Biogeosciences Discuss., 11, C2545–C2553, 2014
www.biogeosciences-discuss.net/11/C2545/2014/

Biogeosciences
Discussions
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Interactive comment on "Comparative validation of UAV based sensors for the use in vegetation monitoring" *by* S. von Bueren et al.

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Received and published: 16 June 2014

Response from: S. von Bueren, A. Burkart, 16.06.2014

We sincerely thank Dr. Arko Lucieer for the review of our manuscript and the valuable comments on our research article. We would like to respond to the comments below:

1.From the introduction it is not entirely clear what the specific aim of this paper was and how it builds onto previous work. Burkart et al. (2014) previously presented the UAV STS system and described the spectral performance of this system. Nijland et al. (2014, link provided below) presented in great detail how consumer-grade cameras can be utilised for spectral imaging (and where they fall short). There are other UAV papers that deal specifically with the TetraCam mini-MCA. This papers seems to

combine these sensors and approaches in a single study within the context of pasture management. However, the authors should be more specific about the research niche of this paper. Can you be more explicit about the innovation and contribution of this study? How does it build onto previous studies?

We have edited the introduction to contain more background information that covers the frame of the study and to be more clear about the aim and contribution of the study.

2.One of the key issues in this study is the difference in spatial scale and field of view of the different sensors. When comparing spectral performance, the spatial footprint and area sampled should be identical. The fact that there are major spectral differences between the ASD ground spectra, TetraCam imaging spectra, and STS UAV-based point spectra does not surprise me. I would expect these differences to be caused by the differences in footprint (area measured/imaged) and BDRF effects. One of the key contributions of this paper could be to quantify and test these effects.

The issue of footprint area and matching is now more extensively discussed in the discussion section of the manuscript. BRDF is an issue that is important in remote sensing of vegetation. In trial experiments conducted during February 2013, we have assessed the influence of BRDF and decided to neglect it for the current publication as it would go beyond its scope to discuss BRDF implications. For clarification, we would like to show some preliminary results from the BRDF focused experiments over pastures. The STS UAV spectrometer was hereby flown over a pasture paddock like a goniometer. The highest measurement with small backscattering was near the hot spot.

Investigated zenith angle 0° - 17.5°; investigated azimuth angles 0°-360°; –> 36 observation points each Waypoint 2: Average Reflection at 780 nm = 0.299 SD = 0.0193 Waypoint 5: Average Reflection at 780 nm = 0.367 SD = 0.0159 Instrumental noise at 780 nm was estimated with an SD of 0.007

Data is not shown here as it is part of another study covering BRDF assessments over different vegetation types

3.Another key issue is the inaccurate positioning and sensor pointing ability of the UAV systems. This relates to my point about footprint above. If the uncertainty in the waypoint position is 5 – 10 m (typical for navigation-grade GPS) in addition to uncertainty in the pitch, roll, and yaw of the sensor (caused by multi-rotor movement and inaccuracies in the gimbal) there is potentially a very large difference in the area being sampled. Repetitive and overlapping sampling over homogenous sites might reduce this effect, however, this needs to be described in more detail in the paper.

We have added a more detailed explanation how we ensured accurate footprint matching between the sensors and how we accounted for the uncertainties of the on board GPS. For the MikroKopter the uncertainty in waypoint positioning can be up to 10 meters on an autonomous GPS waypoint flight. This inaccuracy prompted us to manually pilot the UAV over the waypoint to ensure the areas of interest with the tarpaulin marker were imaged. The Falcon-8 UAV performed stable hovering flights over the targets with minimal deviations from the area of interest.

4.This study in carried out in the context of pasture management. It would be nice to see some practical applications of how point-based and image-based spectral information might be used in the context of pasture management. There is no need to go into derivation of standard vegetation indices, but it would be good to illustrate the power of high spectral resolution vs high spatial resolution sensors in the context of remote sensing products (biophysical and biochemical derivatives) for pasture management. This is another area where the paper falls short, but where it could make a significant contribution. In the discussion and conclusion the paper could suggest how the systems could be used in practice and what the advantages and disadvantages of each of the sensors are (rather than it just being a comparison of standard vegetation signatures).

Context of pasture management has been included more specifically in the manuscript

with added references.

5.I was wondering if the ASD HandHeld2 was calibrated. The device is used to measure on-ground reference spectra, but can it be trusted as a 'reference' instrument?

The ASD was calibrated in September 2011, when it was bought. A cross-comparison to the UAV spectrometer showed that the ASD is a valid reference instrument.

6.The second half of the abstract seems too generic about the main findings. More specific information about the results could be included.

Abstract is now more specific.

7.P.3 l.25: I recommend adding some information on the type of remote sensing products that are required on a dairy farm. What are the typical spectral derivatives that could benefit pasture management? Is it important to get information on biomass, nutrients, and other specific biophysical and biochemical characteristics, or is a simple NDVI sufficient for estimation of overall grass density?

We have included more pasture management specific information in the introduction and have more clearly stated what information on pastures can be derived from remote sensing methods.

8.P.4 l15: 'remote sensing data' is very generic. What type of remote sensing data is required for precision agriculture applications and pasture management specifically?

Generic term is replaced in the sentence. As for the type of products that are relevant for precision agriculture, especially for pasture management, we would like to refer to the revised introduction.

9.P.4 l23: I recommend replacing table 3 with a graph showing the spectral response function of the MCA filters. If these are 'standard' Andover filters this should be straightforward as the spectral response functions are provided on the Andover website. This would give a good visual indication of band width (FWHM), wavelength position, and transmission.

We have added the bandwidth at FWHM in table 3 as a useful additional information. We would ike to not add another figure on the specifications on the Tetracam as we visualised the filters in Figure 2 and provided the information in Table 3 in a compact manner on purpose as to not make the manuscript even longer.

10.P.5 l6: Perhaps come up with a name for the custom designed STS, e.g. STS UAV.

We changed it to 'UAV STS'.

11.Also, please specify what customisations were employed. How is this STS different from the standard OO STS?

Refering to Burkart et al. 2013 the STS spectrometer was a standard system based on the Ocean Optics STS without any customisations. Different to the common way of operating the STS it was used with a microcontroller rather than a computer to trigger and save measurements. Additional efforts , exceeding the factory calibrations, were put in correction of dark current as well as crosscalibration of the two different units used.

12.P.5 l9: How was the "high spectral accuracy" verified? Is this statement based on the instrument specifications or was it cross-calibrated with the ASD? If so, how did the sensors compare on the ground?

The STS system was used as a standalone spectrometer with it′s own white reference on the ground. Thus it is totally independent from the ASD and was calibrated in the lab before the experiments. During ground tests against the ASD the system performed well in accuracy of reflectance estimations. When used as UAV sensor the high correlation to the ASD are in that way a hint for two well calibrated systems.

13.P.5 l15: Was the FOV of the STS spectrometer and the RGB camera the same?

No, as stated in the sensor comparison table the field of view is very different (eg.

73.7° Sony to 12° of the spectrometer). The very different lense parameters of the instruments used in this study were tackled by the rather lambertian pasture as well as different flight heights and placing markers in the images.

14.P. 5 l25: Important to mention here that the spectral response of this camera is also based on the Bayer pattern and that there is significant overlap between the three bands. A good reference is Nijland et al. (2014) Monitoring plant condition and phenology using infrared sensitive consumer grade digital cameras (downloadable from http://www.geo.uzh.ch/microsite/rsl-documents/research/publications/peer-reviewed-articles/Nijland2014_AFM-1460242176/Nijland2014_AFM.pdf)

This important information is now in the manuscript and relevant literature has been referenced.

15.P. 6 l15: Was georeferencing done with a navigation-grade GPS (5-10 m accuracy) or a more accurate geodetic RTK GPS?

In hindsight we have decided that the actual georeferencing of the waypoints is not relevant to our results and discussion. As stated in the paper we used in field tarpaulin markers to accurately locate the areas of interest. We do have the GPS locations of the points for our own reference.

16.P.7 l12: Were the aperture and shutter speed settings fixed on the Sony RGB camera? This seems important if the image pixel values were used for spectral measurements. Also, were images recorded in the RAW format?

Thanks for this valuable comment. This is a major and valid point of critisism in this study, as we performed measurements with the RGB camera rather rough, it was used in a fully automatic way. There is, as seen in the data no influence of this mistake due to the following reasons. As we used overview images for the comparison of waypoints, multiple waypoints were shot within the same image. In between the overview images light conditions fortunately did not change thus from the EXIF values of the used pictures ISO-100, shutter speed 1/640 remained constant while aperture changed from 5 to 5.6. As this is a very good point, we will adress this in the discussion, to prevent future UAV studies from this error.

17.P.7 l13: It would be good to show the spectral signatures of these tarpaulins. Isn't it common practice to use spectrally 'flat' reference targets at different reflectance intensities for empirical line correction rather than coloured targets?

We decided to not add another figure to the already long manuscript and also to keep the foucs of the paper on the practical application. We have now more extensively discussed the implications of using tarpaulins in the discussion and also recommend more suitable materials to be used for the empirical line calibration method.

18.P.8 l1 and Fig.3: please explain how the six MCA bands were spatially aligned.

Tetracam supplies a camera specific alignment file (.mca) that can be used to align the six cameras dependent on the flying height. In this study we did not need to generate an aligned image because we worked with the six individual bands. The image shown in figure 3 is just a raw RGB composite image. We believe it is a bit misleading to show this and decided to show the red band as an example of a RAW image instead as we did not work with multiband images in this study. All six bands were processed separately for image calibration and spectra extraction.

19.P.11 l9-16: Could you explain the value in looking at the correlations between cameras/sensors? It might be clearer just to compare each sensor to a reference, e.g. ASD.

During the experiments we were evaluating the best way to compare the different instruments. As three of the sensors were calibrated against ground truth data of the ASD it made not much sense to compare them against the ASD again. But as this paper was intended to explore the problems of the use of different UAV sensors, we decided to follow the approach a normal survey pilot would do (eg. use one sensor

and calibrate it to a ground reference) and assess the differences between the sensors. The different results of different sensors are shown in Table 4 and are a good estimation what magnitude of difference can be expected if data of different sensors are compared.

20.P.12 l15-20: I would expect that such a large difference in footprint of the spectrometers would result in large differences in the measured spectra.

The waypoints to compare the different sensors where chosen from overview image information as well as from walking through the area, to find the most homogeneous places. As full match of the 5 different sensors area is not possible (some have a round, some a rectangular FOV) we attempted to achieve a good agreement between theoretical and practical optimum.

21.P. 13 l22-29 (and section 2.2): I recommend to only briefly list the UAV system and not compare the two platforms. The focus of the paper is on the sensors, not on the platforms. There are probably more suitable commercial platforms available now (and the market is changing rapidly). From an academic perspective it is best to focus on the sensors in this paper and I recommend reducing the comparison between platforms.

For this suggestion there was a contradiction between reviewers. We find that although it is important to briefly introduce the UAVs involved in the study that the actual type and system used is not one of the main points of the study. UAV platform development is continuously advaning and newer systems with better specifications and technical performance become available all the time. Our experiment could have also been performed with different platforms and the systems used (Falcon-8 and MikroKopter) are state of the art off the shelve products that are widely known to the scientific community we believe. We have therefore decided to neither shorten nor extend the description of the platforms. Our conclusions are not UAV platform specific as most of the limitations encountered are not limited to the type of platform used in this study.

22.P.14 l11-13: The overly positive start of the conclusions contradicts the more critical/negative experience just outlined in the last paragraph of the discussion.

We have revised the conclusions to ensure they match the general tone of the rest of the paper.

23.Technical corrections -Please see annotations in PDF of manuscript

Thank you very much for the technical corrections, we have worked through them.

Interactive comment on Biogeosciences Discuss., 11, 3837, 2014.