The RapidEye Red Edge Band

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1 Introduction

The presence of a Red Edge band is a unique feature that distinguishes RapidEye's satellites from most other multi-spectral satellites.

The relevance of the Red Edge spectral region for vegetation characterization has been recognized for many years. Several studies have suggested that the transition between the red absorbance and the Near-Infrared (NIR) reflection is able to provide additional information about vegetation and its characteristics.

Since the RapidEye system was conceived to serve the agricultural and forestry markets, the Red Edge band was chosen as part of the RapidEye spectral band set. Over the years, several studies have been corroborating the value of the Red Edge band. Some of the most relevant findings are presented in this paper.

2 RapidEye's Multi-Spectral Imager and the Red Edge Band

RapidEye's Multi-Spectral Imager (MSI) acquires image data in five different spectral bands; each one with a geometric pixel resolution (or ground sampling distance, GSD) of 6.5m (at nadir).

| Blue	440 – 510 nm
Green	520 – 590 nm
Red	630 – 685 nm
Red Edge	690 – 730 nm
Near-Infrared	760 – 850 nm

Table 1: RapidEye's Spectral Bands

All of RapidEye's products are collected by a 12 bit imager. During on-ground processing, radiometric corrections are applied and all image data are scaled up to 16 bit dynamic range. The scaling is done with a constant factor that converts the (relative) pixel DNs from the sensor into values directly related to absolute radiances. The scaling factor was originally determined pre-launch. However, absolute radiometric calibration for each sensor element of each band is now continually monitored and adjusted. This factor is applied so that the resultant single DN values correspond to 1/100th of a Watt/m^2 sr^{-1} μm^{-1}.

The Red Edge band is spectrally located between the Red band and the NIR band without overlap. In a typical spectral response of green vegetation (green line in Figure 1), the Red Edge band covers the portion of the spectrum where reflectance drastically increases from the red portion towards the NIR plateau.

The red portion is one of the areas where chlorophyll strongly absorbs light and the NIR is where the leaf cell structure produces a strong reflection (green line in Fig. 1). Therefore, variations in both the chlorophyll content and the leaf structure are often reflected in the Red Edge band. Accordingly, several studies have suggested that this band is able to provide additional information in order to identify plant types, nutrition and health status, and characterize plant cover and abundance, among other features.
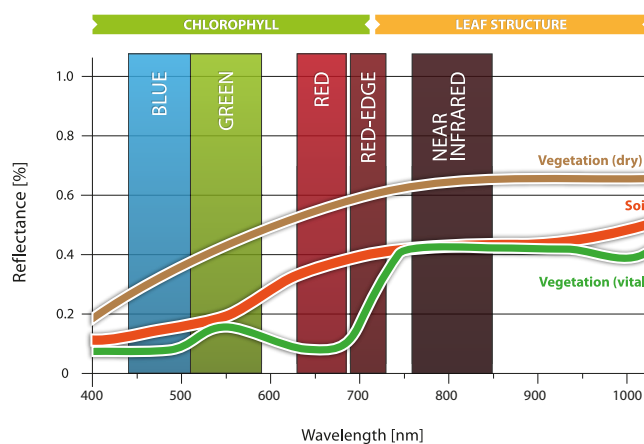
Figure 1: Typical spectral reflectance curves of selected surfaces in relation to the RapidEye spectral bands

3 Applications of RapidEye's Red Edge Band

3.1 Agriculture

Crop yield strongly depends on an adequate supply of nitrogen (N). Therefore, knowledge about N-status represents an important factor for agricultural management. Additionally, N-fertilizer is one of the largest input cost factors of many crops such as corn, wheat and rice, which makes the assessment of the N-status of a crop critical for optimum fertilizer

management. Since N-status cannot be directly measured through remote sensing, an indirect indicator is needed. The N-status of crops can be assessed through Chlorophyll (Chl) measurements, given the strong correlation between the two in several major crop types (Daughtry et al. 2000).

The use of spectral measurements and spectral indicators for the determination of Chl content is based on the fact that Chl, as well as a number of other pigments, are strong absorbers of light in certain well-defined wavelengths, specifically in the blue and the red spectral region (Fig. 1). Many studies have been conducted to investigate the relationship between the biological status of plants and their spectral responses, particularly in the Red Edge domain.

Among others, Pinar and Curran (1996), and Filella and Peñuelas (1994) found that the Red Edge region is sensitive to Chl content and N-status. These studies revealed that if Chl concentration increases, the typical slope in the Red Edge spectral region shifts towards the Near-Infrared (NIR). Very often the Red Edge inflection point wavelength (λi) is used as an indicator for this shift. However, both the detection of this inflection point and the assessment of the shift is only possible with very narrow spectral bands (Baranowski and Rokne 2005). Accordingly, several spectral indices using narrow bands, both from ground-based spectroradiometers or airborne sensors have been successfully applied to determine green biomass, water content, Chl content and N-status (see for example, Rodriguez et al., 2006).

This raises the question of whether a broader band sensor like RapidEye's MSI can detect changes in the Red Edge domain, thus combining this capability with the possibility of monitoring extensive areas at a high temporal frequency. Recent studies support the hypothesis that a broad Red Edge band, as used in the RapidEye sensors, is also suitable for obtaining information about the Chl and N content of plants (Eitel et al. 2007). For example, a combination of the widely-used Normalized Difference Vegetation Index (NDVI) and the Normalised Difference Red Edge Index (NDRE) was able to predict Chl concentration in wheat with a coefficient of determination of $R^2=0.77$ (Schelling 2010).

Based on these findings and on further research by RapidEye´s Research and Development team, RapidEye's Relative Chlorophyll Map was developed. This service product calculates and depicts the spatial variation of the relative Chl content within a field. The maps produced (Fig. 2) typically show different Chl contents, which when occurring within a single field could indicate differences in the nutritional status of the crop. Given how rapidly these maps can be generated after image acquisition and the relative simplicity and straightforwardness of the results, these maps are a valuable tool for improving field management and crop yield.
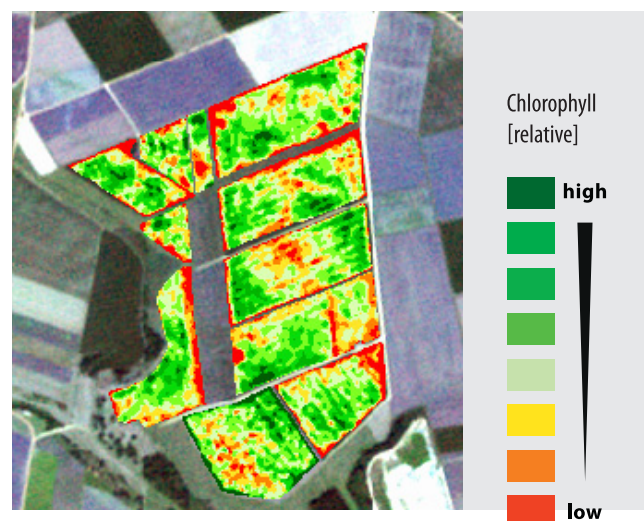

Figure 2: Example for a Relative Chlorophyll Map

3.2 Vegetation Classification

The classification of land cover, in particular different types of vegetation, is a fundamental tool for monitoring environmental quality and land productivity. Reliable information on the amount and extent of the main plant types on a landscape constitute the basis for assessing crop productivity, environmental degradation, and the effects of disturbances.

Since RapidEye's Red Edge band is sensitive to Chl status and leaf and canopy structure, it is expected that this band would contribute to the characterization of different plant cover types. Schuster, Förster & Kleinschmidt (2012) tested the Red Edge band in a land use classification project. Sixteen land use/land cover classes including two forest classes (deciduous and coniferous) were assessed. They found that with the Red Edge band, the overall classification accuracy was consistently higher than without it. In terms of individual classes, the most significant improvements were obtained with classes comprised of open landscape vegetation.

Recio et al. (2011), when comparing RapidEye images with other satellite and aerial multispectral data to classify cropland and grassland, found that the best results were obtained by RapidEye data (either alone or combined with images from other sources) and that the highest accuracies could be achieved by involving variables derived from the Red Edge band. Conrad et al. (2012) used indices combining RapidEye's Red Edge, Red and Near-Infrared bands in a multi temporal approach to separate several crop types. The authors concluded that using the three bands as a way to characterize this sensitive portion of the reflectance spectrum permitted an accurate separation of the crop types under investigation.

The following scatterplots (Fig. 3) present an indication of the vegetation class separability improvements by using the Red Edge band. Each ellipses represents a particular class, e.g. red indicates grassland, green indicates forest, the yellow and orange identify two different agricultural crop types. Using only the red and NIR bands, a significant overlap between the agricultural classes and grassland is visible (Fig. 3a), whereas

the introduction of the Red Edge band (Fig. 3b, 3c) shows a much better class separability in particular between these vegetation classes.
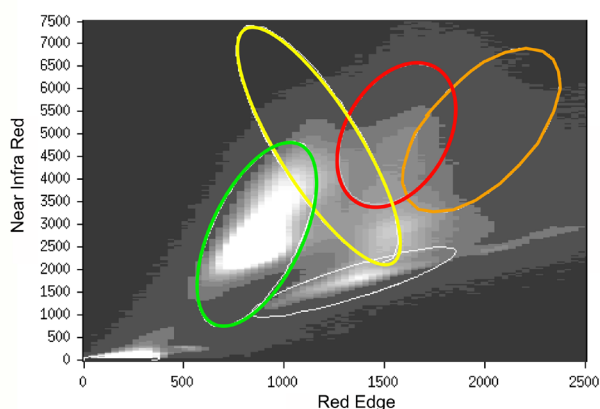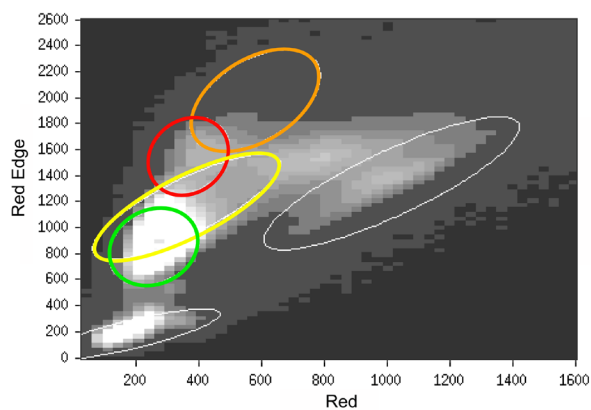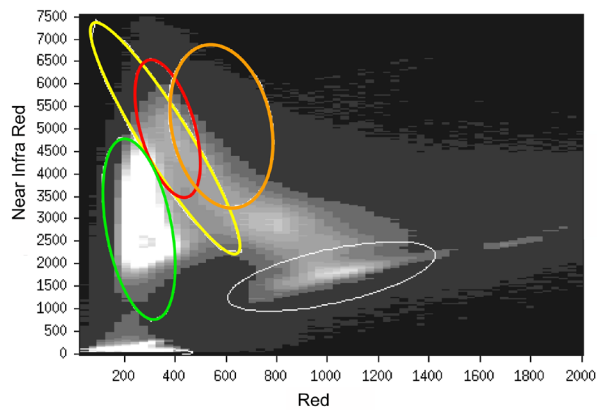

Figure 3: (a, b, c) Scatterplots of different combinations of two RapidEye bands including the representation of selected land cover classes. a: Red vs. NIR bands, b: Red vs Red Edge bands, c: NIR vs. Red Edge bands.

While the establishment of a process that incorporates all the potential of the Red Edge band for classification is still in progress, RapidEye is presently able to utilize its five bands to produce accurate land cover maps. For example, in a recent study in Germany, five land cover types were mapped in a full automated process (Fig. 4) using all five RapidEye bands and applying a machine learning algorithm, attaining an overall accuracy higher than 85%.
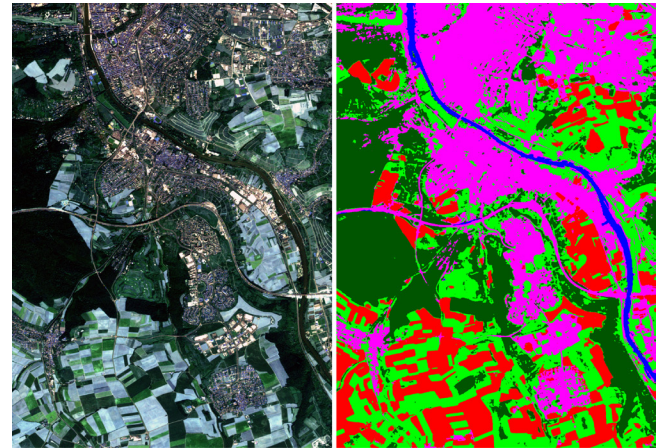
Figure 4: Classification of the main five land cover categories in Würzburg, Germany using RapidEye satellite imagery

3.3 Forestry

Forest stands and plantations are subject to a wide range of pests and diseases. Monitoring and early detection of infestations such as bark beetle are important for the protection of the forest. Traditional ground-based monitoring techniques or airborne surveys are costly, and the results are often subjective. In addition, early indications of disease or infestation are usually not visible on the ground.

The Red Edge band's utilization in forest remote sensing applications have been the subject of some studies in recent years. Research to better understand the potential of the Red Edge broad band for remote sensing applications in forestry is still ongoing.

A study on bark beetle infestation conducted by the RapidEye Research group in 2009 and 2010 based on test sites in the State of Thuringia (Germany), indicated that the most accurate vegetation indices used for damage detection included the Red Edge band (Marx, 2010). In a study by Eitel et al. (2011), conifer trees were girdled to produce stress symptoms. Three seperate vegetation indices calculated from a time series of 16 RapidEye images were tested and assessed. Results showed that the Normalized Difference Red Edge Index (NDRE, Fig. 5) was able to detect stress symptoms at an earlier stage (13 days after the treatment) than the other vegetation indices. Given the sensitivity of the NDRE, this index can be used for a variety of forest health applications such as drought stress, bark beetle damage, fire damage, and disease mapping.
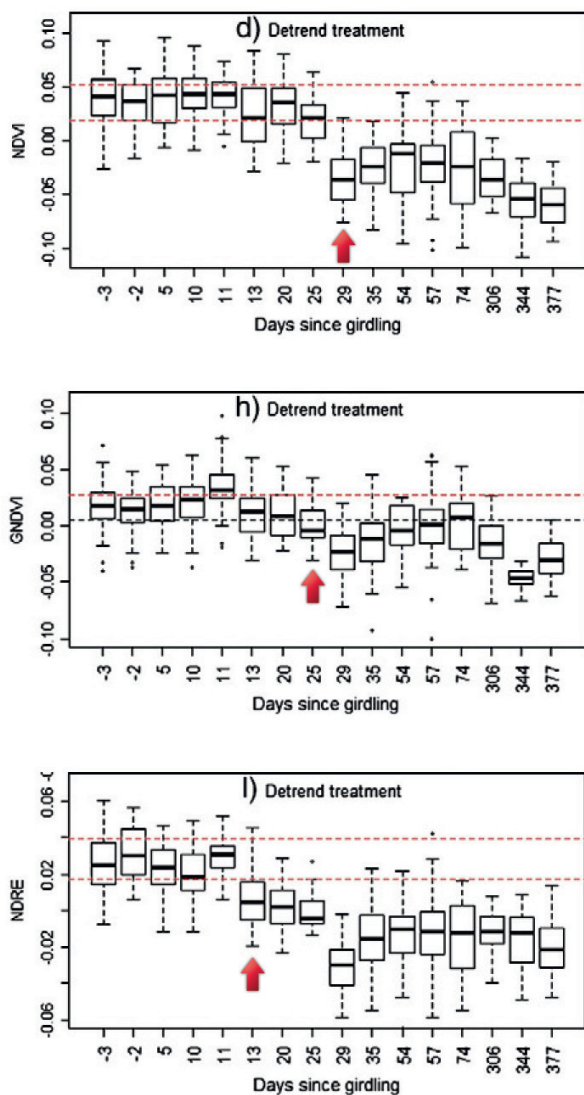
Figure 5: Tree stress detection using the Red Edge. Stress symptoms are evident when means fall outside the 25% and 75% percentiles (dotted lines). The red arrow shows the day of the first indication of tree stress (after Eitel et al. 2011).

3.4 Water Monitoring

Chlorophyll-a (Chl-a) is an indicator of the biological quality of a lake and Secchi depth is a parameter that indicates the transparency of a lake. Both parameters are used to assess lake water quality under the European and German water framework directive. RapidEye's Red Edge band is a useful instrument for the detection of these water quality parameters in productive inland water bodies with a relatively high phytoplankton content.

Studies of productive freshwater systems showed that the reflected signal between 670 and 740 nm allows for the estimation of Chlorophyll (Chl) concentration (Ruddick et al. 2001, Thiemann 1999, Schalles et al. 1998, Gitelson 1993). Within this wavelength range, Chl information is not affect-

ed by dissolved organic matter and other pigments. Figure 6 shows some typical field spectra of four lakes with varying amounts of Chl. The reflectance peak near 700 nm is a result of an interaction between strong absorption by Chl and water, as well as scattering by algae cells on other sestonic matter. As seen by comparing the different lines in Fig. 6, this reflectance peak is also a good indicator of Chl-a concentration.
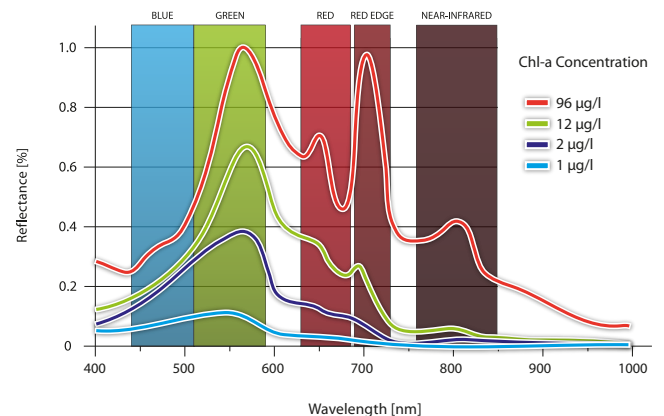

Figure 6: Chlorophyll-a reflectance for different concentration in water in the visible and NIR spectrum. The RapidEye bands are also shown.

The Red Edge band records the complete reflectance peak near 700 nm, which indicates that measurements of the Chl concentration are more accurate when this band is used. Analyses with RapidEye and ground truth data have shown that a relatively high accuracy (Root Mean Square Error, RMSE, < 1µg/l between predicted and observed values) can be obtained for lakes with low (< 10 µg/l) Chl content (Reigber, in prep.; Gallegos 1990).

Several studies have shown that the Red Edge band can play an important role in the assessment of Secchi depth in productive inland water bodies (Reigber, in prep.). The Secchi depth is mainly a function of the light attenuation coefficient (Reigber et al. 2012). Due to the fact that light at a wavelength between 690 and 730 nm is more attenuated by water than blue light, the former can be used for the estimation of Secchi depth. In fact, studies using RapidEye and ground truth data showed a high accuracy (RMSE < 0.7 m between predicted and observed values) for lakes with Chl contents lower than 10 µg/l (Reigber, in prep.; Gallegos 1990).

The studies described above constituted the basis for the development of water Chlorophyll and water visibility (Secchi depth) assessment methods using the Red Edge band. Figures 7 and 8 show a depiction of RapidEye's Chlorophyll and Secchi depth maps, respectively. These maps can reliably and efficiently guide water quality monitoring of even small lakes at local and regional scales.
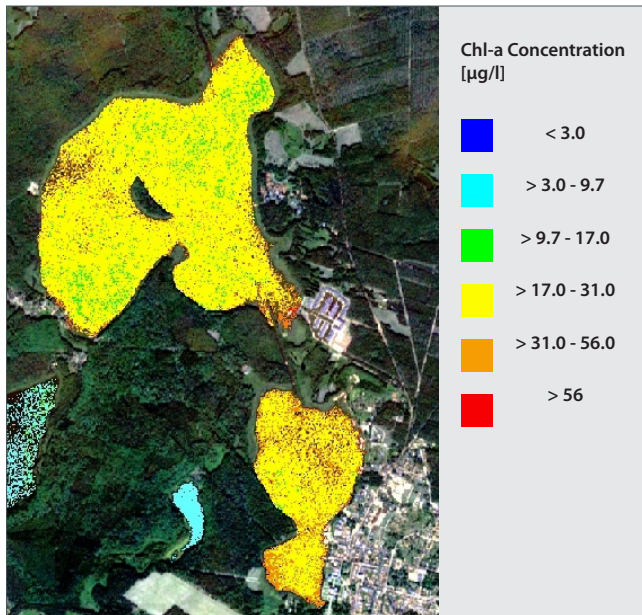
Figure 7: Chlorophyll-a concentration for two lakeS in Brandenburg, Germany, assessed with RapidEye images taken on August 31, 2009
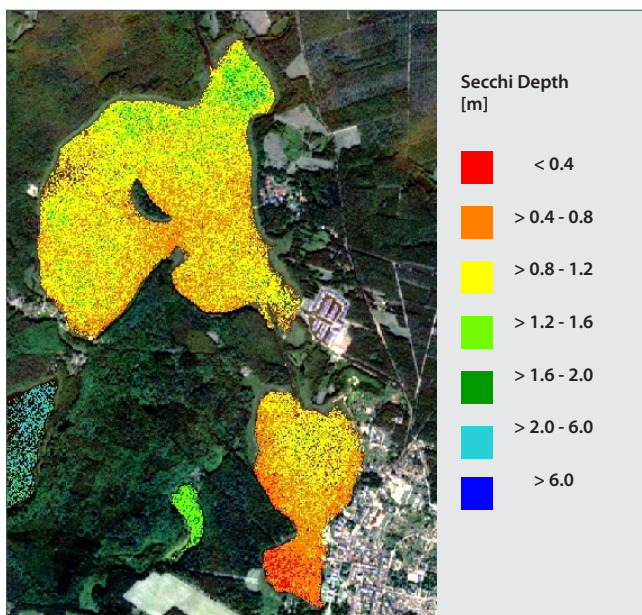

Figure 8: Secchi Depth for two lakes in Brandenburg (Germany), assessed with RapidEye images on Aug. 31, 2009.

4 RapidEye's Satellite System, Products and Services

The RapidEye constellation of satellites offers a data source containing an unrivaled combination of large-area coverage, frequent revisit intervals, and multispectral capabilities at high spatial resolution. The system is able to collect and catalog more than 4 million square kilometers of Earth Observation (EO) data daily at 5 meter pixel size.

RapideEye's five satellites contain identical sensors and are positioned in the same orbital plane. This means that an image from one RapidEye satellite will have the same characterics as an image from any of the other four satellites, thus allowing the user access to an unprecedented amount of global imagery. Each satellite measures less than one cubic meter and weighs only 150 kg (bus and payload).

RapidEye began commercial operations in February 2009. Its image archive grows at a rate of almost one billion square kilometers every year.

RapidEye Standard Image Products are offered in two different processing levels:

RapidEye Basic (Level 1B) products are sensor level products with a minimal amount of processing (geometrically uncorrected) for customers who prefer to geo-correct the images themselves; and

RapidEye Ortho (Level 3A) products are orthorectified products with radiometric, geometric and terrain corrections in a map projection.

For a more detailed description of all image product types, refer to the RapidEye Standard Image Product Specifications at: http://www.rapideye.net/about/resources.htm

5 Authors

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