# Improvement of DEM Quality Derived by Interferometric SAR by Using Multiple Baseline Data Pairs

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**Abstract:** In this paper the possibility to improve the quality of the DEMs generated by space-borne interferometric SAR (InSAR) is investigated by using multiple InSAR data pairs with different baseline lengths. The multiple interferometric data pairs by JERS-1/SAR repeat-pass observation with different baseline lengths are used to generate DEMs in several mountain test areas in Japan. After DEM generation by individual data pairs, they are merged into a final DEM product based on the regression analysis of them. The result indicates that the use of multiple baseline data pairs significantly improves DEM quality with a little increase of height error.
**Keywords:** Interferometric SAR, JERS-1, DEM, Phase unwrapping, Data-deficient area/rate, Height accuracy

## 1. Introduction

Recently interferometric SAR (InSAR) technology has been widely recognized to be an effective and important tool to extract three-dimensional information of the earth surface, namely to generate digital elevation model (DEM). Studies on the quality of DEM derived by space-borne InSAR have been conducted mainly by using ERS SAR data [1,2]. However, in the case of using the data pairs obtained from repeat-pass observations by a space-borne SAR, L-band SAR is considered more suitable for DEM generation because of smaller temporal decorrelation compared with C-band [3]. The authors have been studying on the quality of DEM derived by JERS-1 repeat-pass InSAR data pairs for the application of coming ALOS/PALSAR data for DEM generation [4].

In a previous study, statistical height error sources were analyzed based on random phase noise and it was indicated that the phase noise increases according to the decrease of coherence [1]. It was also indicated experimentally that the height error increases with the decrease of coherence [2]. However, the above study by the authors with JERS-1 InSAR suggests that the height error can be specified by baseline length better than by the average coherence value in the test site [4].

For practical application of InSAR for DEM generation, height accuracy is important, however, there is another important factor, data-deficient area or data-deficient rate, to evaluate DEM quality. The data-deficient area is defined as the area where height computation cannot be performed, and the data-deficient rate as the rate of data-deficient areas within the test site. Data-deficient areas are caused by the failure of phase unwrapping, which might be caused mainly by phase noise. The existence of data-deficient areas is very serious to degrade DEM quality because they are not generated in pixel-wise manner but in wide plane areas, and therefore, it is generally difficult to interpolate the data-deficient areas by using surrounding height values. The above study with JERS-1 InSAR also suggests that the data-deficient rate is correlated to baseline better than to average coherence.

As there is an essential limit to improve DEM quality by using individual InSAR data, one possible approach might be the use of multiple InSAR data. The study mentioned above with JERS-1 InSAR have already suggested that DEM quality is significantly affected by baseline lengths. Therefore, in this paper, the author attempts to improve the quality of DEM generated by L-band InSAR by using multiple InSAR data pairs with different baseline lengths.

## 2. Background and Method

### 2.1 Relationships among Baseline Length, Height Accuracy and Data-Deficient Rate

In height computation by InSAR, it is theoretically clear that data pairs with longer baseline lengths result in higher sensitivity for phase changes caused by height changes, but they result in larger phase noise or lower coherence due to larger spatial decorrelation. The authors have conducted several experimental studies on the relationships among baseline lengths, height accuracies and data-deficient rates by using JERS-1/SAR repeat-pass data pairs and three Japanese mountainous test sites.

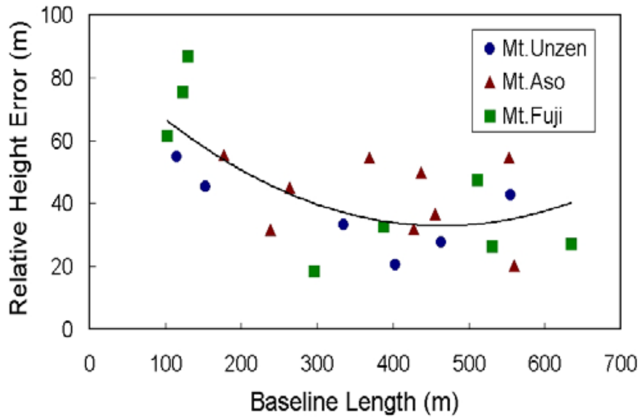


**Fig.1. Relationship between baseline length and relative height error.**

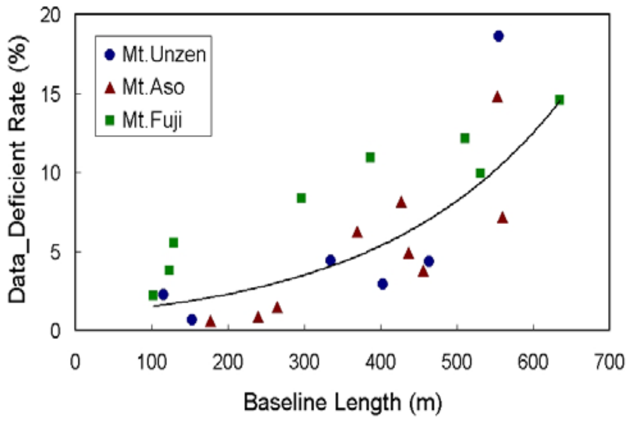


**Fig.2. Relationship between baseline length and data-deficient rate.**

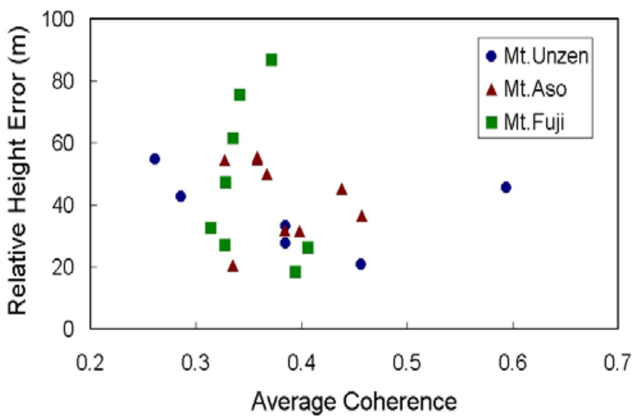


**Fig.3. Relationship between average coherence and relative height error.**

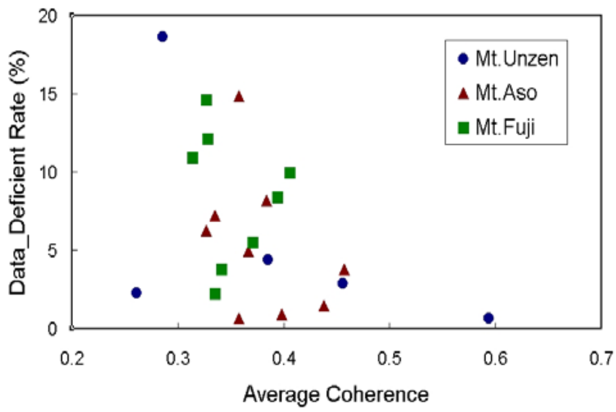


**Fig.4. Relationship between average coherence and data-deficient rate.**

The results obtained from these studies on the relationships between baseline and relative height error (see the comment under Table 1 for the definition of relative height error.) and those between baseline and data-deficient rate are indicated in Figure 1 and 2 respectively. In addition, the relationships between average coherence and relative height error and those between average coherence and data-deficient rate are shown in Figure 3 and 4 respectively.

According to these figures, it is clear that height accuracy and data-deficient rate are correlated to baseline better than to coherence. The data-deficient rate clearly decreases with smaller baseline lengths. This fact suggests that the probability for phase unwrapping failure is related to the slope for spatial phase changes as well as to random phase noise. On the other hand, the height accuracy tends to decrease with smaller baseline lengths and the range from 400 to 500 m in baseline lengths brings in the best accuracy, although the data-deficient rate is generally larger than that with smaller baseline length. In addition, it was found that the seasonal and climate factors (e.g. snow fall) also affect the height accuracy.

The experimental results shown in Figure 1 and 2 clearly indicate that it is basically impossible to obtain the best accuracy and data-deficient rate at once by a single repeat-pass data pair. In addition, it is also difficult to select the best pair without considering season, weather conditions and so on. Therefore, for practical application, it is necessary to use multiple data pairs with different baseline lengths and also different seasons/weather conditions for the achievement of more reliable DEM generation than by a single data pair. In this sense, SAR data are superior to optical data due to its all weather characteristics.

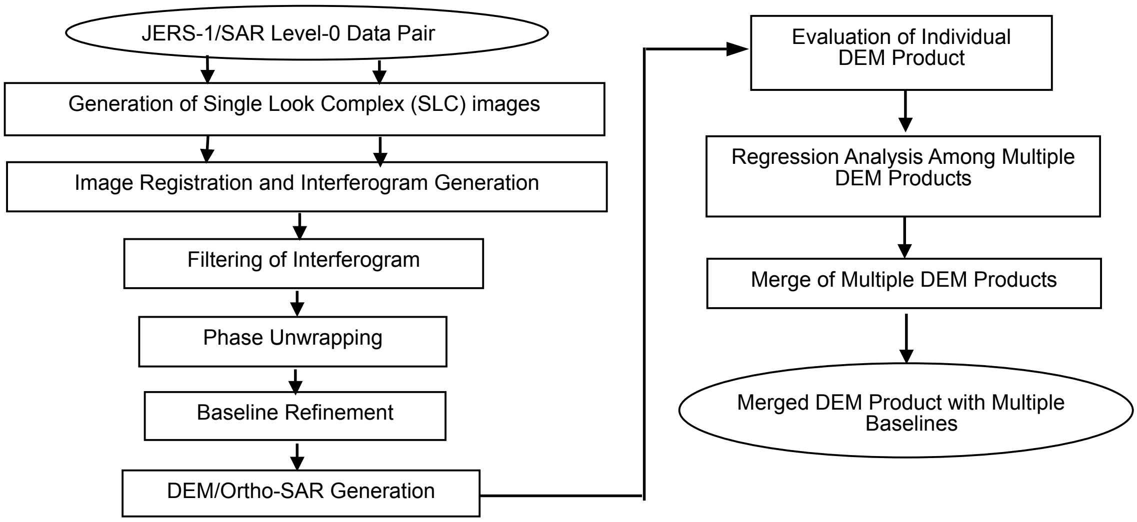


**Fig.5. Flowchart of data processing for DEM generation based on multiple baseline InSAR data pairs.**

### 2.2 Data Processing Method for DEM Generation

The flowchart for DEM generation based on multiple baseline data pairs is indicated in Figure 5. Vexcel 3dSAR Processor developed by Vexcel Co. in U.S.A is used for the interferometric data processing shown in the left part of Figure 5. For the refinement of baseline lengths, about 20 GCP's are necessary to be selected in the test site with their geo-location and ground height values. The height accuracies and data-deficient rates of individual InSAR-derived DEMs are evaluated compared with the DEM issued by Geographical Survey Institute of Japan (GSI).

Then regression analyses are performed among the multiple DEM products by InSAR with a standard which is selected from the multiple products in an arbitrary manner. The non-standard individual DEMs are converted to the standard DEM based on the results of regression analyses, and finally all DEM products are merged into a single DEM product.

## 3. Results and Discussion

We conducted several experiments to use multiple baseline data pairs and to apply the data processing method shown in Figure 5 at the test areas of Mt.Unzen, Mt.Aso, and Mt.Fuji. A total of seven, nine and eight JERS-1/SAR repeat-pass data pairs were used for above three test areas respectively.

### 3.1 Results by Individual Data Pairs in Mt. Fuji

Table 1 indicates the result of the DEMs created by eight single baseline data pairs in Mt. Fuji. The shortest observation interval for repeat-pass observation by JERS-1 is 44 days and all data pairs were selected with this shortest interval and with baseline lengths shorter than 700 m.

**Table 1. Test data pairs for DEM generation and their results on height accuracy and data-deficient rate in Mt. Fuji.**

| Pair-No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Observation Dates (yy.mm.dd) | 93.07.07<br>93.08.20 | 93.10.03<br>93.11.16 | 95.04.28<br>95.06.11 | 95.09.07<br>95.10.21 | 95.12.04<br>96.01.17 | 97.04.01<br>97.05.15 | 97.06.28<br>97.08.11 | 98.02.39<br>98.03.19 |
| Baseline (m) | 511 | 635 | 387 | 296 | 531 | 123 | 102 | 129 |
| Relative HE* (m) | 47.420 | 27.045 | 32.755 | 18.430 | 26.256 | 63.565 | 61.476 | 86.768 |
| Absolute HE* (m) | 53.150 | 31.104 | 37.917 | 30.595 | 28.779 | 92.061 | 70.701 | 95.098 |
| Data-deficient rate (%) | 12.132 | 14.587 | 10.916 | 8.375 | 9.937 | 3.752 | 2.214 | 5.527 |

*HE means the height error compared with the DEM by GSI. Relative HE means the standard deviation of the residues after the pixel-wise regression between InSAR-DEMs and the GSI-DEM. Absolute HE means the root-mean-square value of the pixel-wise differences between InSAR-DEMs and the GSI-DEM.

The height accuracy was evaluated for the DEMs generated by InSAR (InSAR-DEMs) from the data pairs in Table 1 by comparing them with the DEM issued by Geographical Survey Institute of Japan (GSI-DEM). The indices for height accuracy are relative height error (RHE) and absolute height error (AHE). The former is obtained by the residues after the pixel-wise regression between an InSAR-DEM and the standard GSI-DEM, and the latter by computing the pixel-wise differences between the two DEMs. The data-deficient rate (DFR), which indicates the rate of impossible areas for height computation in the test site, is also shown in Table 1 for each data pair.

It is definitely clear in Table 1 that DFR is the minimum for the shortest baseline pair (Pair No.7) and the maximum for the longest baseline pair (No.2), and that DFR is almost proportional to the baseline length. On the other hand, the RHE and AHE are not the least for the shortest baseline pair (No.7). In Table 1, better HEs are obtained for the baseline range from 300 m to 500 m (No.4 and 5) and their DFRs are around 10 percent. As to the seasonal factor, the HEs of the data pair acquired in non-summer seasons (September to May) result in relatively better HEs than those in summer season (June to August) except the data pair No.8 acquired in February and March.

The test site around Mt. Fuji has not much snow in winter season because it is located in the Pacific Coast of the Japan Islands, however, there are sometimes heavy snow falls in February. Therefore, the reason for the worse HE in the data pair No.8 than other winter data pairs is considered due to the effect of snow cover melting on the ground surface from February to March.

### 3.2 Results by Multiple Baseline Data Pairs in Mt. Fuji

As the next step, the DEM products by multiple data pairs acquired with different baseline lengths were merged in order to generate the DEM with better quality, namely smaller DFR and better HE. Although the best data pair on HE exists among the data pairs in Table 1, it is actually difficult to select this pair *apriori* because there is no definite relationship between baseline and HE at the moment, and therefore, the best pair happens to appear. So, the selection of the standard data pair was made in an arbitrary manner, namely the first data pair in Table 1 was selected as the standard.

First pixel-wise regression analyses between the standard InSAR-DEM (DEM generated from the selected standard pair) and other InSAR-DEMs were performed. Then height values in non-standard InSAR-DEMs were converted to those in the standard DEM based on the regression analyses. Finally the standard and the converted non-standard DEMs were merged into a single DEM product. In the merge process, the pixel data in all DEMs were averaged if the pixel was not included in any data-deficient areas.

Figure 6 shows the result of merging of multiple baseline data pairs. The figures (a) and (b) indicate the DEM for the best RHE (No.4) and the best DFR (No.7) respectively. The figure (c) shows the merged DEM product by all data pairs in Table 1. From the figures (a), (b), and (c), the height patterns of the merged DEM are significantly improved compared with those of (b) and become closer to those of (a), and at the same time, the data-deficient areas are also much reduced. The RHE and DFR for the merged DEM (c) were 34.639 m and 0.379 % respectively. The DFR is smaller than any data pair in Table 1, and the RHE is not the least but much smaller than that of data pair No.7, which gave the best DFR. We excluded the data pair No.8 because of the considerable effect by snow cover as described above, and then the RHE and DFR became 28.266 m and 0.963 % respectively.

### 3.3 Results in Other Test Areas

Table 2 indicates the results of the DEMs by multiple baseline data pairs and single baseline data pairs in Mt. Unzen and Mt. Aso together with Mt. Fuji. In Table 2, the results by single baseline are indicated for the best pairs in RHE and in DFR respectively. Table 2 indicates that in both test areas of Mt. Unzen and Mt. Aso the application of multiple baseline data pairs succeeded to create the DEMs with ten times smaller DFR and with a little increase of HE. Figure 7 and 8 show the DEMs by multiple baseline data pairs with those by GSI in Mt. Unzen and Mt. Aso respectively.

**Table 2. Result of DEMs by multiple baseline data pairs.**

| Test Site | Data Pair (BL:Baseline) | Relative HE (m) | Data-deficient rate (%) |
|---|---|---|---|
| Mt.Unzen | Multiple-BL | 24.54 | 0.072 |
| | Single-BL | 24.23 | 2.90 |
| | | 71.95 | 0.654 |
| Mt.Aso | Multiple-BL | 26.65 | 0.066 |
| | Single-BL | 20.45 | 7.20 |
| | | 55.41 | 0.635 |
| Mt.Fuji | Multiple-BL | 34.64 (28.27)* | 0.379 (0.963)* |
| | Single-BL | 18.43 | 8.375 |
| | | 61.48 | 2.214 |

* Excluding DEM affected by snow cover.

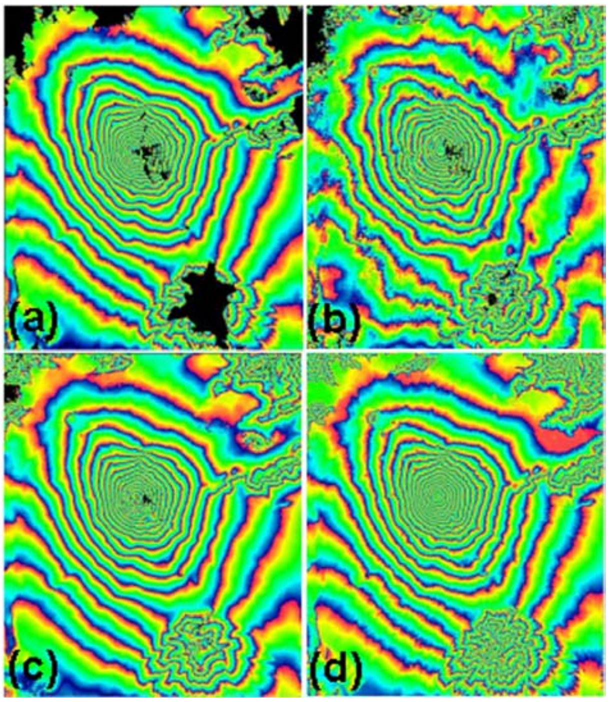


Fig.6. Height patterns of Mt. Fuji by the DEMs generated by JERS-1 InSAR ( (a): Best DEM for relative height error (Pair-4), (b): Best DEM for data-deficient rate (Pair-7), (c): Merged DEM product by eight multiple data pairs ) and the DEM issued by GSI(d). The height patterns are represented by wrapped color image with 200 m intervals (same in Fig.7 and 8).

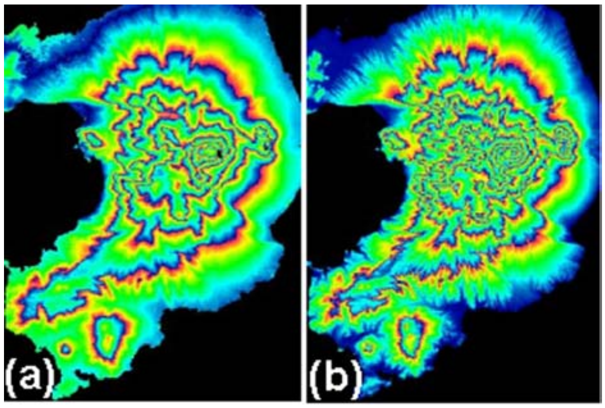


Fig.7. Height patterns of Mt. Unzen. [(a): Merged DEM product by seven multiple data pairs, (b): DEM issued by GSI].

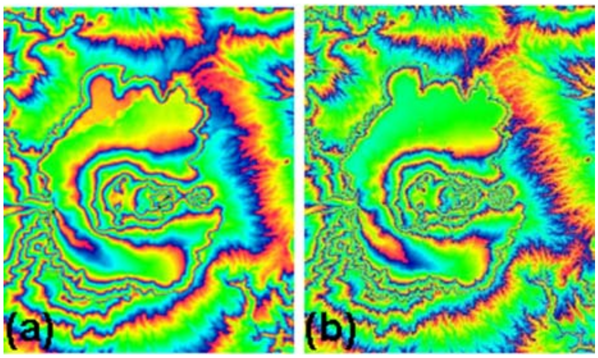


Fig.8. Height patterns of Mt. Aso. [(a): Merged DEM product by nine multiple data pairs, (b): DEM issued by GSI].

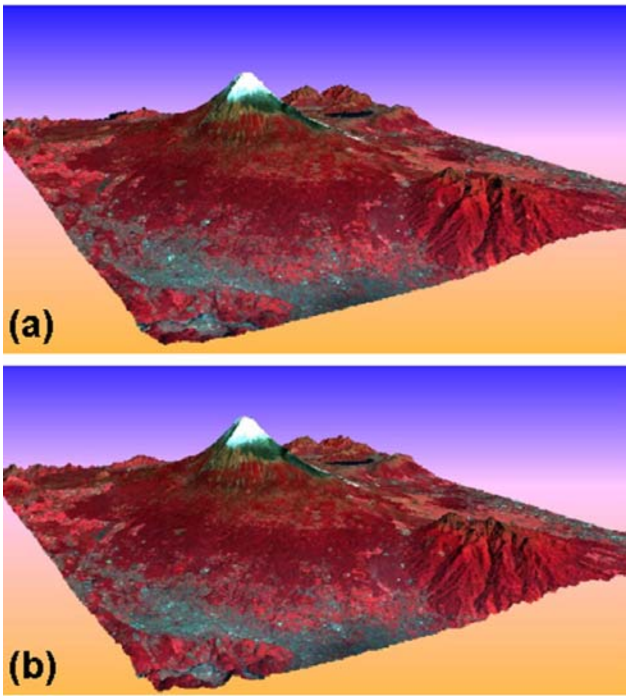


Fig.9. Bird's eye view images by the DEMs created by InSAR (a) and issued by GSI(b) in Mt. Fuji study area.

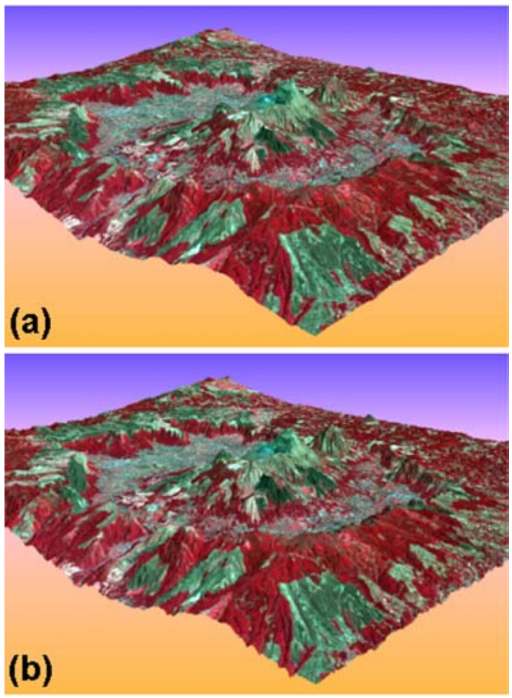


Fig.10. Bird's eye view images by the DEMs created by InSAR(a) and issued by GSI(b) in Mt. Aso study area.

### 3.4 Bird's Eye View Image Generation by InSAR-DEM

As the data-deficient rate significantly reduces according to the use of multiple baseline data pairs as described above, it becomes much easier to interpolate data-deficient areas by surrounding height values and to generate a complete DEM product. To evaluate the final InSAR-DEM product, bird's eye view images were generated with the final DEM derived by InSAR and the DEM issued by GSI together with Landsat-7/ETM+ data. Figure 9 and 10 show the generated bird's eye view images in Mt. Fuji and Mt.Aso respectively. The qualities of InSAR-DEM are evaluated by comparing the bird's eye view images between InSAR-DEM and GSI-DEM. Figure 9 and 10 clearly support that InSAR-DEM by multiple baseline data pairs have sufficient qualities to generate natural bird's eye view images.

### 3.5 Discussion

In Table 2 the increase of height error by multiple baseline data pairs for Mt. Fuji is rather larger compared with those for Mt. Unzen and Mt. Aso. One of the reasons is considered that the height differences within the test areas are the largest for Mt. Fuji because Mt. Fuji is the highest mountain in Japan and therefore the height errors much changes according to data conditions. Actually the differences in height errors among individual data pairs are the largest for Mt.Fuji in Figure 1. Another reason might be due to the existence of small mis-registration among the DEMs by individual data pairs, which might bring small distortion in height patterns. This effect is seen around the top of Mt. Fuji in Figure 6 (c).

There still remain some problems as described above in the data processing method in this study. However, as the height error is actually much affected by various factors such as baseline, season, weather condition etc, the quality of the DEMs derived by indivdual InSAR data are considered rather unstable in general and also it is difficult to select the best one *apriori* among them. Therefore, foregoing data processing method is considered to be one of the practical approaches for realizing acceptable DEM generation based on space-borne InSAR technology.

## 4. Conclusion

In this study, it was proved that the combined use of multiple baseline data pairs gives significant improvement of qualities of the DEMs generated by space-borne InSAR. It results in significant decrease of data-deficient rate over ten times, although the height error slightly increases compared with the best one among possibly usable data pairs. By considering the results obtained in this study, the data processing method proposed in this paper is to be one of the practical approaches for realizing acceptable DEM generation based on space-borne InSAR technology.

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