TWO DEDICATED SPACEBORNE FIRE MISSIONS

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ABSTRACT

After the extended fire and smoke-haze episode of 1997-98 in South East Asia and other regions of the world a series of international activities were initiated to address national and international problems arising from fire and smoke pollution. Most prominently the UN Decade for Natural Disaster Reduction (IDNDR), the World Health Organisation (WHO), the Food and Agriculture Organisation of the United Nations (FAO), and the World Bank strongly recommended further development and improvement of spaceborne sensors to provide information on vegetation fire occurrence and impacts, on early warning and monitoring of fire, prediction of smoke pollution and health effects, etc.

There are serious limitations of existing meteorological satellite sensors used so far for the fire product generation (e.g. partly channel saturation with insufficient high temperature event discrimination, spatial resolution less than 1 km) if accurate geophysical parameters have to be obtained.

The German Aerospace Center (DLR) and its industrial partners OHB-System and Carl Zeiss - after analysing these limitations - are working now on two new spaceborne fire missions: 1) the Bi-spectral IR Detection – BIRD - small satellite mission, and 2) the Innovative Infrared Sensor System FOCUS to be flown as an early external payload of the International Space Station (ISS).

BIRD is running in Phase C/D and shall be piggyback launched in a ~ 500 km near polar and non-sun synchronous orbit in 2000 or 2001 for a 1-year life time mission.

FOCUS is a prototype mission combining a number of proven technologies and observation techniques to provide the scientific and operational user community with key data for the classification and monitoring of forest fires and volcano activities by means of its innovative features: a forward looking imaging IR sensor with direct link to a processor dedicated for near real-time on-board autonomous seeking, detection, and selection of hot spots, and a high resolution IR-spectrometer/ IR-imager sensor combination for remote sensing of the hot event gas emissions applying data fusion techniques.

Keywords: high temperature events, vegetation fires, spaceborne fire recognition, dedicated fire sensors

INTRODUCTION

The concern of the international science community and international politic makers about climate change and environmental degradation has highlighted the requirement for better information on the dynamics of vegetation fires at all scales from local to global, in order to evaluate the role of fire as an agent of change.

Vegetation fires occur all over the world. They influence globally climate through the emission of radioactively active trace gases and aerosols, and by modifying the capacity of the vegetation cover to act as carbon sink. At a more local scale they cause smoke and haze which can adversely affect human health. Lightning is a particular important cause of fire in the world's boreal forests, but over the rest of the globe human activity is the major source.

Wildfires associated with increasing human population density, economic activities and other multiple vegetation stresses in the tropics and in the boreal zone have led to a change of natural and anthropogenic fire regimes (Crutzen and Goldammer 1993; Goldammer 1993). In the last two decades it was observed that wildfires in many locations cause considerable damage to vegetation cover, biodiversity, landscape stability (erosion), and productivity. The fire season of 1997-98 demonstrated that in extremely dry years smoke from vegetation burning - both from wildfires and land-use fires - created widespread air pollution which affected the health of several million people in South East Asia and South America.

After the extended fire and smoke-haze episode of 1997-98 in South East Asia and other regions of the world a series of international activities were initiated to address national and international problems arising from fire and smoke pollution.

LIMITATIONS AND IDENTIFIED GAPS

The principal reasons preventing an operational utilisation of the currently available satellite data for fire detection & monitoring is the absence of:

- Satellite sensors which are optimised for this task (with optimal spectral bands, spatial resolution and dynamic range),
- Satellite platforms with small revisit times, and
- Near real-time data processing and information delivery capability.

Data from general purpose operational satellite sensor systems such as the Advanced Very High Resolution Radiometer (AVHRR) on NOAA weather satellites and the Along Track Scanning Radiometer (ATSR) on the ERS 1 and 2 satellites are used mainly to derive "Fire Products" (fire distribution maps and fire seasonality at country, continent, and global level) at the moment.

E. Dwyer, D. Stroppiana, S. Pinnock, J.-M. Gregoire, from the Global Vegetation Monitoring (GVM), Space Application Institute, JRC, EC, Ispra, stated in 1998:

"The imagery only presents a snapshot of the total number of fires which burn in a 24 hour periods, fire counts may be either overestimated due to a confusion with hot surfaces and sun glints from reflective surfaces such as water and clouds. Although flaming fires with fronts as short as 50 m can be detected, in general no information on the fire characteristics (e.g. size, temperature) is available."

Even after the launch of Moderate Resolution Imaging Spectrometer MODIS (and ASTER) on board of EOS satellites ("Terra " mission in 1999) and the launch of the Advanced Along Track Scanning radiometer AATSR on board of ENVISAT the spaceborne fire observation situation will not change in general:

- **AATSR and MODIS can provide data with 1 – 1.5 km pixel resolution only.** MODIS will be able to provide data for the retrieval of quantitative fire characteristics in the sub-pixel domain, such as the temperature and area of High Temperature Events (HTE), whereas IR data from AATSR can be used for the detection only of fire occurrence and of fire scar observation.
- Higher resolution IR data from TM/ Landsat and ASTER / EOS AM 1 can not be used for an accurate retrieval of HTE temperature and area at day time, due to the missing 3 – 5 µm MIR channel in both sensors.
- No direct messaging of HTE data from space – based on on-board real time HTE detection and analysis – is foreseen in the above mentioned sensor systems.

No retrieval of HTE gaseous emission products - based on DATA FUSION of high resolution IR imagery and high resolution IR spectrometry – is possible with MODIS and AATSR.

TWO PROTOTYPE MISSIONS FOR FIRE RECOGNITION UNDERWAY

The German Aerospace Center (DLR) and its industrial partners OHB-System and Carl Zeiss – with respect to the above listed limitations and gaps - aim to create a dedicated world wide operating spaceborne Fire Recognition System (FIRES) and are working on two new spaceborne fire missions since 1995:

- The Bi-spectral IR Detection – ***BIRD***-small satellite mission, and

- The Innovative Infrared Sensor System ***FOCUS*** to be flown as an early external payload of the International Space Station (ISS).

BIRD is running in Phase C/D and shall be piggyback launched in a ~ 500 km near polar and non-sun synchronous orbit in 2000 or 2001 for a 1-year life time mission.

FOCUS is a prototype mission combining a number of proven technologies and observation techniques to provide the scientific and operational user community with key data for the classification and monitoring of forest fires and of volcano activities by means of the following innovative features:

- A forward looking imaging IR sensor with direct link to a processor dedicated for near real-time on-board autonomous seeking, detection and selection of hot spots, and

- A high resolution IR-spectrometer / IR-imager sensor combination for remote sensing of the hot event gas emissions (allowing to estimate the burning efficiency and the emission factors of vegetation fires as well as volcanic gas emissions), applying innovative data fusion techniques.

FOCUS was selected by ESA as one of five European "Groupings" to be flown as an externally pallet adapter mounted payload in the period 2003 – 2005 and now Phase A is completed.

BIRD MISSION OBJECTIVES

The objectives of the BIRD mission are summarised in Table 1.

THE BIRD PAYLOAD

The payload is designed to fulfil the scientific requirements under the conditions of a small satellite. It consists in the following main parts:

- The 2-channel infrared sensor system for hot spot recognition,

- The Wide-Angle Optoelectronic Stereo Scanner (WAOSS),

- The payload data handling with a mass memory,

- A neural network classificator.

The main sensor parameters of BIRD are given in Table 2.

THE BIRD SPACECRAFT

The satellite (see Figure 1) consists primarily of a spacecraft bus service segment, an electronics segment, a remote sensing payload segment, and fixed and deployable appendages. The main spacecraft characteristics of BIRD are given in Table 3.

Two options are considered now for piggyback launch of the BIRD satellite:

1. Launch in first half of 2000 together with the German satellite CHAMP into a non sun-synchronous circular orbit.

BIRD - Mission objectives		
Primary Objectives	1.	test of a new generation of infrared array sensors adapted to Earth remote sensing objectives by means of small satellites
	2.	detection and scientific investigation of hot spots
Secondary Objectives	3.	thematic on-board data processing more precise information about leaf mass and photosynthesis for the early diagnosis of vegetation condition and changes
	4.	real time discrimination between smoke and water clouds

Table 1. Mission objectives of BIRD.

Sensor parameter	WAOSS	MIR	TIR
Wavelength	(forward) 600-670nm (nadir,back) 840-890nm	3.4-4.2µm	8.5-9.3µm
Focal length	21.65mm	46.39mm	46.39mm
Field of View (FOV)	50°	19°	19°
f# number	2.8	2.0	2.0
Detector element number	2884	512x2 staggered	512x2 staggered
Detector element size	7x7 µm	30x30µm	30x30µm
Ground pixel size (altitude 450 km)	145m	290m	290m
Swath width (altitude 450 km)	420km	148km	148km
Quantisation	11Bit	14Bit	14Bit
Data rate	597 kbps compressed	420kbps	420kbps

Table 2. Sensor parameters of the BIRD Mission.

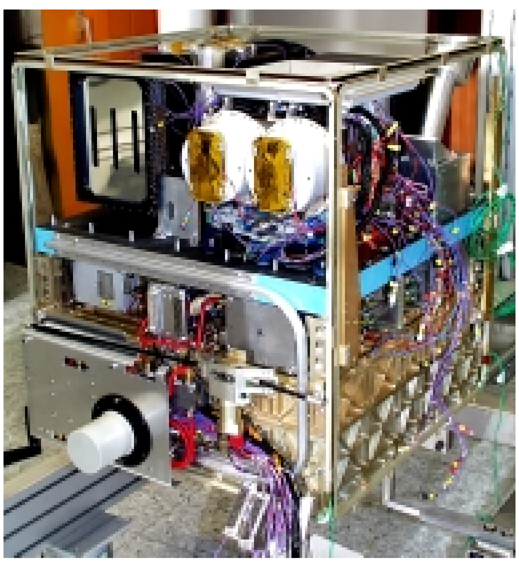

Figure 1. Structure Thermal Model of BIRD satellite.

2. Launch in second half of 2000 or in 2001 on an Indian Rocket (together with other spacecraft) into a sun-synchronous orbit.

Table 4 gives an overview of the expected orbits and the respective main BIRD viewing geometry and detection characteristics for the above introduced two launch options.

	baseline
Total spacecraft mass	85kg
Payload mass	26kg
Power (average consumption)	60W
Stabilisation method	3-axis stabilised
Pointing accuracy	±5’ per axis
Pointing knowledge	±0.2’ per axis
Communication	S-Band
Planned launch date	2000 or 2001
Life span in orbit	1 year

Table 3. BIRD satellite characteristics.

GEOPHYSICAL VARIABLES RELATED DATA PRODUCTS

Geophysical parameters fire area/temperature/gas emission is urgently needed for a regional and global upgrade of the fire-product. Here above all a data product well geo-referenced is needed.

The derivation of the column content of fire and volcanic gases from remote measurements, as well as the determination of combustion gas/smoke plume three-dimensional extent, requires the combined IR-spectrometric and IR-imaging data acquisition and storage. Table 5 summarizes scientific tasks and main requirements for advanced spaceborne fire recognition.

Parameter	Champ Option	Indian Option	Comments
Orbit inclination	87.28 degree	98.69 degree	
Orbit altitude	~ 470 km	817 km	
Orbit type	polar, non sun-synchronous	polar, sun-synchronous	
Node drift per day	- 0.37 degree	no	given for an inertial reference angular co-ordinate system
Swath width of the MIR and TIR sensors	~ 155 km	269 km	FOV = 18.8 degree
Pixel size of the MIR and TIR sensors	~ 300 m	528 m	IFOV = 0.64 mrad
Sampling step of the MIR and TIR sensors	~ 150 m	264 m	due to the staggered detector array and the double sampling
Swath width of the VNIR sensors	~ 440 km	765 km	FOV = 50 degree
Pixel size and sampling step of the VNIR sensors	~ 150 m	264 m	IFOV = 0.32 mrad
Minimal resolvable 800 K fire area at nadir	~ 100 m^2	280 m^2	estimated for a non smoke covered fire and by using adaptive thresholding

Table 4. BIRD launch and orbit opportunities and respective observation characteristics.

Task	Radiometric Requirements	Geometric Requirements for Global Analysis		Geometric Requirements for Local & Regional Studies	
		Ground Resolution (m)	Swath Width (km)	Ground Resolution (m)	Swath Width (km)
Remote measurement of hot event temperature and area and classification of fire type	VIS, NIR, MIR, and TIR channels: VIS, NIR – 8-12 bit, MIR – ~22 bit, NEΔT = 1 K, TIR – ~14 bit, NEΔT = 0.5 K	300 - 500	1300 - 1600	50 - 100	300 – 500
Determination of hot event coordinates		~ 500 m		100 m	
Estimation of burned areas and re-grow of fire scars	8 bit quantisation in several spectral channels for the raw estimation of the spectral signature in the VIS/NIR range, detection of the 'red edge' must be possible	~ 500	> 1500	~ 30	300 – 500
Determination of smoke plumes	VIS/ NIR channel: 8 – 12 bit	1000	> 1500	300	300 – 500
Determination of combustion gases of selected events	High resolution IR (3 – 16 µm) spectroscopy: 16 bit, plus image in VIS, MIR, and TIR channels	spectrometer foot print diameter 5 – 10 km	small, but across track tiltable	spectrometer foot print diameter 5 – 10 km	small, but across track tiltable

Table 5. Tasks and main requirements for advanced spaceborne fire recognition.

MAIN OBJECTIVES OF FOCUS

The main objectives of the FOCUS mission are: **Reliable autonomous on-board detection and analysis of High Temperature Events (HTE),** e.g. vegetation fires, volcano eruptions, through:

- Simultaneous co-registration of a combination of Infrared (IR) and Visible (VIS) channels, and

- Sophisticated and high performance on-board processing and thematic data reduction.

Generation of new IR data products and assessment of ecological consequences of HTE based on:

- Sophisticated IR spectrometric & multispectral imaging DATA FUSION, and

- Geophysical parameter extraction for selected HTE and their emissions

Near real-time HTE-cluster data geo-referencing and transmission to ground terminals.
Figure 2 shows the FOCUS observation geometry.

PROOF OF AN ADVANCED SENSOR / PROCESSOR CONCEPT

The advanced technological features of FOCUS are unique as compared to the other sensors/ missions given in Table 6.

A three channel **Fore-Field Sensor (FFS)** covering a relative broad swath together with the **FOCUS Brain** is foreseen to detect, select, and identify unknown hot spots in the Autonomous Detection & analysis Mode (ADM) data take sequence:

- Detection of hot spots with false alarm rejection and retrieval of surface temperature and area,

- Coupling of hot spot imaging data with on-board navigation data (geo-coding),
- Selection of relevant hot spots for detailed investi gation by the FOCUS Main Sensor,

- Derivation of control signals for pointing of the FOCUS Main Sensor instruments (taking into account the Space Station's angular drifts),

Mission/ Sensor	Resolution of the MIR channel	Minimal detectable 800K fire area	Capability for a quantitative retrieval of fire parameters	General mission Character
AVHRR (operational)	~1 km	~1000 m^2	**Not available** due to the low-temperature saturation of the MIR channel	Meteorological sensor partly used for global mapping of large fire occurrence
ATSR (operational), AATSR (2001)	~1 km	~1000 m^2	**Not available** due to the low-temperature saturation of the MIR channel	Meteorological sensor partly used for global mapping of large fire occurrence
MODIS (2000)	~1 km	~1000 m^2	Fire temperature and area retrieval expected	Global scientific quantitative investigations
BIRD (2000 / 2001)	300 m	~ 100 m^2	**Fire temperature and area retrieval possible**	Scientific quantitative investigations of medium and large fires. Technological demonstrator
FOCUS Fore Field Sensor (FFS) Main Sensor Imager (MS)	700 m 100 m	~500 m^2 ~10 m^2	**Fire temperature and area retrieval capability** **Spectrometric / Imaging capability to analyse fire plumes**	On-board fire detection and near-real time test information delivery Scientific quantitative investigations of fire emissions by Data Fusion
FFEW$^{*)}$ (proposal): detect. channel monitor. channel.	144 m 72 m	~20 m^2 ~5 m^2	**Very limited** due to the low-resolution and to the relatively high noise in the TIR channel	Operational fire detection and monitoring for Southern Europe (and other areas at similar latitudes). No on-board real time detection

Table 6. Comparison of fire detection and analysis capability of various missions.

$^{*)}$ *Forest Fire Earth Watch = FFEW has been considered in a refinement study which refers in the instrumentation proposal to FUEGO, a multi-satellite based fire alert system with the emphasis on the Mediterranean region.*

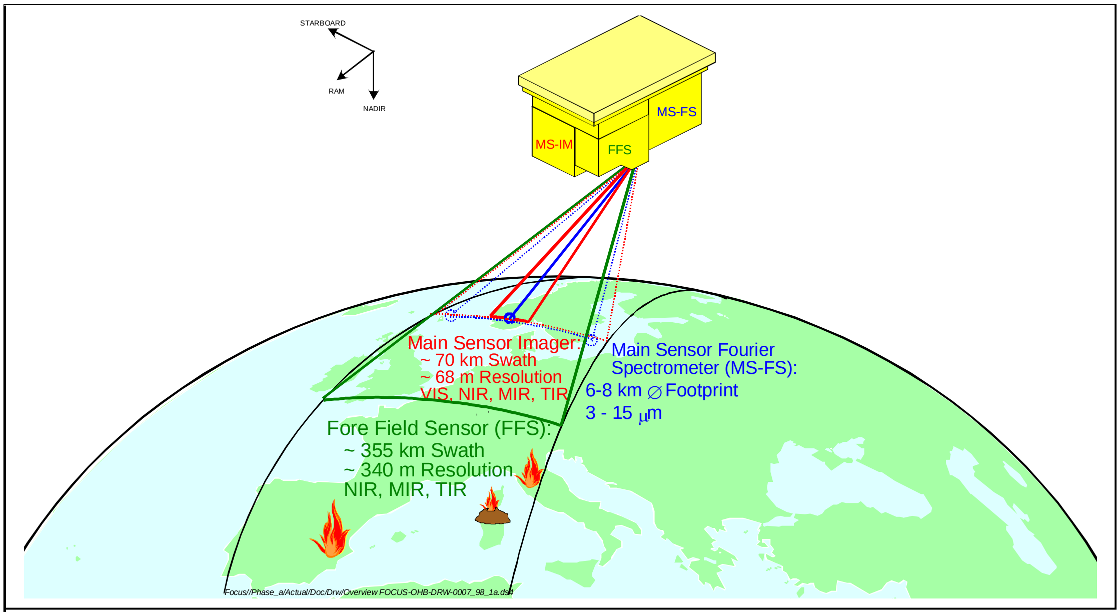

Figure 2. FOCUS observation geometry.

- Thematic data reduction by on-board processing to allow near real-time low data rate information on the identified HTE being provided to potential users.

During the ADM the FOCUS Brain has to generate a control signal for the drive of the **Across Track Tilt Mirror (ATTM) to point the Main Sensor (MS)** within less than 15 sec after the registration of a hot spot signal by the FFS.

The FOCUS Main Sensor (MS) view, tilted by the ATTM towards the selected hot spot, performs a close investigation and analysis of the selected HTE. Emphasis is put on the hot spot parameter determination and the analysis of the gas and smoke exhaust from that source. The latter have to be analysed on ground (off-line) based on combined data obtained simultaneously by the high resolution IR-spectrometer and the IR imager.

The FOCUS imaging sensors will be pushbroom instruments and will be built on Cadmium Mercury Telluride (CMT) detector line array with more than 1000 detector elements each. These sterling machine cooled IR sensors and their dedicated front end electronics provide an adaptive dynamic range of ~20 bit as demonstrated at DLR with the BIRD airborne model in spring 1999 (Lorenz et al, 1999).

For the FOCUS spectrometric sensor (MS-FS) a Fourier transform spectrometer with unique driving system is proposed: Instead of the back-and-forth moving plane mirror of the classical Michelson interferometer set-up a continuously rotating corner cube reflector is implemented. This concept has demonstrated high mechanical stability during missions on-board of aircraft. Features such as a spectral resolution better than 0.5 cm^{-1} at measurement rates higher than 10 Hz without generating linear acceleration forces make this design specially suitable for spaceborne applications. To cover the wide spectral range of gas components to be investigated, two cooled IR detectors – Cadmium Mercury Telluride (CMT) and Indium Antimonide (InSb) - will be installed.

The following FOCUS **on-board data handling** operations will be realised:

- Recording of the FFS data (they will be used for the on ground off-line validation of the on-board hot spot detection and selection procedure as well as additional multispectral image windows from the selected region of interest for combined use with the IR-spectrometer data),

- Synchronous data registration of the IR-spectrometer and the main imaging sensor to allow the on-ground off-line study of the spectrometric and imaging DATA FUSION,

- Buffering of all raw data and high level data products into a mass memory,

- Down link of all raw data and corresponding high level data products over certain payload ground stations for verification and scientific investigations.

For the detection of known or expected hot events and their detailed analysis by FOCUS the Main Sensor control will be performed via commanded and programmed instructions from the ground control centre leading to command control of tilting the main sensor to the area of interest which is pre-defined from the users. This is the Controlled Detection & analysis Mode (CDM) of FOCUS, which is considered for:

- Controlled vegetation fire observation where ground truth is obtained in the frame of fire field experiments for FOCUS sensor/data fusion validation purpose,
- Observations on request of the Global Fire Monitoring Centre (GFMC), national forest service centres, and the World Fire Web (WFW),
- Test and verification of fire models & fire-atmosphere models,
- Monitoring of volcanic activities (temperature, affected area, emissions),
- Monitoring of coal seam burning (preferably in China and India),
- Special field tests to compare the potential of an advanced spaceborne fire monitoring sensor with the alert capability of airborne and ground based forest fire alert systems (manned and/or automated observations from towers),
- Spaceborne proof of the "Forest Fire Earth Watch" detection sensor instrument concept (which is now under evaluation in the ESA study on "Forest Fire Earth Watch Utilisation Study and Mission Concept Refinement"),
- Observation of industrial fires or fires as a result of military activities,
- Observation of "moderate temperature difference phenomena" on Earth surface.

NEW SPACEBORNE FIRE DATA PRODUCTS

Both BIRD and FOCUS will provide new geophysical relevant ***Fire Data Prototype Products (FPDP)*** of wildfires and other HTEs, such as volcanic activities and coal seam fires:

- Surface temperature, area, and geo-location of fires (with an absolute accuracy of 300 m)
- Temperature and hot surface of active volcanoes

FOCUS will provide additionally the following new geophysical data products:

- Gas temperature,
- CO/CO_2 ratio as an indicator of combustion efficiency and fire type,
- Column content of fire and volcano gases, such as CO, NO, CH_4, H_2O, CO_2,
- CH4/CO, NO/CO_2 and aerosol/CO ratios,
- Temperature and humidity profiles, aerosol optical depth of smoke and larger plumes.

Table 7 gives an overview of some of these new Fire Prototype Data Products.

COMPLEMENTARITY

BIRD and FOCUS, to be operated simultaneously with MODIS/ ASTER on EOS AM1/ PM 1 and with AATSR/ MIPAS/ SCIAMACHY on ENVISAT, will timely provide new geophysical relevant spaceborne high temperature event data.

FOCUS is considered to contribute unique data to a multi-source fire data set, combining data with different spatial, spectral and temporal resolutions.

Product (FPDP)	Geophysical variable	Sampling step on Earth (m)	Geo-referencing accuracy (m)	Data processing specifics	New sensor, (sensor sub-system)
P 1	HTE area & Temperature	300 – 500	300 -500	off-line, on ground	BIRD
P 1 with Autonom. Detection	HTE area & Temperature	300 – 500	300 -500	on-line, on board	FOCUS (Fore Field Sensor and Brain)
P 2	HTE area & Temperature*	50	< 500	off-line, on ground	FOCUS (Main Sensor Imager)
P 3	Gas column content & temperature	<10.000	~ 500	off-line, on ground	FOCUS (Main Sensors)

Table 7. Expected new Fire Prototype Data Products (FPDP).

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