A UNIQUE CONSTELLATION OF OPTICAL SATELLITES FROM EUROPE

SPOT Tandem Completed

The launch of SPOT 7 on 30 June 2014 at 6:22 a.m. CET completed the constellation of four optical spacecraft operating in the same orbit. The constellation further consists of twin sister SPOT 6 and Pléiades 1A and 1B. To mark the occasion, the author discusses the features of the extended family of 7 SPOT satellites here.

The English word 'spot' means a small area, but SPOT is also the acronym for *Système Pour l'Observation de la Terre* ('Earth Observation System'). The SPOT 1 to 5 satellites are a product of the CNES (*Centre National d'Etudes Spatiales*) in France which were initially built with the support of Sweden and Belgium. SPOT 6 and 7 have been designed by Airbus Defence and Space. Two key design features in all SPOT generations are continuity and adaption to changing user needs.

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SPOT 1, 2 AND 3

The sensors of the early Earth observation satellites such as Landsat looked straight down to Earth, i.e. they scanned left and right to the track. Users could order the imagery from an archive. SPOT 1, launched February 1986, brought major progress as a pointable mirror enabled a push broom scanner to look to the side of the track. Now users could – for the first time – request capture of a specific area within a certain time span. SPOT 2 was launched on 22 January 1990 and was in service for 19 years. SPOT 3 started to orbit on 26 September 1993, but failure of the attitude control system limited its lifetime to just four years. The SPOT 1, 2 and 3 sensors are identical and consist of two HRV (High Resolution Visible) push broom scanners operating simultaneously, each with a swath width of 60km when pointing nadir. The two spectral modes are panchromatic or B/W (0.51 - 0.73µm) with a ground sample distance (GSD) of 10m, and multispectral (MS) with a GSD of 20m. The MS mode captures three bands: green (0.50 - 0.59µm), red (0.61 - 0.68µm) and NIR (0.79 - 0.89µm). The scenes cover 60 x 60km^2. Each HRV can be pointed up to 27 degrees left or right to nadir. The off-nadir facility allows the capture of strips with a width of nearly two times 60km (117km to be precise) within a 950km corridor. The oblique viewing increases the revisit interval to between four days and as little as one day depending on latitude, and enables DEMs to be created from overlapping images with different viewing angles acquired from adjoining passes.

SPOT 4 AND 5

On 24 March 1998, SPOT 4 was launched with two HRV sensors on board plus a sensor capturing the shortwave infrared band (1.58 - 1.75µm) and a GSD of 20m. The name

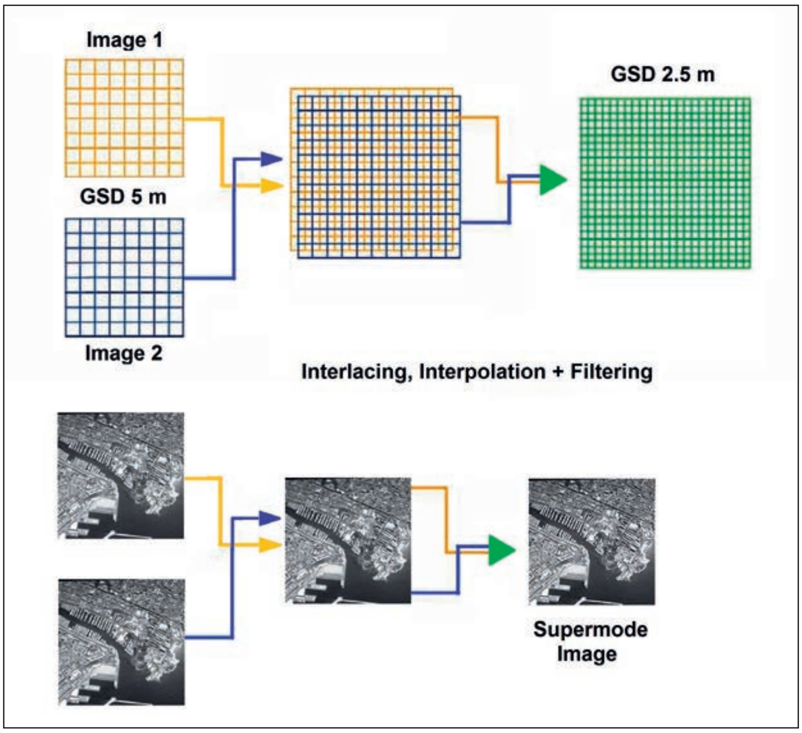


Figure 1, Schematic overview of the creation of supermode images.

SUPERMODE

The supermode imagery of SPOT 5 has a GSD of 2.5m. This is not the result of placing a new sensor on board, but instead is based on advanced processing on the ground of two B/W images which have been captured of the same scene yet shifted slightly. By interlacing and interpolating the two images, which have an offset of 2.5m both vertically and horizontally, a new image is created. This is then filtered to compensate for blur and to remove noise, resulting in an image which is twice as sharp as each of the original two images (Figure 1).

HRV was thus extended to HRVIR. SPOT 4 retired in 2013. The two HRG (High Resolution Geometrical) sensors on board SPOT 5, which has been orbiting since 4 May 2002, differ from the HRVIR in that the GSDs of the B/W and MS modes have been augmented by a factor of 2 to 5m and 10m respectively, but the GSD of the SWIR band has remained at 20m. In supermode, a GSD of 2.5m can be obtained (see sidebar). Added to this, SPOT 5 features a B/W sensor system that points forward and backward; the along-track stereo pairs are free of temporal differences as they are captured nearly at the same time, which eases DEM creation. The payload of SPOT 5 differs considerably from its four precursors, but the real game-changer came with SPOT 6, which was put into orbit on 9 September 2012.

SPOT 6 AND 7

Although SPOT 6 and 7 preserve the swath width of 60km, which can be viewed as the hallmark of the SPOT family, the spot size of the B/W mode has been improved more than 40-fold to 1.5 x 1.5m^2 compared to the 100m^2 of SPOT 1 to 4. SPOT 6 and 7, each weighing 712kg, are positioned in the same orbit, but when SPOT 6 passes Spitsbergen SPOT 7 passes Antarctica, i.e. they are phased at 180°. The 10-year design lifetime ensures that images will be on offer until at least 2024. At an altitude of 694km, SPOT 6 and 7 complete a full cycle within 98.79 minutes. They pass each other at 10 a.m., i.e. the orbit is sun-synchronous, and the nadir revisit rate is 26 days. However, the pointing agility allows each site to be captured once a day if SPOT 6 and 7 operate in conjunction. The two imaging systems – the New AstroSat Optical Modular Instruments (NAOMI) – produce B/W products with 1.5m and MS imagery products with 6m resolution. The radiometric resolution is 12bit (4096 values) per band per pixel; its predecessors have to make do with 8 bits. Details can be made visible in parts of 12-bit imagery made bright by reflections or overcast and dark due to (cloud) shadow. It is also easier to detect objects in areas with little texture such as dunes and ice. Table 1 shows the five spectral bands. Colour images with 1.5m resolution are produced through pan-sharpening (Figure 2). SPOT 6 and 7 together capture up to 6 million square kilometres a day, which is equivalent to an area ten times larger than Texas, USA. While any other direction is possible, the images are oriented north to south by default, i.e. the scan lines are

Figure 2, Pan-sharpening.

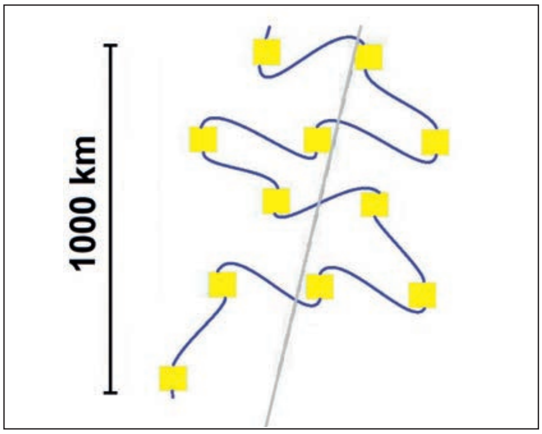


Figure 3, Rapid pointing allows distributed areas of interest within a corridor to be captured in a single pass.

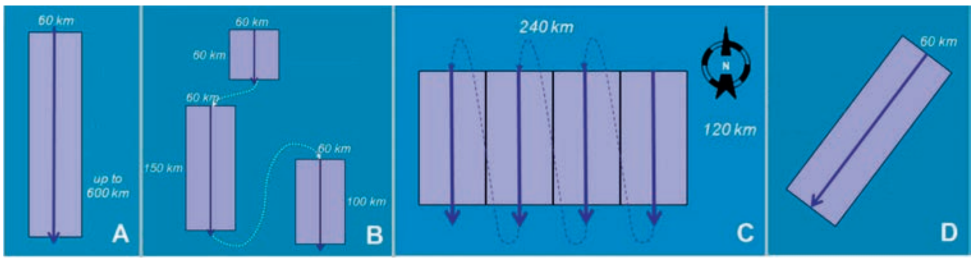
not perpendicular to nadir but are skewed. To maintain the north-to-south direction, the sensors have to be slowly moved away from nadir while the satellite orbits. But at a certain moment, the north-to-south recording has to be discontinued and the sensors have to rotate to their start positions. Therefore, the maximum length of one north-to-south strip is 600km.

Three functionalities enhance the flexibility of SPOT 6 and 7: (1) high agility; (2) automatic uploading of weather forecasts, and (3) tasking plans with a high update frequency.

AGILITY

Control moment gyroscopes (CMGs) allow high agility for capturing areas of interest located off-nadir on the same pass. Thanks to CMGs, SPOT 6 and 7 can pitch and roll forward, backward and sideways up to 45°, i.e. the sensors can point to areas of interest within a 1,500km-wide corridor twice as fast as earlier solutions. This opens up the opportunity to conduct various image collection set-ups in a single pass, and one of these is the capture of no less than 11 scenes measuring 60 x 60km by rapidly switching views up to 750km to the right or to the left of nadir within a 1,000km orbit segment (Figure 3). This enables a multitude of users to be served without priority conflicts even when their areas of interest lie close together. The areas may be larger than the standard size of 60 x 60km. Longer north to south-oriented strips with a maximum length of 600km can be captured (Figures 4A and 4B) as well as more than one target on the same pass at the same latitude (Figure 4C). For example, SPOT 6 covered Cyprus's entire land area of 9,251km^2 in 4 strips from east to west within 90 seconds (Figure 5). SPOT 6 and 7 may also be tasked to follow elongated objects such as power lines, rivers or other corridors (Figure 4D). The agility not only enables the capture of along-track stereo images created through oblique views but also tri-stereo through a nadir image, which looks straight down to the bottom of (urban) canyons. This enhances DEM quality as occlusions are avoided (Figure 6).

Figure 4, High agility allows various coverage scenarios.



WEATHER AND TASKING

The high agility allows tailored tasking based on the requests of users, who may define the area of interest, desired viewing angle, capturing in (tri-)stereo and other parameters. However, the tasking is not programmed blindly, solely based on user requests, as areas may be covered by clouds. Another asset is that weather forecasts are incorporated in the mission planning. Based on the forecasts, mission plans are adjusted to steer

Figure 5, SPOT 6 image of Cyprus covered in 4 strips within 90 seconds.

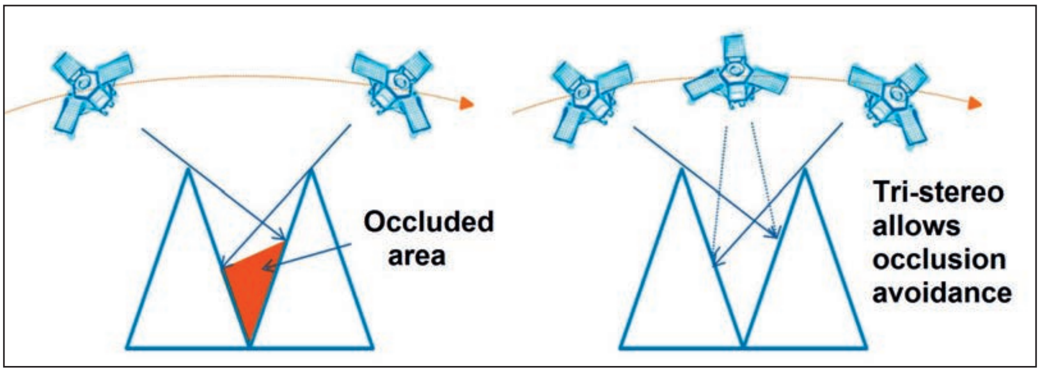


Figure 6, Difference between stereo and tri-stereo.

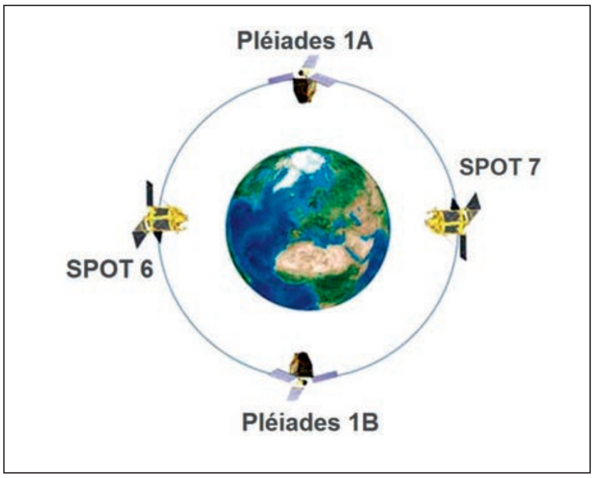


Figure 7, SPOT 6 and 7 and Pléiades 1A and 1B operate in the same orbit, each phased at 180°.

the pointing of the sensors away from clouded areas and thus to minimise the number of scenes hidden by clouds. As a result, 60% of images have less than 10% cloud cover. Users facing an emergency situation are served by instant tasking. Mission plans are uploaded 6 times per day enabling requests to be executed quickly. Fully automatic processing and immediate (online) delivery ensures that the imagery is rapidly ready for use.

SPOT 6 covered Cyprus's entire land area of 9,251km^2 in 4 strips from east to west within 90 seconds

FOUR IN HAND

SPOT 6 and 7 circle in the same orbit as their Pléiades twins, launched on 17 December 2011 and 2 December 2012, respectively (Figure 7). Likewise, Pléiades 1A and 1B are phased 180° apart, have a repeat cycle of 26 days, acquire stereo imagery in the same pass and capture five bands (see Table 1), while the CMGs provide similar agility abilities. Pléiades also refreshes its mission plans three times a day, leading to similar low cloud cover and time reactivity. The main operational differences between the two sets of twins can be typified by the number 3 or its multiple 6. The swath width is 20km vs. 60km, the GSD of the B/W band is 0.5m vs. 1.5m and the GSD of the MS bands is 2m vs. 6m. The daily acquisition capacity per satellite is 0.5 million km^2 vs. 3 million km^2. Designed as a dual civil/military system, Pléiades meets the needs of defence and civil purposes in a scheme in which over 90% of the capacity is available for commercial use.

CONCLUDING REMARKS

As SPOT is commercially operated, the imagery is not available for free and there are some licensing restrictions on usage and sharing. Because the tasking facility means that sites are visited on demand, gaps in location and dates may occur. Prices vary depending on the level of processing, GSD, scene size and the use of tasking. The images that have been archived since 1986, covering over a billion square kilometres, are for sale but some of them are free for the public and research institutes. One question remains: can the two sets of twins fulfil high-definition topographic demands? The answer: yes they can, as the content, spatial resolution and positional accuracy of Pléiades imagery are high enough for topographic mapping at the scale of 1:5,000 while SPOT 6 and 7 are suited for mapping at scale 1:25,000.

	SPOT 6 & 7	Pléiades 1A & 1B
Panchromatic	0.450 - 0.745	0.480 – 0.830
Blue	0.450 - 0.520	0.430 – 0.550
Green	0.530 - 0.590	0.490 – 0.610
Red	0.625 - 0.695	0.600 – 0.720
Near Infrared	0.760 - 0.890	0.750 – 0.950

Table 1, The five spectral bands of SPOT 6 and 7 and Pléiades 1A and 1B; band range in µm.