Evaluation of the Representativeness of Networks of Sites for the Global Validation and Intercomparison of Land Biophysical Products: Proposition of the CEOS-BELMANIP

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***Abstract*—This study investigates the representativeness of land cover and leaf area index (LAI) sampled by a global network of sites to be used for the evaluation of land biophysical products, such as LAI or fAPAR, derived from current satellite systems. The networks of sites considered include 100 sites where ground measurements of LAI or fAPAR have been performed for the validation of medium resolution satellite land biophysical products, 188 FLUXNET sites and 52 AERONET sites. All the sites retained had less than 25% of water bodies within a 8×8 km^2 window, and were separated by more than 20 km. The ECOCLIMAP global classification was used to quantify the representativeness of the networks. It allowed describing the Earth's surface with seven main types and proposed a climatology for monthly LAI values at a spatial resolution around 1 km. The site distribution indicates a large over representation of the northern midlatitudes relative to other regions, and an under-representation of bare surfaces, grass, and evergreen broadleaf forests. These three networks represent all together 295 sites after elimination of sites that were too close. They were thus completed by 76 additional sites to improve the representativeness in latitude, longitude, and surface type. This constitutes the BELMANIP network proposed as a benchmark for intercomparison of land biophysical products. Suitable approaches to conducting intercomparison at the sites are recommended.**

***Index Terms*—Global land biophysical products, intercomparison, leaf area index (LAI), validation.**

I. Introduction

SINCE the first launch of the National Oceanic and Atmospheric Adminstration's (NOAA) Advanced Very High Resolution Radionmeter (AVHRR) in 1981, land surfaces have been monitored frequently in an almost continuous manner. Starting from 1997, other sensors including POLDER/ADEOS, VEGETATION/SPOT, SEAWIFS, MODIS/EOS, MERIS-AATSR/ENVISAT, SEVERI/MSG have complemented the still operational NOAA/AVHRR series. This new generation of sensors provides a better sampling of the radiance field in the spectral (all), directional (POLDER, SEVIRI, MISR), and spatial (MODIS, MERIS) dimensions. In addition, the improved radiometric and geometric performances allow a better interpretation of the signal recorded in terms of key surface characteristics. These observables are required for a range of investigations and applications such as land cover mapping, change detection, vegetation ecosystem dynamics studies, climate and biogeochemical cycles modeling, or food security. The scientific community investigating the associated processes at the regional to global scales is increasingly utilizing high level products corresponding to estimates of state biophysical variables such as leaf area index (LAI), vegetation cover fraction (fCover), fraction of the absorbed photosynthetically active radiation (fAPAR) and surface albedo [1]. These state biophysical variables are used either as inputs for forcing the models, or as diagnostic variables to better control the temporal trajectory of the models within assimilation approaches [2].

To fulfill the user community requirements, estimates of such state biophysical variables have been developed for some sensors. These will be later called land biophysical products or just products for simplification. They currently include LAI, fAPAR, and albedo products proposed from MODIS [3], fAPAR, LAI, and fCover from MERIS [4], [5], LAI, fCover, and albedo from POLDER [6]–[8], LAI from VEGETATION [9], [10], or LAI, fAPAR, fCover, and albedo from the fusion of VEGETATION, AVHRR, MERIS, and POLDER through the CYCLOPES project [11]. The algorithms developed to generate these land biophysical products are derived either from different radiative transfer model inversion techniques [12], [13] or from calibration of empirical relationships over a set of ground measurements [9], [10]. Recent studies have already outlined significant discrepancies among several existing LAI products [4], [14]–[16]. The multiplicity of available products prompts the need for a strategy for their validation and the intercomparison to define how multiple products can be used in combination, and how a consistent time series can be

Manuscript received January 7, 2005; revised October 15, 2005.

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Digital Object Identifier 10.1109/TGRS.2006.876030

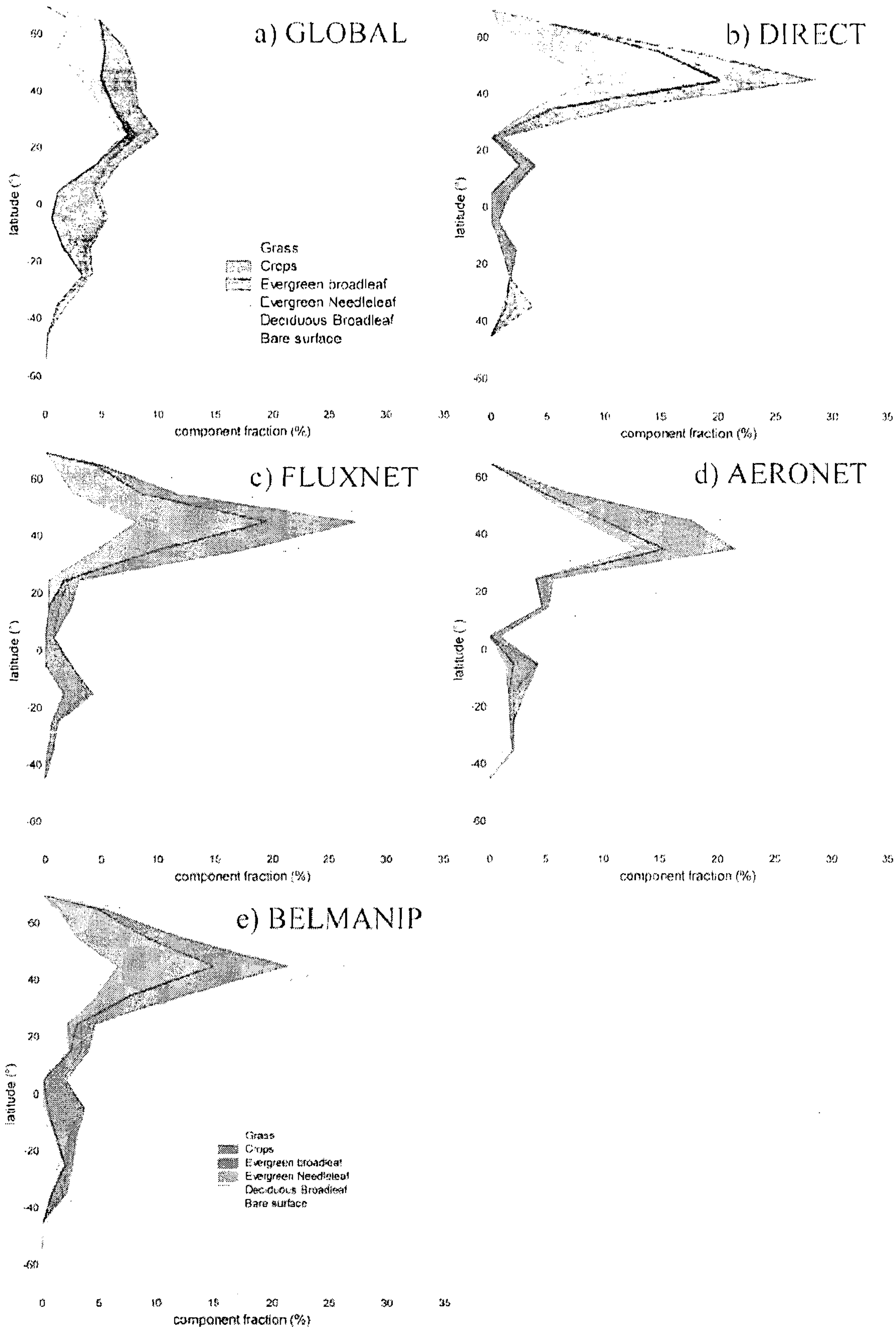

Fig. 1. (a) Latitudinal distribution of the six surface types relative to the global emerged area within the [−70° 70°] latitude domain. The latitudinal resolution is 10°, and the component fractions are computed according to their actual area. Panels (b)–(e) correspond to the latitudinal distribution of the surface types for three networks of sites: (b) DIRECT, (c) FLUXNET, (d) AERONET, and (e) BELMANIP computed similarly over the [−70° 70°] latitude domain with 10° latitude steps. The extent for each site is 8 × 8 km^2.

TABLE I

FRACTION (PERCENT) OF SURFACE COMPONENTS OBSERVED GLOBALLY FOR DIFFERENT ENSEMBLE OF SITES. THE FIRST COLUMN CORRESPONDS TO THE DISTRIBUTION OF SURFACE COMPONENTS OVER THE EMERGED SURFACES AND WOULD CONSTITUTE THE REFERENCE. THEN, THE THREE OTHER COLUMNS REPRESENT THE DISTRIBUTION FOR THE DIRECT, FLUXNET, AND AERONET NETWORKS OF SITES. THE COLUMN "COMPLET" REPRESENTS THE DISTRIBUTION OF THE ADDITIONAL SITES USED TO COMPLETE THE THREE PREVIOUS TO GET THE BELMANIP NETWORK (SEE SECTION IV-A). THE EXTENT OF SITES USED WAS 8×8 km^2. THE LAST LINE DISPLAYED THE NUMBER OF SITES CORRESPONDING TO EACH NETWORK. NOTE THAT THE NUMBER OF BELMANIP SITES IS SMALLER THAN THE SUM OF DIRECT+AERONET +FLUXNET+COMPLET BECAUSE FEW SITES WERE SEPARATED BY LESS THAN 20 km DISTANCE (SEE SECTION IV-A)

Component Fraction	GLOBAL	DIRECT	FLUXNET	AERONET	COMPLET	BELMANIP
Grass	30.0	21.1	24.3	28.4	32.9	26.1
Crops	11.1	19.8	20.0	20.6	10.7	18.5
Evergreen Broadleaf	11.7	5.4	8.1	3.5	16.7	8.7
Evergreen Needleleaf	9.7	29.4	28.1	4.6	8.7	22.0
Deciduous Broadleaf	4.9	15.3	14.7	12.8	3.5	11.2
Bare surface	32.5	9.0	4.8	30.2	27.6	13.5
Total	100.0	100.0	100.0	100.0	100.0	100.0
Number of sites	-	100	188	52	76	371

constructed from several sensors. Proper validation will ensure the required continuity both in time and space between the products derived from different algorithms and sensors. It will also provide confidence intervals associated to each product.

The Committee of the Earth Observation Satellites (CEOS) has established the Land Product Validation (LPV) subgroup that is in charge of proposing a consistent strategy as well as dedicated methods and tools for the validation and intercomparison of land biophysical products [17], [18]. The evaluation of such products is a difficult task because of the extent and resolution of global products.

Direct comparison with ground measurements have been achieved over a limited number of sites and dates. More than 100 sites and dates have been sampled during these last ten years. They can provide high spatial resolution maps of the state biophysical variables considered, derived from local ground measurements that have been up-scaled to $\sim$30-m spatial resolution using high resolution satellite data such as SPOT HRV, Landsat Thematic Mapper or Enhanced Thematic Mapper Plus [19]. However, in addition to the question of the proper uncertainty associated to this ground validation process, the effort needed to perform the exercise limits the number of sites that can be sampled, and brings into question the representativeness of this sampling with regards to the global variability of land characteristics. The same applies to the temporal sampling, particularly regarding the large seasonal variation observed for some vegetation types. Consequently, the first objective of this paper is to propose a methodology for evaluating the representativeness of these direct validation activities over the global extent.

Intercomparison between products would be very useful to complement the direct validation exercise by providing a far better sampling, both in space and time. In addition, inspection of the smoothness of the time series of the products at a given site can yield key information on the sensor and the algorithms performances with regards to cloud screening, atmospheric correction, bidirectional effects, and soil background or understory variations. Such an intercomparison needs to represent the variability observed globally. The second objective of this paper will be therefore to propose a network of sites dedicated to the intercomparison of land biophysical products: the CEOS- Benchmark Land Multisite Analysis and Intercomparison of Products (BELMANIP).

The ECOCLIMAP world classification [20] was used to evaluate the global representativness of candidate sites. ECOCLIMAP provides some estimates of the monthly LAI values together with a land cover classification. Amongst all the possible state biophysical variables considered here (fAPAR, fCover, albedo, LAI), LAI is certainly the most important one and also the most difficult to estimate [13], [21]. In addition, fAPAR, fCover, and albedo are strongly related to LAI. For these reasons, the spatial and temporal representativity of the sites used for direct validation or for intercomparison will be evaluated using LAI as a proxy.

In the first part of this study, the ECOCLIMAP classification is briefly presented along with some key global statistics. In the second part, the representativity of the direct validation sites is described. Also considered are sites from existing networks such as FLUXNET and AERONET. In the third part, an ensemble of sites sampling the variability of vegetation types is proposed and described: the CEOS-BELMANIP network. Finally, conclusions are drawn on the directions where the product development and validation exercise should go to improve our capacity to describe and understand surface processes.

II. ECOCLIMAP GLOBAL CLASSIFICATION

ECOCLIMAP was primarily developed by [20] to provide monthly $1/120^\circ$ resolution (around 1 km at the equator) state biophysical variables fields such as LAI that are required by the soil–vegetation–atmosphere transfer models (SVAT's) used for atmospheric modeling. ECOCLIMAP is based on a global classification into 15 main land surface types derived from multiple sources [22]–[25], combined with a world climate distribution derived from [26] and [27]. The LAI range of variation (minimum and maximum LAI values) for each class was computed by combining the LAI values derived from the literature for the 15 original surface types. The temporal evolution was derived from NOAA/AVHRR monthly NDVI composite. The ECOCLIMAP LAI fields showed reasonable level of agreement when compared with local LAI measurements reported in the literature, as well as with POLDER LAI products and ISLSCP

TABLE II
MEAN VALUES OF THE MINIMUM, AVERAGE, AND MAXIMUM MONTHLY LAI VALUES OF SEVERAL DATA SETS. THE FIRST COLUMN CORRESPONDS TO THE LAI VALUES AS OBSERVED OVER THE EMERGED SURFACES AND WOULD CONSTITUTE THE REFERENCE. THE VALUES IN PARENTHESES CORRESPOND TO LAI COMPUTED OVER THE NONPERMANENTLY BARE SURFACES. THEN, THE THREE OTHER COLUMNS REPRESENT THE DISTRIBUTION FOR THE DIRECT, FLUXNET, AND AERONET NETWORKS OF SITES. THE COLUMN "COMPLET" REPRESENTS THE DISTRIBUTION OF THE ADDITIONAL SITES USED TO COMPLETE THE THREE PREVIOUS TO GET THE BELMANIP NETWORK (LAST COLUMN). THE EXTENT OF SITES USED WAS 8×8 km^2

	GLOBAL	DIRECT	FLUXNET	AERONET	COMPLET	BELMANIP
Minimum	1.03 (1.34)	1.21 (1.21)	1.33 (1.33)	1.10 (1.15)	1.28 (1.49)	1.27 (1.31)
Average	1.58 (2.04)	2.23 (2.23)	2.37 (2.38)	1.60 (1.66)	1.79 (2.08)	2.14 (2.21)
Maximum	2.25 (2.90)	3.43 (3.44)	3.50 (3.52)	2.11 (2.20)	2.44 (2.84)	3.13 (3.24)

LAI data [7]. The 15 elementary surface types were grouped into seven main surface components: 1) water bodies (including inland water, seas, and oceans); 2) bare surface (including dense urban built up, rocks, deserts and permanent snow and ice); 3) evergreen needle leaf forests; 4) evergreen-broadleaf forests; 5) deciduous broadleaf forests and shrubs; 6) crops; and 7) grass. The grouping reduces the number of classes while preserving distinct vegetation structure and phenology.

The distribution of the seven ECOCLIMAP component fractions for 10° latitude bands shows that the same surface type could be present over relatively different climatic situations: the grass type that is observed from −55° at the most southern extremity of America, up to 70° north latitude [Fig. 1(a)]. A wide range of vegetation variability and seasonality is therefore expected within grasses. It applies also to crops [−40° 60°] and to broadleaf deciduous forests [−50° 65°]. Evergreen needleleaf forests are mainly located in the midlatitudes of north of the Northern Hemisphere [20° 70°], while evergreen broadleaf forests are concentrated near the equator [−25° 25°]. Table I shows the corresponding figures of the global area fraction for each of the six surface types other than waters. Bare surfaces and grass components represent the widest fractions, close to 30% of the global emerged area. Crops, conifers and broadleaf evergreen forests are about equally represented with around 10% of the global emerged area. Deciduous broadleaf forest is the smallest component, with less than 5% of the emerged area.

The yearly average, the minimum and the maximum monthly values were used to summarize the LAI seasonality from the monthly values provided by ECOCLIMAP. Their statistical distribution is described by the cumulated frequencies allowing easier comparison of the yearly LAI average with the seasonal minimum and maximum values. Fig. 2 shows that at the original resolution of ECOCLIMAP (1°/120), the maximum LAI value is 6.0 which is probably lower than the actual maximum values, even observed at 1-km resolution [7], [10]. The shape of the distribution would actually suggest that higher but infrequent LAI values are expected. However, the higher LAI values are relatively scarce: less than 10% of the emerged area has maximum monthly LAI values lower than 5.0 (Fig. 2). Conversely, the lowest values of LAI are well represented: more than 50% of the emerged surface has yearly LAI values lower than 1.0! Note that the median values for the minimum monthly LAI is about 0.5, and 2.0 for the maximum. The average values for the minimum and maximum monthly LAI are respectively 1.0 and 2.2, as compared to the 1.6 average yearly LAI value (Table II). The permanently bare emerged surfaces (LAI $= 0$ in Fig. 2) represent about 23% of the global emerged surfaces which is slightly lower than the 32% bare surface component fraction (Table I) because a bare surface component occupies not necessarily the whole pixel at the original ECOCLIMAP spatial resolution (case of many shrub-land classes). For yearly LAI values in the range [1.0–5.0], the seasonality (difference between minimum and maximum monthly values) reaches a maximum around 2.0. It is obviously minimum at the two extreme yearly LAI values: permanent bare surfaces and evergreen forests show no seasonality. Note that for a given pixel, the distribution of LAI values is relatively symmetric about the yearly average LAI value.

III. REPRESENTATIVENESS OF CURRENT DIRECT VALIDATION SITES

Once the baseline for the description of vegetation type and conditions at the Earth's surface is set via ECOCLIMAP, the representativeness of current networks of sites can be investigated. Note that all the results presented here after derive from ECOCLIMAP. The time domain of their validity corresponds roughly to some average state of the surface as observed along the last ten years.

A. Network of Sites

We considered in first place the network of sites where ground measurements of the main state biophysical variables were performed specifically for the validation of the medium resolution products. This network will be called later "DIRECT." We then considered the FLUXNET sites where some ground truth is also available. We additionally considered the AERONET network that may provide some useful information on the atmospheric correction performances. Finally, after analyzing the representativeness of these three networks, we proposed to improve it by including additional sites that will lead to the CEOS-BELMANIP network of sites providing a benchmark for intercomparison of products.[1]

1) DIRECT Validation Sites: This ensemble of sites results from the compilation of the main validation exercises including those corresponding to core sites referenced by CEOS/LPV in 2000,[2] Bigfoot [28], VALERI [29], The Canadian contribution [9], [10], [30], and other individual initiatives. A total of 114

[1]The list of sites described in this section is available at http://landval.gsfc.nasa.gov/LPVS/lai_intercomp.php.

[2]For more information, see http://modis.gsfc.nasa.gov/MODIS/LAND/VAL/CEOS_WGCV/lai_intercomp.html

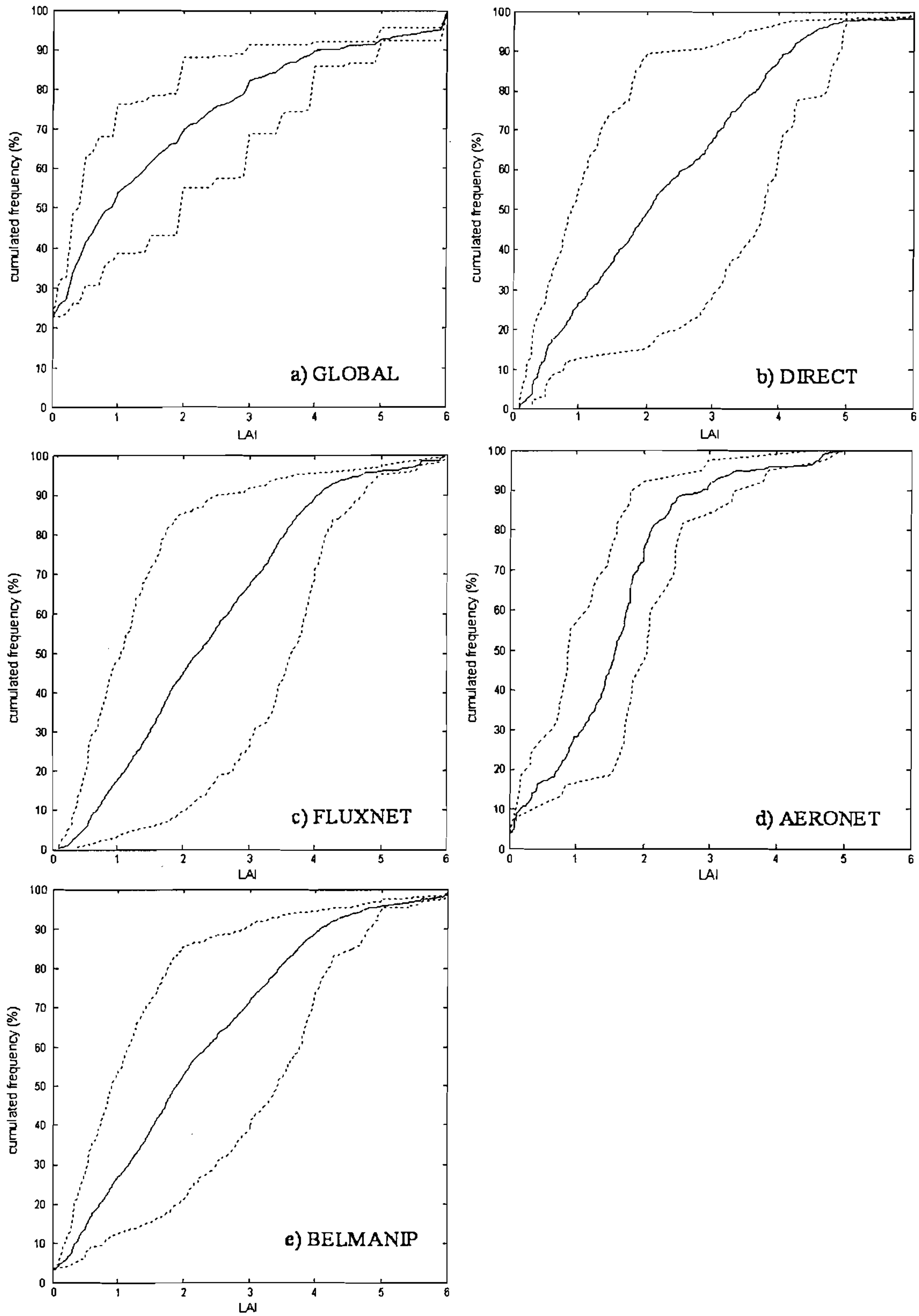

Fig. 2. (a) Cumulated frequency of LAI values observed globally over emerged surfaces in the [−70° 70°] latitude domain. The solid line represents the distribution over the whole year. The dashed lines represent the minimum and maximum monthly LAI values as observed during the year. Panels (b)–(e) correspond to the cumulated distribution of LAI values as observed over four networks of sites over emerged surfaces in the [−70° 70°] latitude domain: (b) DIRECT, (c) FLUXNET, (d) AERONET, and (e) BELMANIP. The extent for each site is 8×8 km^2.

sites is identified. Their extent varies roughly from 1×1 km^2 to 10×10 km^2 [19]. To avoid possible replication of sites between the different sources used, only one site (the first appearing in the original list) was retained if other sites were present within less than 20 km distance. A total of 100 sites were finally selected.

2) FLUXNET: FLUXNET is a large international initiative dedicated to the measurement of carbon fluxes over a network of sites. It is of great interest for the remote sensing community for two reasons: first, remote sensing offers a unique opportunity to characterize over a larger extent the vegetation type and status required for the modeling; second, the complementary measurements available around the flux towers can be used as additional information for the validation of land biophysical products. A total of 266 sites were available at www.fluxnet.ornl.gov/fluxnet/siteplan.cfm. The sites are centered on the towers. However, some sites were dedicated to the characterization of fluxes over seas or oceans. Therefore, only those with less than 25% water bodies over an 8×8 km^2 area centered on the tower were retained. In addition, similarly to the DIRECT sites, if several sites are within less than 20 km distance, only one (the first in the original list) was selected. Finally, 188 sites were selected.

3) AERONET: AERONET sites [31] are primarily dedicated to the characterization of aerosols. However, because of the importance of atmospheric correction in the derivation of land biophysical products, these sites are included in our analysis. The center of each site corresponds to the location of the automatic sun-photometer. AERONET is made of a variable number of sites, some of them being almost permanent, and some others being set up only for a short period. They were extracted from http://aeronet.gsfc.nasa.gov/cgi-bin. Only the sites with more than three years existence were selected, resulting in a total of 80 sites. Similarly to the direct validation sites, if several sites were within a distance smaller than 20 km, only one site (the first in the original list) was selected. In addition, because the objective of this study is dedicated to land, the sites with more than 25% of water bodies at the 8×8 km^2 area extent were rejected. Finally, 52 sites remained.

B. Representativity of the Network of Sites

The representativity of the three networks of sites was investigated at the 3×3 km^2, 8×8 km^2, 20×20 km^2, and even 50×50 km^2. However, results show (not presented here) that they were very consistent. We will thus present only the results corresponding to the 8×8 km^2 site extent. This lies in between the smallest and the largest direct validation site extent. In addition, the resolution of some sensors such as POLDER and the corresponding products is very close to this area.

1) Surface Type: The surface type is characterized by the six main emerged surface components as described earlier. The global distribution is presented in Table I. Note that by definition, the bare surfaces are poorly represented in DIRECT and FLUXNET. Grass is under-represented in DIRECT and FLUXNET with respect to the global distribution. Crops are largely over represented for the three networks. Evergreen broadleaf forests are under-represented in DIRECT and AERONET. Evergreen needleleaf forests are overrepresented for DIRECT and FLUXNET, while under-represented for AERONET. Deciduous broadleaf is overrepresented for the three networks. A closer inspection of the latitudinal distribution of these networks of sites explains why it is relatively unbalanced: The northern midlatitudes are largely over represented: almost 50% of the sites are within the 30° to 50° latitudes, although they only represent about 25% of the global emerged surfaces. These latitudes correspond obviously to the main countries that initiated these networks and therefore, most of the sites are located at these latitudes.

2) LAI: The distribution of the monthly LAI values and the corresponding yearly maximum and minimum are shown in Fig. 2. The main difference with the distribution of LAI over the global emerged areas [Fig. 2(a)] is the lower amount of bare surfaces where LAI $= 0$. Note that there is almost no sites with LAI $= 0$, although the distribution of components shows a small fraction of bare surfaces. This apparent contradiction is explained by the fact LAI is averaged over each individual site while the distribution of surface components was built from the highest resolution ECOCLIMAP data, with the possibility to get few pixels with a significant bare surface component fraction. It appears also that LAI values higher than 4.0 are less represented, presumably because of the lower number of sites in the evergreen broadleaf forest latitudinal domain. The amplitude of variation between the minimum and the maximum values is slightly larger (≈ 2.5) than that of the global distribution for DIRECT and FLUXNET, while AERONET shows much restricted amplitude (≈ 1.2). However, similarly to the global LAI distribution and for the same reasons, the amplitude decreases at the extremities of the distribution.

The average LAI values observed over the three networks of sites are higher than those corresponding to the global distribution (Table II) mainly because of the weak representation of bare surfaces. Note also that the LAI values when computed over non permanently bare surfaces are very similar for the three network of sites investigated (values in parenthesis in Table II) conversely to what is observed for the global LAI distribution. AERONET LAI values are however closer to the global values because of the lower amount of forests and the larger amount of bare surfaces.

IV. Building a Network of Sites for Intercomparing the Products: CEOS-BELMANIP

In the previous section, we showed that the three networks of sites were not perfectly representing the variability of surface types and conditions. Here we develop a set of sites complementing the existing networks of sites to improve global representativness.

A. Completion of the Initial Network of Sites: CEOS-BELMANIP

The BELMANIP network of sites aimed at getting a good representativity of the surface types and conditions. The surface types are roughly characterized by the dominant surface component and the latitude that greatly influences the way one component expresses. For this purpose, additional sites were included to improve the representativity of the latitudinal distribution of the dominant surface components. The goal was to get a network of around 400 sites. This corresponds to a compromise between under-representation with too small number of sites and excessive number of sites more difficult to handle. The selection of additional sites was achieved using the following procedure.

- Merge the three networks of sites and retain only one site if several are within less than 20 km distance. In this case,

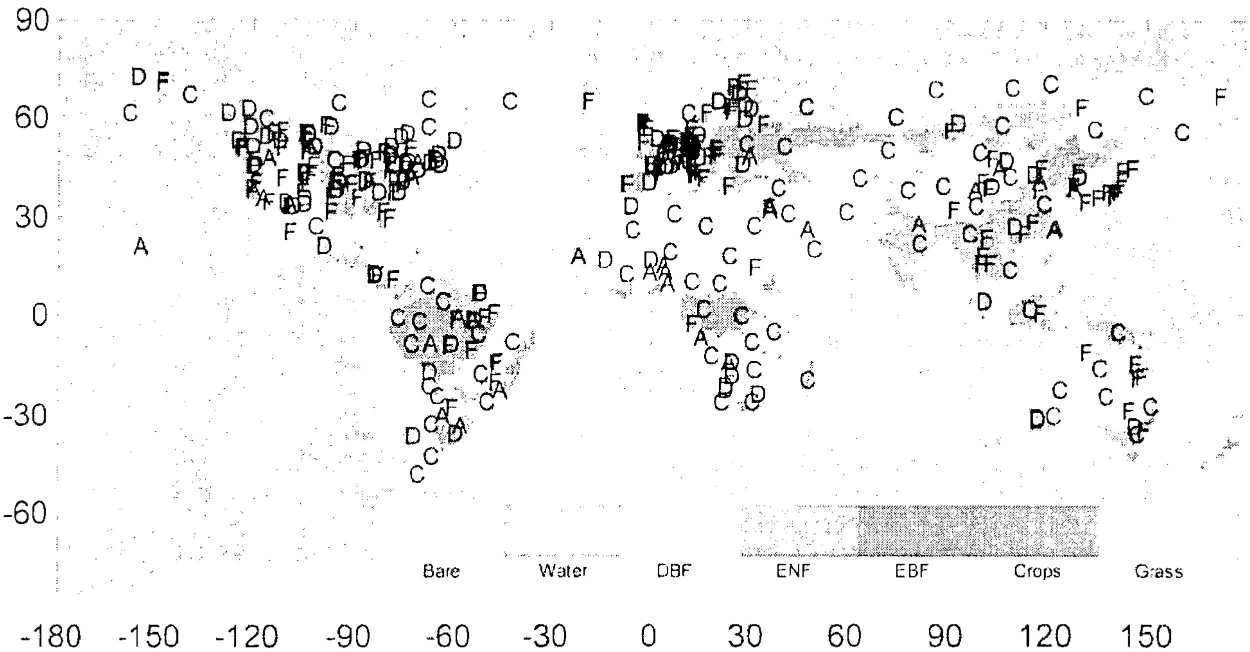

Fig. 3. Distribution of the BELMANIP sites over the Earth. The letters correspond to the location of the sites belonging to DIRECT (D), FLUXNET (F), AERONET (A), and COMPLET (C). Colors correspond to the dominant surface type in the 1° × 1° cell as extracted from ECOCLIMAP.

preference was given to DIRECT, then FLUXNET, and then AERONET sites. This rejection process allows eliminating duplicates between the three networks. This resulted in a total of 295 sites after rejecting 45 that were too close to other sites.

- Select the new sites that will be called COMPLET. When a surface component was undersampled by the 295 sites of the merged networks at a given latitude, additional sites were selected manually on the global map to tend to get evenly distributed sites in space for this surface component. Note that for northern midlatitudes, the merged networks were already slightly overrepresenting the "ideal" distribution. However, additional sites were included to get a better longitudinal distribution for crops and evergreen needleleaf forests that were under-represented at longitudes larger than 20° east.

The addition of the 76 sites "COMPLET" sites to the 295 sites of the three merged networks resulted in the proposed CEOS-BELMANIP network of sites with 371 sites (Fig. 3). The location of the BELMANIP sites appears to be relatively even, except in Europe, North America, and Japan where there is greater density of sites. We note also that few islands belonging either to the AERONET or FLUXNET networks are represented, because the site had more than 75% of the 8×8 km^2 of emerged area.

In the following, the characteristics of this new network of sites will be described.

B. Statistics Associated to CEOS-BELMANIP

The latitudinal distribution of the BELMANIP sites [Fig. 1(e)] still shows a peak for the northern midlatitude. This corresponds to the overrepresentation already noticed for these latitudes. This was therefore only partly compensated for by the addition of the "COMPLET" sites, mainly located outside this latitudinal domain. We note also that all the components are represented over their nominal latitudinal domain.

Although bare surfaces were considered in the BELMANIP network by including a significant fraction of sites in COMPLET, this was not sufficient to get LAI distribution similar to that observed globablly over emerged surfaces. However, if permanently bare surfaces are not considered, the BELMANIP average minimum, mean and maximum values are closer to those of the global distribution [Table II and Fig. 2(e)].

V. Conclusion

The compilation of the sites where LAI and/or fAPAR ground measurements have been performed specifically for the validation of medium-resolution products (the "DIRECT" network) shows that a potential of around 100 sites is available. However, most of them are located in the northern midlatitude, with an under-representation of grass and evergreen broadleaf surfaces. New efforts for the direct validation of satellite land biophysical products should preferentially focus on these surfaces. These direct validation sites are generally sampled close to the maximum leaf development. This represents only a small fraction of the growth cycle, particularly under the northern midlatitude, where seasonality is most pronounced. However, direct validation efforts are very expensive in terms of time and resources. It will therefore not be possible to have more frequent measurements over the season. Consequently, new measurements should probably include some sites sampled outside the LAI peak, where, in addition to the LAI level, different structures could be experienced, particularly regarding the understory dynamics in forest surfaces. Nevertheless, the direct validation efforts should be completed by some spatial and temporal consistency exercises, as well as intercomparison between different products. To be efficient, the intercomparison has to be organized. The CEOS LPV subgroup has proposed to set up a benchmark network of sites that will be the basis of the intercomparison exercise.

In order to make use of possible ancillary information, the network of sites used for the intercomparison should possibly rely on other networks of sites. The representativity of FLUXNET and AERONET networks was thus investigated to possibly complement the direct validation ensemble of sites. Results showed however that FLUXNET (188 sites) and in a lesser way AERONET (52 sites) similarly oversampled the northern midlatitudes and undersampled grass and evergreen broadleaf surfaces. Merging these three networks of sites (295 sites) was therefore not sufficient to get a better representativity of surface type and conditions. These were thus completed by new sites selected in the undersampled latitudes and surface types using an adaptative sampling scheme. The additional 76 sites lead to the BELMANIP network including 371 sites. Although not perfect from the latitudinal and surface type distribution, mainly because of the existing overrepresentation of the northern midlatitude evergreen needleleaf and deciduous broadleaf forests, it provides a minimum sampling of all the surface types at all the latitudes and longitudes. The desert surfaces were also included in the exercise because the LAI is known to be extremely low and very stable, constituting a good test of the robustness of the products in these conditions. The coordinates of the center of each of the 371 BELMANIP sites are available[3] along with the surface type and ECOCLIMAP monthly LAI.

This work was based on the ECOCLIMAP classification which offers a good basis as a first approximation. However, ECOCLIMAP should not be considered as an absolute reference, and even needs improvement that would ultimately come from the compilation and processing of the whole set of land biophysical products available.

This study was focusing on the statistical distribution of the surface types. However, additional tests have also to be conducted to evaluate the robustness of the algorithms under particular conditions where possible problems are expected such as in areas with significant topography, particular landscape patterns, and places with scattered small water bodies.

The intercomparison of products over a consensus benchmark set of sites will indicate a fair level of maturity within the scientific community through CEOS/LPV. It will constitute a solid basis for future improvement of the products. This type of representative network of sites could be used for validation and intercomparison of any biophysical product such as albedo, or chlorophyll content. Ultimately, these sites could be used within a product calibration process, although a different set of sites (or subsites) is required to preserve the independency between the validation and the calibration processes. Together with the direct validation exercise, the intercomparison will provide to the users quantitative evidence of the performances of the products over a very large range of conditions.

To be efficient and transparent, the intercomparison needs a minimum organization. It is thus proposed that the developers of products make their extracts over the BELMANIP sites available at a web address that should be referenced at the CEOS/LPV web site. These extracts should extend to the quality assessment flags associated to the products. Once the location is defined, the extent both in space and time has also to be defined. The area of the extracts for each site should be a good compromise between the resolution of the products to be evaluated and the corresponding amount of data. We thus propose to have sites of 50×50 km^2 that are large enough compared with the coarser resolution considered (close to 8 km) and still allowing additional processing such as "visual" cloud screening, improved registration, spatial pattern comparison, or even selection of additional subsites within the 50×50 km^2 window. The corresponding volume of data is still tractable. The projection system should ideally be also consistent, and it is proposed to use the WGS84/UTM system that would allow a good consistency with the way ground measurements are generally referenced, as well as being an almost equal area projection system for these restricted 50×50 km^2 domains. The temporal extent of the exercise should ideally cover a growth cycle. Because this exercise focuses on the intercomparison of products, a higher priority will be given to the periods where most sensors are operating simultaneously. Year 2003 seems a very good candidate because AVHRR, VEGETATION (SPOT4 and SPOT5), SEAWIFS, MODIS (Terra and Aqua), MISR, MERIS, and (partly) POLDER sensors were all operational. It is thus proposed to extract 50×50 km^2 windows centered over the 371 sites for year 2003. This corresponds obviously to a minimum requirement, and extraction for other periods could yield complementary information.

[3]http://landval.gsfc.nasa.gov/LPVS/lai_intercomp.php

ACKNOWLEDGMENT

The authors would like to thank V. Masson (CNRM, Toulouse, France) for the use of the ECOCLIMAP biome classification database. This work was also supported thanks to the contribution of CNES to the VALERI project, and to the European Commission through the funding of the CYCLOPES project within the 5th framework programme. The authors thank also G. Derive for his participation to the setup of the sites.

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