >95% group were included for analysis of their rainfall datasets pre-1950. Also, as in the case of the Giles station, the 1950-2008 >95% rule was relaxed in regions of low station density. Finally, a significant difference from the first case (1950-2008) was that the 1900-2008 stations could be either single or composite stations. The methods used to determine candidate, single or composite, stations is discussed in the following sections.

Composite stations

For many regions, a combined record of existing stations can provide a meaningful representation of rainfall variability and trends over the 20^{th} century. Composites are typically constructed in data sparse regions where long records of continuous length are difficult to find. In most instances two station records will be combined, one covering the early part of the 20^{th} century, and one covering the later part of the 20^{th} century. Station composites are in general confined to two, and less often three, stations to minimise potential inhomogeneity issues with the data.

The overlapping rainfall measurements in the composite candidates were statistically (correlation and regression) tested to see how closely their measurements, and rainfall trends, agreed. As for most single site candidates, the earliest date of the rainfall in the composite stations is in the first decades of the 20^{th} century.

Data Completeness

Of the 228 high-quality candidate stations identified for Western Australia in this work, there are 180 single stations and 28 composite stations. The stations that passed the 95 % completeness criteria test for the 1950-2008 period are shown in Figure 1.4.2.

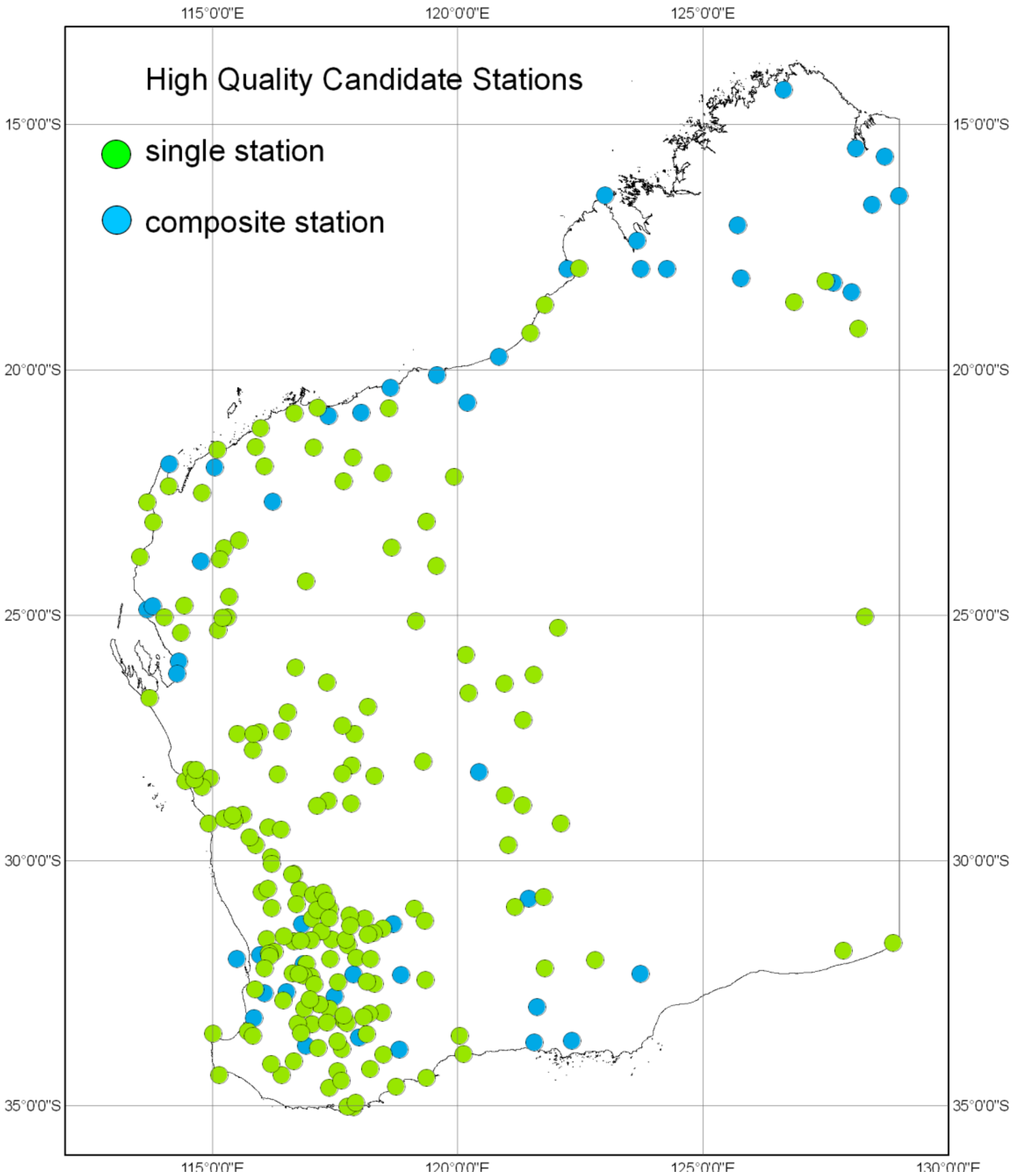

Figure 1.4.2: Candidate rainfall stations which passed the 1950-2008 > 95%.

Further Analysis Using Statistical Tests

In order to determine the quality of the 228 stations, additional statistical tests were applied. These statistical tests focussed on the agreement between stations, or more specifically, the covariance and correlation between the yearly and seasonal rainfall totals. In general, it is expected that nearby stations should have higher correlations, especially in the winter period in the southwest of the state. The stations in the north of the state are expected to be less in agreement in their summer (wettest) period because of the patchiness (high spatial variability) of monsoonal rainfall patterns.

If nearby stations are found to be well correlated, then this suggests that the measurements of the stations contains relatively little errors, or be affected by other factors (such as the topography of an area, which is mostly unlikely due to the relative flatness of most of Western Australia).

For example, the agreement between the annual rainfall totals of Halls Creek Airport (2012) - Fox River (2062) two stations in the south-east Kimberley region of Western Australia), would be expected to be reasonably high due to their (relative) close proximity.

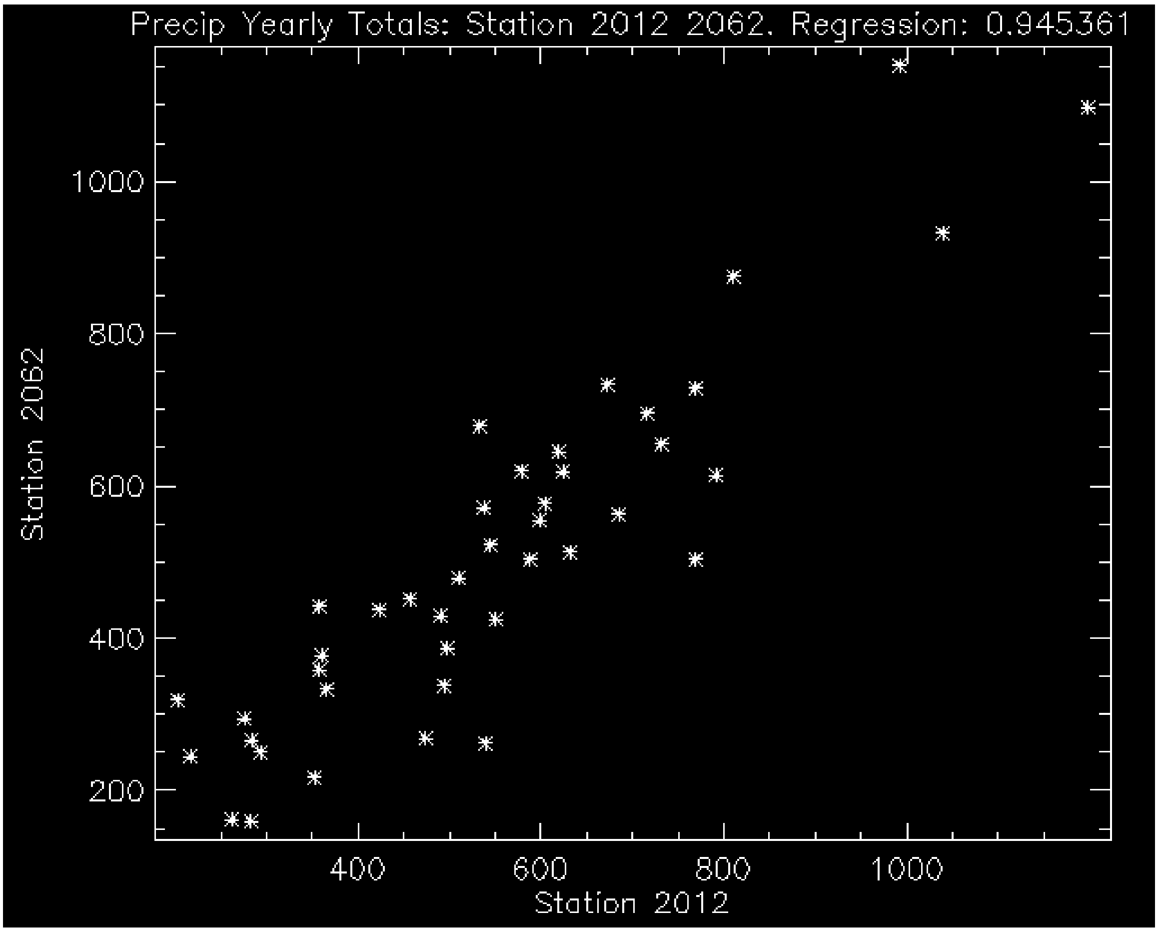

Figure 1.4.3: Comparison of yearly total rainfall at Halls Creek Airport and Fox River.

In both cases, for the years 1950 to 2008, this is the reflected in the high correlation of the yearly totals (0.91 in both cases). Also, as shown in Figure 1.4.3, there is a good linear agreement between these stations. Finally, the yearly total regression (trend with time) for each station is in close agreement (5.0mm/yr for Halls Creek Airport and 4.48mm/yr for Fox River). This positive trend is also consistent with the observed trend in the north of Western Australia.

Additionally, the trends and totals for the 1950-2008 and 1900-2008 are mapped as an additional tool to complement the statistical analysis across stations. For example, figure 1.4.4 shows the total annual rainfall, in millimetres, at the high-quality stations and how these compare with a climatology generated from the entire rainfall network. These maps allow the degree of agreement between stations to be easily visualised and for clear outliers to be more easily identified for additional investigation, and possible elimination.

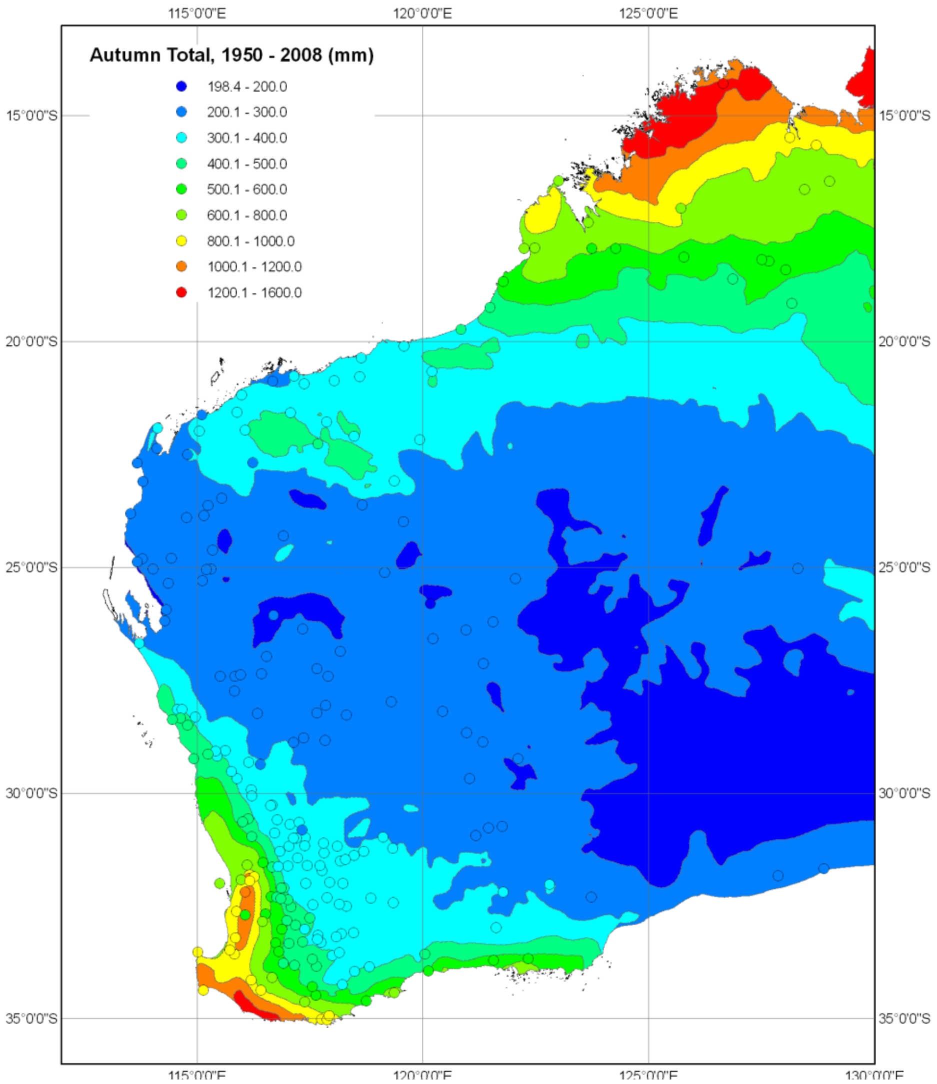

Figure 1.4.4: Annual average rainfall for Western Australia together with station totals for the high-quality stations overlaid.

Summary

This project has expanded the high quality daily rainfall network from 40 stations, in the previous Lavery et al. (1997) study to a potential 228 daily reporting stations. There has been a particular increase in the north-west of the state, where previously there were very few high-quality stations. This improvement in the network is essential for properly characterising climate change at fine spatial and temporal scales. Such observations are also an important input of downscaling techniques aimed at predicting future rainfall changes. This information will be essential for the planning and management of existing and future agricultural areas, mining industry activities and ecological and environmental studies.

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MILESTONE 1.4.2: EXTENDED HIGH-QUALITY AND SCIENTIFICALLY DOCUMENTED DAILY STATION TEMPERATURE DATASET EXTENDED BACK TO 1910

Senior Investigator

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Background

The previously existing Australian high-quality daily station temperature dataset included 103 stations over Australia, including 19 in Western Australia, and generally extended from 1957 to 1996 (Torok and Nicholls, 1996). The new dataset extends the record back to 1910, including a large quantity of recently digitised data which were not available for use in previous studies, as well as fully incorporating more recent data. The new set has also been extended to 112 stations, with six new stations in Western Australia, making a total of 25 (as shown in Figure 1.4.5). This will improve the spatial resolution of long-term temperature analyses, particularly in the south-west.

Introduction

Long-term temperature datasets are subject to numerous external influences which can affect data for reasons not associated with changes in the background climate. These include site relocations, changes in instrument specifications, changes in observing practices (such as the time at which observations are made), and changes in the local site environment, including, but not limited to, urban development in the site's vicinity. A detailed review of such influences and their impact on temperature observations may be found in Trewin (2009).

In order to develop long-term data sets suitable for climate change monitoring, it is necessary to identify these external influences, and either remove stations subject to them, or make adjustments to data ('homogenisation') where necessary to counteract their effect on the observations. There are numerous data sets, both at the national (e.g. Torok and Nicholls, 1996; Menne *et al.,* 2009) and global (e.g. Jones and Moberg, 2003; Smith *et al.,* 2008) scale, where such adjustments have been used in developing long-term temperature data sets at the annual and/or monthly timescale.

A further issue in dealing with daily data is that an external influence can have varying impacts on temperature data depending on the weather situation; for example, urban influences on temperature tend to be strongest on calm, clear nights, which (in Australian climates at least) are also likely to be cool nights. Two case studies from the inland NSW locations of Inverell (Trewin and Trevitt, 1996) and Coonabarabran (Trewin, 2005) found minimum temperature differences between sites within a few kilometres of each other which ranged from 5-10°C on the coldest winter nights but were near zero on the warmest nights. Such variable influences, if not corrected for, can lead to time series of temperature extremes remaining inhomogeneous even if the means have been successfully homogenised.

A number of methods have been proposed to address this problem (e.g. Trewin, 2001; Della-Marta and Wanner, 2006; Brandsma and Können, 2006). The original version of the high-quality Australian temperature dataset (Trewin, 2001) employed methods based on the matching of percentile points in frequency distributions, a broadly similar method to that used for the updated dataset and described more fully below. While the field is currently an active area of research (see http://www.homogenisation.org), to our knowledge this remains the only national-level dataset homogenised at the daily timescale.

Technical Details

Methodology

The updated dataset contains a total of 112 stations, including 25 in Western Australia (Figure 5). Compared with the original version of the dataset, ten stations (six in Western Australia) have been added, and one Queensland station deleted on the grounds of inadequate data quality after inspection of metadata.

At the time the original dataset was developed, most stations only had digitised daily data from 1957 onwards, rendering pre-1957 data effectively inaccessible. Since then a major digitisation project has made a much larger quality of data available back to 1910. Some pre-1910 data also exist but were not considered for use in this study because of the widespread use of instrument shelters which were not compatible with post-1910 standards (Torok and Nicholls, 1996).

The first stage in the process was to subject the data to detailed quality control procedures, involving checks for internal consistency between maximum and minimum temperatures and between those and hourly or three-hourly data (where available), as well as spatial consistency with surrounding stations. The purpose of this was to subject all of the historical data, as far as possible, to a level of quality control comparable with that carried out as part of the National Climate Centre's present-day routine quality control procedures.

The second stage was to identify potential inhomogeneities in the data at each station. A detailed search of metadata, in particular the hard-copy files of station correspondence and inspection reports maintained by each Regional (state) Office of the Bureau of Meteorology, was carried out to identify potential inhomogeneities such as site moves. As metadata are often incomplete or open to interpretation, inhomogeneities in monthly data were also identified by statistical methods (e.g. Easterling and Peterson, 1995), using comparisons with data from nearby sites.

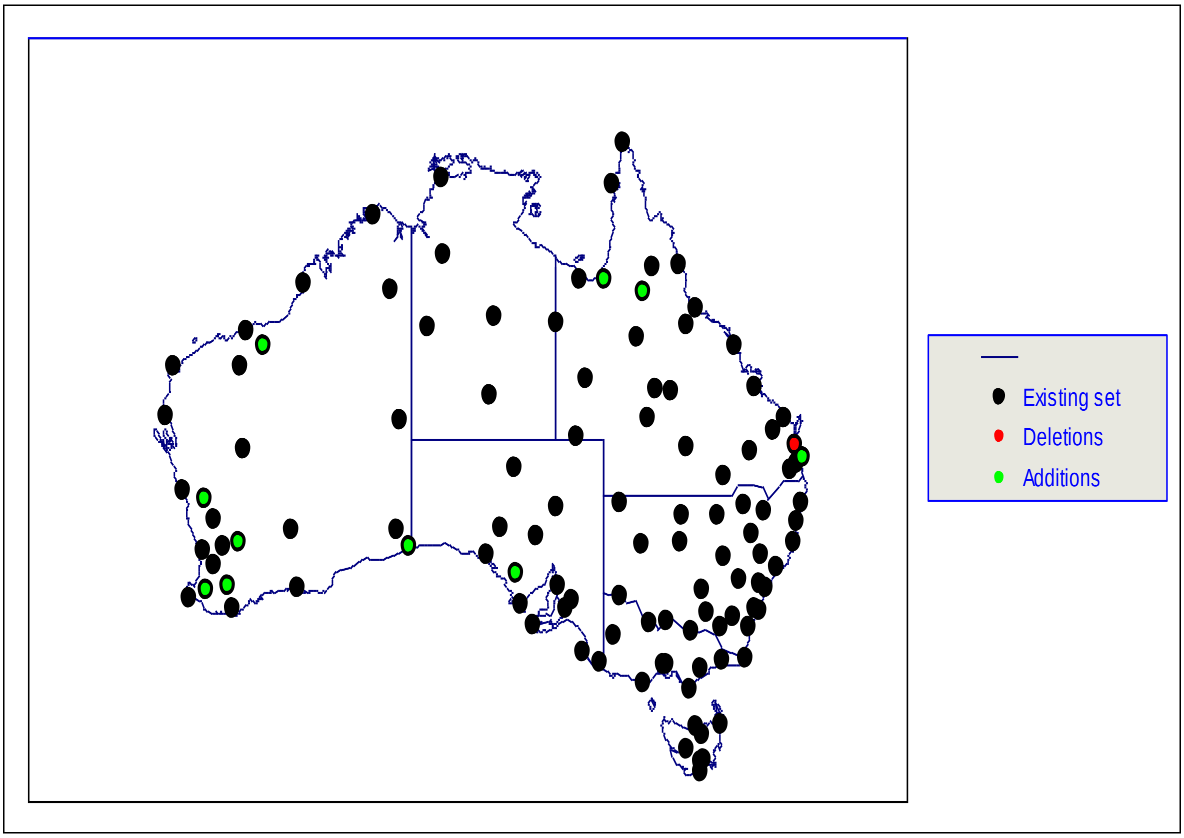

Figure 1.4.5: Stations in the updated daily temperature dataset, including additions and deletions from the previous version.

Once all known inhomogeneities were identified at the monthly timescale, adjustments were then carried out on the daily maximum and minimum temperature data. Where overlapping data existed, these were done by defining a transfer function based on the differences between the 5th, 10th,…, 95th percentile points of the frequency distributions during the period of overlap. Where no overlap existed a two-stage process was carried out using up to four neighbouring sites.

Improvements arising from the new dataset

The most obvious benefit of the new dataset, compared to the previous version, is its much greater length, extending from 1910 to 2009. This will allow century-scale analyses of changes in temperature extremes, both in Western Australia and elsewhere, and will also allow monthly data from the 1910-1949 period to be included in the Bureau's real-time monitoring products. Whilst the 1957-1996 data set has been progressively updated using real-time data, no further homogenisation had taken place, resulting in some anomalous results in analyses where there have been significant inhomogeneities in the post-1996. The new analysis makes adjustments for such recent inhomogeneities.

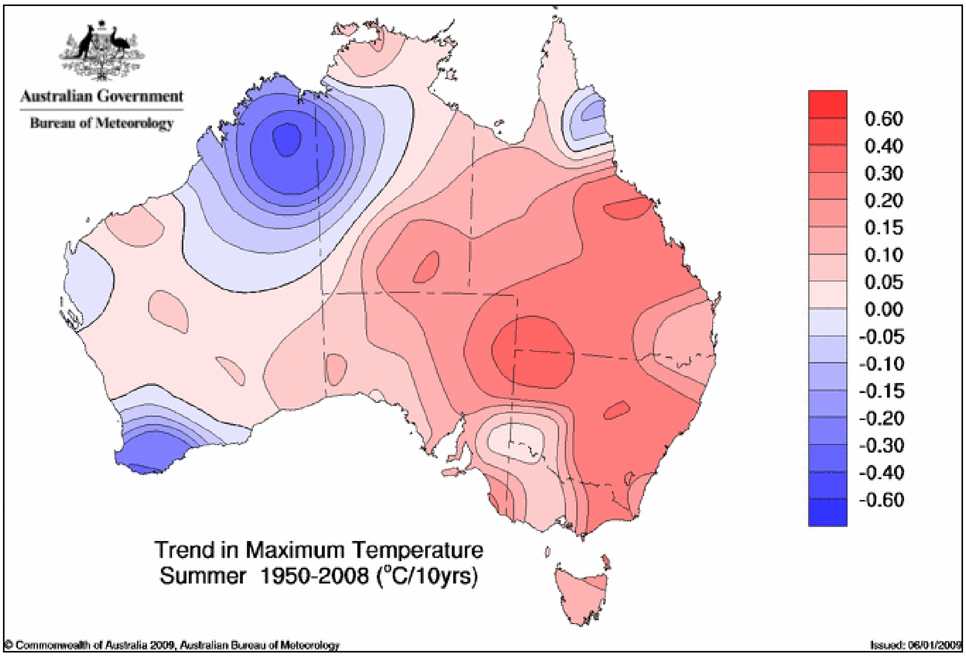

Figure 1.4.6: Summer maximum temperature trends over the 1950-2008 period, derived using the previous dataset.

A particular benefit to Western Australia of the new data set is increased data density and quality in the southwest of the state. Four new stations have been added in this area (Morawa, Merredin, Bridgetown and Katanning). In addition, records from Albany were severely affected by a 1965 move, with no overlap period, from the town centre to the airport 10 km inland, but the re-opening in 2002 of a site near the pre-1965 location has greatly improved the confidence with which adjustments for that area can be made. A specific goal which the updated dataset will fulfil is to allow the apparent summer cooling since 1950 (Figure 1.4.6) to be resolved more precisely; in the previous, relatively coarse, network, analyses "projected" anomalies at Albany a substantial distance inland, an effect which will be reduced by the new network.

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MILESTONE 1.4.3: DEDICATED WEBSITE PROVIDING ACCESS TO RELEVANT CLIMATE DATASETS FOR WA IN SUPPORT OF IOCI 3 PROJECTS

Senior Investigator

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Background

The rainfall and temperature high-quality data sets produced in project 1.4 of the IOCI will be made available via a purpose built web area attached to the Bureau of Meteorology's website. This web area will use the OpenLayers platform, which allows innovative site navigation and provides users with other relevant information, such as roads, rivers, elevation and place names.

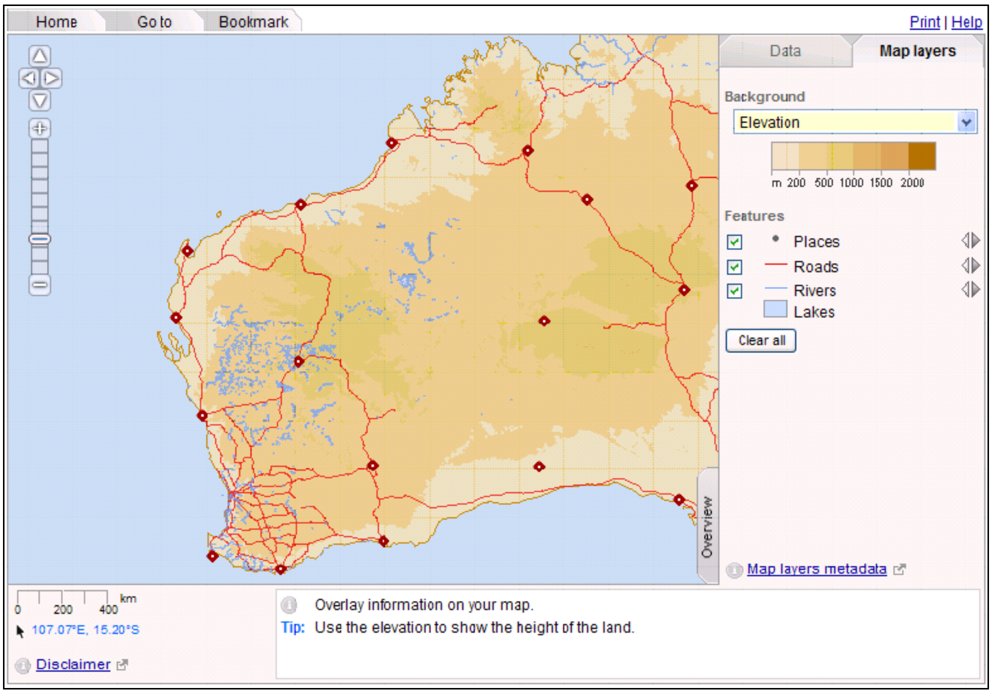

Figure 1.4.7: IOCI web portal screen shot.

Technical Details

Users will be able to zoom into a location of interest and view the data held at stations in that area, as shown in Figure 1.4.7 and 1.4.8. In addition, web pages for all high-quality station have been produced. Each page contains graphs of the time series of data, links to the raw data, metadata information (Figure 1.4.9). This style of webpage has been used by the Bureau of Meteorology for several climate data products and has received very good feedback on the usability and functionality of the system.

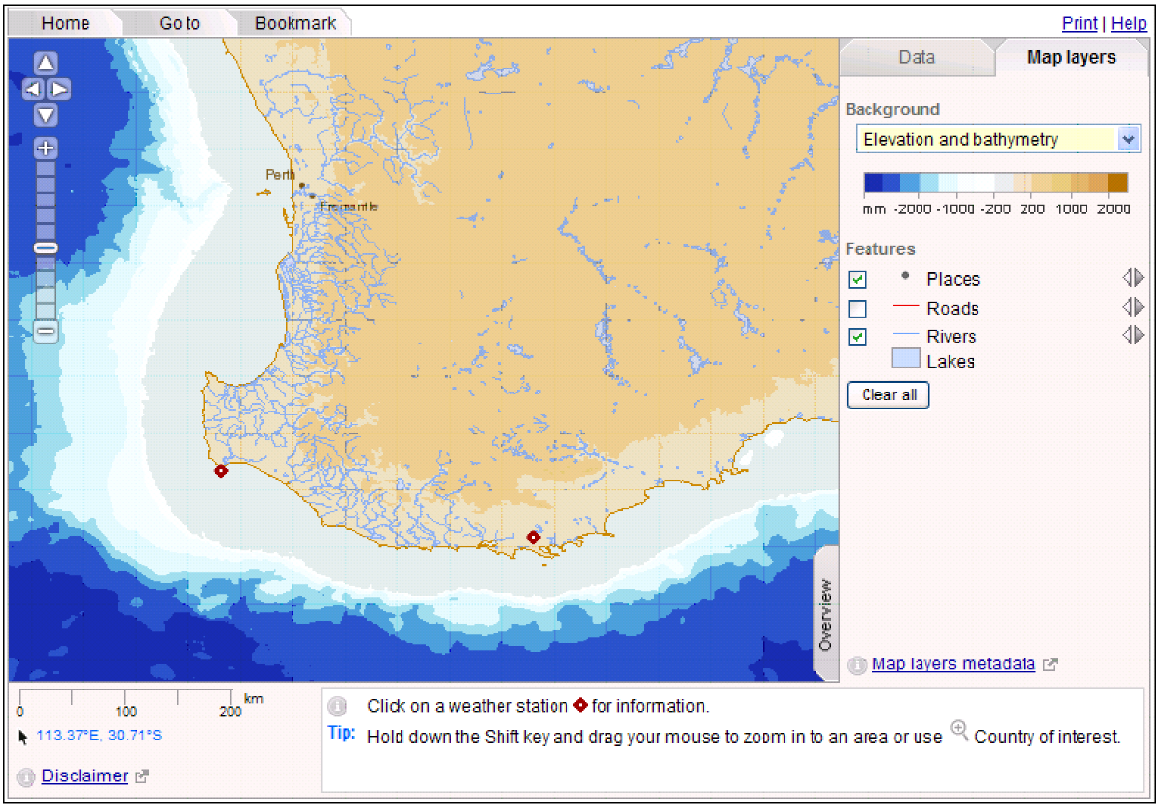

Figure 1.4.8: IOCI web portal – site allows the user to zoom into a location and access data for a specific location as shown in Figure 1.4.9.

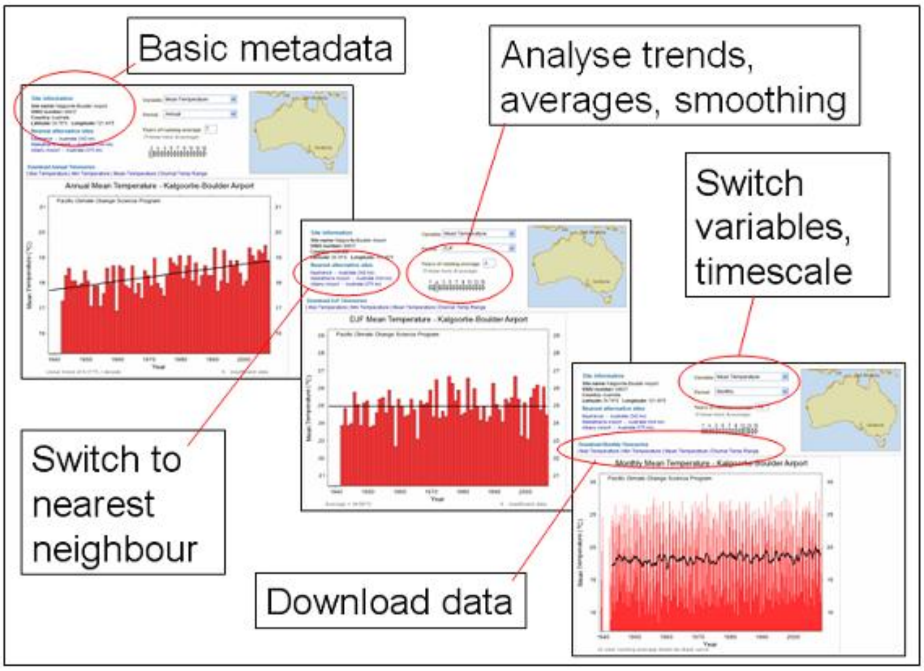

Figure 1.4.9: Site data portals allow time series, raw data, metadata and data trends to be easily accessed.

MILESTONE 1.4.4: ENHANCED LOCAL CAPACITY IN CLIMATE ANALYSIS AND MONITORING, INCLUDING AND ENHANCED PRESENCE IN THE WESTERN AUSTRALIAN REGIONAL OFFICE.

Senior Investigator

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Background

Dr Marco Marinelli was recruited as a climate scientist to work for IOCI project 1.4. Marco's major focus during the past year has been on Milestone 1.4.1 (see above).

Marco has enhanced skills in climate analysis in Western Australia, particularly in the area of Geographic Information Systems, statistical analysis, and climate data manipulation. He has also provided a focal point for interaction with IOCI partners, whilst also liaising with the partners to understand their climate data needs. This interaction has developed over the past year with attendance at IOCI forums, as well as presentations at Greenhouse 2009, and the WA Marine Science Institution (WAMSI)/Australian Meteorological and Oceanographic Society (AMOS) symposium - A changing climate: Western Australia in focus.

It is anticipated that interaction with IOCI partners will continue to increase in 2010 with the release of the high-quality datasets as a result of the IOCI project work, and progress on other project 1.4 milestones, including the high resolution spatial analyses and sector relevant climatologies.

The availability of other Bureau of Meteorology datasets in 2010 such as the new high resolution gridded climatological analyses will provide further scope for an enhanced services and science, and generally expanded level of service to IOCI partners and the

WA public. A workshop presenting the data and services offered by the Western Australian Regional Office for IOCI partners is planned for early 2010.

LIST OF FIGURES