THE GERMAN MOMS CONCEPT FOR GEOSCIENTIFIC APPLICATIONS AND FUTURE DEVELOPMENT

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ABSTRACT

The development of the **M**odular **O**ptoelectronic **M**ultispectral Stereo Scanner MOMS started with MOMS-01 in 1979. A further experiment MOMS-02/D2 was flown 1993 on the Space Shuttle mission STS-55. The development will be continued this year with the start of the MOMS-2P sensor on the Russian Space Station Mir/Priroda.
The MOMS-02 sensor was successfully launched on board of the Second German Spacelab Mission D2 on Space Shuttle flight STS-55 from April 26 to May 6 1993. The MOMS-02 system itself is a combination of two modules, a panchromatic, high-resolution stereo module with one nadir-looking (resolution 4.2 m x 4.2 m) and two tilted channels as well as 4-channel multispectral module covering the visible (VIS) and near infrared (NIR) range of the electromagnetic spectrum at 12.8 m x 12.8 m ground resolution. The width and centre wavelength of the multispectral spectral bands are optimised for the detection of the spectral response of vegetation and for the discrimination of Fe-bearing rock and soil surfaces due to significant absorptions in the VIS/NIR spectral range. This paper gives an assessment of the MOMS-02/D2- and intended MOMS-2P mission, the data quality and an overview on the methodological approaches and application orientated investigations for various geoscientific significant areas.
After the successful experimental mission on Spacelab D2, MOMS-02 will be deployed in 1996 on the Russian space platform MIR incorporated in the environmental PRIRODA module. This promising mission, offers the opportunity of multisensor data registration covering the Earth within the latitudes +/- 51.6° with a repetition rate of 2 to 7 days. It is considered as an indispensable step to achieve high spatial, spectral and temporal resolution environmental monitoring at a continental to global scale with free flyer satellite missions planned for the late 90th.

1. INTRODUCTION

MOMS-02 is the technological continuation of MOMS-01, which was the first instrument in space using the "push broom scan" principle. It was successfully flown aboard the Space Shuttle missions STS-7 and STS-11/41-B in 1983 and 1984 (Bodechtel et al., 1985) mounted on the Shuttle **PA**llet Satellite SPAS and built by MBB, Munich. MOMS-02, built by DASA, Munich, was launched aboard the Second German Spacelab Mission D2 on Space Shuttle flight STS-55 and aquired data between April 26 and May 6 1993.

In comparison with other optical sensors of Earth Observation Satellites the advantages of MOMS are a better spatial resolution, better band positioning, reduced bandwidth and inflight stereo possibilities. The comparison is given in Fig. 1.

The photogrammetric and geoscientific goals of the MOMS-02/D2 mission were focused on the combination of topographic and spectral information, which are derived from the simultaneously acquired multispectral, multiresolution and stereoscopic data (Ackermann et al. 1989; Bodechtel et al. 1990). To meet these goals, 3 panchromatic bands for inflight stereo capabilities and 4 spectral bands were defined in the visible (VIS) and near infrared (NIR) range of the electromagnetic spectrum. Width and centre wavelength of these bands are optimised for the detection of the spectral response of vegetation and for the discrimination of Fe-bearing rock and soil surfaces due to significant absorptions in the VIS/NIR spectral range (Kaufmann et al., 1989). With the same system parameters MOMS-2P will cover large areas world-wide during the PRIRODA mission on the Russian MIR station from 1996 to 1998.

2. TECHNICAL PARAMETERS FOR MOMS-02 AND MOMS-2P

MOMS-01 was based on a dual lens principle to cover a swath of 140 km with 4 CCD arrays (each with 1728 photosensitive elements) and had 2 spectral bands in the red and near infrared. The experiences gained during the missions 1983/84 and components of the hardware served for the development of

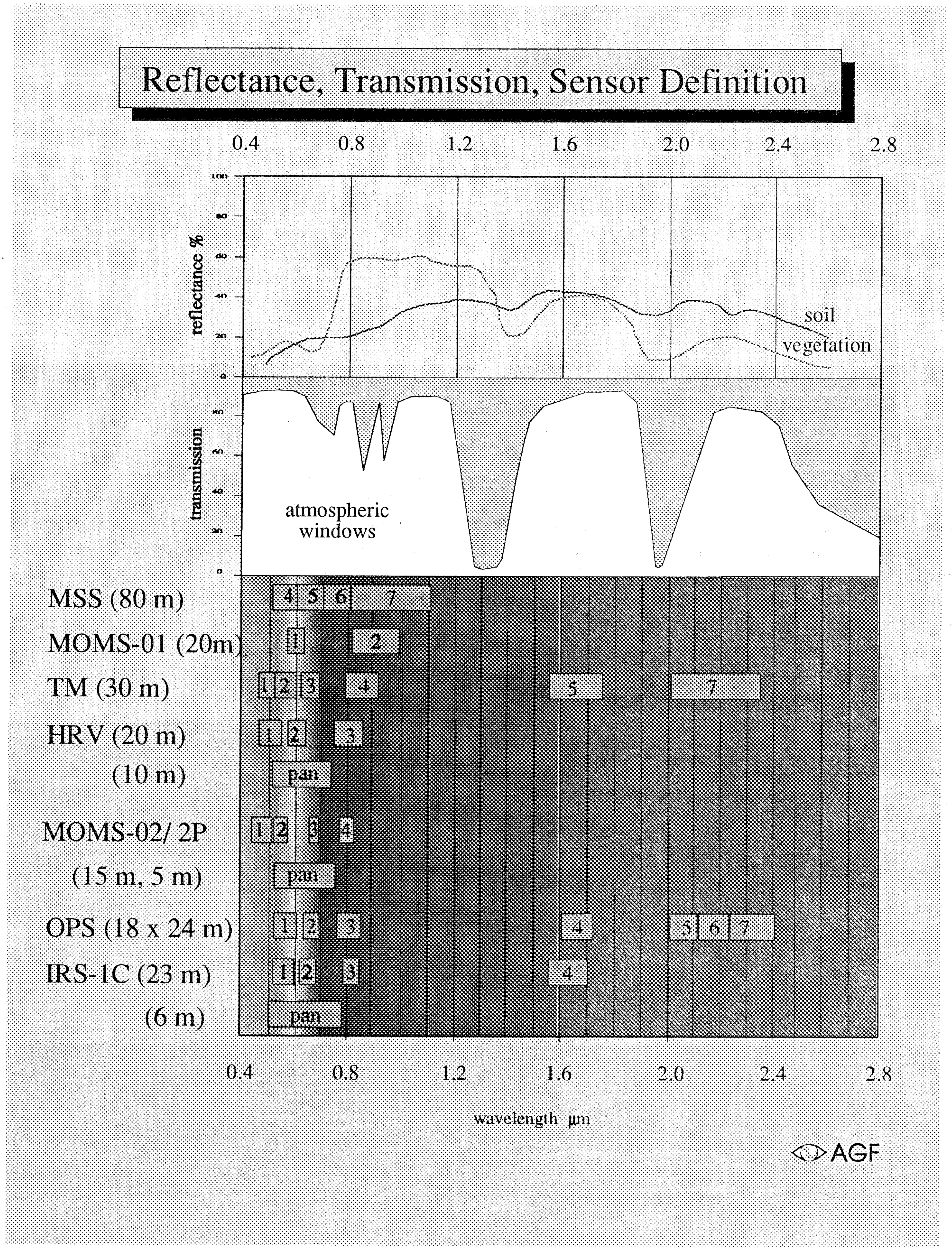

Fig. 1: Comparison of different Earth Observation Satellite Sensors

MOMS-02. The technical features of the MOMS-02 camera are oriented toward the requirements of today's photogrammetric and thematic applications. Characteristic features of the sensor design include:

- three-line stereo imagery
- along-track stereo imagery
- high resolution imagery
- multispectral imaging
- combination of stereo - and multispectral imaging

Figure 2 shows the MOMS-2P imaging geometry and the resulting ground track. The swath width for the high resolution channel is between 44 and 50 km, depending on the recording mode, and between 90 and 105 km for the other channels, depending on a nominal orbit altitude between 390 and 420 km. Because of the viewing angle of 21.4° of the two off-nadir stereo channels, the image swath on the earth's surface for these channels is separated from the swath of the nadir channels by about 130 km.

Figure 3 gives a schematic representation of the MOMS-02/2P optical concept. In order to fulfil the different user requirements a modular concept was selected. The system consists of five lenses, three were designed for stereoscopic applications, whereas the other two enable the acquisition of multispectral data sets. The central lens, with a focal length of 660 mm, forms the core of the camera system. This camera acquires the high resolution imagery with a ground pixel size of 5 m x 5 m. In combination with the central high resolution lens, there are two other stereo lenses, each with a focal length of 237.2 mm. Because of their tilt angle of +21.4° and -21.4°, respectively, relative to the direction of flight, threefold stereoscopic imagery is enabled. The focal length of these lenses was selected in a way to obtain a 1:3 ratio for the ground pixel size of the high resolution and the tilted stereo channels. In addition, two other lenses, each with a focal length of 220 mm, enable the multispectral imaging of a total of four channels.

MOMS-2P was designed for spectral data acquisition in the VIS and NIR range (four channels) and for along-track stereo recording using a panchromatic channel for one nadir and two off-nadir looking modules. A ground pixel size of 15 m x 15 m for the spectral channels was a sound compromise between a high spectral resolution and a sufficient signal-to-noise ratio. In addition, the IFOV of the spectral bands and the tilted modules is an integer multiple of that of the panchromatic nadir module, which significantly simplifies the merging of simultaneously recorded data. Figure 4 shows the position and width of the spectral bands of MOMS-02/2P.

The stereo module of MOMS-02/2P allows to reconstruct high quality 3D products. The most important property of the sensor is the along-track stereo capability (Bodechtel et al. 1984). An automatic procedure for generating Digital Terrain Models (DTM) from three line stereo was developed (Ackermann et al., 1989). To achieve DTM's with high accuracy the camera had to combine the along-track imaging with the three line principle. Significant is further the combination of high resolution nadir imaging with lower resolution tilted imaging (5 m versus 15 m). The accuracy of automatic derived DTM's is better than 5m absolute. For stereo mapping from satellite the MOMS stereo module provides unique possibilities.

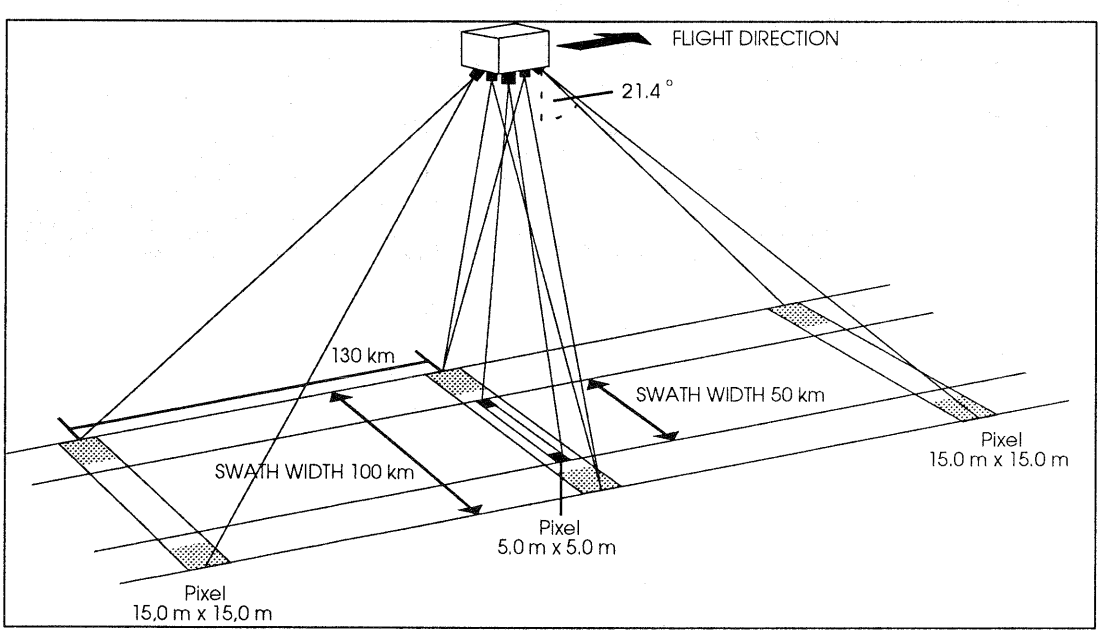

Fig. 2: MOMS-2P imaging geometry

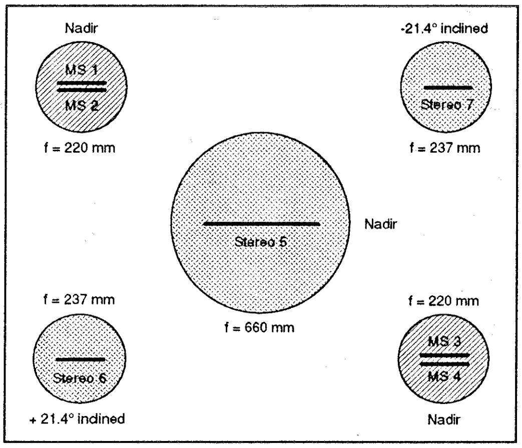

Fig. 3: MOMS-02/2P optical concept

Merging of panchromatic high resolution (5 m) with multispectral (15 m) proved to gain optimal result for thematic evaluation and allowed to resolve spectral signatures in the mix-pixel domain of the lower resolving multispectral pixels for targets with small scaled surface pattern.

From a technical point of view MOMS-02/2P is today the most advanced sensor in optical remote sensing due to the combination of high resolution stereo and multispectral data. The definition of the four spectral bands of MOMS-02/2P allows more seperability, especially for vegetation in comparison with other satellite sensors. The high redundancy between the green and red bands, as it occurs with TM, SPOT HRV and IRS 1C could be avoided. On the other side the Indian Remote Sensing satellite IRS 1C, which was launched in December 1995, meets very good performances concerning the resolution (Fig. 1).

The definition of the width and location of the spectral bands of the MOMS camera is based on spectral signatures of relevant objects, mainly vegetation and Fe-bearing rocks and soils. The definition of the panchromatic band was based on the differences of apparent albedo of soils versus vegetation due to the steep increase of reflectance at the "red edge" of vegetation.

In the following the spectral characteristics of the multispectral and panchromatic bands are summerized (see Figure 4). Band 1 covers the blue absorption of vegetation and allows good penetration in water bodies. Additionally it includes the right wing of the charge transfer band for Fe-bearing rocks and soils. Band 2 is centred on the "green peak" of vegetation. This position allows to avoid the high correlation between the green and the red bands. Band 3, only 32 nm wide, lies exactly in the principal absorption of chlorophyll-a in the red wavelength region. This enables the acquisition of precise reflectance values at the "red edge", an important indicator for the detection of vegetation stress. Band 4 was defined on the infrared plateau of vegetation between two significant water absorption bands. This position guarantees exact reflectance values for the maximum infrared reflectance of vegetation. This band is also centred for the charge transfer absorption of iron.

The panchromatic high resolution and stereo bands (Fig 4) are defined to get most contrast between albedo of vegetation and of non vegetated targets (rocks, soils and sealed areas). The short-wave end of the panchromatic band is placed to avoid most of the noise and lowpass characteristics introduced by atmospheric scattering, but also allows some penetration of water bodies. The long wave edge was determined to enclose the steep raise of vegetation reflectance at the "red edge".

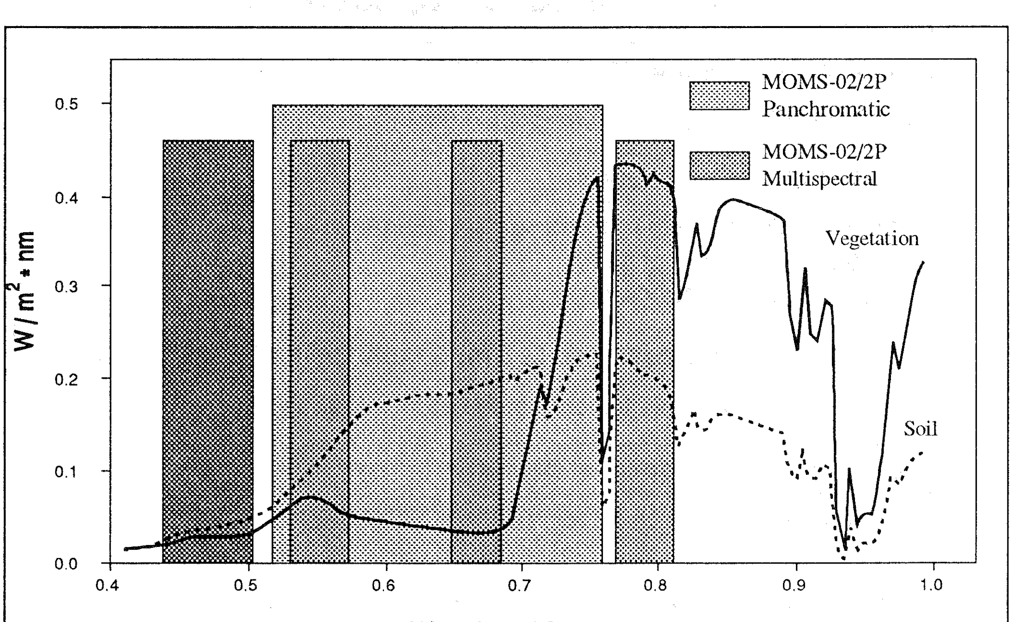

Fig. 4: Position and Width of the MOMS-02/2P spectral and panchromatic bands

Comparison of historical, actual and future MOMS spezifications

	MOMS-01	MOMS-02	MOMS-2P
Multispectral bands (MS)	575 - 625 nm 825 - 975 nm	440 - 505 nm 530 - 575 nm 645 - 680 nm 770 - 810 nm	440 - 505 nm 530 - 575 nm 650 - 685 nm 770 - 810 nm
Panchromatic bands (HR + ST)		520 - 760 nm, nadir(HR), 21° tilted(ST)	520 - 760 nm nadir(HR), 21° tilted(ST)
Spatial resolution	20 m	12.8 m	15.9 - 18 m
Spatial resolution (HR)		4.2 m	5.3 - 6.0 m
Swath width	140 km	78 or 37 km (HR)	90 - 105 km, 44 - 50 km (HR)
Radiometric resolution	7 bit	8 bit (select. from 12)	8 bit
Orbit inclination	28.5°	28.5	51.6 °
Orbit altitude	300 km	296 km	390 - 420 km
Launch	June 83, Febr. 84	April 93	May 1996
Mission Duration	7 days	10 days	1.5 - 2 years

Tab. 1: Development from MOMS-01 to MOMS-2P

Highlights of MOMS-2P for Thematic Applications

A - Stereo in High Spatial Resolution

derivation of high quality digital terrain models (5 m)

B - 4 Multispectral Bands

enhanced detection of relevant surface parameters
- optimized position of bands
- narrow spectral bandwidths

C - High Spatial Resolution (5.3 m) & Multispectral Bands (15.9 m)

detection of smallscale textures of the earth surface (e.g. landuse, urban)

D - Stereo & Multispectral Bands

topographic information for an enhanced evaluation of remote sensing data

Tab. 2: Highlights of MOMS-2P in the 4 operation modes A-B-C-D

ALL CHANNELS WITH 6000 ELEMENTS/DETECTOR ARRAY		
RADIOMETRIC RESOLUTION		8 bit selectable from 12
on-board data compression		8 to 6 bit (only for full stereo)
7 DIFFERENT OPERATION MODES MOMS-02		
stereo/spectral channel combinations:		
mode 1	channel 5,6,7	(HR + ST, all stereo)
mode 2	channel 1 - 4	(MS, all multispectral)
mode 3	channel 3,4,6,7	(2 MS / 2 ST)
mode 4	channel 1,3,4,6	(3 MS / 1 ST)
mode 5	channel 1,3,4,7	(3 MS / 1 ST)
mode 6	channel 2,3,4,5	(3 MS / HR)
mode 7	channel 1,3,4,5	(3 MS / HR)
4 DIFFERENT OPERATION MODES MOMS-2P		
stereo/spectral channel combinations:		
mode A	channel 5,6,7	(HR + ST, all stereo)
mode B	channel 1 - 4	(MS, all multispectral)
mode C	channel 3,4,6,7	(2 MS / 2 ST)
mode D	channel 2,3,4,5	(3 MS / HR)
RECORDING MOMS-02		DDR-100 HDT recorder max. storage cap. 5.5 h max. data rate 100 Mbit/s coverage ca. 10 Mio.km^2
RECORDING MOMS-2P		HDT video recorder max. storage cap. 1 h max. data rate 100 Mbit/s max. dumping rate 64 Mbit/s
MOMS-02		
SPACE PLATFORM		German Spacelab D2 Mission
MISSION DURATION		April 26 to May 6 1993
ORBIT INCLINATION		± 28.5°
ORBIT MEAN ALTITUDE		296 km
MOMS-2P		
SPACE PLATFORM		Russian Space Station Mir Priroda-Module
MISSION DURATION		1,5 - 2 years, launch May 1996
ORBIT INCLINATION		± 51.6°
ORBIT MEAN ALTITUDE		390 - 420 km
RECEIVING STATIONS		Neustrelitz Obninsk, Moscow

Tab. 3: Performance and operation modes of the MOMS-02/2P system.

3. The MOMS sensor development line

MOMS-01 was a technical experiment to test CCD technology and to gain better results with more precise defined band position and width. Two bands were flown, red and near infrared 50 and 150 nm wide and the resolution achieved was 20 m, at that time superior to all other sensors. Due to a principle of double optics a swath of 140 km could be achieved. The radiometric resolution of 7 bit proved to be to low to get SNR clean data.

MOMS-02 was a complete new instrument which combined narrow band multispectral with inflight stereo. It proved to be the instrument type for operational monitoring and assessment for the next decade.

MOMS-2P will be the operational version of MOMS-02. This instrument is able to provide automatic topographic maps in a scale of 1:50000. Thematic evaluations are possible up to a scale of 1:25000. Due to the mission duration of 2 years monitoring of dynamic phenomena is also granted.

The comparison and historical development of the MOMS camera is summerized in Table 1 and Table 3. Table 2 highlights the 4 operation modes of MOMS-2P.

4. Thematic Objectives

The MOMS data allows the improved interpretation and verification of natural phenomena and man made changes. The main investigations are focused on the fields of land-cover, geomorphology, geology, ecology and urban planning. The 4 narrow multispectral bands in combination with the high spatial resolution enable an enhanced detection of relevant surface parameters, e.g. small scale textures of the earth's surface. Stereo data sets in high spatial resolution allow the derivation of high quality digital terrain models with an accuracy of up to 3 meters. The combination of simultaneously acquired stereo and multispectral data sets provide topographic and thematic information for environmental assessment and monitoring.

The major test areas of the thematic-geoscientific group of investigators and their principal research topics are:

- Egypt, Eastern Desert and Saudi Arabia: rock and soil spectral signatures, lithologic mapping, mineral exploration
- Ethiopia: vegetation spectral signatures, vegetation changes, land-use, pedology
- Zimbabwe: vegetation mapping, regional planning
- Australia: stratigraphic and tectonic mapping, mineral exploration
- China: land use, natural risk assessment, mineral prospecting
- Mexico: coastal environment, natural risks, lan use mapping, DTM, morphology
- Chile: neotectonic, petrographic differentiation, mineral exploration

The availability of simultaneously acquired stereoscopic and multispectral information requires new ways of image processing and data extraction. The data extraction through optimised image enhancement and classification plus the quantitatively determinable third dimension enables the derivation of a variety of new data layers from one single system. These layers will be compiled in a Geo-Information-System with intelligent concepts for the combination of the extracted information.

The stereo capabilities combined with multispectral data will considerably improve the detectability of surface phenomena. The comparison of images taken under different observation angles allows to investigate the directional effects of surface texture on the spectral response. Simultaneously acquired multiresolution data will provide unique possibilities to study surface textures and mixed pixels for understanding the physical and geometric properties of the scanned objects. For vegetation studies and landuse purposes an improvement of classification accuracy is expected, especially in natural forest areas, biotop detection and monitoring regions with agroforestry as well as in urban zones.

In addition MOMS 02/2P narrow band multispectral data leads to an improved differentiation of spectral signatures of minerals, rocks, soils and vegetation. MOMS 02/2P modes combining multispectral bands with off-nadir stereo channels, provide specific object dependent signal differences, which might be used to improve the differentiation of various vegetation communities.
Furthermore, the suitability of MOMS-02 for atmospheric research (scattering, thickness of layers), hydrologic-ecological and coastal studies (transparency, water depth, suspended matter), the detection and classification of instable slopes (areas endangered by land-slides), the mapping of watersheds and drainage area in karst regions, and the modelling of water flow has been investigated and will be pushed forward with the acquisition of MOMS-2P data.

5. Examples and some results of MOMS-02 data

Figure 5a and 5b show a multispectral and high resolution MOMS-02 image from an area east of Antofogasta, Chile, which was acquired in Mode 5. The data take consists of 3 multispectral bands (see Table 3). These bands were used for a false colour composite: 4 (infrared range), 3 (red range), 1 (blue range), superimposed by the pan-chromatic high resolution band (12.8 and 4.2 m).

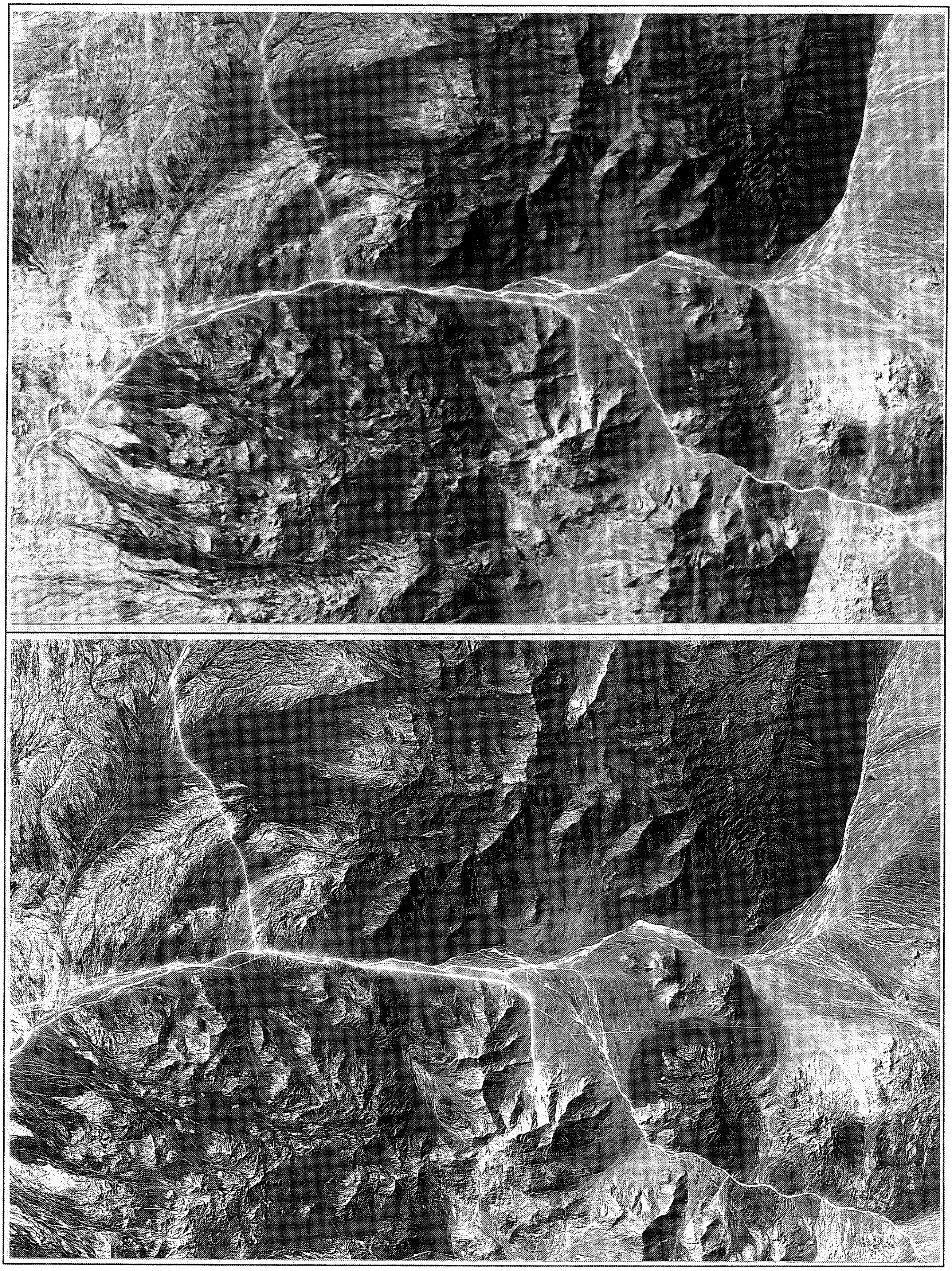

Fig. 5a and 5b: Subscene of a MOMS-02 data set of an area east of Antofagasta, Chile. B & W Image of MOMS-02 band 4. Spatial resolution is 12.8 meters for the multispectral- (5a) and 4.2 meters for the panchromatic high resolution image (5b).

Fig. 6: MOMS-02 subscene, High resolution panchromatic band (4.2 m), south-eastern part of the Salar de Atacama area.

The two images (5a) multispectral and (5b) high resolution demonstrate the potential of the MOMS-02 narrow multispectral bands (in this example the infrared band 4) and the high resolution panchromatic band to detect even minor changes in morpho-logy, geology and geochemistry (e.g., Fe^{2+}/ Fe^{3+} contents) and the capability of merging multispectral resolution with high spatial resolution to enhance small scaled pattern and to resolve sub pixel multispectral features. The area is characterized by granitic and andesitic rocks intercalated with mesozoic/tertiary sediment. Hydrothermal alterations in 2 of the 6 mining zones are distinct visible. The gypsum rich dump material is shown in bright grey values. The high resolution subimage (5b) shows detailed morphologic features, streets, railways and mesoscale tectonic pattern in the Cordillera Central. Small textured erosional pattern are more distinct recognizeable in comparison with the spectral image (5a). The composition of alluvial deposits, joints and fractures and shades of grey of the vulcanic, intrusive and sedimentary rocks allows very detailed differentiation.

Figure 6 shows an area located in the northern Chile east of Antofagasta including parts of the Salar de Atacama, unveiling manifold geological features. The geologic setting is characterised by sediments with grey values ranging from light grey to dark, which were intensively fractured as a part of the central Andine depression (Puna de Atacama). The southern shore of the Salar de Atacama with dry fallen salt flats lies in the left upper corner. The area is rich of granitic and dioritic intrusions in light grey values belonging to the West Pacific Subduction Zone. Represented in dark grey values are basic and andesitic vulcanic cones and lava streams in the lower half of the image. Different iron content and typical mophological features characterize ignimbrite flows. The high spatial resolution of this image enables mapping of thin layers of sediments as well as detection of small-scale tectonic structures and the detailed morphologic shape of the vulcanic rocks. Neotectonic traces of recent faulting and thrust faults, composition of alluvial deposits (mainly volcanic ashes) and shades of grey and white in the partly dry fallen salt lake of the

Salar de Atacama were evident shrinkage cracks are differentiated.

6. Conclusions and Preview of the Future MOMS Programme

The technical design of the MOMS instrument is based on up to date sensor, optic and electronic technologies resulting in narrow spectral bands at reasonable SNR values. The position of the multispectral bands were determined with respect to the optimisation of vegetation and pedological/geological feature extraction. Results from simulated data and first assessments of transmitted raw data lead to the conclusion that considerable improvements can be expected through improved spatial and spectral resolution combined with stereo capabilities as compared to existing operational sensors.

The along-track stereo acquisition capability of the MOMS sensor allows the evaluation of DEM's from data registered under the same irradiation conditions. This will be useful not only for photogrammetric purposes, but also for the interpretation of spectral response in regions with orographically developed topography.

After the successful experimental mission on Spacelab D2, the MOMS camera will be deployed in May 1996 on the Russian space platform MIR incorporated in the environmental earth observation module PRIRODA. This promising mission, offers the opportunity of multisensor data registration covering the Earth within the latitudes ± 51.6° with a repetition rate of 2 to 7 days. Free flyer satellite missions, which are planned for the late 90th, are considered as an essential step to accomplish data with a high spatial, spectral and temporal resolution for an environmental monitoring at local to global scale.

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