Mapping the first summer rains in the Northern Agricultural Region of Western Australia

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Abstract
Perennial pastures are being investigated as alternate farming systems for the fragile soils of the Northern Agricultural Region (NAR) of Western Australia. We plan to use satellite imagery to map the location and extent of these perennial pastures to assess the success of their adoption by farmers. Pastures, crops and native vegetation senesce at different rates and this change in greenness can be mapped from satellite imagery. The starting point for mapping this change is the first vegetative flush after summer rains, therefore the time, location and extent of the summer rains must also be mapped. This paper investigates mapping summer rains from daily climate data surfaces (SILO). These data are widely available for Australia but are a challenge to query and manipulate as there are few generic tools for this purpose. Here we combine Climate Data Operator tools and GIS functionality to generate maps of the first summer rains in the NAR from 2001 to 2010.

Key Words
GIS, Climate Data Operators, Spatio-temporal climate data

Introduction
Perennial pastures are being evaluated across the Northern Agricultural Region (NAR) as an alternate pasture for the region's fragile soils (Ward et al. 2012). Subtropical perennial grasses can stabilise sandy soils, make use of the out of season summer rains and potentially fill the region's autumn feed gap (Finlayson et al. 2012; Ward et al. 2012). Mapping perennial pastures is an important measure of their adoption by NAR farmers. The expansion of these pastures across the NAR is of interest to Evercrop, a Future Farm Industries CRC project and the current extent maybe indicative of potential future sites. We plan to map perennial pastures (2001 to 2010) from satellite images by tracking their senescence over successive images starting from their first green flush 4 to 6 weeks after the summer rains. To do this it was essential to first map the time, location and extent of the NAR's summer rains, defined in this study as rains between 1st January and 31st May. Satellite images are costly so deciding the image dates most likely to show the first green flush was important to reduce research costs. We hypothesised that summer rain events can be mapped from spatio-temporal climate data.

Widely available spatio-temporal climate data, SILO (Jeffrey et al. 2001), are suitable for mapping summer rainfall events in the Northern Agricultural Region (NAR) of Western Australia. The NAR has a Mediterranean climate of wet winters and dry summers. Rain events greater than 20 mm can trigger sufficient growth in perennial pastures (Moore et al. 2006) to ensure they can be mapped from Landsat satellite imagery four to six weeks later (Lawes and Wallace 2008). The mapping of these summer rain events is a precursor to mapping perennial pastures over the 10 year period 2001 to 2010.

This study integrates SILO, GIS, Python and Climate Data Operators (CDO; Schulzweida et al. 2012) to map the NAR's first summer rains defined here as a total rainfall of 20 mm or more over a 3 day period (Moore et al. 2006).

Methods
Study Area
The area of interest for this study was defined by the two adjacent Landsat scene boundaries (dashed line in Figure 1) that cover the majority of the NAR (Figure 1). Landsat satellites recorded images along an approximately north-south path and covered the same area every 14 days. Scenes that were adjacent along the north-south path were consecutive in time and images from the same day were used if the start date for the summer rain in the northern and southern scenes were the same. A rectangle that completely contained the total extent of the two Landsat scenes (shaded area in Figure 1) was set as the study area.

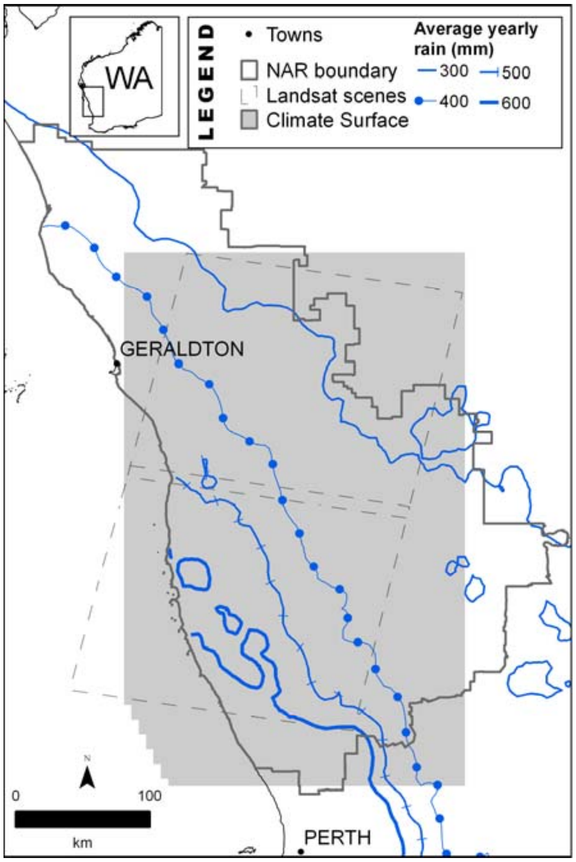

Figure 1. Map showing study area in relation to NAR boundary, Landsat scenes and annual rainfall isohyets.

Climate Data
The Queensland Climate Change Centre of Excellence (QCCCE) interpolate data from Bureau of Meteorology (BOM) rainfall and weather stations across Australia into daily rainfall surfaces (SILO; (Jeffrey et al. 2001). The SILO interpolated rainfall surfaces were collated into a single array orientated file and queried using CDO tools in a similar approach to that used by Nidumolu et al. (2010).

CDO tools were used to clip the SILO surfaces to the study site (shaded area in Figure 1), extract daily rainfall for January to May, 2001 to 2010 (Nidumolu et al. 2010) and to calculate the rolling total rainfall over 3 day time steps.

Mapping Rainfall Events
The rolling total over 3 days is the sum of rainfall from day 1 to 3, then day 2 to 4 and so-forth. The date assigned to the rolling total was the middle day's date. Each total was stored as a new layer in the resulting array file and Python (Python Software Foundation 2012), a scripting language, was used to access GIS tools to convert the 3-day rainfall layers into files suitable for use within the GIS ArcMap.

Each 3-day cumulative rainfall dataset was used to create a unique GIS layer. Each layer was queried and cells with ≥ 20 mm rainfall were assigned the corresponding date value. All layers for a single year were combined and the minimum date value for each cell was calculated so representing the earliest date when more than 20 mm of rain fell over a 3 day period, the first summer rains. This process was repeated for each year from 2001 to 2010 resulting in yearly maps depicting the first summer rains between January and May (Figure 3). Rainfall events were spatially discrete ensuring no overlap.

The first summer rainfall maps for 2001 to 2010 were coloured on identical red-blue graduating palettes to make comparison across years easier (i.e. red for January and blue for May).

Image Selection
Satellite images for mapping perennial pastures were selected based on the date between 4 and 6 weeks after the summer rain event. If a single summer rain event did not cover the majority of the NAR, the 2 scenes (Figure 1) were viewed independently. The rain event covering the majority of a scene was used to choose the subsequent satellite image date. In years with little rain the earliest event with the greatest extent was used to select the image dates for the entire area.

Results
The area covered by each year's first summer rainfall event was calculated as a percentage of the total study area (Figure 2). These data were grouped and their percentages summed for rainfall events over consecutive days. In all years the majority of the first summer rains occurred over 3 to 5 days and in most years this was a single event that covered the majority of the study area (Figure 2). In 2004 and 2006 these single events covered 74% of the study area but in both 2001 and 2003 there were 2 initial summer rainfall events of almost equal extent and duration (Figure 2). Summer rains over 5 and 7 days were also mapped and compared with the 3-day maps. Little visual difference was detected so the 3-day maps were used for analysis.

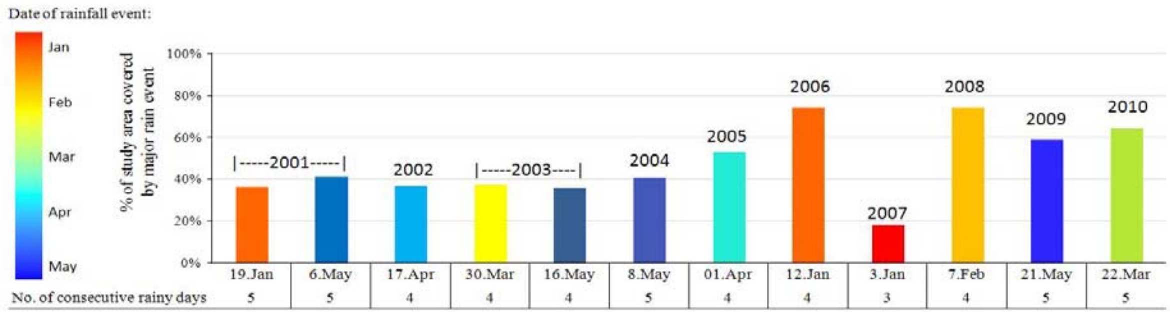

Figure 2: Percentage of NAR study area covered by major rain events, 2001 to 2010

The extent and timing of the summer rains differed for each year (Figure 2 and 3). The 400 mm rain isohyet (line with dots Figure 3) defined the boundary of the medium and the low-medium rainfall zone (250-400 mm), with the low-medium rainfall zone being north east of the line, and the medium rainfall zone, south west of the line. In 2001, 2002, 2004 and 2007 there was a clear visual difference in first rain dates either side of this line (Figure 3). In 2001, 2002 and 2007 the earliest summer rains came in January in the medium to low rainfall zone and in April-May in the medium zone.

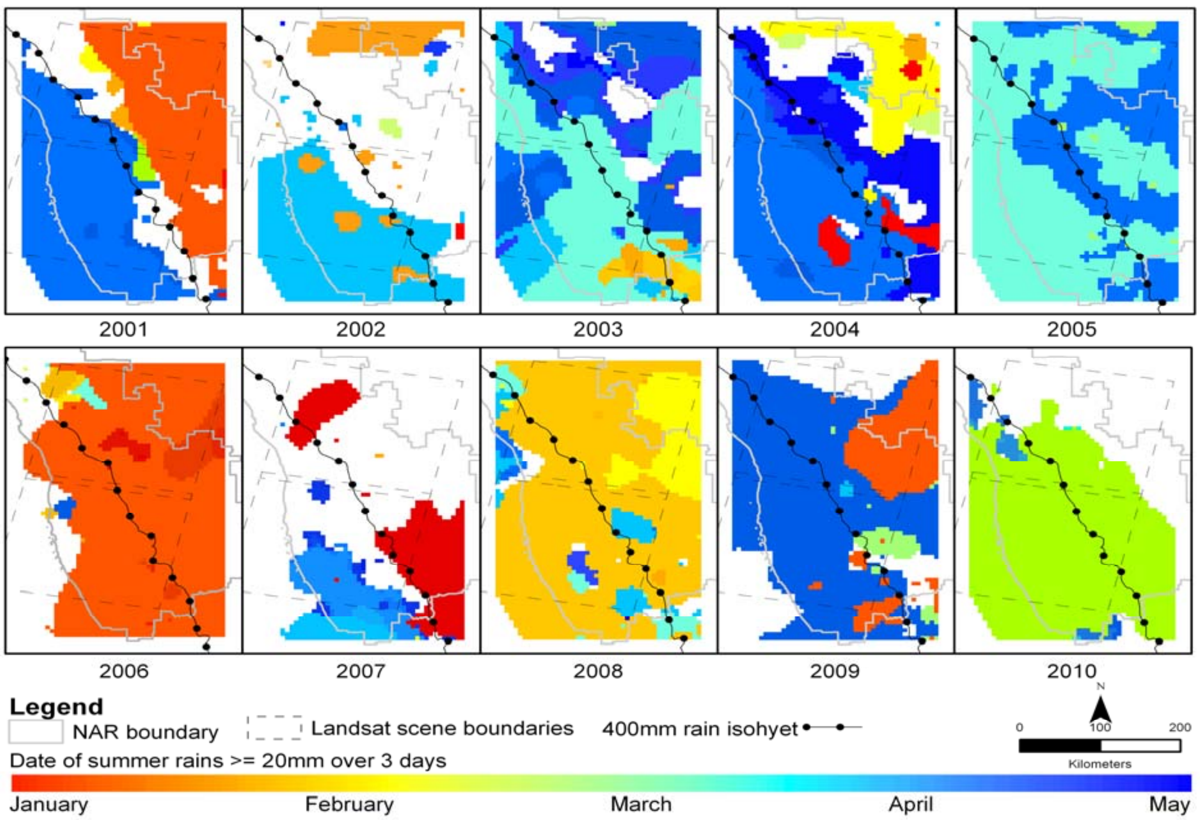

Figure 3. Maps showing the time of the first summer rains ≥ 20 mm over a 3 day period between January 1st and May 31st for the years 2001 to 2010.

The summer rain dates in Table 1 were derived from Figure 3. Satellite images 4 to 6 weeks after these dates were selected to map perennials from 2001 to 2010 as they were most likely to show the green flush caused by the first rains.

Discussion

The methods employed here allowed SILO interpolated climate data to be used to map the first summer rains in the NAR from 2001 to 2010. The maps in Figure 3 show the time, location and extent of the first summer rains and can be used to select the Landsat scenes needed to map perennial pastures.

Table 1. Date of first summer rain event within each NAR Landsat scene, 2001 to 2010

<table>
<tr><th>Year</th><th>Landsat – North</th><th>Landsat – South</th><th>Year</th><th>Landsat – North</th><th>Landsat – South</th></tr>
<tr><td>2001</td><td>19th Jan</td><td>6th May</td><td>2006</td><td colspan="2">12th Jan</td></tr>
<tr><td>2002</td><td colspan="2">17th Apr</td><td>2007</td><td colspan="2">3rd Jan</td></tr>
<tr><td>2003</td><td>16th May</td><td>30th Mar</td><td>2008</td><td colspan="2">7th Feb</td></tr>
<tr><td>2004</td><td>19th Feb</td><td>8th May</td><td>2009</td><td colspan="2">21st May</td></tr>
<tr><td>2005</td><td colspan="2">8th May</td><td>2010</td><td colspan="2">22nd Mar</td></tr>
</table>

It can be seen from the maps in Figure 3 and the percent area covered in Figure 2 that the time, extent and location of the first summer rains varied from year to year. In 4 of the 10 years it was obvious which satellite image dates should be selected because single rain events covered more than 60% of the area but in other years it was more difficult. In 2001 the January and May rain events were spread equally either side of the 400 mm rain isohyet and each rain date covered the majority of the north and south Landsat scenes. In this case the majority rain date for each scene was selected. In years when it was hard to determine which rain date covered the majority of the scene, such as 2003 (south), 2004 (north), 2005 (north) and 2007 (south) the earliest date was selected to ensure the green flush was captured (Figure 3).

Conclusion

This work has mapped critical dates of first summer rains across the NAR. The dates derived from first summer rain maps can be used to select which satellite images can be expected to display the first green flush in the perennial pastures brought about by sufficient summer rain.

In the next phase of this work, mapping of perennials from satellite imagery, the actual temporal association between the first summer rains and the first green flush will be more evident. From this, our assumptions of 4 to 6 weeks elapsed time may need to be revised.

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