HyEurope 2004 Summary Report

1 Scope of the Document

The following document describes the HyEurope 2004 campaign including the characteristics of the HyMap sensor and the campaign schedule. Furthermore, it describes the specific flight planning and data processing for the individual projects.

2 Introduction

HyVista Corp. and DLR since 1998 have regularly carried out joint airborne campaigns utilising HyVista's imaging spectrometer HyMap.

In the year 2004 a European campaign took place between beginning of May and mid August.

The HyMap instrument was operating out of DLR's research center Oberpfaffenhofen, Germany on board of two different Dornier Do 228 aircraft.

145 hyperspectral image cubes or about 40 Gbyte of data have been acquired in eight different European countries. Quicklooks of most of the recorded data can be fund at:

http://www.caf.dlr.de/caf/anwendungen/umwelt/abb_spektroskopie/qlooks/qlooks04/_qlooks04/qlooks04_en.htm

Fig. 1 Geographic distribution of test areas für HyEurope 2004.

The instrument was calibrated before the beginning of the flight campaign at Oberpfaffenhofen using HyVista calibration gear. This calibration cycle including spectral and radiometric characterisation, the initial installation in the Do 228 aircraft and the sensor operation during the first test flights were carried out by HyVista. In the course of the campaign DLR took over the sensor operation and handling.

3 HyMap™ Airborne Imaging Sensor

The HyMap sensor is an airborne imaging system that is used for earth resources remote sensing. It records a digital image of the earth's sunlit surface underneath the aircraft but unlike standard aerial cameras, the HyMap records images in a large number of wavelengths. In essence, the HyMap is an airborne spectrometer and like spectrometers used in analytical chemistry, it can detect and identify materials by the spectral features contained in the recorded data.

The HyMap records an image of the earth's surface by using a rotating scan mirror which allows the image to build line by line as the aircraft flies forward. The reflected sunlight collected by the scan mirror is then dispersed into different wavelengths by four spectrometers in the system. The spectral and image information from the spectrometers is digitised and recorded on tape.

To minimise distortion induced in the image by aircraft pitch, roll and yaw motions, the HyMap is mounted in a gyro-stabilised platform. While the platform minimises the effects of aircraft motion, small image distortions remain. These residual motions are monitored with a 3 axis gyro, 3 axis accelerometer system (IMU – Inertial Measurement Unit). The system currently used with the HyMap is a Boeing C-MIGITS II.

Associated with the actual HyMap optical system is an electronics sub-system which is rack mounted in the aircraft. This electronics sub-system provides the sensor with power and contains a computer system that controls the data acquisition process. There is a touch screen monitor used by the operator to set data acquisition parameters, start and stop recording, view the image as it is being acquired and review various engineering status indicators (power, temperature etc).

The HyMap system has been designed to operate in aircraft that have standard aerial photo-ports. The angular width of the recorded image is 61.3 degrees or about 2.3 km when operating 2000m above ground level. Typically, the spatial resolution achieved with the HyMap is in the range 3 to 10 m.

The general technical specifications of the HyMap system are given in the tables below:

Table 1: HyMap Spatial Parameters

Spatial Configurations	
IFOV	2.5 mr along track 2.0 mr across track
FOV	61.3 degrees (512 pixels)
Swath	2.3 km at 5m IFOV (along track) 4.6 km at 10m IFOV (along track)

Table 2: HyMap Spectral Performance

Typical Spectral Configuration			
Module	Spectral range	Bandwidth across module	FWHM
VIS	0.45 – 0.89 µm	15 – 16 nm	15 nm
NIR	0.89 – 1.35 µm	15 – 16 nm	15 nm
SWIR1	1.40 – 1.80 µm	15 – 16 nm	13 nm
SWIR2	1.95 – 2.48 µm	18 – 20 nm	17 nm

The following figure shows the HyMap mounted on a DO228.

Fig. 2: HyMap in its stabilised platform mounted in a DLR Do-228

4 Description of Data Products

In operation, the HyMap sensor records 128 spectral bands. However, the delivered data contains 126 bands because the first and the last band of the first spectrometer are deleted during the pre-processing.

All image data are delivered as ENVI compatible binary files (e.g. a BSQ file with ENVI header file). Data collected during the HyEurope 2004 campaign is delivered on DVD. The actual files delivered will vary from client to client depending on specifics of the survey contract.

4.1 Level 1 Product Files

The following products are generated during the system correction and radiometric data processing (Level 1).

File Type	Description
*rad.bsq	Image data, 126 channels x 512 pixels x N lines
*rad.hdr	ENVI compatible header file
*.gps	UTC time, position and attitude per image line
*.jpg	Quicklook image, RGB

"filename"rad.bsq

This file refers to a 126 bands, 512 pixel wide image in BSQ format that has been converted to physical units of at-sensor radiance in µW/cm² sr nm.

The in-flight recorded DN (digital numbers) have been corrected for dark current/electronic offsets and converted to radiance using laboratory radiometric calibration information and in-flight measurements of the on-board calibration lamp.

When converting data from real numbers to integer, HyVista Corp first rescales the data to preserve dynamic range, especially in the SWIR range. This rescaling involves multiplying bands 1 – 62 by 1000 and bands 63 – 126 by 4000. After scaling, the data is converted to integer format.

The wavelength and bandwidth (in nanometres) information is imbedded in the ENVI header file (*.hdr).

The HyMap sensor has 4 spectrometers (VIS, NIR, SWIR1 and SWIR2), each producing 32 spectral bands of imagery. The VIS and NIR provide contiguous sampling across the 900 nm region. In fact, the spectrometers are set up to provide a slight overlap in the long wavelength region of the VIS spectrometer and the short wavelength region of the NIR spectrometer.

Image data is written to DVD in band order from the VIS to the NIR to the SWIR1 to the SWIR2 spectrometer and this leads to the bands being in wavelength order except at the VIS – NIR overlap.

Typically, band 30 (the last band of the VIS spectrometer) of the radiance data will have a wavelength larger than band 31 (the first band of the NIR spectrometer).

When radiance spectra are plotted as a Z-profile in ENVI, the line of the plot is connected to the data points in band order, not wavelength order. This can give a "strange" appearance to the plot in the VIS-NIR overlap region.

"filename".gps

The *.gps file is a multi-column ASCII file derived by HyVista Corp. proprietary software, which synchronises times and generates an output which is indexed by scan line number. The table below shows the list of output parameters.

Parameters	**Example**	**Description**
Line	1	Scan line number
UTC Time	48835.0462/20/5/2004	DGPS output Time of day in seconds/day/month/year
VME Time	929386852.0	Internal computer tick time in microseconds
CMIGITS Time	2048825953.1	Internal CMIGITS time in microseconds
Latitude	48.03321015	DGPS output Decimal degrees (positive = north, negative = south)
Longitude	11.28140200	DGPS output Decimal degrees (positive = east, negative = west)
Altitude	2970.79892155	DGPS output Meters above MSL
Pitch	0.22235917	IMU output Decimal degrees (positive = nose up)
Roll	0.54269902	IMU output Decimal degrees (positive = right wing up)
Heading	0.37774316	IMU output Decimal degrees (positive = N-E-S direction, negative = N-W-S direction)
True Track	1.00507651	DGPS output Decimal degrees (0 to 360)
Ground Speed	72.90907700	DGPS output Meters / second
Sat	5	Number of satellites being received
DGPS	1	DGPS status 1 = DGPS being received 0 = no DGPS received

All of the above timing, position and pointing information has been referenced to the end of the image scan line.

The parameters are derived as follows.

Once per second, the DGPS receiver generates an interrupt signal. At the time of this interrupt, the system records the VME time (referred to as tick time) and the CMGITS time, both in microseconds. The DGPS receiver then sends UTC time, lat, long, altitude etc to the system referenced to the time of the interrupt signal.

At the end of each image scan line, VME time is recorded. The CMIGITS sends pitch, roll and heading information to the system at a 10 Hz rate and time tagged with CMIGITS time.

The program uses the CMIGITS and VME tick times to synchronise (and interpolate) the other parameters, including UTC time, to the time corresponding to the end of a scan line.

One question that might arise is “if the time is referenced to the end of the image scan line, what positional difference occurs from the centre pixel of the scan line to the end pixel?”

In the following table, the relationship between scan rate (lines per second) and along track positional difference between middle and end pixel is shown.

Line Rate (lines per second)	**Time period per scan line (pixel 1 to pixel 512) in milliseconds**	**Difference(centre to last pixel) at 100 Kts**	**Difference (centre to last pixel) at 120 Kts**	**Difference (centre to last pixel) at 140 Kts**
8	42.6	1.05 m	1.3 m	1.5 m
10	34.1	1.35 m	1.0 m	1.2 m
12	28.4	0.7 m	0.85 m	1.0 m
14	24.3	0.6 m	0.75 m	0.85 m
16	21.3	0.55 m	0.65 m	0.75 m

Thus it can be seen that unless positional information and/or geo-correction is being attempted at the metre or less precision, that the fact that the timing information generated is referenced to the end of the scan line rather than the centre contributes minimal error. The differences are smaller than the positional information derived from the DGPS and smaller than the accuracy of the IMU pointing information when traced to actual ground positions.

4.2 Level 2 Product Files

File Type	Description
*geo.img	Ortho-rectified image data
*geo.hdr	ENVI compatible header file
*sca	Angular output file
*sca.hdr	ENVI compatible header file
*atm.bsq	Atmospherically corrected image data
*atm.hdr	ENVI compatible header file
*atm_geo.img	Ortho-rectified atmospherically corrected image data
*atm_geo.hdr	ENVI compatible header file
*geo_atm.bsq	Ortho-rectified atmospherically corrected image data
*geo_atm.hdr	ENVI compatible header file

"filename"geo.img

Ortho-rectified radiance data performed with ORTHO based on the parametric model using recorded attitude and flight path data in combination with a digital terrain model.

"filename"sca.bsq

File with the following two bands:

1. Scan angles. Negative values refer to the right hand part of the scan line with respect to flight heading, positive for left hand part. Scale factor 100. The value 9100 indicates a background pixel.
2. Absolute azimuth angles (range 0-360 degree). Scale factor 10.

"filename"atm.bsq

Surface reflectance file with atmospheric correction performed with the ATCOR4 model based on atmospheric lookup tables generated with the radiative transfer model MODTRAN4. For more information about the ATCOR4 model see http://www.rese.ch/atcor/atcor4/ . A typical reflectance spectrum of a vegetation canopy after atmospheric correction is shown below.

The HyMap laboratory wavelength calibration was checked against absorption features of atmospheric gases using a fitting algorithm. Spectral shifts of up to 3 nm were found varying from spectrometer to spectrometer (cf. Table XX). Investigating approx. 30 individual data takes this shift was found to be constant for the entire flight campaign. No significant influence on the radiometric calibration of the sensor is expected from this shift

The determined new centre wavelength values were used in the atmospheric correction. Consequently, atmospherically corrected (and subsequently geocoded) data files will have a slightly different wavelength compared to at-sensor radiance data. The reason for the spectral shift is currently under investigation.

Table 3 Spectral shifts values with respect to the original laboratory calibration of HyVista.

Spectrometer	Shift of center wavelengths in nm
1	-3.00
2	-1.15
3	+0.50
4	+2.10

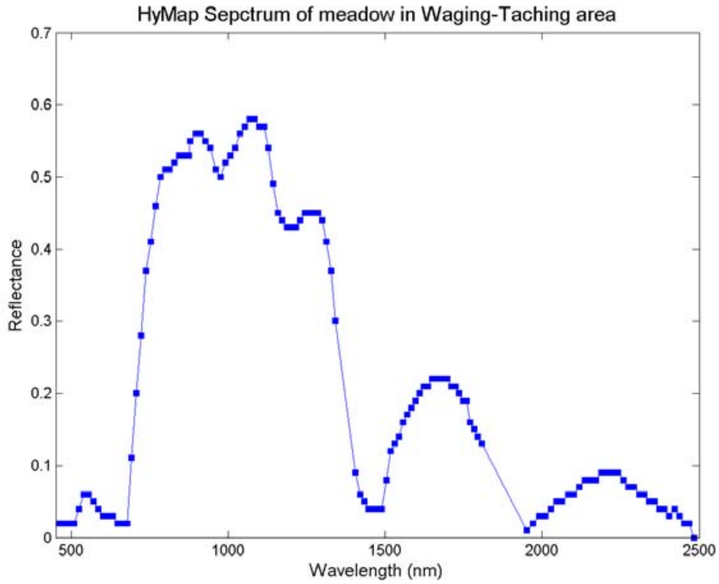

Fig. 5: HyMap Spectrum after atmospheric correction using ATCOR

"filename"atm_geo.img / "filename"geo_atm.bsq

Orthorectified surface reflectance data.

5 HyEurope 2004 Overall Schedule

May	June	July	August
1	1 Demounting	1 Testflight	1
2	2	2	2 Netherlands, DT
3	3 Mounting [4]	3	3 Demounting [5]
4	4	4	4 Finland
5	5	5	5 Finland, DT
6	6	6	6 Finland
7 Calibration	7 OP-Ref	7 Germany, DT	7
8 Calibration	8 Belgium, DT	8	8
9 Calibration	9	9	9 Germany, DT
10 Mounting [1]	10	10	10
11 Testflight	11	11	11
12	12	12	12 Spain, DT
13	13	13	13 Spain, DT
14	14 Wales, DT	14	14 Spain, DT
15	15	15 Italy, DT	15 Spain
16	16	16	16
17 Spain, DT [2]	17	17	17 Demounting [6]
18 Spain, DT	18	18	18
19 Spain, DT	19	19	19
20 OP-Ref [3]	20	20	20
21	21	21	21
22	22	22 Ground Test	22
23	23	23	23 Processing Start
24	24	24	24
25 Bavaria, DT	25	25	25
26 Bavaria, DT	26 Bavaria, DT	26	26
27	27	27	27
28 Germany, DT	28	28 Benelux, DT	28
29	29	29 Switzerland, DT	29
30	30 Germany, DT	30 Germany, DT	30
31		31	31

[1] Mounting of HyMap sensor on DO228-101 (D-CODE)

[2] DT = Data Take

[3] OP-Ref = Data Take of the Ground Control Point Field in Oberpfaffenhofen

[4] Mounting of HyMap and ROSIS sensor on DO228-212 (D-CFFU)

[5] Demounting of ROSIS sensor

[6] Demounting of HyMap sensor

6 Data Processing Information

Name of Project			Swiss			
Date of Acquisition			04/07/29			
Resampling Method (orthorectification)			bilinear			
Map projection						
Geodetic datum						
Strip Number	**Flight Altitude**	**Scan Frequency**	**Flight Heading**	**Solar Azimuth**	**Solar Zenith**	**Pixel Size**
Vordemwald 1	2930	13,25	179,23	124,3	39,4	5
Vordemwald 2	2930	13,25	0	127,1	38,2	5
Vordemwald 3	2928	13,25	89,64	130,3	36,9	5
Chur 1	3227	13,25	201,04	164	28,1	5
Chur 2	3225	13,25	342,5	168,9	62,3	5
Bettlach	2930	13,25	176,7	137,7	36,3	5
Küttigen	2926	13,25	88,86	142,5	32,9	5
Sihlwald 1	2924	13,25	146,85	147,4	31,7	5
Sihlwald 2	2921	13,25	329,83	151,6	30,8	5