University of Southern Queensland

Faculty of Health, Engineering and Sciences

Application of MODIS and Google Earth Data to Assess the Health of the Mitchell Grasslands through Web Based GIS

A Dissertation submitted by

Thomas Robertson

In fulfilment of the requirements of

ENG4111 and ENG4112 Research Project

towards the degree of

Bachelor of Spatial Science (Honours)
(Surveying)

Submitted October 2016

Abstract

In North Western Queensland and the Central Eastern portion of the Northern Territory lie the Mitchell Grasslands. Covering approximately 320 000 square kilometres, the area is grazed by approximately 12 million cattle. The use of the Grasslands for grazing pasture has placed pressure on the natural processes of the area. Also, working in the unpredictable conditions that occur from year to year has certain challenges for graziers and land managers alike. By aiming to find a spatial solution is assess the health of the grassland, and applying the knowledge gained, better economic, social and environmental outcomes can be achieved.

This study has used the remote sensing method of multi-spectral imaging to generate 'greenness' or vegetation index (VI) plots of a selected portion of Mitchell Grassland. By comparing the red and near-infrared bands detected by the Moderate Resolution Imaging Spectroradiometer (MODIS) satellites, Terra and Aqua, differentiation can be made between sections of healthy and stressed vegetation. Images were collected over the 17 year period that MODIS has been operating, at an interval of 3 months. From these images GIS analysis and data manipulation was completed and a number of statistics were calculated including average normalised difference vegetation index (NDVI) value and percentage of pixels above a specified NDVI value.

The Queensland Department of Science, Information Technology and Innovation (DSITI) along with its regional climate/meteorological program, The Long Paddock run GRASP (Grass Production) model, as well as the spatial implementation of the results called Aussie Grass. Data produced includes pasture biomass, relative pasture biomass, pasture growth, rolling average relative pasture growth 1, 3, 6, 12 and 24 months, pasture growth seasonal probability, pasture curing index, grass fire index, rolling average relative rainfall 1, 3, 6, 12 and 24 months and total monthly rainfall. Pasture coverage data was extracted and compared with the percentage of NDVI values above a specified range to estimate a comparison. Some positive results were seen from this analysis with regression analysis showing a weak correlation.

The NDVI data, particularly the average over a seasonal and annual basis were also compared to weather and climate data including rainfall averaged over 3 nearby Bureau of Meteorology stations and SOI data for the same time period. A strong correlation was seen with the rainfall data, confirming the findings of previous work, while a weak correlation was found between the NDVI and the SOI. This is likely due to the small study area in terms of the area that SOI covers.

Finally, each NDVI snapshot of the study area was processed into a colour-scaled image and presented in the form of a KML time-series for easy use, sharing and editing. It is hoped that this study will inspire further investigation into areas such as the analysis of bushfires using this technology, comparison with other datasets including the Aussie Grass pasture growth rates and the use of LIDAR to analyse grassland dynamics as well as grass height/availability of feed.

University of Southern Queensland
Faculty of Health, Engineering and Sciences

ENG4111 & ENG4112 Research Project

Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Thomas Robertson

Student Number: 0061049290

Acknowledgements

This project would not have been possible without the assistance, guidance and moral support from the following people:

- Dr Kithsiri Perera, my supervisor;

  I would like to thank Kithsiri, who gave me the idea for the project as well as some important data and access to his previous work in the area.

- Grant Stone, from the Department of Science, Information Technology and Innovation;

  I would like to thank Grant who provided me with access to the Aussie Grass premium data as well as some advice on it use and how it is generated.

- Sarah Robertson, my wife;

  Finally, I would like to thank my wife Sarah for her contribution to this project and my Spatial Science degree by providing advice, someone to discuss ideas with and all the other ways in which she helped.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

This report is a final dissertation that outlines and details the entire process of the 12 month undergraduate research project. It is the culmination of the Bachelor of Spatial Science Honours, majoring in surveying degree. The introductory section outlines the aim, background, objectives, and scope of the project.

1.1. Project Aim

The aim of the project is to improve the ability of land managers, land owners, scientists and others to manage the Mitchell Grasslands in a sustainable way. This will be done through a spatial solution to assess the health of the grassland. By applying the knowledge gained, better economic, social and environmental outcomes can be achieved.

1.2. Background

The need for research into this area does not immediately seem obvious. The combination of advances in technology, the increased availability of data and the need to continue previous research in the area have driven this project. Also, the increasing call to balance the desires of Australia's human population for food and the natural processes vital to sustaining Australia's desert landscapes and ecosystems means more work is needed.

Since the launch of Landsat in the 1970's the availability of satellite data for a wide range of applications has been increasing each year. MODIS, as well as a number of other satellite systems produce free-to-use multi-spectral imaging that have an almost unlimited number of applications for research and scientific studies into various land, ecological, agricultural and environmental phenomena and problems. Every year Australia requires more food including meat produced from the Mitchell Grasslands. As production becomes more intensive resulting from a scarcity of land, the need to practice and uphold sustainable farming practices becomes greater. This is only possible by understanding the processes which govern the effects that are seen on the ground.

For those that experience the grasslands on a day-to-day and season-by-season basis, the changes do not come as a surprise. Figure 1 and Figure 2 show an example of the changes that can be seen.

Figure 1: Looking North, 15km West of Hughenden January 2008

Figure 2: Looking North, 15km West of Hughenden December 2014

Previous work includes a number of studies which are discussed in later sections. The most prominent of these are Perera and Apan's 2009 work where Mitchell grassland MODIS NDVI data was compared to rainfall totals in the wettest rainy seasons. There have also been a number of studies on the links between NDVI and climate/weather, bushfire as well as stocking rates and other agricultural practices in the US Great Plain grasslands and China's Sichuan and northern grassland regions.

The project topic *Application of MODIS and Google Earth Data to Assess the Health of the Mitchell Grasslands through Web Based GIS* can be expanded upon by detailing the research ideas within this. The subject area is the Mitchell Grasslands, and as will be shown in later sections, a particular study location has been chosen and this will be focused upon for the duration of the research. The key word in the project is "health" and a research methodology was needed to design a series of tests that determined the "health" of the grasslands. Following this, a number of recommended methods for improvement of the health or alternatively advice on how the current conditions can be sustained.

1.3. Objectives

As opposed to the aim, the objectives outline what exactly is hoped to be achieved by undertaking a project such as this. This project will use methods including remote sensing, spatial modelling, geographic data manipulation, statistical analysis of data and web design. The specific objectives include:

- Make a comparison between MODIS remote sensing techniques and industry standard methods of determining pasture production/health;
- Correlate temporal patterns of weather/climate to patterns found in the NDVI;
- Offer conclusions on how well MODIS data is able to predict grass variables and the impact of meteorology;
- Present results in a easy to use, edit and share format, and;
- Discuss methods of implementation of the results to achieve the aims outlined.

1.4. Scope

Research in this area using these methods is in its infancy, therefore a large area has been chosen, and a big picture approach taken. This means that some details are left for later research that has the ability to focus on detail. As will be outlined in later sections, the study area chosen for analysis is approximately 200km by 220km. The results found will therefore apply specifically to this region.

Other regions of the Mitchell Grasslands and other grasslands around the world could have the results and principles of this project applied however the same outcomes cannot be guaranteed.

The medium resolution satellite data from MODIS' Terra and Aqua satellites has been used. Although other data, of higher resolution is available free of charge, this was the most appropriate data due to computing power available and the resolution data it will be compared to.

2.0 Literature Review

The following sections will introduce the topic of remote sensing of vegetation and provide the context for the intended study into the use of this technology in the study of the Mitchell Grasslands. Several previous studies in this area have been considered, as well as background information relevant to the region, its history, ecology and land use, other methods used to model the environment and the current state of online geographic data presentation. This information will provide the reader with the basic understanding required to read and comprehend the study. The information in this section will also link the study to the real world, show why it is needed and show its usefulness in everyday terms.

2.1. Mitchell Grassland History, Ecology and Land Use

In North Western Queensland and the Central Eastern portion of the Northern Territory lie the Mitchell Grasslands. Covering approximately 320 000 square kilometres (Savanna Explorer, 2010), the area consists of vast treeless plains dominated by Mitchell Grass (Astrebla sp.). Prior to European inhabitation, aboriginal people live on and used the land in the region for at least 20 000 years (Rowland & Border, 1990). Beginning from the mid-nineteenth century (Forrest, 1988), until the present day the area has been primarily used for sheep and cattle grazing, with cattle grazing more common on properties located in the Northern Territory Mitchell grasslands (Federal Department of Environment, 2008). Approximately 12 million cattle currently reside on Mitchell Grasslands in Queensland alone (Perera & Apan, 2009).

Figure 3: Mitchell Grasslands near Hughenden**(Perera & Apan, 2009)**

The Mitchell Grasslands are defined as the area where species of Mitchell Grass (Astrebla sp.) dominate the vegetation. In Queensland, they stretch from Hughenden and Blackall in the east to the Mckinlay River in the west and the Thomson/Barcoo rivers in the south (Rowland & Border, 1990). This area includes the towns of Longreach and Winton. The region surrounding Mt Isa and Cloncurry are dominated by Spinifex grassland, while to the south Gidgee, Mulga and Acacia woodland are prevalent (Rowland & Border, 1990). Further west Mitchell grass is again prevalent stretching from Camooweal and the Georgina River, west into the Northern Territory (Rowland & Border, 1990). Other grasses, forbs, trees and shrubs inhabit the Mitchell Grasslands, however are not as prevalent as the Mitchell Grass (Orr & Phelps, 2013). These include Mint Bush, Dichanthium sp., Eulalia fulva, Aristidia latifolia, Eragrostis sp., whitewood (Atalaya hemiglauca) and Vine tree (Ventilago viminalis) (Rowland & Border, 1990).

The Grasslands occur as a result of the complex geology and soil profile of the region. Much of the region consists of cretaceous sedimentary rock, with areas of Cainozoic sediments to the north and east of Hughenden, and north of Cloncurry, Triassic formations to the east of Hughenden and Blackall and Tertiary formations around Ilfracombe, and the northern bank of the Flinders River (Rowland & Border, 1990). Mitchell Grasslands occur mostly on grey and brown cracking clays on undulating or alluvial plains – these are commonly associated with the cretaceous sediments that underlie the clays (Rowland & Border, 1990).

Prior to European exploration and inhabitation of the grasslands, historical and archaeological evidence shows that region supported vast numbers of aboriginal people (Rowland & Border, 1990). Some estimates give a greater number of aboriginal people than the number of residents in the region today (Rowland & Border, 1990). In the eastern region of Mitchell grasslands between Hughenden, Blackall and the McKinley River, 8-10 aboriginal nations existed (Rowland & Border, 1990).

The first of the European explorers to visit the Mitchell grasslands was Thomas Mitchell in 1846 (Forrest, 1988). After several successful expeditions in the south of the continent, Mitchell endeavoured to find the answers to geographic and scientific questions that puzzled the European inhabitants of Australia at the time (Forrest, 1988). Upon reaching the wide expanse of Mitchell Grass, Mitchell commented “I there beheld downs and plains extending westward beyond the reach of vision” (Rowland & Border, 1990), indicating the size of the area which is dominated by Mitchell Grass. It was not long before sheep and cattle graziers were to take up portions of land in the region with several homesteads and cattle stations set up in the Ilfracombe district in the first 20 years following Mitchell’s first journey through the area (Forrest, 1988). This tradition of sheep and cattle grazing for both wool and meat production, based on the area’s abundant grass resources has continued to the present day. The region has played a major role in the agricultural development of Australia and is a testament to the observation that Australia economically “rode on the sheep’s back” for much of its first 150-200 years of European inhabitation (Gordon, 2003).

A region of study between Hughenden, Winton and Julia Creek in central-western Queensland was chosen for study. The final dimensions and location as well as a justification are included in section 4.2. This area is within the Mitchell Grass Downs biogeographic region (Rowland & Border, 1990). Within this area, a number of broad vegetation groups (BVGs) occur, these are useful in understanding the flora and fauna which naturally inhabit an area as well as the underlying climatic and geological conditions that dictate primary productivity(Queensland Government, 2016). The BVGs include:

- 30b – Tussock Grasslands dominated by *Astrebla* spp. (Mitchell Grass) or *Dichanthium* spp. (Bluegrass) on undulating downs or clay plains
- 30a - Tussock Grasslands dominated by *Astrebla* spp. (Mitchell Grass) or *Dichanthium* spp. (Bluegrass) on alluvia
- 27a – Low open woodlands with a variety of species including *Acacia tephrina* (boree), *Atalaya hemiglauca* (whitewood) and *Ventilago viminalis* (supplejack).

- 16a – Open forest woodlands dominated by *Eucalyptus camaldulensis* (river red gum), *E. Tereticornis* (blue gum) and *E. Coolabah* (coolabah). Melaleuca spp, *Corymbia tessellaris* (Moreton Bay Ash) and *Casuarina cunninghamiana* (riveroak) are also common.
- 26a – Open forest/tall shrubland with *Acacia cambagei* (gidgee) and *Acacia argyrodendron* (Blackwood).
- 19d – Low open woodland with *Eucalyptus persistens* (Normanton box), *E.tardecidens* and *Triodia* spp.

The locations of these vegetation groups within the study area are shown in Figure 4. 30a is in aqua, 30a in pink along watercourses, 27a in light green, 16a in pale green, 26a in light purple and 19d in dark purple.

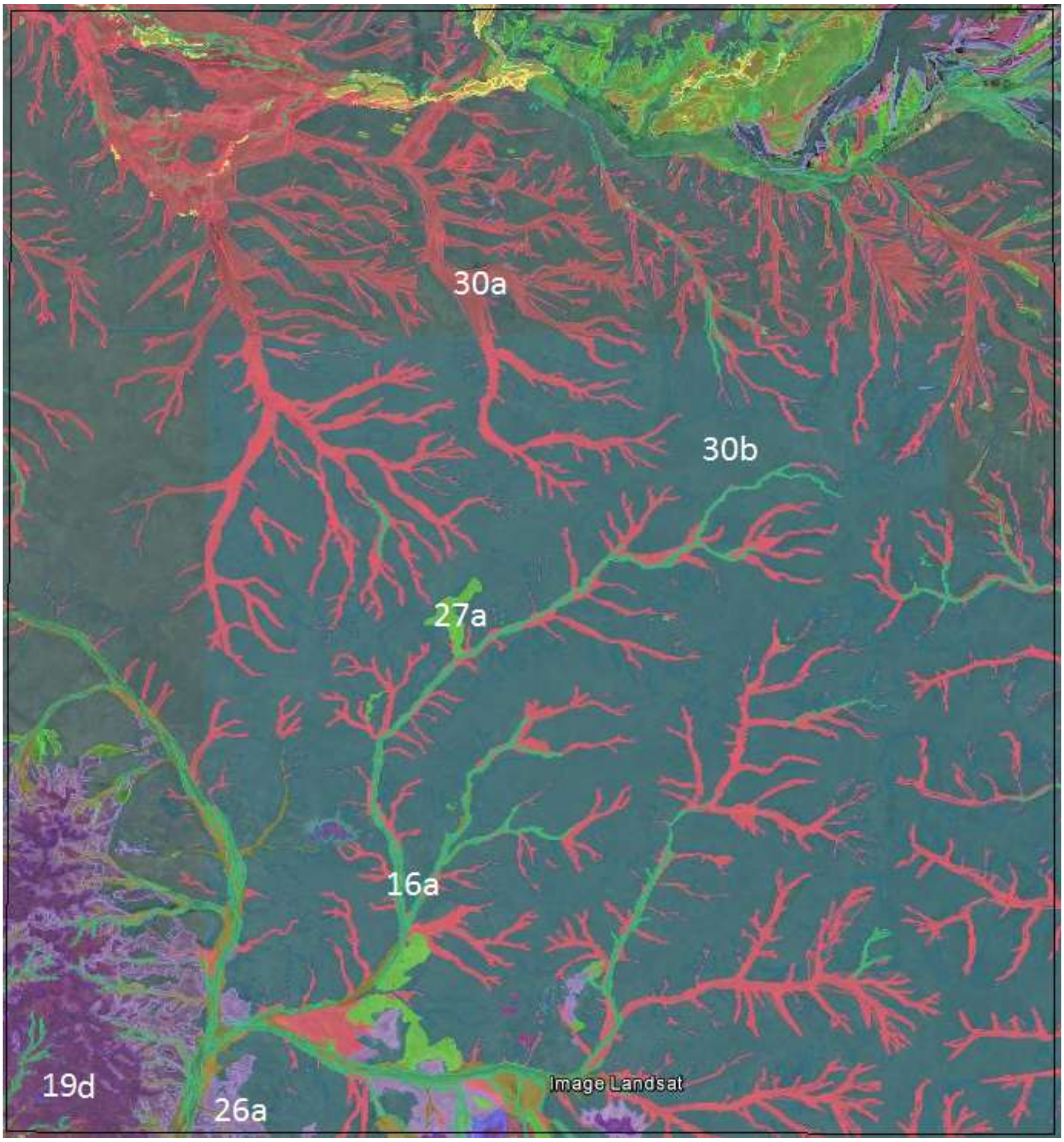


Figure 4: Location of Broad Vegetation Groups In Study Area(Queensland Government, 2016)

2.2.Satellite Systems and Remote Sensing

Using satellite systems, imagery and scans of the earth surface can be captured and analysed for a variety of scientific purposes. This process is known as remote sensing and refers to the sensing, recording and analysis of physical and environmental phenomena without manually visiting the location in question. This means that studies over very large areas can be conducted with general results produced more efficiently. Remote sensing can be done in a variety of ways including from aircraft, however most remote sensing is done from spacecraft. It is the process of detecting, recognising, and analysing the changes or variations in reflected and radiated electromagnetic waves from objects on the earth's surface. Passive remote sensing refers to those devices which rely upon other sources of electromagnetic radiation, for example a device which detects reflected visible, infrared or ultraviolet sunlight, for example a camera. Active remote sensing is done by devices that emit a precise band of radiation, and then detect its reflected signal; these systems most commonly use radio or microwaves.

To understand the mechanics of remote sensing a basic knowledge of electromagnetism is required. The electromagnetic spectrum includes all types of waves that may be emitted or, absorbed, radiated or detected by objects and scanning devices. A representation of the spectrum is shown in Figure 5.

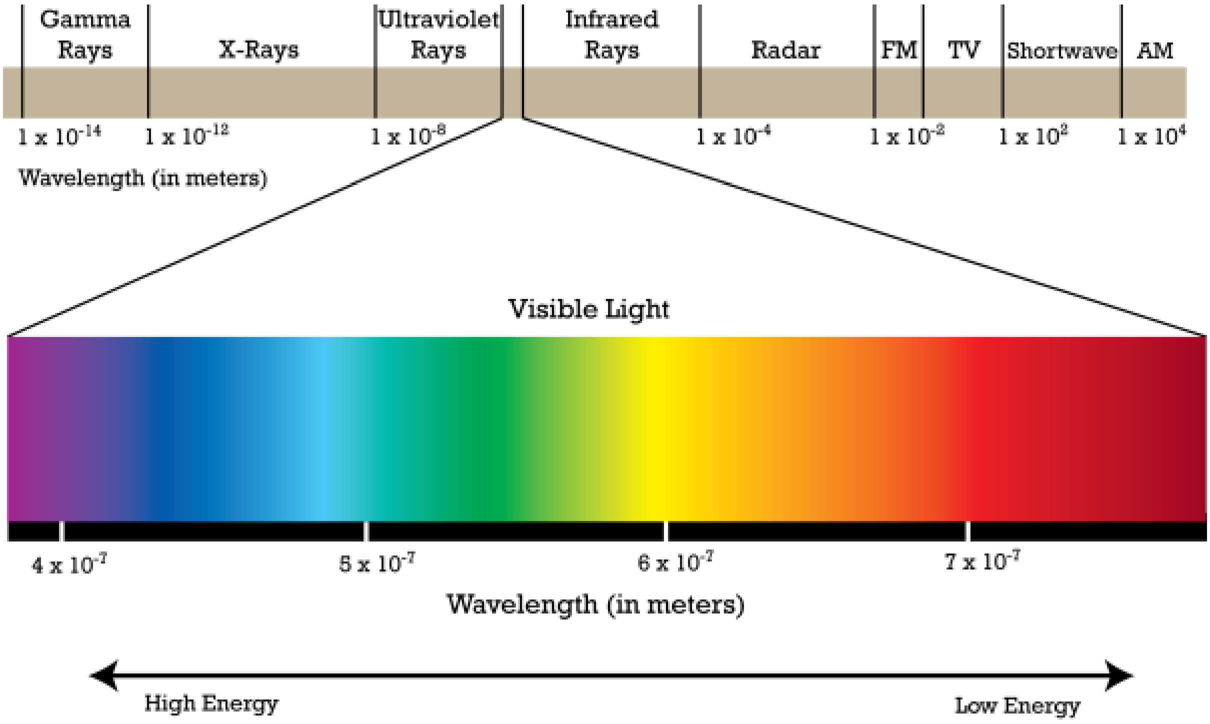


Figure 5: The Electromagnetic Spectrum

Almost all remote sensing is done using visible light (wavelength approx 10^{-7}m – 10^{-6}m), infrared and microwaves (wavelength approx 10^{-6}m – 1m). Sunlight contains a wide spectrum of electromagnetic wavelengths; this means that passive remote sensing can be done across this full range. Active remote sensing is also done over this range due to the availability of low cost emitters and sensors of visible and infrared radiation.

Remote sensing of vegetation is most efficient using the red and near infrared ranges. This is due to the difference in spectral response that can be detected in comparison to most other objects in the natural environment including various soil types and water. The level of radiation and the mix of spectral responses are dependent upon the pigmentation (colour), moisture content and physical factors such as leaf thickness and density. Vegetation under stress has reduced chlorophyll content, causing it to reflect more in the red range of the spectrum. This effect is more pronounced in the infrared range, reduction in chlorophyll changes the appearance of vegetation on colour infrared film from magenta (healthy) to red (under stress). This concept is the basis of common vegetation indices used to detect vegetation patterns and changes in the natural environment. This will be discussed further in the following section.

There are several satellite systems available today that provide land mapping data that can be used for analysis of vegetation and land use change over time.

2.2.1. Landsat

Landsat was the first earth observing satellite to be launched with Landsat 1 reaching obit in July 1972. Landsats 2,3,4,5, 7 and 8 have been launched and together have provided an almost continuous view of the entire planet at moderate resolution for 40 years. Landsat 9 is currently planned to join its predecessors in 2023 (U.S. Geological Survey, 2015).

Landsat 7 and 8 currently orbit the earth at 705km altitude, moving from north to south and scanning a 185km swath (U.S. Geological Survey, 2015). They move in a sun-synchronous orbit, completed every 99 minutes, and together scan each position in the earth’s surface every 8 days (U.S. Geological Survey, 2015). While previous Landsat missions carried multi spectral scanners (MSS), which collected data at 79m resolution, across the visible and near-infrared bands, Landsat 7 carries the Enhanced Thematic Mapper Plus (ETM+) scanner(U.S. Geological Survey, 2015). ETM+ scans 30m visible, near-infrared, shortwave infrared (SWIR), 60m thermal and 15m panchromatic (U.S. Geological Survey, 2015).

Landsat 8 captures images using a push broom type scanner; this improves upon the whiskbroom scanner as it has less moving parts and is less prone to failure (NASA, 2015). The scanners are the Operational Land Imager (OLI), and the Thermal Infrared Sensor (TIRS), together these collect 30m visible, near IR and SWIR and 15m panchromatic (U.S. Geological Survey, 2015). More bands are detected than previous missions with bands that specialise in coastal aerosol studies and cirrus cloud detection (U.S. Geological Survey, 2015).

Until 2008, Landsat data was only available for a fee (Central African Regional Program for the Environment, 2014). It is now free to use for scientific organisations after registration of a free account. In terms of vegetation detection Landsat does not have a dedicated band for capturing vegetation data. Rather OLI and TIRS feature bands for aerosol and cloud analysis, while the previous MSS, TM and ETM+ produced data over a range of bands without specifying their use (U.S. Geological Survey, 2015). This benefits some work, as the raw data can be used in research.

2.2.2. SPOT

Satellites Pour l’Observation de la Terre (SPOT) is a civialian remote sensing program set up by France, Belgium and Sweden in 1978(Central African Regional Program for the Environment, 2014). SPOT1 was launched in 1986 with two visible high-resolution scanners; it collected data in three bands at 20m and 10m panchromatic (Central African Regional Program for the Environment, 2014). SPOT2 was launched in 1990, SPOT3 in 1993 and SPOT4 in 1998, scanning four bands - – blue, red, near- and mid-IR as well as a vegetation sensor at 1km resolution using a wide angle radiometric camera(Central African Regional Program for the Environment, 2014). SPOT5 was launched in 2002; it had a higher resolution scanner and a similar vegetation band to SPOT4 (Central African Regional Program for the Environment, 2014). SPOT6 and SPOT 7 are now operational with further expanded capabilities (GeoImage, 2016).

The SPOT program is now owned and operated by Airbus Defence and Space with imagery and post-processed data available for a fee only (GeoImage, 2016). The vegetation sensor was not included on the SPOT6 and SPOT7 missions; however vegetation imagery is still available from previous SPOT missions (GeoImage, 2016).

2.2.3. AVHRR

The Advanced Very High Resolution Radiometer (AVHRR), first launched in 1978 is a scanner aboard the National Oceanic and Atmospheric Administration’s (NOAA) satellites (National Oceanic and Atmospheric Administration, 2016). The objective of the scanner is to provide radiance data or passive remotely sensed data on oceanic, atmospheric and terrestrial phenomena. Data collected to date includes clouds, land-water boundaries, snow and ice extent, ice and snow melt inception, day and night cloud distribution, radiating surface temperature, sea surface temperature, vegetation classification and greenness (National Oceanic and Atmospheric Administration, 2016). NDVI data was collected from the AVHRR prior to the launch of MODIS in 1999. The Current AVHRR mission collects imagery at a 1.1km resolution over 5 spectral bands.

The primary purpose of AVHRR is atmospheric and climatic research, with vegetation detection being a secondary use (Central African Regional Program for the Environment, 2014). As will be discussed in the following section, MODIS is now the primary source of vegetation detection data. While the AVHRR plays a secondary role and is used in some situations where MODIS data is unavailable or doesn’t suit the study.

2.2.4. MODIS

The Moderate Resolution Imaging Spectroradiometer (MODIS) was the first earth observing satellite system to be designed as open source – that is for all data to be freely available from the beginning(Central African Regional Program for the Environment, 2014). MODIS refers to the instrument aboard the Terra and Aqua satellites. MODIS is different to other satellite systems in that it collects data in 36 different bands, giving it a huge range of applications (Goddard Space Flight Centre, 2010). Terra and Aqua have a revisit time of 1-2 days when their products are combined (Goddard Space Flight Centre, 2010). MODIS collects data at moderate resolution with 2 bands available at 250m, 5 bands at 500m and the remaining 29 at 1km (Goddard Space Flight Centre, 2010).

Terra was launched in December 1999, while Aqua followed in May 2002(Central African Regional Program for the Environment, 2014). The two satellites are able to collect and ensure scientific applicability of the data using the large number of instruments on board including: a high performance passive radiative cooler, photodiode readout technology, a programmable gain and offset clock, a space viewing angle module (SAM), a forward viewing analogue module (FAM), a solar diffuser (SD), a v-groove blackbody (BB), a spectroradiometric calibration assembly (SRCA) and a solar diffuser stability monitor (SDSM)(Goddard Space Flight Centre, 2010).

Vegetation detection and land cover analysis is ideally suited to MODIS data due to the high number of small wavebands available for analysis. MODIS also produces a number of post-processed datasets that are applicable for inputs to scientific studies (Goddard Space Flight Centre, 2010). These include specialised vegetation index products, normalised difference vegetation index (NDVI), gross primary production and several others.

Due to the specialised nature of MODIS vegetation products as well as the extensive body of research that has been done using its data, this study will use MODIS data exclusively to analyse the Mitchell Grasslands.

2.3. Vegetation Detection and Analysis

As previously discussed, vegetation is best analysed using remote sensing data in the red and near-IR bands due to the large change in spectral response resulting from small changes at ground level. A now very commonly used metric is the vegetation index which is simply a ratio of response in the red band, to a response in the near-IR band (Bureau of Meteorology, 2016). The NDVI value is considered to be a measure of vegetation 'greenness' as it changes in response to the level of chlorophyll being produced in the particular area of vegetation.

The normalised difference vegetation index (NDVI) is one such metric which is calculated as follows.

$$NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}}$$

Where ρNIR and ρRED are reflectances of near-IR and red radiation (Bureau of Meteorology, 2016)

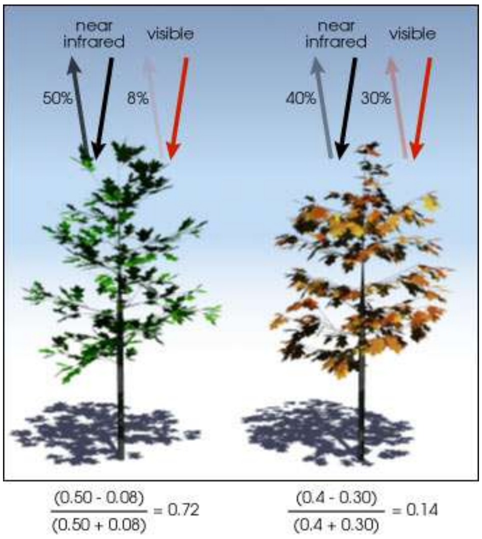


Figure 6: Vegetation Index Calculation **(Earth Observatory, 2000)**

Looking at the equation alone, NDVI values between 1 and -1 are possible however in reality, the range is much smaller, with NDVI values of approximately 0.1 for bare rock to 0.9 for dense tropical vegetation (Bureau of Meteorology, 2016).

An alternative to NDVI is the Enhanced Vegetation Index (EVI). EVI uses updated MODIS detection capabilities and some new post-processing methods to correct for distortions in reflected light, airborne particles as well as ground cover below vegetation (Earth Observatory, 2000). EVI improves upon NDVI, especially in heavily forested areas by providing a higher spatial resolution and atmospheric haze correction, also EVI is able to better differentiate between forest and ground (Earth Observatory, 2000). Wardlow and Egbert (2010) found that differences in the two indices were negligible in cropland in Kansas, USA (Wardlow & Egbert, 2010). It can therefore be assumed that this will also be true in the similar environment of grassland, therefore for this study the more easily accessible NDVI will be used only.

Gross Primary Productivity (GPP) is the total biomass produced by primary producers (usually vegetation) at the base of a food chain (University of Michigan, 2008). Understanding and being able to predict the GPP of an area of pasture is important in estimating the number of cattle or other animals that can be sustained. GPP can be estimated using a number of different methods including through the use of eddy flux towers and/or remote sensing (Numerical Terradynamic Simulation Group, 2010). Eddy flux towers measure vertical turbulent fluxes within atmospheric boundary layers. Apart of this measurement, they are able to detect the exchange of CO_2 and water vapour between vegetation and the atmosphere at finite locations. Using a light use efficiency model, several of these towers over a region of homogenous vegetation are able to calculate a gross primary productivity (Numerical Terradynamic Simulation Group, 2007).

Figure 7: An Eddy Covariance Tower **(Central African Regional Program for the Environment, 2014)**

GPP may also be calculated without the use of eddy covariance tower data using the MOD17 algorithm developed by the Numerical Terradynamic Simulation Group at the University of Montana (Numerical Terradynamic Simulation Group, 2010). Based on Monteith's (1972) radiation use efficiency logic, it is assumed that the productivity of crops/vegetation is linearly related to the amount of absorbed Photosynthetically Active Radiation (APAR)(Numerical Terradynamic Simulation Group, 2010). APAR can then be used to calculate GPP and NPP (net primary production) using the light use efficiency parameter (ε) which varies by vegetation type and climate (Numerical

Terradynamic Simulation Group, 2010). More advanced models now also take into account daily lead and fine root maintenance respiration, annual growth respiration and annual maintenance respiration of live cells in woody tissue (Numerical Terradynamic Simulation Group, 2010). The MOD17A2 dataset is available free of charge alongside the other MODIS datasets (LPDAAC, 2016).

2.4.Aussie Grass and GRASP

The Queensland Department of Science, Information Technology and Innovation (DSITI) along with its regional climate/meteorological program, The Long Paddock run GRASP (Grass Production) model, as well as the spatial implementation of the results called Aussie Grass (DSITI, 2016). Observed data from the SILO Climate Database which has stations across Australia, are interpolated to produce a grid of 0.05° x 0.05° (approximately 5km x 5km)(DSITI, 2016). Data includes rainfall, evaporation, temperature, vapour pressure, solar radiation, soil and pasture type, tree and shrub cover as well as domestic and other herbivore numbers (DSITI, 2016). Much of the data produced is available free online, while some advanced modelling is available for a fee. Freely available data includes a number of low-resolution maps and the data that makes up the maps. Data produced includes pasture biomass, relative pasture biomass, pasture growth, rolling average relative pasture growth 1, 3, 6, 12 and 24 months, pasture growth seasonal probability, pasture curing index, grass fire index, rolling average relative rainfall 1, 3, 6, 12 and 24 months and total monthly rainfall (DSITI, 2016). Also available for a fee is stream flow modelling, GIS format data for statistical analysis, time series graphs of data on a sub-bioregion basis, as well as daily estimates of fuel load and experimental products (DSITI, 2016).

Due to the interpolated nature of the Aussie Grass inputs, results should not be used to study patterns over small areas, particularly those with long distances between AWS (DSITI, 2016).

2.5.Southern Oscillation

The southern oscillation index is a measure of the intensity of the Walker Circulation (Bureau of Meteorology, 2016). This is usually associated with the cycle of La Nina and El Nino weather patterns that affect the South Pacific Ocean as well as the South American and Australian Continents (Bureau of Meteorology, 2016). Factors affecting the walker circulation and affected by it include ocean surface temperatures, ocean themocline, air pressure over different parts of the ocean and rainfall intensity over both continents (Bureau of Meteorology, 2016). In Australia El Nino is associated with low rainfall along the east coast, while La Nina is associated with high rainfall. The opposite is the case for South America under these conditions (Bureau of Meteorology, 2016).

The cycle is commonly called El Nino Southern Oscillation (ENSO). ENSO is quantified through the southern oscillation index (SOI). The SOI values for the study period are given in Figure 8. These are calculated by taking into account the current mean sea level air pressure (MSLP) in Tahiti and Darwin, the long term average of these two values, as well as the long term standard deviation of the difference between these values (Bureau of Meteorology, 2012). The SOI is calculated using the following equation:

$$SOI = 10\,\frac{P_{diff} - P_{diffav}}{SD_{P_{diff}}}$$

Where:

P_{diff} = MSLP Tahiti – MSLP Darwin

P_{diffav} = Long term average P_{diff}

$SD_{P_{diff}}$= Long Term standard deviation of P_{diff}

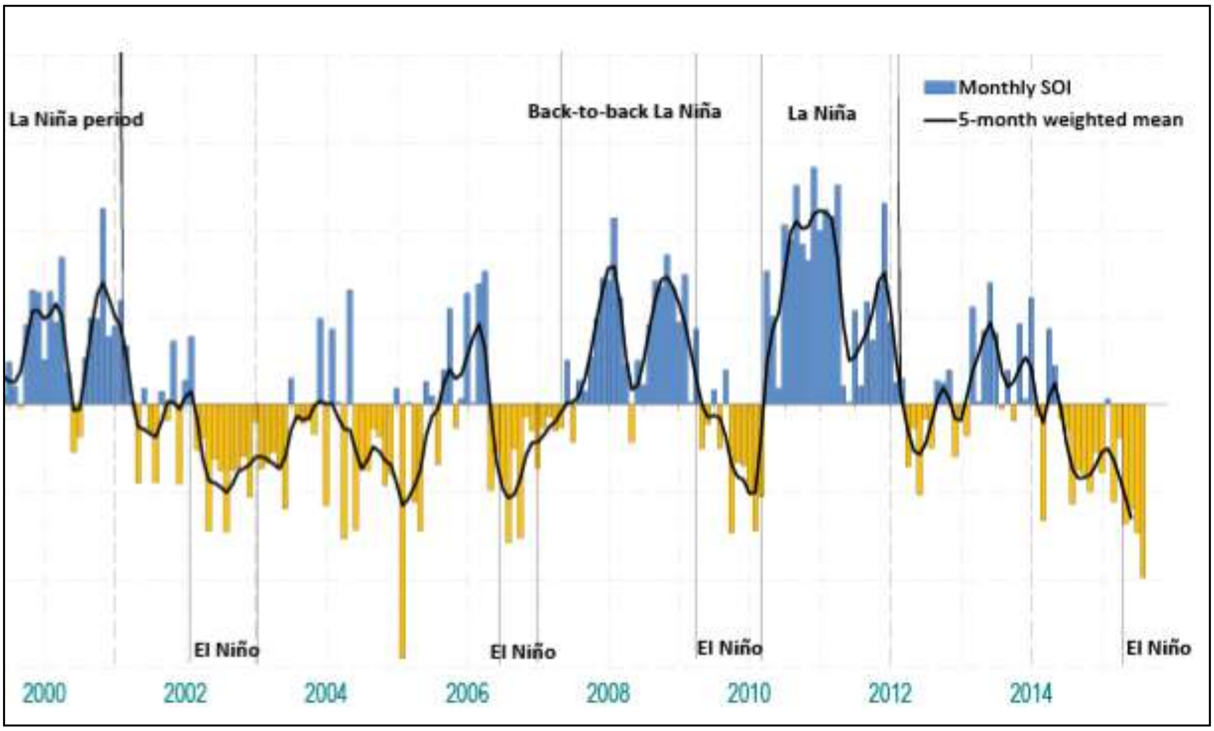


Figure 8: Southern Oscillation Index 2000-2016

2.6.Context for the Current Study

The applicability of MODIS-derived NDVI data both in terms of greenness and gross primary productivity in analysing the Mitchell Grasslands is the primary focus of this study. Secondly, the response of this metrics to differing weather pattern is also of interest. While some studies have looked at the Mitchell Grasslands, there is still work to be done in determining what remote sensing methods are suitable and calibrating these to produce accurate results. In other areas of grassland/rangeland around the world, extensive study has been done, however it is not known whether the conditions in these environments are similar enough to extend the results to the Mitchell Grasslands. One such area is the Central Great Plains, USA, particularly the expansive cereal cropping areas of Kansas in the mid-west of the United States(Wardlow & Egbert, 2007), (Wardlow & Egbert, 2010), (Leroux, Jolivot, Begue, Seen, & Zoungrana, 2014). The grasslands of northern China have also been studied using NDVI (Yuan, Li, Chen, & Shi, 2015), (Fu, Tang, Zhang, Fu, & Jiang, 2014). Some other common uses for NDVI data are land cover change detection (Lunetta, Knight, Ediriwickrema, Lyon, & Dorsey Worthy, 2006) and seasonal change in greenness resulting from differing temperature and rainfall (Perera & Apan, 2009), (Houts, Price, & Martinko, 2001), (Wang, Rich, & Price, 2003).

Crop mapping and grassland studies can be considered to be similar due to the small size of the vegetation and potential for areas of soil to be visible. Wardlow & Egbert (2007) found that MODIS data, combined with several post processing techniques and statistical analysis, was able to classify the common crops of Kansas, USA grown in large paddocks using MODIS 250m data. By splitting the state into 9 regions, and creating a four tiered decision tree system, four maps were produced including crop/non-crop, general crop type, summer crop type and irrigated/non-irrigated (Wardlow & Egbert, 2007). The study also took advantage of the short time between images in MODIS data to create a time-series and further improve the mapping when combined with knowledge of planting and harvesting times. Some issues were encountered with the north-eastern area of the state where paddock sizes are much smaller and other features such as roads influenced the 250m pixel coding (Wardlow & Egbert, 2007). When validated against actual crop locations, the MODIS-derived maps showed a high degree of accuracy (Wardlow & Egbert, 2007). In terms of the Mitchell grasslands, the use of MODIS data is suitable due to the expansive homogenous environment and expected changes associated with weather and climate patterns only.

In another study, Lunetta, Knight, Ediriwickrema, Lyon and Dorsey Worthy (2006) showed that MODIS data, especially when used as a time series with existed databases on land use data, was able to detect land use change(Lunetta, Knight, Ediriwickrema, Lyon, & Dorsey Worthy, 2006). This is useful in the event of illegal land clearing or other changes which can be seen easily from the air. Rather than using the comparison of two images, several image-dates were used to confirm changes. The self-checking method proposed increased accuracy of identifying changes that were not from natural causes (Lunetta, Knight, Ediriwickrema, Lyon, & Dorsey Worthy, 2006). As mentioned previously the Mitchell Grass Downs bioregion is under-represented in protected areas in terms of land area (Rowland & Border, 1990). A system similar to that proposed could be used to monitor land use change over the huge area of Mitchell grassland. Again small areas of 1.5ha or smaller were not modelled accurately, however due to the large area able to be monitored the method is efficient in time, computational requirements and costs (Lunetta, Knight, Ediriwickrema, Lyon, & Dorsey Worthy, 2006).

Several studies have looked at the link between climate/weather data and the response of NDVI values. In some cases the NDVI was used exclusively, while in others metrics such as gross primary productivity and leaf area index were studied for correlation with climatic patterns. In Perera and Apan's 2009 study, the variation in Mitchell grassland greenery after very high and very low rainfall wet season events derived from NDVI data was investigated (Perera & Apan, 2009). The results showed promise and more work, especially in the area of moderate rainfall years is needed (Perera & Apan, 2009). In Houts, Price and Martinko's 2001 work, the onset of greenness, usually in spring in response to seasonal climatic patterns was measured by NDVI from AVHRR. Rather than attributing differences to rainfall and/or temperature, the study found links between the onset of greenness and land cover type (Houts, Price, & Martinko, 2001). The onset of greenness is marked by a sharp increase in photosynthesis and as a result a sharp increase in NDVI values. By understanding the patterns of the onset of greenness, combined with the NDVI data, more accurate land cover change maps could be produced, also changes in the timing of the onset of greenness due to climate change or unseasonal weather could be detected (Houts, Price, & Martinko, 2001).

A large proportion of China's land mass is naturally occurring grasslands, currently the majority of China's grasslands are used for cattle grazing (Yuan, Li, Chen, & Shi, 2015), similar to Australian conditions (Rowland & Border, 1990). Yuan, Li, Chen and Shi (2015) conducted a study similar to that proposed here, where NDVI data was correlated against rainfall and temperature data over a long period. This study found that increasing rainfall intensity, decreasing total rainfall and increasing temperature due to climate change are having significant impacts on grassland in the region. In a similar study, rainfall and temperature were correlated with NDVI values in Kansas over a nine year period (Wang, Rich, & Price, 2003). This study looked at the response time of NDVI values to rainfall events and the long term correlation over an entire growing season (Wang, Rich, & Price, 2003). NDVI was found to increase strongly with precipitation and decrease slightly with temperature (Wang, Rich, & Price, 2003).

Aussie Grass has been running for two decades and now has data available for the variables and time periods previously discussed back to 1890, based on historical climate observations (DSITI, 2016). Where it was available, remote sensing data including greenness and ground cover have been incorporated into the model. This means that comparing the Aussie Grass results with vegetation index data will show only the difference resulting from other variables. Analysing the difference is still useful in validating the study.

Several studies, particularly into climate change and climate variability have taken advantage of the extensive and wide scoped dataset available from Aussie Grass. Lau, Young, McKeon, Syktus, Duncalfe, Graham and McGregor (1999) described the development of an operational framework to enhance the use of seasonal climate forecasts, for sustainable environmental and natural resource management. By doing so it showed how global information can be used for regional benefit (Lau, et al., 1999). In another study by Reagain and Scanlan (2013) Aussie Grass data was used to study long term carrying capacity (LTCC) of cattle and the use of seasonal climate forecasts in cattle management(O'Reagain & Scanlan, 2013). Constant stocking at LTCC was compared to variable stocking to analyse the impacts on profitability, sustainable land use and income variability (O'Reagain & Scanlan, 2013). These studies show that Aussie Grass data is used in research for a wide range of modelling, it is the accepted standard for climate data, pasture modelling and rangeland forecasting for fire, growth and other conditions.

This study has been born out of the need for further research into the applicability of satellite-based vegetation analysis to estimating and modelling grassland productivity, particularly in central Queensland and the Northern Territory. Much of the available literature has focused upon croplands, boreal forests and grasslands on other continents. The Australian and particularly Queensland agricultural industry relies heavily on grassland, especially native grassland to feed stock and generate an income. The ability to use this resource to its full potential through better farming practices and knowledge of the grassland will be vital in the future.

2.7.Web-GIS

Web GIS refers to the use of the web to view, share, edit, create or display geographic information. A web GIS as a minimum includes a single server and a single client that is a desktop application that is connected via the web to the server. The server contains geographic data that the client wishes to access. There are many examples of web GIS used by millions of people every day, including searching for addresses, getting directions from an online map and others.

Keyhole Markup Language (KML) is a file format which uses a tag based structure with nested elements and attributed and is based on the XML standard format (Google Developers, 2016). KML files can be displayed in any earth browser, the most common of which is Google Earth (Google Developers, 2016). A KML file can contain placemarks (point data), ground overlays (georeferenced images), paths (polylines) and polygons (Google Developers, 2016). KML is useful in the communication and display of spatial data as it is easily transferrable, easy to understand and with the assistance of an earth browser provides context for any spatial explanation of a concept. KML is commonly used by casual users, scientists, real estate agents, students, teachers and large organisations such as National Geographic, UNESCO and the CSIRO (Google Developers, 2016).

Ballagh, Raup, Duerr, Khalsa, Helm, Fowler and Gupte (2011) discussed the use of KML in the communication of scientific research results, particularly NASA's World Wind and Google Earth. They found that the National Snow and Ice Data Center had used KML files to support quality control of integration of data into an existing database, supported viewing of complex data as well as communicating science in a very visceral way (Ballagh, et al., 2011). There are several KML creation tools available, however in many cases the simplest and method is simply to view another KML file and adapt it to the application's needs (Ballagh, et al., 2011). One of the best tools however is the Google KML Interactive Sampler, which allows viewing of changes in real time (Ballagh, et al., 2011)(Google Developers, 2016).

2.8. Current Grassland Management Practices

For the vast majority of the history of grazing on Mitchell Grasslands, very little or no advice was available for graziers as to how many sheep or cattle could survive on a given pasture (Forrest, 1988). It was not uncommon for grazing to begin in a good year, then in a later dryer year, the same stocking rate was used and a severe shortage of feed led to financial ruin, not to mention the terrible conditions the livestock endured. As graziers become accustomed to the conditions on the grasslands and the variability of seasons, local knowledge combined with anecdotal evidence allowed for a better estimate of sustainable stocking rates as well as other management practices including at what time of the year pasture should be rested, the location of water sources and others (Forrest, 1988).

In 1984, Toorak station near Julia Creek in Queensland was acquired by the department of primary industries (DPI), (now DEEDI) to begin a long-term trial site of Mitchell Grass production and grazing research (Orr D. , 2010). This study has shown that moderate stocking returns the best results in terms of economic output for graziers as well as sustainable conditions for the Mitchell Grass to complete its long life cycle (Orr D. , 2010). While heavy grazing leads to feed shortages, a paddock that is not grazed over a long period will also fail to produce grass – in one trial all grass died in paddock left for 12 years without grazing (Orr D. , 2010). Low stocking rates, while good for individual animal performance and still allowing grass to regenerate is not economically viable (Orr D. , 2010). The optimal conditions are a moderate stocking rate, approximately 30% pasture use by weight; this is sustainable for the grassland as well as economically (Orr D. , 2010).

This study also noted that the dominant factor in Mitchell Grass health as well as yield and quality was rainfall (Orr D. , 2010). To achieve the goal 30% pasture use, stocking rates needed to be adjusted to match the preceding summer rainfall, in an effort to predict the availability of feed through the winter (Orr D. , 2010).

3.0 General Considerations

When undertaking research it is important is recognise the real-world impacts it will have both positive and negative. Also, safety of researchers, support personnel as well as the general public both during and after the work takes place must be considered. These and other issues not traditionally considered apart of research will be discussed in this chapter.

3.1. Discussion of Consequential Effects

In all research and development studies, there are flow-on effects, both positive and negative which may result from the completion and distribution of the study results. Since the aim of most research is to improve understanding of a certain topic it is the aim of most work for the positive outcomes to outweigh the negative outcomes, however this is not always the case, therefore each work should consider this carefully before proceeding.

Some of the effects this work may have both positive and negative include:

- Greater confidence in remote sensing methods for use in Australian grassland conditions
- Greater integration of methods of biomass estimation
- Highlight the availability of free scientific quality satellite imagery and datasets to a wider audience
- This work may represent a step toward larger farms as a result of more efficient management practices, in the short term this may mean greater profits, however in the long term fewer cattle farmers may be required resulting in fewer jobs
- It may also be a step toward more efficient cattle stocking density on the Mitchell Grasslands, leading to more efficient cattle farming and/or better environmental outcomes
- If used inappropriately or taken out of context, the work could cause confusion amongst farmers, other land holders, state and local governments as to what work has actually been completed and what assumptions can be made

These effects are the most significant for this project. Those that are negative can have their impact reduced by ethical economic activity surrounding grassland cattle grazing, and ensuring the results are presented with all accompanying information and the complexity of the methodology and results are explained in detail.

3.2. Risk Assessment

Current occupational health and safety (OH&S) legislation does not give numerical standards for safety practices, rather it emphasises a duty of care that each person involved in an activity is expected to undertake in order to keep themselves as safe as possible from potential harms.

In each stage of this project, a number of hazards will be present. This risk assessment will outline methods in which the risk of this causing injury or another type of physical or mental harm can be reduced. The project is primarily desktop-based therefore few hazards will actually be present to the researcher and supervisor.

Hazard	Likelihood	Exposure	Consequences
Fatigue	Slight	Regularly	Minor Injury
RSI	Very Slight	Regularly	Minor Injury

Electric Shock	Extremely Slight	Regularly	Major injury/Death
Computer Virus	Slight	Regularly	Minor equipment damage

Fatigue – Resulting from excessive work or working at hours when the body is usually sleeping can cause an inability to concentrate, impaired vision, headaches and other symptoms. The result of this can be poor quality work, as well as implications in other activities such as driving. Taking regular breaks and knowing the symptoms to look out for can reduce the risk of fatigue.

RSI – Repetitive Strain Injuries result from tasks that are completed over and over again where the same muscles are performing the same movements many times over. This is common in the hands and wrists due to typing. Taking breaks and knowing the symptoms to look out for can reduce the risk and impacts of RSI.

Electric Shock – This occurs when a source of electrical current passes through the body. Usually as a result of faulty wiring, or inappropriate use of an electrical device, it has the potential to cause major injury or death. The equipment that caused the shock will also likely be severely damaged as well. Only equipment that meets electrical safety standards should be used and wiring should be installed by a qualified electrician.

Computer Virus – These enter computers either via the internet through a file that is downloaded either deliberately by the user or unknowingly in the background or from a memory drive/CD storage device that is inserted into the computer. The risk of computer virus issues can be reduced by ensuring anti-virus software is up to date, suspicions emails and files are not downloaded and the source of storage drives inserted is checked prior to use.

4.0 Methodology

To achieve the objectives of the project, a clear methodology was needed to guide the research and keep it on track. The following sections outline the steps that were taken.

4.1. Literature Review and Background Information

The project began with a review of available literature and research of background information relating to the topic. By searching academic databases, past research projects were reviewed and notes were taken on methods, results and analyses done. With each work that was reviewed, careful attention was paid to the location of the study, the assumptions made, over what timespan the study was completed, the methodology used, the aim of the study and whether or not it was achieved. The collation of relevant data collected from this literature review is in chapter 2.0.

In the review of grassland studies from around the world, some regions have been very closely analysed with several studies available. These are typically the more productive regions, agriculturally and economically including the United States Great Plains in states such as Kansas as well as the plains and steppe of Central Asia. These represent a large proportion of the food bowl of these regions. The Mitchell Grasslands fit into this category so it was surprising to see that in comparison, little study into sustainable management had been done.

4.2. Collection of MODIS Data

As outlined in section 2.2, MODIS data consists of multi-spectral imaging of the earth's surface. The Terra and Aqua satellites image the globe every nine days with a full picture in terms of a variety of outputs including vegetation indices generated every 16 days. Data is outputted on the same Julian day annually, allowing analysis of annual cycles to be done with scientific rigour. A day representing each season was selected, approximately three months apart that aligned with the cycle of MODIS data output. Summer - January 17 (Julian day 017), autumn - April 6 (Julian Day 093), winter - July 11 (Julian Day 193) and spring - October 15 (Julian Day 289) were used. Data was downloaded for the full 17 year period MODIS has been running, with the exception of summer 2000 and spring 2016. The first MODIS output was on February 18, 2000, data from this output was substituted. Spring 2016 data was not yet available at the time of download.

A variety of online tools are available to access the free data. While some are text-based, the graphical interface of NASA's distributed active archive centre (DAAC) was found to be most efficient with the entire range of data able to be downloaded without continual supervision. The MOD13Q1, 250m combined vegetation index dataset was downloaded. From this, pre-calculated NDVI and other vegetation indexes, as well as the base red and near infrared data, all geo-located were able to be extracted. MODIS data is available in tile sizes of 10° latitude by 10° longitude, at low latitude such as that in northern Australia, this represents an area of approximately 1 000 000 km^2. The initial area selected was revised as it covered two of these tiles. Had this not have been done, a lot of extra processing time would have been required to extract and process twice the number of files, before stitching them together using a GIS program. This was not necessary to cover the scope and aims of this project. The final study area was 20.5° S, 22.5°S, 142°E and 144°E. This location was chosen as it contained a majority - approximately 85% of Mitchell grassland landscapes and it was close to areas used in previous studies, allowing for easier comparison of results. This area is bounded by the box in Figure 9.

Figure 9: Study Area

4.3.Collection of Aussie Grass Data

Next, the data output from the AussieGrass models was downloaded from The Long Paddock website. To gain access to the premium data, the username and password was obtained from the DSITI staff. As an undergraduate student this was free of charge. The pasture coverage data is only available in graphical format, so to do statistical analysis values were interpolated. The study area is located primarily in the central downs sub-IBRA – the pasture coverage data from this area was selected. Pasture growth statistics were available in numerical format and geo-located allowing import into ArcGIS.

4.4.Collection of Climate and Weather Data

Climate and weather data was collected for the study area, particularly at Winton, Hughenden and Julia Creek. The locations of these can be seen in Figure 9. Using the bureau of meteorology's (BOM) *Climate Data Online* service, rainfall intensity and daily totals for the study period were collected. This meant that rainfall statistics could be calculated from the downloaded spreadsheets.

For Hughenden the "Hughenden Station - **30025**" data was used, for Winton "Winton Airport – **37039**" was used, while for Julia Creek, the "Eddington Station – **29015**" weather data was used.

To align the weather data with the seasonal data output created for the NDVI data, the 3 months prior to the NDVI data date were summed to produce 3 month totals ending at the beginning of the month in which NDVI was collected. That is 3 months ending; 1 January, 1 April, 1 July and 1 October. The format of the rainfall data made this method convenient, but also this was estimated to be a reasonable time for the grass and other vegetation to uptake the moisture.

4.5.Geographic Data Manipulation

As mentioned in section 4.2, MODIS data was downloaded from NASA's DAAC. The data arrived in the hierarchical data format (HDF). This format is widely used by scientific organisations where very large files need to be transferred or stored. This allows more efficient sharing or archiving of data for future use. To extract the required dataset, a separate program was needed. Several are available however in this case the HEG (HDF-EOS to GeoTIFF) conversion tool was used. This tool was developed by NASA's earth observing system program and is recommended for this type of data extraction. As the name suggests, GeoTIFF is the common output, however other formats such as TIFF, HDF-EOS and binary files can be generated. The extraction of GeoTIFF files for the 67 dates on which data was required was a tedious process with no iterative function available.

The ArcGIS suite of programs was then used for GIS data conversion and analysis. The GeoTIFF files were imported into ArcMAP. To further compress the files when in HDF-EOS format, NDVI values are multiplied by 10. They were reduced back to their true values before a legend was added and a colour ramp was integrated. Finally, the images were exported in JPEG format for display in KML.

Also in ArcMap, statistical analysis was started, with much of the calculation completed using Microsoft's Excel spreadsheet program. Statistics including mean NDVI value on a seasonal and annual basis were calculated as well as standard deviations and % of NDVI values above 0, 0.1, 0.2, 0.3 and 0.4, allowing each image to be quantified.

The AussieGrass pasture growth values were also analysed in ArcGIS. Some issues were encountered with NDVI values and pasture growth statistics unable to be correlated. AussieGrass pasture coverage statistics proved to be more closely relatable to the NDVI data, allowing further analysis to be done. This is discussed in later sections.

4.6.Generation of KML Output

To create the KML files showing the time series of NDVI images of the study area, only basic programming language knowledge was needed. First a single timespan-capable KML file was created using an image overlay template from the Google earth website. To this the "Timespan" XML tags were added, the relevant dates inserted and testing of the file completed. KML references images stored online. In this case the free image hosting service 'Imgsafe' was used; non-commercial users can store an unlimited number of images here and reference them in KML files for use by third parties. For commercial users including government departments, an in-house hosting service should be used. 'Imgsafe' was appropriate for the purpose of this study.

Following this it was then a case of uploading each season from the 17 year study period, referencing them in the correct location in the KML text file and adding notes and timespan entries to suit. Finally, testing was done by opening the files in KML and cross-checking the images against the original data. The KML files could then be used for further analysis by overlaying other KML data such as broad vegetation groups (BVG), cadastre and others.

Taking into account the results, current grassland management practices, how quickly data becomes available and the supply of data to land managers, conclusions and recommendations were able to be drawn. These are also discussed in the following sections.

5.0 Results

The study was successful in producing some reasonable results, from which some moderately strong conclusions can be drawn. The results including some statistical analysis and various iterations are included in the following sections. A discussion of these results as well as how they relate to the objectives of the study is included in section 6.0.

5.1.Climate and Weather Data

The rainfall data collated from the BOM website was imported into excel where it could be analysed in parallel with the AussieGrass and NDVI data. As described in section 4.4, rainfall statistics including three-monthly rainfall totals were calculated. The raw rainfall data on a daily basis is in Figure 10.

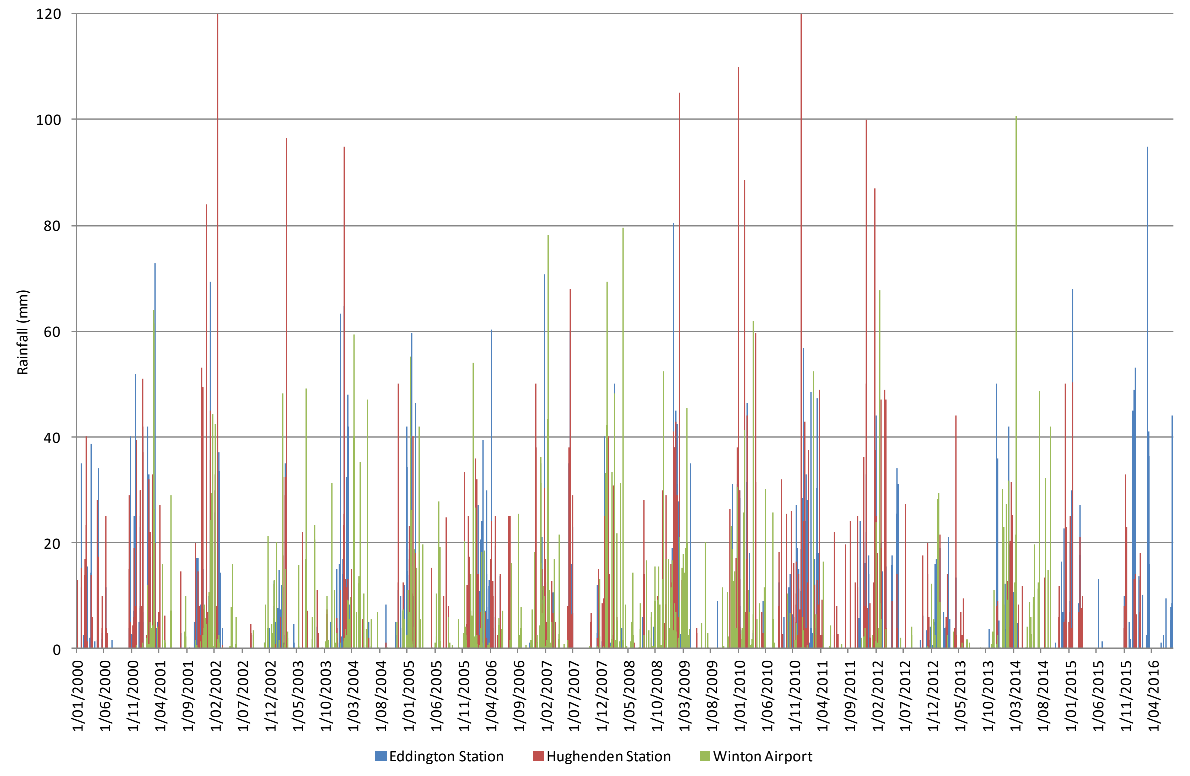


Figure 10: Raw Rainfall Data

The rainfall data averaged over the three stations in shown in Figure 11.

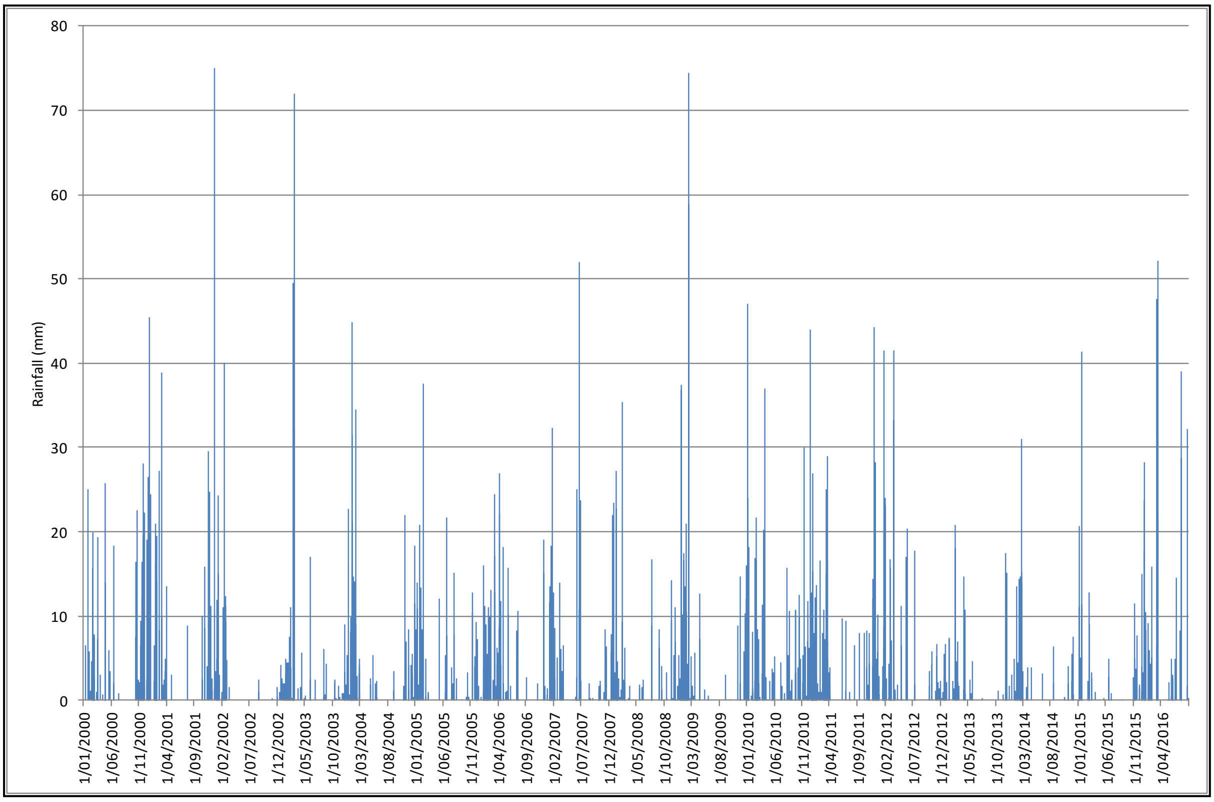


Figure 11: Daily Rainfall Averaged Across the Study Area

The three-monthly/seasonal rainfall data was calculated from this and is in Figure 12

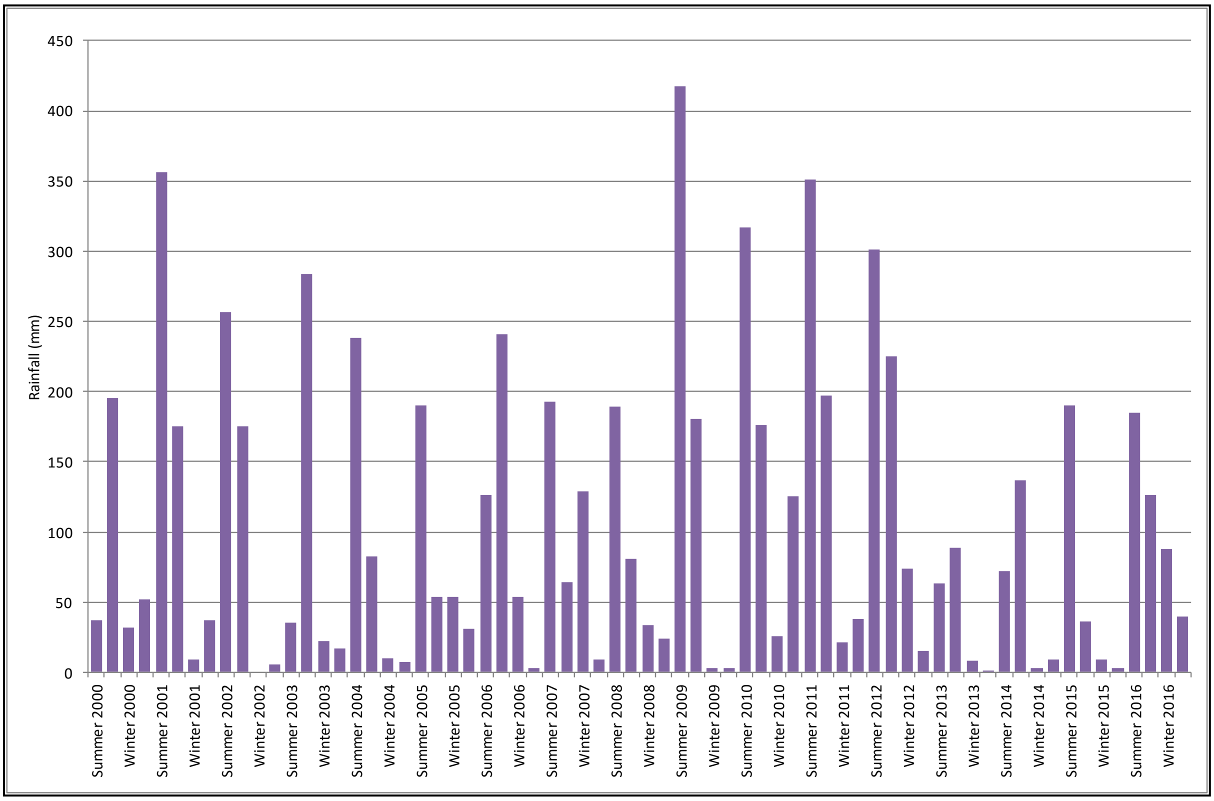


Figure 12: Three Month Rainfall Averaged Across the Study Area

From this data it can be seen that the area has a wet season during the summer months, while the dry season occurs in winter. As with much of northern Australia, winter/summer temperature differences are not as pronounced as areas further south. This means that the dry season results in a widespread drying out of the ground and can lead to bushfires and very low feed availability for cattle.

The relationship between ENSO and rainfall patterns in Eastern Australia is well established. In particular, for the study area the impact of ENSO on rainfall and by extension grassland health can be analysed by comparing a number of the available datasets. Figure 13 shows the relationship between the SOI values and rainfall across the study period.

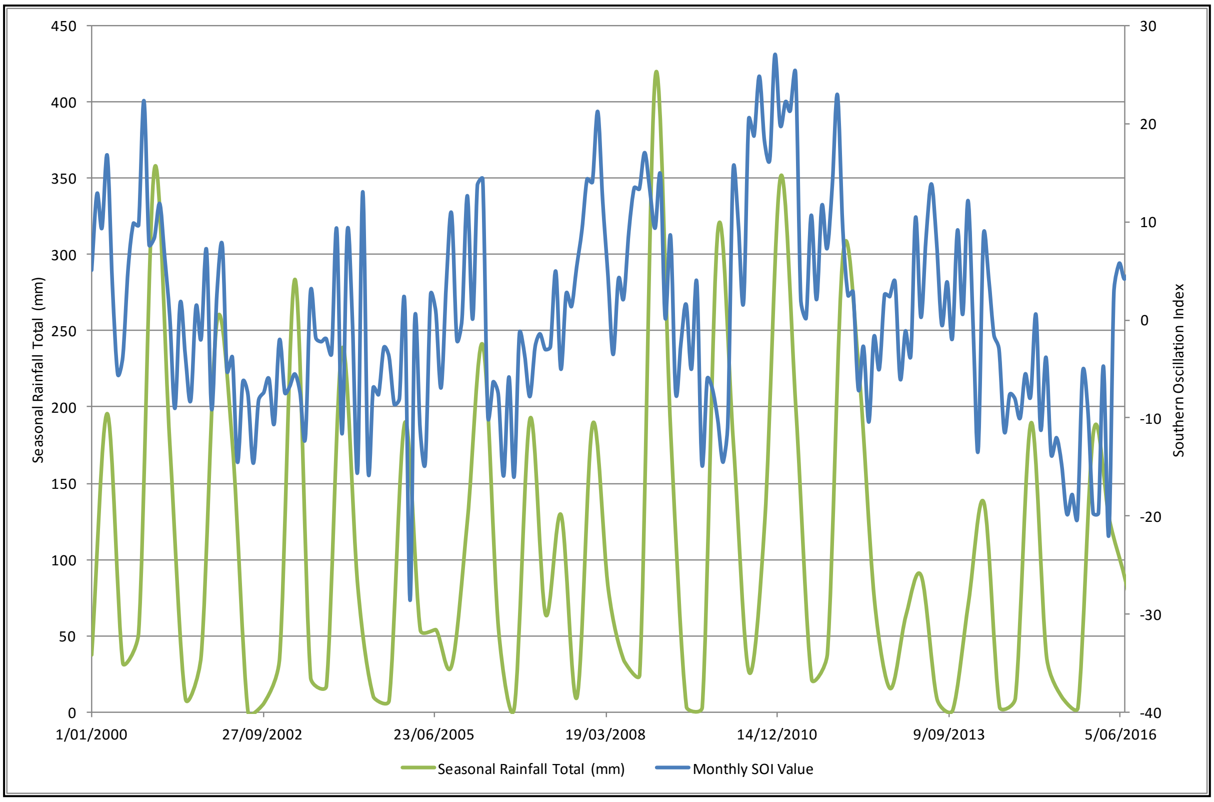


Figure 13: Seasonal Rainfall Compared to SOI

Very little correlation can be seen here, this is likely to result from the small area over which the rainfall totals were collected. ENSO is a phenomenon that affects a large proportion of the globe (Bureau of Meteorology, 2012), so analysis at this scale is unlikely to produce clear results.

5.2.Aussie Grass

The Aussie Grass data as obtained from the DSITI website includes pasture coverage and pasture growth data predicted by the Aussie Grass model based on the data available as discussed in section 4.3. For the central downs sub-IBRA region Figure 14 shows the raw graphical output from AussieGrass. Data is only available up until 2012. From the data it can be seen that the model predicted high pasture coverage at the beginning of the study period, reaching 75% in late 2001. Predicted coverage then drops off sharply, possibly resulting from the low rainfall seen in the period 2003-2006. A minimum value of 30% coverage is seen in early 2006, before coverage begins to climb again. Annual cycles of wet and dry season can be seen before coverage again reaches 75% in early 2012.

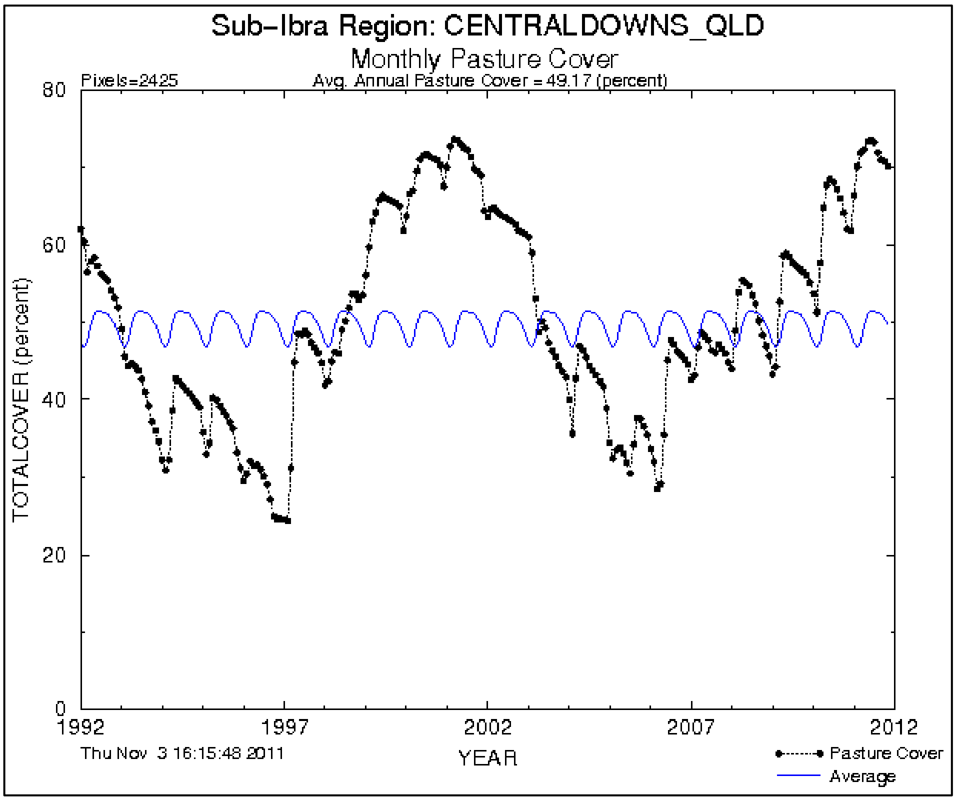


Figure 14: Central Downs Sub-IBRA Monthly Pasture Cover

This data has been digitised for further analysis for the union of the study period and the available data, 2000-2012.The digitised data is in Figure 15.

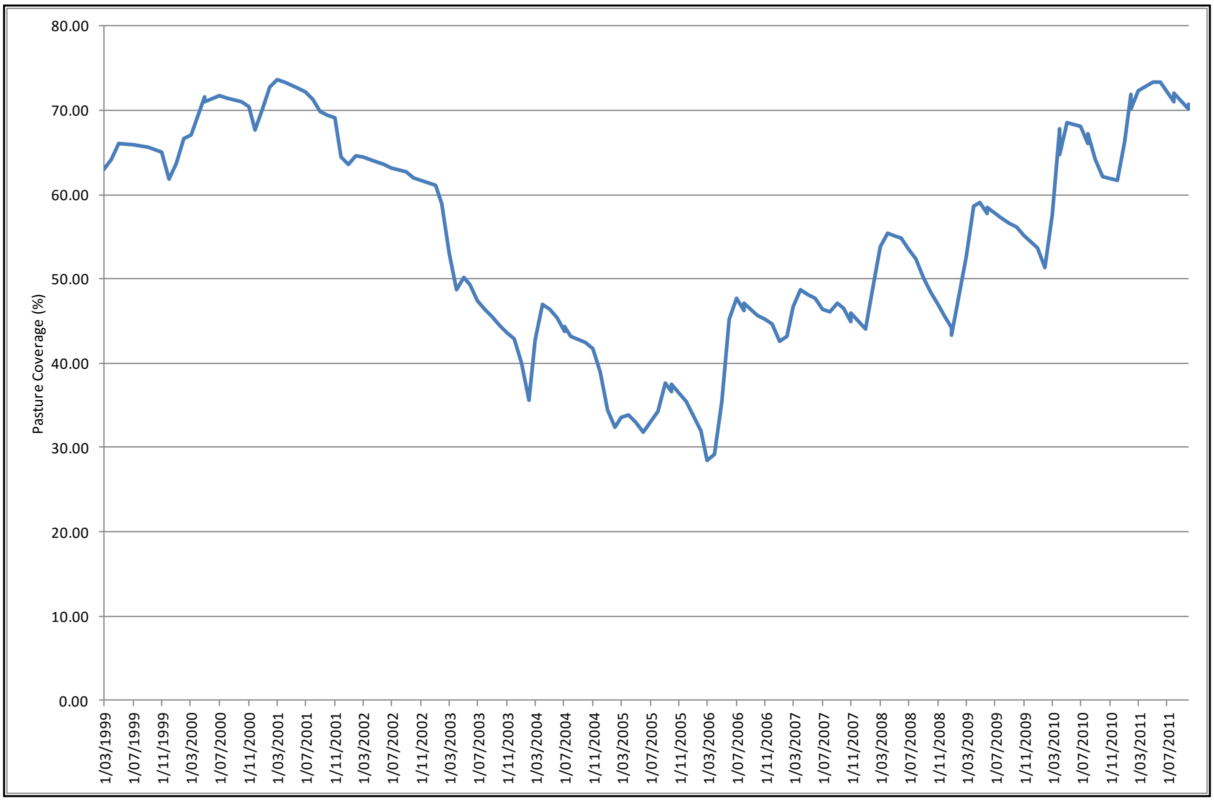


Figure 15: Digitised Pasture Coverage Data

Some initial research and testing was done into pasture growth statistics and data as produced by AussieGrass modelling. The initial results were less than sufficient for a good quality, rigorous comparison, therefore little further work was done and the results are not included in this study. It is recommended in section 6.3 *Further Research,* that this area be investigated further.

5.3.NDVI

As outlined in the section 4.5, using ArcGIS, the MODIS data for the study area was converted to an ASCII table format. From here it was able to be imported into excel where the statistics could be computed. The results of these calculations are in Table 1. A mean NDVI value and standard deviation over the study area were calculated to quantify the results.

To compare the predicted pasture coverage and NDVI results for each season, an NDVI value at which the pasture can be considered to be covered needed to be estimated. A limitation of this study is that no field validation was possible; therefore the values calculated were not able to be checked by this method. The NDVI values of 0, 0.1, 0.2, 0.3 and 0.4 were chosen for testing. The percentages of NDVI values in each season in the study area that lie above this NDVI value represent the covered pasture proportion of the study area. Percentage above 0 and 0.1 values are not included in the table as they remained were very close to 100% for all seasons except a flood in January 2009.

Table 1: NDVI Calculation Results

Season	Mean NDVI	Standard Deviation	% Above NDVI 0.2	% Above NDVI 0.3	% Above NDVI 0.4
Summer 2000	0.308	0.08	95.0	47.9	13.1
Autumn 2000	0.525	0.11	99.9	95.9	84.2
Winter 2000	0.291	0.06	95.1	40.5	3.2
Spring 2000	0.193	0.03	31.0	1.7	0.2
Summer 2001	0.461	0.10	99.6	90.7	77.1
Autumn 2001	0.260	0.08	81.3	21.7	5.7
Winter 2001	0.190	0.05	29.1	3.8	0.9
Spring 2001	0.161	0.04	9.0	1.4	0.3
Summer 2002	0.254	0.09	68.3	25.8	6.8
Autumn 2002	0.186	0.06	24.4	4.3	1.5
Winter 2002	0.171	0.04	14.4	2.4	0.7
Spring 2002	0.154	0.03	6.7	0.9	0.0
Summer 2003	0.161	0.03	8.2	1.3	0.1
Autumn 2003	0.251	0.07	71.1	22.7	4.8
Winter 2003	0.179	0.04	15.3	2.6	0.8
Spring 2003	0.152	0.03	5.1	0.9	0.1
Summer 2004	0.268	0.11	65.9	31.7	13.5
Autumn 2004	0.220	0.04	67.8	3.4	0.7
Winter 2004	0.175	0.04	16.0	2.0	0.6
Spring 2004	0.151	0.03	4.8	0.5	0.0
Summer 2005	0.273	0.09	72.7	36.0	10.5
Autumn 2005	0.186	0.04	26.8	1.8	0.3
Winter 2005	0.186	0.05	27.9	3.3	0.4
Spring 2005	0.155	0.03	8.0	0.6	0.0
Summer 2006	0.183	0.07	25.2	7.3	1.5
Autumn 2006	0.403	0.12	96.2	76.5	49.2
Winter 2006	0.264	0.06	90.2	21.0	3.3
Spring 2006	0.168	0.03	8.7	1.1	0.1
Summer 2007	0.333	0.12	86.9	55.5	28.5
Autumn 2007	0.201	0.05	43.3	3.4	0.5
Winter 2007	0.203	0.05	44.0	4.3	1.0
Spring 2007	0.186	0.04	25.0	1.9	0.2
Summer 2008	0.446	0.11	96.1	87.1	71.9
Autumn 2008	0.247	0.06	76.0	18.3	1.7
Winter 2008	0.204	0.05	46.1	3.3	0.6
Spring 2008	0.144	0.03	5.1	0.8	0.1
Summer 2009	0.359	0.12	92.5	65.6	36.2
Autumn 2009	0.373	0.08	99.5	80.9	34.1
Winter 2009	0.213	0.05	53.7	5.1	1.2
Spring 2009	0.175	0.03	13.3	1.1	0.1
Summer 2010	0.332	0.07	97.8	65.8	16.5
Autumn 2010	0.364	0.08	99.4	79.8	29.3
Winter 2010	0.229	0.05	69.2	8.0	1.6
Spring 2010	0.270	0.10	69.3	34.7	12.4
Summer 2011	0.440	0.12	99.5	85.9	59.4
Autumn 2011	0.487	0.10	99.9	96.6	81.3
Winter 2011	0.232	0.06	67.1	10.2	2.0
Spring 2011	0.174	0.04	14.2	1.7	0.3
Summer 2012	0.211	0.07	39.9	9.5	3.6
Autumn 2012	0.470	0.08	99.8	95.3	83.5
Winter 2012	0.296	0.06	95.7	42.6	4.5
Spring 2012	0.177	0.04	14.8	1.7	0.4
Summer 2013	0.195	0.07	31.4	7.2	2.4
Autumn 2013	0.197	0.05	35.0	4.6	1.2
Winter 2013	0.173	0.05	14.7	3.0	0.9
Spring 2013	0.156	0.03	7.6	1.1	0.1

Summer 2014	0.160	0.04	9.9	1.3	0.2
Autumn 2014	0.202	0.05	37.9	4.6	0.8
Winter 2014	0.170	0.04	12.9	2.5	0.6
Spring 2014	0.147	0.03	5.8	0.6	0.0
Summer 2015	0.364	0.13	89.8	64.3	37.9
Autumn 2015	0.171	0.04	13.4	1.9	0.5
Winter 2015	0.166	0.04	11.3	2.0	0.6
Spring 2015	0.148	0.03	5.5	0.8	0.1
Summer 2016	0.326	0.13	85.0	48.7	25.7
Autumn 2016	0.309	0.11	81.6	49.4	22.3
Winter 2016	0.261	0.10	70.7	22.7	9.9

These relationships between coverage and NDVI values are in Figure 16, Figure 17and Figure 18.

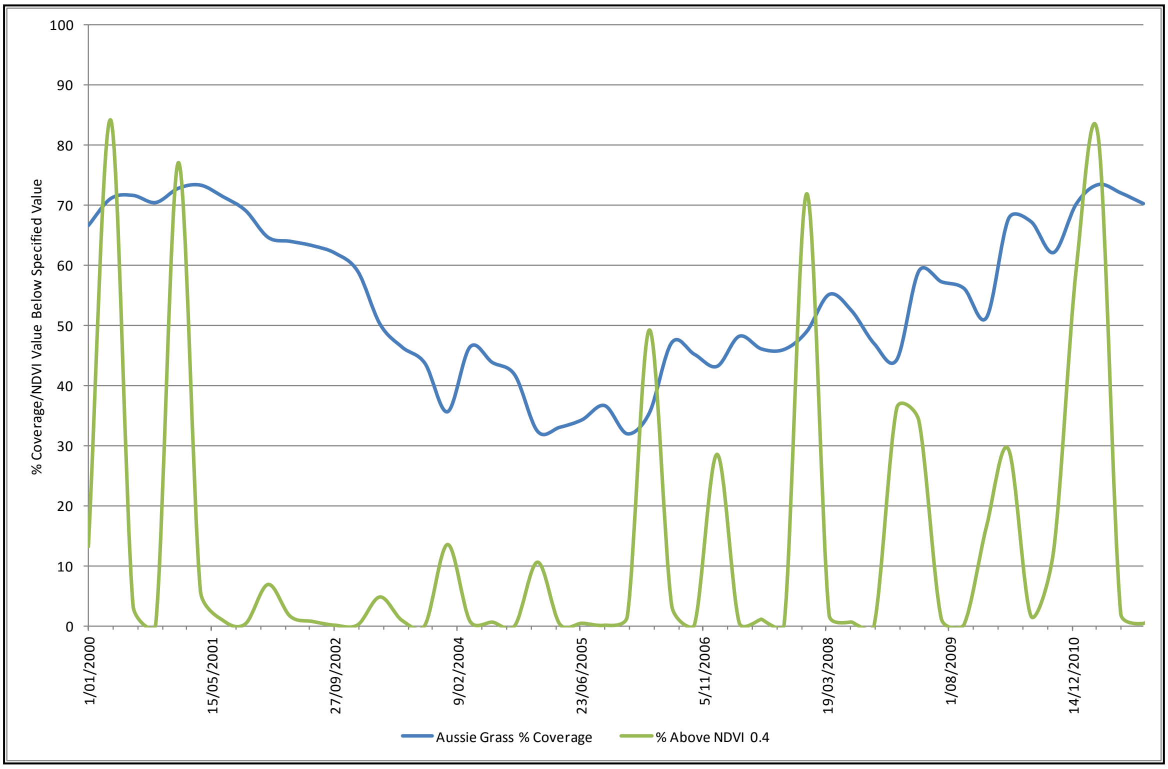


Figure 16: Aussie Grass % Coverage vs % Above NDVI 0.4

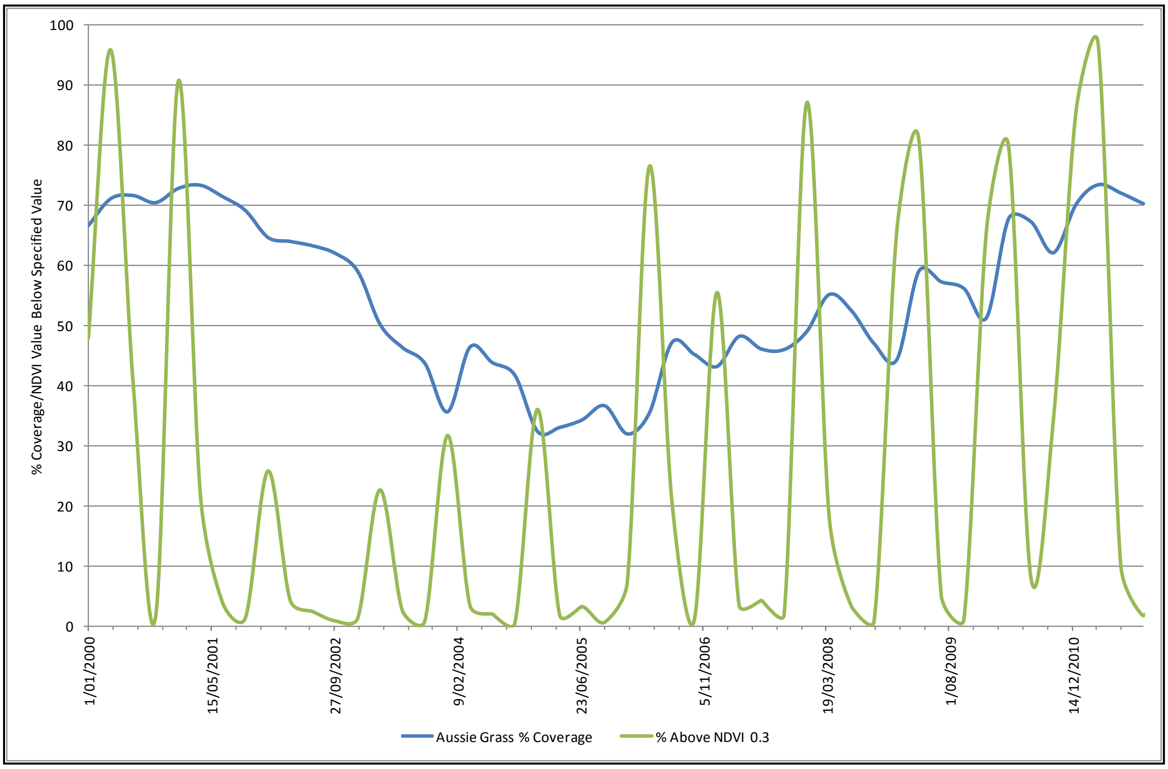


Figure 17: Aussie Grass % Coverage vs % Above NDVI 0.3

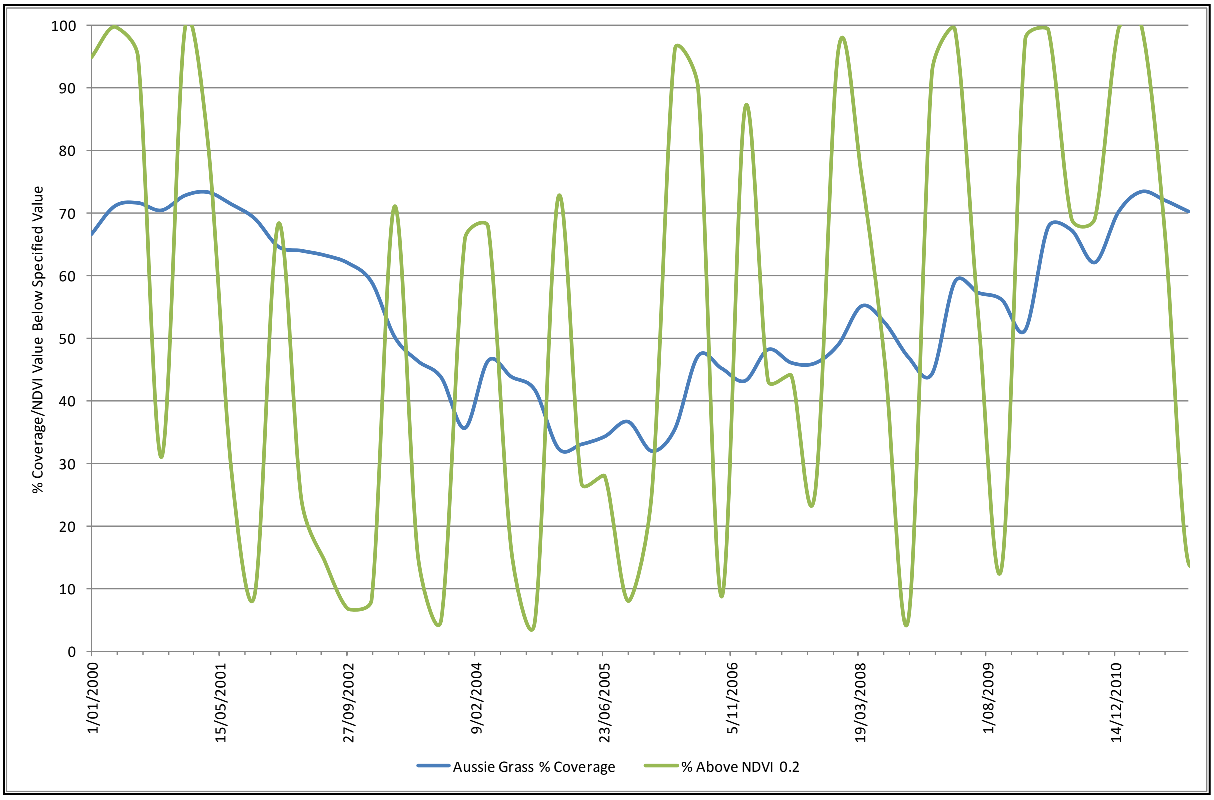


Figure 18: Aussie Grass % Coverage vs % Above NDVI 0.2

From these graphs it can be seen that only a loose correlation is evident between predicted Aussie Grass pasture coverage for the central downs sub-IBRA region and the NDVI observations. For all three tested values, seasonal variation is much stronger than that predicted by Aussie Grass. Some seasonal variation can be seen in the Aussie Grass data, particularly in the later part of the study period; however it is not as strong as that observed.

Very little correlation can be seen; therefore further statistical analysis will not be useful in understanding the results. Predicted pasture coverage drops slowly during the period 2001-2006. This drop can also be seen in the NDVI observations, however at a much more rapid pace, with summer maximums as early as 2002 limited to 7% for 0.4, 26% for 0.3 and 68% for 0.2. NDVI observations remain at this low level for the duration of the period in which predicted coverage drops.

The same pattern is then evident as predicted pasture coverage rises during the second half of the decade. As early as summer 2006, NDVI autumn maximums reach 49% for 0.4, 76% for 0.3 and 96% for 0.2. These maximums rise slowly up until 2012, following the general trend of the predicted pasture coverage values.

To test the variation across the study area of the NDVI values, the mean for each season was graphed against the standard deviation. The results of this are in Figure 19.

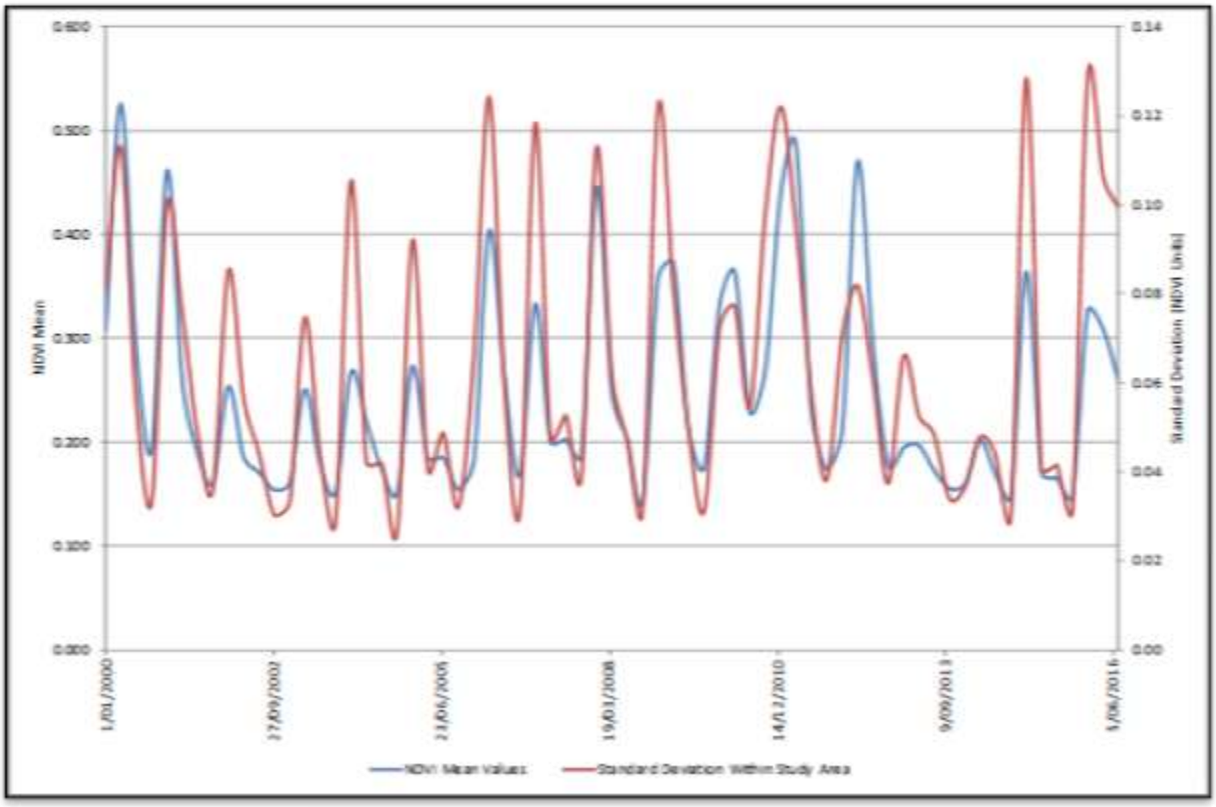


Figure 19: NDVI Mean and Standard Deviation

From this figure it can be seen that a strong correlation is evident between higher mean NDVI value and a greater variability of NDVI values across the study area. This means that at times of greater vegetation greenness, some areas of the study area remain at low NDVI values, seemingly not responding to rainfall in the same way or missing out of rainfall. This pattern will be discussed further in section 6.0.

Previous studies have shown a strong correlation between rainfall and NDVI values/grassland growth including (Orr D. , 2010) and (Perera & Apan, 2009). However, these have not looked at the trend over a long term. In Figure 20, for the 17 year study period, average NDVI values are graphed against average seasonal rainfall.

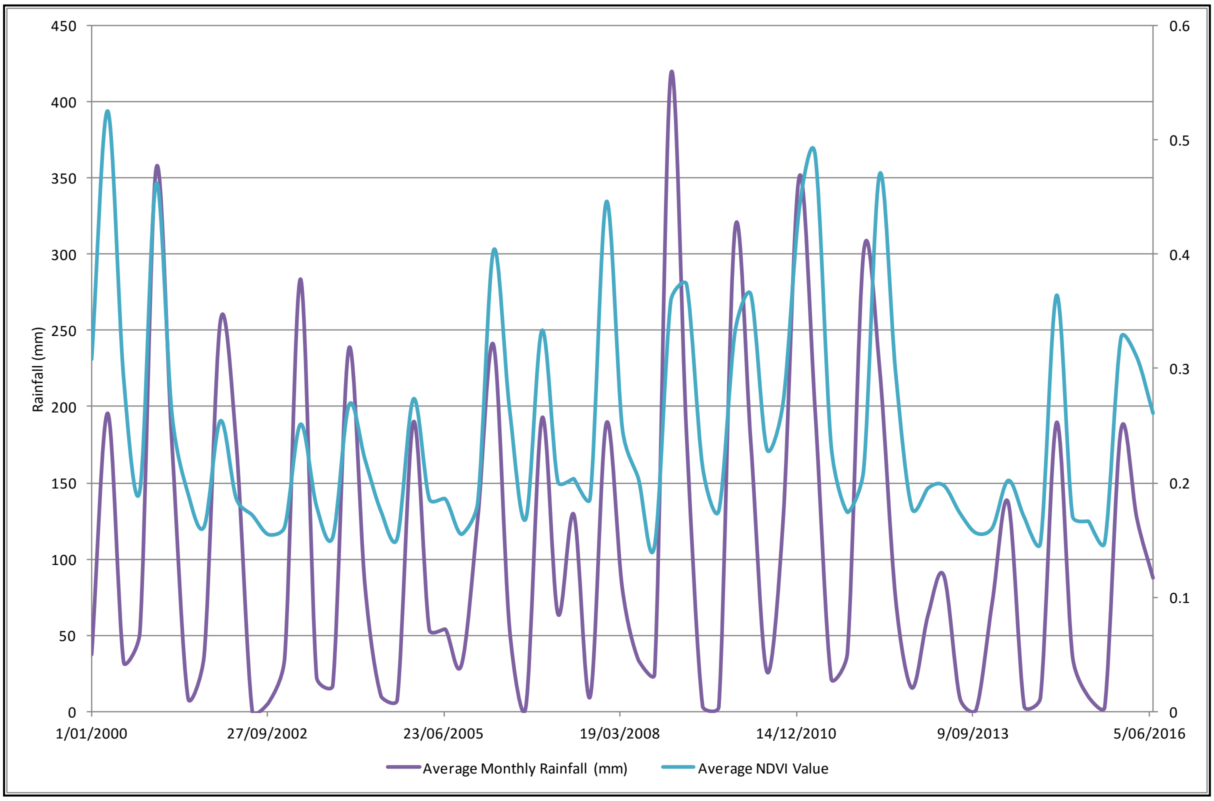


Figure 20: Average Seasonal Rainfall vs. Average NDVI Value

From this it can be seen that the trend of high NDVI in 2000-2001, followed by lower greenness in 2002-2006, a gradual increase to 2012 and a drop off of NDVI in 2013-2016 is matched loosely by the rainfall seen in each year. Although some winter rains were recorded at the weather stations, NDVI and therefore grass production appears to have dropped significantly during these months. A large increase in greenness is then seen in most years when rain increases slightly.

Regression analysis has been completed to test the strength of the correlation. The results are in Table 2.

Table 2: Seasonal Rainfall and NDVI Regression

Regression Equation (with Standard Errors)	R^2	P-Value Intercept	P-Value Rainfall
NDVI Value = 6.6×10^{-4} (7.85×10^{-5}) x Rainfall + 0.177(0.011)	51.7%	1.69×10^{-23}	5.08×10^{-12}

To get a clearer picture of this relationship, annual average rainfall and NDVI values have been calculated and are in Figure 21.

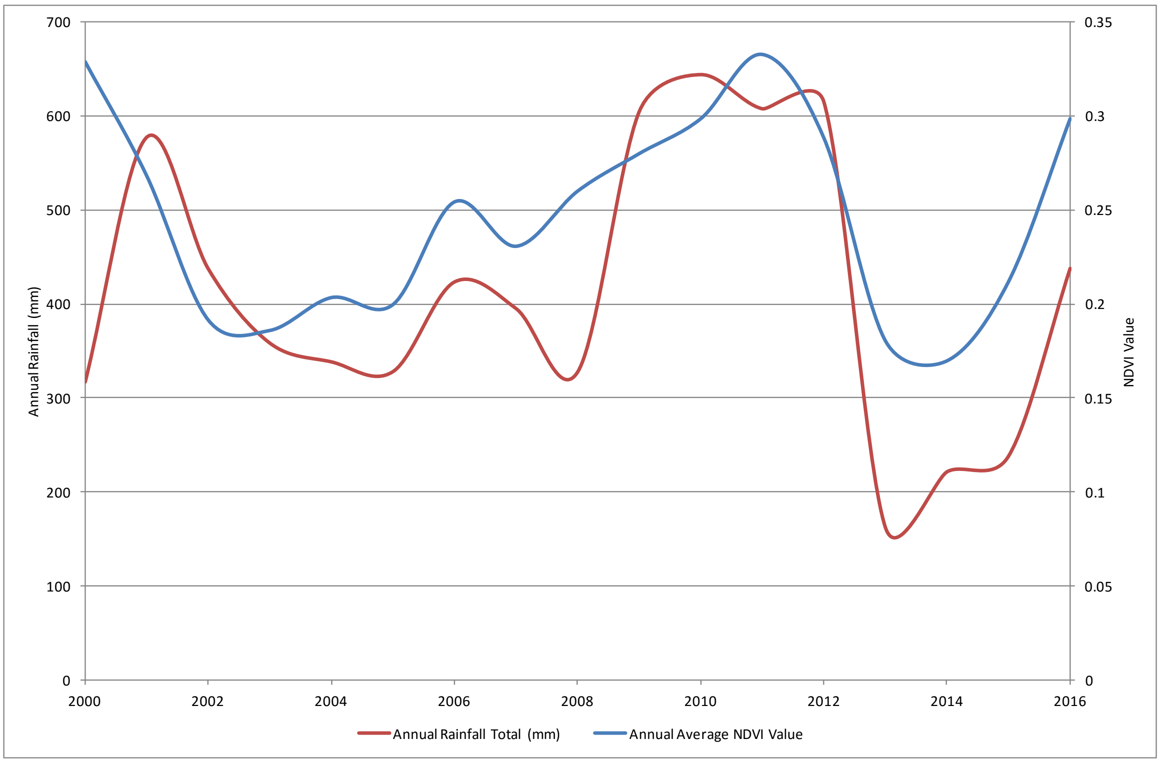


Figure 21: Annual Average NDVI Value vs. Annual Rainfall Totals

The general trends as explained earlier are again evident in this comparison. The trends seen in the NDVI values may also be explained by comparing the results to the SOI values seen during the study period. NDVI results are compared to SOI values in Figure 22.

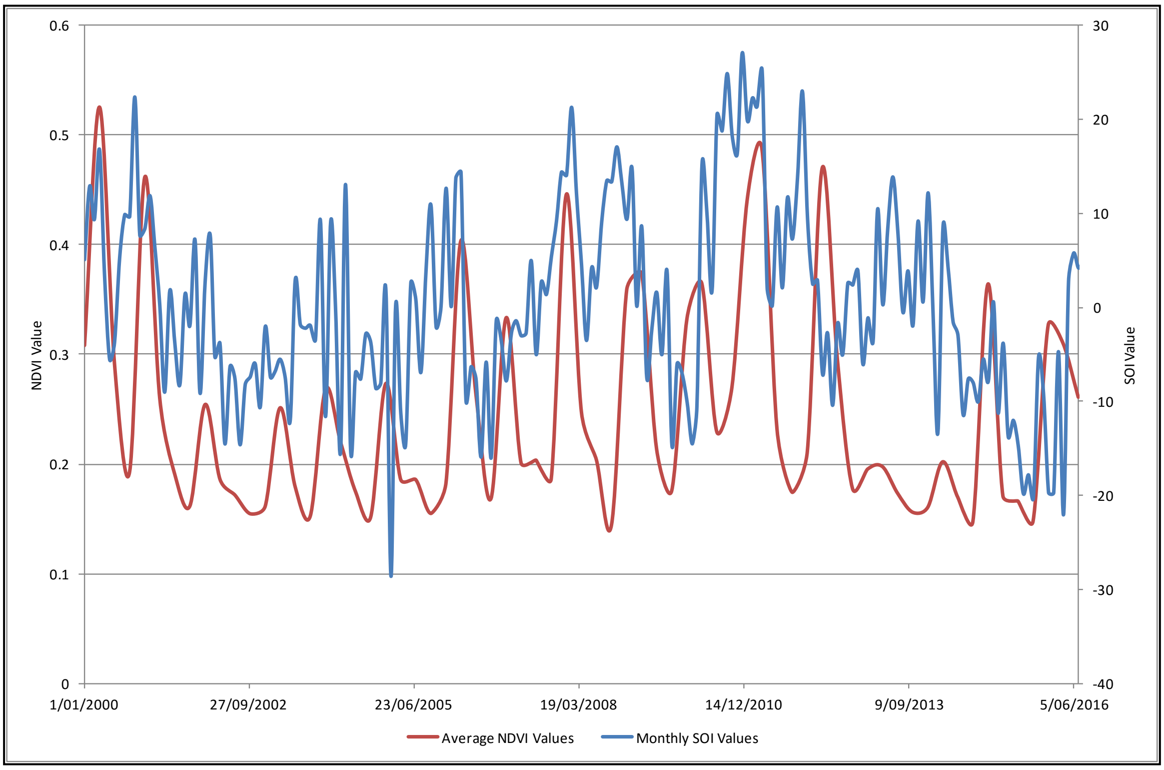


Figure 22: NDVI Value and SOI Value

Regression analysis has been completed to test the strength of the correlation. The results are in Table 3.

Table 3: SOI and NDVI Regression

Regression Equation (with Standard Errors)	R^2	P-Value Intercept	P-Value SOI
NDVI Value = 0.087 (0.031) x SOI + 95.951(3.349)	10.8%	1.78×10^{-37}	0.0066

5.4.KML Output

The NDVI images were processed as described in section 4.5 and a series of KML files that allowed the viewing of all images by season were generated. A selected series of NDVI images are included here, while a full set is included in Appendix A. The code for the KML files is also included in Appendix B. It should be noted that the same colour scaling has been used on all images for ease of comparison.

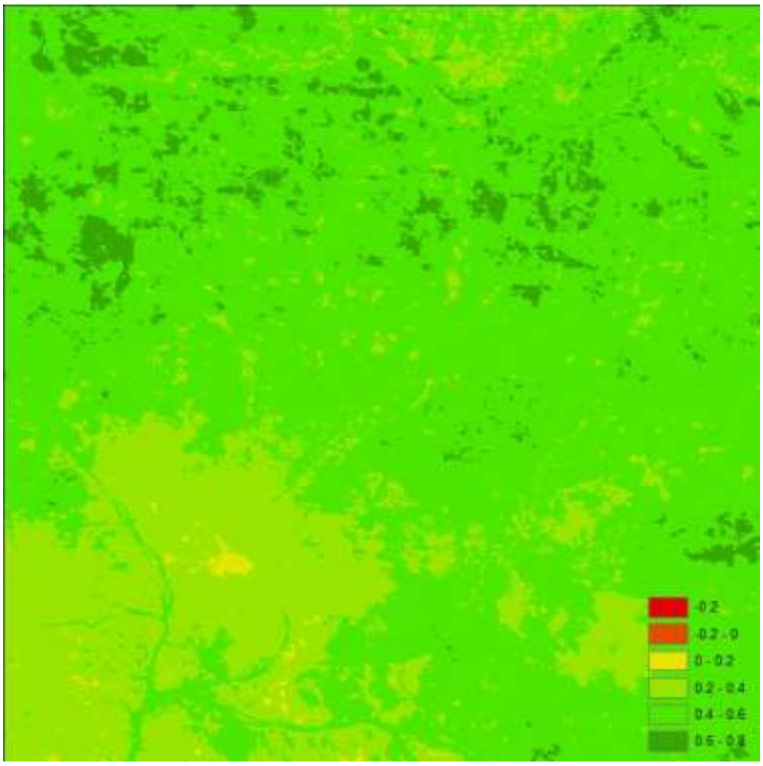


Figure 23: A Wet Year - Summer 2001

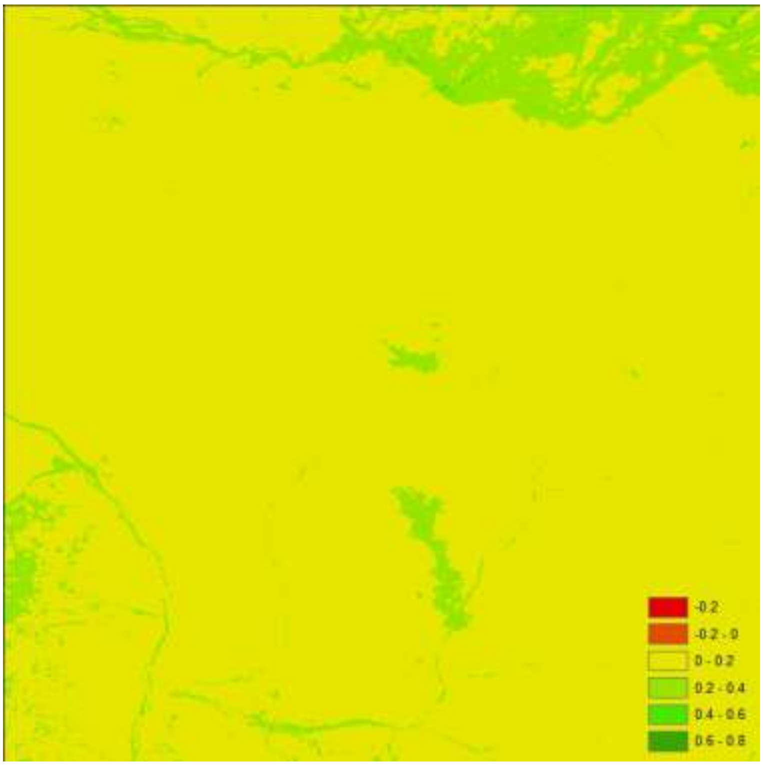


Figure 24: A Dry Year - Summer 2003

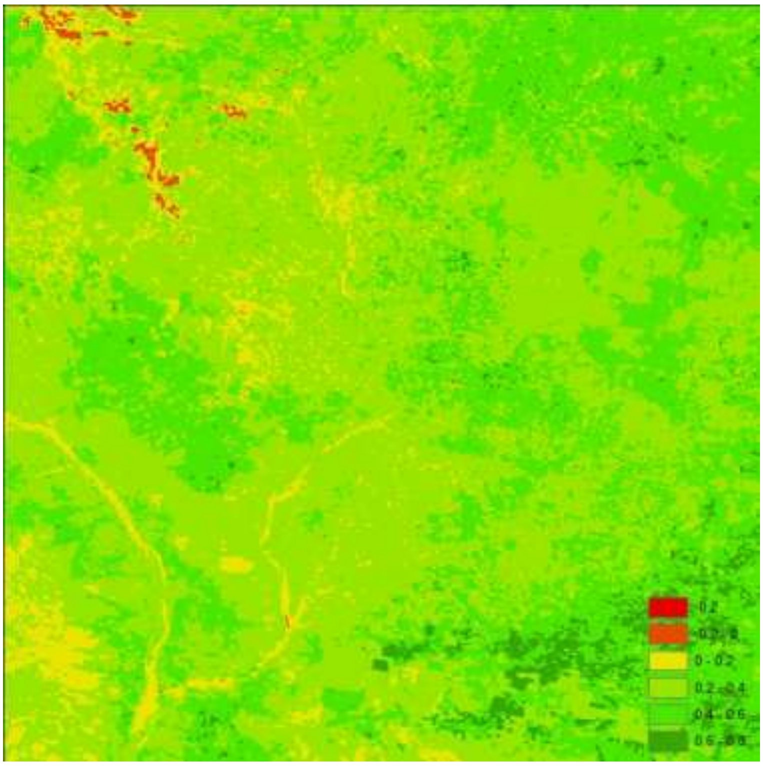


Figure 25: Flooding in Julia Creek/Flinders River

The images have also been included in a KML file for ease of viewing. As mentioned in section 4.6, using timespan tags in a text editor, a KML file overlaying the 17 images of each season was generated. A sample of the KML code is included in Figure 26 while ... shows an overlayed image in Google Earth with the time slider in view.

```
<?xml version="1.0" encoding="UTF-8"?>
<kml xmlns="http://www.opengis.net/kml/2.2" xmlns:gx="http://www.google.com/kml/
  <Folder>
  <name>Autumn</name>
  <GroundOverlay>
    <name>Autumn 2000</name>
    <TimeSpan>
    <begin>2000-04-06</begin>
    <end>2000-04-07</end>
    </TimeSpan>
    <description>NDVI Image of Study Area April 6, 2000.
    </description>
    <Icon>
      <href>https://i.imgsafe.org/ce7b5b0147.jpg</href>
    </Icon>
    <LatLonBox>
      <north>-20.5</north>
      <south>-22.5</south>
      <east>144</east>
      <west>142</west>
      <rotation>0</rotation>
    </LatLonBox>
  </GroundOverlay>
```

Figure 26: Sample KML Code

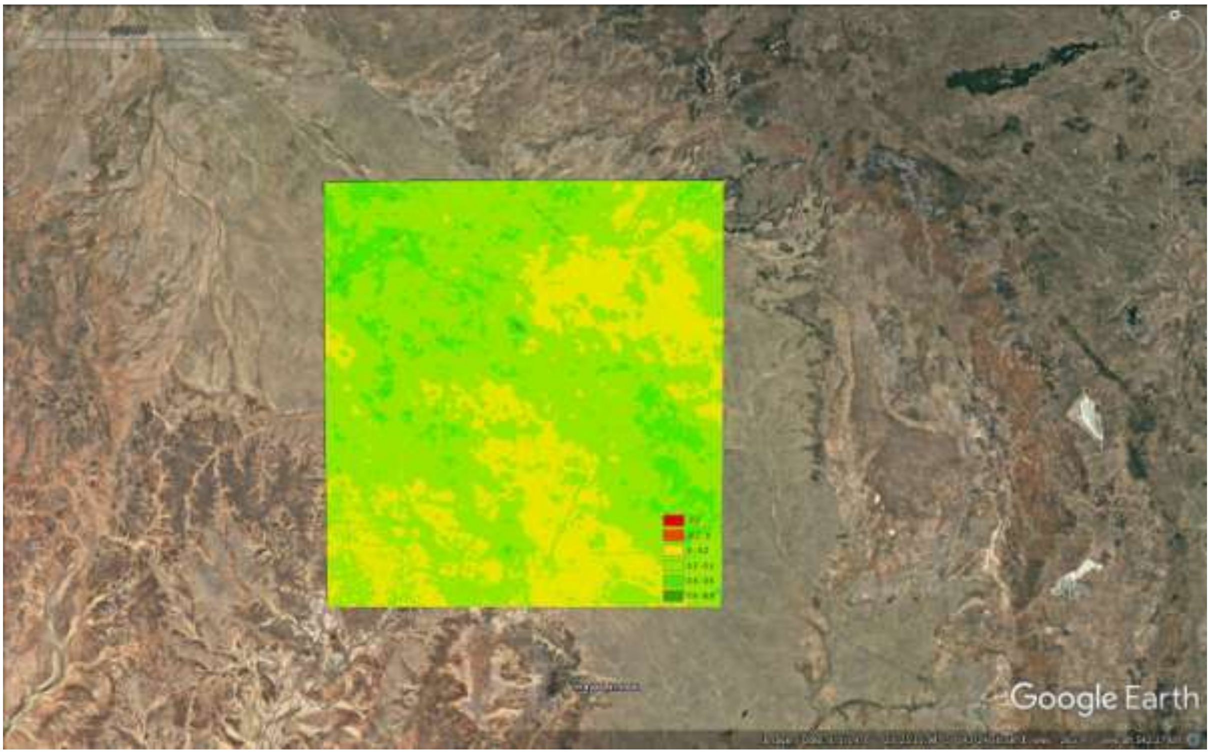


Figure 27: KML File in Google Earth

6.0 Discussion

6.1. Discussion of Findings – Rainfall

Previous studies have shown a relationship between increased rainfall and increased growth of Mitchell Grass through observation methods including remote sensing and vegetation indexes. This has been recreated in this study, however over a longer time period. From both Figure 20 and Figure 21, at the point where rainfall begins to increase or decrease, the NDVI value does the same either simultaneously or with a slight delay.

In some cases such as during 2007 and 2014, rainfall drops to lower levels or remains lower, while average NDVI can be seen to remain at higher levels or increase without explanation. There appears to be some other factors having an effect here, not registered or thought of by this study. One such factor is the variability of rainfall over the study area. Over such a large area and in a semi-arid climate, rainfall variability can be high. Using three weather stations to cover such a large area is not an ideal situation to be in. This could be rectified in the future by introducing more rainfall recording stations, or generating a model that predicts rainfall more accurately than those available now.

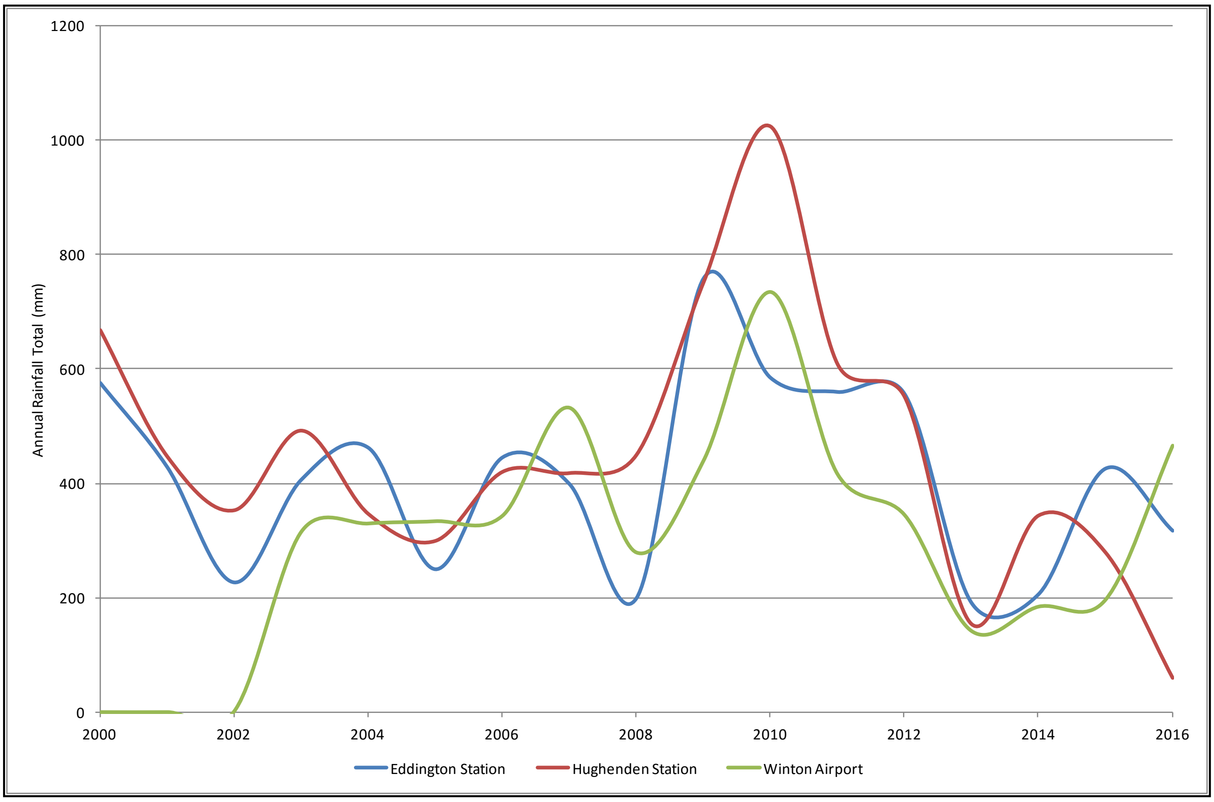


Figure 28: Rainfall Variability

The variability of the rainfall at the three selected stations can be seen in Figure 28. Due to the proximity of the stations the same general trend can be seen. The variability across other portions of the study area could be either greater or smaller than that seen here. This could explain the periods where NDVI moved independently of the annual rainfall total.

Comparisons of NDVI with the SOI provided similar results to the comparison with rainfall. While some correlation can be seen, it is not enough to be able to draw solid conclusions or make any broad remarks. ENSO is a very large scale measure; therefore it was unlikely to see it predicting NDVI or rainfall data. There are many factors which come into play to determine the growth rate in the Mitchell Grasslands, so it is not surprising that results from these comparisons have been unpredictable.

ENSO does appear to be loosely related to the NDVI results. This is a good outcome due to the large variability that is seen in climate and weather patterns. Also, it confirms previous knowledge in this area that ENSO has an either positive or negative effect depending on the SOI value, on the amount of rainfall that occurs in Eastern Australia.

6.2. Discussion of Findings – Aussie Grass

It has been estimated that an NDVI value of 0.3 approximates the point at which a section of pasture is no longer ‘covered’, by comparison to predicted pasture coverage. This is unlikely to be a reflection of reality since NDVI detects greenness of a plant and its production of chlorophyll, as opposed to whether or not the plant is actually present. In Orr’s study from 2010, it was found that in a sustainably managed pasture Mitchell Grass plants have a very long life cycle – up to 26 years has been recorded.

In dryer years such as that shown in Figure 24, a blanket NDVI value between 0 and 0.2 is seen. It is most likely that this area remains covered by Mitchell and other Grasses, however chlorophyll production and therefore red reflectance has dropped to almost zero. This theory lends itself to the idea of pasture growth statistics from Aussie Grass being a better dataset for comparison with NDVI data. Preliminary testing of this concept was unsatisfactory therefore it was removed from the remainder of the study. It would however make sense as NDVI measures greenness, a sort of wet mass, rather than a dry mass is probably what predicted pasture coverage is measuring.

In poorly managed pastures, such as those subjected to overgrazing, broad-leafed weeds and annual grasses with short life cycles have been found to be more prevalent. This may explain the high sensitivity of NDVI to rainfall and its sharp rises and falls when compared to the predicted pasture coverage from Aussie Grass. In the early part of the 2000s, poor management is likely to have occurred following a number of wet years in the 1990s. It has been shown that increased profits can be seen in the first 5 years of overgrazing, and then using the same pastures leads to financial ruin as the established grasses and feed have been destroyed and cannot regenerate(Orr & Phelps, 2013). Over the long term, this initial period of unsustainable grazing is quickly overtaken by the grazier who used sustainable practices from the beginning(Orr & Phelps, 2013).

6.3. Further Research

This project is likely to generate more questions than it has answered, however this opens up a range of potential future areas of research that have the potential to improve outcomes for graziers and the ecology & environment of the Mitchell Grasslands. These include topics in both the spatial sciences as well as other scientific disciplines.

NDVI measures could be used for bushfire detection or locating areas that are in need of a hazard reduction burn. While the use of MODIS data for this purpose may not be suitable due to its resolution, other free, multi-spectral data from which NDVI can be calculated is available.

Alternatively, study could be done, looking at the proportion of the study area used in this project or another area that is covered by Mitchell Grass, as opposed to trees, other grass types or broad-leafed weeds. Combined with the NDVI data and weather patterns in this study, this may improve the predictions of NDVI based on rainfall and SOI. The use of higher resolution imaging would be useful in this case.

LIDAR is a mature technology that could be implemented on the Mitchell Grasslands. Grass height is a known measure of the availability of cattle feed. Using LIDAR scans of the grasslands, grass height above the surrounding terrain height could be measured.

Finally, as previously mentioned, the Aussie Grass pasture growth rate data which was removed from this study could be investigated further. A different approach would be needed however and some more information would be needed as to how the data is generated and what is being measured.

7.0 Conclusions

The objectives of this study were set out in section 1.3, briefly they included, comparing MODIS and industry standard grassland data, correlating NDVI, weather and climate data, the presentation of results in an easy to view, use and edit format as well as discussing methods of implementation.

Weather and climate data in the form of rainfall and ENSO data were collected and analysed for correlation as should have been seen based on literature. This however was not the case over the study period and the study area. A weak pattern was found however and this is likely to be as a result of the large variability of weather systems and the small area studied, relative to the scale of the ENSO system.

NDVI data was also calculated and manipulated into a useable form with the help GIS software. It was then compared individually to the weather and climate data. Some correlation could be seen, giving positive results. This means that it can be concluded that using weather patterns or by extension predicted weather patterns including that of SOI, the availability of feed in the Mitchell Grasslands may also be predicted.

NDVI images of the study area have been successfully generated using the methods outlined. They have then been included in a Google Earth – KML time series file for viewing. These images are not particularly useful in the prediction of future conditions on the grasslands; however they are very useful for the study of past conditions. Taking into account past management practices combined with observed weather patterns, conclusions can be drawn as to whether or not the right decisions have been made.

This study has created more questions than it has definitively answered and generated scope for a lot of further research. Further work could be done into the impact and location of bushfires, vegetation mapping of the Mitchell Grasslands using multi-spectral imaging or LIDAR. Also, existing Aussie Grass pasture growth rate data could be analysed and validated against the NDVI output.

8.0 List of References

Ballagh, L. M., Raup, B. H., Duerr, R. E., Khalsa, S. S., Helm, C., Fowler, D., & Gupte, A. (2011). Representing scientific data sets in KML: Methods and Challenges. *Computers & Geosciences 37*, 57-64.

Bureau of Meteorology. (2012). *Southern Oscillation Index*. Retrieved from Climate Glossary: http://www.bom.gov.au/climate/glossary/soi.shtml

Bureau of Meteorology. (2016). Retrieved from Normalised Difference Vegetation Index: http://www.bom.gov.au/climate/austmaps/about-ndvi-maps.shtml

Bureau of Meteorology. (2016). *The Southern Oscillation Index*. Retrieved from http://www.bom.gov.au/climate/enso/history/ln-2010-12/SOI-what.shtml

Central African Regional Program for the Environment. (2014). Retrieved from Congo Basin Satellite Imagery Resources: http://carpe.umd.edu/geospatial/satellite_imagery_resources.php

Chaowei, Y., Wong, D., Yang, R., Kafatos, M., & Li, Q. (2005). Performance Improving Techniques in Wed-Based GIS. *International Joournal of Geogrphical Information Sciences 19 (3)*, 319-342. DOI 10.1080/13658810412331280202.

DSITI. (2016). Retrieved from Australian Grassland And Rangeland Assessment by Spatial Simulation: https://www.longpaddock.qld.gov.au/about/researchprojects/aussiegrass/index.html

Earth Observatory. (2000, August 30). Retrieved from Measuring Vegetation (NDVI & EVI): http://earthobservatory.nasa.gov/Features/MeasuringVegetation/

Eleveld, M. A., Wagtendonk, A. J., Pasterkamp, R., & De Reus, N. O. (2007). WATeRS: an open Web Map Service with near real time MODIS Level 2 standard chlorophyll products of the North Sea. *International Journal of Remote Sensing 28 (16)*, 3693-3699. DOI 10.1808/01431160701253204.

Federal Department of Environment. (2008). *Mitchell Grass Downs Bioregion.* Retrieved from https://www.environment.gov.au/system/files/resources/a8015c25-4aa2-4833-ad9c-e98d09e2ab52/files/bioregion-mitchell-grass-downs.pdf

Forrest, P. (1988). *A Rush For Grass.* Brisbane: Ilfracombe Shire Council.

Fu, X., Tang, C., Zhang, X., Fu, J., & Jiang, D. (2014). An improved indicator of simulated grassland production based on MODIS NDVI and GPP data: A case study in the Sichuan province, China. *Ecological Indicators 40*, 102-108.

GeoImage. (2016). Retrieved from SPOT 6 & 7: http://www.geoimage.com.au/satellite/spot-6

Goddard Space Flight Centre. (2010). Retrieved from MODIS - Specifications: http://modis.gsfc.nasa.gov/about/specifications.php

Goddard Space Flight Centre. (2010). Retrieved from MODIS - Data: http://modis.gsfc.nasa.gov/data/

Google Developers. (2016, February 9). Retrieved from KML FAQ: https://developers.google.com/kml/faq#getting-started

Google Developers. (2016, February 9). Retrieved from KML Tutorial: https://developers.google.com/kml/documentation/kml_tut#for-more-information

Gordon, J. (2003, July 16). We Slid off the sheep's back, now sliding off the land, too. *The Age*.

Houts, M. E., Price, K. P., & Martinko, E. A. (2001). Differences in Onset of Greenness: A Multitemporal analysis of Grass and Wheat in Kansas. *Proceedings, Annual Convention American Society of Photogrammetric Engineering and Remote Sensing.* St Louis, Missouri.

Lau, L., Young, R. A., McKeon, G., Syktus, J., Duncalfe, F., Graham, N., & McGregor, J. (1999). Downscaling global information for regional benefit: coupling spatial models at varying space and time scales. *Environmental Modelling and Software 14 (6)*, 519-529. doi:10.1016/S1364-8152(99)00016-X.

Leroux, L., Jolivot, A., Begue, A., Seen, D. L., & Zoungrana, B. (2014). How reliable is the MODIS land cover product for crop mapping sub-saharan agricultural landscapes? *Remote Sensing 6(9)*, 8541-8564. DOI:10.3390/rs6098541.

LPDAAC. (2016). Retrieved from Land Processes Distributed Active Achive Center - MODIS Products Table: https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table

Lunetta, R. S., Knight, J. F., Ediriwickrema, J., Lyon, J. G., & Dorsey Worthy, L. (2006). Land cover change detection using multi-temporal MODIS NDVI. *Remote Sensing of Environment 105*, 142-154.

NASA. (2015). Retrieved from Earth Observing-1: http://earthobservatory.nasa.gov/Features/EO1/eo1_2.php

National Oceanic and Atmospheric Administration. (2016). Retrieved from AVHRR: https://www.nsof.class.noaa.gov/data_available/avhrr/index.htm

Numerical Terradynamic Simulation Group. (2007). Retrieved from MODIS Flux Tower Comparison: http://www.ntsg.umt.edu/project/ameriflux

Numerical Terradynamic Simulation Group. (2010). Retrieved from MODIS GPP/NPP Project (MOD17): http://www.ntsg.umt.edu/project/MOD17/

O'Reagain, P. J., & Scanlan, J. C. (2013). Sustainable management for rangelands in a variable climate: evidence and insights from northern Australia. *Animal 7(1)*, 68-78. http://dx.doi.org.ezproxy.usq.edu.au/10.1017/S175173111100262X .

Orr, D. (2010). Secrets Unlocked After 26 Year Mitchell Grass Study. *Australian Farm Journal*, 52-54.

Orr, D. M., & Phelps, D. G. (2013). Impacts of level of utilisation by grazing on an Astrebla (Mitchell grass) grassland in north-western Queensland between 1984 and 2010. 2. Plant species richness and abundance. *The Rangeland Journal*, 17-28. doi:10.1071/RJ11069.

Perera, K., & Apan, A. (2009). Analysing Biomass Fluctuations in Mitchell Grassland, Australia, in wet and Dry Rainy Months Using MODIS Data. *Surveying and Spatial Sciences Institute Biennial International Conference.* Adelaide, Australia.

Queensland Government. (2016, August 18). *Queensland Globe*. Retrieved from Business and Industry Portal: https://www.business.qld.gov.au/business/support-tools-grants/services/mapping-data-imagery/queensland-globe

Rowland, M. J., & Border, A. (1990). *The Mitchell Grass Downs Biogeogrphical Zone: A Heritage Resource Assessment.* Brisbane: Department of Environment and Heritage.

Savanna Explorer. (2010). Retrieved from Mitchell Grasslands: http://www.savanna.org.au/mg/

U.S. Geological Survey. (2015). *Landsat - Earth Observation Satellites Fact Sheet.* Reston, VA: U.S. Geological Survey.

University of Michigan. (2008, 10 31). Retrieved from The Flow of Energy: Primary Production to Higher Trophic Levels: http://www.globalchange.umich.edu/globalchange1/current/lectures/kling/energyflow/energyflow.html

Wang, J., Rich, P. M., & Price, K. P. (2003). Temporal responses of NDVI to precipitation and temperature in the central Great Plains, USA. *International Journal of Remote Sensing 24(11)*, 2345-2364.

Wardlow, B. D., & Egbert, S. L. (2007). Large-area crop mapping using time-series MODIS 250m NDVI data: An assessment for the US Central Great Plains. *Remote Sensing of Environment 112*, 1096-1116.

Wardlow, B. D., & Egbert, S. L. (2010). A comparison of MODIS 250-m EVI and NDVI data for crop mapping: a case study for southwest Kansas. *International Journal of Remote Sensing 31(3)*, 805-830.

Yuan, X., Li, L., Chen, X., & Shi, H. (2015). Effects of Precipitation Intensity and Temperature on the NDVI-based Grass Change over Northern China during the period 1982 to 2011. *Remote Sensing 7(8)*, 10164-10183. DOI 10.339/rs70810164.

Appendix A. Project Specification

For: Thomas Robertson

Title: Application of Google Earth and MODIS data to assess the health of Mitchell Grasslands, QLD, through a Web-Based GIS approach.

Major: Surveying

Supervisor: Kithsiri Perera

Sponsorship: None

Enrolment: ENG4111 – EXT S1, ENG4112 – EXT S2

Project Aim: Investigate the remote sensing capabilities of low-cost/publically available satellite data in determining vegetative growth in response to various climatic patterns of grazing pasture, particularly the Mitchell grasslands in Queensland.

Programme: Issue A, March 2016

1. Research Background Information on current methods of vegetation detection, including greenness (NDVI – Normalized Difference Vegetation Index), moisture content, disease capabilities and any other available methods.

2. Research background information on the Mitchell Grass Downs and identify the most important criteria which determine grassland health and grazing productivity.

3. Selection of Study Area – An area around Hughenden, QLD, will be selected due to available MODIS NDVI images from NASA, and some of the previously conducted field investigation records.

4. Design the methodology

5. Collect satellite images and climate/weather data as appropriate

6. Investigate the link between NDVI images, respective weather conditions, and actual ground conditions (based on Google Images). Produce Web based output of results using HTML and KML

7. Draw conclusions regarding the application of low-cost/publically available satellite data to this subject matter.

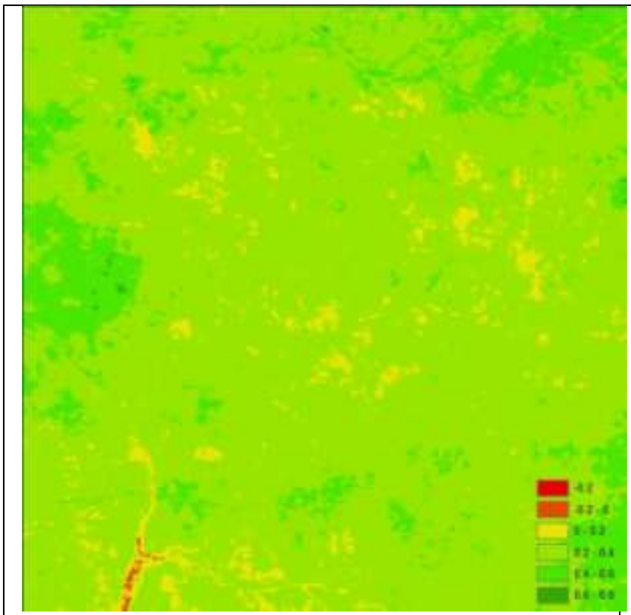
If Time Permits:

8. Research and suggest improvements to grass land use with a view to improving environmental and agricultural outcomes.

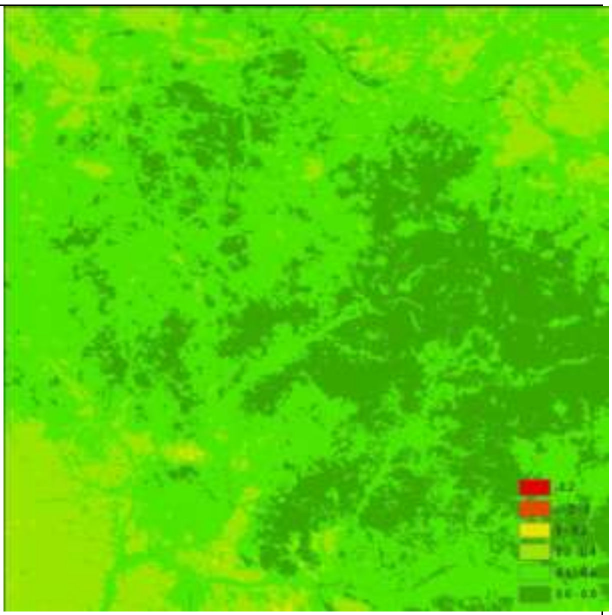
9. Broaden the scope of the project to provide a wider analysis of the Mitchell Grass Downs using the methodology established.

Appendix B. NDVI Images

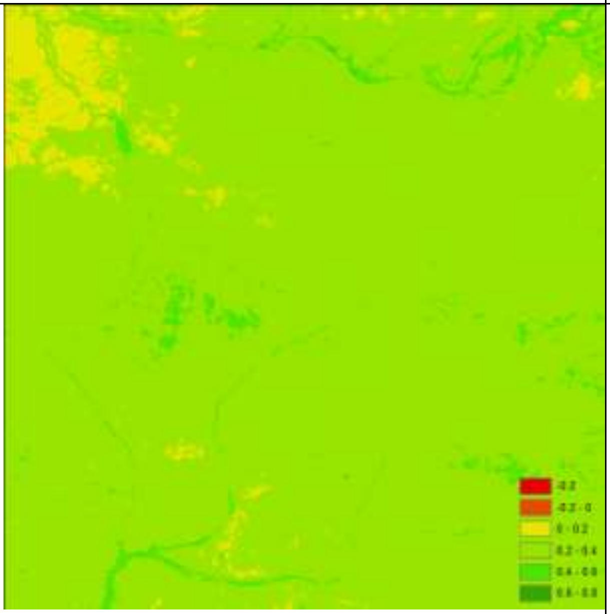
2000



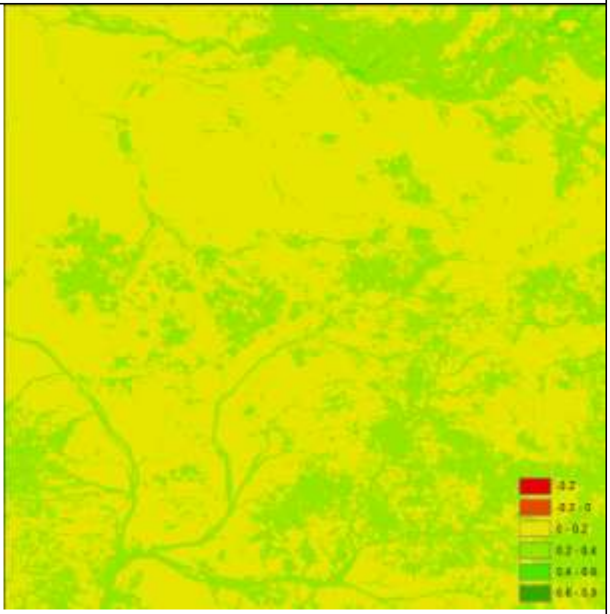
Summer



Autumn

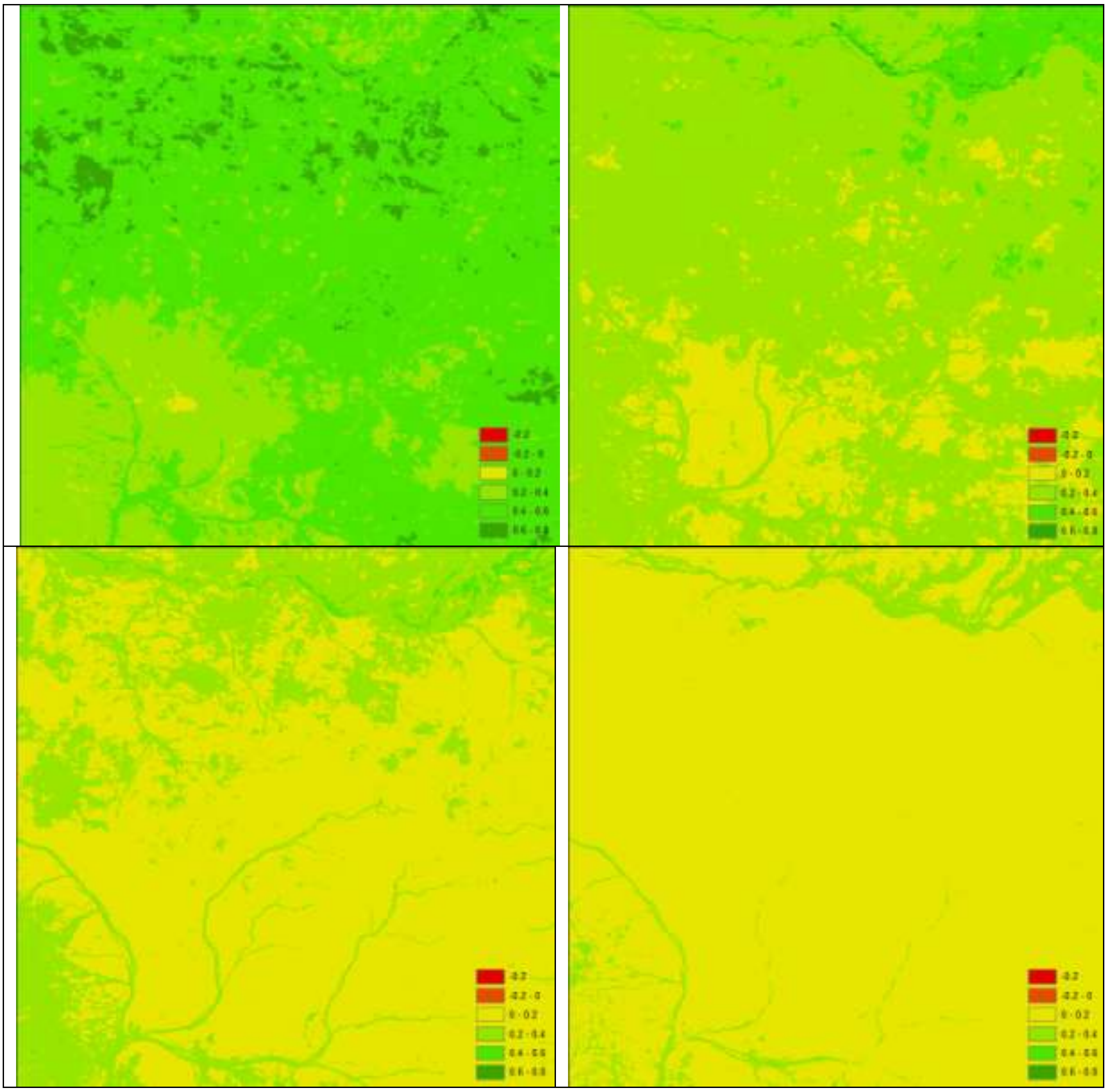


Winter

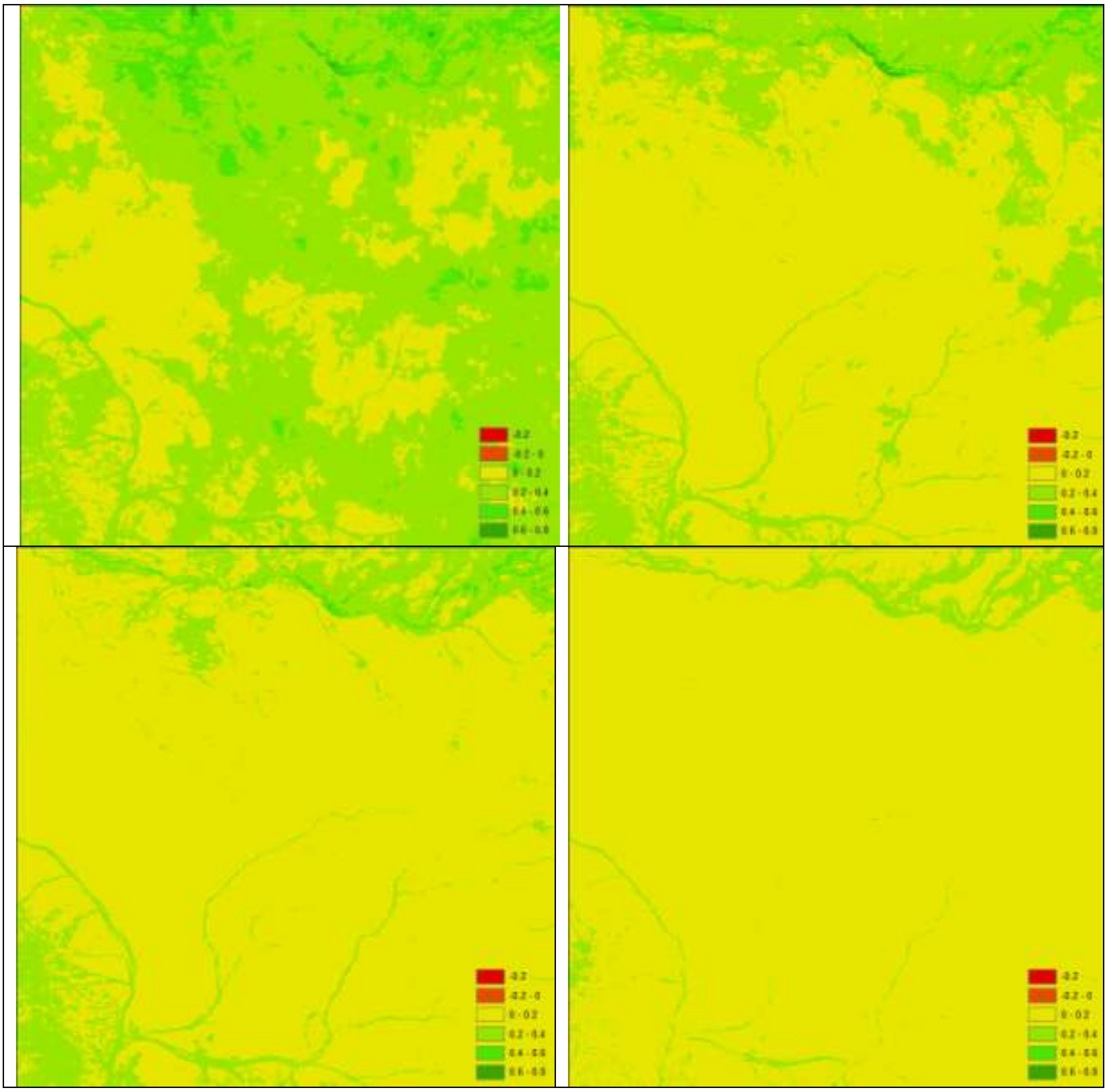


Spring

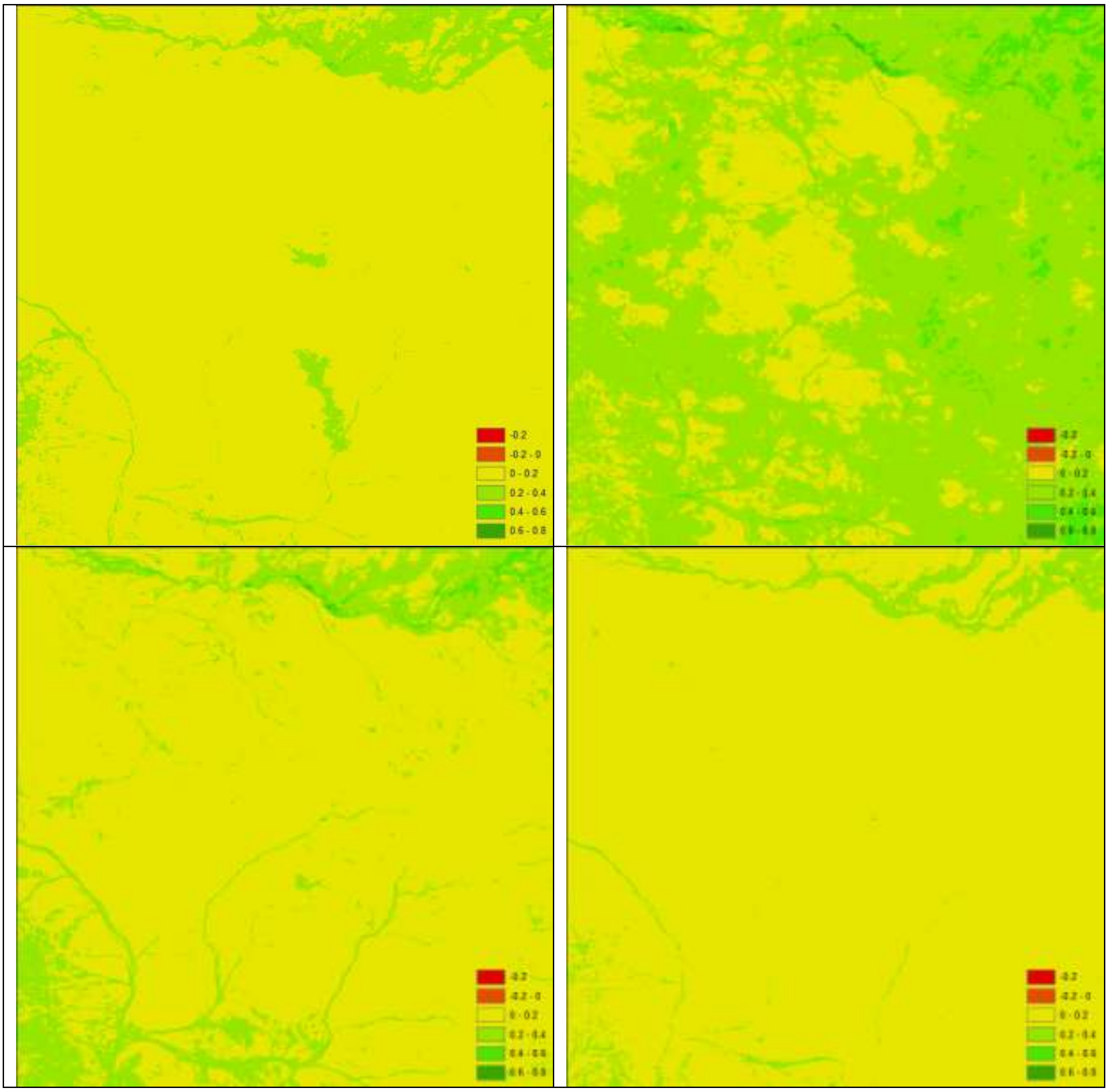
2001


-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8

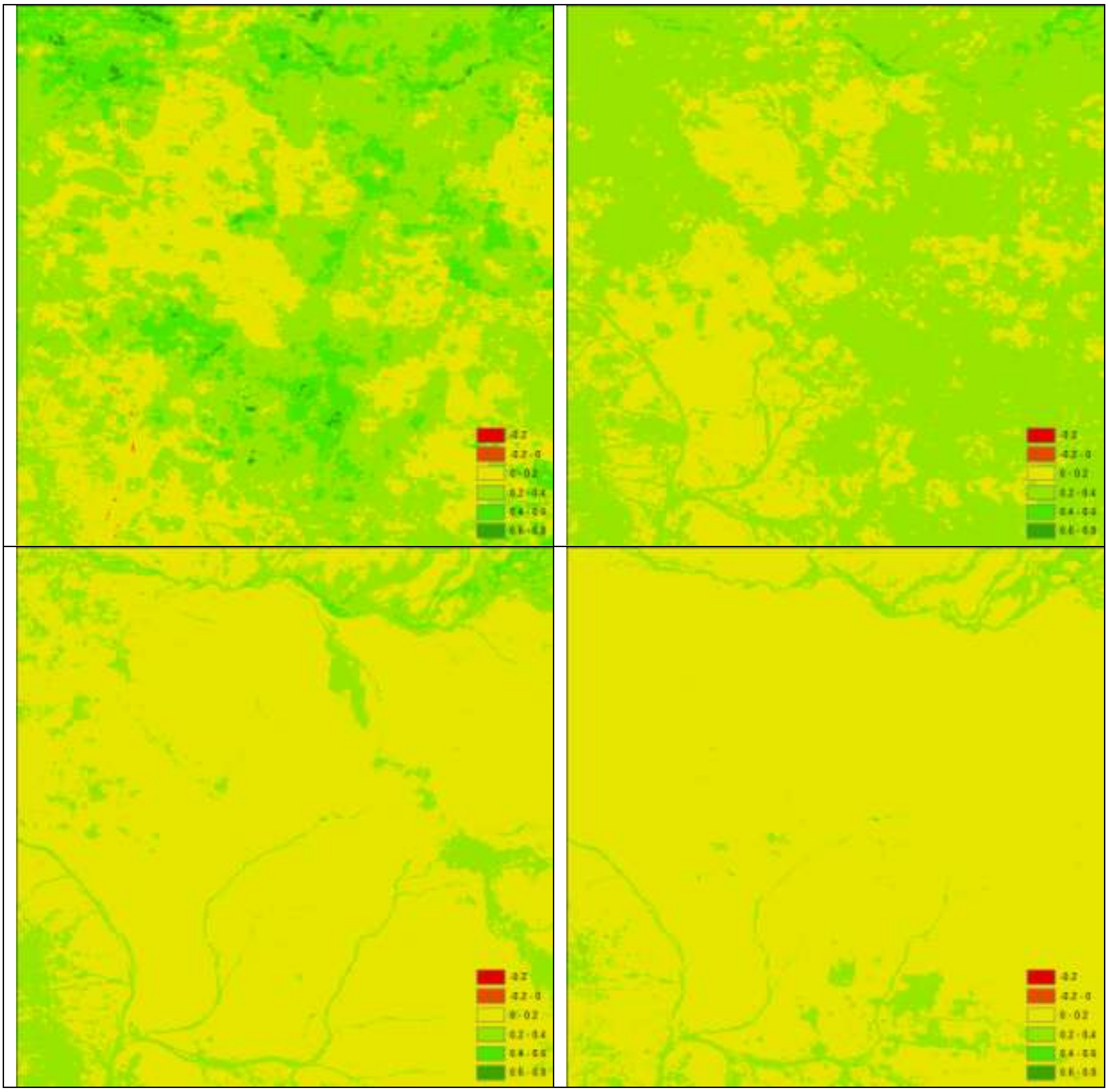
2002



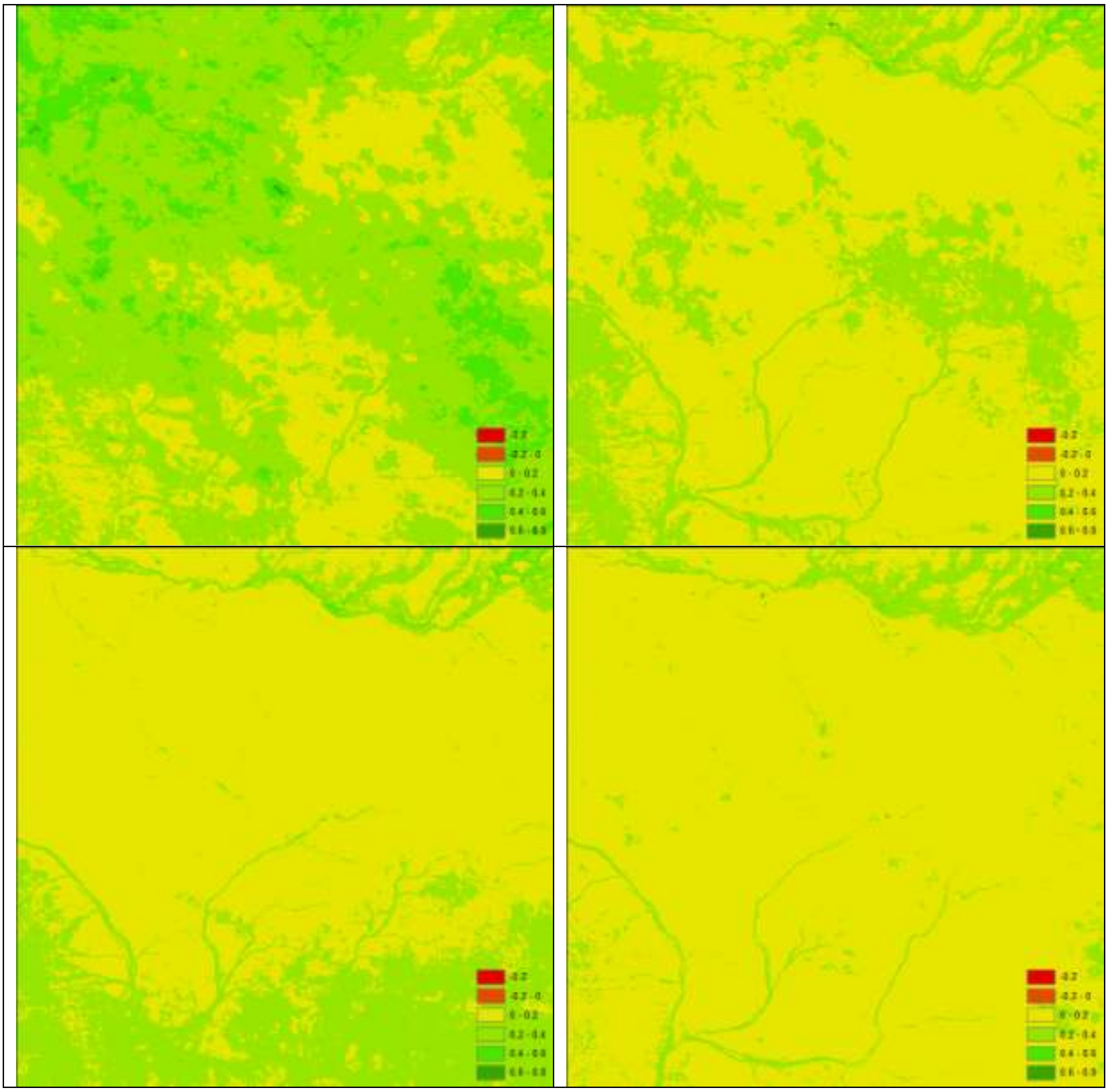
2003



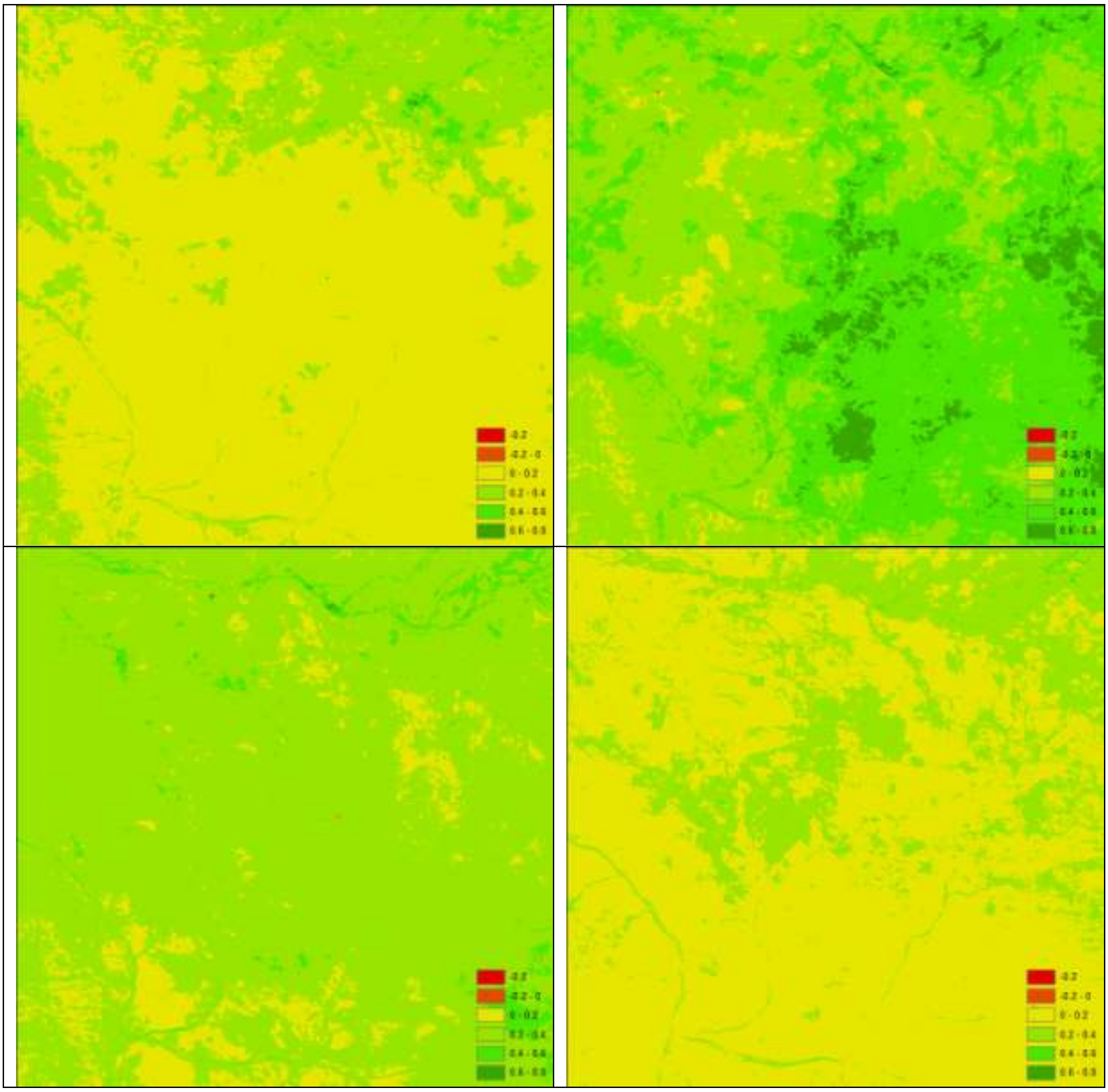
2004



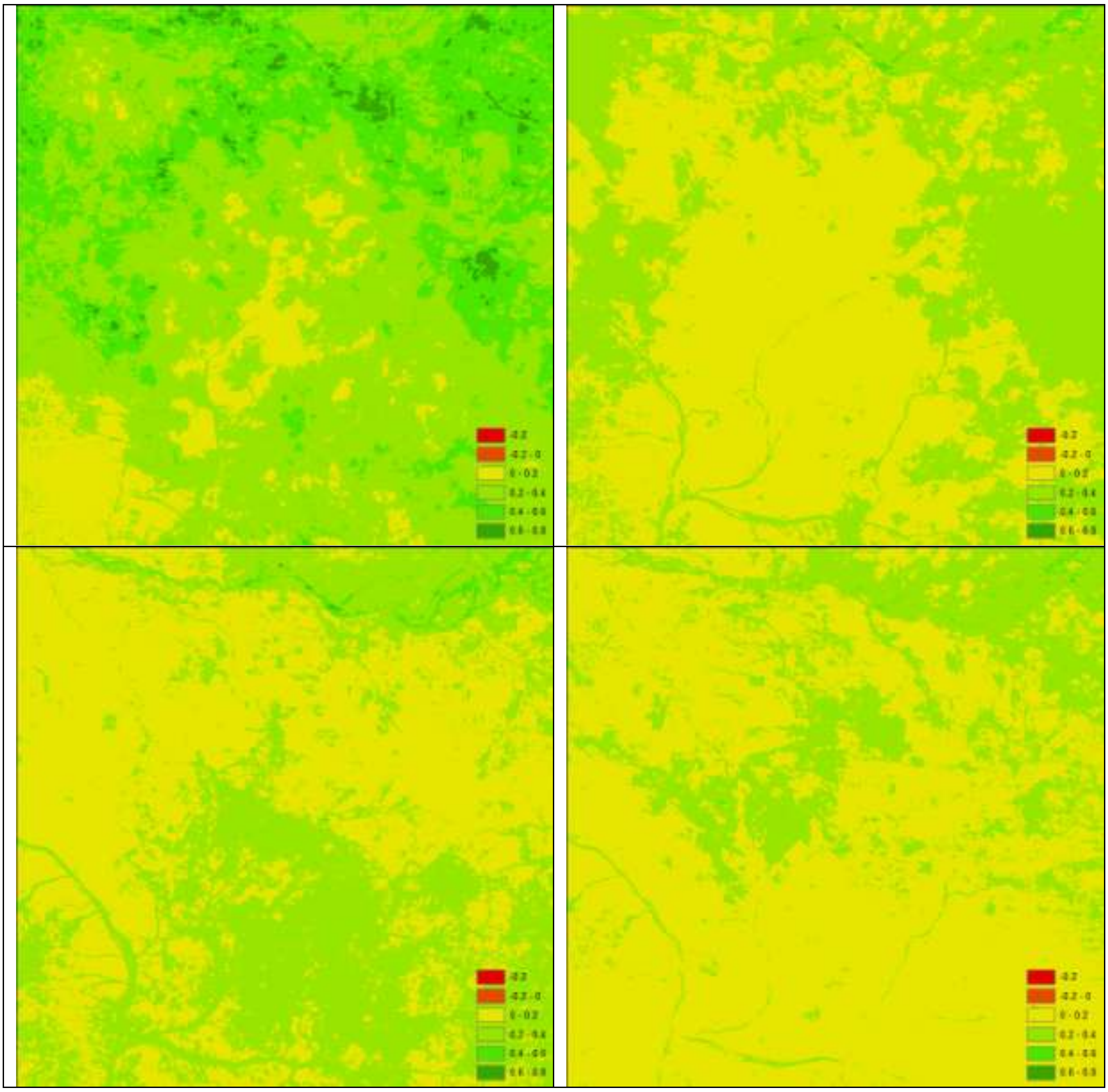
2005


-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.9
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.9
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.9
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.9

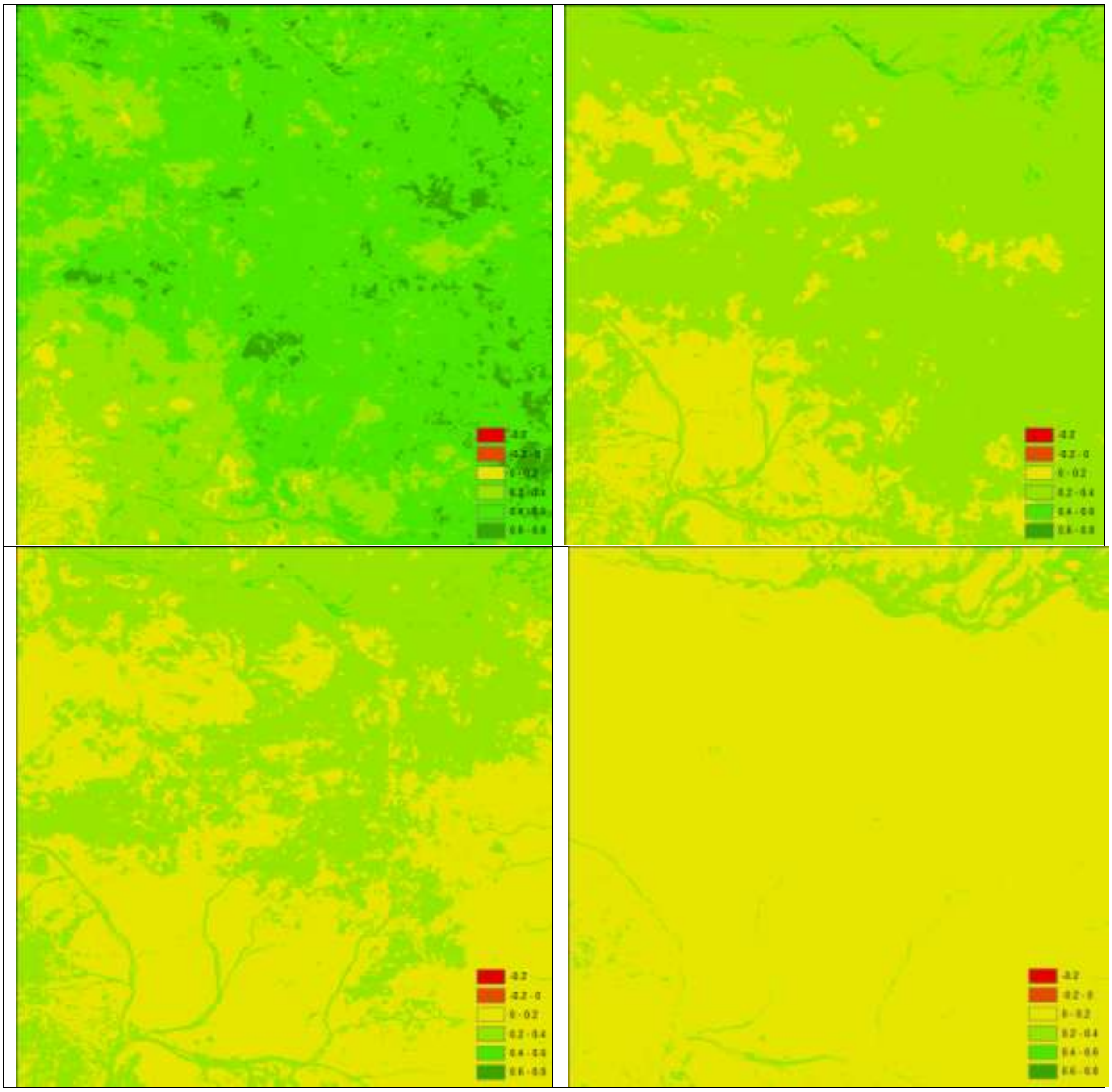
2006



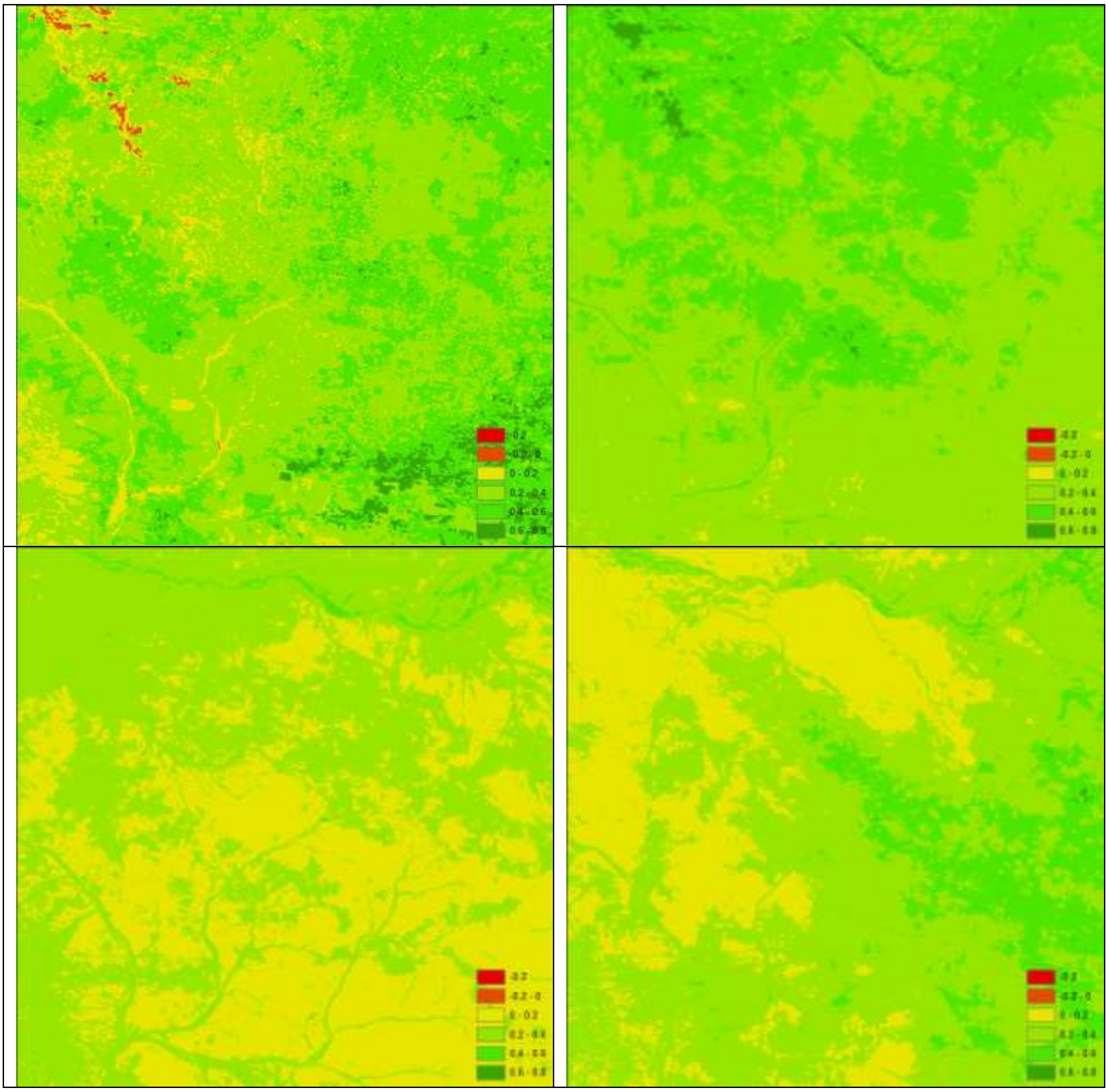
2007



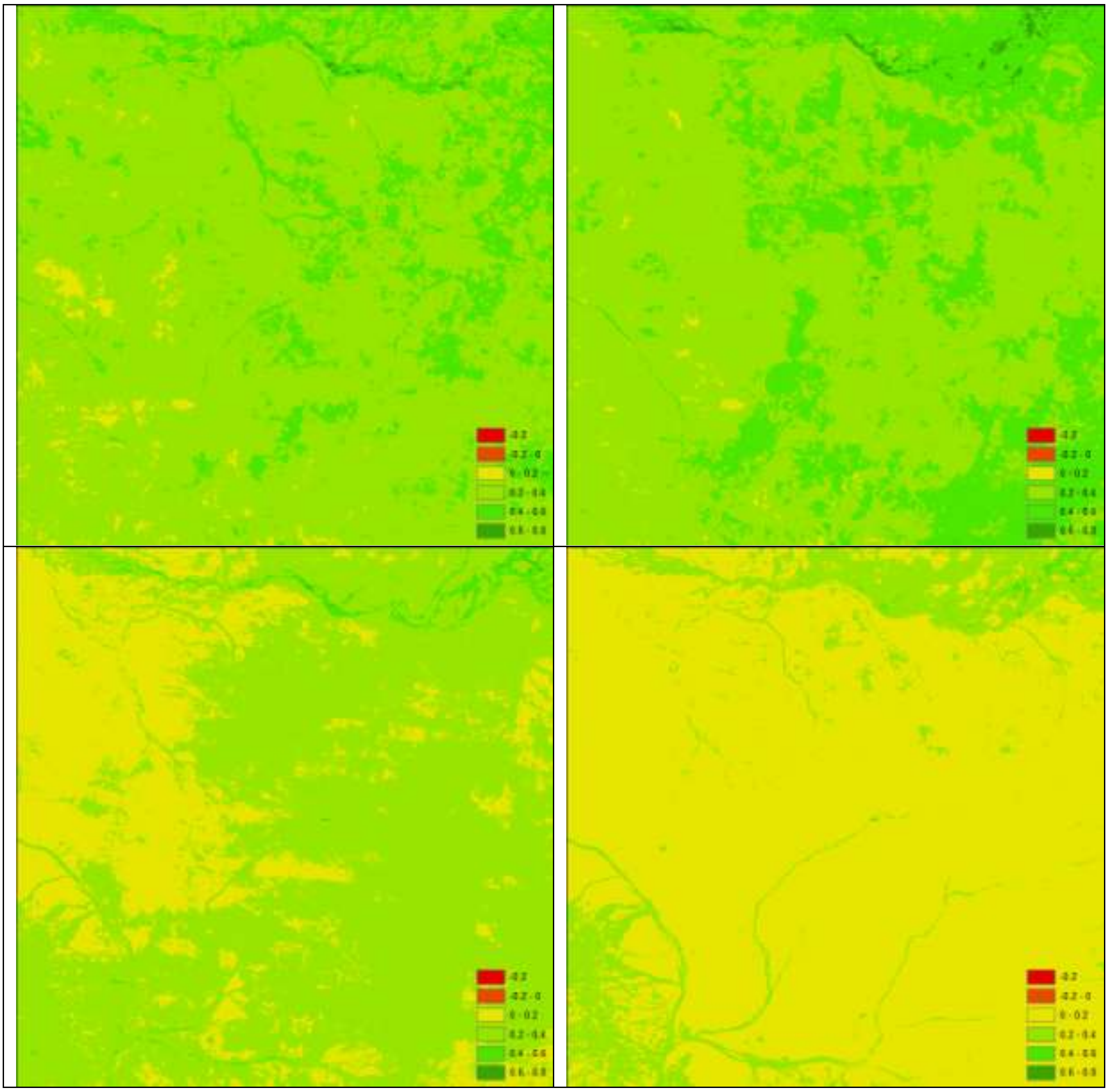
2008



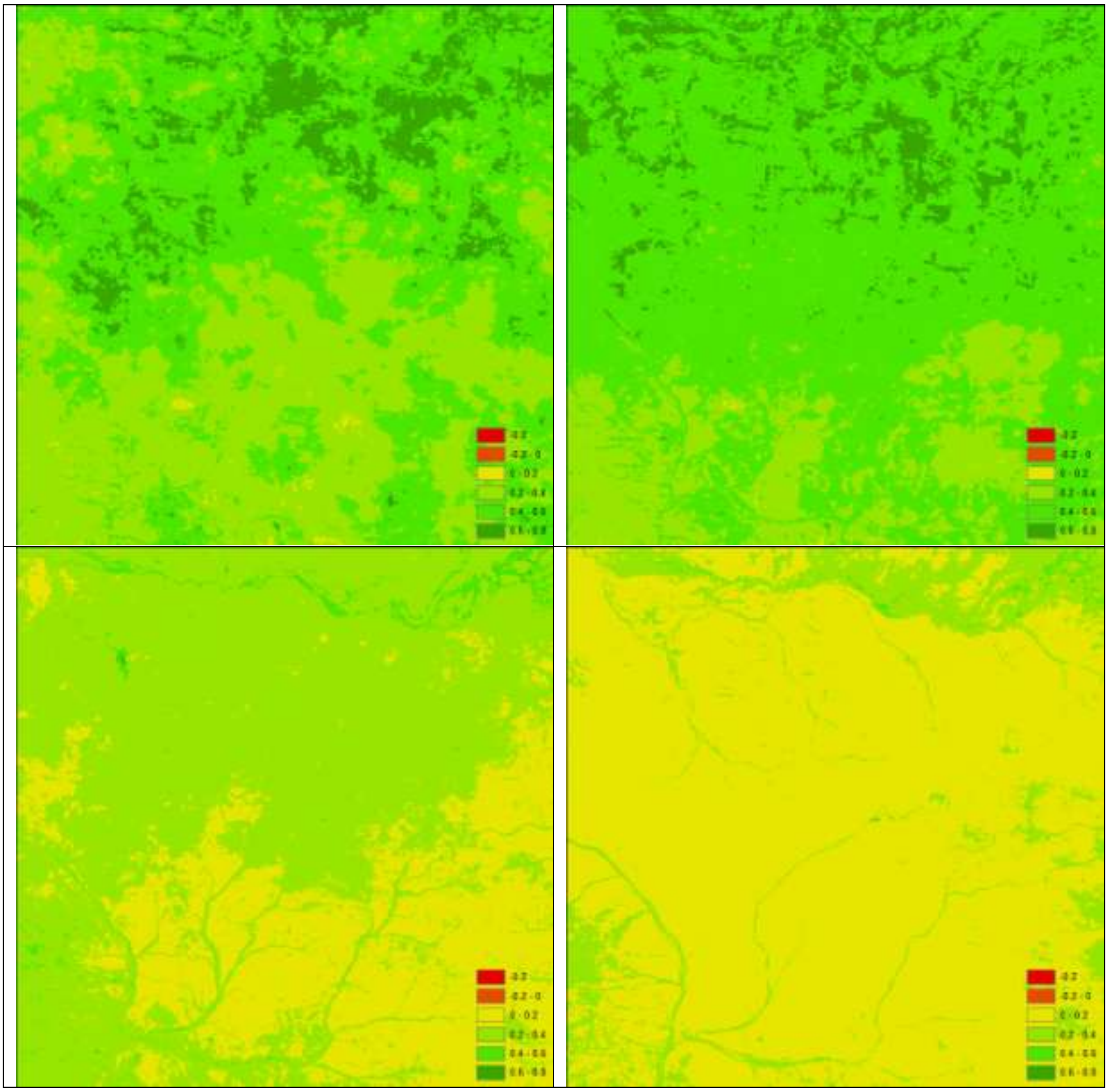
2009


-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8

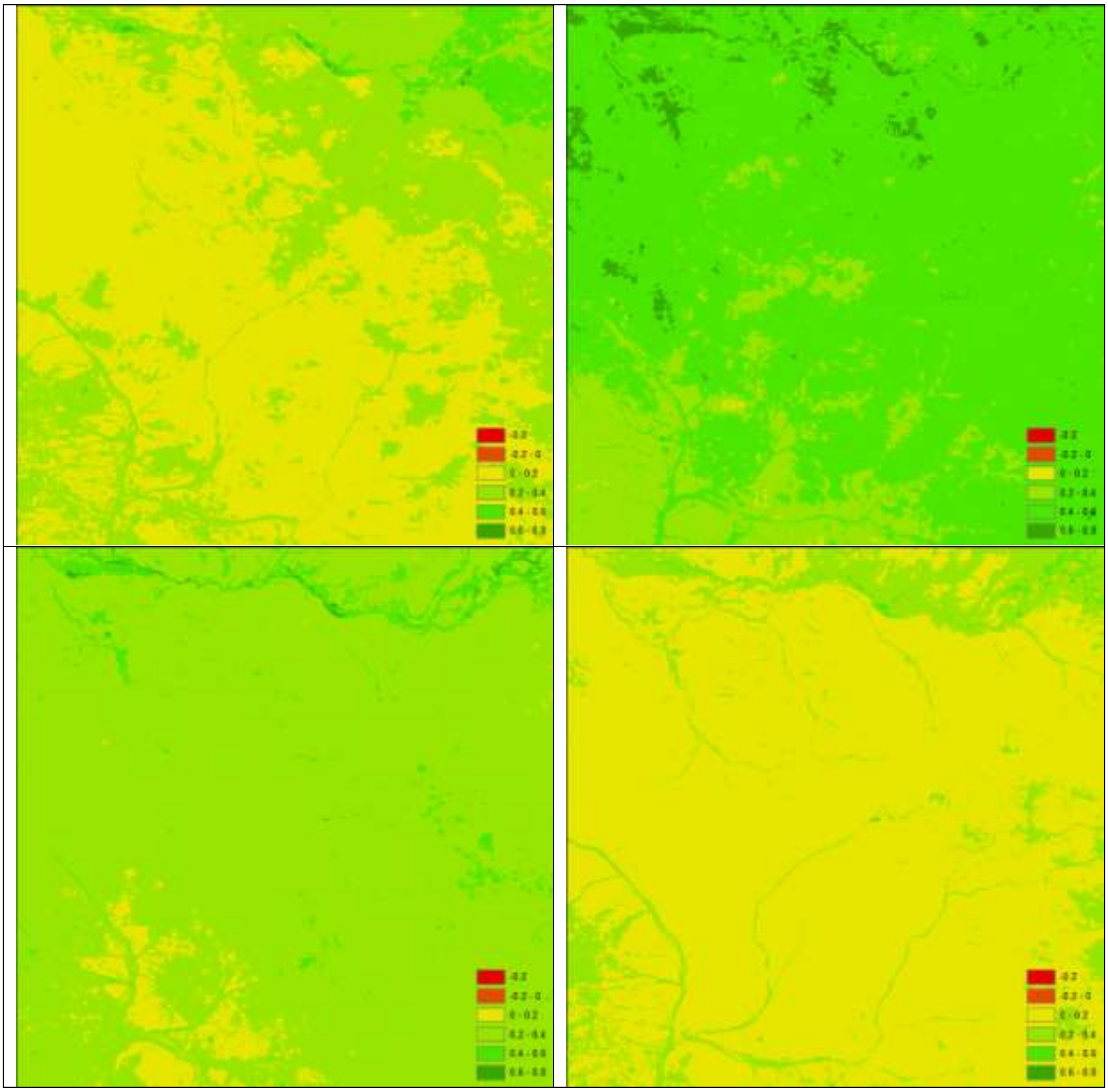
2010



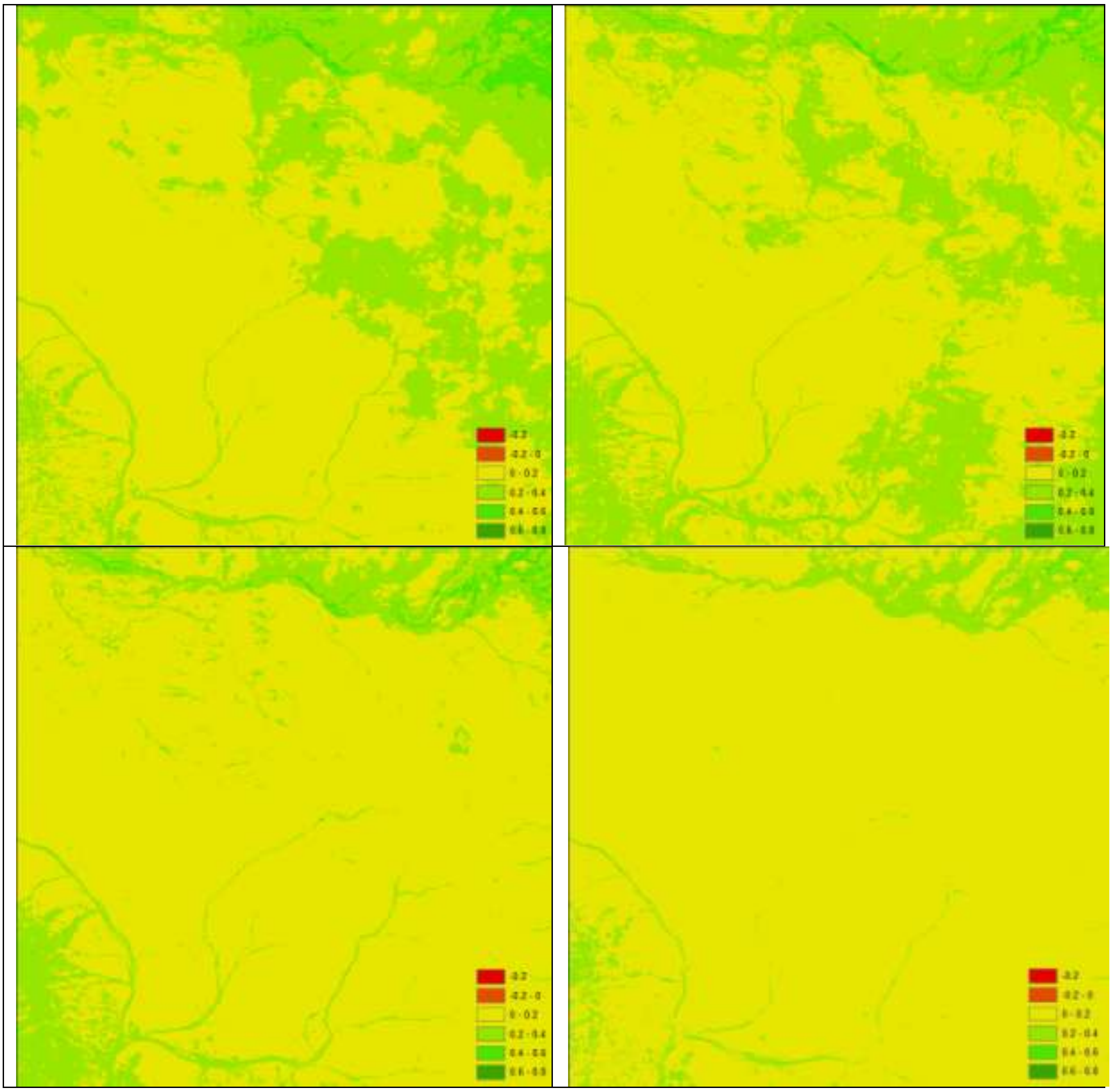
2011


-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8

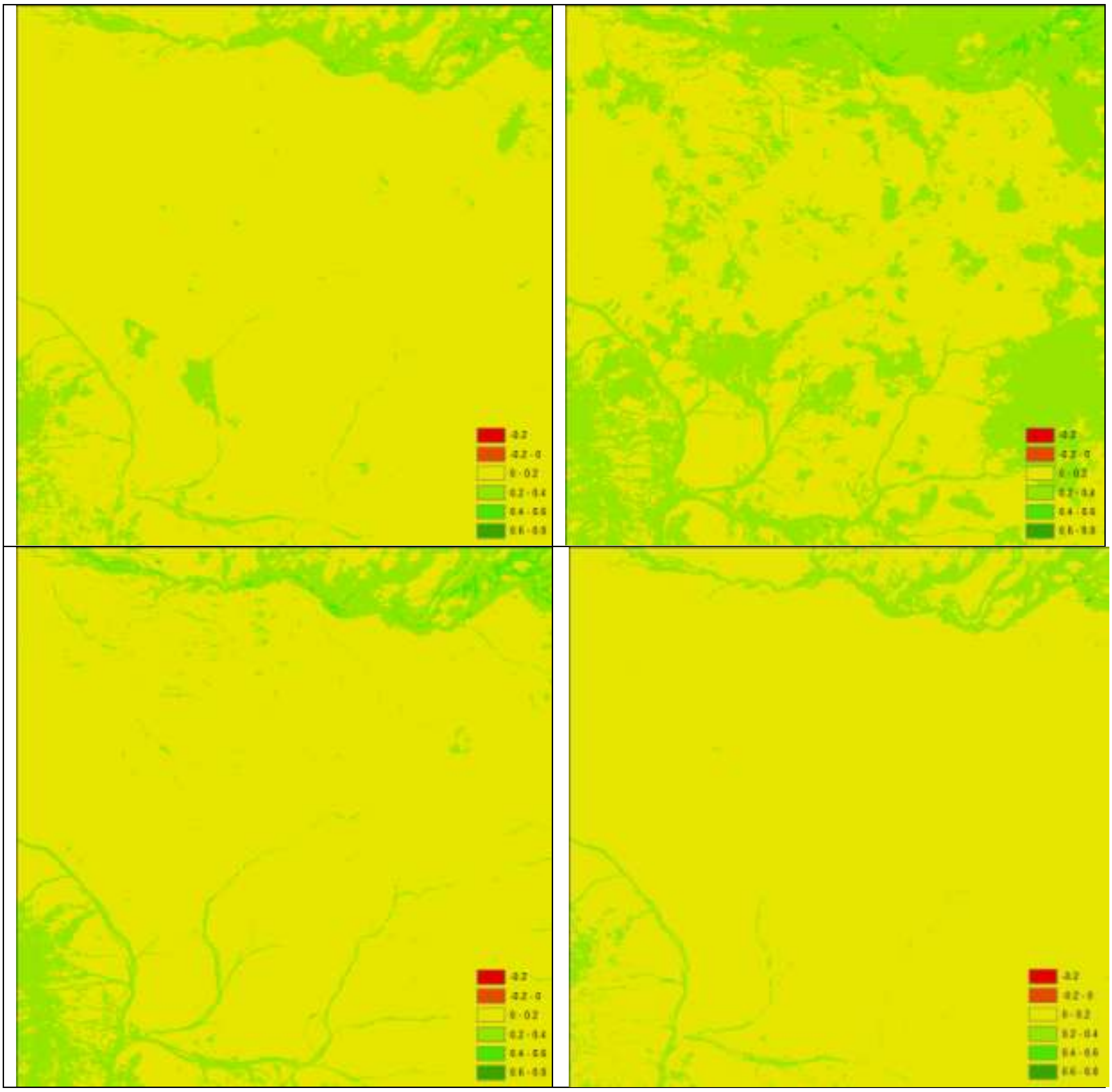
2012



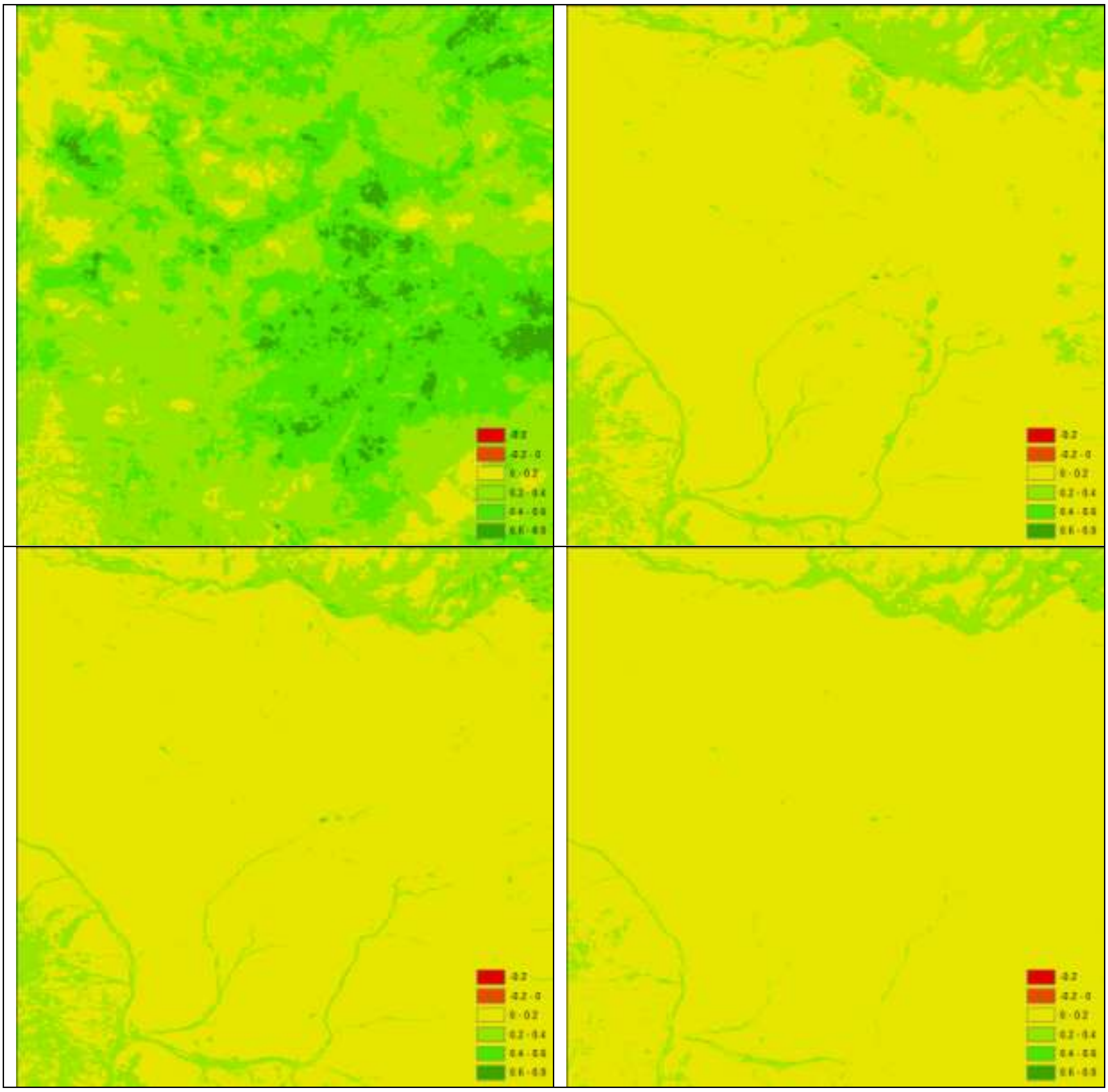
2013



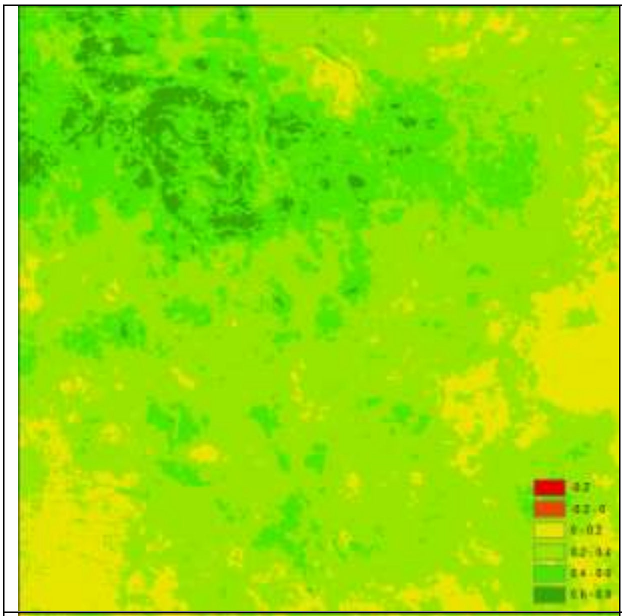
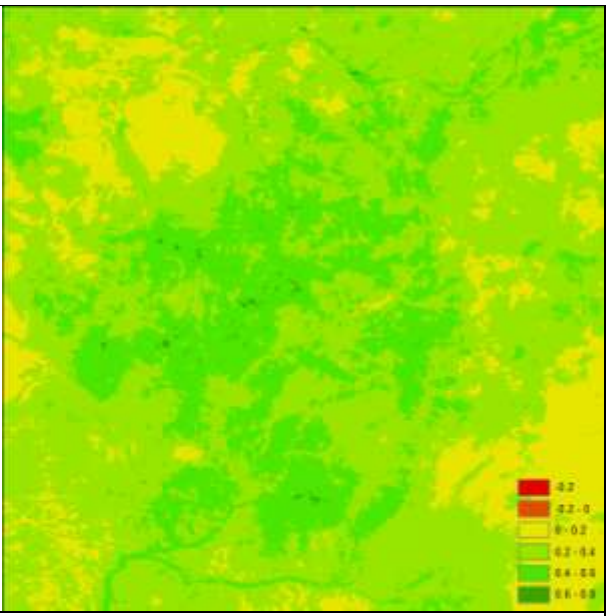
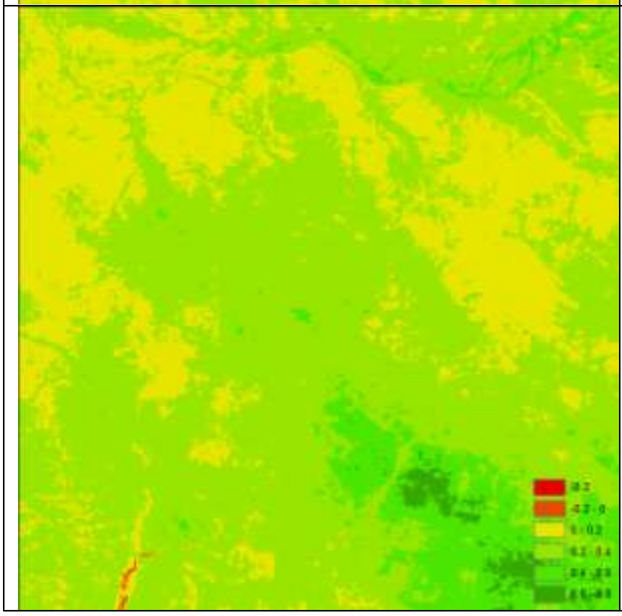
2014


-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8

2015


-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
-0.2
-0.2 - 0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8

2016

-0.2 -0.2 - 0 0 - 0.2 0.2 - 0.4 0.4 - 0.6 0.6 - 0.8	-0.2 -0.2 - 0 0 - 0.2 0.2 - 0.4 0.4 - 0.6 0.6 - 0.8
-0.2 -0.2 - 0 0 - 0.2 0.2 - 0.4 0.4 - 0.6 0.6 - 0.8	**N/A**

Appendix C. KML Code

Note: KML files for the other seasons have not been included – they are identical to this, except the date, URLs and name are changed.

“Summer.KML”

```
<?xml version="1.0" encoding="UTF-8"?>
<kml xmlns="http://www.opengis.net/kml/2.2" xmlns:gx="http://www.google.com/kml/ext/2.2"
xmlns:kml="http://www.opengis.net/kml/2.2" xmlns:atom="http://www.w3.org/2005/Atom">
 <Folder>
 <name>Summer</name>
 <GroundOverlay>
  <name>Summer 2000</name>
  <TimeSpan>
  <begin>2000-02-18</begin>
  <end>2000-02-19</end>
  </TimeSpan>
  <description>NDVI Image of Study Area February 18, 2000.
        </description>
        <Icon>
   <href>https://i.imgsafe.org/359248ea21.jpg</href>
  </Icon>
  <LatLonBox>
   <north>-20.5</north>
   <south>-22.5</south>
   <east>144</east>
   <west>142</west>
         <rotation>0</rotation>
  </LatLonBox>
 </GroundOverlay>

  <GroundOverlay>
  <name>Summer 2001</name>
  <TimeSpan>
  <begin>2001-01-17</begin>
  <end>2001-01-18</end>
  </TimeSpan>
  <description>NDVI Image of Study Area January 17,2001.
        </description>
        <Icon>
   <href>https://i.imgsafe.org/3635e583be.jpg</href>
  </Icon>
  <LatLonBox>
   <north>-20.5</north>
   <south>-22.5</south>
   <east>144</east>
   <west>142</west>
         <rotation>0</rotation>
  </LatLonBox>
 </GroundOverlay>

  <GroundOverlay>
  <name>Summer 2002</name>
  <TimeSpan>
  <begin>2002-01-17</begin>
  <end>2002-01-18</end>
  </TimeSpan>
  <description>NDVI Image of Study Area January 17,2002.
        </description>
        <Icon>
```

```
  <href>https://i.imgsafe.org/3635f0c7f2.jpg</href>
 </Icon>
 <LatLonBox>
  <north>-20.5</north>
  <south>-22.5</south>
  <east>144</east>
  <west>142</west>
         <rotation>0</rotation>
 </LatLonBox>
</GroundOverlay>

 <GroundOverlay>
 <name>Summer 2003</name>
 <TimeSpan>
 <begin>2003-01-17</begin>
 <end>2003-01-18</end>
 </TimeSpan>
 <description>NDVI Image of Study Area January 17,2003.
        </description>
        <Icon>
  <href>https://i.imgsafe.org/3635dbb92e.jpg</href>
 </Icon>
 <LatLonBox>
  <north>-20.5</north>
  <south>-22.5</south>
  <east>144</east>
  <west>142</west>
         <rotation>0</rotation>
 </LatLonBox>
</GroundOverlay>

 <GroundOverlay>
 <name>Summer 2004</name>
 <TimeSpan>
 <begin>2004-01-17</begin>
 <end>2004-01-18</end>
 </TimeSpan>
 <description>NDVI Image of Study Area January 17,2004.
        </description>
        <Icon>
  <href>https://i.imgsafe.org/36360b5fe5.jpg</href>
 </Icon>
 <LatLonBox>
  <north>-20.5</north>
  <south>-22.5</south>
  <east>144</east>
  <west>142</west>
         <rotation>0</rotation>
 </LatLonBox>
</GroundOverlay>

 <GroundOverlay>
 <name>Summer 2005</name>
 <TimeSpan>
 <begin>2005-01-17</begin>
 <end>2005-01-18</end>
 </TimeSpan>
 <description>NDVI Image of Study Area January 17,2005.
        </description>
        <Icon>
  <href>https://i.imgsafe.org/363602f195.jpg</href>
 </Icon>
```

```
 <LatLonBox>
  <north>-20.5</north>
  <south>-22.5</south>
  <east>144</east>
  <west>142</west>
          <rotation>0</rotation>
 </LatLonBox>
</GroundOverlay>

 <GroundOverlay>
 <name>Summer 2006</name>
 <TimeSpan>
 <begin>2006-01-17</begin>
 <end>2006-01-18</end>
 </TimeSpan>
 <description>NDVI Image of Study Area January 17,2006.
         </description>
         <Icon>
  <href>https://i.imgsafe.org/36362180d6.jpg</href>
 </Icon>
 <LatLonBox>
  <north>-20.5</north>
  <south>-22.5</south>
  <east>144</east>
  <west>142</west>
          <rotation>0</rotation>
 </LatLonBox>
</GroundOverlay>

 <GroundOverlay>
 <name>Summer 2007</name>
 <TimeSpan>
 <begin>2007-01-17</begin>
 <end>2007-01-18</end>
 </TimeSpan>
 <description>NDVI Image of Study Area January 17,2007.
         </description>
         <Icon>
  <href>https://i.imgsafe.org/3636571eef.jpg</href>
 </Icon>
 <LatLonBox>
  <north>-20.5</north>
  <south>-22.5</south>
  <east>144</east>
  <west>142</west>
          <rotation>0</rotation>
 </LatLonBox>
</GroundOverlay>

 <GroundOverlay>
 <name>Summer 2008</name>
 <TimeSpan>
 <begin>2008-01-17</begin>
 <end>2008-01-18</end>
 </TimeSpan>
 <description>NDVI Image of Study Area January 17,2008.
         </description>
         <Icon>
  <href>https://i.imgsafe.org/3636760968.jpg</href>
 </Icon>
 <LatLonBox>
  <north>-20.5</north>
```

```
    <south>-22.5</south>
    <east>144</east>
    <west>142</west>
            <rotation>0</rotation>
  </LatLonBox>
</GroundOverlay>

  <GroundOverlay>
  <name>Summer 2009</name>
  <TimeSpan>
  <begin>2009-01-17</begin>
  <end>2009-01-18</end>
  </TimeSpan>
  <description>NDVI Image of Study Area January 17,2009.
          </description>
          <Icon>
    <href>https://i.imgsafe.org/36366c746f.jpg</href>
  </Icon>
  <LatLonBox>
    <north>-20.5</north>
    <south>-22.5</south>
    <east>144</east>
    <west>142</west>
            <rotation>0</rotation>
  </LatLonBox>
</GroundOverlay>

  <GroundOverlay>
  <name>Summer 2010</name>
  <TimeSpan>
  <begin>2010-01-17</begin>
  <end>2010-01-18</end>
  </TimeSpan>
  <description>NDVI Image of Study Area January 17,2010.
          </description>
          <Icon>
    <href>https://i.imgsafe.org/36366ae865.jpg</href>
  </Icon>
  <LatLonBox>
    <north>-20.5</north>
    <south>-22.5</south>
    <east>144</east>
    <west>142</west>
            <rotation>0</rotation>
  </LatLonBox>
</GroundOverlay>

  <GroundOverlay>
  <name>Summer 2011</name>
  <TimeSpan>
  <begin>2011-01-17</begin>
  <end>2011-01-18</end>
  </TimeSpan>
  <description>NDVI Image of Study Area January 17,2011.
          </description>
          <Icon>
    <href>https://i.imgsafe.org/3636865487.jpg</href>
  </Icon>
  <LatLonBox>
    <north>-20.5</north>
    <south>-22.5</south>
    <east>144</east>
```

```
  <west>142</west>
          <rotation>0</rotation>
 </LatLonBox>
</GroundOverlay>

 <GroundOverlay>
 <name>Summer 2012</name>
 <TimeSpan>
 <begin>2012-01-17</begin>
 <end>2012-01-18</end>
 </TimeSpan>
 <description>NDVI Image of Study Area January 17,2012.
         </description>
         <Icon>
  <href>https://i.imgsafe.org/36365aa1b0.jpg</href>
 </Icon>
 <LatLonBox>
  <north>-20.5</north>
  <south>-22.5</south>
  <east>144</east>
  <west>142</west>
          <rotation>0</rotation>
 </LatLonBox>
</GroundOverlay>

 <GroundOverlay>
 <name>Summer 2013</name>
 <TimeSpan>
 <begin>2013-01-17</begin>
 <end>2013-01-18</end>
 </TimeSpan>
 <description>NDVI Image of Study Area January 17,2013.
         </description>
         <Icon>
  <href>https://i.imgsafe.org/3636885d6e.jpg</href>
 </Icon>
 <LatLonBox>
  <north>-20.5</north>
  <south>-22.5</south>
  <east>144</east>
  <west>142</west>
          <rotation>0</rotation>
 </LatLonBox>
</GroundOverlay>

 <GroundOverlay>
 <name>Summer 2014</name>
 <TimeSpan>
 <begin>2014-01-17</begin>
 <end>2014-01-18</end>
 </TimeSpan>
 <description>NDVI Image of Study Area January 17,2014.
         </description>
         <Icon>
  <href>https://i.imgsafe.org/3636749643.jpg</href>
 </Icon>
 <LatLonBox>
  <north>-20.5</north>
  <south>-22.5</south>
  <east>144</east>
  <west>142</west>
          <rotation>0</rotation>
```

```
  </LatLonBox>
 </GroundOverlay>

  <GroundOverlay>
  <name>Summer 2015</name>
  <TimeSpan>
  <begin>2015-01-17</begin>
  <end>2015-01-18</end>
  </TimeSpan>
  <description>NDVI Image of Study Area January 17,2015.
          </description>
          <Icon>
   <href>https://i.imgsafe.org/3636b33799.jpg</href>
  </Icon>
  <LatLonBox>
   <north>-20.5</north>
   <south>-22.5</south>
   <east>144</east>
   <west>142</west>
           <rotation>0</rotation>
  </LatLonBox>
 </GroundOverlay>

  <GroundOverlay>
  <name>Summer 2016</name>
  <TimeSpan>
  <begin>2016-01-17</begin>
  <end>2016-01-18</end>
  </TimeSpan>
  <description>NDVI Image of Study Area January 17,2016.
          </description>
          <Icon>
   <href>https://i.imgsafe.org/36368d49cf.jpg</href>
  </Icon>
  <LatLonBox>
   <north>-20.5</north>
   <south>-22.5</south>
   <east>144</east>
   <west>142</west>
           <rotation>0</rotation>
  </LatLonBox>
 </GroundOverlay>
 </Folder>
</kml>
```