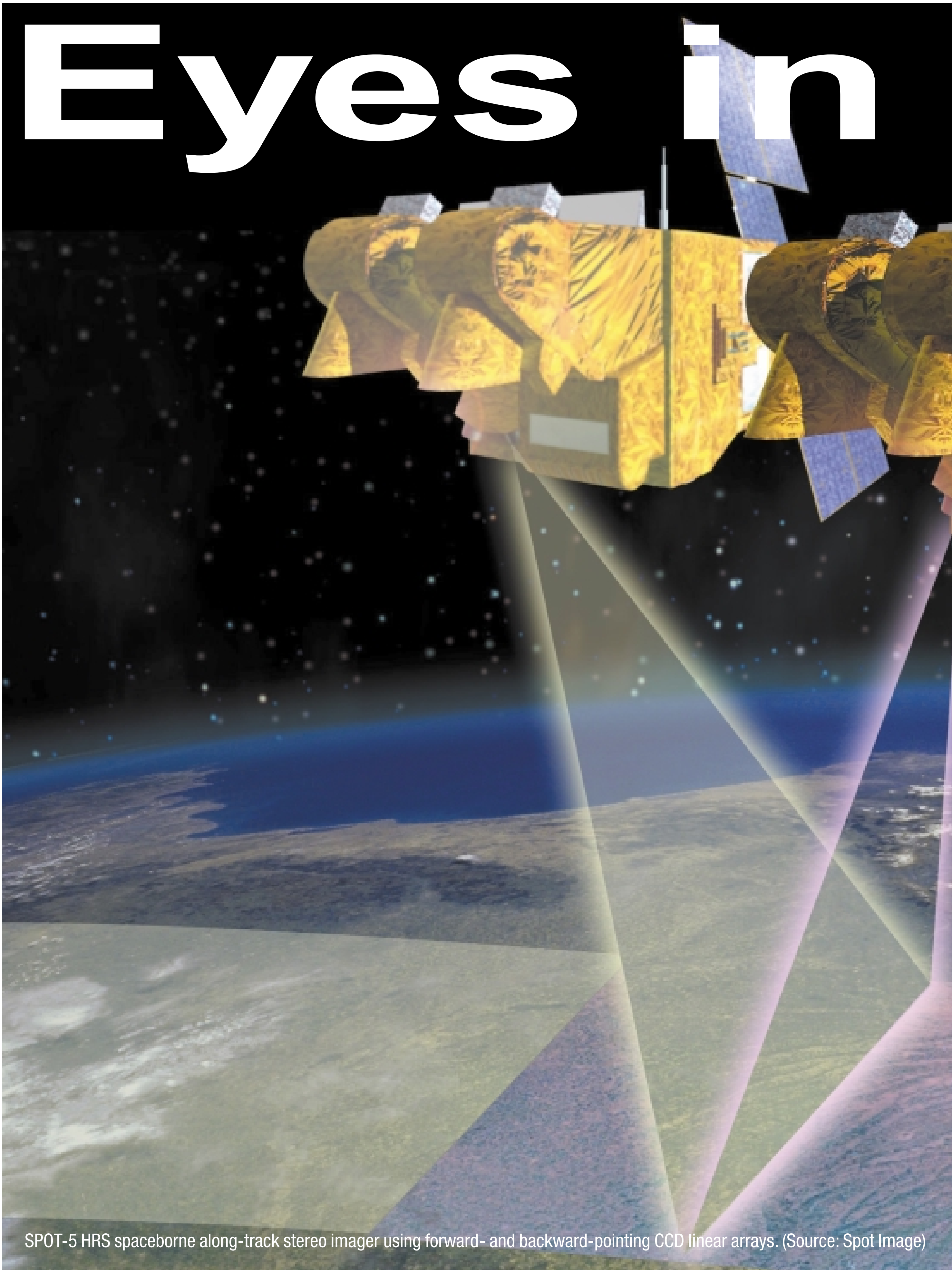
Eyes in

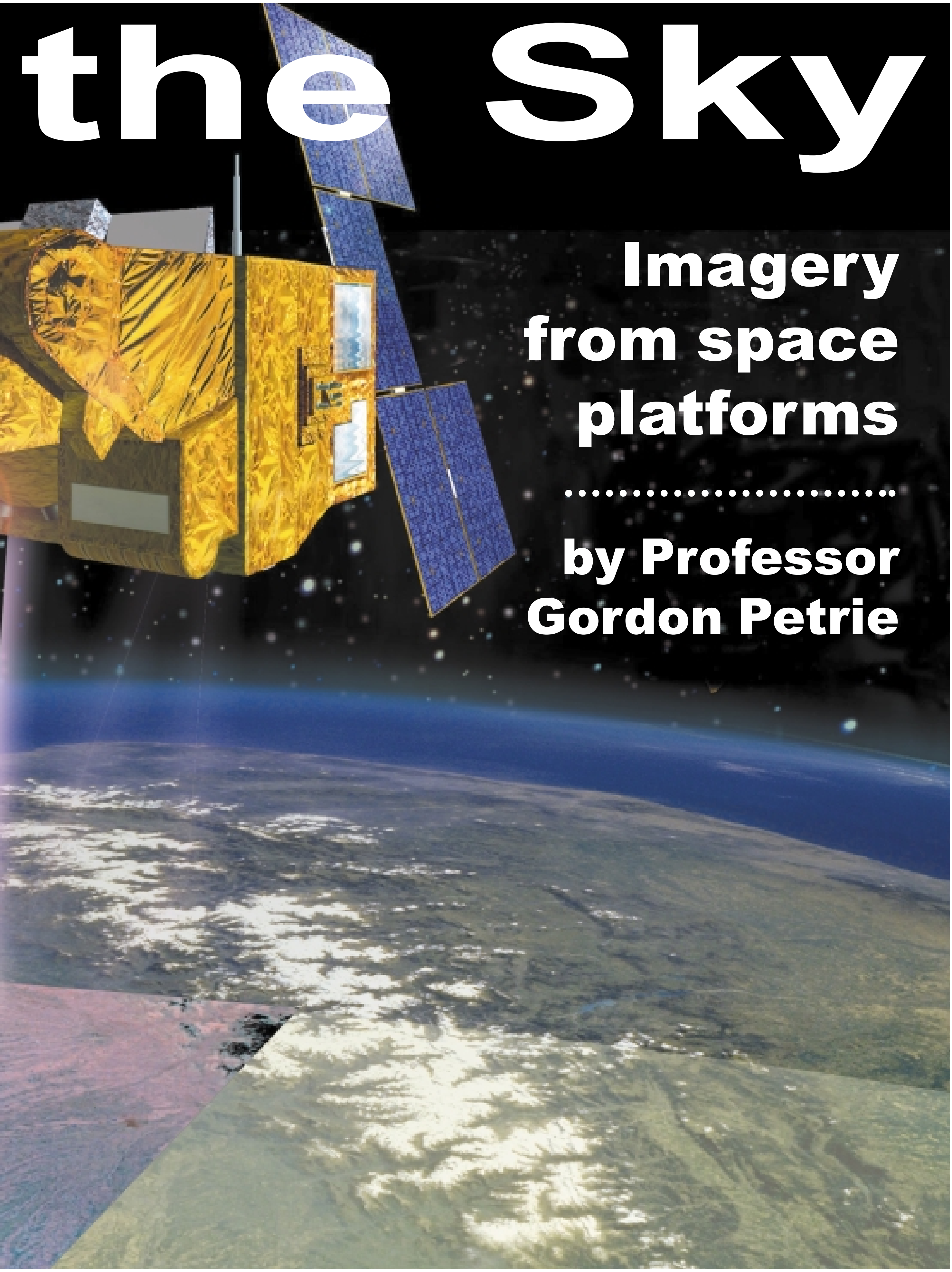


SPOT-5 HRS spaceborne along-track stereo imager using forward- and backward-pointing CCD linear arrays. (Source: Spot Image)

the Sky

Imagery from space platforms

by Professor Gordon Petrie



Over the last few years, the terrain imaging field has expanded into an almost bewildering array of imagers, from frame cameras and line scanners to microwave imagers. In the first of these two articles, we focused on imagers that are used mainly on airborne platforms. This month, we look at the imagers mounted on spaceborne platforms.

For spaceborne platforms, the operating altitude may vary from an absolute minimum of 160 kilometres to a practical maximum of 1,000 kilometres. All spaceborne platforms operating within this altitude range travel at very high speeds (up to seven kilometres per second) over the ground. This means that rapid image motion may need to be considered in the design or operation of the imager. Furthermore, on the one hand, the high operating altitude of a spacecraft allows a synoptic view of the ground to be imaged that cannot be obtained from any airborne platform. On the other hand, it also means that very powerful and physically large telescopes are needed if high-resolution optical images are to be acquired from space. In turn, these pose size and weight problems in the spacecraft and need powerful launchers to lift them into a suitable orbit.

The provision of adequate power to allow active radar (SAR: synthetic aperture radar) imagers to be operated over long distances from orbiting space platforms is a special problem for the designers and operators of these devices. The size, weight and cost of the large satellites that can accommodate high performance imagers has grown enormously. For example, the European Space Agency's Envisat, launched in March 2002 with its optical and microwave imaging sensors, is the size of a large bus, weighs eight tons and cost $2.3 billion. It also required the use of the most powerful and most costly European launcher (Ariane-5) to place it in orbit.

Therefore, there is a strong move towards smaller, cheaper satellites as exemplified by the SSTL (Surrey Space Technology Ltd) micro- and mini-satellites. These can carry small yet quite powerful optical imagers. However, one certainly can't mount the large ultra-high-performance optical and SAR imagers used by the American National Reconnaissance Office on such small satellites.

IMAGERY FROM SPACEBORNE PLATFORMS

Spaceborne frame cameras

As with the airborne platforms, both film and digital frame cameras have been used from space, though in much smaller numbers.

Photographic frame cameras

Since the Space Shuttle flights with the ESA Metric Camera and the NASA Large Format Camera (LFC) in 1983, no Western film cameras have been flown in civilian spacecraft, though this is not to say that film cameras may not have been used since then in American military reconnaissance satellites.

However, the main known operators of film frame cameras from space have been Russian agencies. These cameras have been used on numerous short duration missions from comparatively low altitudes (220 to 270 kilometres) using film return capsules. By contrast, the corresponding American agencies appear to have discontinued their use of this particular technique in the mid to late 1980s.

Extensive coverage has been acquired for topographic mapping purposes using the Russian TK-350 large format film camera having a ground resolution of 7 to 10 metres. A similar performance (5 to 10 metre ground resolution) has been achieved using the KFA-1000 reconnaissance camera, a pair of which have often been operated together within a single satellite using a split-vertical (low oblique) configuration to increase the cross-track coverage. However, the KFA-3000 (a higher-resolution model in the KFA series) and the KVR-1000 panoramic film camera have produced images with still better ground resolutions of two to three metres. These have been sold quite widely to a variety of users in the Western world, besides their use by Russian agencies. Since 2000, the Russian Sovinformsputnik organisation has been making available imagery with one metre (DK-1) and 1.5 metre (DK-2) ground resolution. It is not clear whether these images have been produced using film cameras or line scanners, or perhaps even both.

> The area of high-resolution pushbroom scanners has been the one where commercial activity has been greatest, but it has also been one of considerable disappointment and large financial loss. In turn, the EarlyBird (in December 1997), EROS-A (in January 1998), IKONOS-1 (in April 1999), QuickBird-1 (in November 2000) and OrbView-4 (in September 2001) satellites have all been lost either at launch or immediately afterwards. The only successful launches have been those of the second IKONOS (in September 1999), EROS-A1 (in December 2000) and QuickBird-2 (in October 2001).

Digital frame cameras

For spaceborne digital frame cameras there has been considerably less development activity than in the airborne field. Both the commercial EarlyBird and the NASA Clark satellites were to have orbited the same types of digital frame cameras in 1997. These would have provided both panchromatic (three-metre ground pixel) and multispectral (15-metre ground pixel) images. However, EarlyBird suffered a power supply failure a few days after its launch, and the Clark satellite was cancelled due to cost overruns. In each case, a 2k x 2k pixel CCD areal array was to have been used as the imaging sensor in the camera.

Apart from these non-operational examples, the main builder and actual user of digital frame cameras has been SSTL, based in Guildford. Its cameras have been deployed as both panchromatic and multispectral imagers. In the case of the UoSAT-12 satellite launched in 1999, a pair of multispectral frame cameras have been mounted side-by-side in the satellite with each camera being tilted in opposite directions relative to the flight line (or ground track) to provide a wider coverage in the cross-track direction, as has been done with the KFA-1000 film camera mentioned above. The additional pan camera mounted on the UoSAT-12 satellite points in a vertical (nadir) direction to produce a 10 x 10 kilometre image with a 10-metre ground pixel size. The CCD areal arrays used in both the pan and multispectral frame cameras of the UoSAT-12 are only 1k x 1k pixels in size. The TMSat built by SSTL for Thailand uses three vertically pointing cameras, each equipped with a different colour filter, mounted side-by-side with parallel optical axes in the same arrangement as that used on the Z/I Imaging and the various American airborne frame cameras discussed earlier. Again simple and inexpensive 1k x 1k pixel CCD areal arrays from Kodak have been used as the imaging sensors in each of these cameras.

Spaceborne line scanners

Line scanners are the classical type of imaging device used for remote sensing from space. Over the last 30 years, there has been a steady progression in line scanners producing digital image data with ever smaller ground pixel sizes – from 80 metres (MSS), through 30 metres (TM), 10 metres (SPOT), six metres (IRS-1C/D) and one metre (IKONOS) to 0.6 metre (QuickBird) – in the pan imagery available for civilian use.

Very low resolution scanners

However, it is interesting to note the continuing strong interest by the scientific community in quite low-resolution line scanners that provide synoptic views and wide-area coverage, principally for environmental monitoring and the mapping of land cover and vegetation on a regional or global scale. Thus there is a surprisingly large use of the low-cost AVHRR (Advanced Very High Resolution Radiometer) imagery with its coarse 1.1 kilometre ground pixel size combined with a swath width of 2,400 kilometres. It comprises 4-band images in the visible (VIS), near infrared (NIR), medium-wave infrared (MWIR) and long-wave infrared (LWIR) regions respectively. Often maps showing Normalised Difference Vegetation Index (NDVI) values over extensive (continent-wide) areas are derived from these images. Into the same category falls the data from the so-called Vegetation imager mounted on SPOT-4, again having a one-kilometre ground pixel size and a 2,250-kilometre swath, but giving coverage in the blue, red, NIR and short-wave infrared (SWIR) spectral bands. This imager has also formed part of the instrumental package on the SPOT-5 satellite that was launched in May.

Falling into the same general category is the SeaWIFS imagery with 1.1 kilometre ground pixel size and 2,800-kilometre swath provided by the OrbView-2 satellite. Finally, there is the Along Track Scanning Radiometer (ATSR) that has been operated on board the ERS-1 and ERS-2 satellites. A more advanced version (AATSR) has been mounted on the new Envisat (figure 1). This produces four images in the SWIR, MWIR and LWIR (2) bands respectively having a one-kilometre ground pixel size over a 500-kilometre swath. These infrared images are supplemented by three other images recorded in the green, red and NIR parts of the spectrum, principally for vegetation studies.

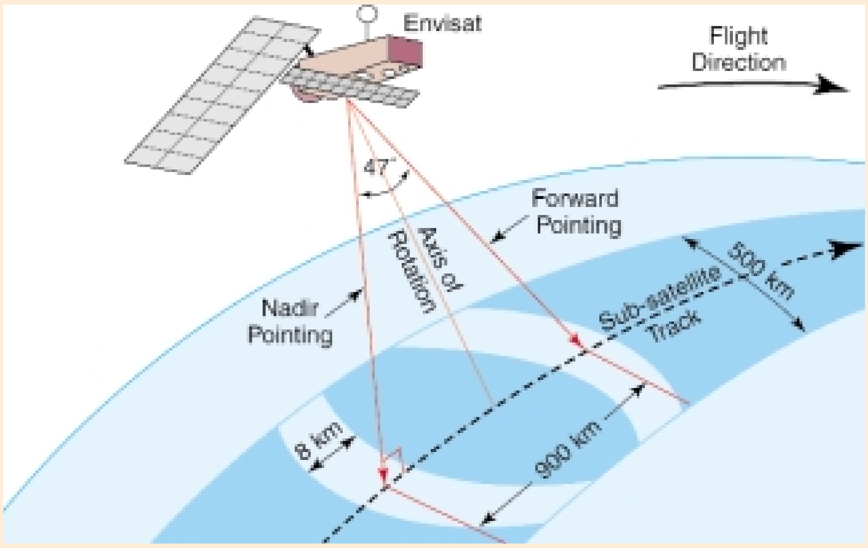


Figure 1: The Advanced Along Track Scanning Radiometer (AATSR) makes use of an unusual conical scanning system which has its rotation axis pointing ahead of the satellite in the along-track direction. This allows a double scan to be made across the earth's surface – the one at an angle of 47 degrees to the nadir ahead of the satellite, the other in the nadir direction. (Drawn by Mike Shand).

Low resolution scanners

Next we come to the group of linescan imagers that give an improved ground resolution, but with a narrower swath width. These include the Indian WiFS (Wide Field Scanner) with its 188-metre pixel/804-kilometre swath combination and the Russian RESURS-01 with its 160-metre pixel/600-kilometre swath.

Into the same group falls the Medium Resolution Imaging Spectrometer (MERIS) that is now being operated from the new Envisat. This provides images in 15 spectral bands with a 300-metre ground pixel over a swath width of 1,150 kilometres. However, much of the current interest in this sector is focused on the imagery being acquired by the MODIS (Moderate Resolution Imaging Spectrometer) scanners that are mounted on NASA's Terra and Aqua satellites. These give 36 spectral bands ranging over the whole of the optical spectrum (λ = 0.4 to 14μm) with ground pixel values varying from 250 metres to one kilometre over a swath width of 2,330 kilometres. The second MODIS instrument is mounted on the Aqua satellite, which was launched in May. The MODIS image data, together with that from AVHRR and SeaWIFS, is being taken down routinely for much of Europe by the ground receiving station at the University of Dundee in Scotland, which is supported by NERC (Natural Environment Research Council).

Medium resolution scanners

This is the original sector of civilian satellite remote sensing. With the recent withdrawal from service of Landsat-5, only Landsat-7 of this classic series remains in operation. Its ETM+ line scanner provides continuous strips of pan imagery with a 15-metre ground pixel size. This is combined with its multispectral TM scanner providing 30-metre ground pixel images in seven spectral bands; and it still retains its original wide 185 x 185 kilometres areal coverage. This attractive specification, combined with its very low pricing, means that it retains a very prominent, if not the leading, position in this sector.

Certainly the SPOT-1 to SPOT-4 satellites with their 10-metre pan and 20-metre multispectral imagery (but with only four bands) do have an edge in terms of their somewhat higher ground resolution. However, the more limited ground coverage of a single SPOT scene of 60 x 60 kilometres means that a minimum of nine SPOT scenes is needed to cover the area of a single L-7 scene – which gives an enormous price advantage to the L-7 imagery.

The IRS-1C/D imagery continues to be acquired, but apparently only in small quantities. For the future, both Spot Image with its newly launched SPOT-5 satellite and ISRO with its forthcoming Cartosat-1 – which is scheduled to be orbited later this year – have decided to move upwards in the resolution stakes through the installation of line scanners producing pan imagery in the 2.5 to 5 metre ground pixel range.

Slightly further along the line, with a scheduled launch in November 2003, is the UK's TOPSAT (figure 2). This enhanced micro-satellite is being built by SSTL, while its pushbroom linescan imager is being designed and built by the Rutherford Appleton Laboratory. TOPSAT will generate imagery with ground pixel values of 2.5 metres (pan) and 5 metres (multispectral) over a 10 x 10-kilometre area. The project is being funded by the British National Space Centre and the Ministry of Defence, though apparently more as a technology demonstrator than the semi-commercial SPOT and IRS series. DERA (now QinetiQ) and Infoterra are also partners in this project.

High resolution scanners

The area of high-resolution pushbroom scanners has been the one where commercial activity has been greatest, but it has also been one of considerable disappointment and large financial loss. In turn, EROS-A (in January 1998), IKONOS-1 (in April 1999), QuickBird-1 (in November 2000) and OrbView-4 (in September 2001) satellites have all been lost either at launch or immediately afterwards.

The only successful launches have been those of the second IKONOS (in September 1999), EROS-A1 (in December 2000) and QuickBird-2 (in October 2001). Although they all fall within this group and all feature off-nadir pointing and stereo-imaging capabilities, they are otherwise quite different in terms of their imaging performance. IKONOS generates pan and multispectral imagery with ground pixel sizes of one metre and four metres respectively. EROS-A1 produces pan imagery only, having a 1.8-metre ground pixel size. QuickBird – now fully operational – produces 0.6-metre pan and 2.5-metre multispectral images.

The EROS-A1 satellite continually changes the orientation, or pointing direction, of its scanner imager as it travels forward over the target area. This gives a longer dwell time for its linear array sensor, thus allowing more light to reach it and so improving the quality of the resulting image. The QuickBird images have a greater swath width, in spite of their higher resolution. This is achieved by using multiple linear arrays butted together in the focal plane. While OrbView-3 is scheduled for launch early in 2003 (if ORBIMAGE's present financial problems can be overcome), the follow-on satellites to the present IKONOS, EROS and QuickBird satellites are not scheduled to appear until 2003 or 2004 at the earliest. The Indian Cartosat-2 with its one-metre ground pixel imagery is also due to be launched around the same time.

Satellite stereo-imagery

Although it has been possible with the SPOT and IRS satellites to generate stereo-imagery for mapping and DEM (digital elevation model) production from overlapping images taken cross-track from different orbits using the satellites' off-nadir pointing facility, this often poses difficulties since the images may be taken several months apart. In this case, due to seasonal changes in the terrain vegetation and hydrology, the ground area will look quite different on the two overlapping images, so making stereo-viewing and automatic image matching impossible. The German MOMS-2 imager, flown on both the Space Shuttle and the MIR space station during the 1990s, demonstrated the advantages of along-track stereo-imagery taken near-simultaneously using the three-line imaging technique with fixed forward-, nadir- and backward-pointing linear arrays.

This success has given rise to further imagers of this type. The first of these is the ASTER imager built in Japan and mounted on NASA's Terra satellite. This operational satellite features nadir- and forward-pointing linear arrays with a 27.6-degree angle between them. The ground pixel size is 15 metres and the swath width 60 kilometres. The users are very enthusiastic about this imagery. The second instrument is the HRS imager that has been mounted on the newly launched SPOT-5 satellite (figure 3 – being the main, introductory picture on page 42). This features forward- and backward-pointing arrays with a ±20-degree angle between them and generates a rectangular 5 x 10 metre ground pixel over a 120-kilometre swath width. The payload of the Indian Cartosat-1 is also reported to include a similar forward/ backward pointing stereo-imager, though not too much is known about it. It is now scheduled for launch in 2003. A fourth stereo-imager is the Japanese PRISM device with the full three-line implementation of the technology. It will produce overlapping images with a 2.5-metre ground pixel size over a 35-kilometre swath. This will operate from the ALOS satellite which, after several delays and postponements, is now scheduled to be launched in the summer of 2004.

It will be most interesting to see the results of the wide-area DEMs that can be generated from these dedicated optical stereo-imagers in comparison with those derived from the SRTM radar interferometric (InSAR) mission in terms of their respective geometric accuracies.

Hyperspectral imagery

This area, like that of high-resolution optical imaging satellites, has been one of considerable disappointment and loss. NASA's Lewis satellite, with two alternative types of imaging spectrometers on board, was lost shortly after its launch in August 1997. OrbView-4, carrying a similar device, suffered a failed launch in September 2001.

But now there has been some success. The experimental Hyperion hyperspectral imager producing images with 220 bands and a 30-metre ground pixel size over a narrow 7.5-kilometre wide swath has been

> If the whole spaceborne SAR scene has been full of delays, it is also full of innovative proposals or projects, especially with regard to the acquisition of InSAR imagery. Part of the rescheduling of Radarsat-2 is due to the redesign and upgrading of the satellite so that it can carry out the proposal for a tandem mission with a Radarsat-3 satellite to be produced some years later. In this mission, the two satellites would fly side-by-side in a closely controlled formation with an optimised base line to allow the generation of InSAR data for the production of DEMs (digital elevation models).

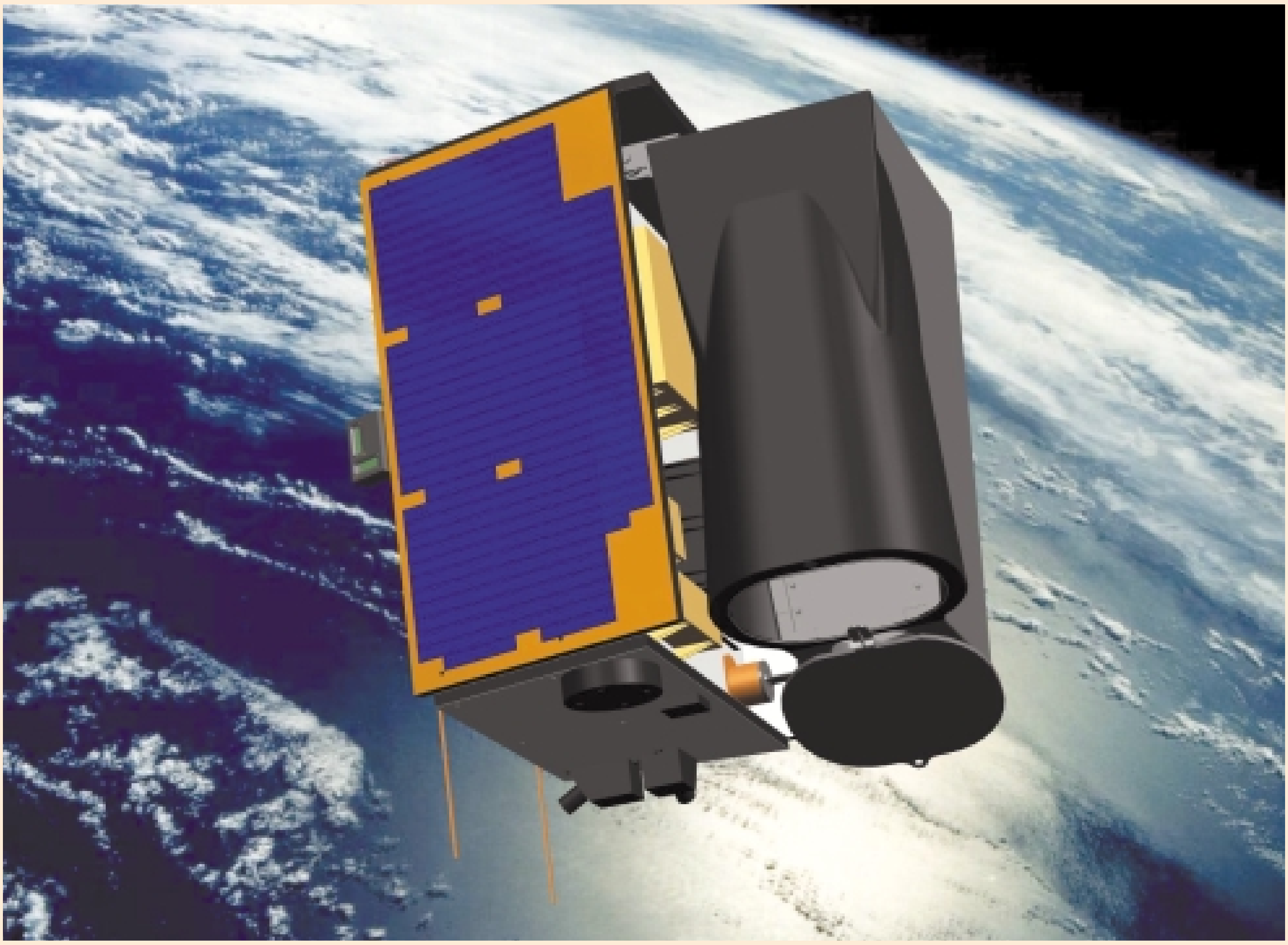
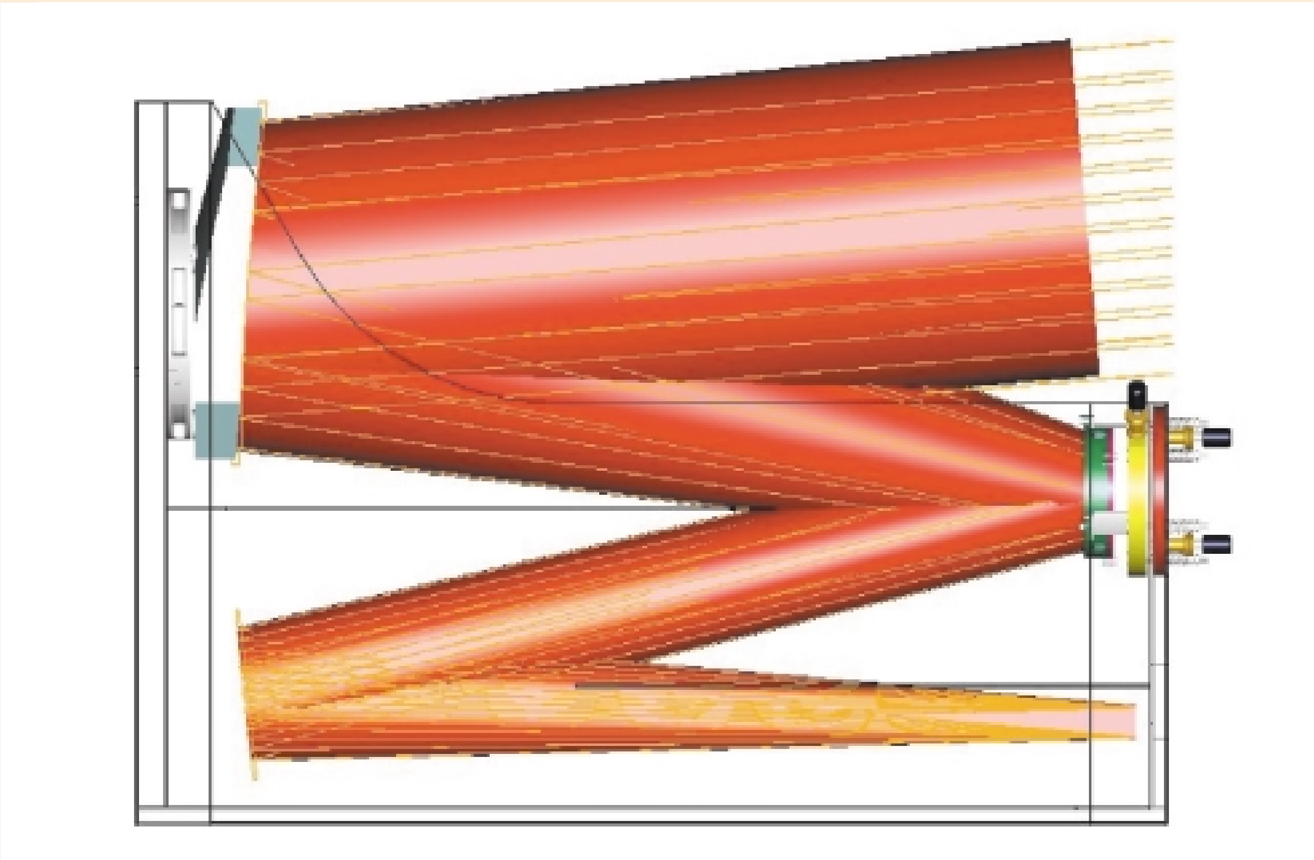
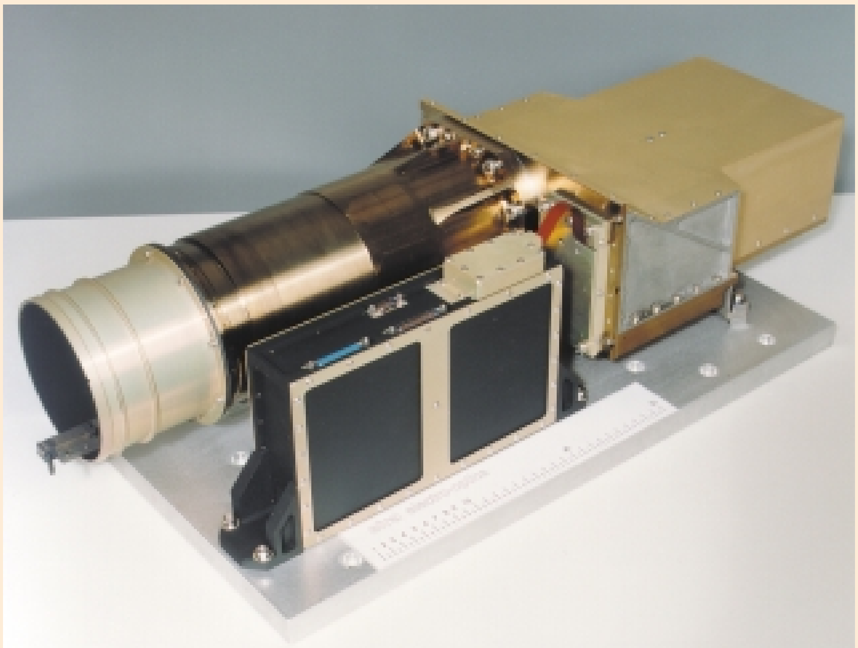


Figure 2: above (a): Artist's impression of the TOPSAT satellite currently being constructed at the Surrey Space Centre in Guildford by SSTL. (Source: SSTL)
below (b): A cross-section diagram showing the folded optics of the pushbroom scanner being constructed by the Rutherford Appleton Laboratory for use on TOPSAT. (Source: RAL)





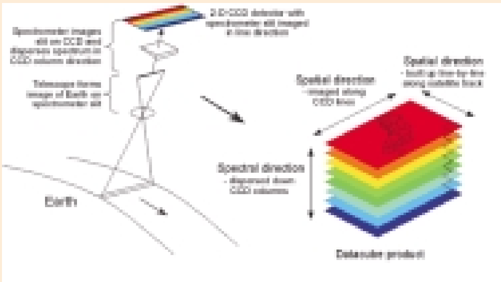


Figure 4:

above (a): The CHRIS hyperspectral imager that is mounted on the recently launched ESA PROBA satellite.

left (b): Diagram of the imaging spectroscopy principle used in the CHRIS imager. (Source: SIRA Electro-Optics)

operational on board NASA's EO-1 satellite that was launched in November 2000. Obviously MODIS with its 36 bands (though with a 1.1 kilometre ground pixel size) can also be considered to fall within this class. Following on from this, ESA's small PROBA experimental satellite built in Belgium was orbited successfully in October 2001 using an Indian launcher. It features the CHRIS imaging spectrometer built in the UK by Sira Electro-Optics (figure 4). The resulting hyperspectral images produce 19 different spectral bands with a ground pixel size of 17 metres over an area of 13.5 kilometres square. The results of the hyperspectral images being generated by all of these imaging spectrometers are eagerly awaited by the scientific community.

It is worth noting that Sira has also been nominated to build the multispectral imagers with six spectral bands for the proposed German RapidEye satellites for which SSTL has also been selected to build the mini-satellite platforms. The RapidEye images will have a 6.5-metre ground pixel size over a 160-kilometre swath width, produced by a pair of pushbroom scanners mounted side-by-side in the satellite. The projected dates for the launch of the four RapidEye satellites, which are to be launched in two pairs, are 2003 and 2004.

While OrbView-3 is scheduled for launch early in 2003 (if ORBIMAGE's present financial problems can be overcome), the follow-on satellites to the present IKONOS, EROS and QuickBird satellites are not scheduled to appear until 2003 or 2004 at the earliest. The Indian Cartosat-2 with its one-metre ground pixel imagery is also due to be launched around the same time.

Satellite microwave imagers

The routine SAR imaging of the Earth from space has continued via the ERS-2 and Radarsat-1 satellites, both of which were launched and came into operation in 1995.

ERS-2 remains operational despite the loss of both its original and its back-up gyros. The satellite uses its horizon sensors to provide signals to its reaction wheels to maintain the correct pointing of its SAR for image data collection. Radarsat-1 also continues in operation. Although SAR imagery is not to everyone's taste, the Canadian Space Agency remains indefatigable in terms of promoting the use of Radarsat imagery and finding fresh applications for it. In this respect, the SAR radar mosaics covering the whole of Australia and the whole of Antarctica have been particularly noteworthy.

Now attention is being focused on their successors. After several postponements, the launch of ESA's Envisat with its Advanced SAR (ASAR) took place on 1 March 2002. The first images (with 30-metre ground pixel size) were released at the end of March. In the case of Radarsat-2, there was a very strong difference of opinion between the US and Canadian governments concerning the security aspects of its higher resolution SAR imagery – three-metre ground pixel in fine beam mode v. the eight-metre of Radarsat-1. After a good deal of public acrimony, the matter now seems to have been settled with certain restrictions placed on the dissemination of the data. Radarsat-2 is now scheduled to be launched in November 2003, instead of in 2002 as originally planned.

Yet another spaceborne SAR that has suffered delays is the PALSAR, which is to be mounted on the Japanese ALOS satellite. This is an L-band SAR with its fine beam mode producing imagery with a 10-metre ground pixel size. Again, as noted above, the launch of ALOS has been postponed from 2002 to 2004.

The TerraSAR-X is a newly announced German project to orbit an X-band SAR, being funded jointly by DLR – the German Space Agency – and Astrium under a public-private partnership. It is scheduled for launch in 2005.

Interferometric SAR

If the whole spaceborne SAR scene has been full of delays, it is also full of innovative proposals or projects, especially with regard to the acquisition of InSAR imagery. Part of the rescheduling of Radarsat-2 is due to the redesign and upgrading of the satellite so that it can carry out the proposal for a tandem mission with a Radarsat-3 satellite to be produced some years later. In this mission, the two satellites would fly side-by-side in a closely controlled formation with an optimised base line to allow the generation of InSAR data for the production of DEMs (figure 5).

Besides the Radarsat-2/3 tandem mission, another interesting proposal is that of an 'interferometric cartwheel' which forms part of the Franco-Italian Pleiades project. The basic concept is based on the use of three passive micro-satellites flying in a precise formation behind a single active SAR satellite and carrying receivers that would pick up the reflected signals from the ground illuminated by the active SAR transmitter (figure 6). It has been suggested that Envisat could in fact act as the active 'illuminator' satellite for the Cartwheel – which is quite a thought! In the meantime, intensive processing work continues on the InSAR data collected by the Shuttle Radar Topography Mission (SRTM). NASA-JPL (Jet Propulsion Laboratory), with the help of Boeing Autometric, Intermap and the Vexcel Corporation, is processing the C-band data, while DLR in Germany is mainly processing the X-band data.

CONCLUSION

As this article has tried to show, we are in an exciting and hectic period of development of new digital imagers, both in the optical and microwave areas. Already numerous examples have been built or are being built and will be coming into operational use soon. Still more imagers are being developed.

So the future is indeed bright, and end users can look forward to acquiring a great variety of imagery from these many different devices.

However, some tough decisions about pricing will have to be made by the operators of these new airborne and spaceborne imagers. They certainly do not come cheaply.

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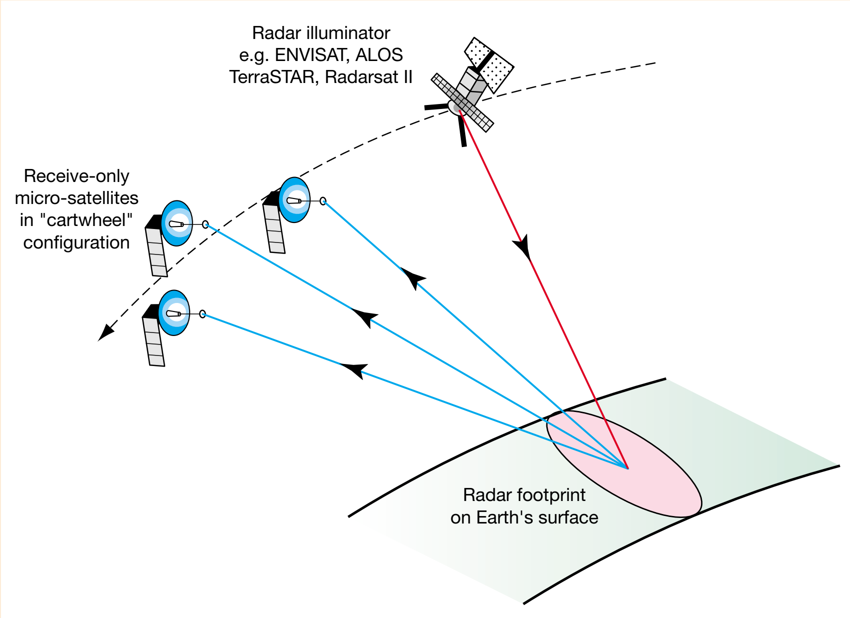
Figure 5: The Radarsat-2/-3 Tandem Mission. (Source: Radarsat)

Figure 6: The concept of the 'interferometric cartwheel' to be implemented as part of the Franco-Italian Pleiades project. (Drawn by M. Shand)



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