POTENTIAL FOR ADVANCEMENTS IN REMOTE SENSING USING SMALL SATELLITES

R. Sandau[1], K. Brieß[2]

[1]German Aerospace Center, Rutherfordstr. 2, 12489 Berlin, Germany, rainer.sandau@dlr.de
[2]Technische Universität Berlin, Institute of Aeronautics and Astronautics, Marchstr. 12, 10587 Berlin, Germany, Klaus.Briess@ILR.TU-Berlin.de

KEY WORDS: Earth observation, small satellites, systems, sensors, platforms

ABSTRACT:

Small satellites for remote sensing – how is a small satellite characterized, what is the basis for it and what are the trends, how can small satellite missions be achieved, what are the cost drivers and what the application areas. The paper gives some insights in related facts and trends. The requirements concerning GSD and revisit time for the manifold application areas indicate the wide range of application for small satellites. By means of the fire monitoring micro-satellite BIRD one design approach is exemplified. For disaster monitoring applications trends are given concerning the ground, programme and space segments are given.

1. INTRODUCTION

Small satellite missions can be achieved by using different approaches and methods. One approach is to focus on a single task and use available off-the-shelf technology to build a small satellite system (bus and payload) for the intended remote sensing purpose. Another possible approach is to take full advantage of the ongoing technology developments leading to further miniaturization of engineering components, development of micro-technologies for sensors and instruments which allow to design dedicated, well-focused high-performance Earth observation missions.

Since the advent of modern technologies, small satellites using off-the-shelf technologies or missions focused on specific physical phenomena have also been perceived to offer an opportunity for countries with a modest research budget and little or no experience in space technology, to enter the field of space-borne Earth observation and its applications. Small satellite technology is a major mean to bring within the reach of every country the opportunity to operate small satellite Earth observation missions and utilize the data effectively at low costs, as well as to develop and build application-driven missions. It provides the opportunity to conduct or participate in Earth observation missions using small, economical satellites, and associated launches, ground stations, data distributions structures, and space system management approaches.

The situation in the field of small satellite missions for Earth observation has matured in the last ten years. This may be, for instance, observed from the topics and the quality of contributions to the series of conferences taking place in Berlin, Logan, at the annual IAC or conducted by space agencies like ESA or CNES.

ESA:	Small	350 kg – 700 kg
	Mini	80 kg – 350 kg
	Micro	50 kg – 80 kg
EADS Astrium:	miniXL	1000 kg – 1300 kg
	Mini	400 kg – 700 kg
	Micro	100 kg – 200 kg
CNES:	Mini	500 kg + P/L (Proteus)
	Micro	120 kg + P/L (Myriade)

Table 1. Confusion of small satellite definitions

But what exactly is a small satellite? Table 1 gives some examples how different entities define or name small satellites in dependency on their products or programmes. To end this confusion, IAA proposed a simplified definition (see table 2).

Figure 1 refers to additional features which are essential when discussing small satellite characteristics like cost and response time.

• mini satellites	< 1000 kg
• micro satellites	< 100 kg
• nano satellites	< 10 kg
• pico satellites	< 1 kg

Table 2. Small Satellite definition of IAA (Sandau, 2006)

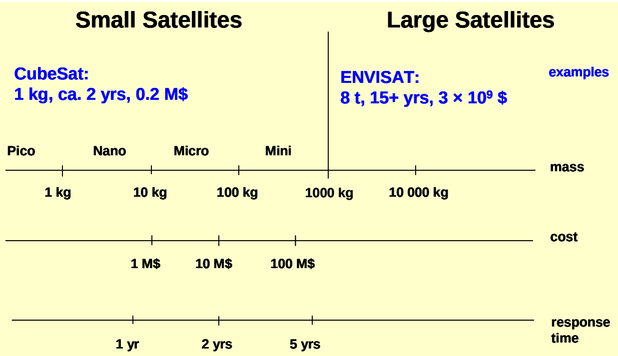


Figure 1. Some features of small satellites

At UNISPACE III (Background Paper, 1998), the costs of developing and manufacturing a typical mini-satellite was indicated to be US$ 5-20 million, while the cost of a micro-satellite was correspondingly US$ 2-5 million. The cost of a nano-satellite could be below US$ 1 million (prices as of 1999). Whereas the development and production time for large satellites is observed to be 15+ years, the corresponding time for minis should be 3–5 years, for micros 1.5 years, for nanos about 1 year, and for picos less than 1 year. Of course, cost and duration figures are to be considered ball park figures. They are bases on the usage of state-of-the-art technology by professional teams. They may deviate considerably if key technology is to be developed and/or the implementation teams are at the beginning of the learning curve. Figure 1 is complemented by two examples showing the edges of the feature ranges.

2. SMALL SATELLITE MISSIONS: FACTS AND TRENDS

From figure 1 we can learn that, roughly, the smaller the satellite the less the cost and the response time. This is a strong motivation to try to go for small satellite missions. The IAA study (Sandau, 2006) presented the state of the art of small satellite missions and examined more factors that enable one to produce a cost-effective small satellite mission for Earth observation. It seems, while there are several examples of such missions flying today, the lessons that must be learned in order to produce cost-effective small sat missions have neither been universally accepted nor understood by all in the space community. One of the intentions of that study was to point out how a potential user can produce a cost effective mission. One of the key enablers of designing a cost-effective mission is having the key expertise available. As the number of successfully space-faring nations grows, the pool of expertise available to meet the challenges of small mission grows.

2.1 General Facts

Small satellite missions can be achieved by using different approaches and methods.

Since the advent of modern technologies, small satellites have also been perceived to offer an opportunity for countries with a modest research budget and little or no experience in space technology, to enter the field of space-borne Earth observation and its applications.

One of the possible approaches is taking full advantage of the ongoing technology developments leading to further miniaturization of engineering components, development of micro-technologies for sensors and instruments which allow to design dedicated, well-focused Earth observation missions. At the extreme end of the miniaturization, the integration of micro-electromechanical systems (MEMS) with microelectronics for data processing, signal conditioning, power conditioning, and communications leads to the concept of application specific integrated micro-instruments (ASIM). These micro- and nano-technologies have led to the concepts of nano- and pico-satellites, constructed by stacking wafer-scale ASIMs together with solar cells and antennas on the exterior surface, enabling the concept of space sensor webs.

The advantages of small satellite missions are:

- more frequent mission opportunities and therefore faster return of science and for application data
- larger variety of missions and therefore also greater diversification of potential users
- more rapid expansion of the technical and/or scientific knowledge base
- greater involvement of local and small industry.

After some years of global experience in developing low cost or cost-effective Earth observation missions, one may break down the missions into categories like: Commercial – Requiring a profit to be made from satellite data or services

- Scientific/Military – Requiring new scientific/military data to be obtained
- New technology – Developing or demonstrating a new level of technology
- Competency demonstration – Developing and demonstrating a space systems competency
- Space technology transfer/training – Space conversion of already competent engineering teams
- Engineering competency growth – Developing engineering competence using space as a motivation
- Education - Personal growth of students via course projects or team project participation

Large satellite missions and small satellite missions are considered to be complementary rather than competitive. The large satellite missions are sometimes even a precondition for cost-effective approaches.

2.2 Trends

Small satellite missions are supported by several contemporary trends:

- Advances in electronic miniaturization and associated performance capability;
- The recent appearance on the market of new small launchers (e.g. through the use of modified military missiles to launch small satellites);
- The possibility of ‘independence’ in space (small satellites can provide an affordable way for many countries to achieve Earth Observation and/or defense capability, without relying on inputs from the major space-faring nations);
- Ongoing reduction in mission complexity as well as in those costs associated with management; with meeting safety regulations etc.;
- The development of small ground station networks connected with rapid and cost-effective data distribution methods.

3. APPLICATIONS

3.1 Remote sensing requests

Different remote sensing applications need different approaches for cost-effective missions. Figures 2 and 3 show the very divers requirement coming from the different remote sensing application fields.

The range of GSD covers centimetres to several hundred meters. The revisit time ranges from less than one hour to 10 years. The range of spectral requirements starts with panchromatic only for topographic mapping and ends with hyperspectral resolution, for instance in the field of hydrology. Even within the different application fields, the related subtasks may cover huge areas again. Figure 4 shows the requirement range for different coastal applications. In fig. 4 the GSD ranges from meters to kilometres with revisit times from half an hour to several years.

It is obvious, a satellite system for remote sensing needs to focus on one of the application fields and within that application field on a specific task or group of tasks where feasible.

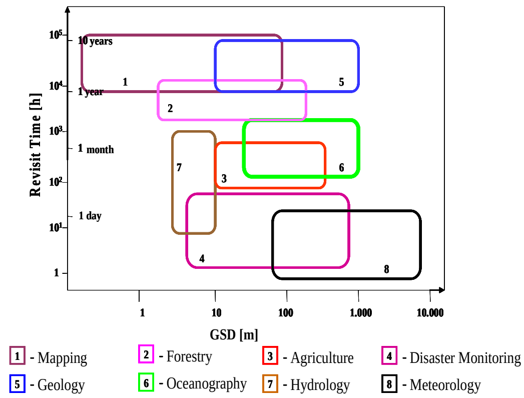


Figure 2. Earth observation request: GSD versus spectral resolution

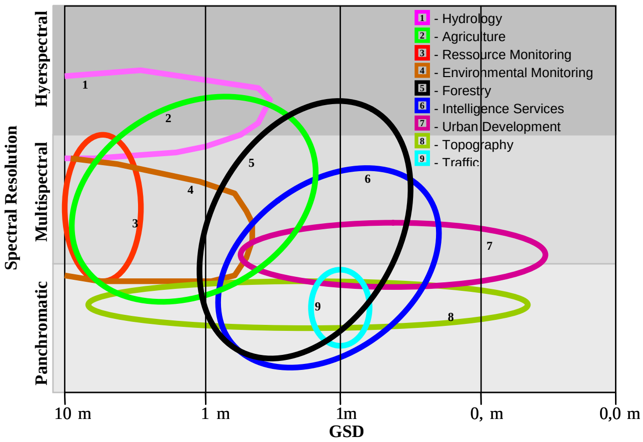


Figure 3. Earth observation request: GSD vs revisit time

3.2 Example Disaster Monitoring: The Micro-Satellite BIRD

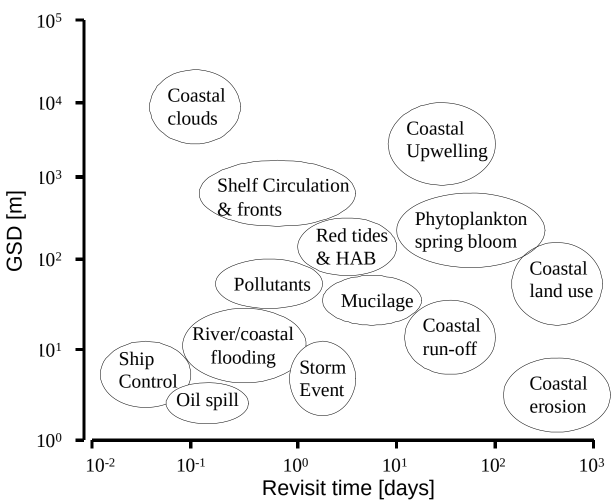


Figure 4. Spatial and Temporal Requirements for Coastal Studies (after Hoepffner)

As already shown, the application areas are complex which is indicated by the wide range of GSDs (Ground Sample Distance), revisit times, and spectral requirements. If we concentrate on disaster monitoring which can be further split into many categories, like

- Cyclones and storms,
- El Nino,
- floods,
- fires,
- volcanic activities,
- earthquakes,
- landslides,
- oil slicks,
- environmental pollution,
- industrial and power plant disaster,

we need to focus on one specific category. In this paper, the fire category may serve as an example of how to approach the problem of defining and developing a small satellite system in order to improve the actual fire monitoring and fire parameter assessment situation.

The micro-satellite BIRD (Bi-spectral InfraRed Detection) is used to describe a possible approach for detection and quantitative characterisation of high-temperature events like vegetation fires on the Earth surface (Brieß et al., 2003). BIRD was successfully piggyback launched by an Indian Polar Satellite Launch Vehicle (PSLV-C3) in a circular sun-synchronous orbit with an altitude of 572 km on 22 October 2001.

Both the global change scientific community and the fire fighting authorities demand new and dedicated space-borne fire observation sensors with resolution of 50-100 m for local/regional monitoring and of a few hundred metres for global observations that would be able to detect fires from a few to a few tens of square metres and to estimate quantitatively variables such as location, temperature, area, energy release, associated aerosol and gaseous emissions.

The existing satellite sensors with 3-4 µm mid-infrared channels (AVHRR/NOAA, MODIS/TERRA, GOES) used so far to provide data on active fires on Earth have limited spatial resolution of 1 km or coarser and a low-temperature saturation of the MIR channels (with the exception of MODIS) leading in some cases to false alarms and preventing a quantitative characterisation of larger fires.

Fine spatial resolution multi-spectral sensors like TM or ETM on Landsat or ASTER/TERRA do not have a 3-4 µm channel, the principal channel for daytime fire recognition. Their 2.3 µm channels are less sensitive to smouldering fires and more affected by solar reflections.

The saturation limitations can be avoided using solid state infrared detector arrays and real time digital signal processing to provide an adaptation of the sensor radiometric dynamic range. These are the key elements of new imaging infrared (IR) sensors on BIRD.

The BIRD small satellite mission is a technology demonstrator including new infrared push-broom sensors dedicated to recognition and quantitative characterisation of thermal anomalies on the Earth surface. BIRD primary mission objectives are:

- test of small satellite technologies, such as an attitude control system using new star sensors and new actuators, an onboard navigation system based on a new orbit predictor and others,test of the latest generation of infrared array sensors with an adaptive radiometric dynamic range,
- detection and scientific investigation of High Temperature Events (HTE) such as forest fires, volcanic activity, and coal seam fires.

Figure5 shows the BIRD satellite. The BIRD main sensor payload consists of:

- a two-channel infrared Hot Spot Recognition Sensor system (HSRS),
- a Wide-Angle Optoelectronic Stereo Scanner (WAOSS-B).

Figure 5. Micro-satellite BIRD,Mass of s/c: 94 kg, Mass of p/l: 30.2 kg

WAOSS-B is a modified version of a scanner that was originally developed for the Mars-96 mission. It is a three-line stereo scanner working in the push-broom mode. All three detector lines are located in the focal plane of a single wide angle lens. The forward- and backward-looking lines have a visible (VIS) and near-infrared (NIR) filters, respectively, while the nadir-looking line has a NIR filter.

	WAOSS-B	MWIR	TIR
Wavelength	600-670nm 840-900nm	3.4-4.2µm	8.5-9.3µm
Focal length	21.65mm	46.39mm	46.39 mm
Field of view	50°	19°	19°
f-number	2.8	2.0	2.0
Detector	CCD lines	CdHgTe Arrays	CdHgTe Arrays
Detector cooling	passiv, 20°C	Stirling, 80K	Stirling, 80K
Pixel size	7µmx7µm	30µmx30µm	30µmx30µm
Pixel number	2880	2x512 staggered	2x512 staggered
Quantization	11bit	14bit	14bit
Ground pixel size	185m	370m	370m
GSD	185m	185m	185m
Swath width	533km	190km	190km

Table 3. Characteristics of the BIRD main sensor payload (orbit altitude = 572km)

HSRS is a two-channel push-broom scanner with spectral bands in the mid-infrared (MIR) and thermal infrared (TIR) spectral ranges. The detectors are two Cadmium Mercury Telluride (CdHgTe) linear photodiode arrays.

Their characteristics are given in table 3.

The lines - with identical layout in the MIR and TIR - comprise 2 x 512 elements each in a staggered structure where two linear detector arrays are arranged parallel to each other with an along-line shift of a half element size. The HSRS sensor head components of both spectral channels are based on identical technologies to provide accurate pixel co-alignment. Both spectral channels have the same optical layout but with different wavelength-adapted lens coatings. Figure 6 shows the spectral signatures of vegetation fire and the standard vegetation in relation to the spectral channels selected for BIRD. The spectra contain information on land surface, atmospheric gases and aerosols. The second atmospheric window (MIR) is the optimum for the "hot spot" detection.

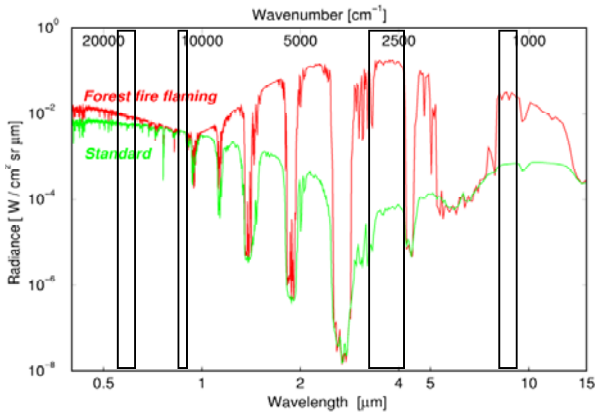
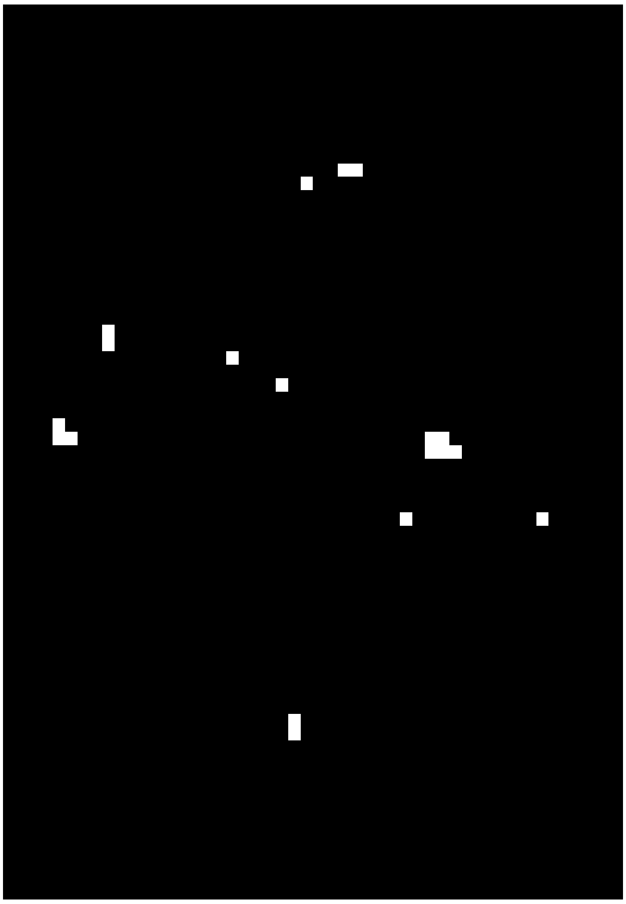


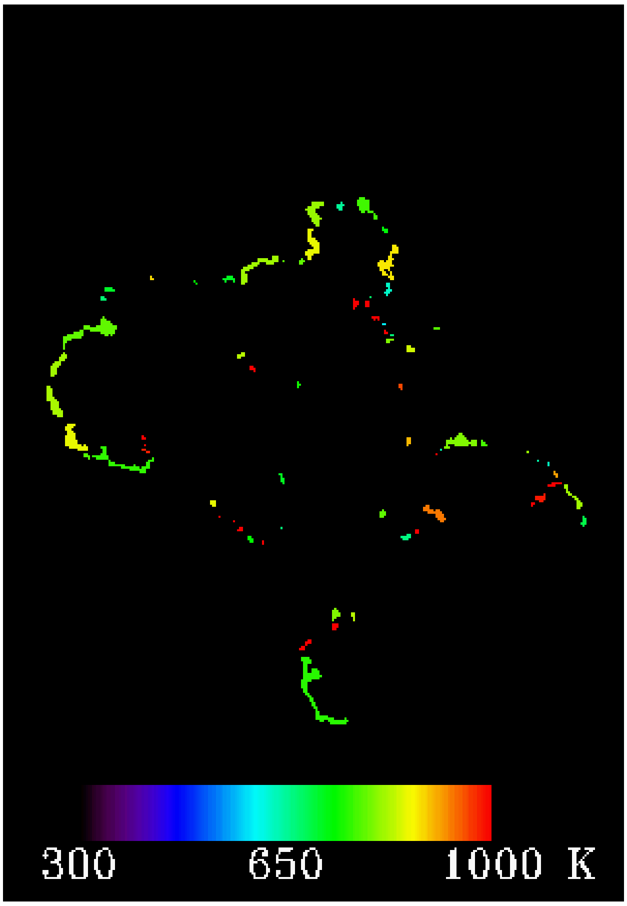
Figure 6. Signatures of vegetation fire and background

The detector arrays are cooled to 100 K in the MIR and to 80 K in the TIR. The cooling is achieved by small Stirling cooling engines. The HSRS sensor data are read out continuously with a sampling interval that is exactly one half of the pixel dwell time. This time-controlled "double sampling" and the staggered line array structure provide the sampling step that is a factor of 2 smaller than the HRSR pixel size, coinciding with the sampling step of the WAOSS NIR nadir channel. Radiometric investigations of thermal anomalies require (a) a large dynamic range not to be saturated by HTE occupying the entire pixel and (b) a large signal to noise ratio to be able to observe small thermal anomalies at normal temperatures and detect small sub-pixel HTE. To fulfil these requirements, a second scene exposure is performed with a reduced integration time (within the same sampling interval!) if the real-time processing of the first exposure indicates that detector elements are saturated or close to saturation. As a result, the effective HSRS radiometric dynamic range is significantly expanded preserving a fine temperature resolution of 0.1-0.2 K at normal temperatures.

BIRD can provide an order of magnitude smaller minimal detectable fire area than AVHRR and MODIS due to a higher resolution of its MIR and TIR channels. A possibility to observe fires and other HTE without sensor saturation makes it possible: (a) to improve false alarm rejection capability and (b) to estimate temperature, area and energy release ever for large HTE. Figure 7 demonstrates the capabilities of MODIS and BIRD.



MODIS: Fire map



BIRD: Fire map

Figure 7. Fire detection by MODIS and BIRD (Australia, January 5, 2002)

3.3 General prospects and trends to improve the status quo

Each of the application fields implies an individual set of measures and trends to improve the status quo. The general prospects for disaster warning and support may serve as an example. They can be grouped into the following main topics: space, ground, and program segment.

Trends in the space segment: The trends of technology development in the space segment relevant for disaster management are characterized by:

- Higher performance of micro-satellites busses due to new developments on the component and subsystem level such as onboard computers, data handling systems, transmitters, solar arrays, batteries, GPS-receiver and others,
- Higher performance optical payloads for small satellites suitable for disaster monitoring tasks (high geometric and radiometric resolution, more spectral channels),
- Investigation of the feasibility of passive Radar (SAR) micro-satellites flying in formation with an active Radar satellite,
- Low-cost satellite technology makes operational satellites affordable for dedicated constellations,
- Novel international partnerships show new ways for new space nations to achieve effective systems through collaboration,
- Building of disaster monitoring constellations with small and micro-satellites,
- Decreasing the revisit time for monitoring tasks by using different satellites and constellations,
- Experimental on-board remote sensing data processing to produce a high level data product.

In summary, one can say that small satellites can provide data more quickly with a better match to user needs.

Trends in the ground segment: The trends in technology development for the ground segment relevant to disaster management are characterized by:

- increasing the flexibility of mission operations of satellites by building a flexible ground segment,
- building of networks of ground stations for increasing the satellite operational performance and data access without time delay,
- improving response time in imaging according to user requirements,
- data processing and distribution to the final user without delay,
- data policy is in many cases to restrictive for fast disaster response and must be addressed beforehand,
- distribution of data and algorithms for support of disaster management using COTS products running on personal computers will enable better use of the data, very small ground stations for in-situ measurements with data transmission facilities via satellites are available and they are independent on existing infrastructure,
- data processing and modeling of disaster conditions by experts are in progress, but there are gaps in the information extraction process for decision makers,
- tailoring of information for particular users,
- improving and disseminating knowledge of the utility of space-based sensor information.

In summary, technology developments in the ground segment address networking, improving response time and providing user-oriented space-segment control. The education in using spaceborne data has to be improved but also the information extraction process for decision makers has to be tailored and optimized to their needs.

Trends in the program segment: The trends in the program segment of cost effective Earth observation missions for disaster warning and support are focused on new applications and new data products. Some key points are:

- tele-medicine applications are important for disaster management and should be extended,
- medical weather maps should be integrated into public health applications,
- tele-education should be built up for disaster applications,
- national disaster preparedness should be improved and should include the appropriate use of the space segment,
- new monitoring applications using space technologies (GPS) should be applied to rescue teams and people in high risk areas,
- integration of space-based sensors into the spectrum of sensors that includes ground- and aircraft-based systems,
- use of new airborne platforms such as UAVs (Unmanned Air Vehicle) or transportable tethered balloons or dirigible airships may augment the space segment,
- integration and fusion of data from all available sources and the development of models related to disaster conditions are progressing to the point where expert systems may become available
- multi-temporal analysis of regional changes and conditions based on already existing satellite data is currently done by experts and must be simplified or improved to address a broader potential user community

In summary, tele-health and tele-education applications should be included in a disaster monitoring program. In addition, the entire spectrum of assets, from ground to space, must be integrated into an environment that provides the information needed to make decisions. This “expert system” needs to be developed: too much of the data is of meaning to, and accessible, only to experts and too little is in a form that can be used for disaster relief and mitigation personnel.

REFERENCES

Background Paper (No. 9). Small Satellite Missions - for the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space. United Nations Document A/CONF. 184/BP/9, 26 May 1998

Brieß, K., Jahn, H., Lorenz, E., Oertel, D., Skrbek, W., Zhukov, B. (2003). Fire Recognition Potential of the Bi-spectral Infra-Red Detection (BIRD) Satellite. *International Journal of Remote Sensing*, Taylor & Francis, Volume 24, Number 4/ February 10, 2003, pp. 865 - 872

Sandau, Rainer (ed.), 2006. *International Study on Cost-Effective Earth Observation Missions*. A. A. Balkema Publishers, a member of Taylor & Francis Group plc, Leiden, The Netherlands, ISBN 10: 0-415-39136-9, ISBN 13: 9-78-0-415-39136-8, 160 p.