Chapter 7

Climate and Weather Risk Assessment for Agricultural Planning

Coordinated and edited by Anice Garcia

Written by Romisio Andre, Anice Garcia, Jose Paulo de Melo á Abreu,

Rosana Nieto, P.V.V. Prasad and David White

This chapter was externally reviewed by Isabel Ferreira, Olga Penalba and Roger Stone and internally reviewed by the chapter facilitators Christophe Cudennec, Doan van Diem, Naguib Lallmahomed and Roberta Millini.

1. Introduction

This chapter defines the assessment of climate and weather risk and its importance in agricultural planning to mitigate the impacts of climate variability and extreme events.

The term weather is used to describe day-to-day variations in our atmosphere. This includes precipitation, temperature, humidity, cloud cover, among other variables. Weather forecasts are essentially short-term, the reliability of forecasts falling off rapidly after five days. Weather is therefore an instantaneous concept.

The climate of a region is described by collating the weather statistics to obtain estimates of the daily, monthly and annual means, medians and variability of the weather data. Climate is therefore a long-term-average of weather.

Agricultural planning – strategic (long-term) and tactical (<10 days) – needs to appreciate climate-related and other risks to attain the producer's goals and to spell out the sort of information that farmers need to aid their planning – climate, technical/managerial, market. A key aspect needed in linking climate and weather risk to agricultural planners is to appreciate the overall management system in question from the decision-makers viewpoint. Managers need information for both tactical and strategic decision-making.

As an example, an Australian survey of agricultural planners provided a myriad of planning horizons and key decisions (sometimes referred to as 'decision-points') that could be

influenced by weather and climate variability at different time scales. Additionally, it has been realized that the decision system extends across the whole value-chain in agricultural production that is affected by weather and climate variability. As an example for the sugar industry that has relevance to many agricultural planning systems there are decisions at the farm-scale (irrigation, fertilization, fallow practice, land preparation, planting, pest management), the transportation and milling scale (improved planning for wet season disruption, planning for season start and finish, crop size forecasts, civil works schedules), catchment scale issues (land and water resource management, environmental management), issues at the 'marketing scale' (crop size forecasts, planning for high-premium early season supply, shipping and global supply management), and at the policy scale (water allocation planning, planning for extreme events) (Everingham *et al.*, 2002; Stone and Meinke, 2005;)

Varying time scales and key agricultural decisions are also important, especially in the need to recognize how different climate and weather systems impact on different farming decisions. Table 1 below provides a further example of the complexity inherent in matching appropriate climate forecast systems with the farming decision type (from Meinke and Stone, 2005).

Farming Decision Type	*Frequency (years)*
Logistics (eg. scheduling of planting / harvest operations)	Intraseasonal (> 0.2)
Tactical crop management (eg. fertiliser / pesticide use)	Intraseasonal ($0.2 - 0.5$)
Crop type (eg. wheat or chickpeas) or herd management	Seasonal ($0.5 - 1.0$)
Crop sequence (eg. long or short fallows) or stocking rates	Interannual ($0.5 - 2.0$)
Crop rotations (eg. Winter or summer crops)	Annual/bi-annual ($1 - 2$)
Crop industry (eg. grain or cotton; native or improved pastures)	Decadal (~ 10)
Agricultural industry (eg. crops or pastures)	Interdecadal ($10 - 20$)
Landuse (eg. agriculture or natural systems)	Multidecadal ($20 +$)
Landuse and adaptation of current systems	Climate change

Table 1: Agricultural decisions at a range of temporal and spatial scales that could benefit from targeted climate forecasts (Meinke and Stone 2005).

1.1 Understanding the climate mechanisms that contribute to climate and weather related risks

Weather and climate variability can result from interactions between the climate system's various components – the atmosphere, oceans, biosphere, ice layer, land surface and anthropic action.

The Framework Convention on Climate Change, in its Article 1, defines "climate change" as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". The UNFCCC thus makes a distinction between "climate change" attributable to human activities altering the atmospheric composition, and "climate variability" attributable to natural causes

Climate disasters can be divided into extreme events and regional climate anomalies. Global climate change may produce a larger number of climatic disaster occurrences. This is based on the fact that a linear increase in the average of a climatic variable implicates a non-linear increase in the occurrence probability of extreme values of such variable. Also, an increase in its variability means an increment on the occurrence probability of extreme values (Cunha, 2003).

Das (2003a) observed that "Although natural calamities cannot be avoided, their destructive impact, in terms of human losses and animal lives related to ecological equilibrium, could certainly be considerably minimized. Planning and management for the prevention and mitigation of extreme events are matters of vital significance for the safety and well being of millions of people who inhabit exposed disaster areas. In addition to local and national action, international and regional cooperation should be promoted for an enhanced prevention and mitigation."

Micro to large scales studies have showed anomalies for isolated climatic elements (Grimm et al, 1998; Souza et al., 2000; Garcia et al., 2002; André et al. 1996; André et al. 2004; Krishnamurti et al., 2001; Chiang and Sobel, 2002; Su and Neelin, 2003). However, the vast majority of the Earth's surface is void of data. Moreover databases are essential for determining current global and regional climate anomalies analysis and trends.

Climate data are essential in planning and reducing the risks associated with climate anomalies. Assessing and forecasting the impacts of short-term climate variability and weather

risks as well as their relationship to extreme events could help mitigate the effects of climate variability and scheduling agricultural activities.

The difference between risk, hazard and anomalies is as follows:

a) hazard is an event or process that is potentially destructive; probability of occurrence of a potentially damaging phenomena within a given time period and location of interest;

b) risk is the magnitude of a potential loss (of lives, persons injured, property damaged, and economic activity disrupted) within the area subject to hazard for a particular location and a reference period;

c) anomaly is the deviation of a meteorological quantity value in a given region from the normal (mean) value for the same period.

Impacts from natural disasters on agriculture, rangeland and forestry can be positive or negative. While the impacts are predominantly negative and do affect human society significantly (Joy 1991), there are some positive impacts or benefits that should be pointed out in any discussion of the impacts of natural disasters.

Positive impacts of natural disasters include increased rainfall to inland areas from tropical cyclones along coastal areas (Ryan 1993), the fixing of atmospheric nitrogen by thunderstorms, the germination of many native plant species as a result of bushfires and the maintenance of fertility of flood-plain soils due to flooding (Blong 2002). The influx of funds into disaster-relief activities after the occurrence of natural disasters can also sometimes be positive for local communities, as was shown for the city of Mobile, Alabama after Hurricane Federic (Chang 1984).

Negative impacts will be discussed in detail in this chapter.

2. Climatic hazards

2.1 Types

a. Extreme events

Extreme events can vary from short-lived, violent phenomena of limited extent such as tornadoes, flash floods and severe thunderstorms to the effects of large systems such as tropical and extra-tropical cyclones and the effects of prolonged drought and floods. Drought and floods are responsible for more significant impacts on human life and property and can affect one area for several months to years. About 63% of the estimated worldwide natural disaster-damage is

of meteorological origin. Meteorological disasters contribute to 87% of the people affected and 85% of deaths by natural disaster (WMO, 2004).

Recent scientific studies also indicate that the number of extreme events and their intensity might increase as the global temperature continues to increase due to climate change.

b. Regional climate's anomalies.

Mesoscale storms; severe local storms. Hail causes millions of dollars of damage to crops and property each year; . Tornadoes are probably the most feared natural phenomena. More tornadoes occur on the North American continent than anywhere else in the world, though they can (and have) affect(ed) nearly all regions of the world. Fortunately, their scale is relatively small (diameters range from about 15 m to over 2 km) so that they affect a limited area.

Small-scale severe weather phenomena (SCSWP) are weather events that are sparse in space and time and may have important impacts on societies, such as loss of life and property damage. Their temporal scales range from minutes to a few days at any location and typically cover spatial scales from hundreds of meters to hundreds of kilometers. The Technical Summary of the Working Group I Report of the TAR describes SCSWP with the following: "Recent analyses of changes in severe local weather (e.g., tornadoes, thunderstorm days, and hail) in a few selected regions do not provide compelling evidence to suggest long-term changes. In general, trends in severe weather events are notoriously difficult to detect because of their relatively rare occurrence and large spatial variability." (IPCC, 2002)

2.2 Categories
a. Drought

Drought is a shortage of water for essential needs, which for agricultural purposes relates to plant growth. However, it is also a relative term, in that it might be considered a deficiency of water for a few weeks or months in a high rainfall area or a lack of water over several years in arid lands. It also should not be confused with desertification, which is a consequence of human activity such as overstocking the land relative to its carrying capacity, this being particularly common in arid lands in times of below average rainfall. Excessive tillage is another cause of desertification.

Drought differs from other natural hazards in that its effects often accumulate slowly over a period of time, and may linger for years after the termination of the event (Wilhite, 2000). Because of this, drought is often referred to as a creeping phenomenon (Tannehill, 1947).

Droughts must be viewed as an integral part of a natural climatic cycle, even though extreme droughts can have disastrous consequences. Treating drought simply as a disaster that could not be anticipated, with subsequent pleas for national or international assistance, ignores the fact that the impact of all but the most severe droughts can be mitigated through careful planning and risk management (O'Meagher *et al,*. 1998; 2000; Botterill, 2003, 2005). It is also useful to distinguish between meteorological, hydrological and agricultural drought, in that the severity of these are only partially correlated, the severity of an agricultural drought depending on how deficiency of rainfall and soil moisture is expressed in terms of plant growth, and ultimately in terms of the health and welfare of rural communities (e.g. du Pisani *et al.*, 1998; Keating and Meinke, 1998; Stafford Smith and McKeon, 1998; White *et al.*, 1998).

Massive and devastating fires can be triggered during and after periods of drought, by lightning or by human action in almost all parts of the world. As well as destroying forests, grasslands and crops, they kill livestock and wild animals, damage or destroy settlements and put the lives of inhabitants at risk (WMO, 2006).

b. Heavy rainfall and floods

According to the WMO, flood hazards represent about 32% of the total damage from–natural disasters (WMO, 2006). It is estimated that extreme weather events will increase in frequency and severity during the 21st century as a result of changes in mean and/or variability of climate. Changes in temperature and precipitation may lead to dramatic shortening of the return periods of floods. Flood disasters are enhance by environmental degradation, urbanization, demographic shifts and poverty, industrialization and overall economic development.

Prevention of these disasters requires the development of programs that include the management of the water cycle as a whole, in order to adopt an integrated hazard management approach. The WMO and the Global Water Partnership (GWP) promote a new concept of Integrated Flood Management (IFM). IFM ensures disaster reduction through prevention of flooding, mitigation of adverse impacts through appropriate adaptation strategies and the preparation of the community to respond appropriately to flood forecast and warnings.

c. Strong winds: tornadoes, storm and tropical cyclones

Tropical cyclones are among the most destructive of all natural hazards, causing considerable human suffering in about 70 countries around the world. They form over all tropical oceans, with the possible exception of the South Pacific east of about 140°W. In western North Pacific, mature tropical cyclones are known as typhoons (they are also referred to as hurricanes in the western hemisphere and cyclonic storms or tropical cyclones in other areas. As Das (2003b) described, tropical cyclones are the off-spring of ocean-atmosphere interactions, powered by heat from the sea, steered by the easterly trades and mid latitude westerlies. An average of 80 tropical cyclones form annually over the tropical oceans, 30 of which in the typhoon region of the western North Pacific (Obasi 1997). The impact of tropical cyclones is greatest over coastal areas that bear the brunt of the strong winds and flooding from rainfall. For example, while the annual average for the Bay of Bengal and the Arabian Sea is only five tropical cyclones per year, some of the most destructive tropical cyclones in history have occurred in that region, such as the severe tropical cyclone in Bangladesh in 1970, which claimed 300.000 lives.

El Niño is generally associated with worldwide changes in the patterns of precipitation and temperature, tropical cyclones and hurricane activity, the behavior of subtropical jetstreams, and many other general circulation features over various parts of the world.
The magnitude of hurricanes is assessed with the Saffir-Simpson scale, which takes into account maximum sustained winds and minimum storm central pressure.

Losses to agriculture, rangelands and forests from tropical cyclones can be due to direct destruction of vegetation, crops, orchards and livestock, damage of infrastructure such as canals, wells and tanks, and long term loss of soil fertility from saline deposits over land flooded by sea water. Typhoons have been known to inflict severe damage on agriculture: for example, in southern Hainan on 2 October 1999, some 25 million timber and rubber trees were blown down (WMO, 1994). A typhoon that struck Thailand on 4 November 1989 wiped out some 150.000 ha of rubber, coconut and oil plantations and other crops (WMO, 1997).

However, not all the impacts of cyclones are negative, some reports cite beneficial effects of tropical cyclones. Ryan (1993) mentioned some important benefits of tropical cyclones in Australia. Increased water availability in water-critical regions makes agricultural production less susceptible to the dry season. Researchers estimate that nine major hurricanes in the United States since 1932 terminated dry conditions over an area of about 622.000km^2 (Sivakumar, 2005).

d. Temperature: frost and heatwaves

A "frost" is the occurrence of an air temperature of 0 °C or lower, measured at a height of between 1.25 and 2.0 m above the ground, inside an appropriate weather shelter (Snyder and De Melo-Abreu, 2005). Most frost events occur during clear and calm nights, often preceded by relatively warm and sunny days. This type of frost originates from the reduction of downward long-wave radiation from the atmosphere, due to the absent or low cloud cover, and from the stratification of the air near the ground that develops under weak wind conditions. Because cold air flows down-slope, much like water, the valley floors and lower portions of the slopes are colder. This type of frost is classified, in relation to its origin, as a "radiation frost". Another less common, but relevant type of frost is the "advection" or "wind" frost, which originates from the advection of freezing cold air into a region. This type of frost is accompanied by wind and clouds and affects preferably the higher portions of valleys.

Frost damage is the number one weather hazard, on a planetary scale, as far as agricultural and forest economical losses are concerned. Only a small fraction of the farm land is frost free and few crops never experience frost damage. Frost reduces substantially the world's production of vegetables, ornamentals, field and row crops, pasture, forage and silage crops, fruit trees (deciduous and evergreens), vines and berries. Sometimes forest trees are also affected (Snyder and De Melo-Abreu, 2005).

Frost damage is only possible after the onset of freezing. Thus it is, probably, more correct to refer to "freeze damage". Freezing inside the protoplasts (*intracellular freezing*) is always lethal, and is probably due to the disruption of the membrane systems that compartmentalize cells. Fortunately, this type of damage is rare or does not occur in nature (Levitt, 1978). Under natural cooling rates, freezing of the plant tissues starts outside the cells (*extracellular freezing*) in the intercellular solution, because this solution is more diluted than the solution present in the cytoplasm. As the temperature of the freezing tissue gets lower the ice masses grow pulling out water from the protoplast that, therefore, shrinks. The driving force behind this water movement is the gradient of vapour pressure, since saturation vapour pressure over ice is lower than over water at the same temperature. The loss of water by the protoplast (i. e., desiccation) may affect or not the viability of the cells, depending on the tissue/plant hardiness. Some tissues can't recover after any amount of ice has formed extracellularly, but, on the other extreme, there are plants/tissues that can endure freezing down to the temperature of liquid nitrogen (-196 ºC).

The temperature at which a given level of freeze damage is expected is called a *critical temperature*. Critical temperatures change with species/variety, phenological stage, and a number of hardening factors. For most crops, critical temperatures have been published and compiled (Snyder and De Melo-Abreu, 2005). Forest trees are mostly affected by frost if there is a deacclimation period and loose their hardiness prior to a frost event. Nevertheless, there are also published critical temperatures for some forest trees (Larcher, 1982; Tibbits and Reid, 1987; Ashworth and Kieft, 1995; Ryyppö et al., 1998).

Heat waves are most deadly in mid-latitude regions, where they concentrate extremes of temperature and humidity over a period of a few days or even weeks in the warmer months. The oppressive air mass in an urban environment can result in many deaths, especially among the very young, the elderly and the infirm. In 2003, much of western Europe was affected by heat waves during the summer months. In France, Italy, The Netherlands, Portugal, Spain and the United Kingdom, they caused some 40 000 deaths. Extremely cold spells cause hypothermia and aggravate circulatory and respiratory diseases (WMO, 2006).

e. Others

Duststorms and sandstorms are ensembles of particles of dust or sand lifted to great heights by strong and turbulent wind. They occur mainly in parts of Africa, Australia, China and the USA. They threaten lives and health, especially of persons caught in the open and far from shelter. Transportation is particularly affected as visibility is reduced to only a few meters.

Precipitation in the form of large hailstones can reach diameters of over 10 cm and can fall at speeds of over 150 km/h. Worldwide losses to agriculture in a typical year are more than US$ 200 million. Hailstorms have also caused deaths and great damage to cities around the world. In a matter of minutes, an ice storm can deposit a layer of ice heavy enough to bring down power and telephone lines and snap branches from trees. The ice covers roads, rail tracks, and runways, making driving extremely hazardous, delaying trains, and closing airports.

Fog is a suspension of very small, usually microscopic, water droplets in the air. Dense fog has a serious impact on transportation when the visibility is significantly reduced. Highways, airports and ports are closed for safety. Fog can cause considerable economic losses. Smog is a combination of fog and air pollution. It has serious implications for human health.

Pollutants include particulate matter and noxious gases from industry, vehicles and human activities. Smoke and haze result from forest or wildland fires or from slash-and-burn

forest or crop clearing or from ash from volcanic explosions in stable air conditions. Smoke, haze and pollution have serious implications for human health—the local population may have to wear gas masks. They reduce visibility; air and road traffic can be disrupted. Smog, acid rain, the ozone hole and an adverse increase in the greenhouse effect are also caused by air pollution. Stable atmospheric conditions often lead to a concentration of pollutants.

Desert locusts inflict damage in Africa, the Middle East, Asia and southern Europe. When weather and ecological conditions favour breeding, the insects are forced into a small area. They stop acting as individuals and start acting as a group. Within a few months, huge swarms form and fly downwind in search of food. Swarms can be dozens of kilometres long and travel up to 200 km a day. A small part of an average swarm (or about one tonne of locusts) eats the same amount of food in one day as 10 elephants or 25 camels or 2 500 people. They jeopardize the lives of millions of farmers and herders in already fragile environments. Locust plagues during or immediately after drought conditions can spell even greater disaster, as was the case in several Sahelian countries in 2005 (WMO, 2006).

3. Scale studies for climatic anomalies

When investigating climate trends, due to different force balances, it is important to note that atmospheric motions behave with varying temporal and spatial scales, and are often non-linear.

3.1 Space

Atmospheric circulation patterns are of critical importance in determining the climate of a location. On a global scale, atmospheric motions transport heat from the tropics towards the poles. Evaporation over the oceans supplies much of the water molecules that support precipitation over land. These circulation patterns are in large part driven by energy differences between regions of the globe. On a smaller scale, precipitation on the lee side of a mountain is typically less than on the windward side. On a still smaller scale, the amount of snow downwind of a snow fence is on average larger than the amount upwind (Ackerman & Knox, 2003). Spatial scales may be classified as follows:

   a) Microclimate - near the ground over a front yard, climate conditions near the surface over distances of a few meters. Large perturbations to the microclimate can rapidly affect plant life.

   b) Mesoclimate - climate conditions over a few square kilometers, for example, climate of a town, valley, or beach. Other examples of mesoclimate features are orographic precipitation,

lake effects, gravity waves and stratospheric-troposphere exchange through mixing at the top of deep cumulonimbus clouds.

c) Macroclimate - climate conditions for a state or a country - over scales ~1000 km or greater.

d) Global climate -– this is the largest spatial scale, since it refers to climate conditions over the entire earth climate change and climate variability, stratospheric dynamics and the general circulation fit into this category. Energy input from the sun drives global climate. The solar gain is controlled by the orbit of the Earth around the sun and determines the length of seasons. The so-called climatic controls, or factors that produce the observed climate in any given place are: latitude, distribution of land and water, ocean currents, prevailing winds, position of high and low pressure systems, and topography.

3.2 Time

Atmospheric fluctuations occur on various different time scales. Long-term fluctuations in climate can be caused by changes in ocean circulation or changes in the concentration of greenhouse gases due to human activity, for example. Fluctuations on shorter time scales can be caused by changes in cloudiness and water vapor, for example. Atmospheric timescales are divided as follows:
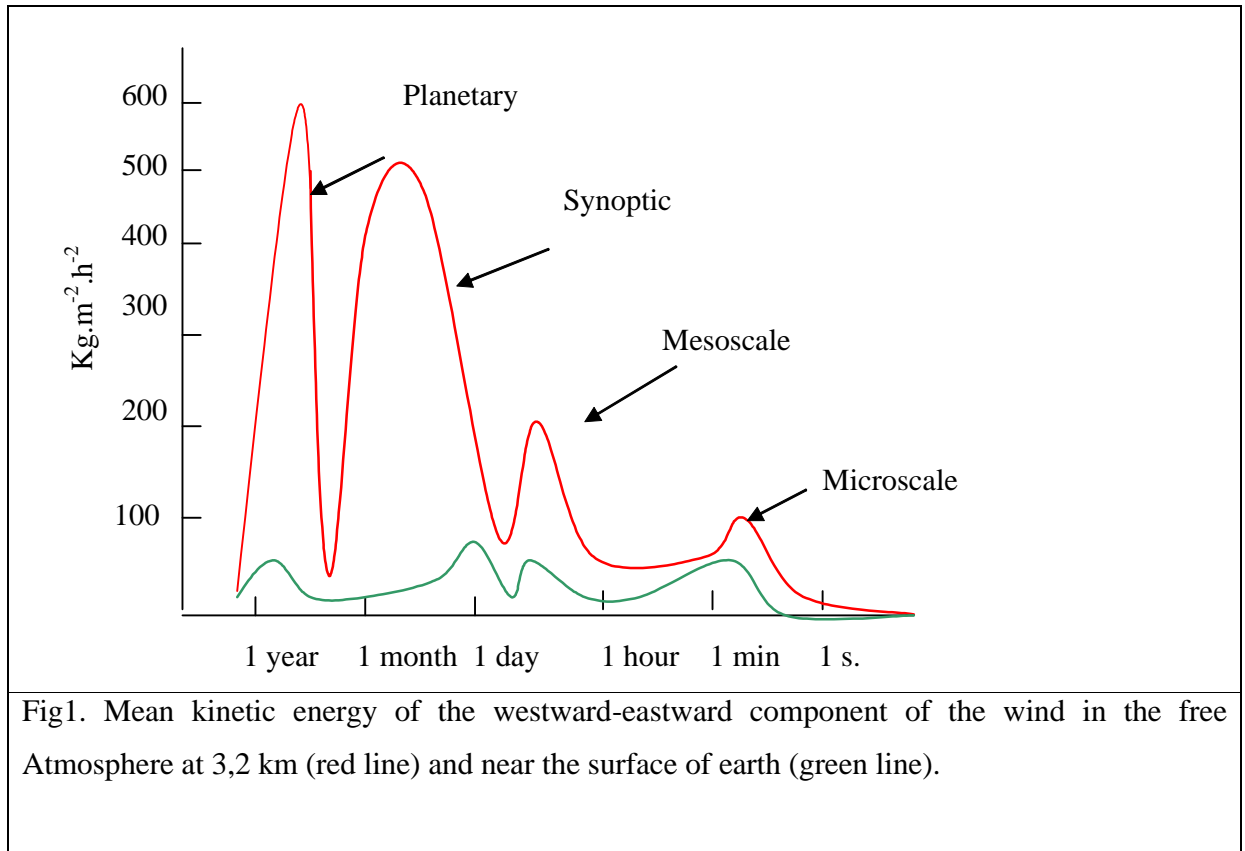
Microscale – seconds-to hours

Mesoscale – hours to days

Macroscale - days to weeks

Global scale – weeks to months or years

3.3 Space–time scales

Figure 1 shows the energy spectrum in all scales of motion showing peaks in frequencies of a few days (synoptic scale) or some weeks (planetary scales). There are also peaks at one year, one day and a few minutes. Nevertheless, the spectrum is a continuum.

Fig1. Mean kinetic energy of the westward-eastward component of the wind in the free Atmosphere at 3,2 km (red line) and near the surface of earth (green line).

Orlanski (1975) proposed a set of scales that include the micro-, meso- and macroscales. These three are further subdivided from larger to smaller into (alpha), (beta) and (gamma) scales, as shown in figure 2. As the scale becomes smaller, the effects of some processes become increasingly more difficult to treat explicitly or deterministically. Depending on the horizontal scale of interest, different atmospheric processes become significant. Turbulence, the gustiness superimposed on the mean wind can be visualized as consisting of irregular swirls of motion called eddies. Eddies produce effects at the microscale. The small-scale phenomena associated with the microscale are so transient in nature that deterministic description and forecasting of individual eddies is virtually impossible.

The scales of atmospheric motions are interconnected and nearly continuous. Macroscale processes drive mesoscale and microscale processes as energy is transferred from larger to smaller scales. Conversely, small-scale processes can organize to develop larger-scale systems, such as convective storms.
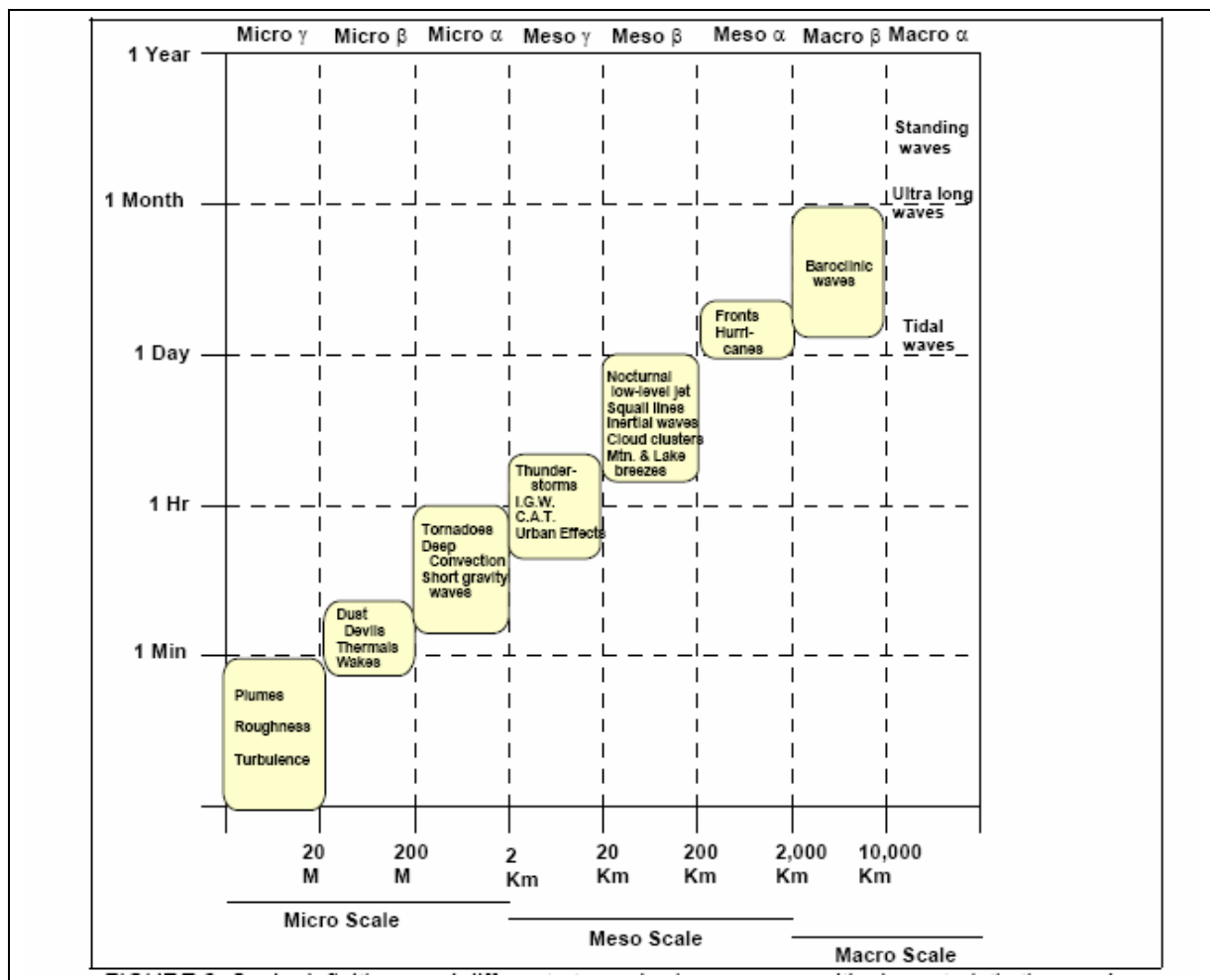
12

FIGURE 2. Scale definitions and different atmospheric processes with characteristic time and horizontal scales (adapted from Orlanski, 1975). C.A.T is Clear Air Turbulence and I.G.W. is Inertial Gravity Waves (font: OFCMSSR, 2004)

The figure 3 show the examples of the range and scales of natural hazards that are observed, detected, monitored and forecast by WMO networks (WMO, 2006).
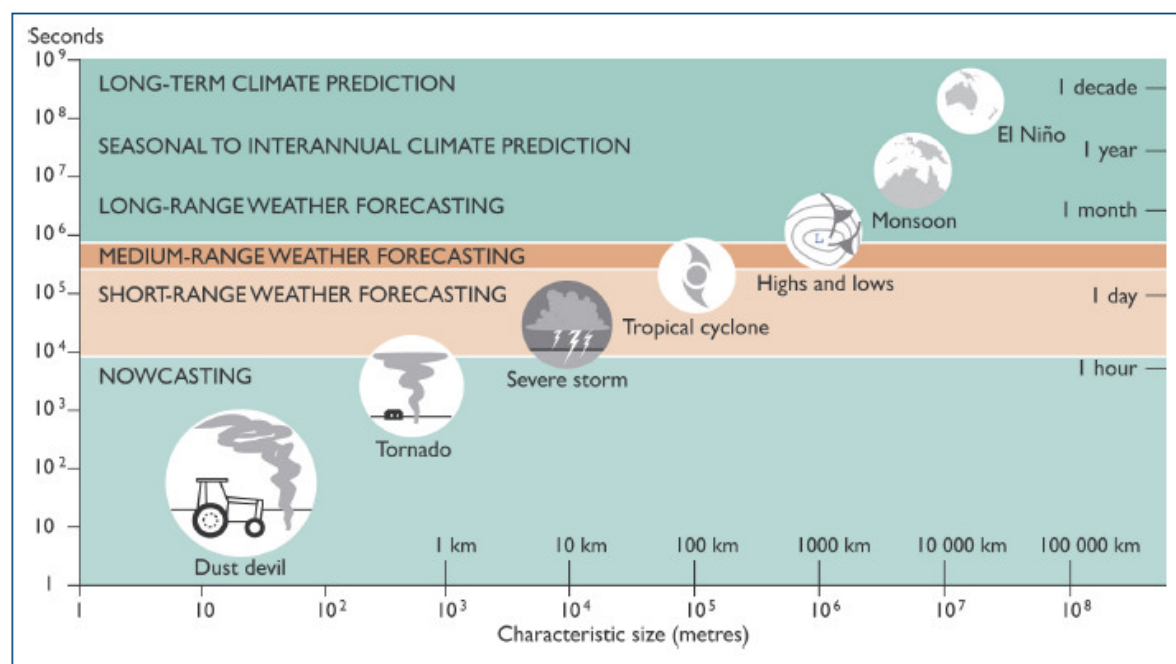
Fig 3. Range and scales of natural hazards that are observed, detected, monitored and forecasted by WMO networks.

4. Agrometeorological applications on characterization of climatic hazards - Modeling and data needs

The IPCC (Intergovernmental Panel On Climate Change) was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to assess scientific, technical and social-economic information relevant for the understanding of climate changes, its potential impacts, and options for adaptation and mitigation.

On the third evaluation report (2001), IPCC concluded that "the earth's climate system has undergone changes on both global and regional scales since the pre-industrial era", and "there is newer and stronger evidence that the Earth's warming observed over the last 50 years is due to human activities". Among the hazards foretold to occur due to global change, the most threatening for mankind is an increase in the intensity and frequency of storms, floods, droughts, heat waves and the effects of sea level rise in coastal areas. There is, however, very large uncertainty in these predictions and research that aims to improve climate model predictions is

under way in many research centers around the world. A number of empirical mathematical models have also been developed and applied (review: Long and Drake, 1991; Long, 1991). Predicting how vegetation will respond to climate change is critical to understand the impacts of atmospheric changes on both natural ecosystems and crop growth.

4.1. General circulation models (or at least stay consistent if using global circulation models)

Characterization of climatic hazards for some crops has been carried out using general circulation models (GCMs) and the confidence in the ability of these models to project future climate has been increasing. The most detailed predictions are based on coupled atmosphere-ocean general circulation models which provide credible simulations of climate, at least for sub-continental scales. However, models cannot yet simulate all aspects of climate. For example, they still cannot account fully for the observed trend in the temperature difference between the surface and the lower atmosphere. There are also significant uncertainties regarding clouds and their interaction with radiation and aerosols (UNFCCC, 2004).

There are numerous GCMs in use and under construction in research centers around the world. For instance, some of the general circulation models that participated in the Intergovernmental Panel on Climate Change are the French ARPEGE model, the American NASA GEOS-2, GISS and NOAA CCM2 models, the German ECHAM model, the Canadian MAM model, to name a few.

4.2. Regional circulation models

Regional Circulation Models (RCM) are used in many parts of the world to determine specific characteristics of the weather in mesoscale. RCMs have a regional domain, say, over one state or country, and provide more spatially detailed predictions than those obtained with GCM. Many RCMs are being adapted and implemented in different places of world. The principal RCMs in use are:

RAMS - Regional Atmospheric Modeling System (Pielke et al. 1985);

ETA - RCM – with Eta. Coordinate (Mesinger et al. 1988);

MM 5 - Penn State Mesoescale Model – 5th generation (Chen, F., J. Dudhia, 2001);

ARPS - Advanced Regional Prediction System (Xue, Ming et al. 1995);

MBAR – Brazilian Model of High Resolution (INMET).

4.3. Historical local climate data

Climate information can benefit rural producers through the use of seasonal forecasts, and through improving the management of climate variability *per se*. Significant climate variability implies the likely occurrence of drought and floods.

Historical climate information is crucial to plan the production year. It influences the long-term strategies on which crops to grow and when to plant or sow, which for most crops is the primary determinant of when harvesting takes place. Tactical decisions on how much to sow have to be made in relation to climate and market forecasts, along with decisions on when and how much to irrigate, pest control and crop protection.

Increased self-reliance by rural producers requires the ability to manage both crop and livestock enterprises exposed to a variable climate and to minimize the impact of drought. It also requires the ability to more effectively manage risk: production risk, environmental risk, financial risk and market risk (White 1997). Improved seasonal outlooks are but one approach to assist farmers to become more self-reliant. Ways of offsetting the risks associated with climate variability in order to create opportunities, require a systems approach (Hammer and Nicholls, 1996; Hammer *et al.*, 2000).

Climate data have long proved invaluable for making farm management decisions, including in areas where seasonal forecasts have proved unreliable. Historical records of rainfall, temperature and even windspeed have been used to determine optimal times for the sowing and harvesting of crops, and for lambing and calving on grassland farms as well as for irrigation planning.

Ancillary information that can help a producer assess a current season and decide on various tactics include: rainfall to date (e.g. within a growing season), amount of standing herbage (or crop development), weight of livestock, amount of stored supplements and the capacity to deal with adverse seasons. Weather forecasts (<10 days) are of particular value in making tactical decisions.

A range of decision support systems (DSS) are available for analyzing historical data to determine probabilities of rain, frosts, and the beginning and end of growing seasons. In Australia, for instance, these include Australian Rainman (Clewett *et al*. 2003) which provides more detailed analysis of rainfall probability distributions and CSIRO's MetAccess (Donnelly *et al*. 1997). More complex DSS and models are able to simulate changes in soil moisture, pasture or crop growth, liveweight change, supplementary feed requirements and cash flow. An example

includes the *Whopper Cropper* cropping systems DSS where the DSS can play a valuable role in encouraging farmers to be more tactical in their decision-making and consider planting a crop when there is adequate stored moisture or to be more strategic and encourage debate on the design of planned and flexible cropping rotations.

In this respect the development of DSS has made it apparent that the best way to obtain an appropriate balance between demand and supply-driven development of a DSS is via dialogue among the key participants in the decision-making. Including this dialogue in a participatory action research program suggests the term 'decision-support systems' may be better described as 'discussion-support systems'. Discussion support systems such as *Whopper Cropper* , which can be applied in most agricultural environments, can then provide a complimentary vehicle for delivery of agricultural simulation-aided discussions. These systems can also focus on farm management advisers as key intermediary agents who then act as facilitators in the process (Nelson, *et al*, 2002).

Thus these DSS, in combination with the findings of field experiments and farm surveys, are useful in determining optimal management strategies (e.g. long-term stocking rates, cropping rotation strategies) and short-term tactics (e.g. supplementary feeding, buying and selling decisions with respect to livestock, buying grain futures or cheap supplies if available, sowing pastures in spring, or sowing summer crops, determining areas for cutting hay – whether for conservation or sale, whether or not to irrigate, and controlling for pests or diseases).

The use of long series of weather data have also been used to determine probabilities and risk associated with frost. Snyder et al. (2005) published personal-computer programs that calculate the probabilities of having a minimum temperature lower than a given value in a specified time period, last spring and first autumn frost dates, length of growing season, and probabilities and risk of frost damage to a specified crop.

4.4. Agronomic models

Biophysical models of agricultural systems can provide useful and often necessary complementary information to field experimentation and farm surveys, since if properly validated they enable the system response to be assessed over many locations and seasons. They provide a logical link between climate information and performance of plants and livestock in the field, and can therefore be an effective means of determining the responsiveness of soil moisture, plants and livestock to changing climatic conditions. Since such models should also be

17

realistically responsive to changes in management, the effects of both management and climate can be studied simultaneously. For example, Fouché et al. (1985) used a model to show how the frequency and duration of droughts on the South African veldt increased with stocking rate. The models are also proving to be invaluable for spatial and temporal simulations within Geographic Information Systems in terms of drought monitoring, and as mentioned above in estimating the value of seasonal forecasts for various locations and farming systems.

4.4.1 Crop response

Plant growth models need to be sufficiently mechanistic to predict plant responses to changes in the environment. However, although considerable attention has been given to defining the appropriate functional forms within vegetation models (Thornley and Johnson 1990), most models are specific to the major ecosystem in which they have been developed and have a important empirical base. This include many of the crop models that have been developed to predict grain yield, or evaluate management strategies such as different sowing dates, and how the efficiency of water use and of use of nitrogen and other fertilizers may be manipulated.

A number of crop models are now being used in both modeling the effects of climate variability on crop production, and in determining management strategies that can identify the genotypes and management strategies that enable the impact of below-average seasons to be mitigated. Examples of the use of crop models for modeling and forecasting crop production include Keating and Meinke (1998), Stephens (1998), and Potgieter et al., (2005) in Australia, and Lourens and de Jager (1997) and de Jager et al. (1998) for southern Africa the maize model.

4.4.2 Pasture response

Models of grazing system, such as GRASP in northern Australia (McKeon et al., 1990) and DYNAMOF (Bowman et al,. 1993, 1995) and GrazPlan (Donnelly et al., 1997; Freer et al., 1997; Moore et al., 1997) in southern Australia, are of considerable value in determining appropriate long-term stocking rates, and supplementary feeding and strategies. In other words they can be of fundamental importance in achieving sustainable grazing systems and improving the management of climate variability per se.

Such models are of value in assessing the impact and severity of different droughts on grassland and rangelands comprising a range of and vegetation types in different locations (Donnelly *et al.* 1998; Stafford Smith and McKeon 1998; du Pisani *et al.* 1998; White *et al.* 1998). The GRASP model has also been incorporated into a GIS-based prototype of a national drought monitoring system in Australia (Carter *et al.* 2000). Experimentation is underway with an alternative but simpler spatial/temporal model, GrowEst Plus, based on the original model of Fitzpatrick and Nix (1970), to develop indices which may be used to analyze specific events, such as drought, or characterize the reliability of a growing season as an aid to managing environmental sustainability (Brinkley *et al.* 2004).

4.5. Vegetation suitability maps

An example of the use of data and models for the construction of suitability maps are the Agro-ecological zoning systems. The main system for land resource assessment is FAO's agro-ecological zoning (AEZ) methodology and supporting software packages for application at global, regional, national and sub-national levels. AEZ uses various databases, models and decision support tools which are described below.

The AEZ concept involves the representation of land in layers of spatial information and the combination of the layers of spatial information using a Geographic Information System (GIS). The combination/overlay of layers produces agro-ecological cells. In this way a land resources database is created which contains information on the AEZ cells. AEZ integrates in the database various kinds of geo-referenced data sets , which can include the following: topography; administrative boundaries; road/communications; towns and settlements; rivers/water bodies; geology; soil; physiography; landform; erosion; rainfall; temperature; moisture regime; watersheds; irrigable areas; land use/land cover and forest reserves; population. The AEZ methodology and models have been applied in developing a global digital AEZ land resources database based on the digitized soil map of the world (DSMW). The database contains information on soil and landform, temperature regime and length of growing period, agro-ecological zones, forest and protected areas, land suitability for about 30 main crops. (http://www.fao.org/ag/agl/agll/cropsuit.asp).

4.6. Remote sensing

Remote sensing can provide useful estimates of vegetation cover and condition, plant water status and the spatial limits to severe droughts over large areas of land (McVicar and Jupp, 1998; McVicar *et al*., 2003). Such information is invaluable in monitoring changes in land use, the impact of changing seasons and years on vegetation cover and "greenness", beginning and end of growing seasons, the impact of grazing livestock intensity on vegetation, the extent of erosion and other forms of land degradation, and as a valuable source of data for validating agronomic models.

McVicar and Jupp (1998) describe four ways in which remote sensing can assist in mapping and monitoring agronomic conditions in relation to climate variability. These include:

1. Vegetation condition monitoring with reflective remote sensing;
2. Environmental condition: monitoring with thermal remote sensing;
3. Soil moisture: monitoring with microwave remote sensing; and
4. Environmental stress: combining thermal and reflective remote sensing.

4.6.1   Vegetation indices

Most vegetation indices use combinations of the red and near infra-red (NIR) reflective bands recorded by the LANDSAT Thematic Mapper ™, the National Oceanographic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) sensors and other remote sensing instruments used on satellite platforms.

Vegetation indices derived from satellite data, include measurements of leaf area index (LAI) (Tucker, 1979), plant condition (Sellers, 1985) as well as the simple ratio (NIR/Red) and the Normalized Difference Vegetation Index (NDVI, (see extensive review by McVicar and Jupp 1998).

4.6.2   Soil moisture index

Thermal remote sensing is an instantaneous observation of the status of the surface energy balance. This is driven by the net radiation of the surface, dominated during the daytime by incoming shortwave radiation from the sun, the amount reflected depending on the albedo of the surface.

The difference between daytime and night-time soil temperatures can be used to monitor changes in superficial soil moisture. McVicar *et al*. (1992) and Jupp *et al*. (1998) jointly

developed the normalized difference temperature index (NDTI) to remove seasonal trends from the analysis of daytime land surface temperatures derived from the AVHRR sensor. The NDTI, which is a very close approximation to the moisture availability, has the form:

$$NDTI = (T_\infty - T_s)/(T_\infty - T_0)$$

where T_∞ is a modeled surface temperature if there is an infinite surface resistance, i.e. evapotranspiration (ET) is zero; T_s is the surface temperature observed from the AVHRR sensor, and T_0 is a modeled surface temperature if there is zero surface temperature resistance; hence ET equals ETp (potential evapotranspiration). As McVicar and Jupp (1998) explain, T_∞ and T_0 can be thought of as the physically limited upper and lower temperatures, respectively, for given meteorological conditions and surface resistances. If T_0 is close to the T_∞ value it is an indication of conditions being 'wet' as when soil moisture in surface layers approaching 'field capacity'.

4.6.3   Drought Early Warning Systems

Drought early warning systems can help achieve a greater level of drought preparedness. Although some of these systems have shortcomings like being unreliable, poorly targeted or not user friendly (Wilhite, 2005), others are proving invaluable at the regional and national level for monitoring and mitigating the effects of drought.

Integrating spatial data sets, including remotely sensed data, with agronomic models, is leading to the development of integrated spatial/temporal systems for both grasslands (du Pisani *et al.*, 1998; Carter *et al*. 2000; Brinkley *et a.l,* 2004) and crops (Lourens and de Jager, 1997; de Jager *et al.,* 1998; Stephens, 1998).

Drought monitoring systems are also being used in developing countries (e.g. the Famine Early Warning System (FEWS), the Regional Remote Sensing Unit of the Southern African Development Community (SADC) based in Zimbabwe; and FAO's Global Information and Early Warning System on Food and Agriculture (GIEWS)). However, these often appear to be used primarily to focus reactive relief efforts on 'drought disasters', rather than being integral to the implementation of carefully thought out policies aimed at managing for drought and improving the sustainability of agricultural production systems. Furthermore, having such systems in place will only be of limited value if the required transportation and telecommunications infrastructure and extension services are inadequate.

In arid, semi-arid, and marginal areas with a probability of drought incidence of say, at least once in ten years, it is important for those responsible for land-use planning, including agricultural programmes, to seek expert climatological advice regarding rainfall expectations. Drought is often the result of the interaction of human pattern of land-use and the rainfall regimes. Thus, there is urgent need for a detailed examination of rainfall records of these regions. In this regard, the development of methods of predicting many weeks or months in advance, the occurrence of rainfall deserves high priority.

Since technological inputs quickly reach an optimum level, more emphasis should be placed on drought management policies, especially in dryland farming areas. Agricultural planning and practices need to be worked out with consideration to the overall water requirements within an individual agroclimatic zone. Crops that need a short duration to mature and require relatively little water need to be encouraged in drought prone areas. Irrigation, through canals and groundwater resources, need to be monitored with optimum utilization, avoiding soil salinity and excessive evaporation loss. A food reserve is needed to meet the emergency requirements of up to two consecutive droughts. A variety of policy decisions on farming, human migration, population dynamics, livestock survival, ecology, etc. must be formulated (Das, 1999).

Sustainable strategies must be developed to alleviate the impact of drought on crop productivity. In areas of recurring drought, one of the best strategies for alleviating drought is varietals manipulation, through which drought can be avoided or its effects can be minimized by adopting varieties that are drought resistant at different growth stages.

If drought occurs during the middle of a growing season, corrective measures can be adopted; these vary from reducing plant population to fertilizations or weed management. In high rainfall areas where there are a series of wet and dry spells, rainfall can be harvested in either farm ponds or in village tanks and can be recycled as lifesaving irrigation during a prolonged dry spell. The remaining water can also be used to provide irrigation for a second crop with a lower water requirement, such as chickpea. However, no one strategy can be adopted universally. In fact, all such strategies are location, time, crop, crop stage and (to some extent) socio-economic condition specific. Developing such strategies for each specific factor can help make agriculture sustainable (Das, 2005).

5. Methods of risk assessment.

5.1. Managing risk

Risk management is recognized by producers as an important activity in their decision-making process, enabling them to manage their businesses more effectively in a physical environment where drought or other extreme events are common, though unpredictable, occurrences. Risk management recognizes that producers also operate in an economic environment of less than perfect knowledge. There are three types of risk in agriculture: production, financial, and marketing.

Production risk is imposed primarily by seasonal variability. This risk may be reduced by avoiding excessively high stocking rates, developing strategies for reducing stock numbers in the event of abnormally dry conditions, sowing drought-resistant pasture plants and crops, choosing flock and herd structures and dates of lambing and calving that better relate the nutritional demands of the livestock to the available feed supply, providing shelter for livestock, conserving fodder or growing fodder crops, installing irrigation, and diversifying enterprises.

Strategies that are less risky in terms of production may be much more prone to financial risk. For example, low stocking rates may not allow enough income to be generated in the good seasons to allow a farmer to survive the poor seasons (White, 1987). Stocking according to season may result in stock being purchased at high prices and sold at low prices (Arnold and Bennett, 1975). Dates of lambing or calving that favour production may not favour marketing. Fodder may be conserved on the farm to support high stocking rates, but with the extra stock numbers, less surplus is available to be conserved (Bishop and Birrell, 1975). Irrigation schemes will often be unprofitable even though they reduce the production risk. Diversifying from wool or beef production, for example, into crops or specialist livestock enterprises such as deer or alpaca farming may require substantial capital investment and associated financial risk, and farmers who do diversify often do not have the necessary specialist skills.

Climate predictions may be used to reduce risk. For example, farmers planning to prepare land for sowing winter crops might not do so if they were given an adverse forecast in autumn. However, a farmer in desperate need of cash to meet financial commitments might sow a crop anyway in the hope that the forecast was incorrect. A farmer might decide to feed a "failing" crop to livestock in the spring on the basis of an adverse forecast.

5.2. Analyses of long term weather data to identify occurrence of particular risk.

To identify of occurrence of particular risk (such as water stress, heat stress, cold stress – including frosts and freezing, and floods, and risk of wild fires) it is necessary the analysis of long term weather data.

Snyder et al. (2005) developed applications and models to compute frost probability and risk of damage. Using the approach developed by Haan (1979), an MS Excel application program (TempRisk.xls) was written to make the calculations of the probability and risk of temperature falling below a critical value for a user-selected time period. Another application program (FriskS.xls) computes the probability and risk associated with the last spring and first autumn frost dates, and the probabilities for the length of the growing season. A model, the MS Excel Damage Estimator application program (DEST.xls), is used to calculate expected frost damage and crop yield using site-specific maximum and minimum temperature climate data for crops having no protection against frost, and using up to 11 different frost protection methods. Up to 50 years of maximum and minimum temperature data can be used in the analysis. Critical temperatures associated with 90% and 10% damage are input corresponding to specific phenological dates.

5.3. Based on weather forecasts

One of the most effective measures for disaster preparedness is a well-functioning early warning-system that delivers accurate information dependably and in a timely manner.
Therefore, it must rely on:
*(*a) advanced, accurate, detailed and understandable forecasts of hazardous conditions;
*(*b) rapid, dependable distribution system for forecasts, advisories, watches and warnings to all interested parties; and
*(*c) prompt, effective response to warnings at the national to local levels.

WMO's programmes related to monitoring the atmosphere, oceans and rivers provide the crucial time-sequenced information that underpins the forecasts and warnings of hydrometeorological hazards. WMO's global network of RSMCs (Regional Specialised Meteorological Centres) and WDCs (World Data Centres) provides critical data, analysis and forecasts that enable the NMHSs (National Meteorological or Hydrological Services) to provide early warning systems and guidelines for various natural hazards such as tornadoes, winter storms, tropical cyclones, cold and heat waves, floods and droughts.

For example, WMO's network proved to be highly effective in 2004, during one of the most intense hurricane seasons in the Atlantic and Caribbean regions. Atmospheric data collected via in situ and space-based instruments were transmitted to the United States National Hurricane Center, one of WMO's RSMCs (RSMC-Miami), where forecasts and hurricane advisories were developed around the clock. These advisories were transmitted through the GTS (Global Telecommunications System), facsimile and Internet at intervals of three to six hours to the NMHSs of countries at risk. The forecasters at the NMHSs used these hurricane advisories to produce their national hurricane warnings, which were dispatched immediately to newspapers, radio and television stations, emergency services and other users. In response to this information, many lives were spared through timely evacuations. There is no doubt that a lot more could be achieved by deploying resources to strengthen further early warning systems. The challenge is to ensure that all countries, particularly the least developed countries, have the systems, infrastructure, human capacity and organizational structures to develop and utilize early warning systems to reduce risks of natural disasters.

5.4. Based on seasonal forecasts

Temporal climate risk weighs heavily on many of the regions. Recent advances in model-based climate forecasting have expanded the range, timeliness and accuracy of forecasts available to decision-makers whose welfare depends on stochastic climate outcomes. There has consequently been considerable recent investment in improved climate forecasting for the developing world (Lybbert et al, 2003).

The past decade has seen a great deal of progress in the understanding of our climate systems, and in anticipating climate events, particularly El Niño. This has resulted in a cultural change in those countries that experience high climate variability, not only within the meteorological community, but also amongst many farmers and their advisers. This has been particularly so in north-eastern Australia, where the impact of El Niño has been particularly severe, and where many agricultural and other natural resource scientists have gained a significant appreciation of the underlying climatological concepts and then developed tools that would aid rural producers in their farm planning and decision making. There has also been a major education program involving the community.

Seasonal forecasts which may be for three or more months ahead are derived in a completely different way from weather forecasts. Weather forecasts rely upon knowledge of the precise conditions of the atmosphere at the time when the forecast begins (initial conditions) in order to make forecasts for one-to-two weeks into the future. However, given the strongly chaotic nature of the atmosphere weather forecasts have virtually no skill after two weeks or so.

Forecasts beyond this two week weather forecast barrier rely on the fact that slowly changing sea surface temperatures or land surface effects (boundary conditions) are driving atmospheric circulations that affect certain regions of the world. Seasonal prediction therefore can be skillful in regions of the globe where the atmosphere is driven by local or remote sea surface temperature or land surface effects. Empirical as well as dynamical tools are used to make seasonal forecasts. Statistical models fall into the empirical category and have been used successfully in various parts of the world as described below. General circulation models of the ocean-land-atmosphere fall into the dynamical category and are also discussed below.

5.4.1 Tools

Statistical forecasts

In 1989 the Australian Bureau of Meteorology began issuing seasonal outlooks for the next 3 months, based primarily on the Southern Oscillation Index (SOI). Since 1997, this initial approach has been replaced by a method based on Pacific Ocean and Indian Ocean sea-surface temperature patterns, although methods and systems using the SOI (or SOI 'phases') remain popular in eastern Australia where strong relationships exist between the SOI and key rainfall periods for agriculture and with variables such as the start and finish of the frost season. Additionally, methods based on the SOI have proven more amenable to incorporation into crop and pasture simulation models, thereby providing increased capability for uptake by agricultural planners. The SOI is based on the long-term trend in the differences in atmospheric pressure between Darwin and Tahiti, and has proved a reasonably reliable indicator over much of eastern Australia, and elsewhere, with respect to winter, spring and summer rainfall (McBride and Nicholls 1983; Stone, *et al*,, 1996). Such information is used in other countries susceptible to the influence of the El Niño – Southern Oscillation (ENSO) effect, including southern Africa, parts of South America, Indonesia, and India.

More recently a new forecast system based on near-global patterns of sea surface temperatures (SSTs) has been developed. The system shows more skill than the former SOI-

based system and is now in operation in some countries. The phase of the SOI (Stone *et al*. 1996) is proving another valuable tool for producing seasonal outlooks. Both rainfall-forecast methodologies (ENSO and SOI phases) were applied in the Pampas, located in central-eastern Argentina, one of the areas of greatest agricultural and farming potential throughout the world (Penalba et al, 20050. A lead-time of three to six months, especially for November (0), appears to be feasible. However, the lead-time found in SOI phases methodology does not improve the "forecast" provided by the ENSO methodology occurrence; given ENSO event has already entered into the development stage.

Northeast Brazil is noteworthy as a region of the world where remarkable skill has been achieved for the seasonal prediction of wet season rainfall anomalies. These forecasts are based on the observation that wet season (February to May) rainfall in Northeast Brazil is strongly affected by the previous months (November through January) sea surface temperature anomalies in the Atlantic and Pacific oceans. Statistical real-time predictions of Northeast Brazil wet season rainfall have been issued by the British Met Office since the early 1990ies following the work of Ward and Folland (1991).

General Circulation Models (GCMs)

Lead times in terms of years rather than months are needed to attain significant financial benefits in many pastoral systems. There is therefore a robust case for further research to extend seasonal forecasts to annual and beyond.

Coupled ocean-atmosphere GCMs of the global climate have been shown to offer more promising in extending forecasts from 3 to 12 months than the statistical SOI methods, particularly because they directly forecast changes in SSTs in the central and eastern tropical Pacific. Such longer lead times would certainly be more useful to livestock producers. GCMs have yet to be properly tested for rainfall prediction, although their SST predictions can be used statistically to estimate changes in the SOI and rainfall with reasonable success.

Generally speaking, dynamical seasonal forecasts require performing large ensembles of GCM simulations and analyzing the results to look for regions where most simulations produce similar results. In such regions, atmospheric circulations may be more strongly driven by slowly varying ocean or land effects and therefore the prospect for making skillful seasonal prediction is improved. Our experience with seasonal forecasting has shown that in general the tropical regions of the world present a better promise for seasonal predictability than extratropical

regions, although when seasonal climate forecast systems can be integrated into agricultural simulation models an increase in applicability of seasonal forecasting systems appears possible in extra-tropical regions and even some high-latitude locations (Meinke and Stone, 2005).

5.4.2 Accuracy, timeliness and value

The forecasts can influence decisions on when and what area to sow, and whether to irrigate and/or fertilize a crop. Accuracy of forecasting does not necessarily equate with its value to resource managers. Obviously, if the information is not used, then even though it may have value, no benefit is obtained. If the forecast is inaccurate then the information is likely to have negative value in the current season. However, even accurate information can be of limited value if the lead time is only say three months, many livestock producers requiring lead times in excess of six months or even a year.

The value of seasonal forecasts to crop producers can be significant, but it varies with management and initial conditions, as well as with cropping systems and location (e.g. Hammer *et al*. 2000; Marshall *et al*. 1996).

Preliminary studies of the value of seasonal forecasts using models of grassland systems have shown that the financial benefits may not be easily realized based on existing skill levels, lead times (say three months) and decision points within a calendar year. However, these analyses also demonstrate that the same level of cash flow could be achieved for a much lower risk of environmental degradation with use of climate forecasting. (Stafford Smith *et al*. 2000). In some areas even high skill levels appear to offer low financial benefits in the medium term, despite increased animal welfare and protection for soils and vegetation (Bowman *et al*. 1995). This highlights the need for further research to determine whether and how the management and timing of decisions of many grassland systems should be modified to take advantage of forecast information.

6. Example of risk assessment for particular weather and climate events from literature.

In North-West China, informal herder groups counteract risk and manage disaster situations by jointly preparing emergency plans and organizing pasture movements should an emergency situation such as a snow storm occur (Yongong *et al*. 1999). "According to the herders, village leaders and production team leaders are the most active persons in dealing with the risk management (...). They even fulfill extension tasks, since there are no township and village

extension line agencies (...). In those townships which have no concentrated village settlement pattern, there is another non governmental informal organization locally called "zhangquan" situated between the production team and households. A "zhangquan" normally composes about 4-5 herder's households on average. In general, they are comprised of families or of neighboring families settled in the same area. Generally, these individuals collaborate as unofficially formed herders groups. Such groups jointly organize the grazing, they exchange their labor force, share information, protect animals from theft, address risk avoidance, organize meetings and make decisions together" (Yongong et al. 1999)

Synoptic and mesoscale predictions of minimum temperature are usually undertaken by national or regional weather services, using large amounts of equipment and man-power. These are usually public institutions that release frequent updates at no cost for the public. Local (microscale) forecasts are typically unavailable unless provided by private forecast services. At the microscale, complex energy-balance models have been used to predict short-range minimum temperature, with uncertain results (Sutherland, 1980; Cellier, 1982, 1993; Kalma et al., 1992). However, simple empirical models calibrated locally often give satisfactory results in the prediction of minimum temperature in a given day. Snyder and De Melo-Abreu (2005) present an empirical forecast model "FFST.xls", which can be easily calibrated for local conditions. The model uses historical records of air and dew-point temperature at two hours past sunset and observed minimum temperatures to develop site-specific regression coefficients needed to accurately predict the minimum temperature during a particular period of the year. This model will only work during radiation-type frost events in areas with limited cold air drainage.

In coastal Asia where flood risk is severe, for example in Bangladesh and Cambodja, several projects have been built specifically focusing on: people's perception of flood risk; the purpose and tools of community flood risk assessment; the strategies for community organization; and resource mobilization and capacity building. In these cases, the rationale for doing so can be traced back to the sequencing of DRM activities, with an emphasis on local scoping studies and capacity building that are to precede community interventions.

In India, following the cyclone of 1971 (which cost the lives of 10.000 people), the government of the state of Orissa prepared a report outlining a series of measures to be taken to prepare for future cyclones, which later led to the Orissa Relief Code. This code provides the basic framework for the implementation of emergency measures under all types of emergency situations, as it details the specific responsibilities of the state's Special Relief Commissioner

and its different line ministries. During the latest cyclone of 1999, planning responses were still hindered by a lack of updated and available vulnerability maps and databases on conditions on the coast.

In Nicaragua, the 'Asociación de Consultores para el Desarrollo de la Pequeña, Mediana y Micro-Empresa' (ACODEP), one of the largest MFIs (microfinance institutions) in the country, has been learning from the experience of hurricane Mitch in 1998 and more recent disasters. The association has developed a 'Disaster Prevention Plan' whose objectives are to identify, prepare for and mitigate natural and manmade disasters in order to protect the institution, its clients and staff from possible losses. The Plan is rather comprehensive, including measures to protect the institution's staff, portfolio, facilities, equipment and information systems and records, as well as measures to better respond to the many disasters that affect Nicaragua. The Plan recognizes that priority should be given to assisting clients in finding medical aid, contacting relief organizations and joining FFW (food for work) programmes, but, in keeping with the sector's orthodox 'best practices', it does not consider that the institution should provide relief directly.

Hurricane Michelle ripped through Cuba in November 2001, the most powerful storm since 1944. But, in contrast to the 20.000 victims of hurricane Mitch in Honduras, just five people died in Cuba. Successful civil defense and Red Cross planning ensured that 700.000 people were evacuated to emergency shelters in time. Search-and-rescue and emergency health-care plans swung into action. In Havana, electricity and water supplies were turned off to avoid deaths from electrocution and sewage contamination. Cuba's population was advised in advance to store water and clear debris from streets that might cause damage (Messer, 2003)

The severity of the El Niño/La Niña phenomenon of 1997-1998, led to the establishment of the Andean Regional Programme for Risk Prevention and Reduction (PREANDINO) with the objective of promoting the development of disaster risk prevention and mitigation policies and new institutional arrangements aimed at incorporating prevention into development planning.

The Lempira Sur rural development project in the south of Honduras has promoted improved agricultural practices, river basin management, ecological sustainability, increases in on and off farm incomes and economic resilience among poor families. This has been achieved with the introduction and appropriation of improved land use practices, water management schemes, maintenance of biodiversity, local credit schemes, and the strengthening of local government and the abilities to plan urban and rural development. The notion of disaster risk

reduction was never considered in the project document. However, the project demonstrates how ecologically sustainable, best practice agriculture, will lead to reductions in disaster risk, although this was not a defining character of the project as such. Hazard reduction associated with flooding and landslides has been achieved, along with increases in the resilience of the local population when faced with extreme conditions. During Hurricane Mitch the area covered by the project suffered little damage due to the types of land use and slope-stabilization methods that were utilized, and it was able to provide food assistance to other areas severely damaged by the hurricane.

An efficient telecommunication system is a prerequisite for an effective typhoon warning system. WMO´s Global Telecommunication System (GTS) was development under the World Weather Watch (WWW) Programme to collect data from the national observing stations and exchange these with other countries. This elaborate telecommunication system also functions for the prompt dissemination of typhoon warnings, as well as for transmitting data to monitor them (Lao, 2006)

7. Extreme cases related.

Although large uncertainty is involved in the assessment of climate-related human health risk, visible progress is under way. Climate related health risks range from the direct effects of extreme temperature and flooding which every year cause deaths and the spread of infectious diseases, to the more indirect effects of climate variability on the global distribution of infectious diseases such as malaria, dengue fever, cholera, and Rift Valley fever, hantavirus, among many others.

The role of climate and the environment in human disease dynamics has been clearly demonstrated for the case of cholera, an acute intestinal infection caused by the bacterium *Vibrio cholerae*. The dynamics of cholera outbreaks involves the *V. cholerae* bacterium and plankton is such a way that during periods of warm sea surface temperatures *V. cholerae* is active and abundant and the number of cholera cases in certain geographical areas are elevated (Colwell, 1996). On a global scale, the clear link between cholera epidemics and climate variability such as El Niño, offers the possibility for the creation of an early-warning system which would help prevent future cholera epidemics given reliable climate prediction.

Climate change can affect agriculture in many ways, for example, (a) in soil-plant processes, with an increase in soil water deficits by changes in soil water balance; (b) in crop

31

development since crops will be affected by temperature and soil humidity changes; (c) weeds, pests, and diseases; weeds are expected to benefit from higher CO_2 concentration; increases on precipitation and temperature are favorable to early crop diseases development and the risk of crop damage by pests and diseases increases in all regions under climate warming. (d) in economic and social effects. Rosenzweig and Liverman (1992) observed that the tropical regions could also be more vulnerable to climate changes because of economic and social disparities. Greater economic and individual dependence on agriculture, widespread poverty, inadequate technologies and lack of political power are likely to exacerbate the impacts of climate change in tropical regions.

Global assessments of climate change impacts in agriculture and agricultural markets have been produced (Rosenberg and Crosson, 1990; Rosenzweig and Hillel, 1998; Mendelsohn and Neumann, 1999; Siqueira *et al*., 1999; Salinger *et al*., 2000, Reilly *et al*., 2001; Das, 2003a).

It is expected that atmospheric CO_2 concentration will rise from its current level of 354 ppm to 530 ppm, by the year 2050, and to 700 ppm by the year 2100 (Watson *et al*., 1990). Changes in the concentration of the infra-red absorbing gases in the atmosphere are expected to produce a general warming of the global surface raging from 3-4 ^{o}C by the year 2100 (Bretherton *et al*., 1990). According to Marengo (2001) in most of Latin America, there are no regional studies that show conclusive effects of climate change. However, some changes in the atmosphere circulation at regional level were detected for example, for precipitation, and hydrological cycles in the Amazon region (Marengo *et al.,* 2001; Costa and Foley, 1999; Curtis and Hastenrath, 1999) and for temperature including several Brazilian regions (Victoria et al, 1998; Marengo and Rogers, 2001).

The storm called "Catarina" that affected parts of Santa Catarina and Rio Grande do Sul states in Brazil, in March 2004, may be an early example of the effect of climate change in the South Atlantic Ocean.. A technical note published by CPTEC (the Brazilian Center for Weather Forecasting and Climate Studies) and INMET (the Brazilian National Institute of Meteorology) informs that the storm formed as a cyclone in the South Atlantic Ocean acquiring hurricane characteristics while moving towards the South American continent. A storm of Catarina's intensity (never before been observed in the South Atlantic Ocean Winds) of up to 180 km/h caused unprecedented destruction in that region: more of US$ 350.000.000,00 in damages.

Climate change may therefore result in an increase of climate variability and climate extremes. Such climate changes will most certainly affect crop growth and productivity. However, there is not enough information about the potential impact of climate change in agriculture, because of the complex response of plant and soil processes to several weather variables.

Climatologists at the National Oceanic and Atmospheric Administration's National Climatic Data Center in Asheville, North Carolina, have selected some of the most notable floods, typhoons, hurricanes, droughts, heatwaves, tornadoes, winter storms and blizzards, and climate events of the 20th century. Factors taken into consideration included the event's magnitude, meteorological uniqueness, as well as its economic impact and death toll (WMO, 2000).

Recurring floods occur in the middle and lower reaches of the major rivers in China, kill from several thousand to several hundred thousand people. During the last century major flooding disasters occurred in 1900,1911, 1915,1931,1935,1950, 1954,1959, 1991 and 1998 mainly in the Yangtze River Valley.

- *Yangtze River Flood, 1931.* The summer flood along the Yangtze during July-August 1931 was the most severe, with over 51 million people affected (1/4 of China's population). 3.7 million people perished during what is considered the greatest disaster of the 20th century due to disease, starvation or drowning. This flood was preceded by a prolonged drought in China during the period from 1928-1930.

- *Flood in Vietnam, 1971.* Heavy rains caused severe flooding in North Vietnam, killing 100.000 people.

- *Great Iran Flood, 1954*. A storm over Iran produced flooding rains resulting in approximately 10.000 deaths.

Many of the devastating floods that occur in parts of Southeast Asia are also associated with typhoons or tropical systems. See the typhoon section for more information. In contrast, the U.S. Midwest Flood of 1993 reported 48 deaths.

Among the most devastating hurricanes of all times were Hurricane Georges (September 1998) and Hurricane Mitch- (October 1998). A category 5 hurricane, Hurricane Mitch was one of the most powerful Atlantic Hurricanes. With 290 km/hr winds, a minimum storm pressure of 0,1 mPa, and quite a long life span (14.5 days) Hurricane Mitch turned out to be the deadliest of the century. It caused loss of life, destruction of property, damage to food production, food reserves and transportation system as well as increased health risks.

Deadly Typhoons Killer Cyclones strike coastal areas along the Bay of Bengal with periodic frequency much like the floods along the Yangtze River in China. They historically have also devastated the Chinese coast, Korea, Japan, the Philippines and Southeast Asia.

Bangladesh Cyclone, November 1970. The greatest tropical system disaster the last century occurred in Bangladesh in November 1970. Winds coupled with a storm surge killed between 300.000 and 500.000 people. These cyclones usually cause the most devastation, loss of life, and suffering in low lying areas of Bangladesh and coastal India.

Bangladesh Cyclone 02B, April 1991. Another cyclone struck the Chittagong region in Bangladesh in 1991 killing over 138,000 people and causing damage in excess of US\$ 1.500.000.000. The tropical cyclone devastated the coastal area southeast of Dacca with winds in excess of 200 km/h and a 6 m storm surge.

China Typhoons, Early Half of last Century. Several typhoons also struck the eastern China coast during the early half of the last century causing great hardship and deaths from some of the storms reaching the tens of thousands. For example, Typhoons striking the China coast in August 1912 and August 1922 resulted in fatality counts of 50.000 and 60.000 respectively.

Hurricane Mitch, November 1998. One of the strongest late season hurricanes on record formed in the western Carribean in October 1998. Although the system eventually weakened before landfall, its slow passage westward over the mountainous regions of Central America unleashed precipitation amounts estimated as high as 1.9 m. The resulting floods devastated the entire infrastructure of Honduras and also severely impacted other countries in the area. The final estimated death toll was 11.000, the greatest loss of life from a tropical system in the western hemisphere since 1780.

Typhoon Vera, September 1958. This typhoon's passage over Japan in 1959 caused Japan's greatest storm disaster. The death toll reached nearly 5000, with 1.5 million left homeless. Typhoon Vera dealt a staggering blow to Japan's economy with tremendous damage to roads, bridges and communications from wind, floods and landslides.

Typhoon Thelma, October 1991. Thelma was one of the most devastating tropical systems to affect the Philippines the last century. Reports indicated that 6000 people died by catastrophic events including dam failure, landslides, and extensive flash flooding. The death toll exceeded that of the Mt. Pinatubo eruption. The highest casualties occurred on Leyte Island where widespread logging in recent years had stripped the hills above the port city bare of vegetation.

Hurricane Katrina, August 2005. Katrina was the deadliest hurricane to hit the U.S. since 1928, killing more than 1400 people. Katrina inundated 80 percent of the city of New Orleans and caused damages of over 70 billion dollars.

Table 2 shows typhoon damages in North Central Vietnam.

Table 2.   Typhoon damages in North Central Vietnam (15N to 20N)

Year	Deaths (no.)	Value of losses (Us $ million)	Paddy fields (submerged) (in 1000 ha)	Houses flooded (in thousand)	Boats sunk (no.)
1995	57	106.3	139	131	528
1996	499	720	590	829	741
1997	63	16	82	43	54
1998	214	104		461	208

Table 3 shows disaster impacts in those areas.

Table 3.   Disaster impacts – North central region (1979-1998)

	Total killed		Typhoons		Floods		Flash flood		Tornado	
	No.	%	No.	%	No.	%	No.	%	No.	%
People killed	2642	100	1769	67	592	22	0	0	262	10
Houses collapsed	417941	100	306646	73	46829	11	1	0	10172	2
Paddy crop un harvested	399531	100	253775	64	52583	13	390	0	10524	3
Money loss (in '000 million vnd)	2736	100	1890	69	728	27	2	0	114	4

Source: Van Viet (1999)

Losses from a single tropical cyclone may therefore run into the billions of dollars, and is forecasted to increase due to the ever increasing numbers of people living in coastal areas. For example, in 1998, El Nino-related weather phenomena caused US$ 6.600.000.000 of damages in Argentina, Peru and Ecuador, while Hurricane Georges alone caused US$2.100.000.000 in damages in the Dominican Republic and Hurricane Mitch produced damages of US$2.400.000.000 in Honduras and Nicaragua (Charveriat, 2000).

In May 2002, the cyclone Kesiny hit Madagascar affecting more than half a million people, making them homeless or in need of emergency food, shelter and drinking water. Up to 75% of the crops were destroyed, 20 people died and 1,200 were injured (CIDI, 2002).

The Orissa cyclones on 17-18 October and again on 29-30 October 1999 in Orissa, India caused devastating damage. The cyclones on 29-30 October with wind speeds of 270-300 km/h for 36 hours were accompanied by torrential rain ranging from 400 to 867 mm over a period of 3 days. The two cyclones together severely affected around 19 million people in 12 districts (Roy et al. 2002). Sea waves reaching 7 meters rushed 15 kms inland. 2.5 million livestock perished and a total of 2.1 million ha of agricultural land was affected.

The effects of droughts, famines, and heatwaves are much harder to quantify. The effects are devastating and impacts can span just a couple of months or stretch to a decade or more. Some historical drought/famines with loss of life are listed bellow:

Asian Droughts. Numerous drought related disasters have occurred over the Asian mainland this century. The most notable include:

* Indian Drought of 1900- 1/4 to 3 1/4 million died due to drought, starvation and disease;

* Chinese Famine of 1907- Over 24 million perished from starvation;

* Chinese Famine of 1928-1930- Over 3 million perished in northwest China;

* Chinese Famine of 1936- 5 million Chinese died in what is called the "New Famine";

* Chinese Drought 1941-1942- Over 3 million perished from starvation;

* Indian Drought of 1965-1967- Over 1.5 million perished in India;

* Soviet Union (Ukraine and Volga regions) 1921-1922- 1/4 to 5 million perished.

Sahel Drought, various years. Famines/droughts have occurred in the Sahel of Africa in 1910-1914, 1940-1944, 1970-1985. The drought in the Sahel claimed over 600.000 in 1972-1975 and again in 1984-1985.

The American 'Dust Bowl' of the 1930ies lasted almost an entire decade and covered virtually the entire United States Great Plains. The 'Dust Bowl' drought and associated high temperatures, strong winds, dust storms, and insect infestations resulted in an agricultural depression that further aggravated the Great United States Depression of the 1930ies, affecting the livelihood and health of millions of people. The rainfall deficits that caused the 'Dust Bowl' are caused by natural cycles of the atmosphere in the Great Plains, In fact, paleoclimatic evidence points to the occurrence of multi-year droughts in the Great Plains at a rate of one or two per century, with even longer droughts, or mega-droughts that last for many decades,

occurring at a rate of one to three per thousand years (Overpeck, 2000). Although the rainfall deficits during the Dust Bowl were caused by natural variability of the atmosphere, poor land management and agricultural practices during the 1920ies further aggravated the situation by making the Great Plains more vulnerable to wind erosion, depletion of soil moisture and nutrients, and drought. The 'Dust Bowl' event highlights the importance of assessing risk on a regional basis and putting in place land management and agricultural practices that will help mitigate the possibly devastating effects of drought (Warrick, 1980).

Severe and damaging tornadoes are mainly a U.S. phenomena. The U.S. is the "Tornado Capital of the World" and has more tornadoes annually than any country on the globe. Two notable outbreaks include: "Super Tornado Outbreak of 1974" (315 deaths) and the "Tri State Tornado of 1925" (695 deaths).

Iran Blizzard, February 1972 A blizzard in Iran in Feb 1972 ended a four-year drought but the week--long cold and snow caused the deaths of approximately 4,000 people.

Europe Storm Surge, 1953. One of Europe's greatest natural disasters occurred during the winter months of January and February 1953. Violent winter storms caused storm surges which caused flooding in areas of the Netherlands and the United Kingdom. Almost 2,000 people perished due to these storm surges.

The Great Smog of London, December 1952. Stagnant air due to an inversion combined with industrial and residential emissions to create an air pollution episode without parallel in this century. 4000 deaths were attributed to the poisonous air with 4000 additional fatalities due to related causes.

El Niño and La Niña events tend to alternate within every three to seven years. However, the time from one event to the next can vary from one to ten years.

1982 to 1983 El Niño. The economic impacts of the 1982-83 El Niño were huge. Along the west coast of South America, the losses exceeded the benefits. The fishing industries in Ecuador and Peru suffered heavily when their anchovy harvest failed and their sardines unexpectedly moved south into Chilean waters. Also, changed circulation patterns steered tropical systems off their usual tracks to islands such as Hawaii and Tahiti, which are usually unaffected by such severe weather. They also caused the monsoon rains to fall over the central Pacific instead of the western Pacific. The lack of rain in the Western Pacific led to droughts and disastrous forest fires in Indonesia and Australia. Winter storms battered southern California and caused widespread flooding across the southern United States, while unusually mild weather and a lack

of snow was evident across much of the central and northeastern portion of the U.S. Overall, the loss to the world economy in 1982-83 as a result of the changes to climate due to the El Niño amounted to over $8 billion. The toll in terms of human suffering is much more difficult to estimate. (NOAA/OGP Our Changing Planet Spring 1994).

8. Developing and implementing policy to reduce the (risk and) impact of extreme events

In 1968, the Typhoon Committee, the first of the five tropical cyclone regional bodies, was established under the auspices of WMO and ESCAP. The Committee continues to work towards the reduction of damage caused by typhoons and floods in the western north Pacific and South China sea region. In its more than 20 years of existence, substantial advances have been made by National Meteorological Centers in the region towards meeting their responsibilities for providing warnings of tropical cyclones and storms surges (Lao, 2006)

Government and private sector institutions servicing government and rural communities have a role in helping rural producers cope with climate variability and extreme climate and weather events.

a. Need for policy and implementation plans and infrastructure (meteorology, agriculture/natural resources). Ready access to global, regional, national, and local warning systems and broad dissemination of warnings (see the example of Tsunami in December, 2004)

b. Understanding climate variability, preparing for and managing through drought – at national and regional level – mitigating the impact of drought, flood, wildfire (public awareness, training, and education)

Drought planning is an integral part of drought policy (Wilhite 1991, 2005). A generic set of planning objectives has been developed that could be considered as part of a national, state/provincial or regional planning effort (Wilhite, 2000). This include:

* Establish criteria for declaring drought and triggering various mitigation and response activities.

* Provide an organizational structure that assures information flow between and within levels of government, as well as with non-governmental organizations, and define the duties and responsibilities of all agencies with respect to drought.

* Maintain a current inventory of drought assistance and mitigation programs used in assessing and responding to drought emergencies, and provide a set of appropriate action recommendations.
* Identify drought-prone areas and vulnerable sectors, population groups, and environments.
* Identify mitigation actions that can be taken to address vulnerabilities and reduce drought impacts.
* Provide a mechanism to ensure timely and accurate assessment of drought's impacts on agriculture, livestock production, industry, municipalities, wildlife, health, and other areas, as well as specific population groups.
* Collect, analyze and disseminate drought-related information in a timely and systematic manner.
* Keep the public informed of current conditions and mitigation and response actions by providing accurate, timely information to media in print and electronic form.
* Establish a set of procedures to continually evaluate and exercise or test the plan and periodically revise the plan so it will remain responsive to the needs of the people and government ministries.

Drought plans in which mitigation is a key element should have three principal components: monitoring, early warning, and prediction; risk and impact assessment; and mitigation and response. A description of each of these components follows.

a) Production monitoring – remote sensing, ground validation field observations, agronomic models

b) Policies to promote land care and minimize soil erosion, weed invasion, salinization; likewise with water – safeguarding flows, minimizing algal blooms, to dam or not to dam, improving water use efficiency, etc

c) Mitigating the effects of extreme events – e.g. policy to limit grazing pressure and wind and water erosion, promote use of seasonal forecasts, promote on-farm self-reliance and risk management, drought-resistant plants etc

Due to major advances in technology and notable progress in scientific under–standing, the accuracy and timeliness of weather and flood warnings have significantly improved over the last few decades. The accuracy of forecasts of large-scale weather patterns for seven days is today the same as those for two days in advance only 25 years ago (Obasi 1998). Forecasts up to 10 days are nowadays showing remarkable accuracy, and there is now the capability to provide

some skillful information on expected weather patterns several seasons in advance. For example, early information on El Nino episodes is now allowing advanced national planning, with considerable advantage in many sectors of the economy, such as in water resources management, tourism, and fisheries and agricultural production (Obasi 1996). In the case of the 1997-98 El Nino event, advances in El Nino related science and in monitoring the sea-surface temperatures in the Pacific Ocean, enabled scientists to predict its formation further in advance than any of the previous events. With recent developments in communication technology, including the use of the internet, information on the El Nino was disseminated in a rapid and timely manner throughout the world. These enabled many governments to take appropriate measures, and stimulated international cooperation and integrated efforts to address the associated impacts.

The accuracy of tropical cyclone track forecasts and the timeliness of warnings have also been steadily improving in the past few years. Global efforts, especially within the context of the Tropical Cyclone Programme of the WMO have resulted in a noticeable improvement in the warning systems in many parts of the world and resulted in saving many lives and limiting property damage. For example, the decrease in the death toll in Bangladesh, from about 130,000 to 500 caused by similar tropical cyclones in 1991 and 1994 respectively was attributed in large part, by government sources, to improvements in early warning and evacuation systems (Obasi 1997).

The evolving internet has proven to be an invaluable tool in facilitating the exchange of global and regional climate monitoring and prediction information. However many users require assistance in the selection, interpretation and application of appropriate information.

Effective early warning systems coupled with community education for protective action has reduced the potential human loss from these events. Floods as a disaster also lend themselves well for preparedness measures both structural and legislative (land use laws, zoning plans and urbanization). Preparedness of life-saving techniques and evacuation plans should be promoted actively in these high risk zones (Sivakumar, 2005)

9.   On-farm planning to reduce the risk and impact of extreme events
Stigter et al. (2003) have emphasized the importance of on-farm preparedness.
    9.1. Crop selection and cropping sequence.

The method to select crop varieties based on agroclimatic requirements consists of comparing, on one hand, the regional availability of agroclimatic resources and, on the other, the climatic requirements of selected crop varieties on which the selection is to be made. The selection of varieties of plants at local or regional levels should be based on agroclimatic studies carried out to determine the climatic requirements of the different crop varieties. Agroclimatic characterization of crops include solar radiation, temperature, humidity and photoperiod, among the most important climatological factors.

There are large differences in sensitivity to frost damage amongst crops. On a farm scale, frost sensitive species should, if ever, be planted on middle slopes. The bottom of the valleys and locations where cold air can flow should be avoided. Planting deciduous crops on slopes facing away from the sun delays spring-time bloom and often provides protection. Subtropical trees are best planted on slopes facing the sun where the soil and crop can receive and store more direct energy from sunlight. Rootstock often influences the earliness of flowering of deciduous fruit trees and therefore potential frost damage. On evergreen fruit trees, rootstock may be also related to frost hardiness. For example, navel oranges are more frost hardy when grown on trifoliate rootstock than when grown on sweet orange rootstock (Snyder and De Melo-Abreu, 2005).

The method to select crop varieties based on agroclimatic requirements, consists of comparing, on one hand, the regional availability of agroclimatic resources and, on the other, the climatic requirements of selected crop varieties on which the selection is to be made. The selection of varieties of plants at local or regional levels should be based on agroclimatic studies carried out to determine the climatic requirements of the different crop varieties. Agroclimatic characterization of crops include solar radiation, water, temperature, humidity and photoperiod, among the most important climatological factors.

9.2. Selection of varieties.

Intra-specific variability for resistance to drought, frost, and heat stress is often large. Hence, there is often room for plant breeding for resistance to these risks. For example, in citrus growing frost may not be avoidable but selecting for tolerance to subzero temperatures is a valuable option (Ikeda, 1982). The selection of an appropriate variety for a given area should take into account the frost hardiness of the varieties in the species.

9.3. Land preparation

a.   Deep ploughing: as far as frost protection is concerned, deep ploughing as about the same effect as shallow ploughing on heat transfer, since the layer of soil that is involved in heat transfer to the surface by conduction, on a daily basis, is not thicker than about 0.3 m.

b.   Tillage methods: during periods when frost is likely to occur, cultivation should be avoided, because it increases porosity of the soil and may conduce to more evaporation in the top layer. Since air is a poor heat conductor, when compared to soil matrix and water, cultivation reduces the amounts of heat stored in the soil during the day and transferred to the surface during the cold night. If cultivation can't be avoided, use a roll to compact the soil to counteract the increase of air space generated by the mobilization of the soil.

9.4. Crop management

a.   Irrigation management : on a frost protection perspective, soils should be moist before a frost period is likely to occur. Hence, irrigation one or two days in advance of a frost night brings a soil to near field capacity what results in an increased soil heat flux during a subsequent frost night. Various irrigation methods are also used in the night of frost (i. e., as active methods), with the objective of using the heat liberated as the water cools and freezes. For details see Snyder and De Melo-Abreu (2005)..

b.   Fertilizer management: use of fertilizers, and in particular nitrogen, accelerates crop growth and helps crops develops profuse root systems thus making plants more capable to face the drought. The time and method of application are important. Nitrogen and other nutrients are known to affect frost sensitivity. In general, nitrogen may reduce frost resistance, and phosphorus and potassium are likely to increase it (Bagdonas et al., 1978). New growth is more frost sensitive to frost, because it tends to have less solute content in the tissues. Therefore, management should minimize new growth in frost prone periods. However, nitrogen may result in increased frost resistance if the biophysical effect of a bigger canopy offsets the physiological effect (Snyder and De Melo-Abreu, 2005).

c.   Weed management: during a dry spell or water stress conditions, weed competition is a problem for crops because weeds also use the little moisture that is available. In dryland crops sown in line, weed control through interculture operations are found to be beneficial under water stress conditions. Cover crops and weeds in orchards tend to trap air and thus reduce heat diffusivity of the ground. Hence, under these circumstances, minimum

temperature is lower and frost risk increases. Mowing the plants, without removing them, or cultivation to remove them, has little if any effect on minimum temperature. However, spraying with herbicide has a substantial positive effect on minimum temperature.

It is possible that the presence of cover crops or weeds has a negative effect on frost resistance that results from a higher concentration of ice-nucleation active (INA) bacteria that is known to occur on cover crops and weeds. Fruit trees, namely citrus and grapevines, are known to have lower INA bacteria concentrations (Snyder and De Melo-Abreu, 2005).

d.   Earlying or delaying harvest: A practical method to avoid frost damage that many farmers adopt consists in harvesting before a frost period is likely to occur. This is in general feasible in small farms, but often impossible in larger ones.

9.5 Pasture and livestock management

Preparing for and managing through drought

An essential part of farming in a variable climate is anticipating and preparing for the next drought. This needs to be incorporated into the farm's long-term management strategy, a good manager being cognizant of those factors that threaten the sustainability and long-term financial viability of the property.

At the farm level, it is essential that sustainable systems are developed and implemented that minimize the impact of drought on the soils and vegetation, and ensure that livestock are humanely cared for or disposed of. The wellbeing of farming families will also be enhanced through better financial and risk management. Although the threat of drought cannot be removed, its impact on the community, and on soils, vegetation, and livestock, may be reduced.

Conditions conducive to soil erosion by wind and water are more prevalent in drought periods (Marshall, 1973). The area of bare ground within a pasture increases with stocking rate, particularly in adverse seasons (White *et al*., 1980). This is caused by the associated reduction in vegetative cover and the drying out of the surface soil. The decision to retain stock during drought may therefore exacerbate the degradation of vegetative cover (Morley and Daniel, 1992). Wind velocity near the ground increases considerably when vegetation is removed. Further degradation can therefore follow, with soil erosion exacerbated by the action of wind or intensive drought-breaking rains on bare soil.

Self-reliant drought management is inextricably linked to the concept of economic and environmental sustainability. Rangelands and improved pastures should be managed so that

degradation of soils and vegetation is minimized. This requires the choice of an appropriate long-term stocking rate and strategy for grazing management, destocking early in drought (Morley and Daniel 1992), and possibly planting perennial fodder trees. Only a nucleus of productive and breeding stock should be fed, wethers and steers and the eldest age groups of breeding ewes and cows should be sold or destroyed, depending on the most profitable options. Failed crops can be harvested for grain, cut for hay, or used for grazing.

a. Planning for managing in the face of uncertainty (with respect to climate)

Budgeting is a vital part of managing risk and preparing for drought. At a minimum it involves planning for the year ahead assuming a) an average or better season, and b) a drought year, and then applying a probability to each. This can then be extended to say a 2- or even a 5-year estimate of cash flow, possibly including a wider range of seasons. Where seasonal forecasts are being used one can include the probability of a drought or an average or better season being forecast, but then one must also include the probabilities of these forecasts as perceived as being wrong (Table 4). It is essential that all possible outcomes are budgeted in advance.

However, Meinke *et al* (2003) point out that management decisions based on seasonal forecasts will have positive outcomes in some years and negative outcomes in others. This should not be regarded as either a 'win' or a 'failure' of the strategy employed using seasonal forecasts since each season or year is only a sample of one from a 'not very well-defined distribution of possible outcomes'. They add that in order to assess the true value of this type of probabilistic information requires a comparison of results in each season against outcomes that would have been achieved in the absence of such information. A lot of the perceived problem in use of seasonal forecasts appears to stem from the fact that as a consequence of the delivery of weather forecasts, prediction information was initially issued as a deterministic forecast. Murphy (1993) stresses the need for uncertainties that are inherent in judgments to be properly reflected in climate forecasts.

Table 4. Determining seasonal probabilities when seasonal forecasts are available

Forecast -	Drought -	true v false
	Good season -	true v false

Financial strategies identified by Blackburn (1992) as leading to greater self-reliance are summarized in Table 5.

When frost protection is likely to be necessary, the appropriate method(s) to be used must be selected based both on the physical and economical risk. An MS Excel application (FrostEcon.xls), programmed in VBA, was developed by Snyder et al. (2005) to help farmers anywhere in the world conduct the cost effectiveness and risk analyses essential to making wise financial decisions concerning the adoption of frost protection methods.

Table 5. Financial strategies to aid drought preparedness and management

Pre-drought	Build up cash reserves during good years
	Budget each year assuming both normal and drought years
	Stabilize income through off-farm investments
Drought forecast	Budget for long range forecast being a) right, b) wrong
	Unload prime or surplus livestock before prices drop
	Identify least-cost feed supplements
	Purchase fodder before its value increases
	Budget to compare feeding and selling strategies
	Sensitivity - drought duration, feed costs, stock prices
	Evaluate alternative strategies, e.g. droving, agistment
	Budget for selling all stock and investing off-farm
Drought	Minimize financial losses to facilitate post-drought recovery
	Continue comparing feeding and selling strategies
	Consider raising capital by selling off-farm investments

b.   Stocking rate and carrying capacity of the land

Long-term stocking rates should be both biologically and financially sustainable after allowing for drought (Morley 1981; White 1987). Stocking rates that fail to sustain pastures or viable vegetation are not economic in the long term. In this regard, the sustainability of

agricultural systems in some areas may need to be reassessed, given the underlying capacity of the land.

      c. Adaptation of livestock

A variety of management adaptations are available for livestock production systems. For example, Hahn and Mader (1997) outline a series of proactive management countermeasures that can be taken during heat waves (e.g., shades and/or sprinklers) to reduce excessive heat loads. Historical success in coping with climate variability suggests that livestock producers are likely to adjust to climate change successfully. Johnson (1965) provides examples from advances in genetics and breeding as related to the environment. These capabilities should allow adaptation to changing, less favorable circumstances associated with projected rates of climate change.   However, coping can entail significant dislocation costs for certain producers. For individual producers, uncertainties associated with potential climate change imply additional risks related to how and when to adapt current production practices (Lewandrowski and Schimmelpfennig, 1999). Confidence in the foregoing projections of the ability of livestock producers to adapt their herds to the physiological stresses of climate change is difficult to judge. The general lack of simulations of livestock adaptation to climate change is problematic. This absence of a well-developed livestock counterpart to crop modeling of adaptation assessments suggests a major methodological weakness. Hence, we give only low to moderate confidence in projections of successful livestock adaptability. (IPCC, 2001)

10. Significance of climate change

a.   *Climate is always changing*

Better understanding of weather and climate requires monitoring and analyzing the climate signals at different timescales. These include:

1. the Madden-Julian (30-50 day) Oscillation, or Intraseasonal Oscillation, increases the likelihood of rain every time it passes over northern Australia;
2. the Quasi-Biennial Oscillation (QBO), a quasi-periodic stratospheric oscillation that affects the distribution of stratospheric ozone and monsoon precipitation, for example.

3. the El Niño-Southern Oscillation (ENSO) is a global coupled ocean-atmosphere phenomenon that has a cycle of about 3 to 7 years and has profound effects on global climate;

4. the Pacific Decadal Oscillation (PDO) is a decadal oscillation of Pacific Ocean sea surface temperatures that affect Northern Hemisphere climate;

5. a 50-80 year variability associated with the tilt of the Earth's axis (hemispheric);

6. Milankovitch cycles (Ice-ages; inter-glacial periods) based on variation of the Earth's orbit around the sun.

The overriding certainty is that climate has always changed and will continue to change. Whether climate change is natural or anthropogenic is relevant here only in the context of the likely direction and rate of change. The important issue at stake is the capacity of farmers and ranchers to adapt the management of crops, rangeland and grassland ecosystems to a changing climate minimizing adverse consequences.

Climate change will include changes in rainfall, temperature and atmospheric CO2 concentrations. For instance, in Australia, which has the highest climate variability of any continent in the world, comparable with southern Africa, it is anticipated that the most noticeable changes will be an increase in rainfall intensity and variability and an increased frequency of extreme high temperatures, with a likelihood of more severe droughts and a greater fire risk (Jones *et al*., 2000).

Some of the consequences of climate change are likely to be beneficial. For example, increased atmospheric CO^2 concentrations can offset the detrimental effects of drier seasons through increased water-use efficiency and yields. For grassland systems, particularly those based on C4 species, this can be reflected in higher carrying capacities and less variability between years in stocking rate (Howden *et al*., 1999; Reyenga *et al*., 1999).

b.   Adaptation to climate change

Knowledge of climate variability can assist in adapting to climate change. In eastern Australia there is a strong correlation between the Southern Oscillation Index (SOI) in winter and spring and subsequent spring and summer rainfall (McBride and Nicholls, 1983; Stone, *et al*., 1996; Nicholls, 1998). If producers stock their land in response to changes in the SOI, then if climate change leads to either drier or wetter summer seasons, they will *ipso facto* adjust their stocking rates accordingly (McKeon *et al*., 1993). This of course assumes that the prevailing relationship

between the SOI and summer rainfall remains unchanged, which may not be the case (Walsh *et al*., 1999). Other indices such as sea surfaces temperatures in the equatorial Pacific and Indian Oceans could similarly be used.

Climate may also change outside the range of previous experience, especially in regard to the severity and frequency of extreme conditions. Longer-term adaptation will require some foreknowledge of the nature of the climate change, not simply reliance on recent experience.

REFERENCES

Ackerman, S. A. and Knox, J.A., 2003: *Meteorology: Understanding the Atmosphere.* Brooks/Cole, 486 pp.

André, R. G. B., Ferraudo, A. S. and Molion, L. C. B., 1996. Contrastes climáticos entre as estações seca e chuvosa para a Floresta Amazônica. *Revista Brasileira de Meteorologia, Rio de Janeiro, v. 11, n. 2,*

André, R. G. B. ; Pinheiro, F. M. A. ; Marques, V. S. . Índice de aridez e de umidade para a região Norte Fluminense. In: Congresso Brasileiro de Meteorologia, 2004. Fortaleza - CD. XIII Congresso Brasileiro de Meteorologia, 2004.

Arnold, G.W. and Bennett, D., 1975. The problem of finding an optimum solution. In *Study of Agricultural Systems*, edited by G.E. Dalton, Applied Science Publishers, London, pp. 1129-173.

Ashworth, E.N., Kieft, T.L., 1995. Ice nucleation activity associated with plants and fungi. Pp. 137-162 in: R.E. Lee, Jr., G.J. Warren, and L._V. Gusta (eds.), Biological Ice Nucleation and Its Applications. APS Press, St. Paul, MN.

Bagdonas, A., Georg, J.C. & Gerber, J.F., 1978. Techniques of frost prediction and methods of frost and cold protection. *World Meteorological Organization Technical Note,* No. 157. Geneva, Switzerland. 160p.

Birrell, H., 1987. In *Managed Grasslands B. Analytical Studies*, edited by R.W. Snaydon, Elsevier, Amsterdam, pp. 247-253.

Bishop, A.H. and Birrell, H.A., 1975. Effect of stocking rate, fodder conservation and grazing management on the performance of wether sheep in south-west Victoria. 1. Wool production. *Australian Journal of Experimental Agriculture and Animal Husbandry* 15: 173-182.

Blackburn, A.G., 1992. Principles of managing for recovery. *Proceedings of the National Conference for farm financial counsellors*, Perth.

Blong, R., 2002. Estimating residential flood damage. In Smith, D.I. and Handmer, J. (eds) *Residential flood insurance: the implications for floodplain management policy.* Canberra: Water Research Foundation: 175–200

Botterill, L.C., 2003. Government Responses to Drought in Australia. In: *Beyond Drought - People, Policy and Perspectives*, edited by Linda Courtenay Botterill and Melanie Fisher Melbourne, CSIRO Publishing, pp. 49-65.

Botterill, L.C., 2005. Lessons for Australia and beyond. In *From disaster response to risk management: Australia's National Drought Policy*, edited by Linda Courtenay Botterill and Donald A. Wilhite, Springer, Dordrecht, pp. 177-183.

Bowman, P.J., Cottle, D.J., White, D.H. and Bywater, A.C. ,1993. Simulation of wool growth rate and fleece characteristics of Merino sheep in southern Australia. Part 1. Model description. *Agricultural Systems* 43: 287-299.

Bowman, P.J., McKeon, G.M. and White, D.H., 1995. The impact of long range climate forecasting on the performance of sheep flocks in Victoria. *Australian Journal of Agricultural Research* 46: 687–702.

Bretherton, F. P., 1990, in Climate Change: The IPCC Scientific Assessment, J. T. Houghton *et al.*, Eds. (Cambridge Univ. Press, Cambridge, 1990), pp. 173–194.

Brinkley, T.R., Laughlin, G.P., Hutchinson, M.F. and Rananunga, 2004. GROWEST PLUS – A tool for rapid assessment of seasonal growth for environmental planning and assessment. *Environmental Modeling and Software* ***

Buxton, R. and Stafford Smith, M., 1996. Managing drought in Australia's rangelands: four weddings and a funeral. *Rangelands Journal* 18: 292-308.

Carter, J.O., Hall, W.B., Brook, K.D., McKeon, G.M., Day, K.A. and Paull, C.J. ,2000. Aussie GRASS: Australian Grassland and Rangeland Assessment by Spatial Simulation. In *Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems - The Australian Experience*, edited by G. Hammer, N. Nicholls and C. Mitchell, Kluwer Academic Publishers, Dordrecht, pp. 329-349.

Cellier, P., 1982. Contribution a prévision des températures minimales nocturnes en conditions de gelées de printemps. Etude de l'évolution des températures de l'air et du sol au cours de la nuit [in French]. PhD Thesis, INA Paris-Grignon.

Cellier, P. 1993. An operational model for predicting minimum temperatures near the soil surface under clear sky conditions. Journal of Applied Meteorology, 32(5): 871–883.

Charveriat, C., 2000. Natural Disasters in Latin America and the Caribbean: An Overview of Risk. Working Papers Series; 434, Washington D.C.

Chiang, J. C. H., and A. H. Sobel, 2002: Tropical troposphere temperature variations caused by ENSO and their influence on the remote tropical climate. *J. Climate,* 15, 2616–2631.

Clewett, J.F. Clarkson, N.M., George, D.A., Ooi, S.H., Owens, D.T., Partridge, I.J. and Simpson, G.B., 2003. Rainman StreamFlow version 4.3: A comprehensive climate and stream flow analysis package on CD to assess seasonal forecasts and manage climatic risk. QI03040, Queensland Department of Primary Industries.

Colwell, R. R., 1996. Global climate and infectious disease: the cholera paradigm. Science. 274(5295):2025-31.

Costa, M., Foley, J., 1999. Trends in the hydrologic cycle of the Amazon basin. J.Geophys.Res. 104, 14189-14198.

Cunha, R. G., 2003. Meteorologia: Fatos & Mitos. Passo Fundo: Embrapa, 410p.

Curtis, S. Hastenrath, S., 1999. Trend of upper-air circulation and water capor over equatorial South America and adjacent oceans. Int.J.Climatol., 19, 863-876.

Das, H.P., 1999: Management and mitigation of adverse effects of drought phenomenon. In: *Natural disasters – some issues and concerns*. Natural Disasters Management Cell, Visva Bharati, Shantiniketan, Calcutta, India.

Das, H.P., 2003a. Agrometeorology related to extreme events; CAgM-XI Working Group on Agrometeorology Related to Extreme Events. Geneva, Switzerland: Secretariat of the World Meteorological Organization, 2003.

Das, H.P., 2003b. Incidence, predicition, monitoring and mitigation measures of tropical cyclones and storm surges. In Agrometerology related to Extreme Events. WMO no., 943, World Meterological Organization, Geneva.

Das, H.P., 2005. Agrometeorological impact assessment of natural disasters and extreme events and agricultural strategies adopted in areas with high weather risks. In: Sivakumar, M.V.K., Motha, R. P., Das, H.P. (eds), 2005 *Natural disasters and Extreme events in agriculture.* pp. 93-118. Springer. Berlin.

De Jager, J.M., Potgieter, A.B. and van den Berg, W.J., 1998. Framework for forecasting the severity of drought in maize in the Free State Province of South Africa. *Agricultural Systems* 57: 351-365.

Donnelly, J.R., Freer, M. and Moore, A.D., 1997. GRAZPLAN: decision support systems for Australian grazing enterprises. I. Overview of the GRAZPLAN project and a description of the MetAccess and LambAlive DSS. *Agricultural Systems* 54, 57-76.

Donnelly, J.R., Freer, M. and Moore, A.D. , 1998. Using the GrassGro Decision Support Tool to evaluate some objective criteria for the definition of exceptional drought. *Agricultural Systems* 57: 301-313.

Du Pisani, L.G., Fouché, H.J. and Venter, J.C., 1998. Assessing rangeland drought in South Africa. *Agricultural Systems* 57: 367-380.

Everingham, Y.L., Muchow, R.C., Stone, R.C., Inman-Bamber, G., Singels, A., and Bezuidenhout, C.N., 2002. Enhanced risk management and decision-making capability across the sugarcane industry value chain based on seasonal climate forecasts. *Agricultural Systems* 74, 3, 459-477.

Fitzpatrick, E.A.; Nix, H.A., 1970. The climatic factor in Australian grassland ecology. In: MOORE, R.M. (Ed.) Australian grasslands. Camberra: Australian National University Press.

Fouché, H.J., de Jager, J.M. and Opperman, D.P.J., 1985. A mathematical model for assessing the influence of stocking rate on the incidence of droughts and for estimating the optimal stocking rates. *Journal of the Grassland Society of South Africa* 2(3): 3-6.

Freer, M., Moore, A.D. and Donnelly, J.R., 1997. GRAZPLAN: decision support systems for Australian grazing enterprises. II. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. *Agricultural Systems* 54, 77-126.

Fujita, T. T., 1981. Tornadoes and downbursts in the context of generalized planetary scales. *J. Atm. Sci.,* 38,1511-1534.

Garcia A., Andre, R.G.B., Carrer, T.T., 2002. Distribuição temporal da precipitação em Ituverava – SP.   In: CONGRESSO BRASILEIRO DE METEOROLOGIA, 12,. Anais... Foz do Iguaçu:: Sociedade Brasileira de Meteorologia, Editado em CD-ROM

Grimm, A., Ferraz, S.E.T., Gomes J., 1998, Precipitation anomalies in Southern Brazil associated with El Niño and La Niña events. *Journal of Climate*, 11, 2863-2880.

Guenni. L. , Hernandez, A. and Fillipone, M., 2003. Modeling population vulnerability and risk to extreme rainfall events in Venezuela, Acta Científica Venezolana, Vol. 54, Suplemento No. 1: 2–12.

Haan, C.T., 1979. Risk analysis in environmental modifications. Pp.30-51, in: B.J. Barfield & J.F. Gerber (eds). Modification of the aerial environment of crops. American Society of Agricultural Engineering (ASAE), Monograph no.2. St Joseph, Michigan: ASAE.

Hahn, G.L. and Mader, T.L., 1997. Heat waves in relation to thermoregulation, feeding behavior and mortality of feedlot cattle. In: Proc. Fifth Int. Livest. Envir. Symp. Am. Soc. Agric. Eng., St. Joseph, MO. p. 563.

Hammer, G. L., and Nicholls, N., 1996. Managing for climate variability - The role of seasonal climate forecasting in improving agricultural systems. Proceedings, Second Australian Conference on Agricultural Meteorology, Brisbane, 1-4 October. 1996.

Hammer, G.L., Nicholls, N. and Mitchell, C., 2000, Eds. Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems – The Australian Experience. Kluwer Academic, The Netherlands, pp 469.

Heathcote, R.L., 1991. Managing the droughts? Perception of resource management in the face of the drought hazard in Australia. *Vegetatio* 91: 219-230.

Heathcote, R.L., 1999. She'll be right mate. Coping with drought: strategies old and new in Australia. In *Hazards and Disasters: A Series of DefinitiveWorks. Volume II: Drought, A Global Assessment*, edited by D.A. Wilhite, Routledge Publishers, London, pp. 59-69.

Howden S M, McKeon G M, Carter J O and Beswick A, 1999. Potential global change impacts on C3–C4 grass distributions in eastern Australian rangelands. *In* VIth International Rangeland Congresss Proceedings Vol. 1 Eds. D Eldridge and D Freuden- berger. pp 41–43. Fyshwick, ACT, Australia: Elect Printing

Ikeda, I.,1982. Freeze injury and protection of citrus in Japan. pp. 575–589, *in:* P.H. Li and A. Sakai (eds). *Plant Cold Hardiness and Freezing Stress. Vol.II*. Academic Press Inc.
IPCC, 2001. Intergovernmental panel on Climate Change, Report:Climate Change 2001:Impacts, Adaptation and Vulnerability, http://www.ipcc.ch

IPCC, 2002. Intergovernmental panel on Climate Change, Workshop Report IPCC Workshop on Changes in Extreme Weather and Climate Events Beijing, China, 11-13 June, 2002, http://www.ipcc.ch

Johnson , H.D., 1965: Response of animals to heat. *Meteorological Monographs*, 6, 109–122.
Jones,J.W., J.W. Hansen, F.S. Royce, and C.D. Messina, 2000: Potential benefits of climate forecasting to agriculture. Agric. Ecosys. Env., 82, 169-184.

Joy, C.S., 1991. *The cost of natural disasters in Australia*, paper presented at Climate Change Impacts Workshop, Climatic Impacts Centre, Macquarie University, New South Wales, Australia, 13– 15 May.

Jupp, D.L.B., Tian, G., McVicar, T.R., Qin, Y. And Li, F., 1998. *Monitoring Soil Moisture and Drought using AVHRR Satellite Data I: Theory.* CSIRO Earth Observation Centre Technical Report, 98.1, Canberra, ACT.

Kalma, J.D., Laughlin, G.P., Caprio, J.M. & Hamer, P.J.C., 1992. Advances in Bioclimatology, 2. The Bioclimatology of Frost. Berlin: Springer-Verlag .144p.

Kane, S., J. Reilly, and R. Bucklin, 1989. Implications of the greenhouse effect for world agricultural commodity markets. US Department of Agriculture Washington, DC.

Keating, B.A. and Meinke, H.R.,1998. Assessing exceptional drought with a cropping systems simulator: a case study for grain production in northern Australia. *Agricultural Systems* 57: 315-332.

Krishnamurti, T. N. et al. Seasonal Forecasts of Precipitation anomalies for North American and Asian Monsoons, 2001. In: Workshop on Regional Climate Research: Needs and Opportunities. Colorado: National Center for Atmospheric Research.

Lao, C. G., 2006. Managing tropical cyclone disasters. *WMO Bulletin, Vol. 55 No. 1, p. 31-36.*

Larcher, W.,1982. Typology of freezing phenomena among vascular plants and evolutionary trends in frost acclimation. pp. 3–15, in: P.H. Li and & A. Sakai (eds). Plant Cold Hardiness and Freezing Stress, Vol. I. Academic Press.

Levitt, J., 1978. Stress overview and interrelationships. In *Plant Cold Hardiness and Freezing Stress*, (eds P. H. Li & A. Sakai). pp. 3–15. Academic Press, New York

Lewandrowski, J. and Schimmelpfennig, D., 1999. Economic implications of climate change for US agriculture: assessing recent evidence. *Land Econ 75:39–57.*

Lybbert, T., Barrett, C. B., McPeak, J., and Luseno, W., 2003. Bayesian Herders: Asymmetric Updating of Rainfall Beliefs in Response to External Forecasts.*Manuscript*, Cornell University.

Long, S.P., 1991. Modification of the response of photosynthetic productivity to rising temperature by atmospheric CO_2 concentrations. Has its importance been underestimated? - Opinion. Plant Cell and Environment 14, 729-739.

Long, S.P. & Drake, B.G.,1991. Effect of the long-term elevation of CO_2 concentration in the field on the quantum yield of photosynthesis of the C3 sedge, *Scirpus olneyi*. Plant Physiology 96, 221-226.

Lourens, U.W. and de Jager, J.M., 1997. A computerised crop-specific drought monitoring system. *Agricultural Systems* 53: 303-315.

Marengo, J. and Rogers, J., 2001. Cold front and Polar Air Outbreaks in the Americas during: Moderm climate assessments and impacts, and some past climate evidences. In: Present a past inter-hemispheric climate linkages in the Americas and their societal effects. V. Markgraf Ed., New York. 31-49.

Marshall, G.R., Parton, K.A. and Hammer, G.L.,1996. Risk attitude, planting conditions and the value of seasonal forecasts to a dryland wheat grower. *Australian Journal of Agricultural Economics* 40, 211-233.

Marshall, J.K., 1973. Drought, land use and soil erosion. p. 55-77. In: J.V. Lovett (ed.). The environmental, economic and social significance of drought. Angus and Robertson, Publ. Sydney, Austrália.

McBride, J.L. and Nicholls, N.,1983. Seasonal relationships between Australian rainfall and the Southern Oscillation. *Monthly Weather Review,* 111, 1998-2004.

McKeon, G. M.; K. A. Day; S. M. Howden; J. J. Mott; D. M. Orr; W. J. Scattini; and E. J. Weston, 1990. Northern Australian savannas: Management for pastoral production. *Journal of Biogeography* 17:355–72

McKeon, G.M., Howden, S.M., Abel, N.O.J. and King, J.M.,1993. Climate change – adapting tropical and sub-tropical grasslands. In *Proceedings of the XVII International Grassland Congress*, 8-21 February 1993, Palmerston North, New Zealand, pp. 1181-1190.

McVicar, T. R., Briggs, P. R., King, E. A., and Raupach, M. R., 2003. A Review of Predictive Modelling from a Natural Resource Management Perspective: The Role of Remote Sensing of the Terrestrial Environment. CSIRO Land and Water Client Report to the Bureau of Rural

Sciences, Canberra, Australia. 26 pp. http://www.clw.csiro.au/publications/consultancy/2003/ Review Of Remote Sensing.pdf.

McVicar, T.R. and Jupp, D.L.B., 1998. The current and potential operational uses of remote sensing to aid decisions on Drought Exceptional Circumstances in Australia: A Review. *Agricultural Systems* 57, 399-468.

McVicar, T.R., Jupp, D.L.B., Yang, X. And Tian, G., 1992. Linking regional water balance models with remote sensing. In *Proceedings of the 13th Asian Conference on Remote Sensing*, Ulaanbaatar, Mongolia, 7-11 October, pp. B.6.1-B.6.6

Meinke, H. and Stone, R.C., 2005. Seasonal and inter-annual climate forecasting: the new tool for increasing preparedness to climate variability and change in agricultural planning and operations. *Climatic Change* 70, 221-253.

Meinke, H., Wright, W. Hayman, P. and Stephens, D., 2003. Managing cropping systems in variable climates. In: Pratley, J. (editor). *Principles of field crop production*. Fourth Edition. Oxford University Press, Melbourne, Australia, p. 26-77.

Mendelsohn, R. and J.E. Neumann (eds.)., 1999. The Impact of Climate Change on the United States Economy. Cambridge University Press, Cambridge, UK.

Messer N., 2003. The Role of Local Institutions in Disaster Risk Mitigation: a Literature Review, FAO/SDAR, Rome.

MINISTÉRIO DA CIÊNCIA E TECNOLOGIA, 2004. *Convenção-Quadro das Nações Unidas sobre Mudanças Climática* - um guia para iniciantes. [on-line]. <URL: http://www.mct.gov.br/clima>. Acessed in 2004-05-22].

Moore, A.D., Donnelly, J.R. and Freer, M., 1997. GRAZPLAN: decision support systems for Australian grazing enterprises. III. Pasture growth and soil moisture submodels and the GrassGro DSS. *Agricultural Systems* 55, 535-582.

Morley, F.H.W., 1981. Management of grazing systems. In *World Animal Science : Grazing animals*, edited by F.H.W. Morley, Elsevier, Amsterdam, pp. 379-400.

Morley, F.H.W. and Daniel, G., 1992. Drought, stocking rate and soil loss. *Proceedings of the Australian Society of Animal Production* 19, 323-325.

Murphy, A.H., 1993. What is a good forecast? An essay on the nature of goodness in weather forecasting. *Weather and Forecasting* 8, 281-293.

Nelson, R.A., Holzworth, D.P., Hammer, G.L., and Hayman, P.T., 2002. Infusing the use of seasonal climate forecasting into crop management practice in north east Australia using discussion-support software. *Agricultural Systems*. 74, 3, 393-414.

Nicholls, N., 1998.William Stanley Jevons and the climate of Australia. Aust Met. Mag., 47, 285-293.

O'Meagher, B., M. Stafford Smith, and D.H. White, 2000. Approaches to Integrate Drought Risk Management (Chapter 37, pp. 115-128). *In:* Wilhite, D.A. (ed.) *Drought: A Global Assessment* (Volume 2), Routledge Publishers, London, U.K

O'Meagher, B., Stafford Smith, M. and White, D.H., 1999. Approaches to integrated drought risk management: Australia's National Drought Policy. In *Hazards and disasters: a series of definitive major works. Volume II. Drought, a global assessment,* edited by D.A. Wilhite, Routledge Publishers, London, pp. 115-128.

Obasi G.O.P., 1997. Adress at the opening of the second Joint Session of the WMO/ESCAP Panel on Tropical Cyclones and the ESCAP/WMO Typhoon Committee, 20 February 1997, Phuket.

Obasi, G.O.P., 1996. Climate, climate change, variability and predictability. RGICS Paper No. 36. New Delhi, India: Rajiv Gandhi Institute for Contemporary Studies. 35 p.

Obasi, G.O.P., 1998. Address at the opening of the International IDNDR-Conference on Early Warning Systems for the Reduction of Natural Disasters, September 7, 1998, Potsdam, Germany.

OFCMSSR, 2004. *Federal Research and Development Needs and Priorities for Atmospheric Transport and Diffusion Modeling*. FCM R23 2004. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Washington, DC, September 2004. Joint Action Group for Atmospheric Transport and Diffusion Modeling (Research and Development Plan). 207 p. http://www.ofcm.gov/r23/r23-2004/pdf/fcm-r23-2004.pdf (accessed May 5, 2005).

O'Meagher, B., du Pisani, L and White, D.H., 1998. Evolution of drought policy and related science in Australia and South Africa. *Agricultural Systems* 57, 231-258.

Orlanski, I., 1975. A rational subdivision of scales for atmospheric processes. Bull. Amer. Meteor. Soc., 56, 527-530.

Overpeck, J., 2000. Climate Surprises. In Forces of Change: A New View of Nature, published by the Smithsonian Institution in association with National Geographic Magazine. ISBN 0-7922-7596-9.

Penalba O.C., Beltran A. and Messina C. Monthly Rainfall In Central-Eastern Argentina and ENSO. A Comparative Study of Rainfall Forecast Methodologies. Revista Brasileira de Agrometeorología, Vol 13, N° 2, 2005, in press.

Potgieter, A.B., Hammer, G.L. and deVoil, P., 2005. A simple regional-scale model for forecasting sorghum yield across North Eastern Australia. *Journal Agricultural and Forest Meteorology.*, 132, 1-2, 143-153.

Reilly, J., F. Tubiello, B. McCarl, and J. Melillo, 2001. The potential consequences of climate variability and change. Chapter 13 in *Climate Change Impacts on the United States*, *Report for*

the U.S. Global Change Research Program U.S. National Assessment Synthesis Team. Cambridge University Press, Cambridge, UK.

Reyenga PJ, Howden SM, Meinke H and McKeon GM , 1999. Impacts of global change on cropping in SW Queensland. Environmental Modelling and Software 14, 297-306.
Rosenberg, N.J. and P.R. Crosson, 1990. Processes for Identifying Regional Influences of the Responses to Increasing Atmospheric CO2 and Climate Change: the MINK Project an Overview. Resources for the Future. Washington, DC

Rosenzweig, C. and D. Hillel, 1998. *Climate Change and The Global Harvest: Potential Impacts of the Greenhouse Effect on Agriculture*. Oxford University Press, New York.

Rosenzweig, C., and D. Liverman, 1992. Predicted effects of climate change on agriculture: A comparison of temperate and tropical regions. In *Global climate change: Implications, challenges, and mitigation measures*, ed. S. K. Majumdar, 342-61. PA: The Pennsylvania Academy of Sciences.

Ryan, C. J., 1993. Costs and benefits of Tropical Cyclones, Severe Thunderstorms and Bushfires in Australia. Climatic Change 25, pp. 353-367

Ryan, C. J., 1993. Costs and benefits of Tropical Cyclones, Severe Thunderstorms and Bushfires in Australia. Climatic Change 25, pp. 353-367.

Ryyppö, A., Repo, T., and Vapaavuori, E., 1998. Development of freezing tolerance in roots and shoots of Scots pine seedlings at nonfreezing temperatures. Can. J. For. Res./Rev. Can. Rech. For. 28(4): 557-565.

Salinger, M.J., Renwick, J. A. and A.B. Mullan, 2000: Interdecadal Pacific Oscillation and South Pacific climate. *International Journal of Climatology* (submitted)

Sellers, P. J., 1985. Canopy reflectance, photosynthesis, and transpiration. *Int. J. Remote Sens.* 6: 1335–1372

Siqueira, O., L. Salles, and J. Fernandes, 1999: Efeitos potenciais de mudancas climaticas na agricultura brasileira e estrategias adaptativas para algumas culturas. In: *Memorias do Workshop de Mudancas Climaticas Globais e a Agropecuaria Brasileira, 1-17 de Junho 1999, Campinas, SPO, Brasil.* Brasil, pp. 18-19 (in Portuguese).

Sivakumar, M.V.K., 2005. Impacts of natural disasters in agriculture, rangeland and forestry: an overview. In: Sivakumar, M.V.K., Motha, R. P., Das, H.P. (eds), 2005 *Natural disasters and Extreme events in agriculture.* pp. 23-37. Springer. Berlin

Snyder, R. L., De Melo-Abreu, J. P, Matulich, S., 2005. Frost Protection: Fundamentals, Practice and Economics. Vol. II. United Nations, Food and Agriculture Organization, Rome, 64 pp.

Snyder, R. L., De Melo-Abreu, J. P., 2005. Frost Protection: Fundamentals, Practice and Economics. Vol. I. United Nations, Food and Agriculture Organization, Rome, 223 pp.

Souza, E.B., Kayano, M.T., Tota, J., Pezzi, L., Fisch, G., Nobre C., 2000. On the influence of the El Niño, La Nina and Atlantic dipole pattern on the Amazonian rainfall during 1960-1998. *Acta Amazonia*, 30, 305-319.

Stafford Smith M., Buxton, R., McKeon, G., Ash, A., 2000. Seasonal climate forecasting and the management of rangelands: Do production benefits translate into enterprise profits? In Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems - The Australian Experience, (Ed. GL Hammer, N Nicholls and C Mitchell), pp.271- 289, Kluwer Academic Press.

Stafford Smith, D.M. and McKeon, G.M., 1998. Assessing the historical frequency of drought events on grazing properties in Australian rangelands. Agricultural Systems and Information Technology Newsletter 57(3):271-299.

Stafford Smith, M., 2003. Linking environments, decision-making and policy in handling climate variability. In: *Beyond Drought: People, Policy and Perspectives*, edited by L.C. Botterill and M. Fisher, Melbourne, CSIRO Publishing, pp. 131-151.

Stafford Smith, M., Buxton, R., McKeon, G. and Ash, A., 2000. Seasonal climate forecasting and the management of rangelands: do production benefits translate into enterprise profits? In *Applications of seasonal climate forecasting in agricultural and natural ecosystems - the Australian experience*, edited by G. Hammer, N. Nicholls and C. Mitchell, Kluwer Academic Publishers, pp. 271-289.

Stephens, D.J., 1998. Objective criteria for estimating the severity of drought in the wheat cropping areas of Australia. *Agricultural Systems* 57: 333-350.

Stigter, C.J., Das, H.P and Murthy, V.R.K., 2003. Beyond climate forecasting of flood disasters. Invited Lecture on the Opening Day of the *Fifth Regional Training Course on Flood Risk Management (FRM-5)* of the Asian Disaster Preparedness Center (Bangkok) and the China Research Center on Flood and Drought Disaster Reduction (Beijing), Beijing, September. Available from ADPC (Bangkok) on CD-ROM.

Stone, R.C., and Meinke, H., 2005. Operational seasonal forecasting of crop performance. *Philosophical Transactions of the Royal Society B* 360, 2109-2124.……………

Stone, R.G., Hammer, G. and Marcussen, T., 1966. Prediction of global rainfall probabilities using phases of the Southern Oscillation Index. *Nature* 384: 252-255.

Su, H. Neelin, J. D., 2003. The Scatter in Tropical Average Precipitation Anomalies. J. Climate, 16, 3966-3977, 2003.

Sutherland, R.A., 1980. A short-range objective nocturnal temperature forecasting model. Journal of Applied Meteorology, 19: 247–255.

Thornley, J.H.M. and Johnson, I.R., 1990. Plant and Crop Modelling: A Mathematical Approach to Plant and Crop Physiology. Clarendon Press, Oxford, 669 pp.

Tibbits, W.N and Reid, JB., 1987. Frost Resistance in Eucalyptus Nitens (Deane & Maiden) Maiden: Physiological Aspects of Hardiness. *Australian Journal of Botany* 35(3) 235 – 250.

UNFCCC, 2004. The evidence from climate models. Climate Change Information Sheet 7. In: URL: http://unfccc.int/resource/iuckit/fact07.html. (Acessed in 2004-05-21)

Van Viet, N, 1999. Climate disasters and promotion of changing cropping patterns in the Central Region of Vietnam. Scientific report, 175p (in Vietnamese). IMH, Hanoi, Vietnam, 1999.

Victoria, R., Martinelli, L., Moraes, J., Ballester, M.V., Krushche, A., Pellegrino, G. Almeida, R., Richey, J.. 1998. Surface air temperature variations in the Amazon region and its border during this century. J. Climate, 1, 1105-1110.

Walsh, K., R. Allan, R. Jones, A.B. Pittock, R. Suppiah and P. Whetton, 1999. *Climate change in Queensland under enhanced greenhouse conditions*. Available from CSIRO Atmospheric Research, PMB 1, Aspendale, VIC. 3195, Australia. 84 pp

Ward, M. N., and C. K. Folland, 1991. Prediction of seasonal rainfall in North Nordeste of Brazil using eigenvectors of sea surface temperature. Int. J. Climatol., 11, 711-743.

Warrick, R.A., 1980. Drought in the Great Plains: A Case Study of Research on Climate and Society in the USA. In J. Ausubel and A.K. Biswas (eds.). *Climatic Constraints and Human Activities*, pp. 93–123. IIASA Proceedings Series, Vol. 10. Pergamon Press, New York.

Watson, R.T., Rodhe, H., Oeschger, H. and Siegenthaler, U., 1990. Greenhouse gases and aerosols. In: *Climate Change. The IPCC Scientific Assessment* (eds. J.T. Schimel, G.J. Jenkins and J.J. Ephraums) pp.1-40. Cambridge University Press, Cambridge

White, D.H., 1987. Stocking Rate. In *Managed Grasslands B. Analytical Studies*, edited by R.W. Snaydon, Elsevier, Amsterdam, pp. 227-238.

White, D.H., 1997. Risk assessment and management: Case study - drought and risk. *Proceedings of the National Outlook Conference: Commodity markets and resource management*, 4-6 February 1997, Australian Bureau of Agriculture and Resource Economics, Canberra, pp. 98-103

White, D.H., 2000. Drought policy, monitoring and management in arid lands. *Annals of Arid Zone* 39(2): 105-129.

White, D.H., 2000. Implementing drought policy in Australia. *Agricultural Science* 13(2): 27-32.

White, D.H. and Karssies, L., 1999. Australia's National Drought Policy: aims, analyses and implementation. *Water International* 24: 2-9.

White, D.H., Botterill, L.C. and O'Meagher, B., 2005. At the intersection of science and politics: defining exceptional drought. In *From disaster response to risk management: Australia's National Drought Policy*, edited by Linda Courtenay Botterill and Donald A. Wilhite, Springer, Dordrecht, pp. 99-111.

White, D.H., du Pisani, L. and Fouché, H., 2001. Implementing drought policy in southern Africa. *Agricultural Science* 14: 25-29.

White, D.H., Howden, S.M., Walcott, J.J. and Cannon, R.M., 1998. A framework for estimating the extent and severity of drought, based on a grazing system in south-eastern Australia. *Agricultural Systems* 57: 259-270.

White, D.H., McConchie, B.J., Curnow, B.C. and Ternouth, A.H., 1980. A comparison of levels of production and profit from Merino ewes and wethers grazed at various stocking rates in northern Victoria. *Australian Journal of Experimental Agriculture and Animal Husbandry* 20, 296-307.

Wilhite, D. A., 1991. Drought planning: A process for state government. *Water Resources Bulletin* 27(1):29-38

Wilhite, D.A., 1993a. The enigma of drought. In *Drought Assessment, Management and Planning: Theory and Case Studies*, edited by D.A. Wilhite, Kluwer Academic Publishers, Boston, pp. 3-15.

Wilhite, D.A., 1993b. Planning for drought. In *Drought Assessment, Management and Planning: Theory and Case Studies*, edited by D.A. Wilhite, Boston, Kluwer Academic Publishers, pp. 87–108.

Wilhite, D.A., 2005. Drought policy and preparedness: the Australian experience in an international context. In *From disaster response to risk management: Australia's National Drought Policy*, edited by Linda Courtenay Botterill and Donald A. Wilhite, Springer, Dordrecht, pp. 157-176.

Wilhite, D.A., 2000. Drought as a natural hazard: conceptions and definitions. In: WILHITE, D. A. Drought: a global assessment. London: Routledge, p. 3-18.

WMO, 2000. Our World. International Weather. [on-line]. <URL: *http://www.wmo.ch/wmo50/ e/world/weather_pages/chronicle_e.html >.* Acessed in 2005-07-18].

WMO, 2006. Natural Hazards. [on-line]. <URL: http://www.wmo.ch/wmd >. Acessed in 2006-02-18].

Yongong et al. ,1999. "Strengthening pastoral institutions in North-West China pastoral area to access improved extension services for risk management and poverty alleviation", prepared by Liu Yongong, Center for Integrated Agricultural Development (CIAD), China Agricultural University, Stephan Baas, FAO, and Ni Hongxing, Wang Jinbiao, Ministry of Agriculture/Department of Animal Husbandry, Qinghai Province, Xining.

Yongong et al., 1999. "Strengthening pastoral institutions in North-West China pastoral area to access improved extension services for risk management and poverty alleviation", prepared by Liu Yongong, Center for Integrated Agricultural Development (CIAD), China Agricultural University, Stephan Baas, FAO, and Ni Hongxing, Wang Jinbiao, Ministry of Agriculture/Department of Animal Husbandry, Qinghai Province, Xining.