WAGENINGEN UNIVERSITY
ENVIRONMENTAL SCIENCES
ALTERRA

# Monitoring of Natura 2000 sites using hyperspectral remote sensing

## Quality assessment of field and airborne data for Ginkelse & Ederheide and Wekeromse Zand

Lammert Kooistra, Sander Mücher
and Ada Niewiadomska

CGI Report CGI-08-001
ISSN 1566-7197

Centrum voor Geo-Informatie (CGI)

WAGENINGENUR

# Monitoring of Natura 2000 sites using hyperspectral remote sensing

## Quality assessment of field and airborne data for and Ginkelse & Ederheide and Wekeromse Zand

**Lammert Kooistra, Sander Mücher and Ada Niewiadomska**

**Wageningen University and Research Centre, Centre for Geo-Information**

**CGI Report CGI-08-001**

**Wageningen UR, 2008**

# Contents

## Preface

In 2007, an airborne imaging spectroscopy campaign was organized in the frame of the HABISTAT project. Airborne data with the AHS sensor were acquired in the Netherlands and Belgium. CHRIS-PROBA and AHS images were provided by the STEREO programme of the Belgian Science Policy Office. One test site in Belgium was recorded, the Kalmthoutse Heide and one in the Netherlands: the Edese and Ginkelse Heide and the Wekeromse Zand. This report describes the quality assessment of the field and airborne data for the the Edese and Ginkelse Heide and the Wekeromse Zand site. The results for the Kalmthoutse Heide will be presented in a separate report (INBO, 2008).

The field campaign was carried out as a joint activity of a bi-national team of Belgian and Dutch researchers. The team in the Netherlands consisted of the following people: Ada Niewiadomska, Zbynek Malenovsky, Sander Mücher and Lammert Kooistra. The project partners in the HABISTAT project are acknowledged for their additional support.

Finally, we would like to acknowledge the Ministry of Defence for their permission to perform the required field work in the Nature Reserve of the Edese and Ginkelse Heide and Rense Haveman (Alterra) for his stimulating excursion through the area. And the KennisBasis programme of the Ministry of Agriculture for financing the project.

## Summary

This report presents the first results of a hyperspectral remote sensing campaign carried out in October 2007 as a joint activity of a bi-national team of Belgian and Dutch researchers in the frame of the HABISTAT project.

An integrated approach of assessing the complexity of managed natural ecosystems is an exploratory case to focus airborne imaging spectroscopy activities on protected habitats. The test sites Ginkelse & Ederheide and Wekeromse Zand were chosen to demonstrate the potential of imaging spectroscopy data to support habitat monitoring and assessment.
The sites are located on the Veluwe which is the largest protected NATURA 2000 designated in the Netherlands consisting mainly of heathland and forest vegetation.

A ground team supported the data acquisition of the AHS sensor during overflight on the 7th of October 2007. Field measurements concentrated on two approaches: first, radiometric measurements were performed to support the required atmospheric correction of the imaging spectroscopy data (e.g., field radiometry and surface temperature) and secondly measurements were performed to characterize the spatial distribution of the habitats present in the study area according to the BioHab methodology.

We report on the applied field methodology and data quality evaluation of the various data sources and their assimilation into an integrated system. This deals with various aspects of spatial sampling schemes and potential spatial discontinuities, as well as uncertainty measures.

In the outlook an overview is given of the current status of the project and some examples will be presented of spatially distributed products derived from either ground based measurements and inventory mapping, extrapolated to the full coverage of the test site or imaging spectrometer derived products.

# 1 Introduction

Timely and accurate habitat reporting is vital to monitoring the biodiversity and ecological quality of our environment. Within Europe, The Pan-European Biological and Landscape Diversity Strategy (PEBLDS, Council of Europe, 1995), Natura 2000, initiated the creation of an ecological network of protected areas in the EU covering valuable natural habitats and species of particular importance for the conservation of biological diversity (EU Birds and Habitat Directives, 1979 and 1992 respectively). As a consequence, EU member states.
have to embody the targets in their own legislation and develop instruments and procedures to achieve the goals. Thus, the implementation of the Habitat Directive by the designation and appropriate management of 'Special Areas for Conservation' (SACs) and the accurate reporting on the state of the environment, is currently the main concern for European agencies and for most of the national and regional authorities, responsible for nature conservation.

Remote sensing methods and especially hyperspectral techniques could be utilized to this end but existing data and classification methods fall short for the purposes of habitat reporting in several aspects:

- Airborne hyperspectral data are suitable but coverage is yet inadequate;
- Existing methods have not addressed the issue of habitat structure and functioning which is most important for assessing habitat quality;
- Most existing remote sensing methodologies have not been tested vigorously for operational purposes.

The objective of the HABISTAT project is to provide a tool that allows better status reporting on habitats using remote sensing data. For this, an enhanced state-of-the-art classification framework will be designed and modelling techniques will be used. In this project, we intend to create a transferable platform which integrates novel and advanced remote sensing methodologies that are developed specifically for operational habitat reporting.

The HABISTAT project (research project SR/00/103) is a cooperation between Belgian and Dutch partners and funded by the Belgian STEREO program. The program will run from 2006 – 2010 and consists of the following partners:

- VITO (Vlaamse Instelling voor Technologisch Onderzoek)
- VUB (Vrije Universiteit Brussel - Centre for Cartography and GIS)
- INBO (Instituut voor Natuur- en Bosonderzoek)
- WUR (Wageningen University and Research Centre - Alterra)
- UA (University of Antwerp – Visielab)

More information can be found at:
http://eo.belspo.be/Directory/ProjectDetail.aspx?projID=824.

Three study areas will be covered by satellite data and airborne hyperspectral data: Kalmthoutse heide, Dijle valley and Veluwe (NL). The areas contain relevant habitat types and are well studied by the partners in the past. During this project, new field work will be performed. This will provide new reference data, required for training and validating the classification framework.

In this report we present the activities which were carried out by Alterra in 2007 and the first 6 months of 2008 for the Ginkelse & Ederheide and the Wekeromse zand which were selected as study area on the Veluwe. In this period, the following activities we carried out:

- Description of historic and actual land use and vegetation development;
- Preparation of a geo-database with all actual and historic information for the study area;
- Flight campaign with hyperspectral sensor and accompanying field work.

In this report, the general set-up of the project, the methodology, and the first results and the associated quality assessment for the different activities will be described. It will be limited to the HABISTAT activities carried out for the Ginkelse & Ederheide and the Wekeromse zand.

# 2 User requirements

## 2.1 EU requirements for habitat monitoring

Member states are obliged to report every six years to the EC about the conservation status of the habitats for the designated NATURA 2000 sites. Given their extent (for instance 141 Habitat areas in the Netherlands with a total area of 750,841 hectares), authorities and agencies throughout Europe are looking for new methodologies that enable them to achieve the reporting objectives properly. Conservation status is defined in terms of:

- the evolution of the range and the area covered by the defined habitat types;
- the overall quality of the habitat type as expressed by its structure and ecological functioning (species composition, amount and distribution of different plant life forms, conservation status of the typical species, ...).

Collecting these data by field-driven survey alone is not feasible and has serious financial consequences. In this chapter, we will shortly present which strategy the Netherlands has developed and implemented to monitor the Habitats Directive.
An overview of the requirements as derived from EC Natura 2000 monitoring is presented in Appendix 1 (Janssen et al., 2007).

## 2.2 Current status for the Netherlands

For the Dutch situation, the user requirements and perspectives for monitoring Natura 2000 habitats can be derived from the advisory report "Toekomstige monitoring van soorten en habitattypen" of Schmidt et al. 2008 (Future monitoring of species and habitats). It gives an advise towards the Dutch Ministry of Agriculture, Nature and Food Quality (Ministry of LNV) about the future monitoring of Dutch species and habitat types in relation to the reporting obligations in the framework of the Bird and Habitat Directives. The advisory report is based on two earlier reports of Van Swaaij and Van Strien (2008) and Janssen et. al. (2008).

According to the Habitat Directive all EU member states are obliged to report every six years about their measures made and the effect of these measures on the conservation status of habitats and species. A first assessment of the conservation status of Dutch habitats and species has been made on basis of already available data and knowledge. However, a second assessment of the conservation status in 2012 needs to be based on real monitoring data.

The conservation status of habitats and species will be determined on the basis of several parameters. The parameters for habitat types are: spatial distribution, acreage (surface area), structure and function (including the characteristic species and their perspectives). For each parameter a score will be given in three thematic classes: favourable, moderately unfavourable, and unfavourable. The norms for these three quality classes (thresholds) will be determined by each member state independently. It is not clear at this moment which quality standards are required for each parameter. All parameters need to be measured every six years.

It is recommended to use the Dutch National Database of Flora and Fauna and ECOGRID as the main data source including the vegetation data from the "Landelijke

Vegetatiedatabank". For monitoring the trends in quality (read structure and function) of the habitat types it is recommended to exploit the existing monitoring schemes (het Landelijk Meetnet Flora Natuur en Milieukwaliteit en het Meetnetfunctie-vervulling). For monitoring the total surface of each habitat type in the Netherlands it is recommended to implement surveys using remotely sensed information. However, for rare habitat types the use of remote sensing will be limited. Expert knowledge should be limited as much as possible, however, assessment of future perspectives will heavily depend on expert knowledge.

**References**


Janssen, J.A.M., R. Haveman, S.M. Hennekens, H.P.J. Huiskes, J.H.J. Schaminée & C.Y. Weebers, 2007. Nulmeting Natura 2000 habitattypen - Achtergrond, methode en voorbeelden. Alterra-rapport nr. 1378, ISSN 1566 – 7197, Alterra, Wageningen.

Janssen, J.A.M., H.F. van Dobben, R. Haveman, S.M. Hennekens, H.P.J. Huiskes, J.H.J. Schaminée, A.M. Schmidt and M van Meerlo, 2008. Monitoring van Natura 2000 habitattypen – advies voor een landelijk meetprogramma. Rapport in het kader van het WOT programma Informatievoorziening Natuur i.o. (WOT IN). Alterra-rapport nr. 1633, ISSN 1566 – 7197, Alterra, Wageningen. Pp.73.

Schmidt, A.M., A.J. van Strien, L.L. Soldaat en J.A.M. Janssen, 2008. Monitoring van Natura 2000 soorten en habitattypen – advies voor een landelijk meetprogramma ten behoeve van de rapportageverplichting in het kader van de Europese Vogelrichtlijn en Habitatrichtlijn. Alterra rapport 1646/ WOT IN serie nr. 11.

Swaay, C. van & Strien, A.J. van, 2008. Monitoring van Natura 2000 soorten: advies voor een landelijk meetprogramma. Rapport in het kader van het WOT programma Informatievoorziening Natuur i.o. (WOT IN). Alterra-rapport nr. 1644, ISSN 1566 – 7197, Alterra, Wageningen. Pp.117.

# 3 Site characterization

## 3.1 Introduction

Within the HABISTAT project, representative study sites have been selected for which a hyperspectral remote sensing based habitat monitoring system will be developed. One of these study sites is located in the Netherlands and for this the Veluwe was chosen as search area. The Veluwe is one of the largest Natura 2000 sites in the Netherlands (91.200 ha) which consists of some highly valued habitats, e.g., inland sand dunes, dry and wet heath land[1]. Several locations would be potentially suitable to investigate the objectives as defined by the HABISTAT project. Finally it was decided to take the Ginkelse & Ederheide and Wekeromse Zand (Figure 3.1) as study areas because of the presence of a large number of habitat types within a small surface area, the availability of large amount of actual and historic data-sources and easy accessibility. In addition, the habitat types present in the area are comparable to the Kalmthoutse Heide and allows comparison of analysis methods and training and validation schemes between the two sites in Belgium and the Netherlands.


Figure 3.1: Location of study sites Ginkelse & Ederheide and Wekeromse Zand in the Netherlands

[1] http://www.synbiosys.alterra.nl/natura2000/

## 3.2 Ginkelse and Ederheide

### 3.2.1 Land use history

The Ginkelse & Ederheide is known for its large area covered by Calluna heath vegetation. The Ginkelse Heide is the area located to the south of the main road N224 going from Ede to Arnhem, and the Eder Heide is located to the North of this road (Figure 3.2). Besides its ecological values, it has also archaeological values: urn fields date back from 1100 - 500 before C. The heath land vegetation has developed during the Middle Ages as part of agricultural use. For many centuries, the organic layer was removed from the surface by sod-cutting. That organic layer was transported to a stable where it was mixed with the animal manure and subsequently re-used on arable land. Due to overexploitation and mismanagement, the sandy soils lost fertility and heath land and inland dune systems developed. This practice continued until the 19$^{th}$ century, in addition the area was used intensively for grazing.

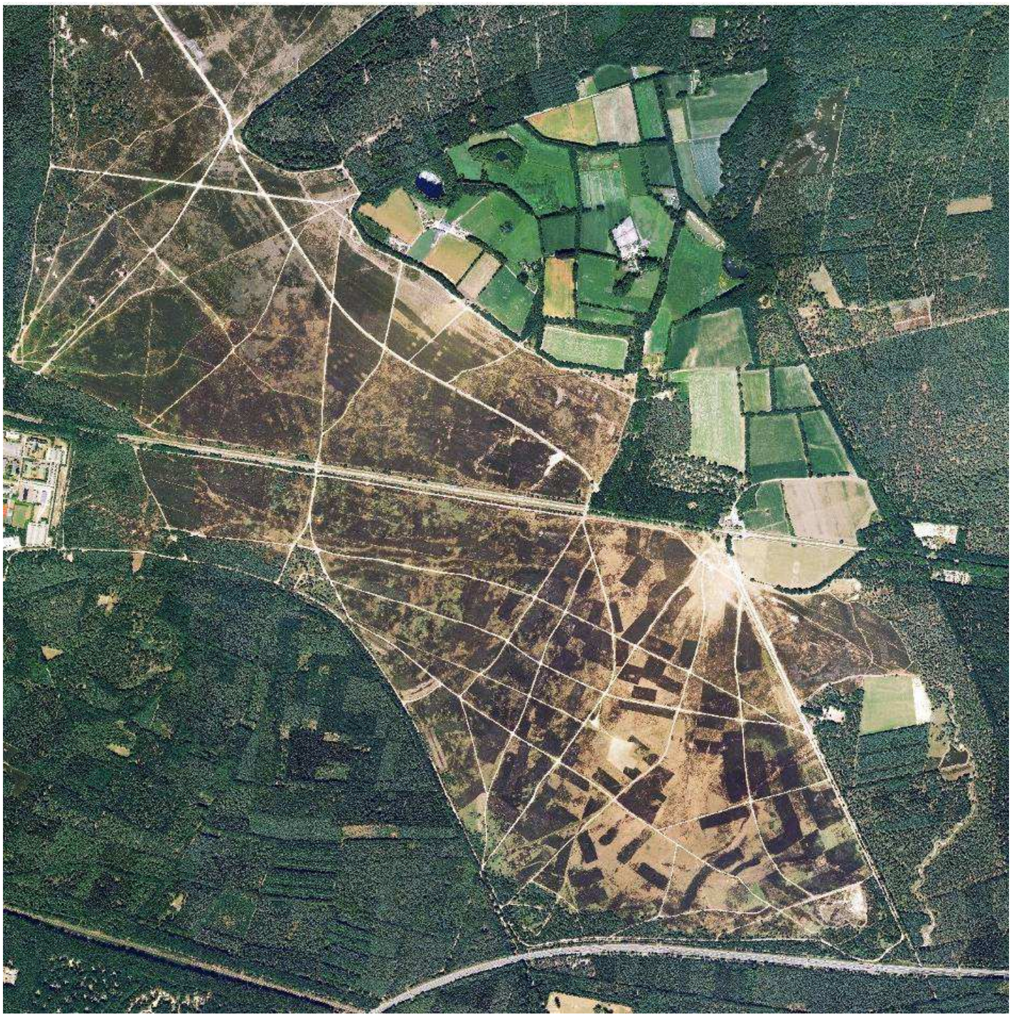


Figure 3.2: Aerial photograph (2006) showing the location and main vegetation types on the Ginkelse & Ederheide.

Starting already at the beginning of the 20$^{th}$ century, the Ginkelse & Ederheide was used as a military terrain and intensively used for exercises. A historic milestone for the area is its use as landing place for paratroopers during the operation Market Garden in the

Second World War to liberate the Netherlands. Heavy fighting took place in and around this area. During the last 30 years military use has been combined with tourism (e.g., hiking, cycling). As a result ecological processes are under pressure and this causes continuous change of the landscape. Currently, the area is managed and owned by the Ministry of Defence. The current management objectives for the area are:

- to keep heath land vegetation (Calluna and Erica) in its optimal condition (age differentiation);
- to prevent grass encroachment;
- to prevent natural generation of trees;
- prevention of the loss of sand dunes;
- to provide optimal environmental conditions for heath fauna.

Especially as a results of increased nitrogen deposition the quality of the heath land declined rapidly during the 1980s due to grass and shrub encroachment. Several management practices were carried out to influence this process: sod-cutting, ploughing, grazing etc. Based on our analysis of a time-series of aerial photographs, the management over the period 1982-2006 was reconstructed (Figure 3.3). Initially ploughing was applied on a large scale which still can be detected in the patch like structure of the heath land in especially the Ginkelse heide (Figure 3.2). At the beginning of the 1990s less intensive practices like mowing and sod cutting were applied more frequently, however clearly with a lower surface coverage.

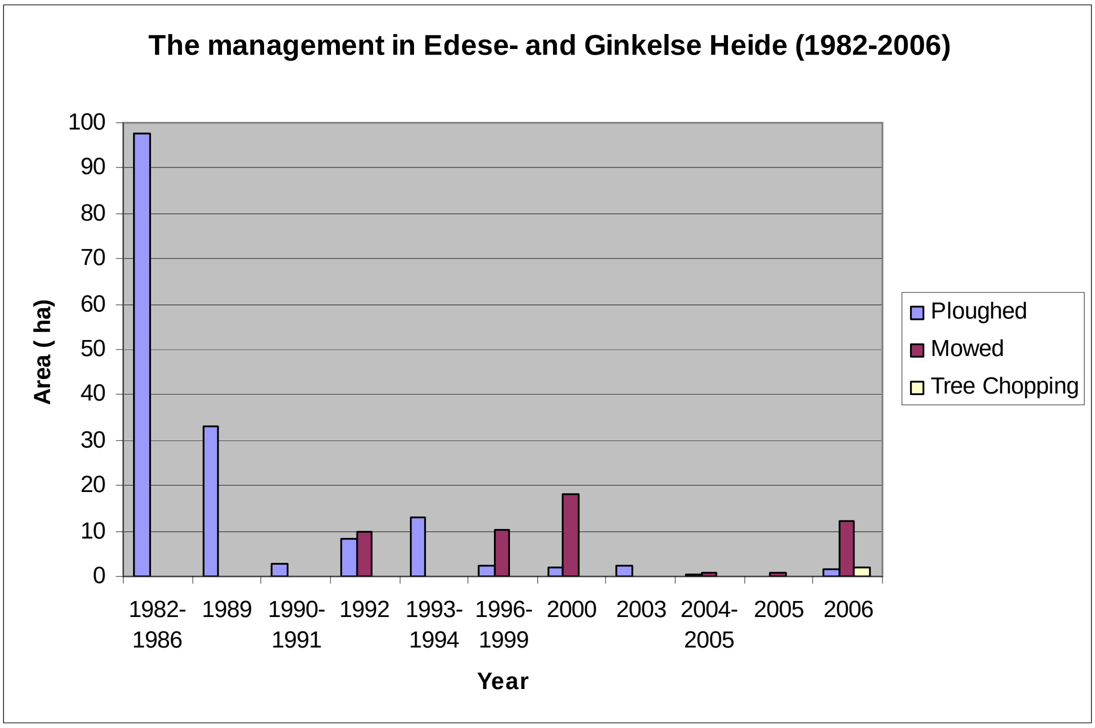



Figure 3.3: Management practices for the Ginkelse and Ederheide over the period 1982-2006 (after Niewiadomska, 2007).

### 3.2.2 Habitat types

Main vegetation on the Ginkelse & Ederheide consist of dry and wet heath land, grassland vegetation, herbaceous and shrub vegetation, and forest. In addition, small areas with open sand can be found. A detailed description of the vegetation types can be found in Haveman and Pahlplatz (2002).


Figure 3.4: Example of vegetation map for the Ginkelse Heide.

## 3.3 Wekeromse Zand

### 3.3.1 Land use history

The Wekeromse Zand is situated North of the Eder Heide (Figure 3.1), with a total area of 513 ha. About 100 ha are covered by open space with active inland sand dunes. The origin of the inland sand dunes is man made due to intensive agricultural use of the heath land vegetation during the middle ages. The historic agricultural use of the area can be deduced from the presence of Celtic fields in the area which date back to the Iron Age. Those active sand dunes make the Wekeromse Zand an ecologically unique landscape, almost not occurring any more in Europe. However, in the last 200 years, those sand dunes have been partly overgrown. In 1800, the sand dunes still covered an area of around 300 ha, in 1900 around 170 ha, in 1960 around 40 ha and in 1993 only 14 ha[2]. The Wekeromse zand is currently owned and managed by the Dutch foundation “Geldersche Landschap”. To promote natural dynamics, in 1972 en 1973 the Geldersch Landschap has cut more than 35 ha of forest to ‘give the wind its way’ and an area of open sand again could develop and expand again.

[2] http://www.natuurkaart.nl/kvn.landschappen/natuurkaart.nl/i001286.html

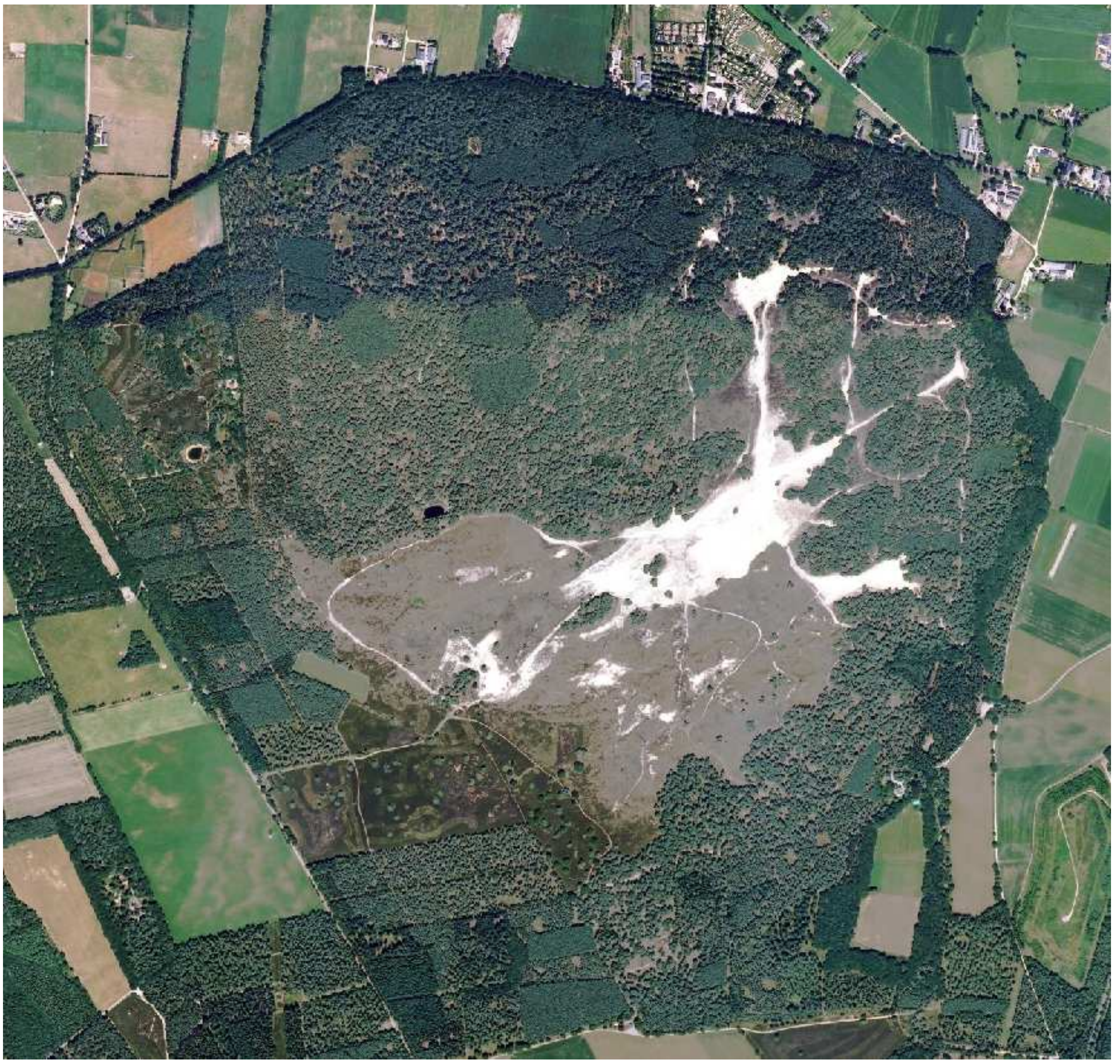


Figure 3.5: Aerial photograph showing the location and main vegetation types on the Wekeromse Zand.

### 3.3.2 Habitat types

Open sand forms a very extreme biotope with large temperature differences between day and night. Often the ecosystem is very dry as the sand has a low water holding capacity. As a result only some specialized species are able to survive in these kind of systems. In the central part of the area all stages of natural succession of sand are present. First inhabitnats of the sand are Grey Hair-grass (Dutch: buntgras; *Corynephorus canescens*) and Sand sedge (Dutch: zandzegge; *Carex arenaria*), followed by polytrichum moss (Dutch: ruig haarmos; *Polytrichum piliferum*). In this more stable environment, different types of lichens are able to develop. In a next succession stage, heathland vegetation is starting to develop. High quality dry heath land are present around the central sand dune area. The complete area is surrounded by areas of needle and mixed forests.

## 3.4 Building a geo database for the study sites

For the two study sites an assessment was made of available geo-datasets. These data sets were stored and made available through a geo-database. A detailed description of the content and the structure of the database can be found in Niewiadomska (2007). The following sources were identified:

- Topographical maps;
- Digital elevation model;
- Vegetation and structure maps;
- Aerial photographs for 1989, 1992, 1995, 2000, 2003, 2005, 2006 and 2007;
- Several remote sensing data sources (e.g., Landsat, SPOT);

A complete overview of the available geo-data sources is given in Appendix 2.

Based on the analysis of a time-series of aerial photographs for the Ginkelse and Ederheide, a historical heathland management map was developed (Figure 3.6). The methodology for the development of this management map has been described in Niewiadomska (2007).

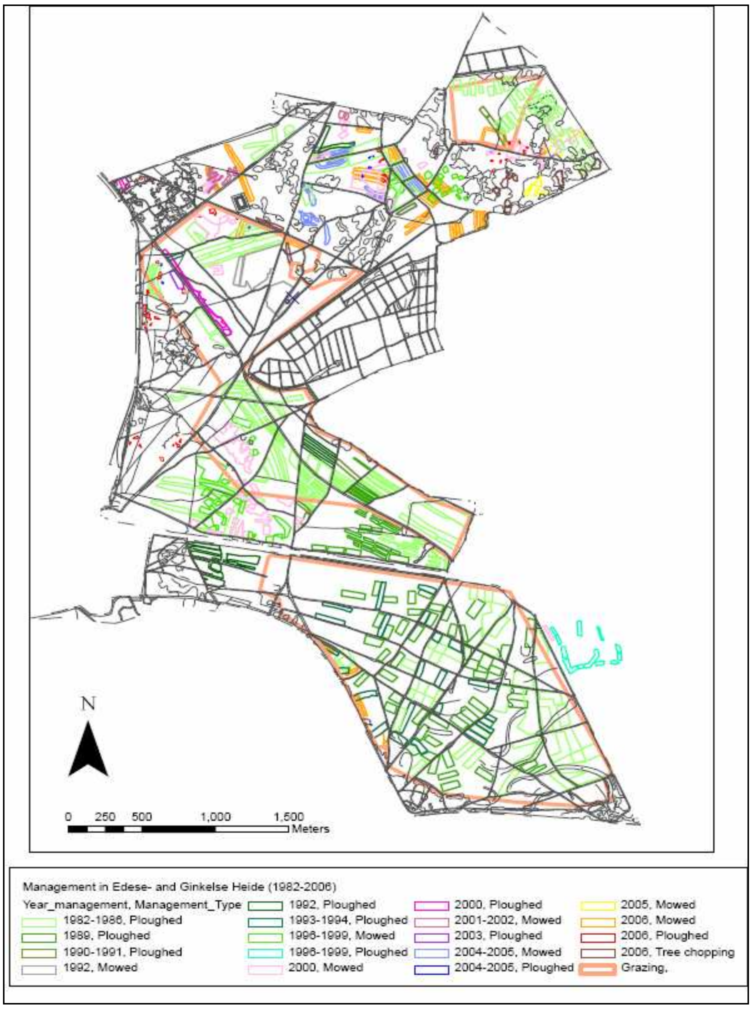



Figure 3.6: Heath land management map for Ginkelse and Ederheide (1982-2006).

## References

Haveman, R. & R. Pahlplatz (2002). Inventarisatie en Monitoring van Natuurwaarden op Defensieterreinen: Eder en Ginkelse Heide. – Dienst Gebouwen, Werken en Terreinen, afdeling Inventarisatie en Monitoring.

Niewiadomska, A. (2007). Reconstruction of heathland management for the Edese en Ginkelse Heide using aerial photographs. Internship Report MSc Geo-Information, WUR.

# 4 Sampling strategy

## 4.1 Introduction

Optimal use of the imaging spectroscopy images can only be achieved, when it is supported by a complete and accurate set of field measurements acquired during and around the day of the flight. In the set-up of the sampling plan for the field work the following elements were planned:

- Measurements for radiometric correction of images
- Measurements for radiometric characterization of vegetation
- Non-destructive characterization of the vegetation

Different sampling strategies were followed to cover the defined aspects above. An overview of the measured parameters during the field campaign is given in Table 4.1. Measurements for the description of vegetation were made around the days of the image acquisition.

Flight lines for acquisition of hyperspectral images with the AHS-160 sensor were based on the location of the selected study areas (Eder and Ginkelse Heide and Wekeromse Zand) and the specifications of the sensor. The location of the flight lines is presented in appendix 4. The coverage of the CHRIS-PROBA acquisition was based on the centre coordinates of the identified flight line and covers and area of approximately 15 x 15 km (Figure 4.1).

Table 4.1: Overview of the operational equipment around the acquisition date of 7th October 2007 for the Eder and Ginkelse Heide in the Netherlands.

| | **Instrument** | **# locations** | **date** | **variables** |
|---|---|---|---|---|
| **radiometric correction** | Fieldspec FR, digital camera | 12 (10x10 m) | 28/7 and 2/8 2004 | VNIR spectra (sand, clay, asphalt, water) |
| **radiometric vegetation** | Fieldspec FR, digital camera | 15 (5x5 m) | 28/7 2004 | top-of-canopy (VNIR) |
| **vegetation description** | BioHab method | 21 (2x2 m) | 13-16/8 2004 | structure, species composition |
| **surface temperature** | temperature gun | 20 (10x10 m) | 28/7 2004 | surface temperature |
| **Imaging spectroscopy** | AHS (2.5 m) | 2 flight-lines | | **specifications** |
| Acquisition time | | 7/10/07 13:12 | 7/10/07 13:22 | 63 bands |
| Quality flight line | | okay | okay | 450-2480 nm |
| | CHRIS-PROBA | | | |
| Acquisition time | nadir GSD 17 m | 22/10 | | 18 bands, 5 angles |
| Quality flight line | | okay | | 438–1002 nm (mode 3) |

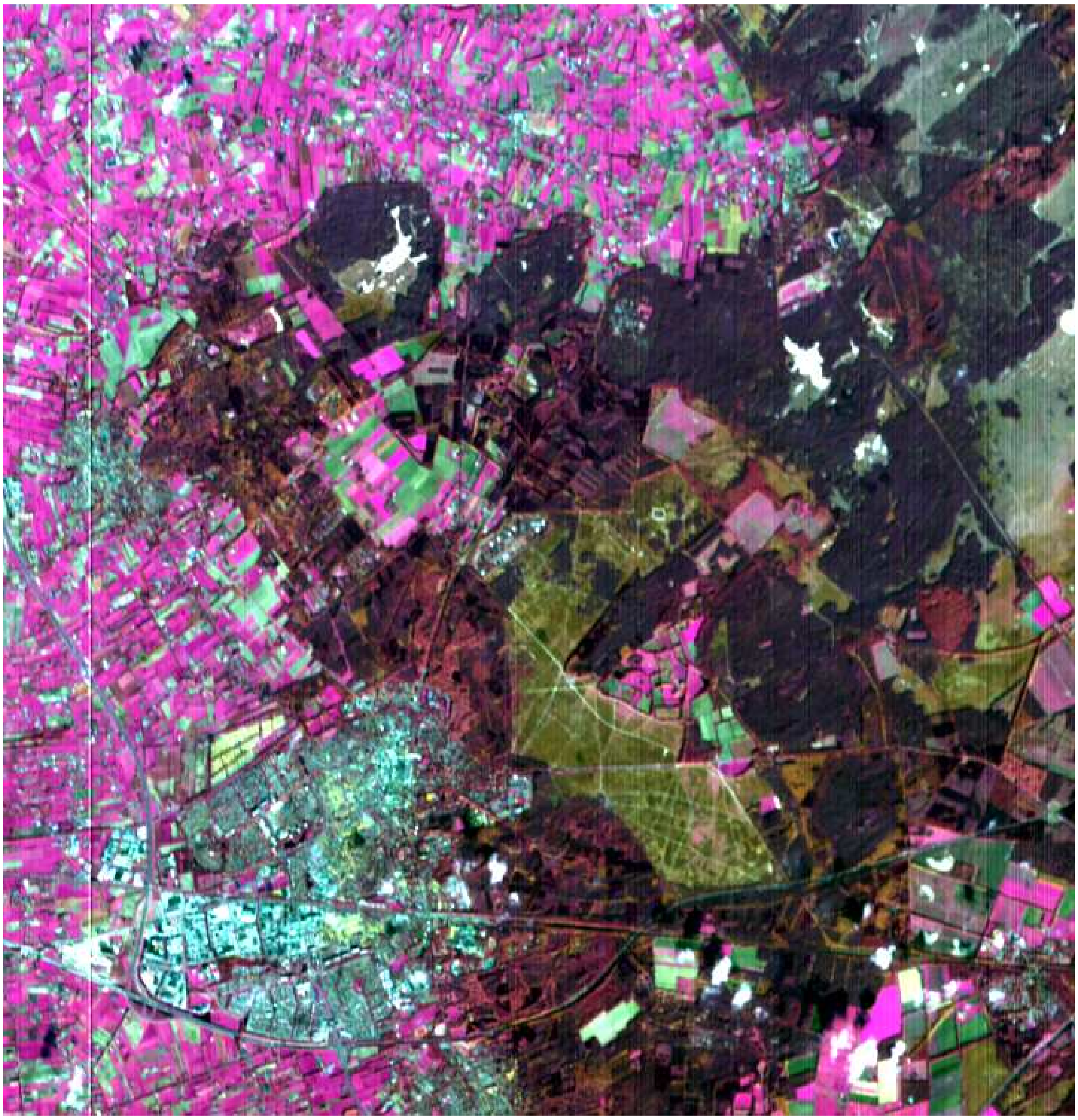


Figure 4.1: Coverage of CHRIS-PROBA data set for the area around Ginkelse and Ederheide. As an example a colour composite of the nadir image is shown (no geometric and atmospheric correction). On the lower left the city of Ede is located.

## 4.2 Reference plots

To support and validate the atmospheric correction of the acquired hyperspectral images, reflectance measurements were made for homogeneous areas with bright or dark characteristics (e.g., sand, water, asphalt etc.). Based on available aerial photographs for 2006, suitable locations were selected within the planned flight line prior to the acquisition date covering both the Eder and Ginkelse Heide and the Wekeromse Zand. Since the AHS images have a spatial resolution of 2.5 m, the reference plots should have a minimum dimension of 10 x 10 m but most of the time they were larger. On the day of the overflight measurements could be made for 10 locations (Figure 4.2).

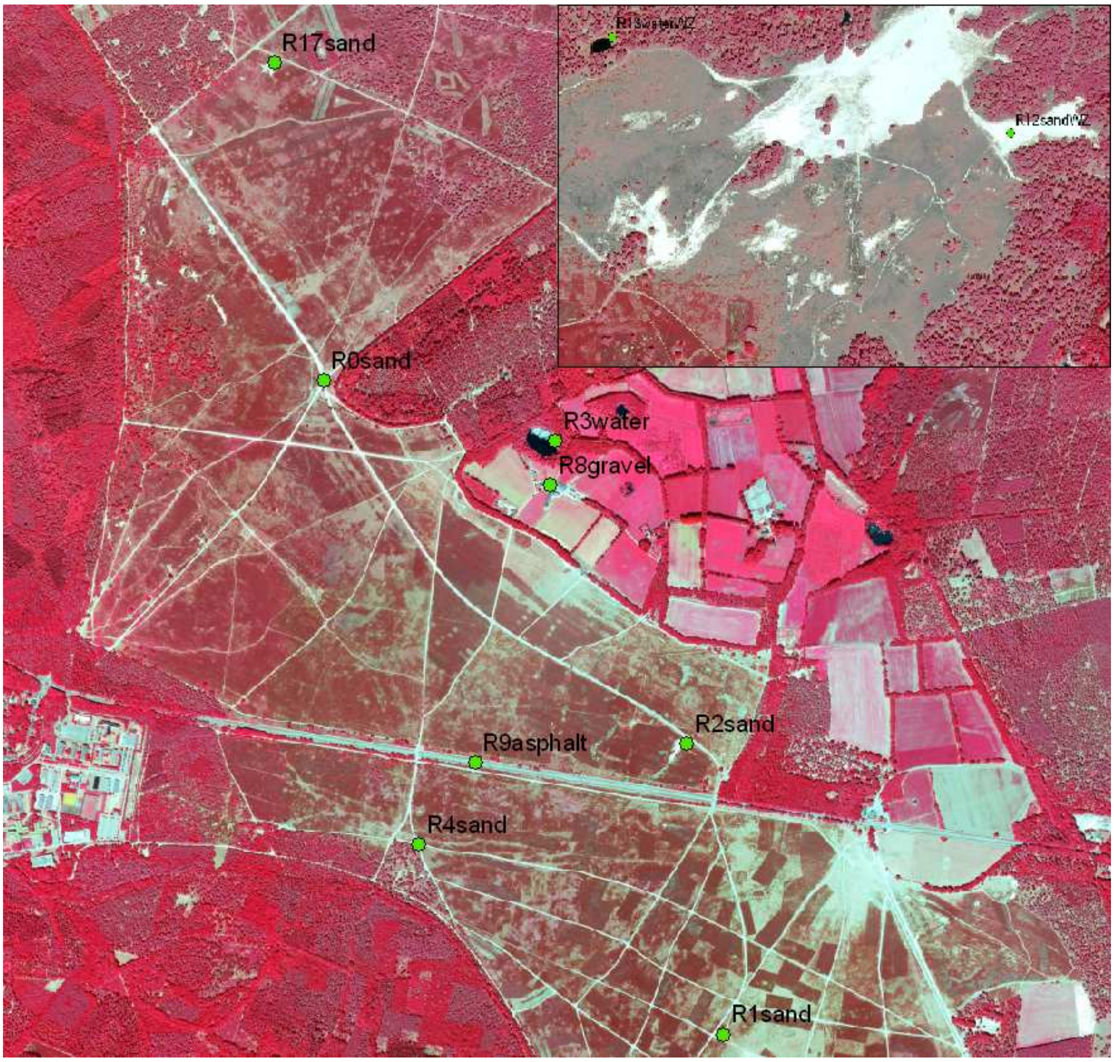


Figure 4.2: Location of radiometric reference measurements in Ginkelse & Ederheide. The inset shows the 2 locations in the Wekeromse zand.

## 4.3 Transect plots

To characterize the reflectance properties of a selected set of vegetation types within Ginkelse & Eder heide during the overflight, locations for transect plots were selected. These plots also have a secondary objective as we would like to measure the temporal spectral signature of these plots over the growing season. This second objective will be realized during the growth season of 2008. An important requirement was the location of the plots within a relative small area so they could be measured within one day under comparable atmospheric conditions. Locations for measurement of the vegetation transect plots were identified and evaluated before the fieldwork campaign (Figure 4.3). During the day of the overflight reflectance measurements were made for these plots and in the period after the overflight the vegetation in the plots was characterized (section 6.2). The plots should have a minimum dimension of 15 x 15 m but most of the time they were larger. To characterize the variability within the plot, five reflectance measurements per location were performed along a transect of 10 m (0, 2.5, 5, 7.5 and 10 m) in a West-East direction (details section 5.2).

Figure 4.3: Location of transect plots for Ginkelse & Ederheide. The colors refer to different vegetation types.

## 4.4 Grid plots

Finally, a systematic sampling scheme was designed which could be used for calibration and validation of the vegetation classification schemes which will be developed within the HABISTAT project. As a starting point, a regular grid was overlaid over the area of the Eder and Ginkelse heide with a grid spacing of 300 m for the Ginkelse Heide and 400 m for the Eder Heide (Figure 4.4). In 2007, vegetation was described for a selection of the identified locations. This exercise has been continued starting from the spring of 2008 to complete coverage of the study area including the Wekeromse Zand. Some of the identified locations will fall out as they don't fullfill the homogeneity requirement within an area of 10 x 10 m. In addition, some of the identified vegetation types will be underrepresented. For these classes, additional random points will be sampled in the field. These activities will be carried out in the first half of 2008.


Figure 4.4: Location of grid plots (green) for Ginkelse and Ederheide.

# 5 Radiometric characterization of study area

## 5.1 Introduction

The vegetation of the Ginkelse and Ederheide was radiometrically characterized on canopy level employing two spectrometers. This information is essential to analyse and validate the relation between the classification of habitat types and the AHS and CHRIS PROBA images. In addition, spectral measurements were made for several reference targets (e.g., bare sand, clay, asphalt, water) which were used for atmospheric correction of the AHS images.

On October 7th, 2007 a field campaign with the FieldSpec Pro FR spectroradiometer was performed to characterize vegetation and reference targets. The FieldSpec instrument is built by Analytical Spectral Devices (ASD) in the US. It has the following advanced features (ASD, 2005):

- A notebook-sized, Windows based computer interface providing functional access to all instrument controls and real-time display of spectral data;
- A flexible 1.5 m fiber optic cable with a 25° field of view that allows rapid scanning and data collection over large target areas;
- RS3 advanced remote sensing software for trouble-free acquisition and storage;
- DriftLock™ dark current compensation to ensure high accuracy;
- Compact housing in an ergonomic and adjustable field backpack;
- A powerful NiMH battery providing 4 hours of portable operation.

Table 5.1: Specifications of the FieldSpec PRO FR spectroradiometer (ASD, 2005).

| | |
|---|---|
| Spectral range | 350 - 2500 nm |
| Spectral resolution | 3 nm @ 700 nm<br>10 nm @ 1400/ 2100 nm |
| Sampling interval | 1.4 nm @ 350 - 1050 nm<br>2 nm @ 1000 - 2500 nm |
| Scanning time | 100 milliseconds |
| Detectors | One 512 element Si photodiode array 350 - 1000 nm<br>Two separate, TE cooled, graded index InGaAs photodiodes 1000 - 2500 nm |
| Input | Optional foreoptics available |
| Noise Equivalent Radiance (NeDL) | UV/VNIR 1.4 x $10^{-9}$ W/cm²/nm/sr @ 700nm<br>NIR 2.4 x $10^{-9}$ W/cm²/nm/sr @ 1400nm<br>NIR 8.8 x $10^{-9}$ W/cm²/nm/sr @ 2100nm |
| Weight | 7.2 kg |
| Notebook Computer | 1 GHz processor, 256 MB Ram, 20GB Hard Disk Drive, 1024x768 graphics resolution, 24 bit color, bi-directional parallel port, AC/DC adapter/charger, 64 MB USB Flash memory drive |

## 5.2 Methodology

All spectral measurements (reference and vegetation transects) were made on the day of the over-flight with the AHS sensor.

*Measurements reference locations*

Locations for measurement of reference spectra were identified before the fieldwork campaign. They consisted of bare sand areas, asphalt roads, gravel covered areas and water in small ponds (Figure 4.2). The coordinates for the identified potential locations for reference measurements were located on a map and stored in a handheld GPS. On the day of the over-flight (October 7, 2007) between 11:30 AM and 15:30 PM (local time), spectral measurements for 10 reference locations could be made (Table 5.2). These locations were both situated on the Ginkelse and Eder heide and the Wekeromse zand.

For every location the same experimental set-up was used. First, an area of 10 x 10 m was selected with a relatively homogeneous coverage. About 10 measurements per object were performed, whereby each measurement is the average of 50 readings at the same spot. Spatial sampling within the plot was conducted in a regular grid. Spectral sampling was conducted by holding the ASD fibre probe in nadir position (zenith = 0; azimuth = 0) and with a distance of ~100 cm above the ground (GFOV = ~44 cm). Although weather conditions were constant, the spectroradiometer was calibrated regularly using a spectralon calibration panel. This panel was calibrated very accurately in the laboratory and its characteristics were stored as calibration files on the computer. Before performing a new calibration, the Spectralon reference was measured just like the other objects. The latter measurement could be used for checking whether measurement conditions remained constant between two calibrations. Each area was characterized by a digital photograph and characteristics of the location were noted. Coordinates of the location were georeferenced by handheld GPS and checked on a aerial photograph.

Table 5.2: Characteristics for spectral reference plots

| **Object -id** | **Field_id** | **Description** | **Dutch RD** | | **UTM (WGS84) zone 31** | |
|---|---|---|---|---|---|---|
| | | | **xcoord** | **ycoord** | **northing** | **easting** |
| R01 | R1sand | Crossing sandy roads Ginkelse heide | 178341 | 449169 | 5767927.204 | 687088.534 |
| R04 | R4sand | Crossing sandy roads Ginkelse heide | 177253 | 449847 | 5768569.174 | 685978.727 |
| R09 | R9asphalt | Parking area + road N224, Asphalt | 177454 | 450143 | 5768871.650 | 686169.917 |
| R02 | R2sand | Sand area Ederheide | 178211 | 450210 | 5768963.491 | 686924.392 |
| R00 | R0sand | Crossing sandy roads Edese Heide along biking path | 176913 | 451509 | 5770219.288 | 685584.270 |
| R08 | R8gravel | Gravel area near farm | 177722 | 451135 | 5769872.030 | 686405.211 |
| R03 | R3water | Kreelse plas (water) | 177742 | 451294 | 5770031.619 | 686419.978 |
| R17 | R17sand | Sand area Ederheide | 176736 | 452649 | 5771352.979 | 685369.885 |
| R12 | R12sandWZ | Large sand area Wekeromse Zand | 175820 | 457090 | 5775761.937 | 684308.298 |
| R13 | R13waterWZ | Small lake in forest Wekeromse zand | 174931 | 457274 | 5775916.625 | 683413.638 |

*Measurements vegetation transect plots*

Locations for measurement of the vegetation transect plots were identified and evaluated before the fieldwork campaign. The locations should cover a large range of habitat and/or vegetation types representative for the study area. In addition, the transect plots should be located in a limited range so they can be measured within one day. This last condition was added because in the next phase of the project we would like to monitor the spectral development of the habitat types during the growing season. Therefore locations were only located on the Ginkelse and Ederheide (Figure 4.3).The coordinates for the identified potential locations for reference measurements were located on a map and stored in a handheld GPS. During the day of the over-flight (October 7, 2007) between 11:30 AM and 15:30 PM (local time), spectral measurements for 15 vegetation transect plots have been made (Table 5.3: 00P till 15P). Photos of the measurement sites were taken with a GPS camera.

For the spectral characterisation of the vegetation canopy, the same experimental set-up was used. First, an area of 15 x 15 m was selected with a relatively homogeneous (vegetation) coverage. Five measurements per object were performed along a transect of 10 m (0, 2.5, 5, 7.5 and 10 m) in a West-East direction. Each measurement is the average of 50 readings at the same spot. Spectral sampling was conducted by holding the ASD fibre probe in nadir position (zenith = 0; azimuth = 0) and with a distance of ~100 cm above the ground (GFOV = ~44 cm). Although weather conditions were constant, the spectroradiometer was calibrated regularly using a spectralon calibration panel. This panel was calibrated very accurately in the laboratory and its characteristics were stored as calibration files on the computer. Before performing a new calibration, the Spectralon reference was measured just like the other objects. The latter measurement could be used for checking whether measurement conditions remained constant between two calibrations. Each area was characterized by a digital photograph and characteristics of the location were noted. Coordinates of the location were georeferenced by handheld GPS and checked on a aerial photograph.

Table 5.3: Characteristics for vegetation transect plots

| transectid | xcoord | ycoord | INBO_type | Description |
|---|---|---|---|---|
| 00P | 177453 | 450089 | Hdgd | grass-encroached heathland |
| 01P | 177247 | 450010 | Hdcy | dry heathland, well developed: young |
| 02P | 177248 | 449958 | Hdgd | grass-encroached heathland |
| 03P | 177820 | 449911 | Hdcy | dry heathland, well developed: young |
| 04P | 177811 | 449981 | Hdgm | grass-encroached heathland |
| 05P | 177871 | 449943 | Hdcy | dry heathland, well developed: young |
| 06P | 178057 | 449880 | Hdcy | dry heathland, well developed: young |
| 07P | 178031 | 450004 | Hdgd | grass-encroached heathland |
| 08P | 178408 | 449826 | Hdgd | grass-encroached heathland |
| 09P | 178491 | 449677 | Hdgg | grass-encroached heathland |
| 10P | 178808 | 449666 | Gpap | semi-natural grasslands (dry) |
| 11P | 178648 | 449776 | Hdcm | dry heathland, well developed: mixture |
| 12P | 178643 | 449845 | Hdcy | dry heathland, well developed: young |
| 14P | 178095 | 450260 | Hdcm | dry heathland, well developed: mixture |
| 15P | 178204 | 450479 | Hdgg | grass-encroached heathland |
| 16P | 178123 | 450359 | Hdcm | dry heathland, well developed: mixture |
| 17P | 178181 | 450365 | Hdcd | dry heathland, well developed: degenerating |
| 18P | 178212 | 450387 | Hdcd | dry heathland, well developed: degenerating |
| 19P | 178143 | 450427 | Hdgg | grass-encroached heathland |
| 02P01 | 177304 | 449886 | Hdcd | dry heathland, well developed: degenerating |
| 03P01 | 177813 | 449910 | Hdgd | grass-encroached heathland |
| 06P01 | 178060 | 449903 | Hdgg | grass-encroached heathland |
| 06P02 | 178053 | 449934 | Hdca | dry heathland, well developed: full grown |
| 09P01 | 178462 | 449762 | Hdgg | grass-encroached heathland |
| 09P02 | 178492 | 449725 | Hdcy | dry heathland, well developed |

*Data processing*

The collected spectra were first exported to ASCII files with the Field Spec Pro software. One ASCII file was created for all spectra. Subsequently, all the data were imported into Microsoft Excel for further processing. Reflectance spectra where grouped per measurement plot. Averages and Standard deviations where computed for each location.

A visual quality assessment was performed for every spectrum to identify incorrect spectra which were removed. Next, water absorption bands where removed. Each water absorption value was removed individually and substituted by the wavelength average value. Standard deviations where again calculated and a visual quality analysis was performed. After quality control, data in excel were converted again into ASCII files. These corrected ASCII files where imported into ENVI 4.0 software to create spectral libraries.

## 5.3 Data

Figure 5.3 presents measured reflectance spectra for the reference objects. Both relatively dark (lake and asphalt) and light objects (open sand and sand road) were measured and used for atmospheric correction of the AHS images (chapter 8). In Figure 5.3, wavelength regions influenced by atmospheric water vapour around 1400 and 1900 nm are removed. In the region between 2450 and 2500 nm the influence of the relative low amount of incoming radiance is visible.

Figure 5.4 presents the canopy reflectance spectra for 15 transect plots. For illustration the unprocessed data are shown which present the high spectral variability due to atmospheric water vapour around 1400 and 1900 nm. Further details on the difference between vegetation types are explained in the next chapter.

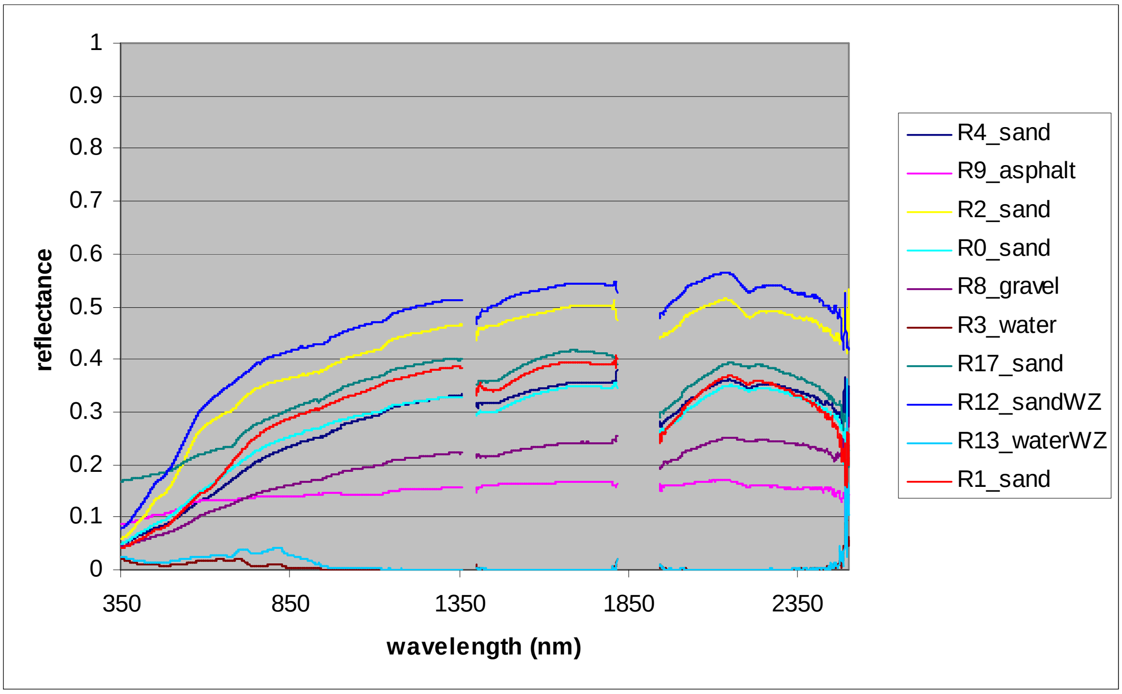



Figure 5.3: Reflectance spectra for reference objects that were measured on October 7, 2007 on the Ginkelse and Ederheide and Wekeromse zand (WZ).

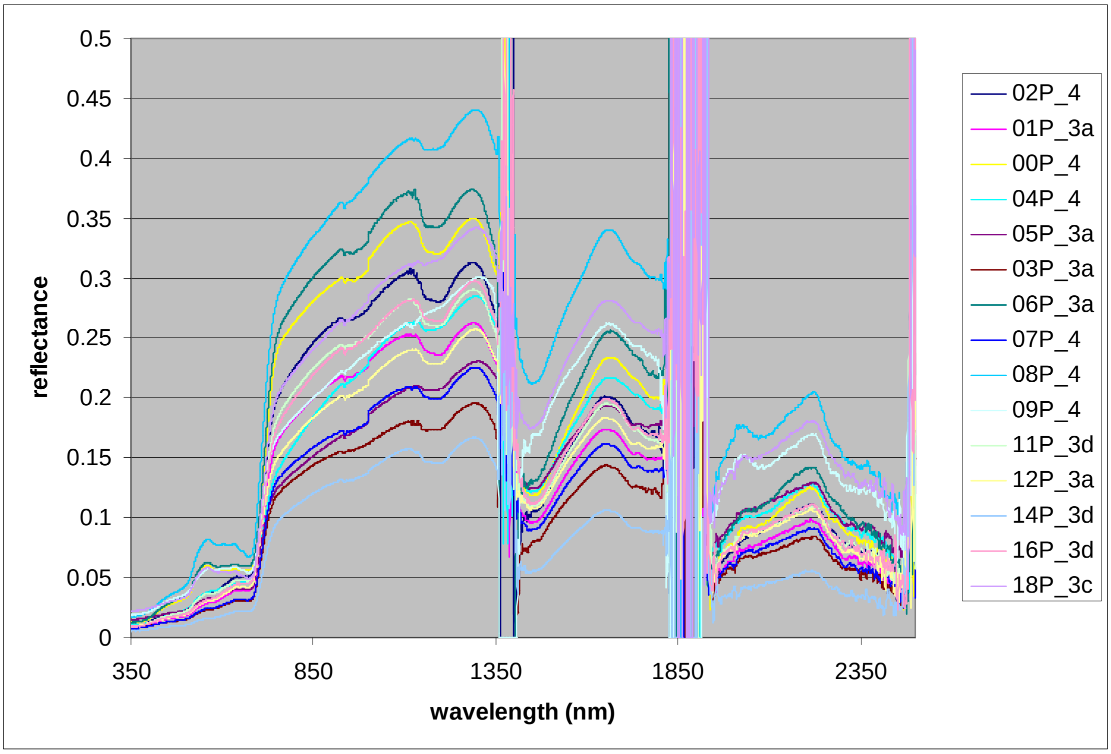



Figure 5.4: Canopy reflectance spectra for 15 vegetation transect plots on the Ginkelse and Ederheide measured on October 7, 2007. Spectra without processing are shown.

## 5.4 Quality assessment

Visual quality assessment was done to filter out incorrect spectra. For the vegetation, two spectra were removed because of erroneous measurement conditions. Average and standard deviation calculations per wavelength per plot were made in excel using the AVERAGE and STDEV functions. Outliers were found, thus no further quality control actions were needed. Based on outlyers in standard deviation per wavelength band, extreme spectral bands were removed (Figure 5.4). The processed reflectance spectra were stored as ASCII file and imported into an ENVI 4.0 spectral library.

## 5.5 Archive

Spectral datasets for reference targets, vegetation canopy and leaf reflectance are stored in three formats: Excel, ASCII and in ENVI spectral library.

## 5.6 Outlook

*Atmospheric correction and image quality assessment:*
After the quality control of reflectance spectra for the reference objects was performed, the atmospheric correction of the AHS images was assessed (chap 8). For atmospheric correction of the AHS images, the georeferenced radiometric measurements of the sandy objects and the water of the lake were used (Figure 5.3). The atmospheric correction consists of transforming the reflectance values at the atmosphere level into reflectance values at ground surface level. This correction was carried out by VITO (Belgium).

*Spectral library and temporal profiling*

The collected data of reflectance spectra of the leaves will be used to support and validate vegetation mapping of the study area. Also this dataset is very useful to assess ecological monitoring. In addition, the collected canopy reflectance spectra can be used as input for spectral unmixing classification of the AHS image.

In a next step which will be carried out in 2008, the seasonal development of the spectral reflectance of the different vegetation types will be characterized. This means that during the growing season at regular intervals, reflectance spectra will be acquired using the Fieldspec for a selected set of vegetation transect plots.

# 6 Vegetation description

## 6.1 Introduction

Main objective of the HABISTAT project is to explore the use of hyperspectral sensors to classify habitat types and its associated quality. During the field campaign, vegetation descriptions were made for vegetation transect plots and vegetation grid plots according to the BioHab methodology (Bunce *et al.*, 2008). Every plot was classified according to a classification key developed by INBO (Appendix 3). At this stage no destructive measurements of the vegetation canopy were made. In this chapter, the followed methodology is presented in more detail.

## 6.2 Methodology

We used the BioHab method (Bunce *et al.*, 2008) as a basis for the field work protocol. This is a method that defines vegetations based on the life forms present. Within each life form, dominant species are then recorded, with their % coverage. This protocol was used to characterize both the vegetation transect plots and the vegetation grid plots. Below the different steps of the followed protocol are given:

- Plot selection based on homogeneity and size of vegetation patch. Minimal size of the plots should be at least 15 x 15 m. The description was based on a central area of 5 x 5 m;
- Determine plot coordinates using handheld GPS;
- Make photos of plot and surrounding landscape;
- Determine General Habitat Category (GHC) according to key developed by INBO (Appendix 3). This is given by the dominant life form or the combination of two or three dominant life forms;
- Determine abiotic conditions: soil moisture and pH, coded as in BioHab-method (no real measurements in the field);
- Determine management (e.g., mowing, sod-cutting);
- Determine height of the mean highest vegetation, i.e. the mean height of what are generally the highest culms in the entire vegetation patch;
- Determine patchiness (Figure 6.1) as one of four classes:
    - Uniform: no patches of species, dominance by one species
    - Coarse mosaic: coarse mosaic of plant species
    - Fine mosaic: fine mosaic of plant species
    - Intensely mixed: no patches, different plant species intensely mixed
- Note all life forms covering 10 % or more. Per life form, dominant species are noted, together with their % cover within the life form and within the total vegetation.
- Note additional species present are, together with an indication of their abundance, using a (somewhat adapted) Tansley-scale:
    - S = sporadic (1-3 plants)
    - R = rare (4-10 plants)
    - O = occasional (10-20 plants)
    - F = > 20 plants, but less than 10% coverage
- Note additional remarks.

To note the different items as gathered in the field a standardized field form was used.

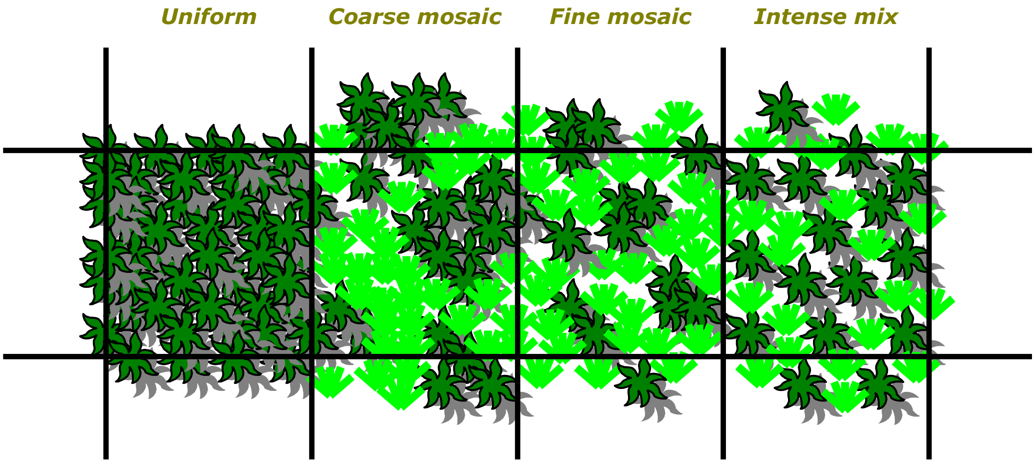


Figure 6.1: Schematic representation of the different classes for patchiness as identified within the procedure.

The following life forms were used to characterize the vegetation (Bunce et al., 2008):

- HEL: helophytes (marsh plants, e.g. Reed Phragmites australis)
- LHE: leafy hemicryptophytes (most dicotyledonous forbs, e.g. Ranunculus)
- CHE: cespitose hemicryptophytes (most rushes, grasses and sedges, e.g. Juncus, Carex, Molinia, Eriophorum)
- GEO: geophytes (often monocotyledons with bulbs or corms, e.g. Narthecium ossifragum)
- CRY: cryptogams (mosses and lichens, e.g. Cladonia, Sphagnum)
- SCH: shrubby chamaephytes under 30 cm height, e.g. Erica, young stage of Calluna)
- LPH: low phanerophytes (30 – 60 cm height), e.g. Calluna in the full grown stage
- AQU: aquatic, open water
- TER: terrestrial, bare soil
- Litter: soil covered with dead material

In total, 24 plots were described for the vegetation transect plots and a limited number of plots was described as vegetation grid plot. Starting from March 2008, additional field work has been carried out to increase the number of vegetation descriptions for the grid points. In total vegetation descriptions for 98 points has been made.

All information from the field forms was made digital and stored in an excel work sheet and as GIS data-layer.

## 6.3 Data

Different types of analysis can be carried out with the acquired vegetation description. In the scope of the HABISTAT project, the data will be used to calibrate and validate the developed classification schemes. For example, the unique signature for a specific vegetation type could be used as input for a spectral mixture analysis (SMA). For more details see final chapter which gives an outlook of the further activities within the project.

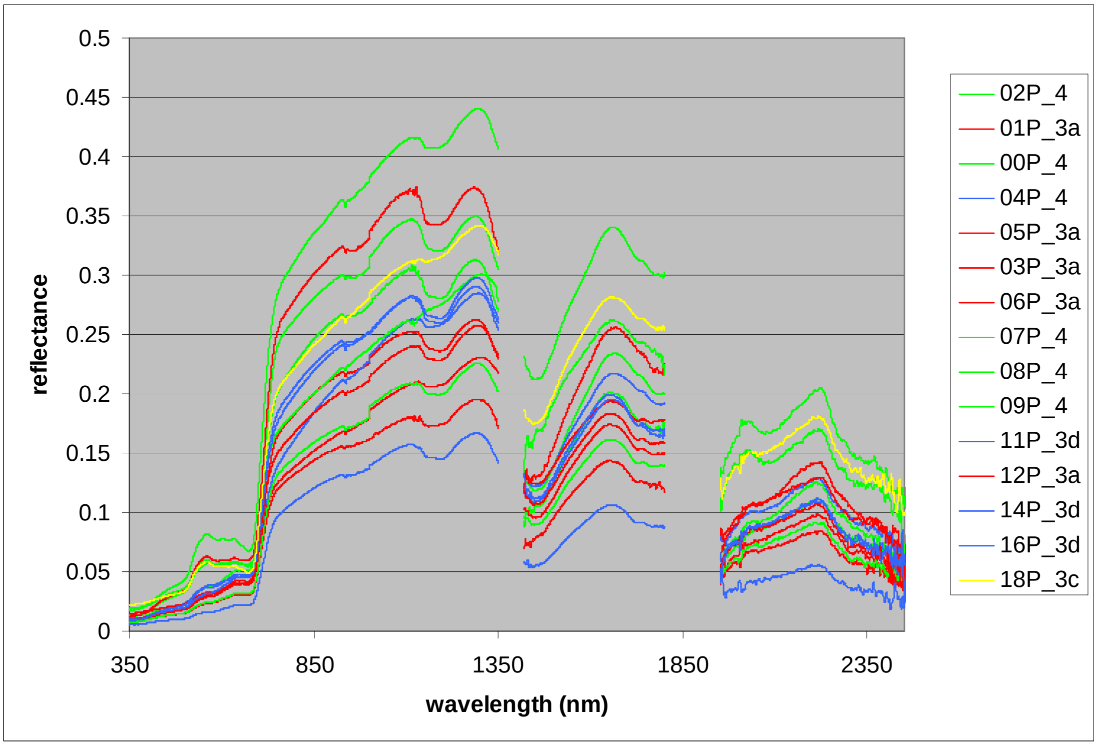



Figure 6.2: Reflectance spectra for vegetation transect plots identified according to their general habitat category: 3a) dry heath land: young phase; 3c) dry heath land: degenerating phase; 3d) dry heath land: mixture of age classes; 4) dry heath land: poorly developed, grass encroachment;

## 6.4 Quality assessment

Standardized methods and procedures (see references) were used for the description of vegetation plots and the management of the data.

## 6.5 Archive

Data for vegetation descriptions are stored in excel-worksheets and in shp files. The dataset consists of the following fields as indicated in Table 6.1 and consists of 100 point observations.

## 6.6 Outlook

Starting from March 2008, additional field work has been carried out to increase the number of vegetation descriptions for the grid points. In transect plots vegetation types with mixed moss and heath land coverage and with only moss cover are currently missing. A dataset of 104 point observations has been developed and is distributed to the partners within the HABISTAT project.

### References


Bunce R. G. H., Metzger M. J., Jongman R. H. G, et al (2008). A standardized procedure for surveillance and monitoring European habitats and provision of spatial data. Landscape Ecology 23: 11-25.

Table 6.1: Overview of data fields of database for vegetation descriptions of Ginkelse & Eder Heide.

| **Field name** | **Description** |
|---|---|
| ID | unique identifier |
| NAME | field name of location |
| XCOORD | x coordinate in RD |
| YCOORD | y coordinate in RD |
| SOURCE | campaign date + GPS source |
| LEVEL1 | level 1 classification |
| LEVEL2 | level 2 classification |
| LEVEL3 | level 3 classification |
| LEVEL4 | level 3 classification |
| CLASS | final classification |
| MOLINIA | % coverage of Molinia caerulea |
| CALLUNA | % coverage of Calluna vulgaris |
| ERICA | % coverage of Erica spp. |
| DESCHAMPSIA | % coverage of Deschampsia cespitosa |
| CORYNEPHORUS | % coverage of Corynephorus canescens |
| OTHGRSP | % coverage of other grass species |
| CAMPINTR | % coverage of campintr |
| WATER | % coverage of water |
| SAND | % coverage of bare sand (no OM) |
| SOIL | % coverage of organic soils |
| MOSS | % coverage of moss species |
| RUBUS | % coverage of Rubus fruticosus |
| CONITREE | % coverage of coniferous trees |
| DECITREE | % coverage of decidious trees |
| VEGHGT | vegetation height (cm) |

# 7 Surface temperature

## 7.1 Introduction

Next to reflectance in the optical domain, the AHS sensor is also capable to measure emissivity in the longterm thermal infrared (8-13 μm). Therefore, next to reflectance measurements also thermal measurements were made in the field for a selected set of reference plots on the day of the AHS overflight. These measurements can be used for calibration (from emmitance to temperature) and validation of the acquired AHS images for the Edese and Ginkelse heide and Wekeromse zand.

## 7.2 Methodology

Temperature measurements were made with the ST20 Raytek temperature gun (Fig. 7.1). Measurements were made for all reference plots and some additional plots with different vegetation types between 11:30 a.m. and 15:30 p.m. during the day of the overflight with the AHS sensor, October 7, 2007. For every plot, between 5 and 10 measurements were made in a regular random sampling design over the complete surface area of the plot (approx. 10 x 10 m). The GPS coordinates for the centre of the plots were stored. The gun was positioned approx. 1 m above the ground surface resulting in a measured surface with a diameter of 8 cm.


Figure 7.1: Measurements principle of the ST20 Raytek temperature gun.

## 7.3 Data processing

For a total of 18 locations, measurements were made on the the Edese and Ginkelse heide and Wekeromse zand (see Figure 4.2 for locations). Measurements were written down in the field and digitized back in the office: id, time, surface type, etc. Data are stored and managed in an excel worksheet. For all locations, mean, standard deviation, mimimum and maximum values were calculated. Figure 7.2 shows the mean surface temperature for all measured locations.

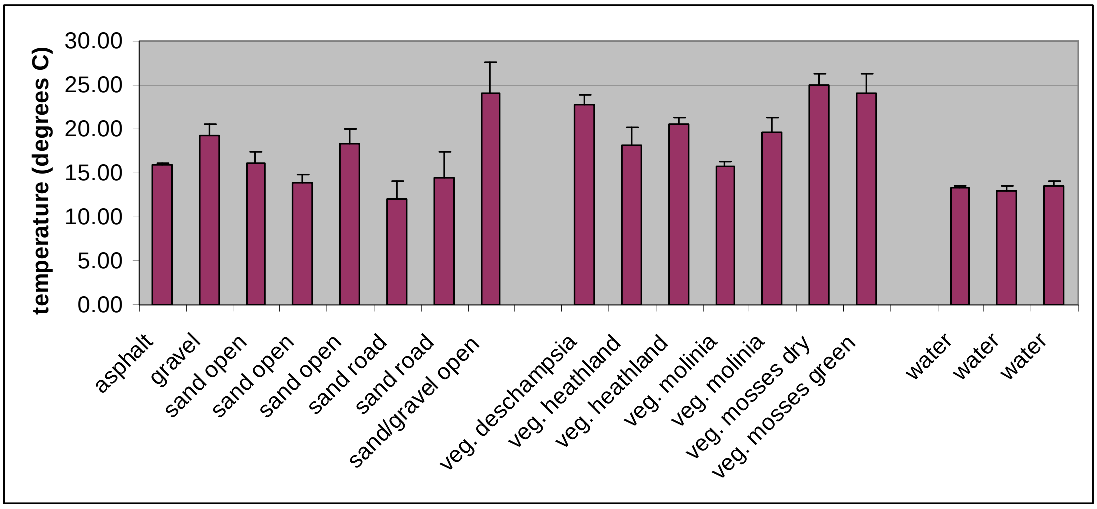



Figure 7.2: Comparison of surface temperature for different vegetation and surface types in the Edese and Ginkelse Heide and Wekeromse zand. Measurements were made with a ST20 Raytek temperature gun between 11:30 and 15:30 on October 7, 2007.

The water bodies clearly have a homogeneous temperature over the day and for different locations. In general the temperature in the plant canopy is relatively higher compared to the temperature in open sand. For some surface types, which were measured at different times during the day, a small warming effect can be observed (e.g., heath land, molinia).

## 7.4 Quality assessment

The acquired data have a reasonable quality, taking into account warming effects over the day and the effect of local heterogeneity due to the small measurements surface (8 cm diameter). The differences between surface areas give a first indication and can be used for calibration (from emmitance to temperature) and validation of the acquired AHS images for the Edese and Ginkelse heide and Wekeromse zand.

**Reference**

Product description: http://www.atlasscreensupply.com/download/ST20SPEC.pdf

# 8 Meteorological data Wageningen

## 8.1 Introduction

The weather station at the Haarweg in Wageningen is a special AgroMeteo-Station; the measurements include radiation and soil temperature. The coordinates of the location are 51° 58' NB; 5° 38' OL; and is about 7 metres above the sea level (see http://www.met.wau.nl/).

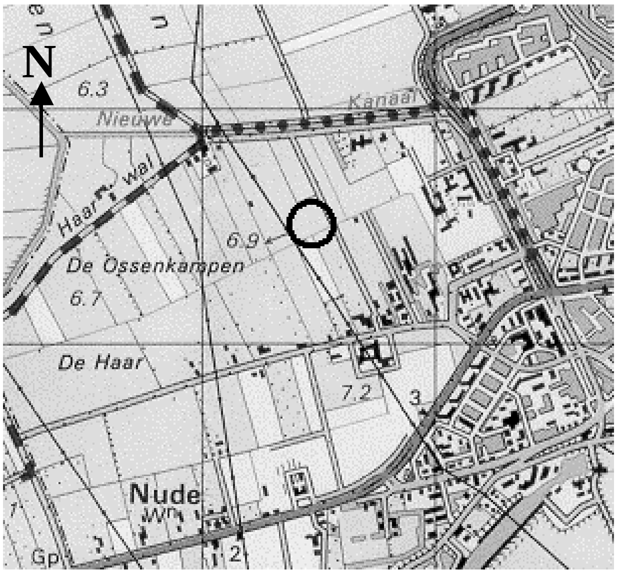



Figure 8.1: View of the location of the weather station (circle).

## 8.2 Available data

Table 8.1: Instruments at the weather station

| Data | Instruments | Type |
|---|---|---|
| Relative humidity | Hair hygrometer | |
| Temperature and relative humidity | Thermo-Hygrometer | |
| | Ventilated Thermo-Hygrometer | |
| Air Pressure | | |
| Wind speed at 4 levels | Cup anemometer (4x) | |
| Wind direction | Wind vane | |
| Short wave Radiation (global, reflected, net) | Pyranometers | Kipp en Zonen CM11 |
| Long wave radiation | Pyrgeometer | |
| Amount of precipitation | Precipitation meter | Mierij Meteo |
| Precipitation duration | Precipitation meter | Thies |
| Sun duration | Sunshine Sensor | Kipp&Zonen CSD1 |
| Soil temperature (bare soil and grass) | Thermocouple | PT 100 |
| Sensible heat Flux | Large Apenture Scintillometer | Self construction |

The following figures illustrate some of the meteorological measurements obtained at Wageningen on 7 October 2005. Net radiation and humidity are illustrated as hourly data for this day.

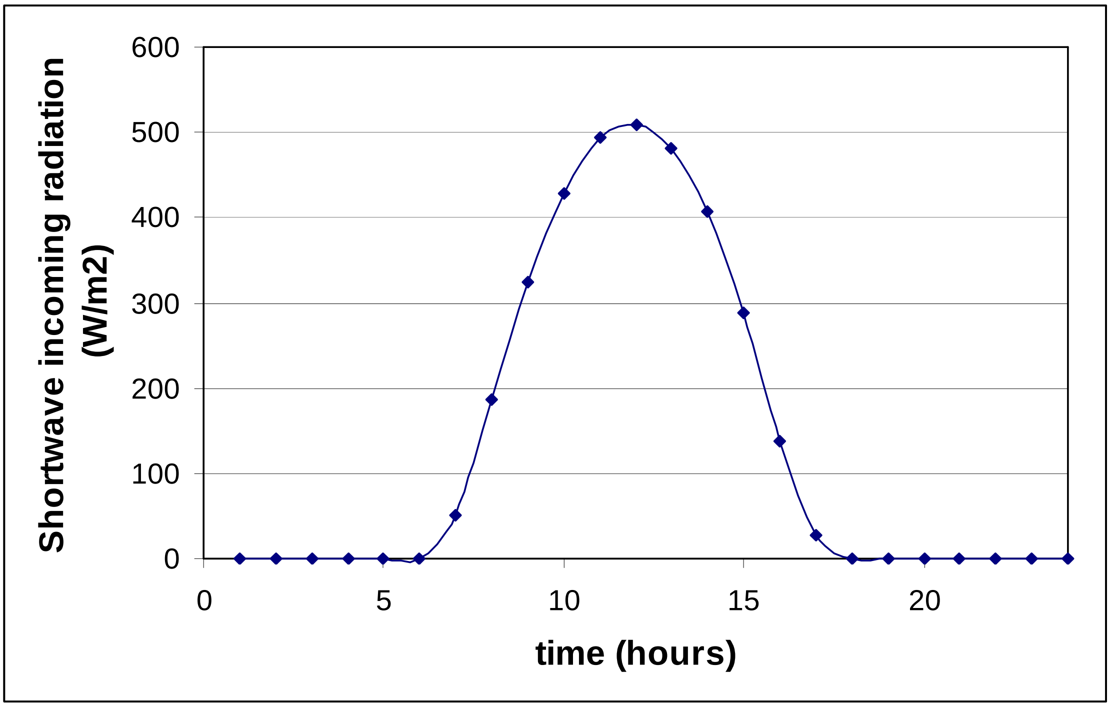



Figure 8.2: Amount of incoming shortwave radiation measured on the Wageningen station for October 7, 2007.

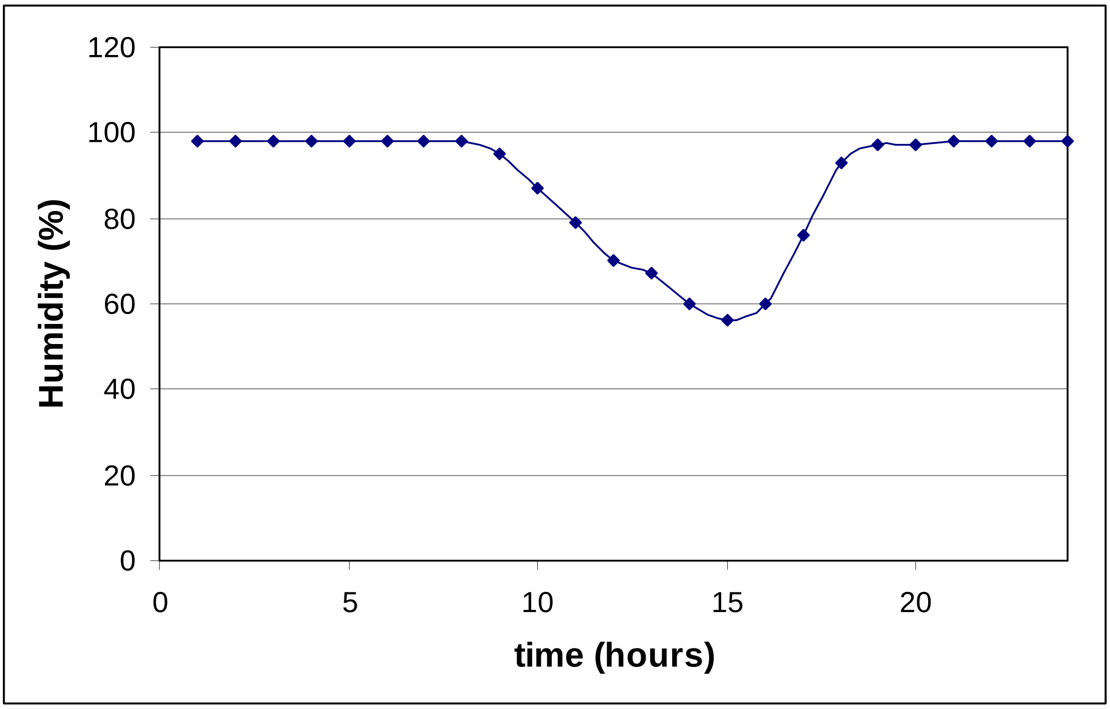



Figure 8.3: Humidity measured on the Wageningen station for October 7, 2007.


Figure 8.4: View on weather situation in Western-Europe from Meteosat on October 7, 2007 at 12:00 UTC.

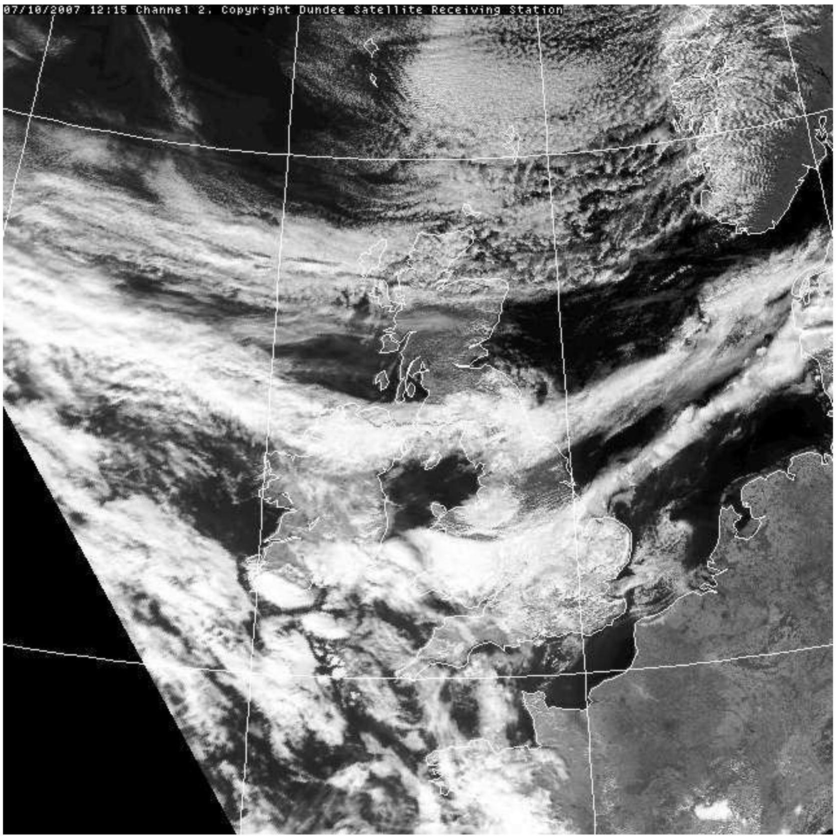



Figure 8.5: View on weather situation in Western Europe from NOAA band 2 on October 7, 2007 at 12:15 UTC.

# 9 Imaging spectroscopy data: AHS-160

## 9.1 Introduction

The data quality description in this chapter is aiming at a full assessment of potential shortcomings present in the AHS-160 data acquired for the HABISTAT project. At the end of the chapter there will be recommendations for the further use of the data. In the next chapter a description and quality assessment is given for the CHRIS PROBA images which were acquired for the study area.

## 9.2 Description of AHS-160 data

Hyperspectral data over the Eder and Ginkelse Heide were acquired using the AHS-160 sensor. Specifications of the AHS-160 sensor can be found in the tables 9.1 and 9.2. The acquisition of the AHS-160 images was done by INTA (SP) using a CASA 212-200 aeroplane. Additional preprocessing of the images from DN values to radiance and surface reflectance was carried out in the processing and archiving facility of VITO (BE). The PARGE model was used for geometric correction of the data. The ATCOR model was used for atmospheric correction of the data. Further details can be found in Biesemans et al. (2006).

Study area specific characteristics for the two flight lines which were acquired by the AHS-160 are presented in table 9.3 and 9.4. Quick looks of the AHS images can be found at http://campaigns.vgt.vito.be/quicklook2007.htm. An overview of the processed AHS images is given in Appendix 3.

Table 9.1: Specifications of the AHS-160 sensor as operated by INTA

| | |
|---|---|
| Field of View | 90° |
| Instantaneous Field of View | 2.5 mrad |
| No. of channels | 80 |
| No. of samples/lines | 750 |
| Scan principle | whiskbroom |
| Scan frequency | variable |
| Ground resolution | 2.5 – 10 m |
| Radiometric resolution | 12 bit |

Table 9.2: Band specifications of the AHS-160 sensor as operated by INTA

| Optical port | Number of bands | Spectral region (nm) | Band width (nm) |
|---|---|---|---|
| 1 - Visible and Near Infrared | 20 | 430 – 1030 | 30 |
| 2A - Short wave Infrared | 1 | 1550 – 1750 | 200 |
| 2B - Short wave Infrared | 42 | 1994 – 2540 | 13 |
| 3 - Mid Infrared | 7 | 3.3 – 5.4 µm | 300 |
| 4 - Long Wave Infrared | 10 | 8.2 – 12.7 µm | 400 |

Table 9.3: Flight strip specific AHS parameters for HABISTAT'07 of Edese Heide (NL)

| | **Strip1 = EH_ahs1 (P07-01)** | **Strip 2 = EH_ahs2 (P07-02)** |
|---|---|---|
| Acquisition date | October 7, 2007 | October 7, 2007 |
| Acquisition time | 11:12 (UTC) | 11:22 (UTC) |
| Flight altitude | 3300FT | 3300FT |
| Flight heading | 337° | 157 ° |
| Flight direction | South-North | North-South |
| Length | 12.4 km/2m52s | 12.4 km/2m52s |
| Solar position[3] | Air mass: 1.897<br>Zenith: (refracted): 58.272<br>Azimuth: 193.512<br>Cos incidence: 0.5259<br>Cos zenith: 0.5259 | Air mass: 1.897<br>Zenith: (refracted): 58.272<br>Azimuth: 193.512<br>Cos incidence: 0.5259<br>Cos zenith: 0.5259 |
| Solar day | Solar time:<br>Julian day: 2454393.5 | Solar time:<br>Julian day: 2454393.5 |
| Start latitude / start longitude | 682336 577302 | 683209 5777578 |
| End latitude / end longitude | 687525 5766027 | 688399 5766305 |
| Dimensions geocoded (x = across track, y = along track, z = spectral bands) [pixels] | 3522, 6482, 80 | 3444, 6204, 80 |

Table 9.4: Geometric characteristics of AHS data of Eder Heide (NL)

| **Sampling** | |
|---|---|
| Line rate (lines per second) | 35 rps |
| Pixel size | 2.40294 x 2.402716 m |
| Resampling | Nearest Neighbour |
| Map projection | UTM, Zone 31 N |
| Geodetic Datum | WGS-84 |

## 9.3 Assessment of data quality AHS-160 data

Both the geometric and radiometric quality of the processed images was evaluated.

*Geometric quality*
The geometric quality was checked by overlaying the corrected image data with the available topographic map for the area. The topographic map has a high geometric accuracy.

*Radiometric quality*
The radiometric accuracy was evaluated both in qualitative and quantitative way. First, color composites and grey scale images per band were visually checked to identify global patterns of noise which could be identified in a visual way.

For each existing AHS-160 image, the mean and the standard deviation over the whole spectral range is computed. In addition, typical very 'bright' and 'dark' targets are listed. The results will allow getting an estimate of the radiometric dynamic range in the images. The analysis is performed for the radiance images.

[3] http://www.nrel.gov/midc/solpos/solpos.html

A comparison was made between the reflectance spectra which were acquired in the field during the overflight and the image derived reflectance spectra for the same location. Finally, the parameters which were derived from Modtran model for the atmospheric correction of the images were assessed.

## 9.4 Results of data quality assessment of AHS-160 data

### 9.4.1 Geometric quality

Based on visual interpretation of an overlay between the AHS strips and the topographical map (Figure 9.1), the quality of the geometric correction of the images is high. A small shift is occurring along the edge of the strips as can be observed in the lower left corner of Figure 9.1. Here we see, that the red lines are shifted a few pixels from the white pixels of the sandy road in the heath land. Additional information and a validation of the geometric correction based on AHS data from 2005can be found in the PAF Integrated Test Report v1.0 (VITO, 2005).

Figure 9.1: Overlay of AHS strip 2 with topographic map (red line).

### 9.4.2 Radiometric quality

The AHS data consists in total of 80 bands. However, the thermal bands (band 64-80) have not been processed. Quality of the spectral bands varies considerably per wavelength area. Based on the assessment of the grey scale images per band (Appendix 5), the following observations were made:

**Visible till Short Wave InfraRed (port 1 and 2A)**
Bands in the visible till SWIR (band 1-21) show a good quality. Objects and vegetation types and characteristics can be observed in the individual bands. In the Northern part of both strips there seems to be a problem with some random pixels with a different value (speckle) which appear especially in agricultural fields. This feature has a random location and is present for different bands. An example is shown in Figure 2.

**Short Wave InfraRed (port 2B)**
Bands within this region have a relative high noise level. This is already known from earlier campaigns with the AHS sensor and from information which is provided by the data provider INTA. However, with the application of filter techniques or other signal improvement techniques possibly information from bands 31-48 can still be used.

**Mid till long wave Infrared (port 3 and 4 )**
For a large part of the spectral bands in this wavelength region no information was provided in the provided dataset: bands 67-80. Only bands 65 and 66 contained some usable signal while the bands 63-64 mainly contain noisy data which cannot be used.

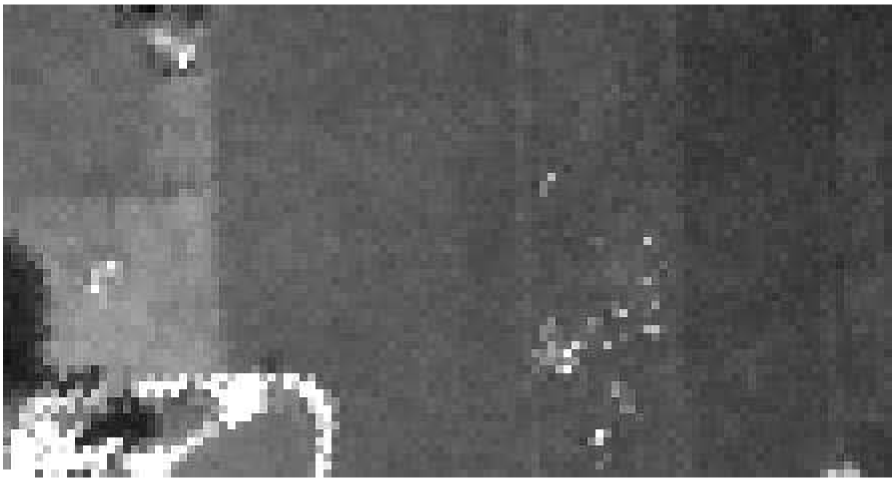


Figure 9.2: Example of random pixels within the image which have a different value compared to the surrounding pixels.

When an overlay is made for the two AHS strips over the Eder heide (appendix 1 and Figure 3), a clear difference in illumination is observed along the edge of the two strips. This means that in the overlapping areas of the two strips have different surface reflectance values for the same pixel (Figure 9.6). This feature occurs at all edges of the strips and could be related to the water vapour estimates which are derived from Modtran (see Figure 4). Before the data can be further analysed, first a solution needs to be found to remove or reduce this feature.

Figure 9.4 and 9.5 present the image statistics per flight strip for the VNIR spectral range. Figure 9.6 present the comparison between field measured reflectance (ref) and the image based reflectance from strip 1 and 2 for the 8 reference points for which spectral measurements were made during the day of the over flight. A general observation is that field measured reflectance for all points is higher over the complete wavelength range compared to the image derived reflectance (except for reference plot R08!). For some plots, reflectance for strip 1 and 2 overlap quit well while some reference plots there is a large difference (R09 and R13).

Figure 9.3: Overlap between the strips 1 and 2 over the Edese Heide. Notice the clear difference in surface reflectance at the edge of strip 2 compared to strip 1.

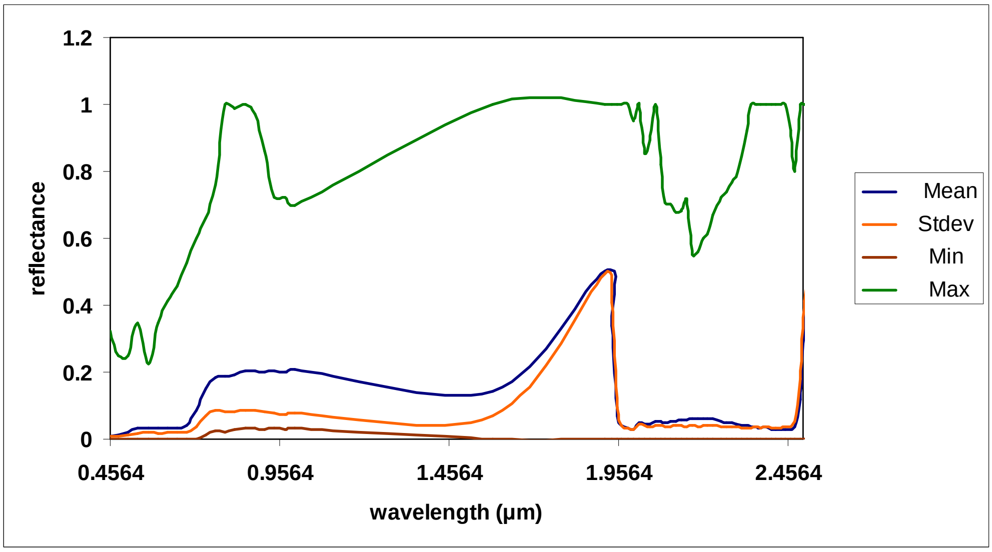



Figure 9.4: Band statistics for AHS image of strip 1.

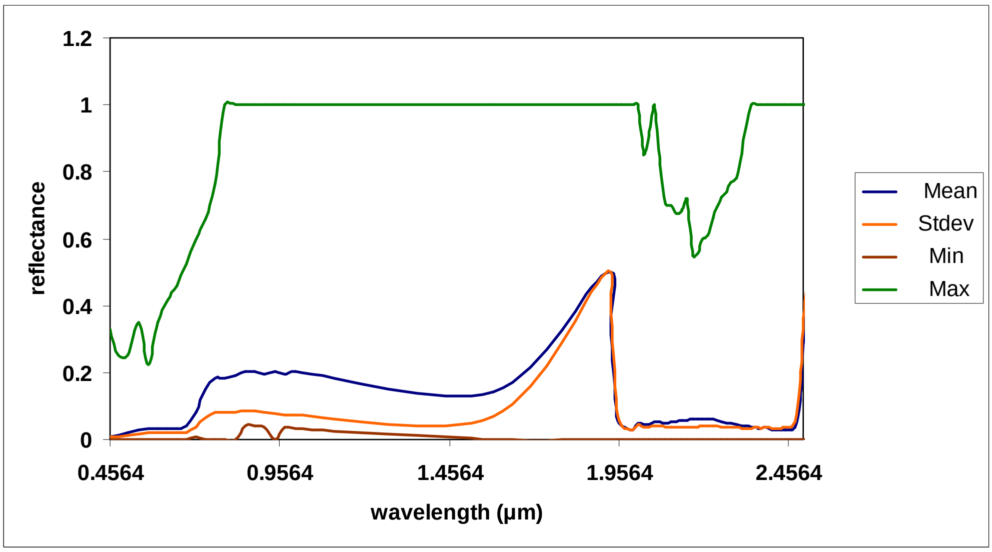



Figure 9.5: Band statistics for AHS image of strip 2.

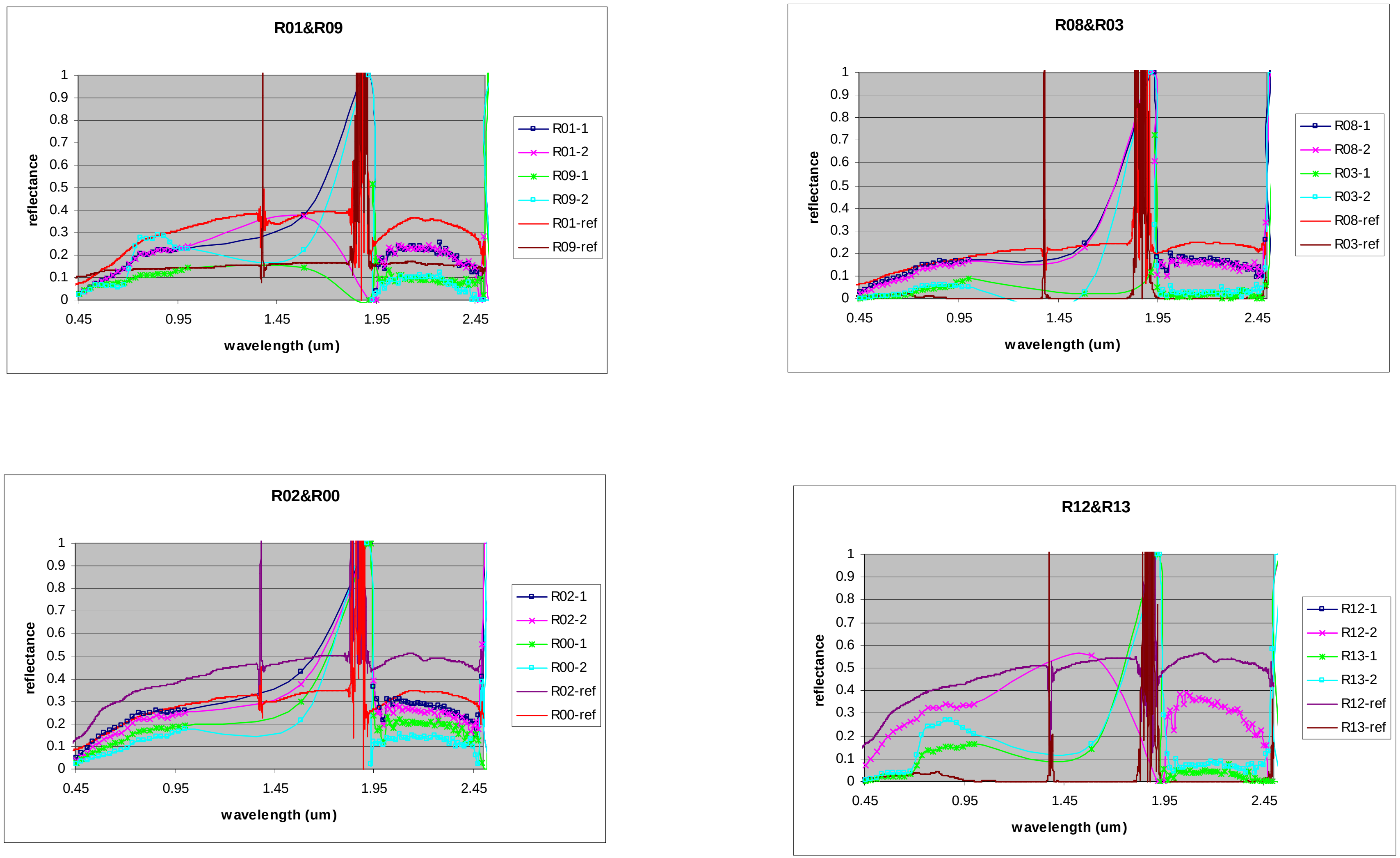



Figure 9.6: Comparison of field spectra (ref) and image spectra (strip 1 and 2) for reference plots measured during the overflight.

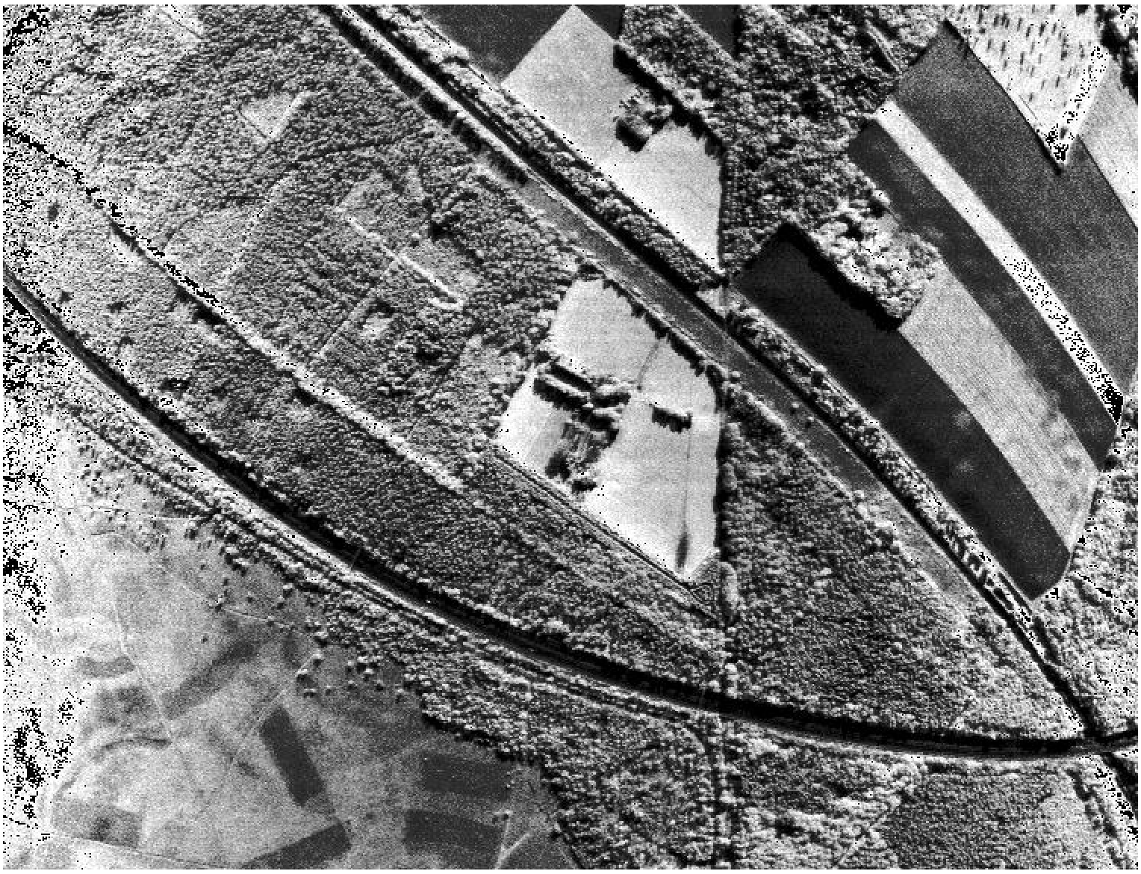


Figure 9.7: Detail of water vapour image derived from Modtran for Eder Heide (NL).

From the water vapour image (Figure 9.7) an edge effect can be observed based on different spatial structures for same land-use type. For example in the lower left part of Figure 9.7, heath land occurs, however water vapour estimations along the edge differ from estimations more to the middle of the image. This results in no data values for some areas and over estimation of water vapour for other areas along the edge.
This effect is larger on the West side of the image compared to the East side. This water vapour also has a significant effect on estimated surface reflectance, as can be observed from Figure 9.3.

### 9.5 Conclusions for AHS-160 data

From the quality assessment of the AHS-160 images for the Eder and Ginkelse heide we derive the following conclusions:

- The geometric accuracy of the processed images is good, only some shift along edges
- The radiometric quality of the VNIR is good (port 1 and 2A), the SWIR (port 2B) is probably useable with additional filtering. The data for port 3 and 4 has not been processed and can not be used at this stage. However, if required these ports can be processed by VITO.

- At the edge of the images, brightness gradients are present due to BRDF effects: this requires careful processing when mosaiking images. If possible, the images could be re-processed by VITO after an additional BRDF correction tool has been implemented.
- Generally, the image derived reflectance spectra have a lower reflectance curve compared to field measured reflectance.

### References


Biesemans J., S. Sterckx, E. Knaeps, K. Vreys, S. Adriaensen, J. Hooyberghs and B. Deronde, 2007. Image processing workflows for airborne remote sensing. 5th EARSeL Imaging Spectroscopy Workshop, Bruges, Belgium.

VITO, 2005. Processing and Archiving Facility for Airborne Remote Sensing: Software System Validation Report AHS160 Campaign 2005. VITO Internal report, Mol, Belgium.

# 10 Imaging spectroscopy data: CHRIS PROBA

## 10.1 Introduction

The data quality description in this chapter is aiming at a full assessment of potential shortcomings present in the CHRIS PROBA data acquired for the HABISTAT project. At the end of the chapter there will be recommendations for the further use of the data.

## 10.2 Description of CHRIS PROBA

CHRIS (Compact High Resolution Imaging Spectrometer) is a physically compact payload as its name implies (weighing under 15 kg) and operates in the 'push-broom' mode[4]. The telescope in the CHRIS instrument is nadir pointing. CHRIS has the additional advantage of being relatively cheap and easy to manufacture since it has no moving parts. Its main applications will be in environmental monitoring, forestry inventory and precision farming (Table 10.1).

The first version of the instrument will fly on the PROBA (Project for On Board Autonomy) platform. It will carry the instrument in a sun-synchronous elliptical polar orbit, at a mean altitude of about 600 km . All parts of the Earth's surface will be accessible when PROBA's across track pointing ability is used.

From a 600 km orbit, CHRIS can image the Earth in a 14 km swath with a spatial resolution of 18 m (this is somewhat variable as the altitude varies artound the orbit). Using PROBA's agile steering capabilities in along and across track directions enables observation of selectable targets well outside the nominal field of view of 1.3o . Images will generally be acquired in sets of 5, these being taken at along track angles of +/- 55 degrees. +/- 36 degrees, and as close to nadir as possible.

CHRIS operates over the visible/near infrared band from 400 nm to 1050 nm and can operate in 63 spectral bands at a spatial resolution of 36m, or with 18 bands at full spatial resolution. Spectral sampling varies from 2-3 nm at the blue end of the spectrum, to about 12 nm at 1050nm. Sampling is about 7nm near the red edge (~690-740nm). The instrument is very flexible and different sets of bands can be used for different applications (Table 10.2 and Figure 10.1).

[4] http://www.chris-proba.org.uk/mission/instrument_characteristics.html and http://earth.esa.int/missions/thirdpartymission/proba.html

Table 10.1: Specifications of the CHRIS-PROBA sensor

| | |
|---|---|
| Spatial sampling interval | 18m on ground at nadir |
| Image area | 14 km X 14 km (748 X 748 pixels) |
| Number of images | Nominal is 5 downloads at different view angles |
| Data per image (for a 14 X 14 km2) | 131 Mbits |
| Spectral range | 410nm to 1050 nm |
| Number of spectral bands | 19 bands at a spatial resolution of 18m, 63 at 36m |
| Spectral resolution | 1.3 nm @ 410nm to 12 nm @ 1050nm (i.e it varies across the spectrum) |
| Programmable operation | |
| Across track pixel size | 18m or 36m |
| Along track pixel siz | finest resolution is 18m but can be made coarser by changing the integration time |
| Spectral | variable bandwidth and location |
| Digitisation | 12 bits |
| Signal-to-noise ratio | 200 @ a target albedo of 0.2 |

The CHRIS instrument is programmable, so that a variety of band selections are possible. For this mission the number of different configurations is kept small. The principal configurations, based on a pre-launch wavelength calibration, are set out below in tables. Graphs are also provided, showing the locations of the bands compared to a typical spectrum of green vegetation, and to the spectrum of atmospheric absorption.

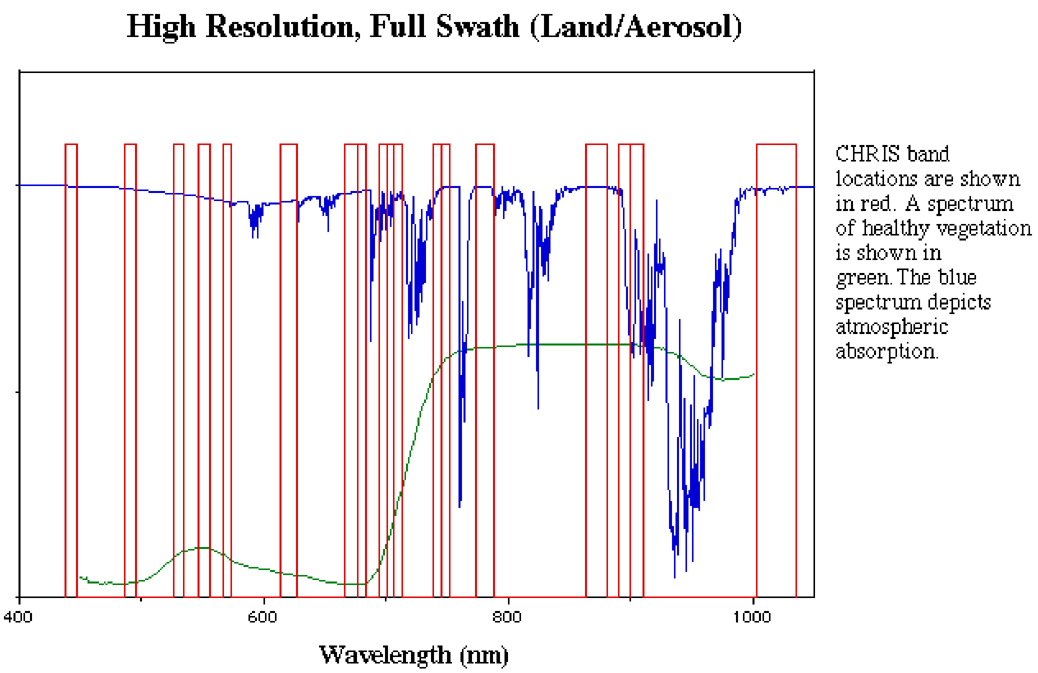



Figure 9.8: Band positions of the CHRIS-PROBA sensor for MODE 3 compared to a vegetation (green) and atmospheric (blue) spectrum.

Table 9.6: CHRIS PROBA bands For Full Swath, High Resolution Land/Aerosols (MODE 3)

| Band | Detectors | From | To | lmid | Width |
|---|---|---|---|---|---|
| L1 | 41-45 | 438.0 | 446.8 | 442.4 | 8.8 |
| L2 | 65-68 | 485.6 | 494.8 | 490.2 | 9.2 |
| L3 | 81-83 | 525.6 | 534.2 | 529.9 | 8.6 |
| L4 | 88-90 | 546.4 | 556.1 | 551.2 | 9.7 |
| L5 | 94-95 | 566.3 | 573.4 | 569.8 | 7.7 |
| L6 | 109-110 | 626.6 | 636.0 | 631.2 | 9.4 |
| L7 | 115-116 | 655.8 | 666.3 | 661.0 | 10.5 |
| L8 | 117-118 | 666.3 | 677.2 | 671.7 | 10.9 |
| L9 | 122 | 694.3 | 700.1 | 697.2 | 5.9 |
| L10 | 123 | 700.2 | 706.2 | 703.2 | 6.0 |
| L11 | 124 | 706.2 | 712.4 | 709.3 | 6.2 |
| L12 | 129 | 738.2 | 745.0 | 741.6 | 6.8 |
| L13 | 130 | 745.0 | 751.9 | 748.4 | 6.9 |
| L14 | 134-135 | 773.3 | 788.4 | 780.8 | 15.0 |
| L15 | 145-146 | 863.1 | 881.3 | 872.1 | 18.3 |
| L16 | 148 | 890.7 | 900.2 | 895.4 | 9.5 |
| L17 | 149 | 900.2 | 909.8 | 905.0 | 9.7 |
| L18 | 159-161 | 1002 | 1035 | 1019.0 | 32.9 |

CHRIS PROBA data were acquired for the area around the Ginkelse and Ederheide on October 22, 2007 in MODE 3.

### 10.3 Assessment of data quality CHRIS PROBA data

When the CHRIS PROBA data were received no geometric or atmospheric correction procedures have been applied. The coverage of CHRIS PROBA data set is indicated in Figure 10.2.Additional pre-processing steps and quality assessment are required before the images can be used to analyze vegetation distributions in the HABISTAT study area.

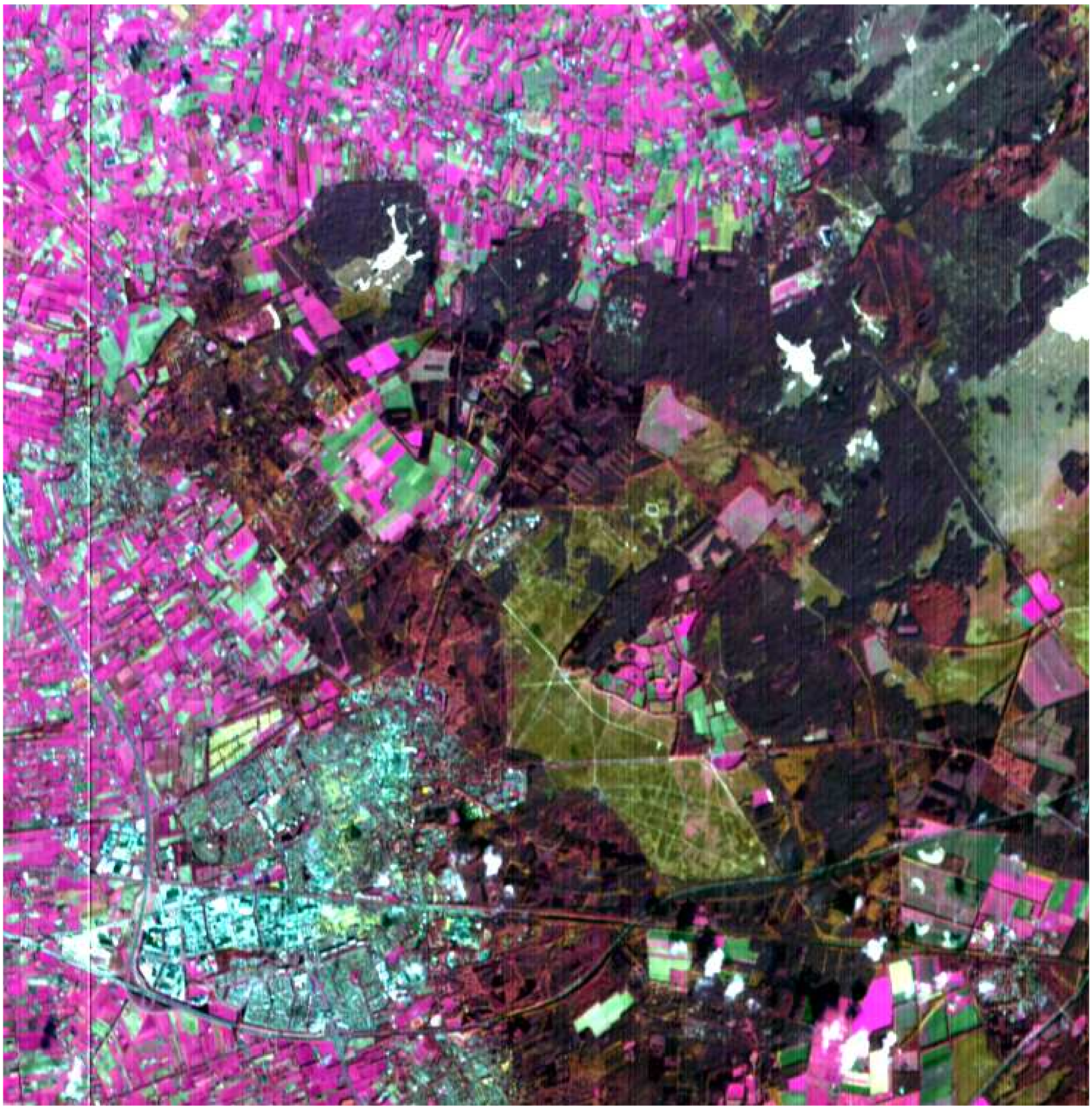


Figure 10.2: Coverage of CHRIS-PROBA data set for the area around Eder Heide. As an example a colour composite of the nadir image is shown (no geometric and atmospheric correction).

## 10.4 Outlook

The CHRIS PROBA data will atmospherically processed using different approaches: VITO processing chain and procedure developed at University of Valencia (Guanter, 2005). In a next step, the directional images will be used to investigate the opportunities to characterize the structure of the different heathland classes.

## References

Guanter L., Alonso L., and Moreno, J., 2005. A Method for the Surface Reflectance Retrieval rom PROBA/CHRIS Data Over Land: Application to ESA SPARC Campaigns. IEEE Transactions On Geoscience AND Remote Sensing, 43: 2908– 917.

# 11 Outlook

In a next step, the acquired data of both the Ginkelse and Eder Heide and the Kalmthoutse heide will be used to train and validate the state-of-the-art classification techniques which will be developed within the HABISTAT project.

For the area of the Eder and Ginkelse Heide, we will specifically deal with:

- Classification of vegetation and habitat types using spectral mixture analysis based (SMA) methods, to derive not only classes but also continuous fields with abundances of specific vegetation structure types;
- Investigate enhanced radiative transfer based methods to characterize vegetation structure (photosynthetic and non-photosynthetic vegetation) and processes: grass and forest encroachment;
- Investigate the opportunity to use remote sensing derived variables as input for dynamic vegetation models to predict the future succession in the system in order to assess management scenario for the study area;
- Investigate the use of segmentation techniques to derive a first stratification of the heathland structure which in a next step can be used for the classification procedure.
- … and much more

Figure 11.1: Heath land on Wekeromse Zand (NL)

## Appendices

## Appendix 1: Evaluation matrix for Habitat Types (according to Janssen *et al.*, 2007)

| Parameter | Conservation Status | | | |
|---|---|---|---|---|
| | Favourable ('green') | Unfavourable – Inadequate ('amber') | Unfavourable – Bad ('red') | *Unknown (insufficient information to make an assessment)* |
| **Range** | Stable (loss and expansion in balance) or increasing AND not smaller than the 'favourable reference range' | Any other combination | Large decrease: Equivalent to a loss of more than 1% per year within period specified by MS OR More than 10% below 'favourable reference range' | *No or insufficient reliable information available* |
| **Area covered by habitat type within range** | Stable (loss and expansion in balance) or increasing AND not smaller than the 'favourable reference area' AND without significant changes in distribution pattern within range (if data available) | Any other combination | Large decrease in surface area: Equivalent to a loss of more than 1% per year (indicative value MS may deviate from if duly justified) within period specified by MS OR With major losses in distribution pattern within range OR More than 10% below 'favourable reference area' | *No or insufficient reliable information available* |
| **Specific structures and functions (including typical species)** | Structures and functions (including typical species) in good condition and no significant deteriorations / pressures | Any other combination | More than 25% of the area is unfavourable as regards its specific structures and functions (including typical species) | *No or insufficient reliable information available* |
| **Future prospects** (as regards range, area covered and specific structures and functions) | The habitats prospects for its future are excellent / good, no significant impact from threats expected; long-term viability assured | Any other combination | The habitats prospects are bad, severe impact from threats expected; long-term viability not assured | *No or insufficient reliable information available* |
| **Overall assessment of CS**[4] | All 'green' OR three 'green' and one 'unknown' | One or more 'amber' but no 'red' | One or more 'red' | Two or more 'unknown' combined with green or all 'unknown' |

# Appendix 2: Overview of spatial data in geo-database for Eder and Ginkels Heide and Wekeromse Zand

The available geo-data layers for the Ginkelse and Ederheide are stored on Alterra server nesg0101\cgidfs, directory **cgi_store4$\Imaging_Spectroscopy_data\habistat_AHS2007\DATA\NL** This contains all available data with metadata for the research area and the fieldwork. Below and overview of available data-sources in given.

It contains 7 main folders:

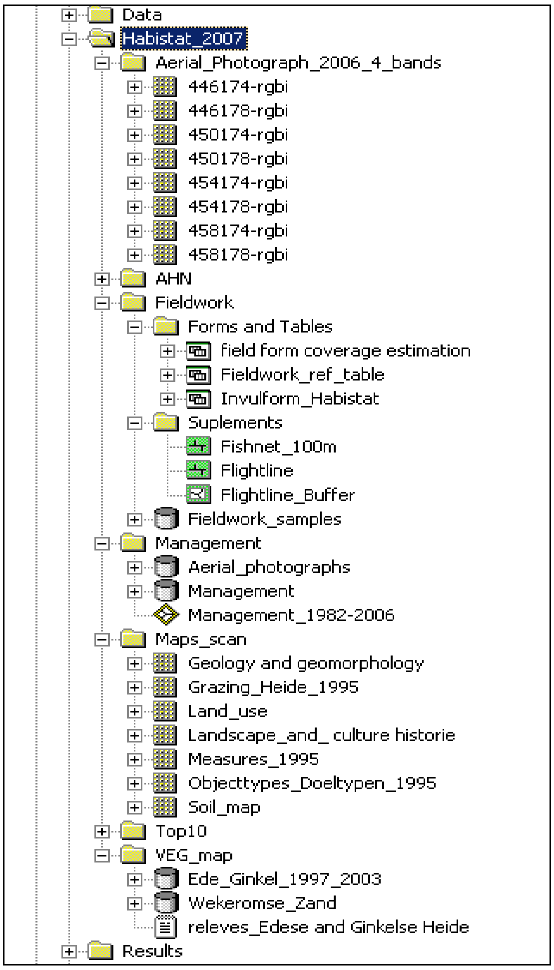



*Figure : The directory Habistat_2007*

- **Aerial_Photograph_2006_4_bands**- contain an aerial photography of whole research area, 4 bands,resolution=0.5m

- **AHN -** is a digital elevation model (DEM) with grid cell size of 5m.* 5m. covering the whole research area.(Source: GeoDesk)

- **Fieldwork -** comprise all available data for the fieldwork

- **Management** – with the old aerial photographs and information about management

- **Maps_scan** – with scanned maps from “Beheersplan EderHeide en Ginkelse Heide – 1996-2005”

- **Top 10 -** vector dataset – covering whole research area

- **VEG_map** – include 2 databases with the information on vegetation in Edese Heide, Ginkelse Heide and Wekeromse Zand

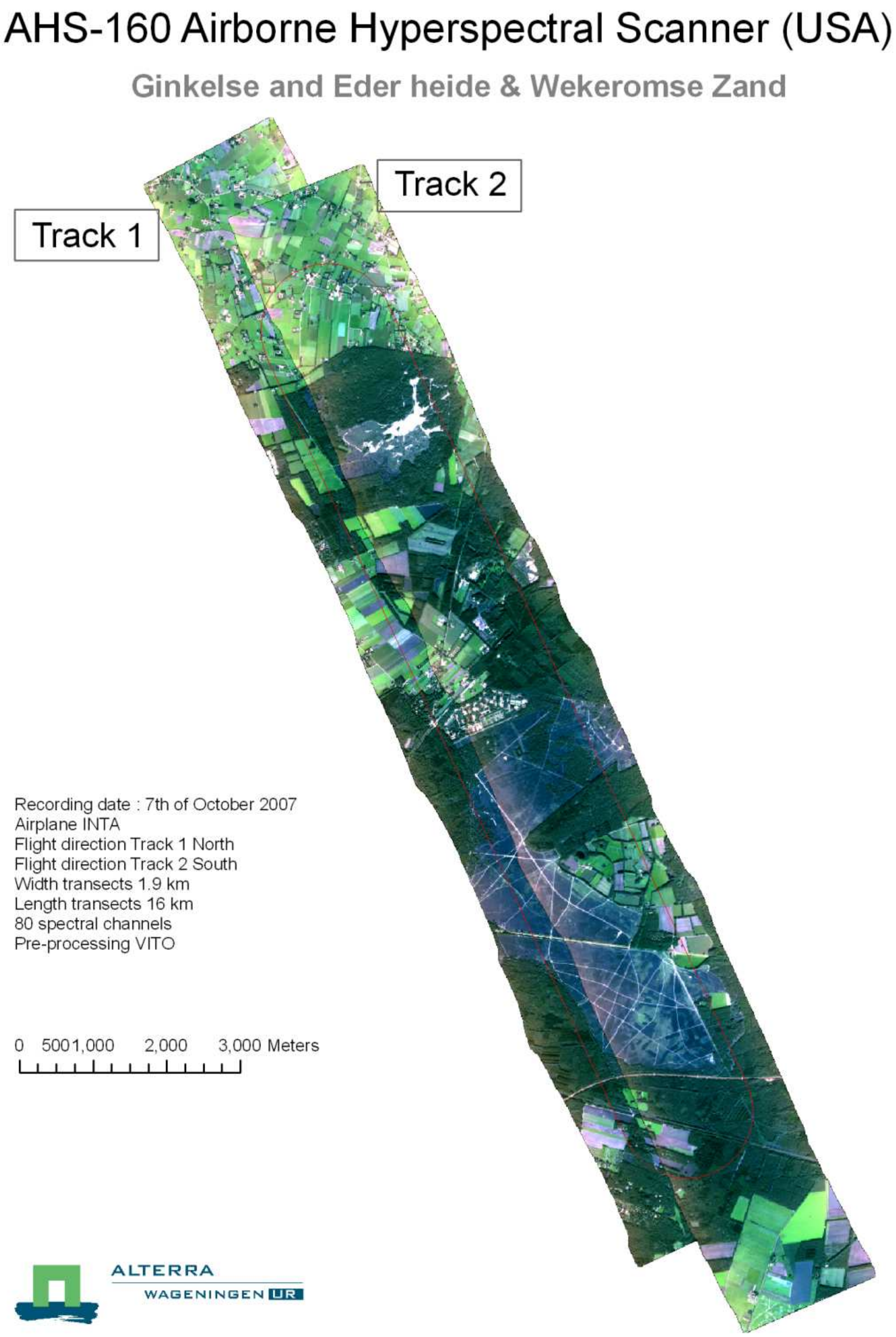
## Appendix 3: Habitat types identified for study areas within Habistat

| Level1 | | Level2 | | Level3 | | Level4 | |
|---|---|---|---|---|---|---|---|
| H | Heathland | Hd | Dry heathland | Hdc | Calluna-dominated heathland | Hdcy | Calluna-stand of predominantly young age |
| | | | | | | Hdca | Calluna-stand of predominantly adult age |
| | | | | | | Hdco | Calluna-stand of predominantly old age (open) |
| | | | | | | Hdcm | Calluna-stand of (2 or 3) mixed age classes |
| | | Hw | Wet heathland | Hwe | Erica-dominated heathland | Hwe- | Erica-dominated heathland |
| | | Hg | Grass-encroached heathland | Hgm | Molinia-dominated heathland | Hgmd | Molinia-stand on dry soil ( developed from former Hdc) |
| | | | | | | Hgmw | Molinia-stand on moist (wet) soil ( developed from former Hwe) |
| | | | | Hgd | Deschampsia-dominated heathland | Hgdd | Deschampsia-stand on dry soil (developed from former Hdc) |
| | | | | Hgg | Grass-domianted heathland (other than Mol or Desc) | Hggd | Grass (other than Mol or Desc)-stand on dry soil (presumed to have developed from former Hdc) |
| G | Grassland | Gt | Temporary grassland | Gt- | Temporary grassland | Gt-- | Temporary grassland |
| | | Gp | Permanent grassland | Gpa | Permanent grassland in intensive agricultural use | Gpap | Species-poor permanent agricultural grassland |
| | | | | | | Gpar | Species-rich permanent agricultural grassland |
| | | | | Gpn | Permanent grassland with semi-natural vegetation | Gpnd | Dry semi-natural permanent grassland |
| | | | | Gpj | Juncus effusus-dominated grassland | Gpj- | Juncus effusus-dominated grassland |
| F | Forest | Fc | Coniferous forest | Fcp | Pine (Pinus sp.) forest | Fcpc | Corsican pine (Pinus nigra laricio) |
| | | | | | | Fcps | Scots pine (Pinus sylvestris) |
| | | Fd | Deciduous forest | Fdb | Birch (Betula sp.) forest | Fdb- | Birch (Betula sp.) forest |
| | | | | Fdq | Oak (Quercus sp.) forest | Fdqz | Pedunculate oak (Quercus robur) |
| S | Sand dune | Sb | Bare sand | Sb- | Bare sand | Sb-- | Bare sand |
| | | Sf | Fixated sand dune | Sfg | Sand dune with grasses as important fixators | Sfgm | Sand dune fixated by grasses and mosses |
| | | | | Sfm | Sand dune with mosses as dominating fixators | Sfmc | Fixated sand dune with predominantly Campylopus introflexus |
| | | | | | | Sfmp | Fixated sand dune with predominantly Polytrichum piliferum |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Habitat types continue** | | | | | | |
| W | Water body | Wo | Oligotrophic water body | Wov | Shallow, vegetated oligotrophic water body (banks of 'moorland pools') | Wov- | Shallow, vegetated oligotrophic water body (banks of 'moorland pools') |
| | | | | Wou | Unvegetated (deep) oligotrophic water (centre of 'moorland pools') | Wou- | Unvegetated (deep) oligotrophic water (centre of 'moorland pools') |
| A | Arable fields | Ac | Arable field with crop | Acm | Arable field - maize | Acm- | Arable field - maize |
| | | | | Aco | Arable field - other crops | Aco- | Arable field - other crops |

Note: the habitat types indicated in grey are added to the typology based on their presence at the Ginkelse and Eder heide

## Appendix 4: Overview of AHS-160 images acquired over the Eder and Ginkels Heide and Wekeromse Zand



# Appendix 5: Definition of band positions for AHS-160

In the table below the band definitions for the AHS-160 sensor are presented which are valid for both flight lines. In addition, the quality assessment results per band are indicated for flight line 1 which more or less similar to the results for flight line 2.

| bandnr. | center wvl | fwhm | data: yes/no | quality | remarks |
|---|---|---|---|---|---|
| 1 | 0.4564 | 0.0295 | yes | good | speckle |
| 2 | 0.4817 | 0.0316 | yes | good | speckle |
| 3 | 0.51 | 0.0325 | yes | good | speckle |
| 4 | 0.539 | 0.0322 | yes | good | speckle |
| 5 | 0.5676 | 0.0314 | yes | good | speckle |
| 6 | 0.5959 | 0.0316 | yes | good | speckle |
| 7 | 0.624 | 0.0321 | yes | good | speckle |
| 8 | 0.6531 | 0.0321 | yes | good | speckle |
| 9 | 0.6811 | 0.0322 | yes | good | speckle |
| 10 | 0.7102 | 0.0325 | yes | good | speckle |
| 11 | 0.7384 | 0.0314 | yes | good | speckle |
| 12 | 0.767 | 0.032 | yes | good | speckle |
| 13 | 0.7952 | 0.0315 | yes | good | speckle |
| 14 | 0.825 | 0.0321 | yes | good | speckle |
| 15 | 0.8549 | 0.0323 | yes | good | speckle |
| 16 | 0.8839 | 0.0317 | yes | good | speckle |
| 17 | 0.9126 | 0.0327 | yes | good | speckle |
| 18 | 0.9419 | 0.0325 | yes | good | speckle |
| 19 | 0.9733 | 0.0335 | yes | good | speckle |
| 20 | 1.0022 | 0.0335 | yes | good | speckle |
| 21 | 1.5858 | 0.091 | yes | good | speckle |
| 22 | 1.917 | 0.0192 | yes | noise | |
| 23 | 1.9337 | 0.0184 | yes | noise | |
| 24 | 1.9504 | 0.0179 | yes | noise | |
| 25 | 1.9657 | 0.0183 | yes | noise | some structures can be identified |
| 26 | 1.9821 | 0.0187 | yes | noise | some structures can be identified |
| 27 | 1.9987 | 0.0187 | yes | noise | some structures can be identified |
| 28 | 2.015 | 0.0183 | yes | noise | structures can be identified |
| 29 | 2.0311 | 0.0182 | yes | noise | structures can be identified |
| 30 | 2.0471 | 0.0184 | yes | noise | structures can be identified |
| 31 | 2.063 | 0.0181 | yes | noise | striping + structures can be identified |
| 32 | 2.079 | 0.0182 | yes | noise | striping + structures can be identified |
| 33 | 2.0949 | 0.0183 | yes | noise | striping + structures can be identified |
| 34 | 2.1108 | 0.0181 | yes | noise | striping + structures can be identified |
| 35 | 2.1265 | 0.0181 | yes | noise | striping + structures can be identified |
| 36 | 2.1422 | 0.018 | yes | noise | striping + structures can be identified |
| 37 | 2.1577 | 0.0181 | yes | noise | striping + structures can be identified |
| 38 | 2.1732 | 0.0181 | yes | noise | striping + structures can be identified |
| 39 | 2.1886 | 0.0181 | yes | noise | striping + structures can be identified |
| 40 | 2.2041 | 0.018 | yes | noise | striping + structures can be identified |
| 41 | 2.2193 | 0.0181 | yes | noise | striping + structures can be identified |
| 42 | 2.2345 | 0.0181 | yes | noise | striping + structures can be identified |
| 43 | 2.2584 | 0.0183 | yes | noise | striping + structures can be identified |
| 44 | 2.2735 | 0.0181 | yes | noise | striping + structures can be identified |
| 45 | 2.2884 | 0.0182 | yes | noise | striping + structures can be identified |

| | | | | | |
|---|---|---|---|---|---|
| 46 | 2.3033 | 0.018 | yes | noise | striping + structures can be identified |
| 47 | 2.3181 | 0.018 | yes | noise | striping + structures can be identified |
| 48 | 2.3328 | 0.018 | yes | noise | striping + structures can be identified |
| 49 | 2.3477 | 0.018 | yes | noise | some structures can be identified (not in heathland) |
| 50 | 2.3624 | 0.0179 | yes | noise | some structures can be identified |
| 51 | 2.3769 | 0.018 | yes | noise | some structures can be identified |
| 52 | 2.3915 | 0.0179 | yes | noise | some structures can be identified |
| 53 | 2.4059 | 0.0177 | yes | noise | some structures can be identified |
| 54 | 2.4205 | 0.0179 | yes | noise | some structures can be identified |
| 55 | 2.4348 | 0.018 | yes | noise | some structures can be identified |
| 56 | 2.4491 | 0.018 | yes | noise | some structures can be identified |
| 57 | 2.4634 | 0.0174 | yes | noise | some structures can be identified |
| 58 | 2.4775 | 0.0172 | yes | noise | |
| 59 | 2.4916 | 0.0177 | yes | noise | |
| 60 | 2.506 | 0.0173 | yes | noise | |
| 61 | 2.5202 | 0.0168 | yes | noise | |
| 62 | 2.5347 | 0.0176 | yes | noise | |
| 63 | 2.5477 | 0.0196 | yes | noise | |
| 64 | 3.2455 | 0.3665 | yes | noise | |
| 65 | 3.5435 | 0.3295 | yes | noise | striping + structures can be identified |
| 66 | 3.9065 | 0.324 | yes | noise | striping + structures can be identified |
| 67 | 4.266 | 0.4365 | no | no data | area within strip has value 1 |
| 68 | 4.6455 | 0.354 | no | no data | area within strip has value 1 |
| 69 | 5.048 | 0.3555 | no | no data | area within strip has value 1 |
| 70 | 5.353 | 0.2785 | no | no data | area within strip has value 1 |
| 71 | 8.315 | 0.433 | no | no data | area within strip has value 1 |
| 72 | 8.731 | 0.423 | no | no data | area within strip has value 1 |
| 73 | 9.234 | 0.413 | no | no data | area within strip has value 1 |
| 74 | 9.693 | 0.425 | no | no data | area within strip has value 1 |
| 75 | 10.159 | 0.42 | no | no data | area within strip has value 1 |
| 76 | 10.623 | 0.525 | no | no data | area within strip has value 1 |
| 77 | 11.272 | 0.539 | no | no data | area within strip has value 1 |
| 78 | 11.839 | 0.552 | no | no data | area within strip has value 1 |
| 79 | 12.434 | 0.499 | no | no data | area within strip has value 1 |
| 80 | 12.98 | 0.554 | no | no data | area within strip has value 1 |