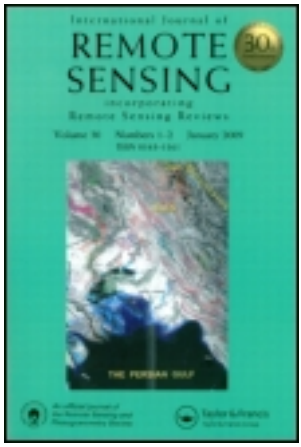

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Developments in the 'validation' of satellite sensor products for the study of the land surface

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Developments in the 'validation' of satellite sensor products for the study of the land surface

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Abstract. Increased availability of global satellite sensor data is resulting in an increase in satellite sensor products for global change research and environmental monitoring. The ensuing research and policy directives that will utilize these satellite products puts a high priority on providing statements of their accuracy. The process of quantifying the accuracy of these geophysical products is herein termed 'validation'. This Letter provides examples of international land product 'validation' research and describes a new international forum for coordination within the Committee on Earth Observation Satellites (CEOS) Calibration and Validation Working Group (CVWG).

1. Introduction

Researchers have long been concerned with the need to quantify the accuracy of remotely sensed land cover classifications at the local scale but with the increase in data sets from coarse resolution sensing systems, attention has turned to the challenge of global product 'validation' (Justice and Townshend 1994, Robinson 1996, Justice *et al.* 1998a). 'Validation' is the process of assessing by independent means the accuracy of the data products derived from the system outputs, 'validation' is distinguished from calibration which is the process of quantitatively defining the system response to known, controlled signal inputs (WWW 1). In general, 'validation' refers

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to assessing the uncertainty of higher level, satellite sensor derived products (e.g. land cover, leaf area index) by analytical comparison to reference data, which is presumed to represent the target value. Intercomparison of data products or model outputs provides an initial indication of gross differences and possibly insights into the reasons for the differences, however independent 'validation' data are needed to determine product accuracy. Whereas there are accepted standards for instrument calibration, standards for 'validation' of higher order products have yet to be developed.

The space agencies will have several moderate and coarse spatial resolution (250 m–4 km) sensing systems in orbit over the next few years, providing similar land products, e.g. vegetation indices, albedo, leaf area index (LAI), land cover and fire, e.g. from MODIS, AATSR, VEGETATION, GLI, NPP. Establishing standard methods and protocols for 'validation' of these products will enable a broader participation in 'validation' campaigns and programs, the sharing and multiple-use of 'validation' data, and comparisons and inter-use between products. Common field sites and standard methods for data collection and presenting product accuracy can be expected to foster product standardization and synergy from these various sensors.

2. Example 'validation' initiatives

2.1. *IGBP 1 km Global Land Cover 'Validation'*

A Global 1 km Land Cover product was developed by the IGBP-DIS using AVHRR data (Belward *et al.* 1999, WWW 2). A 'Validation' Working Group was established to specify and coordinate the implementation of a practical and achievable methodology for 'validation' of this global product. The approach consisted of a core sampling strategy using a stratified random sample of c. 400 high-spatial resolution (Landsat Thematic Mapper and SPOT HRV) images and a larger areal coverage of confidence sites (WWW 3). This activity was possible only through international collaboration needed to create the data product and design and undertake its 'validation'.

2.2. *EOS MODIS 'Validation'*

The NASA's Earth Observing System (EOS) will generate data sets for the global change research community (Ranson *et al.* 1998). The EOS program has made 'validation' an explicit responsibility of the investigators responsible for these sets and has funded independent investigators to undertake supplementary 'validation' activities (WWW 4). The 'validation' approaches involve the collection of independent *in situ*, aircraft, and satellite sensor data. For land products, considerable effort has been made in developing a set of global test sites to be used for 'validation' (Justice *et al.* 1998a, Privette *et al.* 1999). This initiative has evolved from the NASA Landsat Pathfinder Global Land Cover Test Site project (WWW 5). Sites representing different biomes were selected from a global shortlist of experimental stations established for long-term *in situ* monitoring (WWW 6). These sites, selected by the EOS sensor teams, can provide a basis for international cooperation and expansion for 'validation' of products from other sensing systems. For example, preliminary discussions on validation coordination have been held with ESA's MERIS program (WWW 7), the Land-Surface Processes and Interactions Mission (WWW 8), CNES's VEGETATION program (WWW 9) and NASDA's GLI program (WWW 10).

The first EOS platform (Terra) includes the MODIS sensor (Ranson *et al.* 1999). The MODIS (WWW 11) will provide global land products (Justice *et al.* 1998b).

The MODIS land discipline team (MODLand) is using two types of field sites for 'validation': the EOS Core Sites (WWW 6) and product-specific sites (Justice *et al.* 1998b, Hall *et al.* 1999, Wan 1999). The primary components of the MODLand 'validation' system will involve ground-based measurements at 'validation' sites, airborne measurements and coordinated acquisition of high-resolution satellite sensor data.

To facilitate access to these distributed 'validation' data sets, the Oak Ridge National Lab (ORNL) Distributed Data Archive Center's (DAAC) provides the 'Mercury System' (WWW 12). The system allows 'validation' investigators to register their field data into a database (WWW 13), while storing the data on a local computer connected to the Internet. The Mercury system points to a local URL or ftp site and the investigator maintains control of that site (WWW 14). Data from field campaigns will be complimented by continuous data collection such as atmospheric aerosol properties by AERONET (Holben *et al.* 1998, WWW 15, WWW 16) and CO_2 flux measurements by FLUXNET (Running *et al.* 1999, WWW 17).

The airborne component of MODLand 'validation' will utilize NASA's aircraft validation program and a portable, digital camera/radiometer package named MQUALS, which has been developed to provide high spatial resolution data from light-aircraft for scaling between field measurements and 30 m spatial resolution (Huete 1999, WWW 18, WWW 19).

Multi-date high-spatial resolution satellite sensor imagery will be acquired for each Core Site. These images will help bridge between field and airborne measurements and the coarse spatial resolution MODIS products. At roughly one metre panchromatic and four metre multi-spectral, an 11 km × 11 km IKONOS scene will be available for each site through NASA's Scientific Data Buy Program (WWW 20, WWW 21). Multi-temporal data at 15–30 m spatial resolution from Landsat ETM+ (WWW 22), and ASTER (WWW 23) will be acquired to match vegetation phenology and field campaigns. MISR 'Local Mode' data, providing multiple viewing angles at 250 m resolution will be available through the Langley DAAC (WWW 24).

Protocols are also being developed to provide guidance for field data collection, instrumentation, sampling strategy, use of higher resolution spatial data, and scaling algorithms to compare the ground, airborne, and satellite sensor data, e.g. the 'validation' protocol designed for the MODIS LAI/FPAR by the BigFoot program (Thomlinson *et al.* 1999, WWW 25).

2.3. *VALERI*

The 'Validation' of Land European Remote Sensing Instruments (VALERI) Network involves researchers from INRA Avignon, CESBIO, CNRM, CIRAD, CEFE and INRA Bordeaux, funded by the French Government. The network will provide coordinated ground measurements of LAI, fAPAR, albedo and similar variables for developing and testing new generation algorithms and validating level 3 (biophysical variable) products. Rather than being aimed at a specific sensor program, data from the network will be used with a range of forthcoming sensors such as POLDER (WWW 26), MERIS (WWW 7), AATSR (WWW 27), and Meteosat Second Generation (MSG, WWW 28). Particular emphasis is being given to sensors that sample the surface as a function of viewing and illumination angles and the associated BRDF algorithms.

The VALERI test sites are chosen to cover a range of latitudes and biomes, and are concentrated in Europe and Africa. Sites are located in France (five sites), Estonia,

Niger, Mali, Sudan, Guyana, and Sumatra. Collaborative validation efforts on products from the MSG sensor and MODIS provide a direct link with the EOS Core Sites by involving researchers from both networks. Data from both networks will be used to provide intercomparison of European and US satellite products.

Sampling at the VALERI sites (each around 10 km × 10 km) will involve intensive field campaigns two to four times per season, involving measurements of the various ground parameters. In addition the sites will be instrumented with Sun-photometers to characterize the atmosphere and contribute to AERONET. Spatial extrapolation of ground measures will be achieved by mapping through a classification derived from high-resolution satellite data.

2.4. *Field experiments and satellite sensor product 'validation'*

Over the past two decades, several large-area, international field campaigns have provided important test-beds for current land-product 'validation' activities (table 1). These campaigns have involved intensive field studies at representative sites sampled at different times of the year (e.g. Justice *et al.* 1998a), involving: ground measurements linked to flux measurements (Running *et al.* 1999, WWW 17), atmospheric characterization (Holben *et al.* 1998, WWW 15), models and methods for scaling (Cohen and Justice 1999), algorithm development and testing and data archiving and sharing (Strebel *et al.* 1998).

Ground based procedures for measuring ecosystem 'variables' are well established but need to be adapated for use in satellite sensor data validation and over a broad range of vegetation types and presented as easily understood protocols (Gower *et al.* 1999, Privette *et al.* 1998). Methods are also needed to scale from point measurements to satellite sensor spatial resolutions particularly in spatially heterogeneous landscapes (Milne and Cohen 1999). For continuous biophysical variables, methods have been developed to interpolate field measurements into 'layers' that can be compared to either airborne or satellite sensor data by statistical methods (Gohin and Langlois 1993, Atkinson *et al.* 1994) or to use field data to parameterize models to simulate the biophysical response over the area of interest (Lewis 1999, Lewis *et al.* 1999).

There is a large body of research that needs to be undertaken before land product 'validation' can become operational. For example for land cover and fire product 'validation' research challenges include designing statistically valid and logistically feasible field sampling, assessing the accuracy of reference data, registering and correlating coarse and high spatial resolution satellite sensor data, establishing accuracy metrics and presenting them in ways that facilitate product use.

3. Conclusions

Determining the accuracy of global satellite sensor data sets presents a challenge to the remote sensing community. From the above studies some generic areas for research and development can be identified. The IGBP Discover activity provided a pathfinding activity, showing the advantages of international collaboration for global product 'validation', enabling sharing of resources and the pooling of talent and expertise. The 'validation' activities described above can provide a basis to develop concerted efforts to address 'validation' research questions and articulate the need to martial resources. Following a meeting at the Committee on Earth Observation Satellite (CEOS) Calibration and 'Validation' Working Group (Dowman *et al.* 1999) a new sub-working group was formed on Land Product 'Validation' (WWW 1). Initial focus for this activity will be on 'validating' the data

Table 1. Examples of previous field campaigns with a validation component.

Activities	Principal sensors	Reference	Primary purpose
BOREAS	MAS, AVIRIS, TM, ASAS	http://boreas/BOREAS/BOREAS_Home.html	Biophysical 'validation', LST, snow, BRDF, VI, Fire
HAPEX Mobility	ASAS, TM	http://www.orstom.fr/hapex/	VI-biophysical, BRDF/ albedo
HAPEX-Sahel	AVHRR, Meteosat		
Maricopa	ATLAS	http://gaia.fcr.arizona.edu/MARICOP.html	Multi-product algorithm
MONSOON-'90	ASAS, TM, AVIRIS	Kustas *et al.* 1994	Land Cover, BRDF/albedo, VI-seasonal study
OTTER	ASAS, TM	http://www-eosdis.ornl.gov/daacpages/otter.html	Land Cover, BRDF/albedo, VI-biophysical coupling, LAI/ FPAR
Forest PROVE	CIMEL (BRDF), GOES	http://modarch.gsfc.nasa.gov/MODIS/Land/VAL/prove/forest/prove.html	Tall canopy structure, scaling of FPAR, LAI, albedo and cover type, topography effects
Grassland PROVE	CIMEL (BRDF)	http://modarch.gsfc.nasa.gov/MODIS/Land/VAL/prove/grass/prove.html	Short canopy structure and optics, product scaling in heterogeneous cover
Railroad Valley, CALWEST	MAS, TIMS	http://www.ices.ucsb.edu:80/~wan/modis_projects.html	LST & TIR cal./val.
SAFARI '92, SAFARI-2000	AVHRR, TM MODIS, MISR, ASTER	Thompson *et al.* 1996	Fire validation LAI/FPAR, Fire, Land Cover
SCAR-A, C	MAS	http://ltpsun.gsfc.nasa.gov/MAS/scarahome.html	Surface reflectance
SCAR-B	MAS, AVIRIS	http://ltpsun.gsfc.nasa.gov/MAS/scarbhome.html	VI in smoke, VI saturation analysis, Fire
WINCE	MAS, MIR	http://cimss.ssec.wisc.edu/wince/wince.html	Snow cover detection

products planned for the GTOS Global Observation of Forest Cover (GOFC, WWW 29) project, a pilot activity for the Integrated Global Observing Systems (WWW 30). GOFC datasets include land cover, land cover change, LAI/FPAR, and fire. Over the next few years, the subgroup will hold topical workshops and develop collaborative activities, furthering international cooperation on 'validation'.

Global satellite sensor product 'validation' is an important development for remote sensing. It comes at a time when international agencies and the global change research community are evaluating their needs for long-term space-borne measurements. High-quality and consistent data sets of known accuracy with product continuity between instruments and missions are clearly important goals. Well-developed and international coordinated satellite sensor product 'validation' activities will be an important step to achieving these goals.

Appendix: WWW sites

WWW 1, CEOS WGCV homepage, http://wgcv.ceos.org/
WWW 2, IGBP DIS Global 1 km land cover, http://edcdaac.usgs.gov/glcc/glcc.html
WWW 3, IGBP DISCover 'Validation' Working Group, http://keystone.geog.ucsb.edu/igbp.html
WWW 4, EOS 'Validation' Investigations, http://eospso.gsfc.nasa.gov/validation/frame.html
WWW 5, Landsat Pathfinder Program, http://edcdaac.usgs.gov/pathfinder/pathpage.html
WWW 6, EOS Land 'Validation' Core Sites, http://modarch.gsfc.nasa.gov/MODIS/Land/VAL/core_sites.html
WWW 7, MERIS homepage, http://envisat.estec.esa.nl/instruments/meris
WWW 8, Land-Surface Processes and Interactions Mission, http://www.estec.esa.nl/vrwww/LSPIM
WWW 9, VEGETATION homepage, http://www-project.cst.cnes.fr:8050/
WWW 10, GLI homepage, http://www.eorc.nasda.go.jp/ADEOS-II/GLI
WWW 11, MODIS homepage, http://modarch.gsfc.nasa.gov/
WWW 12, Mercury homepage, http://mercury.ornl.gov/
WWW 13, Mercury Metadata Editor login, http://www-eosdis.ornl.gov/cgi-bin/MDE/MERCURY/access.pl
WWW 14, Mercury Land 'Validation' Search, http://mercury.ornl.gov/servlet/landval
WWW 15, AERONET homepage, http://aeronet.gsfc.nasa.gov:8080/
WWW 16, AERONET status at the EOS Land 'Validation' Core Sites, http://modarch.gsfc.nasa.gov/MODIS/Land/VAL/EOSaeronet.html
WWW 17, FLUXNET homepage, http://daacl.esd.ornl.gov/FLUXNET
WWW 18, EOS Airborne Information, http://eospso.gsfc.nasa.gov/eos_homepage/airborne.html
WWW 19, MQUALS homepage, http://gaea.fcr.arizona.edu/MQUALS/newmqual.html
WWW 20, Space Imaging: IKONOS, http://www.spaceimaging.com/
WWW 21, NASA's Science Data Buy program, http://www.crsp.ssc.nasa.gov/databuy
WWW 22, Landsat 7, ETM+ homepage, http://mtpe.gsfc.nasa.gov/landsat/
WWW 23, ASTER homepage, http://asterweb.jpl.nasa.gov/

WWW 24, MISR Langley DAAC Project Guide, http://charm.larc.nasa.gov/GUIDE/campaign_documents/misr/misr_ov.html
WWW 25, BigFoot program, http://www.fsl.orst.edu/larse/bigfoot/
WWW 26, POLDER homepage, http://polder@www-projet.cst.cnes.fr:8060/
WWW 27, AATSR homepage, http://envisat.estec.esa.nl/instruments/aatsr/
WWW 28, Meteosat Second Generation homepage, www.esrin.esa.it/msg/
WWW 29, Global Observation of Forest Cover, http://www.gofc.org/gofc/index.html
WWW 30, Integrated Global Observing Systems, http://www.igospartners.org/

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