3

Clarification of SAR Data Processing Systems and Data Availability to Support InSAR Applications in Thailand

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1. Introduction

The Geo-Informatics and Space Technology Development Agency (GISTDA) was established since 2000, and it is the major organization in Thailand that responsible for geo-informatics and all space technology development activities under ministry of science and technology. Currently, GISTDA acquired data from Earth Observation Satellites such as THEOS, LANDSAT-5, RADARSAT-1 and -2, etc. by using remote sensing systems which extensively to be used in the past and tremendously useful from now on for acquiring the satellite data. Consequently, the recognition on the development of this technology and operation acceptant are very beneficial. Moreover, the users are necessary to understand the data processing procedures, as for their applications which depend on the satellite imageries and data processing quality. This article describes and discusses mainly about the data processing and production systems of SAR sensor, including the application example on Bangkok land subsidence using InSAR.

GISTDA has archives of many European, Canadian and Japanese SAR images of Thailand that are instantly available to InSAR applications in Thailand. With our capability to acquire the data direct down-link using 9- and 13-meter antennas, it provides the potential of times series SAR data available for the environmental change detection using InSAR techniques.

In Thailand, the land deformations are not a new phenomenon for major cities and some specific zone whose location lay on the tectonic plate. The applications such as land subsidence, flash flood induced land slide, coastal erosion and fault monitoring are subjected to the country apprehension. However, the irregular deformation patterns put severe demands to the traditional geodetic techniques such as levelling survey, GNSS etc. with respect to the number of stations and the time interval between consecutive measuring sessions. Therefore, to overcome the limitations, InSAR (Interferometric Synthetic Aperture Radar) techniques provide a high spatial resolution and accuracy at the sub-centimetre level. InSAR has all weather, day and night, capability, and the sampling rate of current space-borne systems is improving, 45 days (ALOS-PALSAR), 24 days (RADARSAT-1 and RADARSAT-2) to 11 days (TerraSAR-X), which is satisfactorily high to the monitoring of land deformations.

For SAR data, the production requests were submitted through a Product Generation System (PGS) interface for RADARSAT-1, RADARSAT-2 and APEX CMDR via Vexcel control processor system for ALOS-PALSAR at the ground receiving station facility. The necessarily data employed in most research for deformation is required to be in single look complex (SLC) products in CEOS format where generally each of them consists of five files containing various descriptive records. Each image pixel is represented by complex I and Q numbers to maintain the amplitude and phase information which makes it suitable for interferometric processing. Therefore, the clarification such as the processing algorithm, system configuration, data available to support applications will be provided to certify the potential of using SAR data in Thailand. Finally, a case study on using InSAR techniques for land subsidence monitoring in Bangkok and its vicinity area will show that the successful cooperation between data provider and the user will lead to conquer the best practice.

2. Brief background of satellite remote sensing in Thailand

Historically, Thailand Satellite Remote Sensing Program of the National Research Council of Thailand (NRCT) was established on September 14, 1971 (NRCT, 2000) with the main reason of participating in NASA Earth Resources Technology Satellite (ERTS) Program. The program was promoted to become the Remote Sensing Division under NRCT in 1979, and internationally known as the Thailand Remote Sensing Center (TRSC). Subsequently, in late 1981, the ground receiving station was set up to acquire Landsat-MSS data, and it was capable of receiving and processing data from major remote sensing satellites throughout consistent upgrading of the facilities. In 1982, Thailand Ground Receiving Station was set up as first of its kind in Southeast Asia with the available satellite data such as LANDSAT, SPOT, NOAA, ERS and MOS at that time.

On June 27, 2000, the Cabinet was approved the establishment of Geo-Informatics and Space Technology Development Agency (GISTDA) as the self-governing public organization for conducting technological research, development and applications of satellite remote sensing and GIS, related space technologies for providing relevant services to Thai and international community. Basically, GISTDA is the merging of the TRSC and the IGIS section of Information Center of MOST. Therefore, GISTDA is the national main organization implementation of remote sensing, GIS, and satellite development programs for Thailand. Due to the main mission, Thailand Earth Observation Center (TEOC) has become the common name of TRSC since then.

One of the big movement of space activity in Thailand has been recorded on October 1, 2008, that Thailand Earth Observation Satellite (THEOS) was successfully launched by Dnepr launcher from Yasny, Russian Federation. THEOS is the first operational earth observation satellite of Thailand. The THEOS program was developed by GISTDA, EADS Astrium, the prime contractor, initiated work on the satellite in 2004. Nowadays, GISTDA is developing a worldwide network of distributors to allow the users to use and access to all GISTDA products which is able primarily to access via web-site www.gistda.or.th.

On the other hand, Synthetic Aperture Radar (SAR) satellite systems formerly in function at TEOC include European Remote Sensing Satellite 1 (ERS-1) from the European Space Agency's (ESA) which was launched by July 1991, and the Japanese Earth Resources satellite (JERS-1), launched in February 1992. The ERS-1 sensor operated in the C-band frequency (approx. 5.6 cm wavelength) and JERS-1 operated in the L-band frequency (approx. 23 cm wavelength). Both sensors have a nominal spatial resolution of approximately 30 m. The ERS-1 satellite, with a projected lifespan of three years, was followed by an ERS-2 satellite to continue SAR data acquisition into the late 1990s.

The operations of SAR data at that time has been applied to several major applications such as land-use and land-cover information mapping, coastal monitoring, crop monitoring, etc. The mission record of SAR data had been started with ERS-1 in March 1993 after almost 2 year launched, and the contract had been expired in September 1995. In parallel, JERS-1 SAR ground system had been functioned from October 1993 until October 1998, respectively. Before the coming of RADARSAT-1 (Canadian Space Agency) in July 2000, TEOC had set up the new contract with ESA again for acquiring SAR data from ERS-2 mission which records from August 1996 to October 1999. Currently, the RADARSAT-1 (2000-present), RADARSAT-2 (2010-present) and ALOS-PALSAR (2007-2011) have been the main SAR satellite acquisition of TEOC. However, please note that, JAXA announced that ALOS satellite has been completed its operation due to power generation anomaly since May 12, 2011.

TEOC plays an important role in the area of remote sensing technology in the country and also in the Asian region. The center has some collaborative activities with several international agencies including NASA, JAXA, ESA, CSA, etc. TEOC is located at Ladkrabang district, Bangkok, which is about 4 kilometers from Suwanaphum International airport. It has radius coverage of 2,500 km, covering 17 countries such as Malaysia, Singapore, Philippines, Indonesia, Brunei, Myanmar, Laos, Vietnam, Cambodia, Thailand, Bangladesh, India, Nepal, Sri Lanka, Phutan, Taiwan, and South China and Hong Kong (see figure 1).

3. Fundamentals of synthetic aperture radar

Synthetic Aperture Radar (SAR) is a powerful active coherent imaging system that operates in the microwave frequency band. The system could be placed onboard an airbourne or a spacebourne plarform. It provides capabilities of working in daylight-independent and all-weather condition, and penetrating cloud cover. These capabilities allow SAR an attractive instrument for many applications i.e. change detection, disaster management and environmental monitoring. New applications increase as new technologies are developed.

SAR system imaging the Earth's surface by transmitting pulses and collecting echoes reflected from an illuminated area. To perform this, the transmitter generates pulses of electromagnetic energy at the regular time interval and sends to the antenna. Then the antenna radiates the energy from the transmitter in a directional beam. Each pulse travels at the speed of light to the target area. The returning echo energy are also picked up by the same antenna and passed to the receiver. By measuring the time delay between the transmitted pulses and the reflected return pulse or echo, SAR system is able to determine the distance of the target.

To construct an image, time delay of the received echo must be precisely measured in two orthogonal dimensions. One dimension is parallel to the antenna beam while another is orthogonal to the antenna beam. In the first dimension, parallel to the antenna beam, the SAR system places the received echo at the correct distance from the platform's sensor,

Fig. 1. TEOC Area Coverage for direct downlink.

along the x-axis of the image. The x-dimension is referred as range direction, or cross-track. For the second dimension, orthogonal to the antenna beam, the received echoes are placed in the y-axis of the image, according to the current position of the platform's sensor. The y-dimension is called azimuth direction, or along-track.

The basic geometry of imaging SAR is shown in figure 2. As illustrated, a platform, which could be an airplane or a satellite, travelling along the flight track with velocity V at altitude H. It carries a SAR antenna that illuminates the Earth's surface with pulse of electromagnetic energy. SAR antenna is typically rectangular with dimensions of length L and width W. The antenna is oriented parallel to the flight track and looking sideward to the area on the ground. The distance from the flight track to the target is denoted as range direction and direction along the flight track is referred as the azimuth direction. An area on the ground covered by the consecutive pulses is called swath. Antenna beam footprint is an area on the ground reflected by the pulse. θ is defined as the incident angle or look angle.

In fact the SAR system images an area on the ground but for simplicity, a single point on the ground is considered. This point is known as a point target. The data received from the SAR system are referred as raw data. The data are then demodulated to in-phase-quadrature-phase (I-Q) baseband data. The demodulated SAR signal, s, received from a point target can be modeled as (Cumming & Wong, 2005)

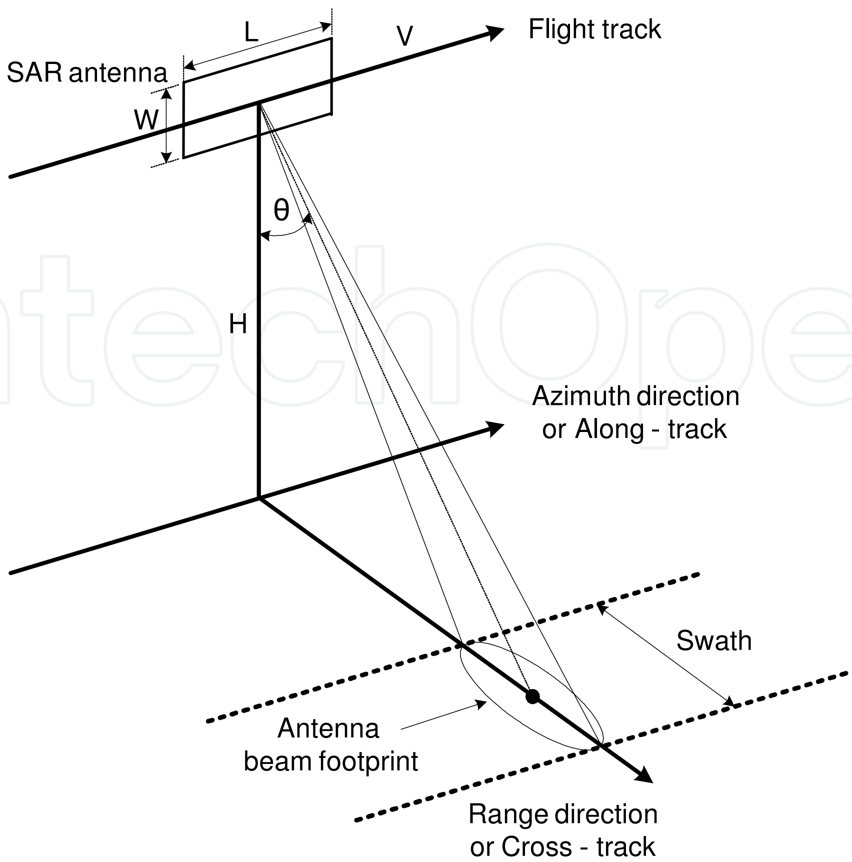


Fig. 2. Basic geometry of imaging SAR.

$$s(\tau,\eta) = A\omega_r[\tau - 2R(\eta)/c]\omega_a(\eta-\eta_c) \times \exp(-j4\pi f_0 R(\eta)/c) \times \exp(j\pi K_r(\tau - 2R(\eta)/c)^2) \tag{1}$$

where A = an arbitrary complex constant
τ = range time
η = azimuth time
η_c = beam center offset time
$\omega_r(\tau)$ = range envelope
$\omega_a(\eta)$ = azimuth envelope
f_0 = radar center frequency
K_r = range chirp FM rate
$R(\eta)$ = instantaneous slant range.

The raw data is not an image due to the point targets are spread out in range and azimuth direction. It will be compressed in two dimensions by SAR data processor, to produce the image. The purpose of SAR processing is to convert the raw data into an interpretable image. Several algorithms have been developed and each algorithm has its advantages in either imaging quality or computation efficient. In the following section two SAR image processing techniques will be briefly introduced: the range–Doppler and the sprectral analysis.

There are three SAR satellites acquiring data at the TEOC: RADARSAT-1, RADARSAT-2 and ALOS. RADARSAT-1 is Canadian first commercial Earth observation satellite launched on November 1995. It employs a SAR sensor operating in the C-band frequency (5.3 GHz). The RADARSAT-1 SAR sensor has two right-looking operational modes, Single Beam mode and ScanSAR mode. The modes of observation offer the real-time swath width ranging from a narrow high-resolution beam of 50-km, Fine beam in Single Beam mode, to a full 500-km swath in ScanSAR mode.

The Next-generation SAR satellite, RADARSAT-2, follow-on RADARSAT-1, was launched on December 2007. All RADARSAT-1 operational modes maintain in RADARSAT-2. The major extended capabilities are a new observation beam, ultra-fine with 3-meter resolution, a fully polarimetric imaging and ability to look either left or right side of satellite track. More details on the RADARSAT-1 and RADARSAT-2 satellites are provided by (Ahmed et al., 1990; Thompson et al., 2001).

The Advanced Land Observing Satellite (ALOS) is Japan's research earth observation satellite operated by JAXA. It was launched on January 2006. The ALOS carries three remote-sensing instruments onboard: (i) the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM), the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) and the Phase Array type L-band Synthetic Aperture Radar (PALSAR). PRISM and AVNIR-2 are optical sensors while PALSAR is a microwave sensor. In this paper , we mainly focuses on the data processing system for PALSAR data only.

The PALSAR is L-band synthetic aperture radar operating in the microwave L-band frequency (1270 MHz). It was designed to achieve cloud-free, all-weather and day-and-night collecting high-resolution land observations data on a global scale. PALSAR has three imaging modes: single-polarimetric stripmap mode, ScanSAR mode, and multi-polarimetric mode. More information on the ALOS satellite can be found in (Japan Aerospace Exploration Agency [JAXA], 2008).

4. SAR processing algorithms

SAR processing algorithm is a processing tool used for transforming unfocused raw SAR signal data into a complex image data. Each processing algorithm is suitable for different SAR data types. For continuous SAR data such as data from the stripmap in SAR imaging mode, the most common algorithm is the Range-Doppler (RD) algorithm, but the burst data such as data from the scanning SAR imaging mode, the Spectral Analysis (SPECAN) algorithm, is best suitable.

The Range-Doppler algorithm is the most common algorithm used in most SAR processor. The algorithm was developed since SEASAT program. This algorithm has simplicity of one-dimensional operations and archive block processing efficiency by using frequency domain operations in both range and azimuth. These two directions processing can be independently performed by using range cell migration correction (RCMC) between the two one-dimensional operations.

Computation of the RD algorithm is divided into two processing steps: range compression and azimuth compression. The unfocused raw SAR data compression in each direction is first taking the fast Fourier transform (FFT), and then multiplied in frequency domain by the reference function and finally taking the inverse fast Fourier transform (IFFT). For azimuth compression the RCMC is applied after the azimuth FFT. The most important modification of this algorithm called secondary range compression (SRC) has been added to handle data with a moderate amount of squint.

The SPECAN algorithm was developed to produce a quick-look image for real-time SAR processing. It is the most efficient processing algorithm for ScanSAR data. The key property is computing efficiency which makes the algorithm require less memory than the RD algorithm does but may suffer from some image quality effects. The compression in range direction is the same as in the RD algorithm but different in the azimuth compression.

After range compression, the RCMC is applied before the azimuth compression. The RCMC is efficiency performed a linear correction only. The compression in azimuth direction performs deramping and FFT. Then there are two possible optional way, mutli-looking and phase compensation. The multilook processing is to be performed as the RD algorithm while the phase compensation replaces when single-look processing is to be performed. Reference [4] provides more details of these algorithms.

5. SAR data processing systems

SAR data processing system (SDPS) is used to transform unprocessed raw SAR data or signal data into georeferenced and geocoded image data. The TEOC has two SDPS: the RADARSAT SDPS for data from RADARSAT-1 and RADARSAT-2 SAR sensors and ALOS SDPS for data from ALOS PALSAR sensor. The RADARSAT SDPS is a sub-system of the Product Generation System (PGS) developed by MDA. ALOS SDPS is a sub-system of the ALOS Data Reception and Processing (ALOSRP) system developed by JAXA. The PGS and ALOSRP also have a capability to process data from optical sensor satellite such as LANDSAT TM for the PGS or ALOS AVNIR-2 for the ALOSRP.

5.1 RADARSAT SAR data processing system

The RADARSAT SAR data processing system is a sub-system of the Product Generation System used to transform RADARSAT-1 and RADARSAT-2 raw SAR data into the georeferenced and geocoded image data. This system is a hybrid computer system between UNIX and Windows platform. An advantage of this system is combining power, scalability and reliability of the UNIX with the ease of operation of the Windows. The physical architecture diagram of the RADARSAT SDPS is illustrated in figure 3.

In figure 3, the multi-CPU UNIX server is the SGI Origin 350 executes the core processing software of the RADARSAT SDPS. Its processors are based on Microprocessor without Interlocked Pipeline Stages (MIPS) architecture so that they can take advantage of the multiprocessor environment to parallelize the processing operations to provide efficient, scalable, and accurate data product generation. The Archive Management System (AMS) is a component to manage the archived data in Framed Raw Expanded Data (FRED) format. It tracks and retrieves a large volume of archived data in online, near-line and offline locations. The Windows terminals are Windows operating system HP Workstation used to control and monitor the processing.

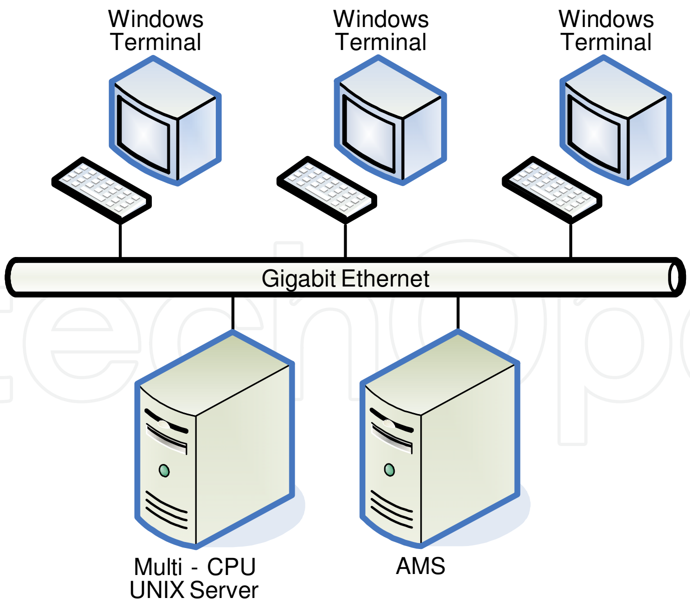


Fig. 3. RADARSAT SDPS Physical Architecture.

The RADARSAT SDPS is driven by a graphical user interface called Human Machine Interface (HMI) on the Windows terminal. The HMI provides the operator with full control over the product generation process via operator control panel. The product generation process is initiated by creating a work order. Work orders can be reviewed and edited via a work order editor panel. Multiple work orders executes in parallel, which each operator can customize to display only information of interest.

For image quality assessment, the HMI also provides the image viewer to perform visual quality assessment on an image. Image viewer tools includes map overlays, measuring distances, displaying average image intensity, displaying Doppler centroid plots and displaying product coverage. Map overlays turn on the overlays in the image to see various map features. Measuring distance allows operator to measure distance between any two points in the image. Average image intensity displays the image intensity in both range and azimuth direction. Doppler centroid plots display SAR Doppler centroid estimation results graphically. Product coverage used to check the product coverage against the expected product boundaries.

The RADARSAT SDPS software can be divided into four processing modules: Data Ingest module, SAR Processor module, Geocoded module and Product Formatting module. The logical architecture diagram of RADARSAT SDPS software is illustrated in figure 4.

The Data Ingest module is responsible for retrieving archived data in FRED format and transferring as signal data to the SAR processor module. The archived data sources could be (i) Magnetic Tape Device Storage (MTDS), (ii) Direct Archive System (DAS) or (iii) Robotic Tape Library (RTL). The MTDS is the offline storage, currently uses super digital linear tape (SDLT), the DAS is an online storage stores downlink data from RADARSAT satellites in the redundant array of independent disks (RAID), and RTL is the near-line storage using the automatic tape archive.

The SAR Processor module is used to focus the raw SAR data into single-look and multi-look image data. It consists of two major software-based SAR processors: the Single-Beam

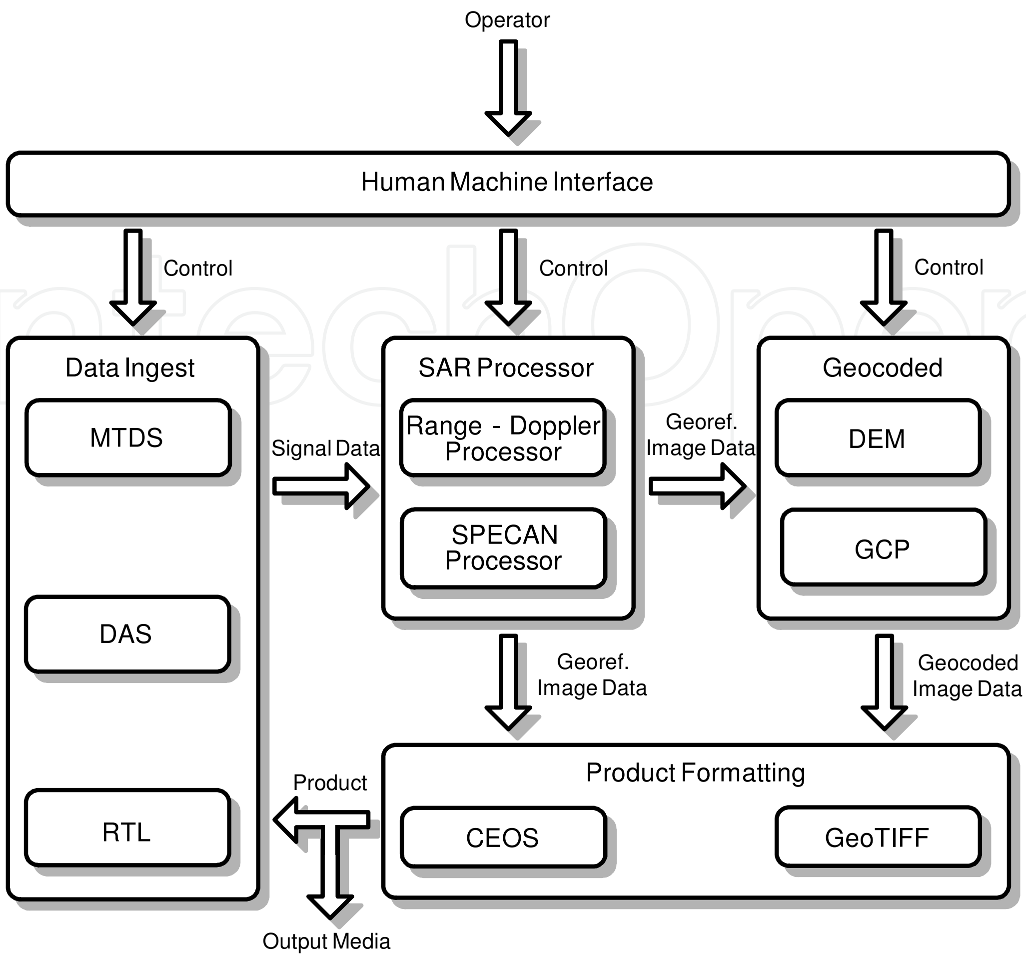


Fig. 4. RADARSAT SDPS Logical Architecture.

processor and the ScanSAR processor. The Single-Beam processor employs the Range-Doppler algorithm as a processing algorithm and suitable for processing Single Beam mode data while the ScanSAR processor employs the SPECAN algorithm as a processing algorithm and suitable for processing ScanSAR mode data. The processed data are georefernced image data stored on disk to be transferred to the Product Formatting module or the Geocoded module.

The Geocoded module is an optional module performs prior to the Product Formatting module. This module supports both systematic and precision geocoding. The digital elevation model (DEM) is employed to produces the systematic geocoded data. The ground truth sources in the form of ground control points (GCP) are used to refine a satellite acquisition model for the precision geocoded data. The output of the Geocoded module is geocoded image data stored on disk to be transferred to the Product Formatting module.

The Product Formatting module receives processed image data from the SAR processor module and the Geocoded module, formats the data, according to the MDA's data product specifications and then writes to output media. The data product format may be CEOS or GeoTIFF. Available output media of the data product can be in the form of disk, CD, DVD or electronics delivery i.e. FTP. The data product can be also archived back to the AMS.

Available data products generated from the RADARSAT SDPS are five georeferenced data products and two geocoded data products. There are single-look complex (SLC), SAR georeferenced fine resolution (SGF), SAR georeferenced extra-fine resolution (SGX), ScanSAR narrow (SCN), ScanSAR wide (SCW), SAR systematic geocoded (SSG) and SAR precision geocoded (SPG).

The throughput of the RADARSAT SDPS generates one standard georeferenced or systematic geocoded data product within twenty minutes. For the eight operation hours, minimum standard thirty SSG data products can be generated. The efficient resources sharing and parallel processing architecture of the system enabling up to twelve work orders can be processed at the same time.

5.2 ALOS SAR data processing system

The ALOS SAR data processing system is a sub-system of the ALOS Data Reception and Processing system used to transform ALOS raw PALSAR data into the standard data products and higher level data products. The ALOS SDPS consists of processing cluster servers, higher level processing servers, a product generation server, an archive server and a workstation terminal. All servers are Linux-based Dell server with Xeon processor. The physical architecture diagram of the ALOS SDPS is illustrated in figure 5.

In figure 5, the processing cluster servers and the higher level processing servers are multiple processors, multiple users and multiple work-order environments, so it can provide high capacity and excellent performance of the system. The data archive server is used to collect and maintain data received directly from ALOS satellite, and received as level 0 from JAXA, as well as higher level data products. All archived data are stored on the automatic tape archive in Sky Telemetry Format (STF). A workstation terminal is used for controlling and monitoring processing of data product via a product generation server. The throughput of the ALOS SDPS for each product and each sensor is at least ten scenes per eight working hours.

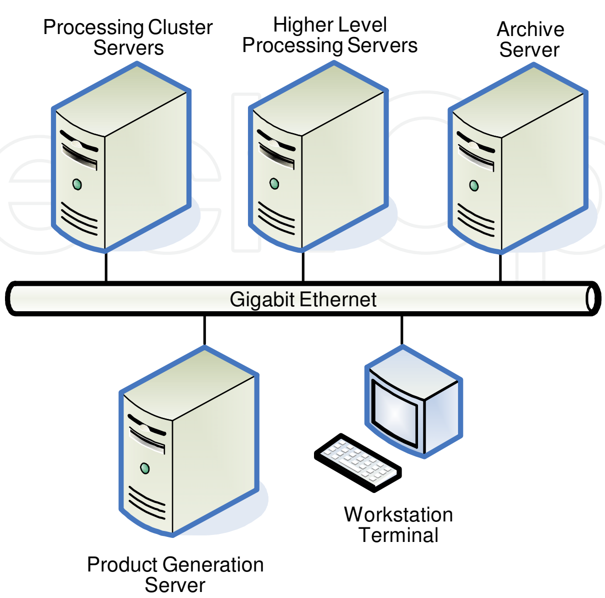


Fig. 5. ALOS SDPS Physical Architecture.

The ALOS SDPS software can be divided into four processing modules: Data Ingest module, PALSAR Processor module, Higher Level Processor module and Product Formatting module. The logical architecture diagram of the ALOS SDPS is illustrated in figure 6.

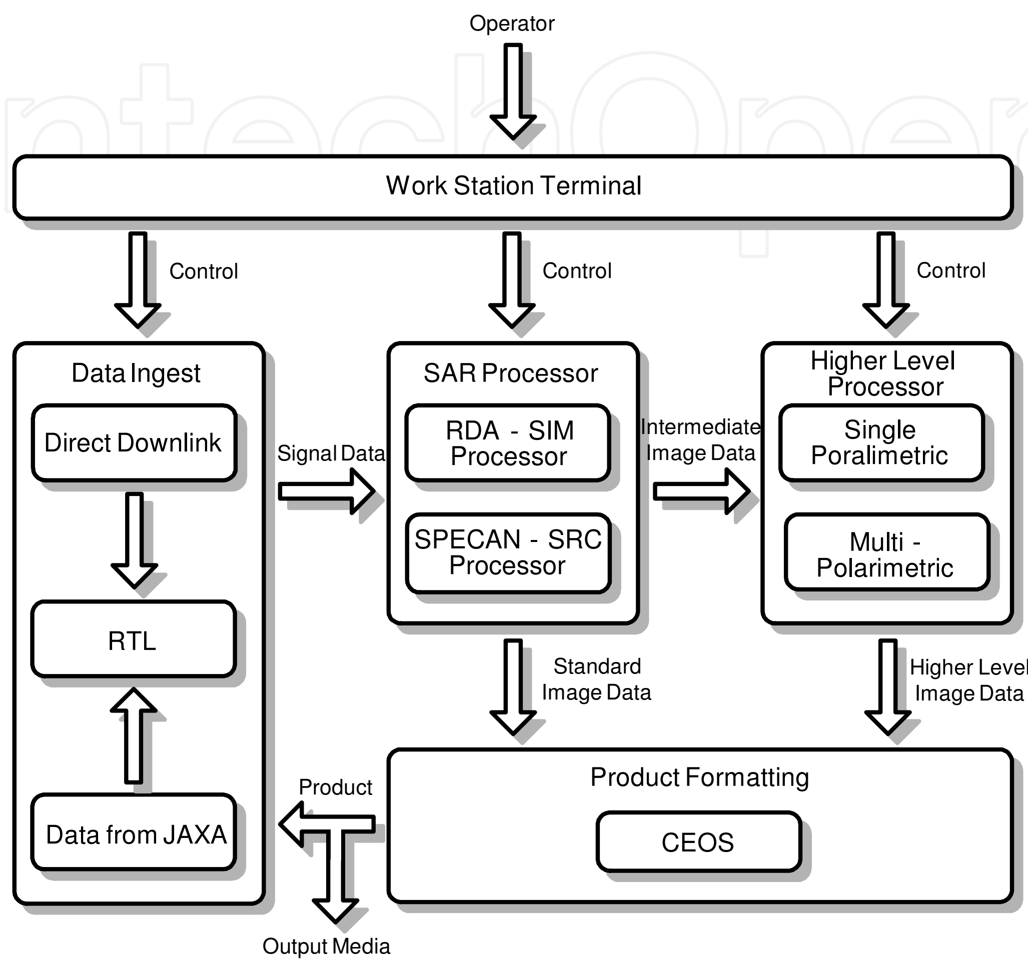


Fig. 6. ALOS SDPS Logical Architecture.

The Data Ingest module is used for retrieving archived data or level 0 data in STF format from the Robotic Tape Library (RTL). There are two possible archived data sources: (i) direct receiving ALOS PALSAR data received at the TEOC (Wide Area Observation Mode or WB1 only) and (ii) imported data from JAXA stored on DTF-2 and LTO-4. The archived data is then transferred to the PALSAR Processor module.

The PALSAR Processor module used to focus on the raw SAR data into standard image data and intermediate image data. It consists of two major software-based SAR processors: the Single Beam processor and the ScanSAR processor. The Single Beam processor employs the Range-Doppler algorithm with squint imaging mode (RDA-SIM) as a processing algorithm. It is suitable for processing Single Beam mode data. The ScanSAR processor employs SPECAN algorithm with chirp transform and secondary range compression (SPECAN-SRC) as a processing algorithm. It is suitable for processing Scanning SAR mode data.

When the STF archived data arrives at the PALSAR Processor module, the sky telemetry data and corresponding parameter are extracted and formatted into CEOS format. Then the formatted data are processed with Doppler parameter file by either of two SAR processors depending on the input data type. The processed data are stored on disk. The RDA-SIM processor can produce the standard SLC image data (L1.1), and level 1.5 (L1.5) image data referred to georeferenced and geocoded images. The data product is CEOS format with the available output media on CD, DVD or electronics delivery i.e. FTP.

6. SAR image quality characteristics

The image quality characteristic consists of a large variety of different parameters. The basic image quality parameters for general users are range resolution, azimuth resolution, peak side lobe ratio, integrated side lobe ratio and absolute location error. The specifications of these parameters are defined by the satellite operating agency and each satellite differently. The specifications of the image quality characteristics for RADARSAT-1 SLC Wide beam mode data products and ALOS level 1.1 Fine beam mode data products are summarized in table 1 and table 2. (MacDonald, Dettwiler and Associates [MDA], 2000; Earth Remote Sensing Data Analysis Center [ERSDAC], 2009) provide a full set of image quality characteristics for RADARSAT-1 and ALOS data products respectively.

Parameter	**Specification**
Range Resolution (RR)	15.7 m
Azimuth Resolution (AR)	8.9 m
Peak Side Lobe Ratio (PSLR)	< -20.0 dB
Integrated Side Lobe Ratio (ISLR)	-11.2 dB
Absolute Location Error (ALE)	< 750 m

Table 1. RADARSAT-1 SLC wide beam data products image quality characteristics.

Parameter	**Specification**
Range Resolution (RR)	16.0 m – 17.1 m
Azimuth Resolution (AR)	5.8 m
Peak Side Lobe Ratio (PSLR)	< -20.0 dB
Integrated Side Lobe Ratio (ISLR)	< -15.0 dB
Absolute Location Error (ALE)	< 750 m

Table 2. ALOS level 1.1 fine beam data products image quality characteristics.

Impulse response function is a two-dimensional signal appearing in a processed image as a result of the compression of returned energy from a point target. The width of the impulse response function at a power level 3 dB below the peak of the function is defined to be the impulse response width (IRW). The IRW is commonly referred to as the resolution, and its values are given separately for the two dimensions of the image. The IRW in the range direction is defined as the range resolution (RR), and the IRW in the azimuth direction is defined as azimuth resolution (AR). The azimuth resolution is constant within each beam.

A side lobe of the impulse response function is any local maximum other than those within the contour around the peak, which passes through points 3 dB below the main lobe peak. Side lobes are measured relatively to the main lobe peak. The peak side lobe ratio (PSLR) is defined to be the ratio of the maximum side lobe level and the main lobe level. The integrated side lobe ratio (ISLR) is defined to be the ratio of the integrated energy in the side lobe region of the two dimensional (range and azimuth) impulse response function relative to the integrated energy in the main lobe region. The absolute location error (ALE) is specified as the distance along the ground between the actual geographical location of a point within a processed image and the location as determined from the data product. It may be separated in two direction, range absolute location error (RALE) and azimuth absolute location error (AALE).

7. SAR interferometry

A more recent geodetic measurement technique is interferometric synthetic aperture radar (InSAR) which based on the combination of two radar images. It's earliest the measurement for allowing us to retrieve a Digital Elevation Model, and it has been developed to measure the large-scale surface deformation monitoring or so call Differential InSAR (D-InSAR). The principle of D-InSAR is to first obtain two interferograms of a study area, and then make a differential between for the detection of deformation information. Then, the topographic phase will be removed, and leave just only deformation phase. However, there are several limitations essentially due to temporal and geometric decorrelation. These limitations are well addressed in the time series InSAR techniques, which will be introduced in the following.

7.1 Permanent scatterer InSAR (PSI)

First algorithms of Permanent Scatterer technique were developed by (Ferretti et al., 2000, 2001). Similar processing strategies have been developed by (Crosetto et al., 2003; Lyons et al., 2003; Werner et al., 2003; Kampes, 2005). This method has been very successful for InSAR analysis of radar scenes containing large numbers of man-made structures. The numbers of differential interferograms are generated with respect to a single master (see figure 7). Pixels are selected based on its amplitude stability along the whole set of images, but the stable scatterers with low amplitude may not be detected.

In contrast, StaMPS (Hooper et al., 2007) algorithm uses spatial correlation of phase measurements, so it is applicable in areas undergoing non-steady deformation with no prior knowledge of the variation in deformation rate. PS pixels are defined by phase stability, so

PS candidates are selected on the basis of their phase characteristics. It takes advantage of pixels dominated by a single scatterer to reduce the influence of atmosphere and decorrelation. Then, the phase is corrected for non-spatially correlated errors and "unwrapped" using a statistical-cost approach (Hooper, 2010). After phase unwrapping, spatially-correlated DEM error is estimated from the correlation of phase with perpendicular baseline. The phase is the re-unwrapped with the DEM error subtracted, to improve unwrapping accuracy for larger baselines. Atmospheric artefacts are estimated by high-pass temporal filtering and low-pass spatial filtering. Finally, we can subtract this signal from the estimate value of phase and leave just deformation phase while spatial uncorrelated error terms can be modeled as noise.

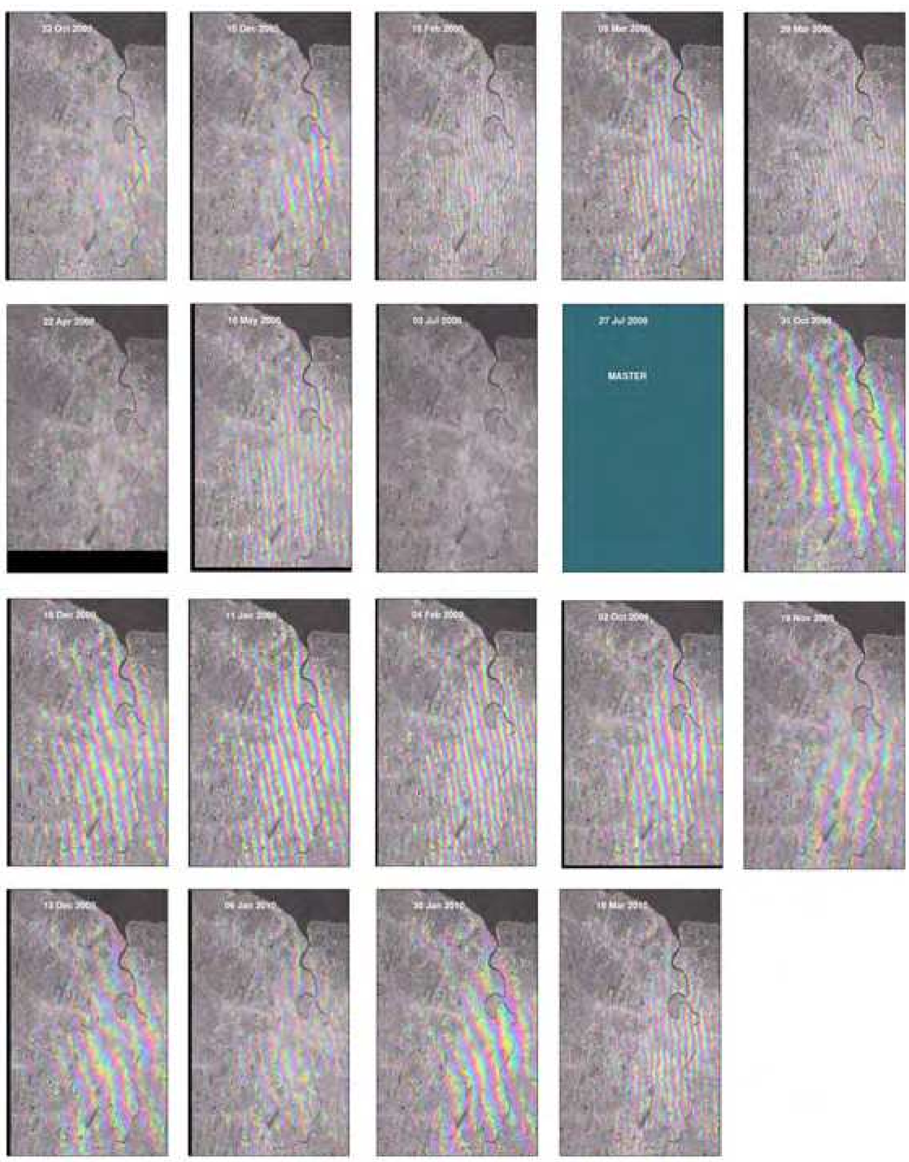


Fig. 7. Interferograms for PS using single master with no spectral filtering.

7.2 Small baseline subset (SBAS)

The Small Baseline Subset (SBAS) proposed by (Berardino et al., 2001, 2002) that the data pairs involved in the generation of the interferograms are carefully selected in order to minimize the spatial baseline. Thus, the mitigation of the decorrelation phenomenon and topography errors will be reduced. The SBAS method was initially exploited the investigation of large scale deformations by calculating the time sequence deformation and estimating DEM error and the atmospheric artifact in a similar way as PS. Noise is then further reduced by multilooking and applying range and azimuth filters (Just et al., 1994) with the aim of unwrapping them spatially. SB methods (Hooper, 2008) on the other hand seek to minimize the separation in time, in space and Doppler frequency of acquisition pairs to maximize the correlation of the interferograms formed. Slow-varying filtered phase (SFP) pixels are identified among the candidate pixels the same way as for PS pixels. For each pixel in the topographically corrected interferograms, its phase can be considered to the wrapped sum of five terms as (Hooper, 2008)

$$\phi_{int,x,i} = \phi_{def,x,i} + \phi_{top,x,i} + \phi_{atm,x,i} + \phi_{orb,x,i} + \phi_{n,x,i} \quad (2)$$

where $\phi_{def,x,i}$ is the deformation phase in the satellite line-of-sight (LOS) direction, $\phi_{top,x,i}$ is the topographic phase caused by uncertainty in the DEM, $\phi_{atm,x,i}$ is the atmospheric phase delay, $\phi_{orb,x,i}$ is orbital phase error, and $\phi_{n,x,i}$ is the noise term.

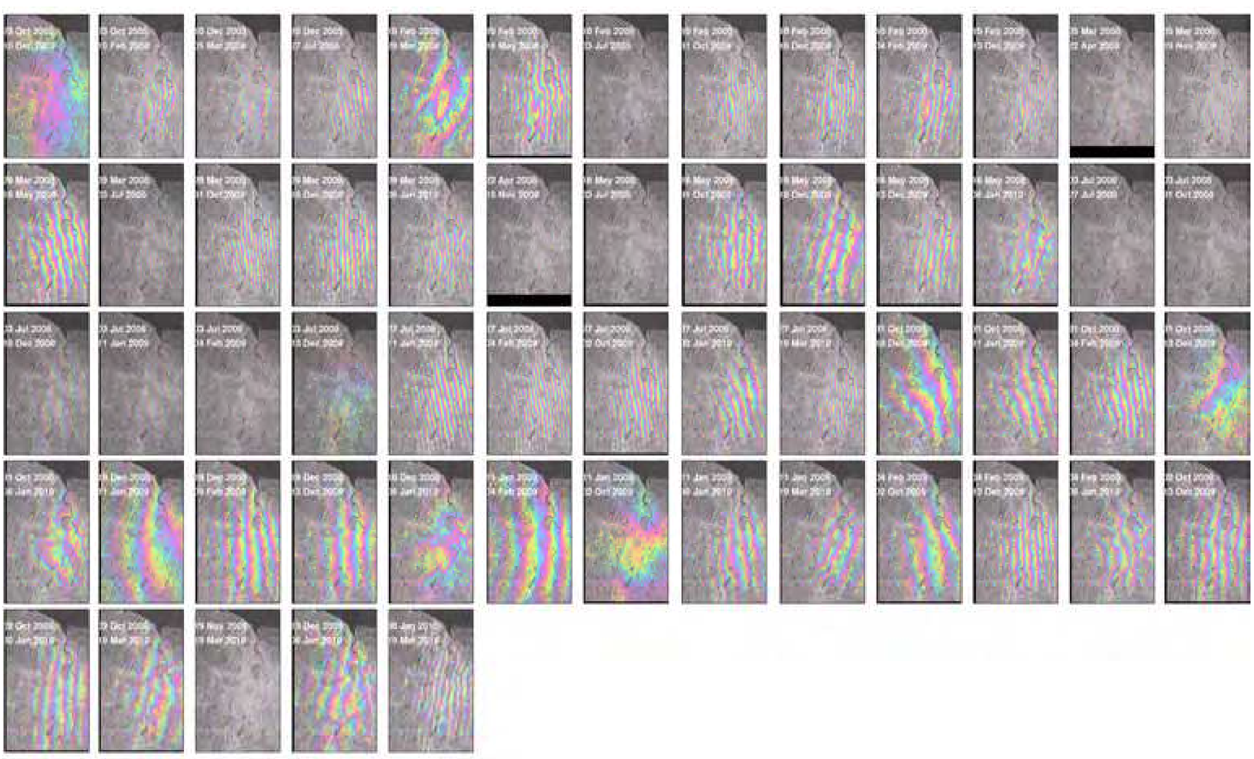


Fig. 8. Interferograms for SBAS using multiple masters with spectral filtering.

All phases error can be subtracted, and leave just deformation phase as the same algorithm used for PSI. Note that different sets of pixels are selected based on different sets of interferograms (single master with no spectral filtering vs. multiple masters with spectral filtering (see figure 8).

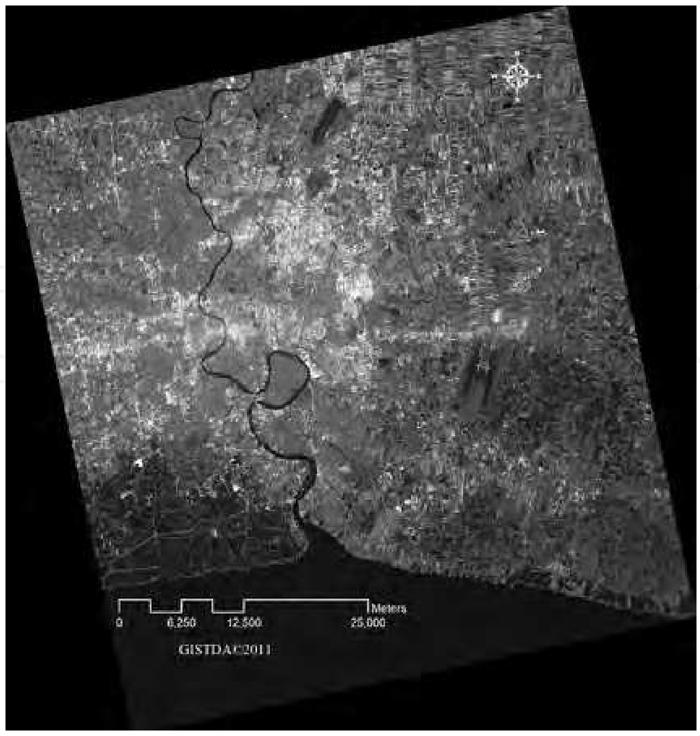
8. Application of SAR interferometry in Thailand

8.1 Land subsidence in Bangkok, Thailand

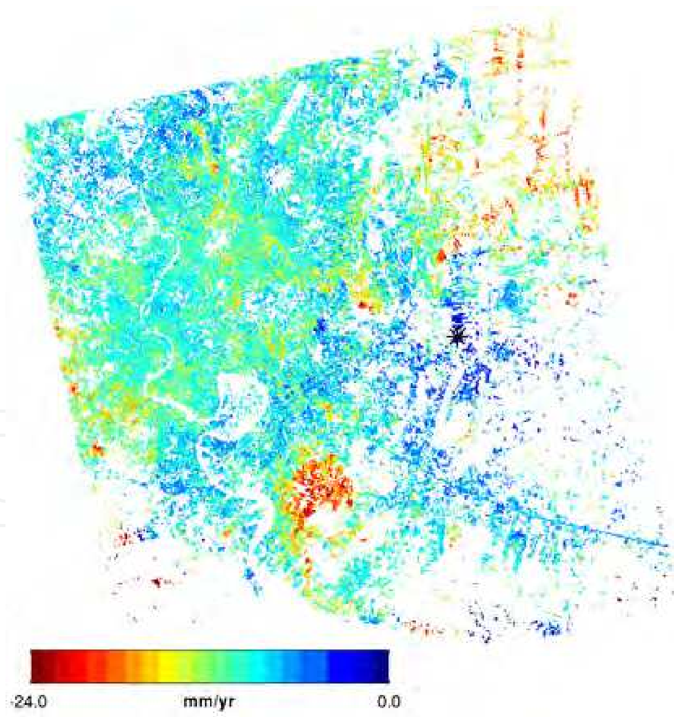
Land subsidence in Bangkok is caused primarily by groundwater over-pumping for the past decade. Monitoring has been carried out by levelling survey technique. The technique cannot provide many benchmarks due to the cost and the difficulty to maintain the overall benchmarks. The locations of the benchmarks are also limited by the urban development to access any area that should be considered. On the other hand, InSAR technology has become more interested since it is overcome the limitation of levelling survey technique, and it has been firstly applied by (Kuehn et al., 2004) during the time spanning February 1996 to October 1996. They reported the maximum subsidence rate -30 mm per year in the southeast and southwest alongside Chao Phraya River. However, with only 4 images and the short time span, it was difficult to estimate the deformation reliably due to decorrelation noise and variable atmospheric phase delay. Nevertheless, the maximum subsidence rates for this area agreed with the levelling survey.

Later on, (Worawattanamateekul, 2006) applied PSI technique using ERS1 and ERS2 data (16 and 10 interferograms) for the time period of 1992-2000. However, the limited number of interferograms made it difficult to achieve reliable results from PSI analysis, as indicated by the accuracy of -6 to -8 mm per year reported by the study. (Aobpaet et al., 2008) applied L-Band ALOS-PALSAR to evaluate the potential and possibility of land subsidence detection using the DInSAR technique. The subsidence map derived from ALOS PALSAR L-band between November 25, 2007 and April 11, 2008 for Bangkok revealed the spatial extent of the deformations and subsidence estimates. However, the subsidence might not reflect long-term subsidence rates because of the short temporal base line and the seasonal cycle of surface movement. (Aobpaet et al., 2009) showed the potential of time series analysis by detecting more than 200,000 pixels that could be used as monitoring points. The results showed a maximum subsidence rate of around -15 mm per year in eastern central Bangkok. However, the study area is preliminary study on sub-scene basis for the processing approach in order to reduce analyzing time and modifying parameters.

The latest study has been successes on apply InSAR time series algorithms, the Persistent Scatterer and Small Baseline, to remotely detect subsidence in Bangkok (Aobpaet et al., 2011). The data set is composed of 19 images acquired in fine beam mode by the RADARSAT-1 satellite (see figure 9a). More or less 300,000 pixels were successfully detected as monitoring points in the analysis, a two order of magnitude greater than the number of ground monitoring points (see figure 10). The average pixel density in the study area is 120 PS per km^2 with over 150 PS per km^2 in the urbanized areas. The subsidence velocities fall mostly between 0 to -24 mm per year (see figure 9b). Finally, the validation of the results against levelling surveys has been performed and found agreement at one standard deviation in 87% of cases. They concluded that InSAR time series analysis shows strong potential as an alternative tool for monitoring land subsidence in Bangkok.



(a)



(b)

Fig. 9. (a) The study area of Bangkok has been presented using RADARSAT-1 data in Fine beam mode with the coverage area 2,500 km². (b) The subsidence rate from InSAR indicated that the maximum subsidence rate is -24 mm per year relative to all pixels in the whole scene with respect to the reference benchmark represented by black star.

Fig. 10. The south-east Chao Phraya river estuary area which many permanent structures can serve as monitoring points which represent the subsidence rate in mm per year.

9. Conclusion

The establishment of the GISTDA and the long history of Thailand Earth Observation Center are the significants development and contribution to remote sensing activities in Thailand. From that time, Thailand has become one of the most successful countries for the space technology development program especially in remote sensing applications such as flood monitoring, fire monitoring, rice crop monitoring, disaster management, etc. Thus, the capability of direct acquisition in real-time data from SAR satellites such as RADARSAT-1 and RADARSAT-2 make the user who interested in InSAR can set up the plan to acquiring the data from current SAR satellite in time series analysis. Moreover, TEOC was the ALOS sub node, so the large ALOS data archive is still very attractive for the users' intent to study the past disaster or relate applications that may helpful for the prediction model creation.

Finally, the fully operational of TEOC can provide the customers and the users with rapid real-time satellite data for various applications to meet the country's requirement. The application of land subsidence in Bangkok reveals the potential of InSAR time series analysis, but the knowledge how to get the data is much challenged since the large amount of data is required. With the clarification of TEOC systems for especially SAR user, we believe that TEOC will be able to serve as a complimentary component to the development of remote sensing technology and space activities in Thailand and international.

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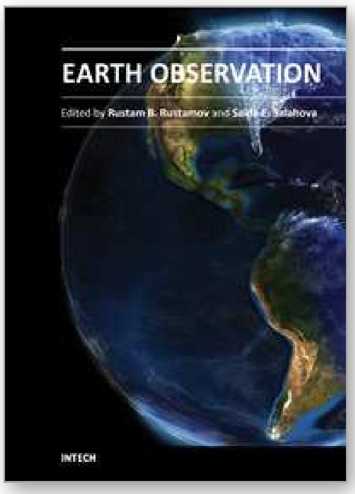

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Today, space technology is used as an excellent instrument for Earth observation applications. Data is collected using satellites and other available platforms for remote sensing. Remote sensing data collection detects a wide range of electromagnetic energy which is emitting, transmitting, or reflecting from the Earth's surface. Appropriate detection systems are needed to implement further data processing. Space technology has been found to be a successful application for studying climate change, as current and past data can be dynamically compared. This book presents different aspects of climate change and discusses space technology applications.

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