Earth Observation from Space -

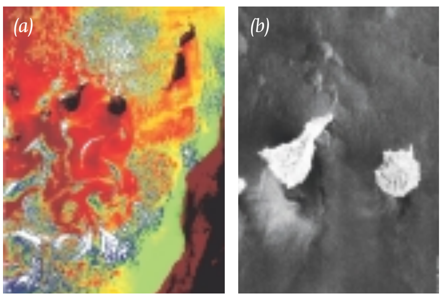
A Perspective on EO Activities in the UK

In general, the U.K. is often regarded as having a rather low level of involvement when space remote sensing activities are being considered. This is indeed the case with certain of the fields being covered by GeoInformatics - which often require the use of high-resolution imagery. However, over the last ten years, the U.K. has, in fact, become much more active in terms of conducting Earth Observation (EO) from space. Mostly this has been concerned with environmental mapping and monitoring on a regional or global scale. Essentially the emphasis in the U.K. has been on the acquisition of imagery having a wide spatial coverage and rather coarse (large) ground pixel sizes, mostly for use by the environmental science community. Besides this activity, the U.K. has developed a leading position in the design, development, construction and operation of micro- and mini-satellites. This has attracted widespread attention, especially from developing space nations wishing to acquire a national capability of Earth Observation (EO) from space.

By Prof. Gordon Petrie

U.K. Space Policy

Over the last 30 years, the U.K.'s space policies and activities have certainly been very different to those of its European neighbours. Prior to this, in the 1960s and early 1970s, the U.K. played an important part in the initial efforts to develop launchers in Europe through the activities of the European Launcher Development Organisation (ELDO). This was based partly on the Blue Streak launcher. Also the smaller Black Arrow launch vehicle was developed as a national project. However, in the early 1970s, the U.K. government decided to opt out of this area almost entirely. Thus it has played only a very minor role in the development of the European Ariane launcher programme since then. For the next 15 years (from the early 1970s till the late 1980s), the U.K. concentrated its efforts principally on telecommunications satellites. It also supported quite a number of space science activities - mainly concerned with astronomy, planetary and solar science missions and with meteorological satellites. However, over the last 15 years (from the late 1980s onwards), much more interest has been taken in Earth Observation (EO) from space by U.K. agencies, especially for environmental science and monitoring purposes. Thus, during the 1990s, an increased level of support has been given to this area with a large reduction in the funding and support previously given to telecommunications.



(a) Canary Islands - An ATSR optical scanner image of the Sea Surface Temperature (SST) as recorded by its thermal (LWIR) channel. The land areas are black. The measured SST values are shown in the range green (coolest) to red (warmest). The coolest water lies along the African coast. (Source: ESA/RAL).
(b) Canary Islands - ASAR radar image. Oceanic surface features associated with areas of precipitation can be seen north of the islands. To the south of the islands are areas of relatively calm and sheltered water lying in the lee of the islands' mountains which block out the effects of the area's northerly winds. (Source: ESA)

U.K. Support for Civil Space

The total budget devoted to U.K. civil space activities is only a fraction of that being spent by each of the other European countries - France, Germany and Italy - of roughly comparable size in terms of their population and economic activity. In spite of the U.K.'s somewhat ambivalent attitude towards many European institutions, in the civil space area, much of the government's funding is, in fact, channelled through the European Space Agency (ESA). Of the total U.K. funding for civil space activities, which approaches £200 million ($320 million) per year, only between £50 to 60 million is spent on national programmes. The rest - £120 to £140 million (roughly two-thirds) - is spent on ESA programmes. This sum includes both the U.K.'s mandatory contributions to the Agency and its additional contributions to certain specific programmes, which are chosen by ESA members on an 'a la carte' basis. By comparison, the total annual expenditure of France on civil space activities approaches £1,250 million ($2,000 million). The corresponding figures for Germany are £470 million ($750 million) and for Italy, £300 million ($500 million). The ESA **mandatory programmes** include space science, as well as the Agency's studies into future projects and investments and into technology research. The U.K. participates fully in these mandatory programmes and especially in the space science programme. Turning next to

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UK Style!

the five **optional programmes** - in **(i)** Earth Observation (EO); **(ii)** telecommunications; **(iii)** space transportation (Ariane); **(iv)** space station (ISS); and **(v)** micro-gravity research - that are offered to its members by ESA, the U.K. has concentrated its efforts on the first two of these areas. Thus it plays virtually no part in the Ariane or International Space Station (ISS) programmes.

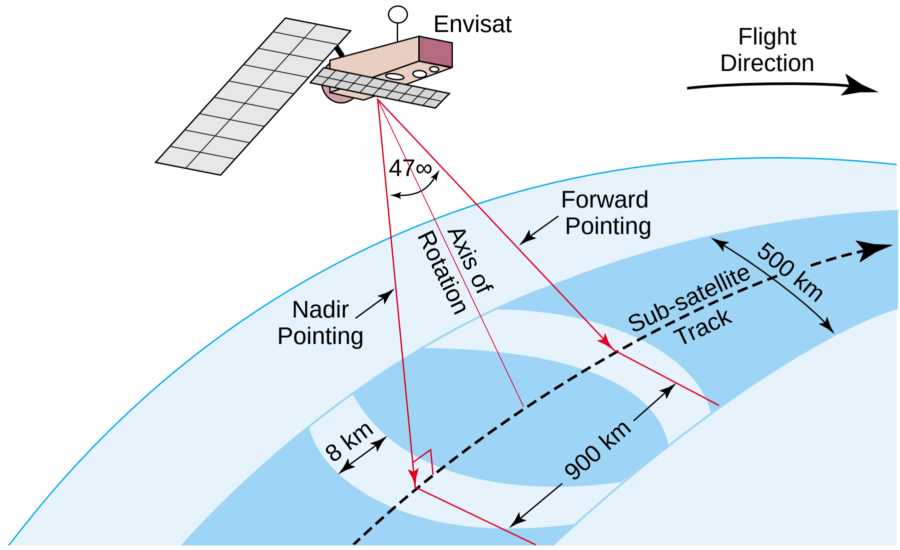

Figure 2: The conical scanning action of the ATSR & AATSR imagers give two scans of each patch of the Earth's oceanic and land surfaces - the one from a nadir position; the other from an off-nadir along-track position. (Source: ESA)

British National Space Centre (BNSC)

Originally established in 1985, the British National Space Centre (BNSC) declares itself - both on its Web site and in its written publications - to be "Britain's Space Agency". However, it certainly does not resemble, in the smallest way, either the American NASA space agency with its myriad of laboratories and centers, technological initiatives, air and space transportation programmes, etc. or even the space agencies - CNES (France), DLR (Germany) and ASI (Italy) - of its European partners. Instead BNSC is essentially a relatively small inter-Departmental body that coordinates the civil space activities of those U.K. government departments and research councils that have an interest in this area and are willing to provide financial support for it. These have comprised principally the Department of Trade & Industry (DTI) and, to a much lesser extent, the Department of Environment, Transport & the Regions (DETR) [which, under a recent government re-organisation, is now the Department of Environment, Food & Rural Affairs (DEFRA)], together with the Particle Physics & Astronomy Research Council (PPARC) and the Natural Environment Research Council (NERC). A fifth agency, the U.K. Met Office, also contributes funding, principally to the relevant ESA and EUMETSAT programmes. Of these five organisations, DTI contributes roughly half of the total U.K. spend (£90 million); the PPARC spends £50 million annually; the Met Office, £25 million per year; and NERC around £15 million per year. Normally the DETR contribution is relatively small (circa £5 to 10 million per year) and there is a further small contribution (£6 million) from the Ministry of Defence. Arising from its coordinating role, BNSC provides the main voice representing the U.K.'s interests in Europe, especially with respect to ESA's activities. In the BNSC document entitled "Space Strategy, 1999 - 2002: New Frontiers", priority was to be given to telecomms, navigation and enabling technologies and to support excellence in space astronomy and environmental research. Currently a new civil space strategy is being discussed and defined by BNSC.

ESA EO Programmes - ERS & Envisat

Besides the space science field, from the mid-1980s onwards, much of the support for ESA from the U.K. has been focused on the Agency's EO programme - in particular on the two Earth Resource Satellites (ERS-1 and -2) and the subsequent follow-on Envisat mission. ERS-1 was launched on 17th July 1991, ERS-2 on 21st April 1995 and Envisat on 1st March 2002. Since both the ERS satellites far exceeded their design lifetimes, the result has been an almost continuous stream of EO data from these two satellites throughout the 1990s and into the new century. In fact, ERS-2 is still operational and returning imagery to its ground receiving stations - including the main U.K. station located at West Freugh in south-west Scotland. The newly launched Envisat is intended to ensure both the continuity of the ERS data sets and the acquisition of new types of environmental data. While the platforms on which these satellites have been built are based on those developed for the SPOT and Helios satellites and have been built by Matra Marconi Space (now Astrium) in France, the U.K. contribution has been focused mostly on the imagers. In particular, the series of optical scanning radiometers (ATSR, AATSR) and synthetic aperture radars (AMI, ASAR) deployed on the ERS satellites and Envisat have, to a substantial extent, been developed and built in the U.K.

Spaceborne Optical Imagers - ATSR & AATSR

- **ATSR**

The original ATSR (Along Track Scanning Radiometer) imager was conceived and developed by a team headed by the Rutherford Appleton Laboratory (RAL) - the central laboratory of the U.K. research councils - with considerable assistance from the Mullard Space Science Laboratory (MSSL) at University College London; the Department of Atmospheric, Oceanic and Planetary Physics at Oxford University; and the U.K. Met Office. Initially the main objective of the **ATSR-1** scanner (mounted on ERS-1) was to measure Sea Surface Temperature (SST) globally to high levels of accuracy (±0.5°C). It employed a unique conical scanning arrangement which gave a dual-angle viewing geometry (Fig. 2). The use of this unusual optical scanning arrangement allowed two different sets of temperature measurements of the same small patch of the ocean surface to be made - the one from the nadir position, the other at an angle of 53° to the nadir. Since the measurements take place over quite different path lengths, it is possible to calculate corrections to the measured temperature values for the effects of atmospheric absorption. The ATSR imagers com-

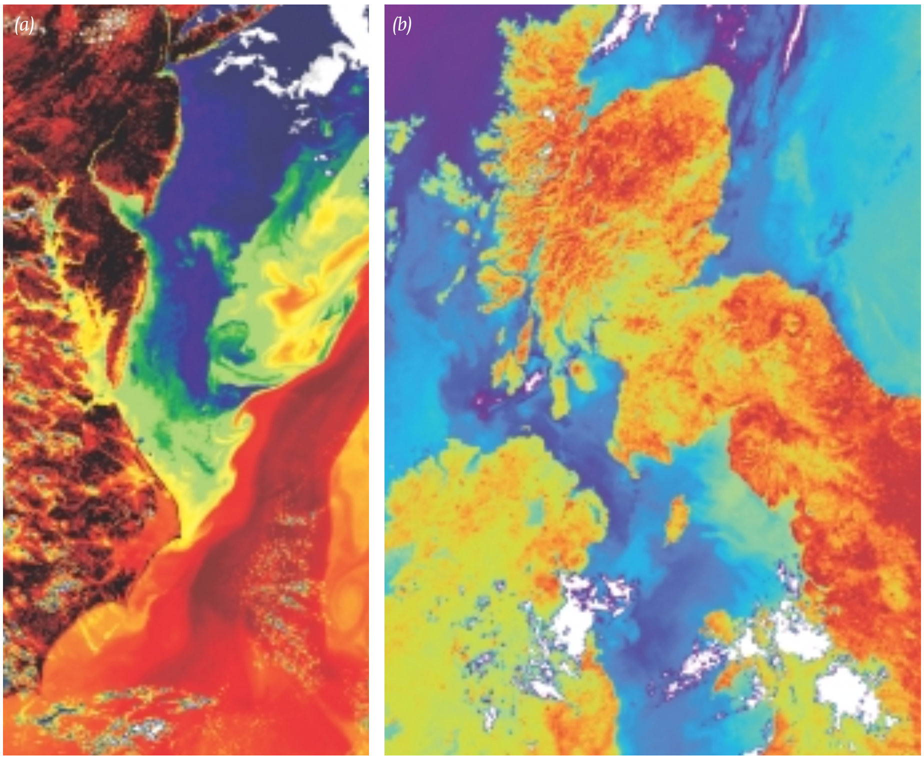

Figure 3: (a) An ATSR thermal (LWIR) image of the coast of the U.S.A. lying between North Carolina and New York. The warmer water (in red) of the Gulf Stream can be seen leaving the coast and moving into the main ocean to form the North Atlantic Drift. (Source: ESA & RAL)
(b) An ATSR land image of the northern part of the British Isles. The cooler sea is shown in blue; the warmer land is shown in green and red. (Source: ESA, RAL & Univ. of Leicester)

bine these measurements with an on-board calibration system whose black-body targets are viewed and measured during every scan. This helps further to ensure the absolute radiometric accuracy of the SST measurements. The infra-red (IR) detectors of the ATSR-1 generated images at three different wavelengths with l= 3.7m m (MWIR), 10.7m m and 12m m (LWIR) to match those of the AVHRR radiometers on the American NOAA weather satellites. There was also a reflected IR channel operating at l= 1.6m m (SWIR) that could be used to detect clouds during the day.

• ATSR-2
The ATSR-2 scanner imager that was mounted on the ERS-2 satellite was upgraded considerably compared with that of the original ATSR-1. In particular, it was fitted with three additional channels providing images at much shorter wavelengths - at l= 0.55m m (green), 0.67m m (red) and 0.865m m (NIR). The provision of these additional channels in the VIS/NIR spectral area was designed to allow applications of the imager over land, especially to vegetation studies. However, like the predecessor instrument (ATSR-1), it still generates its images with a relatively moderate swath width of 500km and having a quite low spatial resolution with a ground pixel size of 1 x 1km.

• AATSR
The third imager in the series - the **AATSR** (Advanced ATSR) that has been mounted on the recently launched Envisat - uses the same conical scanning principle and covers the same spectral channels as the ATSR-2. The main change with the AATSR is that it provides full digitization of all of the channels all of the time. Obviously the main objective of the AATSR is to extend the global sets of SST and vegetation and land cover data collected by the ATSR-1 and -2 imagers (Fig. 3). The SST data from the MWIR and LWIR bands are proving to be invaluable for climate prediction and research purposes. While the visible and NIR data sets are being used to monitor the health of vegetation over large areas of the globe and produce low-resolution vegetation index maps. Besides the actual instrumentation, U.K. contributors have also been active in the development of the algorithms used in the processing of the ATSR/AATSR data sets. A large international community of users of the data sets has grown up and a near real-time (NTR) service of SST data is now being provided on behalf of ESA by the Tromsøe ground receiving station in Norway.

Most of the hardware components of the ATSR and AATSR imagers have been built by Matra Marconi Space (UK) [now Astrium UK Ltd.]. The off-axis paraboloid optics that are used to focus the radiation from the Earth for all three ATSR imagers have been supplied by Optical Surfaces Ltd. While the earlier ATSR-1 and -2 imagers were funded largely by the two relevant U.K. research councils (SERC and NERC), the AATSR has been funded on a quite different basis. £11.5 million was provided by the DETR's Global Atmospheric Division; £1.8 million was provided by NERC; and £5 million by Australian government agencies. Indeed, from the outset, Australia has been the main partner to the U.K. in the development of the ATSR instrumentation. Its contribution to the first two ATSR instruments included electronic units, the focal plane assembly and ground support equipment. For the AATSR, the supply of the pre-amplifiers and fore-optics were additional contributions, besides the same instrumentation components that had been supplied for the earlier ATSR imagers from Australian sources. The main Australian contractor has been Auspace, now also part of Astrium.

Spaceborne Radar - AMI & ASAR

A substantial part of the SAR instrumentation operated on both the ERS satellites and on Envisat has also been developed in the U.K. In the case of Envisat, the main contractor for the ASAR radar imager has been Matra Marconi Space (UK) [now Astrium UK Ltd.] based in Portsmouth in Southern England. The company has been largely responsible for the overall design and development and a good deal of the manufacture of the imager. However substantial parts of the ASAR have been produced by European partners - Alcatel Space (France), Alenia Spazio (Italy), Contraves (Switzerland), CRISA (Spain), etc. In this respect, ASAR has been built as a core **'ESA-Developed Instrument' (EDI)** for Envisat, whereby the the work is shared out on a 'juste retour' basis among all those countries contributing to a specific project or mission. Whereas the AATSR scanner - like the DORIS (France) and Schiamachy (Germany/Netherlands) instruments - has been built as an **'Announcement-of-Opportunity Instrument' (AOI).** Essentially these three AOI instruments have been additional items to the Envisat payload that have been developed nationally or via bilateral partnerships, rather than by ESA as a whole.

• ASAR
Prior to the construction of the ASAR radar imager, Matra Marconi Space had played a

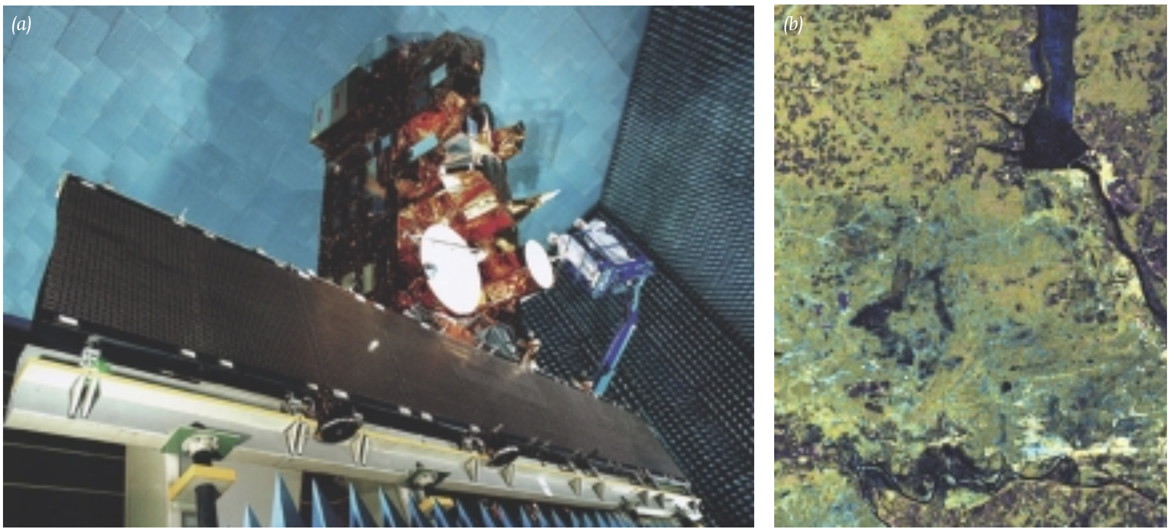

Figure 4: (a) The massive (10m x 1.5m) active antenna of the ASAR. Prior to its launch on Envisat, it was folded into five 2m x 1.5m panels. After launch, these panels were then unfolded and deployed using stepper motors to give the full length of the antenna. (Source: ESA-ESTEC)
(b) An ASAR radar image of the area of Dzerzhinsk, Russia lying along the Volga River, 300km east of Moscow. The generation of images having different polarisation patterns, when combined together, allows classified coloured images to be formed. (Source: ESA)

similar role as the developer and major manufacturer of the **AMI** (Active Microwave Instrument) that was mounted on the ERS-1 and -2 satellites. It could be operated either as a C-band SAR or as a wind scatterometer measuring wind speed and direction over the Earth's oceans. However **ASAR** is a significantly more advanced instrument. In particular, the passive waveguide antenna of the AMI used in combination with a centralised high-pass amplifier was replaced by an active phased array antenna system using

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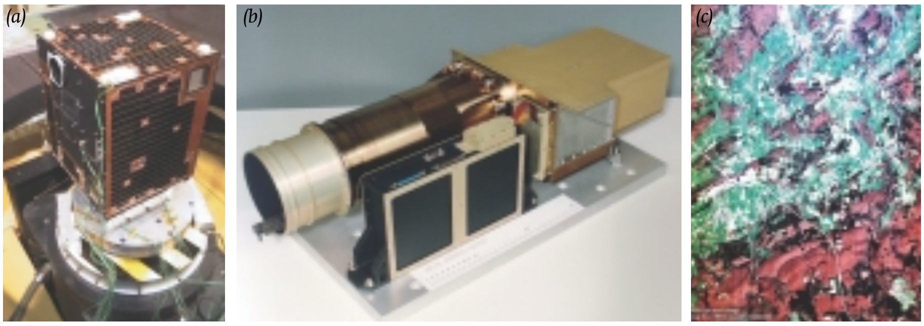
transmit/receive modules distributed across the antenna (Fig. 4). This allows the C-band SAR beam to be configured and steered to produce either a narrow ground swath (100km) with a reasonably high spatial resolution (30m) or alternatively a wider ground swath (405km) with a much lower spatial resolution (150m). The ASAR also features dual polarisation capabilities. These allow it to transmit or receive signals having either horizontal (H) or vertical (V) polarisation. Furthermore the instrument can generate two simultaneous images of the same scene with different polarisations and has a cross-polarisation option. Thus for example, a signal can be transmitted having a horizontal polarisation and the reflected signal received using vertical polarisation. Using these different polarisation options can produce SAR images having either HH, VV, HV or VH combinations. These can offer better discrimination between different terrain, soil and vegetation types; between sea ice and open water; and between different oceanic features.

Other UK Contributions to Envisat

Besides the AATSR and ASAR imagers, U.K. companies have supplied a number of important opto-electronic elements to the other EDI instruments mounted on Envisat. These include **(i)** the eight IR detectors and pre-amplifiers supplied by BAE Systems for the MIPAS infra-red spectrometer used to measure the trace gases that are present in the atmosphere; **(ii)** the various CCD arrays supplied by Marconi Applied Technologies (now E2V Technologies) both for the MERIS superspectral imager and the GOMOS ozone monitoring instrument; and **(iii)** part of the hardware for GOMOS that was supplied by Sira Electro-Optics. According to a statement made in February 2002 by the U.K. Minister for Science, Lord Salisbury, over the ten year period of the development of Envisat, the U.K. provided £300 million ($500 million) of the £1.4 billion ($2.3 billion) that has been invested in the Envisat programme.

PROBA & CHRIS

As well as its very large and expensive EO missions, ESA has a number of much smaller and lower cost programmes. Often these are intended to develop and validate new space technologies. One of these missions is a small (100kg) micro-satellite called PROBA (Project for On Board Autonomy). As the name suggests, it is intended primarily to demonstrate the autonomous operation of a small satellite with a minimum of involvement or intervention from the ground. It has been built for ESA by a consortium of mainly small companies from seven different European countries + Canada, headed by the Belgian company, Verhout. Besides the technology demonstration side, PROBA also carries an EO payload (Fig. 5). This includes two small-format digital cameras supplied by a Belgian company, OIP. However, the primary instrument on PROBA is the Compact High Resolution Imaging Spectrometer (CHRIS) This is a hyperspectral imager based on the use of a 2D CCD areal array that was proposed and built by Sira Electro-Optics from the U.K. It is a pushbroom scanner that operates over the VIS/NIR spectral range from $\lambda = 0.45$ to $1.05 \mu m$. It is fully programmable in orbit to produce images in 19 spectral bands at its full ground resolution. In that mode, images having a 17m ground pixel size and a ground coverage of 13.5 x 13.5km are produced from the PROBA satellite's lowest orbital altitude of 575km. A larger number of bands (up to 63) can be produced: however, this results in a corresponding reduction in the ground pixel size to 34m. Since the EO payloads on PROBA were not funded by ESA, the support for the development of the CHRIS imager has come primarily from BNSC. PROBA also features a space-hardened GPS supplied by SSTL and an Autonomous Star Tracker (AST) to give accurate information on the spacecraft's position and attitude. The AST was developed jointly by Sira and Matra Marconi Space (UK) [now Astrium UK Ltd.] supported by the U.K. Defence Evaluation & Research Agency (DERA) [which is now called QinetiQ]. Numerous CHRIS images have already been generated and supplied to the 40 principal scientific investigators, who mainly use them to carry



(a) The PROBA micro-satellite during vibration testing. (Source: ESA) (b) The CHRIS hyperspectral imager developed and built by Sira Electro-Optics. (Source: Sira)
(c) A CHRIS hyperspectral image of part of the Ardennes region received by the ESA ground station located at Redu in Belgium. (Source: ESA)

out vegetation studies and mapping. A selection of these images has been made available on the Web by ESA in July 2002 (see http://www.esa.int/export/esaCP/ESAAGZJE43D_Benefits_0.html)

QinetiQ & STRV-2

Sira Electro-Optics have also been involved in another EO imaging project which however is not connected to an ESA mission. This has concerned the design and construction of the reflective (mirror) telescope and refractive (lens) relay optics for a medium-wave infra-red (MWIR) pushbroom scanner (Fig. 6) that has been designed and built by DERA (now QinetiQ). This produces images with a ground pixel size of 35m in one of six bands selectable through a filter wheel over a ground swath width of 15km. This unusual imager was included in JPL's STRV-2 package that formed part of the payload of the American TSX-5 military research satellite that was launched on 7th June 2000. It has been used both to detect aircraft in-flight from space (for defence purposes) and to build up a library of images that provide information on the different land cover types that can be discerned at MWIR wavelengths (λ= 4 to 6 μm). The instrument has operated perfectly and delivered over 300 images during the 18 months of the TSX-5 mission.

Surrey Satellite Technology Ltd. (SSTL)

Outside the U.K. government funded activity that has mostly been channelled through ESA, the main activity within the EO field in the U.K. has been that associated with SSTL. This company is a wholly owned offshoot of the University of Surrey that was formed in 1985 after it had successfully developed and launched two micro-satellites (UoSAT-1 and -2) for education and research purposes in the early 1980s. It is housed and operates within the University's Surrey Space Centre. Quite a number of the micro-satellites that were built after the company was formed, involved missions concerned with telecommunications and space science. However, in recent years, most of the SSTL company's efforts have been concentrated either **(i)** on the construction and launch of EO micro-satellites mainly for developing space nations; or **(ii)** on small satellites demonstrating new space technologies for clients in France (CNES/Alcatel), the U.S.A. (USAF), etc. Nearly all of the EO micro-satellites have been built under knowledge and technology transfer programmes and have been implemented in cooperation with various developing space nations. Within these low-cost cooperative programmes, teams of engineers from each of the countries concerned have been trained at the University, working alongside SSTL staff and gaining experience in the design, construction and operation of their own country's particular micro-satellite. Table I attempts to summarize those EO satellites that have been built by SSTL over the period 1992-2000. Apart from SSTL's own UoSAT-12, which is a larger and heavier (315kg) mini-satellite, all of the others fall into the micro-satellite (50 to circa 100kg) class. While the earlier satellites were launched by NASA or Arianespace piggy-back on top of larger satellites, from UoSAT-12 onwards, the SSTL satellites have utilized Russian launchers (Cosmos, Dnepr, etc.) which are available more frequently and are competitively priced. Almost all the imagers mounted on these micro- and mini-satellites have been small-format digital frame cameras equipped with CCD areal arrays and lenses selected from commercially available component lists.

- **Disaster Monitoring Constellation (DMC)**

At the present time (in August 2002), construction is under way at SSTL of several micro-satellites that will form part of the Disaster Monitoring Constellation (DMC) that has been promoted and organised by SSTL. The countries participating in this constellation have agreed to coordinate their micro-satellites and pool the resulting image data to generate a daily monitoring capability. This DMC programme is designed specifically to carry out the monitoring of natural and man-made disasters - although obviously other EO remote sensing activities can be carried out as well. The first of these DMC micro-satellites is **AlSat-1** (Fig. 7) which, once again, is being constructed at Surrey under a knowledge and technology transfer agreement with the Centre National Techniques Spatiales (CNTS) of Algeria. AlSat-1 is almost complete and is scheduled to be launched this autumn (2002). Construction of the next three micro-satellites in the DMC constellation - **BILSAT-1** (for Turkey); **UK-DMC** (funded by BNSC) and **NigeriaSat-1** - is already under way. The construction of yet another micro-satellite - **Thai-Paht-2** - that is intended to form part of the constellation is also under way at the Mahanakom University of Technology in Bangkok This is based on the experience gained in building the **Thai-Paht-1** micro-satellite at SSTL in the late 1990s. Negotiations are currently in progress with Chinese and Vietnamese agencies to build further micro-satellites at SSTL with a view to them joining the con-

Table I - EO Satellites Built by SSTL - 1992-2000

Name of the Satellite	Country or Company	Year of Launch	Orbital Altitude (km)	Orbital Inclination (degrees)	Gr. Pixel Size Pan (m)	Gr. Pixel Size M/S (m)	Gr. Pixel Size Met (km)
Kitsat-1	Korea	1992	1,325	66	400	-	4
PoSat-1	Portugal	1993	810	98.6 (ss)	220	-	2.2
FASat-Bravo	Chile	1998	835	98.6 (ss)	120	-	2
Thai-Paht-1	Thailand	1998	835	98.6 (ss)	-	100	2
UoSAT-12	SSTL	1999	650	65	10	32	-
TiungSat	Malaysia	2000	645	64.7	-	80	1.2
Tsinghua-1	China	2000	700	98 (ss)	-	39	-

(ss) = Sun-Synchronous; Pan = Panchromatic; M/S = Multi-Spectral; Met = Meteorological

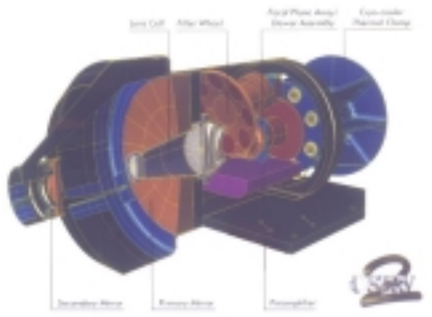


Figure 6: The optical telescope of the medium-wave infra-red (MWIR) pushbroom scanner built by Sira Electro-Optics for incorporation in the imager constructed by DERA. (Source: Sira)

stellation. The DMC micro-satellites are being built along the same lines as **Tsinghua-1** that was launched in 2000. They will be operated from a similar altitude (650km) in a Sun-synchronous orbit and will produce multi-spectral images having a 36m ground pixel size.

BNSC MOSAIC Programme

The UK-DMC micro-satellite mentioned above is one of three purely national (non-ESA) projects that are being funded by BNSC under its MOSAIC (Micro-Satellite Applications in Collaboration) programme. This support will cost £15 million ($24 million) spread over the three year period from 2000 to 2003. Besides the UK-DMC micro-satellite, a second project (called GEMINI) is a low-cost geostationary mini-satellite for telecomms use that is also to be constructed by SSTL. However, the third project, **Topsat**, that is being built under the MOSAIC programme, is yet another EO mission that, in this case, has been devised and will be managed by DERA (now QinetiQ). In fact, the Topsat mission is being funded partly by the UK Ministry of Defence (MoD).

Topsat

Besides being in overall charge of the project, QinetiQ are developing the downlink, the ground station and the data handling. The Topsat team also includes **(i)** SSTL, which is building the micro-satellite plat-

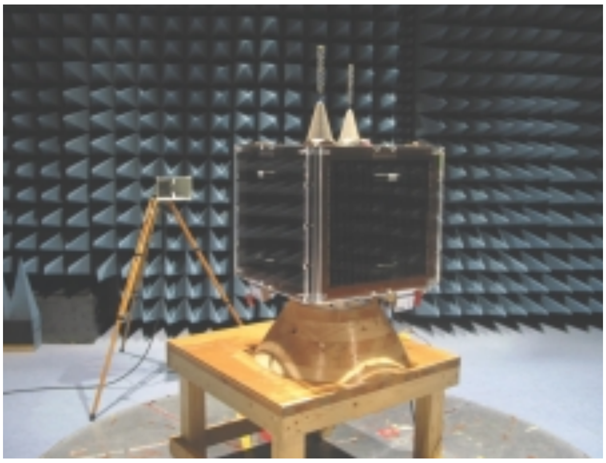


Figure 7: AlSat-1 undergoes electromagnetic compatibility (EMC) testing at ITS, Leatherhead, Surrey. (Source: SSTL)

form; **(ii)** RAL, which is building the imager; and **(iii)** InfoTerra, which is to develop the market for the imagery. The Topsat spacecraft will employ a totally new enhanced (120kg) micro-satellite platform designed and built by SSTL. The RAL lightweight imager is a pushbroom scanner (Fig. 8) that employs a 3-mirror off-axis optical telescope in conjunction with a CCD linear array that can be operated in TDI (time delay integration) mode. This will generate images of the terrain having a ground pixel size of 2.5m (pan) and 5m (multi-spectral) respectively over the relatively narrow ground swath width of 15km. Four 15 x 15km images can be stored on board the Topsat satellite. The image data can then be downloaded either to a fixed ground receiving station or to a mobile ground station such as QinetiQ's RAPIDS facility.

Conclusions

As the above account has endeavoured to show, in spite of relatively restricted government funding and support for civil space activities, the U.K. has developed an interesting and distinctive programme in Earth Observation (EO) from space. Mainly this has been conducted through ESA (via BNSC) with a concentration **(i)** on imaging instrumentation developments; and **(ii)** on environmental science applications on a global scale. These two developments have been tied closely to one another. Thus the two major instrumental programmes - ATSR/AATSR and AMI/ASAR - that have a strong U.K. involvement have resulted in the generation of wide-swath, low-resolution imagery that is primarily of interest to researchers in academic institutions and government labs concerned with environmental matters, especially global monitoring. Perhaps this emphasis is not too surprising since the BNSC represents only government ministries (DTI, DETR), research councils (PPARC, NERC) and government environmental labs. The value-added commercial remote sensing industry is not represented on BNSC at all. Indeed, although the DTI is the principal supporter of BNSC, it is also charged with the task of stimulating British industry. Yet the commercial space remote sensing industry in the U.K. is quite small and comparatively underdeveloped. In marked contrast, the U.K. has a vibrant, efficient and very competitive commercial aerial survey and mapping industry that undertakes a great deal of work all over Europe.

Outside the government dominated sector and occupying a unique niche is SSTL, which works on EO programmes in cooperation with developing space countries. This admirable enterprise has been very successful, especially in terms of creating expertise in the design, development and construction of micro-satellites. In turn, this has resulted in the production of a limited amount of space imagery of a moderate ground resolution and coverage. So far, this has been tied largely to those countries for whom the satellites have been built. It will be very interesting to see how the DMC concept will develop in the future, especially in terms of providing systematic coverage of larger areas of the Earth's surface at a moderate ground resolution.

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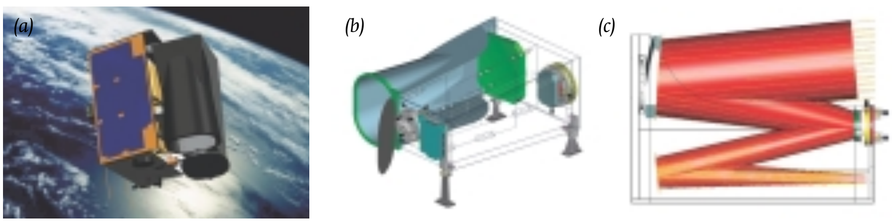

(a) An artist's impression of Topsat operating in space. The pushbroom scanner imager sits on top of and attached to the body of the enhanced micro-satellite. (Source: SSTL) (b) A perspective view of the telescope of the Topsat imager with its three mirrors that is being built by RAL. (Source: RAL) (c) This is a side view showing the folded optical path of the three-mirror telescope. (Source: RAL)