THE MOMS-2P MISSION ON THE MIR-STATION

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ABSTRACT

MOMS is a five lens space camera for multispectral and stereo imaging. It was flown for the first time on a Space Shuttle mission (STS 55) in 1993; in this 10-day mission approx. 7 million square km of the earth surface were covered. After the Shuttle flight the camera system was refurbished and adapted to the new environmental conditions onboard the PRIRODA-Module of the Russian MIR-Space Station. Additionally, the MOMS-payload was extended by a navigation package conisting of a high precision gyro and a GPS system in order to provide the necessary position and attitude data for photogrammetric evaluation of the image data. MOMS-2P was launched into orbit in May 1996 and started its first operation in October 1996. A technical description of the camera system and its operational concept will be presented as well as the present status of data recording. Information how MOMS-data can be accessed and ordered will be given.

1 INTRODUCTION

The camera MOMS-2P (Modular Optoelectronic Multispectral Scanner on PRIRODA) is the refurbished version of the MOMS-02/D2 camera which has been flown on-board the German Spacelab Mission D2. During this Space Shuttle flight (STS-55), from April 26 to May 6, 1993 the MOMS-02 system recorded 4.5 hours of data, of which about 400 radiometrically and geometrically processed scenes are available. First results of the data evaluations can be seen in [1]. The data were taken in the region between +/- 28.5 degrees of geographical latitude (see figure 2).

The Russian Space Station MIR (see figure 1) exhibits since April 1996 a new Module called PRIRODA (nature), which is mainly dedicated to earth observation. It contains a number of instruments for different applications [2]. The simultaneous operation of several instruments is possible. The MOMS camera has been mounted on the outer side of PRIRODA by Russian cosmonauts in May 1996.

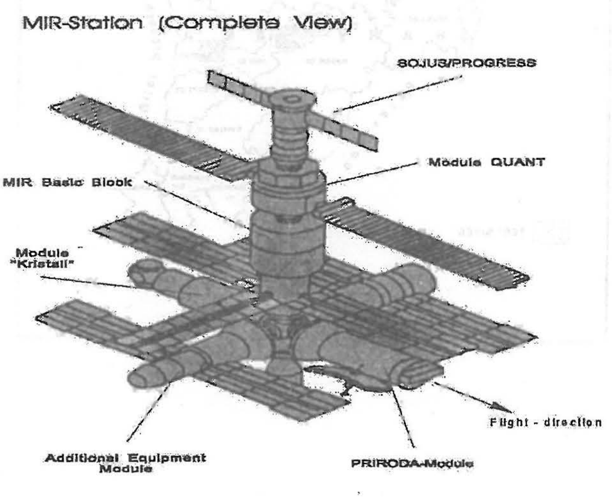

Figure 1: The Russian Space Station MIR

The MOMS-02/2P sensor were proposed and designed in cooperation between the DLR and the Deutsche Aerospace (DASA) under contract by the German Space Agency. The development was supervised by the so called 'MOMS Science Team' coordinated by DLR. The team members are grouped in three main centres:

- the center for coordination of thematic data evaluation, Geo Science Center (GFZ) Potsdam
- the center for coordination of topographical data evaluation, University Stuttgart
- the center for operation, reception, data-processing and validation (Mission Center), DLR (Institute of Optoelectronics, German Space Operations Center (GSOC), German Remote Sensing Data Center (DFD))

The main tasks of these centers are coordination and execution of data processing orders as well as the continuous improvement of existing calibration and evaluation procedures.

MOMS-2P major improvements compared with MOMS-02/D2 are:

- Long term observation capability (more than one year)
- Coverage of higher Latitude between +/- 51,6 degrees
- New high precision NAV (GPS and gyro) System
- Multisensor approach in combination with other PRIRODA - sensors

The three-fold stereo camera of MOMS-2P opens new horizons for earth observation from space. Investigations of the environment, agriculture, forestry and urban development as well as digital mapping and landscape modelling with a high degree of automation will be strongly improved by using the combined stereo and multispectral capabilities of the MOMS-2P sensor. The derivation of high resolution Digital Terrain Models (DTM) from the along-track stereo data is a special feature of the sensor.

2 THE ORBIT OF THE MIR-STATION

The orbit of the MIR - station is nearly circular with an inclination of 51.6 degrees and an altitude of 400 km (mean). With this inclination, the MIR orbit covers the land areas of nearly the whole southern hemisphere and large parts of the northern hemisphere, as can be seen in figure 2.

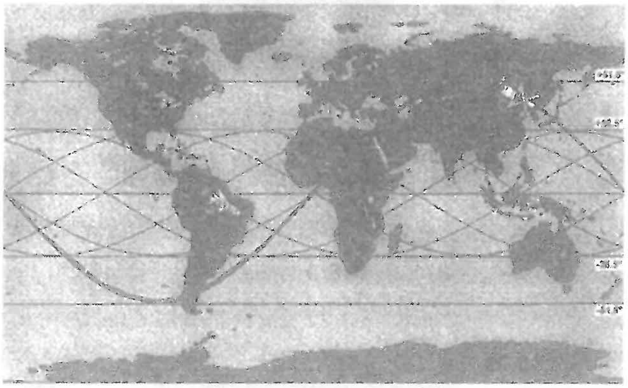

Figure 2: Orbits of Space Shuttle (D2-Mission) and MIR-PRIRODA

The orbit parameters result in a mean precession increment of -23.2 degrees per orbit and a repetition rate between 3 and 18 days, depending on the distance to the equator. These parameters are valid for the so called typical MIR orbit and may vary significantly due to variations of the orbit height. Because of periodical orbit corrections the altitude varies between 380 and 405 km, changing the precession increment and the repetition rate in a corresponding manner.

To plan the PRIRODA - Mission scenario, it is necessary to determine the sun incidence angle at the subsatellite tracks of MIR as shown in figure 3. The picture shows the annual variation of target areas for which the sun elevation is greater than 20 degrees for the MIR overflight times. The figure also points out that with a period of about 30 days either the northern or the southern hemisphere can be seen with a sufficient sun elevation. It is obvious that during two short time periods around the 10th of January and 10th of June, there is no observation possibility.

Due to the MIR orbit, each of the two receiving stations (Neustrelitz in Germany and Obninsk in Russia) allow 4-5 downlinks per day, for approximately 8 minutes each.

3 THE MOMS-2P SYSTEM

MOMS-2P is a follow on development of MOMS-02 which was already successfully flown on-board the German Spacelab Mission D2 brought into orbit by the American Space Shuttle on April 26, 1993. During the 11 day-mission at a flight altitude of approx. 296 km, in total 48 image strips over North Africa, Saudi Arabia, Indian Subcontinent, South East Asia, Australia and South America were taken.

3.1 THE OPTICAL CONCEPT

The refurbished MOMS-02 camera was renamed MOMS-2P and launched a second time on 5 May 1996 with a Sojuz

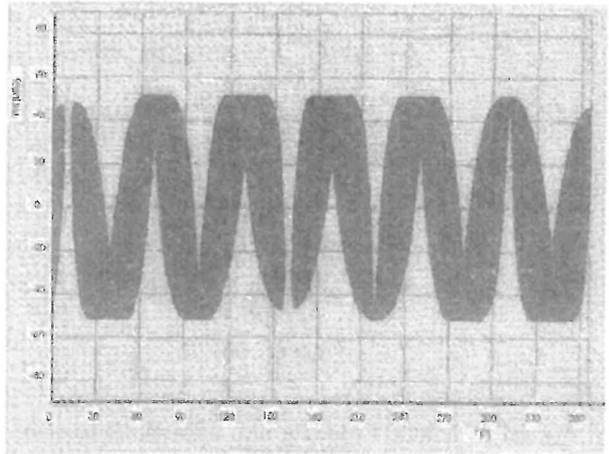

Figure 3: Sun elevation angle greater than 20 degrees for subsatellite track of MIR for the year 1996; ascending passes (dark), descending passes (bright); Altitude = 400 km; x-axis: day of the year; y-axis: geographical latitude

rocket from Baikonur, Kazakstan, to be mounted to the Russian Earth Observation Module PRIRODA which is part of the Space Station MIR.

The main modifications of the MOMS-2P camera system in comparison to MOMS-02 are:

- the camera is mechanically modified for handling by the cosmonauts during extravehicular activities and for mounting the camera system to the outside wall of the PRIRODA-module.
- MOMS-2P is additionally equipped with a navigation package comprising gyros and GPS

The camera and the navigation package were actually installed by the cosmonauts at the outer wall of the PRIRODA-module during an extravehicular activity of several hours duration on 30 May 1996. The position of the camera on PRIRODA and the hardware are shown in Fig. 4 and Fig. 5. For operation of the camera the whole MIR-station has to be turned in such an attitude that allows the camera to look vertical down to the earth.

Fig. 6 shows a schematic drawing of the optical concept of MOMS-2P. The camera consists of five lenses, three for stereoscopic and two for multispectral imaging.

The stereo-module has a nadir looking lens with a focal length of 660 mm and two lenses with 237 mm focal length looking forward and backward with respect to the flight direction under a tilt angle of 21.4 degrees. For the MIR-station altitude of 400 km the ground pixel size is 6.0 m for the long focal length and 18.0 m for the tilted lenses; the swath width is 50 km respec. 105 km. The spectral bandwidth of the three stereo channels is 520 to 760 nm. In order to obtain the 50 km swath width with the high reolution channel, two linear CCD-detector arrays are optically joint to each other in the focal plane (channels 5A and 5B).

The multispectral module has two lenses of 220 mm focal length; in each image plane two linear CCD-detectors covered

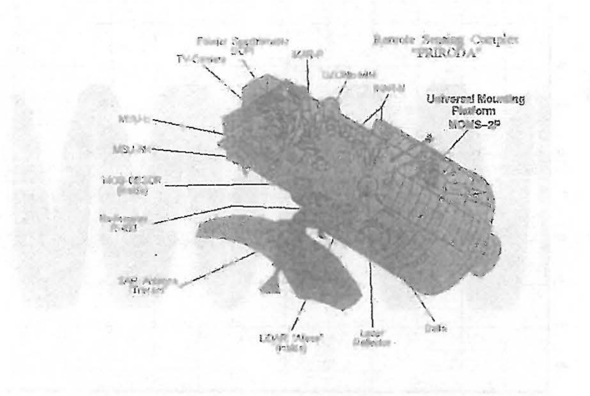

Figure 4: PRIRODA-Module with scientific equipment

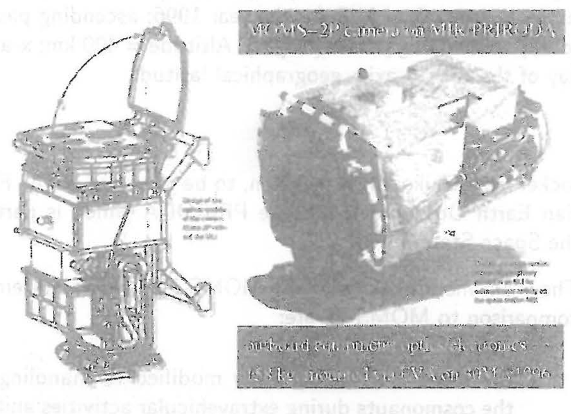

Figure 5: The MOMS camera assembly as used for PRIRODA

with different spectral filter glasses are mounted to enable multispectral imaging in the following four bands: 440 - 505 nm, 530 - 575 nm, 645 680 nm, 770 - 810 nm. The swath width for these channels is 105 km and the ground pixel size is 18.0 m.

The focal lengths of the optics were chosen such that the relationship between the ground pixel size of the long focal length lens to that of the other lenses is 1:3. The imaging geometry and the corresponding parameters for ground resolution and swath width for all channels is shown in figure 7. Table 1 summarizes the main geometric and spectral parameters for all seven imaging channels.

Chan.	Mode	Orienta.	Band Width	Pixel Size	Swath Width
1	M/S	Nadir	440-505 nm	18 m x 18 m	105/50 km
2	M/S	Nadir	530-575 nm	18 m x 18 m	105/50 km
3	M/S	Nadir	645-680 nm	18 m x 18 m	105/50 km
4	M/S	Nadir	770-810 nm	18 m x 18 m	105/50 km
5	HR	Nadir	520-760 nm	6 m x 6 m	50/36 km
6	Stereo	+21.4	520-760 nm	18 m x 18 m	105/50 km
7	Stereo	-21.4	520-760 nm	18 m x 18 m	105/50 km

Table 1: Characteristics of the MOMS-2P channels (M/S = multispectral, HR = high resolution), the swath width is depending on the operation mode

The along track stereo imaging principle is illustrated in figure 8. The nadir- and the for/aft-viewing directions make it possible to image a ground strip A on the earth's surface at

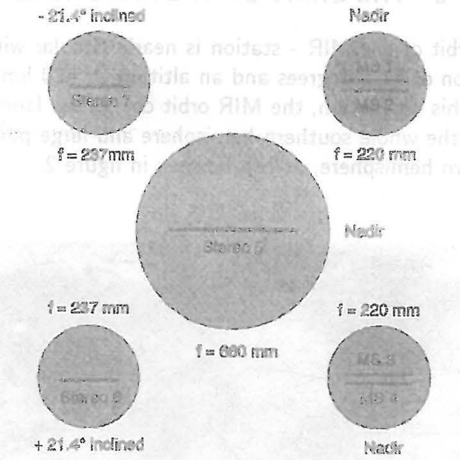

Figure 6: Optical parameters of the five objectives

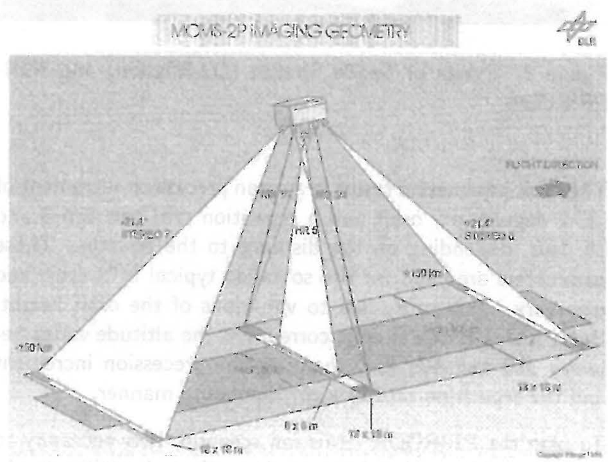

Figure 7: MOMS-2P imaging geometry, nominal flight altitude 400 km

three different times from three different viewing directions The time interval between taking the forward- and backward looking image is only approx. 40 sec corresponding to an orbit distance of approx. 300 km for the two camera positions. The resulting base/height ratio is then approx. 0.8. The fact that the three images (nadir, for, aft) are recorded within 40 seconds make it easy to correlate them in the data evaluation process, because of their radiometric similarity.

The linear CCD-arrays mounted in the image planes are 6000-element detectors from Fairchild with a size of 10 μm X 10 μm for each element. The output signal is digitized to 8 bit. To adjust the output signal to the scene brightness an electronic gain setting with 8 steps can be used.

3.2 OPERATING MODES

The data generated by the MOMS-2P camera are recorded by an onboard tape recorder (AMPEX) located inside the PRIRODA-module. The maximum data rate of this recorder is limited to 100 Mbits/sec. Due to this limitation not all seven channels can be recorded simultaneously.

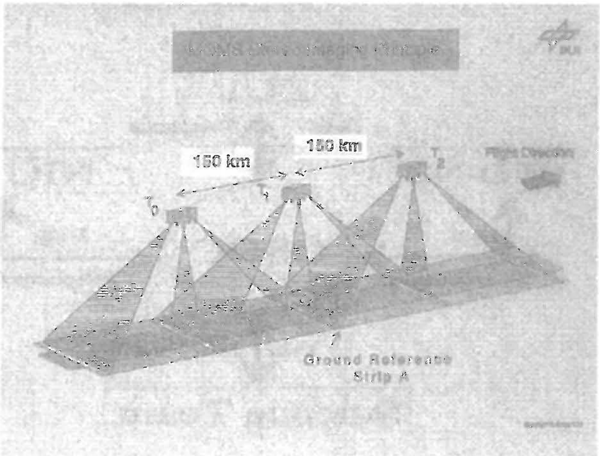

Figure 8: MOMS-2P stereo imaging principle

Therefore, a set of four operation modes has been defined, combining different channels to be selected for various applications. Table 2 summarizes the modes with the corresponding numbers of pixels per imaging line. The tape recorder allows a maximum tape capacity of 48 Gbytes corresponding to a recording time of 80 minutes based on an averaged data rate of 10 Mbytes/sec. After an accumulation of maximum 80 min. recording time, data will have to be dumped to a ground station (Moscow or Neustrelitz) via the onboard antenna system.

Channel	1	2	3	4	5	6	7	swath width
Mode A					8304	2976	2976	50/54 km
Mode B	5800	5800	5800	5800				105 km
Mode C		3220	3220	3220	6000			58/36 km
Mode D	5800			5800		5800	5800	105 km
IFOV (µrad)	45,45	45,45	45,45	45,45	15,15	42,16	42,16	

Table 2: Operating modes and numbers of pixels per line

After transmitting the image data to the ground station the tape can be used again for new data recording. As the tape recorder is installed inside the PRIRODA-module the possibility exists that if required the crew replace full tapes by empty ones. The full data tapes can be returned to earth by Soyus- or Space Shuttle flights. This option were used when technical problems occurred with the transmitting antenna system.

The following modes will be operated during the mission:

- Mode A: bands 5a, 5b, 6 and 7 for generation of Digital Terrain Models (DTM)
- Mode B: bands 1, 2, 3 and 4 for thematic analysis and classification of ground objects
- Mode C: bands 2, 3, 4 and 5a for thematic analysis and classification of ground objects
- Mode D: makes use of 2 multispectral channels plus two stereo channels (channels 1, 4, 6, 7) allows DTM generation and thematic analysis

The diagram (figure 9) shows how the different modi result in scenes with variing pixel sizes and swath width. Since the resolution of channel 5 is three times higher than of the other channels, there appear different scene sizes for single channels in mode A and mode C. The area covered by channel 5 is smaller than that of the other channels.

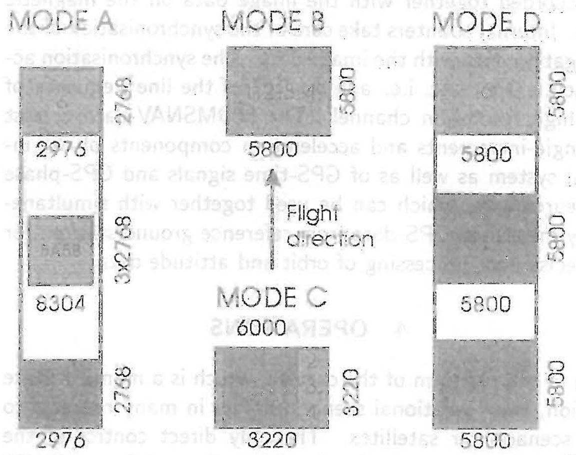

Figure 9: Imaging modes, size of images and channel combinations

3.3 MOMSNAV

In order to support the German MOMS-2P mission on PRIRODA with orbit and attitude data, a high precision navigation package called MOMSNAV has been developed. MOMS and MOMSNAV were launched together in May 1996. MOMSNAV will provide navigation data which may be post-processed to satisfy the accuracy requirements for photogrammetric applications. These are:

- Differential GPS orbit accuracy less then 5 m
- Relative attitude accuracy (non-linearities) less then 10"

over typically 5 minutes operation cycle per data take of MOMS-2P.

The navigation package MOMSNAV was developed by the company Kaiser - Threde, Munich. It comprises a L1 C/A - Code Viceroy GPS-receiver manufactured by MOTOROLA and two redundant inertial systems produced by LITEF. The GPS-antenna system consists of two antenna units which are mounted in 3m-distance on the outside wall of PRIRODA. Each unit has two spatially separated GPS-antennas with 12 (6+6) channels, which make the system considerably insensitive to shading effects caused by solar panels and other Space Station components. The inertial system is divided in two sensor units which are fastened to the optical bench of the camera module of MOMS-2P. Each sensor unit consist of two gyros with two orthogonal rotation axis and three accelerometers. An electronic box inside PRIRODA for data management and system controlling complements the MOMSNAV system.

The GPS-receivers will be switched on approx. 3h in advance to the MOMS-2P camera operation. From this time on the position and velocity data will be recorded and transmitted via the MIR/PRIRODA Low - Bit telemetry channel to the

Russian mission control center. These data can be used to improve the position accuracy by applying appropriate software for orbit determination.

After switching on the MOMS-2P camera all MOMSNAV-data will be integrated in the MOMS-2P data stream and will be recorded together with the image data on the magnetic tape. Internal counters take care of the synchronisation of the navigation data with the image data. The synchronisation accuracy is 0.1 msec, i.e. approx. 1/7 of the line frequency of the high resolution channel. The MOMSNAV-data consist of angle-increments and acceleration components of the inertial system as well as of GPS-time signals and GPS-phase measurements, which can be used together with simultaneously measureal GPS-data from reference ground stations for a precise post-processing of orbit and attitude data.

4 OPERATIONS

Due to the platform of the camera, which is a manned space station, the operational scenario differs in many respects to the scenario for satellites. The only direct control of the station is done from the Russian Space Control Center (ZUP) in Kaliningrad near Moscow, while the planning for the data takes of the camera is made in Germany.

The average data recording time for MOMS is in the order of 5 minutes/day, which is equivalent to a ground track of about 2000 km. For the downlink of the data there are in principle 4 to 5 possible overflights of ground receiving stations per day. But since the MIR-station has to be brought to a special orbital attitude for each data take and downlink, there is only one orbit for MOMS-Operations available per day due to energy restrictions. These orbits have to be defined about 2 weeks in advance due to the other projects executed in the station. To use this kind of operational scenario in an optimal way, a lot of work has to be done in the mission planing, which is mainly performed at GSOC (German Space Operation Centre).

The functional diagram (Figure 10) illustrates a basic overview of the MOMS-2P network communication for the MOMS-Operations between ZUP, DFD (German Remote Sensing Data Center), GSOC, NIC (Russian Image Processing Center) and the Science Team. The signals transmitted between these institutions include data, voice (telephone, intercom) and facsimile.

The generation of the timeline (long- mid- and shortterm timeline of mission planning) is a mean to fulfil user requirements at an optimum. The discrimination of the timeline into three categories is a useful tool to reduce constraints given by boundary conditions, like wheather, sun elevation orbit changes a.o.. The result of this iterative process of timelines is a well defined list of all commands which will be performed in a certain time frame.

The user requirements of MOMS-2P which are stored in a data base run through different processes of mission planning within the above mentioned three consecutive steps, each with a differing period of time:

- Long-term planning (3 month)
- Mid-term planning (2 weeks)
- Short-term planning (6 days to 1 day) and after the execution of the data take:

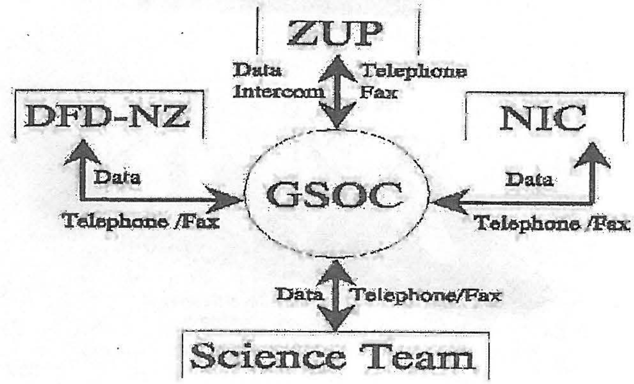

Figure 10: Functional diagramm of the operational szenario

- Logging of the data take information like wheather conditions, sensor performance a.o.

All the timelines are generated in coordination with the Russian Control Center ZUP. The commando generation is done in the German Control Center GSOC and is sent via data link to the ZUP from where they are sent to the MIR-Station and executed automatically. The only crew activity in the nominal case is to change the AMPEX tape on request.

Although there are some disadvantages to have an earth observation camera on the Space Station instead of an unmaned satellite, the advantage is that many failures of the hardware can be repaired during the mission. For example there has been a defect cable at the beginning of the comissioning phase, which could be exchanged by the cosmonauts after sending a new one with the PROGRESS transporter.

5 PRESENT STATUS AND OUTLOOK FOR 1998

The first data were recorded in October 1996 over Australia and South Africa. From that time the comissioning phase started during which the sensor was tested and validated. Radiometric and geometric calibration procedures (see [4] and [5]) were applied with sun calibration and real data to achieve an optimum quality for Level 1A and Level 1B products.

The operational phase was due to start in spring 1997, when several difficulties of the MIR-station hindered new data takes. Since May 1997 also the power box of MOMS showed failures so that no more data could be acquired since then.

The data which have been acquired during the commissioning phase have been processed to the different processing levels and are now available. Table 3 shows the areas of processed data.

The exact position of the data takes can be browsed in the internet under the URL : http://www.op.dlr.de/M2P/asfl/

It is planned to exchange the power box in late December 1997 and start obtaining new data from mid of January 1998.

Date	Data Take Target	Mode
1 Oct. '96	Northern Australia	B
5 Oct. '96	Northern Australia	B
13 Oct. '96	South Africa/Tansania	B
17 Oct. '96	Saudi Arabia	A
22 Oct. '96	Spain	A
25 Oct. '96	Kroatia/Hungary	C
29 Oct. '96	France/Germany	C
16 Nov. '96	Central Australia	B
10 Dec. '96	South Australia	C
11 Dec. '96	Bolivia	A
14 Dec. '96	Bolivia/Brasil	A
18 Dec. '96	Arabian Peninsula	B
18 Dec. '96	Ethiopia/Arabian Peninsula	B
20 Dec. '96	Arabian Peninsula	B
21 Dec. '96	Eritrea/Arabian Peninsula	B
23 Dec. '96	Eritrea/Arabian Peninsula	B
25 Dec. '96	Arabian Peninsula/Iran	B
12 Mar. '97	N/W-Europe/Black Sea	C
13 Mar. '97	France to Israel	C
14 Mar. '97	France to Turkey	A
15 Mar. '97	France to Egypt	C
18 Mar. '97	South Korea	A
1 Apr. '97	Indonesia	B

Table 3: Processed MOMS-2P data of the commissioning phase

6 DATA PRODUCTS

The data products are delivered in two processing levels:

- Level 1A (only radiometrically system-corrected) for stereo processing in mode A and mode D
- Level 1B (radiometrically and geometrically system-corrected) for multispectral processing in mode B and mode C

Together with the image data, the corresponding navigation data (GPS and gyro) are delivered, which are especially necessary for photogrammetric evaluation.

6.1 DATA FORMAT

The data products are delivered in HDF-format developed by NCSA (National Center for Supercomputing Application at the University of Illinois). HDF is a multi-object file format that facilitates the transfer of various types of data between machines and operating systems. HDF allows self-definitions of data content and easy extensibility for future enhancements or compatibility with other standard formats. HDF includes Fortran and C calling interfaces and utilities to prepare raw images of data files for use with other NCSA software. The HDF library contains interfaces for storing and retrieving compressed or uncompressed raster images with tables; an interface for storing and retrieving n-dimensional scientific data sets together with information about the data, such as labels, units, formats, and scales for all dimensions (see ftp.ncsa.uiuc.edu, http://www.ncsa.uiuc.edu/SDG/Software/HDF/ for more information).

The structure of the HDF - files is as follows: HDF-header, Data description, 8 bit raster image.

6.2 BROWSE ACCESS VIA ISIS

Information about MOMS-2P data is also accessible via ISIS (Intelligent Satellite data Information System) which is operated at the DFD, as central user interface of its Data and Information Management System (DIMS). ISIS assists users to solve typical questions concerning data availability and provides the capability for transmitting browse data to the user. These are down scaled and jpeg-compressed versions of the full size images.

For detailed information about ISIS please contact the DFD use the ISIS homepage on World Wide Web with URL:http://www.dfd.dlr.de/ISIS/ or see [6].

More information about the sensor MOMS-2P is available via World Wide Web with the following URL: http://www.nz.dlr.de/moms2p (see figure 11). There one can find image examples, more detailed information about the status, the sensor, the projects and the data products.

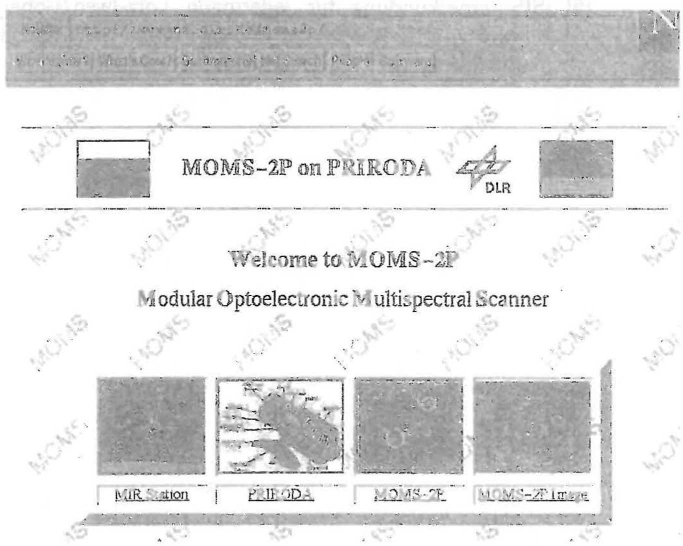

Figure 11: MOMS-2P Homepage

6.3 ORDER ADDRESS

Orders and inquiries should be sent to:

Deutsches Zentrum für Luft- und Raumfahrt (DLR)
DFD Help Desk
Oberpfaffenhofen
PF 1116
D-82230 Wessling Germany

For further questions please contact:
Dr. Ohle DFD phone: +49-3981-480-105 fax:+49-3981-480-299 or
DFD Help Desk phone: +49-8153-28-2802 fax:+49-8153-28-1343

7 ACKNOWLEDGEMENT

We like to thank our Russian colleagues from NIC and ŽUP and the colleagues at DFD Neustrelitz as well as GSOC in Oberpfaffenhofen for the very good cooperation in the MOMS-2P project.

REFERENCES

[1] Proceedings of the MOMS-02 Symposium, Earsel, DARA, DLR, 5.-7. July 1995, ISBN 2-908886-17-4

[2] MOMS on PRIRODA, Data User Handbook, German Aerospace Center (DLR), 1997

[3] MOMSNAV-Location of the Russian Space Station MIR with differential GPS Proceedings of the 2nd ESA International Conference on GNC held at ESTEC, Noordwijk, 12.-15. April 1994 (ESA WPP-071, April 1994)

[4] M. Schroeder, P. Reinartz, R. Müller: "Radiometric Calibration of the MOMS-2P Camera" this proceedings

[5] M. Lehner, W. Kornus: "Band to Band Registration of the MOMS-2P Camera" Workshop 'Sensors and Mapping from Space', Hannover, Germany, Sept. 29-Oct,1997

[6] ISIS-Fernerkundung für jedermann Lotz-Iwen/Göbel/ Markwitz, H. Wichmann Verlag 1995 ISBN-Nr. 3-87907-286-8