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Date: 1/12/2016
GAIN Report Number: AS1602

Australia

Post: Canberra

Crop Monitoring - December 2015

Report Categories:
Grain and Feed

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Report Highlights:
Australia is becoming a more active user of satellite imagery for the purpose of monitoring crop growth and yield prospects, as well as to survey environmental health through measures of soil, water and biomass resources. The main methodology for assessing crop health is the Normalized Difference Vegetation Index (NDVI) using spectral analysis of red and infrared reflectance from medium resolution satellite images to monitor vegetation development and health and possible problems with crop development. Vegetation images show crop growth from planting to harvest, changes over the season and emerging problems including weed growth and low soil moisture. This paper surveys the main Australian users of satellite imagery in the agricultural sector and discusses how this technology is likely to be used in the future as a supplementary source of information to boost farm productivity as well as to facilitate appropriate environmental and land use policies.

OVERVIEW

The use of satellite imagery and other data for crop monitoring in Australia is becoming increasingly widespread. A range of government and non-government agencies survey this information to better understand crop yields and outlook, together with details of soil, water, environmental health and other indicators. This monitoring technology allows farmers to review their growing resources on a paddock-to paddock basis, although interpretation of data may require a range of software applications, which are becoming more widely available. Satellite data provides information that with appropriate algorithms and software applications can measure vegetation health and in the case of agriculture the yield outlook for some crops.

Australian government agencies involved in the coordination and publication of satellite imagery include Agricultural and Resource Economics and Sciences (ABARES), Geoscience Australia, the Bureau of Meteorology and the Commonwealth Scientific and Research Organization. Other Australian organizations involved in the interpretation of this imagery and data include the Australian Bureau of Statistics, the Department of Agriculture, the Department of the Environment, Cooperative Research Centres (CRCs), universities; farming groups and private organisations and individuals, including farmers and farming peak bodies.

The fundamental tool for using satellite imagery to understand biomass growth and vegetation development is the Normalized Difference Vegetation Index (NDVI) which enables vegetation maps to be derived from satellite data. This data provides an overview of the status and dynamics of vegetation across Australia, allowing a measure of the amount of live green vegetation. The satellite data comes from a range of sources, such as the Advanced Very High Resolution Radiometer (AVHRR) instruments on board the National Oceanic and Atmospheric Administration (NOAA) series of satellites that are operated by the United States. Access to satellite data was increased significantly in 2008 when the US Geological Survey decided to make Landsat data available for no cost. By far the most common satellite used for NDVI monitoring of earth land surface is the MODIS satellite. The other widely practiced utilization of earth observation data from multispectral sensors is the identification of crop types through imagery classification. Crop type discrimination is possible because of spectral differences between plants and physical components but depends upon some level of understanding of local conditions.

The NDVI index is based on the emission of green vegetation absorbs visible red wavelengths of light (solar radiation) as part of photosynthesis. At the same time plants scatter (reflect) solar energy in the near infrared. This difference in absorption is unique to live vegetation and provides a measure of the greenness of the vegetation. Crop plants are very absorptive at red wavelengths, and a combination of the two provides an effective measure of vegetation vigor. NDVI is an index which provides a measure of vegetation density and condition. It is influenced by the fractional cover of the ground by vegetation, the vegetation density and the vegetation greenness. NDVI is calculated from the red and near-infrared light reflections of crops and gives an indication of the photosynthetic capacity of the land surface cover and color variation can be an indicator of problems in crop development such as water stress and soil moisture (see Charts 1 and 2). This data can be used to estimate crop yields (Chart 3).

Chart 1: MODUS Satellite Imagery of the Australian wheatbelt using NDVI and CropMask

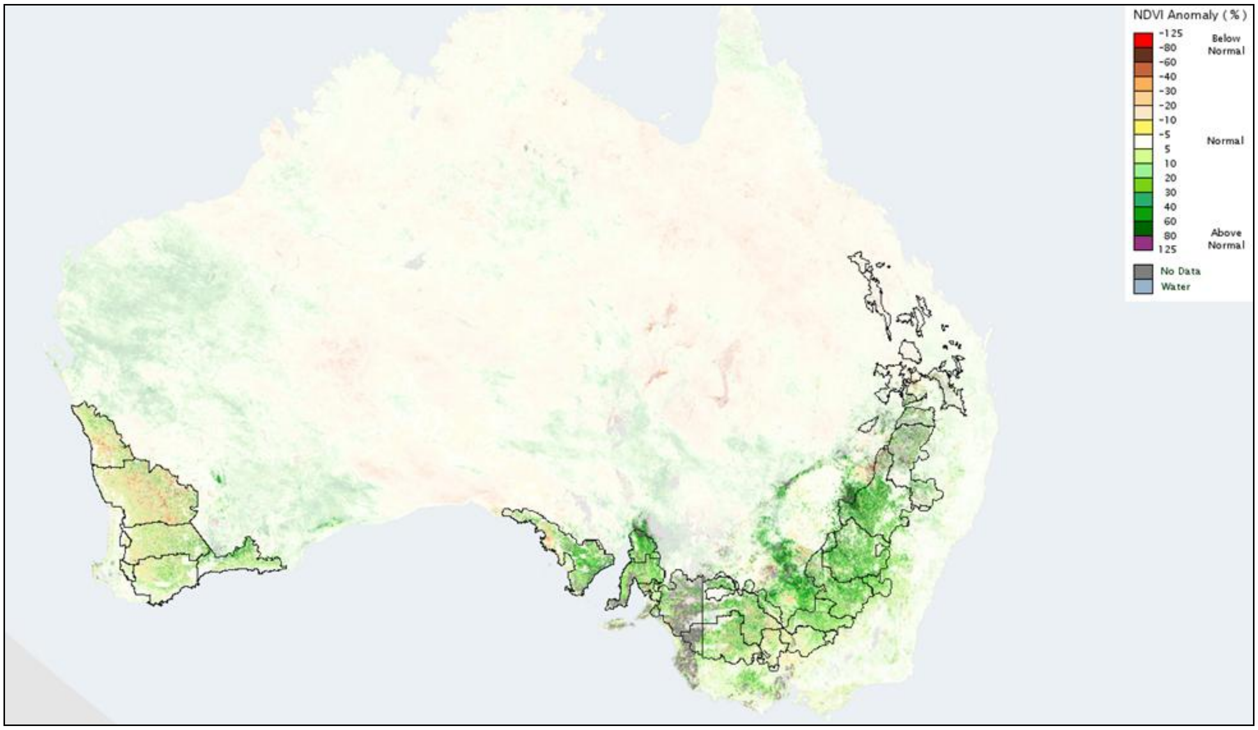
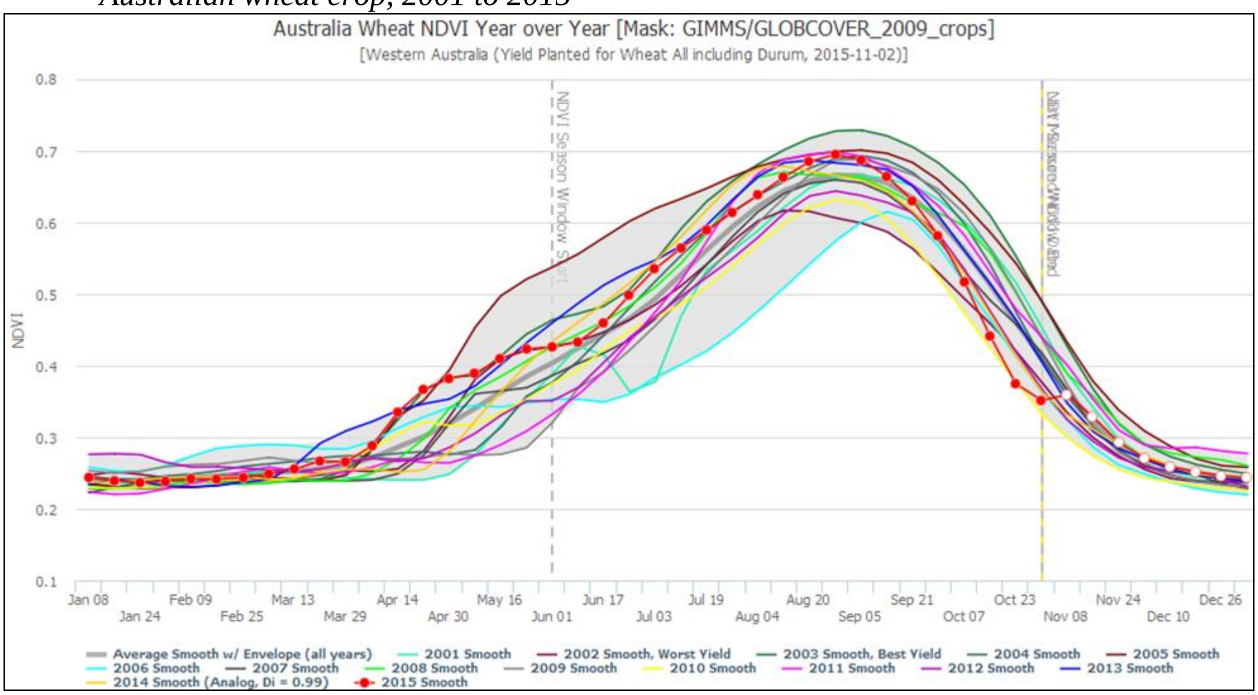


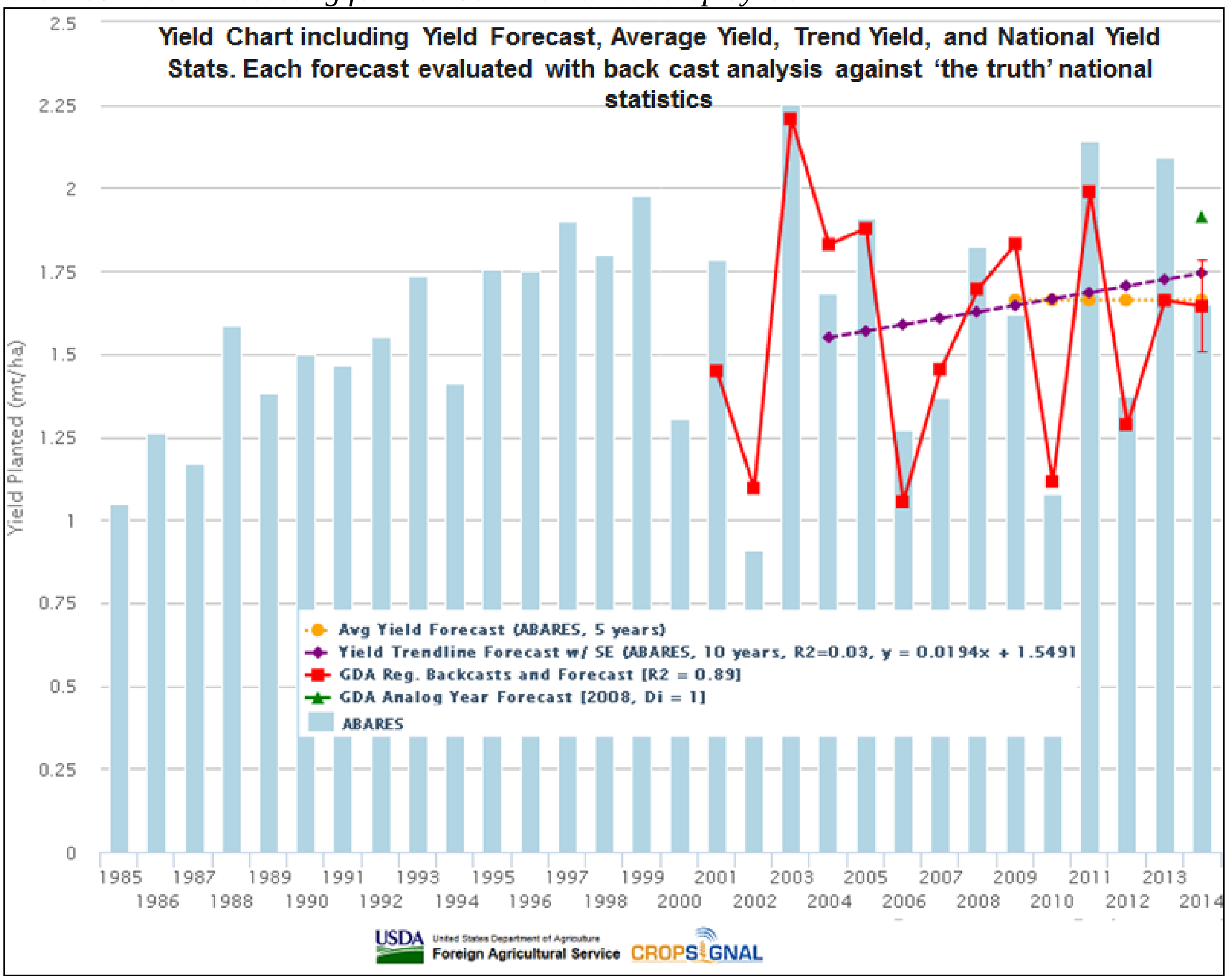
Chart 2: NDVI Yield Model Forecasting and Crop Condition Assessment of the Western Australian wheat crop, 2001 to 2015



Source for Charts: US Department of Agriculture (2015).

Enhancement tools can help make satellite images easier to interpret, while different spatial, spectral and temporal resolutions are available for agriculture and crop assessment, crop health, change detection, environmental analysis, irrigated landscape mapping, yield determination and soils analysis. However, while satellite imagery can provide accurate measures of crop development and environmental indicators, there are a number of possible sources of error. Cloud cover prevents effective coverage by satellite imagery especially in areas of higher rainfall, such as tropical Australia.

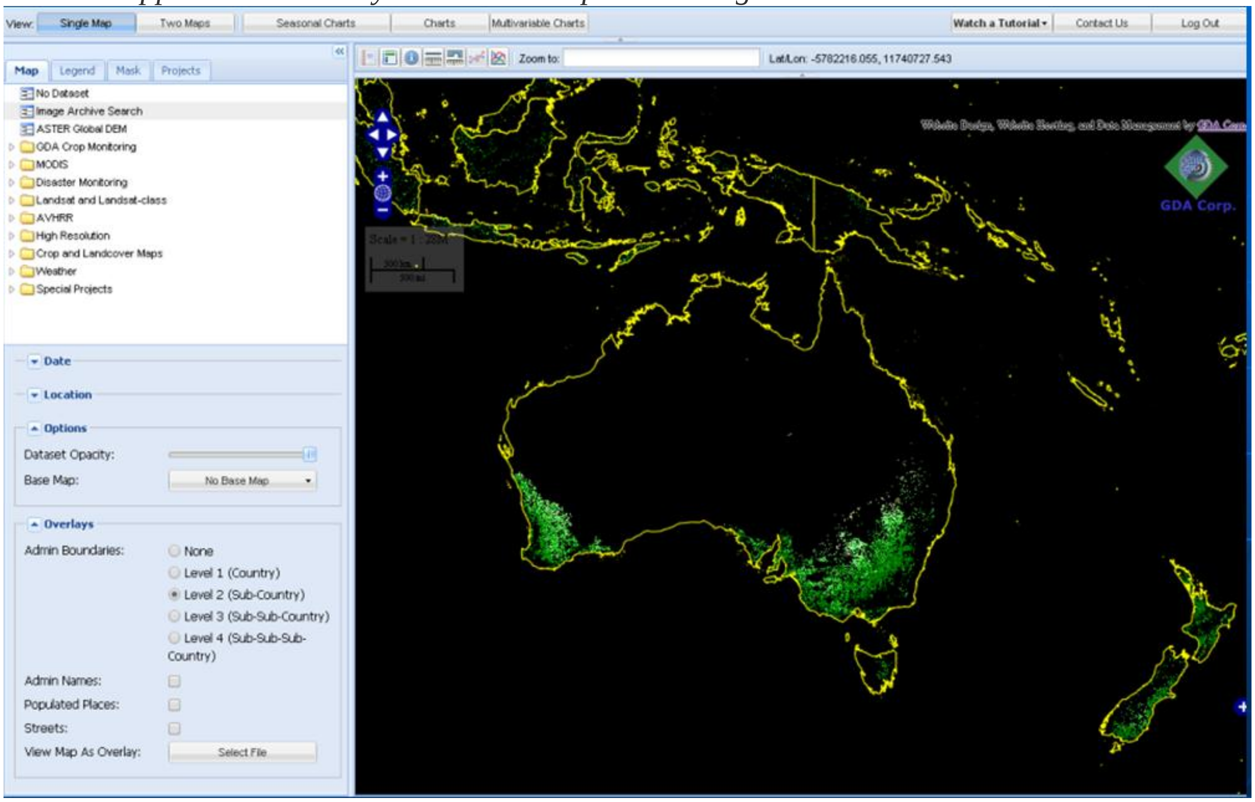
Chart 3: Yield Forecasting for the Australian wheat crop by USDA



Source: US Department of Agriculture.

Further, cloud cover is naturally prevalent in areas of more intensive rain-fed crop cultivation, but in drier areas where broadacre crops are grown such as in Western Australia cloud cover is a less significant problem. As could be expected some monoculture crops, such as wheat in Western Australia, are easier to identify than mixed cropping areas such as in some parts of western Victoria and NSW. In addition, the classification of crops by pixels needs to be accurate and may require ground truthing to verify actual growing conditions and plant varieties. Another factor is that the frequency of available satellite data can be a constraint on reporting accuracy, especially if seasonal events; for example a sudden worsening in the El Nino phenomenon, have a major impact in a marginal growing area such as the Wimmera and Mallee regions of Victoria.

Chart 4: Applications used by the USDA Crop Monitoring Area



Source: US Department of Agriculture (2015).

Overall, however, satellite imagery offers a useful supplementary tool for crop monitoring in Australia, as has occurred already in the United States. In particular, satellite crop monitoring can assist farmers and policy makers to quickly respond to a variety of problems and also assists with marketing decisions and allocation of resources.

CROP MONITORING AGENCIES IN AUSTRALIA

A considerable number of government agencies and private sector organizations in Australia have the capacity to use satellite imagery data to monitor crop health, as well as a range of environmental indicators affecting natural resources such as water, soil and minerals. In addition, broader surveys using satellite data are published by agencies such as the Bureau of Meteorology (see charts 5 and 6).

GEOSCIENCE AUSTRALIA

Geoscience Australia (GA) is Australia's principal earth resource satellite ground station and data processing facility. It is a long-established manager of satellite data and also analyses and distributes satellite imagery data to other agencies. Geoscience Australia is cooperating with the Australian Bureau of Statistics to produce the *Dynamic Land Cover Dataset* (DLCD), which uses satellite imagery data from the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) satellite. The dataset is designed to be a comprehensive land cover reference for Australia, providing information at a 250 meter resolution for the period April 2000 to April 2008, using 34 land cover categories. The methodology can identify different vegetation land cover types, such as crops, using an Enhanced Vegetation Index.

Geoscience Australia uses Earth observation satellites to capture environmental information over the entire Australian continent. The satellites used, including Landsat, the Advanced Land Observing System, and Resourcesat-1, are operated by the United States, Japan and India respectively. Geoscience Australia now holds an archive of satellite observations, over the last 30 years, which supports several nationally significant environmental initiatives. These include the National Carbon Accounting System for the federal Department of Climate Change and the Statewide Landcover and Trees Study (SLATS) by the Queensland Department of Natural Resources and Water.

Since early 2013, Geoscience Australia has been developing a 'cube' of Earth observation datasets by stacking Landsat image 'tiles' in time sequences for the same area of ground, then using fifteen years of Landsat-5 and Landsat-7 imagery for the entire continent of Australia. The Data Cube running on a supercomputer can be used for complex quantitative analysis. Visually it can demonstrate real-time changes in particular indicators, such as water level movements over time including irrigation networks in the Murray Darling Basin – Australia's major food bowl for irrigated crops. However, a significant amount of preparation and resources are required to utilize this resource and crop monitoring has not been developed through the Data Cube.

Chart 5: Imagery of Australian Vegetation Cover using NDVI, September 2015

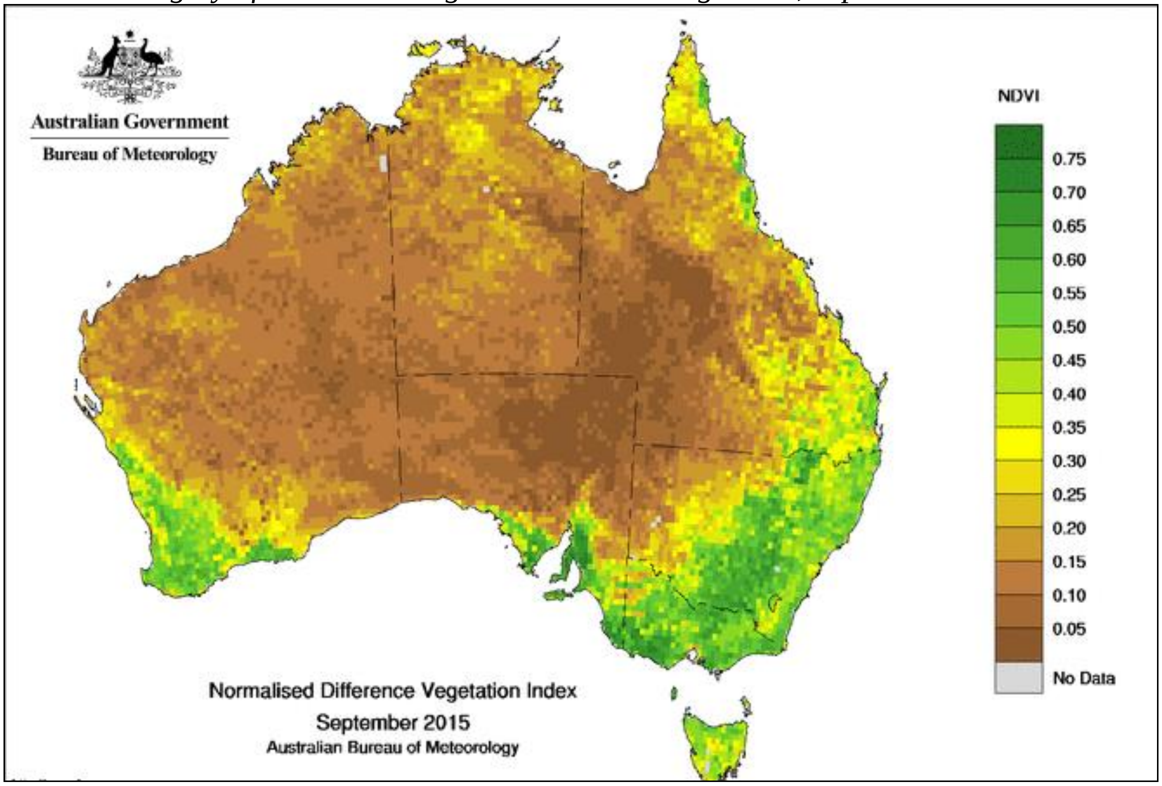
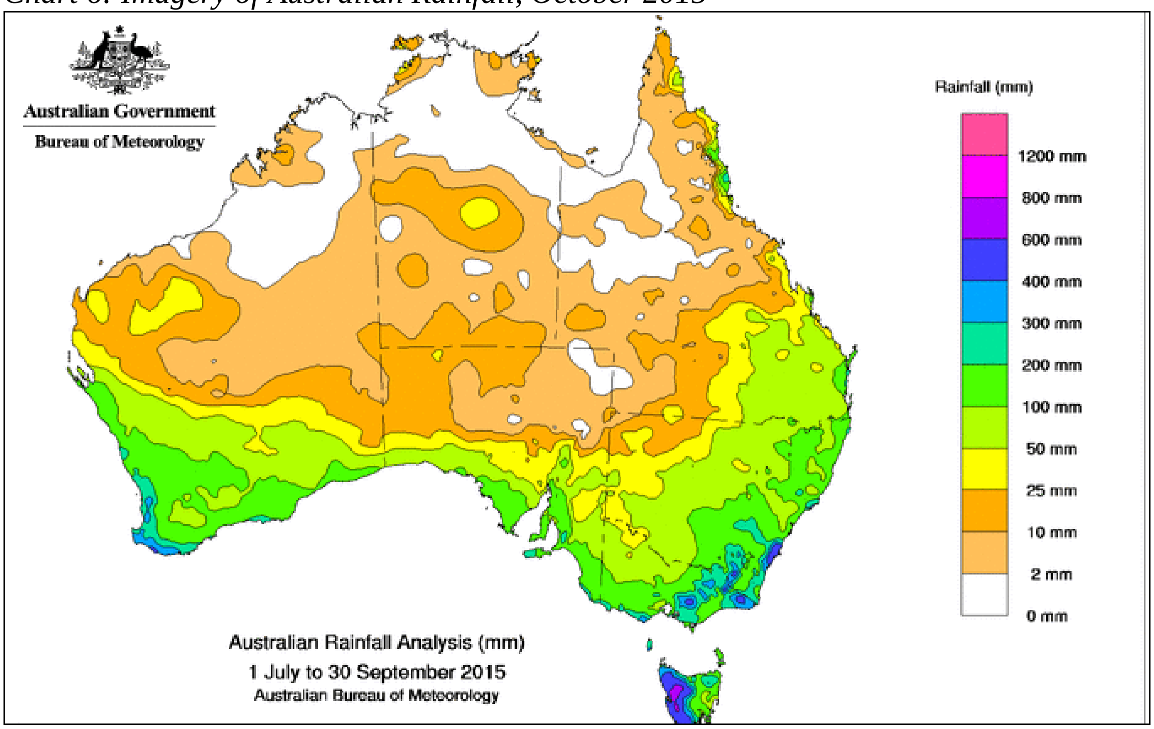


Chart 6: Imagery of Australian Rainfall, October 2015



Source: Bureau of Meteorology (2015).

COMMONWEALTH SCIENTIFIC AND INDUSTRIAL ORGANISATION (CSIRO)

The CSIRO use satellite imagery data for a number of applications, including the Environmental Earth Program which is investigating changes in land surface-climate interactions, coupling of water and carbon balances and the observation and prediction of hydrological processes. The CSIRO Marine and Atmosphere Research (CMAR) project provides remote sensing data time series and satellite imagery based biophysical maps of Australia. CMAR also manages the Atmosphere and Land Observation and Assessment Program which processes and analyses satellite imagery data of land surface features, such as soil moisture and vegetation. CSIRO is building an interactive system to digitally link information about farm soils, climate and other data to aid farm decision-making. Funded under the National Landcare Program, the project will give farmers information and improved spatial resolution.

WESTERN AUSTRALIAN SATELLITE REMOTE SENSING SERVICES

Western Australia's major analyst of land information and geographic data is Landgate which uses NASA satellite data and in-house software to detect bushfire hotspots from MODIS satellite imagery data. Landgate also provides online farm-related data products based on satellite imagery data that measure crop development and pasture vegetation growth rates.

THE REMOTE SENSING AND SATELLITE RESEARCH GROUP (RSSRG)

The University of Queensland manages the Terrestrial Ecosystem Research Network (TERN) which uses remote soil sensing data to estimate key soil attributes for ecosystems TERN have also partnered with CSIRO and Google to put detailed satellite imagery of Australian landscape through Google Earth. The TERN group is aiming to transform satellite imagery area into high quality estimates of crops which could be published as official ABS statistics

Spectral characteristics of fields, results of texture analysis and changes in dynamics of colors brightness are being used to build indices and functions for harvest assessment and control. Processing of the satellite images in the red and infrared spectral range gives an opportunity not only to observe the fields in a real time mode, but also to generate database on the soil temperature and changes in its condition, rainfall, vegetation indexes for different crops, with a time horizon of 10 and more years.

ABARES

The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) is part of the Department of Agriculture and provides independent research, analysis, forecasting and statistics on the agriculture, fisheries and forestry industries. ABARES annual collections of farm business data inform government, industry and other stakeholders about farm production, productivity and financial performance. ABARES produces two main types of land use data, (1) catchment scale land use mapping and (2) national scale land use mapping data.

Catchment scale land use mapping is based on the integration of land tenure and other types of land use data, fine-scale satellite imagery data and information collected in the field. National scale land use mapping is based on coarse-scale satellite imagery data (that is, pixels of size square kilometers), ABS agricultural statistics and ground control point data for agricultural land uses, and various other digital maps, including the finer resolution catchment scale land use data, for non-agricultural land uses (ABARES, 2011).

ABARES also manage the Ground Cover Monitoring for Australia project, a collaborative partnership between the Department of Agriculture and Water Resources, the Commonwealth Science and Industrial Research Organization (CSIRO), the Terrestrial Ecosystem Research Network and the state and territory governments. The project delivers estimates on ground cover at 500m resolution from MODIS satellite imagery data.

ABARES Farm Surveys

ABARES farm surveys national coverage of broadacre (grains, sheep and beef), dairy and vegetable farms and provide data on farm financial and physical performance. The survey program does not effectively cover industries such as sugar cane, wine grapes, fruit growing and intensive livestock. ABARES survey collections are funded mainly by the Department of Agriculture with contributions from Research Development Corporations (RDCs) and the Murray Darling Basin Authority. The major ABARES agricultural statistics products in relation to crop monitoring are:

- *Australian Commodity Statistics*: is an annual statistical summary that covers grains and oilseeds, livestock, livestock products, food, wool, horticulture, forestry and fisheries products. The report also contains statistics on farm inputs, agricultural water use and national macroeconomic indicators such as economic growth, employment, balance of trade, exchange rates and interest rates.

- *Agricultural Commodities:* provides forecasts of prices, production and the value and volume of exports for Australia's major agricultural and natural resource-based commodities.

- *Australian Crop Report*: provides a quarterly assessment of crop prospects for major field crops, forecasts of area, yield and production and a summary of seasonal conditions on a state by state basis.

- *AGSURF***:** allows the generation of data sheets by geographic region, sub-industry and farm level, including livestock numbers, crop production, costs, fertilizer use, receipts and socioeconomic indicators.

- *Australian Collaborative Land Use and Management Program (ACLUMP):* which coordinates land use mapping in Australia to ensure consistent coverage of land use and land management practices. ACLUMP produces national-scale mapping using cost-effective modelling that links the agricultural statistics of various crops and pastures, time-series satellite data, and available spatial data on non-agricultural land use. ACLUMP is a consortium of Australian and State government partners.

- *The Monitor: provides* climatic, production, biophysical and economic information across Australia.

THE AUSTRALIAN BUREAU OF STATISTICS

The Australian Bureau of Statistics has a key role in providing agricultural data in Australia based on both census and survey data, Currently, the Bureau is evaluating methodological approaches for utilizing satellite imagery to estimate official crop area statistics, in order to supplement its partial survey-based methodology which has replaced more comprehensive and regular censuses of agricultural production because of budget constraints. In particular, the ABS is currently reviewing its agricultural statistics surveys and methodology because of gaps in its coverage since the cessation of annual agricultural censuses in 1997, after which a 5-year strategy was adopted for an agricultural census with sample surveys in inter-census years. The last two agricultural censuses were in 2006 and 2011 and a new census is due in 2016. See: link.

The ABS and the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) undertook the National Agricultural Statistics Review (NASR) to consider all aspects of the current agricultural statistical system and assess its capacity to inform decision making. The NASR (2015) was released in July 2015 to consider new sources for data collection and surveys, including the use of satellite imagery. The review is also aiming to reduce stakeholder concerns over respondent burden, while also aiming to improve data quality, enhance the statistical infrastructure and ensure there is strong coordination in the agricultural statistics system.

Further, an agricultural statistics consultative forum will be established to engage stakeholders and drive effective coordination and improved outcomes across the Australian agricultural statistical system. The forum should pursue data gaps and overlaps and mechanisms to address them while identifying additional ways to improve data quality and reduce respondent burden. The ABS also plans to publish an annual calendar of planned statistical collections requested of farmers, fishers and foresters to improve public accountability of survey managers and to more effectively manage respondent burden through greater transparency.

The NASR review process identified a number of potential innovations and technologies in agricultural statistics collection for further consideration. These included the possible use of electronic data reporting forms as have been used for the US Agricultural Census since 2007. Another possibility is increased use of ‘big data’, remote sensing and sensor technologies embedded in production systems such as real time data collection from crop harvesters.

AUSTRALIAN EXPORT GRAINS INDUSTRY CORPORATION

AEGIC produces soil moisture maps using rainfall data from over 900 Bureau of Meteorology weather stations across Australia. These are used to provide soil moisture ranking percentile maps for the last 100 years.

UNIVERSITY OF QUEENSLAND CROP FORECASTING

The Queensland Alliance for Agriculture and Food Innovation (QAAFI) produces a monthly OZ-Wheat regional wheat yield forecast developed from climate data and modelling, remote sensing and historical data. QAAFI) is a joint venture between the University of Queensland and the Queensland State Government. The project also generates crop maps that show likely yield outcomes and incorporates effects of soil moisture and projected rainfall and temperatures based on the Southern Oscillation Index (SOI).

Using satellite imagery, maps can indicate areas of less than average yield (typically shaded in yellow to red), whereas colors in green to blue have a high chance of obtaining above average yield. The project has been relatively successful in forecasting final crop outcomes for sorghum across the summer cropping region although there is variation in the outlook among local regions. QAAFI also operates an innovative approach for ground truthing data by employing crowd sourcing with an online interface.

GEOGLAM

The Group on Earth Observations, a partnership of governments and international organizations, developed the Global Agricultural Monitoring (GEOGLAM) initiative in response to the growing calls for improved agricultural information. The goal of GEOGLAM is to strengthen the international community's capacity to produce and disseminate relevant, timely and accurate forecasts of agricultural production at national, regional and global scales through the use of Earth Observations (EO), which include satellite and ground-based observations. This initiative is designed to build on existing agricultural monitoring programs and initiatives at national, regional and global levels and to enhance and strengthen them through international networking, operationally focused research, and data/method sharing.
http://www.geoglam-crop-monitor.org/

Both GEOGLAM and AMIS were endorsed by the G20 Heads of States' Declaration (Cannes, November, 2011), when GEOGLAM was tasked to "coordinate satellite monitoring observation systems in different regions of the world in order to enhance crop production projections and weather forecasting data." Within this framework, GEOGLAM developed the Crop Monitor reports, which provide crop condition assessments of wheat, soybean, rice and corn for over twenty nations in support of the AMIS market monitoring activities.

The Crop Monitor Tool

The objective of the Crop Monitor is to provide AMIS with an international and transparent multi-source consensus assessment of crop growing conditions, status, and agro-climatic conditions likely to impact global production. This activity covers four primary crop types (wheat, maize, rice, and soy) within the main agricultural producing regions of the AMIS countries. These assessments have been produced operationally since September 2013 and are published in the AMIS Market Monitor Bulletin. The Crop Monitor reports provide cartographic and textual summaries of crop conditions as of the 28th of each month, according to crop type.

Within the first issues of the crop monitor, crop condition maps were based on the EO-derived Normalized Difference Vegetation Index (NDVI) depicting crop growth anomalies. Starting in the May 2014 issue, the Crop Monitor group has provided a more informative set of maps and pie charts that depict crop stage and crop conditions by region, as well as climatic drivers affecting these conditions.

GEOGLAM and Australia Rangeland

Much of Australia's rangeland agriculture occurs in the north, and this is principally used for cattle grazing. This expansive region also encapsulates some relatively untouched ecosystems that support many endemic species. Routine monitoring at management scales of the levels and condition of land-cover and standing biomass in this region underpins responsible management and land-stewardship, as well as providing strategic information to help sustain profitability from year to year for pastoralists and beef producers.

A range of new satellite image datasets from radar and optical sensors have improved the potential to map and monitor a range of vegetation cover parameters including the distribution and dynamics of grassland biomass. This project will develop algorithms for mapping grass biomass in Australia's northern rangelands from radar and optical satellite imagery, and methods to validate these models in the field.

Tasmanian Land and Crop Monitoring

The Tasmanian Spatial Information Foundations (SIF) Project maps agricultural land areas under a comparatively low level of definition, but offers the foundation for more detailed studies using satellite data and of assessment NVDI imagery to differentiate crop types. The Aerial Photo Viewer is a web-based system that gives public access to Tasmania's statewide aerial photography for improved farm management.

Birchip Cropping Group

The Birchip Cropping Group (BCG) is a not-for-profit agricultural research organization led by farmers in the Wimmera Mallee region of Victoria. The region is a leader in dryland farming technologies because of comparatively low rainfall and the BCG has emphasized the use of no till farming and other agronomy methods to maintain soil moisture and increase productivity in the region. BCG has developed the Yield Prophet tool to assist farmers in this region.

- Yield Prophet: is an on-line crop production model designed to present grain growers and consultants with real-time information about their crops, providing integrated production risk advice and monitoring for farm management. Operated as a web interface for the Agricultural Production Systems Simulator (APSIM), the tool accesses climate information for 4,600 weather stations across Australia and provides climate data from the current season which can be used to assess crop growth in a specified paddock from the time of soil sampling to the time of the report.

AUSTRALIAN GRAIN GROWERS

GrainGrowers is a major national grain producer organization, with over 18,500 members which developed the ProductionWise crop monitoring digital tool to help manage their farms. ProductionWise: was developed by GrainGrowers to provide an online crop management and decision support platform for farmers. ProductionWise also uses the APSIM as the engine for generating yield modeling projections.

The APSIM (Agricultural Production systems siMulator) Initiative is a joint venture between the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the State of Queensland Department of Agriculture, Fisheries and Forestry (DAFF) and The University of Queensland (UQ).It uses digital tools including satellite imagery to allow digital farm mapping, online operations and grain management tools. It can generate a production profile based on cropping history to determine production performance. Paddock level gross margin analysis enables the user to track production costs. It provides access to long-term rainfall forecasts, climatic history and biomass monitoring for paddocks.

OUTLOOK AND FUTURE OPPORTUNITIES

In the United States, the National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture uses satellite imagery to enhance rather than to replace its ongoing program of crop acreage estimates. For spring planted crops, the first crop acreage estimates are published at the end of March in the Prospective Plantings Report. Actual plantings are released in the Acreage Report at the end of June. Yield forecasts are published about July 10 for oats, barley, and spring wheat and August 10 for corn, soybeans, sorghum, and cotton, along with forecasts of acres for harvest.

The USDA has three major applications of remote sensing with respect to crop acreage estimates. Firstly satellite imagery has been used as an input for the sampling frame for agricultural statistics since 1978. Secondly, satellite imagery has been to advance the statistical precision of crop acreage estimate indicators since 1972. Thirdly, a publically available annual GIS data file containing field level crop type data called the Cropland Data Layer is used to monitor water reservoirs, soils utilization, crop rotation and animal habitats. The Cropland Data Layer has traditionally used Landsat (30 meter resolution) satellite imagery. At present higher resolution data from The DEIMOS-1 and DMC-UK 2 imagery (22 meter) has been introduced into the production of the Cropland Data Layer product: see link

In recent years, NDVI images have allowed a clearer understanding of many developments affecting agriculture in the United States. Use of this technology for example allowed a detailed and spatially complete perspective on the 1993 flood in the Midwest and 2011-15 drought conditions in California, allowing policymakers and industries to better understand these developments. Such images are virtually impossible to obtain with ground survey data.

Limitations on the efficacy of satellite imagery in the United States are similar to those for Australian crop monitoring agencies. They include cloud cover, image delivery schedules, timing of the existing crop estimates and problems in the exclusivity of spectral signatures for crops which would allow clear identification of crops from satellite images. The USDA has further observed that: 'Perhaps the single greatest reason that NASS has not replaced any conventional crop acreage estimation surveys (farmer reported data) is that satellite collected data cannot meet the time requirements of the crop estimates system. Early in the growing season, until crops reach nearly their full canopies, there would be considerable misclassification among different crops if acreages were estimated by remote sensing': see link.

Currently satellite imagery for crop monitoring is most effectively used for the season final acreage for harvest and differentiation uncertainties in the earlier part of the growing period means that satellite images would mainly be used for predicting acreages based on soil types. Spectral differences between crops become clearer, allowing a separation of corn from soybeans in the upper Midwest by mid-August – but this is less useful for early forecasts. In practice, the NASS publishes three major crop acreage indications (prospective plantings, actual plantings, and forecasted acreage for harvest) before satellite imagery can be accurately used (see link).

As crop monitoring through satellite-based crop classification is based on the measurement of energy emitted or reflected by these plants and future developments, there are many factors such as cloud cover and the exclusivity of spectral signatures that can impede the efficient us of this technology in making timely and accurate forecasts of crop development in both Australia and the United States (see link). However, the more rapid availability of satellite data in the future and the refinement of techniques for understanding and efficiently classifying the digital signatures of crops can be expected to make satellite monitoring of crops an even more effective technology for assessing crop production.