COVER LETTER

bg-2014-318

Dear Dr. Micol Rossini,

first of all, we would like to thank you and the reviewers for the valuable comments and remarks.

With this writing we submit a revised version of our paper for publication in BG. The paper was substantially revised according to the reviewer comments. In particular, we included additional validation data to demonstrate the robustness of our findings, validated our findings using cross-validation methods and added a new analysis based on a Genetic Algorithm in combination with Random Forest in order to complement the correlation analysis. The introduction of this new section required adding a new co-author, Enrico Tomelleri, who did the corresponding analysis.

In summary, we were thus able to address all reviewer comments in the revised manuscript and hope that the manuscript is now acceptable for publication in BG.

All main changes relative to the previous version of the manuscript are detailed in the pdf of the new manuscript (**IN RED** for reviewer 1, **IN BLUE** for reviewer 2 and in **GREEN** for both). All technical and grammar corrections are included in the revised version of the manuscript.

The authors’ response to the comments of reviewer 1 & 2 are enclosed.

Main changes:

Text

Abstract: this part was revised according to the new results.

Introduction: as asked by Reviewer #2 the introduction was restructured and rewritten in order to more clearly show the objectives of the paper. Moreover, we gave a general description of the use of the hyperspectral methods for studying all ecosystems without focusing on grasslands. A comprehensive review of analytical approaches of hyperspectral reflectance (e.g. vegetation indices, statistical methods and radiative transfer models) was also added to the introduction.

Section 2.1 "Experimental site description": details on the sites used for the validation were added in this section.

Section 2.2 "Hyperspectral reflectance measurements": this section was rewritten by describing in detail the hyperspectral measurements as asked by Reviewer #1.

New section 2.3 "Biophysical and biochemical canopy properties": this new section contains the description of the biophysical variables sampled during the hyperspectral field campaigns. These data were used to explore the basis of the model selected for each band combination and for each ecophysiological parameter.

Section 2.3 renamed as 2.4 "CO_2 flux measurements": this section was rewritten including details on fluxes measurements (e.g. system set-up, data processing) as asked by Reviewer #1. The Table 1 cited in this section was accordingly updated (see comment below in the Table section). In addition the new Table 2 containing the description of the flux measurements at the validation sites was added (see comment below in the Table section).

Section 2.5 renamed as 2.6 "Hyperspectral data analysis" revised by adding at the end of this section a new part on the validation of the models found for the selected bands.

New section 2.7 "Band selection based on the combination of random forests and genetic algorithm (GA–rF)": this new section was written to explore the use of a new method, the genetic algorithm, to select the bands.

Results: this section was revised according to the new results, revised figures and tables. The following new sections were added at the end of this part:

New section 3.4 “Evaluation of the model performance”: this section reports the results of the cross-validation methods.

New section 3.5 “Effect of the canopy structure on selected band combinations”: this section shows the results of the correlation analysis between the selected bands and the biophysical variables (i.e. dry phytomass, nitrogen and water content).

New section 3.6 “Band selection using GA-rF method”: this section reports the results of the combination of genetic algorithm and random forest analysis.

Discussion: this part was substantially changed by separating the discussion in the two following main parts: “*Up-scaling of in-situ relationships between VI indices and CO_2 fluxes* and ecophysiological parameters” and “*Grassland structural characteristic and their spectral response*”.

Conclusions: this part was revised according to the new results.

Tables

Table 1 revised by adding new details on the eddy covariance systems and data acquisition and processing.

New Table S2 in the supplemental section with the description of the characteristics of the sites used in the validation was added.

Table 2 was revised. As asked by Reviewer #1 CI was moved in the block of simple ratio indices and was defined as: CI= (R750/R720) – 1. The reference was changed to Gitelson et al. (2005). Red-edge NDVI was added to the block of normalized different vegetation indices and was defined as: Red-edge NDVI = (R750–R720)/ (R750+R720) (Gitelson and Merzlyak (1994).

Table 3 was revised. The rows containing the results for exponential regression model and the columns corresponding to AIC values were removed from this table. The results related to Red-edge NDVI and revised CI were added to this table. The table caption was modified accordingly.

Table 4 was revised. The rows containing the results for exponential regression model and the columns corresponding to AIC values were removed from the table. The results related to Red-edge NDVI and revised CI were added to this table. The table caption was modified accordingly.

New Table 5 with the results the correlation analysis between the best band combinations and biophysical variables (i.e. dry phytomass, nitrogen and water content) for α, GPP_{max}, midday GPP, midday ε and midday NEE.

New Table S3 with the results the correlation analysis between the best band combinations and biophysical variables (i.e. dry phytomass, nitrogen and water content) for daily averaged GPP, ε and NEE.

Table S1 in the supplemental was revised. The rows containing the results for exponential regression model and the columns corresponding to AIC values were removed from the table. The results related to Red-edge NDVI and revised CI were added to this table. The table caption was modified accordingly.

Figures

Figure 1 was revised and the masked correlogram in the right panel of the figure was eliminated. The position on the Red-edge NDVI was added and the position of CI modified following the definition reported in the Table 2. The size of text was enlarged. The definitions of the VI abbreviations were included in the caption.

Figure 2 was revised by changing the values of α, GPP_{max} and GPP parameters derived by new CO_2 fitting method based on new thresholds for u_*.

Figure 4 was replaced by Figure S1 in the supplemental.

Figure 5 was replaced by the new figure with the square shape of the band combinations for SR-type indices.

Figure 6 was replaced by Figure S3 in the supplemental.

Figures 7 to 10 were removed.

New Figure 7 with the results of linear correlation analysis for α, GPP_{max} and midday averaged GPP, ε and NEE and selected best NSD-type indices.

New Figure 8 with the results of validation of linear regression models between α, ε (midday average), GPP_{max} and midday average CO_2 fluxes (NEE and GPP) and NSD-, SR-, SD-type indices.

New Figure 9 with correlation between selected NSD-, SR- and SD-type indices and the total chlorophyll content for α, ε (midday average), GPP_{max} and midday average CO_2 fluxes (NEE and GPP) for Monte Bondone in 2013.

New Figure 10 with results of the GA-rF method for band selection for Amplero, Neustift , Monte Bondone and all sites pooled for midday and daily ecophysiological parameters, fluxes and biophysical variables (i.e. dry phytomass, nitrogen and water content).

Figures S1 to S3 in the supplemental section were removed.

Figures S7 to S9 in the supplemental section were removed.

Figures S10 to S14 in the supplemental section were removed.

Figure S4 in the supplemental section was renamed in Figure S1.

Figure S5 in the supplemental section was replaced by the new figure with the square shape of the band combinations for SR-type indices.

Figure S6 in the supplemental section was renamed in Figure S3.

New Figure S4 with the results of linear correlation analysis for daily averaged GPP, ε and NEE and selected best NSD-type indices.

New Figure S5 with the results of linear correlation analysis for daily averaged GPP, ε and NEE and selected best SR-type indices.

New Figure S6 with the results of linear correlation analysis for daily averaged GPP, ε and NEE and selected best SD-type indices.

New Figure S9 with the results of validation of linear regression models between daily averaged ε and CO_2 fluxes (NEE and GPP) and NSD-, SR-, SD-type indices.

New Figure S10 with correlation between selected NSD-, SR- and SD-type indices and the total chlorophyll content for daily average ε and CO_2 fluxes (NEE and GPP) for Monte Bondone in 2013.

Figure/Table captions

The caption of **Figure 1** was modified by adding the definitions of the VI abbreviations as suggested by Reviewer #1.

The caption of the **Table 3** was modified accordingly to the revision.

The caption of the **Table 4** was modified accordingly to the revision.

The caption of the **Table S1 in the Supplemental section** was modified accordingly to the revision.

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Zarco-Tejada, P. J., Rueda, C. A., and Ustin, S. L.: Water content estimation in vegetation with MODIS reflectance data and model inversion method, Remote Sens. Env., 85, 109–124, 2003.

The following reference was eliminated from the text:

Akaike, H.: Information theory and an extension of the maximum likelihood principle, in: Proceedings of the Second International Symposium on Information Theory, edited by: Petrov, B. N. and Csaki, F., Akademiai Kiado, Budapest, 267–281 (Reproduced in: Breakthroughs in Statistics, edited by: Kotz, S. and Johnson, N. L., 2003), Vol. I, Foundations and Basic Theory, Springer-Verlag, New York, 610–624, 1973.

The following reference was updated:

Sakowska, K., Vescovo, L., Marcolla, B., Juszczak, R., Olejnik, J., and Gianelle, D.: Monitoring of carbon dioxide fluxes in a subalpine grassland ecosystem of the Italian Alps using a multispectral sensor, Biogeosciences, 11, 4695-4712, doi:10.5194/bg-11-4695-2014, 2014.

Interactive comment on "On the relationship between ecosystem-scale hyperspectral reflectance and CO_2 exchange in European mountain grasslands" by M. Balzarolo et al.

Anonymous Referee #1
Received and published: 17 July 2014

General comments:
This manuscript uses hyperspectral data to identify spectral regions that can be used to estimate biophysical characteristics of three grassland sites in Europe using three simple types of vegetation indices. The models are very simplistic considering the complexity of the BPCs examined, i.e. Gross Primary Production (GPP). Most approaches to estimate GPP use multiple inputs, thus, the approach in this study to estimate GPP using VIs developed by all possible band combinations performed poorly across all three sites. While non-linear relationships with BPCs and VIs may produce low error estimates in calibration, they perform poorly when validated, especially when applied to sites not included in the validation. The study should focus on the linear models and provide readers a sense of stability of the bands selected by using a calibration/validation or cross-validation approach. The authors have a rich data set that can be very beneficial to the scientific community; however, the approach to analyze this data needs improvement. Other smaller issues include (1) a very weak methods section that did not provide enough detail regarding the data collection, (2) poor presentation of the results in complicated tables and figures, and (3) needless duplication of figures in the supplemental that could be presented in the manuscript.

The authors thank the anonymous reviewer #1 for his/her constructive comments and the helpful suggestions. We believe that the manuscript will be improved by addressing these comments. We will revise the manuscript accordingly.

Specific comments

2.2 Hyperspectral reflectance measurements

- **P10328L13: Reflectance should be collected near solar noon. In many locations the midday times may be offset from this ideal period of data collection due to local/national rules and regulations such as the implementation of daylight savings. Indicate when the reflectance measurements were collected in reference to solar noon at the summer solstice or the rough time for much of the growing season.**

RESPONSE
We agree with this comment but in general the uncertainty due to a different sun position should not play an important role collecting data close to solar noon. The hyperspectral measurements were collected close to solar noon that occurs around 13:00 Central European time (i.e. not taking daylight savings into account) during the growing season at the location of the study sites. In particular, the hyperspectral measurements were taken in between 11:00 to 14:00 Central European time.

- **P10328L14: Indicate the model number here. While all details are probably not warranted, do not expect readers to read the previous publication. Even the cited publication is lacking some details**

and refers to another publication. Why not refer to the original here? It is already cited in the manuscript?

RESPONSE
We referred to Vescovo et al. (2012) since hyperspectral and biophysical data used in this manuscript were part of the previous publication and therefore the sampling strategy was exactly the same as reported in this paper. However, we agree with this comment and we will give more details about the hyperspectral sampling methodology in the revised manuscript. The reference number of the spectrometers will also be provided.
In Vescovo et al. 2012, the authors referred to Gianelle et al. 2009 for describing the use of the cosine diffuser foreoptic. We already cited in the manuscript this publication for discussing other issues. Nevertheless, we believe that the reference to Gianelle et al. 2009 can be helpful in this part. It can also help to answer to the following question about the foreoptic diffuser.

REFERENCE
Gianelle, D., Vescovo, L., Marcolla, B., Manca, G., and Cescatti, A.: Ecosystem carbon fluxes and canopy spectral reflectance of a mountain meadow, Int. J. Remote Sens., 30, 435–449, 2009.

- **P10328L18-22: Hemispherical reflectance is very unusual as it is easy to have contamination of the nadir view by the sky as the field of view (FOV) is very wide. What is the model of the cosine diffuser used? What is the FOV of the diffuser? What steps were taken to reduce/eliminate the user/tripod from contaminating the FOV?**

RESPONSE
We agree on the fact that hemispherical reflectance is not usual (e.g. of the use of the same experimental set-up given by Fava et al. 2009; Gianelle et al., 2009; Vescovo et al. 2012). On the other hand, when measurements are carried out close to the canopy (e.g. on a small EC tower with a reduced height), a cosine diffuser is able to provide a more scale-appropriate observation. The setup and spatial dimension of spectral measurements at EC sites (e.g., the connection between the sensor support and the EC footprint) is an area of great debate. This issue is related to the spatial representativeness of spectral data (Balzarolo et al, 2011). When the objective of optical sampling is to provide measurements to be coupled with EC data, the footprints of the two systems should be as much as possible comparable. As shown in Meroni (2011), the cosine foreoptic was selected as an optimal compromise for measuring standard sky irradiance values, canopy irradiance from near-surface optical measurement, and comparing the aforementioned observations with carbon fluxes. For our observations, we used the ASD's Remote Cosine Receptor which was provided and calibrated by the manufacturer. The form of ASD's cosine receptor is referred to as a diffusion-disc collector (DDC). The DDC is constructed of a tube with one end covered by a diffusion-disc, designed with a geometry and material that provides a hemispherical FOV (180˚) and optimizes the cosine response. The FOV contamination is very difficult for hemispherical view sensors, both for sky irradiance and for canopy irradiance. To reduce the nadiral FOV contamination, the instrument was placed on a 1.5 m long horizontal arm. To avoid the zenithal FOV contamination, measurements were taken at least at a 15 meters distance from the EC tower (maximum height of the tower was 6 meters).

<u>In detail, to answer to the comments related to the Section 2.2 "Hyperspectral reflectance measurements" this section (P10328L12- P10329L3) will be rewritten as:</u>

The canopy hyperspectral reflectance measurements were collected at each site under clear sky conditions close to solar noon (between 11:00 to 14:00 Central European time) using the same model of a portable spectroradiometer (ASD FieldSpec HandHeld, Inc., Boulder, CO, USA; serial numbers: 1275 for Amplero, 6354 for Monte Bondone in 2006 and 1191 for Neustift and Monte Bondone in 2006) at all sites. The spectroradiometer acquires reflectance values between 350 and 1075 nm with a Full Width Half Maximum (FWHM) of 3.5 nm and a spectral resolution of 1 nm. In order to achieve a better match between the eddy covariance flux footprint and optical measurements, a cosine diffuser foreoptic (ASD Remote Cosine Receptor, Inc., Boulder, CO, USA), calibrated by the manufacture, was used for nadir/zenith measurements (Gianelle et al., 2009; Fava et al., 2009; Meroni et al. 2011). The ASD's cosine receptor is designed with a geometry and material that provides a hemispherical field of view (FOV) of 180˚ and optimizes the cosine response. To reduce the nadir FOV contamination (i.e. sky irradiance and for canopy irradiance) due to the hemispherical view of the sensor the instrument was placed on a 1.5 m long horizontal arm at a height of 1.5 m above the ground. To avoid the zenithal FOV contamination, the measurements were taken at least at a 15 m distance from the eddy covariance tower (maximum height of the tower was 6 m). The vegetation irradiance (sensor pointing nadir) and sky irradiance (sensor pointing zenith) were measured by rotating the spectoradiometer alternately to acquire spectra from the vegetation and from the sky. Hemispherical reflectance was derived as the ratio of reflected to incident radiance. Each reflectance spectrum was automatically calculated and stored by the spectroradiometer as an average of 20 readings. Before starting each spectral sampling, a dark current measurement was done. For more details on experimental set-up see Vescovo et al. (2012). Spectral measurements were collected from spring until the cutting date at Amplero and Monte Bondone, while at the site in Neustift, which is cut three times during the season, spectral measurements were taken about once per week throughout the growing season of 2006.

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Vescovo L., Wohlfahrt, G., Balzarolo, M., Pilloni, S., Sottocornola, M., Rodeghiero, M., and Gianelle, D.: New spectral vegetation indices based on the near-infrared shoulder wavelenghts fro remote sensign detection of grassland phytomass, Int. J. Remote Sens., 33, 7, 2012.

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Meroni, M., Barducci, A., Cogliati, S., Castagnoli, F., Rossini, M., Busetto, L., Migliavacca, M., Cremonese, E., Galvagno, M., Colombo, R., and Morra di Cella, U.: The hyperspectral irradiometer, a new instrument

for long-term and unattended field spectroscopy measurements, Rev. Sci. Instrum. 82, 043106; 2011; http://dx.doi.org/10.1063/1.3574360.

- **P10328L20: It is assumed that the 1.5 m was above the ground, but it was not explicitly stated. Why not above the canopy? This would result in the same area seen by the sensor at the top of canopy. Thus, when the grasses are taller, the less of an area the sensor will be seeing.**

RESPONSE
The height of the hyperspectral measurements was 1.5 m above the ground. The vegetation of the three grasses was very homogenous and dense and the maximum eighth of vegetation was less than 0.7 m for that we assumed that the reduction of the footprint area of optical measurements during the growing season was negligible.

2.3 CO2 flux measurements

- **P10329L5-16: More details are needed to describe the CO_2 flux measurements. What brand/models were used? Describe the methods as they are critical to the interpretation. The book by Aubinet et al 2012 describe multiple methods and it is CRITICAL that readers know exactly which methods were used and why. How was Reco modeled? Daytime estimates are confounded by both plant photosynthesis and different meteorological conditions (e.g. temperature, wind speed). It is quite possible that different models and methods are driving the differences between the sites.**

RESPONSE
As for more details on flux measurements we will add more details to Table 1. As will be possible to see from the data of the new Table 1, instruments and post-processing steps were very similar at all sites.
As written in L8-20 on p. 10330 of the BGD paper, Reco was determined by fitting Eq. (4) to both day and nighttime data. The same model and estimation procedure was used at all sites.

Were key supporting meteorological variables also measured (soil heat flux, humidity, incident solar radiation, etc.)? If so, at least list these variables so users understand what kind of gap-filling strategies could be used without needing to directly look up the cited publication and to see if the suggest gap-filling methods make sense for the site.

RESPONSE
Yes, the relevant meteorological variables were measured at each flux tower and the most important ones will be added to the text (see details below on the section 2.3)

- **P10329L5-8: For an empirical study with mixed results, this seems like a very small sample size (1 year of data for 2 sites and 2 years of data for 1 site).**

RESPONSE
We agree with this comment but joint hyperspectral reflectance and eddy covariance flux measurements have been done at very few sites and even fewer of those have long-term data. In addition, there exists no common protocol for hyperspectral measurements in the eddy covariance networks (Balzarolo et al., 2011). Therefore, available hyperspectral measurements are not standardized and comparable between different sites: how to standardize measurements and make results comparable are still open questions. The dataset used in this paper was built based on a coordinated

field experiment by three groups in order to standardize in-situ hyperspectral measurements and make these measurements comparable.

In detail, to answer to the comments related to the Section 2.3 “CO_2 fluxes measurements” this section (P10329L5- 16) will be rewritten as:

Continuous measurements of the net ecosystem CO_2 exchange (NEE) were made by the eddy covariance (EC) technique (Baldocchi et al., 1996; Aubinet et at., 2012) at the three sites. The three wind components and the wind speed were measured using ultra-sonic anemometers, and CO_2 concentrations using open-path infrared gas analysers (IRGA), as detailed in Table 1. Raw data were acquired at 20 Hz and averaged over 30 min time windows in post-processing. Turbulent fluxes were obtained from raw data by applying block averaging (Monte Bondone, Neustift) or linear de-trending (Amplero) methods with a time window of 30 minutes. A 3D coordinate correction was performed according to Wilczak et al. (2001). The CO_2 flux densities were corrected for the effect of air density fluctuations as proposed in Webb et al. (1980). Low- and high-pass filtering was corrected for following Aubinet et al. (2000) (Amplero, Monte Bondone) or Moore (1986) (Neustift). Data gaps due to sensors malfunctioning or violation of the assumptions underlying the EC method were removed and filled using the gap-filling and flux-partitioning techniques as proposed in Wohlfahrt et al. (2008). Ecosystem respiration (Reco) was calculated from the y-intercept of the light response model (see eq. 4). Gross primary productivity (GPP) was calculated as the difference between NEE and Reco. Half-hourly NEE and GPP values were averaged between 11:00 to 14:00 solar local time (at the time window of optical measurements) to allow for direct comparison with the hyperspectral data, and daily sums were also computed. At each site the following supporting environmental measurements were acquired: photosynthetically active radiation (PAR; quantum sensors), air temperature (Ta; PT100, thermistor and thermoelement sensors), and humidity (RH; capacitance sensors) at some reference height above the canopy, and soil temperature (Ts; PT100, thermistor and thermoelement sensors) and water content (SWC; dielectric and time-domain reflectometry sensors) in the main rooting zone. In this study we used CO_2 flux and meteorological data of the years 2005 and 2006 for Monte Bondone and of 2006 for the other sites.

In addition, the following new Table 1 will be added to the revised version of the manuscript:

Table 1. Description of the study sites and period.

Site characteristics	Amplero (IT-Amp)	Neustift (AT-Neu)	Monte Bondone (IT-MBo)
Latitude	41.9041	47.1162	46.0296
Longitude	13.6052	11.3204	11.0829
Elevation (m)	884	970	1550
Mean annual temperature (˚C)	10.0	6.5	5.5
Mean annual precipitation (mm)	1365	852	1189
Vegetation type	Seslerietum apenninae	Pastinaco–Arrhenatheretum	Nardetum Alpigenum
Study period[1]	111-170, 2006 (9)	122-303, 2006 (16)	129-201, 2005 (13) 124-192, 2006 (12)
Sonic anemometer model	R3, Gill Instruments Ltd., Lymington, UK	R3, Gill, Instruments Ltd., Lymington, UK	R3, Gill Instruments Ltd., Lymington, UK
Infrared gas analyser model	Li-7500, Li-Cor Inc., Lincoln, Nebraska, USA	Li-7500, Li-Cor Inc., Lincoln, Nebraska, USA	Li-7500, Li-Cor Inc., Lincoln, Nebraska, USA
Data acquisition frequency (Hz)	20	20	20
Post-processing software	Developed by University of Viterbo (IT)	EdiRE (Version 1.4.3.1021, R. Clement, University of Edinburgh)	EdiRE (Version 1.4.3.1021, R. Clement, University of Edinburgh)
Outlier removal (method)	Wickers and Mahrt (1997)	-	-
CO_2/H_2O signal lag removal	Covariance maximization	Covariance maximization	Covariance maximization
Coordinate rotation (method)[2]	3D	3D	3D
Detrending of time series (method)	Linear detrending	-	-
Density corrections applied[3]	x	x	x
Sonic buoyancy to sensible heat flux conversion and cross-wind correction[4]	x	x	x
Low- and high-pass filtering corrected for (method)	Aubinet et al. (2000)	Moore (1986)	Aubinet et al. (2000)

[1] from-to DOY, year (number of hyperspectral measurement dates); [2] according to Wilczak et al. (2001); [3] according to Webb et al. (1980); [4] according to Schotanus et al. (1983); [5] according to Mauder et al. (2008).

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2.4 Estimation of grassland ecophysiological parameters

- **P10330L1: Be specific on how the extinction coefficient was calculated. It would be assumed for grasslands, but it should be explicitly stated not just referenced. Also identify that this k was determined for grasslands different from the site.**

RESPONSE
We will add in the revised manuscript that we used a value of k = 0.4 defined for southern mixed-grass prairie in Texas.

- **P10330L15: Citation needed for the Levenberg-Marquardt algorithm.**

RESPONSE
The following citation will be added: Marquardt, 1963

REFERENCE
Marquardt, D. W.: An Algorithm for Least-Squares Estimation of Nonlinear Parameters, SIAM J. Appl. Math., 11, 431–441, doi:10.1137/0111030, 1963.

- **P10330L10-19: It is not clear how respiration was measured and/or fitted. Were nighttime measurements used to estimate daytime measurements?**

RESPONSE
P10330L16 will be modified to „… by fitting Eq. (4) to both day and nighttime data …"

2.5 Hyperspectral data analysis

- **P10331L13-17: Most individuals know how to calculate R2 and RMSE. These equations and associated descriptive text can be deleted.**

RESPONSE
We agree and we will delete this part from the text.

- **P10332L12-18: While AIC is a valid approach to determine if added complexity improves the model accuracy, the purpose of this study was to "develop a common framework for predicting grassland GPP based on optical remote sensing data." Thus, a model that is high accuracy in calibration may not be very useful when validated. This is a critical concern when using non-linear models as the VI becomes insensitive to the biophysical characteristic (BPC; e.g. GPP, NEE). This will reduce scatter (thus increase R^2 and reduce RMSE), but be unusable for practical purposes as similar VI values can represent a wide range of BPC (this problem is especially prominent when using NDVI to estimate LAI). A better metric to use for both linear and non-linear relationships would be noise equivalent (NE). Unfortunately for non-linear models, the NE will change based on the value of the BPC. Thus, in some ranges of BPC they will work better than others. This information could not be easily presented in correlograms. This reviewer suggest eliminating non-linear relationships and focus on linear ones as they are (a) easier to use and (b) more reliable throughout the entire dynamic range of each BPC if the relationship is truly linear. This could be easily tested by plotting the best bands for each VI against the BPC.**

RESPONSE
We agree with this comment and will remove the non-linear statistics from the paper and refer to R^2 and RMSE instead of AIC. In addition, the a new figure C1 representing the linear models for the selected bands for all BCPs for each site and all sites pooled will be added to the revised version of the paper. In these plots the results for the leave-one-out cross validation will be presented. In particular, the cross validated R-squared (R^2cv) and Root Mean Square Error (RMSEcv) will shown in the figure C1.

- **P10330L20-P10332L18: Why not divide the data into calibration/validation data sets or use a leave-one-out procedure to test the sensitivity of these selected bands? If the goal is to estimate GPP using remote sensing data, then determining a robust set of wavebands that works for each site should be the initial goal with a secondary goal of finding a set of wavebands that works for all three sites.**

RESPONSE
Thanks for the comment, we agree. In the revised version of the manuscript we will test the sensitivity of the selected bands for all BCPs for each site and all sites pooled by using leave-one-out cross validation procedure and validating the models against new sites.

In the revised version of the manuscript the metrics obtained by leave-one-out procedure applied to BGD dataset will be reported in the new figure C1 (see previous comment). In particular, the cross validated R-squared (R^2cv) and Root Mean Square Error (RMSEcv) will shown in the figure C1.

In order to evaluate the performance of the found relationships and the new selected bands the authors included three new sites in their database (validation sites – see table S1 below). These three additional sites were already part of the preceding study by Vescovo et al. (2012) and used exactly the same methodology as applied at the main three study sites and thus fully comply with our own standards of intercomparability. Validation will be performed applying to the three new sites all the three site specific models (Amplero, Neustift and Monte Bondone) and a model parameterized grouping Neustift and Monte Bondone since the two sites show similar structural characteristics. Figure C2 here below shows the results of the validation of the models against validation sites. As shown in this figure, correspondence between simulated and measured VIs was reasonable when using the models developed for Monte Bondone and Neustift or both sites pooled, but less so with the models of Amplero. This is understandable as Monte Bondone and in particular Neustift are structurally and functionally much more similar to the validation sites compared to Amplero. Overall, the validation shows that the models developed are transferable.

<u>The following new Table S1 will be added to the revised version of the manuscript:</u>

Table S1. Description of the validation study sites and period.

Site characteristics	Längenfeld (AT-Lan)	Leutasch (AT-Leu)	Scharnitz (AT-Sch)
Latitude	47.0612	47.3780	47.3873
Longitude	10.9634	11.1627	11.2479
Elevation (m)	1180	1115	964
Mean annual temperature (˚C)	5.8	4.8	6.4
Mean annual precipitation (mm)	733	1309	1418
Vegetation type	*Phyteumo-Trisetion*	*Astrantio-Trisetetum*	*Arrenatherum montanum*
Study period[1]	163, 2006 (1)	227, 2006 (1)	184-284, 2006 (5)
Sonic anemometer model	R3, Gill Instruments Ltd., Lymington, UK	R3, Gill Instruments Ltd., Lymington, UK	R3, Gill Instruments Ltd., Lymington, UK
Infrared gas analyser model	Li-7500, Li-Cor Inc., Lincoln, Nebraska, USA	Li-7500, Li-Cor Inc., Lincoln, Nebraska, USA	Li-7500, Li-Cor Inc., Lincoln, Nebraska, USA
Data acquisition frequency (Hz)	20	20	20
Post-processing software	EdiRE (Version 1.4.3.1021, R. Clement, University of Edinburgh)	EdiRE (Version 1.4.3.1021, R. Clement, University of Edinburgh)	EdiRE (Version 1.4.3.1021, R. Clement, University of Edinburgh)
Outlier removal (method)	-	-	-
CO_2/H_2O signal lag removal	Covariance maximization	Covariance maximization	Covariance maximization
Coordinate rotation (method)[2]	3D	3D	3D
Detrending of time series (method)	-	-	-
Density corrections applied[3]	X	x	x
Sonic buoyancy to sensible heat flux conversion and cross-wind correction[4]	X	x	x
Low- and high-pass filtering corrected for (method)	Moore (1986)	Moore (1986)	Moore (1986)

[1] from-to DOY, year (number of hyperspectral measurement dates); [2] according to Wilczak et al. (2001); [3] according to Webb et al. (1980); [4] according to Schotanus et al. (1983); [5] according to Mauder et al. (2008).

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Moore, C.J.: Frequency response corrections for eddy correlation systems, Bound.-Lay. Meteorol., 37, 17–35, 1986.

Schotanus, P., Nieuwstadt, F. T. M., and De Bruin H. A. R.: Temperature measurement with a sonic anemometer and its application to heat and moisture fluxes, Bound. Lay. Meteorol., 26 81–93, 1983.

Webb, E. K., Pearman, G. I., and Leuning, R.: Correction of flux measurements for density effects due to heat and water vapour transfer, Q. J. Roy. Meteorol. Soc., 106, 85–100, 1980.

Wilczak, J. M., Oncley, S. P., and Stage, S. A.: Sonic anemometer tilt correction algorithms, Bound.-Lay. Meteorol., 99, 127–150, 2001.

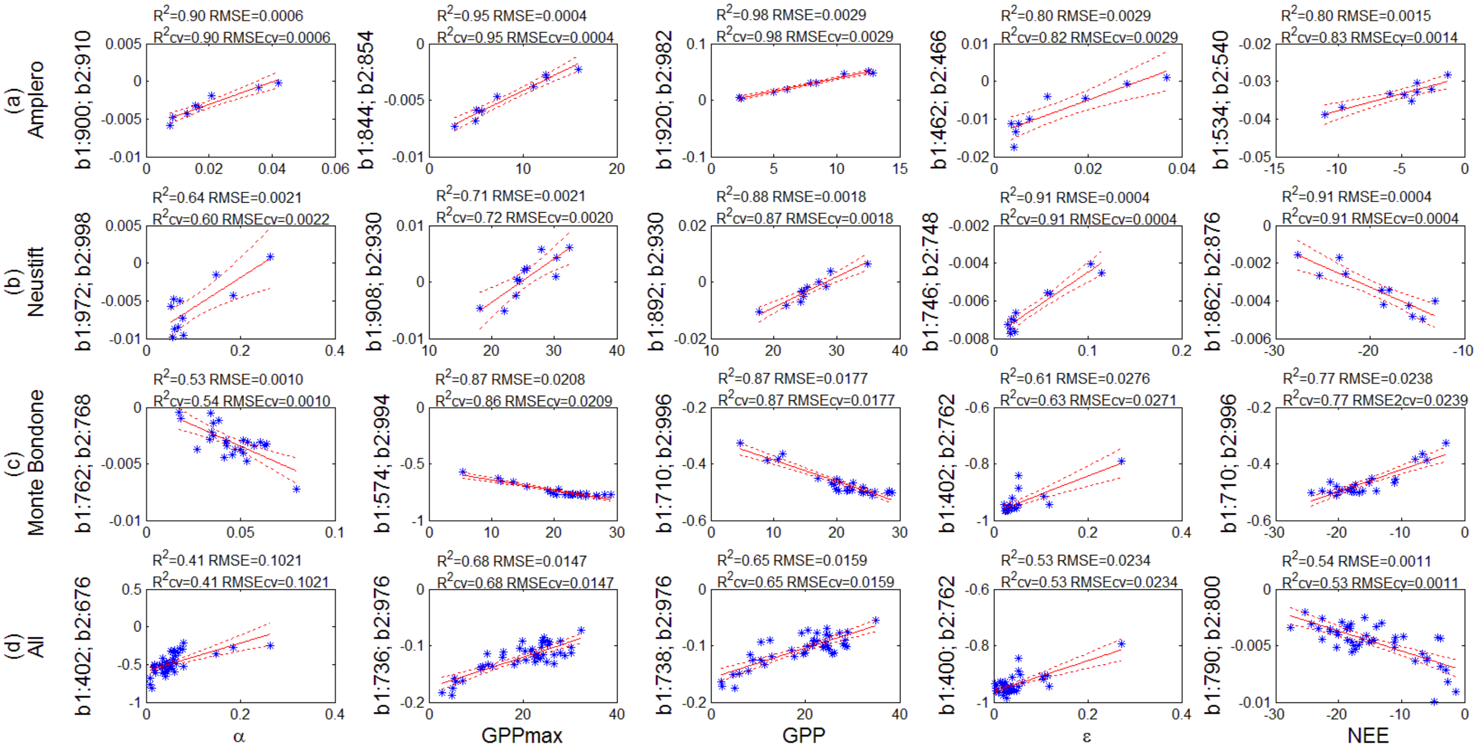

Fig. C1: Results of linear correlation analysis for α, GPPmax and midday averaged GPP, ε and NEE and selected NSD-type indices for (a) Amplero, (b) Neustift, (c) Monte Bondone (both study years pooled) and (d) all sites pooled. R^2—Coefficient of determination; RMSE—Root Mean Square Error; R^2cv—Cross-validated coefficient of determination; $RMSE_{cv}$— Cross-validated root Mean Square Error. The red lines indicate the fitted models and the red dotted lines represent the 95% upper and lower confidence bounds.

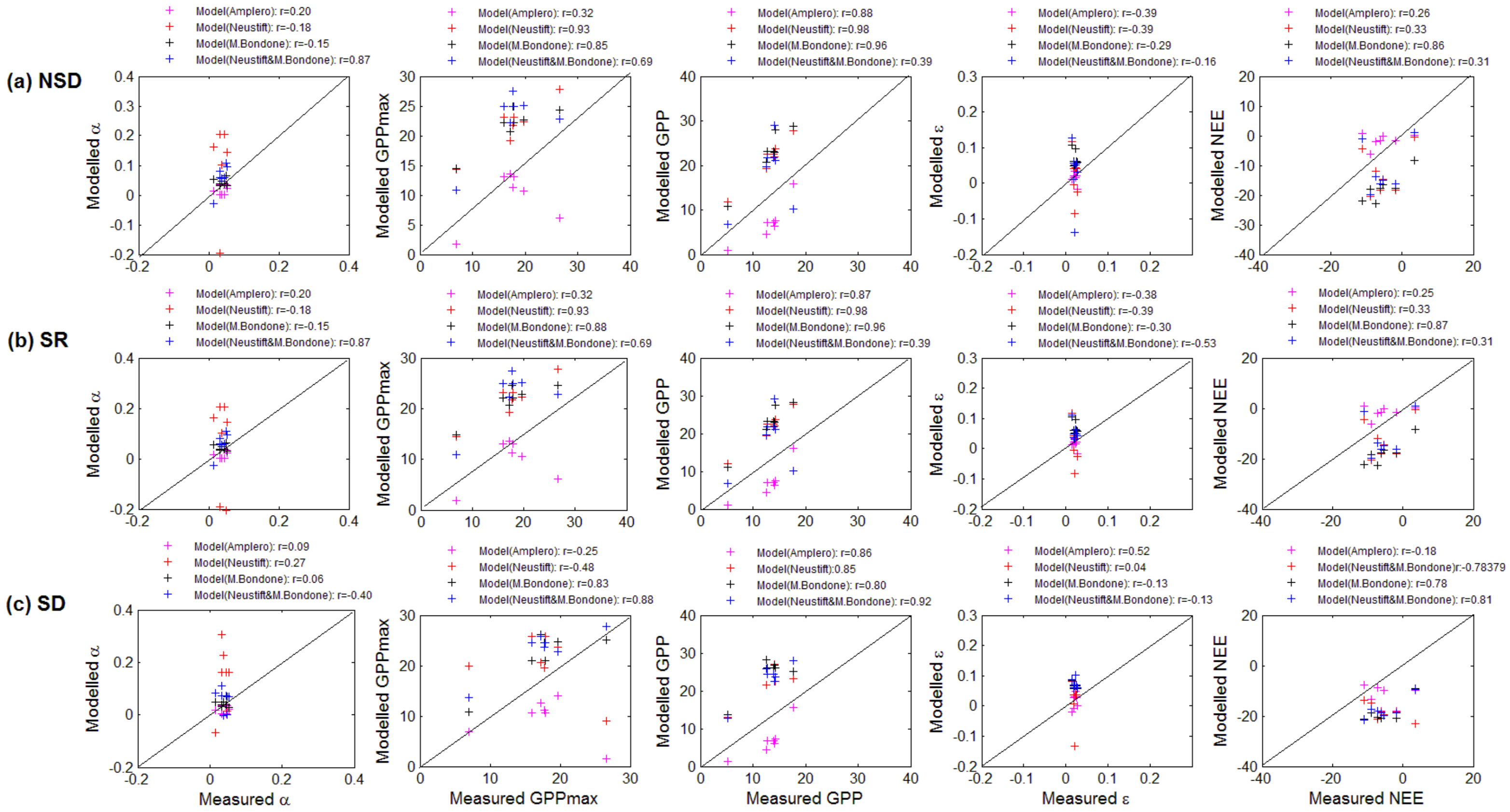

Fig. C2 – Results of validation of linear regression models between VIs ((a) NSD type; (b) SR-type; (c) SD-type) and ecophysiological parameters: α, ε (midday average), GPP_{max} and midday average CO_2 fluxes (NEE and GPP). r—coefficient of correlation. Different colours represent results of the validation performed applying to the three new sites the model for Amplero (in magenta), Neustift (in red) and Monte Bondone (in blue) and a model parameterized grouping Neustift and Monte Bondone (in black).

3.2 Hyperspectral data and their relation to CO2 fluxes and ecophysiological parameters

- **P10333L23-25: Figure 3c does not follow this pattern. The spectra for the highest LAI have lower NIR than the spectra for the next two highest LAI.**

RESPONSE
Thanks for the correction. We agree and we will correct it in the revised version of the manuscript.

- **P10333L27-P10334L1: It is impractical to compare exponential relationships using R^2 values (even RMSE values should not be used) as different slopes/intercepts make it very difficult to conceptualize their real differences. As these relationships were never presented, it is impossible to compare these relationships in this manuscript.**

RESPONSE
Exponential relationships will be removed from the paper.

- **P10334L15-18: One of the problems with correlograms is the end result does not explain causation, only that some correlation exists. There has been quite a bit of research in understanding why specific spectral regions can explain various BPCs. There is no discussion of this research and how it supports the results from the correlograms.**

RESPONSE
We agree, although we would like to stress that no statistical analysis implies causation, and we will add some explanations of the existence of the correlation in some spectral regions. We agree with the reviewer and in the revised version of the manuscript we will add some explanations of the existence of the correlation in some spectral regions. To investigate more the basis of the correlation between the selected band combinations and ecophysiological variables (e.g. alpha, GPPmax, GPP, epsilon) in the revised version of the paper we will analyse the relationship between the selected bands and biophysical parameters such as dry phytomass, nitrogen and water content collected during the field campaign in the same footprint of hyperspectral measurements. The new tables S2 and S3 (here below) will be added to the revised version of the manuscript. This analysis confirmed that the that the spectral response in the selected band combinations for NDS, SR and SD-type indices is strongly related to structural characteristics of the vegetation of the three grasslands (e.g. nitrogen and phytomass) that impact on their spectral response in NIR and VIS regions. For the Mediterranean site (Amplero site) and for all eco-physiological parameters (i.e. a, GPPmax, GPP, epsilon) the dry phytomass is the main driving factor of the spectral response in the selected bands while nitrogen content drive the spectral response in NIR region for Neustift site. For Monte Bondone both dry phytomass and nitrogen content effect spectral response of the grassland. Similar results were obtained for SR and SD-type indices.

Therefore, according to the obtained results, more studies are needed to understand the physical basis of this correlation. The results are somehow confirming the findings of Vescovo et al, (2012) which highlighted a strong relationship, for several grassland types, between an NSD-type index and phytomass. In addition, these new analysis will substantial contribute to the analysis of the structural effect on the ability to estimate canopy nitrogen content that is still a controversial issue (Knyazikhin et al., 2012).

These results will be discussed in detail in the revised version of the manuscript and the corresponding table for the estimation of daily parameters will be added to the supplemental material.

Table S2. Results of the correlation (r – correlation coefficient) between the best NDS, SR and SD-type indices and dry phytomass and nitrogen content for Amplero, Neustift, Monte Bondone for the α, GPPmax, midday GPP, midday ε and midday NEE.

			α		**GPPmax**		**GPP**		ε		**NEE**	
Index	**Site**	**Parameter**	**Band center [i,j]**	**r**	**Band center [i,j]**	**r**	**Band center [i,j]**	**r**	**Band center [i,j]**	**r**	**Band center [i,j]**	**r**
			(nm)	(-)	(nm)	(-)	(nm)	(-)	(nm)	(-)	(nm)	(-)
NSD-type	Amplero	Dry phytomass (g m-2)	[900, 910]	-0.81**	[844, 854]	-0.85**	[920, 982]	-0.76*	[462, 466]	-0.87**	[534, 540]	0.60
	Amplero	Nitrogen content (%)		0.54		0.57		0.44		0.70*		-0.39
	Amplero	Water content (%)		0.53		0.73*		0.75*		0.66		-0.74*
	Neustift	Dry phytomass (g m-2)	[972, 998]	-0.04	[908, 930]	0.51	[892, 930]	0.59	[746, 748]	-0.66*	[862, 876]	0.15
	Neustift	Nitrogen content (%)		0.40		-0.39		-0.46		0.88**		0.18
	Neustift	Water content (%)		-0.07		0.03		-0.18		0.77*		0.31
	Monte Bondone	Dry phytomass (g m-2)	[762, 768]	-0.13	[574, 994]	-0.77***	[710, 996]	-0.70***	[402, 762]	-0.74***	[710, 996]	-0.70***
	Monte Bondone	Nitrogen content (%)		0.29		0.72***		0.62**		0.69***		0.62**
	Monte Bondone	Water content (%)		0.31		0.69***		0.59**		0.65***		0.59**
	All	Dry phytomass (g m-2)	[402, 676]	0.23	[736, 976]	0.12	[738, 976]	0.14	[400, 762]	-0.22	[790, 800]	0.06
	All	Nitrogen content (%)		0.51***		0.19		0.13		0.64***		0.30
	All	Water content (%)		0.03		-0.09		-0.09		0.32*		0.05
SR-type	Amplero	Dry phytomass (g m-2)	[900, 910]	-0.81***	[844, 854]	-0.85**	[920, 982]	-0.76*	[462, 466]	-0.87*	[534, 540]	0.60
	Amplero	Nitrogen content (%)		0.54		0.57		0.43		0.70*		-0.39
	Amplero	Water content (%)		0.53		0.73**		0.74*		0.66		-0.74*
	Neustift	Dry phytomass (g m-2)	[972, 998]	-0.04	[908, 930]	0.51	[892, 930]	0.59	[746, 478]	-0.66*	[862, 876]	0.15
	Neustift	Nitrogen content (%)		0.40		-0.39		-0.46		0.88**		0.18
	Neustift	Water content (%)		-0.07		0.03		-0.18		0.77*		0.31
	Monte Bondone	Dry phytomass (g m-2)	[762, 768]	-0.13	[570, 994]	-0.77***	[714, 996]	-0.73***	[402, 762]	-0.74***	[570, 574]	0.61**
	Monte Bondone	Nitrogen content (%)		0.29		0.73***		0.64***		0.69***		-0.53**
	Monte Bondone	Water content (%)		0.31		0.69***		0.61**		0.64***		-0.50*
	All	Dry phytomass (g m-2)	[402, 676]	0.28	[736, 976]	0.14	[738, 976]	0.15	[400, 762]	-0.22	[790, 800]	0.06
	All	Nitrogen content (%)		0.51***		0.19		0.13		0.63***		0.30
	All	Water content (%)		-0.01		-0.10		-0.10		0.33*		0.05
SD-type	Amplero	Dry phytomass (g m-2)	[900, 910]	-0.80***	[844, 866]	-0.90**	[920, 982]	-0.77*	[492, 496]	-0.76*	[422, 432]	-0.50
	Amplero	Nitrogen content (%)		0.47		0.55		0.46		0.55		0.19
	Amplero	Water content (%)		0.41		0.67*		0.77*		0.43		0.70*
	Neustift	Dry phytomass (g m-2)	[474, 494]	-0.45	[736, 968]	0.20	[878, 922]	0.61	[732, 942]	-0.45	[402, 456]	-0.04
	Neustift	Nitrogen content (%)		0.33		0.09		-0.34		0.90**		-0.28
	Neustift	Water content (%)		0.15		0.51		-0.04		0.80*		-0.72*
	Monte Bondone	Dry phytomass (g m-2)	[762, 768]	-0.38	[444, 482]	0.65***	[436, 488]	0.60**	[658, 682]	0.67***	[450, 486]	0.60**
	Monte Bondone	Nitrogen content (%)		0.53***		-0.58**		-0.58**		-0.62**		-0.59**
	Monte Bondone	Water content (%)		0.52***		-0.58**		-0.58		-0.56**		-0.55**
	All	Dry phytomass (g m-2)	[822, 824]	0.45***	[550, 560]	0.12	[414, 470]	0.00	[732, 928]	0.55***	[468, 660]	-0.11
	All	Nitrogen content (%)		-0.09		-0.09		-0.15		0.16		-0.33*
	All	Water content (%)		-0.08		0.18		0.19		-0.53***		0.24

Statistical significance is indicated as * ($p < 0.05$), ** ($p < 0.01$), and *** ($p < 0.001$).

Table S3. Results of the correlation (r – correlation coefficient) between the best NDS, SR and SD-type indices and dry phytomass and nitrogen content for Amplero, Neustift, Monte Bondone for daily GPP, ε and NEE.

			GPP		ε		NEE	
Index	**Site**	**Parameter**	**Band center [i,j]** (nm)	**r** (-)	**Band center [i,j]** (nm)	**r** (-)	**Band center [i,j]** (nm)	**r** (-)
NSD-type	Amplero	Dry phytomass (g m-2)	[868, 878]	-0.82**	[896, 904]	-0.89**	[902, 922]	-0.83**
	Amplero	Nitrogen content (%)		0.61		0.54		0.56
	Amplero	Water content (%)		0.81**		0.53		0.85**
	Neustift	Dry phytomass (g m-2)	[972, 988]	-0.14	[722, 942]	-0.54	[422, 516]	-0.25
	Neustift	Nitrogen content (%)		0.27		0.91**		0.15
	Neustift	Water content (%)		0.19		0.80*		0.06
	Monte Bondone	Dry phytomass (g m-2)	[580, 986]	-0.75***	[658, 682]	0.69***	[712, 714]	-0.52*
	Monte Bondone	Nitrogen content (%)		0.71***		-0.66***		0.50*
	Monte Bondone	Water content (%)		0.67***		-0.61**		0.43*
	All	Dry phytomass (g m-2)	[736, 976]	0.12	[404, 944]	-0.21	[790, 798]	0.02
	All	Nitrogen content (%)		0.19		0.68***		0.32*
	All	Water content (%)		-0.09		0.36*		0.08
SR-type	Amplero	Dry phytomass (g m-2)	[868, 878]	-0.82**	[896, 904]	-0.89**	[902, 922]	-0.83**
	Amplero	Nitrogen content (%)		0.61		0.54		0.561
	Amplero	Water content (%)		0.81*		0.53		0.85**
	Neustift	Dry phytomass (g m-2)	[868, 878]	-0.14	[722, 942]	-0.54	[422, 516]	-0.254
	Neustift	Nitrogen content (%)		0.27		0.92**		0.142
	Neustift	Water content (%)		0.19		0.80*		0.056
	Monte Bondone	Dry phytomass (g m-2)	[600, 608]	0.56**	[658, 682]	0.69***	[712, 714]	-0.52*
	Monte Bondone	Nitrogen content (%)		-0.52**		-0.66***		0.50*
	Monte Bondone	Water content (%)		-0.54**		-0.61**		0.43*
	All	Dry phytomass (g m-2)	[736, 976]	0.14	[404, 944]	-0.21	[790, 798]	0.021
	All	Nitrogen content (%)		0.19		0.67***		0.32*
	All	Water content (%)		-0.10		0.37*		0.083
SD-type	Amplero	Dry phytomass (g m-2)	[894, 998]	-0.81**	[844, 856]	-0.89**	[816, 834]	-0.84**
	Amplero	Nitrogen content (%)		0.49		0.51		0.56*
	Amplero	Water content (%)		0.76*		0.59		0.84**
	Neustift	Dry phytomass (g m-2)	[972, 988]	-0.16	[732, 942]	-0.45	[400, 410]	0.092
	Neustift	Nitrogen content (%)		0.33		0.90**		-0.672
	Neustift	Water content (%)		0.25		0.80*		-0.293
	Monte Bondone	Dry phytomass (g m-2)	[444, 502]	0.57**	[658, 680]	0.72***	[468, 496]	0.47*
	Monte Bondone	Nitrogen content (%)		-0.56**		-0.67***		-0.55**
	Monte Bondone	Water content (%)		-0.57**		-0.63***		-0.48*
	All	Dry phytomass (g m-2)	[424, 446]	0.28	[734, 928]	-0.44**	[444, 464]	0.167
	All	Nitrogen content (%)		0.14		0.56***		0.070
	All	Water content (%)		-0.16		0.16		-0.032

Statistical significance is indicated as * ($p < 0.05$), ** ($p < 0.01$), and *** ($p < 0.001$).

In addition, to investigate more the basis of the correlation between the NIR band combinations and GPP, we analyzed a similar dataset collected in summer 2013 on Monte Bondone. Measurements were acquired using the same ASD FieldSpec spectrometer used for Monte Bondone in 2006 (serial number: 6354). The measurements were taken on the tower at a height of 6 m, with a field of view of 25°. To obtain reflectance values, white panel radiance spectra and canopy radiance spectra were acquired at approximately weekly intervals. At the same time of the hyperspectral measurements, measurements of the canopy chlorophyll and canopy water content were performed within the spectrometer footprint (5 m2). In the Figure C3, it is possible to see that, NSD- and SR-type indices for the selected bands for estimating GPP (i.e. 710 nm and 996 nm) are strongly correlated with canopy total chlorophyll content ($R^2 > 0.90$). For the band combinations < 750 nm, the correlation is related to chlorophyll content while for band combinations > 750nm (which is the most common situation; e.g. 761 and 770, 761 and 850, 800 and 850, etc.) there is a structural effect which needs to be further investigated (confirmed by Gitelson by a personal communication). In fact, the literature indicates that the wavelenghts in the NIR (>750nm) are not sensitive to chlorophyll content. They are sensitive to leaf and canopy structure (and around the 970nm area to water). These new analysis will substantial help to the analysis of the structural effect on the ability to estimate canopy nitrogen content that is still a controversial issue (Knyazikhin et al., 2012).

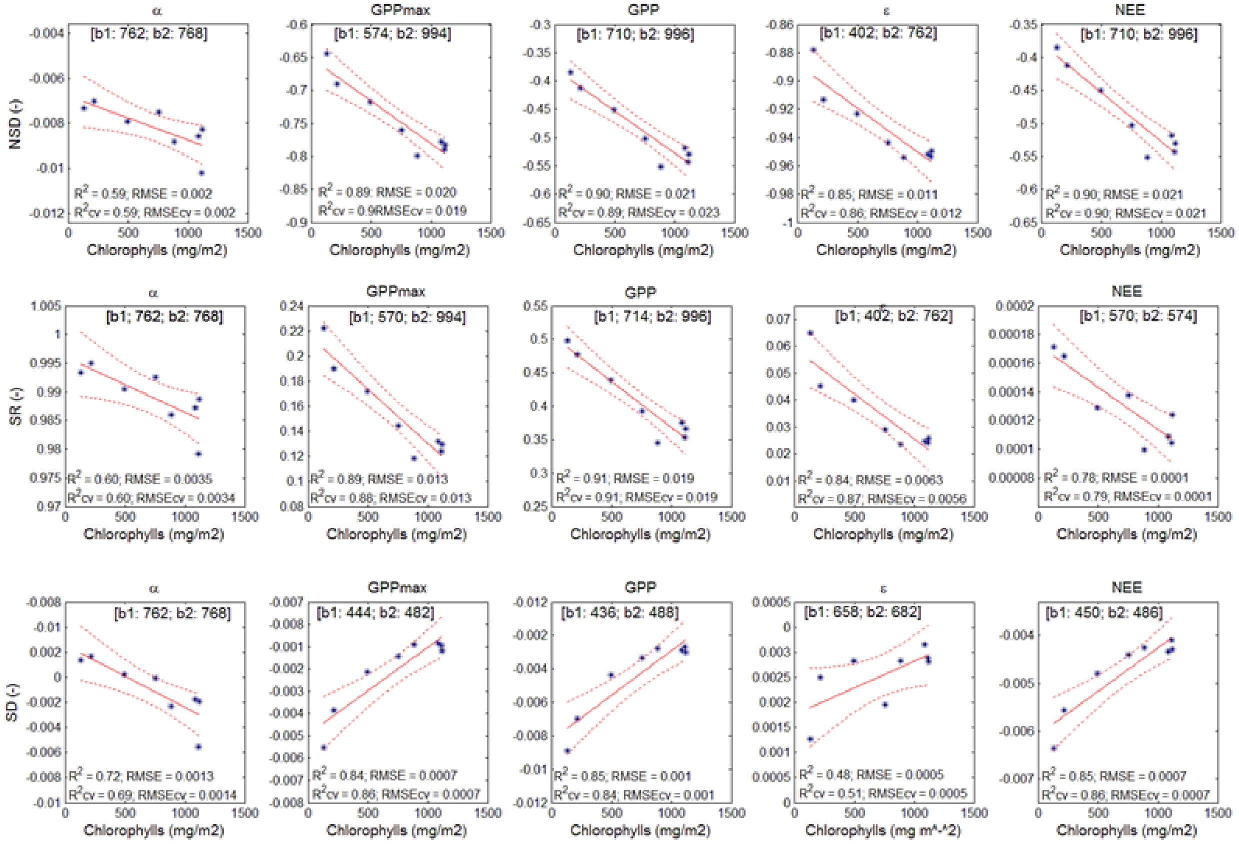

Fig. C3 – Correlation between selected NSD-, SR- and SD-type indices and the total chlorophyll content content for Monte Bondone in 2013. R^2—coefficient of correlation; RMSE—root mean square error; R^2cv— cross-validated coefficient of correlation; RMSEcv— cross-validated root mean square error. The red lines indicate the fitted models and the red dotted lines represent the 95% upper and lower confidence bounds. In the brackets are reported the selected bands to compute NSD-, SR- and SD-type indices.

In the revised version of the manuscript CI index reported in the Table 2 will be re-defined using the following formula: CI = (R750/R720) – 1 as reported in Gitelson et al. (2005). In addition, Red-edge (Red-edge NDVI = (R750–R720)/ (R750+R720); Gitelson and Merzlyak (1994)) will be added to the elaboration. Consequently, Figure 1 of BGD paper will be modified by showing the positions of these new indices and removing the old CI. In addition, in the revised version of the manuscript the Table 3 and Table 4 of the BGD paper and the Table S1 in the BGD supplemental will be modified showing the results of the correlation analysis between biophysical parameters and the new indices.

- **P10334L24-28: Significance is not a good predictor of accuracy as significance can be improved by sample size.**

RESPONSE
We agree and we will correct the text in the revised version of the manuscript.

- **P10334L18-28: It seems that this model is extremely simple and this is why it fails. It is already well known that GPP is controlled by many different factors (temperature, water stress, etc.). One reason VIs are widely used is that they remove some variation (i.e. two different sets of reflectance can yield the same VI value). Thus, VIs may not capture all of the necessary variation to explain GPP. There are GPP models that use multiple VIs to help address each of these components.**

RESPONSE
We agree with this comment. However, our general aim was to understand if there were some spectral regions where VIs and BPCs showed the same performance for each site or for all sites pooled together. Our intention was also to suggest simple measurements to do at all the sites where sensors with few main bands are prioritized.

- **P10339L29-P103340L1-3: The MOD17 algorithm is a very low bar. Most researchers active in the field know it is too simplistic, thus for most site-specific applications, they do incorporate at least several of these aspects.**

RESPONSE
Agreed – sentence will be removed.

Tables

- **Table 2: Chlorophyll index is not a normalized difference VI. It is more similar to simple ratio with the exception of the ratio being subtracted by 1. The CI presented in the table would be more accurately called the Red Edge NDVI. A better citation for CI would be Gitelson et al. 2005, doi:10.1029/2005GL022688.**

RESPONSE
Thanks for the correction. We agree and we will modify the table 2 accordingly. CI will be moved in the block of simple ratio indices and will be defined as: CI= (R750/R720) – 1. The reference will be changed in in Gitelson et al. (2005). Red-edge NDVI will be added to the block of normalized different vegetation indices and will be defined as: Red-edge NDVI = (R750–R720)/ (R750+R720) (Gitelson and Merzlyak (1994).
Figure 1 of BGD paper will be modified by showing the positions of these new indices and removing the old CI. In addition, in the revised version of the manuscript the Table 3 and Table 4 of the BGD paper and the Table S1 in the BGD supplemental will be modified showing the results of the correlation analysis between BPCs and the new indices.

The following new Table 2 will be added to the revised version of the manuscript:

Index name and acronym	Formula	Use	Reference
Simple Spectral Ratio Indices			
Simple Ratio (SR or RVI)	$SR = R_{830}/R_{660}$	Greenness	Jordan (1969)
Green Ratio Index (GRI)	$GRI = R_{830}/R_{550}$	Greenness	Peñuelas and Filella (1998)
Water Index (WI)	$WI = R_{900}/R_{970}$	Water content, leaf water potential, canopy water content	Peñuelas et al. (1993)
Simple Ratio Pigment Index (SRPI)	$SRPI = (R_{430})/(R_{680})$		Peñuelas et al. (1995)
Chlorophyll Index (CI)	$CI = (R_{750}/R_{720}) - 1$	Chlorophyll content	Gitelson et al. (2005)
Normalized Spectral Difference Vegetation Indices			
Normalized Difference Vegetation Index (NDVI)	$NDVI = (R_{830}–R_{660})/(R_{830}+R_{660})$	Greenness	Rouse et al. (1973)
Normalized Phaeophytinization Index (NPQI)	$NPQI = (R_{415}–R_{435})/(R_{415}+R_{435})$	Carotenoid /Chlorophyll ratio	Barnes et al. (1992)
Normalized Pigment Chlorophyll Index (NPCI)	$NPCI = (R_{680} - R_{430})/(R_{680} + R_{430})$	Chlorophyll ratio	Peñuelas et al. (1994)
Red-edge NDVI (Red-edge NDVI)	Red-edge $NDVI = (R_{750}–R_{720})/(R_{750}+R_{720})$	Chlorophyll content	Gitelson and Merzlyak (1994)
Structural Independent Pigment Index (SIPI)	$SIPI = (R_{800}–R_{445})/(R_{800}+R_{445})$	Chlorophyll content	Peñuelas et al. (1995)

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Gitelson, A. and Merzlyak, M. N.: Quantitative experiments estimation of chlorophyll-a using reflectance spectra: experiments with autumn chestnut and maple leaves, J. Photochem. Photobio., 22, 247–252, 1994.

- **Tables 3 and 4: These are too complex to be able for readers to digest easily. Eliminate the exponential relationships. The number of significant digits is not appropriate for all metrics. For example the RMSE for _ and " is not 0.0. Readers cannot make any valid comparisons with insufficiently presented tables.**

Eliminate the AIC from the tables as the AIC values should only be compared between models with increasing complexity using the same data set (i.e. the same VI estimating the same BPC). The table makes it appear that these AIC values can be compared across VIs, when this is not the case due to the different values/dynamic ranges of VIs.

RESPONSE
We agree and we will correct these tables in the revised manuscript.

Figures

- **Figure 1: It is difficult to read the VI text on the figure. Define all abbreviations in figure captions so readers do not need to find them in the text.**

RESPONSE
We agree and we will add the VIs definition in the figure caption.

- **Figures 4-9: Use the figures in the supplemental. The information in the poor relationships are just as valuable.**

RESPONSE
Thanks for the suggestion. We agree and we will substitute figures 4-6 with equivalent figures of the supplemental (figures from S1 to S3). Figures 7-9 will be removed from the text and equivalent figures of the supplement (figures from S7 to S9) will be removed as well.

- **Figure 10: It does not matter if the model is more “accurate” if a significant portion of the dynamic range is insensitive to changes in GPP. It would be helpful to readers if a figure using the proposed VIs vs. BPCs were presented.**

RESPONSE
Thank for the suggestion, the Figure 10 of GBD paper will be removed. A new figure C1 (see above) using the proposed VIs vs. BPCs for each site and all sites pooled together will be added to the revised version of the manuscript. The fitting models and the cross validation metric are presented in the figure.

Other Notes:

- **These correlation matrices are not ideal for identifying the best bands except for very simple cases. An approach that would have yielded a more informative conclusion would be a GA-PLS analysis which can provide insight into more complex interactions between different wavebands.**

RESPONSE
We believe that genetic algorithms (i.e. GA-PLS) are stronger techniques than correlation matrices to identify best bands. In the revision version of the paper we will explore also the use of hybrid feature selection strategy based on genetic algorithm and random forests (GA–rF). The first method was used for the feature selection and the second as regression for predicting the target variables. First of all we aggregated the original dataset to 10 nm in order to lessen the effects of spatial autocorrelation. Li et al. 2010 suggested for the same purpose the use of the information theory. This approach is limited to a specific measurements and can't be applied for this our study since we aimed to compare multiple sites and find generalizable hot spots in the spectral domain. The genetic algorithm is based on an evolutionary principle: "the survival of the fittest". It generates a number of possible model solutions

(chromosomes) and uses these to evolve towards an approximation of the best solution of the model. In our case the genes of each chromosome are the wavelengths. We made use of 5 genes for each chromosome. We opted for such a length to overcome overfitting. Each population of 1000 chromosomes evolved for 200 generations. The mutation chance was set to the inverse of population size increased by one. The fitness of each chromosome was measured by means of the applying the random forest algorithm (Breiman, 2001). This was used as ensemble method for regression that is based on the uncontrolled development of decision trees (n=100). We opted for this method because of it is demonstrated the efficiency with large datasets. In combining the two methods we choose the mean squared error as target variable.

The new section 2.4 “Band selection based on the combination of random forests and genetic algorithm (GA–rF)” containing the above information will be added to the revised version of the manuscript.

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Technical Corrections:

- **P10325L4: The word “lately” implies very recent papers, 2007-2010 are recent, but not very recent. Delete the word or find more recent publications.**

RESPONSE
Thanks for the correction. We will delete this word in the revised manuscript.

- **P10326L12: Misplaced comma after “and”**

RESPONSE
Thanks, we will correct it in the revised manuscript.

Interactive comment on "On the relationship between ecosystem-scale hyperspectral reflectance and CO_2 exchange in European mountain grasslands" by M. Balzarolo et al.

Anonymous Referee #2

Received and published: 11 August 2014

General comments:

This paper reports an experimental study for spectral assessment of grassland CO2 exchange. This study utilizes several datasets in grassland sites that may be unpublished, but the study motivation, research concept and analytical methods do not include any original/innovative ones. In other words, this study seems to be a simple exercise using some new datasets based on similar research motivation, concept and methods as in preceding papers. Although a plenty of results are shown in Tables and Figures, the obtained results do not seem to include any essential findings or robust/useful relationships for remote sensing of ecosystem CO2 exchange. Despite the plenty of dataset, fitting results are not validated using independent dataset. More importantly, the majority of conclusions, insights and messages are confirmation or repetition of well-reported ones in preceding papers. Since this type of datasets have been collected through so-called FLUXnet as well as many other individual experiments, similar analysis can easily be done using a new dataset by using similar analytical approach as in this paper. However, preliminary exercises are not very worthwhile in the context of science and technology as well as operational applicability. Truly comprehensive or comparative studies are strongly expected.

Therefore, unfortunately, it is difficult to recommend this paper for publication as an independent scientific paper

Since this type of datasets have been collected through so-called FLUXnet as well as many other individual experiments, similar analysis can easily be done using a new dataset by using similar analytical approach as in this paper

Reviewer #2 reports that the paper is not an "original/innovative study" and the obtained results do not include "any essential findings or robust/useful relationships for remote sensing of ecosystem CO_2 exchange". We disagree with the reviewer on this position and instead think that the paper contains novel information and results that are of interest for the scientific community, but obviously that we need to better demonstrate the value and strengths of our study. Here below and in the revised version of the manuscript we will try to better explain which was the objective of the work and which are the findings.

A unique feature of our work, which contrasts with previous work relying on multi-spectral data in few wavebands only, is that we explore the entire visible to NIR space for correlations with the CO_2 exchange of European mountain grasslands. In this regard we would appreciate if the reviewer could substantiate his/her claim that this is a repetition of previous papers.

While it is true that our study does not yield robust and significant relationships, we still think that this is an essential finding and that the reviewer is misled in thinking that only significant results should be published. In our understanding this is a gross misconception as such an approach would bias science towards results that yield significant results. Note that we do not overstate our results, but openly acknowledge that despite major efforts to standardize measurements and rather similar ecosystems largely fail to detect robust general patterns. This in our view is a result worth publishing as it may help to design future studies and experiments to track down the underlying causes in addition to serve as reference in the definition of continuous reflectance measurements at eddy covariance sites in large organized networks such ICOS, AmeriFlux or NEON.

The dataset used in this paper was built based on a coordinated field experiment by three groups in order to standardize in-situ hyperspectral measurements and make these measurements comparable. We used the same experimental design at all sites by mounting the same model of spectroradiometer (i.e. ASD Hand Held) on aluminum boom of 1.5 m height in the footprint area of the flux tower. Generally, hyperspectral measurements in flux networks (e.g. FLUXNET, CarboEurope) are made individually by different groups, following their own methodologies and on few selected spectral wavelengths. As shown in Balzarolo et al. (2011), there exists no common protocol for hyperspectral measurements in the eddy covariance networks. Therefore, available hyperspectral measurements are not standardized and comparable between different sites: how to standardize measurements and make results comparable are still open questions. Thus, the dataset used in this paper is unique as it combines hyperspectral and flux measurements from three different studies based on common protocol. Obviously, the reviewer would like to see a different paper, namely one that takes a broader approach by including more sites from a more diverse set of ecosystems. While we acknowledge that such a global synthesis would be a highly interesting scientific endeavor, this is not the scope of our study and we will better clarify this in the introduction of the revised version of the manuscript. In addition we also anticipate major uncertainties to result from the lack of standardization of optical measurements that would be a potentially added problem for such global synthesis with the actual measurements available.

Although in the paper we considered similar ecosystems (belonging to the same vegetation type) the investigated canopies are very different and include Mediterranean, extensive alpine and intensive alpine grasslands with very different canopy structures in terms of leaf orientation, amount and spatial distribution of green and non-photosynthetic components, leaf nitrogen and water content (see Vescovo et.al, 2012). The different grassland structures (spatial distribution of photosynthetic, and also non photosynthetic material, leaf angles, etc.) is affecting our ability to use traditional indices to estimate fAPARgreen (and fluxes) when we consider different grasslands together because the structural effects on scattering are very complex in the NIR response (Jacquemoud et al., 2009; Knyazikhin et al., 2012).

In addition, it is not the main motivation of our study to devise the best possible model for estimating GPP or other carbon flux metrics (which the reviewer apparently would like to see), rather, as formulated in the title, the main objective is to explore the links between the vast information contained in hyperspectral reflectance in the VIS to NIR range and the relationships to CO_2 exchange.

The suggestion of the reviewer to add further sites and data to validate the found relationships is appreciated and carefully take into account by the authors by answering to his/her comments. In the revised version of the manuscript the metrics obtained by the leave-one-out procedure will be applied to BGD dataset and the results will be reported and discussed. In particular, the robustness of the models will be evaluated by: cross validated R-Squared (R^2cv) and cross validated Root Mean Squared Error (RMSEcv). The new figure C1 (here below) will be added to the revised version of the manuscript. Cross-validation showed that the selected models are robust. In addition, in order to evaluate the performance of the found relationships and the new selected bands the authors included three new sites in their database (validation sites – see Tab. S1 below). These three additional sites were already part of the preceding study by Vescovo et al. (2012) and used exactly the same methodology as applied at the main three study sites and thus fully comply with our own standards of intercomparability.

Unfortunately join spectral and eddy covariance measurements are available only for few days and this is why were not included in the BGD paper and in the correlation matrix analysis. Validation will be performed applying to the three new sites all the three site specific models (Amplero, Neustift and Monte Bondone) and a model parameterized grouping Neustift and Monte Bondone since the two sites are characterized by similar environmental conditions. The figure C2 here below shows the results of the validation of the models against validation sites for the midday time scale. In the revised version of the manuscript these results and the results of the validation of the models against validation sites for daily time scale will be added and commented. As shown in this figure, correspondence between simulated and measured VIs was reasonable when using the models developed for Monte Bondone and Neustift or both sites pooled, but less so with the models of Amplero. This is understandable as Monte Bondone and in particular Neustift are structurally and functionally much more similar to the validation sites compared to Amplero. Overall, the validation shows that the models developed are transferable.

The authors think that following unexpected and novel results are presented in the paper.

Considering all sites pooled together, NSD-type "Visible vs. NIR" band combinations (i.e. traditional "greenness" indices) show a very poor correlation with GPP. It is well-reported in the literature (Rossini et al., 2010, 2012; Peng et al., 2010; Sakowska et al., 2014) that “greenness” indices, for grasslands and crops, are good proxies of fAPARgreen (and thus carbon fluxes). Interestingly, in our paper their performance is considerably poorer than expected. This result is of importance for the community which still relies a lot on these relationships, also favored by the availability of cheap narrow-band sensors that allow continuous monitoring of e.g. NDVI. This finding has also a relevant impact concerning the ability to upscale grassland fAPARgreen and carbon fluxes using upcoming sensors (e.g. Sentinel 2).

NSD-type "Visible vs. Visible" band combinations show a better performance than "Visible vs. NIR" ones. "Visible vs. visible" NSD (e.g. green vs. blue or red, green vs. green wavelengths; see e.g. Inoue et al, 2008) are also known to work as “greenness” indices, although their performance is generally much poorer than “Visible vs. NIR" indices. These results are likely due to the confounding effect of the different structures (and consequently of the different NIR response; Vescovo et al, 2012) of the investigated grasslands.

Chlorophyll indices (e.g. NDVI red-edge = (R750−R720)/(R750+R720) – which are considered the best indices for estimating carbon fluxes on grasslands and crops) – show in our dataset a very low performance. It was demonstrated many years ago that the red edge domain, where reflectance changes from very low in the absorption region to high in the NIR, is one of the best descriptors of chlorophyll concentration. On the other hand, it is well known that the canopy structure can be a very strong confounding factor. Our results confirm that this topic needs to be further investigated, as this finding has a relevant impact concerning the use of Sentinel 2 to upscale fAPAR and carbon flux observations.

It is quite interesting to see that the NSD "NIR vs. NIR" (structural indices) appear to be the best proxy for GPP fluxes when all the grasslands are analyzed together. These results can be linked to the controversial paper focused on the strong impact of structure on the ability to estimate canopy nitrogen content (Knyazikhin et al., 2012) and confirm the need for more studies in this direction.

In summary, we will modify the manuscript to better emphasize the novelty and value of our study by including the reasoning above.

<u>The following new Table S1 will be added to the revised version of the manuscript:</u>

Table S1. Description of the validation study sites and period.

Site characteristics	Längenfeld (AT-Lan)	Leutasch (AT-Leu)	Scharnitz (AT-Sch)
Latitude	47.0612	47.3780	47.3873
Longitude	10.9634	11.1627	11.2479
Elevation (m)	1180	1115	964
Mean annual temperature (˚C)	5.8	4.8	6.4
Mean annual precipitation (mm)	733	1309	1418
Vegetation type	*Phyteumo-Trisetion*	*Astrantio-Trisetetum*	*Arrenatherum montanum*
Study period[1]	163, 2006 (1)	227, 2006 (1)	184-284, 2006 (5)
Sonic anemometer model	R3, Gill Instruments Ltd., Lymington, UK	R3, Gill Instruments Ltd., Lymington, UK	R3, Gill Instruments Ltd., Lymington, UK
Infrared gas analyser model	Li-7500, Li-Cor Inc., Lincoln, Nebraska, USA	Li-7500, Li-Cor Inc., Lincoln, Nebraska, USA	Li-7500, Li-Cor Inc., Lincoln, Nebraska, USA
Data acquisition frequency (Hz)	20	20	20
Post-processing software	EdiRE (Version 1.4.3.1021, R. Clement, University of Edinburgh)	EdiRE (Version 1.4.3.1021, R. Clement, University of Edinburgh)	EdiRE (Version 1.4.3.1021, R. Clement, University of Edinburgh)
Outlier removal (method)	-	-	-
CO_2/H_2O signal lag removal	Covariance maximization	Covariance maximization	Covariance maximization
Coordinate rotation (method)[2]	3D	3D	3D
Detrending of time series (method)	-	-	-
Density corrections applied[3]	X	x	x
Sonic buoyancy to sensible heat flux conversion and cross-wind correction[4]	X	x	x
Low- and high-pass filtering corrected for (method)	Moore (1986)	Moore (1986)	Moore (1986)

[1] from-to DOY, year (number of hyperspectral measurement dates); [2] according to Wilczak et al. (2001); [3] according to Webb et al. (1980); [4] according to Schotanus et al. (1983); [5] according to Mauder et al. (2008).

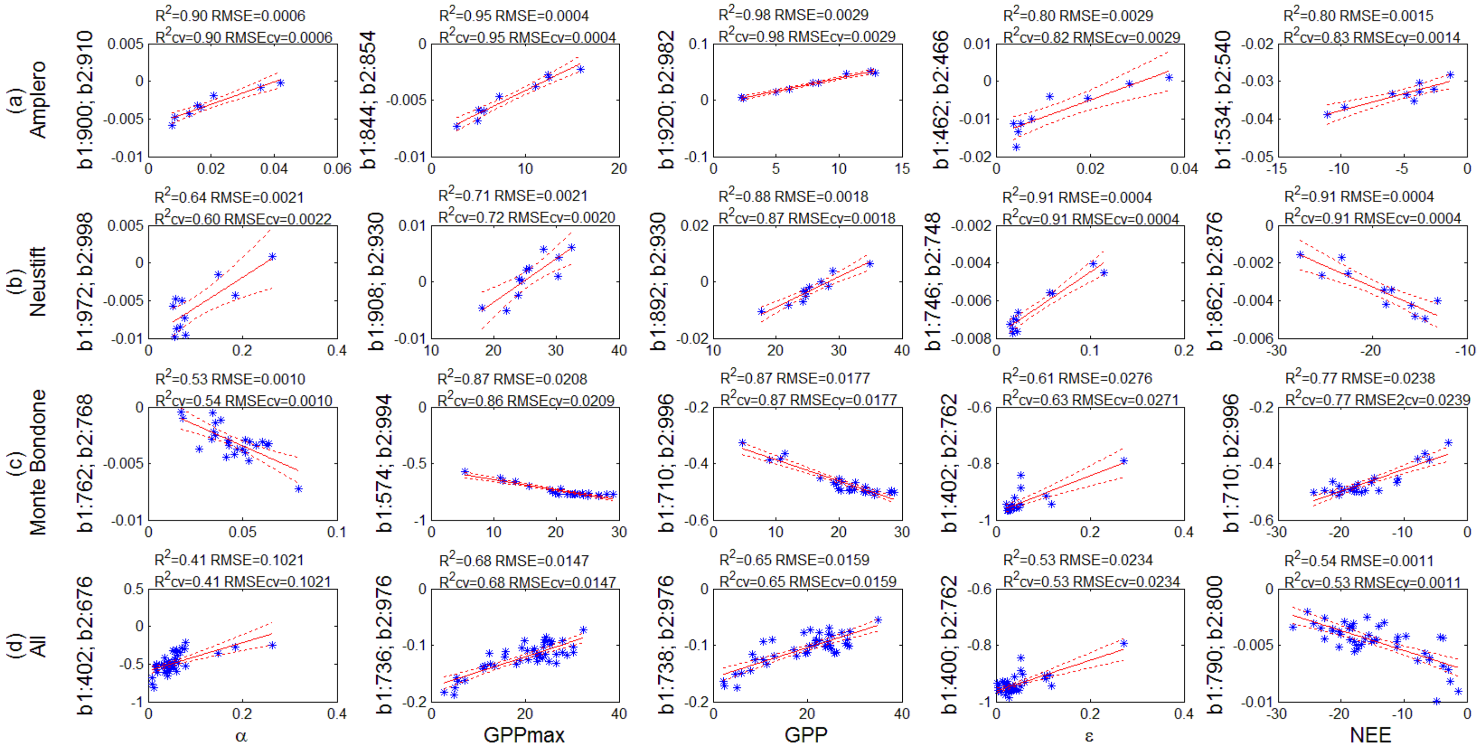

Fig. C1: Results of linear correlation analysis for α, GPPmax and midday averaged GPP, ε and NEE and selected NSD-type indices for (a) Amplero, (b) Neustift,(c) Monte Bondone (both study years pooled) and (d) all sites pooled. R^2—Coefficient of determination; RMSE—Root Mean Square Error; R^2cv—Cross-validated coefficient of determination; $RMSE_{cv}$— Cross-validated root Mean Square Error. The red lines indicate the fitted models and the red dotted lines represent the 95% upper and lower confidence bounds.

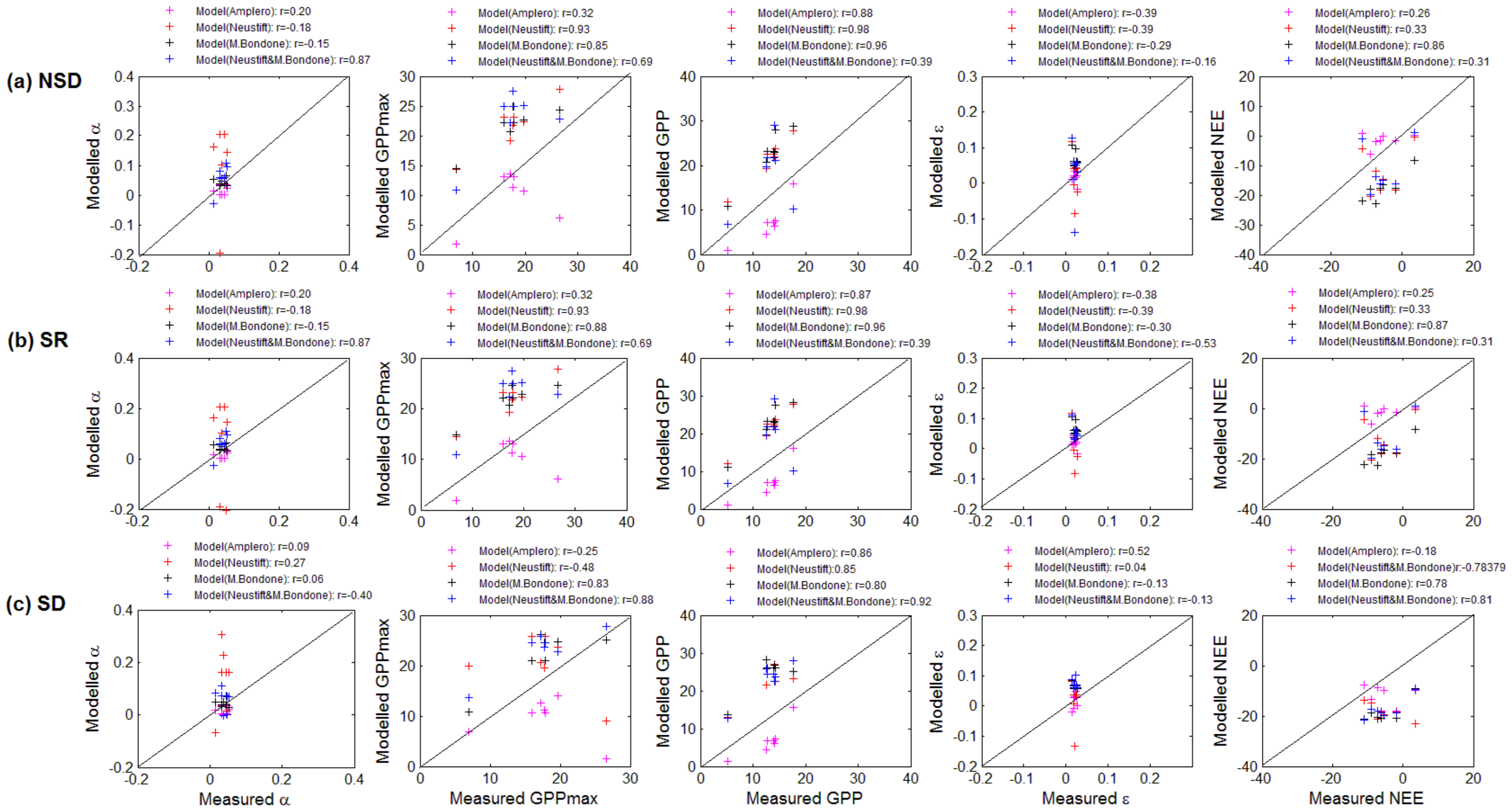

Fig. C2 – Results of validation of linear regression models between VIs ((a) NSD type; (b) SR-type; (c) SD-type) and ecophysiological parameters: α, ε (midday average), GPP_{max} and midday average CO_2 fluxes (NEE and GPP). r—coefficient of correlation. Different colours represent results of the validation performed applying to the three new sites the model for Amplero (in magenta), Neustift (in red) and Monte Bondone (in blue) and a model parameterized grouping Neustift and Monte Bondone (in black).

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Specific comments:

1. P26L6-8: This statement may be misleading because "plant functioning" can be represented by the combination of canopy structure (LAI, 3D distribution), components (chlorophyll, nitrogen, water, etc.), and biophysical/physiochemical reactions. In addition, the observational time resolution would greatly affect the definition and analysis of the "photosynthetic functioning". More precise discussion is needed.

RESPONSE

We agree and we will change this sentence into "…indicators of the amount of green biomass, fAPAR green, rather than plant light use efficiency"

2. P26L24-P27L10: Methodological review in this section is very insufficient. Note that a number of approaches have been investigated for remote sensing of ecophysiological variables such as chlorophyll, nitrogen, LUE, water, LAI, fAPAR, etc. not only in grassland but in the other vegetation types. From methodological point of view, it is not appropriate to limit things to grassland.

RESPONSE

We agree and we will rewrite this part including more approaches used in remote sensing and we will not focus only on grassland. We will include a new part in the revised version of the manuscript where related to the investigation of biophysical variables by remote sensing. Please see the revised version of the introduction in the second part of the answer to the comment 3.

3. P26L24-P27L10: Analytical approaches of hyperspectral reflectance are 1) hyperspectral index methods, 2) multi-variable statistical methods (PLSR etc.), and 3) use of radiative transfer models (PROSAIL etc.). Hence, more comprehensive reviewing on methodologies is needed. In addition, this paper seems to focus only on a part of the approach 1) without showing any rationale. Some reasons and theoretical necessity should be provided.

RESPONSE

The general aim of our paper was to understand if there were some spectral regions where VIs and fluxes and biophysical variables showed the same performance for each site or for all sites pooled together. A set of traditional VIs was selected to analysis the behavior of the three different grasslands. Once to note the specific response of the three grasslands to each biophysical parameter, we processed with correlation matrix analysis to see if there were spectral region where VI vs. biophysical parameters performed in the same ways. We agree that we partially explore the approach (1). By validating the selected models (see general comment) we will improve the BGD paper and we will fully apply this analytical approach.

It is true that there are many studies that showed this type of analysis but there are not studies were different grasslands with different structural and functional characteristics are compared. This is the first reason for which we did this study. Another reason is related to the selection of the spectral bands to use for investigating grassland dynamics.

The introduction of the BGD paper will be restructured and the reasons and theoretical necessity of the study will clearly state in the revised version of the manuscript.

In addition we will include comments on the most used analytical approaches of hyperspectral reflectance. We will add also a new part related to the investigation of biophysical variables by remote sensing (see answer to the comment 2).

In detail, to answer to the comments 2 and 3 the introduction of the BGD paper will be restructured and the reasons and theoretical necessity of the study will clearly state in the revised version of the manuscript. Here below the introduction that will be included in the revised version of the manuscript with the new added references.

Understanding the mechanisms that drive the carbon dioxide (CO_2) uptake of the terrestrial ecosystems is one of the main challenges for the ecologists working on climate changes (Beer et al., 2010). Plant photosynthesis, also referred to as gross primary productivity (GPP), is one of the major components of the global carbon cycle. It interacts in complex ways with environmental factors such as radiation, nutrients, soil water, vapor pressure deficit, air temperature and soil temperature (Drolet et al. 2005). Plant biochemistry and structure determine many fundamental ecosystem patterns, processes and dynamics (Lambers et al. 1998; Waring and Running 1998). The canopy nitrogen content regulates the canopy photosinthtic capacity and the canopy light use efficency (LUE) (Ollinger et al., 2008). In addition, the canopy chlorophyll content plays an important role in controlling ecosystem photosynthesis and the carbon gain (Peng et al., 2011, Gitelson et al., 2006).

Optical remote sensing can help ecologists in qualitatively and quantitatively assessing the plant and canopy properties (e.g. biomass (Vescovo et al. 2012), water content (Clevers et al., 2010), nitrogen content (Chen et al., 2010; Ollinger et al., 2008; Knyazikhin et al., 2012) and chlorophyll content (Gitelson et al., 2006) and photosynthetic rate (Inoue et al., 2008)) that drive ecosystems processes related to the carbon cycle.

Empirical and physical-based methods have been proposed to interpret optical plant and canopy properties. The empirical method consists of (linear) regression analysis between plant or canopy properties and optical data. The most used empirical methods are: hyperspectral index methods (Peñuelas et al., 1993; Sims and Gamon, 2002; Inoue et al., 2008) and multi-variable statistical methods (e.g. stepwise linear regression, genetic algorithm, neural network (Grossman et al., 1996; Riaño et al., 2005a; Li et al., 2007). The physical methods are based on the use of radiative transfer models (RTMs) to simulate light absorption and scattering trough the canopy as a function of canopy structure and leaf biochemical composition (Jacquemoud et al., 2000; Zarco-Tejada et al., 2003). Therefore, RTMs models help in quantifying the contribution of canopy biophysical and biochemical variables to canopy reflectance. The most popular RTM is PROSAIL model based on the coupling of the SAIL bidirectional canopy reflectance model (Verhoef et al., 1984) and the PROSPECT leaf optical properties model (Jacquemoud and Baret, 1990). The model simulations by PROSAIL demonstrated that the red-edge region (between 680 nm to 730 nm) of the spectrum is sensitive to the chlorophyll and leaf area index (LAI) (Baret et al., 1992). It is also well accepted that an increase of LAI includes a decrease of reflectance in the red and da increase in near-infrared (NIR) region (Jacquemoud, 1993). In the NIR region LAI and the leaf angle contribute in the same portions to the reflectance (Bacour et al., 2002a). NIR reflectance between 800 nm and 850 nm is also related to canopy N content (Ollinger et al., 2008; Knyazikhin et al., 2012). In addition, the combination of the reflectance in NIR and in the short wave infrared region (SWIR) is correlated to canopy water content (Colombo et al., 2008) but the reflectance between 1000 nm and 1400 nm is also highly sensitive to LAI. So, some attention is needed when these spectral regions are used to retrieve water content considering that the canopy properties in a given ecosystem often co-vary (Bacour et al., 2002c). Those remarkable optical properties of the canopy need to be taken into account to quantify vegetation properties by hyperspectral index method. The hyperspectral index method consists of the use of spectral vegetation indices (VIs) defined as spectral band ratios, or normalized band ratios between the reflectance in the visible and near-infrared (NIR) region.

The typical optical sampling approach to estimate GPP, which is linking spectral observations with carbon fluxes, is based on the Monteith equation (1972, 1977):

$$\mathrm{GPP} = \varepsilon * \mathrm{PAR} * \mathrm{fAPAR} \tag{1}$$

where ε is the light use efficiency (LUE) and fAPAR is the fraction of absorbed photosynthetically active radiation); both ε and fAPAR can be retrieved by remote optical observations. A wide number of VIs that can potentially be used to model the productivity of terrestrial ecosystems (as a proxy of LUE and fAPAR) has been suggested (Inoue et al., 2008; Coops et al., 2010; Peñuelas et al., 2011; Rossini et al. 2012). The various VIs differ in their sensitivity to changes in photosynthetic status. "Greeness indices" – such the widely used Normalized Difference Vegetation Index (NDVI) – demonstrated to be a good proxy for fAPAR, but are not sensitive to rapid changes in plant photosynthesis which are induced by common environmental and anthropogenic stressors (Gitelson et al., 2008; Hmimina et al., 2014; Soudani et al., 2014). However, in ecosystems characterized by strong dynamics (e.g. grasslands and crops with a strong green-up and senescence), other VIs are able to effectively monitor seasonal changes in biophysical parameters controlling canopy photosynthesis such as fAPAR and chlorophyll content and~~,~~ consequently, can be adopted to monitor seasonal and spatial variability of carbon fluxes (Gitelson et al., 2012; Sakowska et al., 2014). Short-term changes in LUE can be remotely detected through a spectral proxy of the xanthophyll cycle (Photochemical Reflectance Index, PRI; Gamon et al., 1992). The PRI is one of the most promising VIs for a direct estimation of photosynthetic light use efficiency (LUE) and of its seasonal and diurnal variations (Nichol et al., 2002). Latest developments of the sun-induced fluorescence method may allow even more direct remote sensing of plant photosynthesis in the near future (Meroni et al., 2009; Rossini et al., 2010; Frankenberg et al., 2011). At canopy scale, the relationship between PRI and LUE was shown to be site dependent (Garbulsky et al., 2011; Goerner et al., 2011) and strongly affected by environmental conditions (Soudani et al. 2014).

Whereas previous studies have demonstrated the ability of remote sensing data to model ecosystem GPP (e.g. Gianelle et al., 2009; Wohlfahrt et al., 2010; Rossini et al. 2012; Sakowska et al., 2014), a universal model for GPP estimation applicable across different ecosystems and a wide range of environmental conditions is still missing. In addition, those previous studies focussed on single sites with specific characteristics (e.g. climate, vegetation composition, soil type; see Wohlfahrt et al., 2010) and were often based on the use of different sensors, platforms and protocols (Balzarolo et al., 2011), making generalisation difficult. Moreover, most of the studies have either relied on reflectance measurements in a few spectral wavebands (e.g. Wohlfahrt et al., 2010 and Sakowska et al, 2014) or a minimum number of bands needed to calculate the most common VIs, missing potentially important information in under-sampled spectral regions that could explain carbon fluxes and variability. In recent years, SpecNet (http://specnet.info; Gamon et al., 2006), the European COST Action ES0903 (EUROSPEC) (http://cost-es0903.fem-environment.eu/) and the COST Action ES1309 (OPTIMISE;

http://www.cost.eu/domains_actions/essem/Actions/ES1309) focused on the definition of a standardized protocol for making optical measurements at the eddy covariance CO_2 flux towers (Gamon et al., 2010).

The overarching objective of the present paper is thus to develop a common framework for predicting grassland carbon fluxes and ecophysiological parameters based on optical remote sensing data. To this end we combine eddy covariance CO_2 flux measurements with ground-based hyperspectral reflectance measurements at six different grasslands in Europe using a standardised common protocol. This database is unique and we are not aware of any other study collating a similar multi-site dataset. We focused on European grasslands since covering roughly 22% (80 million ha) of the EU-25 land area, grasslands are among the dominating ecosystem types in Europe (EEA, 2005) and their role in the European carbon balance has received a lot of scientific interest (Soussana et al., 2007; Gilmanov et al., 2007; Wohlfahrt et al., 2008; Ciais et al. 2010). While direct measurements of the carbon exchange have been carried out and are still ongoing at a number of different grassland sites in Europe –notably in the two EU projects GreenGrass (Soussana et al., 2007) and CarboMont (Cernusca et al., 2008) – scaling up these plot-level measurements to the continental scale requires a modelling approach, typically based on or supported by remotely sensed data. Therefore, we believe that this study will improve the current knowledge on modelling the carbon dynamics of European grasslands.

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4. P26L24-P27L10: The biophysical and ecophysiological processes for spectral reflection, transmission and absorption by ecosystems have already been understood very well in physical principle, and the major parts of such processes have been modeled. Therefore, it is already obvious that simple linear/non-linear regression models using VIs can never be applicable universally to a wide range of vegetation and/or environmental conditions. Therefore, the simple confirmation of such well-known facts using different datasets is neither new nor useful. Hence, new research should focus on 1) innovative methods to overcome such limitations, or 2) optimization for higher accuracy and applicability using simple approach. Nevertheless, this study is quite insufficient in both aspects.

RESPONSE

We agree with the reviewer and in the revised version of the manuscript we will add some explanations of the existence of the correlation in some spectral regions. To investigate more the basis of the correlation between the selected band combinations and ecophysiological variables (e.g. alpha, GPPmax, GPP, epsilon) in the revised version of the paper we will analyse the relationship between the selected bands and biophysical parameters such as dry phytomass, nitrogen and water content collected during the field campaign in the same footprint of hyperspectral measurements. We selected these biophysical variable because they are related to the vegetation structure and can be helpful for interpreting the spectral response of the grassland in the NIR region. The new tables S2 and S3 (here below) will be added to the revised version of the manuscript. This analysis confirmed that the that the spectral response in the selected band combinations for NDS, SR and SD-type indices is strongly related to structural characteristics of the vegetation of the three grasslands (e.g. nitrogen and phytomass) that impact on their spectral response in NIR and VIS regions. For the Mediterranean site (Amplero site) and for all eco-physiological parameters (i.e. a, GPPmax, GPP, epsilon) the dry phytomass is the main driving factor of the spectral response in the selected bands while nitrogen content drives the spectral response in the NIR region for Neustift. For Monte Bondone both dry phytomass and nitrogen content affect the spectral response of the grassland. Similar results were obtained for SR and SD-type indices.

Therefore, according to the obtained results, more studies are needed to understand the physical basis of this correlation. In addition, these new analysis will substantially contribute to the analysis of the structural effect on the ability to estimate canopy nitrogen content that is still a controversial issue (Knyazikhin et al., 2012).

In addition, to investigate more the basis of the correlation between the NIR band combinations and GPP, we analyzed a similar dataset collected in summer 2013 on Monte Bondone. Measurements were acquired using the same ASD FieldSpec spectrometer used for Monte Bondone in 2006 (serial number: 6354). The measurements were taken on the tower at a height of 6 m, with a field of view of 25°. To obtain reflectance values, white panel radiance spectra and canopy radiance spectra were acquired at approximately weekly intervals. At the same time of the hyperspectral measurements, measurements of the canopy chlorophyll and canopy water content were performed within the spectrometer footprint (5 m2). In the Figure C3, it is possible to see that, NSD- and SR-type indices for the selected bands for estimating GPP (i.e. 710 nm and 996 nm) are strongly correlated with canopy total chlorophyll content ($R^2 > 0.90$). For the band combinations < 750 nm, the correlation is related to chlorophyll content while for band combinations > 750nm (which is the most common situation; e.g. 761 and 770, 761 and 850, 800 and 850, etc.) there is a structural effect which needs to be further investigated (confirmed by Gitelson by a personal communication). In fact, the literature indicates that the wavelenghts in the NIR (>750nm) are not sensitive to chlorophyll content. They are sensitive to leaf and canopy structure (and around the 970nm area to water). These new analysis will substantially help to the analysis of the structural effect on the ability to estimate canopy nitrogen content that is still a controversial issue (Knyazikhin et al., 2012).

Table S2. Results of the correlation (r – correlation coefficient) between the best NDS, SR and SD-type indices and dry phytomass and nitrogen content for Amplero, Neustift, Monte Bondone for the alpha, GPPmax, midday GPP, midday epsilon and midday NEE.

			α		GPPmax		GPP		ε		NEE	
Index	**Site**	**Parameter**	**Band center [i,j]** (nm)	**R^2** (-)	**Band center [i,j]** (nm)	**R^2** (-)	**Band center [i,j]** (nm)	**R^2** (-)	**Band center [i,j]** (nm)	**R^2** (-)	**Band center [i,j]** (nm)	**R^2** (-)
NSD-type	Amplero	Dry phytomass (g m-2)	[900, 910]	-0.81**	[844, 854]	-0.85**	[920, 982]	-0.76*	[462, 466]	-0.87**	[534, 540]	0.60
	Amplero	Nitrogen content (%)		0.54		0.57		0.44		0.70*		-0.39
	Amplero	Water content (%)		0.53		0.73*		0.75*		0.66		-0.74*
	Neustift	Dry phytomass (g m-2)	[972, 998]	-0.04	[908, 930]	0.51	[892, 930]	0.59	[746, 748]	-0.66*	[862, 876]	0.15
	Neustift	Nitrogen content (%)		0.40		-0.39		-0.46		0.88**		0.18
	Neustift	Water content (%)		-0.07		0.03		-0.18		0.77*		0.31
	Monte Bondone	Dry phytomass (g m-2)	[762, 768]	-0.13	[574, 994]	-0.77***	[710, 996]	-0.70***	[402, 762]	-0.74***	[710, 996]	-0.70***
	Monte Bondone	Nitrogen content (%)		0.29		0.72***		0.62**		0.69***		0.62**
	Monte Bondone	Water content (%)		0.31		0.69***		0.59**		0.65***		0.59**
	All	Dry phytomass (g m-2)	[402, 676]	0.23	[736, 976]	0.12	[738, 976]	0.14	[400, 762]	-0.22	[790, 800]	0.06
	All	Nitrogen content (%)		0.51***		0.19		0.13		0.64***		0.30
	All	Water content (%)		0.03		-0.09		-0.09		0.32*		0.05
SR-type	Amplero	Dry phytomass (g m-2)	[900, 910]	-0.81***	[844, 854]	-0.85**	[920, 982]	-0.76*	[462, 466]	-0.87*	[534, 540]	0.60
	Amplero	Nitrogen content (%)		0.54		0.57		0.43		0.70*		-0.39
	Amplero	Water content (%)		0.53		0.73**		0.74*		0.66		-0.74*
	Neustift	Dry phytomass (g m-2)	[972, 998]	-0.04	[908, 930]	0.51	[892, 930]	0.59	[746, 478]	-0.66*	[862, 876]	0.15
	Neustift	Nitrogen content (%)		0.40		-0.39		-0.46		0.88**		0.18
	Neustift	Water content (%)		-0.07		0.03		-0.18		0.77*		0.31
	Monte Bondone	Dry phytomass (g m-2)	[762, 768]	-0.13	[570, 994]	-0.77***	[714, 996]	-0.73***	[402, 762]	-0.74***	[570, 574]	0.61**
	Monte Bondone	Nitrogen content (%)		0.29		0.73***		0.64***		0.69***		-0.53**
	Monte Bondone	Water content (%)		0.31		0.69***		0.61**		0.64***		-0.50*
	All	Dry phytomass (g m-2)	[402, 676]	0.28	[736, 976]	0.14	[738, 976]	0.15	[400, 762]	-0.22	[790, 800]	0.06
	All	Nitrogen content (%)		0.51***		0.19		0.13		0.63***		0.30
	All	Water content (%)		-0.01		-0.10		-0.10		0.33*		0.05
SD-type	Amplero	Dry phytomass (g m-2)	[900, 910]	-0.80***	[844, 866]	-0.90**	[920, 982]	-0.77*	[492, 496]	-0.76*	[422, 432]	-0.50
	Amplero	Nitrogen content (%)		0.47		0.55		0.46		0.55		0.19
	Amplero	Water content (%)		0.41		0.67*		0.77*		0.43		0.70*
	Neustift	Dry phytomass (g m-2)	[474, 494]	-0.45	[736, 968]	0.20	[878, 922]	0.61	[732, 942]	-0.45	[402, 456]	-0.04
	Neustift	Nitrogen content (%)		0.33		0.09		-0.34		0.90**		-0.28
	Neustift	Water content (%)		0.15		0.51		-0.04		0.80*		-0.72*
	Monte Bondone	Dry phytomass (g m-2)	[762, 768]	-0.38	[444, 482]	0.65***	[436, 488]	0.60**	[658, 682]	0.67***	[450, 486]	0.60**
	Monte Bondone	Nitrogen content (%)		0.53***		-0.58**		-0.58**		-0.62**		-0.59**
	Monte Bondone	Water content (%)		0.52***		-0.58**		-0.58		-0.56**		-0.55**
	All	Dry phytomass (g m-2)	[822, 824]	0.45***	[550, 560]	0.12	[414, 470]	0.00	[732, 928]	0.55***	[468, 660]	-0.11
	All	Nitrogen content (%)		-0.09		-0.09		-0.15		0.16		-0.33*
	All	Water content (%)		-0.08		0.18		0.19		-0.53***		0.24

Statistical significance is indicated as * ($p < 0.05$), ** ($p < 0.01$), and *** ($p < 0.001$).

Table S3. Results of the correlation (r – correlation coefficient) between the best NDS, SR and SD-type indices and dry phytomass and nitrogen content for Amplero, Neustift, Monte Bondone for daily GPP, ε and NEE.

			GPP		**ε**		**NEE**	
Index	**Site**	**Parameter**	**Band center [i,j]**	**r**	**Band center [i,j]**	**r**	**Band center [i,j]**	**r**
			(nm)	(-)	(nm)	(-)	(nm)	(-)
NSD-type	Amplero	Dry phytomass (g m-2)	[868, 878]	-0.82**	[896, 904]	-0.89**	[902, 922]	-0.83**
	Amplero	Nitrogen content (%)		0.61		0.54		0.56
	Amplero	Water content (%)		0.81**		0.53		0.85**
	Neustift	Dry phytomass (g m-2)	[972, 988]	-0.14	[722, 942]	-0.54	[422, 516]	-0.25
	Neustift	Nitrogen content (%)		0.27		0.91**		0.15
	Neustift	Water content (%)		0.19		0.80*		0.06
	Monte Bondone	Dry phytomass (g m-2)	[580, 986]	-0.75***	[658, 682]	0.69***	[712, 714]	-0.52*
	Monte Bondone	Nitrogen content (%)		0.71***		-0.66***		0.50*
	Monte Bondone	Water content (%)		0.67***		-0.61**		0.43*
	All	Dry phytomass (g m-2)	[736, 976]	0.12	[404, 944]	-0.21	[790, 798]	0.02
	All	Nitrogen content (%)		0.19		0.68***		0.32*
	All	Water content (%)		-0.09		0.36*		0.08
SR-type	Amplero	Dry phytomass (g m-2)	[868, 878]	-0.82**	[896, 904]	-0.89**	[902, 922]	-0.83**
	Amplero	Nitrogen content (%)		0.61		0.54		0.561
	Amplero	Water content (%)		0.81*		0.53		0.85**
	Neustift	Dry phytomass (g m-2)	[868, 878]	-0.14	[722, 942]	-0.54	[422, 516]	-0.254
	Neustift	Nitrogen content (%)		0.27		0.92**		0.142
	Neustift	Water content (%)		0.19		0.80*		0.056
	Monte Bondone	Dry phytomass (g m-2)	[600, 608]	0.56**	[658, 682]	0.69***	[712, 714]	-0.52*
	Monte Bondone	Nitrogen content (%)		-0.52**		-0.66***		0.50*
	Monte Bondone	Water content (%)		-0.54**		-0.61**		0.43*
	All	Dry phytomass (g m-2)	[736, 976]	0.14	[404, 944]	-0.21	[790, 798]	0.021
	All	Nitrogen content (%)		0.19		0.67***		0.32*
	All	Water content (%)		-0.10		0.37*		0.083
SD-type	Amplero	Dry phytomass (g m-2)	[894, 998]	-0.81**	[844, 856]	-0.89**	[816, 834]	-0.84**
	Amplero	Nitrogen content (%)		0.49		0.51		0.56*
	Amplero	Water content (%)		0.76*		0.59		0.84**
	Neustift	Dry phytomass (g m-2)	[972, 988]	-0.16	[732, 942]	-0.45	[400, 410]	0.092
	Neustift	Nitrogen content (%)		0.33		0.90**		-0.672
	Neustift	Water content (%)		0.25		0.80*		-0.293
	Monte Bondone	Dry phytomass (g m-2)	[444, 502]	0.57**	[658, 680]	0.72***	[468, 496]	0.47*
	Monte Bondone	Nitrogen content (%)		-0.56**		-0.67***		-0.55**
	Monte Bondone	Water content (%)		-0.57**		-0.63***		-0.48*
	All	Dry phytomass (g m-2)	[424, 446]	0.28	[734, 928]	-0.44**	[444, 464]	0.167
	All	Nitrogen content (%)		0.14		0.56***		0.070
	All	Water content (%)		-0.16		0.16		-0.032

Statistical significance is indicated as * ($p < 0.05$), ** ($p < 0.01$), and *** ($p < 0.001$).

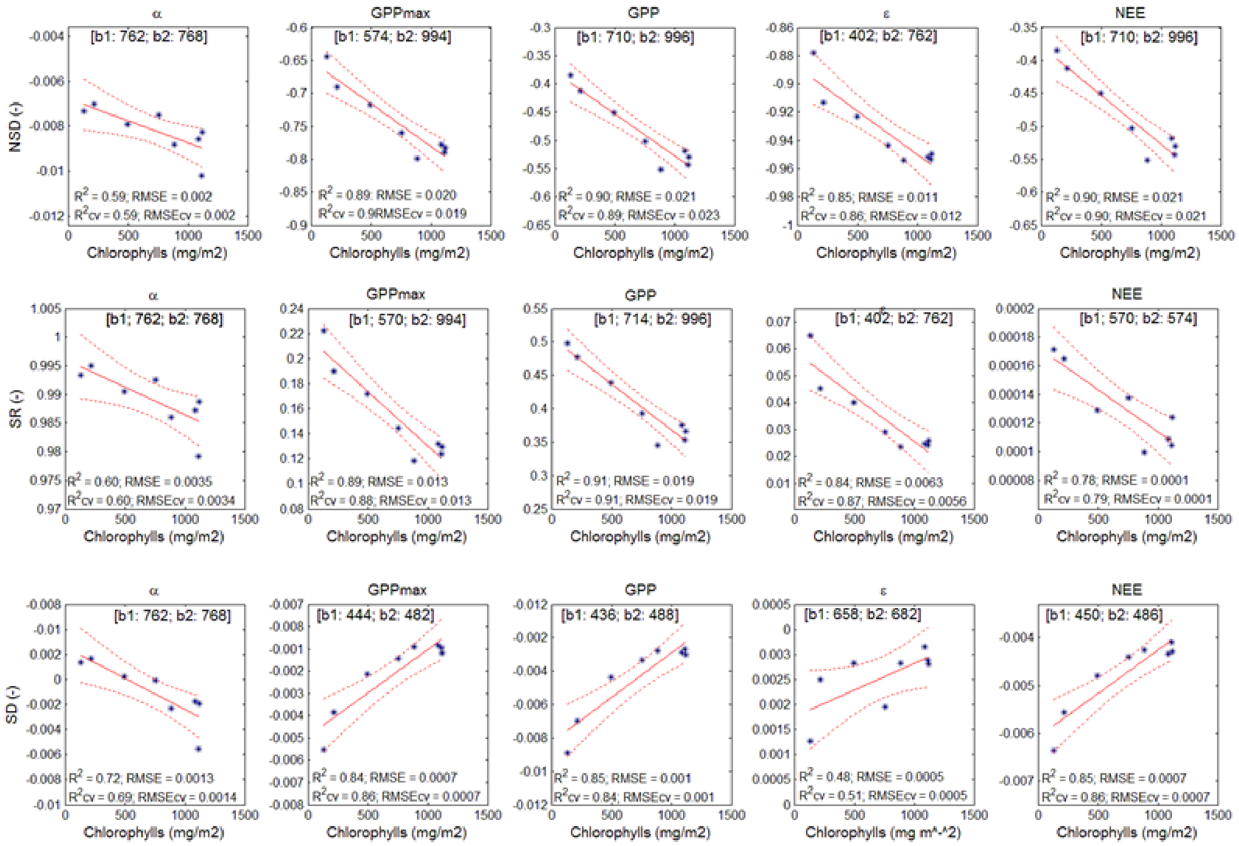

Fig. C3 – Correlation between selected NSD-, SR- and SD-type indices and the total chlorophyll content content for Monte Bondone in 2013. R^2—coefficient of correlation; RMSE—root mean square error; R^2cv— cross-validated coefficient of correlation; RMSEcv— cross-validated root mean square error. The red lines indicate the fitted models and the red dotted lines represent the 95% upper and lower confidence bounds. In the brackets are reported the selected bands to compute NSD-, SR- and SD-type indices.

In the revised version of the manuscript CI index reported in the Table 2 will be re-defined using the following formula: CI = (R750/R720) – 1 as reported in Gitelson et al. (2005). In addition, Red-edge (Red-edge NDVI = (R750–R720)/ (R750+R720); Gitelson and Merzlyak (1994)) will be added to the elaboration. Consequently, Figure 1 of BGD paper will be modified by showing the positions of these new indices and removing the old CI. In addition, in the revised version of the manuscript the Table 3 and Table 4 of the BGD paper and the Table S1 in the BGD supplemental will be modified showing the results of the correlation analysis between biophysical parameters and the new indices.

5. P27L11-15: Note that some comprehensive analytical studies have already been reported for the other type of ecosystems. Therefore, the differences in spectral response between grassland and the other herbaceous or tree plants have to be investigated quantitatively. If such advanced or in-depth investigations are not included, this study may be a kind of routine exercise using preceding approaches and grassland datasets.

It is difficult to address this very general comment not knowing which “comprehensive analytical studies” the reviewer refers to. As detailed above, the focus of the present paper is on a comparison of three mountain grasslands which have been studied with a standardized methodology. Clearly, comparing with other ecosystem types is the desired next step, but the essential prerequisite for doing so is to be able to reconcile how different experimental protocols followed at different sites affect results. We believe that this step still has to be taken, before tackling a global cross-site synthesis.

6. P29L14-16: This averaging around midday (10:00-14:00) is questionable because high time-resolution measurements (both remote sensing and flux data) would be needed to detect the rapid change of photosynthetic functioning (related to CO2 exchange). More essentially, the analytical time-scale is not clear throughout the paper.

This comment refers to analytical time-scale but if not clear if the Reviewer #2 refers only to flux measurements or to both flux and spectral measurements. Trying to answer to this comment, we would specify that the hyperspectral measurements were made during the time frame between 10:00-14:00, but they actually took much less time and therefore they were not average over this time frame. On the other hand, the flux measurements were averaged over this time frame. We selected this time frame since we don't expect fast changes in the photosynthesis for these periods when light is not limiting the process and other the environmental conditions were stable. Moreover, the use of this time frame ensured a reduction of the random noise in the flux data.

7. P29L21-P30L7: The error caused by these simple and conventional assumptions might not be negligible. The possible error should be assessed or discussed. Otherwise, the comparison of predictive accuracy throughout the paper would make little sense. LAI by optical method is basically Plant Area Index rather than Leaf Area Index, so there would be some problem in assessment of green-leaf area index especially during the senescent stage.

We agree that Eq. (3) and the measurements and assumptions used to calculate fAPAR are simplistic and will discuss the implications in more detail in the revised paper.

8. S2.5: Quite similar analytical approach using hyperspectra has been reported in preceding papers (LUE, canopy nitrogen, etc.), so most readers would think that this study is a simple application of such methods to some grassland datasets. See the comments 4 and 5. Hence, first, such preceding studies should be referenced sufficiently. Second, the motivation of the application to grassland should be explained clearly with relevant logic.

Thanks for the suggestion. We agree and we will rewrite this part by clearly explaining the motivation of the research and showing the novelty of the research approach.

9. P33L26: It is strange that graphs for SRs have triangular shape (e.g., Fig. 5). SR maps would have to have a square shape because Ri/Rj and Rj/Ri have different predictive power.

Thanks, we agree – we will show "the other side" of the triangle as well.

10. P37L18-20: This has been a well-known fact in remote sensing of ecosystems. Therefore, investigations should focus on reduction of such confounding factors. Unfortunately in this paper, no alternative methods, findings or insights in such aspects are obtained. Since this type of datasets have been collected through so-called FLUXnet as well as many other individual experiments, similar analysis can easily be done using a new dataset by using similar analytical approach as in this paper.

However, preliminary exercises are not worthwhile in the context of science and technology as well as operational applicability. Please see the comment 4.

As proposed by responding to the comment 4, in the revised version of the manuscript we will put more emphasis on the confounding factors that impact on the spectral response of the vegetation in the NIR. In particular, we will focus on the use of canopy water, nitrogen and chlorophyll content in order to understand if these biophysical variables can help current understanding on this field that is still controversial issue (Knyazikhin et al., 2012).

See our reply above to the general comment regarding the feasibility of a global synthesis study and the value of our study which used a standardized common protocol.

11. S4&5: It is difficult to find significantly original or innovative findings, insights, or message. Major parts in these sections seem to be simple confirmation or repetition of well reported facts, insights or messages by preceding papers. Please see the comments 4 and 5.

RESPONSE
As commented by answering to the general comment part, the authors agree with the reviewer that the discussion of the paper need improvements for clarifying the main important findings obtained by this study (see answer to the general comment) and we hope that we have been able to better clarify and explain why the study should be considered for publication.