ALOS PALSAR: Technical outline and mission concepts

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ABSTRACT - *The Advanced Land Observing Satellite (ALOS) is Japan's next generation Earth Observation satellite, scheduled for launch in the autumn of 2005 by the Japan Aerospace Exploration Agency (JAXA) – formerly known as the National Space Development Agency of Japan, NASDA. Successor to the Japanese Earth Resources Satellite (JERS-1), in operation 1992 – 1998, ALOS will carry two optical instruments – PRISM and AVNIR – and, to maintain Japan's commitment to L-band Synthetic Aperture Radar, the polarimetric PALSAR instrument. PALSAR will not only provide enhanced sensor performance, including full polarimetry, variable off-nadir viewing and ScanSAR operations, but also feature an entirely new acquisition concept, aiming at spatially and temporally consistent, global coverage on a repetitive basis, to accommodate geo- and bio-physical parameter retrieval over semi-continental scales,*

INTRODUCTION

ALOS characteristics

The Advanced Land Observing Satellite (ALOS) is the largest satellite developed in Japan, and it will carry three remote sensing instruments: the along-track 2.5 metre resolution **Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM),** the 10-metre resolution **Advanced Visible and Near-Infrared Radiometer type 2 (AVNIR-2),** and – in focus in this paper – the polarimetric **Phased Array L-band Synthetic Aperture Radar (PALSAR).**

ALOS is planned for launch from JAXA's Tanegashima Space Center in southern Japan in the autumn of 2005. With a total weight of 4000 kg, ALOS will be launched with an H-IIA rocket vehicle, and placed in a sun-synchronous orbit at 691 km, with an orbital revisit period of 46 days.

15 minutes after lift-off, ALOS will have reached its nominal orbit and is separated from the rocket. It will establish its 3-axis attitude, and initiate ground station contact. Communications for tracking and control with local ground stations are performed through the X-band antenna, which is mounted at the nadir side of the satellite body. During nominal operations, this antenna will also be used for direct (120-140 Mbps) downlink of E.O. data.

Five minutes after separation begins the deployment of the 9-segment Solar Array Paddle, which when fully developed, measures 3 m by 22 m and generates a power of 7 kW. 12 hours after launch in turn, follows the deployment of the Data Relay Communications (DRC) antenna, which is mounted on the top of the satellite body to accommodate inter-orbit communication with the geostationary Data Relay Test Satellite. Operating at Ka-band with 240 Mbps data rate, the DRC antenna constitutes the main communications link for data downlink and house-keeping communications.

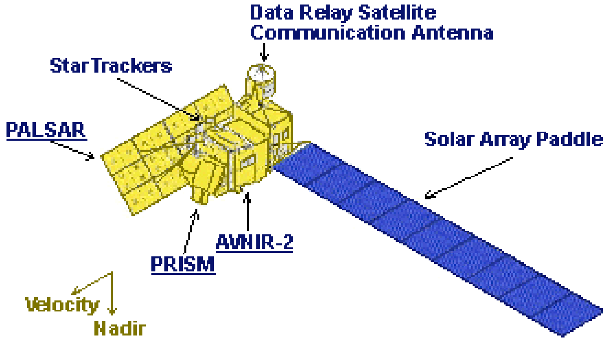

Fig. 1. The Advanced Land Observing Satellite

The PALSAR antenna is deployed two days after launch. Development is performed in three steps: rotation of the folded panel stack 90 degrees from the satellite body, off-nadir tilt of the stack, and subsequently, deployment of the four panels. In order to be better equipped to deal with potential difficulties during antenna deployment, such as were encountered for the JERS-1 SAR (1992), ALOS has been furnished with a Deployment Monitoring System, consisting of five cameras for real-time observation of the deployments of the solar paddle, DRC antenna and PALSAR antenna. An additional DM camera is mounted in nadir view to provide visual information about satellite attitude.

After deployment of the solar panel, DRC and SAR antennas follows orbital control and instrument commissioning. The commissioning phase, during which PALSAR. PRISM, AVNIR-2 and the other mission components are switched on and evaluated, continues for two 46-day cycles, after which ALOS enters the instrument calibration and validation phase (four 46-day cycles). ALOS routine operations begin 9 months (6 cycles) after launch.

Table 1. ALOS characteristics [1,2]

Item	Characteristics
Orbit	Sun synchronous, Sub recurrent
Equator pass time	~10.30 (desc.); ~22.30 (asc.)
Altitude	691.65 km
Inclination	98.16 deg.
Recurrence cycle	46 days $14+{}^{27}/_{46}$ rev./day; 671 rev./cycle
Orbital control	+/- 2.5 km (at equator)
GPS orbital position accuracy	1 m (off-line)
Star Tracker attitude determination accuracy	0.0002 deg (off-line) (~2.5 m on the ground)
Attitude stability	0.0004 deg/5 sec
Time accuracy (abs.)	1 ms
High-speed Solid State Recorder (HSSR)	Capacity: 96 Gbytes Data rate (max): 360 Mbps (recording) 240 Mbps (playback)
Data transmission: Ka-band antenna X-band antenna	 240 Mbps (via DRTS) 120 Mbps (direct GS down-link)
Solar Array Paddle	3 m x 22 m, 9 segments
Generated power	> 7 kW at EOL
Total weight	4000 kg

Fig. 2. ALOS Prototype Flight Model, nadir facing the camera.

Attitude and positioning

For orbital determination, a dual-frequency carrier-phase tracking-type GPS receiver provides 1-metre off-line position accuracy. ALOS also features a high precision 3-telescope Star Tracker (STT), which monitors the positions of distant stars to determine the precise attitude of the spacecraft. The STT is mounted on the top of the satellite body for an un-obscured view into space, and provides 0.0002 degrees (off-line) accuracy in attitude, corresponding to a 2.5 metre nadir pointing uncertainty on ground. The attitude movement (angular velocity) of the ALOS platform is stabilized within 0.0002 degree per 5 seconds.

Rather than utilising a traditional on-board crystal oscillator as internal clock, which requires periodical calibration, the internal clock on ALOS is synchronized within the accuracy of 404 ns (3 sigma) to the GPS absolute time, yielding 1 ms order absolute time accuracy.

Data storage and downlink

JAXA's Earth Observation Center (EOC), located in Hatoyama, north of Tokyo, constitutes the main ground station for data downlink from ALOS. The majority of the acquired data will be transmitted via JAXA's Data Relay Test Satellite (DRTS), which was launched into a geostationary orbit over the Indian Ocean (E90°) in September 2002. Operating at K_a-band, the DRTS provides a downlink capacity of 240 Mbps, and it will be utilised for both real-time acquisitions and for playback of all data recorded onto the 96 Gbyte High-speed Solid State Recorder (HSSR) (Fig. 3).

Fig. 3. Transmission from ALOS to EOC (real-time acquisition or HSSR playback) via DRTS.

As the launch of a second DRTS, originally planned to cover the western hemisphere (W90°), has been postponed indefinitely, data over regions outside of the present DRTS coverage have to be recorded onto the HSSR and down-linked when ALOS subsequently comes into the DRTS view.

Direct transmission from ALOS to local ground stations within the ALOS Data Node network is possible at X-band. Due to the lower, 120 Mbps, transmission speed however, this option is only planned for selected observations in low data rate acquisition modes (AVNIR-2 and PALSAR in ScanSAR mode).

PALSAR

The Phased Array L-band Synthetic Aperture Radar (PALSAR) is an enhanced version of the Synthetic Aperture Radar on JERS-1 (L-band; HH-polarisation; 35°off-nadir angle) Like its predecessor, PALSAR was developed jointly by JAXA and the Japan Resources Observation Systems Organization (JAROS).

PALSAR is a fully polarimetric instrument, operating in fine-beam mode with single polarisation (HH or VV), dual polarisation (HH+HV or VV+VH), or full polarimetry (HH+HV+VH+VV). It also features wide-swath ScanSAR mode, with single polarisation (HH or VV). The centre frequency is 1270 Mhz (23.6 cm), with a 28 MHz bandwidth in fine beam single polarisation mode, and 14 MHz in the dual-, quad-pol and ScanSAR modes. The off-nadir angle is variable between 9.9° and 50.8° (at mid-swath), corresponding to a 7.9 - 60.0° incidence angle range. In 5-beam ScanSAR mode, the incidence angle range varies from 18.0° to 43.0°.

The antenna PALSAR consists of 80 T/R modules on 4 segments, with a total size of 3.1 by 8.9 m when deployed (Fig. 3). As a result of the relatively small antenna size, orbit altitude and large Doppler bandwidth, the pulse repetition frequency varies (1500-2500 Hz) along the orbit.

Fig. 4. PALSAR antenna during deployment tests.

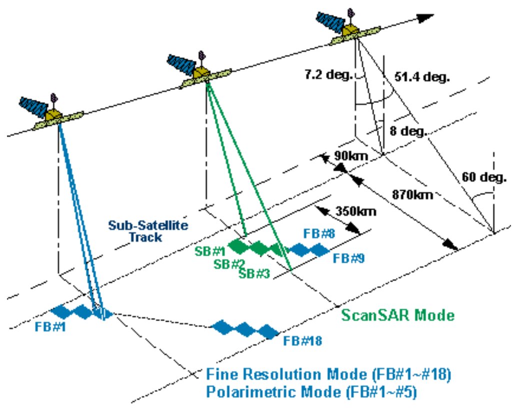

Fig. 5. PALSAR observation characteristics.

Table 2. PALSAR characteristics [3]

Item	Specifications
Centre frequency	1270 MHz / 23.6 cm
Chirp band width	28 MHz (single polarisation) 14 MHz (dual, quad-pol., ScanSAR)
Transmission power	2 kW (peak power)
Pulse Repetition Frequency	1500 – 2500 Hz (discrete stepping)
Image modes	Single polarization (HH or VV) Dual pol. (HH+HV or VV+VH) Quad-pol. (HH+HV+VH+VV) ScanSAR (HH or VV; 3/4/5-beam)
Bit quantisation	3 or 5 bits (5 bits standard)
Off-nadir angle	Variable: 9.9 – 50.8 deg. (inc. angle range: 7.9 - 60.0) ScanSAR: 20.1-36.5 (inc. 18.0-43.3)
Look direction	Right
Yaw steering	ON
Swath width	70 km (single/dual pol.@41.5°) 30 km (quad-pol.@21.5°) 350 km (ScanSAR 5-beam)
Ground resolution Rg (1 look) x Az (2 looks)	~ 9 m x 10 m (single pol.@41.5°) ~ 19 m x 10 m (dual pol.@41.5°) ~ 30 x 10 m (quad-pol.@21.5°) ~ 71-157m (4 look) x 100m (2 look) (ScanSAR 5-beam)
Data rates	240 Mbps (single/dual/quad-pol) 120 or 240 Mbps (ScanSAR)

Table 3. Pre-launch radiometric specifications [3, 4]

Item	Specifications
Noise Equivalent Sigma-0	-24 ~ -27 dB (single pol.@41.5°) -27 ~ -30 dB (dual pol.@41.5°) -30 ~ -31 dB (quad-pol.@21.5°) -23 ~ -32 dB (ScanSAR 5-beam)
S/A (Range)	9 - 26 dB (single/dual pol. @41.5°) 39 - 46 dB (quad-pol.@21.5°; co-pol) 20 - 27 dB (quad-pol.@21.5°; X-pol) 24 - 60 dB (ScanSAR 5-beam)
S/A (Azimuth)	21 dB (single/dual pol.@41.5°) 21 dB (quad-pol.@21.5°) 19 - 32 dB (ScanSAR 5-beam)
Radiometric accuracy	< 1 dB relative (within scene) < 1.5 dB absolute (between orbits)
Cross-talk	< -25 dB
Gain control	Automatic or manual (0 - 44 dB)
Sensitivity Time Control	0 - 7 dB

The characteristics of the PALSAR instrument are given above in tables 2 and 3, limited here to the main polarisations and off-nadir angle modes selected for operations (see below). The transmission peak power is 2 kW, which brings about significant radiometric performance in comparison with that of JERS-1, which exhibited limited sensitivity to low backscatter targets (NES-0 ~ -18 dB). The JERS-1 SAR had to be operated with a reduced (25%) transmission power (325 W), during its entire mission following problems during antenna deployment.

The standard data recording rate for the PALSAR instrument is 240 Mbps, with the exception of the ScanSAR mode, which is to be operated at 120 Mbps, to reduce data amounts and to allow direct transmission to local ground stations.

In order to achieve better geometric accuracy and to improve processing efficiency, ALOS will be operated in zero-Doppler yaw steering mode.

THE PALSAR OBSERVATION STRATEGY

A need for regional-scale consistent data

While provision of systematic observations and establishment of data archives for long-term studies clearly is one of the *potential* strengths of remote sensing – and in particular SAR with its capacity for all-weather operations – sporadic observations with local emphasis, which presently is how fine resolution remote sensing data most commonly are acquired, is not adequate as it results in inconsistent and fragmented data archives that are inapt for any application that require extrapolation of locally developed methods and results to a regional or global scale context.

JAXA has acknowledged the critical need for consistent data and by setting aside a significant share of the ALOS acquisition capacity for this purpose – for PALSAR as well as for PRISM and AVNIR-2 – allowed the establishment of an unprecedented, global Data Observation Strategy in support to climate change research and environmental conventions [5, 6].

Key components of the PALSAR observation strategy

In the design of the PALSAR strategy, which is focused on the acquisition of data over regional scales, the following key concepts for observation planning, defined in [7], have been taken into account:
Spatial consistency: Continuous wall-to-wall acquisitions over extensive regions.
Temporal consistency: Regional acquisitions performed during limited time windows.
Revisit frequency: Semi-annual/annual repetition to accommodate monitoring of bio- or geophysical changes.
Timing: Acquisitions performed during the same time period(s) every year to minimize temporal bias.
Sensor consistency: Selection of a limited number of operational default modes to maximize data homogeneity and minimise user conflicts.
Long-term continuity: Strategy operations until the end of the ALOS mission life.

A key challenge in the PALSAR acquisition strategy planning process has been to reduce the number of programming conflicts, which had inhibited initial acquisition simulations. Ironically for PALSAR, the major cause for conflicts has been its *too* flexible design with variable off-nadir angles, polarisations and spatial resolutions, combined with the associated need for time-consuming pre- and post-calibration following every mode change. Other issues to consider included time-sharing between the three instruments and data down-link. And with access to only one DRTS, acquisitions over the western hemisphere represent a resource constraint which requires particular attention. In order to optimise PALSAR operations, the following major actions were taken:

- **Limitation of operational modes**. For PALSAR, with 132 original mode options, the need to restrict the number of operational modes was imperative. And ultimately a compromise between scientific requirements, user requests, programmatic aspects and satellite operational constraints, six modes were eventually chosen as the default modes to be used (Table 4) – four operational and two semi-operational.
    - A fixed off-nadir angle of **41.5°** (rather than the 34.3° and 43.4° outlined in earlier versions [7] of the plan) selected for the great majority of the acquisitions.
    - The main polarisations to be used are single-pol HH and dual-pol HH+HV.
    - Full polarimetry at 21.5° will be used as an experimental mode to promote R/D.
    - ScanSAR operations in 5-beam HH mode, at 120 Mbps.

- **One mode assigned per cycle.** Acquisitions are planned in units of whole (46-day) repeat cycles, during which only one of the available default modes is selected. One cycle per year is left unplanned, to accommodate unorthodox non-default mode observation requests from ALOS PI's and the ALOS Data Nodes.

- **Separation of ascending and descending operations.** As the two optical sensors are limited to operations during descending (~10:30) passes, PALSAR operations are first and foremost planned for ascending (~22:30) passes. PALSAR acquisitions in descending mode principally at low data rate ScanSAR mode. A limited number of fine beam observations at non-default off-nadir angles (21.5° and 34.3°) have also been included in the descending plan for InSAR and marine applications.

- **Repetitive and long-term planning.** To achieve recurrent observations with consistent timing, the PALSAR descending plans are planned in groups of 8 (46-day) unit cycles that will be repeated on an annual (368 days) basis during the mission life. The PALSAR ascending plan, which accommodates the largest number and variety of observation requests, comprises 16 cycles, which are repeated on a 2-year basis.

Table 4. PALSAR default modes.

Polarization	Off-nadir angle (swath, resolution)	Asc/desc	Comment
HH	41.5 deg. (70 km, 10 m)	Ascending	Operational
HH+HV	41.5 deg. (70 km, 20 m)	Ascending	Operational
HH+HV+VH+VV	21.5 deg. (30 km, ~30 m)	Ascending	Operational
ScanSAR (HH)	5-beam mode (350 km, ~100 m)	Descending	Operational
HH	*34.3 deg. (70 km, 10 m)*	*Descending*	*Limited acquisitions only*
HH	*21.5 deg. (70 km, 10 m)*	*Descending*	*Limited acquisitions only*

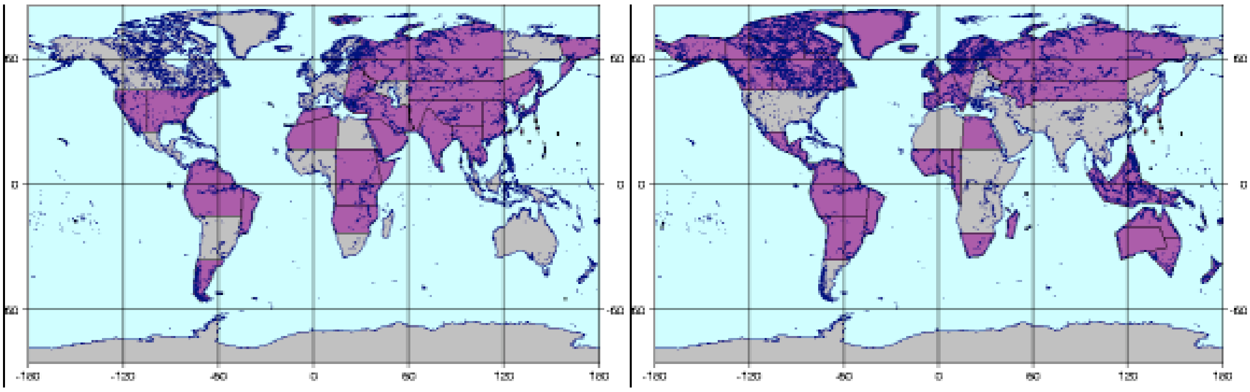

Fig. 6. Observation plan concept: Reqions scheduled for acquisition during two given 46-day cycles.

To assure spatially and temporally homogeneous data collection over regional scales, the Earth has been divided into some 80 adjacent, non-overlapping geographical regions covering all land areas and coastal regions (Fig. 6). The observation strategy is then structured as a set of two-dimensional matrices – one each for PRISM and AVNIR-2, and two (ascending/descending) for PALSAR – with geographical regions in one dimension, and 46-day time units in the other.

Outline of the PALSAR observation plan

The observation strategy for ALOS is being developed by JAXA EORC, refined through a series of computer simulations using the same Mission Management and Operations System software that will be utilised by during ALOS operations. At the time of writing, the observation plans for the three instruments are still being optimized. The tentative plan for PALSAR is outlined briefly in table 5 below.

Table 5. PALSAR observation strategy

Mode	Coverage	Timing	Repetition
HH+HV / 41.5°	Global	June - Aug.	Annual
HH / 41.5°	Global	Dec. - Feb.	Annual
ScanSAR (HH, 5-beam)	Global	Jan. - Dec.	Annual
ScanSAR (HH, 5-beam)	Wetland super sites	Jan. - Dec.	Every cycle during 1 year
Quad-pol. / 21.5°	Pol-InSAR super sites	March - May	Bi-annual

SUMMARY

With the launch of ALOS, JAXA will continue to fulfil its commitment to provide the international science community with L-band SAR data. The PALSAR instrument will not only provide improved sensor characteristics, but also feature a new concept for acquisition planning. It should be emphasised that the global observation strategy for ALOS is implemented as a *foreground* mission, with a priority level second only to calibration/validation activities and emergency observations, hence making it distinctly different from the global background missions that are implemented for most fine resolution SAR and optical sensors. While this admittedly limits flexibility to accommodate common user requests, and does not make use of all the observation modes feasible, it provides for a new way of doing remote sensing, in which regional and global issues of public concern stand in focus.

Going for a comprehensive and long-term data acquisition strategy is a win-win scenario for the public, the science community as well as for JAXA itself, as the availability of comprehensive and consistent data archives can be expected to stimulate also scientific and commercial utilisation of satellite data. The inability for remote sensing technology to take off to become operational despite 30 years in orbit can to a large extent be attributed to the ignorance of the importance of systematic observations. It is time for a change and it is our conviction that this is the way to go. ALOS will pave the way and we hope that other satellite missions will follow suit. Hallelujah.

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