AIT Series

Trends in earth observation

Volume 1

Earth observation advancements in a changing world

Edited by Chirici G. and Gianinetto M.

Earth observation advancements in a changing world

Edited by

Gherardo Chirici and Marco Gianinetto

AIT Series: Trends in earth observation

Volume 1 - Published in July 2019
Edited by Gherardo Chirici and Marco Gianinetto
Published on behalf of the Associazione Italiana di Telerilevamento (AIT)
Via Lucca 50
50142 Firenze, Italy

ISSN 2612-7148
ISBN 978-88-944687-1-7
DOI: 10.978.88944687/17

All contributions published in the Volume "Earth observation advancements in a changing world" were subject to blind peer review from independent reviewers.

Publication Ethics and Publication Malpractice Statement
Editors, Reviewers and Authors agreed with Publication Ethics and Publication Malpractice Statement

Preface

Since 1986 the Italian Remote Sensing Society (Associazione Italiana di Telerilevamento – AIT) aims to disseminate remote sensing culture, disciplines and applications in Italy. Specifically, AIT's mission is to:

- Create a network of people from Research, Academia and hi-tech Companies interested in analysis, development and application of a wide range of remote sensing methods and techniques;
- Promote and coordinate initiatives to expand the use of remote sensing technologies in Italy and across the European Union;
- Foster the exchange of knowledge and cooperation between its members to "shorten" the chain: research→innovation→new applications/markets→research;
- Support the dissemination of remote sensing methods through the organization of congresses, conferences, working groups, including international thematic courses;
- Represent and take care of scientific and cultural interests in remote sensing for institutions, agencies, companies and similar associations, at national and international level.

Recently, AIT was included in the Italian Copernicus User Forum among the representatives of the IV sector. AIT is also the official Society of the European Journal of Remote Sensing, an open-access scholarly journal published by Taylor & Francis.
Until 1995, AIT was used to organise National Conferences, but in 1997, the Society joined a wider Federal Association (Associazioni Scientifiche per le Informazioni Territoriali e Ambientali - ASITA) related to Cartography, GIS, Topography, Photogrammetry and Remote Sensing, which organises annual national conferences to share and diffuse the Geomatic advancements.

In 2016 AIT decided to bring back its tradition to organize its national conferences with a more distinctive research trait. In addition, always in that year, AIT started to organize its annual International Summer Schools for the exploitation of Copernicus data and programmes.
In this framework, we decided to take the opportunity to create a new book series, officially supported by AIT, entitled *Trends in Earth observation*. These volumes want to present to the readers a snapshot of the state-of-the-art in several different application fields.
I hope that *Trends in Earth observation* can contribute to the scientific progress and the continuous innovation of Earth Observation.

AIT President
Livio Rossi

Contents

Introduction .... **vii**

Remote sensing advancements to support modern agriculture practices **1**

1. Using hyperspectral data to differentiate shade coffee varieties with and without rust and other canopy species 2
N. Corona-Romero, J.M. Madrigal Gómez, M. González-Stefanoni
2. Waiting for "institutional" monitoring services of rice crops by remote sensing: is cadastral parcel the proper reference geometry? 6
G. Corvino, A. Lessio, E. Borgogno Mondino
3. A plot sampling strategy for estimating the area of olive tree crops and olive tree abundance in a mediterranean environment 11
M. Grotti, N. Puletti, F. Chianucci, W. Mattioli, A. Floris, F. Clementel, C. Torresan, M. Marchi, A. Gentile, M. Pisante, A. Marcelli, P. Corona
4. Phenology and yield assessment in maize seed crops using sentinel 2 vis' time series 15
M. Croci, F. Calegari, P. Morandi, S. Amaducci, M. Vincini
5. Use of Sentinel-2 images for water needs monitoring: application on an industrial tomato crop in central Italy 19
B. Rapi, L. Angeli, P. Battista, M. Chiesi, R. Magno, A. Materassi, M. Pieri, M. Romani, F. Sabatini, F. Maselli
6. MODIS EVI time series to assess new oil palm plantation dynamics in Borneo 23
S. De Petris, P. Boccardo, E. Borgogno-Mondino
7. Remote sensing characterization of crop vulnerability to flood 28
T. Pacetti, E. Caporali, M.C. Rulli

Earth observation for monitoring forest resources and environmental processes **32**

8. Tree species classification with Sentinel-2 data in european part of Russia 33
E.A. Kurbanov, O.N. Vorobev, S.A. Menshikov, M.S. Ali
9. A GIS-based assessment of land cover change in an alpine protected area 37
M. Zurlo, B. Bassano, M. Caccianiga
10. Presence of European beech in its spanish southernmost limit characterized with Landsat intra-annual time series 41
C. Gómez, P. Alejandro, I. Aulló-Maestro, L. Hernández, R. Sánchez de Dios, H. Sainz-Ollero, J.C. Velázquez, F. Montes
11. Post-hurricane forest mapping in Bory Tucholskie (northern Poland) using random forest-based up-scaling approach of ALS and photogrammetry- based CHM to KOMPSAT-3 and planetscope imagery 45
P. Wężyk, P. Hawryło, K. Zięba-Kulawik
12. Forest type classification using morphological operators and Forest PA method 49
M. Ustuner, F. B. Sanli, S. Abdikan
13. Using Google Earth Engine for the analysis of fog and forest landscape interactions in hyper-arid areas of southern Peru 53
E. Forzini, G. Castelli, F. Salbitano, E. Bresci
14. Detecting tree hedgerows in agroforestry landscapes 57
F. Chiocchini, M. Ciolfi, M. Sarti, M. Lauteri, M. Cherubini, L. Leonardi, P. Paris
15. Evaluating accurate poplar stem profiles by TLS 61
N. Puletti, M. Grotti, R. Scotti
16. Classification of dominant forest tree species by multi-source very high resolution remote sensing data 65
B. Del Perugia, D. Travaglini, A. Barbati, A. Barzagli, F. Giannetti, B. Lasserre, S. Nocentini, G. Santopuoli, G. Chirici

17. ALS data for detecting habitat trees in a multi-layered mediterranean forest 69
G. Santopuoli, M. Di Febbraro, C. Alvites, M. Balsi, M. Marchetti, B. Lasserre
18. Creating a map of reforestation on abandoned agricultural lands in Mari El republic using satellite images 73
S. A. Lezhnin, R. L. Muzurova
19. Monitoring the growth dynamics of water hyacinth (Eichhornia crassipes) 77
J.F. Mas
20. Long-term comparison of in situ and remotely-sensed leaf area index in temperate and mediterranean broadleaved forests 81
C. Tattoni, F. Chianucci, M. Grotti, R. Zorer, A. Cutini, D. Rocchini
21. Evaluation of the atmospheric upward thermal emission towards SSS retrieval at L Band 85
A.V. Bosisio, G. Macelloni, M. Brogioni
22. Use of Sentinel-1 and Sentinel-3 data to initialize a numerical weather model 88
L. Pulvirenti, M. Lagasio, A. Parodi, G. Venuti, E. Realini, N. Pierdicca

Earth observation for disaster risk and geomorphologic application 93

23. Modelling soil erosion in the Alps with dynamic RUSLE-LIKE MODEL and satellite observations 94
M. Aiello, M. Gianinetto, R. Vezzoli, F. Rota Nodari, F. Polinelli, F. Frassy, M.C. Rulli, G. Ravazzani, C. Corbari , A. Soncini, D.D. Chiarelli, C. Passera, D. Bocchiola
24. Soil degradation mapping using GIS, remote sensing and laboratory analysis in the Oum Er Rbia high basin, middle atlas, Morocco 98
A.El Jazouli, A. Barakat, R. Khellouk, J. Rais
25. UAV application for monitoring the annual geomorphic evolution of a coastal dune in Punta Marina (Italy) 103
E. Grottoli, P. Ciavola, E. Duo, A. Ninfo
26. Thermographic characterization of a landfill trough an Unmanned Aerial Vehicle 108
F. Capodici, G. Dardanelli, M. Lo Brutto, A. Maltese
27. UAV digital photogrammetric analysis for soil erosion evaluation in the Rivo catchment: preliminary results 114
A. Minervino Amodio, P.P.C. Aucelli, G. Di Paola, V. Garfi, M. Marchetti, C.M. Rosskopf, S. Troisi
28. Exploitation of GNSS for calibrating space-borne SAR for the study of landsubsidence 118
G. Farolfi, M. Del Soldato, S.Bianchini, N. Casagli
29. Contribution of spatial multi-sensor imagery to the cartography of structural lineaments: case study of the paleozoic massif of Rehamna (moroccan Meseta) 122
I. Serbouti, M. Raji, M. Hakdaoui

Use of remote sensing for water management and protection 126

30. COSMO-Skymed space data supporting disaster risk reduction 127
F. Lenti, M.L. Battagliere, M. Virelli, A. Coletta
31. The use of remote sensing for water protection in the karst environment of the tabular middle Atlas/the causse of El Hajeb/Morocco 131
A. Muzirafuti, M. Boualoul, G. Randazzo , S. Lanza, A. Allaoui, H. El Ouardi, H. Habibi, H. Ouhaddach
32. Analysis of floods, urbanization and morphometry of watersheds in Santo André-Brazil 135
J. Gueiros Fusato, M.C. Valverde
33. Detection of water bodies using open access satellite data: the case study of Kastoria lake in north-western Greece 139
A. Karagianni
34. A comparison between UAV and high-resolution multispectral satellite images for bathymetry estimation 143
L. Rossi, I. Mammi, E. Pranzini
35. Analysis of water bodies under partial cloud conditions using satellite images 147
R. Neware, M. Thakare, U. Shrawankar
36. Estimating vulnerability of water body using Sentinel-2 images and predictive

eutrophication models: the study case of Bracciano lake (Italy) 151
C. Giuliani, M. Piccinno, A. Veisz, F. Recanatesi

Coastal monitoring by remote sensing 156

37. Proneness to future marine inundation of Campania coastal plains (southern Italy) in relation to their subsidence trends assessed by Interferometric SAR techniques 157
G. Di Paola, P.P.C. Aucelli, F. Matano, A. Rizzo
38. Laser scanner and multibeam integrated survey for the assesment of rocky sea cliff geomorphological hazard 162
S. Guida, N. Corradi, B. Federici, A. Lucarelli, P. Brandolini
39. Shoreline changes at Sant'Agata river mouth (Reggio Calabria, Italy) 167
G. Barbaro, G. Bombino, V. Fiamma, G. Foti, P. Puntorieri, F. Minniti C. Pezzimenti
40. Earth observation as an aid to coastal water monitoring: potential application to harmful algal bloom detection 171
C. Lapucci, S. Taddei, B. Doronzo, M. Fattorini, S. Melani, G. Betti, F. Maselli, A. Ortolani, B. Gozzini, C. Brandini
41. Integrating remote sensing data for the assessments of coastal cliffs hazard: MAREGOT project 176
G. Deiana, M. T. Melis, A. Funedda, S. Da Pelo, M. Meloni, L. Naitza, P. Orrù, R. Salvini, A. Sulis
42. Coastal monitoring through field and satellite data 181
M.Perna, G. Vitale, C. Brandini, E. Pranzini, B. Gozzini

Application of remote sensing in urban environments...186

43. Remote sensing and urban metrics: an automatic classification of spatial configurations to support urban policies 187
E. Barbierato, I. Bernetti, I. Capecchi, C. Saragosa
44. Remote sensing of the urban heat island with different spatial and temporal resolutions: analysis by MODIS and LANDSAT imagery 191
S. Bonafoni, C. Keeratikasikorn
45. Building footprint extraction from VHR satellite imagery using a Deep Learning approach 195
C. Sandu, S. Ghassemi, A. Fiandrotti, F. Giulio Tonolo, P. Boccardo, G. Francini, E. Magli
46. An integration of VHR OPTICAL and RADAR multiscale images processing data and geographical information system applied to a geo-archeological reconstruction in the Ferrara area 199
L. Damiani, F. Immordino, E. Candigliota
47. Multitemporal landscape pattern analysis: a quantitative approach to support sustainable land management 203
G. Chirici, P. Rossi, D. Fanfani, D. Poli, M. Rossi, B. Mariolle

LONG-TERM COMPARISON OF *IN SITU* AND REMOTELY-SENSED LEAF AREA INDEX IN TEMPERATE AND MEDITERRANEAN BROADLEAVED FORESTS

C. Tattoni[1,2*], F. Chianucci[3], M. Grotti[4], R. Zorer[2], A. Cutini[4], D. Rocchini[1,2]

[1] University of Trento, Trento, Italy - clara.tattoni@gmail.com, duccio.rocchini@unitn.it
[2] Research and Innovation Centre, Fondazione Edmund Mach, San Michele all'Adige, Trento, Italy - roberto.zorer@fmach.it
[3] CREA, Research Centre for Agriculture and Environment, Rome, Italy – f.chianucci@gmail.com
[4] CREA, Research Centre for Forestry and Wood, Arezzo, Italy - andrea.cutini@crea.gov.it, mirkogrotti@gmail.com

KEY WORDS: Forest canopy, MODIS, LAI-2000/2200, time-series

ABSTRACT:

Monitoring vegetation structure and functioning is critical for modelling terrestrial ecosystems and energy cycles. Leaf area index (LAI) is an important structural property of vegetation used in many land-surface, climate, and forest monitoring applications. Remote sensing provides a unique way to obtain estimates of leaf area index at spatially extensive areas. However, the analysis and extraction of quantitative information from remotely-sensed data require accurate cross-calibration with *in situ* forest measurements, which are generally spatially- and temporally-limited, thereby limiting the ability to compare the seasonal dynamic patterns between field and remotely-sensed time series. This is particularly relevant in temperate broadleaved forests, which are characterized by high level of complexity, which can complicate the retrieval of vegetation attributes from remotely-sensed data.
In this study, we performed a long-term comparison of MODIS LAI products with continuous *in situ* leaf area index measurements collected monthly in temperate and Mediterranean forests from 2000 to 2016. Results indicated that LAI showed a good correlation between satellite and ground data for most of the stands, and the pattern in seasonal changes were highly overlapping between the time-series. We conclude that MODIS LAI data are suitable for phenological application and for up-scaling LAI from the stand level to larger scales.

1. INTRODUCTION

Monitoring forest structure and functioning is critical for understanding changes in forest coverage and health in response to management and climate, and for modelling terrestrial carbon and energy cycles. Remote sensing provides a unique way to obtain estimates of forest attributes at spatially extensive areas, from local to the global scale. In addition, the availability of standardized information over time allows to make projections under different forest management and climate change scenarios (Ciolli et al., 2012, Ferretti et al., 2018, Ciolli et al., 2018).
Among the measured variable, leaf area index (LAI), defined as half the total green leaf area per unit ground surface area (Chen and Black, 1992), is an important structural property of vegetation used in many land-surface, climate, and monitoring programs. LAI directly influences the radiative transfer of sunlight in vegetation, determining the amount of radiation measured by optical (passive) remotely-sensed sensors in the visible and infrared portions of the electromagnetic spectrum (Asnar et al., 1984; Zhen and Moskal, 2009).
Optical remote sensing of leaf area index requires accurate calibration with *in situ* measurements (Boer et al. 2008; Prospatin and Panferov, 2013; Xu et al., 2018). This is particularly relevant in temperate and Mediterranean forests, which are characterized by high level of complexity, which can complicate the retrieval of vegetation attributes from optical remotely-sensed sensors (Angelini et al. 2015; Leroux et al., 2018; Munier et al., 2018; Puletti et al., 2018). However, *in situ* datasets are mainly available in boreal forests (e.g., Kuusk et al., 2009) and austral forests (e.g., Woodgate et al., 2015), while such datasets in temperate and Mediterranean forests are scarce. In addition, the majorities of previous studies build relationships exploiting *in situ* measurements performed in a single period (typically a single field campaign), since the availability of long-term ground-truth data series has been limited by the cost and time required by field sampling. The operational Moderate Resolution Imaging Spectroradiometer (MODIS) sensors have provided an opportunity for opening a new horizon of satellite LAI products (Myneni et al., 2015). The latest version (Collection 6, C6) provides continuous LAI data since 2000. To date, no previous studies have performed a comprehensive temporal investigation of LAI time series, since the preliminary evaluations were temporally limited (Xu et al., 2018).
In this study, we performed a long-term comparison between MODIS LAI products with continuous *in situ* leaf area index measurements collected in temperate and Mediterranean forests from 2000 to 2016. Our specific objectives were:
- Evaluate the temporal consistency of (latest) MODIS LAI product along its operational range;
- Checking the ability of MODIS to detect trend, intra-annual variations, seasonal cycle of LAI as compared with *in situ* measurements in Mediterranean and temperate forests
- Evaluate the applicability of MODIS LAI products at the forest stand scale.

2. MATERIAL AND METHODS

2.1 Study area

The data have been collected within the framework of a wider project (LIFE 14 ENV/IT/000514 "FutureForCoppiceS"; www.futureforcoppices.eu) aimed to demonstrate the effect of different management options on sustainable forest management criteria and indicators in temperate and Mediterranean coppice forests. In the project, 45 stands were surveyed in seven forest districts located in two Italian regions (Sardinia and Tuscany) the area sampled was on average about 2800 m² (800-10000 m²) . Thirteen stands located in Tuscany were amongst selected to be included in this study due to their larger temporal availability of leaf area index data and extent comparable with MODIS resolution. The stands are located in large homogeneous forest stand areas and are representative of two European Forest Types (EFT; Barbati et al., 2014): thermophilus deciduous forests

* Corresponding author

dominated by Turkey oak (*Quercus cerris* L.) (EFT 8.2) and mountainous beech (*Fagus sylvatica* L.) forests (EFT 7.3). The data are available from an open repository (Chianucci et al., 2018). Table 1 lists the characteristics of the studied stands.

Forest district	EFT	Stand density n ha^{-1}	Basal area m^2 ha^{-1}
Alpe di Catenaia	7.3	412	29.77
Alpe di Catenaia	7.3	2046	48.15
Alpe di Catenaia	7.3	419	39.45
Alpe di Catenaia	7.3	108	19.9
Alto Tevere	8.2	436	20.21
Alto Tevere	8.2	1222	33.26
Colline Metallifere	8.2	4509	30.17
Colline Metallifere	8.2	54	1.37
Colline Metallifere	8.2	682	16.31
Foresta di Caselli	8.2	2667	38.89
Foresta di Caselli	8.2	2167	44.11
Foresta di Caselli	8.2	3417	41.66
Foresta di Caselli	8.2	2922	42.67

Table 1. Main characteristics of the studied stands

2.2 *In situ* leaf area index

LAI measurements were performed monthly every year, from 1999 to 2016, in the studied stands, just after dawn or close to sunset and under uniform sky conditions using the LAI-2000. Plant Canopy Analyzer (LI-COR, Lincoln, NE, USA). The optics of LAI-2000 consists of a fisheye lens divided into five concentric rings. Each ring simultaneously integrates incoming radiation in the 320 - 490 nm wavelength (blue light) range.

During each sampling session, one above-canopy reference measurement was recorded in clearings near each stand. Nine to 15 below-canopy measurements were then collected for each stand. The fisheye lens of the instrument was covered by a 90° view cap to avoid the influence of surrounding trees on the reference measurements. Gap fraction was estimated as the fraction of below- to above-canopy readings. Leaf area index corrected for apparent clumping (Ryu et al., 2010) was then calculated using the Miller's (1967) theorem.

2.3 Remotely sensed leaf area index

Remotely sensed LAI measurements for the studied stands were obtained from the MODIS sensor (Moderate Resolution Imaging Spectroradiometer) available on Terra and Aqua satellites, formerly known as EOS AM-1 and EOS PM-1.

MODIS Land Products Subset MOD15A2 was chosen because it provided readily available 8-day composite LAI measurements starting from the year 2000 to present. Data were downloaded from the Distributed Active Archive Center (ORL DAAC, 2018). Data were downloaded for a window of 7x7 km centered on the forest district average coordinates with a resolution of 1km (Myneni, et al., 2015).

2.4 Statistical analyses

Data were processed in R environment (R Core Team 2015). First, the time-series alignment between field and remote sensed data was performed using the 'eXtensible' package (Ryan and Ulrich 2017) and interpolation for missing data. The data were then checked for cross-correlation using the 'CCF' function of the 'nlme' package (Pinheiro and Bates, 2017). CCF was run also on the difference between LAI value at time t and the previous value at time *t-1* to account for the correlation about the direction of change rather than considering the absolute values. A paired T test was then performed to assess the difference in the two time-series for both absolute values and differences between subsequent times, using a significant threshold of $p<0.01$.

3. RESULTS

The studied stands were characterized by relatively-high canopy density, as indicated by the high LAI values observed in summer (vegetation-peak period). Field measurements yielded LAI values ranging between 0.75 and 6.73 in beech stands (average ± standard deviation: 4.4 ± 1.6) and between 0.33 to 7.97 in thermophilous oak stands (3.5 ± 1.1) considering all the seasonal data series. MODIS LAI values ranged between 0.10 and 5.66 in beech stands (4.3 ± 1.2) and ranged between 0.10 to 6.37 in thermophilous oak stands (4.01 ± 1.3).

The analysis was performed for separate districts where the starting year of sampling and the number of field LAI measurements was (brackets): Alpe di Catenaia (1999, 298), Alto Tevere (1999, 178), Colline Metallifere (1999, 259) and Foresta di Caselli (1999, 255). Results showed a significant agreement in trend between field and remotely sensed data considering either the aligned data series (Figure 1) and the data averaged on monthly basis (Figure 2) in the considered forest district ($p<0.01$), with the exception of Foresta di Caselli ($p=0.089$, thermophilous oak forests) and Alpe di Catenaia ($p=0.14$, mountainous beech forests) districts, where the alignment was not significant.

The CCF analysis showed a significant agreement between field and remotely-sensed LAI values (T test) meaning that the LAI changed in the same direction in both types of measurements.

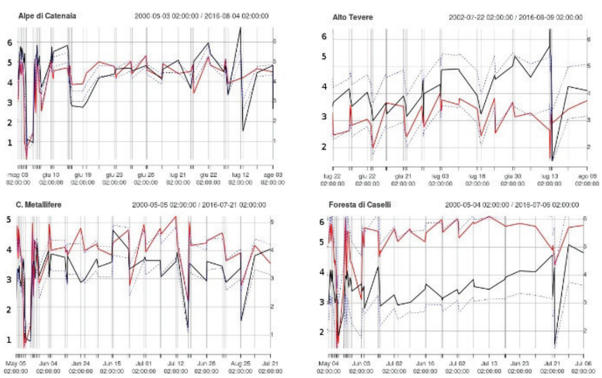

Figure 1 Aligned time series for field (black) and remotely sensed (red) LAI measurements with 95% confidence intervals (blue dashed lines) in the following districts: a) Alpe di Catenaia, b) Alto Tevere, c) Colline Metallifere and d), Foresta di Caselli, Italy.

4. DISCUSSION AND CONCLUSIONS

The main results imbue confidence in the consistency of long-term MODIS LAI time series. The advantage of MODIS products is its large temporal and spatial resolution, which has often been used for large scale studies on LAI across biomes (Weiss et al., 2007). Our results also indicated that MODIS LAI products can be used for medium spatial scale (forest stand level) applications, based on the agreement between satellite and field measurements. The repeated seasonal field measurements also allowed to verify that MODIS LAI can capture the seasonality pattern of LAI at the stand scale, as the speed and sign of change are comparable between field and satellite time-series data.

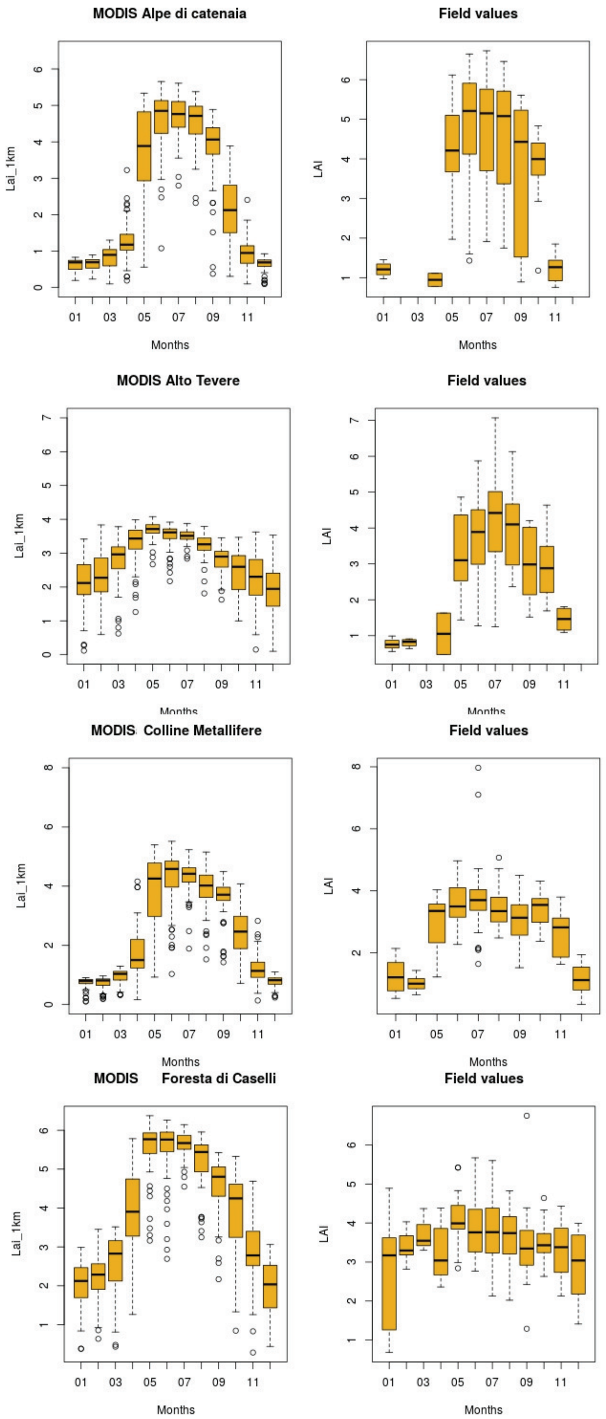

Figure 2 Average monthly values (2000-2016) of LAI measured from MODIS (left) and LAI measured on site (right) for each district, from top to bottom: Alpe di Catenaia, Alto Tevere, Colline Metallifere and Foresta di Caselli, Italy.

While consistent with another study performed in an open canopy stand (Ryu et al., 2012), the results extend the applicability of MODIS LAI in temperate and Mediterranean forests, which are often characterized by very high canopy density (LAI>5 m^2 m^{-2}, Alivernini et al., 2018; Cinnirella et al., 2002; Thimonier et al., 2010; this study) which can limit the retrieval of optical information from satellite data. Indeed, optical measures often saturate at leaf area index values of about 5 (Thenkabail et al., 2000), while vegetation indices using near-infrared bands may saturate at lower values (Davi et al., 2006; Turner et al., 1999). In addition, Mediterranean forests exhibits different phenological patterns according to forest categories and types, and therefore accurate temporal resolution data are strongly required for discriminating different forest types in these environments. Taken together, results indicated that temporal MODIS LAI are suitable for modelling and up-scaling LAI from the stands to larger areas. The discrepancy in the average of LAI measurements from the two sources, which can be observed in some points of the series, can be explained by the different spatial resolution of the data (Rocchini 2007, Geri et al., 2011, Xu et al., 2018). MODIS LAI has the resolution of 1 km, and despite the field measurements were taken in stands that are representative of the surroundings, the above-mentioned limits in measures taken in temperate forest is compatible with the observed pattern. We conclude that the availability of long time-series satellite products with quick revisiting time enabled a reliable investigation of seasonal patterns dynamics, which can support finer application on forests ecology and management and phenological monitoring.

ACKNOWLEDGEMENTS

Financial support was provided by the EU LIFE Project "Shaping future forestry for sustainable coppices in southern Europe: the legacy of past management trials" - LIFE FutureForCoppiceS (LIFE14 ENV/IT/000514). The MOD15A2 was retrieved from the online MODIS/VIIRS Subsetting and Visualization services at https://modis.ornl.gov, courtesy of the NASA EOSDIS Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota, https://eros.usgs.gov.

REFERENCES

Alivernini, A., Fares, S., Ferrara, C., Chianucci, F., 2018. An objective image analysis method for estimation of canopy attributes from digital cover photography. Trees 32, pp. 713-723.

Angelini, A., Corona, P., Chianucci, F., Portoghesi, L., 2015. Structural attributes of stand overstory and light under the canopy. Annals of Silvicultural Research, 39: 23-31 doi: 10.12899/ASR-993.

Asrar, G.Q., Fuchs, M., Kanemasu, E.T., Hatfield, J.L., 1984. Estimating Absorbed Photosynthetic Radiation and Leaf Area Index from Spectral Reflectance in Wheat 1. Agronomy journal, 76(2), pp. 300-306.

Barbati, A., Marchetti, M., Chirici, G., Corona, P., 2014. European forest types and forest Europe SFM indicators: tools for monitoring progress on forest biodiversity conservation. Forest Ecology and Management, 321, pp. 145-157.

Boer, M.M., Macfarlane, C., Norris, J., Sadler, R.J., Wallace, J., Grierson, P.F., 2008. Mapping burned areas and burn severity patterns in SW Australian eucalypt forest using remotely-sensed changes in leaf area index. Remote Sens. Environ. 112, pp. 4358-4369.

Brus, D., Hengeveld, G. M., Walvoort, D. J. J., Goedhart, P. W., Heidema, A. H., Nabuurs, G. J., Gunia, K., 2011. Statistical mapping of tree species over Europe. European Journal of Forest Research, 131, pp. 145-157.

Chen, J.M., Black, T.A., 1992. Defining leaf area index for non-flat leaves. Plant Cell Environ. 15, pp. 421-529.

Chianucci, F., Ferrara, C., Bertini, G., Fabbio, G., Tattoni, C., Rocchini, D., Corona, P., Cutini, A., 2018. Multi-temporal dataset of stand and canopy structural data in temperate and Mediterranean coppice forests. Mendeley Data, v1, [Dataset] http://dx.doi.org/10.17632/z8zm3ytkcx.1

Ciolli M., Tattoni C., Ferretti F., 2012 Understanding forest changes to support planning: A fine-scale Markov chain approach. Developments in Environmental Modelling 25 pp 355-373

Ciolli M., Bezzi M., Comunello G., Laitempergher G., Gobbi S., Tattoni C., Cantiani M. 2018. Integrating dendrochronology and geomatics to monitor natural hazards and landscape changes. Applied Geomatics, DOI:10.1007/s12518-018-0236-0

Cinnirella, S., Magnani, F., Saracino, A., Borghetti, M., 2002. Response of a mature *Pinus laricio* plantation to a three-year restriction of water supply: structural and functional acclimation to drought. Tree Physiology 22(1), pp. 21-30.

Davi, H., Soudani, K., Deckx, T., Dufrene, E., Le Dantec, V., Francois, C., 2006. Estimation of forest leaf area index from SPOT imagery using NDVI distribution over forest stands. International Journal of Remote Sensing 27, pp. 885–902.

Geri F., Amici V., Rocchini D., 2011. Spatially-based accuracy assessment of forestation prediction in a complex Mediterranean landscape. Applied Geography, 31 (3) pp881-890

Ferretti F., Sboarina C., Tattoni C., Vitti A., Zatelli P., Geri F. Pompei E., Ciolli M., 2018. The 1936 Italian Kingdom Forest Map reviewed: a dataset for landscape and ecological research. Annals of Silvicultural Research, 42(1) pp 3-19 doi: 10.12899/asr-1411

Kuusk, A., Kuusk, J., Lang, M., 2009. A dataset for the validation of reflectance models. Remote Sensing of Environment, 113(5), pp. 889-892.

Leroux, D., Calvet, J.C., Munier, S. and Albergel, C., 2018. Using Satellite-Derived Vegetation Products to Evaluate LDAS-Monde over the Euro-Mediterranean Area. Remote Sensing, 10(8), p. 1199.

Miller, J.B., 1967. A formula for average foliage density. Australian Journal of Botany 15, pp. 141-144.

Munier, S., Carrer, D., Planque, C., Camacho, F., Albergel, C. and Calvet, J.C., 2018. 17 years. Remote Sensing, 10(3), p. 424.
Myneni, R., Knyazikhin, Y., Park, T., 2015. MOD15A2H MODIS Leaf Area Index/FPAR 8-Day L4 Global 500m SIN Grid V006. NASA EOSDIS Land Processes DAAC. http://doi.org/10.5067/MODIS/MOD15A2H.006 (Terra).

ORNL DAAC, Oak Ridge National Laboratory, Distributed Active Archive Center, 2008. Modis collection 5 land products global sub-setting and visualization tool. ORNL, Tennessee, USA. Accessed November 03, 2016. Subset obtained for MOD15A2 product at 43.2152N,10.6864E, 43.7423N,12.045E, 42.6492N,11.1022E, 39.2713N, 9.4299E, 39.0505N,8.837E time period: 2000-02-18 to 2016-10-15, and subset size: 7x7 km.
Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D., R Core Team, 2017. _nlme: Linear and Nonlinear Mixed Effects Models_. R package version 3.1-131, https://CRAN.R-project.org/package=nlme

Prospatin, P., Panferov, O., 2013. Retrieval of remotely sensed LAI using Landsat ETM+ data and ground measurements of solar radiation and vegetation structure: Implication of leaf inclination angle. Int. J. Appl. Earth. Obs. Geoinf. 25, pp. 38-46.

Puletti, N., Chianucci, F., Castaldi, C., 2018. Use of Sentinel-2 for forest classification in Mediterranean environments. Annals of Silvicultural Research 42, pp. 32-38 http://dx.doi.org/10.12899/asr-1463

R Core Team, 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Rocchini D., 2007. Effects of spatial and spectral resolution in estimating ecosystem α-diversity by satellite imagery. Remote sensing of Environment, 111(4) pp 423-434

Ryan, J.A., Ulrich, J.M., 2017. xts: eXtensible Time Series. R package version 0.10-0. https://CRAN.R-project.org/package=xts

Ryu, Y., Nilson, T., Kobayashi, H., Sonnentag, O., Law, B.E., Baldocchi, D.D., 2010. On the correct estimation of effective leaf area index: Does it reveal information on clumping effects? Agric. For. Meteorol. 150, pp. 463-472.

Ryu, Y., Verfaillie, J., Macfarlane, C., Kobayashi, H., Sonnentag, O., Vargas, R., Ma, S. and Baldocchi, D.D., 2012. Continuous observation of tree leaf area index at ecosystem scale using upward-pointing digital cameras. Remote Sensing of Environment, 126, pp. 116-125.

Thenkabail P.S., Smith R.B., De Pauw E., 2000. Hyperspectral vegetation indices and their relationships with agricultural crop characteristics. Remote Sensing of Environment 71, pp. 158-182.

Thimonier A., Sedivy I., Schleppi P., 2010. Estimating leaf area index in different types of mature forest stands in Switzerland: a comparison of methods. European Journal of Forest Research 129, pp. 543-562.

Turner P.D., Cohen W.B., Kennedy R.E., Fassnacht K.S., Riggs J.M., 1999. Relationships between leaf area index and Landsat TM spectral vegetation indices across three temperate zone sites. Remote Sensing of Environment 70, pp. 52–68.

Weiss, M., Baret, F., Garrigues, S. and Lacaze, R., 2007. LAI and fAPAR CYCLOPES global products derived from VEGETATION. Part 2: validation and comparison with MODIS collection 4 products. Remote sensing of Environment, 110(3), pp. 317-331.

Woodgate, W., Disney, M., Armston, J.D., Jones, S.D., Suarez, L., Hill, M.J., Wilkes, P., Soto-Berelov, M., Haywood, A., Mellor, A., 2015. An improved theoretical model of canopy gap probability for Leaf Area Index estimation in woody ecosystems. Forest Ecology and Management, 358, pp. 303-320.
Xu, B., Park, T., Yan, K., Chen, C., Zeng, Y., Song, W., Yin, G., Li, J., Liu, Q., Knyazikhin, Y., Myneni, R.B., 2018. Analysis of Global LAI/FPAR Products from VIIRS and MODIS Sensors for Spatio-Temporal Consistency and Uncertainty from 2012–2016. Forests, 9(2), p.73.

Zheng, G. and Moskal, L.M., 2009. Retrieving leaf area index (LAI) using remote sensing: theories, methods and sensors. Sensors, 9(4), pp. 2719-2745.