Microclimatic Variation

in the

Stroud Gloucester Valley

Cover*:* ***Clon Garriff (The Stony Meadow).***

Patricia McCalden – Oil and Acrylic (2012)

A Gloucester Project Research Report

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July 2013

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ISBN 978 0 9808185 1 2

Published by: The Gloucester Project Inc
PO Box 224
Gloucester NSW 2422

www.thegloucesterproject.org.au

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Foreword

This Report is intended as a general introduction to microclimatic concepts, with particular reference to horticultural opportunities in the Stroud Gloucester district. What it is not, otherwise than indirectly, is a guide as to what to grow, and where and when. There is an extensive literature on these topics, and, while some indicative references have been provided in the text, these are not intended to be exhaustive.

The Report should also be viewed as a work in progress. As described in Chapter Three, The Gloucester Project is continuing to gather temperature and other data from representative sites across the Valley, and it is anticipated that an updated version of this Report will be published when the volume of data available justifies this.

Acknowledgments

The principal source of data relied on has been the long-term climatic records available from the Australian Bureau of Meteorology for its network of weather stations. Permission has been generously granted to copy and use tables, maps, and graphs, and these are scattered throughout the report, where they can be readily identified, even if they are not individually acknowledged as to source.

A number of people have read the report in draft form, and I have benefited from their comments and suggestions. In particular . . . . . Needless to say, such errors as may remain are entirely my own responsibility.

Publication of this report, and its distribution to local growers, schools, and other interested individuals and institutions, has been made possible through a grant from the Hunter Central Rivers Catchment Management Authority. Both the Author and The Gloucester Project acknowledge this support with gratitude.

NSW GOVERNMENT | Catchment Management Authority Hunter-Central Rivers

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A TinyTag Data Loggers

Pierre Louys installs a TinyTag Data Logger at the original Tucker Patch in 2010.

This dual temperature and humidity logger was donated to TGP by Hastings Data Loggers of Port Macquarie.

1.0 Introduction

The term "Microclimate" refers to uniform climatic conditions experienced over a relatively small area.

At a general level the whole of the Stroud Gloucester Valley could be viewed as sharing a common climatic regime, and this is certainly so should we have in mind a comparison with, say, the Margaret River vineyard area in West Australia, or the Tamar Valley in Tasmania. But residents of the Stroud Gloucester Valley (SGV) will be well aware that differences do exist even within this limited area. The question, as always, is how significant these differences are, and from whose perspective.

At the extreme lower end of the micro scale, perhaps as little as one square metre, most home gardeners would be keenly aware of the myriad of microclimates which exist in the immediate vicinity of their house and outbuildings. Sites may have a north or south aspect, be sunny or shaded, sloping or level, wind exposed or sheltered, while soil quality may also vary widely.[1]

Yet most gardeners adapt to these realities, and find plants or shrubs which will thrive, or at least survive, in each location. At the other extreme, say a farm of several hundred hectares, there may, depending on the topography and other factors, be little or no variation in climatic conditions across the property, or there might be several distinct microclimatic units which can be identified.

1.1 Scope of this Report

The primary focus of this report is on land parcels intermediate in scale between the above extremes, and typically in the range from about one to five hectares. The reason for this is straightforward, namely that The Gloucester Project (TGP) is concerned to promote both sub-commercial and commercial scale horticulture in the SGV and adjoining areas, and the majority of intensive horticultural farms would fall within this size range.

Such a parcel could, of course, be just a section of a larger landholding, possibly a farm mainly devoted to beef or dairying, or it could encompass the whole of a small rural block with suitable soil and microclimatic characteristics. Yet another option is for landholders to sub-let suitable plots to a full-time commercial market gardener. This option, among others, has been addressed in an earlier TGP research report [1].

While the term SGV will be used throughout this report, it should be understood as including not only the broad syncline stretching from Gloucester town south to Stroud, but also the valleys of the several Manning tributaries lying generally to the west of Gloucester; the Waukivory valley; and the country to the east of Gloucester approximately as far as Krambach. This area approximates to the boundary of Gloucester Shire, but with extensions south into Great Lakes Shire, east into the City of Greater Taree, and west into the Barrington Tops.

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[1] Strictly speaking, soil quality is not a microclimatic attribute . But there is often some association, and it can be convenient to include it sometimes as an additional factor in a site assessment.

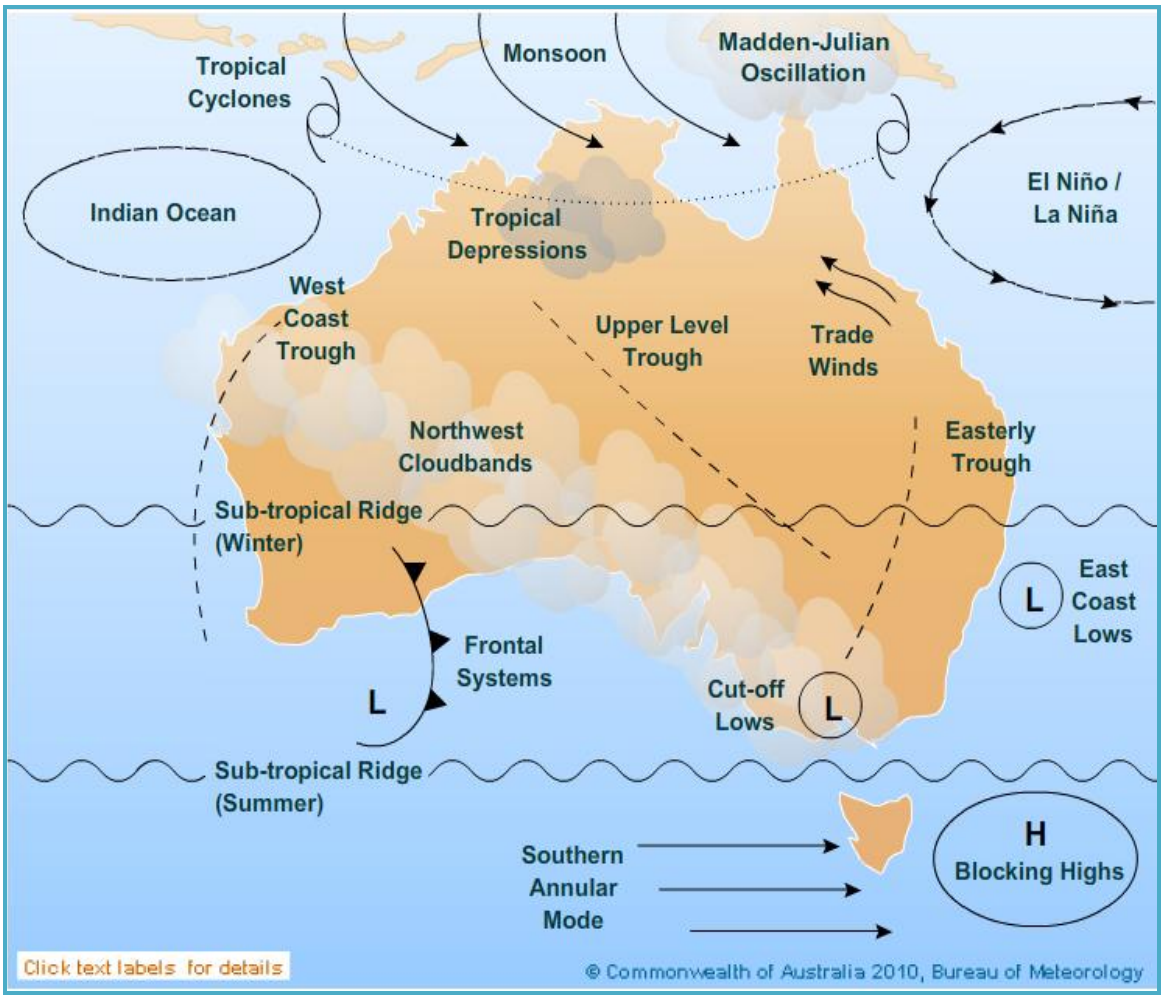


Figure 1.1: Major Australian Climatic Influences

The BOM home page is www.bom.gov.au . At the bottom of the home page are over twenty links to specific information resources. The bulk of the data relied on in this report comes from the "Climate Data Online" link, which is a portal to historical records for weather stations nationwide, both active, and no longer operational.

The link to "Climate Variability & Change" leads to information about both broadscale and local climatic controls, and to information about climatic trends and recent exceptional events. Figure 1.1 above was downloaded from that site (23/05/2013). Other links point to pages dealing with current conditions and short to medium term forecasts.

The present report has a twofold purpose. The first is to provide a basic introduction to micro-claimatological concepts, and to emphasise the practical relevance of these concepts to the expansion of horticultural production at the commercial and sub-commercial scales. The second is to present a summary of such data as is already available for the SGV, and to draw whatever useful conclusions may be possible at this early stage of research.

1.2 Gloucester's Climate

Weather is what we see when we look out of the window – climate is weather averaged over a sufficiently long period for random fluctuations to be ironed out. A thirty-year span is usually considered sufficient to provide a minimum basis for statistically reliable summaries, while longer record periods may also allow detection of trends in climate change.

Situated close to the east coast of a continental mass, at a latitude of 32ºS, the SGV enjoys what is described as a Continental East Coast Maritime (ECM) climate. This zone can be further divided into two sub-zones, termed Sub-Tropical ECM (e.g. Lismore), and Temperate ECM (Merimbula). The primary differences between the sub-zones are slight increases in average temperatures and rainfall as one moves from south to north in the southern hemisphere.

Thus, between Merimbula at about 37ºS, and Lismore at about 29ºS, average annual rainfall increases from 730 mm to 1166 mm, while average temperatures go from 20.6ºC to 25.8ºC. These differences represent gradients of about 55 mm of rain and 0.65ºC in average temperature for each degree of latitude. The climatic gradient is steeper as one moves inland from the coast, partly due to the presence of the Great Dividing Range, and partly to a weakening of maritime influences.

The primary source of long-term climatic data is the Australian Bureau of Meteorology (BOM), which records daily rainfall from a relatively dense network of weather stations, and readings of variables such as temperature, sunshine, cloud cover, and evaporation from more widely spaced locations. Within the SGV, rainfall records are available for both Stroud and Gloucester Post Offices since 1889.

Figure 1.1 shows the main global-scale forces which control climate across the whole of continental Australia. For southeast NSW the primary driver is the ***Sub-tropical (high pressure) Ridge***, which generates an endless sequence of high pressure systems moving slowly from west to east, and which oscillates seasonally from north in winter to south in summer.

In the southern hemisphere summer the typical path followed lies to the south of the continental landmass, while in winter the entire system shifts northwards, so that the high pressure cells tend to track across central NSW. This annual cycle is illustrated clearly by the phase diagram in Figure 1.2, which is based on over one hundred years of observation. In this graph, latitude is shown on the left-hand scale, and atmospheric pressure on the horizontal.

There is an association between these two variables, such that pressure is highest during the winter months of May to August when the highs are centred around Gloucester's latitude of 32 ºS, and weakest during the summer months. The other dominant influences on the SGV are low-pressure systems, which may originate off the NSW coast, or else move up from the vicinity of Victoria, and thunderstorms, which occur mainly in he summer season. More details on how these forces operate to control the SGV's weather is provided in the following chapter.

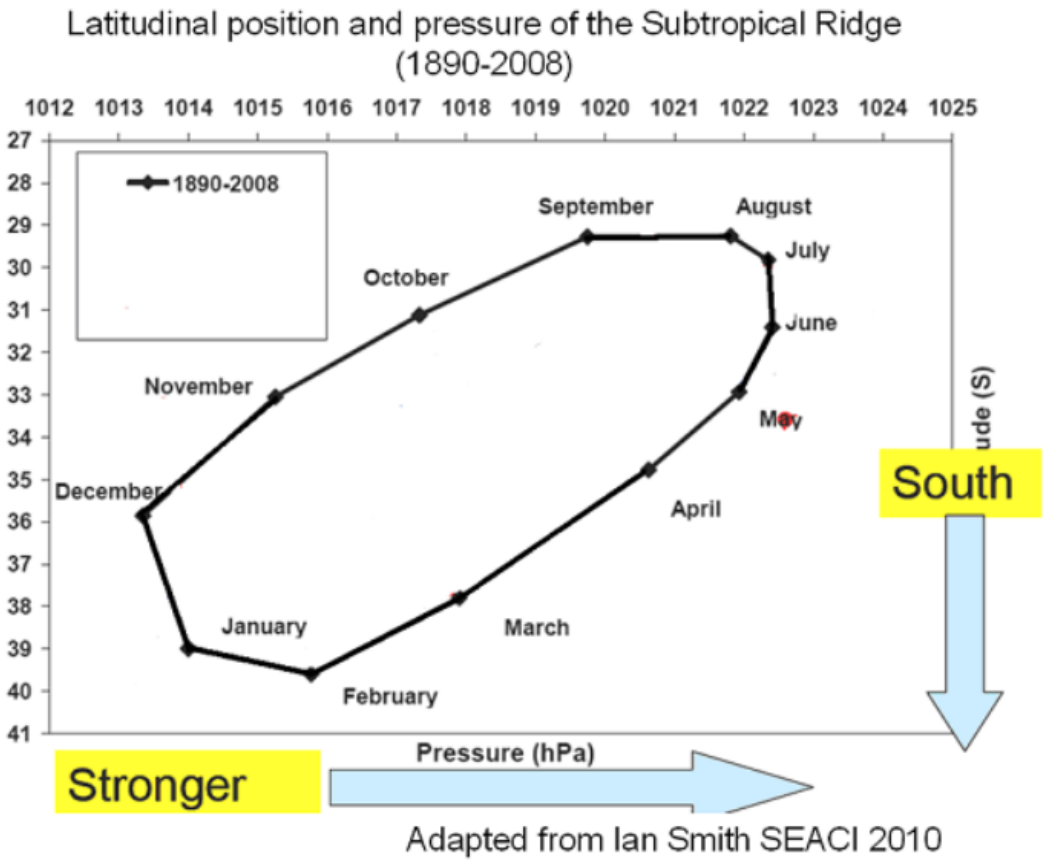


Figure 1.2: Monthly Phase Diagram of the Subtropical Ridge [2]

1.3 Climate and Horticulture

As noted previously, the primary object of this report is to bring together such available data as may be of use to horticulturalists operating in the SGV, and to present it in an accessible form. Obviously, before establishing a horticultural business, the operator should make an objective assessment of all of the factors relevant to the proposed site, with particular emphasis on niche microclimates, wherever these may exist. With this information to hand, it should be easier to make sound decisions as to the varieties of produce to plant, and the expected returns and risks.

There is a wide range of information available on such matters as the germination conditions for each variety of plant, the optimal envelopes for growth and harvesting, and vulnerability to extreme climatic events. Such issues are not touched on directly in this report, but several selected references are included in the Bibliography.

The NSW Department of Agriculture also offers a range of specialised advisory services targeted at very specific sub-sectors of the agricultural production spectrum. These are distributed across regional offices, and may be contacted via a link through www.agric.nsw.gov.au , or directly at www.dpi.nsw.gov.au/agriculture , at least until the next Cabinet shuffle. Follow the "Contact" or "Science and Research" tabs.

[2] © CSIRO 2010 [2]. Present graphic as adapted from that source by the State of NSW through the Department of Trade and Investment, Regional Infrastructure and Services.

2.0 Rainfall

Along with temperature, rainfall is one of the two dominant climatic factors controlling horticultural opportunities and productivity. Generally, the SGV enjoys an average annual rainfall in the range between 900 mm and 1100 mm, though this is exceeded on the Barrington Tops and in the adjacent foothills. Forecasts by Climate Change modelers indicate that the section of the NSW coast to the east and northeast of Gloucester will be favoured with relatively more reliable rainfall in future decades, and that this benefit will extend inland for some distance. This offers the promise that the SGV will be able to sustain a productive horticultural industry through coming generations. More details on climate change are provided in Chapter 9.

2.1 Rainfall Data Sources

There are three sources of rainfall data for the Stroud Gloucester Valley. The primary source is the Bureau of Meteorology (BOM) records, which, in the case of Gloucester and Stroud Post Offices, have been kept almost without break since 1889. A current search of the BOM website shows a total of 14 active weather stations within a radius of 30 kms from Gloucester town. All of these record rainfall on a daily basis, though some may also record additional climatic variables. A list of these stations is provided in Table 2.1, with the stations named in order of increasing distance from Gloucester. Two additional stations (Chichester Dam and Stroud PO) outside the 30 km limit have been included because they contribute relevant information.

At each BOM station where rainfall is recorded, readings are taken daily at 9am of the total precipitation for the preceding 24 hour period. This data is published in full detail on the BOM website: www.bom.gov.au/climate/data/ . The website is well designed and offers intuitive navigational facilities. Weather stations can be identified and selected in various ways, though the station number as shown in Table 2.1 provides direct access for these stations.

A search of the BOM website revealed that a further 14 BOM weather stations had formerly been in operation within the 30 km perimeter, but are now no longer active. However, records from these stations are still available on the BOM website. (Follow the "Climate Data Online" link, but be sure to un-click the "Show open stations only" box to get a complete list).

The second source is the records which have been kept by local landholders, using domestic rain-gauges. Understandably, the reliability of these records is somewhat variable, but they can be a useful supplement to the BOM data on occasions.

Finally, a beneficial outcome of the expansion of resource extraction activities in the SGV is that private weather stations have been established to supply site specific data for use in the preparation of Environmental Impact Statements, and for general environmental management. Typically, these stations record a range of other variables in addition to rainfall. Data from some of these stations has been made available by the respective companies involved, and their co-operation in this is acknowledged.

Number	Location	Records Since	Altitude	Lat.	Long	Average Rainfall
060015	Gloucester PO	1888	105	**32.01S**	**151.96E**	**982**
060112	Gloucester (Hiawatha)	1976	**125**	**32.05S**	**151.91E**	**1023**
060103	Krambach (Tipperary)	1971	**180**	**32.06S**	**152.12E**	**1111**
060155	Waukivory	2008	**158**	**32.13S**	**152.06E**	**(1157)**
060042	Craven (Longview)	1967	**130**	**32.15S**	**151.95E**	**1062**
061075	Upper Bowman	1966	**280**	**31.95S**	**151.79E**	**1104**
060102	Cundle Flat	1971	**80**	**31.83S**	**152.02E**	**916**
060117	Mt George (Manning River)	2001	**15**	**31.88S**	**152.15E**	**(1012)**
061152	Cobark	2009	**300**	**31.96S**	**151.73E**	**(1222)**
060159	Warranulla (Myall Lodge)	2005	**172**	**32.19S**	**152.11E**	**(1110)**
060137	Bretti-Mackay (Barnard River)	2001	**120**	**31.77S**	**151.89E**	**(1106)**
060118	Rocks Crossing (Nowendoc River)	2001	**70**	**31.78S**	**152.08E**	**(1014)**
060021	Krambach Post Office	1910	**75**	**32.05S**	**152.26E**	**1130**
060033	Krambach (Bellevue)	1908	**165**	**32.09S**	**152.25E**	**1060**
061151	Chichester Dam	1942	**194**	**32.24S**	**151.68E**	**1314**
061071	Stroud PO	1889	**44**	**32.40S**	**151.97E**	**1146**

Table 2.1: Active Bureau of Meteorology Rainfall Stations in or near the SGV

2.2 Rainfall Overview

The BOM weather stations in Table 2.1 can be divided into three broad groups. Gloucester and Stroud Post Offices, each with over 120 years of continuous records, stand out as a rare source of long-term information, more particularly as they represent north and south anchor points for the main valley.

Next is an intermediate group of eight stations which have been in operation for periods ranging from 105 years ago (Krambach – Bellevue), up to 42 years ago (Krambach/Tipperary and Cundle Flat). Finally, there are six stations which were established in 2001, or more recently. While this latter group provides useful comparative information on recent rainfall events, the BOM does not yet publish an annual average for them. However, these have been computed for convenience, and the values are shown in parentheses in Table 2.1. Readers who wish to compare these stations with others should do so only on a matched year basis..

The overall impression which can be gained from the average annual rainfalls presented in the final column of Table 2.1 is that there is a general decrease as one moves inland from the coast. Thus, the Krambach area and Stroud, which are 25–30 kms inland, each average around 1100 mm/pa, compared with Gloucester (50 kms inland) which scores only 980 mm/pa.

However, topography can also play an influential role. It is well-known that where a hill or mountain range lies across the line of approach of rain bearing winds, the rainfall on the approach side is heavier than that on the lee side. This is known as the orographic effect, and is due to cooling of the air stream as it rises to pass over the ridgeline. At a reduced temperature the atmosphere's capacity to hold moisture decreases, and so additional rain falls on the upwind slope. Once across the ridge, the air warms again as it descends, resulting in reduced rainfall on the downward side. This is sometimes referred to as a rain-shadow area.

Casual observation suggests that the Gloucester township site may experience a mild rain-shadow effect from its proximity to the Mograni Range, which is up to 450 metres in height, and just 3 kms to the east. If this is so, then the slightly higher Hiawatha (near Rocky Crossing on the Gloucester River) average may be more typical of the northern end of the SGV.

On a broader scale, due to the area's tectonic history, in the vicinity of the SGV and east to the coast, the dominant ridgeline trend is from north to south, and thus across the prevailing onshore summer winds. An implication of this is that quite significant local differences may occur over a short distance.

Westward from the SGV the land rises gradually to the Barrington and Craven Tops, where elevations exceed 1,500 metres. Here, in the headwaters of the Gloucester and Barrington Rivers, and other Manning tributaries, annual rainfall is typically of the order of 2,000 mm. This high rainfall, combined with the groundwater retentive capacity of the basalt capping, ensures that these streams maintain a reliable flow even during drier seasons.

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	114.9	123.4	127.7	77.3	68.1	68.4	51.2	46.5	51.0	68.7	84.0	104.0	982.4
Lowest	0.0	2.5	9.8	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	498.4
5th %ile	22.2	20.9	18.6	8.3	8.1	4.1	2.5	2.3	3.0	4.4	12.2	22.9	612.9
10th %ile	37.6	30.4	32.2	14.6	11.9	8.8	6.2	3.8	9.3	9.2	19.0	32.8	639.2
Median	100.8	90.2	98.7	57.0	48.5	49.5	29.2	30.0	36.1	51.6	73.8	93.1	955.1
90th %ile	203.6	259.2	261.5	179.4	158.7	149.1	139.9	99.4	118.2	149.0	165.4	181.0	1326.6
95th %ile	237.1	341.2	359.1	208.5	202.5	220.9	162.8	162.0	140.8	187.5	185.9	214.0	1498.7
Highest	474.4	752.4	539.5	324.4	343.2	402.4	273.5	353.7	176.1	277.2	236.7	352.5	1875.2

Table 2.2: Summary Rainfall Data for Gloucester PO - 1889 to 2012

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	115.6	126.5	144.5	101.7	91.9	100.5	75.7	64.8	63.2	78.3	84.2	103.2	1147.2
Lowest	1.8	0.0	4.4	5.2	1.3	0.0	1.0	0.0	0.0	1.1	4.6	6.0	541.0
5th %ile	18.9	13.9	25.2	15.0	13.3	9.7	6.0	5.8	3.9	9.0	9.2	23.7	688.2
10th %ile	27.7	21.8	37.7	21.8	20.4	15.6	14.2	9.9	9.7	17.0	17.8	27.6	748.3
Median	99.6	106.7	110.7	84.4	65.2	78.4	61.2	43.0	47.8	57.7	81.6	92.2	1115.4
90th %ile	187.6	241.4	289.3	201.2	175.7	220.8	157.9	138.6	144.7	174.2	152.6	206.5	1519.6
95th %ile	243.1	343.6	425.8	257.8	257.9	275.1	212.7	181.1	161.4	230.8	171.0	224.4	1665.2
Highest	538.3	511.7	527.0	537.8	375.0	521.0	293.9	494.3	245.0	355.9	296.2	301.9	1900.2

Table 2.3: Summary Rainfall Data for Stroud PO - 1889 to 2012

2.3 Variability and Risk

Table 2.4 (on the following page) shows the daily rainfall at Gloucester PO for the year 2012. While one purpose for including this table is to provide an example of the detailed data available from the BOM website, it also provides a relevant discussion point. Overall this was a rather dry year, with an annual total equal to 82% of the long-term average. However one-third of the year's total rainfall came in February, while the five months of July to November inclusive recorded a total of only 115 mm.

Such variability highlights the importance for horticulturalists of risk factors, that is, the probability that an extreme and damaging weather event might occur. An approach to this question can be developed using the summary table provided by the BOM for each weather station with a sufficiently long record period to provide a reasonable degree of statistical reliability. Tables 2.2 and 2.3 show these summaries for Gloucester and Stroud Post Offices, respectively.

In addition to the mean, each table shows the highest and lowest rainfall on record, both month by month, and for annual totals. Since we are dealing here with a record period of over 120 years, these extreme values represent rather unlikely events, assuming a stable regime. However, as will be discussed in Chapter 9, the regime is not stable, and so the likelihood of a given extreme event may be on the increase. So, for example, what at present constitutes a 1 in 100 year rainfall event, may, with climate change, become a 1 in 25 year event.

The median value is also shown. This is the "middle" value if all the values were ranked from lowest to highest. Sometimes, particularly in the case of an asymmetric distribution, the median may be a more useful indicator of the rainfall to be expected in a typical year. However, while this is not the case for either Stroud or Gloucester when annual totals are considered, there are marked differences between the mean and median values for individual months. Since, in all cases, the monthly medians are less than the mean values, this indicates that the mean is being influenced by some extremely wet months in the record.

A more precise description of variability can be achieved though the use of percentiles, which are an extension of the concept of a median value. Once again, the entire set of values is ranked from lowest to highest. Then, the value which divides the bottom 10% of readings from the top 90% is labelled the "tenth percentile". Other percentile values are defined similarly.

Because it is extreme values which are of most concern, Tables 2.2 and 2.3 show the 5th and 10th, and the 90th and 95th percentile points, both for the entire year and individually for each month. So, for example, a gardener in Stroud, making early plantings in August, has a 50/50 chance of getting a rainfall of 43mm or better, but must be prepared for 10mm or less for one year in ten. Despite the long record for Stroud and Gloucester, users should also bear in mind the current trend towards higher average rainfall. This will be discussed in Chapter 9, which deals with climate change.

2012	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Graph												
1st	0	67.6	0	↓	0	0.4	0	0	0	0	0	↓
2nd	0	65.0	4.0	1.6	0	↓	0	0	0	0	0	↓
3rd	0	31.2	↓	0	1.0	↓	0	0	0	0	0	5.2
4th	0	↓	↓	0	2.0	12.2	0	0	0	0	0	0
5th	0.8	↓	19.4	0	↓	0.2	0.2	0	0	0	0	0
6th	0	1.0	0.8	↓	↓	8.2	1.8	0	0	0	0	0
7th	↓	0	6.2	↓	0.2	5.8	↓	0	0	0	0.2	0
8th	↓	15.6	6.4	↓	0	0.2	↓	0	0	0	1.8	↓
9th	1.6	4.0	0	↓	0	↓	2.2	0	0	0	14.0	↓
10th	0	3.4	0	21.4	0	↓	0	0	0	0	↓	11.0
11th	0	↓	0	0	0	↓	2.2	↓	0	0	↓	3.0
12th	0	↓	0	0.6	0	15.4	1.0	↓	0	1.6	2.4	13.2
13th	0	17.4	0	0	0	4.0	7.8	24.0	0	0	0	0
14th	↓	1.4	0	↓	0	2.6	↓	0	0.4	0	3.6	0
15th	↓	6.8	0	↓	0	0	↓	0	0	0	0	↓
16th	4.2	0	0	16.4	0	↓	1.4	0	0	0	0	↓
17th	2.4	0	↓	16.6	0	↓	0	0	0	0	↓	0.8
18th	3.0	↓	↓	3.4	0	1.0	0	0	11.8	0	↓	0
19th	0	↓	19.0	1.0	0	0	1.0	0	9.2	0	6.8	0
20th	0	5.2	12.0	3.0	0	0	0	0	0	0	0	0
21st	↓	46.2	6.6	↓	0	0	↓	0	1.0	0	1.6	0.4
22nd	↓	2.4	0.2	↓	0	0	↓	0.6	0	0	0	↓
23rd	32.4	0.6	0	0.2	0	0	7.4	0	0	2.8	0	↓
24th	9.2	0	0	13.0	0	0	1.0	3.8	0	0	↓	3.8
25th	20.2	0	0	0	1.6	0	0.2	0	0	0	↓	↓
26th	↓	0	0	0	↓	0	0	0	0	0	1.0	↓
27th	30.0	0	↓	0	↓	12.8	0.6	0	0	0	0	30.6
28th	↓	0	↓	↓	0.8	1.8	↓	0	0	0	3.0	0
29th	↓	0	↓	↓	0.4	1.8	↓	0	0	0	0	0
30th	4.0		14.8	5.0	0.2	0.2	0.2	0	0	0	0	0
31st	0		0.4		0		0.2	0		0		0
Highest Daily	20.2	67.6	12.0	16.6	2.0	12.8	7.8	3.8	11.8	2.8	14.0	13.2
Monthly Total	107.8	267.8	89.8	82.2	6.2	66.6	27.2	28.4	22.4	4.4	34.4	68.0

Table 2.4: Daily Rainfall at Gloucester PO for 2012 Table

2.4 Where does our rain come from ?

Rain is delivered to the SGV through four primary processes which can be broadly accorded individual identity. These are, in approximate order of relative importance:

- On-coast anticyclonic winds;
- Frontal systems / cut-off lows moving from the south-west;
- East coast depressions; and
- Thunderstorms.

The first two of the above can be viewed as normal weather processes, which are seasonally linked, but which between them deliver sustaining rainfall throughout the year. The latter two are more dramatic individual events, which occur less frequently, but may deliver an abundant rainfall in a short period. However, no neat and conclusive categorization is possible, as there are endless possible combinations of weather events.

2.4.1 On-shore Anticyclonic Winds

The dominant source of rain in the SGV is from on-shore winds from the east and southeast, commonly referred to as the trade winds. The typical scenario involves a high pressure system moving from the west across the southern part of the continent, often dipping southwards as it nears the east coast. Since there is an anti-clockwise air circulation around high pressure cells in the southern hemisphere, this results in moist oceanic air being fed onto the central, mid-north, and north coastal areas of NSW from the east and southeast.

Most rain from this source comes during the summer months, when the overall global wind pattern has shifted southwards. In winter, as global wind systems shift to the north, the high pressure cells tend to track across the lower centre of the continent, bringing fine clear weather to the SGV, though the far North Coast may receive still some rain from this source.

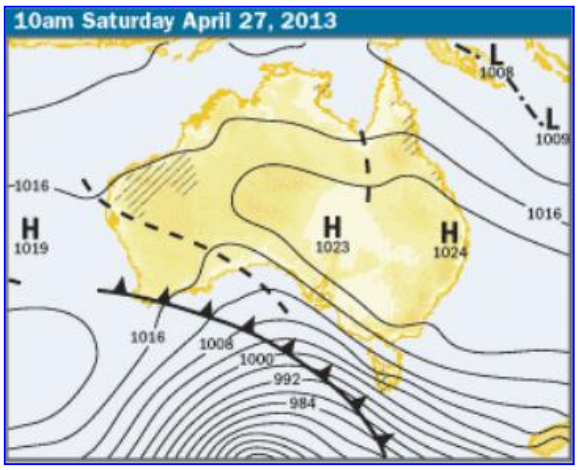
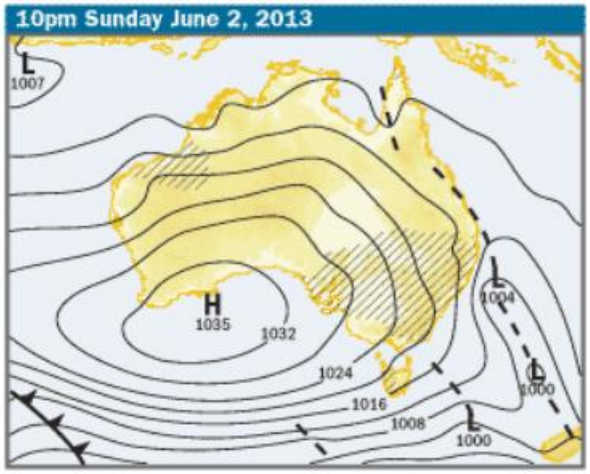


Figure 2.1, which is a snip form the BOM's four-day forecast page, shows such a scenario, when the SGV was enjoying clear sunny skies, but some rain was falling further north. Clearly, a southward shift of 10º of latitude, which is characteristic of the summer months, would direct rain onto the lower east coast of NSW. (See Figure 1.2).

Figure 2.1: Anti-cyclone in Autumn

2.4.2 Frontal Systems from the SW

Referring to Figure 1.1 again, to the south of the Sub-tropical (High Pressure) Ridge there is a low-pressure belt circling the globe. This is characterised by low pressure cells (commonly called Lows or Depressions), which also move from west to east, and which rotate in an clockwise direction. As with the sub-tropical ridge, this low pressure belt also moves further north in winter, and back southwards again in summer. The BOM refers to this annual cycle as the "Southern Annular Mode", but the strong winds generated in this zone may be better known to readers of seafaring stories as the "Roaring Forties".

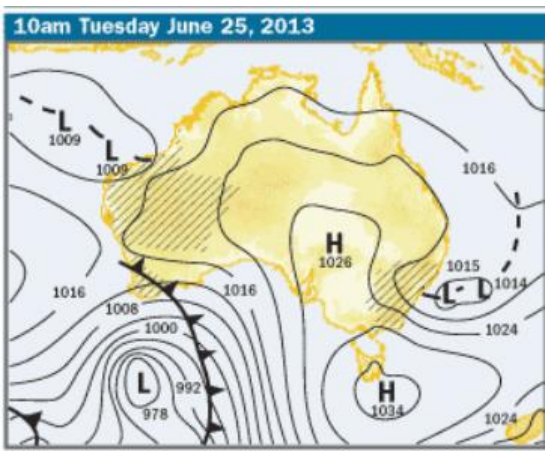


Sometimes a low may breach the STR and move northwards, to become a "Cut-off Low", or a low pressure trough may form spontaneously in the Great Australian Bight. In either case the system may move across Victoria and into NSW, bringing with it cool cloudy conditions and light to heavy rain falls. If there is co-incidentally a relatively stationary high pressure system (a blocking high) to the east of the Bass Strait, the weather pattern over southern NSW may persist for up to a week, and extend north to include the SGV. While such events can occur at any time of the year, they are more common in autumn and winter.

Figure 2.2: Rain from the Southwest

2.3.3 East Coast Lows

Low pressure systems centred just off the NSW coast can bring heavy rainfall episodes, and strong winds. These lows can develop in two ways. Firstly, a decayed tropical cyclone, after tracking across the northern parts of the continent, may turn southwards instead of continuing away to the east. Typically, they move south just off the Queensland and NSW coastlines, before finally dissipating. This process can import a mass of saturated tropical air into a cooler latitude, resulting in heavy rainfall, with likely flooding in the most affected areas. These events occur mainly in summer.



Under a different process, intense low pressure cells may develop spontaneously off the southern NSW or east Victorian coasts. The clockwise swirl of winds about the centre may bring storm-force winds and heavy seas to coastal areas just to the north, along with heavy rain which may penetrate some distance inland. Such systems may remain stationary for a few days, or even move slightly north, before being pushed away to the east by the next high pressure system from the west. Events of this nature are more common in the winter months.

Figure 2.3: East Coast Low

In either situation, if a high approaching from the west moves into proximity to the low, then the anti-clockwise swirl around this system may reinforce the clockwise rotation about the low, increasing the intensity and duration of the event. The chart for the 25th of June 2013, as shown in Figure 2.3, illustrates one such event, which brought heavy rainfall and high seas to the NSW south and central coastal areas, though inland falls were relatively light.

2.3.4 Thunderstorms

In summertime, local thunderstorm cells can develop on warm humid afternoons, often moving across the GSV in an easterly direction. The footprint of such storms may be confined to quite a narrow swathe, which might be less than a kilometre in width. Local folklore holds that there are identifiable and consistent storm-tracks crossing the Valley, but this conjecture has yet to be confirmed. In round terms, about two-thirds of storms occur in the months of November to January inclusive, and a similar proportion are initiated in the afternoon between 2pm and 6pm.

The dynamics of a thunderstorm are complex and dramatic. Initially, as a column of warm moist air begins to rise, local winds are generated at ground level, flowing inwards towards the low pressure centre. The warm air rises rapidly, extending to an altitude of three to five kilometres, or even higher, and, as the temperature falls with increasing height, the characteristic cumulus cloud column forms.

Within this column, the moisture condenses to raindrops, which may initially be carried still higher, and freeze to form hailstones. An enormous amount of latent heat is released through this process, contributing to atmospheric turbulence, and generating static electrical charges, which may cause lightning.

Eventually a downward stream of cool air is established in one sector of the column, bringing intense localised rain or hail to the ground. As noted above, the storm may move across country for several kilometres, until it gradually dissipates. When fully developed, the downdraft may be experienced at some distance from the storm centre as a cold windblast with the potential to cause damage to orchards. Within the storm track, a heavy fall of hail may completely destroy a crop which was ready for, or approaching, harvest.

Thunderstorm incidence in Australia is greatest on the northwestern coastal zone in the Northern Territory, where on average there are over 80 storm-days per year. The incidence decreases inland to as low as ten storm days in parts of South Australia and Victoria. However, there is a localised high incidence peak of 40 storm days per annum along the NSW east coast between Newcastle and Coffs Harbour, and this extends inland to include the SGV. This relatively high likelihood of hailstorm events is a factor which growers in the SGV should take into account.

Figure 2.4 on the following page illustrates the typical stages through which a thunderstorm passes.

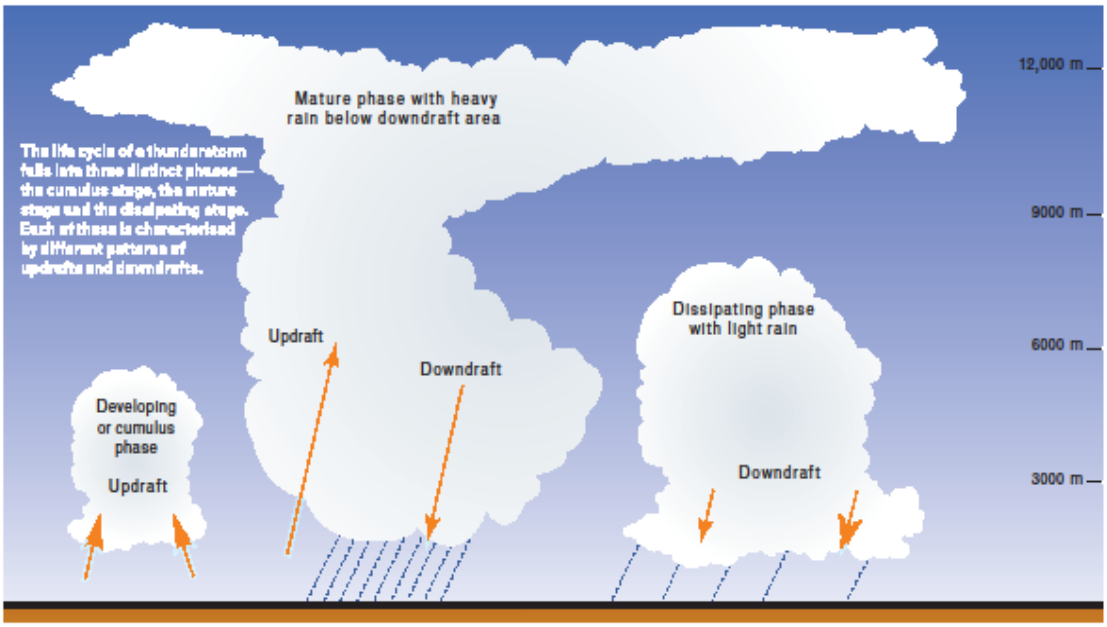


Figure 2.4: Three Stages in a Thunderstorm Cycle [3]

[3] Reproduced with permission from Whittaker, R.: ***The Complete Book of Australian Weather***; Allen & Unwin, Sydney (2010).

3 Temperature

The temperature of the surrounding air is probably the climatic variable of which we are most constantly and personally aware. Globally, recorded temperatures have ranged from an extreme maximum of 56.7^{0}C at Death Valley in California, to a minimum of -89.2^{0}C in Antarctica. The highest official temperature on record for Australia is 50.7^{0}C at Oodnadatta in SA in 1960, and the other States, with the exception of Tasmania, have recorded maxima close to that value. The award for the coldest spot in Australia goes to Charlotte Pass in the Snowy Mountains, but this is hardly a typical location.

3.1 Temperatures for the SGV

Coming closer to home, there is no current BOM temperature data available for any location in the SGV. The closest representative station is Dungog PO, where records were kept for the period 1966 – 1975 only.[4] Table 3.1 shows summary statistics for daily and monthly maxima for that period.

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	29.0	28.8	27.5	25.3	21.1	18.1	18.4	19.3	22.2	25.4	27.5	29.2
Highest monthly mean	34.0	31.1	29.3	27.4	23.6	19.8	20.2	20.8	25.2	28.0	31.4	31.3
Lowest monthly mean	26.9	26.4	24.9	23.5	19.4	17.0	17.3	17.9	19.8	23.3	25.9	27.8
Highest Daily	41.7	43.0	36.5	33.9	28.8	26.2	26.0	28.5	34.0	36.2	45.0	41.1
Lowest Daily	17.7	18.3	18.7	15.6	12.2	10.0	10.0	10.0	12.0	13.3	17.8	16.7

Table 3.1: Maximum Temperatures at Dungog PO - 1966 to 1971

To compute these values, the daily maximum is first recorded for each day of a month. The overall mean (top row) is then the average of these daily maxima for a given month over all the years of record. The highest and lowest monthly means are obtained by calculating individual monthly means over the record period, and then selecting the maximum and minimum for each individual month. The highest and lowest daily temperatures are the highest maximum recorded for any day in that month, over all the years of record, and the least value among those maxima. Minimum temperatures, as shown in Table 3.2 below, are calculated in a similar manner.

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	16.9	17.0	15.0	11.0	7.8	5.8	3.7	5.1	7.2	10.9	12.7	15.1
Highest monthly mean	18.7	19.3	16.1	14.5	9.8	10.1	8.3	7.5	9.4	13.3	14.9	17.7
Lowest monthly mean	15.7	15.5	13.1	7.6	6.1	2.6	0.3	3.7	5.9	7.5	10.8	11.2
Highest Daily	23.9	25.8	21.0	20.1	16.6	14.6	13.0	15.0	16.2	19.6	20.5	21.7
Lowest Daily	7.2	10.0	5.6	3.0	0.4	-0.6	-6.1	-2.2	-0.6	0.6	4.5	6.1

Table 3.2: Minimum Temperatures at Dungog PO - 1966 to 1971

[4] Some temperature data is also available for Chichester Dam for the period 1938 to 1956, and for Tocal and Lostock from 1967 and 1969 respectively to the present.

3.2 Temperature and Altitude

It is well-known that air pressure decreases with increasing altitude, so that mountain climbers, or pilots in a non-pressurised cabin, need oxygen assistance above about 2,500 m. While oxygen supply is not a problem anywhere in Australia, even on the top of Mt Kosciusko, a related factor is that the ambient air temperature also decreases with altitude, and this effect is noticeable over shorter ranges .

The change in air temperature with altitude depends on a number of factors, one of which is the amount of moisture (water vapour) in the air. However, it is the cooling effect induced by expansion under reduced pressure that is the main cause. In the lower parts of the atmosphere, and under calm conditions and average humidity, an increase in altitude of 1000 metres typically results in a decrease in temperature of the air of about 7.0 ºC. This is called the temperature lapse rate.

While a progressive reduction in temperature with increasing height is the norm, extremely windy conditions may reduce the temperature gradient locally through mixing. Conversely, on clear cool nights in calm weather, a phenomenon known as a temperature inversion may occur, whereby the temperature actually increases with height over a short range.

Significant variation in temperature can occur in the layer of air close to the ground, as shown (in a highly idealised manner) in the graphs below. This is particularly evident on cold nights and warm days when there is little or no wind to mix the air.

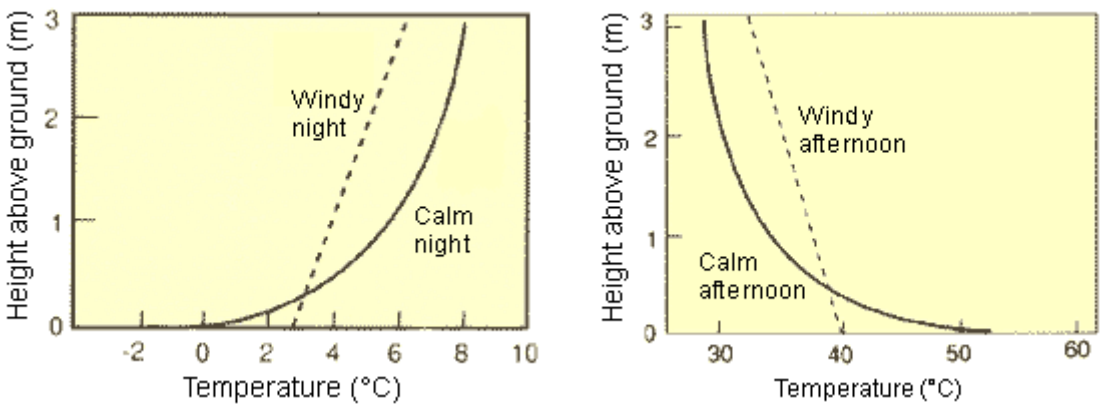


Figure 3.1: Temperature variation close to the ground [5]

Since by far the greater proportion of the arable land in the SGV is a mere 100 to 300 metres above sea level, the differences in temperature due to altitude per se are of the order of one to two degrees. However, properties located in the foothills of the Barrington Tops may present a variety of slopes and aspects, which in combination may offer niche microclimate opportunities for crops with specific requirements, and in such cases altitude may have a role to play in assessing the overall productive potential. Some preliminary data on these aspects is provided in the following section.

[5] These graphs have been copied from the BOM website.

3.3 TinyTag Data Loggers

In order to fill the gap in temperature data for the SGV, and as part of its overall research programme, The Gloucester Project has acquired a number of TinyTag Temperature Loggers (see Appendix A for details).

In 2010, while carrying out research under a Hunter Central Rivers - CMA grant, TGP began using the loggers to map temperature variations between contrasting sites in the SGV and tributary sub-catchments. In an initial trial, four loggers were sited on two grazing properties, located in the middle and upper reaches of the Gloucester River valley, respectively. The loggers were positioned at the end of June 2010, and collected again in May 2011, when they had accumulated a total of 329 days of temperature data at one-hour intervals, which was their maximum recording capacity.

The choice of these locations was determined by the topography of the Gloucester River Valley. After descending from the Gloucester Tops, the river winds between rounded hills, sometimes widening out to receive tributaries, while at other places narrowing to flow between closely spaced bluffs. Frequently, in its meanderings, it has created small alluvial flats, ranging from a hectare or two up to about six hectares in area. Such fertile mini-flats have potential for intensive fruit and vegetable production, and are thus of significance for the future development of the local economy.

Tables 3.3 and 3.4 provide summary comparisons of the temperature records from the four sites, and serve as an introduction to the complexities of microclimate characterization.

Mean temperatures for all four sites had a range of only 1.4ºC, though the effect of higher altitude at the Paskins' property was consistent. Maximum temperatures displayed a slightly wider range of 2.5ºC, with the altitude effect again evident. Within properties, where there were negligible altitude effects, the more sheltered and frost-prone sites recorded the lower temperatures. The recorded minima at all four sites ranged from -2.5ºC down to -3.2ºC, indicating one or more moderate frost events, though it should be noted that the record period excluded late May and most of June.

In summary therefore, while bearing in mind the limitations of this data set, it appears that on average, with an allowance for differences in altitude, the temperatures experienced in this limited trial were consistent between properties and sites. However, averages may hide more than they reveal.

Table 3.4 provides an analysis of the data obtained by taking, firstly, the differences between the individual sites on a property, and, secondly, the differences between the corresponding sites (i.e. hillside versus river-flat) on each property. Here, interest is focused on the differences between the temperatures recorded, hour by hour, at each pair of sites.

The maximum column shows that for each pair, a positive instantaneous difference of up to 9.4ºC was observed, with corresponding negative differences (minima) of the order of five degrees. (The apparent asymmetry is due to the site with the higher average having been placed first in each ordered pair). The range is then derived as the absolute difference between the maxima and minima.

This constitutes persuasive evidence that significant daily and seasonal variations in temperature can exist between sites which are closely spaced but differ in aspect and other characteristics. However, a more detailed analysis of these factors is beyond the scope of this report, and our current state of knowledge.

Property	**Logger Situation**	**Altitude**	**Actual Temperatures**			
			Mean	Median	Max	Min
Paskins (1)	North sloping hillside with scattered trees.	280 m	16.2	16.2	38.9	-2.5
Paskins (2)	Vegetated river flat in western shadow of a hill.	265 m	15.8	16.2	37.5	-3.2
Salvestro (1)	Level ridge top, in open pasture.	165 m	17.2	17.1	41.0	-2.5
Salvestro (2)	River flat close to bank vegetation on east side.	135 m	16.4	16.8	39.4	-2.7

TABLE 3.3: Data Logger Details for Initial Trial

Recording period 24/06/2010 to 17/05/2011 (329 days)

Ordered Pair	**Paired Temperature Differences**			
	Mean	Max	Min	Range
Pas (1) – Pas (2)	0.3	7.5	-3.3	10.8
Sal (1) – Sal (2)	0.8	8.9	-5.0	13.9
Sal (1) – Pas (1)	1.0	9.4	-5.4	14.8
Sal (2) – Pas (2)	0.6	8.4	-6.0	14.4

Table 3.4: Comparative Summary for Initial Trial

3.4 Stage Two

Commencing on the 1st of April 2012, a total of seven loggers were deployed, each set to record at two-hourly intervals over a full year. These were installed over a wider area ranging from Stroud to Tibbuc, which is about 30 kms north of Gloucester. The installation sites were selected giving consideration to the need to build up a broadly representative data base, and also to support members of TGP's Growers Network. The loggers were retrieved on or just after the 1st of April 2013, and the data was analysed using more sophisticated software than that available for Stage One.

Table 3.5 provides a description of the locations and site details of the loggers, while summary statistics are presented in Tables 3.6 and 3.7.

In overview (Table 3.6), the extreme and average readings did not vary significantly, with the annual average ranging from 16.6ºC to 17.4ºC. Similarly, maxima ranged from 43.1ºC to 44.7ºC, while minima displayed a slightly wider range of -1.5ºC to -3.7ºC. The latter two readings were obtained at the Tucker Patch, from sites located only about 70m apart, but with differing frost exposures.

Logger	Location	Altitude	Site Description
T01	Stroud Road	75	Vegetable patch on SSE flank of a 180m hill; moderate slope, with building uphill.
T02	Stroud	25	Vegetable patch on slight SSE slope, with several buildings in the vicinity.
T03	Tibbuc	150	Level garden, with hedges and buildings.
T04	Gloucester Town	100	Backyard block of two-storey dwelling in a slight valley on a north facing slope, surrounded by hedged fences.
T09	Tucker Patch	85	Open pasture on lowest point of the Patch, at 62 Cemetery Rd.
T10	Tucker Patch	100	Level open ridgetop developed as a horticultural farm.
TH1	Tucker Patch	100	Level open ridgetop close to Tucker Patch entry. This logger also recorded humidity.

Table 3.5: Logger Location and Site Descriptions

The lower part of Table 3.6 introduces the concept of a ***degree-hour***. This is related to the ***growing degree day*** (GDD**)**, which may be familiar to some readers, but is a more refined measure.

Essentially, a degree growing day attempts to measure the cumulative amount of heat available to a given crop. First, a base temperature is set, below which it is assumed no growth activity will take place. Obviously, this base temperature will vary from one crop to another. Then for each day on which the temperature exceeds the base, the average between the maximum and minimum readings is calculated, and the base value is subtracted from this. The result is then added into the cumulative total.

For example, a day with a maximum of 28 °C and a minimum of 18 °C would contribute 8.0 GDDs relative to a base of 15 °C:

$$(28 + 18) / 2 - 15 = 8$$

The GDD concept suffers from a couple of shortcomings. First, the max/min average may not reflect the true daily average at a particular site. Secondly, no account is taken of changes in the period of daylight with latitude and seasons. However, it does have the advantage of being easily calculated from minimal data.

Where temperature readings are available at frequent intervals during the daily cycle, e.g. hourly or two-hourly, it is possible to calculate accurately the total number of degree hours experienced above or below a given reference temperature, or within a particular temperature range or bandwidth. This in turn enables the characteristics of a given site to be identified, and facilitates comparisons between sites.

Thus, where a horticulturalist is in possession of information about the critical temperature ranges for germination, growth, and ripening of a particular crop, she can set the band boundaries appropriately, and assess the suitability or otherwise of a particular site. In addition, once a data set has been recorded, it may be analysed repeatedly using different choices of bands.

The lower part of Table 3.6 shows the degree-hour totals for each logger. These have been calculated separately for below zero degrees, above 35°C, and for five-degree bands in between. These bounds were chosen solely for convenience of presentation, though zero is obviously a value of interest. A similar table can be produced using any other choice of boundary parameters (up to a limit of eight).

Numbers such as 151,577 °C hours are challenging to juggle, so in Table 3.7 the degree-hour data is presented in percentage form. Not only does this facilitate comparisons, but it eliminates the small difference in the number of readings taken at each site. However, the Table 3.6 data on frost experience is easy to absorb and compare. Here the degree hours count ranged from 4.6 up to 101.4. Read in combination with the recorded minima (-1.7° and -3.7° respectively), this points to a quite significant difference in frost exposure between the two sites.

TinyTag ID	T01	T02	T03	T04	T09	T10	TH1
Total Readings	4412	4413	4555	4483	4602	4436	4434
Minimum Reading	-1.7 °C	-1.7 °C	-3.0 °C	-2.7 °C	-3.7 °C	-2.5 °C	-1.5 °C
Maximum Reading	43.1 °C	43.7 °C	44.2 °C	44.2 °C	43.7 °C	43.7 °C	44.7 °C
Average Reading	17.3 °C	16.9 °C	16.6 °C	17.1 °C	16.8 °C	17.0 °C	17.4 °C
Area below 0.0 °C	4.6. °C hour	9.3. °C hour	80.2. °C hour	51.6. °C hour	101.4. °C hour	34.5. °C hour	10.4. °C hour
Area above 0.0 °C	152369. °C hour	149455. °C hour	151577. °C hour	153637. °C hour	147115. °C hour	149086. °C hour	152495. °C hour
Area above 5.0 °C	108702. °C hour	106299. °C hour	107721. °C hour	110175. °C hour	105043. °C hour	106395. °C hour	109475. °C hour
Area above 10.0 °C	68145. °C hour	67324. °C hour	68343. °C hour	70741. °C hour	67192. °C hour	67470. °C hour	70049. °C hour
Area above 15.0 °C	35524. °C hour	36027. °C hour	36463. °C hour	38353. °C hour	36362. °C hour	35896. °C hour	37965. °C hour
Area above 20.0 °C	14071. °C hour	15217. °C hour	15669. °C hour	16495. °C hour	15472. °C hour	14904. °C hour	16276. °C hour
Area above 25.0 °C	4536. °C hour	5446. °C hour	5909. °C hour	6186. °C hour	5498. °C hour	5233. °C hour	6066. °C hour
Area above 30.0 °C	1168. °C hour	1524. °C hour	1838. °C hour	1840. °C hour	1569. °C hour	1487. °C hour	1812. °C hour
Area above 35.0 °C	209. °C hour	282. °C hour	342. °C hour	344. °C hour	301. °C hour	277. °C hour	365. °C hour

Table 3.6: Temperature Data for Seven SGV Stations (2012 – 2013)

	%	%	%	%	%	%	%
TinyTag ID	T01	T02	T03	T04	T09	T10	TH1
Below 0.0 °C	0.00	0.01	0.05	0.03	0.07	0.02	0.01
0.0 to 5.0 °C	28.66	28.87	28.92	28.28	28.58	28.63	28.21
5.0 to 10.0 °C	26.62	26.08	25.97	25.66	25.71	26.10	25.85
10.0 to 15.0 °C	21.41	20.94	21.02	21.07	20.94	21.17	21.04
15.0 to 20.0 °C	14.08	13.92	13.71	14.22	14.19	14.08	14.22
20.0 to 25.0 °C	6.26	6.54	6.44	6.71	6.78	6.49	6.70
25.0 to 30.0 °C	2.21	2.62	2.68	2.83	2.67	2.51	2.79
30.0 to 35.0 °C	0.63	0.83	0.99	0.97	0.86	0.81	0.95
Above 35.0 °C	0.14	0.19	0.23	0.22	0.20	0.19	0.24
	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 3.7: % Temperature Data for Seven SGV Stations (2012 – 2013)

3.5 Future Research Programme

Despite the pointless theft of one logger and its casing from The Tucker Patch in 2012, TGP was able to deploy a total of 14 loggers prior to the 1st of May 2013. As before, these were distributed over a wide area, and on sites selected for the potential usefulness of the data to be collected. The loggers have been programmed to record the ambient temperature at two-hourly intervals, commencing at midnight on the 30th of April, and ending exactly one year later.

In the early stages of this project, the primary value of the data is as an aid in discriminating between sites, and in gaining insight into the controlling microclimatic factors. As longer time series are accumulated, increasingly reliable estimates of variability between years and individual seasons will become available. However, this is a long-term project, as most scientists would consider a ten-year record to be the minimum series suitable for even rough risk estimates.

4.0 Insolation

The term ***insolation*** refers to the energy content of the sunlight received at a specific site on the earth's surface. Normally this would be a patch of earth, but the concept may be extended to include a roof or wall, or a tilted solar panel, with obvious relevance to domestic solar systems. However, in this report, the focus is on insolation as received either on bare earth or on vegetation, which in turn relates to the complex of factors such as earth warming, surface evaporation, transpiration, photosynthetic activity, and, ultimately, to vegetation growth rates and our survival.

The sun pours out radiation in all directions, and Planet Earth, at a distance of 150 million kilometres, intercepts a minute fraction of this total effusion of energy. In round figures, and globally, some 30% of this received energy is immediately absorbed or scattered during its passage through the atmosphere, or reflected back to space from clouds or the earth's surface.

The effective insolation received at a given spot on the earth's surface is further determined by a number of factors. Globally, the primary determinants are latitude and seasonal effects. Locally it is the aspect of the site, that is, whether the land is level or sloping, and if so, in which direction.

4.1 Latitude

This refers to the distance north or south from the equator, which is assigned a latitude of zero degrees. The north pole then has a latitude of 90º north, while the south pole is 90º south. It may be helpful to bear in mind that a degree of latitude equates to a surface distance of about 110 kms.

If the earth's axis were perpendicular to the plane of its orbit around the sun (called the ecliptic), then the sun would always be directly overhead at the equator, and its angle of elevation would decrease steadily as one moved north or south, until the sun would be on the horizon at each pole. But in fact, the axis is tilted at an angle of 23.5º from the vertical (or 66.5º from the ecliptic). The result is that at one time of the year the sun is directly overhead at latitude 23.5º north, while six months later it is overhead at 23.5º south. It follows that it is directly overhead at the equator twice in each annual cycle.

4.2 Aspect

Not all of the earth's surface is flat – in fact, in the environs of Gloucester it is generally quite hilly. The local characteristics of a sloping piece of ground can be captured by two parameters, namely ***slope*** and ***azimuth***. Slope refers to the steepness of the land, and is usually measured in degrees from the horizontal. Azimuth refers to the compass direction in which the slope is facing. Due north is labeled 0º, and values increase in a clockwise direction through East (90º). South (180º) and so on back to North, where 360º becomes zero again.

These two measures can conveniently be combined into one by considering the direction in which a small patch of sloping ground is actually "facing", and representing this by a line (e.g. a

post) which is vertical to the ground at that precise spot. This direction can then be referred to as the ***aspect*** of that site, which requires two (spherical) coordinates to identify it.

Think now of an incoming beam of sunlight with a square cross section measuring one metre by one metre. If the sun is directly overhead, then all of the energy content of this beam will fall on one square metre of (level) ground. However, if the sun is lower in the sky, then the square will be elongated into a rectangle with a width of one metre but a length greater than one metre. Furthermore, the smaller the sun's angle of elevation above the horizon the greater will be the factor by which the rectangle is elongated. The net outcome is that a quantum of energy which was originally captured by one square metre of ground is now spread over a larger area, with a resultant decrease in intensity. [6]

4.3 BOM Insolation Data

Prior to 1990 the Bureau of Meteorology gathered data on what it termed ***solar exposure*** at selected stations, using on-site instrumentation. Starting from that year, insolation is now estimated using the known radiation received at the outer shell of the atmosphere, adjusted for factors such as atmospheric absorption and scattering, and cloud cover as obtained from satellite imagery.

In Australia the dominant variables are latitude and cloud cover. Thus, the highest readings are for inland areas, where the sky is generally clear. Values are lower in south-eastern coastal situations, with Tasmania at the bottom of the list.

Insolation intensity is measured in watts per square metre of the receiving surface($W/m^{2)}$, and will vary throughout the day and the seasons under the influence of all of the factors noted above. The instantaneous intensity is then summed over a twenty-four hour period to give a measure of total energy received, which is expressed in kilowatt hours per square metre (kWh/m^2). In themselves, such values are not of direct interest to horticulturalists. What is more relevant are comparative annual ranges; seasonal variations at a given location; differences between localities; and the local effect of aspect on non-level ground.

4.4 Insolation at Gloucester

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	6.3	5.6	4.9	4.1	3.2	2.7	3.0	3.9	5.0	5.6	6.1	6.6	4.8
Lowest	4.9	4.4	4.1	3.0	2.6	2.2	2.5	3.0	4.0	4.4	4.8	5.8	4.4
Highest	7.5	6.7	6.2	5.1	3.9	3.4	3.7	4.6	5.7	6.6	7.6	7.6	5.4

Table 4.1: Daily Solar Exposure at Gloucester Post Office 1990 - 2012 (kWh/m^2)

[6] For those with a mathematical bent, the intensity of the received energy per square metre is proportional to Sine θ, where θ is the sun's angle of elevation above the horizon. The Sine function ranges in value from zero at 0º to 1 at 90º. However, when the sun's elevation is low, there is also a greater loss due to passage of its rays through a greater mass of atmosphere.

The above table shows summary daily cumulative insolation statistics for Gloucester Post Office, which can be considered as representative for the SGV. The peak months are November to January, with a fall-off in February which can be associated with higher rainfall and associated cloud cover. The annual range shows June as receiving only 41% of the December maximum. The monthly ranges between minima and maxima are also significant, with the lowest recording being typically about two-thirds of the highest for each month.

For comparison, the December means at Lismore and Hobart (surprisingly) are equal at 6.8, while the June averages are 3.1 and 1.4 respectively. The annual average at Lismore reads at 5.1, as compared with 4.0 for Hobart.

4.5 Sun Charts

The combined effects of the yearly cycle of the seasons, and differences in latitude, can be represented by a graphical device called a sun chart. In a manner similar to a wind rose, the sun chart compresses an amazing amount of information into a single picture.

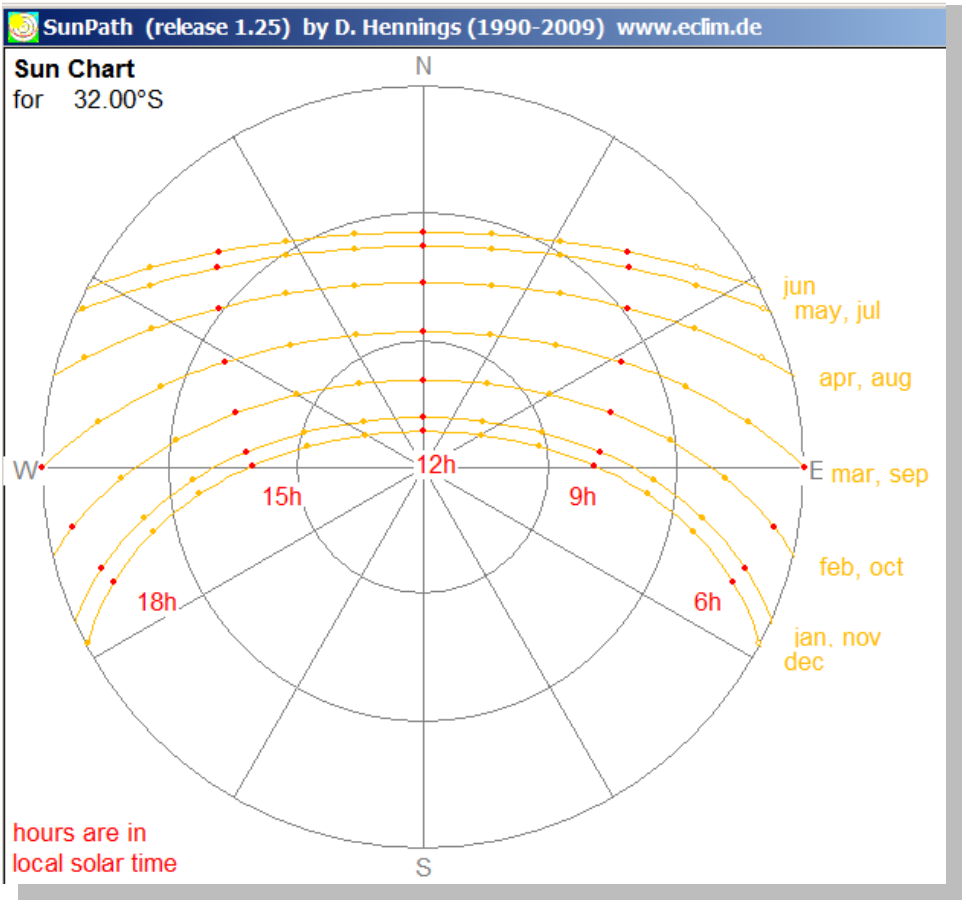


Figure 4.1: Sun Chart for Gloucester

The sun chart above shows the angle of elevation of the sun at each month throughout the year, as seen from Gloucester, and also the length of the day as shown by the small hourly dots. It has been reproduced with permission from detlef.hennings@eclim.de .

The centre of the circle represents the zenith (directly overhead), while the inner circle corresponds to an elevation of 60º above the horizon. Similarly the next circle corresponds to an elevation of 30º, while the outer circle represents the horizon (0º). In December, at the summer solstice, the sun at (solar) midday is due north, and only 8.5º short of being directly overhead. At the winter solstice in June, the sun's midday elevation at Gloucester has been reduced to 55.5º.

The period of daylight can be seen to vary from just under 10 hours in June to 14 hours in December. This may not seem a significant difference, but in combination with the seasonal variation in the sun's elevation, it is, in fact very significant.

A lesser factor is the seasonal variation in the direction in which the sun rises and sets. Since the radii in the above diagram are spaced at 30º, it can be seen that in mid-winter the sun rises about 60º to the East of due North, and sets at an equal angle to the West. In contrast, the mid-summer sunrise is almost 30º south of east, and sunset at the same angle south of west.

Could expand ?

5.0 Wind

Wind is often a significant factor in micro-climatic analysis. This is particularly so in hilly or mountainous areas, and in narrow elongated valleys, such as the SGV, and its tributary valleys along the Gloucester and Barrington rivers. The two primary characteristics of wind movement are direction and speed, but these are qualified by secondary attributes such as temperature and humidity.

Readings to record the direction and speed of airflow are typically taken at specialised weather stations, by sampling at hourly or quarter-hourly intervals. The direction from which the wind is blowing is normally recorded using an eight or sixteen-point compass scale, which correspond respectively to angular intervals of 45.0º or 22.5º around a complete circle. The primary directions are the standard N, S, E, and W, and in between them are slotted the remaining twelve points of the 16 point compass. These are denoted, for example, as NE, which is half-way between North and East, and NNE and ENE, which are in turn half-way between N and NE, and between NE and E. Similar notation is used in the other three quadrants.

Speed is measured in metres per second (m/s), while direction is measured by allocating the observed direction to the closest point on the sixteen point compass. As most people will be aware, wind seldom blows for long in a steady stream from one direction. At the very least, there can be frequent variations in speed, and also in direction. Often, wind movement is characterised by variable "gusts", where direction and speed can be close to chaotic, but over a period meaningful information can be gathered.

5.1 Wind Data for the SGV

Unlike rainfall, where up to 120 years of continuous records are available, the BOM holds no wind data for the SGV. The nearest stations are at Williamtown and Taree Airports, neither of which has any relevance for the Gloucester locality.

However, as noted previously in Section 2.1, some resource extraction companies have established private weather stations, the data from which is publicly available. One of these was installed by Gloucester Resources Ltd at its Forbesdale site, and records are available from July 2010.

5.2 Presentation of Wind Data

In common with other types of climatic data, raw records of wind behaviour are virtually impossible to digest. As discussed in other sections of this report, attributes such as temperature are measured on a single scale, where values simply go up and down. In such cases records taken over a long period can be described in terms of averages, ranges, or percentiles, and by month, year, or any other period.

But wind data is essentially two dimensional. That is, we have to take into account, simultaneously, both speed and direction, and convey to the user the relative frequencies of

each, in a format that can be easily understood, and applied in practice. This is achieved through the use of an efficient graphical device which is able to represent the joint distribution of direction and speed. This is, imaginatively, termed a "Wind Rose".

5.3 Interrogating a Wind Rose

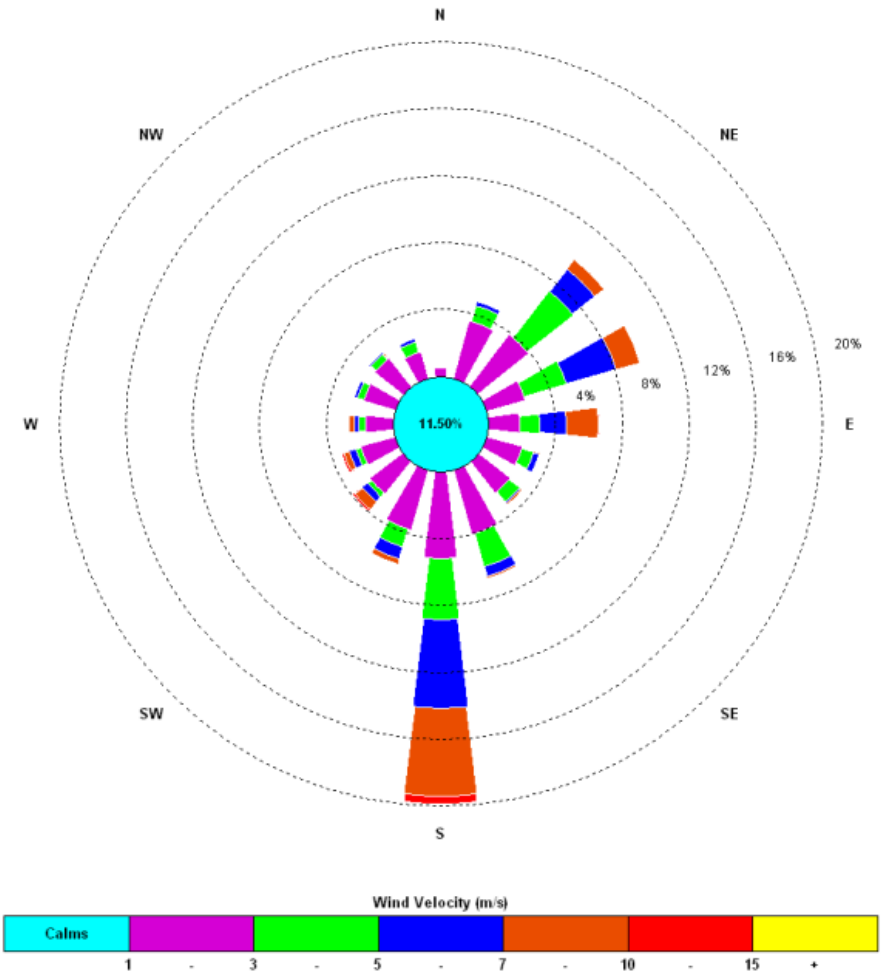


Figure 5.1: Forbesdale Wind Rose for December 2012

The example shown above is for the month of December 2012, as recorded at Gloucester Resources Ltd's Forbesdale weather station, which is about five kms SSE of the township.

Wind velocity is depicted using the coloured scale, which is gradated in metres per second (m/s). Velocities of one m/s or less are classified as "Calms", and coloured pale blue. The increments in the scale increase progressively, so that red indicates velocities greater than 10 m/s and up to 15 m/s, and yellow velocities greater than 15 m/s. In terms of the Beaufort Scale, a velocity of 5 m/s would correspond to a "gentle breeze" in which "loose paper blows around", while 15 m/s is classed as a "moderate gale", in which "large trees sway".

Wind direction, as noted above, is recorded on a sixteen-point compass scale, with each reading allocated to the nearest category. The complete data set for a period (e.g. month or year) can

now be presented as a 7 x 16 table, with 7 rows corresponding to velocity categories, and the 16 columns to direction. The cell values across the table are then converted to percentages, with the overall table total corresponding to 100%.

Finally, the velocity percentages for each row are plotted onto a circular graph, where the distance from the common centre of each of the concentric circles represents the cumulative number of percentage points.

In this example, the innermost circle (pale blue) records that for 11.5% of December 2012 the weather was calm, that is the wind velocity was one m/s or less. For obvious reasons, these readings cannot be attributed to any point of the compass.

The remaining 88.5% can be so represented. This is done by drawing sixteen radii each representing the total percentage of wind received from that direction, and then further dividing these into coloured segments to represent the proportions of wind recorded in different speed bands.

Returning to Figure 5.1 above, the dominant wind direction recorded in that month was from due south, accounting for 20% of the total time, or almost 23% of the total, excluding calms. As a further explanation, reading out along that southerly spoke, it can be seen that for about 5% o f the time the winds were purple, and for another 4% green they were green. Finally, at the extreme outer edge, a brief record (less than 1%) of winds in excess of 10 m/s was recorded.

5.4 Winds in the SGV

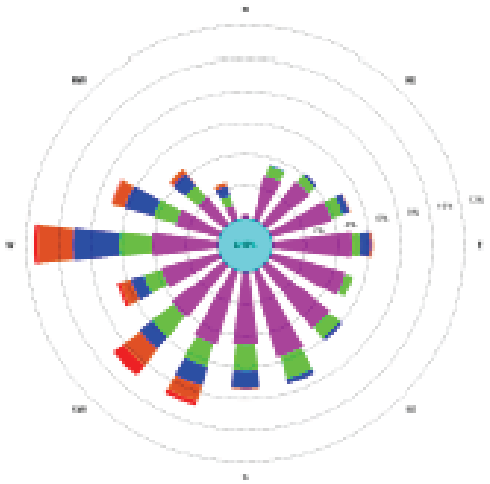
Broadly speaking, the dominant wind sector is from SW around to E, the current direction being determined by the interplay between successive high and low pressure systems, as discussed in Chapter 2. Because of the strong north-south orientation of the ridge systems enclosing the SGV, winds approaching from another angle are subject to diversion along the valley's alignment. It is therefore to be expected that, for winds recorded on the floor of the SGV, there will be a preponderance of north to south, or south to north, wind flows.

In contrast, in the Gloucester River valley, which cuts across the ridges from west to east, wind flows would be aligned along that axis. However, even within that valley, the complex of meanderings, and tributary valleys, has the potential to reduce a steady broadscale wind flow to local chaos.

In summary, it appears that, with the paucity of data available at present, few confident conclusions can be reached with regard to local wind behaviour, and, in particular, the implications for horticulture. Pending further research the following tentative, and very generalised, observations can be made:

(1) In broad straths such as those of the SGV, the Barrington valley to the SW of Barrington Village, and the Upper Bowman River, dominant wind flows on the valley floor may be expected to align with the axis.

(2) In more enclosed and topographically diverse situations, and also on the immediate side slopes of the above straths, localised windflows are quite unpredictable, at least in our current state of knowledge.



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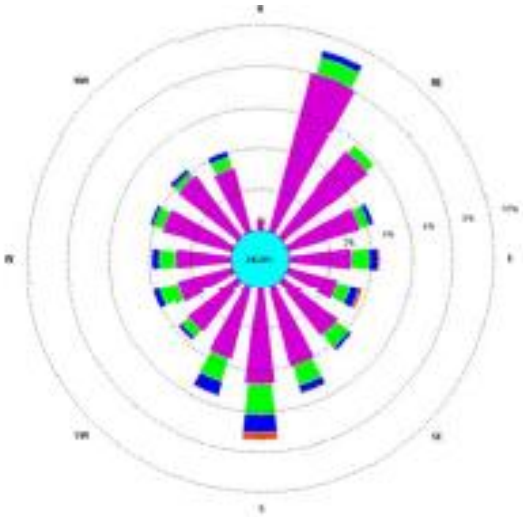

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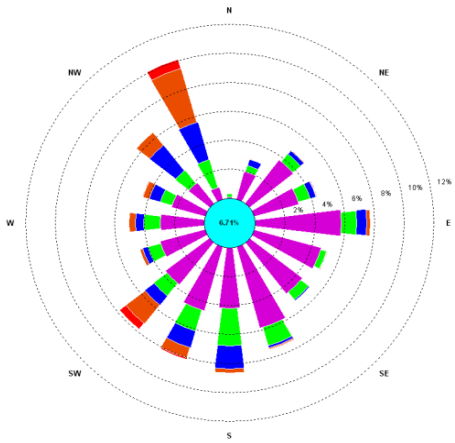

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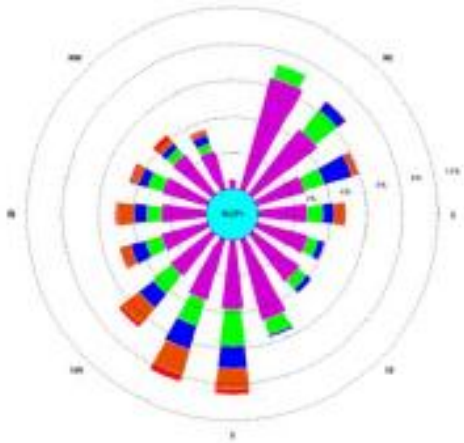

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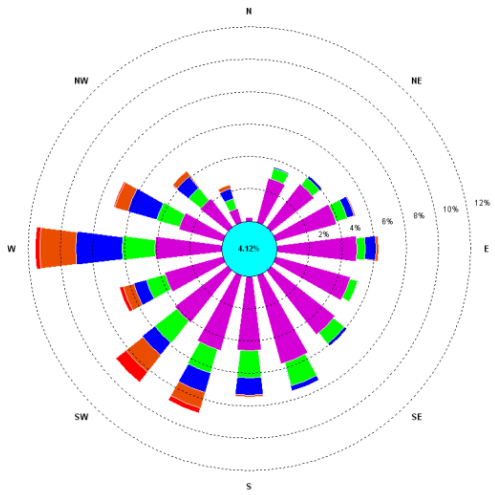
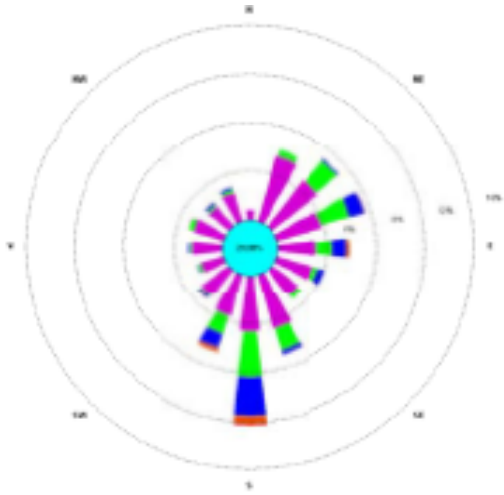


October 2010



October 2011

Figure 5.2: Comparative Wind Roses for Spring in 2010 and 2011

Figure 5.2 compares the Forbesdale wind roses for the three spring months in 2010 and 2011. At first sight, the three 2010 months appear to be more similar to each other than to the corresponding month in 2011. However, first impressions are easily distorted by a single dominant spoke. On closer inspection it can be seen that, apart from October 2011, which was a particularly calm month (22%), there is a basic similarity in that there is a significant proportion of very gentle winds which are distributed fairly evenly around the compass. On average though, 2010 did experience a higher proportion of strong winds

.

5.5 Windbreaks

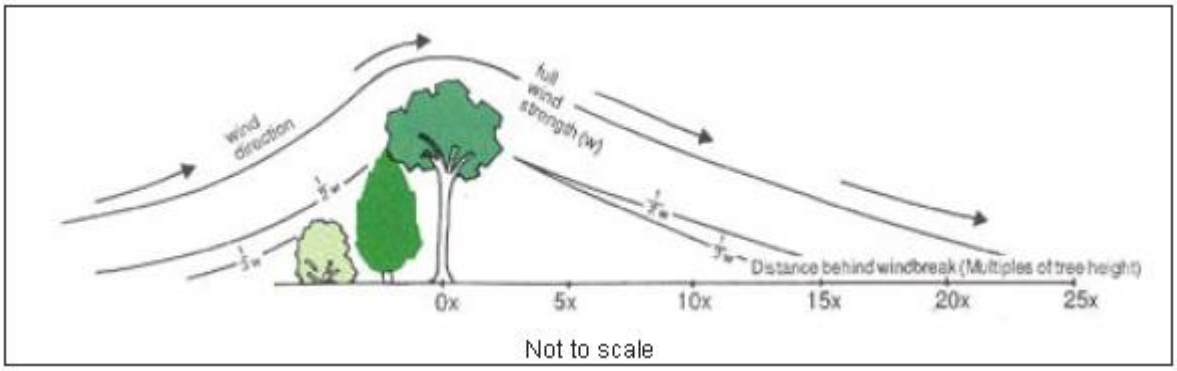


Figure 1: Conceptual presentation of the reduction in wind velocity provided by a windbreak. (Source: Designing Windbreaks for Farms, 1989. Line drawing by Shirley Turner). Copied from: "Windbreaks
for Citrus"; [2].

Not systematically used in GSV - to be completed.

5.6 Conclusions

From a horticultural perspective, wind can be a significant climatic factor, which is both site specific and subject to wide daily and seasonal fluctuations. Using such information as is available, potential growers should carry out a site assessment, and, if so indicated, plant windbreaks along strategically selected lines. Further information on windbreak design and location can be found in the items under [3] in the references section.

6.0 Evaporation

In everyday speech, the term ***evaporation*** is used in a general sense to indicate the various processes through which water that is in, on, or near the earth's surface becomes converted to water vapour which is held in the atmosphere. There are clearly many ways in which this can happen. Familiar examples include rain from a recent shower steaming off a pavement ; bare earth drying out; water loss from the surface of dams, rivers, and lakes; and washing drying on a clothesline. In each of these examples individual water molecules become energized, detach from a surface, and are absorbed into the air.

An additional process, which is conceptually different from the above examples, is the transfer of water from the ground to the atmosphere via plants. Growing plants absorb water from their root zone, and, through a process known as osmosis, convey it to the extremities of their growth envelope. Viewed from down under, the water flow is transferring essential nutrients from the soil up into the developing plant tissue. Viewed from above, water is being delivered to stems and leaves as one input to photosynthesis. Once at the leaf surface, some of this water becomes available for evaporation. This process is termed ***transpiration***, while the two process in combination are described as ***evapotranspiration.***

From an overall catchment perspective, total precipitation, in whatever form it arrives, must on average be balanced by an equal outward water flow. Depending on climatic parameters, this may be through surface or groundwater discharge into streams; absorption into the soil root zone; or return to the atmosphere through evapotranspiration. Depending on a host of factors, the latter process may account for up to 50% of total precipitation in east-coast catchments.

6.1 Measurement

Measurement, or rather estimation, of evapotranspiration is complex, due to the number of determining factors involved. The simplest, and most intuitively accessible, measure of moisture loss to the air is that of "Free Surface Evaporation", which can be loosely defined as the rate of evaporation from a static water surface exposed to the currently prevalent local climatic conditions. The dominant factors in determining the evaporation rate under such circumstances will be the surface temperature of the water body, and the absorptive capacity of the air immediately in contact above. These in turn will depend on the temperature/humidity characteristics of the surrounding air, wind movement across the surface, and solar radiation.

6.1.1 Evaporation

The standard device for measuring such evaporation is the ***Evaporation Pan***, which consists of
a circular container filled with water to a certain depth (see photo below). Daily readings, after adjustment for rainfall, provide a value for surface evaporation measured in millimeters. The BOM operates a wide network of evaporation pans, of which the closest

representative station to the SGV is at Chichester Dam. It should be noted that evaporation as measured from a standard pan as shown is an idealised measure, which can only approximate to local conditions. On the other hand, it does provide a universal reference standard.

Australia wide, annual measured pan evaporation ranges from over 4,000mm in parts of WA, to under 1,000mm on the west coast of Tasmania. A yearly average value of about 1100mm would probably be broadly representative of the SGV. If so, then this is very similar to the average rainfall, though it should be noted that years of higher than average rainfall will tend to have lower than average evaporation, and vice versa. For a number of reasons, farm dams and similar water bodies experience a lesser rate of evaporation than that measured in a standard evaporation pan. A rule of thumb for conversion is that dam loss is about 75% of that from a pan, so that, on the average, local dams experience a net gain.

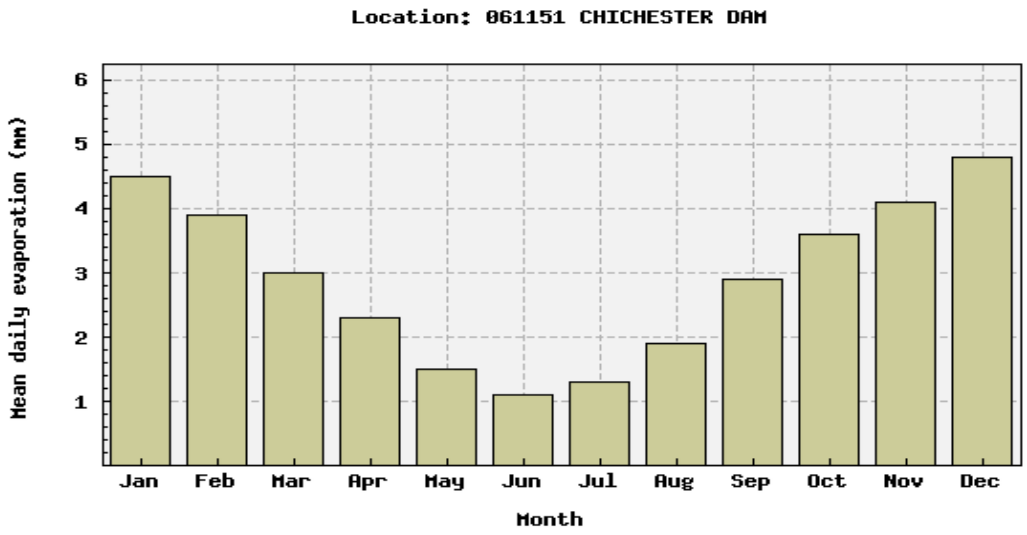


Figure 6.1: Average Daily Pan Evaporation at Chichester

6.1.2 Evapotranspiration

Where there is a continuous or near-continuous vegetation cover, in contrast to bare earth or water, then transpiration will be the dominant process. Wind and insolation will still be important, but the density and type of vegetation are the primary controls. Estimates of moisture loss now rely on complex equations which transform the basic pan

measurements to values appropriate to various categories of vegetation. The basic reference for these calculations is a United Nations FAO technical publication [4].

The BOM employs this methodology, and publishes various estimates of potential evapotranspiration across the continent. Of these, the most relevant for horticulturalists is Point Potential ET. [7] Maps of this, and other measures are available on the BOM website where the Point Potential estimate for the SGV can be read at about 1200mm/annum.

6.2 Relevance to Horticulture

Interesting though this research into definition and measurement may be, for the practicing horticulturalist the problem is not how to measure evapotranspiration, but how to understand, control, and minimise it. The answer lies partly in cultivation practices, and partly in microclimate creation.

Plants need:

- A sustained water supply to their root systems;
- Protection from searing winds (whether hot or cold); and
- For some species, shading from excessive solar exposure.

In the SGV most vegetable and fruit crops will require supplementary irrigation for optimal production. This is most efficiently achieved through controlled trickle irrigation, though the initial capital investment can be substantial. Then, to prevent almost immediate loss to direct evaporation, generous mulching is essential.

Protection from solar heat requires shading to some degree, though not total exclusion. Natural shading may be achieved, for example, through planting a tall variety such as corn to the NW of another low-growing one. Overhead shade cloth is a common solution, and not excessively expensive. Buildings, hedges, or tree breaks can all contribute to wind control, and in some cases may be able to provide partial shade.

There are extensive on-line information resources available on this topic, and the NSW Department of Agriculture operates specialised advisory services.

[7] **Point potential ET** is the ET that would take place, under the condition of unlimited water supply, from an area so small that the local ET effects do not alter local air mass properties. It is assumed that latent and sensible heat transfers within the height of measurement are through convection only. For example, this represents the evapotranspiration which would occur from small irrigated fields with a never-ending water inflow, surrounded by unirrigated land. Point potential ET may be taken as a **rough** preliminary estimate of evaporation from small water bodies such as farm dams .

7.0 Frost

While, as noted in Chapter 3, frost events are but one aspect of the overall seasonal temperature regime, yet their significance for horticulture is such that they merit separate treatment in a report of this kind. Essentially, a frost event occurs when the air temperature at or close to the ground falls below zero Centigrade. The SGV may be viewed as a marginal zone with respect to frost occurrence, as some sites are effectively frost free, while other locations experience several frosts in most winters.

The type of frost experienced in the SGV is termed ***radiation frost***. Typically, these occur on clear calm winter nights when the ground surface cools due to heat radiating out and being lost to the atmosphere or beyond. If the near-surface temperature drops to 0ºC or below, then a frost occurs. This radiation process also occurs on clear summer nights, but there is then sufficient ambient heat to maintain temperatures at a higher level.

7.1 Data on Frosts

The BOM does not provide data on daily minimum temperatures for any station in the SGV. The nearest relevant station is Dungog PO, for which there is a ten-year record period 1966 – 1975. The available data shows the lowest temperature recorded on any day in each month, across the ten year period. This is summarised in Table 7.1 below, for the six coldest months.

	May	June	July	Aug	Sept	Oct
Lowest Min.	0.4	-0.6	-6.1	-2.2	-0.6	0.6
Highest Min.	4.4	2.3	2.5	2.1	3.5	9.4
Frost Years	0	3	6	7	1	0

Table 7.1: Highest and Lowest Monthly Minima at Dungog PO.

Overall, the data shows Dungog as not being severely affected by frosts, though it should be remembered that temperatures in built-up areas are slightly warmer than those in rural settings. The lowest minimum reading of -6.1ºC was a one-in-ten year event, as the next lowest was -3.3ºC.

The second row shows the highest of the daily minima as recorded for each month across the ten-year period. Thus, there was at least one year in which the daily June temperature never dropped below 2.3 ºC. The bottom row in the table shows the number of years in which each particular month was frost-free, so that, for example, a June frost was experienced in only three years out of ten.

What this table does not show is either the number of distinct frosts which may have been experienced in a frost month, nor the total exposure to frost conditions. The degree-hours data provided by TinyTag loggers, as described in Chapter 3, will help to remedy this deficit over time.

7.2 Living With Frosts

For the SGV horticulture industry, frosts may be seen as bringing some mixed benefits. Certainly, they preclude the growing of certain tropical plants, but can favour other varieties. Apples, for example, require a chill season to flourish, and, while citrus are frost-sensitive, they can survive a light frost. One beneficial side-effect is that frosts can help to control some pest species. So, a few frosts in July can be coped with.

What is a problem is the uncertainty regarding the incidence of frosts in the shoulder seasons of May and August-September. Ultimately, there is no solution to this problem – horticulture is inherently a risky business. Careful attention to long-term forecasts may provide some useful information input to decision making as to timing of plantings

7.3 Frost and Microclimates

The most important single fact about frosts is that air condenses as it cools, and therefore becomes heavier. Thus, on land with a reasonable gradient, this cooler air will flow downhill to lower ground, and be replaced by warmer air drawn down from above ground level. Consequently, in narrow confined valleys, an invisible lake of sub-zero air can collect. As this deepens, it can reach back up the slope to a "frost contour". Plantings of citrus or similar fruits below this contour is clearly not advisable, as is that of sensitive ground vegetables within the four-month frost risk-period.

Back upslope, if the land rise culminates in a fairly narrow ridgetop, then an optimal planting location may be just below the ridge. However, other factors, such as aspect, also need to be taken into account. If on the other hand, the rise flattens out to a broad ridgetop, then only ground close to the drop-off edge zone can be considered safe for sensitive species.

Shifting perspective, if the down slope flow of air is blocked by a barrier such as a building, fence, or hedge, then a "pile up" of sub-zero air may result, with enhanced adverse consequences for plants in the immediate area.. The magnitude of this build-up will depend on the height, width, and permeability of the barrier, and the availability of escape paths around each end.

The upside of the downside is that on the downhill side of such a barrier there may be an artificially created frost-free micro-niche. The effectiveness of such a barrier can be enhanced by providing wing barriers at either end, to dampen immediate retro-eddying.

8.0 Humidity

In common with frosts, humidity presents as a sub-topic which, while implicitly covered elsewhere in this report, also merits some separate discussion. Atmospheric physics, which involves interrelated variables such as temperature, pressure, density, altitude, latent energy, and moisture content can get rather complex. It is hoped that in this short chapter, by concentrating on a few variables, the relevance of humidity to horticulture can be explained.

Essentially, the air around us has a capacity to absorb, that is, take in and hold as part of its composition, a certain amount of water, in a form which we term water vapour. This capacity varies with temperature, with warmer air able to absorb and hold more moisture than cooler air. If the temperature of a mass of air drops below a certain level, termed the ***dew point***, then some of the moisture is released. This may form suspended droplets, visible as clouds or fog, may be deposited on available surfaces as dew, or may fall as rain or whatever.

8.1 Measurement of Humidity

There are several measures of humidity in use, but the most common, and most intuitively accessible, is ***relative humidity***. This is measured on a scale from 0% to 100%, calculated as the ratio (expressed as a percentage) of the quantity of water vapour actually present in the air to the maximum which could be held at the present temperature. When the temperature is at dew point, then relative humidity is 100%. A relative humidity of 0% would indicate complete absence of water vapour, a level which is approached only in polar regions.

Note that relative humidity is a relative measure, which varies with changes in temperature, even though the <u>actual quantity</u> of moisture present in the air does not change. Conversely, if additional water vapour is introduced, then the relative humidity will rise, even though the temperature remains the same.

For scientific purposes, an absolute measure such as ***specific humidity***, which is defined as the number of grams of water contained in a kilogram of air, is more useful. However, relative humidity is what we are actually experiencing when we refer to the ambient air as being humid, comfortable, or dry. Plants have similar sensitivities, though their individual comfort zones may differ widely from ours.

8.2 Humidity in the SGV

The closest BOM station for which humidity data is available is at Paterson (Tocal), where readings were taken at 9am and 3pm between 1972 and 2010. The monthly 9am averages for this station ranged from 64% each for September and October, to 80% in March and May. The 3pm readings, which were conditioned by higher afternoon temperatures, ranged from 46% in each of August and September to 59% in June.

Since July 2010 the GRL weather station has also published monthly humidity readings, available from their website at: www.rockyhillproject.com.au > Community Information > Weather Station.

While this station has recorded average maxima ranging up to 100%, as would be expected, some surprisingly low readings have also been recorded – for example, an absolute minimum of 7% in October 2012. Clearly, a lot more local research needs to be done on the validity of RH measurements; variations, if any, in microclimatic niches,; and the practical implications for horticulture.

8.3 The daily humidity cycle

One of TGP's data loggers records relative humidity as well as temperature. This logger was installed at The Tucker Patch from April 2012 to March 2013, set to take readings at two-hourly intervals for a complete year. The graph below shows the variations in RH for the first seven days of April 2012. The units on the horizontal scale represent sequential readings at two-hourly intervals.

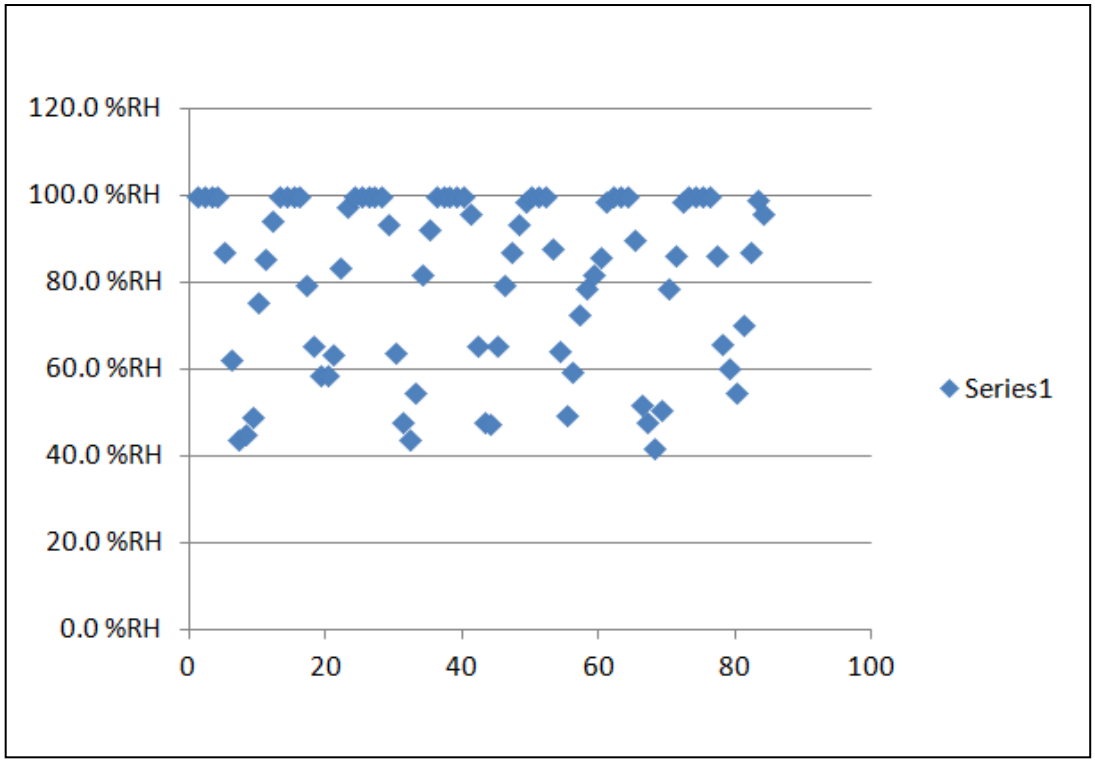


Figure 8.1: Relative Humidity at the Tucker Patch in April 2012

There is a reasonably consistent pattern over the week, with RH falling to around 40% in the afternoon, then rising rapidly to 100%, and remaining at that level for several readings during the small hours. Dewfalls would have been experienced each night, but, as the overnight temperature never fell below 11ºC during that week, there was no danger of frost.

9.0 Climate Change

Debate as to the reality of global warming, the rate at which it is progressing, and the economic and social consequences for the human race, has been raging for more than three decades now.

On the one hand there is a persuasive accumulation of scientific data from around the world which supports the thesis that climate change is a reality, and that the social, environmental, economic, and political consequences will be severe. Evidence ranges from accelerated melting of polar ice, through rising average temperatures, to increases in the incidence of extreme climatic events. The reality of global warming has been accepted worldwide by scientists and by the majority of government agencies.

There remains, however, a block of skeptics who are committed to total denial of this trend, or at least to rejection of the causal mechanism. It would appear that this group is composed of people who have perceived, quite correctly, that recognition of the reality of climate change would require them to accept a reduction in their current level of consumption and wealth accumulation. At this point, short term individual greed triumphs over long term collective vision.

9.1 Evidence for Climate Change

While it is not within the scope of this report to evaluate the pros and cons of the various lines of argument being pursued, two graphs prepared by the BOM are reproduced for content enrichment. These are based on long term (1910 to 2012) records averaged across multiple stations on the East Coast of Australia. (Definition? Number of stations?)

Figure 9.1 shows average annual temperatures for this period, while Figure 9.2 shows average annual rainfall. The values actually graphed are ***anomalies***, that is divergences from a benchmark temperature or rainfall. This benchmark in turn was calculated as the average for the thirty-year period 1961 to 1990 inclusive. [8]

Figure 9.1 shows that for three-quarters of the period temperatures oscillated around a mean anomaly of about - 0.3ºC. Then, starting about 1980, the anomalies shifted into a positive range, with an evident upward trend over time. To date the mean positive anomaly has been about 0.2ºC, but this value will clearly increase if the upward trend continues.

On the other hand, the rainfall series could be viewed as the output from a stable random process, though there is a dominance of high values in the second half of the period. An analysis of individual station records might be more revealing in this case.

[8] It is important to bear this in mind when interpreting the graph. Using a different benchmark could result in an apparently different graph, but the underlying trend would still be the same..

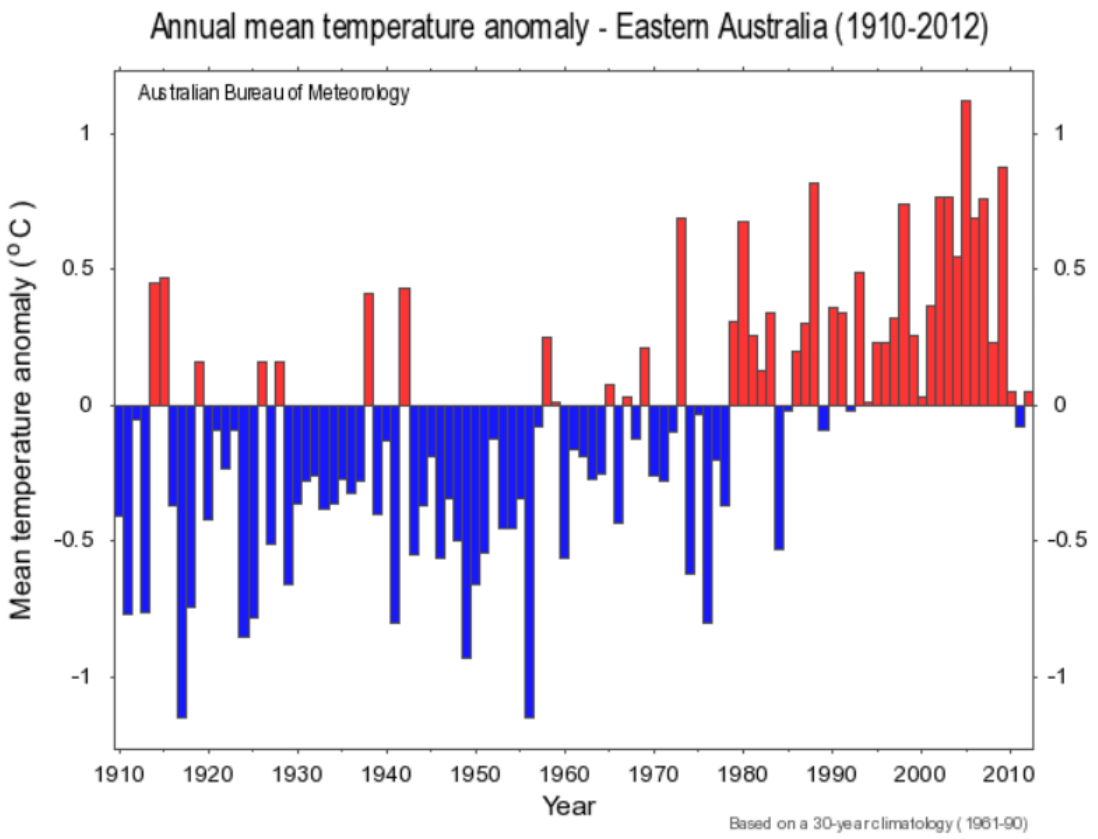


Figure 7.1 Annual Mean Surface Temperature Anomaly – Southern Hemisphere

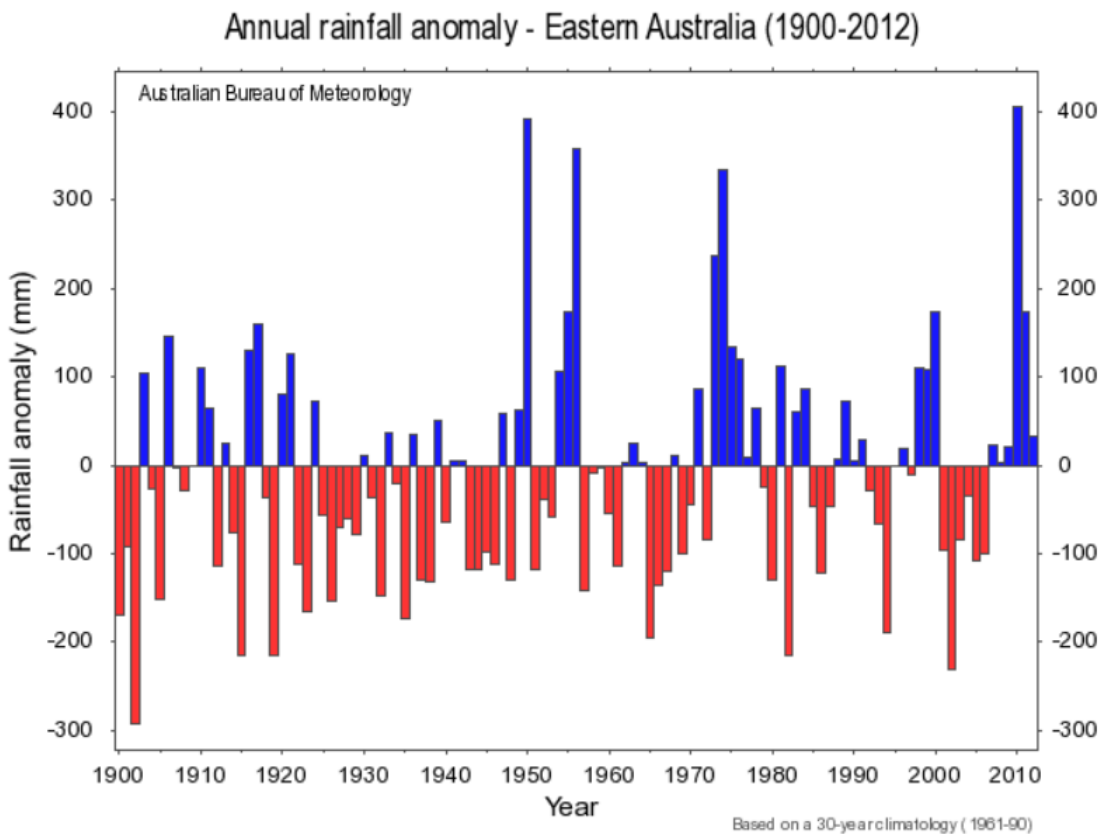


Figure 7.2 Annual Mean Surface Temperature Anomaly – Southern Hemisphere

9.2 NSW Government Action

The significance of climate change for the SGV was mentioned in Chapter 2, where it was noted that the section of the NSW coast to the east and northeast of Gloucester may be favoured with relatively more reliable rainfall in future decades, and that this benefit will extend inland for some distance. In 2008 the NSW Department of Environment & Climate Change published a series of reports summarizing expected climate Change impacts for the State's regions. While Gloucester was treated as part of the Hunter Region, the North Coast Region forecast is probably more relevant [5].

The main features as forecast were a slight increase in rainfall in summer and autumn, a corresponding decline in winter, with no change in spring. This, combined with expected temperature increases, would result in drier soil conditions in winter and spring. With regard to temperatures, the report stated:

> *"Days are projected to be hotter over all seasons (1 to 3°C). The greatest increases are projected for winter (2 to 3°C) and the smallest increases in summer (1 to 1.5°C). Nights are also projected to be warmer, with mean minimum temperatures projected to increase by 2 to 3°C in all seasons."*

Another feature mentioned was a probable increase in frequency and severity of extreme events, such as intense cyclonic rainfalls, thunderstorms, and heat waves. Thus, while overall SGV horticulturalists will be better off, with sustained rainfall, and reduced incidence of frosts, there will also be the factor of increased risk of crop damage or loss from extreme weather events.

In discussing the implications of climate change for Australian agriculture Howden et al note that among the adaptive transformations available are:

> *"…change in land use, change in location of agricultural activities, or increased diversification of income streams."* [6, p. 101).

All of these possible adaptations have relevance for the future of

food production in the Stroud Gloucester Valley - Our Valley !

References

Note: References are numbered in the order of first citation in the text

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[3] "Windbreaks for Citrus" ; Fact sheet published by Cittgroups Australia (Australian Citrus Growers Inc), June 2006.

[4] Allen, R. G. et al: Crop evapotranspiration – Guidelines for computing crop water requirements – FAO Irrigation and drainage paper 56. FAO Rome 1998. ISBN 92-5-104219-5. (www.fao.org/docrep/X0490E/X0490E00.htm).

[5] Summary of Climate Change Impact – Hunter Region: NSW Department of Environment and Climate Change, Sydney, Oct. 2008. ISBN 978 1 74122 969 1.

Summary of Climate Change Impact – North Coast Region: NSW Department of Environment and Climate Change, Sydney, Oct. 2008. ISBN 978 1 74122 970 7.

[6] Howden M. et al: "Australian Agriculture in a Climate of Change"; Published in:.

Jubb, Imogen et al (eds.): Managing Climate Change – Papers from the Greenhouse 2009 Conference; CSIRO Publishing, Collingwood, VIC (2010).

Appendix A

Tinytag Data Loggers

This Appendix provides additional technical details for the temperature data loggers mentioned in Section 3.3. The model in use by TGP is the Tinytag Ultra 2 as shown above, which is powered by a long-life lithium battery.

The sensor and memory storage are housed in a protective casing which is slightly smaller than a typical computer mouse. When deployed in the field, the logger is placed inside a vented weatherproof screen which is suspended about 1.2 metres above ground level (See photo opposite the Introduction).

The logger can be connected to a computer via a special USB cable, and managed using a dedicated software programme. Prior to field installation, it can be programmed to start recording at a selected date and time, and to stop at a subsequent date and time, or when memory is full. The recording interval can also be set to any desired value, expressed either in minutes or hours.

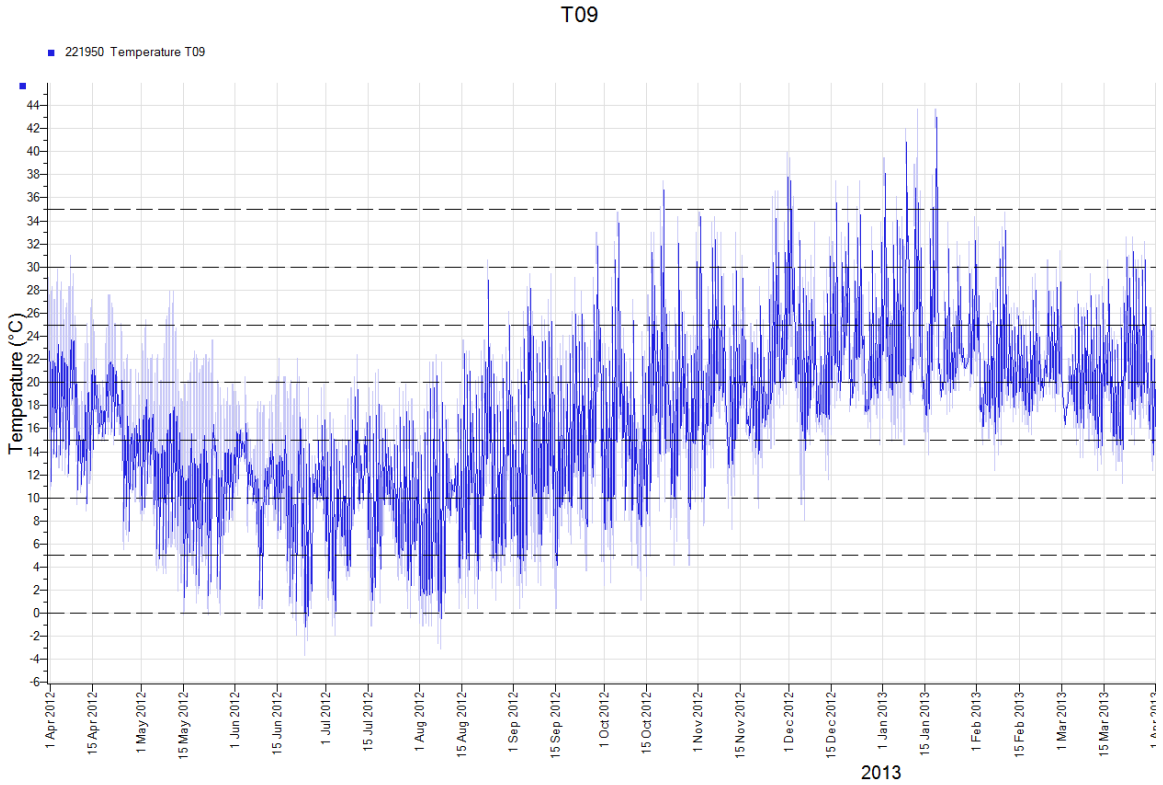
The memory has a capacity of 7,900 readings, which equates to hourly readings over a span of 329 days, or any other equivalent combination. TGP's current standard is for a full year at two-hourly intervals, which does not exhaust memory capacity, but is convenient.

The recorded data is downloaded from the logger using the same software programme, and the data can be analysed to produce a variety of report formats. These include a complete data listing (up to 7,900 lines); a listing of daily minima and maxima; a summary report, including total hours within selected temperature bands; and a dynamically controllable graph. (For further information contact the Australian distributors on www.hdl.com.au).

The graph opposite shows a 12 month trace (April 2012 to March 2013) of two-hourly temperatures recorded at the lowest, and most frost susceptible, point on The Tucker Patch at 62 Cemetery Rd, Gloucester. The five –degree temperature accumulation bands which have been defined between 0ºC and 35ºC can be seen as horizontal dashed lines. These

bands can be varied to suit any specific horticultural requirement. See Tables 3.5, 3.6, and 3.7 for further details.

The table below the graph summarises the data for the entire period of record, including control settings, overall maximum, minimum, and average, and dwell hours within each temperature band. By manipulating the dataset, similar statistics can be produced for any selected sub-period, e.g. the Spring season from mid-August to mid-November, depending on the user's perception of needs.



S/N	221950	Area below 5.0 °C	1870 °C hour
Type	Tinytag Ultra -30/50°C	Time above 10.0 °C	290 days 5 hours
Description	T09	Area above 10.0 °C	67333 °C hour
Property	Temperature	Time below 10.0 °C	75 days 18 hours
Logging Started	30 Mar 2012 23:01	Area below 10.0 °C	7859 °C hour
Logging Ended	1 Apr 2013 04:56	Time above 15.0 °C	222 days 21 hours
Logging Duration	366 days 5 hours	Area above 15.0 °C	36428 °C hour
Offload Operator	Gerald	Time below 15.0 °C	143 days 1 hour
Start Delay	10 hours 12 minutes	Area below 15.0 °C	20870 °C hour
Interval	2 hours	Time above 20.0 °C	122 days 2 hours
Stop Mode	When full	Area above 20.0 °C	15491 °C hour
Offload Time	18 Apr 2013 09:56	Time below 20.0 °C	243 days 21 hours
Number of Readings	4602	Area below 20.0 °C	43850 °C hour
Logging Mode	Minutes Mode	Time above 25.0 °C	53 days 20 hours
Statistics Start Time	31 Mar 2012 05	Area above 25.0 °C	5498 °C hour
Statistics End Time	1 Apr 2013 04	Time below 25.0 °C	312 days 3 hours
Minimum Reading	-3.7 °C	Area below 25.0 °C	77773 °C hour
Maximum Reading	43.7 °C	Time above 30.0 °C	19 days 4 hours
Average Reading	16.8 °C	Area above 30.0 °C	1569 °C hour

Time above 0.0 °C	362 days 13 hours	Time below 30.0 °C	346 days 19 hours
Area above 0.0 °C	147408 °C hour	Area below 30.0 °C	117761 °C hour
Time below 0.0 °C	3 days 10 hours	Time above 35.0 °C	4 days 10 hours
Area below 0.0 °C	101 °C hour	Area above 35.0 °C	301 °C hour
Time above 5.0 °C	336 days 11 hours	Time below 35.0 °C	361 days 13 hours
Area above 5.0 °C	105260 °C hour	Area below 35.0 °C	160410 °C hour
Time below 5.0 °C	29 days 12 hours		

Back cover: This scene, captured by local photographer Linda Benson, illustrates the elongated fog bank which is a characteristic feature of the Stroud Gloucester Valley on Autumn and Winter mornings. It is caused by . . . .

Photo by Linda Benson