INTRODUCTION

Forest fires and other natural and anthropogenic catastrophes that involve high thermal emission, such as gas/oil pipeline failures, power plant accidents, and volcano eruptions, cause the yearly damage in the billion USD range to nature, industry, and human health.

Obviously, the timely detection and localization of such catastrophes could help control them or, at least, reduce the damage. For effective control, administration and emergency services, in the first place, should have adequate information on catastrophe precursors, catastrophe dynamics, and post-catastrophe developments. Depending on the type of emergency, this information may be required at very different spatial scales.

This problem can be solved only with up-to-date spaceborne remote sensing technologies. In particular, the satellite systems should include high-sensitivity infrared sensors, and visible and near infrared hyperspectrometers with high spatial and spectral definition. Hyperspectrometers provide essential added-value information for artifact discrimination, precursor detection, catastrophe after-effect assessment. Effective use of satellite information also requires appropriate ground facilities for information storage, preprocessing, and distribution. An important link in information flow is the decision-making support system based on state-of-the-art thematic processing algorithms.

The BIRD satellite can be considered a prototype and a seed of such a system. Information provided by the infrared sensor on board this satellite proved quite effective for monitoring the forest fires and volcano eruptions. However, to enhance its potential, it is desirable to add a new sensor – the hyperspectrometer “Astrogon- Light” by R&G ‘Reagent’. This instrument is based on the “Astrogon-Vulcan” prototype [1] and was tested in airborne experiments. The instrument complex is planned to use a high-performance, low-fault onboard computer developed jointly by Russian and German industry and based on industrial electronic elements [2], [3].

The proposals targeted to solving these problems were prepared for DLR as an international remote Earth monitoring mission project based on satellite clusters. They were also presented in September, 2003 in Rosaviakosmos, included in the Program “Spaceborne study of global and regional environmental processes on Earth using the infrared and hyperspectral sensors”, and approved for years 2004 – 2015 by the Space

Research Council of Russian Academy of Sciences, section “Earth study from space”.

This preprint presents the proposal for creating a joint Russian and German constellation of small satellites for monitoring the disastrous terrestrial events – natural and technogenous – with high energy emission, such as forest fires. The system is based on combining the infrared and hyperspectral monitoring technology.

Included are experimental results from the BIRD satellite and the airborne hyperspectrometer. They confirm the effectiveness of instrument combination proposed. The Appendix includes the Program “Spaceborne study of global and regional environmental processes on Earth using the infrared and hyperspectral sensors” approved for years 2004 – 2015 by the Space Research Council of Russian Academy of Sciences, section “Earth study from space”.

BIRD Mission Rationale

The areas engulfed in yearly forest fires are a considerable part of major ecological zones of the planet:

- 10^9 ha - savannah area
- 10^7 ha - tropical rain forest
- 10^6 ha - mediterranean vegetation
- 10^8 ha - boreal forests.

The fires produce a negative influence on:

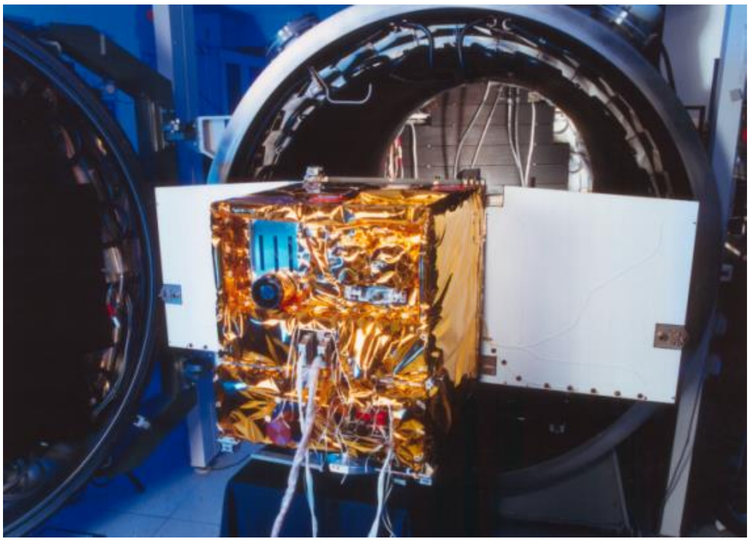
- atmosphere (greenhouse effect, ozone, aerosol, relation CO/CO_2),
- climate (global warming),
- global carbon cycle (closedness).

Up to now, there exists no dedicated fire observation system in orbit (except BIRD).

BIRD Mission Objectives
(BIRD = Bi-spectral Infra-Red Detection)

The BIRD project was awarded by DLR to several German organizations: Fraunhofer FIRST, Jenaoptronik, TUB, Astro and others. Its goals included:

- Test of a new generation of infrared sensors dedicated for fire investigation from space;
- Remote sensing of fires and of the land surface;
- Space demonstration of new micro-satellite technologies.



BIRD = Demonstrator for FIRE MONITORING CONSTELLATION

Mission Idea

The idea of the mission is to use the spaceborne remote sensing to obtain the detailed information on forest fires and other natural and technogenous catastrophes that have a high impact on environment, security, and quality of life.

As implementation of this mission, the Operational Fire Monitoring Constellation (FMC) project is proposed. It is based on integrating the IR technologies with wide viewing angle and the hyperspectral analysis of local areas for detection and localization of high-energy sources. This type of complex monitoring open the way to real-time processing of user request (from scientists, customers, etc.) and within a very short response time obtain the detailed information on the current state of observed processes.

Fire Monitoring Constellation – FMC

FMC Mission Objectives

Mission goals include:

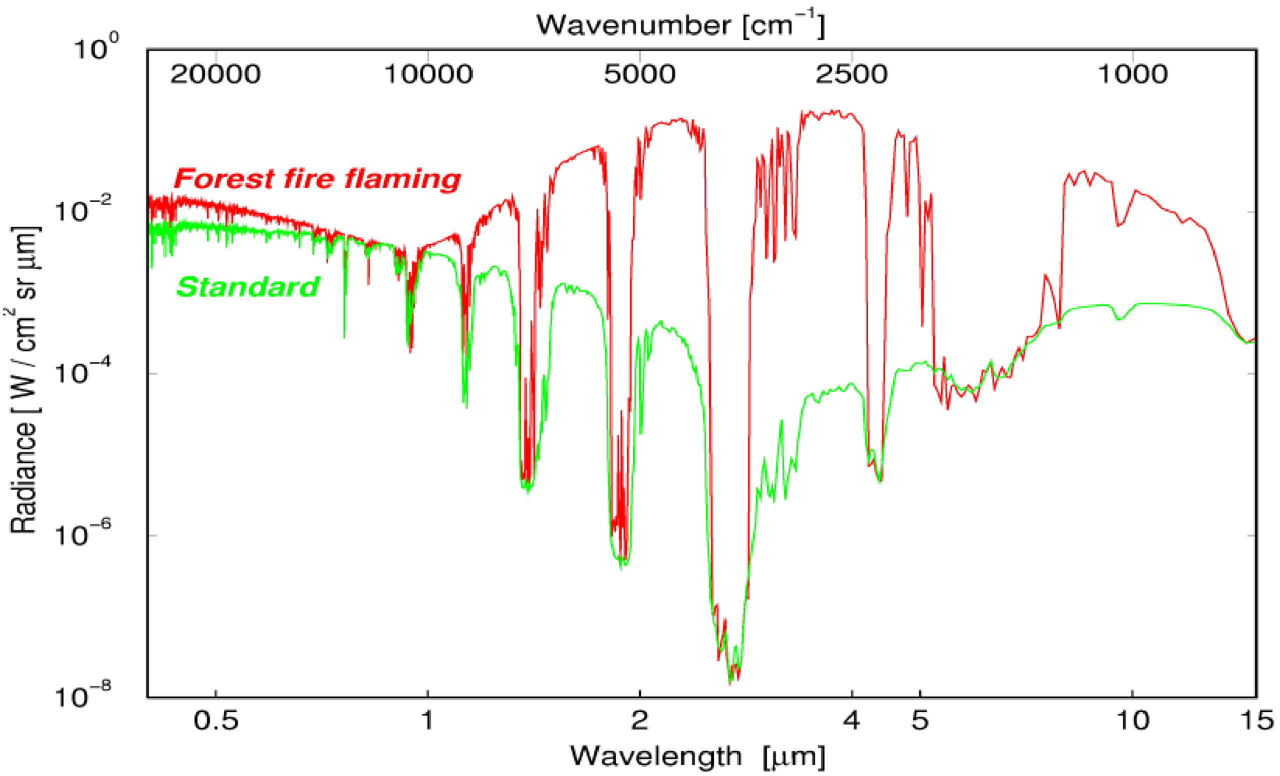
- Detection, monitoring and investigation of high-temperature phenomena („hot spots”), like forest fires, volcano activities, coal seam fires or other from space on commercial basis
- Monitoring of land, sea surface and atmosphere parameters and phenomena with a combination of infrared and hyper-spectral channels for scientific and operational purposes
- Fast delivery of high level data products to the end user as an operational service

FMC Mission Constraints

Development time	2 -3 years
Lifetime	4 years in orbit
Launch constraints	low-cost launch into LEO (as auxiliary payload)
Mission type	micro-satellite constellation mission with operational objectives
Cooperation	German and Russian institutes and companies
Ground base segment	Russian and DLR ground stations
Funding	DLR-German space agency and Russian Academy of Sciences, Rosaviacosmos, industrial enterprises, investors

The optimal infrared channel selection for forest fore monitoring is based on the comparison of forest fire flaming spectra and standard spectra of natural vegetation.

Signatures of Vegetation Fire and Background



This comparison leads to the following conclusions:

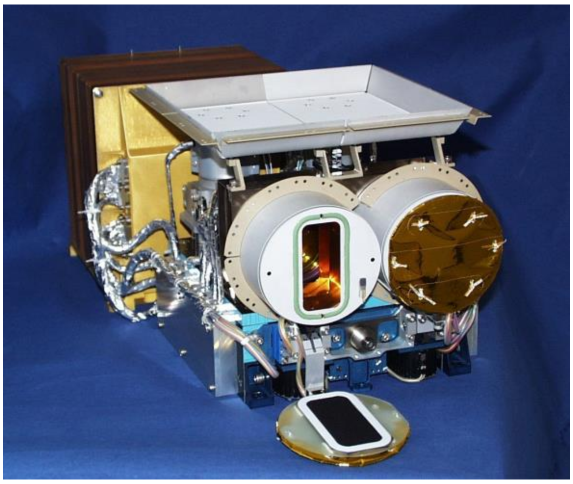
- spectra contain information on land surface, atmospheric gases and aerosols;

- the second atmospheric window (MIR) is the optimum for the „hot spot“ detection.

The key elements of FMC Instruments

The 2-channel-infra-red
sensor system (15kg, 90W)
2x 512pixel CdHgTe detectors
GSD: 185m

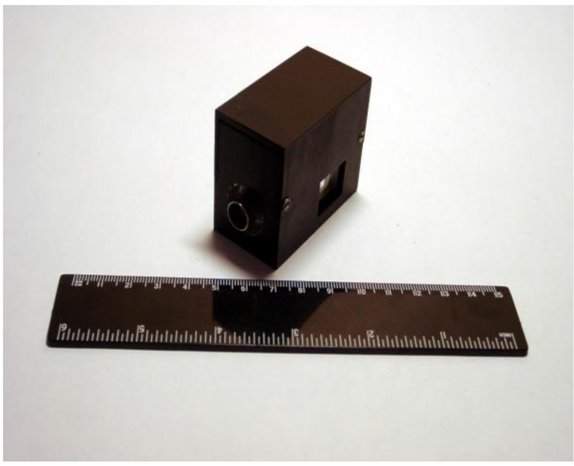
A VIS/NIR
pushbroom
Sensor

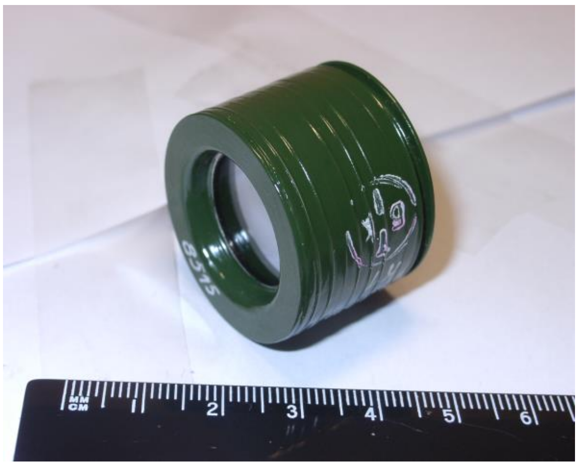


Hyperspectral Sensor instrument (20kg, 30W)
Key elements

Acusto Optical
tunable Filter

Micro Channel Plate –Detector
Sensor





The FMC Instruments

Payload platform of BIRD-type with assembling tools

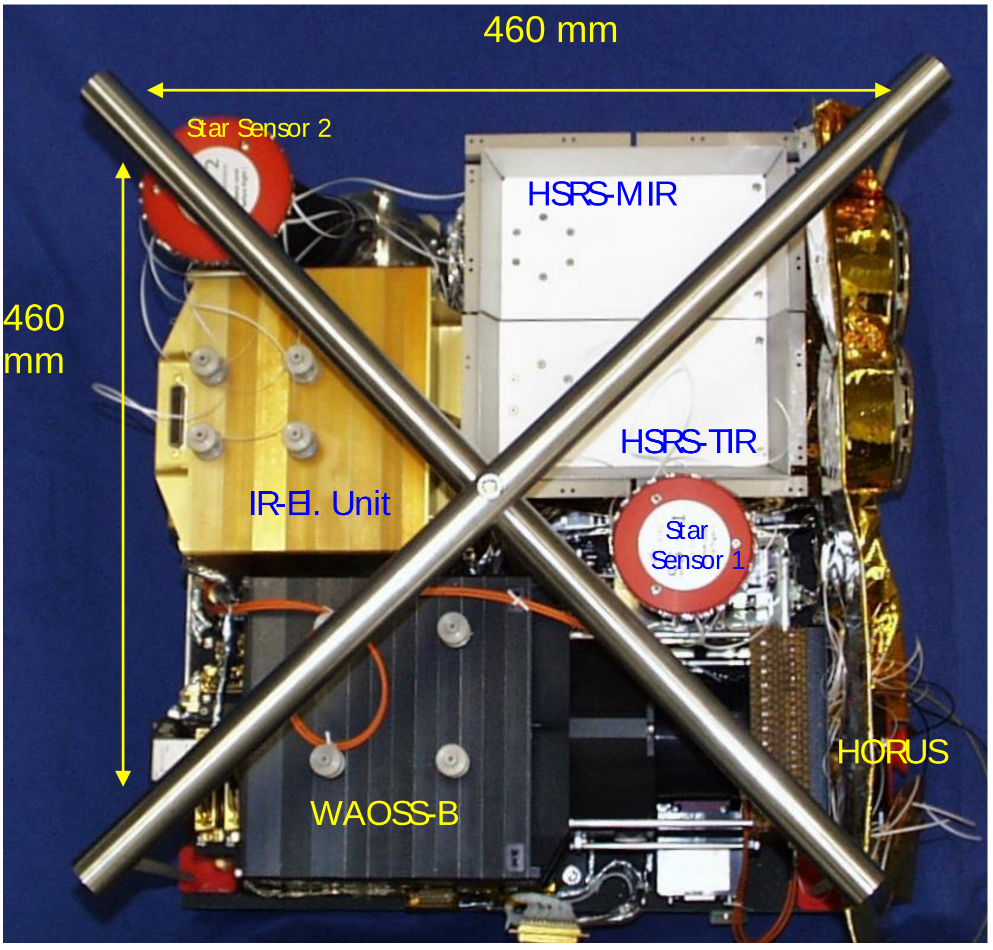
	VIS/NIR	MWIR	TIR	Hyperspectrometer
Wavelength	600-670nm 840-900nm	3.4-4.2µm	8.5-9.3µm	0.4-0.8µm
Focal length	21.65mm	46.39mm	46.39 mm	~700mm
Detector	CCD	CdHgTe	CdHgTe	MCP
Ground pixel size	185m	370m	370m	20m
Ground sampling distance	185m	185m	185m	20m
Swath width	533km	190km	190km	20x20km^2

at 572km orbit altitude

Payload platform of BIRD with assembling tools (without the hyperspectrometer)

FMC Payload Mass and Power Budget

system	mass	Power budget
IR-System	15kg	90W
VIS/NIR-Sensor	4kg	10W
Hyperspectrometer	20kg	30W
Star sensors, Magnetometer	3kg	5W
Structure	2kg	
Harness	1kg	
Total:	45kg	135W



BIRD payload – top view

Comparison FUEGO and FIRE MONITORING CONSTELLATION

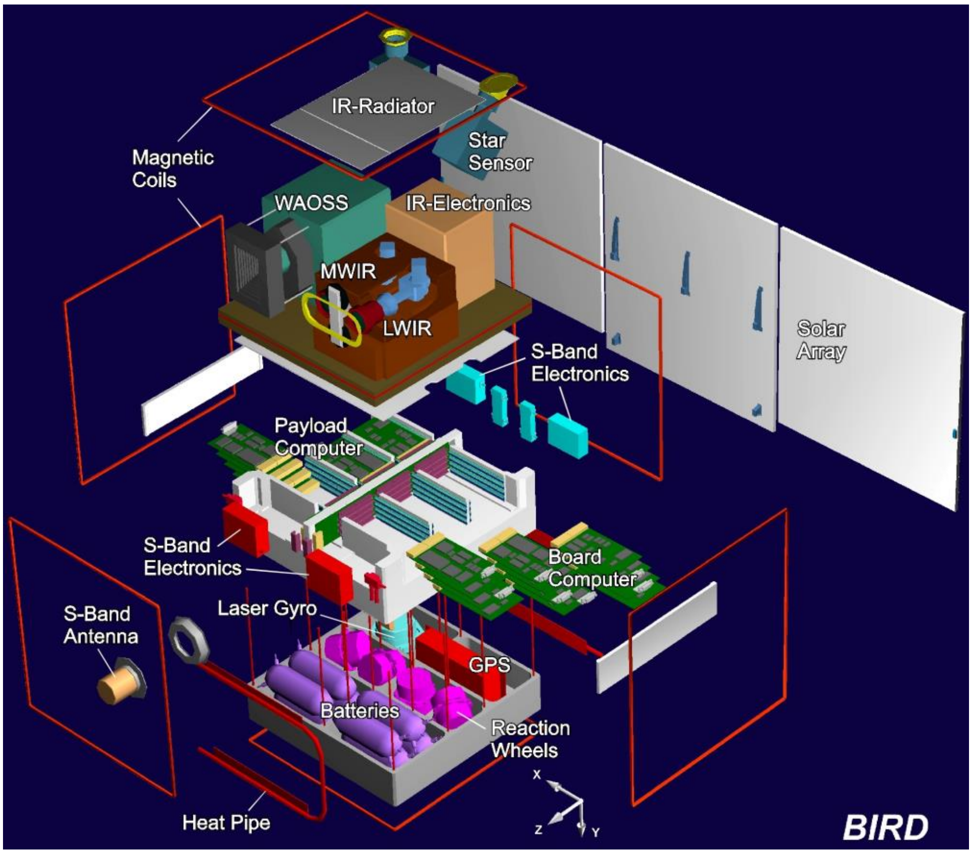
Parameters	FFEW-FUEGO	BIRD-FMC
Orbit geometry	700 km/47.5 °	700 km
No. of satellites	12	3 or 4
MIR channel (res., swath)	144/72 m, 250 km	550 km
TIR channel (res., swath)	390 m, 250 km	550 km
VNIR channel (res., swath) RGB-CCD channel (res., swath	100/25 m , 250 km -	- 225 m , > 500km
Minimal resolvable 800 K fire area at nadir	~5/20 m^2	~5/20 m^2
Revisit Time	30.4 minutes	12 Hours
Average fire detection	15.2 minutes	6 Hours
Data transmission	L-Band, direct to users	S-Band, direct to users

Comparison between hyperspectrometer parameters

	Wavelength Range	Best spectral resolution	Measurement of Polarization	Ground pixel size	Size of a data take
Warfinghter-1 (OrbView3-4)	0.45-2.5μm 2.5-5.0μm	11.4nm	No	8m	$5x20km^2$
Hyperion (NASA, EO-1)	0.4-2.5μm	10nm	No	30m	$7.5x100km^2$
FTHSI (MightySat II.1)	0.47-1.05μm	1.7nm	No	25-250m, 25-51m	6-26km x 20-87km
"Astrogon-Vulkan"	0.25-2.5μm	1nm	Yes	5m	$3x3\ km^2$
"Astrogon Light" Hyper-spectrometer	0.4-0.8μm	1nm	Yes	10m	$10x10km^2$

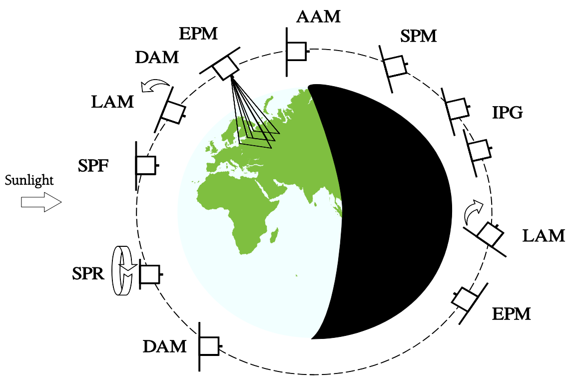
The requirements to the BIRD bus – type satellite bus:

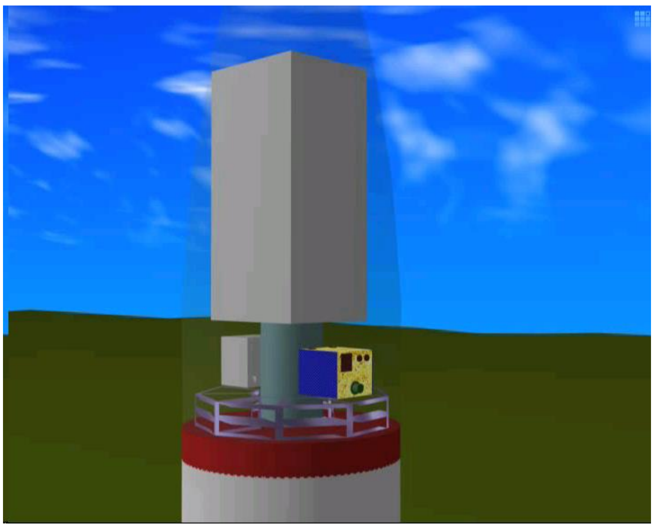
- suitable for different piggy-back launch opportunities in any LEO;
- 200W peak power for 20min;
- total mass max. 95kg incl. payload;
- 3-axes stabilized;
- on-board navigation system;
- S-band telemetry with max. 2Mbps;
- radiation tolerance up to 7krad (Si).



BIRD-type Spacecraft Modes

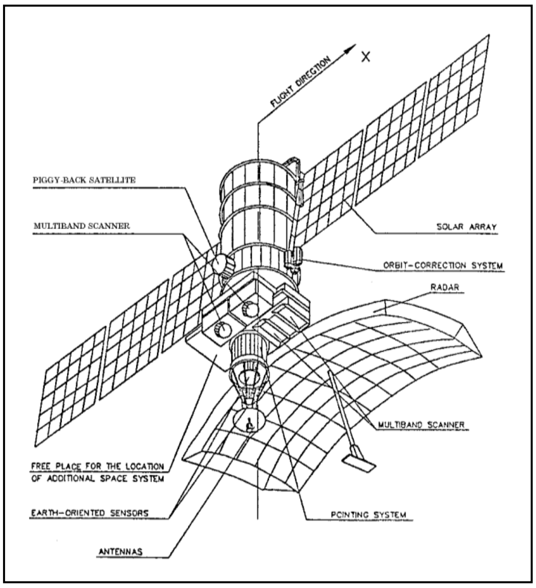
The spacecraft supports the functional flexibility: it can work in different modes.





AAM - Auto Acquisition Mode, DAM- Damping Mode, LAM- Large Angle Manoeuvre, SPF- Sun-pointing Fix, SPR- Sun-pointing Rotate, EPM Earth-pointing Mode, IPG- Inertial Pointing Mode, SPM - Suspend Mode.

Launch Strategy: as Auxiliary Payloads on 2 launchers

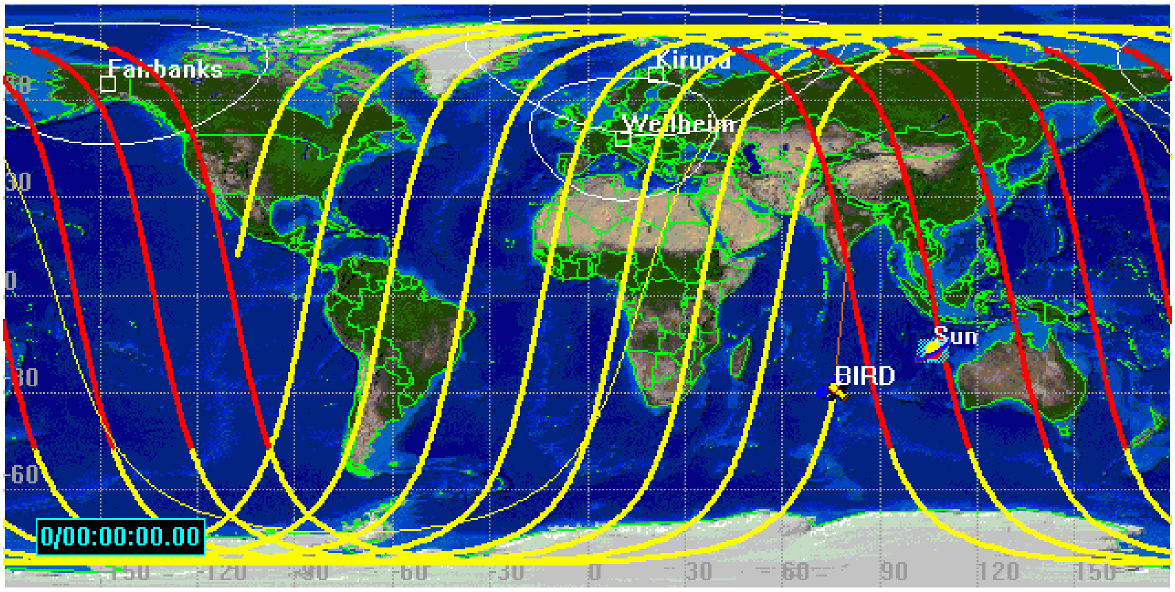


2 examples:

- Cosmos (right)
- Resurs (left)

Target Orbit: 550…800km, circular, i = sun-synchronous

3 or 4 satellites in the same orbit plane but at different positions



FMC Mission Architecture and Ground Segment

Mission operations by DLR

Data reception, processing storage by DLR

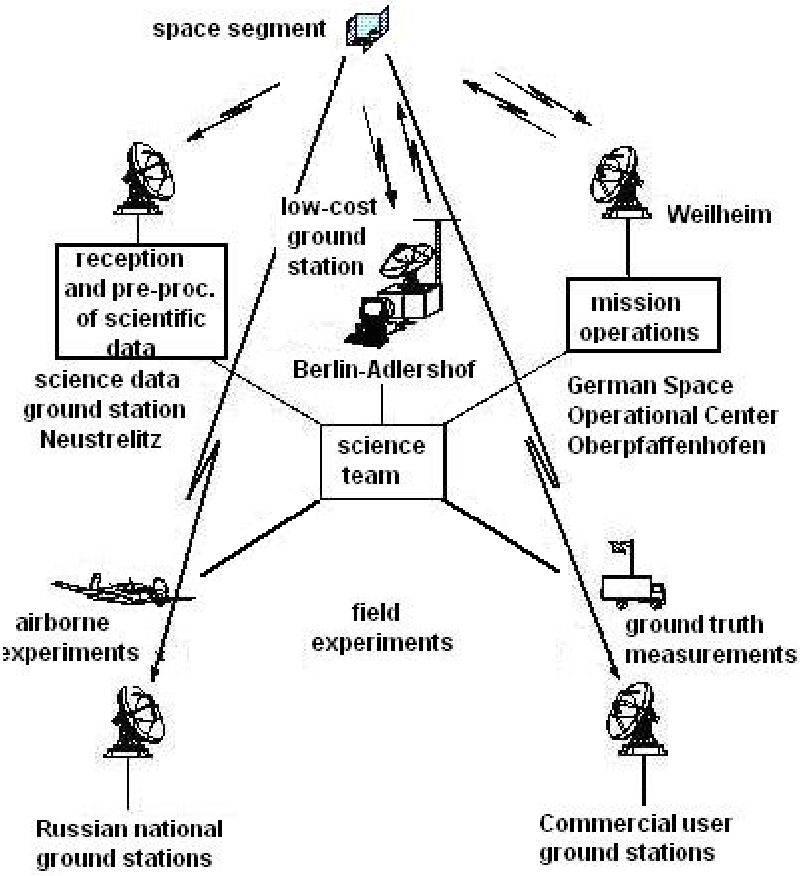
Coordination of the user requirements by an operational user interface

Commercial distribution of fire data products

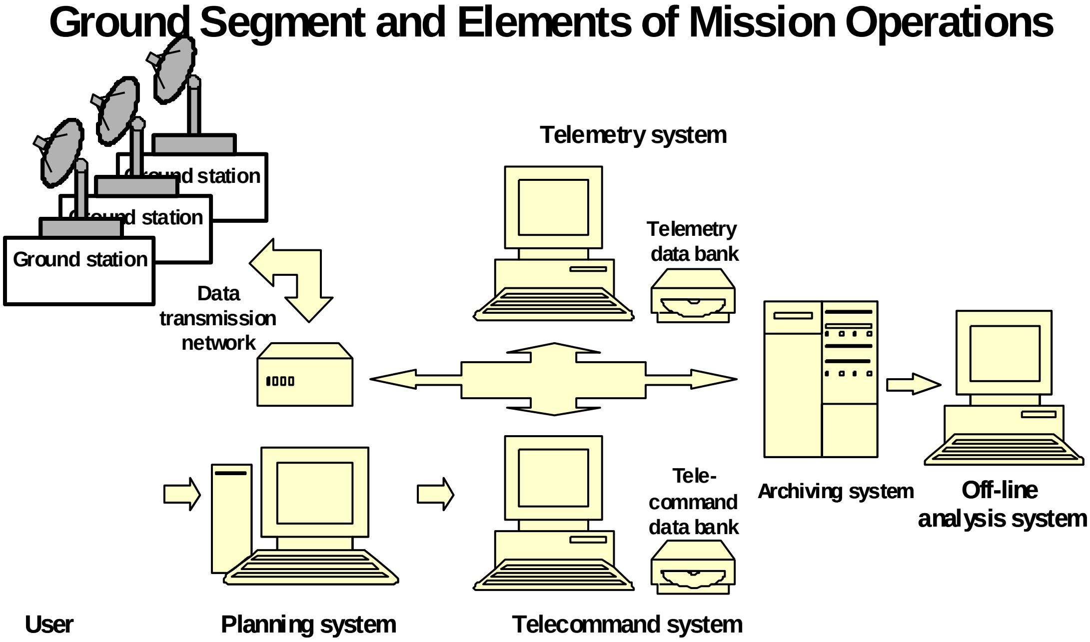
Technology demonstration

of hyper-spectrometer

Option: direct receiving of data

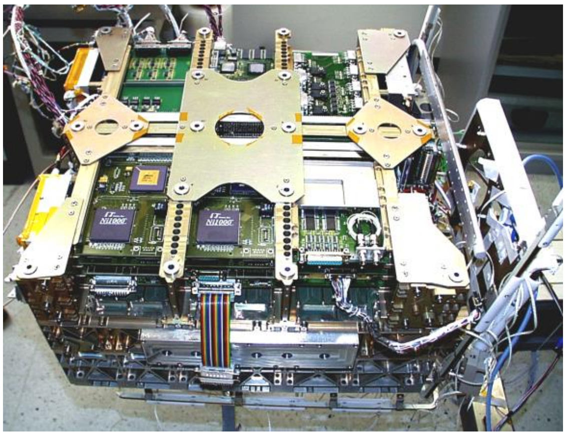


Ground Segment and Elements of Mission Operations



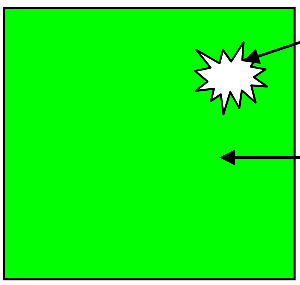
New Technologies of BIRD Spacecraft

1. **Failure tolerant high performance spacecraft bus computer**
2. **High precision reaction wheel for micro-satellites**
3. **Low-cost star cameras**
4. **On-board navigation system with on board orbit propagator**
5. **Autonomous Attitude Control System in state space representation**
6. **On-board-classificator basing on an artificial neural network chip**



BIRD-Highlight:
Hot-Spot-Detection Within the Sub-Pixel Range

(*Dozier, 1981:* Bi-spectral Technique for retrieving temperature and area of sub-pixel hot spots)



q - relative area of the hot spot

T_F - absolute temperature of the hot spot

1-q - relative area of the background

T_{bg} - absolute temperature of the background

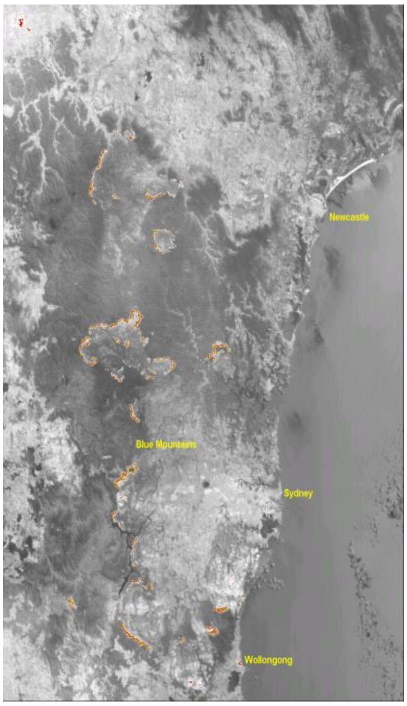
$$L_{MIR}(T_F, q) = q\, B_{MIR}(T_F) + (1-q)\, L_{MIR-bg}$$

$$L_{TIR}(T_F, q) = q\, B_{TIR}(T_F) + (1-q)\, L_{TIR-bg}$$

$B_{MIR/TIR}$ - integral Planck-Function within each channel $L_{MIR/TIR-bg}$ – estimated radiance of background from the surroundings

Infrared+hyperspectral remote sensing technologies: demonstration of usage

First Fire Evaluation From Space -
BIRD gives temperature and area extent of Australian bush fires



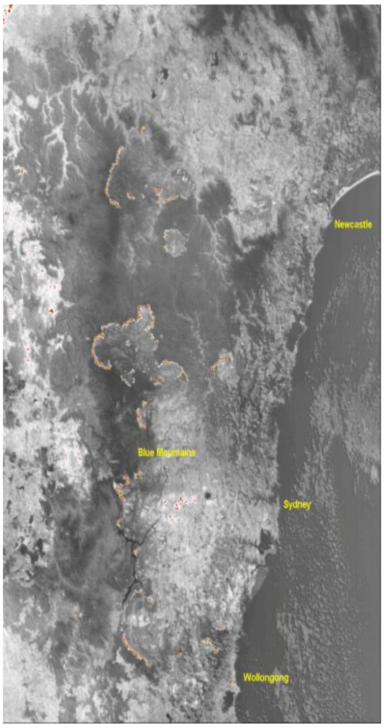
4.Jan.2002 10:08 local time

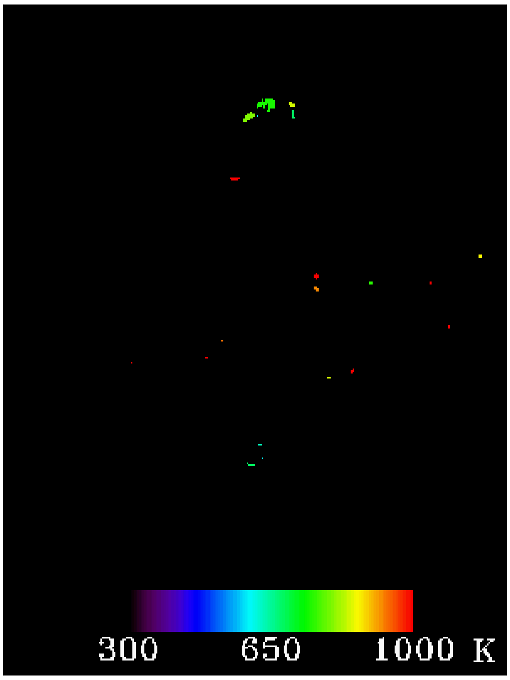
BIRD-image, MIR-channel

5.Jan.2002 10:08 local time

BIRD-image, MIR-channel

Fire colour coded

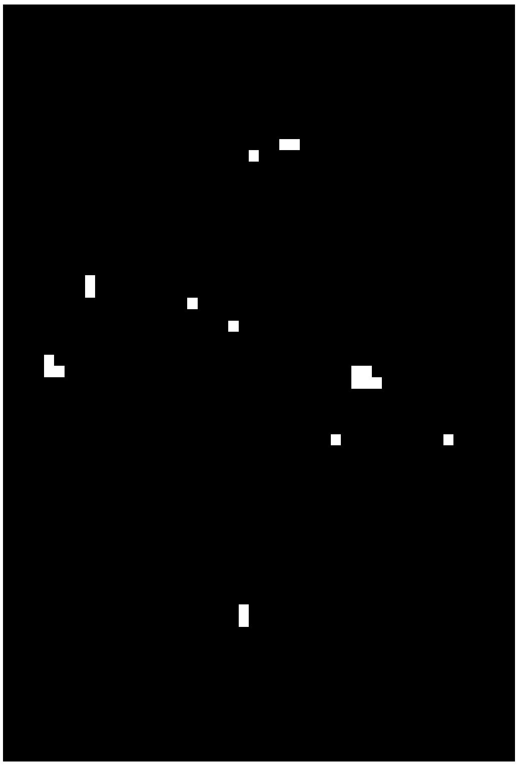




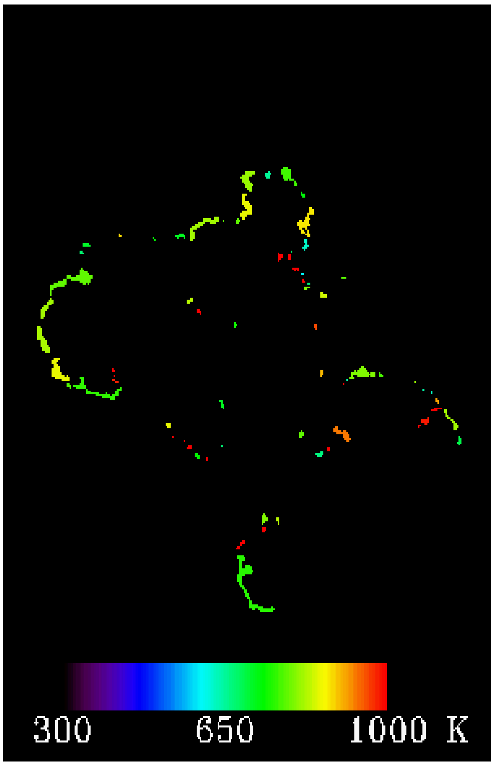
Detail from the BIRD-image at 04. Jan. 2002

1. NIR-channel
2. TIR- channel
3. MIR- channel
4. Fire fronts and temperature distribution
5. Fire fronts and temperature distribution from the image at 05.Jan.2002
6. Fire fronts and temperature distribution from the image at 09.Jan.2002

Comparison of the fire images and fire data products between MODIS and BIRD (detail image from 5. Jan. 2001 of Australia)

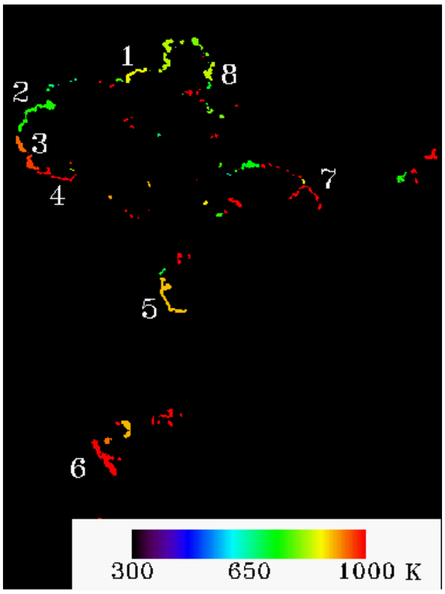


MODIS: Fire map



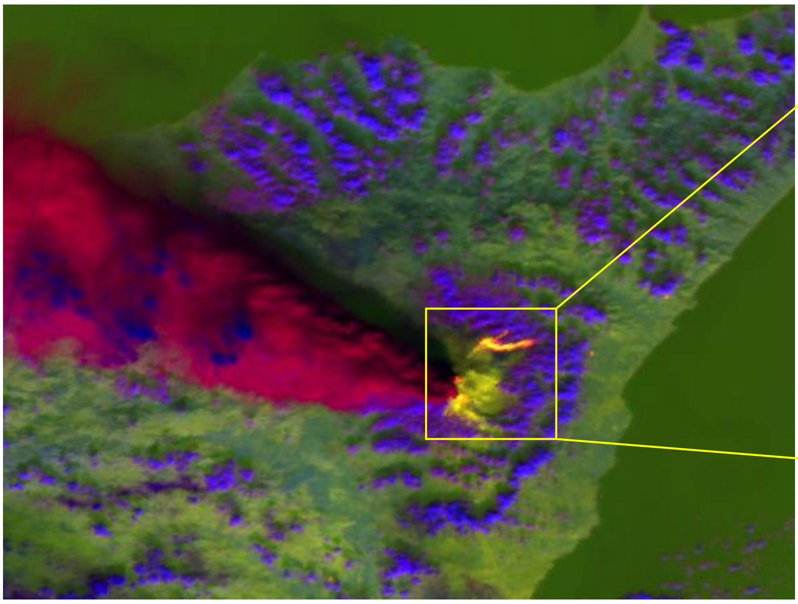
BIRD: Fire map

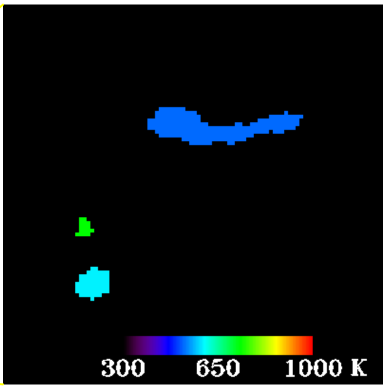
Typical characteristics of fire fronts (BIRD, Australia, January 5, 2002)



No	Eq. fire temp., K	Eq. fire area, Ha	Front length, km	Energy release, MW	Front strength, kW/m
1	815	0.48	4	130	30
2	715	2.3	7.5	310	40
3	893	0.59	3	210	70
4	>670	<0.78	5	79	15
5	852	0.92	10	300	30
6	957	1.0	9	530	60
7	>690	<0.51	4	62	15
8	796	0.39	3	96	30

Etna eruption (BIRD, November 2, 2002)

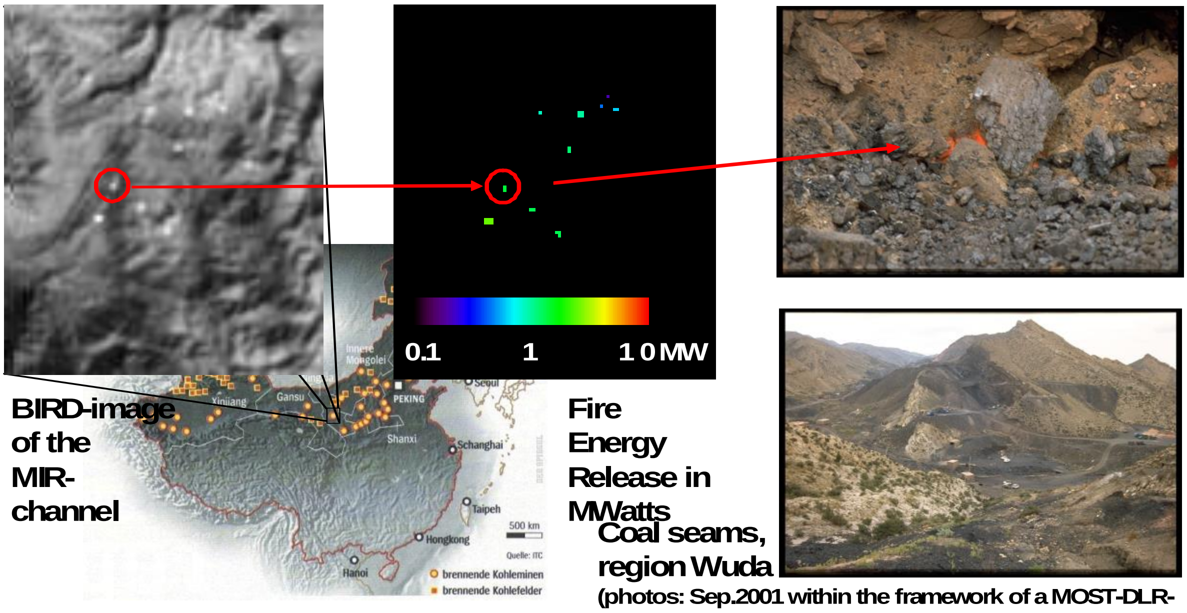




Effective lava temperature

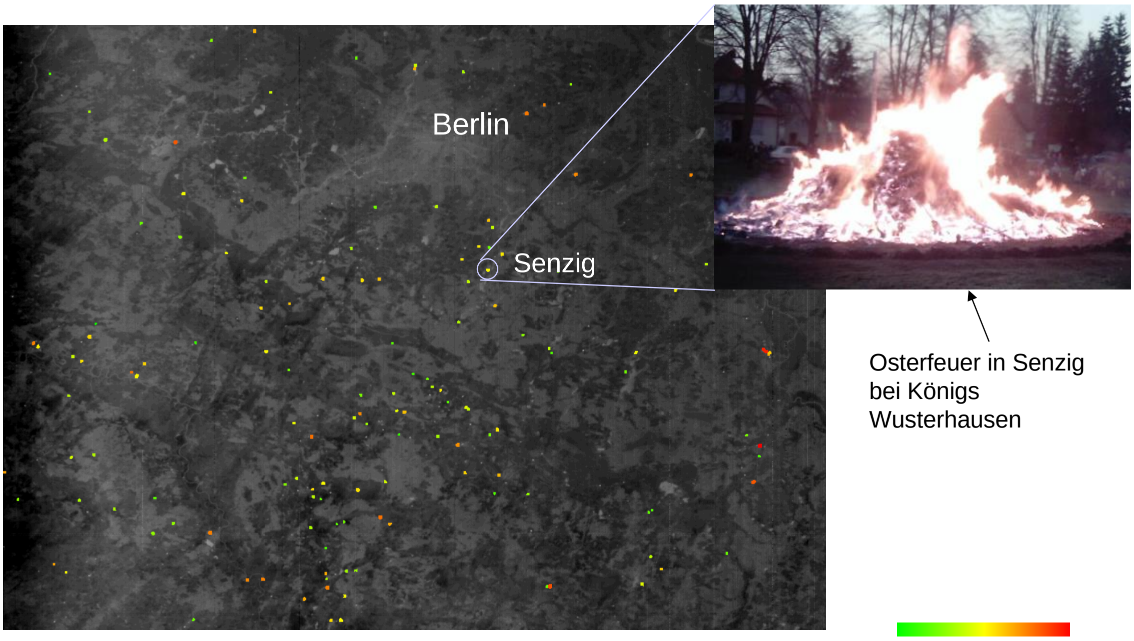
Red: MIR, Green: TIR, Blue: NIR

BIRD Detects Coal Seam Fires in China (February 6, 2002)



(photos: Sep.2001 within the framework of a MOST-DLR-Cooperation)

Osterfeuer (BIRD - Aufnahme, Region Berlin-Süd, 17. April 2003, 22:35 MEZ)



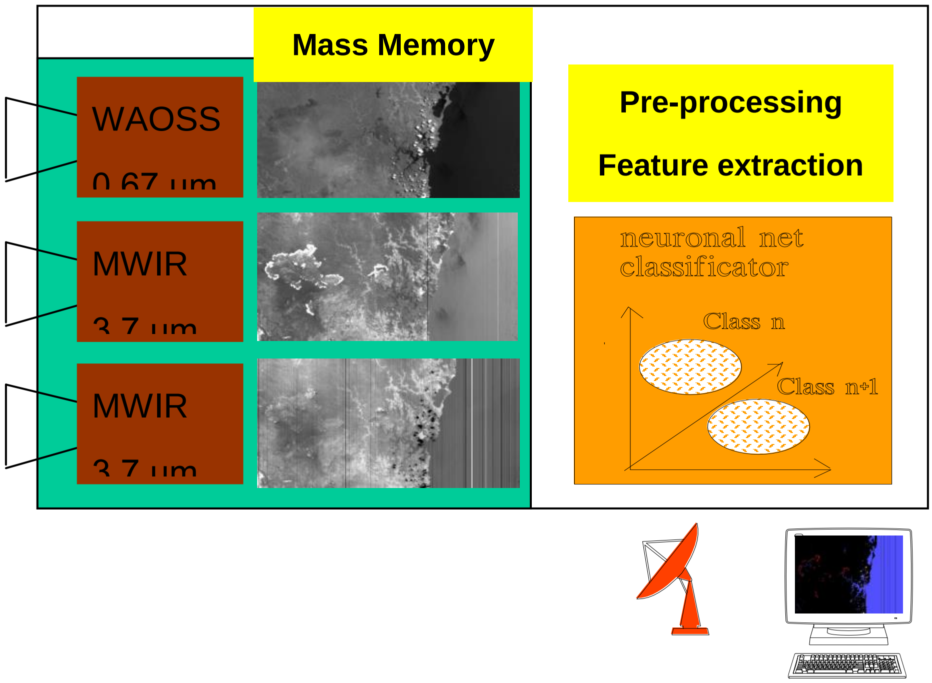
Energetische Bewertung der Feuer auf dem IR-Hintergrund Bild bei 3.4-4.2 µm, siehe Farbskala

Classification of images in VNIR and MWIR

BIRD Technology demonstration: on-board image classification

Technology: artificial neural network based on NI1000-chips

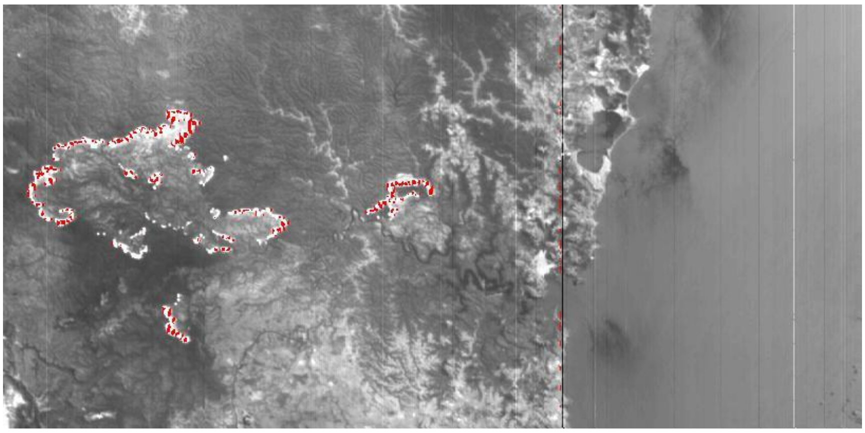
Learning method: Restricted Coulomb Energy (potential function method)



Results of the BIRD-On-board Image Classification

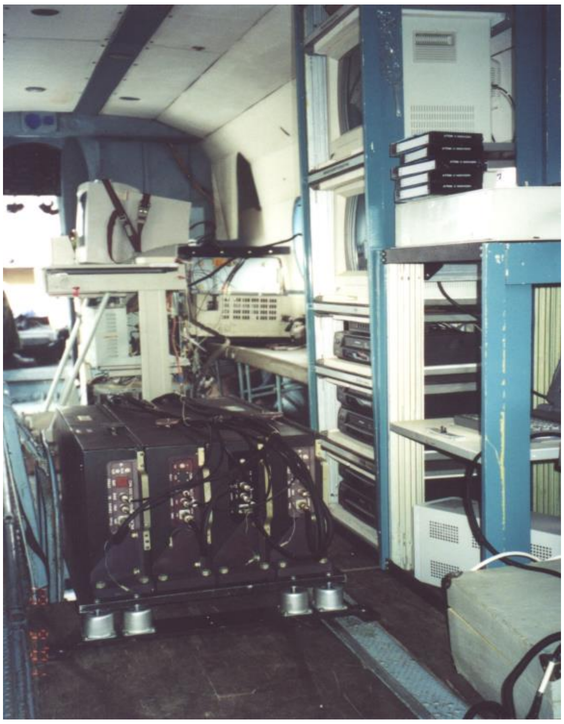
Image detail over Australia, 04.01.02 Medium Infrared channel (4.2µm)

with classification results in red: fire fronts

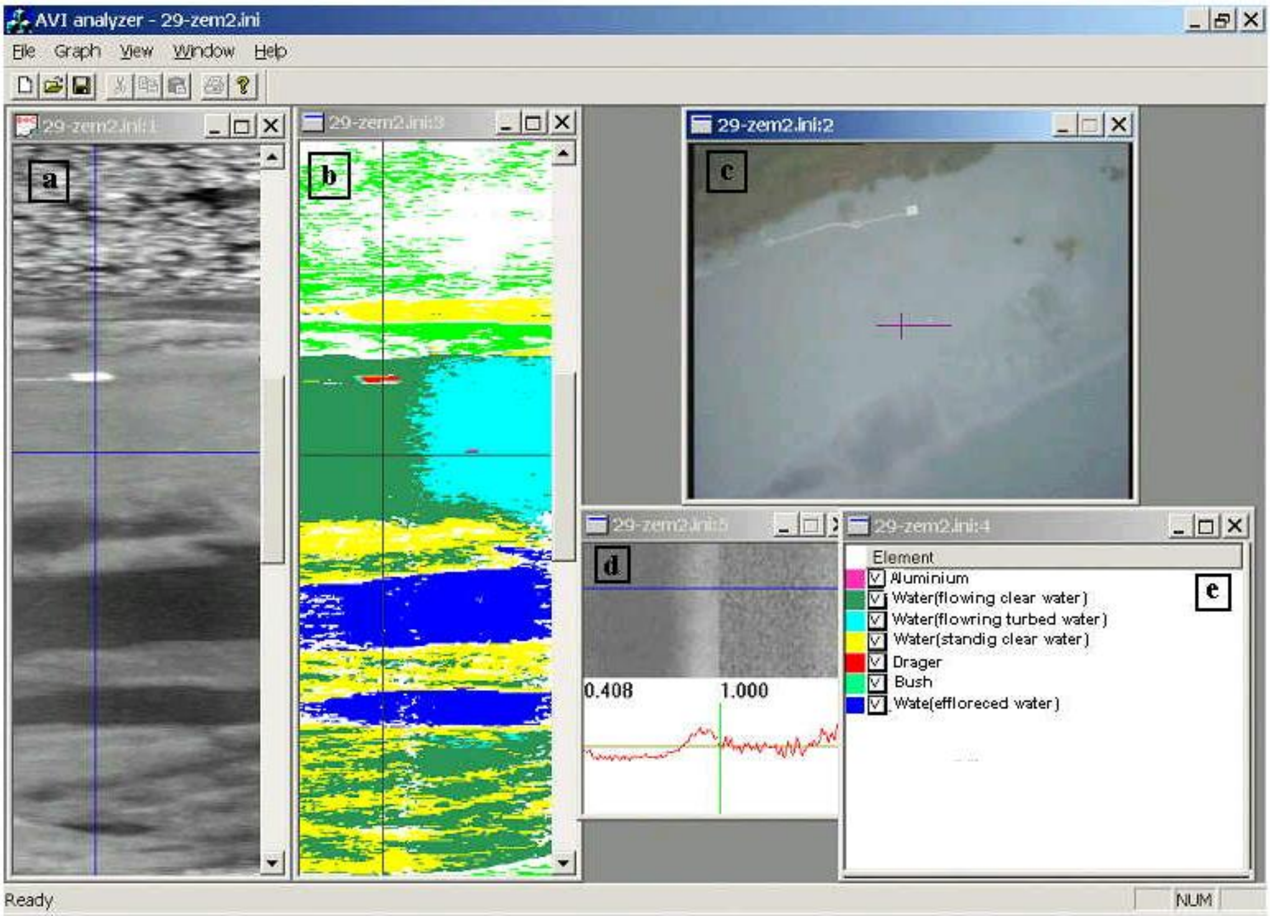


To increase the robustness and accuracy of on-board image classification, hyperspectral data should be used, in addition to IR data. This could provide the additional detailed information on the chemical composition of combustion products and on the environmental impact of fires.

R&G Center "Reagent' has designed, developed, and tested the Astrogon airborne prototype on board the helicopter.



Images from two hyperspectral modules at different wavelengths as seen on board the helicopter.



Examples of hyperspectral information and processing results

a B/w representation of total hyperspectral signal.

b - Classification resulting from correlational processing of hyperspectral data.

c – Accompanying camera view (total camera viewing angle 60^0, hyperspectrometer viewing angle 12^0 shown as a horizontal line).

d – Upper half: data from two hyperspectrometer modules corresponding to the cross-point in a, b, and c. Lower half: spectrum in the cross-point.

e – List of categories used in classification.

Benefits of Cooperation

The hyperspectrometer “Astrogon-Light” on an operational Fire Monitoring Constellation would give:

- New scientific results related to land, sea surface and atmosphere
- Demonstration of advanced technology in space
- New knowledge about environment and security
- Additional scientific results about fire and volcano impacts
- Different application products on user request
- Additional detailed information on the chemical composition of combustion products and terrestrial objects.

Conclusion

The joint Russian-German Project proposed is based on the combined use of an infrared camera and a hyperspectrometer carried by the BIRD-type satellite cluster. It opens a new vista in global and regional monitoring of critical processes and catastrophes, such as forest fires, volcano eruptions, technogenous disasters, etc. The new capabilities are due to the synergistic effect of infrared and hyperspectrometric data. The following features add to the perspective of the Project:

1. Temperature and area extent of vegetation fires or other hot spots can be evaluated from space.
2. The new infrared array sensor system is suitable for small satellite missions.
3. New hyperspectrometer data offer new science and new service for monitoring of environment and security.
4. Micro–satellites are interesting tools for operational missions open because of the low mission costs and the flexibility.
5. An operational Fire Monitoring Constellation is “First to market”
6. An operational hyperspectrometer is “first to science” and “first to market”.

APPENDIX

APPROVED

Vice-President of Russian Academy of Sciences,

President of the Section “Space investigations of the Earth and natural resources”, RAS Scientific Council on Space Investigations, Academician

N. P. Laverov

“15” December 2003

Experimental study of regional and global terrestrial environmental processes using spaceborne hyperspectral and infrared sensors

Scientific program

Moscow, 2003

Introduction

Fires and other natural and anthropogenic catastrophes, such as trunk pipeline failures, large power plant accidents, volcano eruptions etc. lead to emission of enormous quantities of heat and cause several hundred million dollar losses yearly to environment, industry, housing, and population health.

The timely detection of events that start these catastrophes would help their prevention or, at least, would help in reducing their extent. The first thing to do is to provide the local administration and the specialized services with an adequate informational support, in order to track the catastrophe development from precursors to outbreak, the peak of event and then to post-catastrophic processes. A widely varying spatial coverage is usually required for that.

The solution to this problem can be based only on spaceborne remote sensing, armed with sensitive infrared sensors and with visible and near-infrared hyperspectrometers with high simultaneous spatial and spectral resolution. Hyperspectrometers are a must for screening out artifacts, detecting weak precursor symptoms, assessing the slow post-catastrophic dynamics. However, sensors are not the only hardware necessary: receiving stations, preliminary processing complexes, storage and distribution network – all that must be taken into account. The software – thematic processing algorithms and decision support systems adapted to fast response requirements characteristic for catastrophes - is as important as hardware. Both hardware and software should function on a permanent basis, in order to support precursor monitoring and post-catastrophic management.

As a prototype of the space-based part of such a system, one could indicate the BIRD satellite (Germany) with an infrared sensor. It has been functioning from 1999 till 2003. Its information proved quite effective in forest fire and volcano monitoring. However, for this system to live up to challenges listed above, it should be complemented with a hyperspectrometer. In our opinion, an adequate sensor for this purpose is the Astrogon-Light hyperspectrometer developed by R&G“ Reagent” (Russia).

This paper contains a proposal for development of a joint Russian and German small satellite-based Earth monitoring system targeted at natural and technogenic catastrophes with high energetic yield – fires, etc. It should be based on fusion of German infrared data and Russian hyperspectrometric data.

This proposal is supported by Russian Academy of Sciences. It covers the project of the system, experimental results from German infrared sensor, and results of test flights with Russian hyperspectrometer. The appendix includes the scientific program “Space-based experimental study of global and regional environmental processes using hyperspectral and infrared sensors” by Russian Academy of Sciences.

General

Justification

Recent decades have seen a number of programs and experiments in spaceborne remote sensing domain, both in Russia and abroad (LACIE, Seasat, FIFE, BOREAS etc.). Nevertheless, no implementation of regional or global environmental study, either targeted to atmosphere or to oceans or land, can be considered adequate. The basic reason is the so-called inductive approach, so that the objects of study were confined to individual biospheric components or processes, and the global picture was supposed to emerge from later synthesis of results. This approach inherently suffers from possible omissions or duplications or wrong weighting of the objects, and, consequently, leads to dissipation of resources and loss of time.

There is an alternative: the deductive approach based on the search for optimization of a chosen criterion, e.g., sustainability of global environmental and socio-economical development, closure of natural cycles of matter and energy, quality of human life, etc. The list of necessary studies and methodologies would follow as an ‘unfolding’ of the criterion functional. This approach is widely used, e.g., in controller synthesis, statistical decision theory and many other scientific and technological domains.

This approach, if adopted, would call for a new informational support strategy for research, and, in particular, the strategy of space-based remote sensing. Specifically, the set of so-called unfolding parameters, such as wavelength, spatial coordinate, observation angle, scale, etc., should be made as rich as possible. Also, all components and stages of remote monitoring, which use these parameters, should be integrated into a coherent system – beginning with problem statement and ending with marketing issues.

The space-based experiment we propose is a first step towards implementation of this strategy, testing its basic principles and providing a starting point for methodology of further studies. The experiment is based on spaceborne hyperspectral (0.3 – 2.5 μ) and infrared (4 – 12 μ) instruments, and its methodology would be extensible to other wavelengths.

The approach proposed implies the implementation of fundamental science through applied research, so that there is a feedback between scientific and practical problems. In particular, the scientific program is dependent on the #1 marketing issue: the traditional data, such as panchromatic and multispectral images, are a standard product on the market. They have almost a status of utility, their turnover is skyrocketing and could reach $20 billion by the year 2010.

The situation is different for a more complex type of data – the hyperspectral. Their strong point is the possibility of remote physical and chemical analysis of Earth surface. However, the data processing methodology is still to be developed and tested, and until then, the commercialization is delayed. An important part of the program proposed is to remove the scientific obstacles and open the way first towards the engineering applications, and then towards commercialization of hyperspectral data.

The infrared camera, which is a part of onboard instrumentation, will be provided by a consortium of German enterprises:

- OHB System AG, responsible for satellite bus and launch
- Jena-Optronik GmbH, responsible for the Payload Segment
- DLR, responsible for mission operation and IR-technology
- Technical University of Berlin, Mission Planning and project management
- Fraunhofer FIRST, payload interface unit and payload data processing.

At the Russian – German meeting on September 17, 2003, Rosaviakosmos has presented its proposals on the integration of information flows from Russian and German satellites.

Purpose of the program.

This document presents a joint scientific program by a number of leading RAS institutes (Keldysh Institute of Applied Mathematics, Semenov Institute of Chemical Physics, Center of Forest Ecology and Productivity, Institute of Atmospheric Physics, Institute of Oceanology, Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Lebedev Physical Institute), Center of Science-Intensive Export Technologies, and R&G “Reagent”. It includes the following sections:

- goals, objectives, and contents of the experiment;
- basic requirements for the experiment and for the methodologies of data processing;
- organizational requirements for the implementation of the experiment;
- other organizational issues.

Goals and objectives of the experiment

Main goal

Using the spaceborne hyperspectral and infrared remote sensing for discovery and study of interaction mechanisms between various biosphere components (atmosphere, ocean, and land) and between them and anthropogenic systems, in order to develop the strategy of monitoring and controlling these systems' state as an informational support for global sustainable development, economic activities, early natural and anthropogenic catastrophe warning, and assessment of their after-effects.

Scientific and practical objectives

This goal implies:

- Definition, based on the above-mentioned deductive approach, of most urgent and/or most perspective scientific and applied problems, in a setting optimized by informativity of hyperspectral and infrared observations with respect to objects and processes involved;
- Determination of data informativity within each problem group as a function of time, territory, observation schedule, data processing methods. Optimizing the monitoring strategy for each problem group with respect to these parameters;
- Definition of requirements to auxiliary databanks: GIS information, additional databases, knowledge bases, and, most importantly, in situ experimental data. Developing a preliminary version of integrated auxiliary databank.
- Development of requirements for information channels and information shipment conditions, based on the dependence between admissible shipment delay, information volume, and processing depth and quality;
- Assessment of market capacity as a function of problem group and the quality of information. Assessment of total development and exploitation cost and expected profitability of the information system based on hyperspectral and infrared remote sensing.
- Developing the list of standing customers and coordinating the requirements for information products with them. Securing the informational support with problem-related in situ information from customers.

- Forming an expert group for scientific and methodological supervision of the information system;
- Feasibility study for a new way of information shipment based on peer-to-peer Internet networks including both individuals and institutions. This is especially valuable for catastrophe monitoring and control, e.g. targeted to population health during intensive forest fires;
- Feasibility study for a continuous monitoring-control feedback cycle for customers who wish to participate in this study.

Scientific and applied problems and application domains for the results of experiment

The following list of scientific and applied problems and expected results is preliminary. It will be refined as the work listed in section 0 will progress.

Table 1 Application domains and expected results

##	***Problem***	***Expected results***
1.	**Diagnostic of main gas and oil pipelines**	**Pipeline positioning, monitoring of intersections, detection of protection zone infringements, forecast of slumps and arches, detection of micro-fractures and fistulas, detection of corrosion, soil and ice-lens dynamics, illegal cut-ins.**
2.	**Monitoring of deposit infrastructure**	**Monitoring the state of collector networks, roads, production sites**
3.	**Monitoring of underground gas reservoirs**	**Leak zones, leak volumes**
4.	**Monitoring of oil reservoirs**	**Reservoir fillup, shell deformation, product leakage (including subsurface leakage)**
5.	**Environmental support of land-based and offshore drilling**	**Condition of settling pits and reservoirs, leakages of drilling fluid, of mineralized stratal water, oil or condensate. Detection of oil spills on sea surface.**
6.	**Environmental condition of deposits**	**Anthropogenic defects of landscape, soil, vegetation, subsurface flow**
7.	**Environmental condition of trunk pipelines**	**Biota suppression zones caused by micro-leakages**

8.	**Potential borehole positioning. Monitoring of deposit exhaustion**	**Periodically renewed 2-D and 3-D deposit maps. Monitoring of strategic oil and gas reserves**
9.	**Monitoring of construction and repair activity on tracks**	**Monitoring of work progress and of excavation and filling volumes**
10	**Selection of new trunk pipeline tracks**	**Size and value of lands put out of use, soil composition, shorelines, slope stability, river crossing stability**
11	**Exploration geology**	**Delimitation of complex ore-bearing formations, ore typology and chemistry, small deposit halo**
12	**Construction geology**	**Tectonic faults, karst, running sand**
13	**Engineering geology**	**Mine surveys, design of pipelines, dams, channels, and nuclear power stations**
14	**Highway and railway diagnostics**	**Permafrost, subsidence, and landslide-caused deformations, disturbances of road-bed and pavement, condition of railroad track and trolley-wires**
15	**Monitoring of bridges and beam crossings**	**Segments in stressed and deformed state**
16	**Airfield monitoring**	**Condition of landing strips and runways**
17	**Monitoring of power transmission lines**	**Track certification (digitizing the power transmission poles), damage to insulators and poles, disruption of passages**
18	**City infrastructure, surface and subsurface networks, power lines, heating systems, water supply and sanitation, gas supply, transport**	**GIS information: topology of networks and damages, air and soil pollution zones by industry and transport. Approaches by emergency services to potentially dangerous sites and extraordinary events. Zones of town-planning value, cultural heritage.**
19	**Exact cartography**	**Visual maps (CD-ROM) of cities, cross-country, surveying party or tourist routes**

20	**Cadastral mapping and capacity mapping in megalopolises, high farming regions, health resort zones, and natural reserves. Environmental condition of freshwater sources.**	**Updatable database of property rights and differential rent. Detection of continuous and extraordinary pollutant emissions and localization of sources**
21	**Marine fishery monitoring**	**Zones of upwelling and turbulence, currents, spatial distribution, concentration, and gradients of chlorophyll, phytoplankton, organic and inorganic suspended sediments, salinity, and temperature**
22	**Borderguard services**	**Position of commercial fishery ships in zones of economical interest**
23	**Agriculture and forestry, including farming and nurseries**	**Spatial heterogeneity of fertilizers and additives' composition and dosage, sprout condition, vegetation stages, phytomass, diseases and pests, yield forecast, damage assessment for insurance purposes**
24	**Forest fire monitoring**	**Detailed damage localization within fire site, target designation to fire services**
25	**Monitoring of deep and near-Earth space**	**Earth Limb imaging, detection of space debris and other objects, measurement of ozone layer state. Tomography of upper atmosphere.**
26	**Monitoring of catastrophe precursors for floods, ice jams, high dams, quarries, sludge ponds, tailing pits, chemical plants, nuclear power stations.**	**Anomaly identification, forecast of dynamics**
27.	**Volcano monitoring**	**Dynamics of gas, ash, and magma emission. Zones of potential danger to population**

Scientific and methodological basis

Relationship between system-defining factors

Scientific and methodological basis for this program is provided by the methodology for development of information-optimal remote monitoring systems. The methodology was developed in Space Research Institute, Russian Academy of Sciences. Nine major groups of system factors are taken into account and related to each other:

- Monitoring problem statement (major objects, parameters and processes);
- Imaging platform and schedule;
- Parameters of sensors (here, of the hyperspectrometer and IR-camera);
- Prior and in-situ information;
- Algorithms of preliminary data processing and correction;
- Algorithms of thematic data processing, including specific analytical and empirical models used;
- Logistics of information shipment from sensors to processing center and from processing center to users;
- Marketing factors and business process definition focused on overall profitability of the system;
- Procedures used to adapt the system to changes in problem setting, technology, market situation etc.

There are two basic types of relationship between these factors. The first one includes fixed constraints, which limit options within a factor group (e.g., monitoring schedule) as a function of choice made within another factor group (e.g., problem statement choice). The second one includes ‘soft relationships’ defined by coefficients of information transfer from a factor to another factor (e.g., from a model of object dynamics to probability of success in the object detection problem). When all relationships are taken into account, the methodology provides an algorithm for identifying the viable, mutually compatible and informationally optimal configurations of factors. Each distinct cluster of factor configurations defines a distinct feasible type of the monitoring system. The choice between these options is the crucial system design decision. To a large extent, it is determined by the choice and weights of application domains.

The target monitoring problems are detailed into factors:

- Application domain definition (e.g., for the federal forest fire aviation service, this includes fire detection, fire monitoring, and fire extinguishing);
- Definition of objects that have to be detected;
- Definition of spatially extended systems that have to be mapped;

- Definition of quantitative parameters that have to be estimated;
- Definition of dynamic processes to be taken into account within some dynamic modeling framework;
- Indicator characteristics of objects, processes, etc., that allow for remote monitoring.

Capacity and informativity of data channels

Remotely sensed data obtained for training areas with in-situ measurements and other background information are used to calculate the capacity of information channels that connect sensors to users. Other factors are taken into account, as well, as intermediate nodes of information flow: indicator characteristics specific to application domain, methods of preliminary and thematic processing, methods of information shipment etc. Then, marketing studies are used to calculate the expected feedback from quality of information shipped to users to demand for information in different application domains, and then, to expected sales. Iterations of this modeling cycle will converge to the financial equivalent of a unit of information. Then, the cost-effectiveness criterion can be used to optimize the system design. Note that informativity parameter includes only the information that goes intact through this cycle and, in particular, is assigned a financial equivalent.

From experimental to operational mode

The tests that follow this methodology solve two related problems. First, they provide basic data, and in particular, remote sensing data, necessary for model calculations described above. Second, the results of modeling are used to correct the imaging schedules, data processing methods, data shipment procedures, etc. Thus, testing is more than a study: it is a practical informational design optimization of the environmental monitoring system based on hyperspectral and thermal imaging. As a result, the transition from experimental to operational mode will, hopefully, become smoother. In operational mode, the same methodology still remains valid as a way of adapting the monitoring system to changes of market and of other factors.

Improving the technology of hyperspectral and infrared remote sensing

This line of activity includes:

- obtaining the paired sets of remote and in situ synchronous or quasi-synchronous, spatially compatible data, setting up the corresponding archives, databases and knowledge bases;
- development of data validation methodology for remote and in situ studies;
- development of planning and survey methodologies for remote and in situ studies at test sites;
- determining the invariant relations between observed spectral reflectance / brightness temperature and parameters characterizing the state of remotely sensed objects;
- determining the relations between observed spectral reflectance / brightness temperature and parameters characterizing the composition of atmosphere above the remotely sensed objects;
- development of methodology for remote identification of atmospheric pollution sources from estimated pollutant concentrations;
- identifying the existing and developing the new dynamical models to be used in monitoring and control of specific objects;
- improvement of thematic data processing algorithms for remote and in situ measurements;
- development of external calibration technology for onboard imagers.

Requirements for test site selection

Test sites play a major role in implementation of this space-based experiment, especially within the new deductive framework. First, they provide the crucial background information; second, they are necessary for validation of thematic processing results.

Therefore, test sites should be selected so that they a) contain a maximum possible diversity of natural and anthropogenic objects; b) be well studied during many years’ field experiments; c) be related to economically important application domains; d) be well covered with past remote sensing data, with topographic and thematic maps.

Basic requirements for the experiment

Preliminary stage

This stage includes:

- preparation of ranked lists of application domains and specific problems within each domain, linked to potential customers and virtual test sites;
- solving the organizational issues of test site equipment for future experiment, onboard instrument calibration, data processing validation;
- collection, systematization, analysis, and, if necessary, extension of existing background information for selected test sites, in order to support the synchronous spaceborne and in situ experiments and the processing of respective data;
- solving the organizational and methodological issues of information buildup and shipment to users;
- development of advanced thematic data processing algorithms.

Experimental stage

The experimental stage is expected to produce the following results:

- the full set of planned remote and in situ measurements performed;
- informativity of measurements with respect to the preliminary set of application domains should be estimated;
- organizational and marketing measures defined, in order to promote the usage of data in global and regional environmental studies and in geographical information technologies used in various industries;
- potential improvements of remote sensing instruments, increasing their scientific and commercial usability, should be defined.

Organizational issues

The experiment spans the period 2004 – 2015.

The leading executive offices are:

- Keldysh Institute of Applied Mathematics, Russian Academy of Sciences, – in trajectory calculations, imaging schedule, preliminary atmospheric correction;

- Semenov Institute of Chemical Physics, Russian Academy of Sciences, - in studies of chemical composition of remotely sensed objects, methodology and organization of thematical interpretation of remote and in situ data;
- Lebedev Physical Institute, Russian Academy of Sciences, - in studies of tropospheric gases distribution by means of correlational infrared radiometry from spaceborne and mobile terrestrial platforms. Participation in validation of hyperspectral measurements using a multispectral infrared spectroradiometer;
- R&D Center “Reagent” – in providing the onboard hyperspectral and infrared sensors, organization of test site studies, thematical processing of data. Includes the validation of hyperspectral data in helicopter/aircraft flights to obtain test data for analysis;
- Semenov Institute of Chemical Physics Centre of Export High-Tech – in marketing and commercialization of results.

Other participants: Center of Forest Ecology and Productivity, Russian Academy of Sciences; Institute of Atmospheric Physics, Russian Academy of Sciences; Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Russian Academy of Sciences; Institute of Oceanology, Russian Academy of Sciences.

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