Launch of the International Disaster Monitoring Constellation; the development of a novel international partnership in space

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ABSTRACT

Three spacecraft for the UK, Turkey and Nigeria were launched together in September 2003, to join Algeria's satellite, AlSat-1, in the Disaster Monitoring Constellation (DMC). Surrey Satellite Technology Ltd. has designed, built and launched the world's first constellation to provide daily global Earth observation coverage at moderate resolution in three spectral bands. This international initiative will provide daily images for global disaster monitoring, as well as supporting each partner nation's indigenous remote sensing requirements.

The DMC programme establishes a novel model for international collaboration, and demonstrates how small satellite missions can be employed for a wide range of applications. This paper shows the first in-orbit mission results from DMC satellites including examples of unique EO data products comprising up to 600 x 600-km images gathered at 32-metres GSD in 3 spectral bands.

INTRODUCTION

The launch of ALSAT-1 in November of 2002 saw the first Disaster Monitoring Satellite successfully placed in orbit. This was followed in September 2003 by the highly successful launch of 3 satellites, BILSAT (Turkey), NigeriaSat-1 and UK-DMC, on a Cosmos launcher from Plesetsk, Russia.

The Disaster Monitoring Constellation is designed to achieve daily imaging of any part of the world from a constellation of 5 satellites. Each satellite is owned and operated by a single nation, but by cooperating together in the DMC Consortium they can achieve daily imaging worldwide, greatly enhancing the capability of their national space asset.

The DMC demonstrates that small satellites can involve a wide range of nations in worthwhile space programmes. Earth Observation (EO) missions are particularly well suited to stimulate the development of sustainable resource management and environmental monitoring, and can aid the development of new national industries and space capabilities.

The role of satellites in medium and high spatial resolution reconnaissance of the Earth has been well demonstrated in recent years through missions such as Landsat, SPOT, IKONOS, EROS, ImageSat, Quickbird, IRS, and various others. Medium resolution

data products have added significantly to Earth science, but commercial markets have concentrated on further enhancing resolution. The markets for such high-resolution data products are well served, and are likely to become more competitive with further planned high-resolution missions.

In parallel, the small satellite sector has concentrated on reducing the cost of specialised data products that are ill served by current missions, and on the development of systems providing niche services. One such area where smaller satellites can provide a distinct advantage is in meeting the needs for higher temporal resolution by means of an affordable constellation of EO satellites.

The international organisations and communities that consider disaster monitoring and mitigation, using space missions, have identified many detailed requirements for dedicated missions. Accessibility and high temporal resolution have always been key parameters, but due to the diverse nature of disasters this application was found to require a wide range of sensors, including thermal-IR, multi-spectral and hyper-spectral sensors, high-resolution panchromatic sensors and Synthetic Aperture Radar (SAR). As a result the development of dedicated disaster monitoring missions has always remained too costly to contemplate, although an international charter on

disaster management attempts to coordinate existing in-orbit assets in case of disaster.

Figure 1 ALSAT-1 Preparing for Launch

In 1996 SSTL proposed to develop a remote sensing constellation [1] based on the emerging EO capabilities of low-cost small satellites, targeting medium-resolution visual observation of stricken areas using multi-spectral instruments. It argued that a constellation of small satellites provides the most affordable and sensible solution to the problem. The proposed system would never address all the complex requirements, but would provide a useful and practical first step in the development of a dedicated disaster monitoring system. The projected cost of the entire constellation would be well within that of a single conventional remote sensing spacecraft. Yet, rather than targeting a single source of funding for the constellation, a novel concept was adapted based on individual ownership of a single spacecraft and ground station pair. This leads to a relatively small investment for each participant, which can be justified on the basis of meeting individual requirements. However, in combination with a broad collaboration agreement, it not only provides owners with absolute control over their own assets to meet specific national or commercial needs, but it also strongly encourages owners to share resources to reap the benefits of operating the spacecraft as a constellation.

The key benefit is an enhanced temporal resolution, and a unique source of data that is not available from other existing space-based assets. The consortium also provides a method of sharing and spreading risk against a launch failure or spacecraft fault. The consortium charter has been deliberately kept simple, but direct provision has been made for directing free use of the constellation in cases of a disaster area being declared by the United Nations.

DMC CONSORTIUM

In 2000 Algeria's Centre National des Techniques Spatiales (CNTS) the British National Space Centre (BNSC) both funded a satellite in the DMC followed

shortly afterwards by the Nigerian Agency for Space Research & Development (NASRDA). The private Thai Mahanakorn University, and the Turkish Ministry of Science and Technology research institute TUBITAK BILTEN also agreed to become associate members of the DMC consortium, introducing their ThaiPaht-2 and BILSAT spacecraft respectively into the constellation.

Most recently, the Chinese Ministry of Science and Technology also agreed to participate in the constellation with an advanced spacecraft carrying the standard DMC 32m ground-sample distance (GSD) multi-spectral payload, in combination with a higher-resolution 4m GSD panchromatic imager. Additional members are still being considered.

In order to address the user needs in the event of a disaster, partners also include Reuters providing access to their AlertNet network for disaster relief, so that data can be requested, coordinated and delivered to humanitarian aid agencies over the Internet. Within the UK, CHEST will provide data into the academic community to exploit further application of the unique high temporal resolution data, and ESYS Ltd. in the UK is examining the commercial exploitation of the resulting data.

Figure 2 Preparation for the ship-out of ALSAT-1 to the launch site

The first DMC meeting was held in 2001 at Surrey, at which the partners agreed to set up a consortium so that maximum benefit can be derived for all partners by working together in a constellation. Basic principles of data sharing were agreed, such that 5% of system capacity could be reserved for disaster management.

At the second DMC Consortium meeting in Algeria, a Memorandum Of Understanding was signed by all parties. As it proved difficult for the consortium partners to co-align their national funding schedules, it was also decided to launch the constellation using a series of three launches: late 2002 for ALSAT-1, mid 2003 for BILSAT-1, NigeriaSAT-1 and UK-DMC, and a third launch that would cover the remaining satellites. However, the system would be virtually operational following the second launch. The meeting also resulted in a number of working groups being set up to cover a

range of infrastructure designs and developments for the eventual exploitation of the constellation assets.

The third meeting was held in Nigeria in March 2003, where the primary objectives of preparation and planning for the operation of the full DMC following the second launch were discussed. Following the experience gained on the first launch, orbital parameters were agreed for the second launch to insert the three new spacecraft into the constellation. The Consortium also reviewed the ALSAT-1 mission and its preliminary EO data, and further discussions were held on data sharing, exploitation and continuing international collaboration

DMC CONSTELLATION DESIGN

The primary driver for the system design has been to put a baseline conceptual system into operation within a reasonable time, rather than to capture the full set of requirements from the outset of the project.

The requirements for the DMC have been derived by examining the use of LANDSAT imagery in times of disaster, leading to the choice of an instrument which is compatible with LANDSAT bands 2, 3 and 4 (near Infra-red, Red and Green) at similar spatial resolution. Applications include the observation and evolution of both natural and man-made disasters, including those of storm, tides, earthquakes, forest and grass fires, vegetation health, flood, drought, pollution and contamination. Users of imagery currently available complain that they do not have regular and timely access, and that response time is often inadequate for serious use. The aim of the DMC is therefore to provide the ability to revisit and return imagery from any part of the globe, on a daily basis. A system design goal is also to provide a high degree of responsiveness, both in tasking the constellation and in image delivery.

Figure 3 DMC spacecraft in orbit

In order to improve the chances of success, a modest number of spacecraft and owners were desirable. This would keep allow the use of a single dedicated launcher, solving a key risk area in small satellite systems. As a consequence, the constellation design would need to be based on a single orbit plane. In further trading of the constellation requirements with spacecraft capabilities, a set of basic system parameters was derived.

A sun-synchronous orbit is base-lined with a Local Time of the Ascending Node (LTAN) at 10:00 near 700km altitude. With a moderate GSD of 32m, it is possible to provide daily global coverage at the equator with 4 to 8 spacecraft, as long as each spacecraft could access a swath of 300 to 600km. The system design lifetime was set at 5 years.

DMC SPACECRAFT DESIGN

Based on the original mission concept, ALSAT-1, the first DMC spacecraft was designed manufactured and tested ready for ship-out to the launch site in 24 months. The remaining spacecraft were manufactured to the same reference design, but staged behind by several months. Three satellites (ALSAT-1, NigeriaSAT-1 & BILSAT) were part of Know-How and Technology Transfer programmes run at SSTL, where engineers with contemporary training and skills come to Surrey to turn their experience to the particularities of working with spacecraft

Figure 4 DMC-1 Spacecraft

A key decision in the spacecraft design was to reject a 3-axis controlled solution with instrument off-pointing capability, and instead select a nadir-stabilised platform with a wide swath instrument with electronic-controlled sub-imaging to replace off-pointing.

The following description is for the standard DMC spacecraft. The Turkish satellite, BILSAT-1, which is associated as part of the initial constellation, is a far more complex design and is described more fully in reference [2].

DMC PAYLOAD

The DMC EO payload operates in Store-and-Forward mode, so that images can be taken out of range of any control stations. Payload data remain stored on-board until the spacecraft is commanded to return the data once in contact with one of the network ground stations. The payload therefore comprises two banks of cameras, a set of solid-state data recorders, and two high-speed downlinks. As with most small satellites, a balance has been struck between cost and performance. Payload operations are fundamentally resource limited by the on-board power available at the end-of-life, and by on-board storage. Fundamentally, the system design constrains the spacecraft on every orbit to

1. Take images filling half its data recorders
2. Return all these data to a single station

In practice, the system is well balanced between these constraints, but there are cases where any of these becomes the limiting factor. Data storage becomes the limiting factor when the spacecraft does not transit stations on several successive orbits, and power is the limiting factor when the spacecraft transits several stations in a single orbit.

The imager comprises six lens and sensor pairs, configured in two banks as part of an overall optical bench assembly. The banks are mounted angled away from nadir by approximately 12°, to double the swath width, but with a small overlap of approximately 5% to aid image stitching. The Field of View from each bank is 26.6°.

Figure 5 DMC optical assembly and sensor assembly

Each imager includes a customised Kodak linear CCD sensor with over 10,000 pixels measuring 7x7µm each, providing 32m Ground Sampling Distance at nadir. A Schneider lens is employed providing a wide focal plane, and each lens and sensor is integrated into an optical assembly with its own individual spectral filter. The complete instrument provides near 20,000 pixels in the standard LANDSAT bands 2,3 and 4 (Green: 0.52µm to 0.62µm, Red: 0.63µm to 0.69µm and Near Infra-Red: 0.76µm to 0.9µm).

Figure 6 DMC-1 payload data handling

The two main solid-state data recorders are configured to provide 4Gbit each, and a back-up data recorder provides an additional 1Gbit of solid-state storage. Software windowing functions are employed allowing the whole, or only sections of the full swath to be stored. Each instrument bank is cross-connected to the data recorders in a redundant fashion, and there is a third functionally redundant 1Gbit data recorder. Each half of the instrument can be powered separately, which allows flexible management of the on-board power resources. Input from the spacecraft clock allows software on the data recorder to deal with significant parts of the payload-scheduling task.

The primary data recorders are based around a Motorola PowerPC processor, and have the ability to carry out on-board image processing should this be required in the future. The secondary data recorder is based on an Intel StrongArm processor, providing a minimal level of redundancy through alternate technology.

A high speed S-band downlink is employed for data return, with 4W RF power, operating at 8Mbps. QPSK modulation is used, with half rate convolutional coding. A quadrifilar helix antenna is employed, providing a circularly polarised, shaped omnidirectional pattern, with equal power flux density across the entire footprint.

DATA PRODUCTS

Various imaging modes are possible. The accessible swath width of the payload is over 660km from a 686km orbit, when using both halves of the payload.

In order to manage the size of the data products, images are split into "tiles" of 2500x2500 pixels each (approximately 80x80km) in all three spectral bands. Various parameters are stored with each image, including spacecraft position, attitude and attitude rate. Typically, for dynamic Earth Observation only a few image tiles will be selected for regular observation, and up to 24 image tiles can be supported during a single image-take every orbit. Providing sufficient power is available, up to 48 tiles can be accommodated in memory as depicted in Figure 7.

Figure 7 DMC tiling

A further imaging mode is possible as illustrated in Figure 8, which allows very wide swath images to be acquired within very short time-spans over one or several orbits. For instance, four satellites can gather four adjacent image strips within 75 minutes, covering over 2500x560km.

Figure 8 Adjacent swaths capability

The ability to continue extending the swath in longitude then depends solely on ground station location and capacity. Basic pre-launch radiometric and geometric characterisation has been performed, and it is anticipated both raw data products, as well as radiometrically and geometrically corrected products will be available. In-orbit radiometric calibration is planned.

DMC SPACECRAFT PLATFORM

The platform design for the DMC spacecraft is an enhanced micro-satellite measuring 640x640x680mm. The spacecraft weighs 88kg, of which 19kg is payload. The spacecraft is cubic in shape with four body-mounted panels. The remaining facets house the spacecraft launch adaptor, sensors, payload apertures and antennas. The structure is based on Aluminium-alloy and Aluminium Honeycomb panels, and has been designed to be compatible with a wide range of launchers. The internal structure includes a stack of "MicroTray" modules traditionally used by SSTL in all its micro-satellites [3]. However, a number of "NanoTrays" with heritage from the SNAP nano-satellite [4] are also carried. The stack of trays carries an optical platform, and between the stack and the panels, the battery, wheels and propulsion system are carried. The spacecraft employs a fully passive thermal control system.

Figure 9 ALSAT-1 System Block Diagram

A system block diagram is shown in Figure 9. The spacecraft is largely dual redundant, with a controller-area-network (CAN) based data handling system.

A propulsion system is required in order for the spacecraft to be able to operate as part of the constellation, and is used to carry out initial launcher injection corrections, spacecraft separation into their respective orbital slots, altitude maintenance and finally an end-of-life manoeuvre to remove the spacecraft from the operational system. The system does not offer provision for maintenance of the LTAN, and instead the initial altitude and inclination are selected to minimise the LTAN drift over the mission lifetime.

A Butane based monopropellant system was selected, as it provides a high density Isp, allowing lower volume tanks to be used when compared with a conventional Nitrogen system. A further advantage is that the storage pressure is much lower, reducing the shipping and safety concerns.

The propulsion system delivers approximately 20m/s delta-V, and comprises 2 cylindrical tanks holding

2.3kg of propellant, and a single low-thrust thruster augmented by a small resistojet to boost its efficiency. The system is housed on the spacecraft base-plate, alongside the propulsion-controller electronics.

As mission lifetime and reliability were considered key parameters, a momentum biased attitude control system was selected, augmented by a gravity gradient boom. This provides natural platform stability, as well as providing an inherently safe spacecraft attitude configuration.

Figure 10 ALSAT-1 propulsion system

The spacecraft is 3-axis stabilised, using a pitch momentum wheel and yaw reaction wheel, with dual redundant 3-axis magnetorquers. A gravity gradient boom is employed to provide a high degree of platform stability, constraining the body-rotation rates to less than $\pm 2.5 \text{ mdeg/s}$. Two vector magnetometers and four dual-axis sun-sensors are carried in order to determine the attitude to better than $\pm 0.25^\circ$, but, because of the wide swath of the prime instrument, control is relaxed to $\pm 1^\circ$. A GPS receiver is carried to aid navigation during the critical mission phases, and also provides an accurate spacecraft clock.

The power system comprises four body mounted GaAs solar panels and an 8Ah NiCd battery. A raw 28V bus is distributed, alongside a regulated 5V bus. Lines are electronically switched and over-current protected with electronic switches. The system delivers over 30W orbit-average to the platform and payloads, with 12W for the platform, with approximately 16-20W available for payload operations.

The telemetry and telecommand (TTC) system employs S-band with a dual redundant CPFSK 9.6kbps uplink, and a single 38.4kbps QPSK downlink, with redundancy provided by the two payload downlinks. The uplink employs patch antennas, whereas the downlink employs a simple monopole antenna. The data handling system employs a dual redundant CAN bus for distribution of TTC, as well as small file transfers and bootloading. Two functionally redundant on-board processors are carried. The OBC186 is used

for housekeeping, and the OBC386 is used for attitude control.

Figure 11 BILSAT, NigeriaSat-1 & UK-DMC at Plesetsk prior to launch

The DMC spacecraft are designed to be operated using Internet-Protocol (IP)-based protocols for all routine operations, as pioneered on UoSAT-12 [5]. The payload downlink also implements a new Consultative-Committee for Space Data Systems (CCSDS) File Delivery Protocol over IP on the 8Mbps payload downlink.

GROUNDSEGMENT

The DMC is designed to operate with a distributed ground segment, which provides greatest redundancy, ample scope for growth, and encourages cooperation. It can also be operated as a centralised system when necessary, for instance to carry out constellation-wide housekeeping tasks.

Figure 12 DMC 3.7m tracking S-band dish antenna at Centre National des Techniques Spatiales, Arzew, Algeria

The station is based on a 3.7m tracking dish, which includes both S-band TT&C as well as the S-band high-speed payload downlink. It exhibits a G/T of 13dB/K at elevation angles above 10 degrees, and includes an X-over-Y rotor drive so that it does not have any dead zones overhead.

Each participant owns at least one station to access the constellation assets, and maintains the operations schedule and resourcing for its own spacecraft. Each station includes Mission Planning System software, a Data Archive and catalogue, and basic image processing capabilities.

System users can request targets via an internet-based user interface. The scheduling software identifies imaging opportunities on all DMC satellites based on spacecraft resource modelling, and provides feedback based on the various opportunities identified. The operator may then send a request to that partner satellite, which will appear in the partner's scheduling system. If accepted it will then be uploaded to the satellite and acquired.

A second mode is planned for disaster response. Reuters AlertNet will receive requests for images from Aid agencies, activated by the country affected by the disaster asking for international assistance. The DMC consortium will then target the disaster response images with highest priority, and upload a schedule to all available satellites in the constellation.

Since the satellite tasking system is designed to enable disaster requests to be centrally scheduled, this also provides the basis for scheduling of commercial orders. The DMC constellation working in synergy can double the number of images acquired and downloaded in comparison with the sum of the individual satellites. This is because there are considerable more download opportunities to the network of DMC ground stations, which frees the storage capacity of the SSDR for more images.

The DMC capacity will primarily be used to fulfil national EO requirements, such as land use mapping, urban development monitoring etc. However, the capacity of the system is expected to enable imaging to be carried out commercially, thus meeting the demand for high time resolution imaging in various applications.

Stations have so far been installed in the UK, Algeria, Turkey and Nigeria, and are inter-connected via the Internet. This allows remote control and data collection where desirable, but most importantly allows for distributed payload management, which can eventually lead to improved system responsiveness. The Mission Planning system is designed to be cooperative, with the assumption that each spacecraft will nominally be operated from its corresponding station. Requests for commanding the platform or payload from other users will be received over Internet, and reviewed by the spacecraft owner against its own priorities. Commands for disaster monitoring support will be pre-approved and will have the highest priority. It is anticipated that these man-in-the loop systems will eventually be replaced with software proxies to reduce the system response time. Surrey staff will initially carry out constellation management tasks from its UK station.

Only full collaboration leads to the benefits of daily global access to a particular location. Consortium members are free to negotiate full use of the constellation assets with their peers, for instance by using 25% of the constellation for 100% of the time, or 100% of the constellation for 25% of the time.

LAUNCH

The first spacecraft in the constellation, ALSAT-1, was launched on the 28th November 2002 on a COSMOS-3M launcher. The second launch on 27th September 2003 brought the constellation into full operation with a total of four spacecraft, by adding NigeriaSAT-1, UK-DMC and BILSAT-1.

Figure 13 ALSAT-1 Launch on Cosmos-3M from Plesetsk Cosmodrome.

The orbit injection for the 2nd launch was extremely accurate and was achieved within the required 2 second window.

Spacecraft will now be equally spaced along the orbit, and the constellation is planned to operate at an initial LTAN of 10:00am, which will slowly drift to 11:00am, before returning to 10:00 after 5 years. Additional partner spacecraft can be added subsequently, to increase the temporal coverage or provide replacement spacecraft.

The spacecraft platforms were rapidly commissioned from each national ground station. The first images were received from the satellites within 10 days of launch.

RESULTS FROM THE DMC SPACE CRAFT

Imagery has been received from all the spacecraft in the DMC. However the longest experience has been with the first satellite, AlSat-1. The size of the scenes returned has ranged from individual tiles to scenes that fully exercise both imagers and data recorders. Post processing systems have been refined to allow images to be stitched together, and work is in progress refining the process for radiometric and geometric corrections. Within the first six months of operation, over 200 images have been captured, demonstrating that the mission is operational as expected and is being operated in a safe power and thermal regime.

ALSAT-1 IMAGERY

The images generated by the multi-spectral imager payload on ALSAT-1 (e.g. Figures 14 & 15) easily demonstrate the capability of the DMC spacecraft. Various full scenes have been returned, and one example is shown in Figure 16, covering a 600x560km

area of the western USA identified in Figure 17. These images are pre-processed to level-0 – that is the individual bands have been co-registered and, if necessary, images from the two banks have been stitched together.

Figure 14 Desert Irrigation from ALSAT-1

Figure 15 Detail view of Ports of Los Angeles and Long Beach

A significant challenge is the sheer amount of data that can be generated by the spacecraft, with 80x80km image tiles of 75Mbytes, and full scenes of up to 1Gbyte in size. Fast and reliable Internet links between the partner stations are being established to meet the system goals. Furthermore, the availability of data archiving systems that support a low cost COTS approach for the mission is limited, and so the DMC consortium is investing in the development of its own system for image storage, distribution and delivery in the case of disaster imagery.

Figure 16 AL SAT-1 image of the Western United States (600x570km) 32m GSD (NIR R G)

Figure 17 AL SAT-1 image location

Figure 18 Colorado River and Lake Mohave in northwestern Arizona.

The primary SSDRs, when both filled simultaneously with image data from each imager bank can provide a huge image while still benefiting from detail at 32m GSD, as can be seen in Figure 16, with image detail in Figure 18, from the lower right hand portion of the image. SSTL has developed in-house software to allow accurate recombination of the multi-spectral image bands over large areas and assist in the generation of image mosaics from a matched pair of full swath images or a sequence of windowed events to change the format of the images produced.

Figure 19 River discharge following flooding in Western Morocco, Jan 2003

Although complete coverage of the globe for disaster monitoring requires the full constellation, ALSAT-1 has already produced images of affected areas ahead of the DMC. Figure 19, showing the after effects of flooding in Morocco, compares very favourably with NOAA data of the area.

A national users conference for ALSAT-1 was held in Algeria in May 2003, where a number of demonstration applications based on the ALSAT-1 images already acquired were discussed, including monitoring changes in surface response following the Algerian earthquake, and detecting and measuring vegetation burn scars following a series of major forest fires in Alaska.

PLANS FOR THE FUTURE

Work is ongoing in the implementation of a distributed product scheduling and data archiving system to support the DMC requirements.

Plans are being finalised to operate the constellation as a co-ordinated unit, whilst maximising the owner knowledge, capability and control of the individual spacecraft. The Consortium is considering how the DMC can be maintained in the future, and is actively considering additional members to ensure continuity of data. Furthermore, constellations using different sensors are being considered at SSTL and by the international partners. Plans for high-resolution imaging missions with 4 and 2.5m Ground Sampling

Distance are most mature [TOPSAT ref. [6]. Additional concepts include those for Thermal-IR hot-spot detection, Hyper-spectral and ocean colour imaging [7], and sea-state monitoring using radar altimetry.

CONCLUSION

Space is no longer the domain of the superpowers. The development of the Disaster Monitoring Constellation demonstrates that small satellites can involve a wide range of nations in worthwhile space programmes both nationally and internationally. Earth Observation missions are particularly well suited to stimulate the development of sustainable resource management and environmental monitoring. The DMC consortium model provides additional benefits, such as risk sharing and cooperation.

The Disaster Monitoring Constellation includes a number of innovations on different levels. It provides a practical realization of the need for dynamic Earth Observation, with daily imaging capability for any point on the globe. This is achieved through the formation of a novel international partnership, and enabled through small satellites in constellation. The DMC demonstrates how international collaboration can create operational space systems of which the whole is greater than the individual parts. Each partner gains benefits from others in the consortium. Yet each partner has an independent space asset to meet their own needs whilst benefiting from synergy through sharing of capacity with others. The model offers ideal opportunities for new space nations to become involved in space, and build up their national space industries.

Spacecraft such as the DMC small Earth Observation platform are the ideal tool to be used within a constellation to provide higher temporal resolution than can be obtained from individual spacecraft. The DMC payload implements a new way of addressing a wide swath from a small spacecraft, using very wide Field-Of-View sensors and electronic windowing, as opposed to a sophisticated attitude control system. As a result, the spacecraft cost is constrained, and novel imaging data products can be provided with exceptionally wide swath.

This capability combined with an effective know how transfer and training programme has put DMC partners firmly on the list of space nations and provided a framework for future national missions and international cooperation.

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