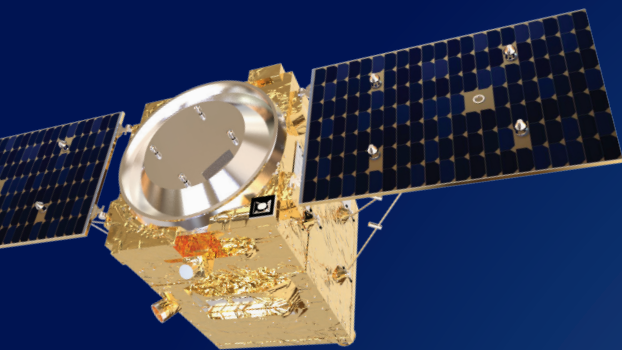


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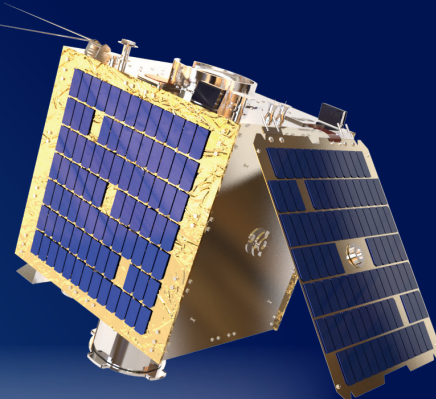
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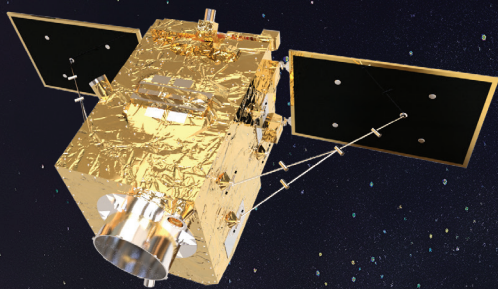
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THEOS-2

User Guide

1 THEOS-2 Main Satellite Overview

The THEOS-2 system is a very high-resolution optical earth observation system fully owned by Thai's government and operated by Geo Informatics and Space Technology Development Agency (GISTDA). THEOS-2 is the second Thailand earth observation satellite following THAICHOTE (THEOS-1) satellite which has been operating for nearly 15 years (launched in 2008). The system delivers 50 cm panchromatic and 2 m. multispectral images.



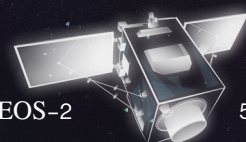
THEOS-2 system provides advanced operational features such as single pass multi mosaic and multi stereo capacity, long strip imaging capacity as well as simultaneous imaging and downloading capacity in quasi real time. The extended roll off-pointing capacity, combined to the altitude orbit offer a mean revisit performance of less than 2 days.

The THEOS-2 spacecraft launched is planned in the last quarter of 2023 by VEGA Launch Vehicle. The satellite will be launched from Europe's spaceport in Kourou, French Guiana. The satellite is expected to be in operation for the minimum 10 years.





Characteristics	
Altitude	621 km
Type	Sun-synchronous, 9:30 – 10:30 AM descending node
Period	97.25 minutes
Inclination	97.9°
Cycle	26 days
Optical System	The telescope is a Korsch type combination with 0.5m aperture diameter, focal length of 14.9m, f/D =30
Spectral Bands	PAN: 0.45–0.74µm, Blue = 0.45–0.53µm, Green = 0.53–0.60µm, Red = 0.63–0.70µm, Near Infrared = 0.76–0.87µm (NIR)
Detectors	Panchromatic array assembly: 3 x 7,000 (21,000 cross-track) pixels Multispectral array assembly: 3 x 1,750 (7,000 in cross-track) pixels
Ground Sampling Distance (nadir)	Panchromatic: 0.5m; Multispectral: 2 m
Swath Width	10.3 km at nadir
Dynamic Range at Acquisition	12 bits per pixel
Viewing Angle	Standard: +/- 30°; Maximum: +/- 45°
Revisit Frequency	Worst case: 4 days within +/- 45° viewing angle Mean at equator: 1.9 days within +/- 45° viewing angle
Pointing Agility	Roll of 30° within 32 seconds including stabilization time Pitch of 60° within 52 seconds including stabilization time
Acquisition Capability	Over 700 square scene/day (consider average downlink duration with respect to GISTDA Ground Station in Sriracha, Thailand)
Location Accuracy at Nadir	Specification: Better than 25 m CE90 (without GCP)
Onboard Storage	1TB
Instrument TM Link Rate	2 x 310 Mbps , dual channels/ dual polarization
Mission Lifetime	10 years

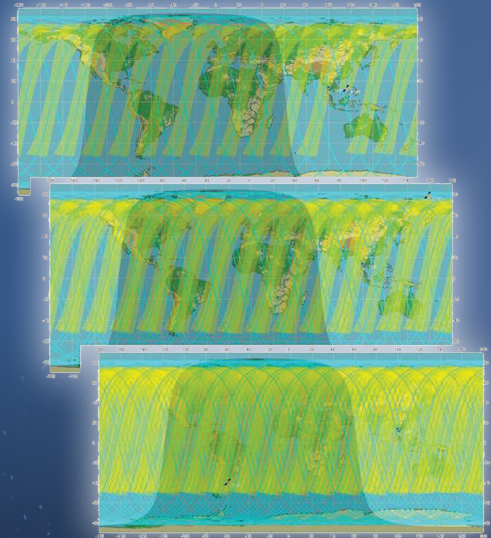


2

THEOS-2 Main Satellite Orbit

The THEOS-2 satellite is a very high-resolution optical satellite orbiting on a Sun-synchronous orbit at 621km. This orbit offers a $14 + 21/26$ revolutions per day within 26 days cycle.

This orbit allows a global access in less than 5 days (considering a $\pm 45^\circ$ roll de-pointing) and allows imaging any area in quasi-nadir viewing angle, i.e., with off-nadir angle lower than 5 degrees, in less than 26 days. The mean revisit period at equator is better than 2 days ($\pm 45^\circ$ roll de-pointing).



Orbit access corridors over 1 day, 2 days and 4 days

Satellite programming and image download is performed through the Sri-Racha ground station located 100 km south-east of Bangkok. This station offers up to 4 visibilities a day.

Routine mission programming is performed every 12 hours to ensure high reactivity and benefit from up-to-date weather forecast.

Last minute programming for urgent requests is possible up to 30 minutes before any visibility. Area in the Sri-Racha visibility circle can then be acquired and downloaded in quasi real time. First image products are made available 30 minutes after the visibility.



Sri-Racha Ground Station Visibility Circle.

3

Acquisition Capacity

THEOS-2 offer high acquisition capacity of up to 74,000 square kilometers per day. It corresponds to 700 square scenes (10.3×10.3 km). Up to 200 acquisitions sequence can be programmed each day.

4

Imaging mode

THEOS-2 system provides a wide range of imaging modes. It includes spot (10.3 x 10.3 km) or long strip image acquisition up to 200 km x 10.3 km. Thanks to very advanced agility performances, the THEOS-2 system allows multiple image acquisitions along the track such as multi-stereo for precise Digital Elevation Model production as well as mosaic imaging for enhanced area coverage in one pass as illustrated hereafter.

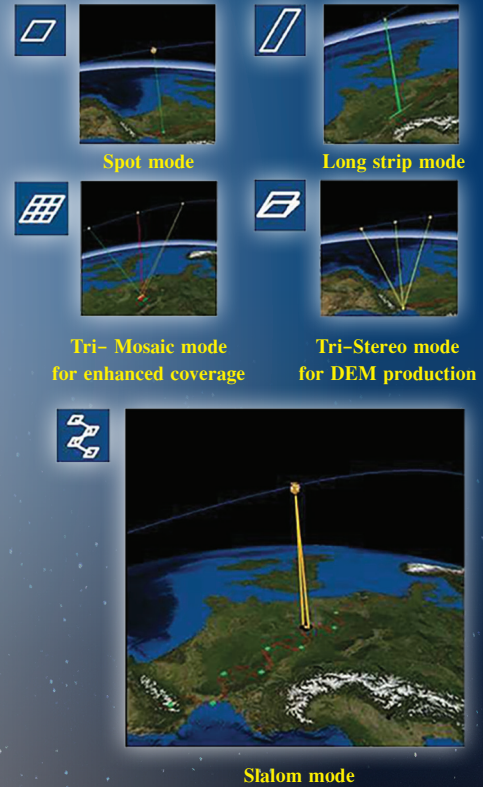
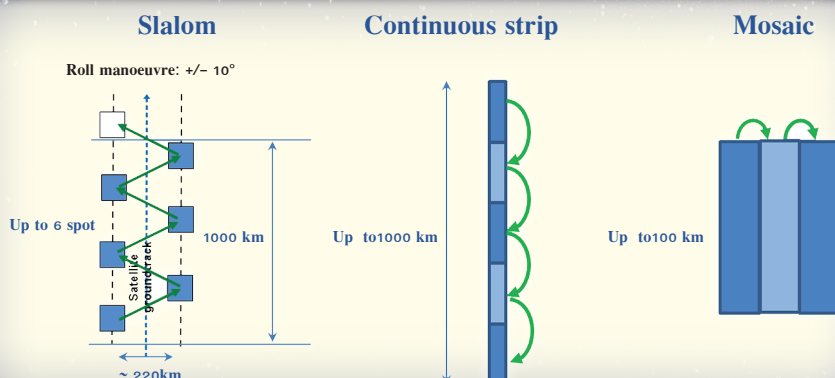


Illustration of THEOS-2 imaging modes

4.1 Single Pass Collection Scenarios

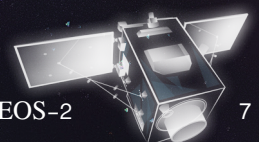
With its great agility, the system offers the possibility to artificially increase the instantaneous field of view. The following area can be acquired on a single pass:

- ☉ A mosaic of 3 contiguous data strips up to 100 km length
- ☉ Up to 5 continuous strips of 200 km.
- ☉ Up to 6 square scenes spaced by $\pm 10^\circ$ in roll over 1,000 km as illustrated on the figure below



4.2 Stereoscopic Capabilities

A great feature of THEOS-2 is to offer a high-resolution stereoscopic cover capability. The stereoscopic cover is achieved within the same pass of the area, which enables a homogeneous product to be created quickly. The system offers the possibility to achieve a "classical" stereoscopic imaging, composed of two images for which the angular difference (B/H) can be adjusted, but also stereoscopic imaging with an additional quasi vertical image (Tri-stereoscopy), thus allowing the user to have an image and its stereoscopic environment.



Tri-stereo images can be used to create more accurate 3D models than can be done with basic Stereo, as the near nadir acquisition minimizes the risk of missing hidden items. This is ideal for dense urban and mountainous areas. Strip of up to 100 km can be acquired in tri-stereo mode.

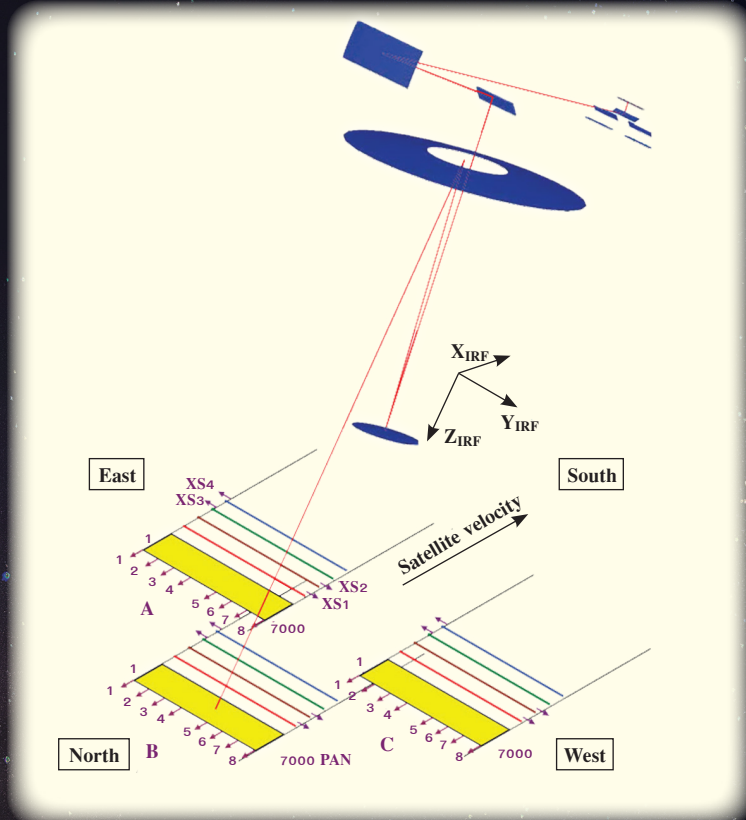
5

THEOS-2 NAOMI System

5.1 NAOMI acquisition system

The NAOMI (New AstroSat Optical Modular Instrument) system is an optical payload operating in pushbroom acquisition mode allowing producing high-resolution top of atmosphere radiance images in panchromatic (PAN) and multispectral (MS) channels.

NAOMI is a single camera instrument, implementing multiple retinas at focal plane level, each retina being made with single chip integrating PAN and MS detectors



Artist view of the NAOMI design, with focal plane projection on Earth; here 3 retinas are implemented to cover the swath.

The panchromatic channel is acquired at high spatial resolution, using TDI signal accumulation technology. The PAN detector element size is $12\ \mu\text{m} \times 12\ \mu\text{m}$, and each retina is made of 7000 columns.

There are four MS channels, having a spatial resolution 4 times less than PAN channel. They have thus 1750 columns for each retina. They are acquiring respectively in blue, red, green and near-infrared spectral ranges. The data acquired by NAOMI are digitized and coded using 12 bits, with the capability of being compressed in order to reduce the image telemetry volume.

5.2 Segment

A segment corresponds to a set of contiguous lines acquired by the optical payload without any interruption, while the system is in imaging mode (in association with the appropriate guidance profile).

The acquisition on-ground projection is at least as wide as the nominal swath width Sw . The length of a segment is usually at least the length of one scene (see next section), and can grow up to several hundreds of kilometers.



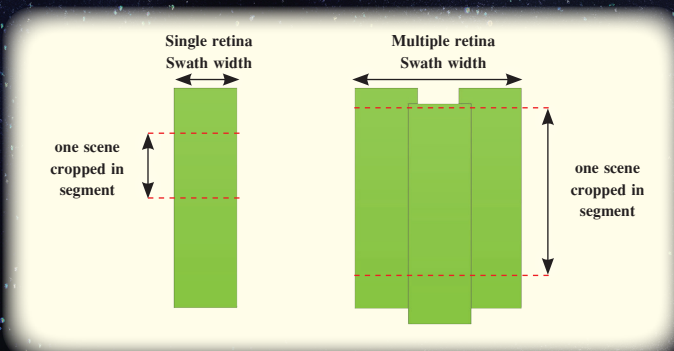


A segment made of one or more sub-swaths

5.3. Scene

A scene is roughly a part of a segment that considers the acquisition full width over a length that is roughly equivalent to the swath width; indeed, it is aimed that a scene is a square area.

Since the effective swath width on Earth and the sampling distance ALT are strongly varying with satellite pointing conditions, the “square” feature associated to a scene may be ambiguous. In order to remove any doubt, the length of a scene is defined in number of nominal acquisition lines, i.e., a scene will be roughly square in term of pixels in the nominal acquisition grid.

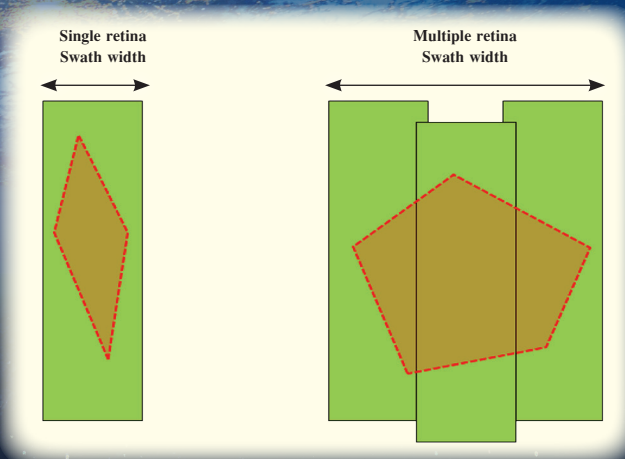


Example of scene, defined inside a given segment; its length is roughly equal to the swath width

5.4 Area of interest (AOI)

An area of interest (AOI) is a part of a segment with a polygonal shape. It is the most generic product shape, as scenes or segments are particular cases of AOI.

The shape of the AOI is defined through shapefiles (.shp), KMZ or KML files. It is only constrained by a minimum surface and an edge number maximum.



Example of AOI, defined inside a given segment.

6

PRODUCTS, SERVICES AND OPTIONS

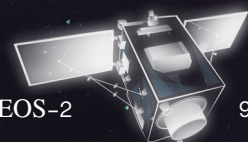
THEOS-2 delivers ready-to-use products, which can be easily integrated in GIS and/or transformed into thematic information while combined with other satellite, airborne or ground information. THEOS-2 satellite always acquires images simultaneously in both modes:

- 🌐 Panchromatic: 1 band (black and white)
- 🌐 Multispectral: 4 bands (RGB + NIR)

Panchromatic and Multispectral image products are co-registered (completely superimposable).

6.1 Spectral Band Combinations

Combining the Panchromatic and Multispectral bands, images can be visualized as either black and white (50-cm product resolution), color (2-m product resolution) or as a merged product (Pan-sharpened color image) with the resolution of the Panchromatic image.



6.2 Panchromatic

The THEOS-2 Panchromatic product includes only one black and white band. It covers wavelengths between 0.45 and 0.74 μm of the visible spectrum. The product pixel size is 0.5 m



Example of THEOS-2 SIMULATED Panchromatic Image

6.3 Multispectral

The Multispectral product includes four Multispectral (color) bands: Blue, Red, Green and Near Infrared. The product pixel size is 2 m



Example of THEOS-2 SIMULATED
Multispectral PRODUCT

6.4 Bundle

The Panchromatic (0.5 m) and Multispectral (2 m) products, simultaneously acquired, are packaged together separately (not merged) for a single delivery (1 file for Multispectral + 1 file for Panchromatic)

6.5 Pan-sharpened

Pan-sharpened products combine the visual information of the Multispectral data with the spatial information of the Panchromatic data, resulting in a higher resolution 0.5-m color product. Image fusion is a concept of combining multiple images into composite products, through which more information than that of individual input images can be generated.



Example of a THEOS-2 Pan-sharpened
Image



The image telemetry raw data, after Demodulation and decryption it contains compressed raw image data and satellite auxiliary data; the Image Archive Product (IAP) data are stored in the long-term archive. Based on IAP data, the Image Ground Segment shall consider the following product definitions:

7.1 Level 0 product:

It corresponds to PAN, MS or bundle PAN+MS image, provided on a Sampling grid equal to the original acquisition grid (no resampling), decompressed, without any processing.



7.2 Level 1A product:

It corresponds to PAN, MS or bundle PAN+MS image, provided on a Sampling grid equal to the original acquisition grid (no resampling), decompressed, with radiometric correction (equalization) and restoration (denoising and deconvolution) applied.

The Level 1A product contains images on the nominal acquisition grid. For multiple retina systems, the product is thus made of sub-products corresponding each to one sub-swath (or retina). Multispectral data, which are nominally acquired with spatial shifts, are only roughly registered (no sub-pixel resampling), considering a shifted cropping of the scene inside the segment.

The Level 1A product contains thus one image per retina (7000 pixels for PAN, 1750 pixels for XS), and per channel; each image is one scene long.

Level 1A product contains following processing:

🌐 Equalisation

Correction of DSNU (Dark Signal Non Uniformity) and PRNU (Pixel Response Non Uniformity)

🌐 Defective pixel correction

If some pixels are defective, their data are replaced by values interpolated between adjacent non-defective pixels

🌐 Cosmic rays correction

Cosmic rays produce pixels with inconsistent values. The correction consists in detecting aberrant pixels and replacing their data by interpolation between adjacent pixels.

🌐 Inter-retina equalization

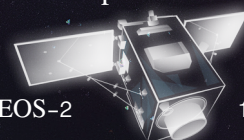
Retinas have slightly different spectral responses. These differences are radiometrically corrected to enable future good merging of overlap areas.

🌐 Denoising

Denoising function enables to improve SNR of image, to compensate degradation caused by following deconvolution block.

🌐 Deconvolution

Deconvolution enables to increase the MTF of the image by applying a deconvolution filter optimized with respect to the instrument MTF



7.3 Level 2A or Restored Sensor Product (RS) or Primary Product:

It corresponds to PAN, MS, bundle PAN+MS, or Pan-Sharpened MS image (PMS), provided on a virtual Restored Sensor sampling grid, and with radiometric correction applied. This product is provided with a RPC.

The Restored Sensor (Level 2A) is actually a virtual acquisition system having similar features than the real system but having a perfect behavior. Thus, the instrument of the RS system is made with one single acquisition line covering the full swath (i.e., one single full swath retina), without any distortion and the satellite motion of the RS system also considers a perfect pointing realization. The geometric model of the RS system is built similarly to the one of the real systems. It is also referred as “Primary product”.

A Primary product is obtained after radiometric correction and geometric resampling onto a virtual perfect sensor grid. The images are registered and all the internal geometric distortions and attitude are corrected.

The Primary product looks like an image at focal plane level that would have been acquired with a perfect sensor with no radiometric or geometric defaults. The associated auxiliary data contained in the DIMAP file are fully

consistent with this geometry, allowing building and using the geometric model with the nominal system accuracy in further processing.

This processing level includes:

- 🌐 Accurate datation, scene extraction and bad detector and missing line interpolation / flagging
- 🌐 Offset and gains correction using calibration files
- 🌐 Cosmic rays detection and correction
- 🌐 Focal plane rearrangement (sub-swaths merging and sensor deformations)
- 🌐 Satellite orbit and attitude correction
- 🌐 Denoising and MTF enhancement (adaptive restoration)
- 🌐 Resampling in the virtual perfect acquisition grid geometry
- 🌐 Pixel radiometric value rounding (16 bits)
- 🌐 RPC (Rational Polynomial Coefficients) generation

7.4 Level 3 or ortho product

It corresponds to PAN, MS, bundle PAN+MS, or PMS image, radiometrically corrected and projected on a cartographic grid sampled at nominal ground sampling distance (GSD); the ortho-rectification processing considers either the Earth ellipsoid or a digital elevation model (DEM). The ortho on DEM considers the real sensor, whereas the ortho on ellipsoid considers the restored sensor and is provided with an RPC.

The ORTHO products (Level 3) result from the sensor projection on ground surface. They are projected on a regular grid in latitude and longitude. The ORTHO on DEM is the projection of the real sensor on SRTM. The ORTHO on ellipsoid is the projection of the restored sensor (not the real one to avoid inter-retinas effects due to elevation and parallax) on Earth ellipsoid (without DEM). It is also referred as “Projected” or “Ortho-ready product”.



The ORTHO products are obtained after radiometric correction, full geometric correction and projection on a cartographic grid sampled at nominal ground sampling distance (GSD). The ORTHO on DEM is the projection of the real sensor on the SRTM Digital elevation model.

This processing level includes:

- ① Accurate datation, scene extraction and bad detector and missing line interpolation / flagging
- ① Offset and gains correction using calibration files
- ① Cosmic rays detection and correction
- ① Satellite orbit and attitude correction
- ① Earth curvature and rotation correction
- ① Projection on UTM map (PROJECTED) or accurate DEM (ORTHO)
- ① Denoising MTF enhancement (adaptive restoration)
- ① Resampling in the corrected geometry
- ① Pixel radiometric value rounding (16 bits)
- ① RPC (Rational Polynomial Coefficients) generation for ortho on ellipsoid

An ortho image is an image where all leaning effects are corrected. Thus all points in the images are seen perfectly from nadir point of view. The track-following acquisition grid is thus resampled on a North / East oriented regular grid, generating some black parts in the image.

8 Delivery Format

THEOS-2 products will be delivered in DIMAP V2,

- ① The image is provided in GeoTIFF format
- ① Rational Polynomial Coefficients (RPCs) are provided to easier orthorectification and geometric processing
- ① A KMZ is included for rapid, easy and user-friendly display of the main metadata in a Google Earth environment
- ① Cloud cover masks are included

The GeoTIFF format consists in a set of tags that provide additional geographic metadata to the Tagged Image File Format (TIFF) described in TIFF specification. GeoTIFF images are generated in TIFF tiled format (or bigTIFF for big images). The GeoTIFF is described in the GeoTIFF Format Specification [<http://trac.osgeo.org/geotiff/>].

8.1 THEOS-2 Products structure

The product structure for PAN or MS consists of “Volumes”, containing only one “component”, while PAN+MS products are “volumes” containing two “components”. As a synthesis:

- ① An execution order corresponds to a single “dataset” that shall be delivered complete.
- ① A “dataset” is composed of one or more “volumes”.
- ① A “volume” is composed of one or more “components”.
- ① A “component” is composed of only one image file at a single resolution, resulting from a single spectral processing and corresponding to a single processing level.

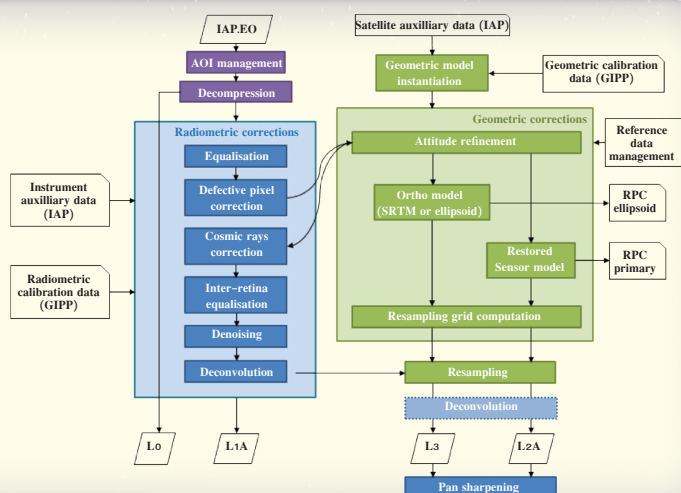
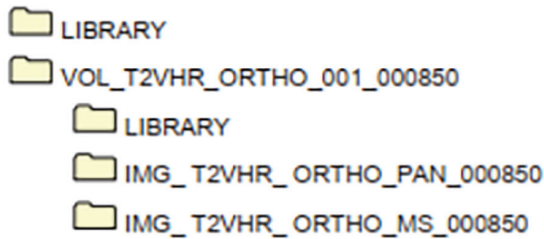


Image production chain of IGS.

8.2 Dataset example

The data set for a PAN+MS production is.

The data set for a PAN+MS production is.



8.3 Files Format

8.3.1 Index Files: <MISSION>_LIST.XML, <MISSION>_VOL.XML

The <MISSION>_VOL.XML describes the images tree structure. It refers to the components of the VOL directory, which are IMG_<DirImage_ID> subdirectories.

The <MISSION>_LIST.XML is derived from the <MISSION>_VOL.XML. It refers to its content with respect to the whole tree structure. No “ICON” associated to the components is defined at that level.

8.3.2 The “DELIVERY.PDF” file

The delivery PDF file is provided with each product delivery. It gathers significant information from the index, product metadata files and imagery files; it is easier to print than the XML/HTML files (A4 page format).

It consists in a medium note and a note for each component (i.e., for each image) delivered within the medium.

The medium note is entitled “Medium Directory” and contains:

- ① The work order reference, in the page header, composed of:
 - » The order number (from <Product_Identification>/<Delivery_Identification>/<OrderIdentification>/<COMMERCIAL_REFERENCE>),
 - » The production date (from <Product_Identification>/<Delivery_Identification>/<OrderIdentification>/<PRODUCTION_DATE>),
 - » The producer logo and copyright,
- ② The number of volumes within the medium delivery,
- ③ The list of volumes within the medium; for each volume:
 - » The sequence number of the volume in the dataset,
 - » The volume identifier,
 - » The list of components within the volume; for each component (contains one image):
 - the component identifier,
 - the image source identifier,
 - the processing level,
 - the spectral processing.

The content of the medium note is generated from the <MISSION>_LIST.XML and <MISSION>_VOL.XML files of the medium tree structure.

- ④ For each component within the medium, the note contains:
 - » The work order reference, in each page header, composed of:
 - » The order number,
 - » The production date

- 🌐 The producer logo and copyright,
- 🌐 The component identifier,
- 🌐 The list of files provided within the image directory (metadata, RPC, KMZ, Masks, Processing Lineage files)
- 🌐 The dataset identifier,
- 🌐 The unitary production date
- 🌐 The image dimension (number of rows and columns),
- 🌐 A selection of metadata (displayed with a style sheet, with at least) :
 - » Acquisition date
 - » Platform name
 - » Spectral processing
 - » Processing level
 - » Number of spectral bands
 - » Spectral band id
 - » Absolute calibration gains (W/m²/sr/μm)
 - » Orientation angle
 - » Incidence angle
 - » Sun angles (degree) Azimuth and Elevation
 - » Image Centre Location (Latitude, Longitude, Pixels number, Line number)
 - » Image Corners Location (Latitude, Longitude, Pixels number, Line number)

8.3.3 The KMZ file format

The kmz file enables the user to see the coverage of the produced image on Google Earth.

This file is a compressed archive that contains:

- 🌐 A kml file
- 🌐 A quicklook copy (PREVIEW_<Product_ID>.JPG)
- 🌐 The satellite icon
- 🌐 Logo

The kml file is composed of several « layers ». A KMZ is included for rapid, easy and user-friendly display of the main metadata in a Google Earth environment

8.3.4 The GeoTIFF image file format

Images are delivered and directly accessible through a standard format called GeoTIFF.

GeoTIFF stands for Geographic extensions to the Tagged Image File Format. It consists in a set of tags that provide additional geographic metadata to the Tagged Image File Format (TIFF) described in TIFF specification. The GeoTIFF is described in the GeoTIFF Format Specification [<http://trac.osgeo.org/geotiff/>]. GeoTIFF images are generated in TIFF tiled format. If images are bigger than 4GB, the bigTIFF format is used

8.3.5 The Metadata Files format

The metadata are spread in several files in the DIMAP structure:

- 🌐 The product metadata file (DIM_<Product_ID>.XML) contains all information concerning image product.
- 🌐 The processing file (PROCESSING_<Product_ID>.XML) gives a description of the product processing.
- 🌐 The Rational Polynomial Coefficients: RPC file (RPC_<Product_ID>.XML) contains the rational Polynomial Coefficients, when computed. This RPC are provided to easier orthorectification and geometric processing.

THEOS-2A

Satellite Overview



1

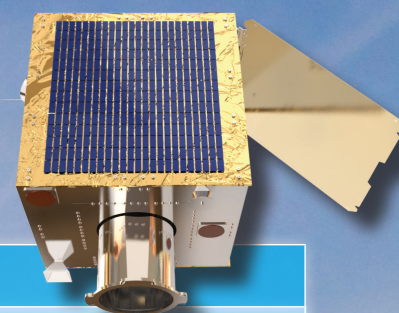
THEOS-2A Satellite Overview

The THEOS-2A system is a part of Know-How Transfer and Training (KHTT) on Space technology from Surrey Satellite Technology Ltd, (SSTL) to Geo Informatics and Space Technology Development Agency (GISTDA). Under the programme, a high-resolution optical earth observation system (THEOS-2A) has been delivered along with THEOS-2 Main Satellite from Aribus.

The Theos-2A spacecraft consists of 3 payloads, which are able to provide several products, such as stereo capacity and video mode imaging from the primary payload and AIS/ADS-B data from the secondary payload. The data from the third payload is for experimental purposes.

The THEOS-2A spacecraft launched is planned around Q4-2023 to Q1-2024 by PSLV Launch Vehicle. The satellite will be launched from Satish Dhawan Space Center, India. The satellite is expected to be in operation for the minimum 3 years.





Characteristics	
Altitude	500 – 520 km @ BOL
Type	Sun-synchronous, 10:30 AM descending node
Period	94.88 – 97.25 minutes (~ 14.8 – 15.1 orbits per day) @ BOL Ground Speed = ~ 6.8–7.0 km/s
Inclination	97.65°
Primary Payload	High resolution imager with CMOS area detector (Bayer filter)
Secondary Payload	AIS and ADS-B receiver
Third Payload	COTS components with Raspberry Pi Processors
Spectral Bands	Blue = 0.41– 0.54µm, Green = 0.46– 0.62µm, Red = 0.58–0.69µm
Detectors	CCD Array ~5,000 pixels x ~5,000 pixels
Ground Sampling Distance (nadir)	Multispectral: 1.07 – 1.11 m. @ BOL
Swath Width	5.7 km. x 5.7 km. – 5.9 km. x 5.9 km. @ BOL
Dynamic Range at Acquisition	10 bits per pixel
Viewing Angle	Maximum: +/- 45°
Revisit Frequency	2 days
Pointing Agility	Roll of 20° within 40 seconds excluding stabilization time
Acquisition Capability	1,100 frames/day
Location Accuracy at Nadir	Geolocation < 250 m. (CE90)
Onboard Storage	512 GBytes
Instrument TM Link Rate	X-band @ 120 Mbps.
Mission Lifetime	3 years



2 THEOS-2A Satellite Orbit

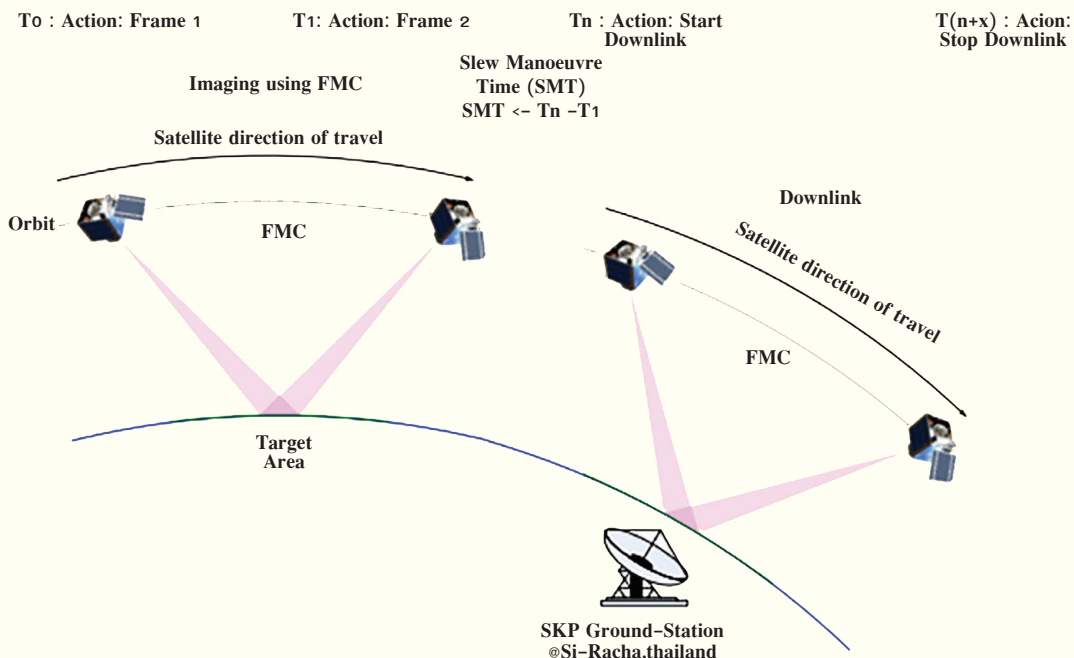
The target operation altitude of THEOS-2A satellite is ranging around 500 – 520 km. The satellite orbit is a Sun synchronous with a local time at descending node around 10.30. Due to the fact there is no propulsion system on the satellite, therefore, the station keeping is not possible which yield no repeat cycle. Thanks to the satellite agility, the satellite capable to visit the same target at every 2 days.

Satellite programming and image download is performed through the Sri-Racha ground station located 100 km south-east of Bangkok. This station offers up to 4 visibilities a day. Routine mission programming is performed every day.

3 Acquisition Capacity

THEOS-2A comes with a high acquisition capacity of 1,100 frames per day. With this number, the user can obtain various products, such as video and stereo, from Primary Payload. In addition, the product from the secondary payload can be acquired and utilized in its place.

The imaging mode and downlink operations in same orbit [not simultaneously]

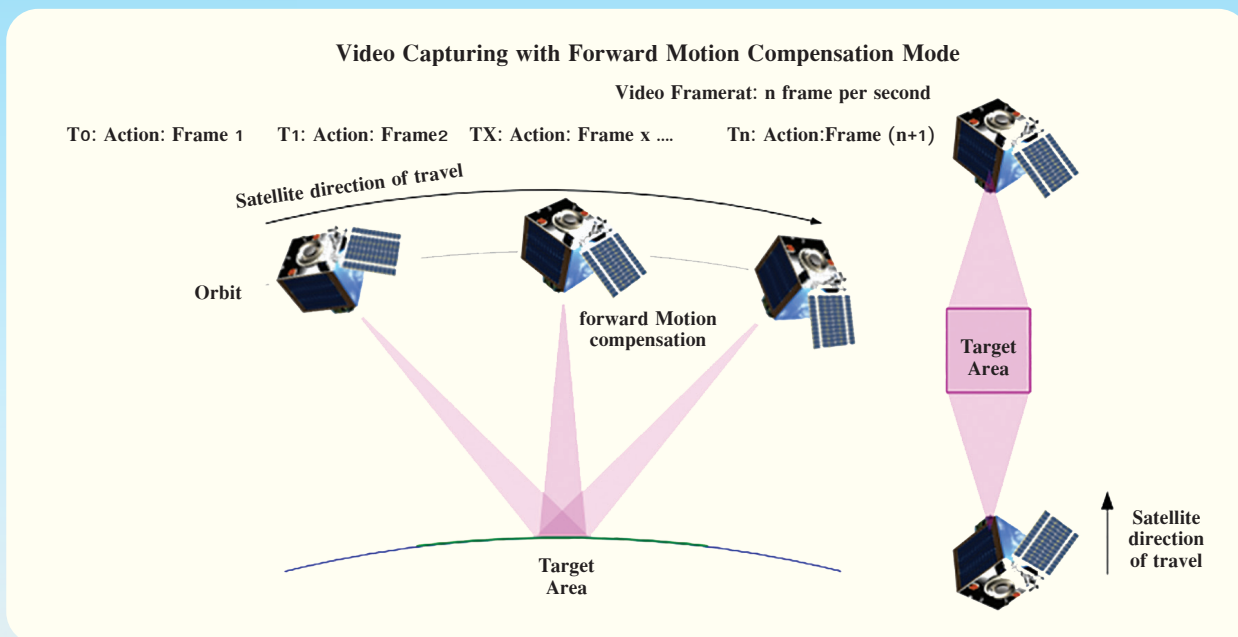


4 Payload Sensing Mode

The THEOS-2A satellite has carried three payloads. Each of them has its own unique sensing mode.

4.1 Primary Payload

This payload can record in either video mode or stereo mode. Their details are as follows:

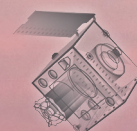


4.1.1 Video – High Rate, Full Frame:

	Mode	Frame per Second (FPS)	Scene Size	Resolution	Payload Capture Session Duration (Seconds)	# Frames captured
A	Video – High Rate, Full Frame	25	5.9 km. x 5.9 km. @ Altitude 550 km. (Reference Orbit)	1.18 m. @ Altitude 550 km. (Reference Orbit)	3	75

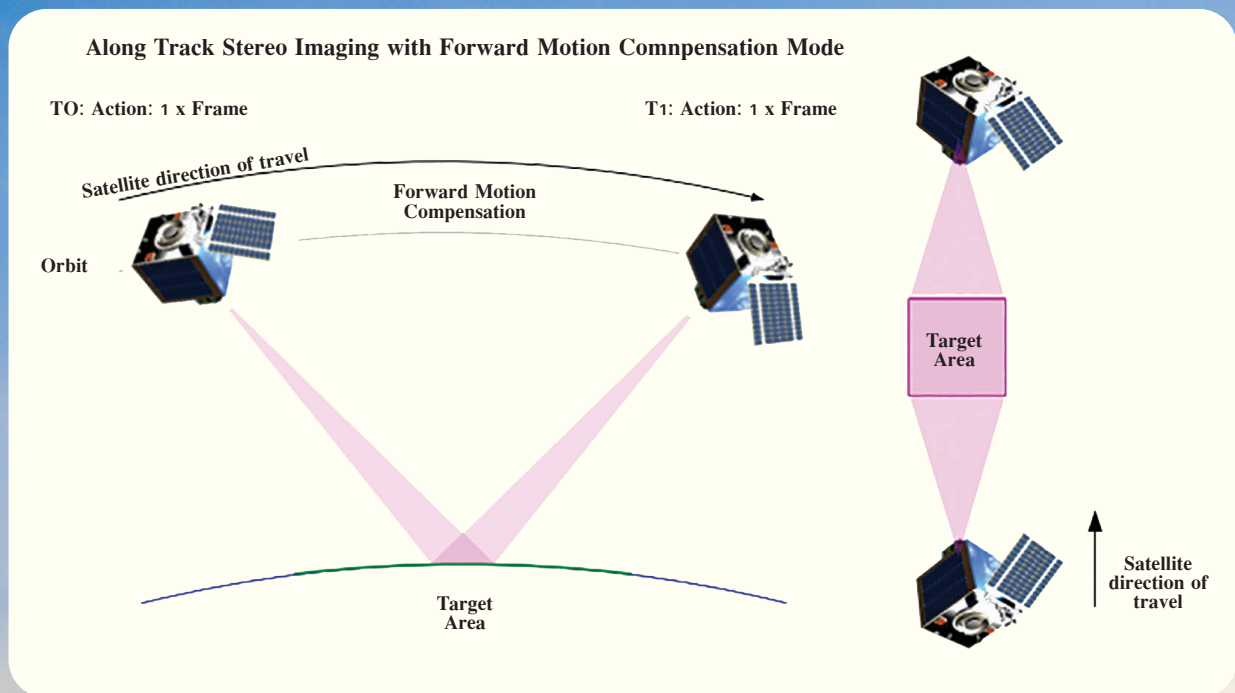
4.1.2 Video – Long Duration, Low Rate, Full Frame:

	Mode	Frame per Second (FPS)	Scene Size	Resolution	Payload Capture Session Duration (Seconds)	# Frames captured
B	Video – Long Duration, Low Rate, Full Frame	10	5.9 km. x 5.9 km. @ Altitude 550 km. (Reference Orbit)	1.18 m. @ Altitude 550 km. (Reference Orbit)	75	750



4.1.3 Video – Long Duration, High Rate, Small Frame:

	Mode	Frame per Second (FPS)	Scene Size	Resolution	Payload Capture Session Duration (Seconds)	# Frames captured
C	Video – Long Duration, High Rate, Small Frame	25	4.5 km. x 2.5 km. @ Altitude 550 km. (Reference Orbit)	1.18 m. @ Altitude 550 km. (Reference Orbit)	75	1,875



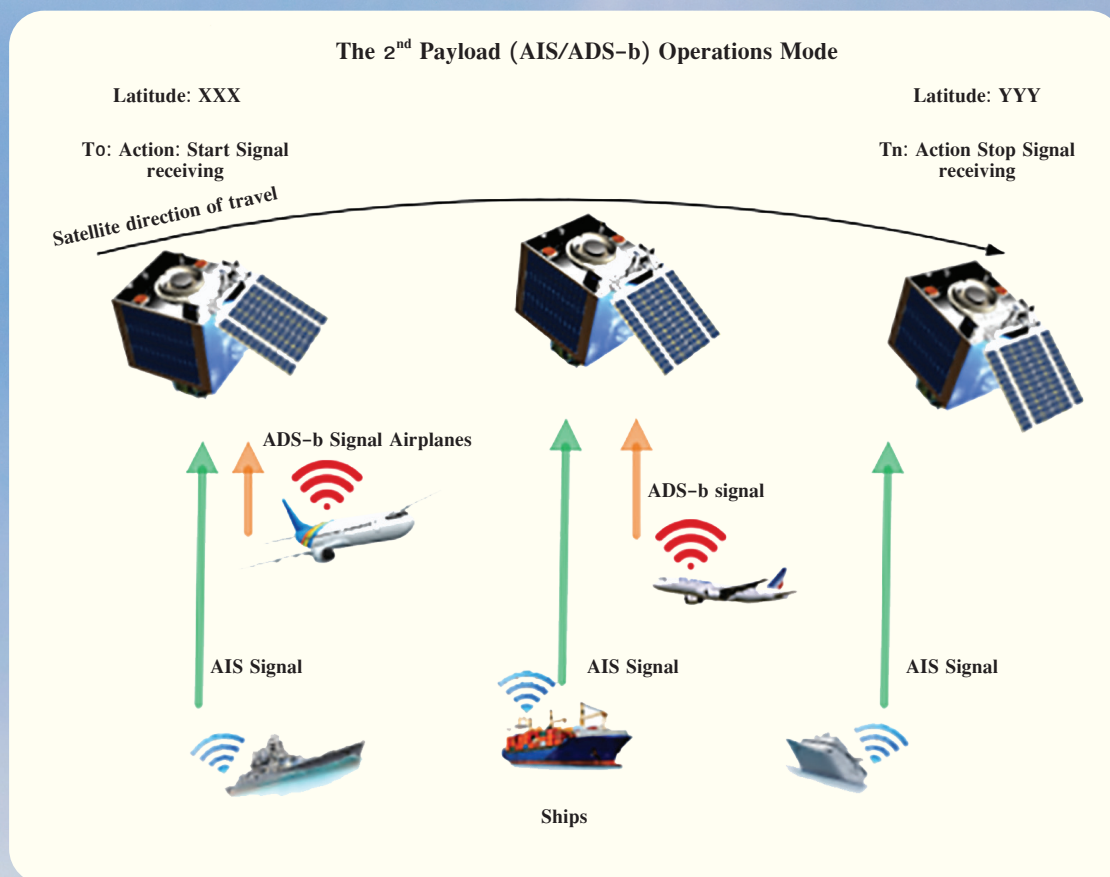
4.1.4 Along Track Stereo:

	Mode	Frame per Second (FPS)	Scene Size	Resolution	Payload Capture Session Duration (Seconds)	# Frames captured
D	Along Track Stereo	N/A	5.9 km. x 5.9 km. @ Altitude 550 km. (Reference Orbit)	1.18 m. @ Altitude 550 km. (Reference Orbit)	92	2

4.2 Secondary Payload

The Secondary Payload consists of the Automatic Identification System (AIS) and Automatic Dependent Surveillance – Broadcast (ADS-B) which can record the AIS and ADS-B signals that are emitted from devices below the satellite.





Due to the limit capability of the satellite, the Secondary Payload cannot operation in parallel with Primary Payload but both AIS and ADS-B can be operated simultaneously.

4.2.1 Automatic Identification System (AIS):

	Mode	Estimate Coverage Radius	RF Uplink	Payload Capture Session Duration (Seconds)	Observation period over Thailand
E-1	AIS	~ 2,450 km, 79.5-degree line of sight angle @ Reference 550 km altitude	Fq1: 161.975MHz Fq2: 162.025MHz (It can be received both frequency at the same time)	1,680 Max (28 minutes)	» 2 Orbit over Thailand in day-time (9 am – 11 am local time) » 2 Orbit over Thailand in night-time (9 pm – 11 pm local time)

Receive Capability

AIS Information: Class A

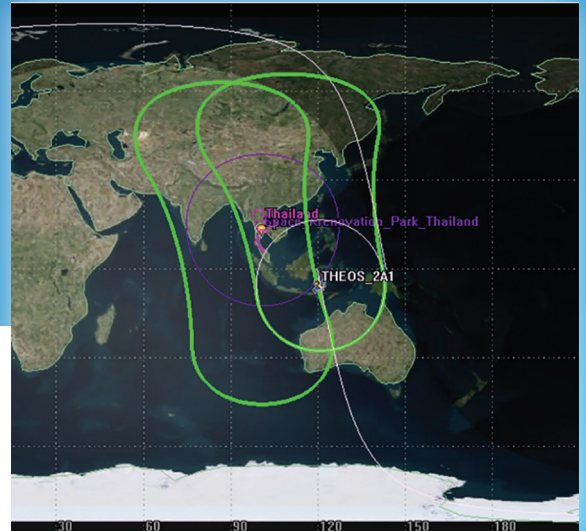
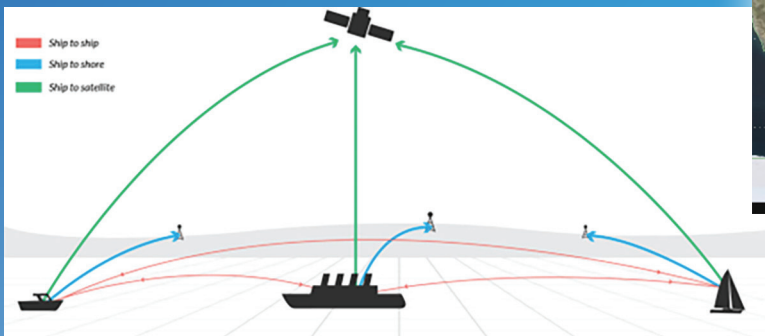
- 🌐 Vessel Identification
- 🌐 Position
- 🌐 Course

AIS Information: Class B

- 🌐 Position
- 🌐 Course



Automatic Identification System (AIS) Technique and coverage



4.2.2 Automatic Dependent Surveillance – Broadcast (ADS-B):

	Mode	Estimate Coverage Radius	RF Uplink	Payload Capture Session Duration (Seconds)	Observation period over Thailand
E-2	ADS-B	» Swath Width = ~ 870 km » Longest distance = ~12,734 km (Satellite velocity ~7.58 km/s)	1090 MHz 978 MHz	1,680 Max (28 minutes)	» 2 Orbit over Thailand in day-time (9 am – 11 am local time) » 2 Orbit over Thailand in night-time (9 pm – 11 pm local time)

Receive Capability

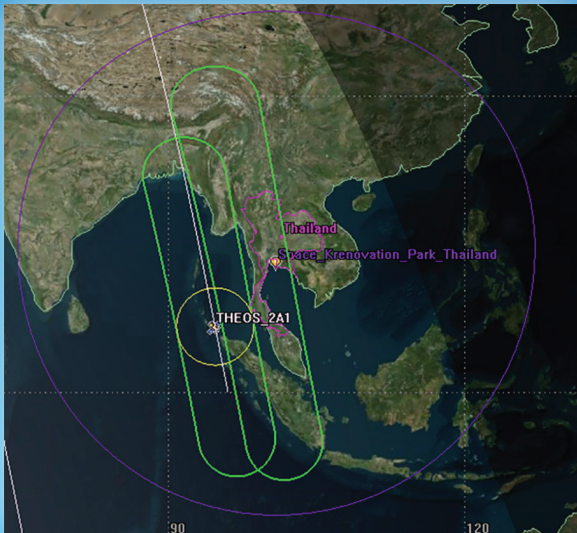
Worldwide and US only

📶 GPS position

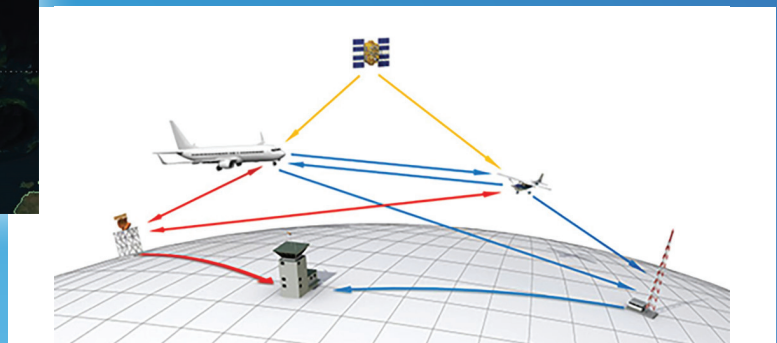
📶 Pressure Altitude

📶 Callsign

📶 Ground speed



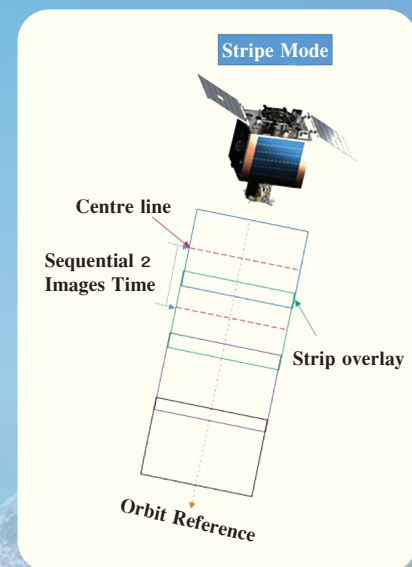
Automatic Dependent Surveillance – Broadcast (ADS-B) Technique and coverage



4.3 Third Payload

The Third Payload is experimental equipment designed, tested, and verified by GISTDA engineers. This unit is based on COTS components with Raspberry Pi processors. There are a number of experimental modes for this sensor.

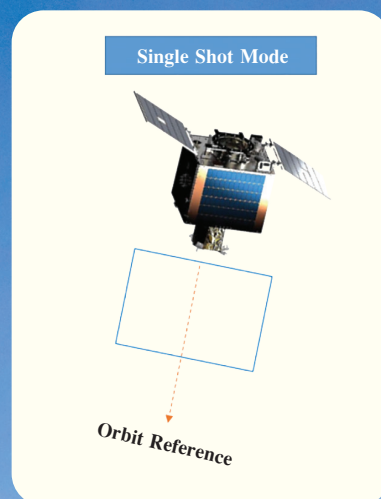
Parameters	Values	Units
Swath Height	441	Km.
SmallSAT Velocity	7.58	Km./s
Strip Overlay %	10%	%
Swath Height - Strip Overlay %	396.9	Km.
Sequential 2 Images Time	58.18	s
Target Length	5100	Km.
No. of Images per Orbit	12	Pics.
Data (MB) per Instant	2.18	MB
Total Data consumption (no compression)	26.11	MB



4.3.1 Strip Mode

	Mode	Frame per Second (FPS)	Frame Size	Payload Capture Session Duration (Seconds)	# Frames captured
F1	Strip Mode	N/A	1920 pixels x 1080 pixels (~784 km. x ~441 km.)	1,285	10

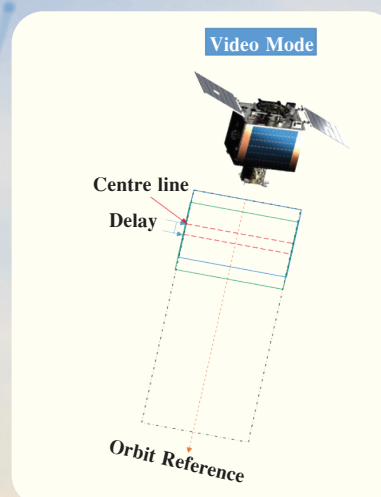
Parameters	Values	Units
Swath Height	753.88	Km.
Swath Width	997.99	Km.
No. of Images	1	Pics.
Data (MB) per Instant	2.18	MB
Total Data consumption (no compression)	2.18	MB



4.3.2 Single Shot Mode

	Mode	Frame per Second (FPS)	Frame Size	Payload Capture Session Duration (Seconds)	# Frames captured
F2	Single Shot Mode	N/A	1920 pixels x 1080 pixels (~997.99 km. x ~753.88 km.)	664.38	10

Parameters	Values	Units
Swath Height	441	Km.
SmallSAT Velocity	7.58	Km./s
Video Capture Time	3	sec
Integration Time	19.14	ms.
Delay	100	ms.
No. of Images (3 sec)	27	Pics.
Total Data consumption (no compression)	56.57	MB

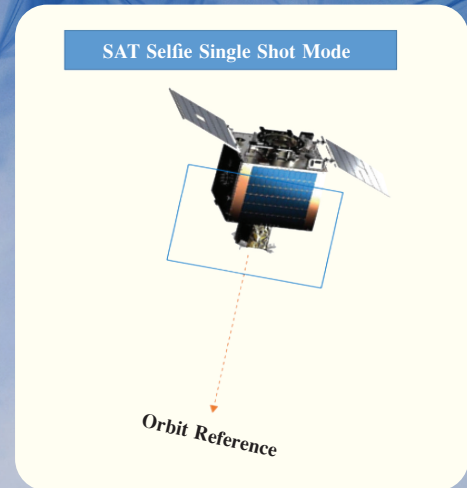


4.3.3 Video Mode

	Mode	Frame per Second (FPS)	Frame Size	Payload Capture Session Duration (Seconds)	# Frames captured
F3	Video Mode	9	1920 pixels x 1080 pixels	899.53	26



Parameters	Values	Units
Swath Height	753.88	Km.
Swath Width	997.99	Km.
No. of Images	1	Pics.
Data (MB) per Instant	2.18	MB
Total Data consumption (no compression)	2.18	MB



4.3.4 Satellite Selfie Single Shot Mode

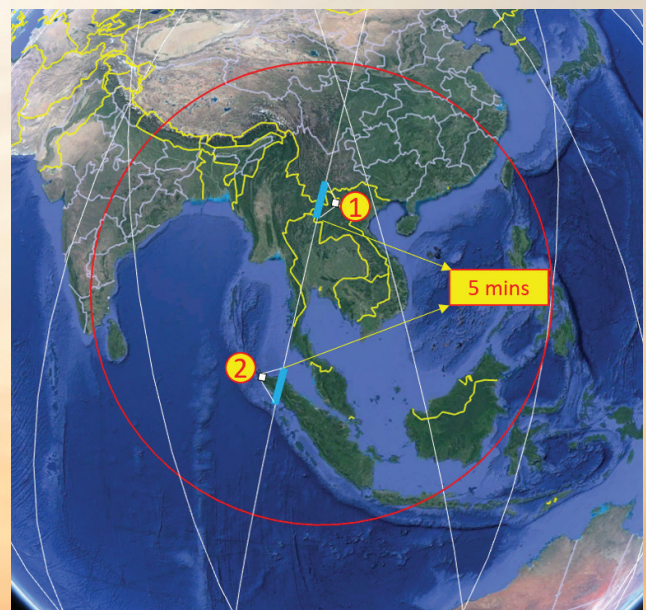
	Mode	Frame per Second (FPS)	Frame Size	Payload Capture Session Duration (Seconds)	# Frames captured
F4	Satellite Selfie Single Shot	N/A	1920 pixels x 1080 pixels	633.54	1

5 Satellite Operation Conditions

THEOS-2A has been designed with the Concept of Operation (CONOP) to utilize all its capacity to acquire the data from all payloads. Nevertheless, since some resources has to be shared with all amount the payloads, the certain conditions have to be considered when operates the satellite.

5.1 Primary Payload Conditions

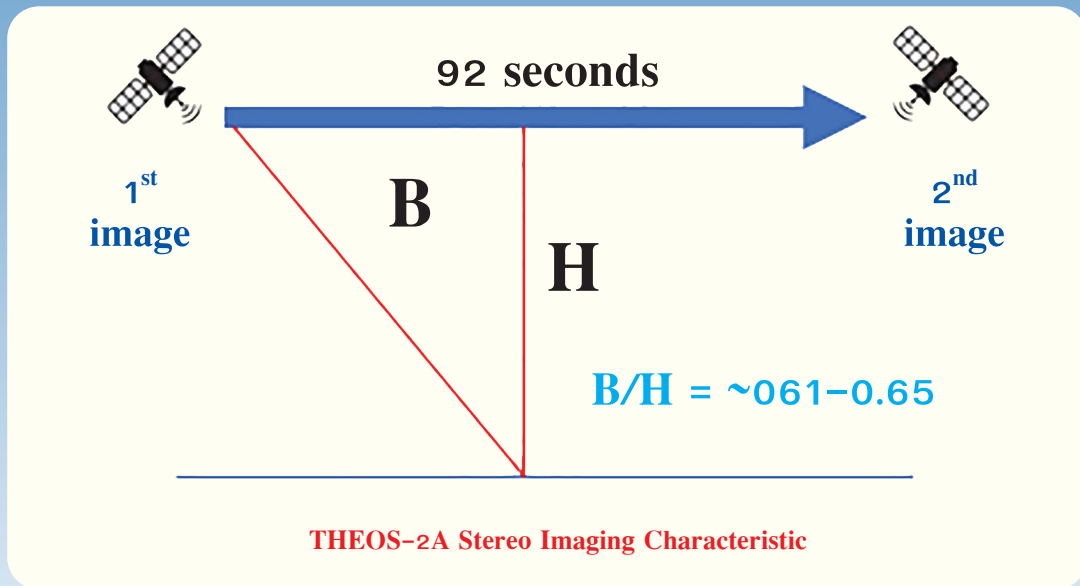
- ④ Primary Payload and Secondary Payload cannot be operated simultaneously.
- ④ Primary Payload and Downlink of image cannot be operated simultaneously.
- ④ The waiting time for 2 consecutive images is 300 seconds (5 minutes) or around 2,100 km apart.



Interval between 2 consecutive images is 300 seconds (2,100 km apart)



- ④ For the Stereo Image, the delay between the first image and the second image is 92 seconds. This corresponds to a B/H ratio around 0.61–0.65



5.2 Secondary Payload Conditions

- ④ Secondary Payload and Primary Payload cannot be operated simultaneously.
- ④ Secondary Payload and Downlink of image cannot be operated simultaneously.
- ④ Both secondary Payload (AIS and ADS-B) can be operated simultaneously.
- ④ The operation time for both AIS and ADS-B per orbit is 1,680 seconds (28 minutes) continuously which can be converted to around 11,520 km long.

The illustration of the secondary payload coverage area, night pass

- ④ The satellite access time estimation for each area can be acquired through MMGS Image Request Service (IRS).



6 PRODUCTS, SERVICES AND OPTIONS

THEOS-2A delivers ready-to-use products from each payload which can be used for the suitable applications. THEOS-2A primary payload always acquires multispectral images with 3 spectral bands (RGB)

6.1 Primary Payload

Mode	Level 0		Level 0R		Level 1R	
	Single Shot Image	Video	Single Shot Image	Video	Single Shot Image	Video
Video – High Rate, Full Frame	N/A	N/A	x	x	x	N/A
Video – Long Duration, Low Rate, Full Frame	N/A	N/A	x	x	x	N/A
Video – Long Duration, High Rate, Small Frame	N/A	N/A	x	x	x	N/A
Along Track Stereo	N/A	N/A	x	x	x	N/A

x = Available

N/A = Not available

6.1.1 Level 0 product

It corresponds to Multispectral of raw and encrypt data, without any processing. This product is not available.

6.1.2 Level 0R product

This product is a process of changing the pixel value. In broad terms, it consists of the following operations

- ④ Dark current correction
- ④ Radiometric calibration
- ④ Cosmetic correction
- ④ Dead pixel correction
- ④ De-Bayering

There are 3 types of L0R products.

- ④ Single Shot Image: Thanks to multiple captured frames, the single image extracted from video mode can be achieved.
» File format available: *.tiff format
- ④ Video: By combining the multiple captured frames, the video product can be achieved.
» File format available: *.mov format
- ④ Stereo Image: A pair of captured frames which captured two images of the same location taken from different angles.
» File format available: *.tiff format

6.1.3 Level 1R product

The final image product that the end-user receives needs to be georeferenced. This gives the correspondence of image pixel data to actual position on the Earth. A GeoTiff format is a standard TIFF format image with the additional geographical information added in a standard form. The geographic information in the image gives a mapping from image pixel position geodetic latitude and longitude.

This processing level includes:

- ④ Find the correct position and orientation of the spacecraft at the time of acquisition.
- ④ Calculate the look vector of a particular pixel (pixel vector) using the intrinsic calibration parameters.

- ④ Rotate this vector to get the same vector in an earth-centered-earth-fixed (ECEF) frame.
- ④ Apply extrinsic calibration
- ④ Define four corners and scene center of image.
- ④ Map projection

There are 2 types of L1R products

- ④ Single shot Image: Based on L0R product, the geometric correction single shot image product (L1R) can be achieved.
» File format available: *Geotiff format
- ④ Stereo Image: Based on a pair of L0R product, the geometric correction stereo image product (L1R) can be achieved
» File format available: *Geotiff format
- ④ Video: Not available.

6.2 Secondary Payload

Mode	Service
Automatic Identification System (AIS):	x
Automatic Dependent Surveillance – Broadcast (ADS-B)	x

x = Available

N/A = Not available

6.2.1 Automatic Identification System (AIS) product

The datasets acquired from Vessel (or other objects that transmit the RF in sensing range) such as identification, position and course are provided.

Filed	Data	Description
1	Create time, Timestamp	The time the vessel record was Created and Transmitting (ISO 8601 formatted).
2	Collection type	How the message was captured via satellite or terrestrial or dynamic.
3	Message Type	AIS message type Position Relate field Position, speed, heading, rate of turn. Static Details Identity, type, size, voyage information
4	MMSI	The Maritime Mobile Service Identity of the vessel transmitting the AIS message.
	IMO	IMO number of the ship Unique International Maritime Organization number for the vessel that stays with the ship for its life.
	Name, Call sign, and Flag	Vessel's name, Call sign, and Flag.
5	Position	Latitude, Longitude, GPS accuracy
6	Traveling Information	Course, Heading, Speed, Destination, Navigation Status, Estimated time of arrivals.
	Dimension	Length, Width, and Distance from AIS Transponder to each sides of the ship.

6.2.2 Automatic Dependent Surveillance – Broadcast (ADS-B) product

The datasets acquired from Aircraft (or other objects that transmit the RF in sensing range), such as GPS position, Pressure Altitude, Callsign, Ground speed are provided.



Filed	Data	Description
1	Create time, Timestamp	The time the vessel record was Created and Transmitting (ISO 8601 formatted).
2	ICAO address	Aircraft N-Number History ("N" is stand for Nationality designator)
3	Position	Latitude, longitude
4	Airborne position (w/Baro Altitude)	The altitude determined by a barometric altimeter pressure level
	Airborne position (w/GNSS Height)	The altitude determined by Ellipsoid, Geoid, Topography
5	Airborne velocities	The speed of the tracking aircraft

6.3 Third Payload

Not available

7 Delivery Format

Due to the variety of THEOS-2A products, the delivery format for each type of product is described here below;

7.1 THEOS-2A Primary Products structure

7.1.1 Single Shot Image Product

The Single Shot image Product consists of the image file (either *.tiff or *.Geotiff format) and its associated Metadata files.

7.1.2 Stereo Image Product

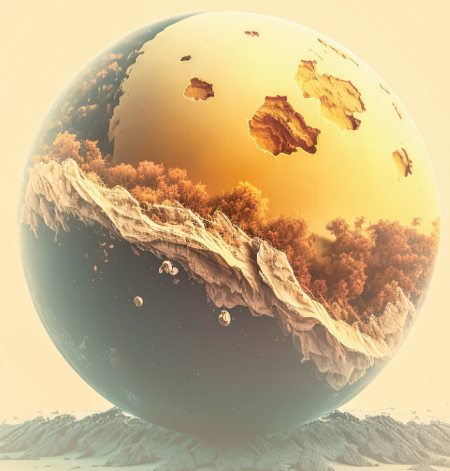
The Stereo Image Product consists of the image file (either *.tiff or *.Geotiff format) and its associated Metadata files.

7.1.3 Video Product

The Video Product consists of the video file (*.mov format) and its associated Metadata files.

7.2 THEOS-2A Secondary Products structure

Both "Automatic Identification System (AIS)" and "Automatic Dependent Surveillance - Broadcast (ADS-B)" product is delivered in *.json file format.





```

1 ADSB_1683023385_T2005721AA_001_1.json
2 {
3   "data": [
4     {
5       "date": "2106-02-06 12:16:13+00:00",
6       "m": "8D88596E583704DD87FBC1CE047B",
7       "icao": "88596E",
8       "tc": "11",
9       "altitude": 9800,
10      "feature": {
11        "type": "FeatureCollection",
12        "features": [
13          {
14            "type": "Feature",
15            "geometry": {
16              "type": "Point",
17              "coordinates": [
18                101.00025,
19                13.52338
20              ]
21            },
22            "properties": {}
23          }
24        ]
25      },
26    ]
27  }

```

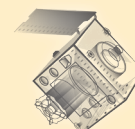
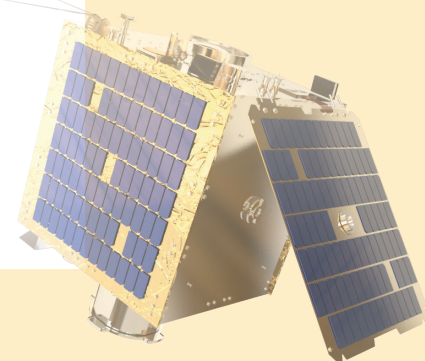
Structure of ADS-B product

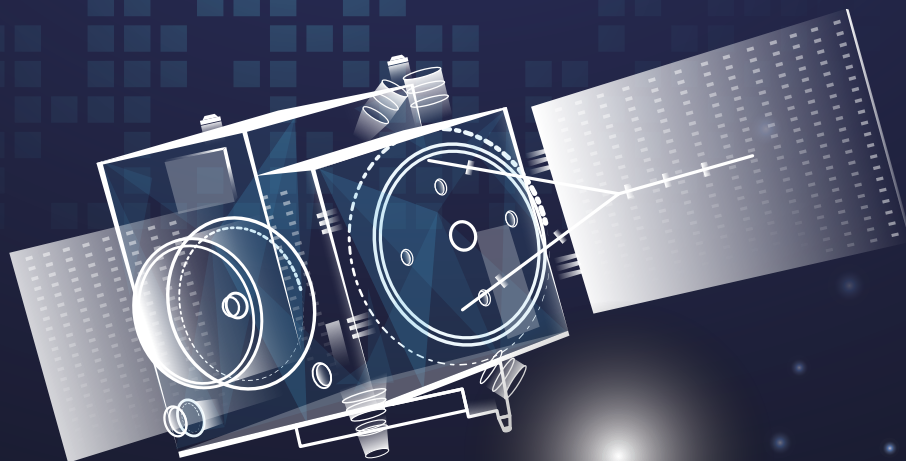
```

1 AIS_1683023385_T2005721AA_001_1.json
2 {
3   "data": [
4     {
5       "date": "2096-06-30 21:30:11+00:00",
6       "msg_type": "1",
7       "repeat": "0",
8       "mmsi": "1417750",
9       "status": "NavigationStatus.UnderWaySailing",
10      "turn": "708.0",
11      "speed": "41.9",
12      "accuracy": "False",
13      "feature": {
14        "type": "FeatureCollection",
15        "features": [
16          {
17            "type": "Feature",
18            "geometry": {
19              "type": "Point",
20              "coordinates": [
21                100.89452,
22                13.17014
23              ]
24            },
25            "properties": {}
26          }
27        ]
28      },
29      "course": "224.1",
30      "heading": "424",
31      "second": "56",
32      "maneuver": "0",
33      "spare_1": "b'\x00'",
34      "raim": "False",
35      "radio": "5283"
36    },
37    {
38      "date": "2097-07-24 06:10:43+00:00",
39      "msg_type": "1",
40      "repeat": "0",
41      "mmsi": "567001958",
42      "status": "NavigationStatus.UnderWayUsingEngine",
43      "turn": "-128.0",
44      "speed": "0.1",
45      "accuracy": "True",
46      "feature": {
47        "type": "FeatureCollection",
48        "features": [
49          {
50            "type": "Feature",
51            "geometry": {
52              "type": "Point",
53              "coordinates": [
54                100.89452,
55                13.17014
56              ]
57            },
58            "properties": {}
59          }
60        ]
61      },
62      "course": "255.7",
63      "heading": "511",
64      "second": "43",
65      "maneuver": "0",
66      "spare_1": "b'\x00'",
67      "raim": "False",
68      "radio": "2214"
69    }
70  ]
71 }

```

Structure of AIS product





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