Long-term remote sensing database, Walnut Gulch Experimental Watershed, Arizona, United States

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

Received 31 October 2006; revised 4 July 2007; accepted 19 November 2007; published 10 May 2008.

[1] The USDA Agricultural Research Service, Southwest Watershed Research Center, Walnut Gulch Experimental Watershed (WGEW), is located in the San Pedro Valley of southeastern Arizona. It is one of the most highly instrumented semiarid 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) (http://aria.arizona.edu). Metadata are available via the U.S. Department of Agriculture, Agricultural Research Service, Southwest Watershed Research Center (SWRC) (http://www.tucson.ars.ag.gov/dap/).

Citation: Moran, M. S., C. D. Holifield Collins, D. C. Goodrich, J. Qi, D. T. Shannon, and A. Olsson (2008), Long-term remote sensing database, Walnut Gulch Experimental Watershed, Arizona, United States, *Water Resour. Res.*, *44*, W05S10, doi:10.1029/2006WR005689.

1. Introduction

[2] 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.*, 2008]. Desert shrubs dominate the lower two thirds of the watershed, and desert grasses dominate the upper one third [*Skirvin et al.*, 2008]. 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 semiarid hydrology at WGEW and surrounding regions [*Renard et al.*, 2008].

[3] 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.*, 2008]. 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.

[4] The combination of RS images with extensive Geographic Information System (GIS) coverage [*Heilman et al.*, 2008] and decade-long hydrologic data sets has increased the value and potential application of all three data sets. 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 Semiarid

[1]Southwest Watershed Research Center, Agricultural Research Service, U.S. Department of Agriculture, Tucson, Arizona, USA.
[2]Center for Global Change and Earth Observations and Department of Geography, Michigan State University, East Lansing, Michigan, USA.
[3]Wu-Wei Software, Tucson, Arizona, USA.
[4]Office of Arid Lands Studies, Arizona Remote Sensing Center, Tucson, Arizona, USA.

0043-1397/08/2006WR005689$09.00

Table 1. A Summary of Some of the Images Archived in the WIGDA06 Database and Available in ARIA[a]

Platform/Sensor	Acquisition Dates	Number of Images	Notes and Relevant Citations
		Satellite Platform, Optical Sensor	
NASA Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+)	1990 to present	96	Path, Row = 35, 38 Landsat satellites 4, 5, and 7 12 clear acquisitions in 1992 Clear acquisitions during each monsoon season 1990 to 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 Two 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 400–2500 nm 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 to 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-m 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 to 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.*, 2008] Multiple view angles and polarizations Not available in ARIA Example: *Rahman et al.* [2008] http://envisat.esa.int/
Canadian Space Agency (CSA), RadarSat SAR	2002 to present	12	Five with identical configurations on different dates Two sets acquired at three 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 (5–15 m) 6-band thermal and TM simulator Images acquired during the dry and wet seasons Plus 9 × 9″ 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

[a]Available at http://aria.arizona.edu.

Hydrology and Riparian Areas) Science and Technology Center (http://www.sahra.arizona.edu/research/resources/sites.html#1).

[5] This report offers a description of the RS data sets 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

[6] 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.*, 2008]. 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.*, 2008; *Goodrich et al.*, 2008]. As a result, the RS database is a mix of imagery with coincident, supporting measurements of subsurface, surface, and atmospheric conditions.

2.1. Imagery

[7] 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 multiyear time series of images from several satellite sensors, but also several unique multisatellite 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).

[8] 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

[9] 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.*, 2008], 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].

[10] 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.*, 2008; *Goodrich et al.*, 2008; *Stone et al.*, 2008; *Nichols et al.*, 2008; *Emmerich and Verdugo*, 2008]. In some cases, these point-based measurements have been interpolated to produce spatially continuous maps of some information, such as precipitation [*Garcia et al.*, 2008, Figures 3 and 4].

2.3. Database

[11] 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.

[12] 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 are represented 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).

[13] 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.)

[14] 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 data sets that meet specific research needs.

3. Data Availability

[15] The WIGDA06 database is available by request from the Web site 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*, 2008]. In many cases, the images can be downloaded directly from the University of Arizona, Arizona Regional Image Archive

Table 2. List of Some Metadata Available for the WIGDA06 Entries

Field Name	Description
	Image Data
File name	A file naming convention was developed to produce 8-digit file names 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, and spatial resolution	These are characteristics of the sensor and image for a given acquisition.
Image quality and 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
File name	A file naming convention was developed to produce 8-digit file names 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., handheld 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, handwritten field notes, or hardcopy flight logs are archived in the field cabinet at Southwest Watershed Research Center.
Location notes	These are generally excerpts from the header of the file. When available, GPS coordinates are included.

(ARIA) at http://aria.arizona.edu under the conditions listed in section 2.1. ARIA is an online clearinghouse for multispectral and hyperspectral satellite imagery, aerial photography, digital elevation models, and digital maps. In addition to serving as a node for accessing certain WIGDA data sets 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 a 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 et al.*, 2006; *Diem and Comrie*, 2000; *White et al.*, 2005; *Wallace and Marsh*, 2005; *Huang et al.*, 2006; *Wright and Ramsey*, 2006]. For WIGDA users interested in data not available in ARIA, Southwest Watershed Research Center (SWRC) considers each image request individually.

4. Examples of Data Use

[16] 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 multitemporal 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 multitemporal 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.

[17] The multisensor 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

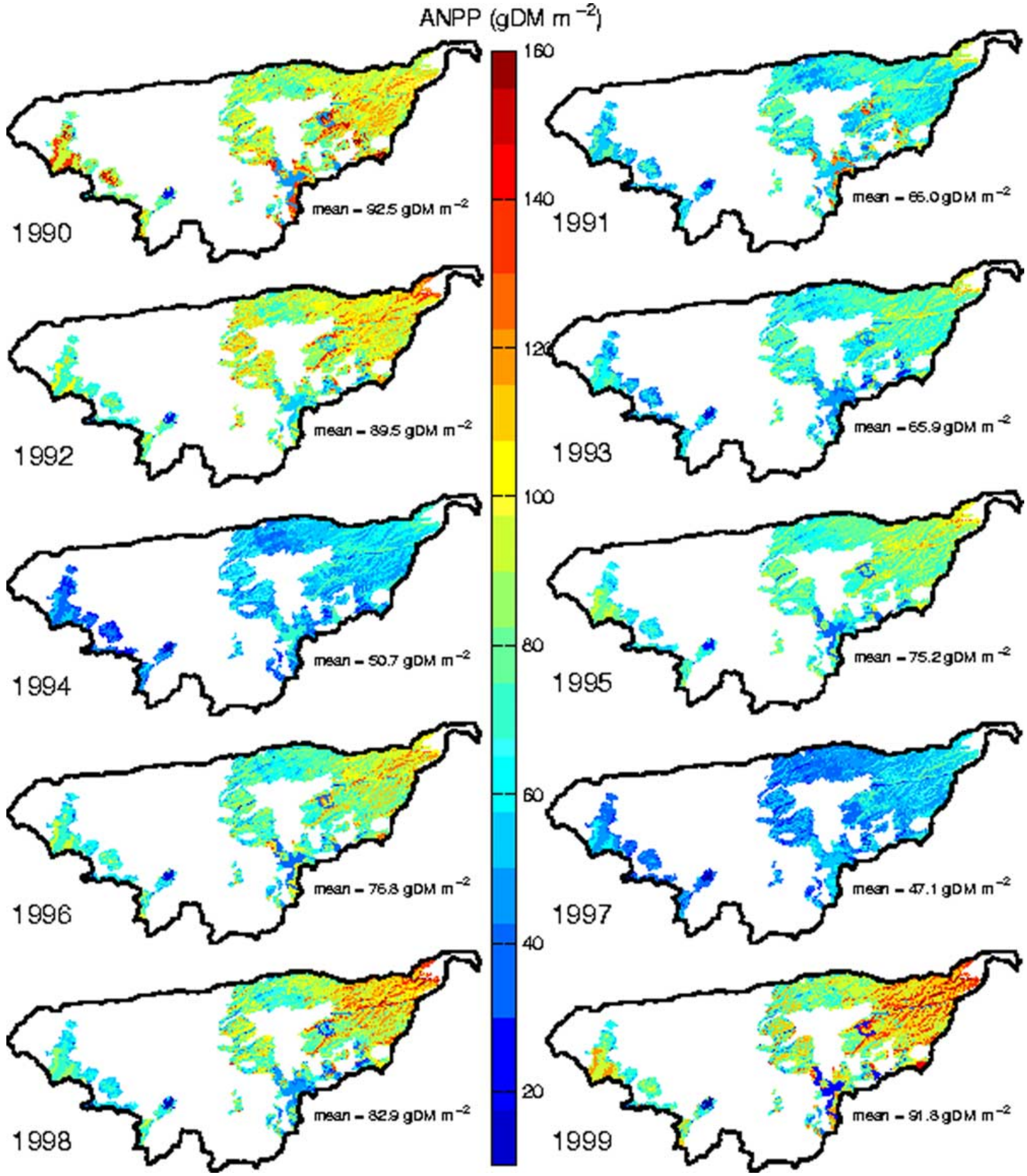

Figure 1. Maps of simulated annual net primary production from 1990 to 1999, produced by coupling a grassland ecosystem model with Landsat imagery for a 10-year simulation. Reprinted from *Nouvellon et al.* [2001] with permission from Elsevier.

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 multitemporal 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.* [2004] used the same data set to develop an optical/

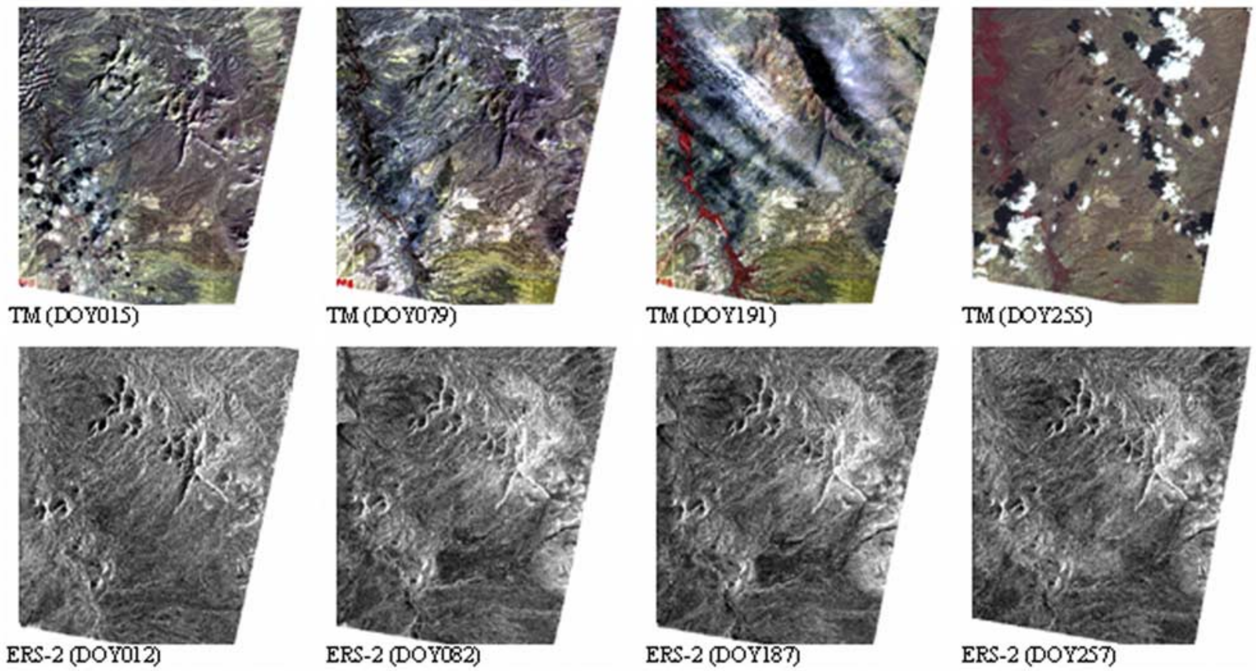

Figure 2. Paired ERS-2/TM images of the study area in three seasons in 1997: winter wet, spring dry, end of spring dry, and summer monsoon. Reprinted from *Wang et al.* [2004] with permission from Elsevier.

microwave synergy model to map soil moisture over desert grass and shrub areas (Figure 2).

[18] The WGEW remote sensing data set also offers multiangle 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 semiarid vegetation. *Rahman et al.* [2008] addressed a classic problem of underdetermination faced when deriving two unknowns (surface roughness and soil moisture) from a single SAR scene. They used multiangle radar images from WGEW to demonstrate a solution that uses multiangle SAR images and provides estimates of both roughness and soil moisture without the use of ancillary field data.

[19] 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 Monsoon '90 Experiment (see special section of *Water Resources Research*, *30*, 1994), the special issue "The Semi-Arid Land-Surface-Atmosphere (SALSA) Experiment" of *Journal of Agriculture and Forest Meteorology*, *105*, 2000, and the special issue "Soil Moisture Experiments in 2004 (SMEX04)" 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.*, 2008] and vegetation water content [*Yilmaz et al.*, 2008].

5. Conclusions

[20] The WIGDA06 database, partnered with the ARIA image clearinghouse, offers the opportunity to study semiarid ecosystem dynamics at the watershed spatial scale and the multidecadal 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 because of 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.

[21] **Acknowledgments.** The initial image and ground data archiving effort was funded primarily through a grant from the NASA Landsat7 Science Team (NASA S-41396-F). Though many people cooperated in image acquisitions, several have been particularly helpful with this image

archiving process: Robin Marsett, Michael Helfert, Darrel Williams, Tom Mitchell, John Masterson, and Wanmei Ni. We are grateful to Richard Danbe at SPOT Image, Bill Bare at Space Imaging, and Luciana Di Domenico at Eurimage for working to develop the very unique and liberal sharing policy. Thanks to Bob Schowengerdt, Eric Pfirman, Stuart Marsh, and Kristin Wisnewski for making our images available in the ARIA environment.

References

Biggar, S. F., D. I. Gellman, and P. N. Slater (1990), Improved evaluation of optical depth components from Langley plot data, *Remote Sens. Environ.*, *32*, 91–101.

Bindlish, R., et al. (2008), Aircraft based soil moisture retrievals under mixed vegetation and topographic conditions, *Remote Sens. Environ.*, *112*, 375–390.

Bryant, R., M. S. Moran, S. McElroy, C. D. Holifield, K. Thome, T. Miura, and S. F. Biggar (2003), Data continuity of Earth Observing One (EO-1) Advanced Land Imager (ALI) and Landsat TM and ETM+, *IEEE Trans. Geosci. Remote Sens.*, *41*, 1204–1214.

Bryant, R., M. S. Moran, D. P. Thoma, C. D. Holifield-Collins, S. Skirvin, M. M. Rahman, K. Slocum, P. Starks, D. Bosch, and M. P. Gonzalez-Dugo (2007), Measuring surface roughness height to parameterize radar backscatter models for retrieval of surface soil moisture, *IEEE Geosci. Remote Sens. Lett.*, *4*, 137–141.

Cosh, M. H., T. J. Jackson, M. S. Moran, and R. Bindlish (2008), Temporal persistence and stability of surface soil moisture in a semi-arid watershed, *Remote Sens. Environ.*, *112*, 304–313.

Diem, J. E., and A. C. Comrie (2000), Integrating remote sensing and local vegetation information for a high-resolution biogenic emissions inventory: Application to an urbanized, semiarid region, *J. Air Waste Manage. Assoc.*, *50*, 1968–1979.

Emmerich, W. E., and C. L. Verdugo (2008), Long-term carbon dioxide and water flux database, Walnut Gulch Experimental Watershed, Arizona, United States, *Water Resour. Res.*, *44*, W05S09, doi:10.1029/2006WR005693.

Garcia, M., C. D. Peters-Lidard, and D. C. Goodrich (2008), Spatial interpolation of precipitation in a dense gauge network for monsoon storm events in the southwestern United States, *Water Resour. Res.*, *44*, W05S13, doi:10.1029/2006WR005788.

Goodrich, D. C., et al. (2000), Preface paper to the Semi-Arid Land-Surface-Atmosphere (SALSA) program special issue, *Agric. For. Meteorol.*, *105*, 3–20.

Goodrich, D. C., T. O. Keefer, C. L. Unkrich, M. H. Nichols, H. B. Osborn, J. J. Stone, and J. R. Smith (2008), Long-term precipitation database, Walnut Gulch Experimental Watershed, Arizona, United States, *Water Resour. Res.*, doi:10.1029/2006WR005782, in press.

Heilman, P., M. H. Nichols, D. C. Goodrich, S. N. Miller, and D. P. Guertin (2008), GIS database, Walnut Gulch Experimental Watershed, Arizona, United States, *Water Resour. Res.*, doi:10.1029/2006WR005777, in press.

Holifield, C. D., S. McElroy, M. S. Moran, R. Bryant, and T. Miura (2003), Temporal and spatial changes in grassland transpiration detected using Landsat TM and ETM+ imagery, *Can. J. Remote Sens.*, *29*, 259–270.

Huang, C., E. L. Geiger, and J. A. Kupfer (2006), Sensitivity of landscape metrics to classification scheme, *Int. J. Remote Sens.*, *27*(14), 2927–2948.

Hutchinson, C. F., et al. (2001), Informing the elk debate: Applying NASA Earth Observing System (EOS) data to natural resource management conflicts in the western states, *IEEE Int. Geosci. Remote Sens. Symp. IGARSS '01*, *2*, 834–836.

Jackson, T. J., M. S. Moran, and P. E. O'Neill (2008), Introduction to Soil Moisture Experiments 2004 (SMEX04), *Remote Sens. Environ.*, *112*, 301–303.

Keefer, T. O., M. S. Moran, and G. B. Paige (2008), Long-term meteorological and soil hydrology database, Walnut Gulch Experimental Watershed, Arizona, United States, *Water Resour. Res.*, *44*, W05S07, doi:10.1029/2006WR005702.

King, D. M., S. M. Skirvin, C. D. Holifield Collins, M. S. Moran, S. H. Biedenbender, M. R. Kidwell, M. A. Weltz, and A. Diaz-Gutierrez (2008), Assessing vegetation change temporally and spatially in southeastern Arizona, *Water Resour. Res.*, *44*, W05S15, doi:10.1029/2006WR005850.

Kustas, W. P., and D. C. Goodrich (1994), Preface: Monsoon '90 multidisciplinary experiment, *Water Resour. Res.*, *30*, 1221–1225.

Moran, M. S., D. C. Goodrich, and W. P. Kustas (1994), Integration of remote sensing and hydrologic modeling through multi-disciplinary semiarid field campaigns: Monsoon '90, Walnut Gulch '92 and SALSA-MEX, paper presented at the Sixth International Symposium Physical Measurements and Signatures in Remote Sensing, Val d'Isere, France, 17–21 January.

Moran, M. S., A. F. Rahman, J. C. Washburne, D. C. Goodrich, M. A. Weltz, and W. P. Kustas (1996), Combining the Penman-Monteith equation with measurements of surface temperature and reflectance to map regional evaporation rates, *Agric. For. Meteorol.*, *80*, 87–109.

Moran, M. S., K. S. Humes, and P. J. Pinter Jr. (1997), The scaling characteristics of remotely sensed variables for sparsely-vegetated heterogeneous landscapes, *J. Hydrol.*, *190*, 338–363.

Moran, M. S., D. C. Hymer, J. Qi, and E. E. Sano (2000a), Soil moisture evaluation using Synthetic Aperture Radar (SAR) and optical remote sensing in semiarid rangeland, *Agric. For. Meteorol.*, *105*, 69–80.

Moran, M. S., J. Qi, W. Ni, and D. T. Shannon (2000b), Water Conservation Laboratory image and ground data archive (WIGDA99) for Arizona agricultural and rangeland regions, paper presented at the 2nd International Conference on Geospatial Information in Agriculture and Forestry, Environ. Res. Inst. of Michigan, Lake Buena Vista, Fla., 10–12 January.

Moran, M. S., R. Bryant, C. D. Holifield, and S. McElroy (2003), Refined empirical line approach for retrieving surface reflectance from EO-1 ALI images, *IEEE Trans. Geosci. Remote Sens.*, *41*, 1411–1414.

Nichols, M. H., and E. Anson (2008), Southwest Watershed Research Center Data Access Project, *Water Resour. Res.*, *44*, W05S03, doi:10.1029/2006WR005665.

Nichols, M. H., J. J. Stone, and M. A. Nearing (2008), Sediment database, Walnut Gulch Experimental Watershed, Arizona, United States, *Water Resour. Res.*, *44*, W05S06, doi:10.1029/2006WR005682.

Norman, L. M., A. Donelson, E. Pfeifer, and A. H. Lam (2006), Colonia development and land use change in Ambos Nogales, United States–Mexico border, *USGS White Pap.*, *Open File Rep. 2006-1112*, 120 pp.

Nouvellon, Y., M. S. Moran, D. Lo Seen, R. B. Bryant, W. Ni, A. Begue, A. G. Chehbouni, W. E. Emmerich, P. Heilman, and J. Qi (2001), Coupling a grassland ecosystem model with Landsat imagery for a 10-year simulation of carbon and water budgets, *Remote Sens. Environ.*, *78*, 131–149.

Qi, J., A. R. Huete, T. R. Clarke, M. S. Moran, and A. Chehbouni (1991), Solar and view angle interactions on bidirectional reflectance factors of a semi-arid region, paper presented at the 20th Conference on Agriculture and Forest Meteorology and 10th Conference on Biometeorology and Aerobiology, Special Session on Hydrometeorology, Am. Meteorol. Soc., Salt Lake City, Utah, 10–13 September.

Qi, J., R. C. Marsett, M. S. Moran, D. C. Goodrich, P. Heilman, Y. H. Kerr, G. Dedieu, A. Chehbouni, and X. X. Zhang (2000), Spatial and temporal dynamics of vegetation in the San Pedro River basin area, *Agric. For. Meteorol.*, *105*, 55–68.

Rahman, M. M., M. S. Moran, D. P. Thoma, R. Bryant, C. D. Holifield Collins, T. Jackson, B. J. Orr, and M. Tischler (2008), Mapping surface roughness and soil moisture using multi-angle radar imagery without ancillary data, *Remote Sens. Environ.*, *112*, 391–402.

Renard, K., M. Nichols, D. Woolhiser, and H. Osborn (2008), A brief background on the U.S. Department of Agriculture Agricultural Research Service Walnut Gulch Experimental Watershed, *Water Resour. Res.*, doi:10.1029/2006WR005691, in press.

Skirvin, S., M. Kidwell, S. Biedenbender, J. P. Henley, D. King, C. Holifield Collins, S. Moran, and M. A. Weltz (2008), Vegetation data, Walnut Gulch Experimental Watershed, Arizona, United States, *Water Resour. Res.*, doi:10.1029/2006WR005724, in press.

Stone, J. J., M. Nichols, D. C. Goodrich, and J. Buono (2008), Long-term runoff database, Walnut Gulch Experimental Watershed, Arizona, United States, *Water Resour. Res.*, *44*, W05S05, doi:10.1029/2006WR005733.

Thoma, D. P., M. S. Moran, R. Bryant, M. Rahman, C. D. Holifield-Collins, S. Skirvin, E. E. Sano, and K. Slocum (2006), Comparison of four models to determine surface soil moisture from C-band radar imagery in a sparsely vegetated semiarid landscape, *Water Resour. Res.*, *42*, W01418, doi:10.1029/2004WR003905.

Troufleau, D., A. Vidal, A. Beaudoin, M. S. Moran, M. A. Weltz, D. C. Goodrich, J. Washburne, and A. F. Rahman (1997), Optical-microwave synergy for estimating surface sensible heat flux over a semi-arid rangeland, *Remote Sens. Rev.*, *15*, 113–132.

Wallace, C. S. A., and S. E. Marsh (2005), Characterizing the spatial structure of endangered species habitat using geostatistical analysis of IKONOS imagery, *Int. J. Remote Sens.*, *26*(12), 2607–2629.

Wang, C., J. Qi, M. S. Moran, and R. Marsett (2004), Soil moisture estimation in a semiarid rangeland with ERS-2 and TM imagery, *Remote Sens. Environ.*, *90*, 178–189.

White, A. B., P. Kumar, and D. Tcheng (2005), A data mining approach for understanding topographic control on climate-induced inter-annual vegetation variability over the United States, *Remote Sens. Environ.*, *98*, 1–20.

Wright, S. P., and M. S. Ramsey (2006), Thermal infrared data analyses of Meteor Crater, Arizona: Implications for Mars spaceborne data from the Thermal Emission Imaging System, *J. Geophys. Res.*, *111*, E02004, doi:10.1029/2005JE002472.

Yilmaz, M. T., E. R. Hunt Jr., L. D. Goins, S. L. Ustin, V. C. Vanderbilt, and T. J. Jackson (2008), Vegetation water content during SMEX04 from ground data and Landsat 5 Thematic Mapper imagery, *Remote Sens. Environ.*, *112*, 350–362.

D. C. Goodrich, C. D. Holifield Collins, and M. S. Moran, USDA ARS Southwest Watershed Research Center, 2000 East Allen Road, Tucson, AZ 85719, USA. (susan.moran@ars.usda.gov)

A. Olsson, Office of Arid Lands Studies, Arizona Remote Sensing Center, 1955 East 6th Street, Tucson, AZ 85721, USA.

J. Qi, Center for Global Change and Earth Observations and Department of Geography, 1405 South Harrison Road, Manly Miles Building 218, Michigan State University, East Lansing, MI 48823, USA.

D. T. Shannon, Wu-Wei Software, Tucson, AZ 85719, USA.