Long-Term Remote Sensing Database, Walnut Gulch Experimental Watershed, Arizona, USA

M.S. Moran[1], C.D. Holifield Collins[1], D.C. Goodrich[1], J. Qi[2], D.T. Shannon[3] and A. Olsson[4]

[1] USDA ARS Southwest Watershed Research Center, Tucson, AZ
[2] Michigan State University, Center for Global Change and Earth Observations and Department of Geography, East Lansing, MI
[3] Wu-Wei Software, Tucson, AZ
[4] Office of Arid Lands Studies, Arizona Remote Sensing Center, Tucson, AZ

Abstract. The USDA Agricultural Research Service, Southwest Watershed Research Center, Walnut Gulch Experimental Watershed (WGEW) is a located in the San Pedro Valley of Southeastern Arizona. It is one of the most highly instrumented semi-arid experimental watersheds in the world and has one of the largest published collections of spectral imagery with coordinated ground observations. The WGEW Image and Ground Data Archive produced in 2006 (WIDGA06) is a collection of images from satellite- and aircraft-based sensors dating back to 1990 with ancillary ground-based measurements archived with each image. This report provides background information on the collection and archiving of this data set, and contact information for obtaining copies of the image and data files. Many images are available in the University of Arizona, Arizona Regional Image Archive (ARIA) at http://aria.arizona.edu. Metadata are available via the U.S. Department of Agriculture, Agricultural Research Service, Southwest Watershed Research Center (SWRC) at http://www.tucson.ars.ag.gov/dap/ .

1. Introduction

The USDA Agricultural Research Service, Southwest Watershed Research Center, Walnut Gulch Experimental Watershed (WGEW) is located in Southeastern Arizona, encompassing the city of Tombstone, Arizona. The hydrology of this region is characterized by the North American Monsoon that supplies roughly two thirds of the annual precipitation during the summer (Goodrich et al., this issue). Desert shrubs dominate the lower two-thirds of the watershed and desert grasses dominate the upper one-third (Skirvin et al., this issue). Starting in 1953 and continuing to the present, measurements of key surface conditions have been made throughout the watershed resulting in an exceptional understanding of semi-arid hydrology at WGEW and surrounding regions (Renard et al., this issue).

The long-term, high-quality data collection conducted over decades at WGEW has encouraged numerous hydrologic remote sensing (RS) experiments funded by National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA) and National Science Foundation (NSF) (e.g. Kustas and Goodrich, 1994; Moran et al., 1994; Goodrich et al., 2000; Jackson et al., 2007). This continuing work has resulted in an accumulation of hundreds of spectral image files from a variety of satellite- and aircraft-based sensors (the “images”) and the association of those images with data files containing high-quality ground-based measurements of soil, plant and atmospheric conditions (the “ground data”). These images and the supporting ground data have been compiled in one location and archived in an orderly fashion to enable easy queries of either image or supporting ground data files. Metadata on all archived images and ground data were entered into a database to link the information in the two data sets.

The combination of RS images with extensive Geographic Information System (GIS) coverage (Heilman et al., this issue) and decade-long hydrologic datasets has increased the value and potential application of all three datasets. As a result, the WGEW was chosen as one of only 15 core sites worldwide by the International Community Earth Observing System (CEOS) for satellite product validation and calibration (see http://landval.gsfc.nasa.gov/MODIS/coresite.php?SiteID=22). WGEW has also been designated as a Global Fiducial site by the U.S. Environmental Protection Agency (EPA) for long-term monitoring of processes associated with the causes or effects of environmental change. For the next 25 years satellites will collect periodic images of WGEW and other fiducial sites using the National Technical Means data from the nation's intelligence and reconnaissance satellites. WGEW is also a key experimental site of the NSF SAHRA (Sustainability of semi-Arid Hydrology and Riparian Areas) Science and Technology Center (http://www.sahra.arizona.edu/research/resources/sites.html#1).

This report offers a description of the RS datasets with references to more detailed information and metadata. It also provides links to web sites from which the images can be downloaded or requested, and the conditions for sharing commercially distributed images.

2. Remote Sensing Data

A concerted effort has been made to include remote sensing in research at WGEW. Research experiments at the watershed scale have generally been designed to coincide with image acquisition and to make ground-based measurements that best support validation and calibration (e.g., Skirvin et al., this issue). Conversely, long-term, continuous WGEW measurements made with permanent instrumentation have been designed to best support regional research that is conducted with RS imagery (e.g., Keefer et al., this issue; Goodrich et al., this issue;). As a result, the RS database is a mix of imagery with coincident, supporting measurements of sub-surface, surface and atmospheric conditions.

2.1 Imagery

Over 100 optical images from satellite and high-altitude aircraft sensors and over 50 radar images from satellite sensors have been purchased over the past 20 years for WGEW (Table 1). These include not only a multi-year time series of images from several satellite sensors, but also several unique multi-satellite combinations. For example, Landsat TM and ERS SAR scenes were acquired within days of each other on 14 different occasions (acronyms are defined in Table 1).

SPOT HRV, Landsat TM and ERS-1/2 SAR images originally purchased from commercial providers were restricted by the company image license agreements with the SPOT Image, Space Imaging/EOSAT and Eurimage, respectively. These three companies have agreed to waive this restriction for the images, and to allow the images to be shared under a reasonable set of conditions defined by each company. The conditions are that

1) the facility receiving the images shall abide by the company's license agreement;

2) the images are used solely by University and Government organizations, for academic and scientific research and not for commercial purposes;

3) the facility receiving the images may not receive commercial funding for the research activity involving the use of these images;

4) the facility receiving the images is not authorized to share the images with additional organizations; and

5) the company requests a periodic report listing organizations that have been furnished a copy of the images (email addresses).

2.2 Ground-based Ancillary Data

Supporting files of ground, atmospheric and low-altitude aircraft measurements – collectively referred to here as "ground data" – were archived with an internal header describing techniques, instrumentation, location and other relevant information. Ground-based measurements include surface reflectance and temperature (e.g., Moran et al., 1996), soil moisture (e.g., Thoma et al., 2006), vegetation density, species and leaf area index (e.g., King et al., this issue), and surface roughness (e.g., Bryant et al., 2007). Atmospheric measurements to obtain atmospheric optical depth and water vapor content were often made on site with a solar radiometer and other instrumentation according to the protocol described by Biggar et al. (1990). Low-altitude aircraft were sometimes deployed to make below-atmosphere measurements of surface reflectance and temperature on satellite overpass dates (e.g., Moran et al., 1997).

In addition to these intermittent measurements made specifically to support satellite and aircraft overpasses, long-term continuous measurements of key conditions are available at distributed locations throughout the watershed (Keefer et al., this issue; Goodrich et al., this issue; Stone et al., this issue; Nichols et al., this issue; Emmerich and Verdugo, this issue). In some cases, these point-based measurements have been interpolated to produce spatially continuous maps of some information, such as precipitation (Garcia et al., this issue; their Figures 3 and 4).

2.3 Database

This database was originally published under the name "Water Conservation Laboratory (WCL) Image and Ground Data Archive 1999" (WIGDA99) by Moran et al. (2000b). Imagery for two sites, WGEW and the Maricopa Agricultural Center (MAC) near Phoenix Arizona, were archived in WIGDA99 and updated by WCL. Since 2000, archiving efforts have been focused on adding imagery for WGEW and associated field sites to the database. The database has since been renamed "WGEW Image and Ground Data Archive 2006" or WIGDA06. The images and ground-based data from experiments at MAC in the 1980s and 1990s are still in the database, but only the data for WGEW are current to the year 2006.

The WIGDA06 database itself is based on a simple schema similar to that of the previous version. Image files are represented by rows in one table, ground data files by rows in another. Because those files have a “many-to-many” relationship -- a single image file may be related to multiple ground data files and a single ground data file may be related multiple image files -- a third table is required to represent those relationships. Additional lookup tables provide standard values for various columns in the two main tables. The metadata are included with abbreviated, yet informative, descriptions that are easily understood by data users (e.g., Table 2).

The WIGDA99 program used to view the database – previously programmed to run in Microsoft Access - has been replaced by WIGDA06, a more flexible and robust interface programmed in Visual Basic.Net for Microsoft .NET Framework 2.0. WIGDA06 is designed to run on the Windows XP operating system and requires Service Pack 2. Mention of proprietary product does not constitute a guarantee or warranty of the product by USDA or the authors and does not imply its approval to the exclusion of other products that may also be suitable.

Users are presented with a separate grid for each of the two main tables and can search, sort, and filter those grids to select the files of interest. Selecting a particular image file in the image data grid reveals all related ground data files, and vice-versa. Users can print reports showing the metadata for a single file, a filtered group of files, or all files, and also have the option of including a listing of the metadata of related files. (For example, a report showing metadata for image files can include a list of all related ground data files under each image file.) With the query power of WIGDA06, it is possible to locate datasets that meet specific research needs.

3. Data Availability

The WIGDA06 database is available by request from the website at http://www.tucson.ars.ag.gov/dap/ maintained by the U.S. Department of Agriculture Agricultural Research Service, Southwest Watershed Research Center in Tucson, Arizona, United States (Nichols and Anson, this issue). In many cases, the images can be downloaded directly from the University of Arizona, Arizona Regional Image Archive (ARIA) at http://aria.arizona.edu under the conditions listed in Section 2.1. ARIA is an online clearinghouse for multi-spectral and hyperspectral satellite imagery, aerial photography, digital elevation models, and digital maps. In addition to serving as a node for accessing certain WIGDA datasets focused on the Walnut Gulch Experimental Watershed, ARIA provides data donated by researchers, agencies, and individuals focusing on the U.S. Southwest and Mexico. Since its establishment in 1998 as part of an NASA Research Infrastructure Grant, it has been used by researchers, land managers, environmental consultants, and the general public for everything from land change detection to outdoor adventure planning (e.g., Hutchinson et al., 2001; Norman, 2006; Diem and Comrie, 2002; White et al., 2005; Wallace and Marsh, 2005; Huang et al., 2006; and Wright and Ramsey, 2006). For WIGDA users interested in data not available in ARIA, SWRC considers each image request individually.

4. Examples of Data Use

The time series of remotely sensed imagery at WGEW has allowed unique research that would not be possible with only a single image or a set of images over only one season, or for a site without the spatial characterization described here. There have been several studies that used the multi-temporal image set associated ground-based data for modeling and algorithm development. With over a decade of Landsat TM and ETM+ scenes of WGEW, Nouvellon et al. (2001) was able to calibrate an ecosystem model and simulate the spatial distribution of model products, such as daily aboveground biomass, leaf area index (LAI) and soil water content on a daily basis (Figure 1). Moran et al. (1996) used ground-based measurements of surface temperature and reflectance with meteorological measurement to test an approach to estimate surface evaporation rates at WGEW. Once tested, Holifield et al. (2003) used this approach with a 10-year data series of Landsat TM and ETM+ images to investigate the temporal and spatial changes in grassland transpiration associated with antecedent rainfall, slope aspect and grassland condition. Thoma et al. (2006) used multi-temporal SAR scenes at WGEW, acquired in both the dry and wet seasons, to derive an image-based index for estimating soil moisture that has operational advantages over approaches based on a single image.

The multi-sensor nature of the remote sensing database has allowed studies of data fusion and optical/radar synergy. Troufleau et al. (1997) utilized the distinctive image data set from 1992 when nine Landsat TM scenes, three SPOT HRV scenes and five ERS-1 SAR images were acquired during the summer growing season. They developed a two-step procedure to estimate sensible heat flux, in which the radar backscatter was used to estimate soil moisture and then determine soil temperature, and the Landsat TM composite temperature was used to deduce vegetation temperature for estimation of sensible heat flux with a two-layer model. Moran et al. (2000a) utilized both the multi-temporal SAR data and optical/SAR fusion for monitoring semiarid range conditions. Using eight pairs of ERS-2 SAR and Landsat TM images in 1997, they developed a new approach to improve regional estimates of surface soil moisture content. Wang et al. (2003) used the same dataset to develop an optical/microwave synergy model to map soil moisture over desert grass and shrub areas (Figure 2).

The WGEW remote sensing dataset also offers multi-angle imagery acquired over a period of days when surface conditions remained relatively constant. Qi et al. (1991) used bidirectional reflectance measurements (with view angles from –40° to +40°) acquired with radiometers mounted on a low-altitude aircraft (flown at 150 m above ground level) to better derive estimates of vegetation cover in sparse semi-arid vegetation. Rahman et al. (2007) addressed a classic problem of under-determination faced when deriving two unknowns (surface roughness and soil moisture) from a single SAR scene. They used multi-angle radar images from WGEW to demonstrate a solution that uses multi-angle SAR images and provides estimates of both roughness and soil moisture without the use of ancillary field data.

The WGEW remote sensing database, compiled and archived by USDA, is also a part of larger databases that were acquired in NASA and NSF funded experiments at WGEW. These include the Monsoon90 Experiment (Special Section of Water Resources Research, Issue 30, 1994), the Semi-Arid Land-Surface-Atmosphere (SALSA) Experiment (Special Issue of Journal of Agriculture and Forest Meteorology, Issue 105, 2000), and the Soil Moisture Experiment 2004 (SMEX04) (Special Issue of Remote Sensing of Environment, in press). These intensive experiments add even more instrumentation, measurements and value to the extensive USDA database, and increase the coverage to river basins, such as the San Pedro River, and larger regions including

Mexico. As part of SALSA, Qi et al. (2000) combined Landsat TM, SPOT 4 VEGETATION and NASA TM Simulator images to map the vegetation cover and leaf area index of the San Pedro River riparian corridor in southwest United States. In SMEX04, image acquisitions and ground-based measurements at WGEW were duplicated in Sonora Mexico and both sites were used to validate image-derived regional soil moisture maps (Bindlish et al., 2007) and vegetation water content (Yilmaz et al., 2007).

5. Conclusions

The WIGDA06 database, partnered with the ARIA image clearinghouse, offers the opportunity to study semiarid ecosystem dynamics at the watershed spatial scale and the multi-decadal temporal scale. The combination of downloadable images with a catalog of supporting ground-based measurements of vegetation, soil moisture and meteorological conditions will encourage studies of regional hydrologic, ecologic and climatic processes. The availability of images from multiple sensors at a single location will facilitate creative applications of multispectral data fusion and help define the best payloads for future orbiting platforms. Spectral data at multiple spatial resolutions ranging from less than a meter to 1 km will be useful for addressing the critical issues associated with scaling plot measurements to regional coverage while retaining data integrity. Such research opportunities and more are only now possible due to the long history of attention to image and data archive at SWRC and the recent progress in WIGDA06 and ARIA to make all data available for academic and scientific studies.

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7. References

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Figures and Tables

Table 1. A summary of *some* of the images archived in the WIGDA06 database.

Table 2. List of *some* metadata available for the WIGDA06 entries.

Figure 1. Maps of simulated annual net primary production from 1990 to 1999, produced by coupling a grassland ecosystem model with Landsat imagery for a 10-year simulation (from Nouvellon et al., 2001).

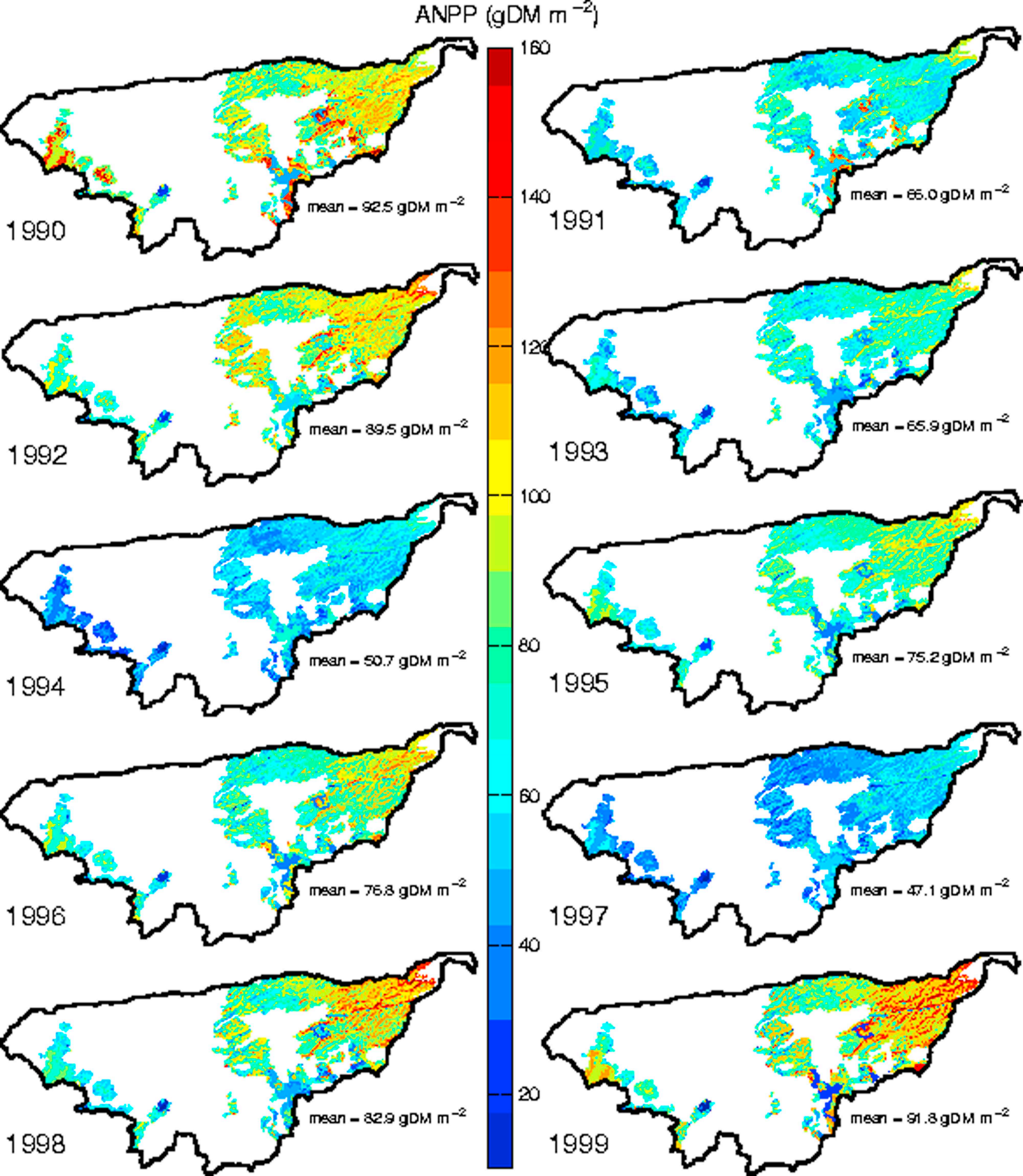
Figure 2. Paired ERS-2/TM images of the study area in three seasons in 1997: winter wet, spring dry, end of spring dry and summer monsoon (from Wang et al., 2004).

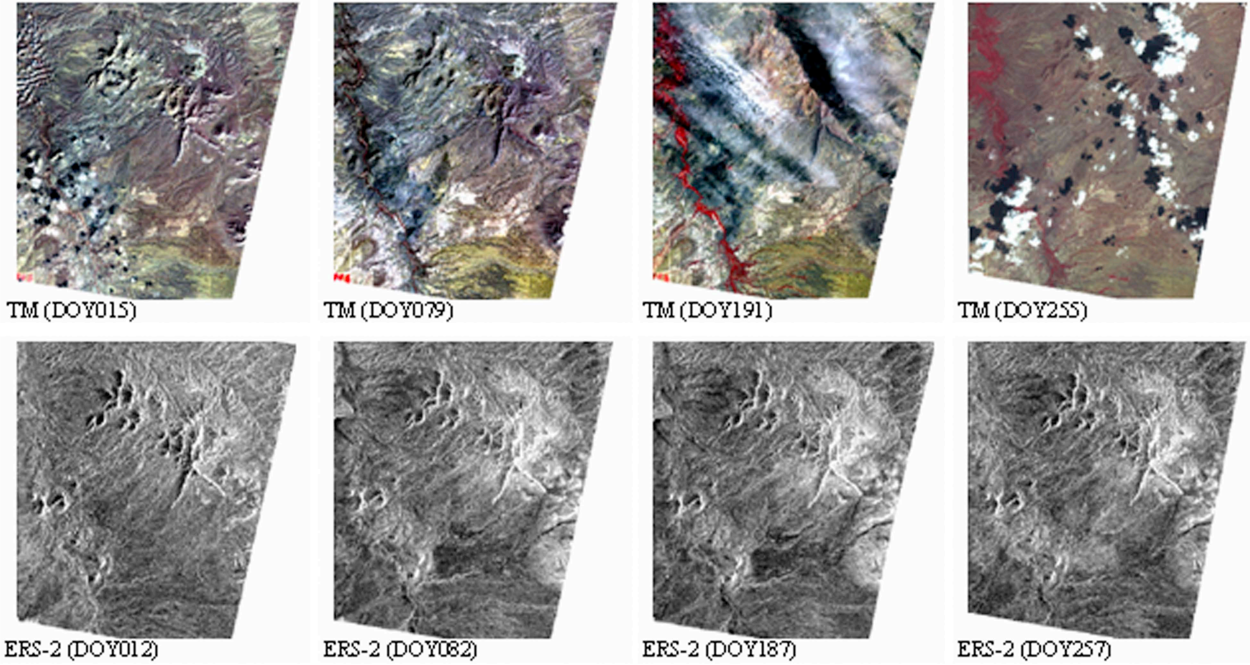
Table 1. A summary of *some* of the images archived in the WIGDA06 database and available in ARIA at http://aria.arizona.edu**.**

Platform/Sensor	**Acquisition Dates**	**No. of Images**	**Notes and relevant citations**
Satellite Platform, Optical Sensor			
NASA Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+)	1990-Present	96	• Path, Row = 35, 38 • Landsat satellites 4, 5 and 7 • 12 clear acquisitions in 1992 • Clear acquisitions during each Monsoon season 1990-Present • available in ARIA • Example: Holifield et al. (2003) • http://landsat.gsfc.nasa.gov/
SPOT Image, SPOT High Resolution Visible (HRV)	1992-2000	5	• K,J = 559,286 • View angles - +5° to -29° • One pair of XS scenes acquired on consecutive days at different view angles • 2 available in ARIA • Example: Qi et al. (1991;2000) • http://www.spot.com/html/SICORP/_401_.php
NASA Earth Observing-1 (EO-1) Advanced Land Imager (ALI) and Hyperion	2001	3	• Hyperion is an imaging spectrometer with 10nm contiguous bands of the solar spectrum from 400-2500nm • ALI provides Landsat-type panchromatic and multispectral bands, with three additional bands covering 0.433-0.453, 0.845-0.890, and 1.20-1.30 µm • Example: Bryant et al. (2003); Moran et al. (2003) • http://eo1.gsfc.nasa.gov/
US DOE Multispectral Thermal Imager (MTI)	2001-2004	11	• spectral bands ranging from the visible to long-wave infrared • available in ARIA • http://www.nnsa.doe.gov/na-20/mtis.shtml
DigitalGlobe Quickbird	2002-Present	5	• 61-cm panchromatic and 2.44-m multispectral at nadir • Not available in ARIA • http://www.digitalglobe.com/
Space Imaging IKONOS		3	• 1-m panchromatic and 4-meter multispectral imagery • Not available in ARIA • http://www.spaceimaging.com/products/
Satellite Platform, Radar Sensor			
European Space Agency, European Remote Sensing (ERS) Synthetic Aperture Radar (SAR)	1992-Present	22	• 14 pairs of Landsat TM and ERS SAR scenes acquired within days of each other • 20 available in ARIA • Example: Moran et al. (2000a) • http://earth.esa.int/
European Space Agency, Envisat SAR	2003, 2004	14	• Acquired in SMEX04 experiment (Cosh et al., 2007) • Multiple view angles and polarizations • Not available in ARIA • Example: Rahman et al. (2007) • http://envisat.esa.int/

Canadian Space Agency (CSA), RadarSat SAR	2002-Present	12	• 5 with identical configurations on different dates • 2 sets acquired at 3 different view angles in a single month • Not available in ARIA • Example: Thoma et al. (2006) • http://www.space.gc.ca/asc/index.html
Aircraft Platform, Optical Sensor			
NASA Thermal Infrared Multispectral Scanner and TM Simulator	1996, 1997	2	• Flown on the C-130, ER-2, and the Stennis Learjet aircraft. • High resolution (5-15m) 6-band thermal and TM simulator • Images acquired during the dry and wet seasons • Plus 9x9” format photographs • http://www.nasa.gov/centers/dryden/research/AirSci/ER-2/tims.html
NASA Thermal and Land Applications Sensor (ATLAS)	1997	1	• Aboard a NASA Stennis Lear jet • 15 multispectral channels across the visible, near-IR and thermal spectrum http://www.ghcc.msfc.nasa.gov/precisionag/atlasremote.html

Table 2. List of *some* metadata available for the WIGDA06 entries.	
Image Data	
Field Name	**Description**
File Name	A file naming convention was developed to produce 8-digit filenames which are coded for experiment, measurement type and date.
Platform and Sensor	This designates the satellite or aircraft (e.g. Landsat7) and the sensor type (e.g. ETM+).
View angle, spectral bands, spatial resolution	These are characteristics of the sensor and image for a given acquisition.
Image quality Weather quality	These are qualitative assessments of the imagery based on image defects (e.g., striping) or weather conditions (e.g., clear, cloudy).
Latitude and Longitude	Geographic coordinates of the image center.
Has Atm Data? Has Radiosonde? Has Aircraft Data? Has Yoke Data? Has Subscene?	These flags show if measurements of atmospheric optical depth or radiosonde measurements were made during the overpass and if a given satellite-based image is supported with a radiometer deployed on low-altitude aircraft or ground-based yoke. For some images, subscenes were extracted and processed for a value added product over a specific site.
Restrictions	This gives information on sharing restrictions, like those listed in Section 2.1 for some imagery.
Archived on CD? Available in ARIA? Has Duplicate?	Imagery is generally archived on CD-ROM and, in many cases, is available for downloading from the ARIA web site. Routinely, a duplicate CD-ROM has been made so that it can be shared on request without jeopardizing the original.
Ground Data	
Field Name	**Description**
File Name	A file naming convention was developed to produce 8-digit filenames which are coded for experiment, measurement type and date.
Experiment	This designates the general location of the field measurements. More detailed information on measurement location is included in the file header. The also designates the specific target of the measurement (e.g., experimental site or special target).
Measurement Type	This designates the instrument used in the measurement (e.g., hand-held 4-band radiometer) or the measurement type (e.g., soil moisture).
Has Atm Corr Notes? Has Field Notes? Has Air Flight Log?	These flags show if measurements of atmospheric optical depth, hand-written field notes or hardcopy flight logs are archived in the field cabinet at SWRC.
Location Notes	These are generally excerpts from the header of the file. When available, GPS coordinates are included.


ANPP (gDM m^{-2})
160
140
120
100
80
60
40
20
1990
mean = 92.5 gDM m^{-2}
1991
mean = 65.0 gDM m^{-2}
1992
mean = 89.5 gDM m^{-2}
1993
mean = 65.9 gDM m^{-2}
1994
mean = 50.7 gDM m^{-2}
1995
mean = 75.2 gDM m^{-2}
1996
mean = 76.8 gDM m^{-2}
1997
mean = 47.1 gDM m^{-2}
1998
mean = 82.9 gDM m^{-2}
1999
mean = 91.8 gDM m^{-2}


TM (DOY015)
TM (DOY079)
TM (DOY191)
TM (DOY255)
ERS-2 (DOY012)
ERS-2 (DOY082)
ERS-2 (DOY187)
ERS-2 (DOY257)