OPTOELECTRONIC IMAGING SPECTROMETERS: GERMAN CONCEPTS FOR REMOTE SENSING

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Abstract:

Two different concepts for imaging spectrometers were developed independently from each other in the former West and East Germany. These concepts and the respective mission goals are presented. The ROSIS (Reflective Optics System Imaging Spectrometer) project is a joint undertaking of the German Aerospace Research Establishment (DLR), the Research Centre Geesthacht (GKSS) and MBB, a company belonging to the German Aerospace group. This instrument represents an advanced technological level of imaging spectrometry. The MOS (Modular Optoelectronical scanning Spectrometer) instrument was developed and built by the DLR Research Centre Berlin-Adlershof, Institute of Space Sensor Technologies (the former Institute for Space Research (IKF) Berlin).

KEY WORDS: CCD-Array, Imaging Spectrometry, Ocean Remote Sensing, Optical Sensors,

1. INTRODUCTION

Imaging Spectrometry gains importance as part of modern optical remote sensing systems. Investigations of global and regional ecological problems require more and more high spectral and spatial resolution of remote sensing data. Imaging spectrometers are capable of obtaining high spectral resolution images in the visible and infrared wavelength bands selectable out of a great number of spectral channels. The information content of imaging spectrometer spectral layers may be increased by being connected with high spatial resolution stereo data using Geo Information Systems (GIS) technologies. GIS, satellite imagery, and GPS are becoming essential tools for collecting, processing, storing, and using vast amounts of remote sensing data needed to monitor the complex environmental problems faced today. With environmental information digitally recorded, processed, and archived, researchers can conduct ongoing studies to help them fully understand the impact of man's and nature's actions on the environment (Lang, 1992). German concepts of imaging spectrometers, as described in this paper may be a contribution to this technological development.

2. EARTH OBSERVATION WITH IMAGING SPECTROMETERS

Future Earth observations to a large extent will be performed by imaging spectrometers or by sensors, which in their performance are closely related to them. Within the present programmes of NASA, ESA, NASDA they are sensors with large swath width and medium spatial resolution for global monitoring (MODIS, MERIS, GLI) on the one hand and with a comparatively low swath width and high spatial resolution (HIRIS, HRIS, COAST) on the other hand. At present, they are planned to be operated on Polar Platform Missions to be launched towards the end of this decade as part of the Earth Observation Systems (EOS).

Sensors to be used for global monitoring of the terrestrial and marine biosphere are listed in Fig. 1.

One of the fields of application of imaging spectrometry is the ocean colour monitoring.
Phytoplankton has the most important effect on the marine food chain and on the flow of matter forming all kind of organic substances. The distribution of phytoplankton is highly variable in time and space. Thus, a global and even a regional assessment of its productivity and its effect on biogeochemical cycles requires a synoptic observation which can only be carried out by remote sensing methods. Other substances in the ocean, particularly in shelf and coastal areas such as all kind of suspended particles and dissolved substances (Gelbstoff), are of similar interest and do require the same observation strategy (Doerffer, 1991).

Another field of imaging spectrometer applications should be the vegetation conditions determination. Global vegetation monitoring is required because the biosphere plays a fundamental role in the preservation of the terrestrial atmosphere composition. It has lowered the content in CO_2 of the primitive atmosphere and produces the oxygen we breathe and also, molecular nitrogen. On the other hand, human activities that have lasted for more than two centuries gradually modify the balance that has been reached in the geological times: since 1800, CO_2 content has thus increased by more than 25%, methane concentration has doubled, increasing thermal

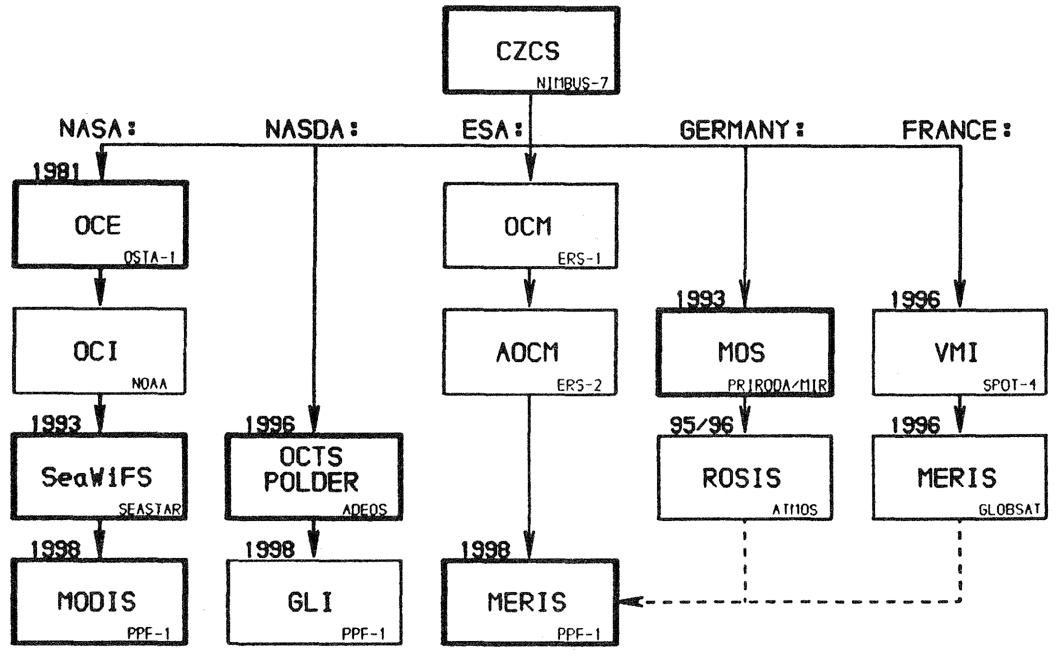


Figure 1. Sensors for global monitoring of the terrestrial and marine biosphere. (The sensors MOS, MERIS and ROSIS represent instrument concepts of imaging spectrometers, the sensors MODIS and GLI represent instrument concepts which in their performance are very close to those of imaging spectrometers.)

radiation of the atmosphere which is responsible for the "greenhouse effect" (Achard &al 1992). The spectral reflection characteristic of vegetation indicates environmental effects on the plants (minerals, herbicides, water stress etc.), well known is the blue shift effect in the red edge of the reflectance curve of the vegetation canopy. This investigations of vegetation conditions are very demanding in respect to high spectral resolution measurements at regional and local scales. They are important as for forestry and agriculture resource management as for environment protection.

The advantages of imaging spectrometers in comparison to conventional opto-mechanical multispectral scanners are
- the large number of spectral channels,
- the possibility of channel selection by command and
- the incorporation of narrow-band spectral channels for the analysis of spectral fine structures.

These features allow the same instrument to be applied to a variety of specific tasks of remote sensing, ranging from water colour monitoring through vegetation condition analysis to cloud observations. The high sensitivity of CCD detectors provides high spectral resolution and large dynamic range of imaging spectrometer data.

3. MOS INSTRUMENT

The Modular Optoelectronical scanning Spectrometer MOS was developed and manufactured by the Institute of Space Sensor Technologies of the DLR Research Centre Berlin-Adlershof (former Institute of Space Research of the Academy of Sciences of GDR). The scientific-technical team of the instrument has more than 15 years experience in the field of space spectrometry. Earlier instruments - MKS (Multi Channel Spectrometer) were flown at Intercosmos satellites IK-20 / IK-21 in 1979/81 and the MKS-M (modified for manned control) was used at the Russian Space Stations SALYUT-7 (1983-86) and MIR (since 1986).

3.1 The Concept of the Instrument

The MOS instrument consists of two different spectrometer modules, each with its own measuring parameters and mission goals:
MOS-B (Bio-Spectrometer) generates imaging data of medium spatial resolution (pixel size about 700 m) and high spectral resolution (spectral half width 10 nm) in the VIS/NIR wavelength band (400-1010 nm, 13 channels). The main goal of this measurements is the analysis of spectral signatures of waterbodies (mainly ocean surface) for determining of water colour and the derivation of ecological parameters (chlorophyll, bioproductivity, surface pollution, water types, sediment content etc.).

MOS-A (Atmosphere Spectrometer) has 4 very small channels (spectral half width 1.5 nm) for measuring the atmospheric scattering radiation in the O_2A-absorption band near 760 nm wavelength. On the base of this data will be realized a new method for correcting the atmospheric influence on remotely sensed multispectral data in the VIS/NIR wavelength spectrum. The method is already verified for correction of data measured over water surfaces using results of MKS experiments. It shall be extendet to land scenes (Zimmermann, 1992).

3.2 MOS Technical Layout

The optical spectrometer principle of both modules is shown in fig. 2a. The focal plane was special designed for spectral aberration correction, using simple refractive optics and special CCD-lines. The instrument will be equiped with devices for sun and internal calibration.

The MOS complex is designed for remote sensing of ocean, therefore great emphasis was layed on good spectral and radiometrical resolutions and accuracy on expense of spatial resolution. The technical parameters of MOS spectrometers are given in table 1.

3.3 Scientific Goals of the MOS Instrument and the Mission

The MOS users programme is part of the International Earth Observation Mission PRIRODA, a joint research programme of the former Intercosmos Association with international cooperation.

The PRIRODA programme includes:
-Launch of a new module of the MIR space station in the middle of 1993 equiped with a multi sensor system: *Microwave radiometer system, *IR radiometer, *Optical scanners, *Imaging spectrometer (MOS), *Syntetic Apertur Radar, *Altimeter, *LIDAR and other instruments. The configuration of this spacecraft is shown in fig. 3.

Parameter		MOS-A	MOS-B
spectral parameters			
spectral range	nm	755-768	400-1010
No. of channels	:	4	13
wave length	nm	756.7;760.6;763.5;766.4 (O_2-A-band)	408;443;485;520;570;615;650;685;750; 870;1010; 815;945 (water vapor)
spectral half width	nm	1.4	10
polarization	%	< 2	< 6
FOV			
along track x	deg	0.343	0.094
across track y	deg	13.6	14.0
Scene geometry (H = 350 km)			
swath width	km	83	86
number of pixels	:	29	128
pixel size (x*y)	km*km	2.82*2.87	0.67*0.7
Measuring range			
L_{min} *)	$\mu Wcm^{-2}nm^{-1}sr^{-1}$	0.1	0.2
L_{max}	$\mu Wcm^{-2}nm^{-1}sr^{-1}$	40	65
$\Delta L/L$	%	0.3	1.0
quantization	bit	12	12
data rate	$Kbit\ s^{-1}$	4	210
calibration in orbit	:	Internal lamps (16 levels) and solar radiation	
detector		CCD L 172 C, 512 elements 23x480 μm^2	
*) at S/N = 100			

Table 1:
Technical parameterts of the MOS spectrometers

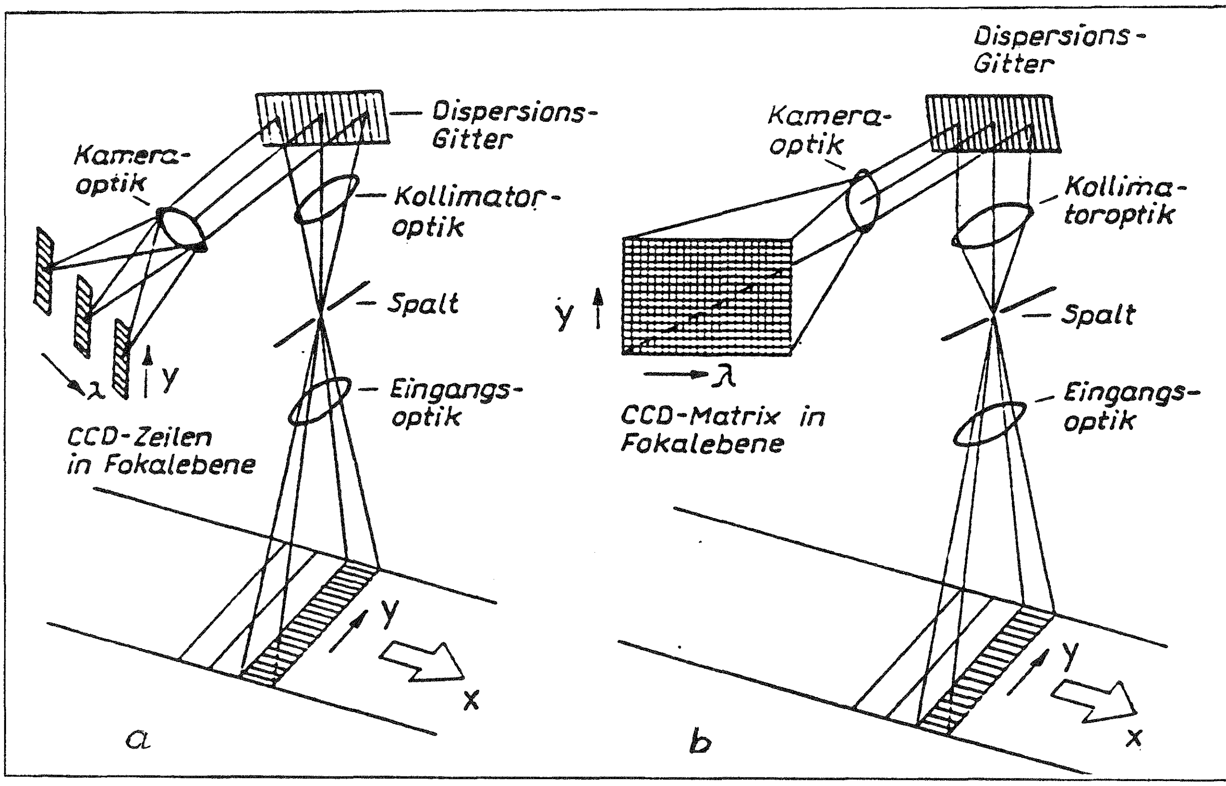


Fig. 2: The optical principle of imaging spectrometers (Zimmermann 1991)

(a) of the MOS instrument using CCD detector lines and simple refractive optics

(b) of the ROSIS instrument using CCD detector matrix and special designed reflective optics

-Scientific Programmes of the International Users Community including experiment proposals of institutes and organisations from *Bulgaria, *France, *Germany, *Italy *Poland, *Romania, *Russia (+CIS), *Swiss, *United States.

MOS data will be used for investigating the following problems:
-Ocean-atmosphere investigations.
*Determination of spectral characteristics of water (water colour, water types),
*derivation of ecological parameters of water bodies (chlorophyll, Gelbstoff, sediments),
*atmosphere aerosol profile measurements,
*atmosphere correction of MOS-B data.
-Ecological investigations (compared with data of other PRIRODA instruments).
*Investigation of ecologically strong endangered areas,
*analysis of conditions of large forest areas,
*landscape investigations in aride and semiaride regions.
-Methodological research, for example
*development of methods and algorithms of space spectrometry,
*development and test of multi sensor interpretation concepts,
*using of MOS data in comparison with SAR data.

4. ROSIS INSTRUMENT

4.1 General

The Reflective Optics System Imaging Spectrometer (ROSIS) project is a joint development of the German Aerospace Research Establishment DLR (Institute of Optoelectronics), the Research Centre Geesthacht GKSS (Institute of Physics)and the German Aerospace Group DASA (MBB).

The instrument represents an imaging spectrometer of high sensitivity and pixel co-registration. It consists of reflective optics system and CCD detector matrix focal plane array. An experimental airborne version of ROSIS is in operation onboard a DLR Falcon Jet (van der Piepen, 1989). Space borne versions are studied on behalf of the
- German Federal Ministry for Research and Technology (BMFT) for ESA's plans for modifying the EURECA platform,
- European Space Agency (ESA) for the POEM-1 MERIS sensor and
- German Space Agency (DARA) for the German ATMOS satellite project.
ROSIS performs quantitative measurements of the reflected radiation of the Earth surface and the atmosphere with respect to marine biochemical, terrestrial and atmospheric parameters, and with respect to interactions between the land/water

MIR-Station - Remote Sensing Complex "PRIRODA"

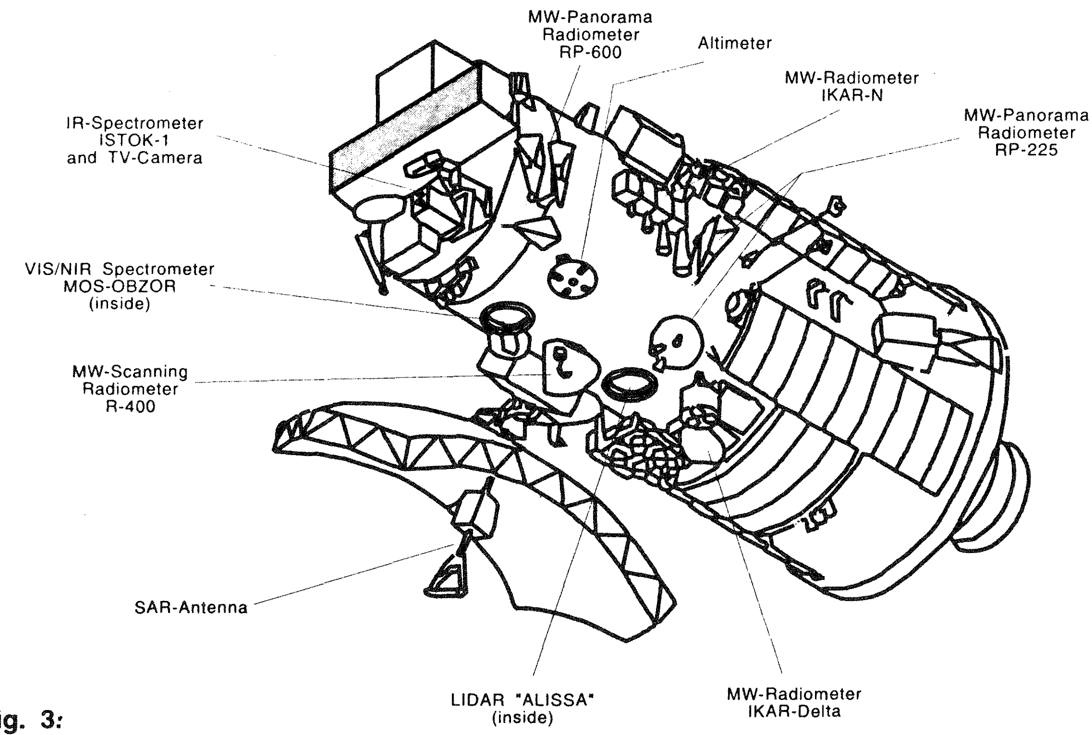


Fig. 3:

surface and the atmosphere. In particular, data are required especially for the following tasks:

- Marine biology and ecology
  *biomass and primary productivity,
  *detection of algae blooms,
  *Gelbstoff analysis.
- Coastal pollution
  *sediment distribution,
  *groups of pollutants,
  *optical properties of water.
- Ocean dynamics
  *upwellings,
  *eddies and currents
- Terrestrial biosphere
  *vegetation cover and conditions,
  *land use and crop prediction,
  *snow and ice analysis,
  *global spectral albedo.
- Atmosphere cloud/aerosol analysis
  *optical density,
  *aerosol type and content,
  *water vapour content,
  *smoke and vulcano plumes.

4.2 The airborne ROSIS concept

The measurement principle of ROSIS is shown in Fig. 2b.

The image on the ground (one line perpendicular to the flight direction) is depicted through a baffle via a tilt mirror. The purpose of this mirror is to shift the scan line either forward or backward for sunglint avoidance above water surfaces. Two telescope mirrors focus the scan line onto the entrance slit of the spectrometer. The entrance slit represents the actual scan line on the ground by cutting off the rest FOV. The focussed scan line is expanded and parallelized through a collimator system (two mirrors) for dispersion by means of a reflective grating. The collimating system (using again the same mirrors) subsequently focusses the beam via a small deflection mirror onto the CCD detector matrix. Trigger and readout electronics are arranged on top of the array so as to avoid long connections, to avoid degradation of the signal.

Optical performance data of the airborne ROSIS are listed in Table 2

Total FOV	±20 degree
IFOV	0.56 mrad
Distortion	≤ 2%
Grating constant	n=55
Spectral range	430-860 nm
Spectral sampling interval	5 nm

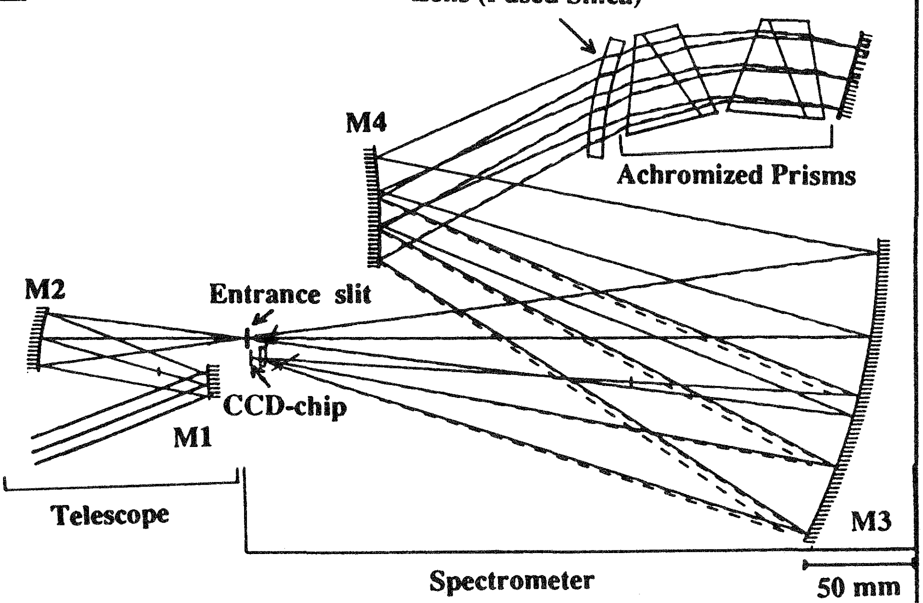
Table 2:
Airborne ROSIS optical performance data

4.3 The spaceborne ROSIS concept

A simplified scheme of the spaceborne ROSIS version is shown in Fig. 4.

The German ATMOS satellite was conceived as environmental monitoring platform to be launched well ahead of the polar platform missions presently scheduled by ESA, NASA, NASDA. ROSIS was part of the envisaged payload for remote sensing of the Earth surface and the atmosphere for better un-

Fig. 4



ATMOS - ROSIS Optical configuration, y / z - view

derstanding of environmental changes and its influence on the climate system. In addition, ROSIS should complement measurements of instruments for monitoring of atmospheric trace gases (MIPAS, AMAS, SCIAMACHY) and that of the radiation budget (CERES) installed on the same satellite. In order to achieve these goals the instrument was modified especially with regard to the spectral range and the total field of view for global monitoring. The requirements are very similar to those of the ESA MERIS sensor (see Tab. 3).

TFOV	±41 degree
IFOV	0.3 mrad
Pixel size (nadir)	250 m
Depointing (along track)	±20 degree
Spectral range	400-1050nm
Number of channels	52*
Record/transmitted chan.	18**
Spectral sampl. interval	1.9-5.0 nm
Radiometric resolution	12 bit

Tab. 3: ATMOS/ROSIS specifications

Remarks:
* selectable upon command at var. $\Delta\lambda$
**18 channels recorded on tape and transmitted in X-band, 7 channels transmitted in S-band

The development of the ATMOS/ROSIS instrument was interrupted after phase B2 because of budget constraints. However, a modified version of ROSIS on an advanced technological level will be investigated further.

4.4 Future Mission Concepts

The ROSIS concept as described offers various possibilities for modifications so as to meet increasing requirements in the future. These refer to
-an extension of the spectral range into the UV or the SWIR (ozone mapping, improved vegetation conditions analysis, soil and geological investigations) and
-an improvement of the geometric resolution (measurement of meso- and small scale features).

In view of the sensors which are planned to be operated on the polar platforms, the present spaceborne ROSIS concept should be modified into an instrument with spatial nadir resolution of 80 m and swath width of 160 km. The spectral range should be extended to 420-2400 nm. The requirements of spectral resolution and band selection are subject of ongoing investigations. Preliminary specifications of an ROSIS-02 instrument are listed in table 4.

FOV	±5.9 degree
Swath width	165 km
IFOV	0.1 mrad
Pixel size (nadir)	80 m
spectral range	420-2400 nm
Spectral sampl. interval	≤ 5 nm (VIS)
Spectral sampl. interval	≤10 nm(SWIR)
Radiometric resolution	12 bit

Table 4:
Preliminary specifications of ROSIS-02

Flight opportunities for this instrument **are** open at present. However, it would be advantageous to employ ROSIS-02 in combination with an instrument for digital stereoscopic mapping like the German MOMS-02 instrument which will be flown in the shuttle D2 mission next year. The connection of imaging spectrometry and high resolution digital stereo imagery seams to be of interest for "**Regional Ecological Land Survey.**"

5. CONCLUSIONS

Germany has a great scientific-technical potential for the development of optical sensors for remote sensing at an advanced technological level. It participates in Earth observation missions in cooperations with NASA and ESA (the former West Germany) as well as with the Russians (the former East Germany).

The MOS/PRIRODA mission is only an experimental scientific mission. The main goal is the verification of methods and algorithms of imaging spectrometry from space. The MOS/PRIRODA team is developing a new device, the High Resolution Environmental Spectrometer (HiRES).

ROSIS is a candidat for operational missions. The instrument concept permits a wide range of design variations depending on specific mission objectives. It allows multispectral measurements of high spectral resolution on global or on regional scales with high spectral and spatial resolutions, including multispectral measurements in the UV or SWIR wavelength range. ROSIS is a strong candidate for future environmental monitoring.

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