Advanced Fire Observation System (FOS) by Intelligent Infrared Sensors

by

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Abstract

Current and planned operational space-borne Earth observation systems provide spatially, radiometrically or temporally crude data for the detection and monitoring of high temperature phenomena on the surface of our planet. High Temperature Events (HTE) are forest and savannah fires, fires of open coal mines, volcanic activities and others.

A simultaneous co-registration of a combination of infrared (IR) and visible (VIS) channels is the key for a reliable autonomous on-board detection of High Temperature Events (HTE) on Earth surface. Furthermore there are ecology-oriented objectives mainly related to the sophisticated data fusion of spectrometric & imaging remote inspection and parameter extraction of selected HTEs, and to the assessment of ecological consequences of HTEs, such as aerosol and gas emission.

For local studies of selected hot spots, high resolution and the possibility to steer the sensor towards the potential high temperature event for close inspection are necessary. The Fore Field Sensor (FFS) will perform the wide-angle hot spot detection and mapping. For the detected and selected hot spots, the Main Sensor (MS) will be targeted and deliver detailed spatial high resolution observation.

FOCUS was selected from ESA as one of five European "Groupings" to be flown as an externally mounted payload during the early utilisation phase of the International Space Station (ISS). The FOCUS mission is the test-bed for technology and autonomy demonstration. The FOCUS Multi Sensor consists of two sensor systems: The multi-spectral Fore Field Sensor (FFS: VIS, MIR, TIR) and the Main Sensor (MS). The MS is composed of an imaging system (MS-IM: VIS, NIR, MIR, TIR) and a Fourier Spectrometer (MS-FS: 3-15µm).

As a follow on to FOCUS, the Fire Observation System (FOS) is foreseen, as a small dedicated satellite, caring the FOCUS qualified sensors system.
1 Overview

FOCUS is an intelligent infrared sensor system for the detection of High Temperature Events (HTEs), such as vegetation fires or volcanos. FOCUS is a scientific and technological demonstrator / precursor of an operational fire observation system and is proposed to be implemented on the early externally mounted European payloads of the International Space Station (ISS).

The Main Objectives of the FOCUS Mission are:

- **Reliable autonomous on-board detection and analysis of High Temperature Events (HTE)** due to:
  - 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 & multi-spectral imaging DATA FUSION, and Geophysical parameter extraction for selected HTE and their emissions

- **Near real-time HTE-cluster data georeferencing and transmission to ground terminals.**

The simultaneous co-registration of a combination of Infrared (IR) and visible (VIS) channels is the key for a reliable autonomous on-board detection of the HTEs on Earth surface. Furthermore there are ecology-oriented objectives of the FOCUS experiment mainly related to spectrometric / imaging remote inspection and parameter extraction of selected HTEs, and to the assessment of some ecological consequences of HTEs, such as aerosol and gas emission.

The FOCUS sensor will consist of a wide-angle fore-field sensor (FFS) for autonomous hot spot detection, a main sensor (MS) for detailed observation and analysis of selected high temperature phenomena (including its pollutant gas and smoke exhausted) and a sensor brain for the classification, parameter determination and geocoding of the fire data to be transmitted (with a low data rate and near real-time) to a world-wide user community. Figure 1 gives an overview of the mission scenario and the technical specifications of the FOCUS project.

The on-board real time autonomous hot spot detection is one of the main objectives of the FOCUS experiment on ISS. A FOCUS Fore Field Sensor (FFS) and a real-time processor are considered to achieve this challenging goal.

![FIG. 1: FOCUS MISSION OVERVIEW](image)
2 Competitor Deficiencies

Satellite fire detection and monitoring observations are currently in an experimental or pre-operational phase and directed to the development and testing of fire detection and analysis algorithms. The principal reason preventing an operational utilisation of the currently available satellite data for fire detection & monitoring is the absence of:

- satellite sensors which are optimized for this task (with co-registration of VIS & IR spectral bands, spatial resolution and very high dynamic radiometric range),
- satellites with required small revisit times, and
- near-time data processing and information delivery capability.

From new and dedicated space-borne sensors the global change research and disaster management community expects quantitative measurements of parameters like exact location (accuracy better than 0.5 km, 50-100 m resolution for local and a few hundred meters resolution for global observations), surface extent, and intensity of fire events, the frequency of their occurrence, and associated aerosol and trace gas emissions.

A dedicated spaceborne High Temperature Environmental Disaster Recognition System has to be developed beginning with a pre-operational experiment. Therefore the Intelligent Infrared Sensor System FOCUS - proposed as an external payload of the International Space Station - should be the prototype of an Environmental Disaster Recognition Satellite System.

3 History

Point of departure for the FOCUS project has been the FIRES (Fire Recognition System for Small Satellites) Phase A Study, initiated by DLR-Berlin and performed together with OHB-System. Starting from this FIRES study, DLR and OHB proposed FOCUS as a new approach to the design of autonomous satellite remote sensing systems. Based on DLR own experimental work and supported by an international team of Co-Investigators, DLR and OHB proposed in 1997 to use the ISS as a platform and test-bed (demonstration of technology and utilisation aspects) for the Intelligent Infrared Sensor prototype FOCUS.

FOCUS is considered by ESA as an important 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. FOCUS was selected as one of five "Groupings" to be flown as an external mounted payload during the ISS early utilisation phase and the peer review evaluation characterised the FOCUS Proposal as "acceptable to excellent". The Earth Science Advisory Committee (ESAC) of ESA recommended during its meeting on 27 June 1997 to retain FOCUS for the further payload selection.

ESA and NASA consider FOCUS as a co-operative Payload of the International Space Station. A nine-months FOCUS Phase A Study was performed by OHB-System (Prime Contractor), DLR and ZEISS under funding and supervision of ESA in 1998/99. Currently the Phase B/C/D/E is in preparation.

4 Intelligent Sensors

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 (see Figure 2) in the Autonomous Detection & analysis Mode (ADM) data take sequence:

- detection of hot spots with false alarm rejection and retrieval of temperature and area,
- coupling of hot spot imaging data with on-board navigation data (geo-coding),
- selection of relevant hot spots for detailed investigation by the FOCUS Main Sensor,
- derivation of control signals for pointing of the FOCUS Main Sensor instruments,
- thematic data reduction by on-board processing to allow near real-time data products being provided to potential users.

FIG. 2: Problem – where are Fires?

An autonomous fire detection algorithm has been successfully developed, simulated and computer tested during the FOCUS Phase A Study in 1999. It includes the outlined hot spot detection tests, auxiliary operations (data correction and co-registration, geo-referencing and adaptation of the algorithm parameters using the navigational data, see Figure 3) as well as selection of a target for detailed observations by the Main Sensor. Its feasibility for implementation on available space-qualified processors has been demonstrated.
During the ADM the FOCUS Brain has to generate a control signal for the drive a mirror to point the Main Sensor (MS) within less than 15 sec. after the registration of a hot spot signal by the FFS. The MS imager (MS-IM) and spectrometer perform a close investigation and analysis of the selected HTE. The FOCUS Imaging sensors will be push-broom instruments:

- Cadmium Mercury Telluride detector line array,
- >1000 detector elements (machine cooled)
- adaptive dynamic range of ~20 bit
- tested at DLR with the BIRD airborne model in spring 1999.

For the FOCUS spectrometric sensor (MS-FS) a Fourier transform spectrometer with 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 – CMT and InSb - will be installed.

In order to retrieve more than just average temperature and gas concentration profiles for the entire scene seen by MS-FS, a combination of the MS-IM and MS-FS (Data Fusion) observations is mandatory. Assuming that the distribution of flaming, smouldering, etc scenes is already known from an analysis of the MS-IM data, the relative area contribution and corresponding surface temperatures are used as input to the radiative transfer calculations (surface term contribution) required to iteratively solve the non-linear least squares problem to fit the spectral data (sequential approach, see Figure 4).
## 5 On-Board Processing

The Autonomous Detection Mode is the main design driver of the FOCUS on-board data handling which has to perform the following tasks:
- Real-time processing of the Fore Field Sensor signals as area of interest definition and coarse hot spot parameter estimation,
- Real-time control of the Main Sensor as needed for directing the MS view to the areas of interest and to avoid MS saturation,
- Near real-time classification, parameter determination, and geocoding of the high temperature event data observed by the Main Sensor.

Besides this on-line tasks, the following off-line tasks have to be performed:
- Data Compression of the imaging data and
- Calculation of Spectra from the MS-FS Interferograms, in order to reduce the data volume to be transmitted via the small bandwidth ISS link to the ground.
- Calibration calculations
- Attitude and position data filtering, in order to improve the accuracy.

The tasks have to be performed within the operation profile shown in Figure 5.

### Requirements

The resulting requirements from operations are:
- 20 min. Nominal Measurement Cycle (NMC)
- 4 NMC per day & within consecutive passes
- 27.8 ms per FFS line for on-line processing
- 28-90 sec. between FFS and MS re-imaging
- ca. 22 MFLOP for AD 0-1-2-3-4
- 90 Mbit/s cumulative raw data to be stored
- 6 Mbit/s raw data to be processed on-line
- 52 Gbit data volume per NMC
- 3.4 – 0.5 Mbit/s transm. rate to the ISS

### Concept

The listed tasks and performance requirements will be realised within the following chains:
- **On-line FFS Data Processing:**
  - HTE detection, ATTM pointing and low data rate downloading to user terminal
- **Off-line Data Processing:**
  - FS spectogram, calibration
- **Data Compression:**
  - Quasi-lossless / lossy data compression
- **Data Transmission:**
  - Data transmission to ExPA I/F.

This tasks are performed by an sophisticated data handling system consisting of (see Figure 6):
- One DSP for each IR-IM detector (total 4 DSPs)
- Two DSPs for the autonomous detection
- Solid State Recorder: 1,2Gbit/s IO rate, 12 input 2 output, channels, Tbit Capacity, modular
- SpaceWire (IEEE-1355) Light Mezzanine Board for the XPLC: 100 Mbit/s link

### FIG. 5: Operation Profile per Day

<table>
<thead>
<tr>
<th>Chain</th>
<th>Processes / Events</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 / 2</td>
<td>SM-1: Cool-down</td>
<td>25 Min</td>
</tr>
<tr>
<td>1 / 2</td>
<td>SM-2: Calibration (ICDT)</td>
<td>5 Min</td>
</tr>
<tr>
<td>1 / 2</td>
<td>SM-3: FFS HTE AD</td>
<td>20 Min</td>
</tr>
<tr>
<td>1a</td>
<td>SM-3: MS Control</td>
<td>&lt; 5 sec</td>
</tr>
<tr>
<td>1b</td>
<td>SM-3: User Downlink</td>
<td>TBD sec</td>
</tr>
<tr>
<td>1 / 2</td>
<td>SM-4: Calibration (CCDT)</td>
<td>5 Min</td>
</tr>
<tr>
<td>2</td>
<td>Off-line Data Processing</td>
<td>TBD Min</td>
</tr>
<tr>
<td>3</td>
<td>Data Compression</td>
<td>305 Min</td>
</tr>
<tr>
<td>4</td>
<td>Data Rate Transmission</td>
<td>305 Min</td>
</tr>
</tbody>
</table>

**FIG. 6: Operation Equipment per Day**
6 System Details

The FOCUS Elements are shown in the Figure 8:

**Instrument:**
- **Payload Sensor Unit (PSU):**
  - Fore Field Sensor (FFS):
    - FFS Imager (FFS-IM)
    - Across Track Pointing Mirror (ATPM) & Calibration Units
- **Main Sensor (MS):**
  - MS-Imager (MS-IM)
  - MS-Fourier Spectrometer (MS-FS)
  - Across Track Tilt Mirror (ATTM) & Calibration Units

**Data Processing Unit (DPU)**
**Data Storage Unit (DSU)**
**User Terminal Unit (UTU)**
**Attitude Determination Unit (ADU, optional)**

The Support Equipment handles the interfacing to the ISS in terms of commands, house-keeping, control, data transfer, power management, thermal control and mechanical interfaces.

**Support Equipment:**
- Payload Control Unit (PCU)
- Power Distribution Unit (PDU)
- Mechanical & Thermal Interface & H/W

The Ground Segment is divided into the ISS External Payload Ground Segment, used for nominal house-keeping and science data download and Command and Schedule upload. An additional user terminal link will provide real-time down-link to mobile user terminals for HTE analysis data products. The External Payload Ground Segment is embedded in the COF Ground Segment, the operational requirements being of the same kind as the COF pressurised payloads.

**Ground Segment :**
- ISS G/S:
  - NASA G/S (SSCC, POIC)
  - ESA G/S (POCC) linked via IGS to NASA G/S
  - FOCUS G/S linked to POCC (mission & ops)
- FOCUS mobile user terminals (real-time data)

**Figure 7** and the performance list at the right side gives an overview of the technical specifications of the FOCUS system consisting of the advanced IR sensors, on-board data processing and the ISS interfacing elements.

- **Mass:**
  - Instrument 160 kg (incl. P/L D/H)
  - total 216 kg (incl. margin)
  ( < 227 kg max.)

- **Power:**
  - Operation 310-760 W (incl. heating)
  - Stand-by 300 W (110 W Stay Alive)
  - Peak 880 W (incl. margin)
  ( < 950 W max.)

- **Data:**
  - Generated 56 Mbit/s (90 Mbit/s w.c.)
  - Vol. per NMC 24 Gbit (52 Gbit w.c.)
  - Dump Rate 0,5 Mbit/s (3,4 Mbit/s)
  & Duration 206 min (305 min w.c.)
  - User Link ≥10 kbit/s (UHF or S-Band)
7  User & Requirements

The potential user for IR high and also medium temperature data products are:
- Research community
- Politicians, Administration
- Commercial users
- Disaster management

User needs are quantitative measurements of geophysical parameters with the resulting requirements for HTE spaceborne sensors are:
- Accurate location (sub-km)
- Surface area and temperature
- Frequency of occurrence
- Trace gas and aerosol emission characteristics

The following moderate temperature difference phenomena can be observed by FOCUS:
- thermal processes in deposit dumps,
- urban heat islands,
- effects of “green belts” on the climate,
- geothermal anomalies,
- thermal pollution of inland waters.

8  Fire Data Products

FOCUS will provide new geophysical relevant imaging Fire Prototype Data Products (FPDP) of wildfires and other HTEs, such as volcanic activities and coal seam burnings (see Figure 9).

FOCUS will provide additionally the following new geophysical data products based on Data FUSION of multi-spectral imagery from the Main Sensor Imager (MS-IM) and the spectral high resolution data provided by the IR Fourier – Spectrometer (MS-FS): CO/CO2 ratio as an indicator of combustion efficiency and fire type, column content of fire and volcano gases, such as CO2, CO, NO, CH4, H2O, aerosol optical depth of smoke and larger plumes.

Table 1 gives an overview of some of these new Level 2 Fire Prototype Data Products.

<table>
<thead>
<tr>
<th>Product (FPDP)</th>
<th>Geophysical variable</th>
<th>Sampling step on Earth (m)</th>
<th>Geo-referencing accuracy (m)</th>
<th>Data processing specifics</th>
<th>Sensor sub-system</th>
</tr>
</thead>
<tbody>
<tr>
<td>P 1 with Autonom. Detection</td>
<td>HTE area &amp; temperature</td>
<td>300 – 500</td>
<td>300 -500</td>
<td>on-line, on board</td>
<td>Fore Field Sensor (FFS) and Brain</td>
</tr>
<tr>
<td>P 2</td>
<td>HTE area &amp; temperature</td>
<td>&lt; 500</td>
<td></td>
<td>off-line, on ground</td>
<td>Main Sensor Imager (MS-IM)</td>
</tr>
<tr>
<td>P 3</td>
<td>Gas column content</td>
<td>10.000</td>
<td>~1000</td>
<td>off-line, on ground</td>
<td>Main Sensors (MS-IM and MS-FS)</td>
</tr>
</tbody>
</table>

FIG. 9: FOCUS FIRE DATA PRODUCTS

Plumes
- temperature and humidity profiles
- spatial distribution of gas / smoke
- composition of fire and volcano gases
- combustion efficiency parameters
- fire classification
- aerosol information
Mission

Table 2 and Figure 10 on the next page (450 km orbit and regions of interest) show the areas foreseen for controlled/active vegetation fire field experiments (mainly in the upper mid latitude belt at 50°), for dedicated volcano observations (Etna in Italy, Merapi in Indonesia) and comparing fire alert experiments (Brandenburg/Germany and Cote d’Azur, France).

Larger boreal forest regions in Canada and in Siberia are in the northern “upper mid latitude belt” which will be very well covered by FOCUS on the ISS providing a unique capability (compared with sensors in sun-synchronous orbits):
- multiple daily observation capacity, and
- fast observation repetition rates

as shown in Figure 11 (orbit segment with overlap regions) of the FOCUS on ISS coverage for a 450 km orbit.

<table>
<thead>
<tr>
<th>Region</th>
<th>Latitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boreal Forests – South Canada</td>
<td>50° N</td>
</tr>
<tr>
<td>Brandenburg / Germany</td>
<td>53° N</td>
</tr>
<tr>
<td>Cote d’Azur</td>
<td>44° N</td>
</tr>
<tr>
<td>Etna</td>
<td>37° N</td>
</tr>
<tr>
<td>Boreal Forests-Russia/Irkutsk</td>
<td>52° N</td>
</tr>
<tr>
<td>Mongolia (Region Ulan Bator)</td>
<td>48° N</td>
</tr>
<tr>
<td>Amur Region</td>
<td>50° N</td>
</tr>
<tr>
<td>Thailand</td>
<td>15° N</td>
</tr>
<tr>
<td>Indonesia</td>
<td>0° N</td>
</tr>
</tbody>
</table>

TAB. 2: REGIONS OF INTEREST

FIG. 10: FOCUS ISS 24H COVERAGE

FIG. 11: FOCUS ISS 24H COVERAGE (ALTITUDE: 450 KM, WITH OVERLAP REGIONS)
The contribution of FOCUS in detecting and characterising forest fires will be very significant in several regions well covered by the ISS orbit:

- **The southern boreal forest regions of Canada and Russia:** This forest belt is becoming increasingly vulnerable to fire due to intensifying land occupation/use associated with human-caused fires.
- **The transition zone between the boreal forest and the steppes in Mongolia:** The extended fire episodes of 1996 and 1997, in which more than 10 and 12 million ha respectively burned, have shown that this region must receive a high priority in fire protection.
- **The mountain-boreal forest of Northern China:** This region has experienced dramatic changes of forest ecosystems due to logging and fire. This process, associated with recurrent extreme dry spells, has resulted in an increasing vulnerability to fire.

The volcanoes Etna, Stromboli in Italy and Merapi in Indonesia have been selected by the FOCUS Co-Investigators involved in volcanic scientific investigations as the main targets for dedicated volcano observations.

FOCUS will allow to **compare within field experiments** the fire recognition capability of advanced spaceborne fire detection sensors and aircraft or ground based forest fire surveillance / alert systems.

**10 Operations**

The following data acquisition aspects are considered for FOCUS:

- Earth Observation Data Take (EODT) duration max. ca. 20 min (due to data volume and ISS data transmission constrains),
- Up to four Earth Observation Data Takes (EODT) in 24 h (mainly due to the data volume limitations),
- Consider and use the illumination variation of the non-sun synchronous ISS orbit,
- Use the excellent upper mid latitude belt coverage / multiple daily observation capacity,
- Possibility of up to three successive overpasses of the same area within the latitudes of ± 50°,

Two main operation modes are considered:

- **The Autonomous Detection and analysis Mode (ADM),** foreseen for the observation of unknown events, and
- **The Controlled Detection and analysis Mode (CDM),** foreseen for the observation of selected and known targets.

The main FOCUS observation scenarios are listed in **Figure 12:**

- Vegetation fire observation,
- Controlled vegetation fire observations,
- Volcano observations,
- Observation of moderate temperature difference phenomena.

**FIG. 12: OPERATION AND INSTRUMENT MODE DEFINITION**

**11 Outlook**

**Scientific and Ecological Benefit**

Compared with the existing satellite sensors – such as AVHRR on NOAA satellites and ATSR on ERS 1 & 2 spacecraft - used so far for the detection of fire occurrence - the experimental IR sensor system FOCUS will have a large delta providing geophysical relevant High Temperature Event (HTE).

**FOCUS will permit first time:**

- Direct messaging of HTE data from space – based on on-board real time HTE detection and analysis of its Fore Field Sensor data.
- The retrieval of HTE gaseous emission products - based on DATA FUSION of high resolution IR imagery and high resolution IR spectrometry of its Main Sensor data.
Possible Pre-operational Application Impacts

FOCUS will allow to compare within field experiments the fire recognition capability of advanced spaceborne fire detection sensors and airborne or ground based forest fire surveillance / alert systems (manned and automated towers).


The potential user community of the Forest Fire Earth Watch (FFEW) will definitely benefit from the implementation of FOCUS, this due to the across track pointing capability of the FOCUS Main Imaging Sensor (MS-IM), which can provide first experimental data sets with a ground resolution and detection capability very close to the current FFEW detection sensor requirements.

FOCUS as a scientific and technological demonstrator / precursor of an operational fire observation system must be implemented by the first flight opportunity for the early externally mounted European payloads of ISS.

Future IR-System

FOCUS will establish the technology, algorithms and products for a high quality High Temperature Event detection, monitoring and analysis:

- **FOCUS is without competition today** in the field of autonomous and global operating High Temperature Environmental Disaster Recognition Satellite System
- **FOCUS demonstrates** the established German IR competence and turns this in commercial Applications.

FOS will convert this knowledge and experience into commercial fruitful system:

- **FOS has a high potential** for commercial, scientific as well as administrative user in the field of earth observation.
- **FOS is attractive for reconnaissance applications (add-on to visible and radar systems).**

FIG. 13: FUTURE IR-OBSERVATION SYSTEM

Next Generation Fire Observation Satellites

12 Acknowledgement

We appreciate very much the valuable support from Dr. Knott and Mr. Sabbatini (European Space Agency, ESA/ESTEC) and from Mr. Koenemann and Dr. Schneppe (national space agency, DLR-BO).

13 References