CALIBRATION AND VALIDATION OF THE ADVANCED LAND OBSERVING SATELLITE-3 "ALOS-3"

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ABSTRACT:

The "Advanced Land Observing Satellite-3" (ALOS-3, nicknamed "DAICHI-3") is the next high-resolution optical mission as a successor of the optical mission by the Advanced Land Observing Satellite (ALOS, "DAICHI") in Japan Aerospace Exploration Agency (JAXA), and will be launched in Japanese Fiscal Year 2020. ALOS-3 is now under developing the flight model. The major missions of ALOS-3 are (1) to contribute safe and secure social including provision for natural disasters, and (2) to create and update geospatial information in land and coastal areas. To achieve the missions, the "WIde-Swath and High-resolution optical imager" (WISH, as a tentative name) is mounted on ALOS-3, which consists of the high-resolution panchromatic- and multispectral-bands. This paper introduces the overview of ALOS-3's mission and the calibration and validation plan at JAXA. The standard product is the system corrected data using the sensor models, which will be provided from the sensor development team. Therefore, the sensor calibration is directly affected to the accuracies of the standard product. In addition, the sensor model based the Rational Polynomial Coefficient will be contained with level 1B2 standard product that can be used to process an ortho rectification and three-dimensional measurement from ALOS-3 images. As the target accuracy of WISH's standard products, the geometric accuracies are less than 5 m in horizontal without ground control point (GCP), and 1.25 m in horizontal and 2.5 m in vertical with GCPs (1 sigma), and the radiometric accuracy is +/- 10 % as absolutely and +/- 5 % as relatively for multispectral band.

1. INTRODUCTION

The "Advanced Land Observing Satellite-3" (ALOS-3, nick-named "DAICHI-3") is the next high-resolution optical mission as a successor of the optical mission by the Advanced Land Observing Satellite (ALOS, "DAICHI") in Japan Aerospace Exploration Agency (JAXA) (Shimada et al., 2010). ALOS-3 is now under developing the flight model after the Critical Design Review (CDR) phase (Katayama et al., 2016). The major mission objectives are (1) to contribute safe and secure social including provisions for natural disasters, and (2) to create and update geospatial information in land and coastal areas. The "WIde-Swath and High-resolution optical imager" (WISH, as a tentative name) will be mounted on ALOS-3, which consists of 0.8 m resolution of panchromatic band and 3.2 m resolution of multispectral six bands with 70 km of observation swath width. This paper describes overviews of ALOS-3's missions, products, and the calibration and validation plan of WISH.

2. CHARACTERISTICS OF ALOS-3

2.1 Mission objectives of ALOS-3

Regarding to two major mission objectives of ALOS-3, utilizations of following various applications and outcomes by ALOS-3 are expected.

2.1.1 Safe and secure social including provision for natural disasters: For responding of natural disasters in Japan, Asian region as well as worldwide, disaster related information e.g. damaged area and volume estimations, damage assessment associate with rescue activities will be provided as soon as after happening the event. To response this requirement, several emergency observation modes are prepared in ALOS-3 operation i.e. the point observation, the observation direction changing, and the wide area observation (Tadono et al., 2018). For analysing the acquired data, this is basically a change detection between before and after the event, therefore it is important to observe the area and archive the data in before the event as well. This will be also able to use maintaining and updating the hazard maps in the prevention phase. JAXA is also considering to use multi-satellites combining ALOS-3 and ALOS-2 if it is still in operating, and ALOS-4 as next Synthetic Aperture Radar (SAR) satellite mission in Japan, and also combining analysis with other earth observation satellites.

2.1.2 Geospatial information in land and coastal areas: The Geospatial Information Authority of Japan (GSI) is responsible to generate and update the official national topographic map in Japan, which is covered by 1/25,000 scales. To contribute this activity, at least 5 m geometric accuracy must be guaranteed. It is also important to identify surface textures, land-use and land-cover (LULC) and their changes to update map as well. The RedEdge multispectral band is provided in WISH and will support to know an activation level monitoring in forests, vegetation and agricultural areas. Therefore, the image quality of ALOS-3 is also important. In addition, terrain

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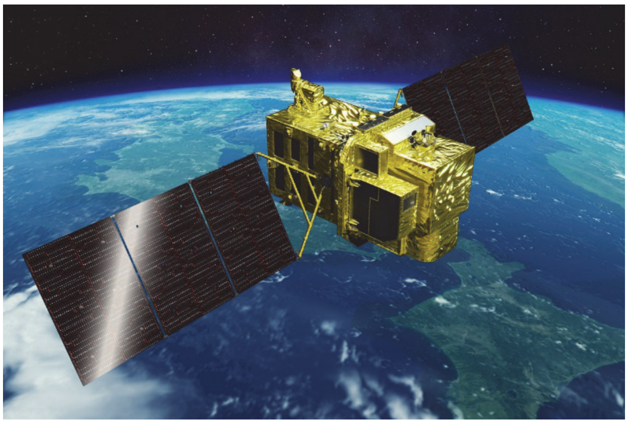

Figure 1. In-orbit configuration of ALOS-3

Items		Specifications
Orbit	Type	Sun-synchronous sub-recurrent
	Altitude	669 km at the equator
	LST	10:30am +/- 15 min.
	Revisit	35 days (Sub-cycle 3 days)
Size		5 m x 14 m x 3.5 m on orbit
Mass		Approx. 3 tons at launch
Design lifetime		Over 7 years
Mission data downlink		Direct transmission: Ka and X bands; *via.* Optical Data Relay Satellite
Instrument		Wide-swath and high-resolution optical imager

Table 1. Specification of ALOS-3

height estimation i.e. digital elevation model (DEM) or digital surface model (DSM) is important to create contour line in the map. These functions are also contributed to activities in the natural disaster responses. JAXA has plan to acquire the stereo imageries by stereoscopic observation mode using sub-cycle orbit of three days difference in nominal situation. At least 2.5 m height accuracy of panchromatic band with ground control point (GCP) is assigned to the target accuracy. In addition, bathymetry and environmental monitoring in coastal regions are defined as this mission that will be contributed by the Coastal channel of multispectral band.

2.2 Specifications of ALOS-3 and WISH

Figure 1 shows expected in-orbit configuration of ALOS-3, and Tables 1 and 2 summarize the current specifications of ALOS-3 and the onboarded instrument WISH, respectively, which is considered to improve and enhance a fine resolution and global observation capabilities achieved by the Panchromatic Remote Sensing for Stereo Mapping (PRISM) and the Advanced Visible and Near Infrared Radiometer type-2 (AVNIR-2) onboard ALOS (Tadono et al., 2009). For example, the ground sampling distance (GSD) is 0.8 m of WISH's panchromatic band compared with 2.5 m of PRISM, and 3.2 m for multispectral bands with 10 m of AVNIR-2, even the observation swath width is same with them of 70 km at nadir. For multispectral observation, two channels are added from AVNIR-2 i.e. the Coastal and the RedEdge. The data quantization is improved to 11 bits/pixel from 8 bits/pixel of PRISM and AVNIR-2. This improvement will contribute to obtain better image quality, however it causes a huge amount of mission data.

Items	Specifications
Panchromatic band (Pan)	
GSD, Swath width	0.8 m, 70 km at nadir
Wavelength	0.52-0.76 micrometres
MTF, SNR	0.1, 200
Quantization	11 bits / pixel
Multispectral band (Mul)	
GSD, Swath width	3.2 m, 70 km at nadir
Wavelength (micrometres)	Band 1: 0.40-0.45 (Coastal) Band 2: 0.45-0.50 (Blue) Band 3: 0.52-0.60 (Green) Band 4: 0.61-0.69 (Red) Band 5: 0.69-0.74 (RedEdge) Band 6: 0.76-0.89 (NIR)
MTF, SNR	0.2, 200
Quantization	11 bits / pixel
Data rate	Approx. 4 Gbps (after onboard data compression: Pan. 1/4, Multi 1/3)
Duty	10 minutes / recurrent
Pointing	< 60 degrees by body pointing

Table 2. Major specification of WISH instrument

Level	Contents and specifications
1A	Raw data (not deliver to user)
1B1	Radiometric system correction; CCD unit image
1B2	Radiometric + Geometric system correction, Geo-reference/Geo-coded with RPC Target geometric accuracy (1 sigma): 5 m (horizontal) without GCPs; 1.25 m (horizontal), 2.5 m (vertical) with GCPs Target radiometric accuracy (Mu band, 1 sigma): +/-10 % (abs.); +/-5 % (relative)
1C	Rough ortho rectification using existing DEM/DSM i.e. AW3D (Tadono et al., 2014)

Table 3. ALOS-3 standard product and target accuracies

The satellite orbit is kept as the sun-synchronous and sub-recurrent with the local sun time at 10:30 am, but the repeat cycle is 35 days from 46 days of ALOS's one. This is enhanced observable frequency at middle and high latitude areas, however small pointing angle observations are necessary to cover the entire area in low latitudes.
Unfortunately, along-track stereo observation by multi-sensors like PRISM had not been selected, however the satellite has the body pointing capability within 60 deg. in cone-shape from nadir that will contribute in an emergency observation if a natural disaster happens for example.

2.3 Data products of ALOS-3

To contribute the missions explained in Section 2.1, JAXA has a plan to produce the ALOS-3 products in two categories i.e. the standard product and the high-level product. The former is basically system corrected product and distribute from the data distributer. The calibration of the instrument and the accuracy assessment of the standard product will be conducted by JAXA. The latter is to demonstrate ALOS-3 capabilities in applications, therefore JAXA will be conducted the development of an algorithm and validation and accuracy assessment.

No	Item		Contents
Calibration			
	Geometric Cal (Relative / Absolute)		
1	Relative CCD-to-CCD alignment		Relative alignment between CCDs and their changes in temperature, temporal, etc.
2	Pointing determination accuracy		External orientation parameters (orbit and attitude errors, sensor alignment etc.)
3	Distortion within scene (middle- and long-frequencies)		Pointing stabilities in individual time-scale (within 400 lines, and 1 scene)
4	Pointing control accuracy		Pointing accuracy evaluation
5	Geometric correction accuracy		Use L1B2 and L1C products acquired in GCP test sites.
6	Pa/Mu co-registration		Use L1B2 and L1C products of Pa and Mu.
7	Band-to-band registration		Relative error between base band and individual band of Mu
	Radiometric Cal (Relative / Absolute)		
1	Absolute	Pre-flight Cal	Spectral radiance evaluation
2		Dark Cal	Sensitivity and temporal stability of the images acquired in nighttime
3		Lunar Cal mode (CT/AT) Deep space Cal	Sensitivity and temporal stability of the images acquired Lunar and deep space
4		Vicarious Cal	Absolute cal will be done by vicarious calibration at the radiometric test sites over homogeneous targets.
5		Cross Cal	The simultaneous observation will be done with the calibrated other satellites/instruments.
6	False dark data		Stability and temporal changes using the onboard dark data.
7	Pixel-to-pixel sens. Variation	Operational evaluation	Acquired images in the test sites.
8		CT Cal mode	Sensitivity and temporal stability using images acquired by 90 degrees yaw-around.
9		Dark Cal	Sensitivity and temporal stability of the images acquired in nighttime.
10		Deep space Cal	Sensitivity and temporal stability of the images acquired the deep space.
11	CCD-to-CCD and Channel-to-Channel sensitivity variations		Sensitivity and temporal stability of the images acquired at the radiometric test sites over homogeneous targets.
12	Linearity		Brighter and darker homogeneous targets.
	Image Quality Evaluation / Sensor Characterization		
1	MTF evaluation		Modulation Transfer Function (MTF) evaluation using the Point Spread Function (PSF) or edge target.
2	Signal-to-noise ratio		Brighter and darker homogeneous targets.
3	Data compression		Image quality evaluation using difference onboard compression rates (nominal: Pa 1/4, Mu 1/3).
4	TDI characterization		TDI number and its differences.
5	Wavelength characterization		Pre-flight test data
6	Defocus evaluation		Defocus (research)
7	Image quality improvement		Image quality improvement method (research)

Table 4. Planned calibration items for ALOS-3 standard products

No	Item	Contents
Validation (High-level and Research Products)		
	High-level Product	
1	RPC (RPC-Pan/RPC-Mul)	
	Physical sensor model approximation	The physical sensor model validation by ・the pointing stability in the different frequency domain, ・using the Attitude Reference System (ARS), and ・using L1B1/L1B2
	Absolute accuracy	Geo-reference accuracy by RPC using GCPs
2	Ortho-rectified Image (ORI-Pan/ORI-Mul)	
	Geolocation accuracy	Geolocation accuracy validation (different DEM/DSM)
	Multi-temporal images registration (Relative accuracy)	Relative registration by multi-temporal acquired images.
3	Pan-sharpened Image	
3-1	Standard product (PSI)	Created using the standard products
3-2	Ortho-rectified, pan-sharpened image (ORI-PSI)	Created by ORI-Pan and ORI-Mul
4	Digital Surface Model (DSM)	
	3-D geolocation determination accuracy	Orientation and bundle adjustment to calculate 3-D geolocation ・GCP and CP residuals ・TP residual between stereo pair image
	Height accuracy	Generated DSM and image matching accuracy ・Absolute accuracy ・Relative accuracy ・with and without GCP ・characterized in LULC differences
	Horizontal geolocation accuracy	Horizontal geolocation accuracy in generated DSM ・Absolute accuracy ・Relative accuracy ・with and without GCP ・characterized in LULC differences
	Mask layer evaluation	Automatic generation of clouds, snow and ice, and water bodies layers (TBD)
5	Atmospheric and Terrain Corr. Image	
5-1	Atmospheric correction (ATC)	Atmospheric correction accuracy and tuning
5-2	Terrain correction (ASC)	Atmospheric and terrain collection accuracy and tuning
6	Research Product	
6-1	Auto- and Semi-auto Change Detection (ACDI/MCDI)	Algorithm development and tuning
6-2	Precise LULC (HRLULC)	Algorithm development and tuning
6-3	Coastal-zone map (CZM)	Algorithm development and tuning
7	New Utilization	
7-1	Hot-spot estimation (HS)	Volcanic activity, forest wild fires, and see surface temperature anomaly

Table 5. Planned validation items for ALOS-3 high-level and research products

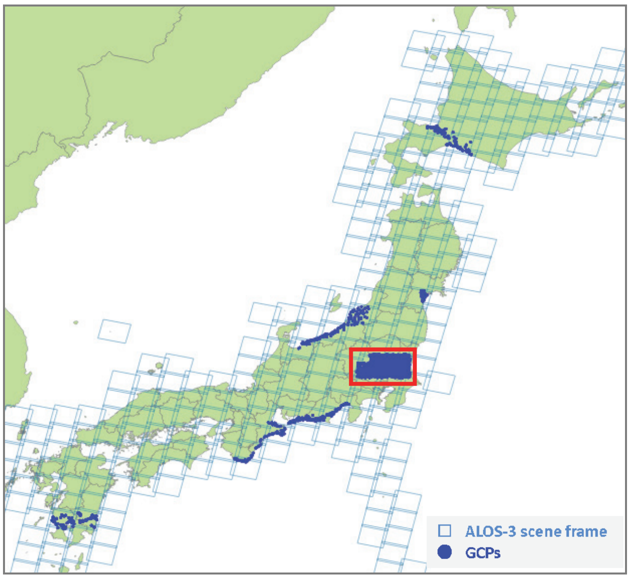

Figure 2. Preparation status of precise GCPs in Japan

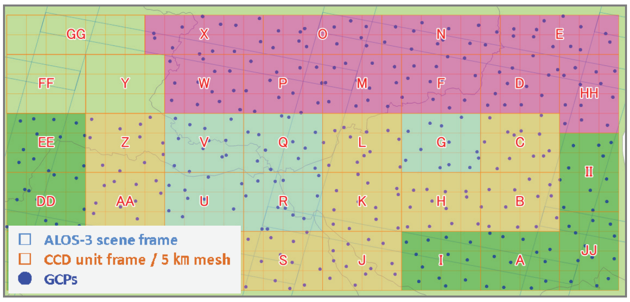

Figure 3. Dense GCPs network in Kanto district, Japan (approx. 150 km x 70 km / 5 km mesh, red square in Fig. 2)

2.3.1 Standard product: Table 3 summarizes the ALOS-3 standard product and target accuracies that will be operationally generated and distributed from the data distributer. These are system corrected products using radiometric and geometric sensor models that will be provided from the sensor development team. Therefore, the sensor calibration is directly affected to the accuracies of the standard product, and effect to quality of following processing and products. In addition, the sensor model based the Rational Polynomial Coefficient (RPC) will be generated and contained with level 1B2. A rough ortho rectified image is prepared as level 1C, which will be used existing DEM i.e. PRISM DSM called AW3D (Tadono et al., 2014).

2.3.2 High-level product: Several high-level products are planned to be investigated using ALOS-3 data to contribute the missions. Typical high-level and research products are as follows;

- Ortho-rectified image of Pan (ORI-Pan)
- Ortho-rectified image of Multi (ORI-Mul)
- Ortho-rectified pan-sharpened image (ORI-PSI)
- Precise Digital Surface Model (DSM)
- Atmospheric corrected image (ATC)
- Automatic change detected image (ACDI)
- High resolution land cover classification (HRLCC)
- Coastal zone environment monitoring (CZM)

Other research products as well as applications will be investigated by individual cooperation research activities and the Research Announcement (RA) activity.

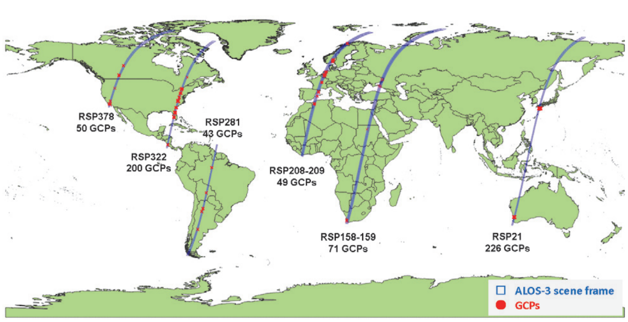

Figure 4. Preparation status of GCPs sites in the world

Figure 5. Candidate of radiometric calibration sites in the world

3. CALIBRATION AND VALIDATION OF ALOS-3

Table 4 summaries the calibration items for ALOS-3 standard product planned to be evaluated after launch the satellite as well as monitor during the operational phase until the end of the mission. The calibration accuracy will be expected to improve and stable with accumulation of the evaluation number. It will be also very important to find degradations, and it should be reflected to sensor model parameters and algorithms update if necessary. Table 5 shows the planned validation items for the high-level and research products of ALOS-3, which is important to demonstrate its capabilities.

ALOS-3 will be conducted the initial checking out (ICO) during three months after launch, then enter the operational phase. The first three months of the operational phase will be assigned as the initial calibration phase that will be done the intensive evaluations of instrument itself and update the sensor model's parameters to improve the accuracies. Three months are impossible to complete all sensor calibrations, especially evaluations of geometric accuracy and stability over seasons and annuals, which should be monitored during the operational phase continuously. Therefore, the initial calibration should be done by ICO + three months as the first priority. However, it still expects that haven't spare time to complete it because ALOS-3/WISH is an optical instrument and the acquired image is affected by clouds.

3.1 Test sites establishment with reference data

To conduct the initial calibration effectively, we are now preparing the calibration test sites with the reference data not only in Japan but also in the world.

Regarding to the geometric calibration, ground control points (GCPs) are collecting as much as possible in pre-launch phase. Figure 2 shows the preparation status of GCPs in Japan, where are conducted the global navigation satellite system (GNSS) measurements along with major coastal lines. These GCPs will be not only used for calibration but also for image correction by bundle adjustment method in Japan. Particularly, a dense GCPs

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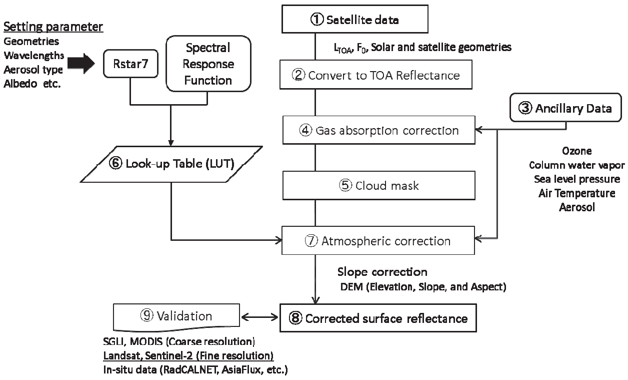

Figure 6. Atmospheric corrected image processing flowchart

network is now creating in Kanto district as indicated by red square in Figure 2. Figure 3 shows an enlarged map of the dense GCPs network in Kanto district, Japan, which is covered area approx. 150 km east to west and 70 km north to south directions with 5 km mesh of GCPs measurements. This network will be able to cover two satellite paths. Figure 4 shows the preparation status of GCPs in the world, which consists of six major satellite paths in continental or semi-continental scales. Some of these GCPs were measured by us, others are collected by commercial bases. Currently, approx. 6,300 precise GCPs were prepared in total, and registered to the GCP database. As the other geometric related test sites, several reference DSM sites are prepared by airborne LiDAR measurements (Takaku et al., 2016).
Regarding to the radiometric calibration, several test sites have been selected in the world as candidates, which are covered by homogeneous targets and had been used for calibrating other satellite optical instruments (Murakami et al., 2009) so far. Figure 5 shows the location of radiometric calibration test site candidates. Some of them are defined as common calibration sites in the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV), and also have ground-based in-situ measurements to collect surface reflectance, atmospheric parameters, etc. continuously. They will be very useful to conduct the cross calibration as well as the absolute calibration.

3.2 Geometric calibration and DSM validation

Regarding to the geometric calibration of WISH, both relative and absolute calibrations will be done using reference data i.e. GCPs, precise DSMs, calibrated other images. We will be firstly evaluated the relative CCD alignments i.e. interior orientation using the densely GCPs test site, which shows in Figure 3. WISH instrument has 12 CCD units to achieve 70 km swath width, which corresponding to approx. 6 km width by each CCD unit. After evaluating the relative CCD alignments, the site will be used to evaluate the image distortions within scene, which will also be done in the dense GCPs test site. We will calculate residual geometric errors in both X- and Y-directions and estimate the updated parameters in sensor model. The band-to-band registration will be evaluated as relative calibration of the multispectral band. The co-registration accuracy between panchromatic- and multispectral-band will be evaluated using acquired the images over the test sites covered by gentle and typical terrain features. This is important to process a pan-sharpening in good quality. The absolute geometric accuracy and its stability will be evaluated using the global GCP sites over the world as shown in Figure 4. They are also used for the pointing control and determination accuracy evaluations.

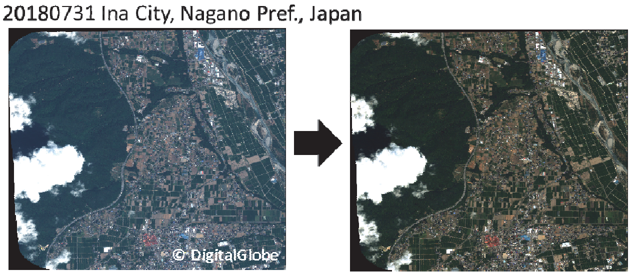

Figure 7. Example of atmospheric correction using WorldView-2 in Ina City, Nagano Pref., Japan

All geometric evaluations will be conducted by applying orientation technique based on the collinearity condition similar with the geometric calibration of PRISM (Takaku and Tadono, 2009). We will calculate and evaluate the sensor model parameters and update them. After updating the parameters, geometric correction accuracy and RPC accuracy will be confirmed using level 1B2 and 1C products.
After the initial calibration, we will also validate the generated precise DSMs and ortho-rectified images (ORI) using ALOS-3 stereopair images as high-level products. The reference GCPs and DSM test sites will be used for the validation of generated DSM and ORI.
To conduct the calibration and validation effectively in particular the initial phase, we are now preparing the calibration sites with the reference data not only in Japan but also in the world. However, it may not be enough to complete it, therefore we have a plan to additional GCPs measurements as well as reference data collections based on the acquired images by ALOS-3 after launch the satellite.

3.3 Radiometric calibration and surface reflectance validation

Regarding to the radiometric calibration, it will be also done by both relative and absolute evaluations. As the relative radiometric calibration, the pixel-to-pixel, CCD-to-CCD, and channel-to-channel sensitivity variations will be evaluated using acquired data over the test sites that have homogeneous targets as well as in night-time observations. The sensitivity linearity and the quasi-dark current will be also evaluated to monitor its stability. After the relative calibration, the absolute radiometric calibration will be conducted by the Lunar calibration mode, the vicarious calibration as well as the cross calibration with calibrated other satellite data in the test sites.
An atmospheric corrected image (ATC) product will generate as a part of the high-level product to demonstrate the potential of ALOS-3. Figure 6 shows a current planned processing flowchart of ATC product in JAXA, where introduces a radiative transfer model (e.g. Rstar 7) to make “look-up tables” under various atmospheric and geometric conditions. The acquired radiance at top of atmosphere is used as input data to the processing, referred the atmospheric parameters (e.g. ozone, water vapor, sea level pressure, air temperature, aerosol) and DEM as ancillary data, and finally obtained the calculated the surface reflectance. Figure 7 shows a test result of derivation of surface reflectance using WorldView-2 image in Ina City, Nagano Pref., Japan. Figure 8 shows a validation example of derived surface reflectance as shown in Figure 7, where Sentinel-2 surface reflectance product was used for comparison. The result indicates 5.5 % differences as root mean square error (RMSE) in near infrared (NIR) channel as maximum error, and less than 1 % RMSE in blue, green, and red channels, respectively.

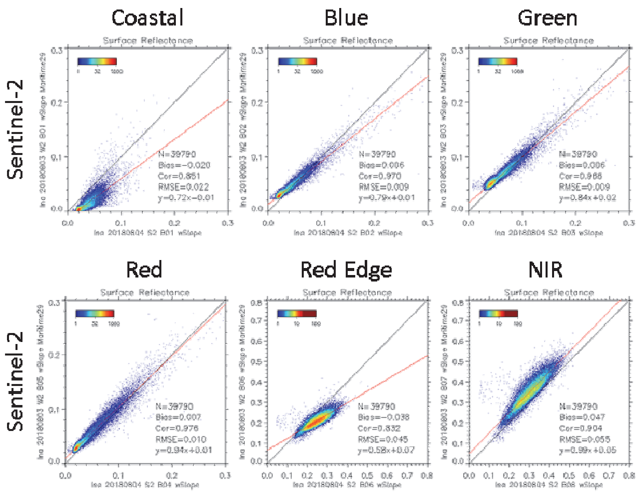

Figure 8. Comparison the surface reflectance between the derived from WorldView-2 and Sentinel-2

3.4 Image quality evaluations

The image qualities of WISH (e.g. the modulation transfer function (MTF), signal-to-noise ratio, effects of the data compression, the time domain integration (TDI) characterization) will also investigate using acquired images after launch the satellite. They will be compared with pre-flight test results, and continuously monitored temporal changes during the operational phase.

4. CONCLUSIONS

This paper introduced the overview of ALOS-3's mission and products, the calibration and validation plan that will be conducted from the initial calibration phase between three and six months after launch. This activity will be continuing as the operational calibration to improve and monitor the accuracies of standard products during the operational phase, and updating the sensor model parameters as well as algorithms if necessary.
ALOS-3 is scheduled to be launch in this fiscal year. As explained in the paper, we are now preparing for launch the satellite as well as the initial calibration that is collecting the reference data and developing the evaluation tools. However, it may not be enough to complete the initial calibration that depends on the availability of actual data number acquired in the test sites. Therefore, we have an option to collect the reference data from available ALOS-3 data. We will make a report on calibration results in near future.

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