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GETTING THE BIGGER PICTURE: MORE BYTES FOR YOUR BUCK

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ABSTRACT

UK-DMC-2 and Deimos-1 will be in orbit after a multi-satellite launch at the end of 2008 and will mark the start of the Next Generation Disaster Monitoring Constellation (DMC-NG). Whereas Deimos-1 is under contract for the Spanish company Deimos Imaging SL, UK-DMC-2 is SSTL's own investment. This paper describes the UK-DMC-2 and Deimos-1 missions and the technical design of UK-DMC-2, focussing on the latest developments and experimental subsystems such as an innovative GPS-receiver, enhanced sun-sensors and a set of COTS heat pipes. New operational modes such as near real time imaging and downlink and a direct broadcast mode to multiple ground stations provides a substitute service for customers currently receiving Landsat data. Due to UK-DMC-2's high throughput potential, it will be used to assist in large area coverage campaigns.

INTRODUCTION

In December 2008 a Dnepr launch vehicle will put UK-DMC-2 and Deimos-1 into a sun-synchronous orbit which will mark the start of the Next Generation Disaster Monitoring Constellation. Whereas Deimos-1, built by SSTL, is under contract for the Spanish company Deimos Imaging SL, UK-DMC-2 is SSTL's own investment. UK-DMC-2 is the first small EO mission completely funded from projected data sales and Deimos-1 is also expected to pay its investment back by selling imagery. Both Deimos-1 and UK-DMC-2 spacecraft are developed to carry out a commercially-focused operational imaging mission, supporting rapid-response, large-area mapping for a range of applications.

UK-DMC-2 will secure data continuity and a new level of imaging output for SSTL's subsidiary DMC International Imaging Ltd (DMCii). With it, the UK contribution to the DMC is maintained. The new spacecraft will also expand the market potential by offering near real time downlink services to customers with receive-only ground stations. Due to the increased storage and downlink data rate UK-DMC-2 is able to cover large areas quickly and provides the capability for multi-season coverage of major agriculture such as the Amazon Basin, Europe and Australia. Furthermore, as an in-house development, it is an ideal opportunity to gain flight heritage on SSTL's latest technological developments.

Deimos-1 will mainly be providing imaging services within the Iberian Peninsula region, but will image Europe and the rest of the world as well. Alongside this, both missions will also support disaster monitoring as part of the International Charter for Space and Major Disasters.

DISASTER MONITORING CONSTELLATION

The Disaster Monitoring Constellation (DMC) is a unique international partnership of nations, which have coordinated their national satellites in space. The satellites, built by SSTL, are designed to achieve daily imaging capability over any site on earth. The constellation is coordinated by DMCii for disaster response, calibration and commercial campaigns.

The DMC Multi Spectral Imager uses a set of linear push-broom sensors to cover a 650km swath, and delivers images with a 32-metre ground sample distance (GSD) at nadir in three spectral bands. The Red, Green and Near Infrared bands use the same filters as Landsat bands 2, 3 and 4, so that the data is broadly comparable.

As a constellation, the system provides the unique benefits of wide swath, large area coverage, and daily repeat coverage. The 32 metre wide swath imagery from the first generation DMC satellites has proved the value of daily revisit capability, and generated strong repeat sales for applications ranging from Amazon deforestation to precision agriculture in Europe and USA.

Figure 1: The Disaster Monitoring Constellation

DMC-NEXT GENERATION

The first DMC spacecraft AlSat-1 reached its design operational life of 5 years in November 2007 and continues to operate since. With the other DMC spacecraft also approaching their design life in the coming 12 months, the time has come to renew the constellation. Besides the launch of UK-DMC-2 and Deimos-1, based on the SSTL-100 platform, a further 2 DMC spacecraft are developed under contract for the Nigerian National Space Research and Development Agency and are due for launch in late 2009.

With the demise of Landsat 5 and 7 there is an urgent need for continued regular monitoring of the world's land surface. Together with Deimos-1, the UK-DMC-2 satellite will provide the capacity to provide world coverage of 20 metre class imagery. The planned inclusion of additional 22 metre DMC satellites from new and existing DMC Consortium members will enable DMCii to provide an enhanced service delivering high frequency monitoring of the world.

The capability of SSTL spacecraft is growing rapidly in terms of Ground Sampling Distance, Data Rate, On Board Storage and Imagery Throughput. The medium resolution 32-m imagery with 650km wide swath from the first generation DMC spacecraft has been improved to 22 metre without the loss of Signal-to-Noise ratio and maintaining the wide swath. Since the Beijing-1 spacecraft, launched in 2005, X-Band transmitters are produced that lead to higher data rates of up to 80 Mbps for UK-DMC-2 and over 200 Mbps in the near future, see Figure 2.

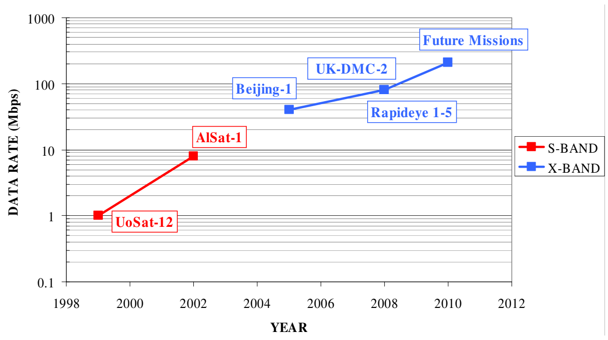

Figure 2: Data Rate Evolution of SSTL Satellites

Storage has increased from 1 or 1.5 Gbyte RAM on the original DMC to 12 Gbyte RAM on UK-DMC-2 and Deimos-1 and is expected to rise above 64 Gbyte in the near future. Because of the advancements in data rate and storage, daily image data throughput is expected to increase from 650,000 km^2 for UK-DMC-1 to a potential 11 Million km^2 for UK-DMC-2.

SSTL is able to offer the SSTL-100 platform with 22 metre imagery for $13-17M (not including launch) depending on the need for a ground station or training and a delivery schedule can be as short as 18 months.

UK-DMC-2 MISSION

The UK-DMC-2 mission will provide 22 metre Multi-Spectral Earth Observation Imagery to SSTL's subsidiary DMCii which provides high quality commercial data products and rapid response disaster monitoring.

The space segment, a DMC spacecraft based on the SSTL-100 platform, has been developed in a fast 18-month schedule using SSTL's evolutionary design approach. A Dnepr launch vehicle, with another 6 satellites on board, is scheduled for launch in December of this year to bring UK-DMC-2 in a near-sun synchronous polar orbit at an altitude of 680 km. After commissioning and in-orbit calibration, the mission duration is 5 years. In combination with the wide imager Field of View of 52°, this orbit allows any place on Earth to be imaged within 5 days. The payload provides imagery in three wavebands (red, green and near-infrared) which are equivalent to the Landsat bands 2, 3 and 4.

The ground segment consists of the existing SSTL Mission Operations Centre containing all the necessary receive electronics, post-processing software and mission planning system and a new S/X-Band ground station near Guildford, UK with a 5.5m reflector. This new antenna can receive data from SSTL spacecraft currently in orbit and will be used to support future missions as well. Customer with their own ground station will be given the opportunity to receive UK-DMC-2 raw data directly and in near real time.

Figure 3: Dnepr Launch Vehicle and UK-DMC-2 Ground Station.

DEIMOS-1 MISSION

The Deimos-1 mission is carried out under contract with the Spanish private company Deimos Imaging SL. Deimos Imaging SL will provide its customers products and services from Earth Observation Data in the fields of disaster monitoring, agriculture, forest management and environment monitoring. Its primary imaging territory will be the Iberian Peninsula (Spain and Portugal) and secondly it will capture imagery in Europe and the rest of the world. Deimos Imaging SL will also support the International Charter for Space and Major Disasters.

The spacecraft will be operated from the control centre located in Boecillo, Valladolid (Spain). The control centre will include two ground stations, one located in Boecillo and a second located in the North of Europe (probably Svalbard) for additional data downlink.

The imager payload is identical to the UK-DMC-2 22 metre multi spectral imager, with a wide swath (650km) and 8- or 10-bit digitization. It will allow covering up to 570.000 km^2 per orbit (8-bit). In support of the payload, the platform, among other sub systems, will include:

- Communication systems in S- and X-Band, operating at rates up to 40 Mbps
- Two solid-state data recorders with in total 4 Gbyte storage capacity

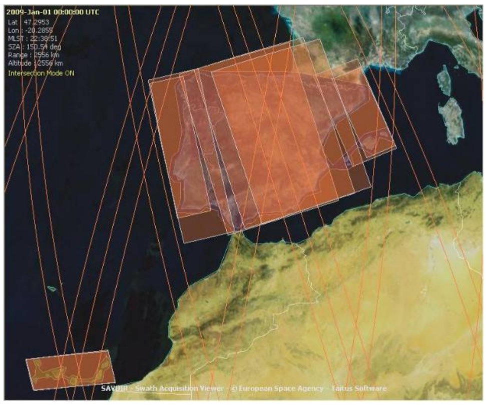

Figure 4: Deimos-1 Coverage of the Iberian Peninsula in just a Few Passes.

UK-DMC-2 SPACECRAFT OVERVIEW

A number of enhancements have been made to the SSTL-100 platform first used in 2002. The basic structure hasn't changed. The Space Facing Facet (SFF) contains the separation ring which is the mechanical interface with the launcher. On top of the SFF a central avionics stack is mounted which supports the imager assembly that protrudes through the Earth Facing Facet (EFF). The outer dimensions are very similar to the first generation of DMC spacecraft. With outer dimensions of X, Y, Z = 630mm, 660mm, 840mm UK-DMC-2 is very compact and because of that allows a wide range of launch opportunities.

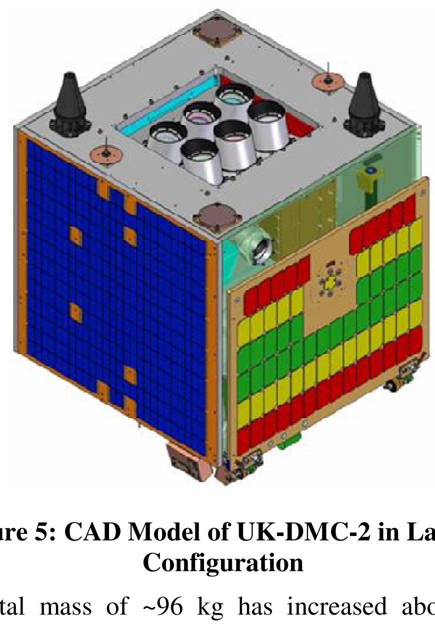

Figure 5: CAD Model of UK-DMC-2 in Launch Configuration

The total mass of ~96 kg has increased about 10% compared to the first DMC's. The most obvious structural change is the addition of a deployable solar panel which increases the Orbit Average Power (OAP) by approximately 60%. See Figure 5 for a CAD model of UK-DMC-2. The following sections describe the satellite per subsystem.

Imager Payload

The imager assembly contains six channels configured in two banks that are mounted angled away from nadir by approximately 13º. In this way the swath width is almost doubled, maintaining a small overlap to aid image stitching. The total imager Field of View (FoW) is 52º which at an orbit altitude of 680 km delivers a swath width of around 650 km. Both banks contain three channels sensitive to the 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).

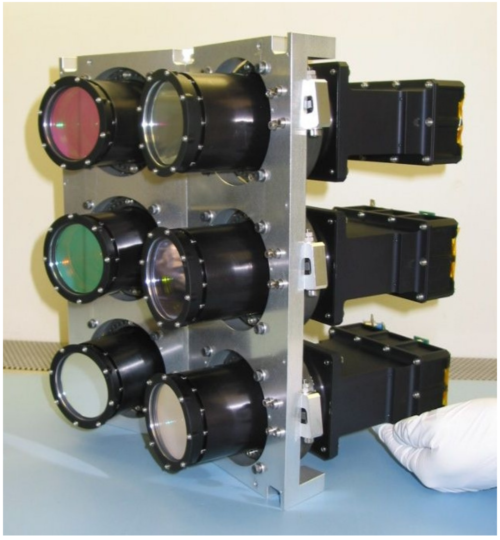

Figure 6: UK-DMC-2 22 Metre Imager Assembly

By using a new custom made lens system that provides a wide focal plane and a customized Kodak linear CCD sensor with over 14,400 pixels measuring 5x5µm each, the imager payload generates a Ground Sampling Distance (GSD) of 22 metre at nadir for an orbital height of 680 km while maintaining the ultra-wide swath. Furthermore the Modulation Transfer Function (MTF) characteristics and Signal to Noise Ratio (SNR) have been improved compared to the first generation 32 m DMC imagers.

As the on-orbit calibration techniques have been refined with the first generation imagers, the radiometric accuracy prior and following launch has been increased. Finally, a new alignment and focusing mechanism is included to support rapid setup of the instrument.

RF Communications

The Telemetry & Telecommand (TT&C) system that is used to command the spacecraft and receive status information consists of SSTL's heritage receivers and transmitters. The two 19.2kbps CPFSK S-Band uplink receivers, each having 2 patch antennas, are always on and provide an omni directional antenna pattern to maintain the RF link at all times. The TTC downlink is provided by two redundant 38.4kbps BPSK S-Band transmitters, each with 2 monopole antennas to provide an omni-directional antenna pattern.

The payload downlink consists of 2 redundant high-speed Diff-QPSK X-Band Transmitters. Each transmitter uses Diff-QPSK modulation and Viterbi Convolutional Encoding with r=1/2 and k=7 for optimised spectral efficiency. Both transmitters are connected to a Saab isoflux antenna on the Earth Facing Facet. The data rate is selectable on orbit between 20 and 80 Mbps.

The payload downlink is designed to maintain a positive link margin when transmitting data to the UK-DMC-2 ground station with a Bit Error Rate (BER) of $<10^{-6}$. For downlinks to receive-only ground stations a BER of $<10^{-9}$ is required and for smaller ground stations a data rate of 20 Mbps may be selected to maintain a positive link margin.

On-Board Data Handling

Two redundant Intel386-based On-Board Computers (OBCs) are used as the 'brains' of the spacecraft. The OBCs provide communications between sub systems, monitors the temperature and current consumptions, maintains log files and executes the imaging schedule.

Data storage is provided by two 2 Gbyte solid-state data recorders (SSDRs) working in parallel. A newly developed 8 Gbyte high-speed data recorder (HSDR) has been added for increased storage and a faster downlink data rate. For full swath imaging both SSDRs are used, each connected to one of the imager banks. The HSDR is able to receive imager data from both banks at the same time. Where the SSDRs can downlink their data at 20 Mbps, the HSDR can support the high-speed 80 Mbps downlink as well.

Attitude and Orbit Determination and Control

The Attitude and Orbit Determination and Control System (AODCS) provides 3-axis momentum biased attitude control. An in-house developed GPS-receiver is used to determine the orbit and to provide accurate timing information. Dual-axis Sun sensors on the four sides of the spacecraft and 2 redundant vector magnetometers provide attitude knowledge by measuring the sun-angle and Earth magnetic field. Based on the sensor knowledge three magnetorquers, which generate a torque by interacting with the Earth magnetic field, and three reaction wheels are used to control the attitude and attitude rates and maintain attitude pointing during various mission stages.

Propulsion System

The heritage DMC Butane cold gas monopropellant system is used to be able to correct for possible launcher injection errors, phasing manoeuvres with other spacecraft and a potential end-of-life manoeuvre to reduce the time it takes before re-entry in the atmosphere. The beginning-of-life orbit parameters are selected to optimize the orbit altitude reduction and Local Time of the Ascending Node (LTAN) drift without use of the propulsion system, but small corrections over life are supported.

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.

Power System

Three body-mounted heritage solar arrays are used containing GaAs/Ge single-junction solar cells providing 65 W at AM0 and 25º C. The fourth body-mounted solar array has been replaced by a deployable solar array containing Emcore triple-junction InGaP/InGaAs/Ge solar cells which provides 65 W at AM0 and 28º C. Because this panel is deployed by a 110º, it increases the total Orbit Average Power (OAP) by 60 %.

An ABSL Li-Ion 15 Ah battery is used to be able to continue operations through the Earth eclipse and provide extra power during heavy operations.

The rest of the power system consists of a Battery Charge Regulator (BCR) Module and a Power Conditioning and Power Distribution Module (PCM/PDM) to regulate the power coming from the solar panels and battery and to distribute the power to all sub systems.

Experiments

A number of experiments have been selected to be included in the UK-DMC-2 spacecraft to gain flight heritage on developed units and to continue SSTL's technological development.

The COTS heat pipes experiment consists of a set of three heat pipes which are extremely good in transporting heat from one end of the pipe to the other and can be very helpful in thermally stabilizing a satellite. Heat pipes in space are used mainly in GEO satellites to transfer heat from high power units to radiator surfaces and/or to distribute heat evenly over large surfaces. The heat pipes are characterized on ground and will be compared with the results on orbit. If the experiment is a success, they can be used on future SSTL missions.

A new type in SSTL's successful range of GPS receivers, the SGR-07, has been included as a second GPS-receiver alongside the heritage SGR-10 unit. Consuming less power and faster in acquiring a fix, the SGR-07 is expected to be a benefit to the UK-DMC-2 mission. The SSTL GPS receivers are very popular on the market and building up flight heritage enhances the reliability.

Two fine sun sensors are included that can measure the sun-angle more accurate than the heritage linear sun sensors. The fine sun sensors are the next step in SSTL's development of more accurate attitude sensors and are expected to replace the linear sun sensors in the near future.

UK-DMC-2 OPERATIONS AND PERFORMANCE

As part of the Disaster Monitoring Constellation UK-DMC-2 will be used to maintain rapid revisit times needed to monitor fast changing phenomena such as fires, floods and crops. Furthermore it also covers large areas quickly including the Amazon Basin, Australia, and Europe, providing the capability for multi-season coverage of major agriculture. To enhance the capability of imaging very large areas as quickly as possible and being able to offer custom data delivery contracts to customers, a number of operational modes are implemented.

Store and Forward Imaging and Downlink

This is the standard imaging and downlink operational mode employed by the current DMC spacecraft.

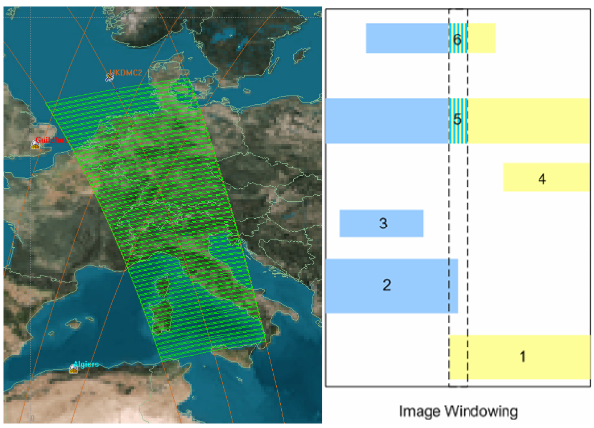

Figure 7: Store and Forward Imaging

One or more images are recorded on the data recorders after which they are put in a lower power storage mode.

Approaching a ground station access, the recorders are put back into full-power mode and all or part of the data is transmitted using the SSTL Saratoga hole-filling downlink protocol. With the full 650 km swath of the imager, strips of up to 1800 km can be imaged, as can be seen in Figure 7, an image from the south of Italy to Denmark can be recorded in one go.

In order to more efficiently acquire image targets, the swath can also be windowed as long as one window at a time is taken Table 1 sums up the achievable image strip lengths for various selected swath widths and digitization. When the Landsat 7 swath width of 185 km is selected, strips of over 6000 km can be acquired, equivalent to an image from South Africa to Algeria or Florida to North-Canada.

Table 1: Maximum Imaging Strip Length for Various Selected Swath Widths and Digitization

Selected Swath (km)	Digitization	Maximum Strip Length (km)
650	8-bit	1800
	10-bit	1450
325	8-bit	3600
	10-bit	2900
185	8-bit	6300
	10-bit	5100

Near Real Time Imaging and Downlink

In addition to Store and Forward operations it is possible to perform a so-called near real time mode. This mode allows imagery acquired within a 2000 km radius of a ground station to be down linked within the same pass. In this way imagery can be delivered directly to customers with only a few minutes delay (not taking into account ground processing).

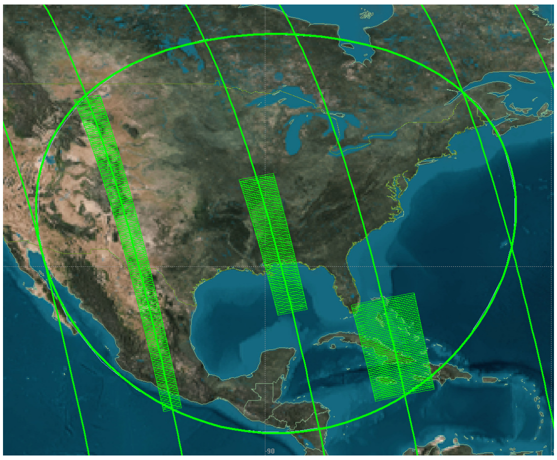

Figure 8: Near Real Time Performance over the USA at 80 Mbps

The data rate of the incoming imagery for full swath imaging is about 3 times higher than the downlink data rate. To be able to get all the imagery down linked, either the swath width needs to be reduced or enough time reserved after the imaging strip to allow the remaining data to be transmitted. Some example near real time imaging strips for a ground station in the USA are shown in Figure 8.

When the swath is reduced to about 215 km (~a 3rd of the full swath), the full ground station access time can be used to image (leftmost strip in Figure 8). For full swath imaging starting at the beginning of the pass, one needs to stop imaging after about a 3rd of the pass (rightmost strip). The middle strip shows a half-swath strip centred around the ground station location.

Broadcast Downlink

To allow receive-only ground stations access to UK-DMC-2 imagery, an asynchronous 'broadcast' downlink is implemented. It provides a substitute service for customers currently receiving Landsat data. This downlink mode doesn't use the standard SSTL hole-filling algorithm and therefore requires a very low Bit-Error-Rate to ensure error-free reception of imagery. Most existing receive-only ground stations are relatively high-spec, for instance the USGS ground station network that is currently downloading Landsat 5 and 7 data has a minimum G/T value of 32.3dB/K @ 5deg elevation and dish sizes of more than 7 m. UK-DMC-2 broadcast data can be down linked at 20 Mbps to ground stations with a minimum of 3 m and a G/T of 25.8 dB/K @ 5 deg elevation (MODIS class). At 80 Mbps a minimum G/T of 31.59 dB/K @ 5 deg elevation is required to receive error-free imagery. For smaller ground stations the minimum elevation can be increased in order to reduce the Bit-Error-Rate.

Multiple Ground Station Support

Another advancement compared to the original DMC spacecraft is the possibility of making use of multiple ground stations. UK-DMC-2 has the capability of taking images every orbit and is therefore not power limited but ground station access time and/or storage limited. The total data throughput is greatly increased when making use of more than one ground station. In combination with the previously mentioned near real time mode and broadcast downlink, it is now possible to offer customers very simple Landsat-type image reception contracts. Customers with existing receive-only X-Band ground stations can sign up to receive data every pass over there area of reception, either full pass at a 3rd of the full swath or a partial pass at full swath. Depending on the power, storage and temperature limits of UK-DMC-2, ground stations can be added that receive data every pass.

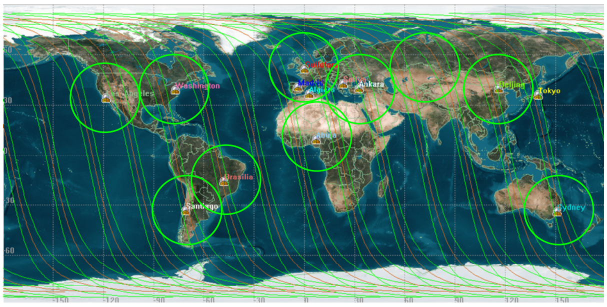

Figure 9: Landsat-Type Image Reception Contracts with Multiple Ground Stations Worldwide

See Figure 9 for a potential globally distributed set of receive-only ground stations that receive UK-DMC-2 data in near real time.

Throughput Performance

Based on spacecraft performance and provided there are enough ground stations available, UK-DMC-2 is able to image and downlink 11 million km^2 every day, which is more than the total area of the USA. Figure 10 shows the daily coverage of UK-DMC-2 assuming 13 ground stations globally distributed. It would take about 2 weeks to cover the equivalent of all Earth's landmass once. Taking into account cloud-cover and overlap of imagery it would take over 3 times the amount of imagery to produce a full cloud-free map of the Earth's landmass. A constellation of next generation DMC spacecraft will therefore be very suitable to DMCii's plans of offering a full world coverage service.

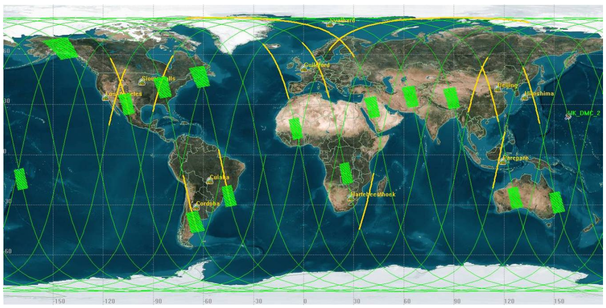

Figure 10: UK-DMC-2 Daily Coverage Using Multiple Ground Stations

Large Area Mapping

In the past years, demand for large area DMC imagery has grown steadily and UK-DMC-2 will be used to carry out these campaigns. The UK-DMC-2 increased resolution and improved dynamic range will assist in providing the detail needed to accurately map areas of rapid deforestation in the Amazon and other parts of the world.

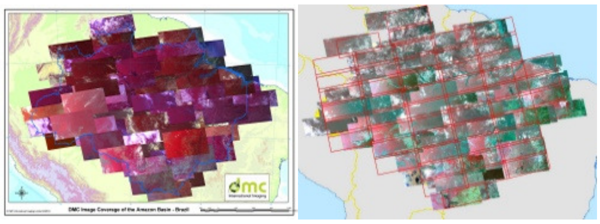

Figure 11: 2005 and 2006 DMC Coverage of the Amazon Basin

Figure 11 shows the result of the 2005 and 2006 campaign to provide coverage of the Amazon Basin. These campaigns have been carried out with two of the first generation DMC spacecraft and took 6 weeks to complete. Because of the increased throughput capacity of UK-DMC-2, the same coverage can be acquired in just 11 days, as can be seen in **Error! Reference source not found.**. The coverage prediction has been made using an in house developed scheduler program and assumes the UK-DMC-2 ground station to be used in combination with the 80 Mbps downlink. An imager tile size of 325 km x 325 km (half-swath) has been chosen to simplify the scheduling algorithm.

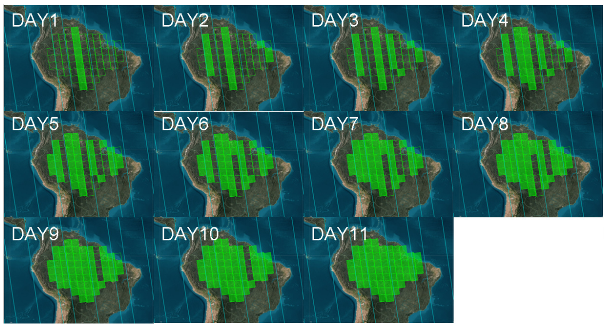

Figure 12: UK-DMC-2 Coverage of the Amazon Basin in 11 Days

In Europe the 20 metre class DMC imagery will supply many of the requirements of the Global Monitoring for Environment & Security (GMES) programme. The ability of the constellation to provide full 38 country coverage at specific dates and with challenging cloud cover specifications was demonstrated successfully in 2007, see Figure 13. In addition to multi-season European coverage requirements, GMES also plans to monitor food security in Africa and other parts of the world, and to provide rapid emergency response. The DMC Consortium is already very experienced in Emergency response, through active membership of the International Charter; Space & Major Disasters, and the 20 metre class wide swath data will add significantly to the level of mapping that can be achieved for large events such as flooding.

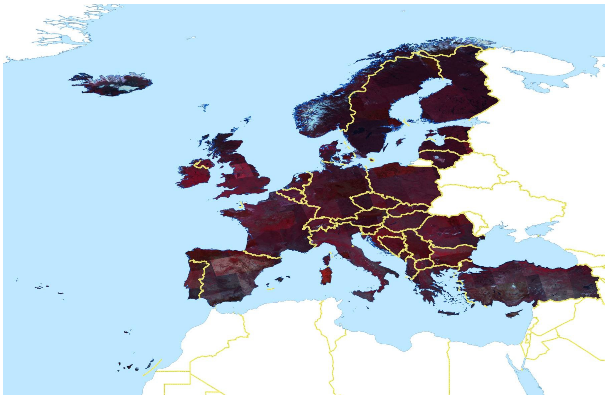

Figure 13: Full European Coverage in 2007

UK-DMC-2's performance in providing coverage over Europe has also been predicted. In less than 2 weeks, the same territory as in the 2007 campaign can be imaged once. To cope with cloud-cover it may be necessary to image areas more than once and taking into account cloud cover statistics full cloud-free coverage could be acquired within 3 months. This is still significantly faster than the 2007 campaign in which 3 spacecraft imaged Europe between March and September. Figure 14 shows that 95% coverage has been achieved after 11 days.

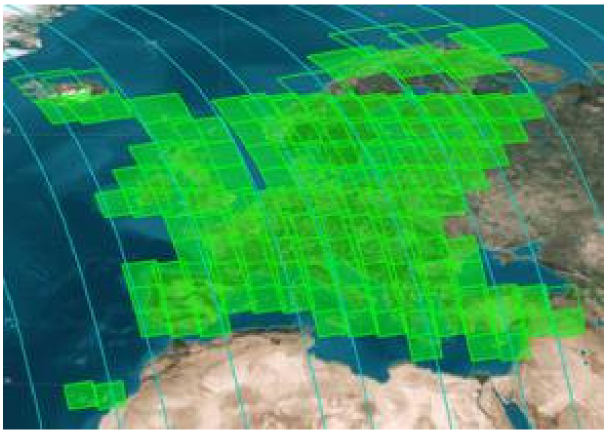

Figure 14: UK-DMC-2 Coverage of Europe After 11 Days

OUTLOOK

With two 20 metre class satellites due to launch in 2008, and others expected to follow, the constellation is being renewed and upgraded to maintain data continuity, and extend the capability for monitoring the world. DMCii, which coordinates the constellation for disaster response and commercial campaigns, sees the demand for medium resolution imagery growing strongly and anticipates the development of new applications and services based upon the reliable regular coverage of the world. The advancements of SSTL spacecraft in terms of throughput performance will allow a 5-satellite constellation of next generation DMC spacecraft to provide daily global coverage of 22 metre GSD imagery, stimulating a new level of EO applications and an enhanced ability to monitor and manage the planet.

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