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MONITORING OF DEFORESTATION IN TROPICAL RAIN FOREST AREAS BY USING INSAR - COMPARISON BETWEEN L-BAND AND C-BAND SAR -

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ABSTRACT: The author compared the capability of coherence information obtained from interferometric SAR (InSAR) by C-band SAR of ERS-1 and 2 and by L-band SAR of JERS-1 for the purpose of monitoring the changes of tropical rain forest due to deforestation. The test site was a southern part of Sumatra Island with 50 by 50 kilometers coverage. The several repeat-pass interferometric data pairs by JERS-1 and ERS-2 acquired from 1996 to 1998 were used to compare the coherence patterns between L-band and C-band SAR. In addition, two tandem pairs by ERS-1 and 2 were used to compare the coherence patterns between repeat-pass and tandem pairs of C-band SAR. The result indicated that the coherence obtained from ERS repeat-pass pairs was almost useless due to its extremely poor quality. On the other hand, the coherence obtained from JERS-1 repeat-pass pairs was proved to be useful for identifying the deforested areas together with the coherence obtained from ERS tandem pairs. The performances for land cover classification with the combined use of intensity and coherence were also compared among JERS-1 repeat-pass, ERS repeat-pass, and ERS tandem data pairs. The result indicated that the classification accuracy for deforested areas was significantly improved by combining coherence with intensity for JERS-1 repeat-pass and ERS tandem pairs. On the other hand, ERS repeat-pass resulted in almost no improvement even by the combination of intensity and coherence. The result of this study strongly suggests the usefulness and the importance of the repeat-pass interferometry by L-band SAR like ALOS/PALSAR for the purpose of monitoring tropical rain forest changes.

1. INTRODUCTION

Recently the coherence information obtained from interferometric SAR (InSAR) has been widely recognized to be useful for forest monitoring or classification. Especially, the coherence by ERS-1 and 2 tandem data pairs has been proved very effective for this purpose (Floury and Toan *et al*, 1997, and Strozzi and Wegmuller *et al*, 2000). In addition, the author has already indicated that the coherence by JERS-1/SAR repeat-pass data pair is also effective for the same purpose (Suga and Takeuchi, 2000 and Takeuchi, 2001). Although the tandem observation is the best for the purpose of land cover monitoring because of its only one day difference of observation, we can not use this kind of observation for a while because ERS-1 already stopped its operation and no tandem mission will appear at least for several years from now. Therefore, for the present, the repeat-pass interferometric pairs by C-band (present ERS-2/SAR or RADARSAT) or L-band (coming ALOS/PALSAR) will be only the options for utilizing coherence for land cover or forest monitoring. This paper describes the result of a comparative study on the capability of coherence by repeat-pass C-band and L-band data pairs for monitoring deforestation in tropical rain forest regions.

2. STUDY AREA

The test site is located at the central area of the southern Sumatra Island in Indonesia and the size of the test site is 50 Km by 50 Km as shown in Fig.1. Wide areas in Sumatra Island are covered by peat and plenty of swamp forests are grown up on the peat bog. This kind of swamp forests are not suitable areas for human living, and so, the swamp forests have been remained almost in natural conditions for long years. However, recent increase for the demand of plantation products such as oil-palm has stimulated the development for economical progress and as a result many plantations have sprung up in the test site. The plantation development described above also resulted in rapid deforestation of the swamp forests and almost of the swamp forests have been disappeared in the test site.

Fig.2 shows three multitemporal images of the test site by optical sensors, MOS-1/MESSER in 1990, SPOT/HRV in 1997 and 1998, respectively. These images clearly indicate the expansion of deforested areas. In 1990, the test site was almost covered by forest, primary swamp forest colored by dark red, and logged forest colored by bright red. However, in 1997, a big part of these forest areas had been deforested and converted into plantation. In 1998, the primary swamp forest in the test site almost disappeared due to deforestation (Takeuchi and Suga, 1999).

3. TEST DATA

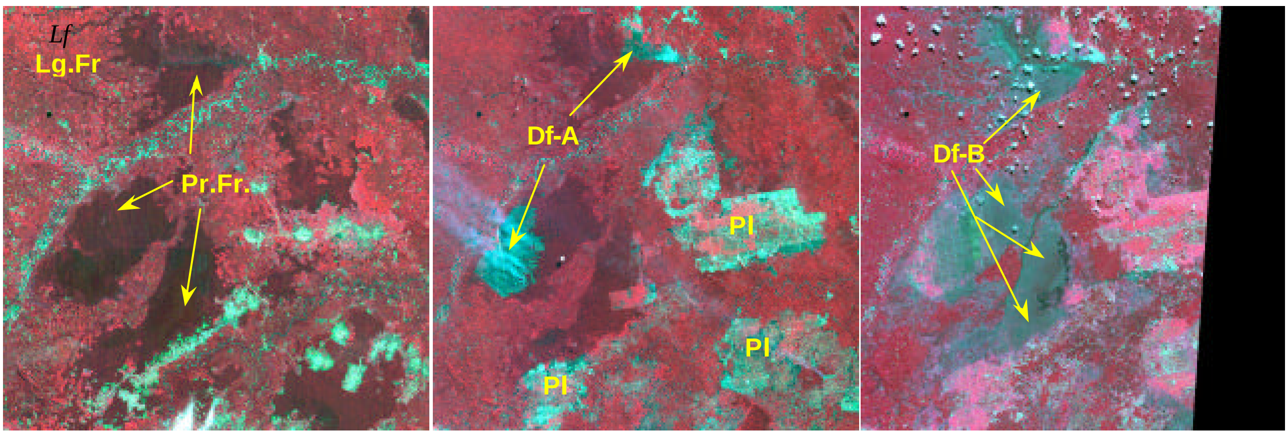
The data pairs used for this study are shown in Table 1 with the baseline length (perpendicular component). Four data pairs respectively by ERS-1,2/SAR (C-band) and by JERS-1/SAR (L-band) were used for comparison. For ERS/SAR data, two of them were acquired by tandem mode and the other two by repeat-pass observation. The numbering from 1 to 4 for each data pair indicates approximately similar observation period between ERS and JERS. The repeat-pass pairs of ERS-2 were almost best data pairs for interferometry because their baseline lengths were very short, 15 and 14 meters respectively.

Fig.1. Study area.

For JERS data pairs, all data pair were acquired by repeat-pass observation and their baseline length were generally longer than those for ERS data pairs. We tried to obtain the data pairs which observation interval was as short as possible, namely by one repeat cycle, 44 days for JERS and 35 days for ERS. However, it was rather difficult for ERS to find a short baseline pairs and one of them (ERS-Rp3) was acquired with 70 days interval (two repeat cycles), which corresponds to JERS-Rp3 with 132 days interval (three repeat cycles).

Table 1. List of interferometric data pairs used for the study.

Name of data pair	Combination of observation dates (yyyy/mm/dd – yyyy/mm/dd)	Observation interval	Observation mode	Baseline length
ERS-Td1	1996/05/04(E1) – 1996/05/05(E2)	1 day	Tandem	139 m
ERS-Td2	1997/10/11(E1) – 1997/10/12(E2)	1 day	Tandem	354 m
ERS-Rp3	1997/08/03(E2) – 1997/11/16(E2)	70 days	Repeat-pass	15 m
ERS-Rp4	1998/09/27(E2) – 1998/11/01(E2)	35 days	Repeat-pass	14 m
JERS-Rp1	1996/10/15 – 1996/11/28	44 days	Repeat-pass	678 m
JERS-Rp2	1997/10/02 – 1997/11/15	44 days	Repeat-pass	1497 m
JERS-Rp3	1997/07/06 – 1997/11/15	132 days	Repeat-pass	109 m
JERS-Rp4	1998/03/27 – 1998/05/10	44 days	Repeat-pass	833 m



MOS-1/MESSR 1990/05/23 SPOT/HRV 1997/06/30 SPOT/HRV 1998/08/10

[Pr.Fr.: Primary swamp forest, Lg.Fr. : Logged forest, Pl : Plantation, Df-A/B : Deforested area]

Fig.2. Multi-temporal optical sensor images of the study area (from May,1990 to Aug.,1998).

(MOS-1: NASDA retains ownership of data. SPOT: ©CNES 1997/1998)

4. COMAPRISON OF COHERENCE BETWEEN ERS AND JERS DATA PAIRS

Fig.3 (a) to (d) show the coherence images obtained from the data pairs in Table 1, where the coherence images by ERS and JERS data pairs of similar period correspond each other. The symbols in the figures, Lg.Fr., Df-A, DF-B and Pl indicate non-deforested logged forest, deforested primary forest-A, deforested primary forest-B and plantation respectively. According to the SPOT images shown in Fig.2, the deforestation for Df-A started in 1996 and completed until the end of June in 1997 and the deforestation for Df-B started in late 1997 and completed until May in 1998 (Takeuchi and Suga, 1999).

Fig.3 (a) and (b) show the comparison of coherence patterns between ERS tandem pairs and JERS repeat-pass pairs. These figures indicate that the coherence patterns by ERS tandem and JERS repeat-pass result in very similar patterns each other. Both patterns indicate that coherence of plantations is clearly high and that of primary forest before deforestation (Df-A and Df-B in (a) and Df-B in (b)) is very low. In the figures of (b), newly deforested forests in 1997 (Df-A) appear in very bright and clear patterns in both ERS-Td2 and JERS-Rp2. This result suggests that the coherence is a very effective parameter to detect deforestation.

On the other hand, Fig.3 (c) and (d) show the comparison between ERS repeat-pass pairs and JERS repeat-pass pairs. It is quite remarkable that the coherence patterns by ERS repeat-pass pairs do not result in any significant patterns compared with those by JERS repeat-pass pairs in spite of very short baseline length for ERS pairs. This result suggests that the coherence by a C-band repeat-pass pair is quite difficult to be used for land cover classification or its change detection in tropical rain forests. On the other hand, in JERS-Rp4, the coherence in Df-B is clearly recognized to increase than that in JERS-Rp1, 2 and 3. This coherence change clearly indicates that the deforestation for Df-B was much progressed or completed until the observation period by JERS-Rp4 (from the end of March to May in 1998).

Fig.4 shows the graphical patterns of coherence values for Lg.Fr., Df-A, Df-B and Pl in ERS and JERS data pairs. From these graphs, it is confirmed that the coherence by both of ERS tandem and JERS repeat-pass pairs can easily identify plantations or deforested areas by its higher value than that of non-deforested forests. On the other hand, the coherence by ERS repeat-pass pairs can not bring any significant information about the discrimination of plantations or deforested areas from non-deforested forests.

One problem for JERS repeat-pass pairs is that the interval for acquiring coherence information is very long, namely 44 days at least. This effect appears in the coherence patterns of JERS-Rp2 and JERS-Rp3, in which the bright coherence patterns became fuzzy or reduced in plantations and deforested areas. This effect is considered due to land cover changes during observation interval. Therefore, the time interval of a data pair should be as short as possible if this data pair is used for land cover analysis.

5. COMPARISON OF CLASSIFICATION ACCURACY BY COBINING COHERENCE WITH BACKSCATERING INTENSITY

The landcover classification accuracies by using only SAR backscattering intensity and by combining coherence with intensity were also compared between ERS and JERS data pairs. The landcover classes are primary swamp forest (Pf), logged forest (Lf), plantation (Pl), and deforested areas-A (Df-A) and B (Df-B) and the maximum likelihood classifier (MLC) was employed as the classification method. The training samples were selected based on the visual interpretation of the optical sensor images in Fig.2.

The classification accuracy was evaluated by the following two indices, true production rate (TPR) and false production rate (FPR). The TPR is the correct production rate within the training samples, and the FPR is the rate for false production within the classified samples. By using confusion matrix obtained from the classification of training samples, the TPR is obtained as the orthogonal component of the confusion matrix, and the FPR is obtained as the rate of the sum of non-orthogonal components to the sum of all components in a specific column of the confusion matrix under the assumption that the probabilities for occurrence are equal among all of the classes. Table 2 shows an example to obtain the TPR and FPR from a confusion matrix. Fig.5 shows the results of the evaluation by TPR and FPR for the cases that only the intensity is used for classification (Intensity only) and both of the coherence and intensity are used for classification (Intensity + Coherence). The intensity was obtained from one of SAR data of an interfometric data pair.

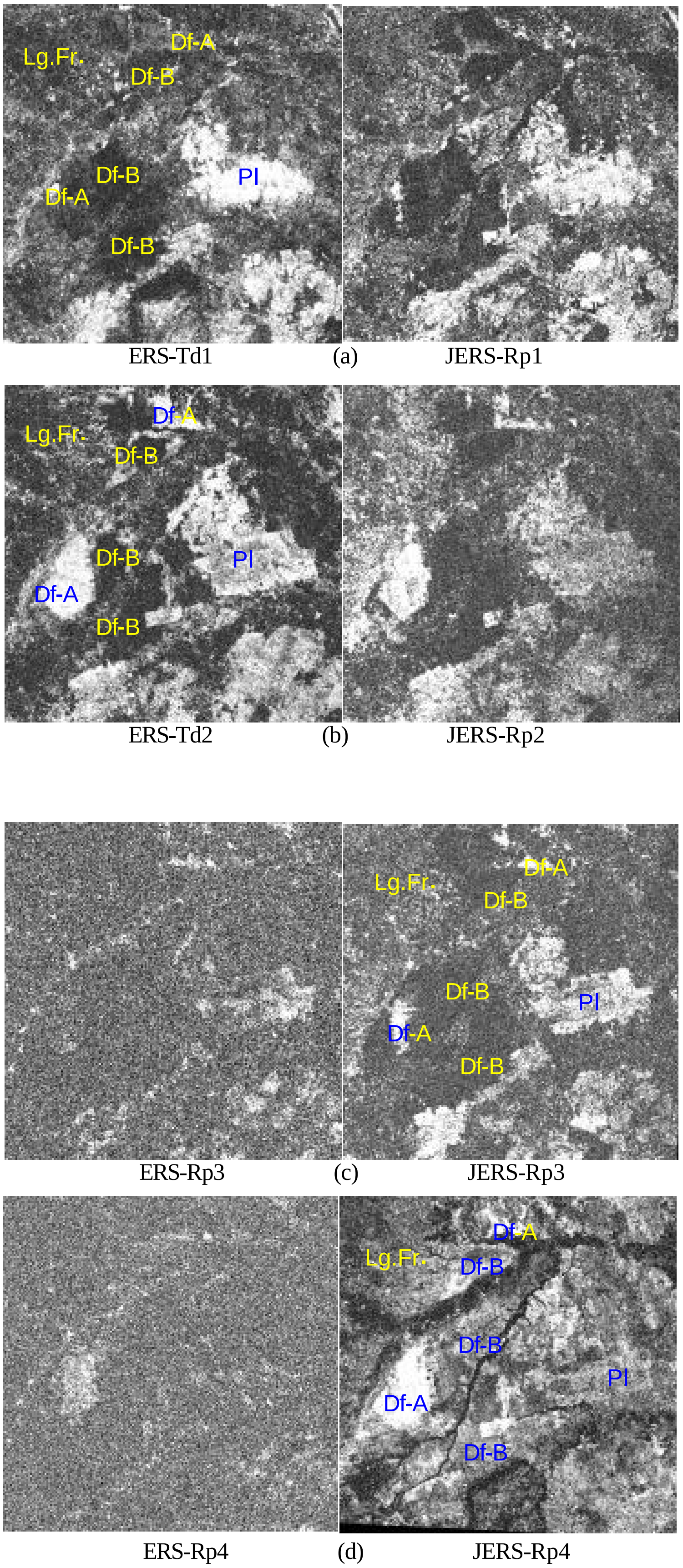
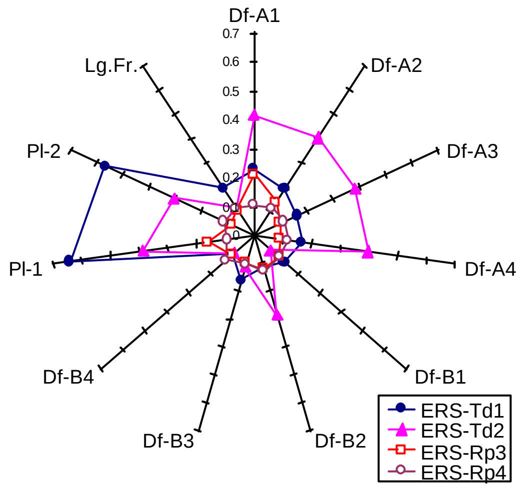
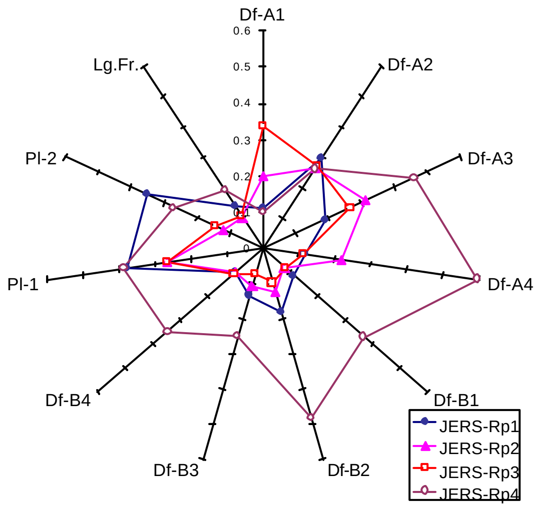


Fig.3. Coherence patterns by ERS and JERS data pairs.



(a) ERS tandem and repeat-pass data pairs.



(b) JERS repeat-pass data pairs.

Fig.4. Graphs of coherence values for sample areas of non-deforested logged forest (Lg.Fr.), deforested forest-A (Df-A1 to A4), deforested forest-B (Df-B1 to B4), and plantation (Pl-1, Pl-2) by ERS data pairs (a) and JERS data pairs (b).

Df-As were deforested after the observation periods by ERS-Td1 and JERS-Rp1 and before the periods by ERS-Td2, ERS-Rp2, JERS-Rp2 and JERS-Rp3. Df-Bs were deforested after the periods by above all pairs and before the periods by ERS-Rp4 and JERS-Rp4.

Table 2. An example of TPR and FPR computed from a confusion matrix.
(The case for combined use of intensity and coherence by JERS-Rp2)

Classes to which training samples belong \ Classes after classification	Pf	Lf	Pl	Df-A	TPR
Primary forest (Pf)	87.1	12.9	0.0	0.0	87.1
Logged forest (Lf)	48.1	40.7	3.5	7.6	40.7
Plantation (Pl)	0.4	7.9	75.1	16.6	75.1
Deforested area-A (Df-A)	3.7	11.4	18.8	66.2	66.2
FPR	37.5	44.2	22.9	26.8	

*The figures in the table represent percent classification scores.
* TPR : True Production Rate, FPR : False Production Rate.

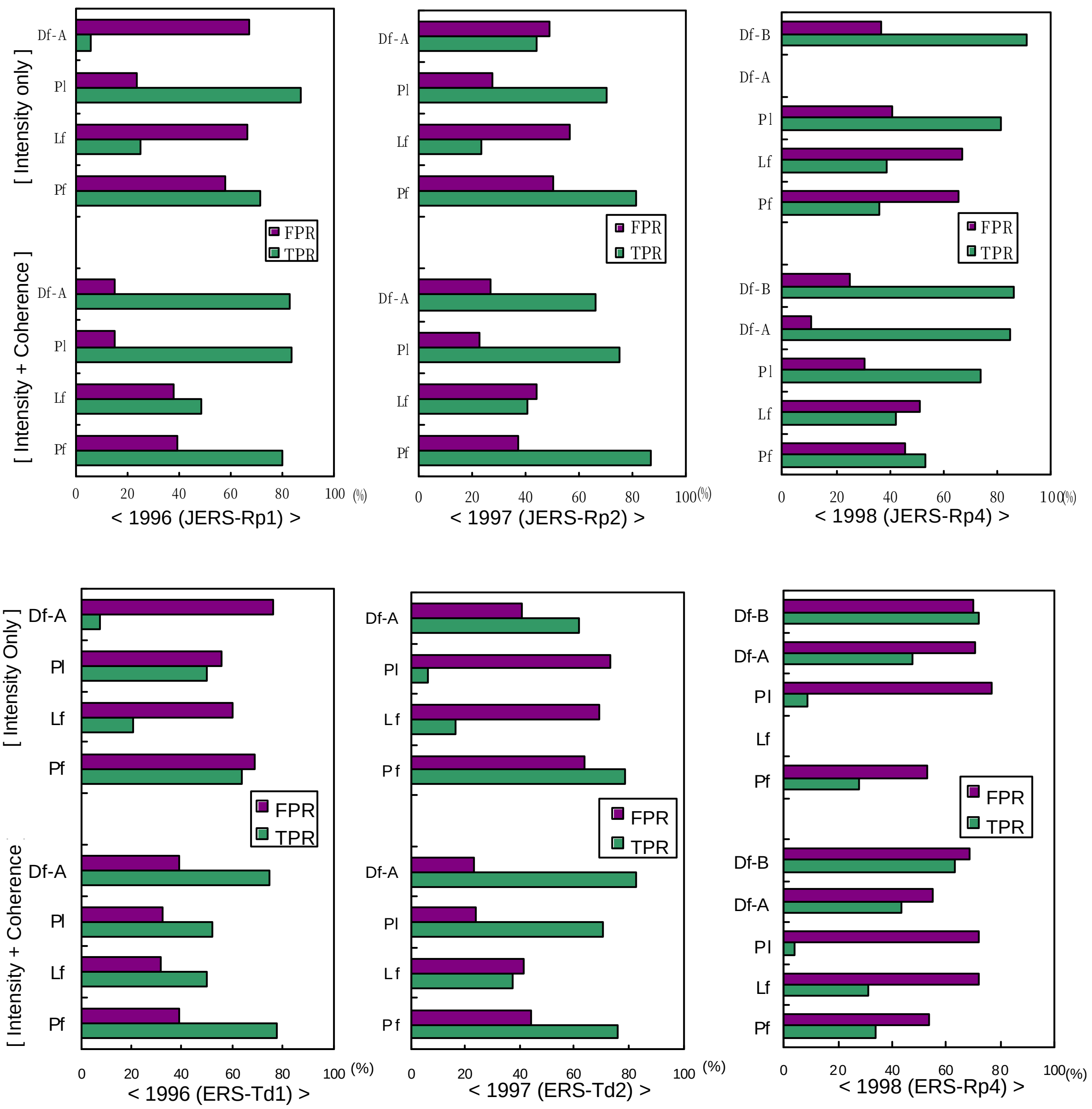


Fig.5. Results of evaluation by TPR (true production rate) and FPR (false production rate) for landcover classification by the use of intensity only and by the combined use of coherence with intensity. The upper row indicates the results for JERS data pairs and the lower indicates those for ERS data pairs.

The results in Fig.5 clearly indicate that the classification accuracies for deforested areas-A and B are significantly improved by combining coherence with intensity for both of JERS repeat-pass and ERS tandem data pairs. The classification accuracies for plantation are also improved for ERS tandem data pairs, although those are not improved much for JERS-1 data pairs because the plantation is well discriminated even by the intensity of JERS-1 SAR data. On the other hand, for ERS repeat-pass data pair (ERS-Rp4), the classification accuracies for deforested areas and plantation are hardly improved even by the combined use of coherence with intensity. This result coincides with the result by the visual interpretation of coherence patterns from ERS repeat-pass data pairs as described in the previous section.

The foregoing analyses on landcover classification by combining coherence with intensity by JERS and ERS data pairs strongly suggest that the repeat-pass InSAR by L-band SAR has almost comparable capability to C-band tandem InSAR for mapping deforestation in tropical rain forest areas. Japan will launch ALOS satellite with L-band SAR named as PALSAR in 2003, and therefore, the experimental result in this paper strongly supports that the repeat-pass InSAR by ALOS/PALSAR will be one of the effective and practical approaches for achieving the monitoring of the deforestation of tropical rain forest areas.

6. CONCLUSION

In this paper the author evaluated the capability of coherence information obtained by InSAR for detecting deforestation in tropical rain forest areas among L-band repeat-pass, C-band tandem and C-band repeat-pass interferometric data pairs. As the result, the following concluding remarks are obtained;

(1) The coherence information obtained by L-band (JERS-1) repeat-pass interferometric data pairs was proved to have almost comparable capability to that by C-band (ERS) tandem data pairs for detecting deforestation in tropical rain forest regions.

(2) Landcover classification accuracy was significantly improved for deforested areas by the combined use of coherence with intensity compared with the use of intensity only for JERS-1 repeat-pass and ERS-tandem data.

(3) For C-band (ERS) repeat-pass data pairs, the coherence patterns were very poor even with a very short baseline length, and the landcover classification accuracy about deforested areas or plantation was hardly improved even by the combined use of coherence with intensity.

(4) These experimental results strongly suggest that L-band repeat-pass InSAR is a very effective and practical approach for tropical rain forest monitoring, and also the high potential of coming ALOS/ PALSAR launched by Japan for tropical rain forest monitoring.

These experimental results also suggest that interferometric SAR is one of the effective and practical approaches for tropical rain forest monitoring in general and that L-band SAR is superior to C-band SAR with the use of repeat-pass interferometry for the purpose of monitoring of forest conditions such as tropical rain forest areas.

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