ADAPTION OF SYNOPTIC CHARACTERISATION METHODOLOGIES AS A SHORT-TO-MEDIUM TERM CLIMATE ANALYTICAL AND FORECASTING TOOL

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EXTENDED ABSTRACT

Global climate change is an increasingly important issue associated with water, energy, and food security. Without appropriate understanding of the relevant atmospheric dynamics that deliver rainfall – and thus water resources – to regions that are water limited, appropriate risk analysis and mitigation methodologies cannot be developed. Historical synoptic data shows that recent climate variability displays greater divergence from the long term trend, suggesting that this variability can be analysed using the synoptic characteristics of the delivery mechanism rather than the occurrence of extreme events. If the variation in rainfall delivery and water availability associated with climate change and its potential impact on essential human activities – such as sanitation, energy production and broadacre farming – is to be clearly understood, then we must consider the short and medium variability of atmospheric parameters from long term trends, rather than the long term trends themselves.

Information gained through the synoptic characterisation of regional climates, in conjunction with other data gathering activities, form the basis for studies that provide a large portion of the data required for evaluating and validating numerical regional and global scale climate models. Information from these studies indirectly assists in the evaluation of the impacts due to potential changes in climate on the regional hydrologic system and ecosystem resilience. This paper argues that synoptic characterisation can be used to establish the connection between climate divergence and rainfall delivery variability associated with extreme events (wet and dry) and deviations from historic and possibly recent rainfall patterns. A review of current synoptic characterisation methodologies is presented, together with an assessment of their suitability for adaption as an effective short-to-medium climate analytical and forecasting tool for understanding these events and deviations and their transitional behaviours, recognising that there may be both primary and secondary drivers associated with regional climate variability.

This paper seeks to demonstrate that such a tool or assessment framework is a key enabler for development of a decision support toolkit that will inform capital investment, industry adaptation, resource condition assessment, and land and water management. This toolkit will provide land and water managers and key decision makers with an effective methodology for improved understanding of short-to-medium term rainfall variability and climate change, and enable them to identify and analyze the risk and forecast the potential impact of rainfall variability on essential human activities in their region. This is particularly relevant to ecosystem resilience, water supply reliability, irrigated food production systems and agriculture in water limited environments.

KEYWORDS: climate change, rainfall variability, synoptic characterisation, land management, water management
1. INTRODUCTION

Water, energy and food are inextricably linked and underpin the development and expansionary nature of current global trade and productivity models. The “forever” nature of this approach that relies on physically and environmentally limited resources presents a challenge to find niche and technological innovations to continue this process, or target stability and zero growth as an alternative (Coles & Hall, 2012).

Adding two billion more people to an increasingly urbanized planet will place significant pressure on energy, water and food demands. Predictably this will require increasing trade-offs among these three sectors that, at the same time, must counter the potential to accelerate ecosystem degradation. Given that water is critical for every aspect of life, if current trends and practices continue over-exploitation, trans-boundary conflicts and ecosystem degradation will continue exponentially. In less than twenty years 40% less freshwater resources will be available than required to ensure water, energy, and food security and to drive global development beyond basic poverty alleviation (Bonn, 2011). This is the challenge that faces the global community today.

If water, energy, and food security for all is to be achieved and sustained, an improved understanding of the linkages between water, energy and food is necessary to achieve increased efficiency, better trade-off outcomes, enhanced synergies and improved governance of resources (Coles & Hall, 2012). Importantly, as we understand more about the ecosystem-ecoservices and planetary dynamics and interrelationships, so must this understanding be reflected in our policies and governance frameworks; this was identified as the NEXUS approach adopted at Bonn 2011 (SEI, 2011) and recognised at the recent United Nations Conference on Sustainable Development (United Nations, 2012).

Natural resource scarcity is at the heart of the ‘nexus’ debate and will be exacerbated by changes in global population and climate. The vast proportion of the natural resources needed to generate fresh water, energy, and food for the world’s growing population are limited: resources such as land, soil, nutrients and fresh potable water. As the Millennium Ecosystem Assessment reminds us, this natural land and water resource base is also degraded and polluted by centuries of human mismanagement (MEA, 2005). Therefore, as the world’s population continues to grow, the agricultural industry will need to reinvent itself to supply this ever expanding demand. Critically, this must be achieved in the face of a changing climate and the declining availability of prime land and water resources due to increasing urbanization and losses to the energy sector.

Global climate change is also having an increasingly dramatic impact on water and food security. Understanding the natural resources base and its functional dynamics is a key component of the nexus strategy (Coles & Hall, 2012). If the dynamics are understood then the activities that impinge on these processes can be evaluated and assessed in terms of a ‘value add’ or a ‘value loss’ to the quality of ecosystem goods and services that are provided within this natural environment. Therefore, understanding the ‘natural’ environment in which we now find ourselves with significantly changed landscapes, urbanisation, polluted water systems and altered climates, presents us with significant issues and challenges (Coles et al, 2013). What is the ‘natural’ environment, and how do we want it to function in the future? If systems have been severely degraded or changed, to what extent can they or should they be restored? Can we actually recover or sustain that which has been altered or lost? For example, without appropriate understanding of the relevant atmospheric dynamics that deliver rainfall – and thus water resources – to regions that are water limited environments, especially those experiencing expanding aridity and growing populations (FAO, 2011) – appropriate risk analysis cannot be conducted and hence effective mitigation strategies cannot be developed.
Improving our understanding of the key interactions of major actors and drivers in natural systems, especially short-to-medium term (i.e. the 3 to 7 year timeframe) climate variability and the impacts of adaptive management strategies, through innovative approaches such as the adaption of synoptic characterisation methodologies as a regional climate analytical and forecasting tool, can provide some answers that will assist us address those issues and challenges.

2. WHAT IS ‘SYNOPTIC CHARACTERISATION’?

An initial review of the application of characterisation methodologies revealed that there is inconsistency in the use of some key words and terms. Therefore, it was important that we establish a clear understanding of what is meant by ‘synoptic characterisation’ in the climate and meteorological context.

Specific uses of ‘synoptic’ in climate and meteorological terminology are **synoptic data** and **synoptic scale meteorology**. ‘Synoptic’ refers to the use of meteorological data (or ‘weather’ data) obtained simultaneously over a wide area for presenting a comprehensive and nearly instantaneous view of the state of the atmosphere. Meteorological data are generally classified as either **synoptic data** or climate data. **Synoptic data** is the real time data provided for use in aviation safety and forecast modelling, whereas climate data is the official data record, usually provided after some quality control is performed on the data (Boissonnade et al, 2002).

**Atmospheric (or meteorological) phenomena** are observable weather events that are bound by the variables that exist in Earth’s atmosphere; temperature, air pressure, water vapor, and the gradients and interactions of each variable, and how they change in time. Our research is limited to phenomena described by micro-, meso- and synoptic scale meteorology, as described in Table 1. It is important to note that the minimum horizontal scale of synoptic meteorology is limited to the spacing between surface observation stations, whose primary function is to collect meteorological data.

<table>
<thead>
<tr>
<th>Microscale meteorology</th>
<th>Study of phenomena that have horizontal scales of about 1 km or less.</th>
<th>Events last from minutes to a few hours, such as individual thunderstorms, clouds, and local turbulence caused by obstacles, including buildings and local terrain.</th>
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<tbody>
<tr>
<td>Mesoscale meteorology</td>
<td>Study of phenomena that have horizontal scales ranging from microscale limits to synoptic scale limits.</td>
<td>Events last from less than a day to the lifetime of the event, which in some cases can be weeks, and include thunderstorms, squall lines, fronts, precipitation bands in tropical and extratropical cyclones and topographically generated weather systems (e.g. mountain waves and sea and land breezes).</td>
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<tr>
<td>Synoptic scale meteorology</td>
<td>Study of phenomena that have a horizontal scale of about 1000 kilometres (620 miles) or more.</td>
<td>Events typically last for several days and sometimes weeks, including extratropical cyclones, baroclinic troughs and ridges, frontal zones and to some extent jet streams, all of which are usually shown on weather maps for the lifetime of the event.</td>
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**Characterisation** is broadly defined as the act of describing distinctive characteristics or essential features. For example; in the arts it may refer to depiction of a character in a narrative or dramatic work of art; in mathematics, a concept to describe the traits exhibited by parameters or functions under certain conditions; in materials science, an external technique used to probe into the internal structure and properties of a material; and in bacteriology, it may be a laboratory technique used to identify a bacterial species, study its features, strain properties and systematically name it according to convention.

We consider that, in the climate and meteorological context, ‘synoptic’ in ‘synoptic characterisation’ highlights the use of synoptic data in studies of meteorological phenomena, not just to studies of those phenomena described by synoptic scale meteorology. Therefore, we define **Synoptic characterisation (meteorological)** as a technique that uses synoptic data to identify and study the distinctive traits and essential dynamic features, such as behavioral characteristics and trends, of atmospheric variables associated with meteorological phenomena.

3. REVIEW OF CHARACTERISATION METHODOLOGIES

An initial review was conducted to identify studies that have used either ‘atmospheric synoptic characterisation’, ‘atmospheric characterisation’, ‘climate characterisation’, ‘environmental characterisation’, ‘synoptic characterisation’ or ‘meteorological characterisation’ as a methodology. These terms are variations of characterisation that could potentially be used synonymously within our definition of ‘synoptic characterisation’, and therefore include applications that have potential for adaption as a short-to-medium term climate analytical and forecasting tool.

The review revealed that ‘atmospheric synoptic characterisation’ is not in use, suggesting ‘atmospheric’ is redundant when referring to ‘synoptic characterisation’ in the meteorological context. The review also revealed that ‘atmospheric characterisation’ is used almost exclusively in the field of Earth and Planetary Astrophysics research, which does not use synoptic data and therefore is not relevant to our studies (UCL, 2010).

‘Climate characterisation’ has been applied in research areas ranging from soil quality, hydrology and oceanography to solar radiation and exoplanets, as well as covering all spatial scales, climatology and astrophysics. That this method has been used with climate data to analyse and forecast medium to long term climate trends in land and water resource scenarios reinforces our view that characterisation using synoptic data can be similarly applied to analyse and forecast short-to-medium term climate trends. The CSIRO report to the Australian Government for the Northern Australian Sustainable Yields Project (Li LT et al, 2009) is particularly relevant. This and associated projects for Tasmania and south-west Western Australia were established to estimate the impacts of catchment development, changing groundwater extraction, climate variability and anticipated climate change on water resources at a whole-of-region scale. The CSIRO report describes the climate data for the three climate scenarios (historical, recent and future climate) used for the hydrological modelling, and documents the data sources and methods used to develop the scenarios. Importantly, the report also provides key climate characteristics of the three scenarios that enable water resource managers to better understand the current and projected climate of the systems they manage.

‘Environmental characterisation’ is being primarily applied in subject areas that involve environmental impact studies, assessments and frameworks. However, some studies in climate and meteorological fields claim to have used ‘environmental characterisation’, indicating that ‘environmental characterisation’ is being used synonymously with either ‘climate’, ‘meteorological’ and ‘synoptic’ characterisation’. One study that is particularly
relevant to our research is the use of ‘environmental characterisation’ methodologies to aid crop improvements in drought-prone environments (Chenu, K, et al, 2010). That study applied crop models to characterise the drought patterns encountered by wheat, in the north-eastern region of Australia where crops experience particularly large spatial and temporal variability in seasonal water availability, given contrasting soil types, crop management systems, and highly variable inter-annual rainfall.

‘Meteorological characterisation’ has been used with climate and synoptic data to study phenomena occurring either on the microscale, mescoscale or, to a lesser extent, the synoptic scale, indicating that ‘meteorological characterisation’, in so far that it has been applied, is synonymous with our definition of ‘synoptic characterisation’ However, its application has so far been very limited, the two main European research programs being analysis of the synoptic and local meteorological conditions during the ground-based cloud passage experiment FEBUKO performed at the Schmücke Mountain, Thüringer Wald, Germany during October 2001 and 2002 (Tilgner et al, 2005), and the “synoptic and meteorological characterisation” of olive pollen transport in Córdoba province, south-western Spain (Hernández-Ceballos et al, 2011). In some cases, hybrid terminology has been used to describe the area of interest to which ‘meteorological characterisation’ has been applied, such as ‘land surface hydro-meteorological characterisation’ (McCabe et al, 2004), and ‘agro-meteorological characterisation’ (Sahel Resources, 2006).

Finally, the review focused directly on the application of ‘synoptic characterisation’. Apart from the FEBUKO hill cap cloud experiments mentioned above, the review revealed several studies linking ‘climate’, ‘climatology’ or ‘climatological’ with ‘synoptic’ characterisation, the main one being the “climatological and synoptic characterisation” of the 2009-2010 Romanian winter (Mircov et al, 2011). The other major research claiming to use this methodology is the “synoptic characterisation of thunderstorms” in Cracow in the period 1896-1995 (Bielec, 2000).

Overall, the review indicates that characterisation methodologies have to date not been widely used to study meteorological phenomena; with few exceptions, most have been European applications. Where they have been successfully applied for this purpose, climate data rather than synoptic data has been used and the focus has been more on analysing the medium-to-long term trends rather than the short-to-medium term climate variability. However, the review has revealed studies that support our view that ‘synoptic characterisation’ – as we have defined it – is a methodology that can be has potentially adapted as a short-to-medium term climate analysis and forecasting tool.

4. CLIMATE DIVERGENCE AND RAINFALL DELIVERY

It is now widely accepted that global climate change is having an increasing dramatic impact on water, energy and food security. Establishing a connection between climate divergence and rainfall delivery variability associated with extreme events (wet and dry) will enable us to gain an improved understanding of the potential impacts of climate variability on essential human activities – such as broadacre farming – via the rainfall delivery mechanism. Hence, development of an effective climate analytical tool for understanding these events and their transitional behaviors is of prime importance, recognising that climate variability may have both primary and secondary drivers.

Information gained through the synoptic characterisation of regional climate, in conjunction with other data gathering activities, can enhance the basis for studies that provide a large portion of the data required for evaluating and validating numerical regional and global scale climate models. Information from these studies indirectly assists in the evaluation of the impacts due to potential future climate changes on the regional
hydrologic system (USGS, 1992). Historical synoptic data shows that recent climate variability displays greater divergence from the long term trend, suggesting that short-to-medium term climate variability can be analysed using the synoptic characteristics of the delivery mechanism rather than the occurrence of extreme events (Coles & Hall, 2012).

We define this characteristic of climate change, being the divergent trend of short-to-medium term variability of atmospheric parameters from the long term trends, as “climate divergence”. Importantly, therefore, if we are to understand the variation in rainfall delivery and water availability associated with climate change and its potential impact on natural resources and reliant human activities – such as soil and agriculture – then we must consider defining the climate divergence from long term trends (both historical and future forecasts), rather than the long term trends themselves. This position is illustrated in Figure 1, which shows conceptually recent rainfall delivery variability from the historical pattern, together with an example of 2012 rainfall statistics compared to the long term mean for a sample station in our research area.

![Figure 1. Rainfall delivery variability from historical long term trend. For example, Pemberton WA: chart of 2012 rainfall against long term mean (1941-2013) (Australian Bureau of Meteorology, 2013).](image)

The main objectives of the research we are undertaking now are twofold: firstly, to establish a connection between climate divergence and rainfall delivery variability using synoptic characterisation methodologies; and secondly, to develop an effective and transportable analytical and risk assessment/forecasting tool that will be an integral part of a decision support toolkit to inform investment, adaptation, resource condition assessment, and land and water management.

Our research is focused on two broadacre farming areas as case studies; the dryland and irrigated agricultural sub-regions of southwestern Australia (SWA) and a comparable region in North America. The SWA case study is being used to establish the connection between climate divergence and rainfall variability and then to develop the climate analytical and forecasting tool. The North American case study will then be used to demonstrate that synoptic characterisation can be applied globally to understand and assess the risks associated with the potential impacts of short-to-medium term rainfall variability at a given location where adequate synoptic data is available. These case studies will also provide the basis for tool validation as selected representative areas at risk of typical and extreme responses to climate change.

In addition, sensor technologies are being developed to compliment the climate analytical and forecasting tool, which will provide input into the dynamics model that can estimate
the likely losses and redistributions of nutrients, and therefore the resilience of the system in response to change. This poses an alternative view of resilience, that is: “a system's ability to absorb disturbances and reorganise itself into a better configuration, whilst retaining its fundamental characteristics” (Walker et al., 2004). By adopting this view we start to see the application of dynamic modelling in a catchment, ecosystem and global context (Coles & Hall, 2012), such as in the earlier CSIRO example (Li LT et al., 2009).

5. CONCLUSION

Applying ‘nexus’ thinking to issues surrounding water, energy, and food security will ultimately encourage the development of improved land and water quality management plans and small and large-scale decision support systems which will provide greatly-increased levels of confidence in predicting water quality under changing climate scenarios. However, this requires the development of new tools and technologies to allow us to make the necessary water and contaminant flux measurements more representative and cost-effective than has so far been the case.

Unfavorable climatic conditions and the degradation of natural resources are the main constraints affecting agricultural productivity (Sahel Resources, 2006). Therefore, an improved understanding of rainfall inputs and the interactions between surface, and subsurface runoff and the re-distribution of nutrient and contaminants will be a significant step forward. By assessing delivery and transport mechanisms greater understanding of the dynamics of catchment systems can be gained, and therefore of the ecosystem goods and services provided. If landscape response times and flux changes in transportation are captured by new and innovative technologies (Coles & Hall, 2012), then they can be linked with synoptic characterisation models to provide an effective climate analysis and forecasting tool that land and water managers can use for identifying and analysing the risk and forecasting the potential impact of short-to-medium term rainfall variability, and hence for better land and water management outcomes to be achieved – this outcome is the primary goal of our research.

An initial review of characterisation methodologies applied in the meteorological context indicates that synoptic characterisation – as discussed and defined herein – can be used to assist us establish a connection between climate divergence and rainfall delivery variability, and thus be adapted as an effective short-to-medium term climate analytical and forecasting tool. The development of such a tool, together with better monitoring technologies and data collection options will provide a framework for better decision making and risk management. This is at the heart of the nexus approach to managing the dynamic nature of inter-related goals and resources, the basic understanding that decisions in one sector will affect another. Without this type of holistic approach, providing secure sustainable access to water and food, while addressing our energy needs, will not be achievable.

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