# Weather Forecasting & Business Management Systems

## Tools for Better Business Management

**A report for**

NUFFIELD AUSTRALIA FARMING SCHOLARS

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2012 Nuffield Scholar

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# Executive Summary

Successfully managing a farm business has never been so complex, so risky and required such a diverse set of skills. Yet many businesses today are managing and even thriving in this climate. What sets them apart from other businesses which are struggling? There are probably many reasons for this but management skills, a good understanding of their risks, and putting systems in place to manage these risks would be part of the answer.

Better day to day and long term farm business decisions can be made with a greater understanding of the weather and climate risks, and the chance of those conditions occurring. Understanding weather cycles and weather forecasting and using decision support tools all adds to a manager's tool kit. This helps to make sure when a decision is made, the odds are highest that it is the right decision.

Accuracy in weather forecasting has improved significantly in the last thirty years. Benchmarking data shows accuracy for the best three day weather forecast has improved by 27 percent, and is now 97 percent accurate. The best five day forecast has improved by 45 percent and is now 90 percent accurate and the best seven day forecast has improved by 45 percent, it is now 78 percent accurate. There was no ten day forecast 30 years ago, but this now has an accuracy of 48%.There are many factors that have a longer term influence on our weather; as these are better understood and computing power increases, accuracy continues to improve.

The improvements in forecasting accuracy mean that weather forecasts can now be a more effective tool in a farm manager's tool kit. Managers need to understand that a forecast will never be 100% accurate. The critical point is that they must be used to manage risk, not create more risk. A good understanding of how the forecasts are produced can significantly affect their usefulness and the management of risk.

Private weather forecasters tend to be at the cutting edge of developing new methods in seasonal forecasting; they tend to take more risks. Although some of their methods are not recognised by the institutional forecasting community, they certainly show where more research can be targeted. Private forecasters tend to have closer links to the agricultural community and so are able to produce forecasts more suited to farmers' requirements.

# Foreword

***Meteorologists I visited agreed that "to their knowledge a project like this had never been undertaken before."***

This has made the project both exciting and daunting.

Receiving a Nuffield Australia Farming Scholarship provided me with an amazing opportunity to gain a perspective of agriculture that only relatively few farmers will ever have. It has introduced me to a network of inspirational and motivated people and challenged me to think beyond our farming business, beyond our town, beyond our region and beyond Australia. It has been far more than just a research project; it has helped me to grow as a husband, father, businessman and member of our community.

In the past 11 years our farming business has grown from cropping 1,000 ha to cropping 9,000 ha. The expanded capital investment now required to manage our business has increased our risk profile. The business is more complex and requires different management skills. During this time we have experienced eight years that have been in the lowest 30 percent of growing season rainfall in one hundred years of records. Five have been in the lowest 20 percent.

The combination of these factors has increased my interest in the weather and in business management systems and led me to undertake a Nuffield Australia Farming Scholarship.

The weather is an essential part of planning daily operations and in the longer term can mean the difference between a profitable and unprofitable year. As a farmer I am also a weather forecaster, I refer to as much information as possible, from as many sources as I have available, then use this information to influence my decision making. The information may be gleaned from a website, an application (app.) on my mobile phone, the television, a subscription-based service, or by observing nature and my environment. How much weight I place on each piece of information, when making decisions, is based on my perception of the reliability of the information.

I use management systems to help with decision making and simplify staff management. They can provide a way of drawing information together to guide our staff and business to achieve the best outcome. They simplify processes.

As a result of undertaking the Nuffield Australia Farming Scholarship, I have increased my knowledge of weather forecasting and now have a better understanding of what goes on behind the forecast. I have learnt how much the science of weather forecasting has improved and understand why it is so complex. This helps me to make better use of the information received in a forecast. I can also see areas where more research is needed.

I have been able to draw on management systems used by farmers and meteorologists in Australia and around the world. These will improve the practical and business management of our farming enterprise and others around Australia.

# Acknowledgements

I am sincerely grateful to the many people who have supported me, and enabled me to share the knowledge I have gained with you, especially to the GRDC for funding my scholarship. Without their sponsorship my scholarship and project would not have been possible. Thank you to my friends and colleagues in the Nuffield Alumni who helped to organise the Contemporary Scholars Conference and the Global Focus programme. Also the businesses and organisations who opened their doors to us, answering our many questions. Thank you to all my fellow 2012 Nuffield Australia Farming Scholarship recipients for sharing the journey.

I would like to specifically thank the following people and organisations who personally gave up time to help me with my research project.

- Manfred Kloepel and staff at European Centre for Medium Range Weather Forecasting (ECMWF) in England
- Ken Mylne, UK Met. Office, England
- Jim Bacon, Weatherquest, England
- Simon Ward, Increment Ltd., England
- Ray Garnett of Agro Economic Consulting, Canada
- Hope Pjesky, an Eisenhower Fellow, USA
- Chuck Coffey and staff at The Samuel Roberts Noble Foundation, USA
- Al Sutherland and staff at The National Weather Centre, USA
- Jesus Fernandez, National Institute of Agricultural Technology (INTA) Research Centre, Argentina
- Ken Ring, Predict Weather, New Zealand

There were many more people who also helped with researching my project but are too numerous to mention; thank you to you all. To Emma Leonard for editorial work in helping to improve my report; a big thank you for the time you put in.

Thank you to my business partner and fellow Nuffield scholar John Gladigau for encouraging me to apply to Nuffield, for helping to set up our business ‘Bulla Burra’ and to make it possible for my 17 weeks absence. Thank you also to our employees for taking on extra responsibility in my absence and to you all for supporting Rebecca and my family.

Finally I would like to thank my wife Rebecca for her support and dedication, and also my children Brianna, Jordan, Caleb, Isaac and Elise. They all took on extra responsibilities and personally grew through my absence. Words cannot express my sincere thanks to you all.

# Abbreviations

AACREA - La Asociación Argentina de Consorcios Regionales de Experimentación Agrícola

AO – Arctic Oscillation

BBSRC – Biotechnology & Biological Sciences Research Council

ECMWF – European Centre for Medium Range Weather Forecasting

ENSO – El Nino Southern Oscillation

IOD - Indian Ocean Dipole

INTA - National Institute of Agricultural Technology Argentina

MJO – Madden-Julian Oscillation

NAO – North Atlantic Oscillation

NAS – North American Snow Cover

NCC – The Australian National Climate Centre

NP – North Pacific Index

PCT – Precision Cropping Technologies

PDO – Pacific Decadal Oscillation

PNA – The Pacific North American Teleconnection Index

POAMA – Predictive Ocean Atmospheric Model of Australia

QBO – The Quasi-Biennial Wind Oscillation

SAM – Southern Annular Mode

SOI – Southern Oscillation Index

SSA – Solar Sunspot Anomaly

SST – Sea Surface Temperatures

USDA – United States Department of Agriculture

WP – Western Pacific Teleconnection Index

# Contents

# Objectives

The objectives of this research project were to answer the following questions:

1. What weather forecasting methods are used by meteorologists?
2. How reliable are current weather forecasts and is their reliability improving?
3. How can these weather forecasts be used to improve the management of farm businesses?
4. What is the future for weather forecasting?
5. What tools or systems are available to help make management decisions?

The aim in answering these questions is to increase awareness, understanding and use of improved methods of weather forecasting and risk management. It will also demonstrate some of the strengths and weaknesses of the systems to help other farmers select tools that suit their weather forecasting and risk management needs.

# Chapter 1: Introduction

Successfully managing a farm business has never been so complex, so risky and required such a diverse set of skills. Yet many businesses today are managing and even thriving in this climate. What sets them apart from other businesses which are struggling? There are probably many reasons for this but management skills, a good understanding of their risks, and putting systems in place to manage these risks would be part of the answer.

***A significant part of risk for broad acre farming businesses relates to weather, the day to day conditions and climate, the average conditions experienced over a long period of time.***

Better day to day and long term farm business decisions can be made with a greater understanding of the weather and climate risks, and of the chance of those conditions occurring. Understanding weather cycles and weather forecasting and using decision support tools all adds to a manager's tool kit. This helps to make sure that, when a decision is made, the odds are highest that it is the right decision.

Probably more so than any other occupation, farming is affected by the weather. In day to day operations decisions are regularly made around the weather. The results of these decisions are affected by the weather, which in turn can affect the outcomes of the decision.

An example would be when a farmer decides to apply a particular herbicide for weed control. The herbicide has a rain-fast period of six hours. The farmer has to decide if rain is likely within that timeframe and which is the greater risk applying today and risking poor control due to rain destroying the herbicide or waiting for better weather when the weeds will be larger and harder to kill. If the herbicide is applied its effectiveness is directly affected by the weather that occurs within the next six hours.

The timeframes that farmers regularly make decisions around can be divided into three main areas.

1. Day to day decisions - usually made for the next 24 to 48 hours;
2. Weekly decisions - planning ahead for the weekly activities; and
3. Seasonal decisions - longer term planning including crop types, area to be cropped, stocking densities, fertiliser strategy.

Weather forecasting can be divided into the same three time frames and each of these was addressed in researching this report. To gather the information for answering these three questions, leading farmers and businesses were interviewed to discover the management systems helping them to manage their businesses.

Australian Meteorologists indicated that they believed the leading institution in worldwide weather forecasting is the ECMWF in the United Kingdom. The UK Met Office is also held in high regard as is the National Weather Centre in Oklahoma, USA. These were the establishments visited as part of this research project.

Private weather forecasters from countries around the world were harder to find. Early research led to New Zealand based forecaster Ken Ring and his techniques which warranted further investigation. The Nuffield network indicated Canadian crop and weather forecaster Ray Garnett was worth a visit and also encouraged visiting an Argentinean farm management movement called La Asociación Argentina de Consorcios Regionales de Experimentación Agrícola (AACREA) to look at the management systems they were using.

# Chapter 2: Key Developments In Weather Forecasting

Weather forecasting has always been important to farmers and those closely connected with the land and sea as their survival and profitability can both be at the mercy of the weather. *To a degree all farmers are meteorologists.*

While the term meteorology (the study of atmospheric disturbances or meteors) was invented by the ancient Greeks in about 300 BC, it was not until the mid 15$^{th}$ century that the foundations of today's systems of weather forecasting were laid.

Despite agriculture's long association with and reliance on weather forecasting, investment in meteorological services across the globe have been driven by defence and aviation. The political profile of climate change and in Australia the Millennium Drought seem to have helped refocus investments in meteorology, which is offering benefits to agriculture.

## A Meteorological Timeline

In ancient civilisations, religious rights and mystery surrounded weather forecasting. However, drilling down into these practices can sometimes uncover scientific principles at work in the background. Details of, and links to, weather forecasting tools that have been used throughout history with varying degrees of success can be found in Appendix 1. Basic research carried out by independent, Australian weather forecaster Ian Holton, shows that there appears to be merit behind at least some of these tools.

In the west the modern science of weather observing and recording began in 1654 when an Italian, Grand Duke Ferdinando II de Medici, sponsored the first weather observing network. This consisted of nine meteorological stations across Europe. The collected data was sent to

Florence. However, this data was not really usable because standardised units of measurement had not been developed.

The following is a timeline of notable developments in meteorology (Wikipedia 2014)

- 1441 Standardised rain gauge developed in Korea
- 1450 Instruments developed to measure wind speed and humidity in Italy & Germany respectively
- 1607 Galileo developed the first instrument for measuring temperature
- 1643 Mercury barometer is invented
- 1654 The first weather recording network was established in Europe
- 1724 Gabriel Fahrenheit developed a reliable scale for measuring temperature
- 1742 Anders Celsius proposed the Celsius temperature scale
- 1847 An English newspaper organised the first weather reports collected electronically by telegraph
- 1849 The Smithsonian Institution establishes an observation network across the USA with 150 observers communicating via telegraph
- 1860 The English telegraph system is first used to gather daily observations and produce the first synoptic charts
- 1889 The Indian Meteorological Department was established following cyclone & monsoon related famines
- 1890 The USA weather Bureau is established under the USDA
- 1892 The first mention of El Nino
- 1904 Vilhelm Bjerknes presents a vision that weather forecasting is feasible based on mathematical methods
- 1906 The Australian Bureau of Meteorology is established

- 1923 The oscillation effects of ENSO were first wrongly described by Sir Gilbert Thomas Walker from whom the Walker circulation takes its name; now an important aspect of the Pacific ENSO phenomenon.
- 1941 A radar network was implemented in England during World War II. Operators started noticing echoes from weather phenomena such as rain and snow
- 1950 The first successful numerical weather prediction experiment
- 1969 Jacob Bjerknes described ENSO
- 1970's Weather radars become more standardised and organised into networks
- 1975 ECMWF established
- 1997 The Pacific Decadal Oscillation (PDO) was discovered simultaneously by Yuan Zhang and Steven Hare, the latter while studying salmon.

## Meteorological Records

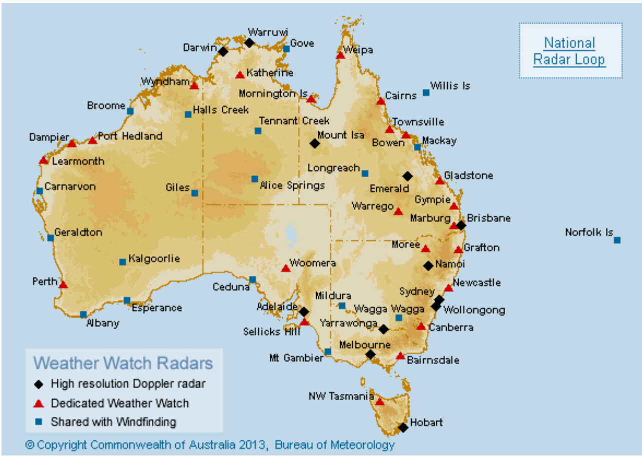
Generally, accurate meteorological records across the world are only available for the last 100 to 150 years, which is a relatively short timeframe when put into the context of the age of our world. Efforts have been made to determine longer term climate by looking at written observations from past civilisations, tree rings, coral growth rates and ice cores from various parts of the world. However, in most of the information they have been used in the context of climate change rather than in monitoring seasonal cycles and seasonal variability.

## Meteorology for defence, aviation and society

Examples of how the rapid evolution of meteorology has been driven by the defence and aviation industries include:

- The invention of weather radar during the Second World War. The go-ahead for the successful D-Day Normandy landings was pivotal on the weather forecast provided by a senior meteorologist. His recommendations proved to be correct and this really propelled forward the use of weather forecasting in the defence.
- The location of weather radar has tended to be in places best suited to aviation, defence and shipping. This can be clearly seen when viewing the map of Australia radar locations (Figure 1).(Australian Government Bureau of Meteorology 2013)

*Figure 1. Radar sites across Australia, generally located in large cities and towns for aviation, defence and the general population. (Australian Government Bureau of Meteorology 2013 )*




## Teleconnections

Teleconnections can be defined as a causal connection or correlation between meteorological or other environmental phenomena that occur a long distance apart (Australian Government Bureau of Meteorology 2013). They were first noted by the British meteorologist Sir Gilbert Walker in the late 19th Century, when his studies revealed the ground breaking description of the Southern Oscillation. (National Oceanic and Atmospheric Administration 2013) Teleconnections are a significant part of seasonal forecasting and can help explain long term climate variability. The following list of teleconnections is a selection of the major ones used in mainstream weather forecasting. Canadian forecaster Ray Garnett has identified 27 different teleconnections for North America alone; however they are not all statistically significant.

### Teleconnections affecting Australia (and other surrounding countries)

(See Appendix 2)

- Madden-Julian Oscillation (MJO)
- El Nino Southern Oscillation (ENSO)
- Indian Ocean Dipole (IOD)
- Southern Annular Node (SAM) - Also known as the Antarctic Oscillation
- Quasi Biennial Oscillation (QBO)

**Other Significant Teleconnections** (See Appendix 2)

- North pacific Index (NP)
- North Atlantic Oscillation (NAO)
- Pacific Decadal Oscillation (PDO)
- Arctic Oscillation (AO)
- Aleutian Low
- Atlantic Multi Decadal Oscillation (AMO)

It is interesting to note that one very important teleconnection discovered in recent times (the PDO), was made at the same time by a meteorologist and a researcher studying fish. This begs the question of what other important teleconnections are yet to be discovered and if there are other areas in nature which could be studied by direct research.

## Forcing

Recent discoveries have shown that some of the teleconnections around the world have influence over each other, this is called *forcing*. Forcing can be described as the way that one weather phenomenon impacts on and changes another. For example, research by Schneider et al (Schneider & Cornuelle 2005) has pointed to a

combination of ENSO and the Aluetian Low having a forcing effect on the PDO (Appendix 2).

## Astrometeorology

Astrometeorology can be defined as the theoretical effect of astronomical bodies and forces on the Earth's atmosphere (Ask 2014). Astrometeorologist Jenifer Lawson describes it as *"forecasting weather by studying the angular positions of the Sun, Moon and planets in relation to each other and to the Earth; this combined influence disrupts and disturbs the Earth's atmosphere, affecting our weather patterns*."(Lawson 2000)

As well as providing long term weather forecasts, even out to many years, astrometeorologists also forecast earthquakes and volcanic activity. Astrometeorology has been used for thousands of years; it has been found to be used as far back as 3,000 BC with the Sumerians (Wikipedia 2013). Dr John Goad in 1686 was the first published astrometerologist with his book *Astro-Meteorologica.* Since then astrometerologists have built on his research. Carolyn Egan on her website "Weathersage"(Weathersage 2013) provides details of books written about astrometeorology and offers web based courses for astrometeorology. An interesting history of astrometeorology can be found at http://www.kimfarnell.co.uk/weather1.htm.

During research undertaken for this report, private weather forecaster Ken Ring from Auckland, New Zealand, was interviewed. Ken uses astrometeorology as a basis for his forecasting. In his book *The Lunar Code* (Ring 2006) Ken writes "*During the mid seventeenth century, scientific circles began to reject talk of planets influencing weather. With scientific attitudes beginning to change, astrometeorology and astrology were dismissed as unscientific. Astronomy became the only officially recognised celestial science."* Mainstream meteorology has gradually begun to recognise some of the influences that astrometeorologists have known for centuries.

# Chapter 3: Weather Forecasting Methods

## European Centre for Medium Range Weather Forecasting (ECMWF)

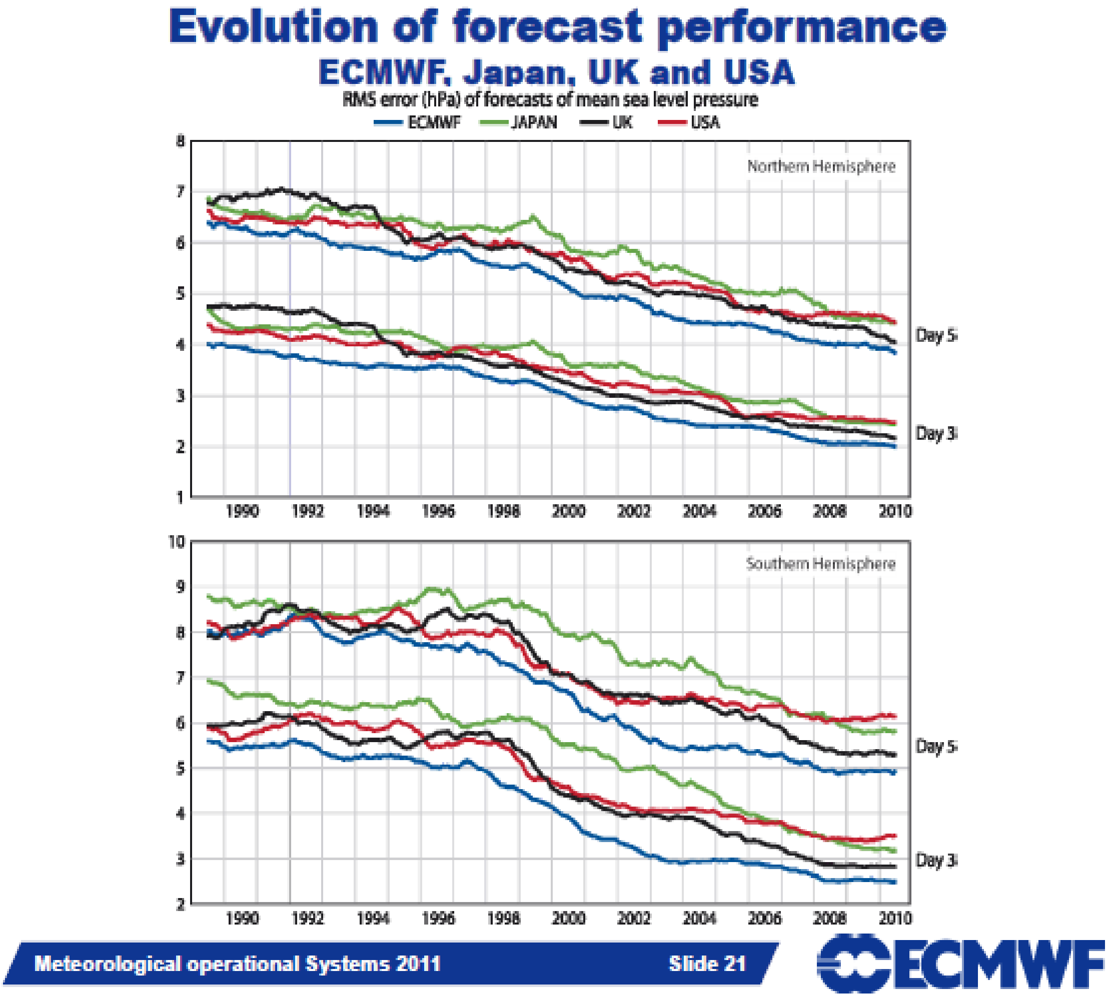
The ECMWF was established in 1975, following a severe storm surge in November 1972 that devastated areas of Europe. It was set up to pool European scientific and technical meteorological resources for the production of medium range weather forecasts (see Appendix 2), resulting in both economic and social benefits to member countries.

Visiting the boardroom of the ECMWF it is immediately obvious that it is an international organisation by the large number of flags on the table, designating the place of each of its members. Equally obvious is the large tapestry depicting the isobars of the 1972 storm hanging behind the chairman as a constant reminder to all members of the reason why the centre exists (Figure 2).

*Figure 2. The ECMWF boardroom showing the flags of the member countries and the tapestry of the storm front which was the catalyst for its creation. The tapestry hangs behind the chairman as a constant reminder to all members of why the centre exists. (Schaefer 2012)*

The ECMWF is known as the world leader in weather forecasting. This is clearly shown in Figure 3, which benchmarks its performance against leading forecasting agencies around the world. The lower the value on the y-axis denotes the lowest forecasting error.

*Figure 3. A comparison of accuracy between the main international weather forecasters for the Southern and Northern hemispheres since 1988. The closer to "1" the higher the accuracy. (ECMWF 2012)*




The ECMWF generally supplies its raw modelled data to its member partners and at a fee to other worldwide weather forecasting agencies, including Australia.

The ECMWF uses two systems for creating their forecasts.

## Deterministic forecasts;

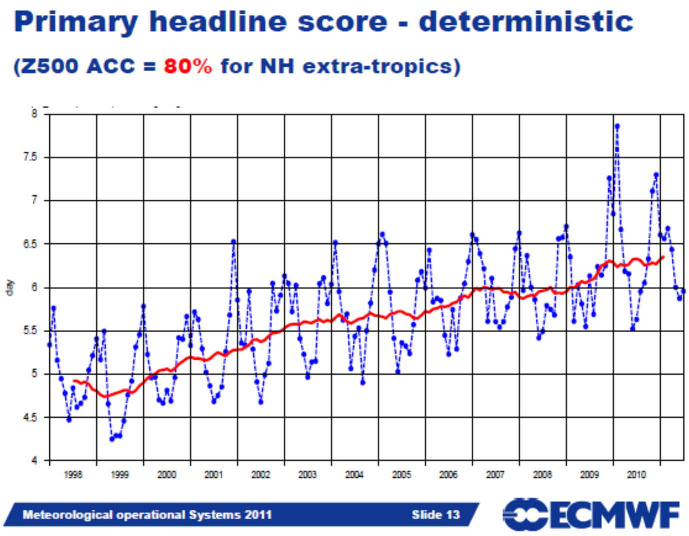
The two main drivers of the improvement in weather forecasting have been the increase in computing power and improvements in the quality and quantity of satellite data.

Deterministic forecasts are produced by computer models using a four dimensional grid pattern to map current weather. The first two dimensions are in the horizontal plane of space – this is made up of 16km grid points (Figure 5.). The third dimension includes 91 vertical levels (Figure 5), and the fourth dimension is time. From these current observations the models can model what the weather is going to do in the near future.

For example, the actual weather data is placed in the model for each grid point and the 91 vertical levels at 12.00 noon. The model determines what it estimates the actual data will be at 12.10 pm; it then uses this data to determine an estimate for 12.20 pm and so on. Each time stamp is called a step.

The ECMWF run the deterministic forecast twice daily; each step is 600 seconds. In each of these runs the model forecasts out to 10 days or 1440 steps. In the Northern Hemisphere the deterministic forecasts are achieving 80 per cent accuracy for forecasts to 6.5 days (Figure 4) Accuracy is greatest in the winter months.

*Figure 4. Chart showing the improved forecasting skill over time of ECMWF deterministic forecasts at 80% accuracy for the Northern Hemisphere. The red line is the running average. In 1998, this level of accuracy could be achieved only to 5 days, in 2010 it was nearly 6.5days. Notice the seasonality of the accuracy, with increased accuracy (the peaks in the blue line) occurring during the winter period. (ECMWF 2012)*



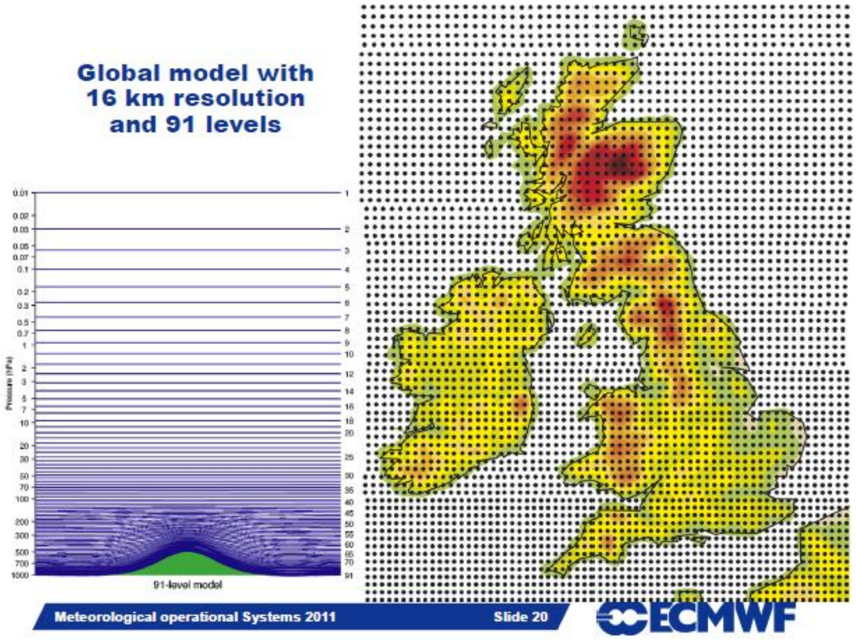

## Ensemble forecasts

When meteorologists are running the deterministic model, the smaller the grid, the more accurate the forecast, but also the more computing power is required. Furthermore real time weather measuring stations are not located across the world on a 16km grid pattern. This means that there are always small inaccuracies inherent in the deterministic forecast. Because weather is extremely dynamic small changes in the accuracy of the information can significantly affect the outcome over time. Also models cannot fully replicate the laws of physics which govern the behaviour of the atmosphere, resulting in errors. The chaotic nature of the atmosphere amplifies these errors over time so that initially small errors can become extremely distorting.

The ensemble method was developed by ECMWF as a forecasting system which manages around this inherent degree of unpredictability. Ensemble means a group of complimentary parts or members that contribute to a single effect. An ensemble forecast in affect is a group of deterministic forecasts that are used to provide a probability-based forecast. The ECMWF uses a 51- member ensemble. The grid points for an ensemble forecast need to be spaced further apart than the deterministic forecast due to the enormous number of calculations that need to be made, which increases the computing power required.

Current observations are used as a base for the ensemble forecast; small errors are introduced into each member and then the member models are run. For example, actual recorded temperature data is available from weather recording stations located at points A & C. A is 21 degrees and C is 25 degrees, however, point B has no station. The deterministic models predict what the conditions are at point B, for example 23 degrees. Obviously it is highly unlikely this will be totally accurate; the error factor introduced into the ensemble members aims to allow for these discrepancies. So one member may have B as 22.5 degrees and another as 23.5 degrees. The ensemble forecast is run twice daily, each time with updated real-time data. This is performed for the following 15 days.

*Figure 5. The distribution of the 91 height levels used for forecasting, and the 16km resolution as it would look over the UK for a deterministic forecast. (ECMWF 2012)*




Monthly and seasonal forecasts are also performed using the ensemble method. The seasonal forecasts are coupled with ocean data and are performed at a lower resolution due to the sheer amount of processing required.

## Agro Climatic Consulting

Ray Garnett is principle of Canadian based Agro Climatic Consulting. Ray grew up on a farm and after graduating began his employment with the Canadian Wheat Board.

During 1972 a severe drought occurred in the then Soviet Union. As there was very little information leaving the Soviet block at that time, the world was unaware of what was transpiring. The Soviets entered the grain market and purchased a very large amount of grain in numerous small parcels from many traders before the market realised what was happening. This was later called the Great Grain Robbery. Following this the Canadian Wheat Board set up a weather forecasting department to help with crop forecasting in Canada and around the world. This is when Ray began his career in agricultural meteorology. Ray has developed a consistent track record of forecasting and early identification of droughts and bumper harvests in major grain growing regions around the world. In 1999 he left the Canadian Wheat Board and established Agro Climatic Consulting. As well as publishing his own newsletter he also writes for the Canadian grain marketing newsletter "Wild Oats". Ray has invested a large amount of time in researching seasonal weather forecasting and the influences behind these. He has published seven papers as either author or co-author.

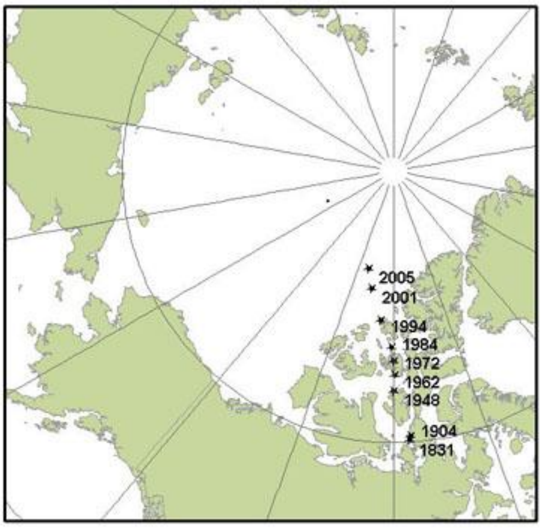
The teleconnections Ray uses include the Arctic Oscillation (AO), Bermuda High, El Nino Southern Oscillation (ENSO), Madden-Julian Oscillation (MJO), Modified Pacific North American Teleconnection Index (PNA), North American Snow Cover (NAS), North Atlantic Oscillation (NAO), Pacific Decadal Oscillation (PDO), Quasi-Biennial Oscillation (QBO), Western Pacific Teleconnection Index (WP) as well as Solar Sunspot Anomaly (SSA) Solar index. (See Appendix 2.)

Spending time with Ray it became obvious that he is very passionate about his work and has spent much time researching global teleconnections and their effect on grain production. Ray has identified 27 teleconnections that affect North America. He has used a Least Angle Regression (LARS) which is a statistical analysis to determine his top ten predictors. Ray's research into the solar cycle effect on our weather has produced interesting results. Ray shared information (Garnett R. February 2013) from Dr. M.L. Khandekar (co-author of a paper on Long Lead Forecasting over the Canadian Prairies) (Garnett & Khandekar 2013). Ray said that the Magnetic North Pole moves 55 to 60km per year ((Figure 6.); this changes the earth's magnetic field.

Brian Vastag wrote in the National Geographic news, "in the last 150 years it has weakened by 10%" ((Vastag B. 2005; Wikipedia 2013). Ray said Dr Khandekar also states these changes in the pole can weaken and strengthen the affect that sunspots and the solar cycle have on Earth's weather by changing the amount of cosmic rays that enter our atmosphere.

Research at The European Organisation for Nuclear Research (CERN) is showing cosmic rays may have a significant effect on cloud development (without clouds there is no rain) (Ideas Inventions & Innovations 2013; Gosselin 2013). This is in line with a theory originally developed by Henrik Svensmark. (Wikipedia 2013). Jasper Kirkby from CERN explains more on that theory in his paper "*Cosmic Rays and Climate*" (Kirkby 2008).

*Figure 6. The change in position of the earth's North Pole over the last 174 years. (How Stuff Works 2013)*




Ray also quoted T. Landschiedt, who in his paper *Trends in Pacific Decadal Oscillation Subjected to Solar Forcing* (Landscheidt 2001), showed a correlation between the PDO and ENSO. He hypothesised that this reflected the 22 year solar cycle. Landschiedt also explained that the shifts in the PDO will affect how an ENSO develops and demonstrated that there is a close correlation between energetic solar eruptions, ENSO and the North Atlantic Oscillation (NAO).

Ray also referenced a paper by William M Gray (Gray, Sheaffer, Knaff 1992), hypothesising how the Quasi Biennial Oscillation (QBO) of zonal wind direction changes in the equatorial stratosphere (middle level atmosphere), possibly affects the strength and timing of ENSO events. Ray has proved the QBO has correlations with Australia's weather.

Regarding his work with grain prices Ray has found that there is an inverse effect between sunspot numbers (solar activity) and grain prices, which also tends to suggest that solar activity is significantly affecting our weather and global grain production. He said there is a strong correlation between the Indian Monsoon and US corn yield. There is also a strong correlation between failed Indian Monsoon and wheat yields in Australia one to two years later. Ray is quite frustrated that the general scientific community does not appear to be eager to embrace the work that he and others had done on the solar influence on our weather.

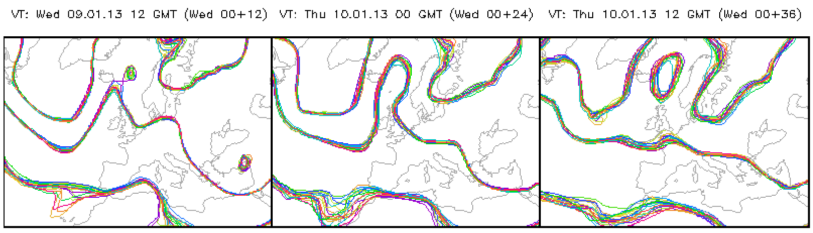
## Weatherquest

Located in Norwich, on the campus of the University of East Anglia, in the east of England, Weatherquest services customers all over the UK. Weatherquest buys weather data including ensemble forecasts from the UK Met Office then uses this data to provide a more specialised service to its customers, which include farmers and insurance companies.

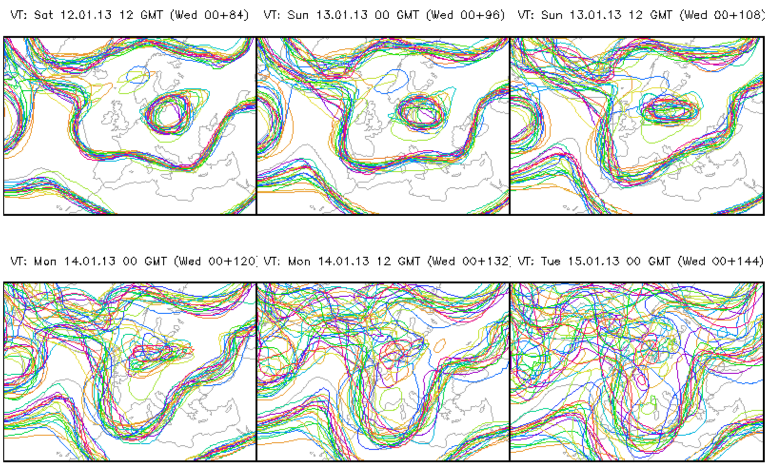
Research for this report included attending a meeting where Jim Bacon, principal of Weatherquest spoke to farmers about the products that Weatherquest offers. His presentation on the Ensemble Weather Forecasting System was excellent (Figure 7). The format really helps to understand the limitations and strengths of the system and will help farmers to use it as a tool.

The weather maps (Figure 7) show a low as it moves across the UK. Each trace is of an outcome that one of the 51 ensemble members produced. Each picture is a 12 hour timeframe of the movement of the feature. Until day five or six the feature is relatively predictable but going past this point the probability of making a reliable forecast decreases dramatically, although for day seven to eight there are locations that are still showing quite good accuracy.

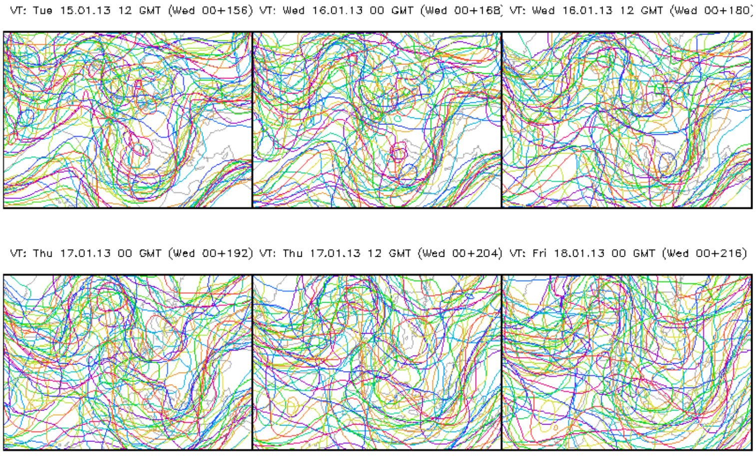
*Figure 7. An ensemble forecast showing the forecast for a low pressure system as it moves across the United Kingdom. Each line depicts how one of the ensemble members is predicting where the low will move. (Bacon J. Weatherquest 2013).*



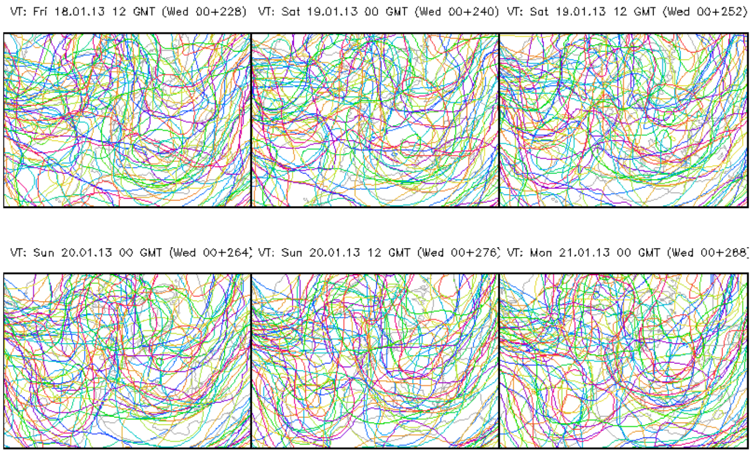

Days 1 to 3




Days 4 to 6




Days 7 to 9

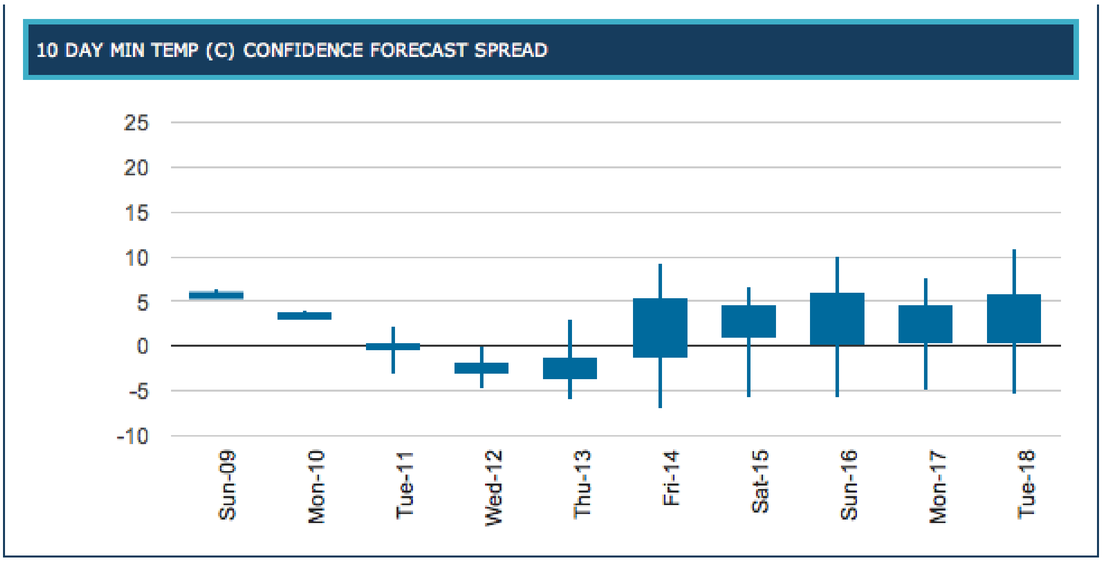



Days 10 to 12

Despite the limitations of lower reliability beyond days five and six, there are still ways to use the longer term information produced by the Ensemble Forecasts to help in making decisions. Figure 8 shows a confidence spread for a ten day minimum temperature forecast. If low minimum temperatures were considered a risk this spread will show when there is an increased risk of temperature deviating from the forecast temperature and by how much. For example, even though the forecast for the 14th to the 18th may have been for the minimum temperature to stay above zero, the models are showing that there is still a risk that it could stay well below zero for all of this period. This type of forecast spread is also available for other features, This is how Weatherquest converts the confusing information from Figure 7 into user friendly material for its clients. Information is supplied to their customers over the phone and through their web portal.

For more information visit  http://www.weatherquest.co.uk/aboutus.php

*Figure 8. Chart showing the spread of ensemble members forecast for temperature on each day of a 10 day forecast. The dark blue boxes show where the majority of members sit, the lines show what the extremes are indicating. (Bacon J.  Weatherquest 2013)*




## Oklahoma Mesonet

This is a network of interconnected, autonomous weather stations that monitor weather at a mesoscale. Mesoscale refers to weather events varying in size between 1500m and about 240km across. They last from several minutes to several hours; because of this they might go undetected without densely spaced weather observations.(Mesonet 2013)

Oklahoma is susceptible to all manner of extreme weather events; these include tornados, snow storms, and heat waves of over 40$^{o}$C for 60 to 80 days and ranging to winter temperatures below -30$^{o}$C.

The Mesonet was established in 1990 at a cost of $2.7m after the two Oklahoma Universities joined forces and lobbied their State Government for its establishment. It is has the best network of real time weather observation in the USA, and of anywhere visited while researching for this report.

There are 120 observation sites evenly spaced 37 to 38km apart on a grid like pattern across the State of Oklahoma, which has an area three quarters the size of Victoria.

The high resolution of real time data significantly improves the ability to forecast and track severe weather events. It also improves the ability to forecast inversion conditions, which are unsuitable for farmers undertaking pesticide application, and to provide a risk assessment of their occurrence. Located at each site are soil moisture sensors that measure stored moisture. This improves monitoring of soil moisture levels and rainfall deficits to help farmers assess the risk of rainfall drought affecting their crops.

The Mesonet has developed a close relationship with emergency services managers, which improves the planning and deployment of staff during an emergency.

Farmers are able to access Mesonet data on an interactive website http://www.mesonet.org/index.php/agriculture/monitor and an iPhone/Android app. The website also contains decision support tools, including a spray drift risk advisor and wheat growth calculator, which will be discussed later in the report.

During an interview with Dr Kevin Kloesel (February 2013) at the Mesonet , the following observation made by Mallee farmers was discussed. When a rainfall event tracks through their district in a defined strip at the start of the cropping season it is not uncommon for that area to receive extra rain during following rainfall events.

Dr Kloesel said that Renee McPherson had published a paper on this phenomenon (McPherson, Stensrud. Crawford K. 2004). Apparently, rainfall, snowfall and drought all have a “memory”. This is due to the strong theta-e (potential for convection) gradient along the edges of the wetter land. Feedback from soil and plant characteristics can all add to the effect. He said that current models are not able to take weather memory into account. He also said that in America, much of the geophysical data that produce these phenomena is held within the indigenous tribes of America.

## Predict Weather

Predict Weather is a private weather forecasting service run by New Zealander Ken Ring. Ken has approached weather forecasting from a very different angle.

Ken had the opportunity to observe weather from a unique perspective when living a semi-subsistence lifestyle on the beach. He noticed a strong correlation between the tides, the moon and weather events. He also had a close association with local Maoris and became familiar with their fishing and farming calendars which were based on the cycles of the Moon. This led him to researching how the moon and weather could be linked. He has also researched links with the sun and planetary cycles. One of Ken's frustrations is that, as soon as the moon is mentioned, many scientists do not take him seriously, however he is able to quote many scientific research papers to back up his methods. When asked about how the moon can influence our weather he begins by talking about the oceans tides and the tidal mechanism. He then points out the atmosphere actually contains more water (as water vapour) than all the rivers and lakes on Earth put together. This still only equates to around 1% of the atmosphere, (nitrogen is 78.09% and oxygen 20.95%). Gas by its nature is a much easier to move around than water, so if the moon can have an effect on the oceans, Ken suggested, why should it not affect the atmosphere?

Instead of focusing on the surface pressure as used by traditional meteorologists, Ken looks at the total volume of the atmosphere. This expands and contracts in a tidal effect with the Moon and to a lesser extent the Sun, and drives our weather. To add weight to this argument in his book, *The Lunar Code*, (Ring K. Random House 2006) Ken mentions that astronomers have discovered that planets without a Moon have a more stable atmosphere.

Regarding the Sun’s solar cycles, Ken says they are driven by the gravitational affect of the orbits of the planets in our solar system. There is also a correlation between lunar cycles and the solar cycle.

Looking at El Nino events in relation to these cycles Ken mentioned (March 2013) that there are interesting correlations. In his book , he discusses how El Ninos can occur just after sunspot minimums and around maximum, midpoint and minimum lunar declinations (where the Moon is in relation to the north/south horizon; this has a monthly cycle as well as a longer cycle of 18.613 years). It would be interesting to study correlations with other teleconnections.

As well as strong supporters of his forecasting techniques in many countries, including Australia, Ken also has some strong critics. When questioned on some of the criticisms that have been levelled at him, Ken says many of these are brought about by misreporting, or by his comments being taken out of context.

More information on Ken’s services can be found at www.predictweather.co.nz

## Holton Weather

Ian Holton spent the first 26 years of his career with the Australian Bureau of Meteorology. In 1996 he undertook a research project to look at the influence of the Indian Ocean on Australia’s weather. Following the publication of his paper he left the Bureau to start his own business providing medium term and seasonal forecasts for Australian farmers.

Since those early years Ian has significantly refined his forecasting techniques. He has continued his interest in researching weather forecasting methods and improving his forecasting ability for his clients. A significant increase in the reliability of his forecasts occurred in 2010 after his research uncovered strong correlations with seasonal fluctuations and solar cycles. Ian now uses inputs from atmospheric, ocean, solar and ionospheric data.

Ian has also performed his own private research on human-induced climate change to see if he needed to include an allowance for this in his forecasting models. His research has shown a relatively small effect of the increase in atmospheric carbon dioxide on our weather. http://www.holtonweather.com/

For the avid weather watcher Ian has also compiled a list of bush forecasting aids; this can also be found in Appendix 1.

# Chapter 4: The Progression of Weather Forecasting

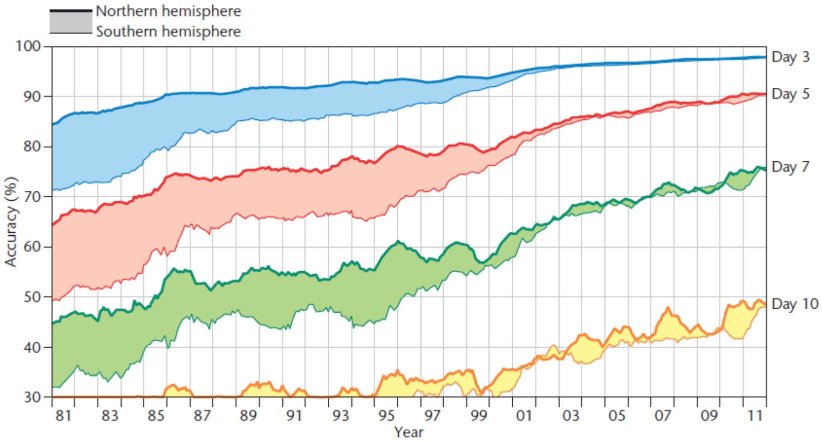
It is easy to dismiss the meteorologists when they supposedly "get it wrong" and to focus on those events rather than the number of times when the forecasts are actually quite accurate. During an interview at the ECMWF (Feb 2012), David Richardson, head of Meteorological Operations illustrated the improvements that have occurred in weather forecasting over the past 25 years.

Most weather forecasters are in essence mathematicians and they do their job very well. They collect information, which is statistically analysed using various computer models. They then try to present this information in a useable manner to a generally meteorologically uneducated public. Sometimes the way it is presented affects the public's perception of its accuracy.

## Short term forecasting

The accuracy of the current 24 to 72 hour forecasts are quite staggering, as is the improvement that has occurred over the past 30 years. This can be clearly seen in Figure 9. which shows the ECMWF forecasting skill level over the past 30 years. (European Centre for Medium Range Forecasting 2013)

*Figure 9. Chart showing the increased forecast accuracy from 1980 to 2011 with a comparison between Northern & Southern Hemispheres.* (European Centre for Medium Range Forecasting 2013)




The coloured area between the narrow and bold lines is the difference between the accuracy of the southern and northern hemisphere forecasts. It can be seen that historically forecasting accuracy for the southern hemisphere has significantly lagged behind the northern hemisphere, until about 2001. This was due to the lack of observations; satellite data has helped to overcome this issue.

Accuracy levels for the short term forecasts are now around 98%, which is an improvement of 25% for the southern hemisphere. It is interesting to note how the rate of improvement for short term forecasts has slowed over the last few years, showing that it is becoming harder to make improvements and increase the accuracy

## Medium term forecasts (See Appendix 2.)

From Figure 9 the dramatic improvement in the five, seven and ten day forecasts can be seen. In the past 13 years alone, the accuracy of the five and seven day forecasts for the southern hemisphere has both increased by over 40%, and the ten day forecast by 20%. If the trend lines continue as they are, the accuracies will only continue to improve.

## Long term forecasts (See Appendix 2.)

Benchmark data for longer term and seasonal forecasting has been difficult to find. This would tend to suggest that there is still plenty of room for improvement in this area. Darren Ray (July 2013) from the Australian Bureau of Meteorology told me that the Bureau's forecasts have about a 65% accuracy.

Clients of private weather forecasters say they believe the private forecasters have a greater skill level in this area. According to Gary McManus from the National Weather Centre in Oklahoma, the reason for this appears to be that weather forecasters in forecasting institutions are hesitant to use new techniques unless they are totally proven; this is especially true for their open access products. On the other hand private forecasters tend to be much more prepared to include a new or unusual tool if they are satisfied it will provide an increase in forecast skill and a more accurate forecast for their clients.

Examples of this include Ray Garnett and Ian Holton who have included solar cycles and other teleconnections in their forecasting systems, and Ken Ring who uses lunar cycles. When Ken Ring (March 2013) was asked if he has had his forecasts benchmarked for accuracy he made the following comment

*"My accuracy has often been assessed at 80 to85%, by my clients and my own assessments, which I am happy with, because it is enough to identify trends. Generally, the lunar method is best suited for the timing of weather events rather than amounts of rain, which are more due to the solar heat cycle. This is because amount of rain depends on prior evaporation rates.*

*An accuracy of 80 to 85% means I might be out by a couple of months over a year, or one or two days in a week. Rain may fall within a radius of 80kms, which is both the applicability of a report and also the error factor. This is as exact as weather forecasting can get at the best of times because weather is typically generated about 13 to19km above the earth's surface and has an unavoidable overshoot factor when it reaches ground."*

# Chapter 5: Micrometeorology

## A New Science

Micrometeorology can be defined as the study of the effect on weather of the small-scale (local) environment, generally at a resolution of about 1km or less. Micrometeorology studies features that are too small to be depicted on a weather map. These features generally include heat and gas movement between vegetation, soil, water and the atmosphere caused by turbulence close to the ground.

Most current weather forecasters tend to look at the big picture (synoptic and mesonet scales) and rarely ever consider micrometeorology in any detail. According to Australian based private micrometeorologist Grahame Tepper (July 2012), if you were to undertake a meteorologist course in Australia you would not encounter a micro-met subject. As far as he is aware there are no micrometeorologist specialists in the Bureau of Meteorology either, although there are in the CSIRO and other specialist organisations.

The difference between micrometeorology and general meteorology can be illustrated by considering the World Meteorological Organisation (www.wmo.int/) standard for measuring temperature. This states that temperatures should be measured at about 1.5m above the surface in a shaded and ventilated box. This advice ensures that extremely variable temperatures experienced at the surface are 'evened out' by turbulent mixing. Micrometeorology is interested in those differences and the rates of exchange between the surfaces and the air immediately above this height. The standard forecasting methods are only interested in the results of the mixture of this air at about 1.5m above the surface.

Currently any micrometeorology data that is collected is not normally available to farmers. As technology improves, with the advent of on-farm instrumentation and communications systems and satellite-derived instantly retrievable information, it will become possible to map microclimate variations. This will be at time scales that are useful for input into business management systems, particularly in regions of complex terrain and for high yielding crops. It will improve understanding of crop performance and management of day to day operations, such as applying crop protectants.

## Stamina, a Micrometeorology Research Project at the Biotechnology & Biological Sciences Research Council (BBSRC) Rothamsted

This research facility is known as the birthplace of the science of agriculture. Located south of Cambridge in the UK, it was the site of an interesting micrometeorology research project, overseen by Goetz Richter. As part of the Stamina project a model to research and quantify the effect of local topography on crop yield has been developed. Sensors measuring radiation and crop temperature were placed at canopy height and 2m above canopy height at regular intervals down the slope. The project found that there is a strong correlation between aspect and yield. South-facing slopes tended to be consistently lower yielding than north facing slopes. This was found to occur because in the northern hemisphere the south-facing slopes receive more sunlight, radiation, and the plants are hotter and become drought stressed sooner than those on the north-facing slope. This effect would be opposite in the southern hemisphere. The findings in regard to yield are consistent with statistical measurements of yield maps collected from our own farm.

Dr Goetz (February 2013) said that they also found that the top of the hills tended to be lower yielding due to the increased evaporation from more wind.

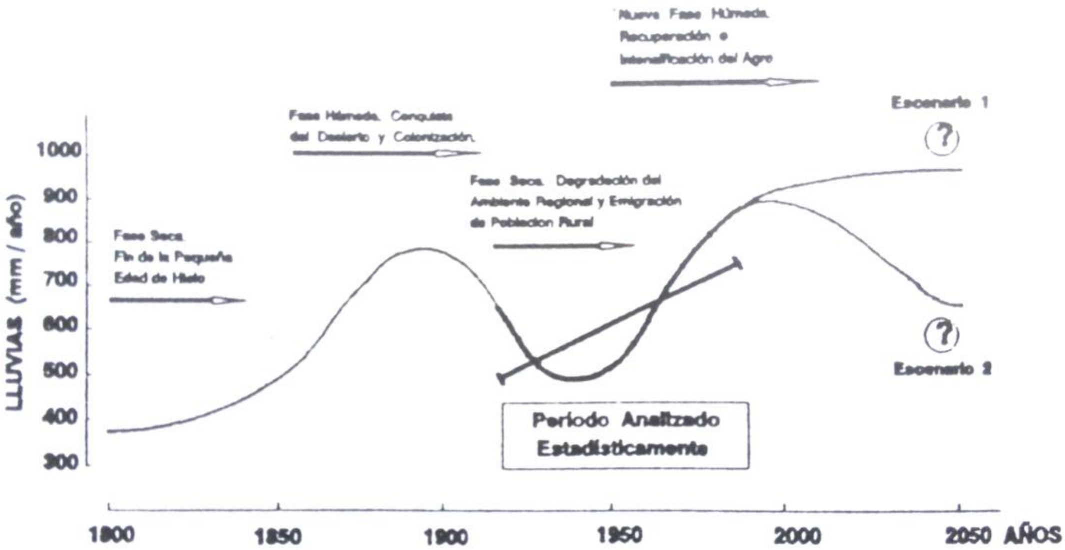
An outcome from the research was that farmers in the northern hemisphere with hill country with a southern aspect should sow this land as well as the hilltops earlier to crops that are faster growing, to help counteract these affects.

# Chapter 6. Natural Climate Variability

There is a large amount of natural variability occurring within the climate. The relatively short timescale of accurate weather records clouds the natural variability that has occurred over a longer timescale. People's memories and even their working lives are also relatively short, so that they have a natural tendency to forget the bad things and remember the good. This affects their perception.

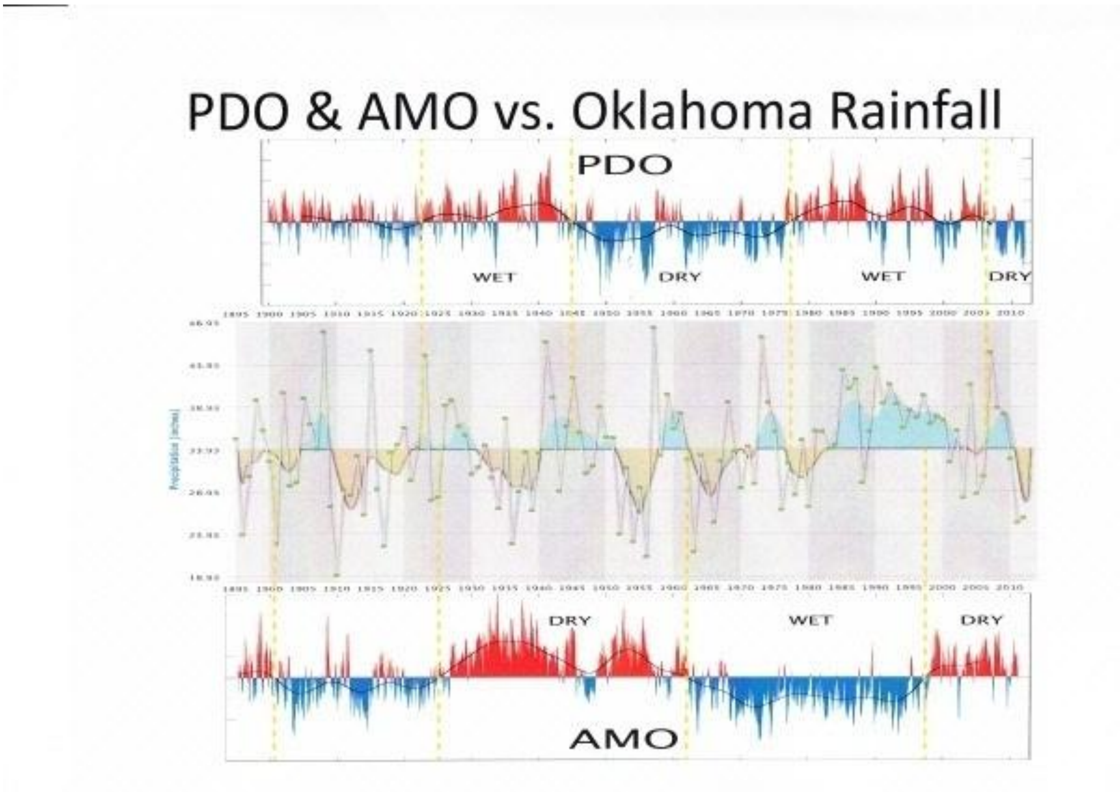
One example of this is illustrated by a chart from the INTA research Centre in Anguil, Argentina (Figure 10). It shows the longer cyclical climate variability which affects the La Pampa region of Argentina. This area naturally has extreme annual climate variability with rainfall varying by up to 60% from one year to the next. To add to this it oscillates between wet and dry phases of fifty to sixty years. This in effect could constitute a farmer's entire farming career. Depending on when they were farming they would have a very different paradigm of the perceived climate of the region.

*Figure 10. The cyclical nature of rainfall in La Pampa Argentina. The x axis shows years and the y axis rainfall. The question marks are asking whether human induced climate change will have an effect on where it trends now. (INTA Research Centre Anguil Argentina 2013)*



Another example was presented by Chuck Cofey from the Samuel Robert Noble foundation in Ardmore, Oklahoma. Chuck gave a presentation on the cyclical nature of Oklahoma rainfall (February 2013). From the period 1980 to 2010 Oklahoma had a run of wetter than average years. The question had been asked was this the “new normal”? Once the influence of the PDO and AMO (See Appendix 2.) was understood it became apparent that the answer was no, as this anomaly was only temporary. (Figure 11.)

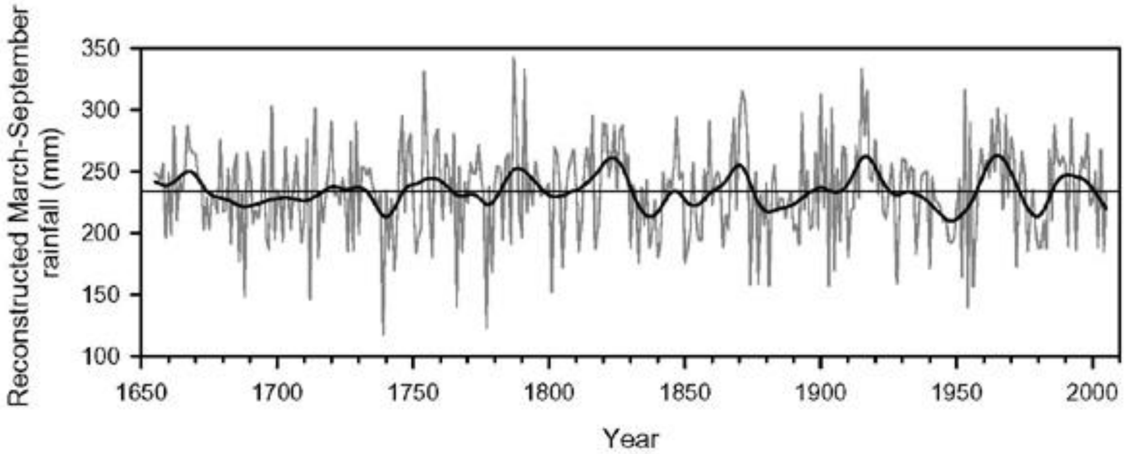
*Figure 11. Chart showing the influence of the PDO & AMO on Oklahoma rainfall between 1895 and 2012 (Samuel Thomas Noble Foundation 2013).*




If a way can be found to look to the past to better understand climate variability in a farms location, the land managers will be better placed to manage for the future. One example of some work done in this area in Australia is by measuring the growth of old trees using tree rings. In other parts of the world tree ring research has been quite extensive, however, in Australia it is relatively new.

Research performed in south west Western Australia reconstructed rainfall back to 1654 AD. It revealed considerable multi-decadal variability in rainfall. There were dry periods that often lasted 20 to 30 years and periods of above average rainfall that tended to persist for approximately 15 years (Cullen, L.E. & Grierson P.F. 2008).

*Figure 12. March to September rainfall for South West Western Australia reconstructed from tree rings. Annual values are plotted in grey and a 20 year smoothing line in black (Cullen, LE & PF Grierson 2008).*




Dr Nathan English from the James Cook University in Queensland is also undertaking research on tree rings in tropical Australia in an attempt to better understand seasonal fluctuations in our climate.

Other indicators which can be studied to determine climate variability include coral cores, lake bed layers and ice cores. There is opportunity for more research to be undertaken in these areas within Australia.

Overall, it can be seen that our weather is cyclical; there are periods when it is wetter and periods when it is dryer. Managers need a good understanding of these extremes, the probability and frequency of them occurring and the affect they can have on the business in order to manage around them. They also need to determine if the current weather they are experiencing is part of a longer cycle and if so what part of that cycle they might be farming in. It may lead to asking if there is a need to change their view of the local climate.

# Chapter 7:The Future of Weather Forecasting

## Private Sector versus Public Sector

As shown in this report there have been amazing advances in weather forecasting over the last 30 years. Short term forecasting looks like it is approaching the maximum attainable accuracy; however, medium range and seasonal forecasting skill will continue to improve. There is good research happening in both public and private sectors, which will continue to improve skill levels. Research into human induced climate change is perceived to be more important than advances in seasonal forecasting; at least advances in seasonal forecasting seem to be a by-product of climate change research. In the places visited, there seems to be more dedicated research into seasonal forecasting in the private sector than the public sector.

## New Radar Technologies

### Dual-polarization technology

One of the downfalls of current radar is that it only measures intensity of precipitation and the direction and speed it is moving. It cannot accurately identify if it is rain, hail, snow, or ice pellets, or measure the size of the precipitation. Dual polar radar overcomes this problem.

Conventional radar uses the return signal of a horizontal electromagnetic wave to measure the horizontal size of an object. Dual pole radar uses a second wave sent at 45 degrees. A computer programme separates the fields into horizontal and vertical information. This 2-D image now provides the forecaster with the size and shape of the object. Armed with the extra information of what the type of precipitation and how much to expect, the confidence of forecasters to accurately assess weather events will increase. Dual pole radar is currently being wound out in the United States and trialled at one site in Queensland.

### Phased Array Radar

Until recently, phased array radar has only been available to the military in the United States. Research is underway in the USA to see if civilian and military use can be combined. The benefits of this type of radar is that it can capture 15 images in the time it takes conventional radar to capture one. It is also able to be electronically steered, so its beam can be focused only where storms are detected leading to faster updates. This is unlike conventional radar that wastes time looking at clean air. Use of phased array radar would improve the lead time associated with severe weather warning forecasts and make these forecasts more reliable.

## Teleconnections

Teleconnections form a very important part of seasonal forecasting; because of their longer term cycles they provide one of the paths to forecast future weather events. No-one interviewed during the research for this report was specifically researching new teleconnections; most of the teleconnections research seems to be included with other climate research. Private forecasters such as Ray Garnett and Ian Holton are certainly doing some of their own research. Increased research into the forcing effect of teleconnections on each other could also provide a way to improve seasonal forecasting.

## Astrometeorology

There are opportunities to further investigate the links between astrometeorology, various teleconnections and seasonal variability, which could improve weather forecasting capabilities

## Cycles

As the global weather record continues to grow we will continue to gain a better understanding of natural cycles and variability. Further studies of tree rings, coral and lakebeds will also help to give us a better understanding of these cycles. Together these will help to understand and improve forecasting of natural cycles. As natural cycles vary in strength there will always be a margin for error when looking at the past.

According to Chuck Coffey of the Samuel Roberts Noble Foundation (February 2013), the current statistical models which use ENSO are based on the past, when the PDO was in a warm phase, and El Ninos occurred every four to five years. Now that the PDO is in a cool phase it is cycling from El Nino to La Nina and back again more frequently. So the discovery of the PDO has really changed the way that the statistical ENSO models can be viewed, and begs the question of what cycles are we not seeing yet and what adjustments will there need to be made to the current models to allow for them.

## Volcanic

Volcanic activity, and especially major eruptions, seem to be related in some way to the weather. Changes in tree growth could be observed in ancient Kaori trees in New Zealand at the times of major volcanic episodes. Some scientists suggest that this is related to atmospheric effects from the volcanoes. Darren Ray from the Australian Bureau of Meteorology (July 2013) said that there is documented evidence that aerosols from fires in Indonesia are causing an increase in rainfall in Northern Australia, which would tend to suggest that volcanic activity could also produce similar effects.

Ken Ring suggests that the volcanic activity and earthquakes can be related to the solar and lunar cycles, which are actually driving the weather. This seems rather far-fetched, however Ken explains that just as there is a tide at sea there is also a land tide (Earth Tide). He says the sun and moons gravitational pull will move the land surface vertically by as much as 20 to 50cm a day. The angle and proximity of the sun, moon and indeed other planets in our solar system, to the earth, can influence plate movement and volcanic eruptions. In a published paper on Earth Tides (Agnew, 2007), it is suggested that earth tides can be as large as 60cm and that as well as vertical movement there is also horizontal movement. As can be seen in Figure 13 (A) & (B) this occurs in a global nature.

Figure 13. *(A). Lunar tidal forcing: this depicts the Moon directly over 30° N (or 30° S) viewed from above the Northern Hemisphere* (Wikipedia 2013)

*(B). This view shows same forcing 180° from view A. Viewed from above the Northern Hemisphere. Red up, blue down.*

*(Wikipedia GNU Free Documentation Licience)*

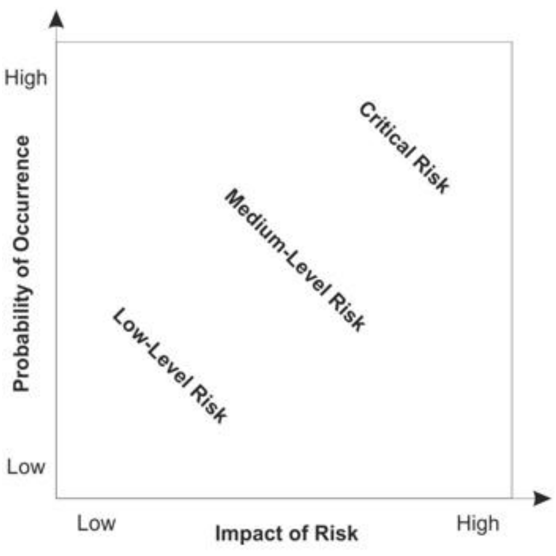
# Chapter 8: Decision Support Tools and Systems

## UK Met Office

The UK Met Office predominantly uses information generated by the ECMWF to produce its forecasts, however it also uses some of its own models. The main clients of the Met Office are the UK Government, civil aviation, defence and now, to a much lesser extent, the UK public.

The Met Office uses a risk prediction system to help decide how to allocate its resources (Figure 14) Ken Mylne, The Ensemble Forecasting Manager, UK Met Office, explained how the risk impact probability chart could be used in any part of a business not just for managing the effect of weather (February 2012). The idea is to identify all of the risks that a business faces. These are ranked from low to high and the probability of each risk occurring is also ranked from low to high. Each risk is plotted on the matrix. This helps to identify which risks pose the most threat to the business so management procedures can be implemented.

*Figure 14. Risk impact probability chart, used to analyse the impact of a risk on your business. (UK Met office 2014)*

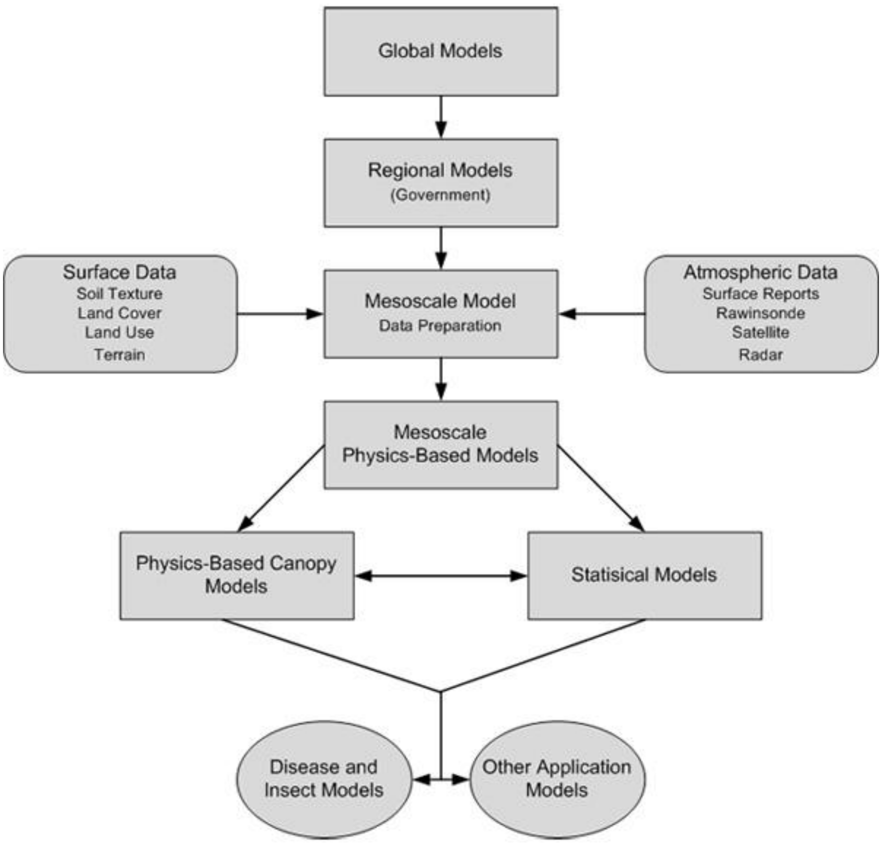


Zed X

Based in Pennsylvania, USA, Zed X specialises in providing high-tech decision support systems for a number of sectors including agriculture. The team have developed models which combine data from global and regional forecasts that have a resolution of 30 to 60km. In addition, the models have mesoscale observations to forecast crop development as well as pest and disease progression in a one to ten kilometre resolution throughout the world (Figure 15). Early in the season their crop yield forecasting accuracy for the USA is within 20 to 30%, but by mid summer (July) they are within 8 to 10% of final yield (http://www.zedxinc.com/products/GRAIN).

Joe Russo from Zed X demonstrated how their models are able to successfully forecast when there is an increased risk of disease or insect pressure. With this knowledge a farmer can undertake preventative crop protection measures.

*Figure 15. Diagram showing the flow of data used to generate high resolution crop and disease forecasting by ZedX (ZedX 2012)*



## The Oklahoma Mesonet

The Mesonet has also developed some unique tools that are useful for Oklahoma farmers. These include a Wheat Growth Calculator, Irrigation Planner, Cattle Comfort Advisor and a Drift Risk Advisor. These products can be viewed at http://www.mesonet.org/index.php/agriculture/monitor

With some modifications the Drift Risk Advisor is something that could be developed for Australian farmers, which would be especially useful if it was available as an app.

## Australia

The following is a brief list of Australian weather and management related systems and tools.

### Climate Kelpie

This is a great point to start when looking at available tools to better understand climate and weather. http://www.climatekelpie.com.au/

### Australian Rainman

This is an excellent Australian designed tool readily available to farmers. It provides rainfall data for 9,700 locations worldwide, for as long as records have been collected. Though it takes a while to learn how to drive it, it is a useful tool to look at seasonal variability for the location closest to your farm.

Australian Rainman also has a function to look at wet and dry cycles, by smoothing seasonal rainfall over a selected number of years. It will do this for any location with long term weather records in Australia and also has a function to import your own data. This can be helpful to determine the climatic pattern that you have been farming in. It has the ability to look at rainfall in relation to some of the teleconnections discussed. This function could certainly be further improved in light of recent discoveries.

### Australian Bureau of Meteorology (BOM)

The BOM website http://www.bom.gov.au/climate/averages/maps.shtml also has the ability to look at historical weather data for weather stations across Australia. It is relatively easy to navigate but lacks some of the features that Australian Rainman has which are useful for analysing wetter and drier periods for specific locations.

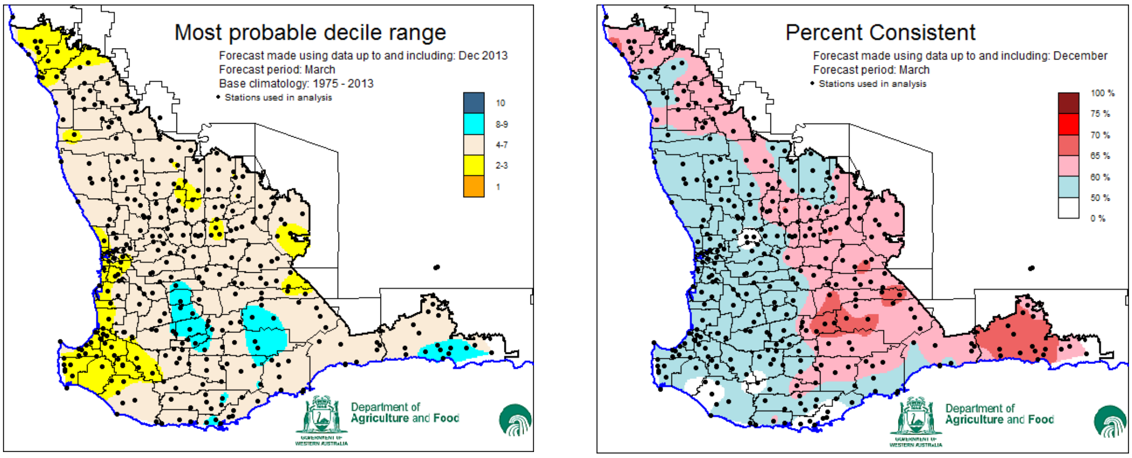
### Production Wise

This is production recording software which is linked to Australian Production System Simulator (APSIM) and Yield Prophet. It has a weather and crop production forecasting module which has some strong advocates. Recent upgrades provide users with an accuracy assessment to give farmers more confidence in the forecasts.

### Ag Seasons

The website https://www.agric.wa.gov.au/climate-land-water/climate-weather/agseasons , was developed by The Department of Agriculture and Food Western Australia. It is targeted specifically at Western Australian farmers. Using historical relationships between rainfall and known teleconnections, it provides probability based forecasts for the Western Australian (WA) grain belt. Produced at least monthly throughout the growing season, the forecasts include an assessment of the accuracy of the forecast which is measured against historical data. As shown in Figure 16, the forecast is map based and has a lead time of three months. The user is able to select the start and end months of the forecast, the period in years from which the base data will be used, and the type of forecast. The three types of forecasts which can be selected are the most probable decile, median rainfall, and probability of exceeding median rainfall. The website also includes features which show stored soil moisture and frost risk for WA.

*Figure 16. Rainfall forecast and accuracy of the forecast for March 2014 for South West Western Australia, as available on the Ag Seasons Website (Ag Seasons 2013)*




### Graingrowers Monthly Rainfall Forecast Reports

This report is produced monthly by Graingrowers Ltd for every square kilometre of Australia. The rainfall forecast in millimetres is produced for one, two, three, six, nine and twelve months. It is produced in a percentile format and includes the median rainfall value for the past fifty years and for each forecast period. It includes a 20 and 80 percent range in the forecast; that is a forecast value of which there is and 80 percent chance of exceeding, and a forecast value of which there is a 20 percent chance of exceeding. They say this helps to provide a stronger level of confidence in the forecasted values. It is available as a stand-alone service for large corporate businesses or governmental land managers or as an add-on to Productionwise. For more information visit http://www.graingrowers.com.au/products-services/rainfallforecastreport

## Weather Related Applications (Apps)

### *Windmeter*

A useful weather related app is the wind meter. This is available for iPhones from the apps Store.

### *Australian CliMate App*

This app. puts many of the functions of Australian Rainman at your fingertips. At the time of writing it did not include a function to look at trends to understand where a location might currently be in a weather cycle. It is certainly a helpful decision making tool.

### *Spraywise Decisions*

Developed by Graingrowers Ltd and sponsored by Nufarm this app provides up to date information on weather conditions for spray operators. Updated every 12 hours it forecasts weather up to 14 days ahead, and for the first seven days, every three hours. It forecasts temperature, wind speed and direction, relative humidity and rainfall. It is available as a subscription service or as an add-on to Productionwise. It is also available for a free trial http://www.spraywisedecisions.com.au/

### *Weatherzone+*

Available for Iphones from the Apps Store this app provides the user with a twenty eight day, seven day, and daily forecast. Also a three hourly, 48 hour forecast. It provides forecast conditions for temperature, wind speed and direction, relative humidity and rainfall probability. The app also has a 24 hour chart showing temperature, rainfall probability and timing

# Conclusion

## Positioning Your Business

Given the uncertain nature of weather forecasts, the riskiest thing anyone could do is to take a weather forecast literally. In the media we see stories of farmers who followed a forecast of a drought literally, made a dramatic business decision, (such as deciding not to sow any crop at all or totally de-stocking), which proved to be the correct decision and resulted in a dramatic escape from its effects.

For every one of these stories, there are many more where a dramatic decision proved to be incorrect resulting in huge losses. As weather forecasts continue to become more accurate farmers will begin to increase their reliance on them. However, this could increase the risk to the business especially when the forecast will inevitably be wrong.

A way to overcome this risk is to gather as much information as possible from a number of sources, then to use this information to make a calculated weighted decision. For example; given no knowledge of any weather forecasting tools, the most profit/risk balanced way to run a business might be to always plan for an average year. However once it is known that there is a significant chance of a below average year occurring, a percentage of resources would be held back, so if the forecast is correct the business is better off, but if it is incorrect the business still remains profitable. If a significant chance of an above average year was forecast, a greater amount of resources may be allocated, increasing the profitability of the business if the forecast proved correct, but not risking too much if an adverse season eventuated.

## Managing Without Weather Forecasts

Another way to set up your business is to develop management systems that do not rely on a weather forecast. These may be developed around obtaining better information about existing conditions and working with what you know. An example of this could be planning crop fertiliser decisions around stored moisture (or lack of) and then adjusting follow up applications as the season unfolds. Further development of tools such as APSIM would help this.

## Further Research

This research is really only an overview of agricultural meteorology in the countries visited. It would be really good for someone to continue this research and to look at the research occurring in India and South Africa, especially in the area of medium range and seasonal forecasting.

India in its own right has been researching seasonal weather forecasting for a long time. Contacts obtained through this research project have also indicated that South Africa is undertaking some interesting work.

Research needs to be targeted at seasonal forecasting. Investigations for this report have confirmed there is plenty of scope to continue to improve seasonal forecasting. To achieve this, researchers need to think outside the square, to be bold and innovative. There is evidence to show that some of the astrometeorological forecasting techniques, like those used by Ken Ring, may have sound scientific principles at work and warrant more investigation. An international symposium on agricultural meteorology would be a good starting point to drive a quicker improvement in seasonal weather forecasting.

On the opposite end of the scale to seasonal forecasting, the emerging science of micro meteorology will become increasingly important as farmers try to manage their businesses around constraints placed on them by the local community. Increased research to build a better understanding of the effect of the local environment on the weather at the paddock scale will help to reduce the risk of placing the community offside to farming practices.

# Recommendations

Australian farmers need to improve their understanding of weather forecasting, and understand how forecasts are generated, with their strengths and weaknesses. They also need to know how they can make better use of the forecasts within their businesses to improve risk management.

1. Australian meteorological research should include an open-minded focus on searching for more teleconnections which impact Australian weather.

2. Weather forecasters need to develop better techniques to communicate forecasts to farmers making the information even more useable.

3. Researchers and Australian Farmers need to take advantage of developments in microprocessors for recording weather data and precision agriculture to increase knowledge in the field of micrometeorology. Using this technology to manage the impacts of weather at a very local level will enable farmers to improve their management of day to day operations and reduce their impact on the local community.

4. Australia should consider hosting a worldwide symposium on Agricultural Meteorology.

# Appendices

## 1. Traditional Forecasting Tools

### Australian Bush Forecasting Aids

Signs that rainfall may be coming shortly to your area

- Ants building high mounded ant-holes & moving eggs up on fence posts
- Black clouds of flying ant swarms above treetops
- Water birds nesting higher around dams & rivers
- Springs starting to flow when the weather is dry
- Plovers arriving earlier than normal
- Emus laying eggs means rain coming in a few weeks
- Lizards sitting on the top of fence posts or in trees (Facing the east in SA Mallee)
- Local area kangaroos found in areas that they don't normally move through
- Huntsman spiders moving inside the house, means rain in a couple of weeks
- Winter type rains will start when the last leaf drops off the fig or apricot tree
- Spiders silk webs floating in the air, and catching on trees, grass & fence-wire
- Mice and rats moving into and/or nesting in roofs and high places
- Floods in Indian sub-continent mean floods in Australia in 2 to 4 months time
- Winter rains will not start until 4 to 6 weeks after the last tropical cyclone off Western Australia
- Airplane contrails remaining in sky for short periods
- Frequent Whirlwinds
- Dust devils turning clockwise means rain ahead...and anticlockwise means fine weather ahead

Part of a list compiled by Ian Holton from information supplied by many farmers, with thanks.



### United States Traditional Weather Forecasting

The Old Farmers Almanac claims an accuracy of 80% for seasonal predictions. It also contains some interesting articles on traditional means for forecasting such as using a persimmon seed, or a pigs spleen for more information please follow the link. http://www.almanac.com/topics/weather/weather-forecasts/predicting-weather

### How to Predict the Weather without a forecast

This is a Wiki page that is quite interesting and gives the average farmer some clues of what to look for in nature and some scientific rationale behind why they might occur. http://www.wikihow.com/Predict-the-Weather-Without-a-Forecast

### Kenya Meteorological Department (KMD)

The KMD is working with traditional rainmakers in the Baynore community in Western Kenya to help scientists develop more reliable systems for predicting the weather. The Nganyi use a combination of natural phenomenon to give advice on optimal planting dates; their reputed accuracy prompted KMD scientists to work with them. Their knowledge seems to improve the accuracy of localised forecasts. For more information please follow the link. http://www.new-ag.info/en/developments/devItem.php?a=2644

## 2. Terms used in this paper

### Short Term Weather Forecasting

Weather forecasts for the next 48 hours

### Medium Term Weather Forecasting

Weather forecasts for 3 to 14 days

### Long Term Weather Forecasting

Weather forecasts longer than 14 days out to seasonal forecasts

### Teleconnections affecting Australia (and other surrounding countries)

#### *Madden-Julian Oscillation (MJO)*

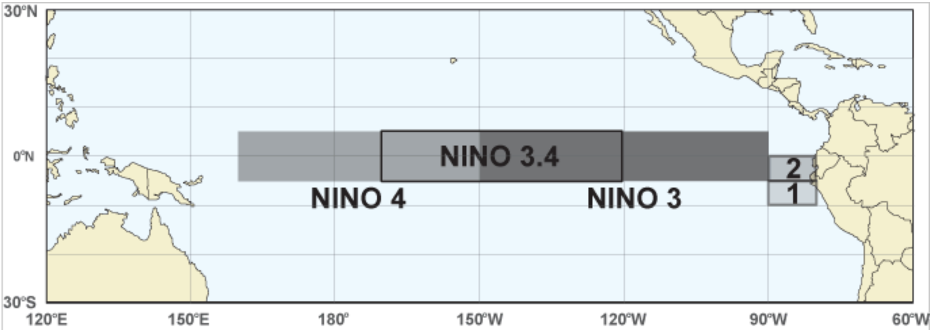
A global surface feature that occurs in the tropical atmosphere, it is a "pulse" of cloud and rainfall occurring near the equator. It has an eastward movement and a typical cycle of 30 to 60 days. As it fluctuates significantly in intensity its location is not yet always measurable. It has an influence on the development, timing and strength of the Monsoon around the world including Australia. (Garnett R 2013)

#### *El Nino Southern Oscillation (ENSO)*

El Nino is a term used to describe warming of a large area of the central and eastern tropical Pacific Ocean. This leads to a major change in weather patterns across the Pacific. Occurring every three to eight years it is associated with drier conditions in Eastern Australia and wetter conditions in parts of the USA & Canadian Prairies. ENSO is the term used to describe the oscillation between the phases which can be in El Nino, La Nina or Neutral. There are a number of different NINO indices that can be used to classify an ENSO event, the Australian

NCC uses the NINO3.4 index which you can see in Figure 17 (Garnett R 2013; Australian Bureau of Meteorology 2013).

*Figure 17. Map showing the different indices that are used around the world to classify an ENSO event. (Australian Bureau of Meteorology 2013)*




Source (45)

Recent findings in light of the discovery of the PDO have resulted in significant changes in the way some models can be reliably interpreted. Statistical models reflect the past, when the PDO was in a warm phase and El Ninos occurred every four to five years. Now the PDO is in a cool phase, it is cycling from El Nino to La Nina and back again more rapidly. Statistical models by their nature underestimate how strong El Ninos are in this new environment. They have a bias toward the Pacific remaining in neutral for a year after a La Nina.

Dynamic models such as POAMA are more reliable since they quickly reflect every change, however this makes them more vulnerable to the pulses of small MJO oscillations. When a warm /dry pulse travels through El Nino, they overestimate the events strength. When a cooler/stormy pulse flows through they underestimate. (The Browning Newsletter October 2012)

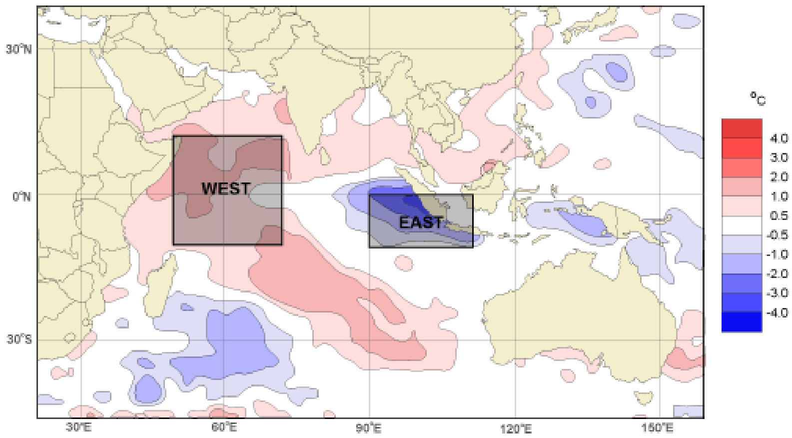
The Southern Oscillation Index (SOI) provides an indication of the development and intensity of an El Nino or La Nina event. It is calculated using a pressure differential between Tahiti and Darwin. A strong SOI does not necessarily indicate the severity of a drought in Australia, however it does increase the risk of drought.

### *Indian Ocean Dipole (IOD)*

The sea surface temperature of the Indian Ocean provides another influence over the rainfall patterns of Australia. The IOD is a teleconnection in the Indian Ocean affecting the weather of Australia and other countries surrounding the Indian Ocean. (Australian Government Bureauof Meteorology 2013 )

It is measured by an index which uses the difference between the sea surface temperatures, close to the equator of the western and eastern Indian Ocean. A positive value leads to suppressed rainfall across Australia and vice versa. The map below shows the areas used to construct this index, the map appears in a positive phase of the IOD (Saji N.H., Goswami B.N., Vinayachandran P.N., Yamagata., 1999) (Figure 18.).

*Figure 18. Map showing the IOD in a positive Phase which means less moisture feeds across Australia from the Indian ocean and drier conditions. (Saji N.H., Goswami B.N., Vinayachandran P.N., Yamagata., 1999)*

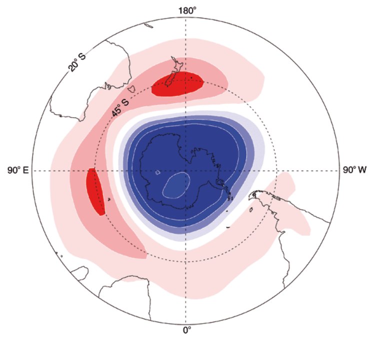



Source (Australian Government Bureau of Meteorology 2013 )

### *Southern Annular Node (SAM)*

Also known as the Antarctic Oscillation it refers to the north south movement of the band of strong westerly winds which dominate the mid latitudes of the Southern Hemisphere or Southern Areas of Australia. The annual shift of this belt produces a change in the amount of storm systems and low pressures over southern Australia. Although documented in the 1970's its effect on Australian weather has only been a relatively recent discovery. (It has a counterpart in the Northern Hemisphere called the Northern Annular Mode (NAM)) The impact on Australia of the SAM varies significantly from season to season and region to region. The diagram below shows the SAM in a positive phase where westerly winds in Australia tend to decrease (Figure 19). An index is used to measure its strength which varies from season to season. (Australian Government Bureau of Meteorology 2013)

*Figure 19. Map showing SAM in a positive phase when westerly winds across Australia decrease (Wikipedia 2013)*




(The National Institute of Water & Atmospheric Research 2006)

### *Quasi Biennial Oscillation (QBO)*

This is a seemingly periodical change of equatorial winds between easterlies and westerlies in the tropical stratosphere over an average period of 28 to 29 months. The alternating wind regimes develop at the top of the lower stratosphere (middle part of the earth's atmosphere) spreading and growing downwards at about 1 km per month until they are dissipated at the tropical tropopause (the boundary between the middle & lower atmosphere). Downward motion of the easterlies is usually more irregular than that of the westerlies. The easterly phase is about twice as strong as the westerly phase. At the top, easterlies dominate, while at the bottom, westerlies are more likely to be found (Garnett R 2013; Wikipedia 2013).

## Other Significant Teleconnections

### *North pacific Index (NP)*

The North Pacific index is an area of weighted sea level pressure in the area indicated in Figure 20. When this pressure is lower than normal in December the probability of drought on the Canadian prairies increases. (Garnett R 2013)

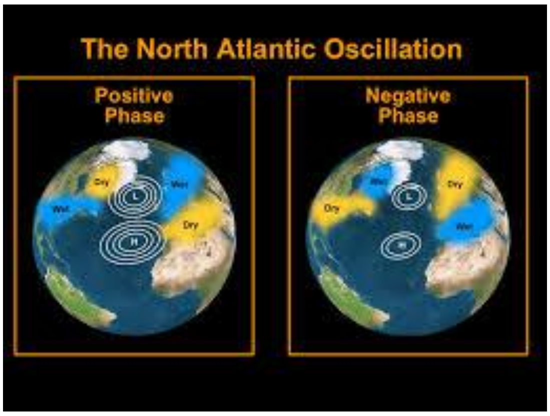
*Figure 20. Map showing where NP index is calculated*

*(NASA Global Change Master Directory 2013)*

### *North Atlantic Oscillation (NAO)*

Closely related to the Northern Annular Mode, it is an atmospheric phenomenon of fluctuations in the difference of pressure at sea level between the Icelandic low and the Azores high (Figure 21.) (Garnett R 2013; Wikipedia 2013).

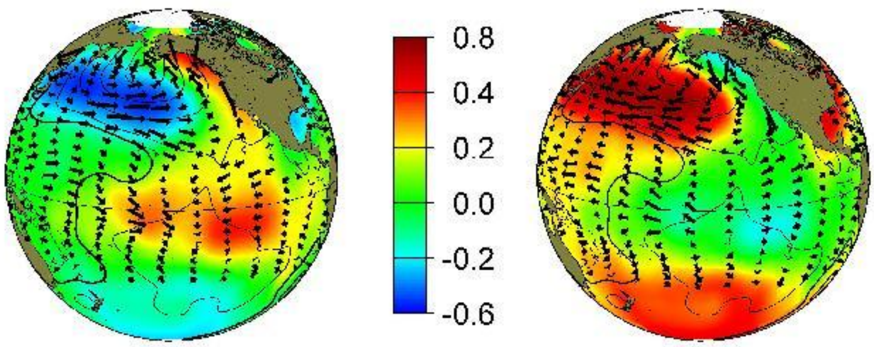
*Figure 21. Northern Hemisphere map showing the effect on rainfall of a positive and negative phase of the NAO. (National Earth Science Teachers Association 2010)*




### ***Pacific Decadal Oscillation (PDO)***

Often described as a long lived El Nino like pattern the PDO operates through a change in the location of warm and cold water in the Pacific Ocean and can persist a decade or more. As with El Nino an index is used to describe an event as either positive or negative. The difference in the water temperatures tends to alter the path of the jet stream. As shown in Figure 22 the effects are most marked in the Pacific Northwest. A positive PDO increases the chances of drier conditions and higher temperatures on the Canadian Prairies and vice versa. It has been negative since 2006. (Garnett R 2013)

*Figure 22. World map showing PDO in a positive & negative phase. (Joint Institute for the Study of Atmosphere and Ocean 2013)*



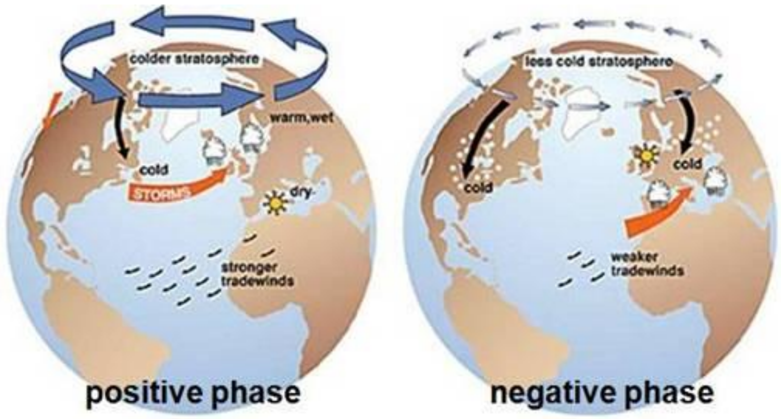

PDO cool Phase PDO warm phase

### *Arctic Oscillation (AO)*

The Arctic Oscillation describes the degree to which arctic air penetrates into the middle latitudes of the northern hemisphere. The Index describes the intensity of a low pressure cell over the North Pole.

A band of upper-level winds circulates around this centre, forming a vortex (Figure 23). A positive AO index indicates an intense vortex, the winds tighten like a noose around the North Pole, locking cold air in place. When the opposite occurs the cold air moves southward into North America, Europe, and Asia. The Arctic Oscillation has been mostly positive in the wintertime since the late 1980's and has strengthened in recent decades, contributing to the unusual warmth over northern regions of the globe. (Garnett R 2013)

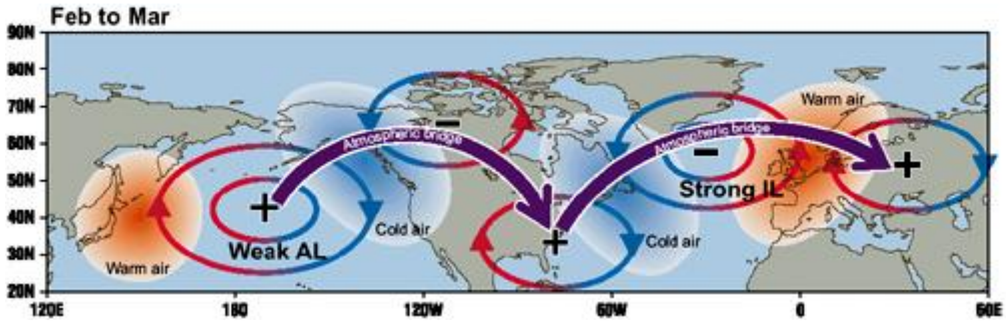
*Figure 23. Showing AO in a positive and negative phase (National Snow and Ice Data Centre 2013) Credit J. Walllace University of Washington*




### *Aleutian Low / Islandic Low*

The Aleutian Low (AL) is a semi permanent low pressure centre located in the northern hemisphere near the Aleutian Islands during the winter. The Islandic Low (IL) is also a semi permanent low pressure centre and is located between Iceland and Southern Greenland. They are most active during autumn and spring. They are the main centres of action in the Northern Hemisphere atmospheric circulation. During summer they weaken, the AL retreats toward the north pole, and the IL splits. In 2001 it was discovered that these features are connected with an atmospheric bridge and change in strength in a seesaw pattern (Figure 24.). The variation in the AL also affects the NAO. (Wikipedia 2013; Japanese Agency for Marine Earth and Science Technology 2003)

*Figure 24. Position of the Aleutian & Islandic Lows in winter and connection with the atmospheric bridge. (Japanese Agency for Marine Earth and Science Technology 2003)*




### *Atlantic Multi Decadal Oscillation (AMO)*

The AMO is an ongoing series of long-duration changes in the sea surface temperature of the North Atlantic Ocean, with cool and warm phases that may last for 20-40 years at a time and a difference of about 1°F between extremes. These changes are natural and have been occurring for at least the last 1,000 years. Since the mid-1990s we have been in a warm phase.

The AMO has affected air temperatures and rainfall over much of the Northern Hemisphere, in particular, North America and Europe. It is associated with changes in the frequency of North American droughts and is reflected in the frequency of severe Atlantic hurricanes. Some scientists say it alternately obscures and exaggerates the global increase in temperatures due to human-induced global warming (Garnett R 2013; National Oceanic and Atmospheric Administration 2005; Wikipedia 2013).

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# Plain English Compendium Summary

| Title | Weather Forecasting and Business Management Systems |
| --- | --- |
| Nuffield Australia Project No.: | 1219 |
| Scholar: | Robin Schaefer |
| Organisation: | Bulla Burra Operations |
| Phone: | 0417877578 |
| Fax: | |
| Email: | Rsc10092@bigpond.net.au |
| **Objectives** | This report aims to investigate weather forecasting from an agricultural meteorological perspective. It is targeted at helping Australian farmers to gain a better understanding of how forecasts are produced, their limitations and strengths. |
| **Background** | Successfully managing a farm business has never been so complex, so risky and required such a diverse set of skills. Yet many businesses today are managing and even thriving in this climate. What sets them apart from other businesses which are struggling? There are probably many reasons for this but management skills, a good understanding of their risks, and putting systems in place to manage these risks would be part of the answer.<br><br>Better day to day and long term farm business decisions can be made with a greater understanding of the weather and climate risks, and of the chance of those conditions occurring. Understanding weather cycles and weather forecasting and using decision support tools all adds to a manager's tool kit. This helps to make sure when a decision is made, the odds are highest that it is the right decision. |
| **Research** | Research for this project included travelling to the United Kingdom, Canada, USA, Argentina, New Zealand, India, Qatar, Ukraine, Turkey, France, Switzerland, and Ireland over a 17 week period. It included visiting a diverse range of experts including leading scientists at the European Centre for Medium Range Weather Forecasting (ECMWF) and Oklahoma National Weather Centre and individuals providing and using private weather forecasting services. |
| **Outcomes** | Accuracy in weather forecasting has improved significantly in the last thirty years. These improvements in forecasting accuracy mean that weather forecasts can be a more effective tool in a farm manager's tool kit. Managers need to understand that a forecast will never be 100% accurate. The critical point is that they must be used to manage risk, not create more risk. A good understanding of how the forecasts are produced can significantly affect their usefulness and the management of risk. Private forecasters tend to have closer links to the agricultural community and so are able to produce forecasts more suited to farmers' requirements. |
| **Implications** | Australian farmers could make better use of forecasting tools to aid in their decision making if they had a better understanding of how weather forecasts are generated, their strengths and their limitations.<br><br>Private weather forecasters need to be encouraged to continue their research and improve their forecasting techniques and tools. This will speed up the rate of improvements in forecasting for farmers. |