Hydrol. Earth Syst. Sci., 13, 833–845, 2009
www.hydrol-earth-syst-sci.net/13/833/2009/

Hydrology and Earth System Sciences

EAGLE 2006 – Multi-purpose, multi-angle and multi-sensor in-situ and airborne campaigns over grassland and forest

Z. Su[1], W. J. Timmermans[1], C. van der Tol[1], R. Dost[1], R. Bianchi[2], J. A. Gómez[3], A. House[4], I. Hajnsek[5], M. Menenti[6], V. Magliulo[6], M. Esposito[6], R. Haarbrink[7], F. Bosveld[8], R. Rothe[8], H. K. Baltink[8], Z. Vekerdy[1], J. A. Sobrino[9], J. Timmermans[1], P. van Laake[10], S. Salama[10], H. van der Kwast[11], E. Claassen[12], A. Stolk[13], L. Jia[14], E. Moors[14], O. Hartogensis[15], and A. Gillespie[16]

[1]International Institute for Geo-information Sciences and Earth Observation, Department of Water Resources, P.O. Box 6, 7500 AA, Enschede, The Netherlands
[2]European Space Agency, Earth Observation Center, Via Galileo Galilei, 00044 Frascati, Italy
[3]Instituto Nacional de Técnica Aeroespacial, Area de Teledetección, Dpto. de Observ. de la Tierra, Teledetección y Atmósfera, Carretera de Ajalvir, p.k. 4 – 28850 Torrejón de Ardoz, Madrid, Spain
[4]ITRES Research Limited, Suite 110, 3553 – 31st Street NW, Calgary, Alberta, Canada
[5]German Aerospace Center, Microwaves and Radar Institute, P.O. Box 11 16, 82230 Wessling, Germany
[6]National Research Council (CNR), Institute for mediterranean agriculture and forest systems (ISAFoM), Via Patacca 85, 80056 Ercolano (NA), Italy
[7]MIRAMAP, ESA/ESTEC (TEC-ST), P.O. Box 299, 2200 AG, Noordwijk, The Netherlands
[8]Royal Netherlands Meteorological Institute, P.O. Box 201, 3730 AE, De Bilt, The Netherlands
[9]Universidad de Valencia, Faculty of Physics, Department of Thermodynamics, Global Change Unit, c/Dr. Moliner, 50, 46100 Burjassot, Spain
[10]International Institute for Geo-Information Science and Earth Observation, Dept. of Natural Resources, P.O. Box 6, 7500 AA, Enschede, The Netherlands
[11]Utrecht University, Department of Physical Geography, Faculty of Geosciences, P.O. Box 80.115, 3508 TC, Utrecht, The Netherlands
[12]FUGRO-Inpark B.V., Dillenburgsingel 69, 2263 HW Leidschendam, The Netherlands
[13]National Institute for Public Health and the Environment, P.O. Box 1, 3720 BA, Bilthoven, The Netherlands
[14]Wageningen University and Research Centre, Alterra P.O. Box 47, 6700 AA Wageningen The Netherlands
[15]Wageningen University, Meteorology and Air Quality Group, P.O. Box 47, 6700 AA Wageningen, The Netherlands
[16]University of Washington, Johnson Hall 070, P.O. Box 351310, 4000 15th Avenue NE, Seattle, WA 98195-1310, USA

Received: 15 February 2009 – Published in Hydrol. Earth Syst. Sci. Discuss.: 6 March 2009
Revised: 21 May – Accepted: 27 May – Published: 18 June 2009

Abstract. EAGLE2006 – an intensive field campaign for the advances in land surface hydrometeorological processes – was carried out in the Netherlands from 8th to 18th June 2006, involving 16 institutions with in total 67 people from 16 different countries. In addition to the acquisition of multi-angle and multi-sensor satellite data, several airborne instruments – an optical imaging sensor, an imaging microwave radiometer, and a flux airplane – were deployed and extensive ground measurements were conducted over one grassland site at Cabauw and two forest sites at Loobos and Speulderbos in the central part of the Netherlands. The generated data set is both unique and urgently needed for the development and validation of models and inversion algorithms for quantitative land surface parameter estimation and land surface hydrometeorological process studies. EAGLE2006 was led by the Department of Water Resources of the International Institute for Geo-Information Science and Earth Observation (ITC) and originated from the combination of a number of initiatives supported by different funding agencies. The objectives of the EAGLE2006 campaign were closely

Correspondence to: Z. Su
(b_su@itc.nl)

related to the objectives of other European Space Agency (ESA) campaign activities (SPARC2004, SEN2FLEX2005 and especially AGRISAR2006). However, one important objective of the EAGLE2006 campaign is to build up a data base for the investigation and validation of the retrieval of bio-geophysical parameters, obtained at different radar frequencies (X-, C- and L-Band) and at hyperspectral optical and thermal bands acquired simultaneously over contrasting vegetated fields (forest and grassland). As such, all activities were related to algorithm development for future satellite missions such as the Sentinels and for validation of retrievals of land surface parameters with optical and thermal and microwave sensors onboard current and future satellite missions. This contribution describes the campaign objectives and provides an overview of the airborne and field campaign dataset. This dataset is available for scientific investigations and can be accessed on the ESA Principal Investigator Portal http://eopi.esa.int.

1 Introduction

1.1 Campaign overview

To understand the role of the terrestrial hydrosphere-biosphere in Earth's climate system it is essential to be able to measure from space hydrometeorological variables, such as radiation, precipitation, evapotranspiration, soil moisture, clouds, water vapour, surface water and runoff, vegetation state, albedo and surface temperature, etc. Such measurements are required to further increase our understanding of the global climate and its variability, both spatially and temporally. The understanding and quantification of bio-geophysical processes of different vegetated surfaces are prerequisite for the development of validated, global, interactive Earth system models for the prediction of global change accurately enough to assist policy makers in making sound decisions concerning the planning, sustainable use and management as well as conservation of water resources and the environment (GEO, 2005). Multi-sensor remote sensing observations (using radar, thermal and optical data) in combination with in-situ process observations are fundamental for the development and validation of models and retrieval algorithms.

While intensive and extensive field campaigns have been conducted in semiarid areas in recent years for the study of parameter retrievals and land-atmosphere processes using airborne and satellite observations (e.g. Sobrino et al., 2008; Su et al., 2008; Timmermans, 2008b, c), the knowledge of bio-geophysical parameter retrieval from multi-parameter optical, thermal and microwave data and the ability of direct modeling of the underlying physical processes in forests and grassland remain challenging due to lack of appropriate observation data in humid climate. In EAGLE2006 an intensive filed campaign was conducted using different airborne instruments – an optical imaging sensor, an imaging microwave radiometer, and a flux airplane – for data acquisition and to collect extensive ground measurements simultaneously over one grassland site and two forest sites in addition to acquisition of multi-angle and multi-sensor satellite data. As such this data set is both unique and urgently needed for the development and validation of models and inversion algorithms for quantitative surface parameter estimation and land surface hydrometeorological process studies.

The EAGLE2006 activities were performed over central parts of the Netherlands (the grassland site at Cabauw and two forest sites at Loobos and Speulderbos; with yearly precipitation around 750 mm and yearly average temperature about 10°C) from the 8th until the 18th of June 2006. EAGLE2006 originated from the combination of a number of initiatives coming from different funding. As such, the objectives of the EAGLE2006 campaign were closely related to the objectives of other ESA Campaigns, including the SPARC2004 and SEN2FLEX2005 campaigns (Su et al., 2008; Sobrino et al., 2008) and AGRISAR2006 (DLR, 2008).

One important objective of the campaign is to build up a data base for the investigation and validation of the retrieval of bio-geophysical parameters, obtained at different radar frequencies (X-, C- and L-Band) and at hyperspectral optical and thermal bands acquired over vegetated fields (forest and grassland). All activities were related to algorithm development for future satellite missions such as the Sentinels and for validations of data collected with different satellite sensors (e.g. CHRIS, MODIS and MERIS data, with activities also related to AATSR and ASTER thermal data validation, as well as the ASAR sensor on board ESA's Envisat platform and those on EPS/MetOp and SMOS). Most of the activities in the campaign are highly relevant for issues related to retrieval of biophysical parameters from higher reolution data (e.g. CHRIS and MERIS as well as AATSR and ASTER), while scaling issues and complementary between these higher resolution sensors (covering only local sites) and global sensors such as MSG/SEVIRI, EPS/MetOP and SMOS are also key elements.

1.2 Campaign objectives

The general purposes of the campaign are:

1. Acquisition of simultaneous multi-angular and multi-sensor data (from visible to microwave domain) over a grassland and a forest.

2. Advancement of process understanding in description of radiative and turbulent processes in land-atmosphere interactions.

3. Validation of primary bio-geophysical parameters derived from satellite data using in-situ and airborne data.

4. Improvement of soil moisture retrieval accuracy by synergy of multi-angular (L-band) SMOS and multi-angular C-band SAR/Optical-thermal observations.

5. Development of operational algorithms to extract land surface parameters and heat fluxes from the future EPS/MetOp mission.

6. Development of physically based drought monitoring and prediction method (Hydro-climatologic modeling) on the basis of EPS/MetOp observations.

In particular, the EAGLE2006 campaign addressed important specific programmatic needs of Sentinel-1 and -2:

1. To assess the impact of Sentinel-1 and Sentinel-2 sensor and mission characteristics for land applications (land use mapping, parameter retrieval) over forest and grassland.

2. To provide a basis for the quantitative assessment of sensor or mission trade-off studies, e.g. spatial and radiometric resolution.

3. Simulate Sentinel-1 and Sentinel-2 image products over the land (forest and grassland).

In the context of Sentinel-1, EAGLE2006 aimed primarily at the investigation of radar signatures over forest and grassland simultaneously which is currently not addressed. An important dataset of coordinated in-situ and airborne SAR measurements was collected which provides support both to studies of the Sentinel-1 technical concept, as well as contributing to studies of future mission concepts involving parameter retrieval at L-band.

As part of the refinement and verification of the Sentinel-1 technical concept, EAGLE2006 data will be used for the assessment of land use classification using the proposed nominal operating configuration (i.e. IW mode, VV + HH polarisation plus co-polarisation). Simulation of Sentinel-1 image products can be performed using the EAGLE2006 data.

By including an optical data acquisition component, the campaign also provides feedback on key issues relating to definition of the ESA Sentinel-2 multi-spectral mission requirements. Attention focuses on the investigation of the optimum position and width of spectral bands for land cover/change classification and retrieval of bio-geophysical parameters (e.g. improved surface classification, quantitative assessment of vegetation status – forest and grassland). The imaging spectrometer data acquired as part of EAGLE2006 has been used to simulate Sentinel-2 L1b products using the proposed different configurations, and to investigate compatibility with the envisaged L2/L3 products (Timmermans et al., 2008a).

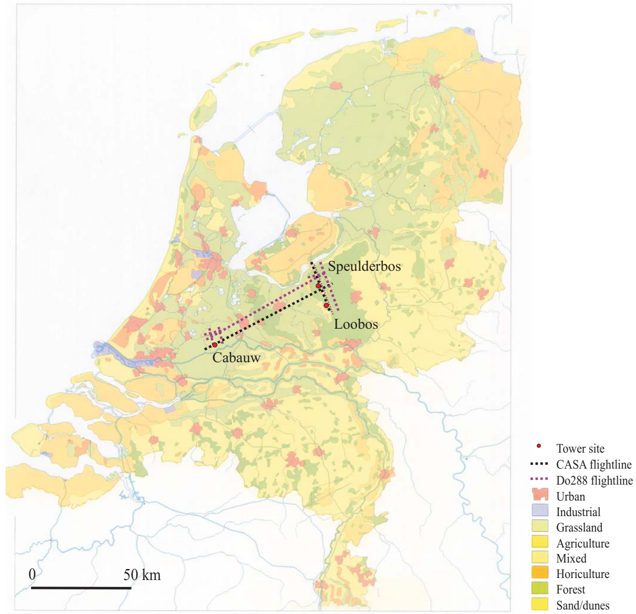

Fig. 1. Location of the EAGLE2006 experimental sites on a landuse map of The Netherlands, flightlines for the CASA 212 AHS/CASI high-altitude and the Do228 ESAR missions are projected.

2 Experimental sites

Simultaneous measurements took place at three sites:

– Cabauw, grassland, 51°58′00″ N, 04°54′00″ E, −0.7 m. a.m.s.l.

– Loobos, forest, 52°10′02.8″ N, 05°44′38″ E, 23 m. a.m.s.l.

– Speulderbos, forest, 52°15′08.1″ N, 05°41′25.8″ E, 52 m. a.m.s.l.

2.1 Cabauw

The Cabauw site is located approximately at the central western part of the Netherlands near the village of Cabauw. In 1972 at Cabauw a 213 m high tower (left panel of Fig. 2.) was built by the Royal Netherlands Meteorological Institute (KNMI). This tower was built to establish relations between the state of the atmospheric boundary layer (ABL), land surface conditions and the general weather situation for all seasons. The Cabauw tower is located in a polder 0.7 m below average sea level in an extensive grassland area. In the immediate surroundings of the tower (corresponding to an area of 1 ha) the grass is kept at a height of 8 cm by frequent mowing. Apart from scattered villages, roads and trees the landscape within a radius of at least 20 km consist of flat grassland. Approximately 1.5 km south of the tower runs the river Lek, which is one of the main branches of Rhine. The river Lek

Fig. 2. Photographs of the observation towers at the grassland site at Cabauw (left) and at the forest sites at Loobos (middle) and Speulderbos (right). (Sources: KNMI, Alterra and RIVM/ECN/ITC).

is a few hundred meters broad. The water holding capacity of the soil at the site is high, the soil being fine grained with a high content of organic matter. The ground water level in the whole catchment area, within which the field tower is located, is artificially managed through narrow, parallel ditches spaced 40 m apart. The water level in the ditches is always kept at 40 cm below the surface level maintaining the level of the ground water table near the surface. Due to the rich supply of water and the fine grained soil, the evaporative fraction rarely falls below 0.6.

More detailed info is provided in (Ulden and Wieringa, 1996). An overview of recorded data is provided on the web at: http://www.knmi.nl/kodac/ground_based_observations_climate/cabauw.html

2.2 Loobos

The Loobos site is located two kilometers south-west of the village Kootwijk. Continuous micrometeorological measurements have been carried out since 1997 at a height of 23 m above the surface, see middle panel of Fig. 2. In a radius of 500 m 89% of the vegetation consists of pine trees, with an average height of about 16 m, 3.5% is open vegetation e.g. heather and the remainder is a mixture of coniferous and deciduous trees.

More detailed information about this site is available on the web-site at: http://www.loobos.alterra.nl.

2.3 Speulderbos

The Speulderbos site, operated by the National Institute for Public Health and the Environment (RIVM), is located near the village Garderen approximately 60 km northeast from Cabauw within a large forested area in the Netherlands. A 47-m high scaffolding tower, right panel of Fig. 2., is placed within a dense 2.5 ha Douglas fir stand planted in 1962. The tree density is 785 trees per hectare and the tree height was approximately 22 m in 1995 and 32 m in 2006. The single-sided leaf area index varies between 8 and 11 throughout the year. The surrounding forest stands have typical dimensions of a few hectares and varying tree heights. Dominant species in the neighborhood of the Douglas fir stand are Japanese Lark, Beech, Scotch Pine and Hemlock. At a distance of 1.5 km east from the tower the forest is bordered by a large heather area. In all other directions the vegetation consists of forest at distances of several kilometers. The topography is slightly undulating with height variations of 10 to 20 m within distances of 1 km.

Another tower, currently used by foresters of the state forest service (SBB), in the area is located in the village Drie at about 2 km distance at 52°15′54.8″ N latitude and 5°40′39.4″ E longitude. A Large Aperture Scintillometer (LAS) is installed between this and the previous tower to obtain spatial average sensible heat fluxes.

2.4 Base data for the experimental sites include topographic data, digital elevation data, and other ancillary national data (see later)

Topographical data for the entire study area is digitally available, originating from scale 1:50 000 and scale 1:10 000 topographical maps.

Digital elevation data from the Actual Height model of the Netherlands (AHN) is available for the areas of interest. The AHN is a detailed elevation model of the entire country obtained from Airborne Laser Altimetry. The Actual Elevation Model is an initiative of three layers of authorities in the Netherlands, i.e. "Rijkswaterstaat" (Ministry of Transport, Public Works and Water Management), the water boards, and the provinces. As such, it consists of a uniform, country-covering dataset that is commercially available to third parties. Two data formats are available for this dataset; the so-called "base database", which contains filtered elevation points, with X, Y and Z coordinates of the RD (triangulation of national grid) and NAP (Amsterdam Ordnance Datum, the Dutch National leveling reference system), and the grid database of the 5×5 m resolution raster data for the EAGLE2006 campaign.

3 Satellite data acquisitions

Successful satellite data acquisitions included: MERIS, MODIS, AATSR, ASAR, ASTER, MSG/SEVIRI for the entire campaign period, depending on weather conditions mainly. Generally the campaign was characterized by clear skies, sunny conditions and increasing temperatures during the first half of the campaign (8th to 13th of June). This was followed by some minor rainfall on the 14th and 15th of June (DOY 165 and 166), accompanied by a drop in temperature.

The second half of the campaign was characterized by locally cloudy conditions with the exception of DOY 168 which was clear and sunny (see details in Sect. 8). This resulted in a number of successful satellite data acquisitions which are summarized in Table 1. Figure 3 shows examples of a MERIS and a SEVIRI image.

Table 1. Satellite observations.

Sensor	# of channels	Spectral range (μm/GHz)	Resolution (m)	Acq. Date (DOY)
ASTER	14	0.52–11.65 μm	15–90	159
MODIS	36	0.4–14.4 μm	250–1000	159–164, 168, 169
MERIS	15	0.39–1.04 μm	300	159, 161, 162, 165, 168, 169
AATSR	7	0.6–1.6/4, 11, 12 μm	1000	159, 162, 165, 168
ASAR	1	5.3 GHz	25–1000	160, 163, 166, 169
SEVIRI	11	0.6–14.4 μm	3000	159–169

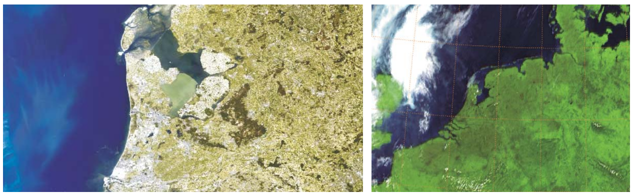

Fig. 3. Parts of a MERIS (left) and SEVIRI scene (right) as acquired on the 11th and 13th of June respectively over The Netherlands.

Fig. 4. Quicklooks of airborne observations over the Cabauw site. Left: AHS (R-G-B: channel 04-08-15), middle: CASI (R-G-B: channel 29-17-05) both obtained on 13 June 2006, right: C-band ESAR image acquired on 15 June 2006. (The Cabauw is visible with its shadow near the center-left of the AHS and CASI images and as a white dotted line near the middle of the ESAR image).

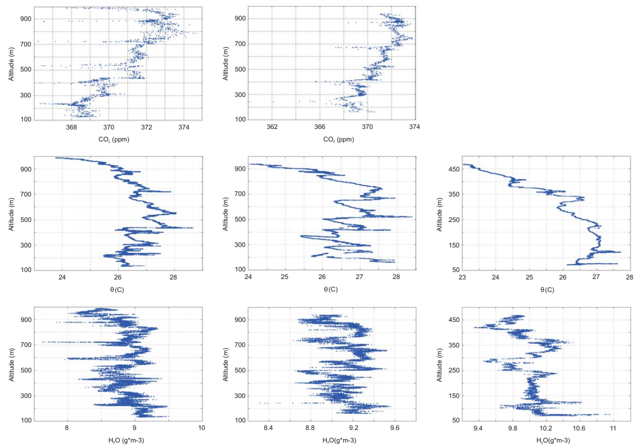

Fig. 5. Atmospheric profiles as measured by Sky Arrow flux airplane over the three sites on 13 June 2006. The left column shows the profiles over the start at the Speulderbos (North), the middle column shows profiles over the Southern part of the Speulderbos, approaching the Loobos area, whereas the right column shows profile measurements over the Cabauw site. From the top to the bottom, the panels in each column show carbon dioxide (CO_2), potential temperature (θ) and water vapour content (H_2O), respectively (carbon dioxide is missig at the Cabauw site).

4 Airborne data acquisitions

Four airborne sensors were operated during the EAGLE 2006 campaign to acquire valuable data for bio-/geo-physical parameter estimation over the grassland and forest sites. The AHS from INTA and the CASI sensor of ITRES were both mounted on the CASA 212-200 N/S 270 "Paternina" airplane of INTA. Because the objective of the campaign was primarily aiming at AHS acquisitions the configuration was designed such that if conflicting criteria between AHS and CASI occurred preference was given to AHS. Furthermore, DLR-HR flew a Do228 aircraft that carried their multi-frequency and multi-polarisation Synthetic Aperture Radar system, and ISAFoM operated a Sky-Arrow airplane for flux measurements.

Successful AHS and CASI acquisitions were made on 13 June 2006. Two quicklooks are shown in the left and middle panels of Fig. 4.

Eleven ESAR flight tracks were carried on 15 June 2006 to cover the three sites of interest flying X-, C-, and L-band configurations, as well as to obtain an X-band DEM. The right panel of Fig. 4 shows a C band polarimetric image of the Cabauw site.

The Sky Arrow flux flights were performed over the three tower sites to compare the airborne flux measurements with the tower flux measurements, and also to quantify the exchange of carbon dioxide, sensible and latent heat, momentum fluxes between the biosphere and different vegetated surfaces. Table 2 shows the flight configurations.

The flight on 13 June 2006 was performed at the same time as the INTA CASA aircraft mission, to collect flux information and hyperspectral data simultaneously. First results of some profiles flown in the first mission over the different areas are shown in Fig. 5.

Table 2. Airborne observations.

Sensor	# of channels	Spectral range (μm/GHz)	Resolution (m)	Acq. Date (DOY)	Start time (utc)
AHS	80	0.43–12.7 μm	2.4	164	09:57
CASI	60	0.41–0.97 μm	1.3	164	09:57
ESAR	4	0.35–9.6 GHz	0.7	166	14:42
Sky-ERA	**Mission ID**	**Target**	**Site**		
	1	Fluxes	Speulderbos, Loobos, Cabauw	164	11:41
	2	Fluxes and divergence	Speulderbos, Loobos	164	16:00
	3	Fluxes	Speulderbos, Loobos	165	11:56

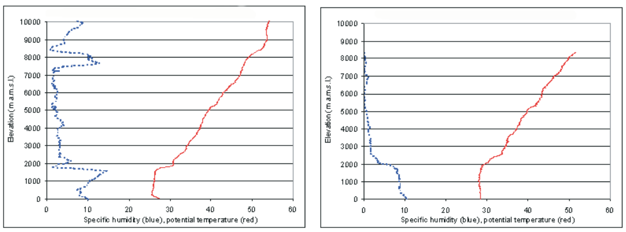

Fig. 6. The processed morning (left) and afternoon (right) soundings output from 13th of June 2006, Cabauw.

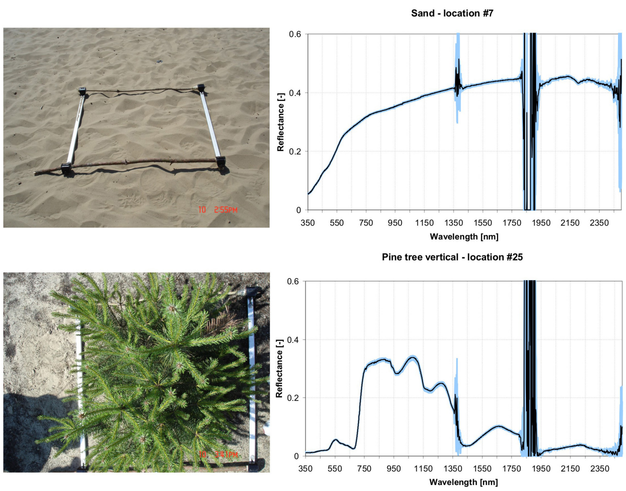

Fig. 7. Example spectra of bright sand (upper panels) and of a young pine tree (lower panels). The frame on the photos represents an area of $1\times1\,\mathrm{m}^2$. On the graphs, the blue area shows the range of the measured spectra, the black line is the accepted characteristic spectrum of the site under consideration. Note the atmospheric disturbances around 1370 and 1850 nm.

5 Atmospheric measurements

Knowledge of the atmospheric conditions, its vertical profile and the water vapour content is required to perform accurate atmospheric corrections of space and airborne observations. Two types of measurements were performed. In-situ atmospheric soundings were carried out during airborne overpasses at the Cabauw site (Fig. 6). Furthermore routine measurements carried out at De Bilt, KNMI and at the Cabauw tower site are available as well.

The Cabauw tower site is also part of the CESAR (Cabauw Experimental Site for Atmospheric Research) Consortium. This is a consortium of seven national institutes in the Netherlands working together on land-atmosphere and atmospheric research. For the duration of the EAGLE2006 Campaign we have direct access to the data recorded and they are included in the EAGLE2006 database.

Table 3. Summary of spectrometric measurement objectives.

Objective	Location	Instrument	Typical target
Reference measurements	Cabauw	GER	Water Grass Concrete Sand
	Speulderbos	ASD	Forest canopy Water Grass Heathland
Angular dependance	Cabauw	GER	Grass Young maize
	Speulderbos	ASD	Forest canopy
Biophysical characteristics	Speulderbos	ASD	Leaves Branches
Water quality	Harderwijk	ASD	Lake water

6 In-situ spectrometric, radiometric and goniometric measurements

Other essential measurements include ground based data, including radiometric data (radiometric data in both solar range and thermal range data) and goniometric measurements. Table 3 shows some details of the spectrometric measurements and Fig. 7 illustrates some typical spectral curves.

For the retrieval of land surface emissivity and temperature, radiometric measurements were carried out in the

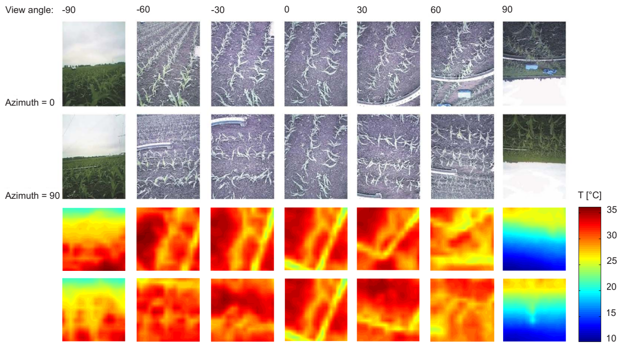

Fig. 8. Goniometer measurements over maize using a digital photo-camera (upper panels) and a thermal (lower panels) infrared imager.

thermal infrared region with various instruments that include fixed FOV and single band or multi bands radiometers.

The measurements included thermal radiometric temperatures, emissivities, atmospheric radiances, air temperature, temperature transects and angular measurements within the site area. Table 4 shows the deployed instruments.

Directional and contact measurements were carried out at the Cabauw and Speulderbos sites. Measurements included several land cover units using several instruments between 10 and 18 June 2006. A summary of the goniometric measurements is given in Table 5, whereas an example of the measurements over maize at the Cabauw site is shown in Fig. 8.

7 Biophysical (soil, vegetation and water) measurements

The bio-physical measurements made during the EAGLE2006 intensive campaign included vegetation, soil and water measurements. The vegetation measurements included volume and biomass, as well as radiation penetration and Leaf Area Index measurements. Surface roughness for the Cabauw grassland site was measured with stereo photogrammetry using NEar Sensing Camera Field Equipment (NESCAFE).

Soil moisture was measured in the field for calibration and validation of soil moisture measurements through remotely sensed data.

Water quality parameters measured included Secchi depth, turbidity and Chl-a. Unfortunately, it was not possible to take spectra for water quality measurements during the AHS overflight. Due to weather conditions, the first suitable day was 4 July 2006. Measurements were carried out at the open water of the "Wolderwijd" (which was covered by AHS airborne imagery for this purpose but at an earlier date) near the city of Harderwijk.

In order to obtain a high accuracy, detailed 3-D representation of the Speulderbos forest site, necessary for among others within-canopy radiation transfer modeling and surface roughness estimates a laser scanning was carried out around the Speulderbos tower site, using the Leica HDS2500 pulsed laser scanner with a single-point range accuracy of +/−4 mm, angular accuracies of +/−60 micro-radians, and a beam spot size of only 6 mm from 0–50 m range, including point-to-point spacing as fine as 1.2 mm@50 m. The scanner was mounted on the elevator of Speulderbos tower site and made slicing of the forest. An example of such scans is shown in Fig. 9.

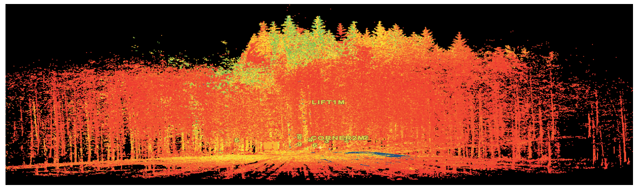

Fig. 9. Example output from the Speulderbos site laser-scanning recorded on 20 June 2006.

The geo-locations of these biophysical measurements were recorded using a Leica 1200 RTK-DGPS. Table 6 gives a summary of the locations.

8 Energy balance and micrometeorological measurements

In addition to the reference meteorological data (continuous data from Cabauw and Loobos), measurements included standard meteorological measurements at different heights (wind speed and direction, temperature, humidity), sensible heat flux measured with a scintillometer, eddy covariance measurements of heat, water and carbon dioxide transport, contact temperatures of vegetation and soil, soil heat flux, soil moisture content and soil temperature. Measurements were carried out in and near the 44 m tall tower at the Speulderbos site between 7 and 22 June 2006. A mobile LAS system was installed at a grassland site next to the Cabauw tower and operated from 13th of June in the afternoon till June the 20st of June 2006 in the morning.

At the Speulderbos site, scintillometer, eddy covariance and radiation measurements were carried out at the top (at 47 m). Other meteorological measurements were conducted just above the canopy crown, around 35 m height. Contact temperatures of different canopy components were measured in the canopy (between 20 and 32 m height), and at ground level. Measurements at ground level were carried out 20 m east of the tower. Table 7 gives an overview of the used instrumentation.

Post-campaign cross-checking showed a systematic overestimation of the incoming (R_{si}) and outgoing (R_{so}) short wave and long wave (R_{Li} and R_{Lo}) radiation of 10% by the sensor. This has been corrected after a re-calibration by the manufacturer.

Table 4. Technical specifications of the instruments.

Instrument	Spectral Range (μm)	Temperature Range (°C)	Accuracy	Resolution	FOV
Cimel CE312-1	8–13	−80 to 50	0.1	8 mK	10°
	11.5–12.5			50 mK	
	10.5–11.5			50 mK	
	8.2–9.2			50 mK	
Cimel CE312-2	8–13	−80 to 60	0.1	8 mK	10°
	11–11.7			50 mK	
	10.3–11			50 mK	
	8.9–9.3			50 mK	
	8.5–8.9			50 mK	
	8.1–8.5			50 mK	
Raytek MID	8–14	−40 to 600	1	0.5	30° (6°)
Raytek ST	8–14	−32 to 400	1	0.1	7°–2°
Optris minisight	8–14	−32 to 530	1	0.7	3°
NEC TH9100	8–14	−40 to 120	2	0.1	22°×16°
EVEREST 1000		Fixed to ambient	0.3	0.1	

Table 5. Goniometric measurements.

Day	Time	Crop	Instrument
2006-06-10	15:44	Pine-tree	ASD
2006-06-12	11:00	Grass	GER
	12:12	Grass	GER
	15:18	Grass	Everest + Irisys
	16:52	Grass	Everest + Irisys + IT-Works
	17:28	Grass	Everest + Irisys
2006-06-13	12:36	Forest	ASD
2006-06-14	11:59	Grass	Everest + Irisys
2006-06-15	17:10	Maize	Irisys
2006-06-17	14:43	Maize	Irisys
	15:20	Maize	Everest + Irisys
	18:27	Maize	CIMEL
2006-06-18	12:16	Forest	ASD
	11:55	Maize	Everest + Irisys
	12:47	Maize	Everest + Irisys + IT-Works
	13:20	Maize	GER
	15:02	Maize	Everest + Irisys

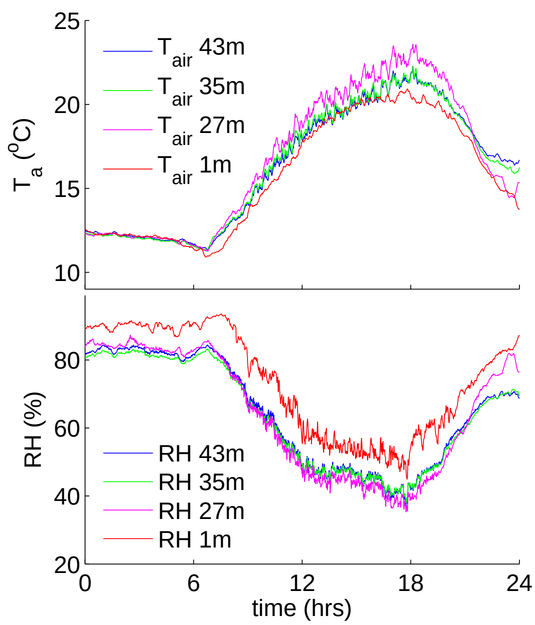

Fig. 10. Temperature and relative humidity at different heights in Speulderbos versus time of the day, on 17 June 2006.

Temperature and relative humidity were measured at 4 heights: 1, 27, 35 and 47 m above the forest floor (Fig. 10). At 1 m height, temperatures are the lowest and relative humidity the highest. In the middle of the canopy, at 27 m, temperatures are the highest and relative humidity the lowest.

A comparison is made between wind speed and direction measured at 34 m height, and those derived from the eddy covariance measurements at 47 m height, which showed a consistent difference in wind direction of about 10 degrees, most likely caused by an error in alignment of the instruments. Wind speed (Fig. 11) is consistently higher at 47 m than at 34 m, as can be expected.

Soil temperature measured at four depths and soil heat flux measured with three heat flux plates installed at 1 cm below the surface are shown in Fig. 12.

Surface contact temperatures were measured with Negative Temperature Coefficient (NTC) sensors on needles, mosses and trunks at ground level, and on needles, branches

Table 6. List of datasets sampled with the Leica RTK-DGPS.

Observation	Site	# of meas.	Date	Max. Error (m)
Emissivity	Cabauw	4	09&10/06/06	0.05
Emissivity	Speulderbos	1	11/06/06	3.08 (large GDOP)
ESAR reflectors	Cabauw	3	14/06/06	0.03
ESAR reflectors	Speulderbos	3	14/06/06	0.04
Goniometer	Cabauw	1	10/06/06	0.06
LAI	Cabauw	1	10/06/06	0.04
LAI	Speulderbos	1	11/06/06	Faulty (large GDOP)
LAS	Cabauw	8	14/06/06	0.04
Laserscan	Speulderbos	13	20/06/06	8.91 (Large GDOP)
Roughness	Cabauw	60	09, 10 & 15/06/06	0.05
Soil moisture	Cabauw	175	12& 21/06/06	0.31

Table 7. Meteorological instrumentation Speulderbos. Instruments in italic are owned by Wageningen University, others by ITC.

Datalogger	Sensors	Height (m)
	LAS	47
CR23X	CSAT3 sonic anemometer (Campbell Sci. Inc.)	47
	LI7500 gas analyzer (Li-cor Biosciences)	47
CR23X	Combined temperature and humidity sensor (Campbell Sci. Inc.)	43
	Anemometer (Vector Instruments Ltd., UK)	37
	Wind direction (Vector Instruments Ltd., UK)	37
	CNR1 radiometer (Kipp and Zonen)	35
	Combined temperature and humidity sensor (Campbell Sci. Inc.)	34
	Combined temperature and humidity sensor (Campbell Sci. Inc.)	27
	9 Contact temperature sensors	17–34
	Barometer (Campbell Sci. Inc.)	1
CR23X	Combined temperature and humidity sensor (Campbell Sci. Inc.)	1
with multiplexer	3 CS616 for soil moisture (Campbell Sci. Inc.)	−0.05,
		−0.30
		−0.55
	4 soil thermistors for soil temperature	−0.01
		−0.03
		−0.08
		−0.90
	8 contact temperature sensors	0–1
	3 soil heat flux plates HFP01 (Hukseflux)	−0.01

and trunks in the canopy between 17 and 34 m height. Figure 13 shows the measured surface temperatures for the sensors at ground level (soil, bold) and in the canopy (canopy, normal) for 17 June 2006. Canopy temperatures are higher than soil surface temperatures. The contact temperatures of the canopy on day 165 until 166 (not shown in Fig. 13) fluctuated very rapidly due to severe rainfall causing the sensors to malfunction.

Two measurement systems were used to measure turbulent fluxes. A Large Aperture Scintillometer (LAS) was used to measure sensible heat flux over the trajectory between the Speulderbos tower and the Drie Forestry tower 2 km north. The receiver was installed at the top of the Speulderbos tower. An eddy covariance system (EC) consisted of a sonic anemometer (CSAT3, Campbell Sci. Inc., USA) combined with a gas analyzer (CS7500, Campbell Sci. Inc., USA) was used to measure sensible heat flux and the exchange of carbon dioxide and water at the top of the Speulderbos tower. Figure 14 shows the components of the energy budget, net radiation, soil heat flux, and sensible and latent heat (upper panel) and the flux of carbon dioxide (lower panel), for a clear day (day 168, 17 June) during the campaign.

In general, the Bowen ratio is approximately unity, but on day 168, a day with high radiation, sensible heat flux is

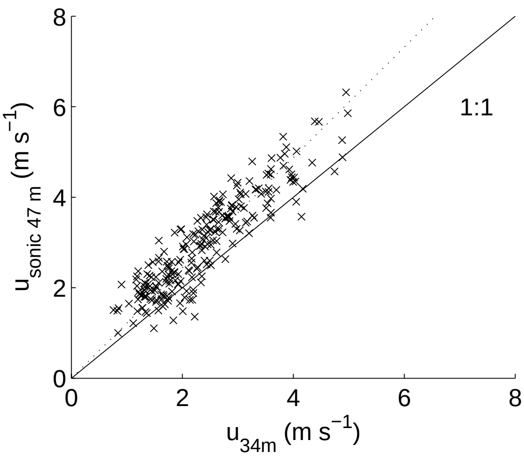

Fig. 11. Wind speed measured at 47 m height (with a sonic anemometer) versus wind speed measured at 34 m height (with a cup anemometer), in Speulderbos, for all measurements during the field campaign. The dashed line represents a linear regression through the origin.

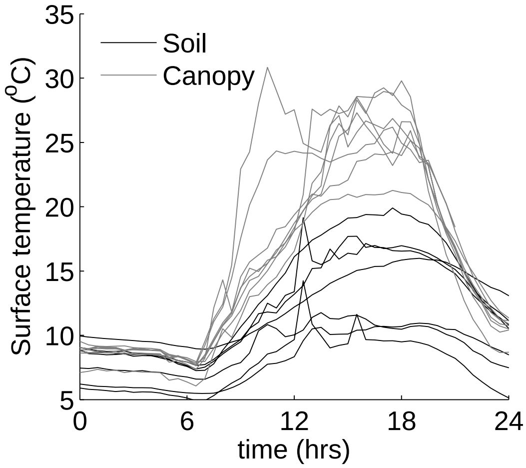

Fig. 13. Component surface temperatures of 8 sensors on the litter, moss and trunks at ground level (soil), and 9 sensors on trunks, branches and needles in the canopy (canopy) in Speulderbos versus time of the day, on 17 June 2007.

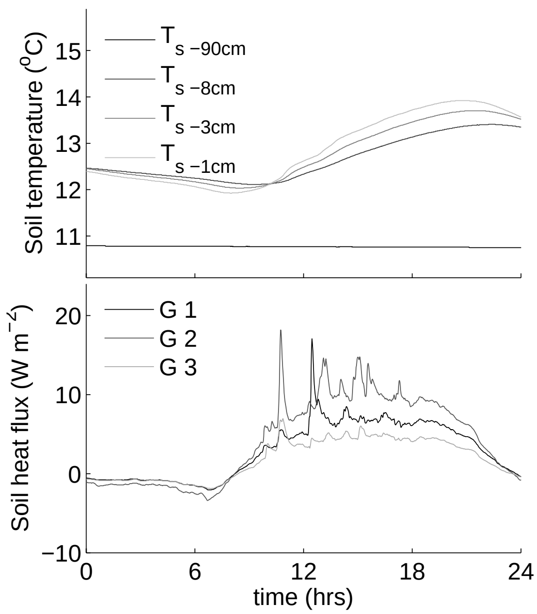

Fig. 12. Soil temperature measured at different depths (upper graph) and soil heat flux measured with three flux plates (lower graph) in Speulderbos versus time of the day, on 17 June 2006.

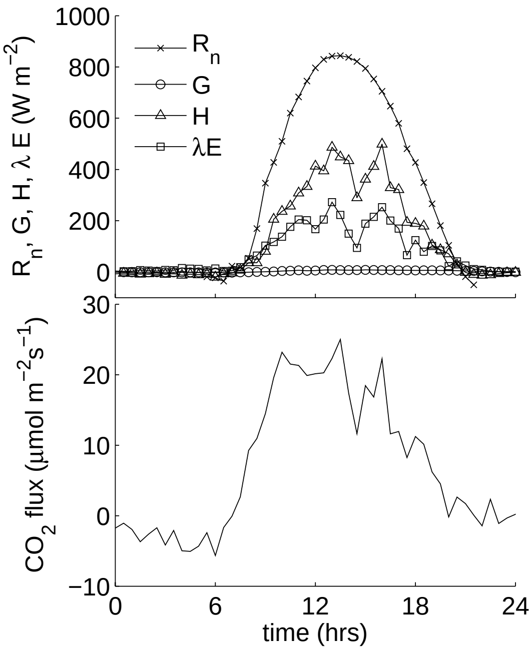

Fig. 14. Sensible (H) and latent (λE) heat flux measured with the EC system, net radiation (R_n) and average soil heat flux (G) (upper graph), and downward flux of carbon dioxide (bottom graph), in Speulderbos versus time of the day, on 17 June 2006.

higher than latent heat flux, whereas on a clouded day (day 172 or 21 June, not shown), latent heat flux is higher than sensible heat flux. Figure 15 shows the energy balance closure: available energy (net radiation less soil heat flux) and the sum of sensible and latent heat flux for all observations during the campaign. A 1:1-line is plotted through the data. The sum of the fluxes in general is lower than the available radiation. This known phenomena in principle can either be attributed to an overestimate of available energy (an overestimate of net radiation or an underestimate of soil heat flux), or to an underestimate of the latent and sensible heat fluxes. However, it is believed that the imbalance is caused by an underestimation of the turbulent fluxes which most likely is attributed to the integration time that is generally used for eddy covariance measurements (Foken et al., 2006).

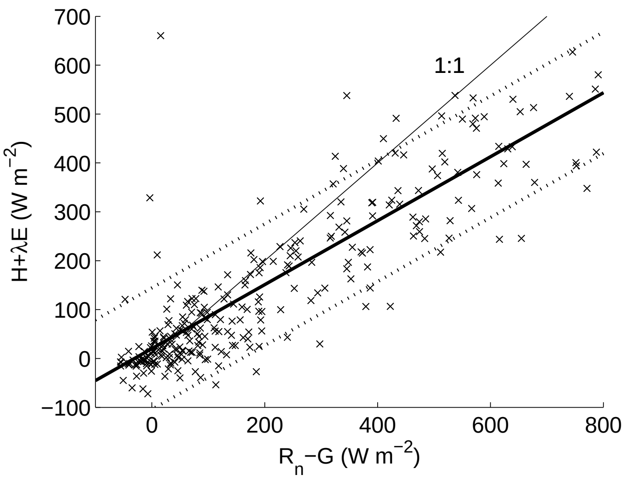

Fig. 15. Sum of sensible and latent heat flux versus available energy ($R_n - G$) for all measurements during the campaign. The bold line is a linear regression through the data. The dashed lines denote the standard error.

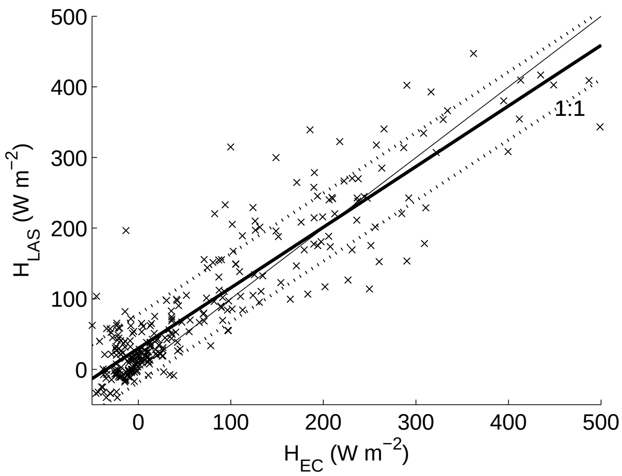

Fig. 16. Left: sensible heat flux measured with the scintillometer (H_{LAS}) versus sensible heat flux measured with the EC system (H_{EC}) for all measurements during the campaign. The bold line is a linear regression through the data. The dashed lines denote the standard error.

In Fig. 16, the sensible heat fluxes measured with the LAS and with the EC system are compared and a 1:1 line is drawn. In general, the sensible heat flux of the LAS is higher than that of the EC system on cloudy days and lower on clear days. The systematic difference between the two may be attributed to the sensitivity of H_{LAS} to roughness. The difference between the two systems on specific days may be related to different footprints (Timmermans et al., 2009a). A closer examination into the effects of wind direction, precipitation and stability is needed to explain those differences.

9 Data analysis and preliminary results

The data analysis included simulation of Sentinels (Sentinel-1/2) and retrievals of biophysical products. Advanced products that can be expected after further detailed analysis include the following:

– Net ecosystem exchange and footprint analysis above forest and grassland (ESA, 2007)

– Temperature and emissivity from AHS data (Sobrino et al., 2008)

– Modeling fluxes of energy, water and carbon dioxide above the Speulderbos (van der Tol et al., 2009)

– BRDF's acquired by directional radiative measurements (Timmermans et al., 2008c, 2009b)

– Soil moisture field observations over the Cabauw grassland (ESA, 2007)

– Technique for validating remote sensing products of water quality (ESA, 2007)

Full details of these data and preliminary products can be found in the EAGLE 2006 final report (Timmermans, et al., 2008a), the description of advanced products are given in contributions to the AgriSAR and EAGLE Final Workshop proceedings (ESA, 2007).

10 Recommendations

This contribution describes the mission objectives of the EAGLE2006 intensive field experiment and provides an overview of the airborne and field measurements. A unique dataset has been acquired, including (quasi)simultaneous SAR and optical (hyperspectral, visible and thermal) and atmospheric turbulence airborne datasets as well ground measurements. Atmospheric data from different ground based sensors has been gathered in combination with in-situ atmospheric soundings to characterize the atmospheric conditions during airborne and satellite acquisitions. The SAR data are of high quality at different frequencies (with relevance to Sentinel-1 simulation) and the optical data are of high quality as well (for Sentinel-2 simulation). In addition, the turbulence data and ground data are also of good quality.

Analysis showed a high potential of the data for use in further studies as well as a high potential for new product development. With respect to SAR, a combination of L- and C-band is preferred for classification purposes and the optical CASI and AHS system specifications are all together optimal for bio-physical parameter retrievals. With respect to the land-atmosphere exchange processes, preliminary analysis of water and energy exchanges have been performed, whereby the thermal data will be an essential input for further analysis of the thermal dynamic characteristics of different canopies and refine the parameterizations in land surface process models.

With respect to potential products for the Sentinel-1 and Sentinel-2 missions, land cover classification maps currently can be considered as in a pre-operational phase. For soil moisture maps, surface roughness, biomass, fractional vegetation cover and LAI products, the algorithms are in an experimental stage, whereas maps of actual evapotranspiration can be considered as a potential level 3 experimental product as well (providing the thermal input).

We have observed the need for a continuous agricultural data acquisition to cover a bigger variability of the land surface states. To this aspect, a higher crop diversity and variability in surface conditions are needed for future field campaigns. In addition, multi-temporal, as well as simultaneous observations with both SAR and optical sensors are desirable. With respect to ground observations, a higher data acquisition frequency might be needed, in combination with the need for investigation of the separation between biophysiological (vegetation growth) and natural (wind, rain) effects.

Preliminary results on retrieval of biophysical parameters are available and the entire EAGLE2006 dataset allows the development of new processing and retrieval algorithms, and the validation of such algorithms by in-situ, airborne and space-borne data. More details on several processing aspects of the data acquired within the campaigns have been presented elsewhere (ESA, 2008). The multi-disciplinary character of the EAGLE2006 field campaign is considered a very strong aspect. Hence, an intensive analysis by the (very) different teams, and external scientific users of the all the collected data should be supported.

All data as acquired in and during the EAGLE2006 Field Campaign are available via the Field Campaign ftp site (www.ftp.itc.nl/pub/eagle06/EAGLE2006Database/). Access is possible via the ESA Principle Investigator portal.

11 List of acronyms

AATSR	Advanced Along-Track Scanning Radiometer
ABL	Atmospheric Boundary Layer
AGRISAR	AGRIcultural bio/geophysical retrieval from frequent repeat pass SAR and optical imaging
AHN	Actual Height model Netherlands
AHS	Airborne Hyperspectral System
ASAR	Advanced Synthetic Aperture Radar
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BRDF	Bidirectional Reflection Distribution Factor
CASA-212	Construcciones Aeronáuticas, S.A.-212
CASI	Compact Airborne Spectrographic Imager
CESAR	Cabauw Experimental Site for Atmospheric Research
CHRIS	Compact High Resolution Imaging Spectrometer
DEM	Digital Elevation Model
Do228	Dornier 228
EAGLE	Exploitation of AnGular effects in Land surfacE observations from satellites
EC	Eddy Covariance
Envisat	Environmental satellite
EPS	EUMETSAT Polar System
ESA	European Space Agency
ESAR	Experimental Synthetic aperture Radar
FOV	Field Of View
GEOSS	Global Earth Observation System of Systems
GMES	Global Monitoring for Environment and Security
LAS	Large Aperture Scintillometer
MERIS	MEdium Resolution Imaging Spectrometer
MetOp	Meteorological Operational satellite
MODIS	Moderate Resolution Imaging Spectroradiometer
MSG	Meteosat Second Generation
NAP	Nieuw Amsterdams Peil (Amsterdam Ordnance Datum, the Dutch National leveling reference system)
NESCAFE	NEar Sensing Camera Field Equipment
NWO	Nederlandse organisatie voor Wetenschappelijk Onderzoek (Dutch organisation for scientific research)
PROBA	Project for On Board Autonomy
SAR	Synthetic Aperture Radar
SBB	Staats Bos Beheer
SEN2FLEX	SENtinel-2 and Fluorescence Experiment
SEVIRI	Spinning Enhanced Visible and InfraRed Imager
SMOS	Soil Moisture and Ocean Salinity
SPARC	Spectra bARrax Campaign
SRON	Stichting Ruimte Onderzoek Nederland (Foundation Space Research Netherlands)

Acknowledgements. This work was funded in part by EU GMES EAGLE Project (FP6, SST3 – CT – 2003 – 502057), NWO/SRON EO-071 and ESA EAGLE2006 (EOP-SM/1504/RB-dr). We thank all participating institutions and colleagues and students for their dedications to a very successful campaign. Two anonymous referees and the editor are thanked for their comments that helped improve the quality of the presentation.

Edited by: J. Wen
Reviewed by: J. Wen and H. Ishikawa

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