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Re-imagining standard timescales in forecasting precipitation events for Queensland's grazing enterprises

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Abstract: The typical presentation of precipitation and climate information is organised according to the Gregorian calendar defined by the months and, in alignment with the temperate, savanna and desert climate zones of Australia, the three monthly seasons. While this is sufficient for many human-centred operations and the currency acceptable norm, grazing land managers (and potentially workers in other agricultural based enterprises) are reportedly restricted in their use of precipitation and climate information presented in this form. Compounding this issue with standard temporal packaging of climate information is the lack of reliability of the forecasts and spatial resolution capacity in the existing precipitation prediction tools that are being promoted to the graziers. Due to a lack of temporally and spatially robust information, graziers are managing their operations in the presence of significant risks, threatening their contributions to Australia's $17 billion red meat and other industries.

Grazing land managers require access to near real-time drought data that will enable the timely and informed decisions to be made about the movement of stock from the cattle stations to the grazing and/or growing properties. Providing graziers with this information having appropriate temporal resolution of the drought status for specific locations will enable the most productive use of the available grazing lands to grow the cattle to specified weights before slaughter. Hence a novel forecasting approach using data driven models of the monthly rainfall decile drought index (RDDI) is being considered in this paper, where the calculation of relative monthly indices are updated on a running weekly basis, providing land managers with spatially and temporally refined information. A similar process is proposed for the determination of relative seasonal rainfall indices, in addition to the consideration of the alternative definitions of Australian seasons as identified in existing literature.

In future development of this research work, this approach will be used to forecast precipitation patterns, where the machine learning models' architecture will be trained and evaluated with historical records of precipitation and other significant climate variables from a selection of sites relevant to the cattle industry around Queensland, Australia. The forecasts are to be derived from the novel implementation of a data intensive hierarchical categorizing support vector machine framework (or alternatively a regression-based data-intelligent model) which is being proposed to deliver the graziers with the appropriate information to plan their operations within the stochastic nature of Australia's climate.

When compared with the seasonal and calendar monthly deciles, the more frequent forecast feeds (i.e., over weekly updated drought status, yet utilizing the concept of decile-based drought) presents a more detailed and robustly reported distribution of rain over the future seasons at specific sites, whilst catering to the graziers' reported decision making processes. The more temporally refined presentation of the predicted rainfall events, for specified sites, has the potential to provide graziers (and other agricultural ventures), with the most relevant information to allow for more confident and profitable management of their enterprises.

***Keywords**:* *Timescale, drought, deciles, month, season*

1. INTRODUCTION

Meteorological drought indices are commonly determined over monthly, seasonal and annual timescales. Gibbs (1967) proposed the monthly and alternatively, the annual rainfall decile drought index (RDDI) which is determined using the Gregorian calendar months based on the lunar cycle. This system has been adopted by the Drought Watch Service of the Australian Bureau of Meteorology in monitoring the drought status (Lee, 1979) and providing information for drought relief systems. However, if the working timescale is not appropriate for the end users, or is maligned with the underlying environmental behaviours, then any application of the drought-status data may potentially be ineffective. Hence, drought and precipitation information may need to be reconfigured in an alternative form to meet the end-user requirements.

Pulwarty et al. (2009) reported some degree of the critiques over the forecast timescales based on a set of surveys of rural land managers. The feedback received indicated that the seasonal forecasts do not detail the distribution of precipitation events over a shorter-timescale, and in fact, the acceptable form of monthly timescales (based on the Gregorian calendar) are too general and stochastic. Likewise, the 10 day and daily drought-status data both are able to provide rainfall distributions, but not with the information about specific precipitation events. The timeframe over which the effects of cumulative rainfall is considered depends upon the specific context. For agricultural applications, accumulation of precipitation at shorter time-intervals is useful, such as weekly rainfall distributions (for paddy rice and cotton: Nidumolu et al. (2015)) and fourteen day rainfall distributions (for sugar: (Kingston, 1976)). In the case of seasonal characterization of precipitation patterns, 20 week intervals have been considered (Kingston, 1976) and provided a summary of rainfall data for the crop span (a 72 week period in total, consisting of 20 week intervals which starts day 1 of each of the 52 weeks in the year). Hudson (1972) cited in Klemm et al. (2017) reports that the farm management decisions, such as decisions related to water resources management based on the predictions of non-moisture stressed days, require five weeks of forecast lead times. In short, the current presentation of the rainfall information is incompatible with the needs of the agricultural land enterprises.

The 12-month Gregorian calendar is a social construct and is thus, not a driving influence in the natural environment. Representing the dynamic, stochastic climate on these static human-centric frameworks may potentially result in the misrepresentation or poor capturing of true environmental characteristics. O'Brien (2016) and Entwisle (2015) have both proposed the rethinking of the designation of seasons based on the Gregorian calendar in Australia, which lies in favour of the identified behavioural patterns of native fauna and flora that are interpreted as signs of seasonal changes in climate. The Australian Indigenous communities have long had their own survival in rural conditions relying on their ability to monitor climatic and related signals from the natural habitat. The partnership between the Australian Bureau of Meteorology and the Australian Indigenous communities, Indigenous Weather Knowledge Project, is aiming to preserve and promote knowledge of the endemic seasons of Australian regions (Ryan, 2013). These re-imagining of the time frames are thought provoking and important, but are yet to have been established prominently in rainfall modelling, simulation and agricultural decision-making processes.

Additional issues associated with the use of the calendar monthly deciles values involve the calendar biases itself, inflicted due to the inconsistency in the number of values used from month to month when basing the calculations on the calendar months, and also the consideration of the extra day in February (29 February) in each leap year (Svoma et al., 2012; Vinnikov et al., 2002). Another disadvantage to the rigid classification of monthly estimates is that there is no facility to investigate the nature of any extreme events that occur between segregated calendar months.

Considering the aforementioned issues and in light of the present discussion, an opportunity exists where a novel fusion of the existing timescales for drought-status detection and attribution may provide precipitation information at an appropriate level of temporal resolution. In this research paper, we propose to consider an iteratively equivalent of the monthly, or seasonal data on a weekly time-step resolution. Determining the precipitation status relative to each weekly time step and updated regularly through an automated drought modelling system, rather than absolutely through monthly of seasonal brackets, will provide at least 52 or 53 drought-status samples annually, and will aim to capture a more detailed distribution of rainfall over the course of a year.

The aim of this research paper is as follows. (1) Using the existing concept of drought assessment by means of the decile threshold, to develop a new measure and to evaluate the rainfall-decile drought index (RDDI) for a moving 12-week window, allowing one to monitor the behaviour of seasonal RDDI at weekly resolutions. (2) To evaluate the newly formulated RDDI for a moving 4-week window to monitor more closely the behaviour of the monthly RDDI at weekly resolutions in order to validate the proposed approach. (3) To compare the performance of the moving window methodology introduced for drought-risk assessment with the typical presentation of the seasonal and the monthly RDDI.

2. MATERIALS AND METHODS

1.1. Data

In this paper, the Scientific Information for Land Owners, SILO (Jeffrey et al. 2001), which is a database of daily time series of meteorological observation (temperature extrema, precipitation, evaporation, vapour pressure and relative humidity at temperature extrema), is utilized. SILO data are available for 4600 point locations across the whole of Australia. This database is hosted by the Queensland Government Department of Science, Information Technology and Innovation (DSITI) and BOM. For this analysis of drought status in this research, precipitation data from 1970-current period are being considered for a selection of stations, nominated for this study based on their association to cattle industry as well as representing a variety of climatic zones.

Table 1. Stations selected for analysis from SILO

Station No	Latitude	Longitude	Name: Climatic Zone (defined by Bureau of Meteorology)
32037	-17.6053	145.9972	South Johnstone Exp Station: High humidity summer, warm winter
40436	-27.5456	152.3289	Gatton QDPI Research Station: Warm humid summer, mild winter
43091	-26.5474	148.7716	Roma Airport: Hot dry summer, warm winter

1.2. Rainfall drought decile index (RDDI)

The severity of drought is characterised by the rainfall deciles drought index (RDDI). RDDI standardises the precipitation behaviour for each geographic context by comparing the precipitation observations with those from a baseline period, and can be applied to a variety of timescales, including month and season.

The deciles are calculated by comparing the precipitation totals for a nominated timescale (month/season) with the historical month/season climatological records, as developed by Gibbs (1967).

A baseline data set is calculated from historical precipitation observations, typically grouped according to months or seasons. The baseline reference period, used as the nominated normal annual cycle in climate index calculation for Australia varies across the literature, with 1971-2000 (Deo et al., 2009) and 1970-2004 (Mpelasoka et al., 2008) used. Consistent with the findings by Smith et al. (2008), 1971-2000 is a commonly used reference period for climatic indices in Australia, and hence will be used in these calculations. The summed sets are organised into deciles, and the values of monthly/seasonal summed precipitation corresponding to the different deciles are recorded. Precipitation data to be converted into decile representations are accumulated as monthly or seasonally summed sets and compared to the baseline data set corresponding to the timescale.

A region is considered drought affected (Kininmonth et al., 2000) if the precipitation total < 10% (first decile) of historical quarter totals taken from 1971-2000. Drought can be further classified as either serious (5%-10%) or severe (0%-5%). In Australia, government drought assistance may be sought when drought conditions corresponding to deciles 1 or 2 persist for longer than 12 months (White et al., 1995).

Drought conditions are considered eased when either:

1. The current month's precipitation total is equivalent to, or greater than, the historical quarter's fourth decile (>30%).
2. The current quarter total >70% (eighth decile) of historical quarters' values.

Due to their importance in ascertaining the drought status of a region, these thresholds will form the basis of the graphical representations of the RDDI.

1.3. Time Unit System

This study advances the notion that a consistent week numbering system is required to facilitate the moving window methodology to achieve the week resolution of the calculation for monthly/seasonal RDDI. The ISO (1988) time and date system ISO8601:1988 is used throughout government and business for timekeeping, and has a week numbering system which may be suitable for the purposes of managing the weekly sampling of precipitation information. Furthermore, many software packages support the conversion of date-time information to the ISO format through inbuilt functions. Hence, it is proposed the ISO8601:1988 weekly numbering system be used for sampling the high resolution temporal information.

According to the ISO8601:1988 standard, the first week starts on Monday and contains the first Thursday in January. Hence, the full ISO year is generally 52-weeks long, with 53-week years occurring every five or six years. Where necessary, a decile table will be compiled for each, to be calculated and applied to the calculation of monthly deciles needing to differentiate between the 52-week and 53-week years.

In order to accommodate the decile calculation across the 53-week years, we propose that the 52-week years will borrow the first week of the next year to act as the 53rd-week. The decile calculation for 52-week years will thus morph the 53-week year by using weeks 2-53 as the proxy for the weeks 1-52. These strategies has been represented in Figure 1.

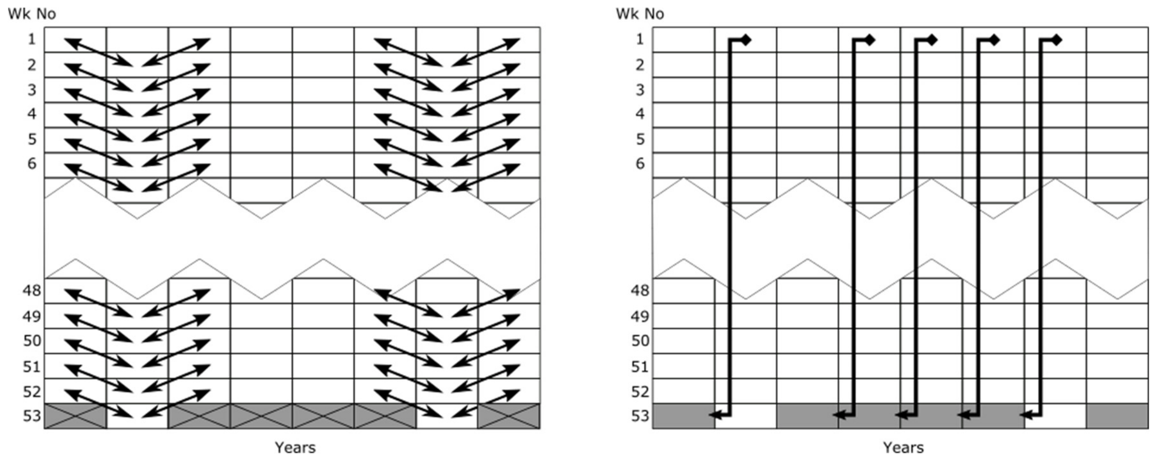

Figure 1. Visualization of the data manipulations used for consistent decile calculations for (a) 52- and (b) 53-week years.

1.4. Standard Timescales

Typically, the data used for the monthly calculation of the RDDI is determined based on the defined months of the Gregorian calendar month system where an annual cycle contains the months of January-December. The seasons' boundaries are associated with the Earth's relative proximity to the sun throughout the year and aligned to the Gregorian calendar month system. Critical features of the Earth's trajectory about the Sun directly correspond to the transition between widely recognised seasons. In the Southern Hemisphere, these features are recognised as the Summer Solstice, Autumnal Equinox, Winter Solstice and Vernal Equinox which mark the initial stages of Summer (December, January, February), Autumn (March, April, May), Winter (June, July, August), Spring (September, October, November) respectively.

1.5. Moving 12-Week and 4-Week Window Timescales

Based on the Gregorian calendar, months are typically four weeks, with the occasional month having five weeks. Using the four season model to describe climatic behaviour trends, each season contains three months, and approximately four weeks in each month. Accordingly, seasons generally extend approximately 12 weeks. Using the ISO calendar standard, the moving window calculation of the immediate equivalent seasonal 12-week decile are determined on day 7 of each week considered. The 12-week season, and 4-week month are used to approximately track the behaviour of these timescales throughout the year to a high weekly resolution.

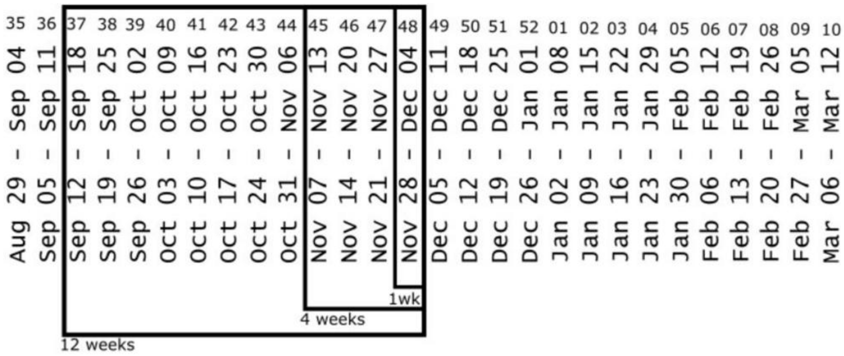

Figure 2. Moving 12-week, 4-week and 1-week windows for the start of 2016 Summer, with ISO week numbers provided along the top row. The corresponding RDDI heatmaps are shown in below diagrams.

1.6. Data Formatting and Presentation

The seasonal and monthly time series calculated using the traditionally defined Gregorian calendar segmentations were resampled to the weekly timescale to be consistent with the resolution of the proposed moving window ISO seasonal, monthly and weekly rainfall indices. Furthermore, the traditionally calculated seasonal and monthly rainfall values, which capture a static snapshot of rainfall behaviour at the later boundaries of Gregorian calendar defined structures, are rescaled from discrete data points to continuous blocks extending the length of the corresponding timeframes. This interpretation is consistent with the usage of these indices in climate, hydrological and agricultural application.

3. RESULTS

Here, we show the heat maps that are organised with the RDDI time-series of the calendar defined months and corresponding seasons alongside the moving window counterparts, with the two methodologies' visualisations separated by a dotted line. The calendar defined index time frames are examples of what is reported to the general community. The remaining time-series presented is that for the weekly precipitation deciles, included to provide contextual information about the precipitation events which drive the changes in the monthly and seasonal decile indices.

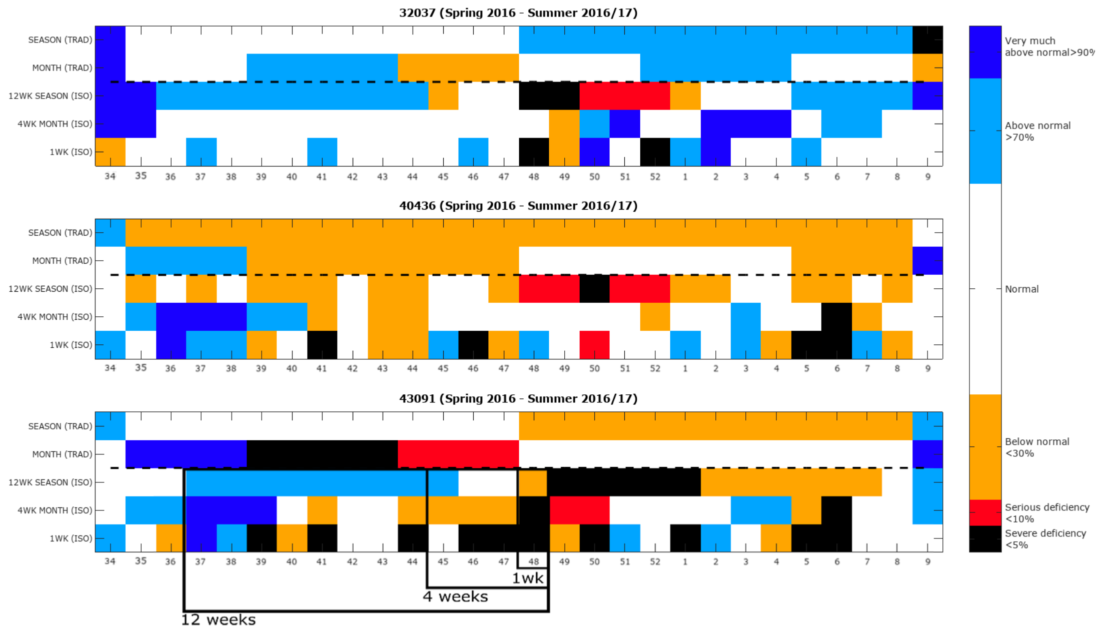

Figure 3. Heatmaps demonstrating calculated values of RDDI at the nominated stations for Spring 2016 and Summer 2016/17 using the calendar seasons, SEASON (TRAD), and calendar months, MONTH(TRAD). These are to be compared against the calculation of equivalent ISO 12-week seasons, ISO 4-week months.

Weekly totals provide a real time update of the precipitation status determining the changes in the ISO 12-week and ISO 4-week RDDI values.

Figure 4 demonstrates the progression of the RDDI drought status of a significant precipitation deficit event such as the Millennium Drought (Dijk et al., 2013) in terms of the typically calculated calendar based seasonal and monthly RDDI, and also the moving window 12-week and 4-week methodology.

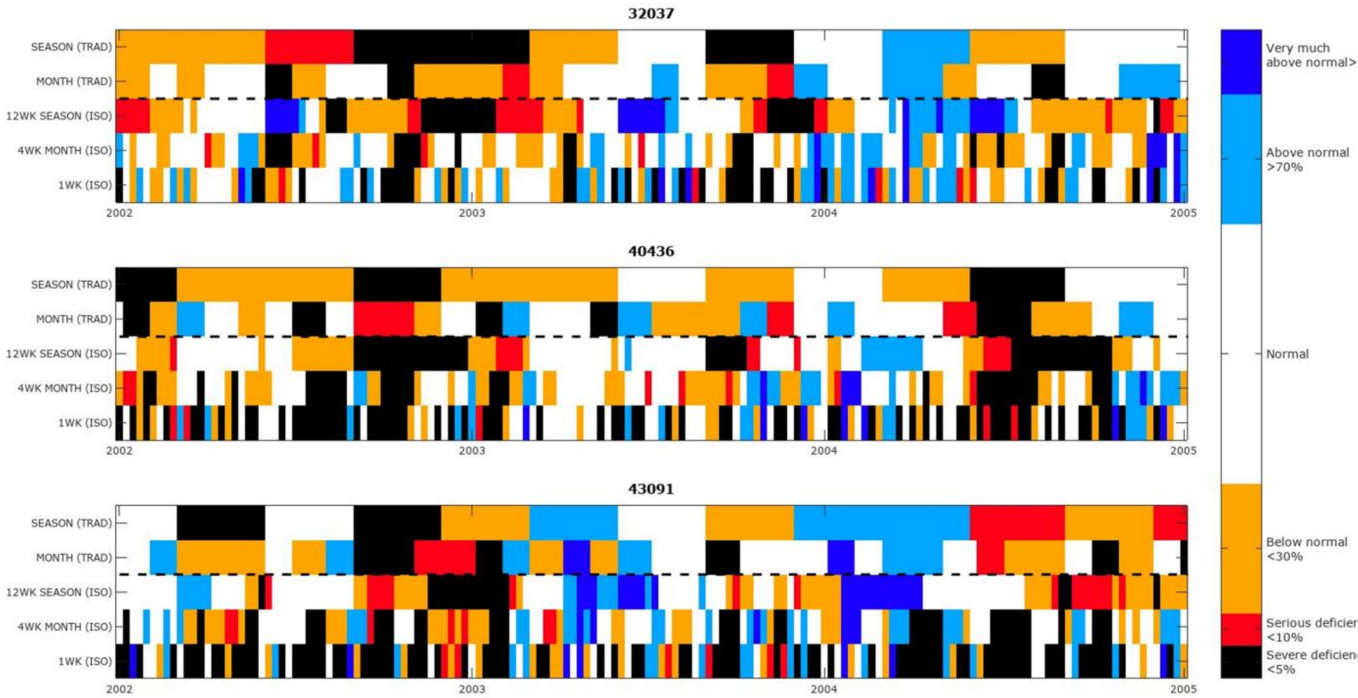

Figure 4. Rainfall Decile Drought Index values over the Millennium drought

4. DISCUSSION AND CONCLUDING REMARKS

Inspecting the heat maps of the RDDI in Figure 3 for the designated stations demonstrates the static nature of the traditionally calculated calendar seasons and months. For each, the RDDI is calculated at the later end of the corresponding season or month, and this single value is used to inform the consumers of the drought status for the entire timeframe. In contrast, the moving window approach however provides information about the behaviour of the seasonal outlook within and between defined calendar seasons. The same observations may be made about the comparisons between the traditional calendar monthly RDDI and the moving window ISO calendar monthly indices. As such, the limitation of using an index calculated at a single point of time to represent and generalise the nature of the entire season or month is highlighted. The moving window calculation of the deciles for equivalent 12-week seasons and 4-week months clearly mark the timing (according to week number) and cumulative magnitude of the precipitation events throughout the timeframes.

The tuple created by reporting the ISO calendar 12 week, ISO calendar 4 week and ISO calendar 1 week RDDI values dynamically on a weekly basis records the long-term, medium term and short term rainfall behaviour across the entire year. The coupling of these values provide a dynamic and conveniently packaged form of summative statistics.

The use of the ISO tuple, that may also be extended beyond reporting on historical events to integration into forecast machine learning models. The predictive summary information provided by the trio of ISO calculated RDDI values presents a fusion of long term, medium term and short term drought status information which is envisaged to provide a more comprehensive and responsive representation of future precipitation and drought. The availability of such information has the potential to detect drought sooner, and when integrated into forecast models may present land managers with information that can allow them to make long term and medium term decisions based on weekly updated information.

The weekly-based drought monitoring system proposed in this study is likely to provide a more continuous, yet detailed information about the drought status over a much shorter-timescale (moving weeks) than currently available by the decile drought index system. Given that the proposed system is in its infancy stage of development, future studies will concentrate on analysis of the method over several drought-prone regions (for drought detection, attribution, and modelling). Since the present weekly-based system is expected to be much more non-discretized and will provide continues updates with weighted numerical information over moving weeks, the utilization of the method for drought modelling offers a viable future study that will follow this initial system development research.

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