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

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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.

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. Until recently, LPV members consisted of a group of practitioners who actively contributed to the development and implementation of validation procedures for a limited number of land products. The current emphasis on the independent and systematic evaluation of the GTOS (Global Terrestrial Observing System) terrestrial ECVs [1] and long-term data records prompted establishment of a more focused organization of the LPV sub-group. Product areas were expanded to seven 'focus groups', each with internationally independent co-chairs who have been actively involved in validation activities and are respected community members (Tab. 1). 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 1. 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 (137)
Fire* (Active/ Burned Area)	Luigi Boschetti (UMD)	Kevin Tansey (U Leicester, UK)	[1]GOFC-GOLD (73)
Surface Radiation (Reflectance, BRDF, Albedo*, Snow/Ice*)	Crystal Schaaf (BU)	Gabriela Schaepman (U Zurich, SW)	[2]ARM/SGP [3]BSRN/ [4]SURFRAD, [5]FLUXNET, [6]AERONET (41)
Biophysical (LAI*, *f*APAR*, VI, GPP/NPP)	Richard Fernandes (NR Canada)	Stephen Plummer (Harwell, UK)	[7]IGBP, FLUXNET (72)
Land Surface Temperature / Emissivity	Simon Hook (NASA JPL)	Jose Sobrino (U Valencia, SP)	[8]IVOS (65)
Soil Moisture*	Tom Jackson (USDA)	Wolfgang Wagner (Vienna UT, AT)	[9]GEWEX (48)
Land Surface Phenology	Jeff Morisette (USGS)	Jadu Dash (U Southampton, UK)	[10]PEN, USA Phenocams (76)

*GTOS defined ECVs. [1] GOFC-GOLD (Global Observation of Forest & Land Cover Dynamics), [2]ARM/SGP (Atmospheric Radiation Measurement Program/Southern Great Plains), [3]BSRN (Baseline Surface Radiation Network), [4]SURFRAD (Surface Radiation Network), [5]FLUXNET (international network of flux and micrometeorological towers), [6]AERONET (AErosol RObotic NETwork), [7]IGBP (International Geosphere-Biosphere Programme), [8]IVOS (WGCV Infrared & Visible Optical Sensors sub-group), [9]GEWEX (Global Energy & Water Cycle Experiment), [10]PEN (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 [2]. A template for the validation protocol documents exists to ensure a consistent process across the products. The protocols may be adapted for individual products, however, they 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 [2].

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. The current status of these documents per each focus area will be discussed within section 2.

1.2. Fostering International Collaborations

The LPV sub-group owes much of it 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 GOFC-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 HyspIRI (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 [3]. 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 (Tab. 2).

Table 2. 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 *in situ* or other suitable reference data.
Stage 2	Product accuracy is estimated over a significant set of locations and time periods by comparison with reference *in situ* 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 *in situ* 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.

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. For example, eddy covariance carbon flux measurements can be used to derive gross and net primary production (GPP and NPP, respectively). In addition, many FLUXNET towers are fitted with instruments that provide concurrent measurements of photosynethtically active radiation (PAR), absorbed PAR (APAR) and shortwave albedo, which are highly valuable for the validation of biophysical products. 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.

2. FOCUS GROUP STATUS UPDATES

The following section provides an overview of the status of each LPV focus area. The validation stage of products within each group is highlighted (Tab. 3) as well as current focus area activities, product protocol development and collaborations.

Table 3. 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

2.1. Land cover focus area

The land cover focus area aims to engage the international community in the development of datasets and protocols supporting the validation of remote sensing based land cover, land use, associated change and related area estimates. Recognised as a GTOS ECV [4], reliable observations of land cover from space are crucial for monitoring and understanding ongoing processes of environmental and climate changes. A global effort to assess the accuracy of existing land cover products derived from a variety of satellite sensors over a range of spatial resolutions is being led by the Land Cover Implementation Team of GOFC-GOLD in conjunction with the LPV sub-group [5].

The first phase of this effort is complete and culminated in a publication of community consensus "best practices" for validation and accuracy assessment of global land cover datasets [6]. The next phase in the 2011 timeframe, will involve implementing the recommendations outlined in the 2006 document and writing a protocol for determining land cover and land use change estimates. This document will also be essential for Forest Carbon Tracking efforts needed for

carbon accounting systems such as REDD (Reducing Emissions from Deforestation and Degradation).

A "living database" of 500 global randomized sample sites will form the basis of accuracy assessment for a host of global land cover products (GLC2000, MODIS land cover, GLOBCOVER, United Nation's Forest Resource Assessment (FRA2010), and the Mid-Decadal Global Land Survey). This "living dataset" will take assessments of all global land cover datasets from Stage 2 to Stage 3 validation level. The global stratified sample of land cover validation sites is based on climate/vegetation biomes and population data [5]. The sample sites are 5km x 5km and "ground truth" will be derived from very high resolution imagery with the assistance of local experts. In addition, ESA is expanding on the GLOBCOVER heritage with a new dataset for 2009 (which will utilize the 2005 land cover validation scheme). The ESA CCI for Land Cover will also include a validation component (http://earth.eo.esa.int/workshops/esa_cci/ITT.html).

2.2. Fire Focus Area

The Fire focus area aims to provide a platform for the development of globally representative and consistent validation datasets of Burned Area and Active Fires derived from space observations. Current efforts are centred on producing a protocol for the validation of global, multi-year data sets of burned area. The protocol will provide a procedure for the development of validation data sets that are spatially and temporally consistent and cover the major vegetated systems of the Earth's surface.

Fire disturbance (particularly burned area) has been designated a GTOS ECV [7] and thus the validation of any fire related data sets must have errors characterized and traced. Burned area products are currently at Stage 2 level of validation. Additional resources will be required to make the necessary enhancements to the existing validation data set. While considerable in scope and development, the validation data set is biased towards fire prone regions of the globe. Additional validation data are also required to characterize commission errors in regions that experience little fire activity. Further, a platform for dissemination of the validation data set and methodology is required. Development and improvement of global burned area data sets is a continuous process and is extremely important and timely (i.e. ESA CCI, GEOLAND2 and MODIS).

Future efforts within this focus group will integrate the validation of active fire data sets. This will be supported through the ESA CCI by activities conducted through the prime institution, University of Alcala, Spain as well as the University of Maryland, USA. Focus area leads are currently scouting new validation test sites in Argentina to be used for fire characterization (fire radiative power as well as pre-and post biomass), which will complement existing test sites located throughout South Africa and Australia.

2.3. Surface Radiation Focus Area

The Surface Radiation focus area aims to facilitate consistent combined inter-comparison and validation studies among existing and upcoming satellite-derived surface radiation products. The group is currently focused on the albedo and reflectance anisotropy terrestrial ECV product [8] as well as surface reflectance. At present, snow and ice products also fall under this focus area.

A protocol to support and standardize the validation procedure for existing and emerging albedo products is in progress and should be drafted for community review by early 2011. Albedo in situ measurement standards have been defined by the Baseline Surface Radiation Network [9]. Tower albedometer sites are being evaluated with high resolution imagery and geostatistical measures to assess whether they are representative of moderate resolution satellite products over all seasons [10]. Thus far, 100 sites (from BSRN, SURFRAD, ARM, FLUXNET) have been characterized for leaf-on and leaf-off conditions. A few of these sites have been assessed for snow covered and snow-melt conditions as well.

While existing satellite derived albedo products are currently validated at Stage 2, more representative field sites with high quality calibrated albedometers are required to reach Stage 3 validation of these products. In addition, routine characterization of atmospheric optical depth (available through the AERONET system) is required at these locations to assess both surface reflectance and instantaneous surface albedo. Furthermore, spectral radiometers and airborne multi-angular data also are desired to assess spectral radiation and reflectance anisotropy products.

2.4. Biophysical Focus Area

The biophysical focus area is responsible for products ranging from LAI, fAPAR, Vegetation Indexes as well as global estimates of gross and net ecosystem primary productivity (GPP and NPP). Significant international efforts have been focused on evaluation of the LAI ECV [11]. Increased research is now required for the fAPAR ECV [12]. Validation efforts for VI's and Productivity products have primarily been based on MODIS activities [13, 14] and will continue through VIIRS land validation efforts.

The principles of the validation procedures for LAI products have been established [3, 15] and implemented [16] resulting in Stage 2 validation. However, issues remain to be resolved regarding the quality and consistency of existing in situ observations as well as on the quality of satellite observations of LAI, which are known to be limited in terms of approach and underlying correction issues. A CEOS endorsed validation protocol for LAI products is in development and a draft should be available for community review in early 2011.

Significant work is also required to reconcile algorithms based on different radiative transfer schemes and their underlying assumptions. This applies to LAI, fAPAR and albedo since the three should be consistent. Currently, methods used for each are independent of one another. Also there is an urgent need to reconcile methods, definition and interpretation with the Earth System modeling community such that the products are consistent with models and the models appropriate for the incorporation of these products.

The main limitations to achieving Stage 3 and 4 validation for LAI products relate to the availability of in situ measurements as well as a better characterization of the definition and uncertainties attached to the site measurements. Further, validation activities mostly correspond to a snap shot, i.e. a short experiment representing a limited portion of the vegetation cycle and state for a given site. Development of sites with continuous measurements covering a significant fraction of the season is required. Closer collaboration with networks such as FLUXNET and LTER (Long Term Ecological Research) sites is anticipated.

2.5. Soil Moisture Focus Area

The Soil Moisture focus area aims to encourage cooperation for the establishment of a global in situ soil moisture network (SMN), foster cooperation among soil moisture product teams and prepare guidelines for best practice data collection and validation. The focus area leads have been instrumental in developing and launching the International Soil Moisture Network (ISMN). This network came online in February 2010 and is a collaboration between CEOS, GEWEX and GEO. Inclusion of datasets into the database is ongoing and records are available on from 1980 onwards.

In recent years several global soil moisture data sets derived from microwave scatterometers and radiometers were published and often validated by independent research teams soon thereafter [17, 18]. Validation often involves the direct comparison of the satellite data with in situ soil moisture observations. This method is problematic because the satellite data represent the soil moisture content averaged over large areas (25-50 km) while the in situ measurements are essentially point based. Therefore, the validation teams have also used modeled soil moisture data sets and/or advanced validation strategies such as triple collocation [19] or data assimilation approaches [20]. Validation results have been reported from continents, yet a comparison of these results is difficult due to the lack of common standards. Soil moisture products have thus only reached Stage 1 validation.

Soil moisture is a relatively new GTOS defined ECV and hence a protocol for the validation of these products will be forthcoming. The first dedicated soil moisture satellite, SMOS, was launched in 2009 and will be followed by SMAP in 2014. These missions are addressing the issues of standardization and robustness and it is expected that significant advances will be made toward soil moisture product validation in the next 5 years. In addition, the SMAP project recently initiated an in situ sensor test bed with international participation. This effort is designed to specifically address the problems of varying in situ instrumentation and installations around the world in order to produce a robust data set for validation. Both SMOS and SMAP will be supporting the development of core validation sites. One of the major issues in soil moisture validation is the global distribution of in situ observations. Surveys of available resources indicate that coverage over Africa and South America is almost non-existent. In other regions such as Russia and China, modern technologies have not been implemented, which results in low temporal frequency and high latency. Institutional support for measurement programs in these regions is desperately needed.

2.6. Land Surface Temperature and Emissivity (LST&E) Focus Area

The LST&E focus area aims to encourage community involvement and development of datasets to support validation of remote sensing based LST & Emissivity products. Although not officially a GTOS ECV, GEO has highlighted the importance of land surface temperature for both research and societal benefits [21]. In the last two decades, remote sensing has become the key tool used for measuring LST&E, which in turn is used to improve land cover, land use, and land cover change maps as well as understand ecosystems through studies of evapotranspiration. However, data sets and methods for characterizing the quality of these data sets, especially at national, regional and larger scales, have lagged behind mapping technology. More work is needed to support and encourage international initiatives focused on developing LST&E climate data records and essential climate variables. Specifically, community-based efforts to develop data sets and standardized

methods supporting validation of LST&E products are urgently needed. LST&E products are currently only validated at Stage 1.

Work is underway to develop regional and global LST&E data sets such as the North American ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) Land Surface Emissivity Dataset (NAALSED, http://emissivity.jpl.nasa.gov). Provision of high-quality and accurate maps of LST&E at regional to global scales is an urgent priority, yet methods for validating these data are poorly understood and immature, especially when scaling from the local to regional and global scales. The focus group has been actively involved in the ESA-funded SEN3EXP and THERMOPOLIS field campaigns. The SEN3EXP campaign was conducted to further cal/val and algorithm development activities for the future Sentinel-3 mission. While the THERMOPOLIS campaign was conducted over the city of Athens, Greece, to the study the Urban Heat Island effect.

2.7. Land Surface Phenology Focus Area

The LSP focus area aims to provide a platform for the development of globally representative data sets and methods to enable consistent assessment and validation of LSP products. Satellite-derived LSP products provide information on the seasonal variation in vegetated land surfaces which is becoming increasingly important for estimating carbon dynamics and assessing impacts of global climate change. In light of the importance of vegetation phenological information, there has been a recent proliferation of land surface phenology (LSP) products derived from moderate-resolution, high temporal frequency satellite sensors. There are currently seven LSP products produced via analysis of time-series VI information from several sensors including: MODIS; AHVRR (Advanced Very High Resolution Radiometer); SPOT-Vegetation (Systeme Pour l'Observation de la Terre-Vegetation); and MERIS (Medium Resolution Imaging Spectrometer).

A number of methods exist to extract phenological events from a VI time-series and extend from simple VI growing season thresholds and ratios, to complex analysis of changes in the derivative of the VI slope calculated using mathematical software. These techniques attempt to extract a number of key dates from the time-series, such as the onset of vegetative greenness, maximum development, end of the growing season and duration of the growing season. Several studies have been conducted that relate in-situ data to pixel 'day of year' for green-up and brown-down events [22]. However, in situ data (i.e single species leaf bud-burst, first bloom, unfolded leaves, withered leaves) from ground volunteer networks such as the USA NPN (National Phenology Network), Canada's PlantWatch and the European Phenology network, do not represent bulk vegetation properties measured by a large footprint satellite. Thus all LSP products are currently at Stage 1 validation level. With the increasing number of LSP products available, a mechanism to determine the relative accuracy of the derived metrics from each product is required.

In June 2010, a LPV- Land Surface Phenology topical workshop at the Phenology conference (Trinity College, Dublin, Ireland) brought together producers of continental- to global-scale LSP products; as well as those collecting field, tower, or airborne data useful for validating these products. A consensus for data sharing and coordinated assessment of LSP products was reached. The approach will involve selection of core sites that will comprise of near-surface remote sensing observations including RGB canopy cameras within the USA Phenocam network (http://klima.sr.unh.edu/), hemispherical cameras, and hyperspectral sensors within the Japanese PEN (http://pen.agbi.tsukuba.ac.jp/index_e.html), PAR sensors within the PAR@METER network and / or flux tower measurements. Comprehensive field observations or the ability to collect such data will also be vital. A key component of the LSP product assessment will be analyzing the various product algorithms and definitions of phenological signals as well as defining ways of scaling from field - near-surface – satellite observations. The development of an international protocol to quantify the accuracy of these products and initiate a validation-based inter-comparison will evolve as work progresses in this new focus area.

3. 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 [23]. 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.

The brief overview of the current validation stage of land products provided in this paper allows several important challenges for global land product validation to be 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, GeoEve), 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 [10]. 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 [15]. 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/.

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