ALOS ACHIEVEMENT SUMMARY AND ALOS-2/3

Masanobu Shimada[1], Takeo Tadono[1], Masuo Takahashi[1], Masato Ohki[1], Yousuke Miyagi[1], Manabu Watanabe[1],
Takeshi Motooka[1], Tomohiro Shiraishi[1], Nobuyuki Kawano[1], and Rajesh Tapa[1]

1 Earth Observation Research Center, Japan Aerospace Exploration Agency, 305-8505, Sengen 2-1-1, Tsukuba,
Ibaraki, Japan, Tel: +81-50-3362-4489, Fax: +81-29-868-2961, shimada.masanobu@jaxa.jp

KEYWORDS: ALOS, PALSAR, PRISM, AVNIR-2, Forest mapping

1. ABSTRACT

The Advanced Land Observing Satellite (ALOS) was launched to a low Earth observation orbit of 691.25 km on Jan. 24, 2006, made 28,211 revolutions around the Earth, and collected 12.16 million scenes (equivalent to 955 TB) of data from three sensors during the 5 years and 3 months of mission life until it was terminated on May 12, 2011. The satellite's mission aimed to generate 1:25000-scale maps, to conduct regional observations for forest management, to conduct disaster observation, and to observe resource finding. ALOS achieved all four requirements within the required mission life of 5 years. It conducted emergency observations of the Tohoku coastal areas, where the Great East Japan Earthquake of March 11, 2011 and the subsequent tsunami struck. Fully utilizing the its advantages, i.e., image swath of 70 km, revisit time of 46 days, and off-nadir changing functions, ALOS performed frequent observations of the disaster areas within around 2 days and provided the effective data to the related users. This paper shows a summary of ALOS operation and its achievements, and provides introductions to ALOS-2/3.

2. MALFUNCTIONS

We were surprised when the news of April 22, 2011 came that ALOS was in the light-load mode (hold-mode). ALOS was an Earth observation satellite that performed well, maintained good electric performance, and still held 115 kg of fuel, which would have allowed orbit plane maintenance four times every 2.5 years. We could not have imagined the sudden death of ALOS. At the time, we were in Phetchaburi, on the western coast of the Gulf of Thailand, conducting erosion monitoring as an example of ALOS utilization for foreign countries. We prayed that the satellite would recover from light-load mode. Figure 1 shows the temporal variation of the solar power generation around the failure event. There is a large power variation at the third revolution from the left, and then the power decreases. ALOS is a three-axis satellite, whose z-axis always faced directly at the center of the Earth. In the light-load mode, it was uncontrolled and flying around the Earth loosely. When the sun hit the solar paddle, power could be generated but not enough to activate the satellite. ALOS did not recover and we announced the termination of ALOS [1] on May 12, 2011.

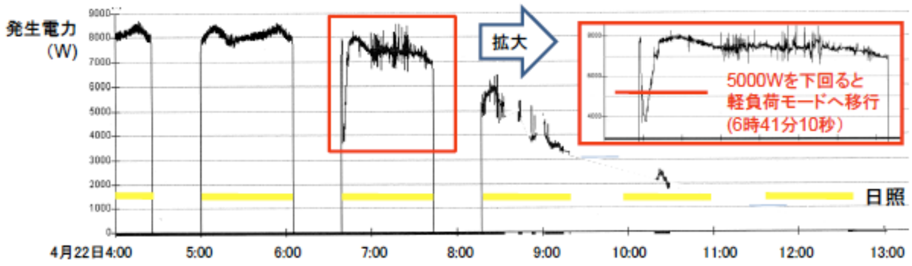
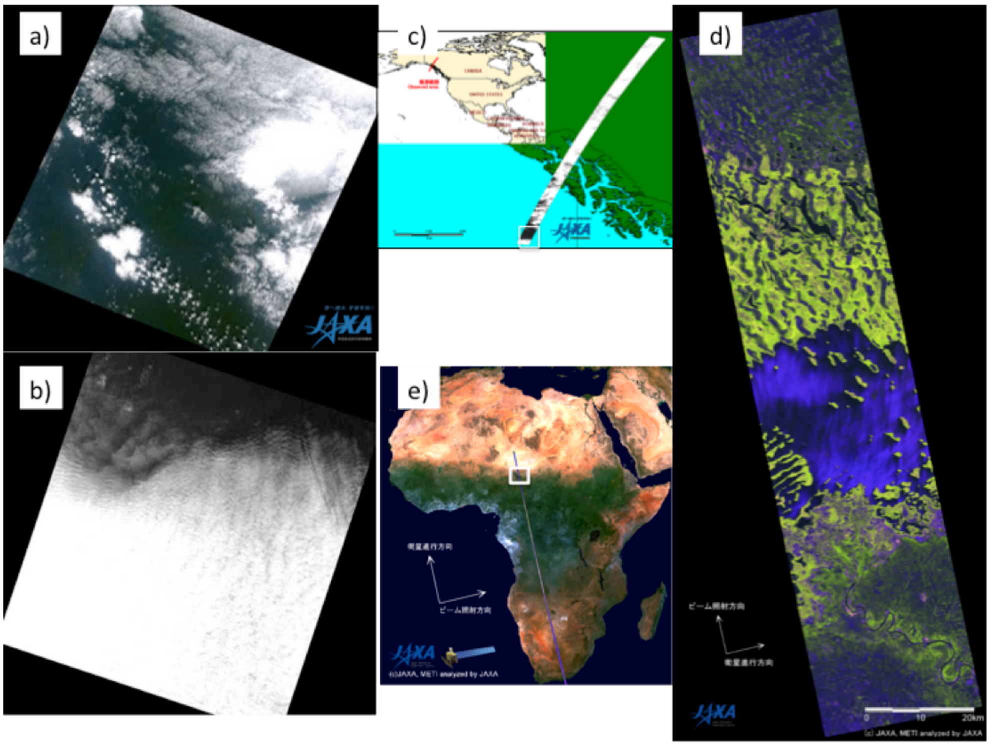


Figure 1 Temporal variation of solar power. Horizontal axis is April 22, Japan Standard Time (JST).

In the press release, we opened the final ALOS images acquired by AVNIR-2, PRISM, and PALSAR [2]. The two optical images view the southern part of Alaska simultaneously. The PALSAR image viewed off-nadir at 21.5 degrees by polarimetry to the center part of Africa from the ascending orbit. It captured Lake Chad and its vicinity. ALOS may be on the orbit and will drop on the Earth by 2068.



Fugure 2 ALOS's final images: a) AVNIR-2, b) PRISM, c) final pass for optical imaging, d) PALSAR image (polarimetry), and e) PALSAR image position

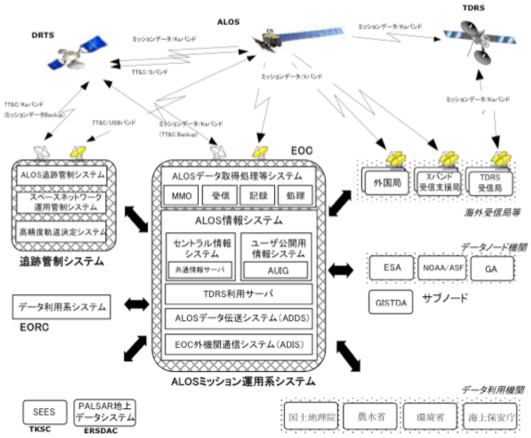
ALOS is the last of JAXA's large-scale Earth observation satellites, of which development began in the mid 1990s. It achieved all its mission objectives and designated mission life of 5 years, while ADEOS, which launched in 1996, and ADEOS-II, which launched in 2002, both failed within a year due to solar array failures. In the end, JAXA's large-scale Earth observation satellite program succeeded. All follow-on satellites are becoming smaller: two-ton classes with fewer sensors installed. There are two streams of future satellite configurations: large satellites with various sensors or several medium satellites with a single sensor on each. More discussion may take place on determining which stream to follow. The three ALOS sensors had different viewing principles (optical and SAR), and their co-registration needed high-level image processing, i.e., ortho-rectification using digital elevation models. Operation was normally divided by optical for daytime and SAR for nighttime; simultaneous observations were not performed often. Before launch, ALOS was tested carefully and repeatedly, and the project succeeded. We believe JAXA recovered the confidence lost by the failures of the two earlier satellites. However, considering ALOS's more complex operation and resource allocation, the simplified, 2-ton class, authorized satellites may simplify future operations.

3. ALOS AND ITS OPERATION

The specifications of ALOS and its sensors have been introduced in [2][3]. ALOS was two times larger than ALOS-2/3 and had an unsymmetrical satellite shape around the satellite's direction of movement. It had a 46-day revisit time, was set in a sun-synchronous orbit at an orbit altitude of 691.25 km, carried three sensors, PALSAR, AVNIR-2, and PRISM, and was an enhanced version of JERS-1, which launched in 1992. PALSAR and AVNIR-2 were equipped with 10-m resolution and PRISM 2.5-m resolution.

Figure 3 shows the ALOS space and satellite system, which consists of two Data Relay Test Satellites (DRTS), ALOS, and the ground segment, NASA's DRTS called TDRS. ALOS differs from the other satellites in its use of the DRTS and TDRS. PALSAR and PRISM (after data compression) were high-resolution sensors and their data rates were as large as 240 Mbps. While direct data transmission from ALOS to the ground segment was only 140 Mbps, DRTS allowed more effective data communication. Direct transmission had only 13 min as the maximum contact and the number of contacts was five daily while the TDRS has 50 minutes and 13.57 respectively. The DTRS fully supported the ALOS operation, but in the beginning, ALOS was supported by DRTS only and the daily data amount acquired and communicated was 9 hours. After April 2009, the addition of TDRS increased the data amount by 20 percent, reaching 11 hours daily.

The main function that Earth observation satellites should have is accurate determination of positioning, timing, and attitude. ALOS relied on GPS for the first two. Since earthquake research requires estimation of surface deformation in the order of centimeters, the dual-frequency GPS on ALOS and global reference points determined the ionospheric phase delay lying underneath the ALOS and obtained accurate position values. The positioning accuracy was 40 cm in three sigmas as bias plus random component. Forty centimeters was very accurate for image positioning but not for surface deformation. This value did, however, give satisfactory deformation results. Attitude determination accuracies are essential to the optical imaging (SAR imaging does not depend on attitude, but instead Doppler frequency and timing delay). ALOS's attitude accuracy improved over the long-term.



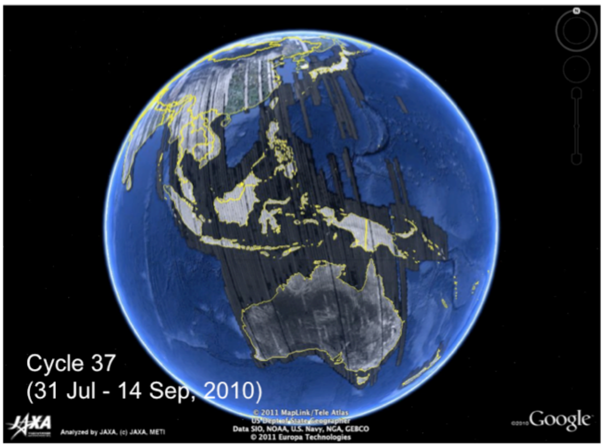


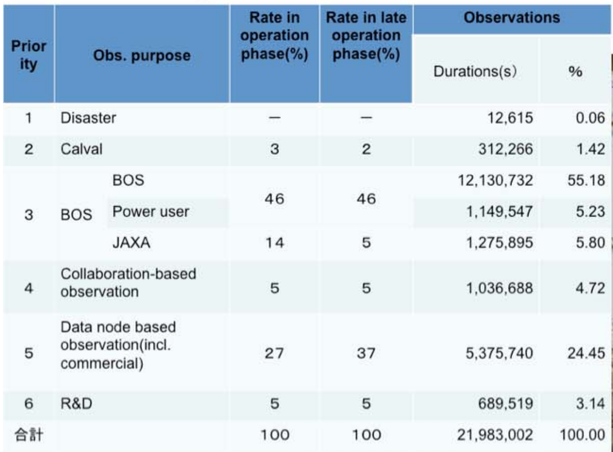
Figure 3 Overview of the ALOS system

Figure 4 PALSAR observation status for Australia to Southeast Asia from July 31, 2010 to Sept. 14, 2010

4. ALOS BASIC OBSERVATION SCENARIO (BOS)

ALOS's data collection capability was the world's largest, i.e., continuous operation of SAR, PRISM, and AVNIR-2 individually with 50 minutes was exceptional (the design value was 70 minutes per resolution). One operation rule stated that one-day data should be downlinked to the ground within a day. In addition, there was a unique global operation rule called the Basic Observation Scenario (BOS) that governed all user requests by means of assigning observation priority to each request (priority rule). The priority of the BOS request was decided by importance of the observation and the mission objectives. Various researcher requests were handled with low priority. CALVAL and regional observation were given higher priority. Table 1 is the current priority table, which additionally shows the total operation time. As a result, regional observation could be done within a shorter time. Figure 4 shows the PALSAR coverage collected over 46 days from June 2010 and shows almost gap-free coverage. Since disaster observation is given the highest priority, BOS was overridden by the disaster.

Table 1 Priority Table of BOS



Prior ity	Obs. purpose		Rate in operation phase(%)	Rate in late operation phase(%)	Observations	
					Durations(s)	%
1	Disaster		–	–	12,615	0.06
2	Calval		3	2	312,266	1.42
3	BOS	BOS	46	46	12,130,732	55.18
		Power user			1,149,547	5.23
		JAXA	14	5	1,275,895	5.80
4	Collaboration-based observation		5	5	1,036,688	4.72
5	Data node based observation(incl. commercial)		27	37	5,375,740	24.45
6	R&D		5	5	689,519	3.14
合計			100	100	21,983,002	100.00

Note: Operation time is in seconds.

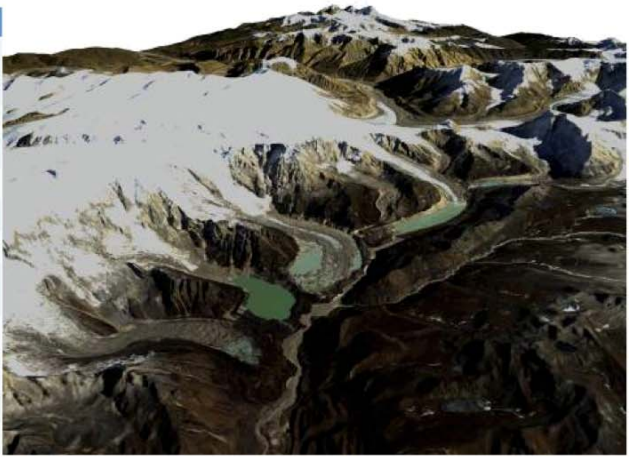


Figure 5 PRISM DSM and pan-sharpened image of the Bhutan

5. ALOS DATA ARCHIVES

The total data amount acquired using the three sensors is 955.12 TB—254.44 TB for PRISM, 96.65 TB for AVNIR-2, and 604.03 TB for PALSAR. The total number of scenes is 8.74 M, 1.32 M, and 2.10 M, respectively. For global coverage, PRISM needed 3000 K, AVNIR 84 K, and PALSAR 70 K. They each observed the globe 10, 15, and 30 times. PALSAR prepared 18 beams and mainly used 34.3, 41.5, 21.5 degree off-nadirs and ScanSAR modes. The statistics showed that PALSAR with 34.3 degrees can observe this area in gap-free. The optical sensors showed a statistics that cloud coverage was 20 percent on average.

6. CALVAL OF ALOS THREE SENSORS

CALVAL of PALSAR, AVNIR-2, and PRISM was conducted during the operation phase and the results were used to improve the image quality when necessary (See the summary of CALVAL in Table 2). Improvement of the geometric accuracy of the optical sensors required the collection of ground control points in both ascending and descending orbits and the modeling of the distortions with regard to the latitude; PALSAR geometric accuracy was satisfactory and any major error was due to ionospheric disturbance. Radiometric accuracy was calibrated and validated using the trihedral corner reflectors (CR). CRs were deployed globally under collaboration with global researchers. Amazon deployment under a condition of lower ionospheric disturbance is representative (Alaska Satellite Facility (ASF) was contracted to deploy the CRs in the Amazon).

Table 2-1 Summary of Orbit Determination

Orbit Determination	Specification	Measurement
Onboard (1 freq.)	< 200 m	35 m
GUTS offline	< 1 m	40 cm (3sigma)

Table 2-3 PRISM/AVNIR-2 Calibration Summaries

PRISM	Absolute Geometric Accuracy (m)	Relative Geometric Accuracy (m)
Forward (m)	11 (cross), 21 (along track)	4×3
Nadir (m)	8×9	4×3
Back (m)	10×20	4×3
AVNIR-2	106×19	4×4

Table 2-2 PALSAR Calibration Summary

PAL SAR	Item	Measurement	Spec.
	Geometric accuracy	9.3 m (RMS)	100 m
	Radiometry	0.64 dB, 0.17 dB	1.5 dB
	PolCAL	VV/HH 0.02 dB VV/HH 0.32° Crosstalk 31~40 dB	0.2 dB 5° 30 dB
	NESZ	-34 dB	-23 dB
	Resolution	Azimuth: 4.49 m Range (14 M): 9.6 m Range (28 M): 4.7 m	4.5 m 10.7 m 5.4 m

7. ALOS RESULTS

In this section, we summarize the ALOS results. Here, the results are limited to the mission objectives. For more information, please refer to the CALVAL results in [4][5][6][7][8].

1) Map generation: This was conducted mainly by the Geospatial Information Authority of Japan (GSI). The Digital Surface Model (DSM) was produced by JAXA and was evaluated at global test sites through algorithm improvement. After calibrating the nonuniformity of the sensor sensitivity and correcting the JPEG decompression algorithm, accurate DSMs were generated. ASF generated a precise DSM for the Alaskan test site and confirmed the height error of less than 3 m as 1 sigma (compared with the lidar data). As an application example, the PRISM DSM is being used in the monitoring of the glacial lake breaking in Bhutan (Figure 5). JAXA is producing a Japan DSM and has completed 90 percent (1080 scenes out of 1200) of a cloud-free area.

2) Forest monitoring: PALSAR is an all-weather sensor that is able to image the cloudy rainforest. Since SAR is very sensitive to forest biomass, JAXA is producing the forest products, i.e., forest/non-forest map, and monitoring the deforestation [9][10]. SAR is a squint observation sensor used to observe sloped areas by range gating. The image location is shifted and the backscattering coefficient varies depending on the slope. To correct this, slope correction and ortho-rectification are mandatory. With SAR strip processing and correction in the strip unit, we were able to produce global 10 m mosaics from the PALSAR summer datasets of 2007-2009 (Figure 6 left). The backscattering coefficient is related to the biomass, and a threshold generates the forest/non-forest map (Figure 6 right). To aid in reducing illegal deforestation in Brazil, JAXA produced ScanSAR high-level products and distributed them to the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) very quickly so the data could be provided five days after the data acquisition in Sept. 2007.

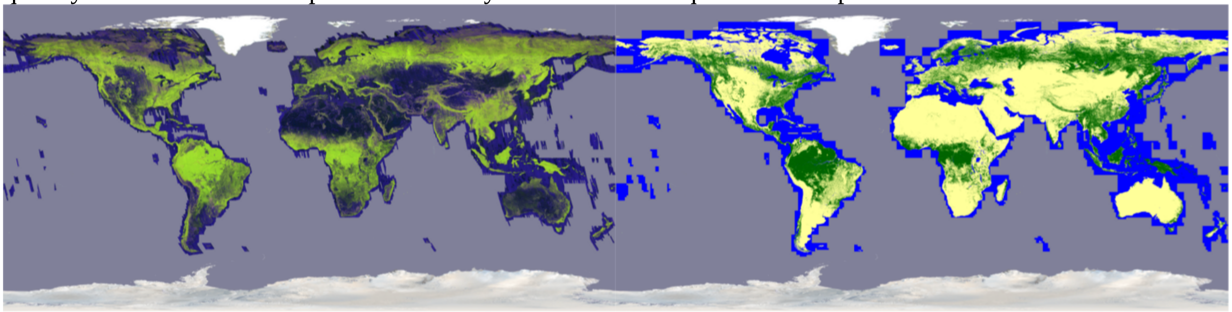


Figure 6 Global PALSAR 10 m mosaic of acquisition year 2009 (left) and its forest/non-forest map (right)

3) Disaster observation: JAXA contributed to international disaster mitigation activities, i.e., International Disaster

Charter, Sentinel Asia, and GEO disasters, using ALOS. JAXA was not only a participant, but also analyzed and distributed the data to the related authorities in various countries. After March 11, 2011, JAXA monitored the Tohoku area using ALOS. As shown in Figures 7 and 8, change detection and InSAR were mainly used. Representative use of the data was monitoring the ocean water flooding, its time variation, and floating objects.

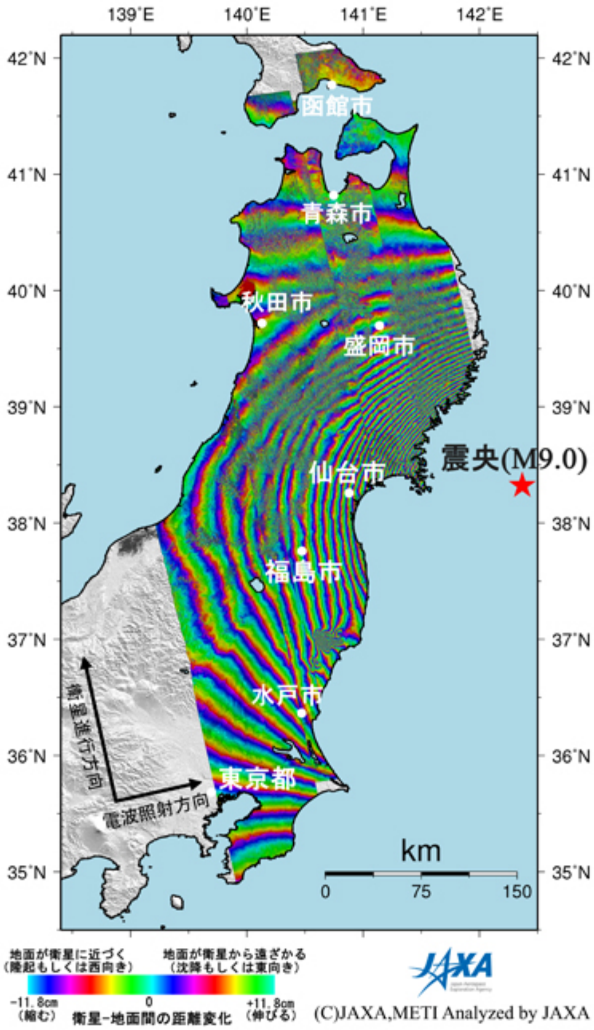


Figure 8 PALSAR DinSAR and five-pass mosaic

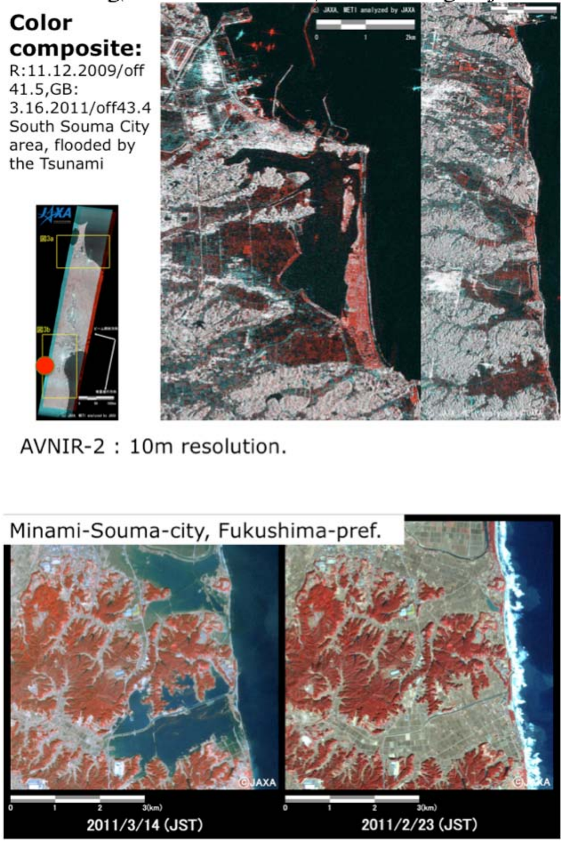


Figure 7 Change detections: complete image (left), PALSAR change detection (middle), and AVNIR-2 change detection (right)

4) PI research: In 2000, JAXA issued research announcements (RA) to solicit research proposals on 14 themes. After that, we announced three RAs, RA-1, -2, and -3, and 329 research projects were conducted. The final PI reporting symposium was held in Tokyo from Nov. 15-17, 2010 with more than 100 presentations made.

5) Other important research: Included in this research was ionospheric observation using the L-band SAR, melting polar glaciers, wind speed distribution over the ocean, drifting ice, oil spills, subsidence, coastal regions, more accurate subsidence, rice filed estimation, accurate land use, forest monitoring using SAR, polar ship route changes related to global warming, soil moisture monitoring, peat land subsidence monitoring, etc.

8. ALOS-2/-3

1) ALOS-2: Investigation of the ALOS follow-on satellite started around 2007. ALOS-2 is a SAR satellite (Figure 9) approved by the Space Activities Commission in 2008. It is being developed for a 2013 launch. There are several features, i.e., 1) observation in either or both right-left directions; 2) selective band width of 14, 28, 42, and 84 MHz; 3) reduction of range ambiguity by 10 dB from that of PALSAR by up-down chirping and random M-series phase shifting; 4) spotlight, strip, and ScanSAR modes; 5) dual polarization for ScanSAR; and 6) a swath covered by 26 beams. A wide bandwidth reduces the imaging swath. A dual-beam method maintains a wider imaging swath of 50 km. It provides a lower noise equivalent sigma zero (NESZ) to enable the imaging of a darker target. As shown in the urban area simulation image in Fig. 13, great improvement over PALSAR is expected. Finally, the mission objectives of ALOS-2 are 1) higher resolution imaging for domestic and foreign areas and quick distribution and evaluation of the image information and 2) land management and resource finding, as well as application of the satellite data and expansion of the data usage.

2) ALOS-3: The target launch year is 2015. The mission objectives are land management, resource management, disaster monitoring, and a new use of satellite data. Sensor performance involves a stereo-viewing PAN image with multiple bands. Figure 10 shows the artistic satellite view.

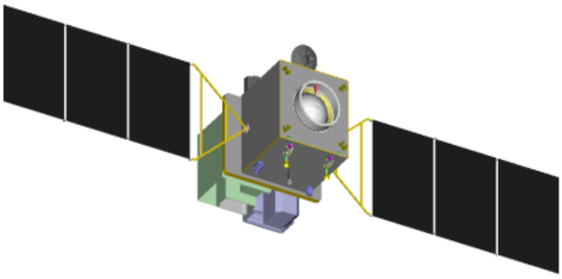


Figure 10 Artistic image of ALOS-3

Figure 9 Artistic view of ALOS-2

9. CONCLUSIONS

This paper describes the ALOS results and offers abstracts of ALOS-2/-3. ALOS was operated for 5 years and 3 months and achieved all its mission objectives, i.e., generation of 1:25000-scale maps, regional observation, and disaster mitigation. These achievements are due to several important points: the sensors were well calibrated and validated, showing great performance in high geometric and radiometric accuracies; a large number of users tried to test and expand the data availability to various fields; the results were effectively combined and reflected in the operation of ALOS; and a stable Earth observation system functioned as a result. ALOS not only improved information accuracy, which is the basis of the satellite system, i.e., observation time, position information, and attitude information, but it also proved that high-volume satellite data can be obtained using the TDRS and DRTS. Based on the ALOS operation experience, we will continue the development of ALOS-2/3.

Acknowledgements

We would like to express sincere thanks to the engineers of the Remote Sensing Technology of Japan (RESTEC) for assisting in the analysis of the ALOS data, and to Mr. Tomoaki Endoh for operating ALOS.

References

[1] On the Termination of the Advanced Land Observing Satellite (Daichi): http://www.jaxa.jp/press/2011/05/20110512_daichi_j.html

[2] Shimada, M., T. Tadono, and A. Rosenqvist, “Advanced Land Observing Satellite (ALOS) and Monitoring Global Environmental Change,” *Proc. IEEE*, vol. 98, no.5, pp.780-799, May 2010.

[3] Iwata, T., and M. Shimada, “Advanced Land Observing Satellite (ALOS): The Technology and the Results,” *Transactions of the Japan Society of Mechanical Engineers*, vol.112, no. 1082, pp.24-27, Jan 2009.

[4] Shimada, M., O. Isoguchi, T. Tadono, and K. Isono, “PALSAR Radiometric and Geometric Calibration,” *IEEE Trans. GRS*, vol. 47, no. 12, pp.3915-3932, Dec 2009.

[5] Tadono, T., M. Shimada, and H. Murakami, “Calibration of PRISM and AVNIR-2 Onboard ALOS ‘Daichi’,” *IEEE Trans. GRS*, vol. 47, no. 12, pp.4042-4050, Dec 2009.

[6] Murakami, H., T. Tadono, H. Imai, J. Nieke, and M. Shimada, “Improvement of AVNIR-2 Radiometric Calibration by Comparison of Cross-Calibration and Onboard Lamp Calibration,” *IEEE Trans. GRS*, vol. 47, no. 12, pp.4051- 4059, Dec 2009.

[7] Isoguchi, O.,, and M. Shimada, “An L-Band Ocean Geophysical Model Function Derived From PALSAR,” *IEEE Trans. GRS*, vol. 47, no. 7, pp.1925-1936, 2009.

[8] Shimada, M.,, “On the ALOS/PALSAR Operational and Interferometric Aspects - in Japanese,” *J. Geodetic Society of Japan*, vol. 56, no. 1, pp.13-39, 2010.

[9] Rosenqvist, A.,, et al., “Special Issue on the Kyoto and Carbon Initiative,” *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 3, no. 4, Dec. 2010.

[10] 地球環境を捉える「だいち」—ALOS 京都炭素観測計画から得られた科学的成果、JAXA document-NDX-100004, March 2010.