

ASSESSING SATELLITE-DERIVED LAND PRODUCT QUALITY FOR EARTH SYSTEM SCIENCE APPLICATIONS: OVERVIEW OF THE CEOS LPV SUB-GROUP

Joanne Nightingale^{(a)*}, Gabriela Schaepman-Strub^(b), Jaime Nickeson^(a), LPV Focus Area leads ^(c)

^(a) *Sigma Space Corporation, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA 20910 -*

Joanne.M.Nightingale@nasa.gov, Jaime.E.Nickeson@nasa.gov

^(b) *Institute of Evolutionary Biology and Environmental Studies, University of Zurich, Switzerland - Gabriela.schaepman@ieu.uzh.ch*

^(c) *LPV Focus Area leads and affiliations are listed within the paper*

Abstract - The value of satellite derived land products for science applications and research is dependent upon the known accuracy of the data. CEOS (Committee on Earth Observation Satellites), the space arm of the Group on Earth Observations (GEO), plays a key role in coordinating the land product validation process. The Land Product Validation (LPV) sub-group of the CEOS Working Group on Calibration and Validation (WGCV) aims to address the challenges associated with the validation of global land products. This paper provides an overview of LPV sub-group focus area activities, which cover seven terrestrial Essential Climate Variables (ECVs). The contribution will enhance coordination of the scientific needs of the Earth system communities with global LPV activities.

Keywords: CEOS, WGCV, Land Product Validation, Essential Climate Variables

1. LPV BACKGROUND AND STATUS

The mission of the LPV sub-group is to foster and coordinate international validation activities for satellite-derived land products, to develop international validation protocols, promote data sharing, and to ensure that data and results are available to the user community. The LPV sub-group was established in 2000 and is led by a peer-nominated chair and vice-chair that serve 3-year terms. As of March 2010, the LPV chair is Dr Joanne Nightingale and co-chair is Dr Gabriela Schaepman-Strub. Funding for support at Goddard Space Flight Center is provided by the NASA (National Aeronautics and Space Administration) Earth Observation Satellite (EOS) land validation program. The current emphasis on the independent and systematic evaluation of the GTOS (Global Terrestrial Observing System) terrestrial ECVs (GCOS 2010) and long-term data records prompted establishment of a focused organization of the LPV sub-group. Product areas consist of seven ‘focus groups’, each with internationally independent co-chairs who have been actively involved in validation activities and are respected community members (Table A). Since the adoption of this structure in mid-2009, significant progress has been made towards the coordination of international land validation activities as will be discussed throughout this paper.

Table A. LPV Focus Group Leads, Affiliations and Community member base.

| Focus Group | North America | Europe | Affiliation/ Listserv # |
|---|---------------------------------|---|---|
| Land Cover * | Mark Friedl (BU) | Martin Herold (Wageningen University, NL) | ¹ GOFC-GOLD (140) |
| Fire* (Active/ Burned Area) | Luigi Boschetti (UMD) | Kevin Tansey (U Leicester, UK) | ¹ GOFC-GOLD (74) |
| Surface Radiation: (Reflectance, BRDF, Albedo*) | Crystal Schaaf (BU) | Gabriela Schaepman (U Zurich, SW) | ² ARM/SGP ³ BSRN/ ⁴ SURFRAD, ⁵ FLUXNET, ⁶ AERONET (42) |
| Surface Radiation: (Snow/Ice*) | New group, leads TBD early 2011 | | |
| Biophysical (LAI*, VI) | Richard Fernandes (NR Canada) | Stephen Plummer (Harwell, UK) | ⁷ IGBP, FLUXNET (72) |
| Biophysical (fAPAR*) | New group, leads TBD early 2011 | | |
| Land Surface Temperature / Emissivity | Simon Hook (NASA JPL) | Jose Sobrino (U Valencia, SP) | ⁸ IVOS (64) |
| Soil Moisture* | Tom Jackson (USDA) | Wolfgang Wagner (Vienna UT, AT) | ⁹ GEWEX (49) |
| Land Surface Phenology | Jeff Morisette (USGS) | Jadu Dash (U Southampton, UK) | ¹⁰ PEN, USA Phenocams (78) |

*GTOS defined ECVs. ¹ GOFC-GOLD (Global Observation of Forest & Land Cover Dynamics), ²ARM/SGP (Atmospheric Radiation Measurement Program/Southern Great Plains), ³BSRN (Baseline Surface Radiation Network), ⁴SURFRAD (Surface Radiation Network), ⁵FLUXNET (international network of flux and micrometeorological towers), ⁶AERONET (AErosol RObotic NETwork), ⁷IGBP (International Geosphere-Biosphere Programme), ⁸IVOS (WGCV Infrared & Visible Optical Sensors sub-group), ⁹GEWEX (Global Energy & Water Cycle Experiment), ¹⁰PEN (Phenological Eyes Network) Japan.

1.1. Role of Focus Groups

Validation activities need to be coordinated in order to reach consensus from the international community and ensure a traceable and transparent process. The role of the co-chairs for each LPV focus groups involves engaging the appropriate research and operational communities as well as coordinating global land product validation activities. Key responsibilities of each focus area include: informing and involving the respective community members on LPV sub-group activities and meetings; organizing topical workshops; expanding LPV involvement in site networks and collaboration globally; leading satellite-derived land product inter-comparison activities; and leading the development of “best practice” land product validation protocols for products within their domain.

The LPV sub-group web site (<http://lpvs.gsfc.nasa.gov>) is the main communication tool for this community. Each focus area has dedicated links outlining the background and current activities, relevant land products as well as previous meeting summaries and upcoming meeting notifications. Much progress has been made over the years by the planning and execution of focused workshops that further collaborative efforts among global land product developers. Through these types of outreach activities, the LPV community base continues to increase. Currently there are close to 500 registered LPV mailing list subscribers globally.

A fundamental role of the LPV sub-group is to provide the international scientific community with protocols for the validation of satellite-derived land products. Land product validation protocol documents will define the community standard ‘best practices’ in relation to current knowledge, available data, and validation methods that are tested and repeatable (Baret *et al.* 2009). The protocols should include three mandatory and complementary components: 1) **Accuracy assessment**, the comparison of global products with reference in situ data; 2) **Precision assessment**, evaluation of the spatial and temporal consistency of the products; and 3) **Inter-comparison**, evaluation of the relative consistencies between similar land products (Baret *et al.* 2009). A generic process for community review and consensus is being adopted to ensure land product validation protocols are CEOS endorsed and published within the WGCV Quality Assurance for Earth Observation (QA4EO) framework (<http://qa4eo.org/index.html>). The documents will be posted on the LPV web site and the CEOS Calibration / Validation Portal (calvalportal.ceos.org/), will undergo periodic review and be updated when new data or improved methods become available. An executive summary of the validation protocol document will be published in a peer-reviewed journal for a wider audience and appropriate referencing.

1.2. Fostering International Collaborations

The LPV sub-group owes much of its success to NASA’s EOS land validation program, which has a strong history in leading international validation activities related to MODIS- (Moderate Resolution Imaging Spectroradiometer). ESA (European Space Agency), CNES (Centre National d’Études Spatiales) and the European Commission have also contributed significantly to validation activities via GLOBCOVER, VALERI and GEOLAND-2 respectively. The LPV sub-group shares in many cross-cutting activities with the GOF-C-GOLD (Global Observations of Forest and Land Cover Dynamics) Land and Fire Implementation teams. These teams are panels within GTOS that aim to improve the quality and availability of satellite observations of forests, land cover and fire disturbance at regional and global scales and to produce useful, timely and validated products and information from these data for a wide variety of users and applications.

LPV members are becoming increasingly involved in validation planning and campaigns preparing for NASA’s Decadal survey missions, in particular HypSIRI (Hyperspectral Infrared Imager) and SMAP (Soil Moisture Active Passive), as well as NOAA’s GOES-R (Geostationary Operational Environmental Satellite-R Series), and the NASA/NOAA (National Oceanic and Atmospheric Administration) JPSS (Joint Polar Satellite System) VIIRS (Visible Infrared Imaging Radiometer Suite). European counterpart missions include SMOS (Soil Moisture and Ocean Salinity), the GMES (Global Monitoring for Environment and Security) Sentinel satellites and the GEOLAND-2 project as well as the recently launched ESA Climate Change Initiative (CCI).

Key to the longevity of LPV will be enhancing links with the existing ground/tower measurement networks as well as establishing partnerships with upcoming nationally funded ecosystem monitoring networks. A hierarchical approach to classify land product validation stages was adopted by CEOS through consensus of the LPV community in 2003 (Morissette *et al.* 2006). In 2009, this hierarchy was revised to provide a clearer definition of the requirements to reach each validation stage and take into account assessment of the spatial and temporal consistency of similar land products, as well as ongoing operational global validation efforts (Table B). The validation stage of currently available land products is highlighted within Table C. Given the expanding time-series and reprocessing of satellite-derived land products, there is a requirement for continuous field-level validation data that can be used to achieve Stage 3 (globally representative) and Stage 4, temporal validation to assess seasonal inter- and intra-annual product variability. Leveraging off of existing field network infrastructures such as BSRN, AERONET, FLUXNET

and IGOS (European Integrated Carbon Observing System) provides a rich source of instrument and field datasets for land validation activities. LPV is also seeking collaboration with nationally funded and sustainable ecosystem monitoring networks such as, NEON (US National Ecology Observatory Network), TERN (Australian Terrestrial Ecosystem Research Network), PEN (Japanese Phenological Eyes Network), as well as dedicated space agency funded cal/val sites located in Russia, France and China, which will complement existing EOS core validation sites.

Table B. The revised four-stage CEOS Land Product Validation Hierarchy.

| | |
|----------------|---|
| Stage 1 | Product accuracy is assessed from a small (typically < 30) set of locations and time periods by comparison with <i>in situ</i> or other suitable reference data. |
| Stage 2 | Product accuracy is estimated over a significant set of locations and time periods by comparison with reference <i>in situ</i> or other suitable reference data. Spatial and temporal consistency of the product and consistency with similar products has been evaluated over globally representative locations and time periods. |
| Stage 3 | Uncertainties in the product and its associated structure are well quantified from comparison with reference <i>in situ</i> or other suitable reference data. Uncertainties are characterized in a statistically robust way over multiple locations and time periods representing global conditions. Spatial and temporal consistency of the product and consistency with similar products has been evaluated over globally representative locations and periods. |
| Stage 4 | Validation results for stage 3 are systematically and regularly updated when new versions of the products are released and as the time-series expands. |

Table C. Satellite-derived land products relevant to the LPV sub-group and the highest CEOS validation stage reached. Full details for all products can be found at: <http://lpvs.gsfc.nasa.gov>

| Variable | Sensors | Validation Stage |
|-------------|--|------------------|
| Land Cover | MODIS, MERIS SPOT VEGETATION AVHRR | 2-3 |
| Active Fire | MODIS, AVHRR, METEOSAT SEVIRI, ATSR | 2-3 |
| Burnt Areas | MODIS, ATSR, AVHRR, SPOT VEGETATION | 2 |
| LAI | MODIS, MERIS, MISR CYCLOPES (SPOT VEGETATION) ATSR, AVHRR, POLDER-2 GLOBCARBON (multi-source), METEOSAT (MSG) GLI, SeaWiFS | 2 |
| fAPAR | MODIS, MERIS, AVHRR SeaWiFS, SPOT VEGETATION | 1 |
| Albedo | SPOT VEGETATION, METEOSAT 2-7, POLDER 1-3, ADEOS1-2 MODIS, MISR, MSG SEVIRI, CERES | 1-2 |

| | | |
|------------------------|---|---|
| Soil Moisture | SMMR, SMM/I, ERS, TRMM TMI, AMSR-E, SMOS MIRAS, SMAP, WindSat | 1 |
| LST/Emissivity | ASTER, METEOSAT MSG SEVIRI, MODIS | 1 |
| Land Surface Phenology | MODIS, MERIS, AVHRR, multi-source | 1 |

2. FUTURE REQUIREMENTS FOR LPV

The goal of all space agency Earth science programs is to develop a scientific understanding of Earth's system and its response to natural or human-induced changes. Fundamental to this scientific understanding is a rigorous quantification of the accuracy of the land/climate data records produced from satellite datasets. Validation is the process by which the accuracy and consistency of satellite-derived land products are evaluated and associated uncertainties are quantified (Justice *et al.* 2000). The CEOS WGCV Land Product Validation sub-group plays a critical role in coordinating and fostering essential global land validation activities primarily through data and information exchange. Several important challenges for global land product validation have been identified:

One of the principal issues that limit the extent of validation activities and thus the maturity of the products is the lack of sustainable support from most space agencies. Although the importance of product validation is recognized as it relates to global climate change initiatives and ECV assessments, the amount of funding allocated to product validation when designing a satellite mission has always been marginal. As a result, product validation is generally conducted by the teams that developed the product. More independency between product development and validation is highly desired to increase the objectivity of the exercise. One activity currently being pursued through the LPV sub-group is the ESA-sponsored OLIVE tool (OnLine Interactive Validation Exercise). This web-interface tool will provide *in situ* and high resolution reference maps for the validation of LAI, fAPAR and albedo products. With the increasing number and importance of satellite data sets in the context of international conventions, there is an opportunity to put in place the mechanisms to provide products that have been independently validated to internationally accepted standards. The CEOS LPV sub-group is a critical component in this process, however, it does not have a direct funding mechanism. As with most international coordination efforts, LPV member support is essentially 'best effort', which is insufficient.

Global land product validation activities will benefit from increased access to high spatial resolution images. Reference *in situ* data for land cover and fire products is generally based on visual interpretation of high spatial

resolution images. Currently, the only free source of such data is Landsat. Other sources of high resolution images are either difficult to obtain (CBERS), or expensive (SPOT, Rapid-Eye, DigitalGlobe, GeoEye), and in some cases covered by a copyright constituting strong limitations for data sharing. Further, sharing of output data as well as the derived higher resolution products is needed to ensure repeatability of the results.

Specific funding for in situ reference data acquisition and contribution to complement existing networks to make tower-based instrument measurements usable for validation is required. One of the limitations in the data sharing process is the time required to pre-process the measurements into the desired format with standardized quality control and to provide the necessary metadata describing the way measurement were acquired. For example, producing good quality ecosystem productivity estimates from eddy covariance flux data. A significant number of reference datasets could be made available if a structured interface with data holders was established. Following this, support for data processing as well as development of software tools that can automatically compute targeted metrics is required. This would constitute the first step toward development of web-based tools that could provide the required transparency and independency of the validation exercises along with the possibility to evaluate new products easily (i.e. OLIVE).

There is a strong need to harmonize and standardize the methods for in situ data collection and pre-processing. For products such as albedo, LAI, fAPAR, soil moisture, and LST&E, the footprint of the reference in situ measurements is generally very small as compared to the typical footprint of global products. Apart from the few situations where the landscape can be considered homogeneous at these scales, most situations show significant heterogeneity. Representativeness of the in situ network location and satellite footprint area can be tested using spatial variograms and high resolution imagery (Roman *et al.* 2009). In heterogeneous landscapes, a dedicated sampling scheme has to be applied based on several replications of individual ground measurements scattered over the footprint of the global product considered (Baret *et al.* 2006). This makes such exercises very labor intensive. Further, the scaling process from the several individual local ground measurements to the product footprint is based on the use of high spatial resolution imagery, which is not always easy to obtain. Finally, most of these exercises are ‘instantaneous’ as opposed to continuous monitoring that would allow evaluation of the seasonality of the products. These issues are currently being addressed within the focus groups.

The revised LPV sub-group structure provides an effective taskforce dedicated to bringing issues related to

the assessment and validation of global land products to the attention of CEOS, GEO as well as space agencies and their respective missions. The evaluation and inter-comparison activities conducted within each focus group will inform data users of the associated errors and thus the most suitable use/application of each product. This information is not only necessary for assessing satellite-derived land ECV's and long-term data records, but will assist the international scientific community in understanding satellite land products and how they maybe be effectively used for climate modeling and related applications.

Globally coordinated activities and financial support for the validation of satellite land ECV's will reduce overall effort while maximizing use of existing and emerging resources. For further information about the CEOS LPV sub-group, validation activities, product focus groups, and to subscribe to the mailing list, please visit lpvs.gsfc.nasa.gov/.

REFERENCES

- Baret, F. Morisette, J. Fernandes, R. & Champeaux, J. & Myneni, R. *et al.*, “Evaluation of the representativeness of networks of sites for the global validation and inter-comparison of land biophysical products: Proposition of the CEOS-BELMANIP,” IEEE Transactions on Geoscience and Remote Sensing, vol 44(7), p.p. 1794-1803, 2006.
- Baret, F. Nightingale, J. Garrigues, S. & Justice, C. *et al.*, “Report on the CEOS Land Product Validation Sub-group Meeting,” The Earth Observer, vol 21(6), p.p. 26-30, 2009.
- GCOS, “GCOS-138 Implementation plan for the global observing system for climate in support of the UNFCCC,” WMO/TD No. 1523, Geneve, Switzerland, 2010.
- Justice, C. Belward, A. Morisette, J. & Lewis, P. *et al.*, “Developments in the validation of satellite sensor products for the study of the land surface,” International Journal of Remote Sensing, vol 21(17), p.p. 3383-3390, 2000.
- Morisette, J. Baret, F. Privette, J. & Myneni, R. *et al.*, “Validation of global moderate resolution LAI Products: a framework proposed within the CEOS Land Product Validation subgroup,” IEEE Transactions on Geoscience and Remote Sensing, vol 44(7), p.p. 1804-1817, 2006.
- Roman, M. Schaaf, C. Woodcock, C. & Strahler, A. *et al.*, “The MODIS (collection v005) BRDF/Albedo product: assessment of spatial representativeness over forested landscapes,” Remote Sensing of Environment, vol 113, p.p. 2476-2498, 2009.