

AIRBORNE SAR DEVELOPMENT AT NICT: CONCEPT FOR NEW GENERATION

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KEY WORDS: Airborne Synthetic Aperture Radar, polarimetry, interferometry, Pi-SAR, Pi-SAR2

ABSTRACT:

The Pi-SAR is a dual-frequency airborne polarimetric and interferometric synthetic aperture radar(SAR). The frequencies of the system are X-band (9.55GHz) and L-band(1.27GHz). X-band SAR has been developed by NICT, and L-band SAR by JAXA. The two SAR systems are jointly equipped with the Gulfstream-II jet-aircraft and operated simultaneously or independently. The resolution for X-band radar has 1.5m and that for the L-band has 3m. The polarimetry function is possessed for both X-band and L-band system. In addition, the X-band has two antennas and has an interferometric function with 2.3 m baseline aiming at a three-dimensional observation. Three high-data-rate recorders achieve more than 10 km swath with full functions: dual frequency, polarimetry, interferometry, and full-resolution. Experiments and observation using this SAR system has been carried out in Japanese territory since 1995. Observations applied for various areas such as environments, forestry, agriculture, hydrology, geology, oceanography etc. had been carried out two or three times in every year usually.

We had quasi-monthly observation applied to volcanic disasters in 2000. Volcano Usu and volcano of the Miyake-jima in 2000. Detail shapes and sizes of the craters were detected clearly for Usu volcano, and thick volcanic ashes covered over forests were discriminated from thin accumulation. The huge caldera appeared on the top of the Miyake-jima on July 8, 2000 was observed clearly by the Pi-SAR and sizes and depth are measured by its data. In 2004, widely disaster monitoring had been carried out by Pi-SAR after the earthquake in Niigata-Chuetsu.

From 2006, the new system - Pi-SAR2 had been developed. The design concept of the radar system is aiming at more practical for disaster monitoring. The system has been completed in 2009.

1. INTRODUCTION

1.1 Airborne SAR development in NICT

The Synthetic Aperture Radar (SAR) provides the ground image with high resolution and wide swath. Also, SAR has an advantage in observing all-weather and day-night. National Institute of Information and Communication Technology (NICT) has been in charge of the development of airborne SAR system. The first system called Pi-SAR has been developed since 1993. Pi-SAR has the dual-frequency SAR system: X-band high resolution system developed by NICT accompanied with the L-band system developed by Japanese Aerospace Exploration Agency (JAXA). Two radar systems are jointly equipped with the Gulfstream-II jet-aircraft and operated simultaneously or independently. Experiments and observation using this SAR system has been carried out in Japanese territory since 1995.

Observations applied for various areas such as environments, forestry, agriculture, hydrology, geology, oceanography etc. had been carried out two or three times in every year usually. Experiments includes calibration and validation for space-borne SAR such as ALOS and SIR-C/XSAR. Also, joint experiments of two airborne SAR system, JPL's AIRSAR and Pi-SAR, were carried out in Japan during NASA's PacRim2 campaign.

Pi-SAR had been used for the disaster monitoring such as volcanic eruptions and earthquake in 2000 and 2004, respectively. The data were contributed to these disasters. After the experience of the earthquake observation, however, it turned

out the necessity of finer resolution and quick delivery of the data for disasters. The Pi-SAR2 began to be developed with the concept for more practical for disaster monitoring.

This paper introduce the outline of the Pi-SAR results using the examples of joint airborne SAR experiments as experimental results, and Miyake volcano and Niigata-Chutetsu earthquake as a contribution for disaster. Also, the paper describes the concept of new radar system: Pi-SAR2.

1.2 Pi-SAR system

The detail of the Pi-SAR system are described in our former papers[1,2]. Table 1 shows the principal performances of the Pi-SAR. The resolution for X-band radar has 1.5m and that for the L-band has 3m. The polarimetry function is possessed for both X-band and L-band system. In addition, the X-band has two antennas and has an interferometric function with 2.3 m baseline aiming at a three-dimensional observation. Three high-data-rate recorders achieve more than 10 km swath with full functions: dual frequency, polarimetry, interferometry, and full-resolution. Listed functions are able to be operated fully simultaneously. The swath width of full mode for X-band is 10km and up to 40km when limited polarization. Such wide swath are aiming at not only experimental but also operational uses.

| | | |
|-----------------|-------------------------|------------------|
| | X-band | L-band |
| Frequency | 9.55GHz | 1.27GHz |
| Polarization | Full Polarimetry | Full Polarimetry |
| Incidence angle | 10-75° | 20-60° |
| Swath width | 4.3km for full function | 19.6km |
| | 19.3km for VV InSAR | |
| Resolution | 1.5m | 3m |
| Baseline | 2.3m | |
| Height Accuracy | 2-4m | |
| Platform | GulfstreamII | |
| Altitude | 6,000-12,000m | |

Table 1. Principal parameters of Pi-SAR

2. TWO AIRBORNE SAR EXPERIMENTS

2.1 Joint airborne SAR observation

Two airborne SAR systems observed jointly over Japan in October 2000. JPL's AIRSAR system has flid over Japan in the NASA's Pacific Rim Campaign 2000(PacRim2). At the same time, Japanese airborne SAR system (Pi-SAR) has observed same test area. One of the main objectives is cross comparison of the capabilities between two systems. Various applications such as forestry, vegetation, urban environment, volcano, and oceanography using four bands full-polarimetry are possible to investigate using combination of Pi-SAR and AIRSAR data. Ground-based experiments for this purpose were carried out at the same time in many area of Japan.

2.2 Pacific Rim 2000 (PacRim2)

Pacific Rim 2000 Campaign (PacRim2) had been carried out in July to October 2000. The campaign was the observation experiment of an airborne SAR (AIRSAR) and an optical sensor (MASTER) of JPL on NASA/DC-8 around Pacific Ocean Rim passing Tahiti, New Zealand, Australia, Singapore, the Philippines, Taiwan, Korea, Japan, Guam, and Hawaii. The AIRSAR is capable of P, L-, and C-band's interferometric or polarimetric observation. Comparison between AIRSAR and Pi-SAR is shown in Table 2. NICT undertook the Japanese side host for the PacRim2, the preparation related to the cost load and permission was advanced. Also, NICT organized the investigation team in Japan with the cooperation of the universities and national institutes.

| | Fre-quency | Bandwidth | Modes | | Swath |
|---------------|------------|-------------|-------------|-----|-------|
| Pi-SAR (G-II) | X | 100MHz | Polarimetry | XTI | 10km |
| | | | Polarimetry | XTI | 20km |
| | L | 50MHz | Polarimetry | | 20km |
| AIRSAR (DC-8) | C | 40MHz | Polarimetry | | 10km |
| | | | | XTI | |
| | L | 40MHz | Polarimetry | | |
| | | | | XTI | |
| P | 20MHz | Polarimetry | | | |

Table 2. Summary of Pi-SAR and AIRSAR

2.3 Objectives of experiments in Japan

Calibration test using common targets by two SAR systems of L-band is expected to adjust both image signals in detail and to be able to compare the data which observed individually. Combining Pi-SAR and AIRSAR, we can treat four frequencies (P,L,C, and X) to apply some ground target efficiently. X-band of Pi-SAR and L,C bands of AIRSAR has cross-track interferometric function. The error estimation of the DEM production are expected the influence of the penetration depending on the wavelength. Ocean wave or current can be measured the ATI function. We conduct the comparison with the HF radar data and X-band SAR.

Comparison using four frequency band data (P,L,C, and X) is expected to discriminate the ground state, especially forest area. Following list is the expected application fields to have advantages of multi-frequency.

- Forestry (biomass measurement using P to X bands)
- Agricultural application (rice crop: harvest season)
- Other vegetation
- Urban and sub-urban environment
- Geology (volcanoes, faults and crust deformations)
- Oceanography (coastal phenomena, current)
- Archeology

AIRSAR had collected the data around Japanese islands on October 2 and 4. Pi-SAR had also observed same test site dividing four days. Main test sites were Tottori (Calibration) and Tomakomai (Forestry), and at the most of other test sites ground truth experiments were carried out by the co-investigators. Most of the Pi-SAR observations were simultaneous interferometric and polarimetric (X) and polarimetric (L) mode, and AIRSAR modes were chosen according to the objectives. ATI mode worked at the ocean site. Only Tottori and Tomakomai observation were allowed the P-band transmitting, because of avoiding interference to the ground radio stations.

2.4 Results of cross-calibration experiment

Cross calibration experiments were carried out at the Tottori sand dune. We used the trihedral and dihedral corner reflectors as standard scatterer. At the same area, the detection experiments of buried materials for basic experiments for archaeological application. The four-band images without cross-calibration are compared. The data are full polarimetric. Cross-calibrated results of L-band between Pi-SAR and AIRSAR are progressed in radiometric, which is reasonable considering the resolution difference.

3. CONTRIBUTION TO DESASTERS

3.1 Volcanic eruption of Miyake-jima, 2000

The first Pi-SAR observation for Miyake Island was carried out on July 6. Figure 1 is the image of the date. Smooth geographical feature over caldera is observed to the top of "Oyama", which is a mountain in the center part of Miyake island. The altitude of the caldera was around 700m from sea level.

On July 8, two days after this observation, large depression occurred on the part of this caldera. In the observation on August 2, the appearance to which the caldera in the top of the island has sunk is clearly caught (Figure 2). The size of sinking obtained from the observation is presumed to be about 1360-

1370m from the measurement of the image taking account of the foreshortening effect of radar image. It is that that many of sinking parts are black areas. This area is shadowing effect by the steep geographical features. Therefore, it has been understood that the depth of sinking can be presumed to be 410 m according to the length of the shadow of Figure 2

The cross-section of the island are derived from the interferometry function of Pi-SAR, which is also good agreement of the size and depth derived from the image analysis.



Figure 1 Miyake island on July 6, 2000 observed by Pi-SAR (X).

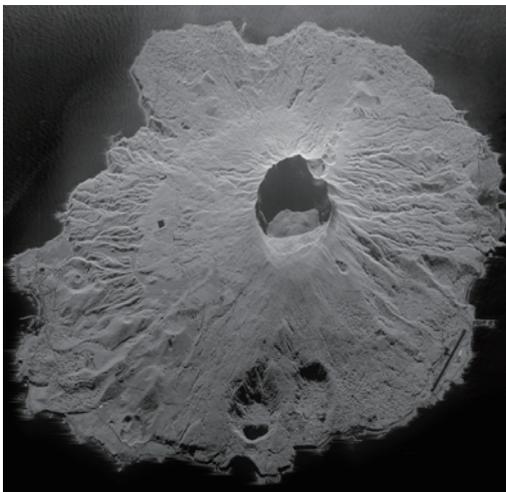


Figure 2. Miyake island after eruptions on August 2, 2000, observed by Pi-SAR (X).

3.2 Earthquakes at Niigata-Chuetsu, 2004

Niigata-Chuetsu earthquake had occurred in the evening of October 23, 2004. The epicenter of the earthquake are almost center of Japanese Honsyu island. As this area is mountainous and many steep slopes are exist, landslides were found everywhere ten kilometers around the epicenter. Roads including high-way , communication, power lines were damaged Train tracks including Shinkansen line were also damaged. About 40 people were killed by the corrupted house or buildings.

On October 26 and November 3, the Pi-SAR observed the disaster area. The weather of the date were rain and it is invisible from the aircraft. The swath of the Pi-SAR is about ten km using both bands, polarimetric and interferometric function. Figure 3 shows the large landslide area which destroyed the road and killed some people who were driving a car. This image are taken by Pi-SAR. We tried to apply polarimetric analysis to the landslide monitoring. Though cross polarization component is expected to excess at the bare soil which was appeared by landslide because of its less complexity, difference between bare soil and vegetated is not clear. The soil must be rough enough. Full polarimetric analysis with scattering mechanism must be necessary.

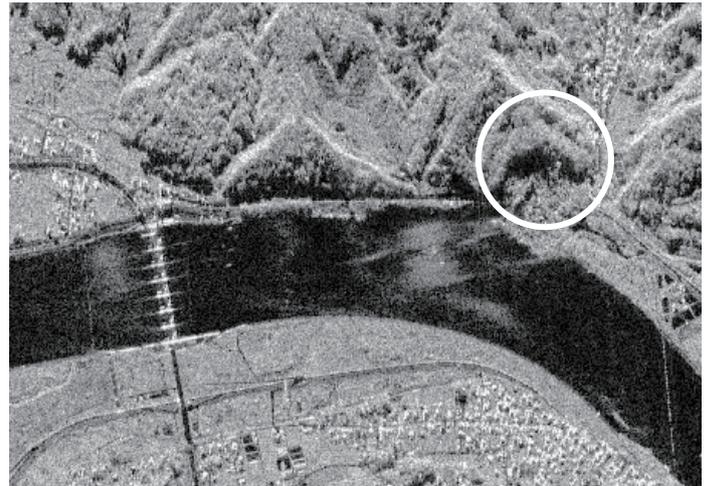


Figure 3 Large landslide had broken the load (circle). This scene size is about 1.5km x 1 km.

4. PI-SAR2: THE SECOND GENERATION AIRBORNE SAR

NICT has developed SAR technology and applications through the experience of Pi-SAR development. Pi-SAR had been used for the disaster monitoring such as volcanic eruptions and earthquake successfully. The data were used for forecasting the volcanic activities day by day and rebuild planning after earthquake. After the experience of the earthquake observation, however, it turned out the necessity of finer resolution and quick delivery of the data for disasters. The resolution of the Pi-SAR (X-band) is 1.5m. The resolution was enough to find the volcanic deformation, but insufficient for finding destroyed small scale infrastructures and landslides after earthquake. Also, the data reached to the devastated area after several days, because SAR processing had been done at ground station at NICT where is departed from airport.

Since 1996, we began to develop an advanced SAR with much higher resolution at least 1m aiming at operational use of SAR in disastrous situation and other widely applications. The realized system: Pi-SAR2 reaches the 30cm resolution and capability of the onboard processing. Detail system will be presented in other papers. Also data transmission from airborne radar to ground nearly real-time will be developed.

References:

- [1] T. Kobayashi, T. Kobayashi, T. Umehara, M. Satake, A. Nadai, S. Uratsuka, T. Manabe, H. Masuko, M. Shimada, H. Shinohara, E. Tozuka, and M. Miyawaki, Airborne dual- frequency polarimetric

- and interferometric SAR, IEICE Trans. Commun., E83-B(9), 1945-1954, 2000.
- [2] T. Umehara, T. Kobayashi, S. Uratsuka, H. Masuko, The Development of the airborne Topographic Imaging radar in CRL, Technical Report of IEICE, SANE95-99, 33-38, 1995.
- [3] S. Uratsuka, T. Umehara, A. Nadai, M. Satake, H. Maeno, T. Matsuoka, H. Masuko, Preliminary results of airborne SAR(Pi-SAR) observation of Usu volcano, Hokkaido, JB84(2), 134-136, 2001.
- [4] Smithsonian National Museum of Natural History ed., Bulletin of the Global Volcanism Network, 25(9), 2000.
- [5] Utilization of Interferometric DEM by Airborne SAR for Volcanic Activities Seiho Uratsuka, Toshihiko Umehara, Hideo Maeno, Akitsugu Nadai, Makoto Satake, Takeshi Matsuoka, Harunobu Masuko, AP-RASC, Tokyo, 2000.
- [6] S. Uratsuka, T. Umehara, M. Satake, H. Maeno, A. Nadai, T. Kobayashi, M. Shimada, H. Wakabayashi, Multiband Polarimetric Interferometric SAR Observation by two airborne SAR, ISTS 2002, Matsue, 2002.
- [7] H. Wakabayashi, S. Uratsuka, Calibration and Data Comparison of Airborne L-band Polarimetric SAR, J. Remote Sensing Soc., 24(1), 64-74, 2004.
- [8] S. Uratsuka, T. moriyama, T. Umehara, A. Nadai, T. Matsuoka, K. Nakamura, H. Masuko, Disastrous Environment after Earthquake observed by airborne SAR (Pi-SAR), 2005 IEEE International Geoscience & Remote Sensing Symposium, Seoul, 2005.
- [9] A. Nadai, S. Uratsuka, T. Umehara, T. Kobayashi, T. Matsuoka, and M. Satake, DEVELOPMENT OF X-BAND AIRBORNE POLARIMETRIC AND INTERFEROMETRIC SAR WITH SUB-METER SPATIAL RESOLUTION, 2009 IEEE International Geoscience & Remote Sensing Symposium, Capetown, 2009.
- [10] T. Matsuoka, T. Umehara, A. Nadai, T. Kobayashi, M. Satake, and S. Uratsuka, Calibration of the High Performance Airborne SAR System (Pi-SAR2), 2009 IEEE International Geoscience & Remote Sensing Symposium, Capetown, 2009.