Small Satellite Constellations; the future for operational Earth Observation

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Pioneering a different approach to space

Low-cost, rapid-response small-satellites built from advanced terrestrial technology
Revolution in Space

<table>
<thead>
<tr>
<th></th>
<th>Mass</th>
<th>Cost</th>
<th>Time</th>
<th>Tech</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESA Envisat</td>
<td>8000kg</td>
<td>$3000m</td>
<td>15yrs</td>
<td>4MIPS</td>
</tr>
<tr>
<td>SSTL SNAP-1</td>
<td>6.5kg</td>
<td>$1m</td>
<td>6 mths</td>
<td>10MIPS</td>
</tr>
</tbody>
</table>

Disruptive Technology: ‘PC in Space’
- Similar impact as PC in computer industry and user community
SSTL delivers the benefits of Affordable Access to Space through low-cost, rapid response, small satellites designed & built with state-of-the-art COTS technologies.

- Reducing the cost of entry into space
- Achieving more missions within fixed budgets
- Making constellations & formation flying financially viable
- Responding rapidly from initial concept to orbital operation
- Bringing the latest industrial COTS component advances to space

SSTL has stimulated growth in two key areas:

- Constellations for high temporal revisit & persistent monitoring
- Military responsive space assets
SSTL: the Company

Surrey Satellite Technology Ltd is a private British satellite manufacturing company owned by the University of Surrey (80%), employees (10%) and USA Space-X (10%)

- Formed in 1985, the Company now employs >200 staff and occupies dedicated facilities at the Surrey Space Centre.

- New purpose-built building on University Research Park ready early 2006

Aiming at a decade of 30% growth
Alliance with Like-Minded Entrepreneur

- **Space Exploration Technologies Corporation**
  - Founded in 2002 by Elon Musk
  - El Segundo, California
  - Aims at “reducing the cost and increase the reliability of access to space ultimately by a factor of ten”
  - Developing a family of launchers:
    - Falcon-1, $6.7m, c. 500kg in LEO
    - Falcon-5, 4 ton in LEO, 1.1 ton in GTO
  - 1st Launch Early 2006
  - $200m order book
Leading supplier of low-cost small satellites

- Entry level satellites
- High performance LEO satellites
- Geostationary & MEO minisatellites

World’s most experienced small satellite engineering team
Small satellite imaging

Improvement in optical imaging resolution of SSTL low cost small satellites

- Microsat
- Minisat
- Enhanced micro
- 3rd party imagers

Ground sampling distance (m)

Year of launch

SSTL missions

TM Sat image – Inchon, 100m multispectral
SSTL missions (cont.)

TiungSat image – Trans-Arabian pipeline, 80m multispectral
SSTL missions (cont.)

UoSat12 image – Algiers, 32m multispectral
SSTL missions (cont.)

UoSat12 image – Algiers, 10m panchromatic
SSTL missions (cont.)

DMC+4 Cairo airport 4m panchromatic imager by SIRA
SSTL missions (cont.)

TOPSAT  QE bridge 2.5m panchromatic/ 5m m/s  imager by RAL
SSTL EO Cameras using COTS components

UOSat-12 multispectral imagers
- 8-filter wheel
- 32m gsd resolution
- 60 x 30km image

SLIM-6 multispectral imagers
- 3 separate filters
- 2 banks of imagers
- 32m gsd resolution
- 600 x 300km image
- 100 x more area
... and at the other end of the scale

... the Nanosatellite
... and at the other end of the scale

... the “LapTop” of space
The DMC Concept

A Unique International Partnership Combining National Objectives, Humanitarian Aid and Commerce...

The Consortium

The Coordinator

- ALSAT-1
- BEIJING-1
- NigeriaSat-1
- BILSAT
- UK-DMC
Disaster Monitoring Constellation
Disaster Monitoring Constellation (cont.)
DMC Launch 2: BILSAT, NigeriaSat-1, UK-DMC
27 September 2003

Kosmos 11K65M, Plesetsk Cosmodrome
DMC Satellites – AlSat-1, NigeriaSat-1, UK-DMC

- 5 year design life
- Weight - 90 kg
- Resistojet Electro-Thermal Propulsion
  - Butane CGT
- Data Handling
  - 386 On Board Computer (OBC)
  - CAN TT&C
  - 1GB Solid Sate Data Recorders
  - Onboard GPS Receiver
- 8Mb S-Band Downlink
  - QPSK/FEC

- ADCS
  - <0.01°/s, accuracy <1.0°
- DMC SLIM6 Imager Pushbroom
  - 32m multi-spectral (3-bands)
  - 600km swath width
  - 1.5Gbytes SSDR
DMC Standard SLIM6 Sensor

Sensor: Eastman Kodak KL10203 Linear CCD
10224 7.0 x 7.0um pixel array

Lens: Schneider Apo-Componom HM
150mm, f/6.3

Per channel
FoV= 26.62 degrees
Swath = 324.58km

Filters: Barr Associates Inc., USA
Landsat equivalent
- NIR 0.77 - 0.90um ETM+4
- Red 0.63 - 0.69um ETM+3
- Green 0.52 - 0.60um ETM+2
DMC in Operation
France (32m GSD 3-band m/s)
DMC in Operation (cont.)
France (32m GSD 3-band m/s)

Charles de Gaulle airport, Paris
- DMC satellite 32m gsd multispectral image - maximum onboard storage is 600km swath x 570km along track. Imaging area normally 24 tiles, but can be selected to cover maximum of 48 image tiles. Each tile is 80x80km

- LandSat image size shown for comparison
Commercial Supplier for DMC Imagery

Objectives

1. International Sales of DMC images
2. Manage DMC Image Quality
3. Coordinate Disaster Response
## Standard Data Products

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>File Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAW</td>
<td>Raw imagery as acquired by sensor. Available upon request.</td>
<td>BIL</td>
</tr>
<tr>
<td>L0R</td>
<td>Individual band files Radiometrically corrected</td>
<td>TIFF</td>
</tr>
<tr>
<td>L1R</td>
<td>Registered bands Radiometrically corrected.</td>
<td>TIFF</td>
</tr>
<tr>
<td>L1G</td>
<td>As L1R plus: Geometric correction of systematic effects Standard cartographic projection (UTM WGS84 default)</td>
<td>GeoTIFF</td>
</tr>
<tr>
<td>L1T</td>
<td>As L1G plus: Orthorectified (1 km DEM) Higher resolution DEMs were available</td>
<td>GeoTIFF</td>
</tr>
</tbody>
</table>

**FTP or DVD/CD Delivery**

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![Image of satellite and data products]

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![Image of delivery methods]

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![Image of data products]

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DMC Data Products: Regular Radiometric Calibration

Principal Scientist Dr Stephen Mackin (Surrey Space Centre, UK)

- Annual Absolute Calibration since July 2004
  - Railroad Valley, Nevada instrumented test site
  - Facilities & TOA radiance supplied by Arizona Uni., USA

- Ongoing Monthly Relative Calibration
  - ‘Pacific at Night’ & ‘Antarctic & Greenland’ images

- No significant performance change noted
- Full documentation available
  - Calibration report

- Finalising Aug 2005 Calibration Coefficients

“In general this is good data.  visible vertical striping…pushbroom sensor…even/odd detector bias… easily correctable in processing…no other radiometric problems in the data.” USGS
• Automated Orthorectification (Spacemetric Keystone)
  - Automatic GCP Extraction from Landsat GLC Orthos

• Precision Manual Orthorectification Service
  - Sub pixel accuracy (Better than 25m RMS)
  - Standard Global reference: Landsat Geocover, GLOBE DEM
  - High precision local data sets utilised where available

Demanding customer routinely achieves 1/2 pixel registration with high precision DEM and local GCPs using simple 2nd order polynomial on L1R data.
## DMC Data Quality Compares Well with Landsat ETM+

<table>
<thead>
<tr>
<th></th>
<th><strong>DMC SLIM6</strong></th>
<th><strong>Landsat ETM+</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise</td>
<td>&lt;1DN (1 SD)</td>
<td>&lt;1DN (1 SD)</td>
</tr>
<tr>
<td>Signal-To-Noise</td>
<td>&gt;100:1</td>
<td>&gt;100:1</td>
</tr>
<tr>
<td>Absolute Radiometry</td>
<td>&lt;10%</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>Gain</td>
<td>Fixed Gain (Aug-2005)</td>
<td>Earth Surface Dependant Gain</td>
</tr>
<tr>
<td>Integration Time</td>
<td>Variable</td>
<td>Fixed</td>
</tr>
<tr>
<td>Swath</td>
<td>640km (20000 Pixels)</td>
<td>182.61km (6087 pixels)</td>
</tr>
<tr>
<td>Quantisation</td>
<td>8bit (From 11)</td>
<td>8bit</td>
</tr>
<tr>
<td>Band: Near IR</td>
<td>0.77 - 0.90 µm</td>
<td>0.77 - 0.90 µm</td>
</tr>
<tr>
<td>Band: Red</td>
<td>0.63 - 0.69 µm</td>
<td>0.63 - 0.69 µm</td>
</tr>
<tr>
<td>Band: Green</td>
<td>0.52 - 0.60 µm</td>
<td>0.52 - 0.60 µm</td>
</tr>
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</table>
Archive Search Tools

Online Archive Search Coming Soon
International Earth Observation Markets

Agriculture
- International Precision Farming
- Illicit Crop Monitoring
- EC AGRIFISH
- Food Security

Environment & Forestry
- Coastal Erosion Monitoring
- Burn Scar Mapping
- Forest Powerline Risk Mapping
- Landcover & Habitat Mapping
- Hydrological Mapping
- Logging & Deforestation Management

Source: ALSAT-1
Our Customers…

Brazilian Space Agency (INPE), Brazil
GTZ – COMIFAC
GTZ – PGDRN  Country Fire Service, Adelaide, Australia
Global Forest Watch (GFW)
Geosys SA, France

WWF – Cameroon  Centre National des Techniques Spatiales, Algeria
Remote Sensing Solutions GmbH, Germany

CIC Mining Resources Ltd., China  Countryside Council of Wales, UK
AFC Consultants International GmbH
EC Joint Research Centre

Vattenfall AB, Sweden

NASRDA, Nigeria

MINFOF (Ministère des Forêts et de la Faune)

ENGESAT, Brazil

EC GSE Global Monitoring for Food Security (GMFS)

Seazone, UK

UNODC

EC GSE Northern View

Metria, Sweden

Coopération Française (through PFBC)
Online Agricultural services Including Field level monitoring of crop health...

DMC 32m data located over 5m aerial photo in UK
Customer: UN Office on Drugs and Crime – Spring 2005

Broad area crop mapping & classification
DMCII has imaged the whole Amazon basin providing the data for annual forest monitoring. Wide area, Rapid coverage reduces cloud risk.
DMC Vietnam coverage, 2004

Thu Bon river basin, Quang Nam, Da Nang province
13,824 ha floods

Con river basin, Dinh Binh province
25,422 ha floods

Da Rang river basin, Phu Yen province
Estimated 12,246 ha floods

Tra Khuc river basin, Quang Ngai province
25,463 ha floods

Thu Bon river basin, Quang Nam, Da Nang province
13,824 ha floods

Flood analysis with DMC data by VAST and MOST
Change detection for clear cut mapping

Comparison of new DMC data with reference SPOT or other satellite data

Clear cut areas on Power map

Digitised Power network
Inter-tidal feature marine data products

- Highly dynamic environment.
- Difficult and expensive to survey by traditional means.
- DMC provides regular and synoptic coverage
Regular Monitoring of Lake Chad with NigeriaSat-1 allows rapid & regular water exploration of the region.
eCognition Segmentation based classification
- From 5707 objects 87 training samples
- Only 0.01% of objects needed to reach ‘satisfactory classification Results’
Increased chlorophyll activity – indicates risk of locusts

Combination of meteorology, Satellite data and ground observation predict locust migration routes

Contribution of the Algerian satellite AlSat-1 in the battle against the Desert Locust.

Images from AlSat-1 supported the preventative phase of the fight against the Desert Locust, enabling a regular monitoring of the swarming areas.
• Monitoring Rates of glacial ice release (Calving flux)
• The Greenland Ice Sheet is melting at rates far quicker than previously realised.
• Predicted global impact: Rising sea levels, Ocean Current instability.
Are the Siberian Forests a Carbon Source or Sink?
Approx. 16,000 forest fires (0.9M hectares) in Russia annually
Future climate change may alter fire frequency and area
There is little easily accessible information on Siberian Boreal forest fire dynamics

Investigators: Dr F. Gerard, Dr. H. Balzter, C. George, Dr. M. Wooster, (CEH & Kings, UK) Dr. Alexander Onuchin, (Russian Academy of Sciences)
Peat Fire Mapping - Central Kalimantan, Indonesia

- Mapping vegetation burning & peat soil fires in Central Kalimantan
- Approx. 11% of Indonesia's total land is peatland (50M Acres 20M Hectares)
- Burning, Logging and Draining has increased fire & flood risk
- In 1997 fires released an estimated 0.87 & 2.57 billion tons of carbon into the atmosphere (13-40% of total annual anthropogenic emissions)

Investigators: Dr. K. Tansey, Dr. S. Page, University of Leicester (UK) Ir. S. Limin, University of Palangka Raya (Indonesia)
Accurate, validated burnt area products for Portugal

- To derive algorithms for mapping burnt areas.
- Determine Severity of burn, pre- and post-burn vegetation characteristics (e.g. biomass)
- Data on the type of fire that has occurred.
- Use data in computing the resultant gas emissions.
- Field validation

Investigators: Dr. K. Tansey, University of Leicester
Dr. JM Pereira, JM das Neves Silva & T Santos, Instituto Superior de Agronomia, Lisbon, Portugal.
## DMC Disaster Response 2005

<table>
<thead>
<tr>
<th>Date</th>
<th>Type</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>26/08</td>
<td>Flood</td>
<td>Hurricane Katrina, USA</td>
</tr>
<tr>
<td>25/08</td>
<td>Flood</td>
<td>Switzerland</td>
</tr>
<tr>
<td>23/08</td>
<td>Fires</td>
<td>Coimbra, Portugal</td>
</tr>
<tr>
<td>27/06</td>
<td>Floods</td>
<td>Sutley River, Himachal Pradesh, India</td>
</tr>
<tr>
<td>09/06</td>
<td>Floods</td>
<td>Bulgaria</td>
</tr>
<tr>
<td>24/02</td>
<td>Earthquake</td>
<td>Zarand, Kerman, Iran</td>
</tr>
<tr>
<td>08/02</td>
<td>Floods</td>
<td>Georgetown, Guyana</td>
</tr>
<tr>
<td>27/12</td>
<td>Floods</td>
<td>Indian Ocean, Tsunami</td>
</tr>
<tr>
<td>05/12</td>
<td>Floods</td>
<td>Manila, Luzon, Philippines</td>
</tr>
</tbody>
</table>

### DMCii Provides:

- International Charter; “Space & Major Disasters”
- Rapid Response Imagery
- Emergency On Call Officers
- Executive Secretariat Member
Philippines floods 8/12/04
DMC Mapped the Entire Indian Ocean Tsunami Zone providing Imagery Before, During and After the Crisis
Smoke plume from wharf
Lake Ponchartrain
Flooded areas
Superdome
Mississippi River
Image: NigeriaSat-1
DMC+4 Satellite – Beijing-1 (Launched Oct 2005)

- **DMC SLIM6 Imager**
  - 32m multi-spectral (3-bands)
  - 600km swath width
  - 8Mbps S-band downlink
  - 1.5Gbytes SSDR

- **4m Pan Imager**
  - 4m pan
  - 24km swath width
  - 40Mbps X-band downlink
  - 3 Gbytes SSDR
  - 120 Gbytes harddisk

- **ADCS**
  - +/- 0.05° pointing knowledge
  - +/- 0.1° pointing control
  - +/- 30° off-pointing capability

- **5-year design life**
  - With orbit station keeping
DMC+4 satellite

- Launched on 27 October 2005
DMC+4 satellite (cont.)

- Launched on 27 October 2005
TopSat

- Customer: QinetiQ (UK MoD and BNSC)
- 2.5 m resolution panchromatic, 5m multispectral imaging
- Enhanced microsatellite: 120 kg
- High performance ADCS
  - Roll/Pitch (time domain integration)
  - Rapid slewing
- State-of-the-art ratio of optical resolution to satellite mass

Launched October 2005 with DMC+4
  - Cosmos LV from Plesetsk
- In commissioning
- First images November 2005
TopSat

- Operational Concept – Time Domain Integration
TopSat (cont.)

- Operational Concept – Time Domain Integration
TopSat (cont.)

- Operational Concept – Time Domain Integration