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An Innovative Conceptual Model of a Forest Fire Management Information and Decision-Support System for Brandenburg State, Germany

Abstract

Research and development conducted within the Forest Fire Cluster of the German Research Network on Natural Disasters is built on a number of separately evolved concepts that were integrated in a cooperative research project. The Forest Fire Cluster has the responsibility of three major components. The first component consists of an innovative conceptual model for a fire information system and decision-support for early warning, monitoring, information management and simulation of wildfires in pine forests of Brandenburg State, Germany. The second component provides the link between the locally applicable system and a global fire information system provided by the Global Fire Monitoring Center (GFMC). The third component includes modelling of historic occurrence and future trends of fire occurrence due to regional climate change and is implemented by an associated project of the Potsdam Institute for Climate Impact Research (PIK), and it is published separately.

The first component is composed by a number of different modules. Firstly, it includes the adaptation of established fire behavior simulations models (BEHAVE, FARSITE) implemented by the Fire Ecology Research Group. For the first time a fire behavior model has been applied for the specific conditions of pine forests in the eastern, continental part of Germany, including the interspersed heathlands that constitute an important carrier of a wildfire at landscape level. The characteristics of these forests are quite typical for temperate-hemiboreal pine forests of Eurasia. Secondly, it includes a fire detection component (Automated Fire Detection System - AWFS) implemented by the German Aerospace Center (DLR). The development of the AWFS meets the requirements for fast, cost-effective and reliable fire detection system. And thirdly, it includes a fire danger rating and forecast system implemented by the (German Meteorological Service - DWD). The national fire-danger rating system has consolidated during the project lifetime. During the research project the work of the Global Fire Monitoring Center (GFMC) constituted the link from national to international levels.

The value added by the research project is a mutual support of individual research projects and their final merging into a comprehensive decision-support tool for fire management. Insight gained by the research project concerning the operational use of satellite remote sensing information in the management of active wildland fires will be useful for the development of urgently needed operational spaceborne fire systems.

Keywords: Forest fire, wildland fire, decision support, fuel classification, fire behavior, fire weather, fire detection, fire modelling, dispatch, remote sensing.

1. Introduction

The current high probability of forest fire occurrence in Brandenburg, Germany resulting in part from low precipitation, sandy soil sites with low water-holding capacity, and the fire hazard of the prevailing fire-prone pine forest stands, might further increase due to climatic change (Thonicke and Cramer, 2006). The cluster "Forest Fire" within the German Natural Disaster Research Network (DFNK) analyses current fire hazards and provides tools required for advanced operational decision support for wildfire response. This cluster research has the responsibility of three major components. The first component consists of an innovative conceptual model for a fire information system and decision-support for early warning, monitoring, information management and simulation of wildfires in pine forests of Brandenburg State, Germany. This component includes the adaptation of established fire behavior simulations models (BEHAVE, FARSITE) implemented by the Fire Ecology Research Group, a fire detection component (Automated Fire Detection System – AWFS) implemented by the German Aerospace Center (DLR) and a fire danger rating and forecast system implemented by the (German Meteorological Service - DWD). The second component provides the link between the locally applicable system and a global fire information system provided by the Global Fire Monitoring Center (GFMC). The third component includes modelling of historic occurrence and future trends of fire occurrence due to regional climate change and is implemented by an associated project of the Potsdam Institute for Climate Impact Research (PIK); the report of the third component is published separately.

Accordingly, the structure of this work follows this general cluster scheme and it is presented in sections each one corresponding to a specific issue raised in each component. To help the readers follow we briefly present this general scheme which it is distinguished into the research components for building a fire information system and the implementation of the fire information system. The former consists of three modules that is fire behavior simulation models, automated fire detection system, and fire danger rating and forecast system. The concepts, methods and results of each one of these modules are presented in details in the following corresponding sections. The implementation of the fire information system operates as an umbrella and intends to put together all modules by providing a common basis for their requirements and needs.

What it is aimed by the implementation of the forest fire management information and decision-support system is a multi-function based system to cover not only the fire behavior modelling-simulation part but to cover also various research and applied issues in wildland fire management. This fire information system could be also utilized as a warning solution by estimating fire risk potential given that a network of weather stations can be online connected with it. The ability to simulate a real process under hypothetical scenarios can help to acquire a prior knowledge about the effects and outcomes resulting from such processes and contribute for a better fire management and planning. An optimized dispersal of fire fighting forces especially under conditions of limited resources can be achieved by utilizing a prior knowledge of fire behavior acquired by the simulation. The fire simulation provides a lot of insight of what has to be expected from a particular fire situation, not only in terms of the physical parameter of a fire (rate of spread, intensity). The simulation on a landscape scale allows the prediction of fire direction and its behavior in the field setting. Dispatching of firefighting resources will be made much easier and effective.

2 Forest and Heathland Characteristics in Brandenburg, Experimental Site of 2001

The Forest Fire Experiment 2001 was conducted at various forest stands that have characteristics typical for extended pine forest stands in Brandenburg State, Germany. For the development of a fire behavior model specific data are essential. As data like fuel load, rate of spread, flame length, temperatures and fire weather were not existing, live burning experiments were conducted to collect these input-data.

The experimental sites of 2001 are owned by Vattenfall Mining Europe (former Lausitzer Braunkohle AG) open-cast coal mining enterprise near the city of Cottbus (51°47'03''N, 14°24'20''E). The location and characteristics of the experimental plots, each between 0.3 ha and 1 ha surrounded by a clearcut buffer zone, provided suitable conditions in terms of safety for an experimental forest fire. Three of the plots were up to 100 years old low-productivity Scotch pine (*Pinus sylvestris* L.) stands with minor dimensions, typical for the region. The fourth plot was a 15-years old *P. sylvestris* stand. The fuel bed at all four plots consisted mainly of grass (*Calamagrostis* spp., *Deschampsia* spp.), forest litter and dead downed woody material. The fuel load (available fuel for the experimental fire) varied from 5 to 15 t ha^{-1}.

For the validation of a heathland fire model experimental fires were conducted in continental heathlands (*Calluna vulgaris* (L.) Hull.) in the Federal Forest Service District Lausitz in summer 2002. For these experimental fires the Federal Forest Service provided three plots (0.5 ha each) with homogeneous *C. vulgaris* cover.

The purpose of a heathland model was to include the heathland-forest interface in the decision support system in case of catastrophic wildfires. Open sites covered by heather vegetation located between forest complexes are suitable to rapidly carry a wildfire from a burning forest to the adjoining forest stand. The fuel loads on the heathland plots ranged between 9 and 15 t ha^{-1}.

Both experimental areas are located in the south-eastern part of Brandenburg State, a region with a very low level of precipitation and sandy soils with little water storage capacity. The climatic conditions for both experimental sites are as follows:

Climatic zone:	medium-dry lowland climate
Average temperature (Cottbus):	8.8 °C
Average annual temperature scale:	19.3°C
Average annual precipitation (Döbern):	627 mm
Precipitation during the vegetation period:	316 mm

The combination of the site characteristics with the inherent characteristics of the *P. sylvestris* stands and the *C. vulgaris* ecosystems result in a high wildfire hazard. Figure 1 provides a scene of the forest fire experiment conducted for the research project in 2001 that shows the spatial arrangement of surface and live crown fuels that lead to high-intensity crowing fire.

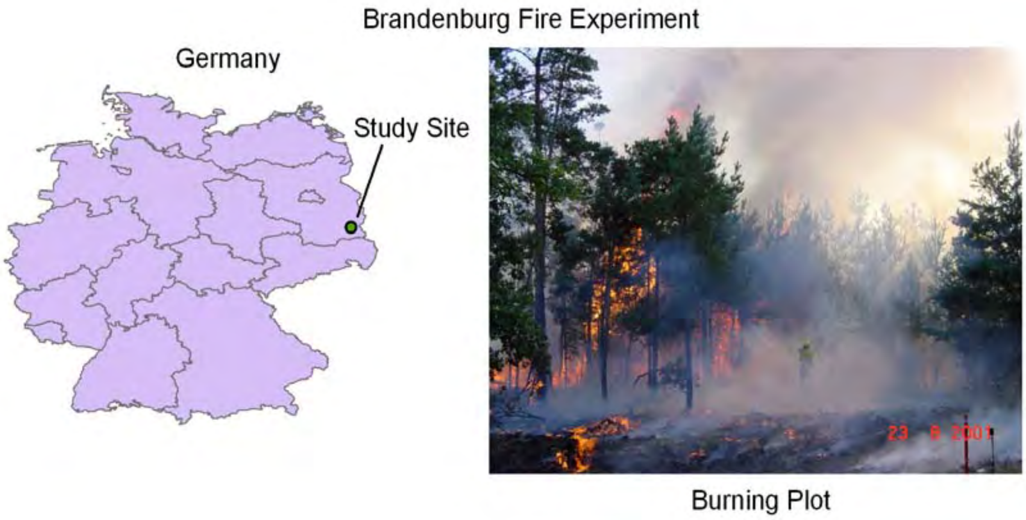

Figure 1. View of one of four burning plots of the Brandenburg Fire Experiment, 23 August 2001. The experimental site was structured inhomogeneously, thus allowing to observe a range of different fuel and fire behavior conditions.

3 The Research Components for Building a Fire Information System

3.1 Automated Fire Detection System AWFS

The Automated Fire Detection System AWFS (Kührt et al., 2000) provides the fire detection and location component of the Forest Fire Management Decision-Support System (Fig. 3). The AWFS was designed to meet the following technical requirements specified by German forest authorities:

- Automatically recognize smoke formation of 10 m expansion within a radius of 10 km and within 10 minutes after becoming visible
- High reliability in respect of fire recognition
- Acceptable rate of false alarms
- Localize the source of the fire
- Easy maintenance
- Automatic transmission of smoke data to a control center
- Full record-keeping of all events
- Data transmission to control center must enable the operator to independently evaluate the potential hazard
- The costs should be lower compared with the conventional method (fire detection towers operated by personnel)

Technical systems for forest fire detection use CCD cameras, infrared sensors, and spectrometers for detecting the smoke gases, laser backscattering, or other methods. AWFS tested in Germany is a system based on a high-resolution Frame Transfer CCD camera with special red-free filter which was originally developed for space missions (Michaelis et al., 1999). AWFS detects fire by the trail of smoke within some minutes after its visibility. One system controls an area of about 300 square kilometers. The camera scans the forests from the top of the observation tower. The pictures are resolved with 14 bits and transmitted via optical fibers to the computer unit which is located in the tower. Here they are analyzed by specially developed software. At any detected smoke formation, compressed pictures and further details (time, position) are reported to the control center, where they are processed in a PC and displayed on a monitor. With a number of computer-assisted supports the operator is able to make reliable decisions.

3.1.1 Tests and results

AWFS was installed and tested on three observation towers in the State of Brandenburg, Germany, during the four forest fire seasons (1999-2002) and with special test activities. One of these activities was the Brandenburg fire experiment on 23 August 2001.

Each of the more than 120 fires which arose in the observed region of about 1000 km^2 during the test period was recognized within some minutes. The false alarm rate due to special weather conditions and harvest activities (dust clouds) commonly remained below 2 %, which is well acceptable for the operator who evaluates the alarms of several systems and calls the fire brigade.

The absolute bearing exactness of every camera is better than 1°. Therefore, several systems can locate the source of fire with approximately 100 m at a distance of 10 km. An impressive example for the precision of locating fires was a smoke signal of a structural fire in a small town in Brandenburg State, several kilometres away from the observing towers. With the intersection of bearings from two towers and the use of the digital map it was possible to determine the name of a short street in the town where the fire had started. The fire department was alerted immediately.

In the forest fire experiment in 2001 AWFS detected all four experimental fires within one revolution of the camera, i.e. within seven minutes. In one case the alert was already given about one minute after the smoke came up.

3.2 Fire Behavior Simulation Models

Since no adequate models exist to describe fire behavior under central European conditions, models developed and successfully applied in other regions had to be used and adapted. The standard software BEHAVE developed at the U.S. Forest Service Intermountain Sciences Laboratory (Rothermel, 1972) provided an appropriate tool, especially since they are representative for homogenous ecosystems and fuel arrangements. Predicted fire behavior parameters from the BEHAVE model were compared with those observed in Brandenburg's pine forests and heathland fires.

In a subsequent step, a fire dispatching and modelling system was created with FARSITE (Finney, 1998) at the forest district level. The FARSITE model contains the same algorithms and formulas as BEHAVE, but can be used to simulate fire on a range of landscape features with different fuel models using a GIS-approach. Thus, the data have to be prepared in raster format. The input data sets contain information about elevation, slope, aspect, fuel type, crown closure, stand height and crown bulk density (Finney, 1998). The fire itself is modelled as a moving elliptical wave, the shape of this ellipse is determined by wind and topography (Huygens’s principle, cf. Richards, 1990, 1995).

The work presented in this section describes the construction and testing of new and appropriate fuel models through fuel inventory and comparisons of predicted versus observed fire behavior parameters. Fuel models are one of the basic inputs to fire behavior simulation modelling and they are described by a number of parameters associated to fire propagation dynamics.

3.1.2 Field inventories

Fuel sampling within 35 pine stands in the region was conducted with the transect method by (Brown, 1974). A classification of fuels is possible into one of the four time-lag classes (1, 10, 100 or 1000 hours). The time-lag is defined as the time period required for a fuel particle to reach approximately 63% of the difference between the initial moisture content and the equilibrium moisture content in a different milieu (see Byram, 1963). This characteristic of the fuel particle is strongly correlated to its diameter, so in fire management one estimates the time-lag period by measuring the particles´

diameter. Dead and downed woody fuels have been grouped into classes that reflect the rate at which they can respond to changes in atmospheric conditions (i.e., 1-hour = <0.6cm, 10-h = 0.6-2.5 cm, 100-h = 2.5-7.6 cm and 1000-h = 7.6-20.3cm diameter).

Additionally, grass and duff sampling was done on 0.5 m^2 plots within the stands. The entire above-ground material was sampled to determine the oven-dry weight (load per ha).

The pine stands were classified using cluster analysis into six groups. Factors determining grouping were stand age and the time since last thinning. In young pine stands (<20yrs.), the litter layer consisted mainly of 1- and 10-h fuels, while grasses were not established yet. Older stands (21-40 yrs.) are structured similarly, but with higher amounts of available fuels. In later stand stages (41-60 yrs.) grasses and shrubs invade due to increased light availability on the forest floor. Old stands are characterized by thick duff layers, a continuous grass layer and less dead and down material. Very high amounts of dead and down material was observed in stands where thinning was conducted before their fifth year. Usually, thinning take place from stand age 35, so that younger stands are not affected. For detailed information on fuel classification in pine stands and other parameters included in the modelling process see Hille and Goldammer (2002).

Heathlands are rather homogenous fuels of a single species. The shrub *Calluna vulgaris* is classified as 'live woody fuel', dead parts of the plants and litter beneath them are considered as 1-h fuels.

Two of the created fuel models were actually validated in the field. Fuel model 23 was tested during a forest fire experiment in summer 2001 (Goldammer et al., 2001). The heathland model 26 was validated in summer 2002. Descriptions of all fuel models developed are summarized in Table 1.

3.2.1 Experiment results – Fuel model validation

Figure 2 shows the simulation results with the measured fuel and weather data during the fire as input into the BEHAVE-model and the observed fire characteristics. For the conditions measured during the fire, the BEHAVE-model calculates a fast increase of fire spread for higher wind speeds, the pine model #23 being more influenced by wind speed than the heathland model.

We observed a high variance of observed spread rates, which was caused by fuel inhomogeneity and short-time changes in wind speed. Therefore, the observed values are visualized by ranges (ellipsoids in Fig. 2). For the pine model #23, the simulated fire spread for a range of wind speeds (line in Fig. 2) goes right through the cloud of observed fire spread (ellipsoids). In heathlands, the predicted rate of spread is below the observed average spread by ~20%.

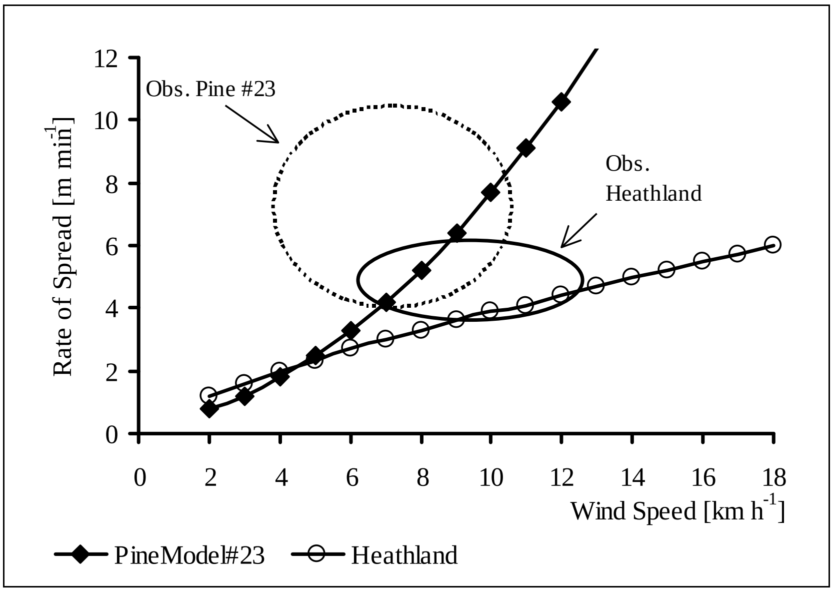

Figure 2. Simulated fire spread (lines) for the two tested fuel models and the observed data from the fire experiments (ellipses). Due to a high variation in wind-speed during the experimental burns, it was impossible, to measure the exact wind-speed and the time when rate-of-spread measurements were taken. Therefore the range of wind speed during the experiment and the measured spread rates are presented here.

Given the high variability of fuel and wind, the fire behavior is well met with the two models. Especially for the pine model #23, the calculated spread rates and flame lengths (data not shown) are in range of the observed values. We therefore assume that also the other created fuel models for pine stands (Tab. 1) will give reasonable results in predicting fire behavior, although they are not validated yet.

Table 1. Fuel models for pine stands of different age and continental heathlands. Fuel loads of the different fuel classes were used as the main input parameter in FARSITE. Fuel model 25 corresponds to all stands independently from their age.

Model	**Stand Type**	**Grass**	**1-h**	**10-h**	**100-h**	**Live woody**	**Fuel bed depth**
#		**t ha^{-1}**					**m**
21	<20 yrs.	0	7.81	7.61	0	0	0.15
22	21-60 yrs.	0	8.06	11.7	4.09	0	0.2
23	61-100 yrs.	0.78	8.13	13.43	2.56	0	0.2
24	>101 yrs.	0.54	11.61	17.84	1.02	0	0.15
25	Thinning <5 yrs.	0.42	10.27	20.57	6.47	0	0.3
26	Heathland	0	3.20	0	0	9.60	

3.2.2 Simulation results – Model application

Using the results and the gained experience of the BEHAVE modelling, a FARSITE simulation was created. On a 1000 ha former military bombing range, covered with pine forests and extensive heathland areas (Federal forest in the Lausitz region, Eastern Germany), fuel and stand information was collected to allow a classification by fuel models specified in Table 1 (see also Burgan and Rothermel, 1984).

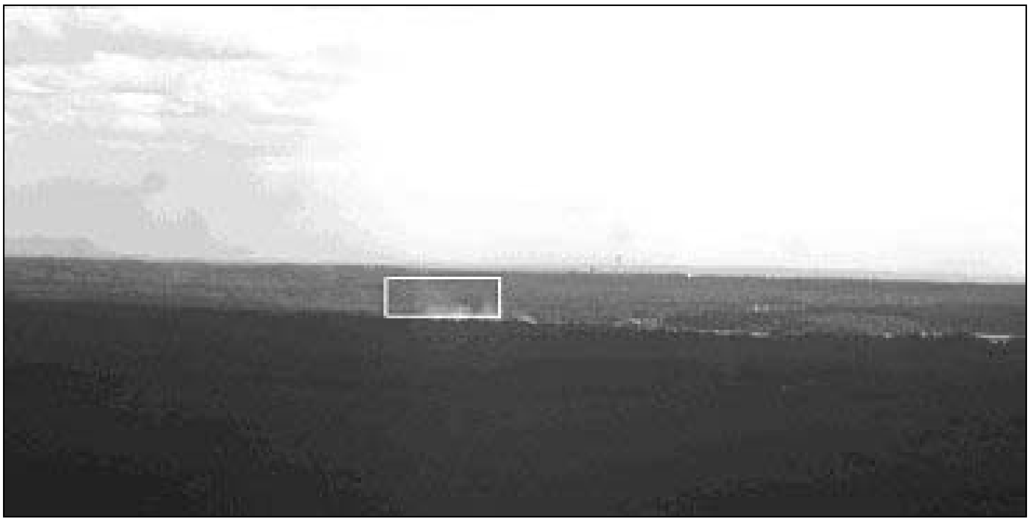

Figure 3. Screenshot of the workable FARSITE 2-D landscape view. Colours represent different fuel models. Forest roads and fire barriers are displayed as grey thin and thick lines, respectively. Two ignitions are modelled for 6 hours under dry weather conditions with strong winds from the west. The two fires are not stopped by forest roads, only the wide fire barriers of bare mineral soil (30 m wide) are able to stop fire's spread.

For the fire simulation, a digital landscape was created, using available information such as maps, digital elevation models, stand boundaries, roads etc. A raster grid of 6 x 6 m was chosen to be able to represent even small compartment and fire breaks (which are 30m wide in reality) within the study area. Figure 4 shows the workable raster view of parts of the simulation area.

The FARSITE model is very useful in extreme fire weather situations, where several fire suppression resources have to be positioned at places where they can reach high effectiveness. One scenario is presented in Figure 4: Under dry conditions in late summer (Temp. 30° C, RH below 50 % and strong winds from the West [17 km h^{-1}]) two ignitions were observed by the Automated Fire Detection System (cf. para. 3.2). The coordinates are imported into FARSITE and the simulation runs for six hours.

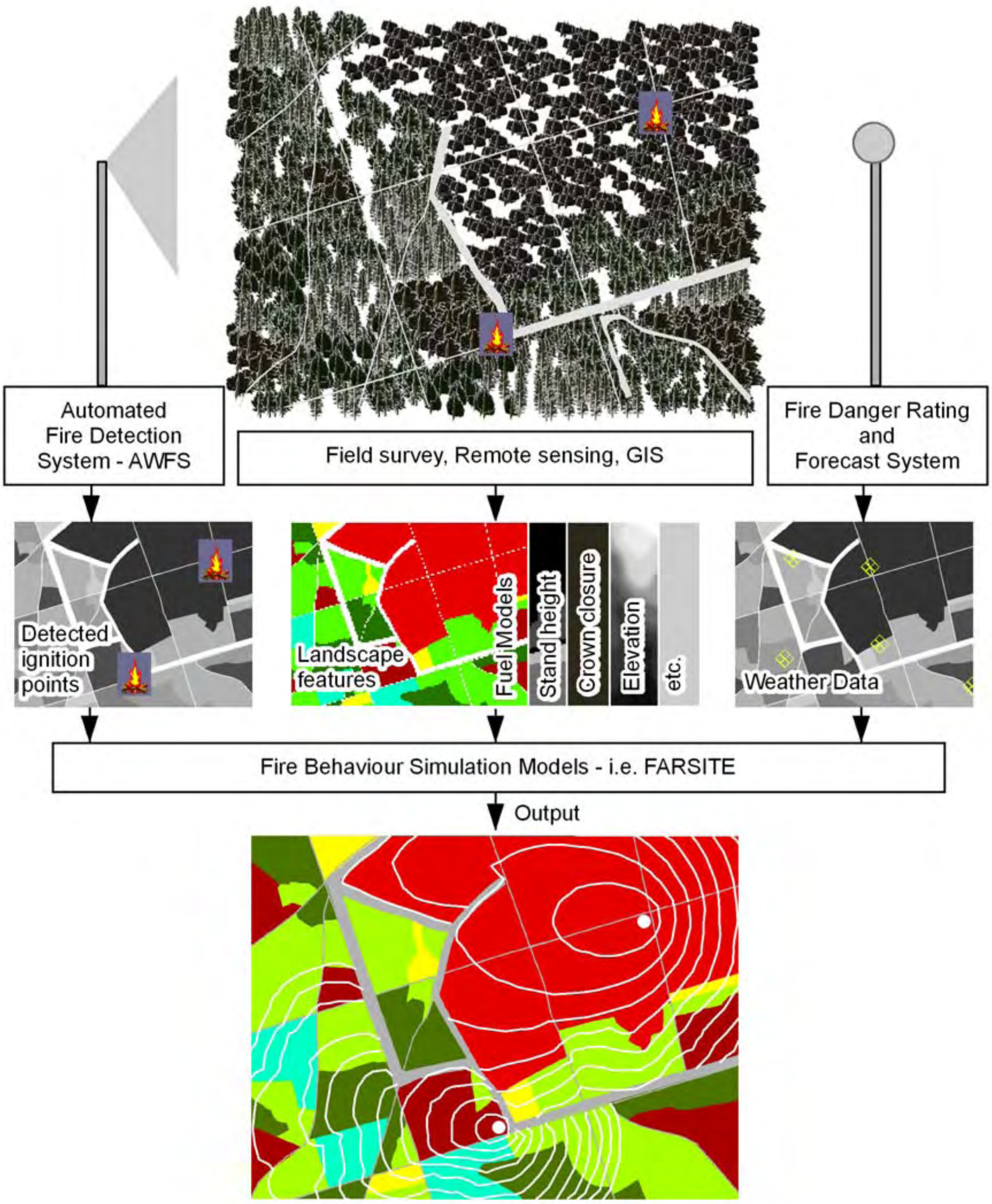

Figure 4. Visual impression of forest fire smoke detection by the AWSF at start of the 2001 Brandenburg fire experiment.

FARSITE calculates the expected spread of the fire in 30-minute intervals, presented as thin white lines in Figure 4. The model outputs reveal that the forest roads are not able to stop or slow down the fire. The fast fire spread in the heathland (Mod. 26) makes suppression very difficult and dangerous. Therefore fire suppression resources have to be positioned at the wide fire barriers (30 m wide fuel breaks) in the sampling area (grey areas).

The second ignition in the southern part of the test area occurred in a pine forest. Here, the spread is slower, but without suppression activities, the fire would not stop at the forest roads, too. Under a situation, where suppression forces are limited, one would decide to locate all engines around the forest fire and trust on the effectiveness of the fire barriers, which will stop the heathland fire according to the simulation.

3.3 Fire Danger Rating and Forecast System

It is commonly known that some of the facets of weather support the ignition and propagation of forest fires: on the one hand, lightning strikes may directly ignite fires, and on the other hand, precipitation and evaporation affects the water content of dead and living vegetation and therefore indirectly controls the success of anthropogenic ignitions. Additionally, air motion influences the oxygen supply of the source of the fire and the spreading of the fire. Finally, fair weather means that the number of people frequenting the forests increases and permits a broad spectrum of activities of foresters and farmers (on neighbouring farmland), so that the number of potential ignition sources (fire risk) increases. In order to prevent fire losses, the objective of the national weather services is to forecast the weather-dependent forest-fire risk and to issue fire-weather warnings to fire-fighting agencies, forest authorities, emergency services and the public when the weather becomes critical.

3.3.1 Implementation of the national to local fire-weather danger forecast

Within the framework of the German Weather Service (Deutscher Wetterdienst – DWD) operational forest-fire danger forecast are currently using domestic and foreign fire-weather ratings, such as the German M-68 index and the Canadian Fire-Weather Index (FWI) (Wittich, 1998). The indices, together with additional meteorological information, are sent to forest authorities and disaster control centres of the Ministries of Interior of the Federal States of Germany so that they can issue the necessary instructions.

During the fire season the DWD daily issues the M-68 index via the internet under http://www.dwd.de/WALDBRAND (Wittich, 2002). Figure 5 shows the danger-rating chart for Germany on 5 June 2002, containing five risk levels (level 1 = low danger, ..., level 5 = extreme danger). Clicking on one of the ~ 200 station circles, one can get a time series over several days, which is composed of the current-day index, the index of two previous days and that of three forecast days, thus illustrating the temporal course of the forest-fire potential.

For the implementation of a local decision-support system based on automatic fire detection and modelling of fire behavior precise on-site real-time fire weather data are required to obtain a realistic model output. In an optimized system weather data would gathered automatically through a dense network of weather stations, transmitted to the data processing center and integrated into the decision-support system. Alternatively, fire weather data could be obtained at or near the fire site by a mobile weather station or by ground personnel using a mobile fire-weather kit. Taking into account the local variability of fire-weather data the latter alternative will meet the demands of on-site weather information.

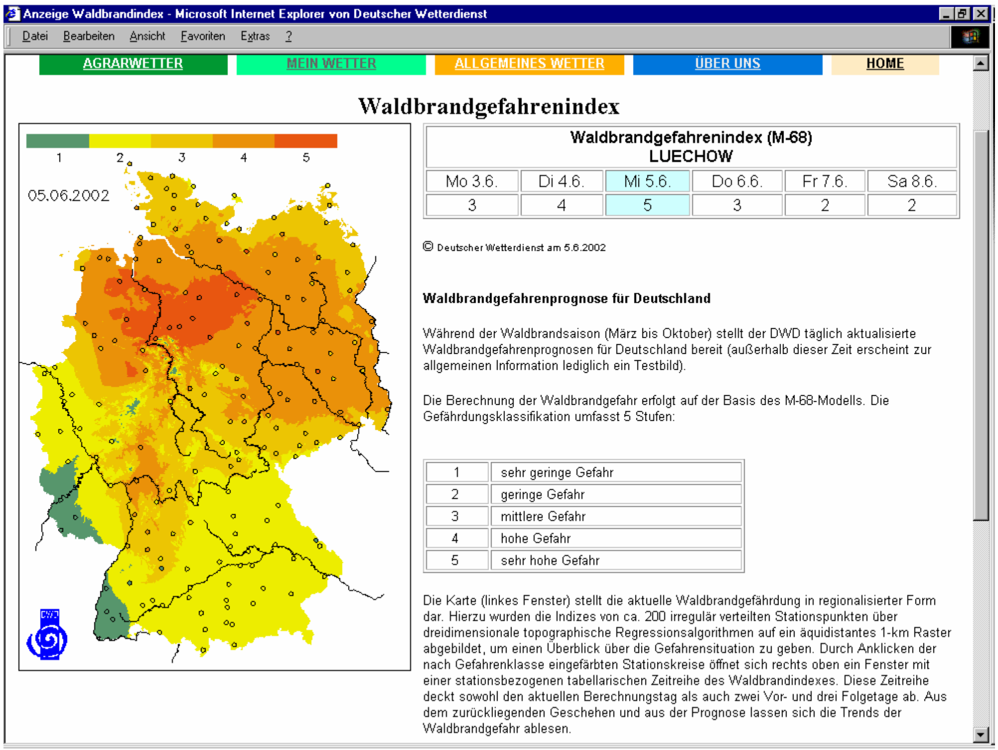

Figure 5. Example of the German Weather Service (DWD) fire-weather / fire-danger forecast via the internet for 5 June 2002. During the fire season a map provides a daily overview for Germany's territory. The system allows the retrieval of the fire danger index (M-68) for individual stations to obtain the fire-danger forecast for the current day (right hand example: Luechow, 5 June 2002), for the past two days and the next two days.

An overview of fire danger at regional level, e.g. for assessing fire danger in Europe and the neighbouring countries, is provided by the Eurasian Experimental Fire Weather Information System generated of the basis of the Canadian Forest Fire Danger Rating System (CFFDRS) by the Northern Forestry Centre, Canada, for the Global Fire Monitoring Center (GFMC). The system allows downloading a number of Fire Weather Index Components (Fine Fuel Moisture Code – FFMC, Duff Moisture Code – DMC, Drought Code – DC, Initial Spread Index – ISI, Buildup Index – BUI, and the Fire Weather Index – FWI) and Meteorological Data (Fig. 6). This regional system is still operating on a provisional basis due to the lack of automated inputs from hourly weather observations, especially in Russia. The Canadian Forest Service is working on a Global Experimental Fire Weather Information System to be displayed at the GFMC in late 2003.

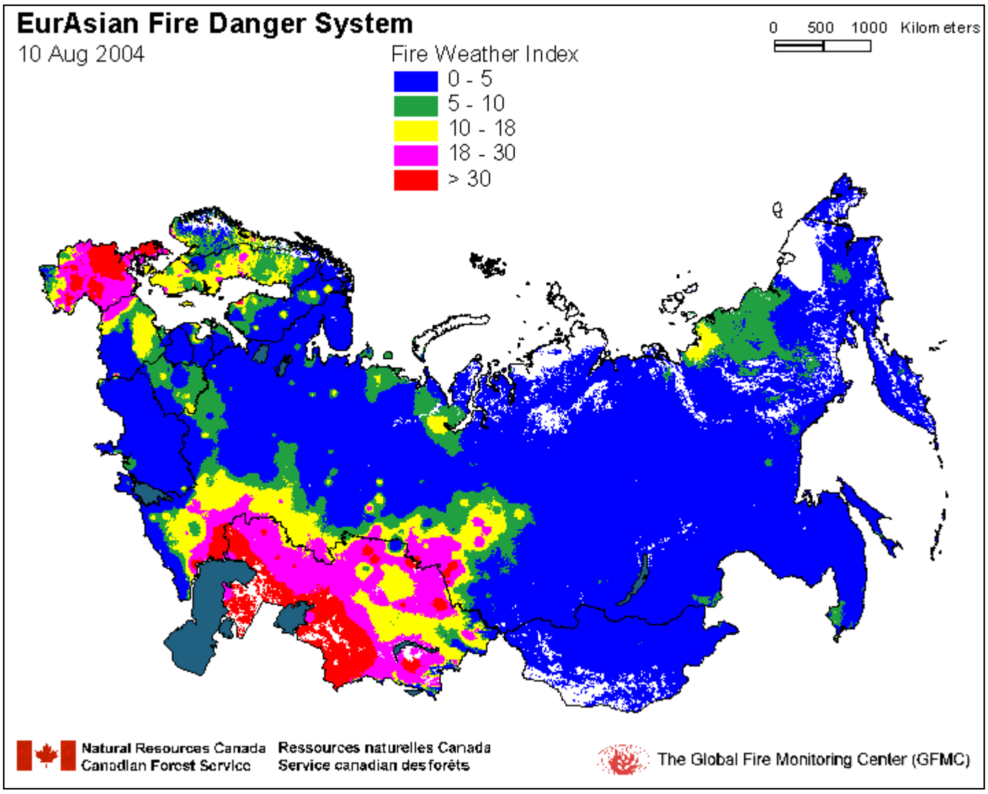

Figure 6. Example of a daily fire weather index map of the Eurasian Experimental Fire Weather Information System generated on the basis of the Canadian Forest Fire Danger Rating System (CFFDRS) by the Northern Forestry Centre, Canadian Forest Service, for the Global Fire Monitoring Center (GFMC).
Source: http://www.fire.uni-freiburg.de/fwf/eurasia.htm

4. Implementation of the Fire Information System

Theoretically, data and information about what it is considered as fire structural parameters (i.e. fuel, weather, and topography), contain the descriptive (i.e. attributes) as well as the spatial (i.e. coordinates) component. The spatial component sets up the basic requirements to consider it as a geographical information system (GIS); for instance, descriptive information of fuel is spatially distributed within the geographical extent of the study area.

Conceptually, the integration of all the necessary information under a common processing scheme presupposes firstly the necessary compatibility among different data layers. To maintain spatial information of any descriptive parameter in a digital form, a number of different alternatives are available including, among others, the format of the data (i.e. raster vs. vector type), the type of spatial objects (i.e. point, line or polygon), the type of measurements (i.e. nominal, ordinal, interval, or ratio), and the spatial resolution or scale (DeMers, 1997).

4.1 Integration of fuel data, fire behavior model, weather and fire detection data in a GIS

Primary observations and data referring to the structural parameters of wildland fires may exist in multiple types and multiple scales. Their integration under a common scheme might be prohibited because of several incompatibilities. For instance, elevation gradients, as well as weather data are better represented by continuously data using the raster data type. However, their primary data source may considerable differ. For instance, fire weather observations are provided at specific points in space that correspond usually to meteorological weather stations. To convert point observations into continuous surfaces by filling the gaps in the between unsampled sites, interpolation procedures have to be applied, like inverse distance weighting, nearest neighbors, splines, or geostatistics (Burrough and McDonnel, 1998). On the other hand, road network and firebreaks, which are depicted as linear or polygon objects depending on the scale level, are introduced into the fire information system as vector or raster type. To allow however their co-processing with other spatial information, as for instance for fire behavior modelling, vector objects should be converted to raster objects by considering during the conversion process the maintenance of the original information.

In addition to the fire structural parameters information, the fire behavior model and the fire detection and monitoring system are another two critical components of a fire information system. Fire behavior, formally is defined as "the manner in which a fire behaves as a function of the variables of fuel, weather and topography". The fire behavior modelling phase enables us to simulate a real fire event and allows us to test hypothetical scenarios about its propagation, and suppression strategy. A fire can be inserted and simulated into fire behavior modelling system either manually by the system operator or automatically if this system is connected online to an appropriate fire detection system. Apart from the input of the ignition source, real data referring to fire propagation can also be introduced into the system so that the modelling phase of the system be continuously supplied with the updated information for validation and self-correction.

GIS, by providing tools, resources and a proper organizational context to gather, manage and process spatial referenced information (Burrough, 1986), can support the integration of fuel data, fire behavior model, weather data, and the fire detection system. The main functional process that has to be resolved is the data management including collection, homogenization, maintenance and future update of the information. Information may come from completely different sources, and be different in scale, content, accuracy, etc. To enable the integration of such different spatial layers of information under a common functional schema, certain procedures have to be implemented and supported.

4.2 New space-borne fire information - decision support systems (a successful demonstrator mission and proposed next steps)

In principle, a fire information – decision support system should support the requirements of the input, maintenance, update and processing of the appropriate information. Concerning the data management subsystem, the ability to work independently under a semi-automatic or fully automatic mode, when possible, is very important. Furthermore, its ability to receive online information about input (i.e. fire weather data) as well as output data (i.e. fire behavior) is another important aspect. Remote sensing and GIS, being complementary tools for gathering and processing data and information, could be the heart of the data management subsystem. Remote sensing can contribute to generation of the information to support the requirements of updated and spatially distributed information. Various remote sensing applications can be found in literature for estimating fuel parameters and fire risk before the fire (Chuvieco and Congalton, 1989; Leblon et al., 2002), for detection and monitoring during a fire (Bourgeau-Chavez et al., 1997; Kasischke et al., 1993), and for burned land mapping and post fire effects assessment after the fire (Jakubuskas et al., 1990; Koutsias and Karteris, 1998).

The research project provided an opportunity to test the advanced spaceborne Bi-Spectral Infrared Detection (BIRD) sensing system for the detection and characterization of high-temperature events (HTE). BIRD is the first space borne sensor that offers the capability to provide daytime detection of small fires with areas exceeding ~15 m^2 and to estimate their radiative energy release. For fires with areas exceeding ~0.15 ha, an estimation of the effective fire temperature and area is also feasible. This capability of BIRD is especially important for the detection of small fires. A quantitative comparison showed that BIRD's Hot Spot Recognition System is an order of magnitude more sensitive than other available space borne sensors used for active fire remote sensing (Oertel et al,. 2004a).

In addition, the high sensitivity of the BIRD IR sensor system allows the characterization of low intensity surface fires in forests (under canopy) which are difficult to be detected by other satellite systems (Oertel et al, 2004b; Zhukov et al., 2005). During the project's scientific forest fire experiment the Advanced BIRD Airborne Simulator (ABAS) was used to test the capabilities of this new spaceborne fire detection and characterization system (Oertel et al., 2002) before BIRD was launched to the orbit in October 2001. The results of the tests of ABAS (Fig. 7) and the semi-operational utilization of BIRD in summer 2003 (Fig. 8) confirmed the capabilities of the new sensor system, the BIRD Hot Spot Recognition System. An integration of prospective BIRD type operational sensors with the prototype decision-support system would provide an opportunity to generate information of additional value for a fire management decision support system.

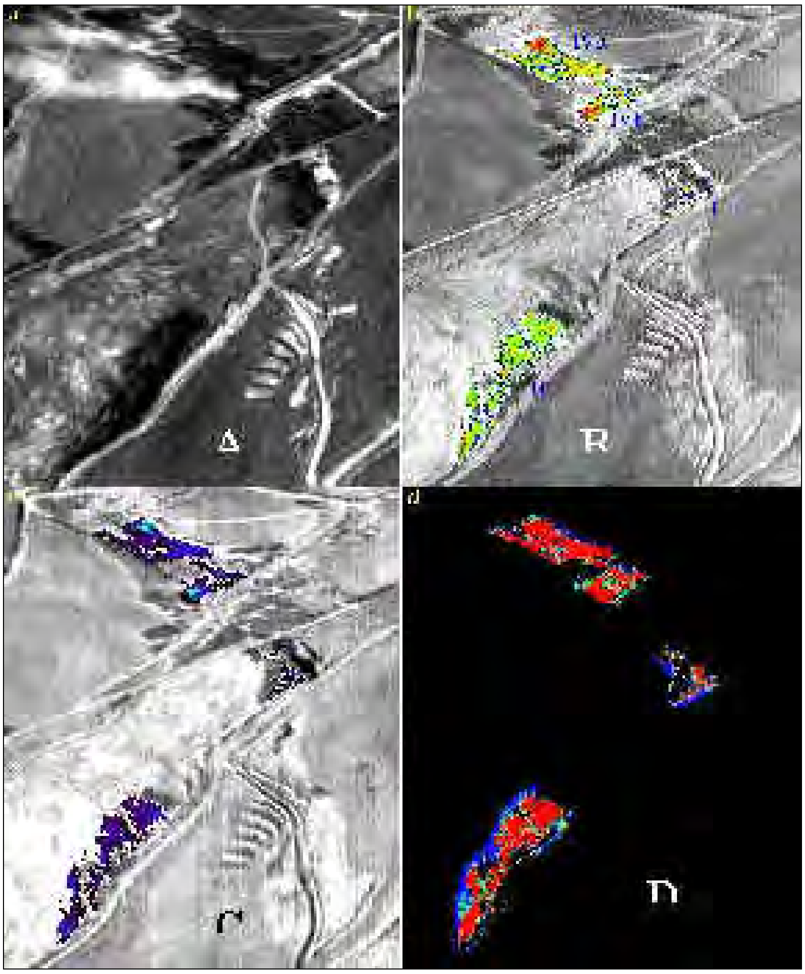

Figure 7. Fragments of an ABAS scene showing the experimental fires in the burning and smouldering Plots I, II und IV of the Brandenburg forest fire experiment on 23 August 2001.

Based on the recent and unique experience with the BIRD demonstrator mission in 2001 – 2004, an operational and commercially based Fire Recognition Satellite System (**FIRES**) is proposed to be developed. FIRES shall consist of four BIRD-like identical satellites, which detect, classify, and geo-reference fire data on board and broadcast the information in real time down to wildland fire managers and agencies. On earth, information on fire location and intensity to be provided by the prospective FIRES constellation satellites shall be received and visualized on-line with mobile, hand-held receivers similar to GPS-receivers (**Fire-GPS**). This tabulated, very compact fire information shall be received instantaneously within the reach of one of the FIRES-satellites radio transmitter to deliver in real time precise information on the spread and intensity of a fire front, thus allowing verifying and updating the outputs of the fire spread model (Oertel and Ruecker, 2005).

Further, the BIRD mission in general and its Hot Spot Recognition System in particular are precursors of the prospective Fire detection and monitoring IR Sensor, the ***InfraRed Element*** *foreseen as a multiple flown payload passenger of the planned ESA satellites "Sentinel 2" and "Sentinel 3" which are part of the Space Component – (ESA/PB-EO(2005)93) – of the European initiative on Global Monitoring for Environment and Security (GMES).*

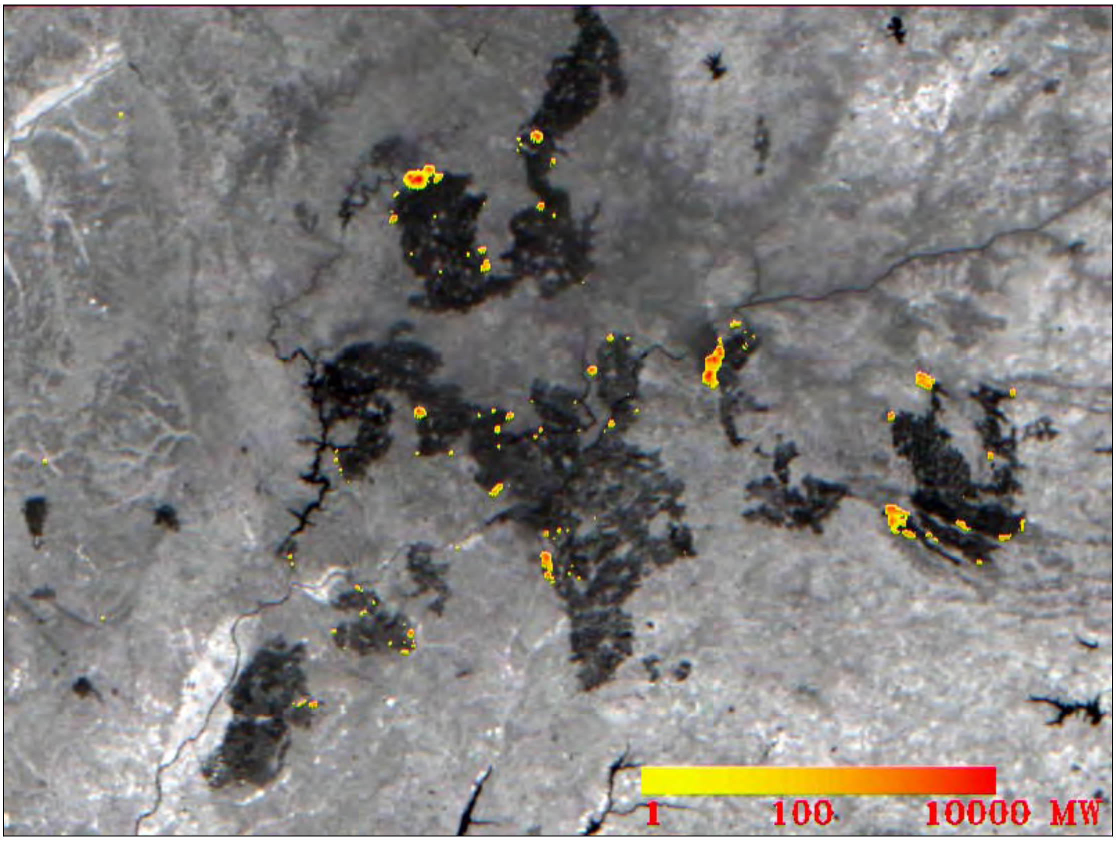

Figure 8. Example of a BIRD fire product image fragment showing forest fires in the center of Portugal on 4 August 2003. The fire radiant power is color-coded in Megawatt per pixel and is overlaid on the black and white background showing the dark fire scars.

5. Conclusions and Outlook

Research and development conducted within the Forest Fire Cluster of the German Research Network on Natural Disasters is built on a number of separately evolved concepts that were integrated in a cooperative research project. For the first time a fire behavior model has been applied for the specific conditions of pine forests in the eastern, continental part of Germany, including the interspersed heathlands that constitute an important carrier of a wildfire at landscape level. The characteristics of these forests are quite typical for temperate-hemiboreal pine forests of Eurasia. Thus, the results of this work can be easily adapted to neighbouring countries where similar pine forests cover large areas, e.g., Poland, Belarus, and the Russian Federation. The development of the AWFS meets the requirements for fast, cost-effective and reliable fire detection system. The national fire-danger rating system has consolidated during the project lifetime. During the research project the work of the Global Fire Monitoring Center (GFMC) constituted the link from national to international levels. Besides the function of a support body for the development of national to international policies and fire management strategies the *modus operandi* of the GFMC provided an opportunity to implement the regional Eurasian Experimental Fire Weather Information System in cooperation with the Canadian Forest Service and to test the BIRD satellite mission in various vegetation types around the world. The concept of the German Natural Disaster Research Network (DFNK) provided an exemplary opportunity to conduct multi- and interdisciplinary fire research and has contributed to establish a new and unprecedented collaborative culture of wildland fire science in Germany. The value added by the research project is a mutual support of individual research projects and their final merging into a comprehensive decision-support tool for fire management. Insight gained by the research project concerning the operational use of satellite remote sensing information in the management of active wildland fires will be useful for the development of urgently needed operational spaceborne fire systems (Ahern et al., 2001).

References

Ahern, F., Goldammer, J.G. and Justice, C. (eds.). 2001. Global and regional vegetation fire monitoring from space: Planning a coordinated international effort. SPB Academic Publishing bv, The Hague, The Netherlands, 302 p.

Bourgeau-Chavez, L.L., Harrell, P.A., Kasischke, E.S. and French, N.H.F. 1997. The detection and mapping of Alaskan wildfires using a spaceborne imaging radar system, Int. J. Remote Sensing 18 (2), 355-373.

Brown, J.K. 1974. Handbook for inventorying downed woody material. USDA Forest Service General Technical Report INT-16.

Burgan, R.E. and Rothermel, R.C. 1984. BEHAVE: Fire behavior prediction and fuel modeling system - fuel subsystem. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, INT-167, Ogden, UT.

Burrough, P.A. 1986. Principles of geographical information systems for land resources assessment. Oxford University Press, Oxford.

Burrough, P.A. and McDonnel, R.A. 1998. Principles of geographical information systems. Oxford University Press, Oxford, 333 pp.

Byram, G.M. 1963. Combustion of forest fuels. In: Forest fire. Control and use (K.P. Davis, ed.), McGraw Hill, New York, pp. 61-89.

Chuvieco, E. and Congalton, R.G. 1989. Application of remote sensing and geographic information systems to forest fire hazard mapping, Remote Sens. Environ. 29, 147-159.

DeMers, M.N. 1997. Fundamentals of geographic information systems. John Wiley & Sons, New York, 486 pp.

ESA/PB-EO(2005)93, from 16 September 2005, “GMES Space Component, Traceability of User Requirements Based on European Policy Priorities”

Finney, M.A. 1998. FARSITE: Fire area simulator – model development and evaluation. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, RMRS-PR-4, Ogden, UT.

Goldammer, J.G., Hille, M. and Held, A. 2001. Feuerexperiment Brandenburg (2001). Forschungsvorhaben A2, Deutsches Forschungsnetz Naturkatastrophen (DFNK). http://www.fire.uni-freiburg.de/dfnk/zwischenbericht.htm

Hille, M. and Goldammer, J.G. 2002. Dispatching and modelling of fires in Central European pine stands: New research and development approaches in Germany. In: Improving dispatching for forest fire control. Proceedings of a workshop held in the Mediterranean Agronomic Institute of Chania (MAICh), Crete, Greece, 6-8 December 2001 (General Secretariat for Civil Protection, Greece, and MAICh, Greece, ed.), 59-74. MAICh, Chania, 162 p.

Jakubuskas, M.E., Lulla, K.P. and Mausel, P.W. 1990, Assessment of vegetation change in a fire-altered forest landscape, Photogramm. Eng. Remote Sens. 56(3), 371-377.

Kasischke, E.S., French, N.H.F., Harrell, P., Christensen, N.L., Jr. and Ustin, S.L. 1993. Monitoring wildfires in boreal forests using large area AVHRR NDVI composite image data, Remote Sens. Environ. 45, 61-70.

Koutsias, N. and Karteris, M. 1998. Logistic regression modelling of multitemporal Thematic Mapper data for burned area mapping, Int. J. Remote Sens. 19(18), 3499-3514.

Kührt, E., Behnke, T., Jahn, H., Hetzheim, H., Knollenberg, J., Mertens, V., Schlotzhauer, G. and Gotze, B. 2000. Autonomous early warning system for forest fires tested in Brandenburg (Germany). Int. Forest Fire News No. 22, 84-90.

Leblon, B., Kasischke, E., Alexander, M., Doyle, M. and Abbott, M.: 2002, Fire danger monitoring using ERS-1 SAR images in the case of Northern Boreal forests, Nat. Hazards 27, 231-255.

Michaelis, H., Behnke, T., Tschentscher, M., Mottola, S., Neukum, G. 1999. MOSES - A modular sensor electronics system for space science and commercial applications. SPIE's International Symposium on Optical Science, Engineering and Instrumentation, Denver, USA, July 1999, SPIE The International Society for Optical Engineering, Materials and Electronics for High-Speed and Infrared Detectors, 115-121.

Oertel, D., Briess, K., Halle, W., Neidhardt, M., Lorenz, E., Sandau, R., Schrandt, F., Skrbek, W., Venus, H., Walter, I., Zender, B., Zhukov, B., Goldammer, J.G., Held, A.C., Hille, M., and Brueggemann, H. 2002, Airborne forest fire mapping with an adaptive infrared sensor, Int. J. Remote Sensing 24, 3663-3682.

Oertel, D., Zhukov, B., Thamm, H-P., Roehrig, J., and Orthmann, B. 2004a. Space-borne high resolution fire remote sensing in Benin West Africa. Int. J. Remote Sensing 25, 2209-2216.

Oertel, D., Briess, K., Lorenz, E., Skrbek, W., and Zhukov, B. 2004b. Detection, monitoring and quantitative analysis of wildfires with the BIRD satellite. Proc. SPIE 5232, 208-218.
Oertel, D., Ruecker, G. 2005. Conception of the FIRES / Fire - GPS System, German Aerospace Center – Optical Information Systems (DLR-OS) and ZEBRIS GbR, Berlin, Munich
Richards, G.D. 1990. An elliptical growth model of forest fire fronts and it's numerical solution, Int. J. Numer. Methods Eng. 30, 1163-1179.
Richards, G.D. 1995. A general mathematical framework for modeling two-dimensional wildland fire spread. Int. J. Wildland Fire. 5(2), 63-72.
Rothermel, R.C. 1972. A mathematical model for predicting fire spread in wildland fuels, U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, INT-115, Ogden, UT.
Thonicke, K. and Cramer, W. 2006. Long-term trends in vegetation dynamics and forest fires in Brandenburg (Germany) under a changing climate, Natural Hazards 38, 283-300.
Wittich, K.-P. 1998. Waldbrandgefahrenvorhersage des Deutschen Wetterdienstes. Allg. Forst Z. - Der Wald 53, 321-324.
Wittich, K.-P. 2002. Prognose der witterungsbedingten Waldbrandgefahr und waldbrandspezifische Forschung des Deutschen Wetterdienstes, 3. Forum Katastrophenvorsorge (Third German Forum on Disaster Prevention), Potsdam, 7-9 October 2002 (in press).
Zhukov, B., Briess, K., Lorenz, E., Oertel, D., and Skrbek, W. 2005. Detection and analysis of high-temperature events in the BIRD mission. Acta Astronautica, Vol. 56, 65-71.

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