

# CALIBRATION AND VALIDATION OF PRISM ONBOARD ALOS

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## ABSTRACT:

This paper introduces the updated plans for sensor calibration and product validation of the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM), which is to fly on the Advanced Land Observing Satellite (ALOS) satellite that will be launched this Japanese fiscal year. PRISM is used to derive digital elevation models (DEMs) with very high spatial resolution, which is also one of the objectives of the ALOS mission. To achieve this objective, PRISM consists of three panchromatic radiometers for forward-, nadir-, and backward-looking in the along-track direction, and acquires the images in the same orbit and at almost the same time. The geometric calibration is important in generating a highly accurate DEM with high spatial resolution by using PRISM's triplet images. Highly accurate ground control points (GCP) are necessary to calibrate the geometric accuracy and validate the generated DEM. Collecting GCP worldwide is difficult and hard work in spite of its importance.

In this paper, we describe the current plans for calibrating and validating PRISM aboard the ALOS, and in particular, our strategies for preparing GCP with evaluation items for geometric calibration, including expected problem effects regarding geometric accuracy.

## 1. INTRODUCTION

The Advance Land Observing Satellite (ALOS) is the next Japanese Earth observation satellite, and will be launched within this fiscal year. The mission objectives of the ALOS are cartography, regional observation, disaster monitoring, *etc.* In particular, geographic information such as elevation, topography, land use, and land cover, are necessary as basic information in many fields of practical applications and research areas. However, only just under 30% of the terrestrial area has been covered by 1:25,000 scale topographic maps worldwide. To achieve the mission objectives, ALOS has three mission instruments, two optical sensors called PRISM and AVNIR-2, and an L-band Synthetic Aperture Radar called PALSAR. PRISM stands for the Panchromatic Remote-sensing Instrument for Stereo Mapping and consists of three independent radiometers for nadir, forward, and backward directions. It will be used for generating a Digital Elevation Model (DEM) with high spatial resolution. The development statuses of the ALOS and its instruments were represented by Ichitsubo *et al.* (2003) and Matsumoto *et al.* (2003).

This paper introduces the updated plans for sensor calibration and product validation of the PRISM, in particular strategies of preparing the ground control points (GCPs) including expected problems based on pre-flight testing of PRISM, orbit simulation, and pointing estimation of each radiometer after launch of the ALOS. GCP is necessary to evaluate the geometric accuracy and validate the generated DEM.

## 2. CALIBRATION AND VALIDATION PLAN

### 2.1 PRISM Characteristics

Figures 1 and 2 illustrate the PRISM observation geometries, and Table 1 summarizes the main characteristics of the PRISM. PRISM is a panchromatic radiometer with a 2.5-meter spatial resolution. It consists of three independent optical systems for

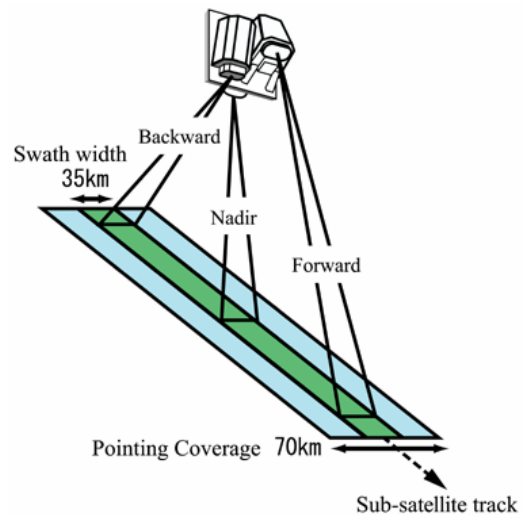


Figure 1. Observation geometry of triplet mode

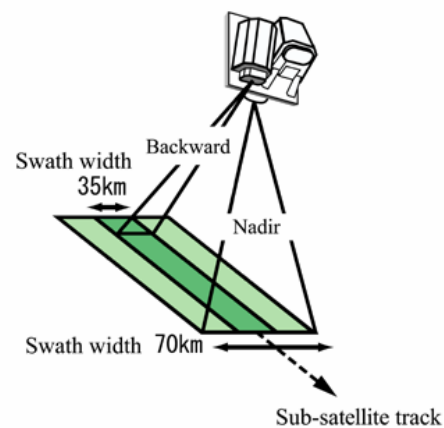


Figure 2. Observation geometry of nadir and backward modes

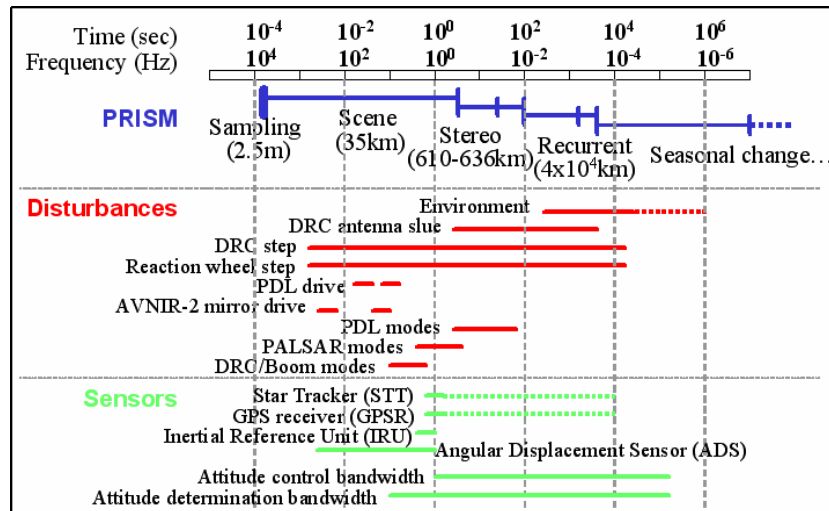


Figure 3. Frequency characteristics of PRISM sampling, expected attitude fluctuations, and attitude/orbit determination sensors (Modified from Iwata *et al.*, 2002)

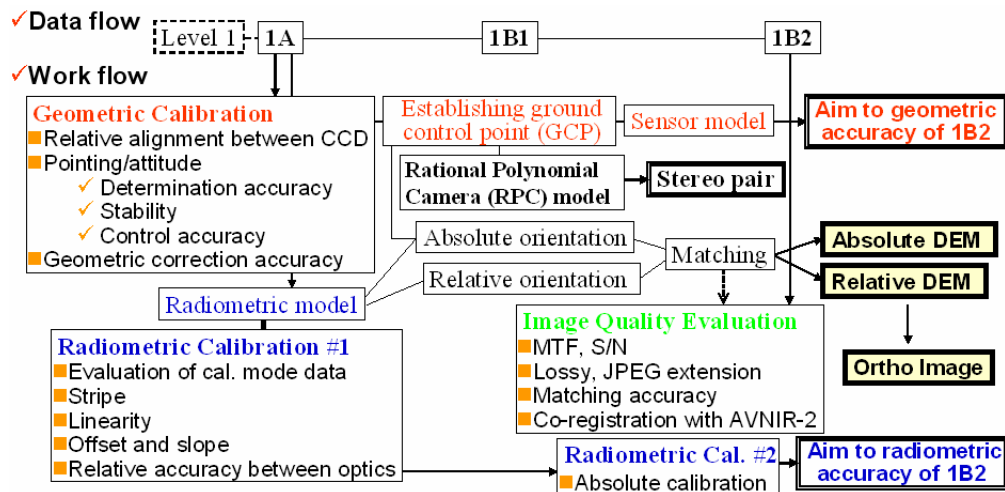


Figure 4. Work flow of PRISM calibration and validation, and evaluation items

Number of bands	1 (Panchromatic)
Wavelength	0.52-0.77 micrometers
Number of optics	3 (Nadir, Forward, and Backward)
Base to Height ratio	1.0 (between Forward and Backward)
Spatial resolution	2.5 m
Swath width	70 km (Nadir or Nadir + Backward) 35 km (Triplet mode)
Signal to Noise ratio	> 70
MTF	> 0.2
Number of detectors	28,000 (70km swath), 14,000 (35km)
Pointing angle	-1.5 to +1.5 deg. (Triplet mode)
Bit length	8 bits/pixel
Data rate	960 Mbps (Triplet mode)
Data compression	Lossy, JPEG extension (onboard)
Data downlink rate	240 Mbps(1/4.5 compression) 120 Mbps(1/9 compression)

Table 1. PRISM characteristics

nadir, forward and backward looking, to achieve along-track stereoscopy. Each telescope consists of three mirrors and six or eight Charge Coupled Device (CCD) detectors for push-broom scanning. The nadir-looking radiometer can provide 70 km

width coverage, and the forward and backward radiometers each provide 35 km width coverage. The radiometers are installed on both sides of the optical bench, which has precise temperature control. Forward and backward radiometers are inclined + and - 23.8 degrees from nadir to realize a base-to-height ratio of one. Each radiometer has the functions of pointing (within + to - 1.5 degree) and cutting electrically to obtain the image of the same observed area between other radiometers in the cross track direction. Thus, fully overlapped three-stereo (triplet) images with a 35 km width are obtained without mechanical scanning or yaw steering of the satellite. Without this wide Field Of View (FOV), forward-, nadir- and backward-looking images would not overlap each other due to the Earth's rotation. Pointing angles of + and - 1.25 degrees are reasonable to observe the whole coverage by triplet mode in global.

The acquired data are separated into odd- and even-numbered detectors, and compressed by lossy compression with Joint Photographic Experts Group (JPEG) extension, which are based on Discrete Cosine Transform (DCT), quantization, and Huffman coding to reduce the downlink data rate from ALOS to ground stations. Averaged compression data rates can be selected either 1/4.5 or 1/9.

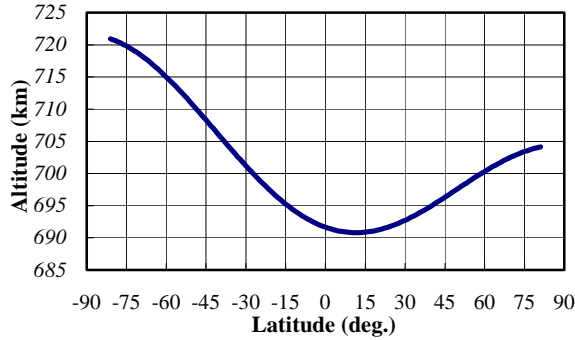


Figure 5. Relationships between latitude and nominal orbit

## 2.2 Expecting Disturbances Affected Geometric Accuracy

Figure 3 presents the frequency characteristics of PRISM's sampling, position and attitude determination sensors aboard ALOS, and expected disturbances *i.e.*, attitude fluctuations that will directly affect the geometric accuracy of PRISM images (modified from Iwata *et al.*, 2002). Each line of PRISM will be sampled in 0.37 msec intervals, which corresponds to 2.5 meters on the ground. Each scene will be composed of five second observations, which corresponds to 35 km in the along track direction. The expected attitude fluctuations will result from thermal distortions of PRISM itself, large strictures such as the solar paddle, PALSAR's antenna due to thermal environment changes on the orbit, and dynamics by driving the data relay antenna (DRC) and pointing mirror of AVNIR-2.

To determine these fluctuations, the ALOS has orbit and attitude sensors such as dual frequencies GPS Receiver (GPSR), Star Tracker (STT), Angler Displacement Sensor (ADS), and Inertial Reference Unit (IRU). Furthermore, the Precise Pointing and geolocation Determination System (PPDS), which is one of the ground processing systems, was developed to determine highly accurate PRISM's pointing based on attitude sensors (Iwata *et al.*, 2002). It is still necessary to prepare many GCPs worldwide to validate the orbit and attitude sensors themselves, as well as to evaluate the geometric accuracy of PRISM because its sampling frequency is the highest among onboard sensors.

## 2.3 Calibration and Validation Plans

Figure 4 summarizes the working flows of calibration and validation for PRISM and their evaluation items. The most important item is the geometric calibration, which is required to generate highly accurate DEMs by PRISM's stereo pair images. First, we will evaluate the relative alignments between each CCD for each radiometer, which were measured on the ground before launching the ALOS in the pre-flight test. However, they may be changed by launching, and also depend on the thermal condition while in orbit. The attitude determination accuracies, stabilities, and control accuracies will also be evaluated for each sampling frequency in Figure 3. To evaluate these items, we require many highly accurate GCPs worldwide. Before the geometric calibration, we may require some radiometric calibration *i.e.*, relative radiometric calibration, because stripes are the main obstacles in image interpretation and matching with GCP. Therefore, we have developed an evaluation tool for relative radiometric correction using available satellite images (Tadono *et al.*, 2003).

The image quality evaluation is also important and uses standard products such as level 1A, 1B1 and 1B2 processed in JAXA's data processing center, EOC.

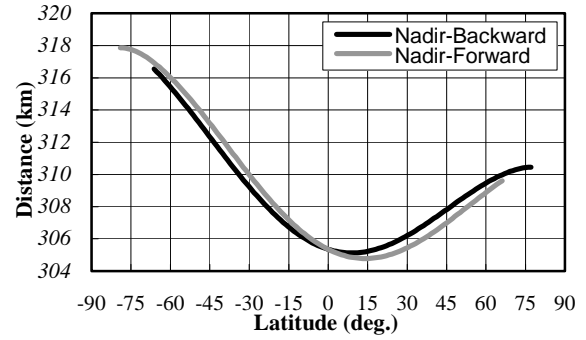


Figure 6. Relationships between latitude and distance between observed areas (Black: nadir-backward; gray: nadir-forward)

The processing software of DEM and ortho-rectified image using PRISM stereo pair images is in development based on the triplet image matching technique (Takaku *et al.*, 2003). This software introduces semi-epipolar line estimation, aerial based matching, automatic window size optimization, coarse to fine techniques, *etc.* The generated DEM and ortho-rectified image are defined as high-level products processed in Earth Observation Research and Application Center (EORC), JAXA. The GCP will also be used to validate the high-level products.

## 3. STRATEGY OF PREPARING GCPs AND EVALUATION ITEMS

### 3.1 Estimation of Simultaneous Observation Areas

Basically, a higher number of GCPs is preferred because the observed images may be affected by cloud cover. To effectively calibrate the PRISM geometrically, we should consider strategies to prepare GCPs worldwide, which depends on target evaluation items and their frequency characteristics. Before preparing a GCP, we simulate the ALOS nominal orbit to estimate the location of each of PRISM radiometer's observation. We then describe the preparation of GCP with evaluation targets of geometric calibration.

**3.1.1 Orbit Simulation:** To estimate the locations of simultaneous observations in triple observing mode, we first simulate the ALOS nominal orbit. Figure 5 describes the relationship between latitude and satellite altitude on Geodetic Reference System 1980 (GRS 80), which is an ellipsoid model using the ALOS. The altitude of the ALOS is 691.65 km above the equator, and the inclination angle is 98.16 degrees for the nominal orbit elements. The nominal orbit radius of the ALOS was calculated as a function of declination, and then subtracted from the radius of the ellipsoid model at the same location. The x-axis of Figure 5 was translated into the geodetic latitude. Satellite altitude is changing 30 km north to south, which produces an observation gap for each radiometer of the PRISM.

**3.1.2 Calculation of Pointing Vector:** Figure 6 illustrates the relationship between the geodetic latitude of the nadir looking radiometer and the distance between each radiometer on the GRS 80 ellipsoid model. The black line indicates the distance between nadir- and backward-looking radiometers. The gray line represents the distance between nadir- and forward-looking radiometers. These lines were calculated from the orbit altitude in Figure 5 and the alignments of each radiometer measured on the ground. Figure 6 depicts the

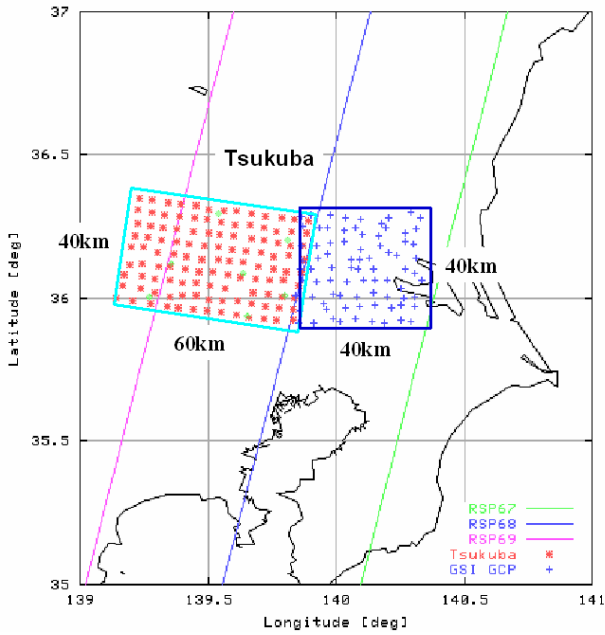


Figure 7. Dense GCPs around Tsukuba, Japan

assumed descending orbit when PRISM is operated normally in the daytime and the ground elevation is assumed to be 0 meters. The variability of distance between each radiometer at the same time is more than 10 km in the recurrent orbit.

### 3.2 Dense GCP to Evaluate the Relative CCD Alignments

First, we evaluate the relative CCD alignment in each telescope after launching the ALOS because that is the affected geometric sensor model to process the standard product. At least one GCP for each CCD is required to evaluate the relative alignment. Figure 7 illustrates the location of the dense GCPs around Tsukuba City, in the northern part of Tokyo, Japan. Three lines (67 to 69) indicate the ALOS paths based on the Reference System of Planning (RSP). This dense GCPs area cover a 100 x 40 km area with a 5km step, and will be used to evaluate the relative alignment of CCD as well as the pointing determination accuracy within 5 seconds, which corresponds to one scene in a PRISM image. This can also be used to validate the high-level products such as the generated DEM and ortho-rectified image. The eastern part of this area (40 x 40km) was established by the Geographical Survey Institute (GSI) of Japan using 1:2,500-scale urban planning maps (blue dots in Figure 7). We prepared the western part of the area (60 x 40km) measured by real-time differential GPS (DGPS) survey (pink dots in Figure 7). One GCP is defined by latitude and longitude in the International Terrestrial Reference Frame 1997 (ITRF 97), height on the GRS 80 ellipsoid model, and an aerial photograph or available high-resolution satellite image such as IKONOS as the chip image.

### 3.3 Along Path GCP to Evaluate Radiometers Alignments

The alignments between each radiometer are important for evaluating the geometric sensor model, as well as for internal orientation to generate DEM using PRISM's stereo pair images. The simultaneous observations of GCP by each radiometer are necessary to evaluate the alignment between each radiometer after ALOS launch. Using the observed images in the same orbit to reduce the effects of thermal condition variability is also convenient.

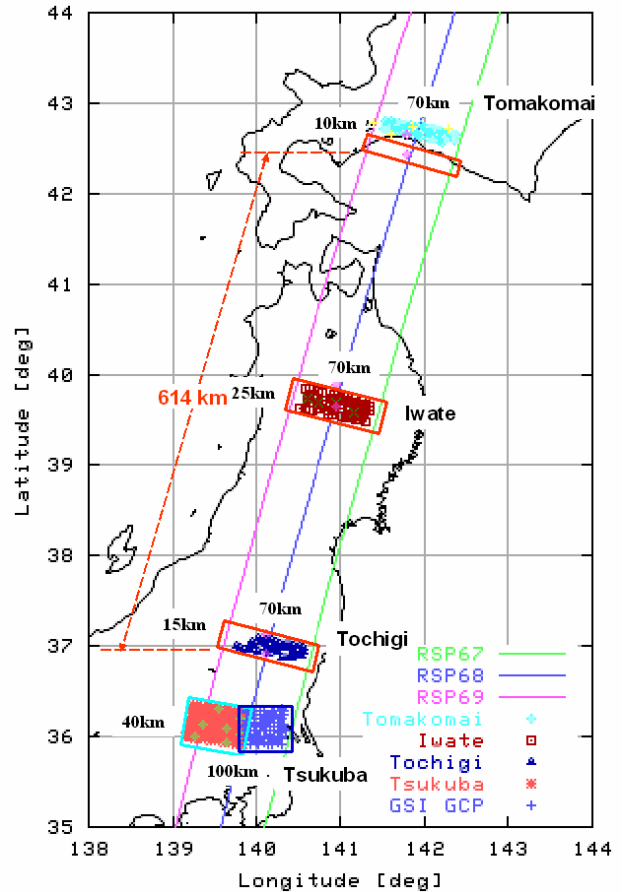


Figure 8. Along-path GCP in Japan

Figure 8 depicts an along-path GCP used to evaluate the alignments between each radiometer in Japan: and green, blue and pink lines indicate RSP 67, 68 and 69. When the nadir-looking radiometer observes around the Iwate area (red dots in Figure 8), the forward-looking radiometer can observe around Tochigi (blue dots), and the backward-looking radiometer can observe around Tomakomai (sky blue dots) in a descending orbit. The distance between Tochigi and Tomakomai is 614 km, which corresponds to the results of Figure 6. We first considered the Tsukuba area in Figure 8 as one GCP area for this purpose. However, the backward-looking radiometer is located over the ocean in this case, so GCPs were moved slightly north. The Iwate area was originally located in a mountainous area. We had to prepare GCPs near urban areas. Unfortunately, as a result, the Tomakomai area has a gap of one PRISM scene in order to obtain observations at the same time. The Iwate area was measured by DGPS as 25 x 70 km with a 5 km step, which can also be used as a dense GCP. The Tomakomai area was measured by DGPS as 10 x 70 km with a 5 km step. The Tochigi area was measured by dual-frequency static GPS with post processing, and covered 25 x 70 km with a 5 km step. Photo 1 shows an example of static GPS measurement. One point was measured in two hours. These GCP areas can be used to evaluate the alignment between radiometers and to validate generated DEMs, pointing determination accuracy, pointing stability, and attitude control accuracy from 5 to 91 second, which corresponds to the triple observation mode.



Photo 1. Example of static GPS measurement in Tochigi area



Photo 2. Overview of GEONET GPS receiving station

### 3.4 Along-Path GCP Using Automatic GPS Stations

Using the along-path GCP in Figure 8, there are only three observations during the 46 day recurrent ALOS orbit because the along-path GCP is only covered by three paths (RSP 67 – 69). That is not enough to evaluate above items, especially in the initial calibration phase. Therefore, we examined the automatic GPS receiving stations for use as GCPs.

In the Japan area, GSI maintains the GPS Earth Observation Network (GEONET). This network was basically established to monitor crustal deformation. Currently over 1,200 automatic GPS receiving stations have been installed and are being continuously monitored. The average distance between each station is 10 km, so these stations can be used as GCPs for PRISM. Their absolute accuracy is very high and stable. In addition, this data is available worldwide *via* the Internet. Available real time data with image acquisition of PRISM after launch of the ALOS will be distributed worldwide.

Photo 2 is an overview of the GEONET stations with a height of about 5 m. Figure 9 depicts the locations of all GEONET GPS stations in Japan. We tried to identify the 133 stations as the test data using aerial photographs, although some could not be clearly identified.

The red dots in Figure 9 indicate the locations of selected the 133 points, which are along ALOS paths *i.e.*, RSP 67-69, 73-75, and 82-84. From the results, 25% (33 points) could be identified in aerial photographs, 68% (91 points) were unclear, and 7% (9 points) could not be identified. This result is dependent on the scale of the utilized aerial photographs.

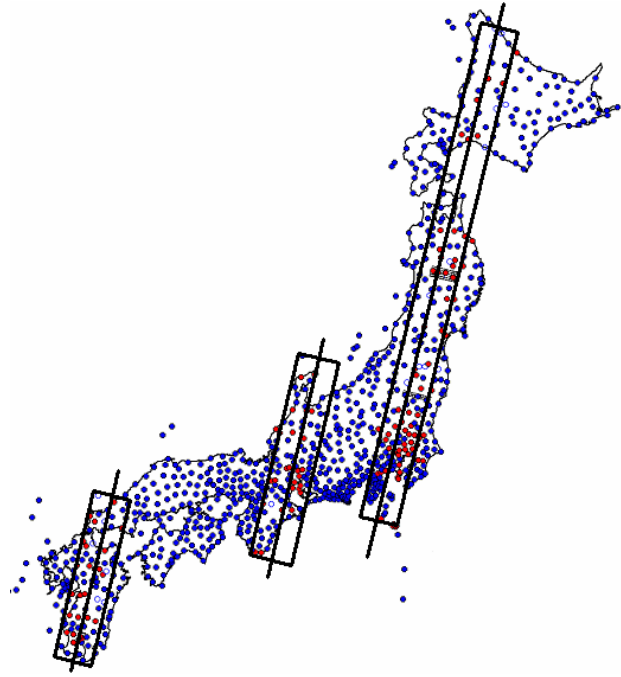


Figure 9. Locations of GEONET station and selected points



Figure 10. Example of the identified GEONET in aerial photo

Therefore, the success rate will be increased using high-scale aerial photographs. Figure 10 is an example of a station identified in a 1:4,000 scale aerial photograph.

### 3.5 Along-Path GCP to Evaluate Thermal Conditions

Figure 11 displays ALOS paths RSP 67 to 69, from north to south latitudes around the East Asia and Oceania regions, and the locations of the prepared GCPs. An along-path GCP must be required for over 91 sec to evaluate the effects of variability of thermal conditions, especially the thermal distortion of CCDs that is a function of latitude. It would be convenient to use identical orbits to reduce other factors. Therefore, we established a GCP around southwest Australia.

Figure 12 indicates the GCP prepared using a DGPS in southwest Australia with ALOS paths RSP 67 to 69. Three GCP areas were established between the cities of Kalgoorlie and Esperance. Each area was composed of only one line from west to east with less than a 10 km step. These areas could not be covered by nadir observation of RSP 67 because they were

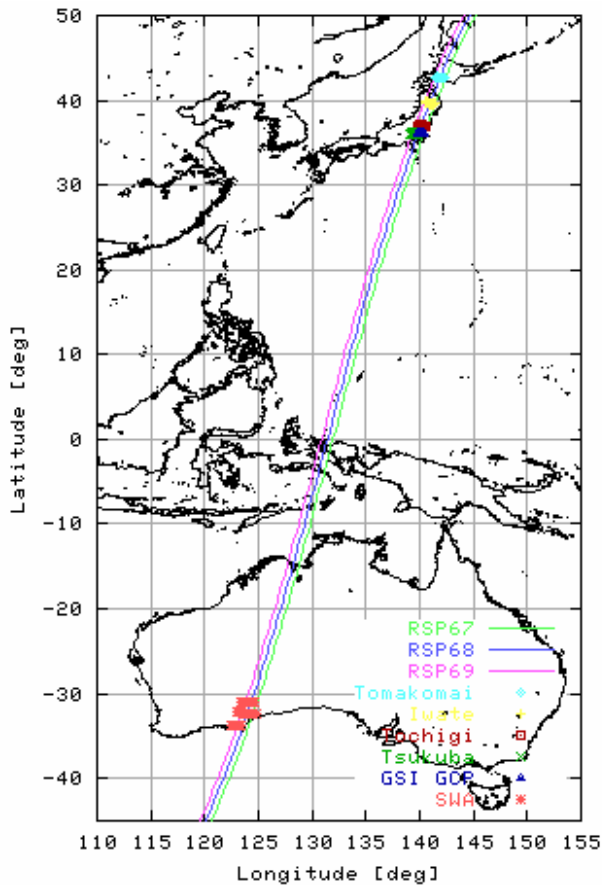


Figure 11. Along-path GCP over 91 sec with RSP 67 - 69

very difficult to access outside of these areas. However, from the result of Figure 6, the Kalgoorlie and Esperance areas will be observed simultaneously with the forward-looking and nadir-looking radiometers, and the nadir-looking and backward-looking radiometers. Evaluating the alignments of CCDs and radiometers, including thermal effects, will be both important and useful. Ideally, additional GCP areas should be prepared to evaluate the geometric accuracy of as many PRISM images as possible.

#### 4. CONCLUSION

In this study, we introduced the current plans for calibrating and validating PRISM, which is carried aboard ALOS, including the strategies of preparing GCPs, which is very important for evaluating geometric accuracy and for validating generated DEMs. These tasks are very important because the results contribute directly to the quality of the products, especially evaluation of the absolute geometric accuracy for PRISM. The accuracy evaluation of the prepared GCPs is also important for this purpose. Furthermore, the tools for matching GCPs with PRISM images, for geometric calibration as well as for radiometric calibration, will be developed until the launch of the ALOS.

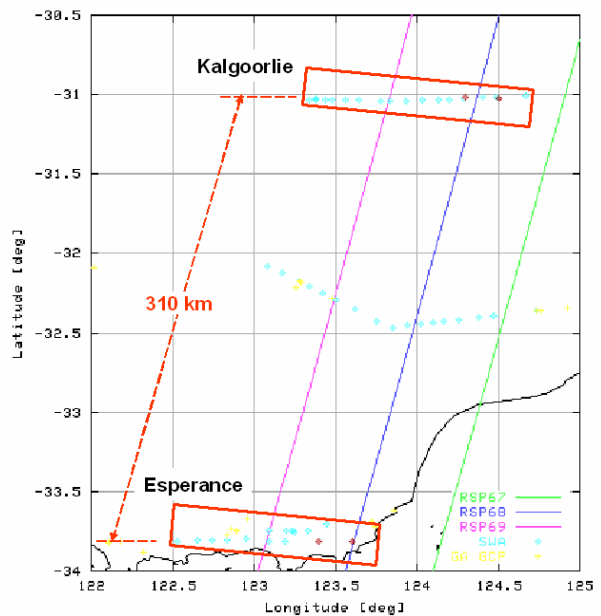


Figure 12. Along-path GCP in southwest Australia

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