ISSN 1346-7328
国総研資料 第 1159 号
令和３年４月

国土技術政策総合研究所資料

TECHNICAL NOTE of
National Institute for Land and Infrastructure Management

No.1159 April 2021

Expository casebook of scattering changes in synthetic aperture radar (SAR) in time of disaster

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国土技術政策総合研究所資料 Technical Note of NILIM
第1159号 2021年4月 No.1159 April 2021

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Synopsis

In time of disaster, it is useful to utilize survey results based on scattering changes of SAR when it is difficult to collect information using optical sensors during the night or bad weather. It is essential to have a broad understanding of various scattering changes of SAR.

This casebook explains scattering change of SAR in recent disaster cases in terms of characteristics and its pitfalls, and shows a survey procedure to better the interpretation of sediment-related disasters using SAR images.

Key Words: Synthetic Aperture Radar（SAR）, Scattering Change, Backscatter Intensity, Sediment-related Disaster

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Introduction

The Ministry of Land, Infrastructure, Transport and Tourism concluded the "Agreement Concerning Cooperation for the Provision of Information on Disasters Using Artificial Satellites, Etc." with the Japan Aerospace Exploration Agency, a National Research and Development Agency, (hereinafter called the "JAXA") in 2017, in order to realize speedy and appropriate response to disasters. This has increased opportunities in which satellite images are utilized in scenes where the situation of disaster damage is grasped during initial response to a disaster.

Our Division conducted the "Joint research on the development of methods to monitor landslide/mudflow using Daichi 2, the advanced land observing satellite" with JAXA, and in April 2020 publicized Technical Note of National Institute for Land and Infrastructure Management No. 1110 "Guideline for the interpretation of sediment-related disasters by synthetic aperture radar（SAR） images (hereinafter called the "Image Interpretation Guideline")" [1)].

The Image Interpretation Guideline showed a method for surveying the situation of occurrence of a sediment disaster by focusing on changes in scattering of SAR that are made by the occurrence of the sediment disaster. By means of this, effects of generalization of the image interpretation technology are expected, by reducing the errors in the results of image interpretation caused by differences in experiences, differences in insight, etc. of the persons in charge of image interpretation.

However, the situations of erosion and deposition associated with the occurrence of a sediment disaster are varied, and they may show irregular changes in the scattering of SAR. Moreover, after a torrential rain or earthquake that would cause a sediment disaster, cases are expected in which there are great changes from the situation before the disaster, such as damage caused to the national land or infrastructure, their disappearance, or their loss by outflow.

When conducting the image interpretation survey of sediment disasters based on changes in the scattering of SAR, it is effective to understand a wide variety of scatter change characteristics of SAR.

This material gives explanations of the features of changes in the scattering of SAR and precautions for image interpretation by using the disaster examples in recent years. It has organized the tendency of changes in the scattering of SAR during a disaster, and has proposed procedures for the image interpretation survey of sediment disasters by means of SAR images.

It is our hope that this material will serve as a technical material for deepening the understanding of the image interpretation of sediment disaster using SAR images, and at the same time the material will lead to the development of monitoring technologies in the fields of the national land and infrastructure during a disaster by using SAR images.

April 2021

Sediment Disaster Risk Management Division, Sediment Disaster Research Department

[SAR images and examples of disasters to be handled in this material]

In this material, HH single-polarized SAR images of 3 m in resolution were used, which were observed in high resolution mode (strip map) of the L-band SAR (PALSAR-2) onboard the "Daichi 2," the advanced land observing satellite No. 2, (hereinafter called "ALOS-2") operated by JAXA [2)]. Therefore, this material is to give explanations based on examples about the scatter change characteristics of SAR in HH polarization of the L-band.

Regarding the changes in the scattering of SAR, the intensity difference SAR images generated according to the Image Interpretation Guideline are used.

The examples to be explained in this material are the events in which there were results of observation before and after the disaster by means of ALOS-2, among the torrential rains, earthquakes, and volcanic eruptions that have occurred from the start of operation of ALOS-2 (autumn in 2014) until the present.

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1. Scattering of a synthetic aperture radar (SAR)

The SAR onboard the artificial satellite circulates at an altitude of several hundred km above the earth irradiates microwaves (a type of radio waves) toward the ground obliquely downward, and observes the reflected and returned microwaves at a high resolution. In observations by means of SAR, 3 types of information are obtained: backscatter intensity, phase, and polarization. In this chapter, 4 types of scattering related to the backscatter intensity will be explained [3), 4), 5)].

1.1 Backscatter

Microwaves irradiated from SAR are scattered in various directions after having collided with ground objects such as the ground, forest, buildings, etc. on the ground surface. Among them, only the scattering that has been generated toward the direction of microwave irradiation becomes the reflected waves that can be observed by the satellite. Since the scattering is backward scattering in relation to the direction of microwave irradiation, these reflected waves are called "backscatter."

By assigning the intensity of this backscatter to color gradation, and by visualizing it so that the higher the intensity, the brighter the image, and the lower the intensity, the darker the image, "SAR intensity images" can be obtained.

Places where backscatter is likely to occur intensely include shapes with lots of dents and projections where scattering is likely to occur in various directions.

[Backscatter]

Of the scattering that occurs on the ground surface, the scattering that occurs in a backward direction to the direction of microwave irradiation.
Backscatter occurs intensely in places with lots of dents and projections, but the intensity varies with the structure and direction of the target.

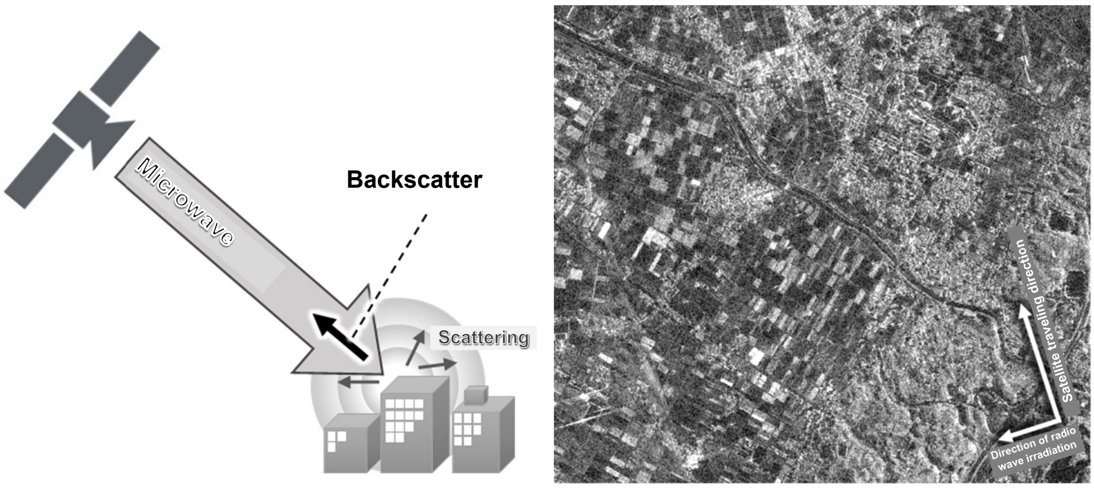


Fig.-1.1 Concept of backscatter (left) and an example of a SAR intensity image showing backscatter (right)

1.2 Forward scatter

When microwaves are irradiated from SAR to a flat ground object without undulations, scattering is intensified by specular reflection in the direction of microwave irradiation, and no backscatter can be obtained. Since scattering occurs in the direction of microwave irradiation, it is called "forward scatter."

Forward scatter is intensified on a still water surface without undulating waves such as a lake or pond and a large-scale river, and in a parking lot, in a playground, and on a flat roof of a large-scale building, etc., and since no reflected waves from these flat ground objects can be observed, the places where forward scatter occurs intensely are expressed as dark areas on SAR intensity images.

[Forward scatter]
Of the scattering that occurs on the ground surface, the scattering that occurs in the direction of microwave irradiation.
On a flat land without undulations, forward scatter is intensified by specular reflection.

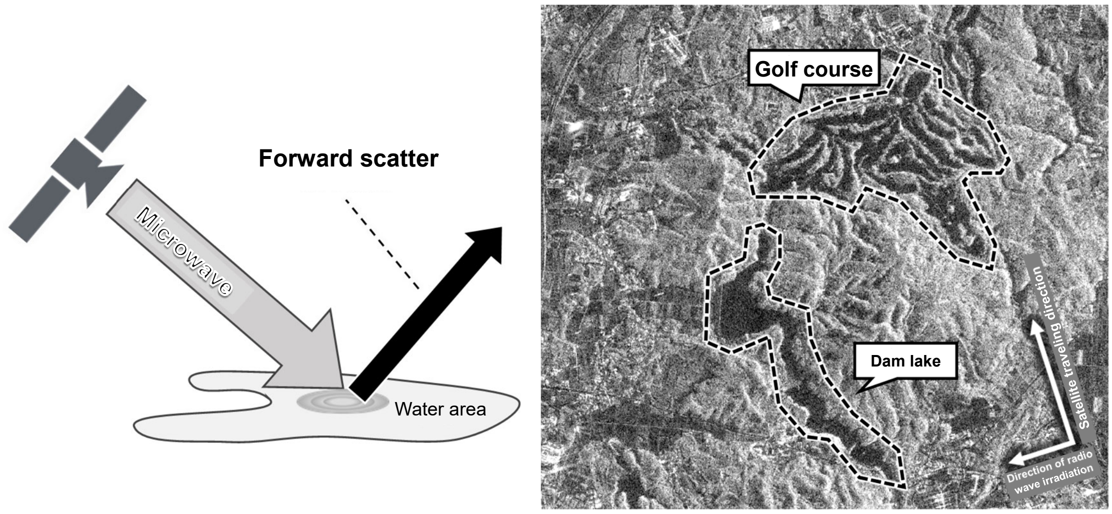


Fig.-1.2 Concept of forward scatter (left) and an example of a SAR intensity image showing forward scatter (right)

1.3 Double bounce scattering

When a ground object such as a building is erected vertically in a direction facing the direction of microwave irradiation from SAR, reflection occurs twice on the ground surface and on the wall surface, and intense waves are reflected back in the direction of microwave irradiation. Thus, backscatter occurring very intensely in addition to the backscatter caused by the target is called "double bounce scattering."

In a SAR intensity image, places where double bounce scattering has occurred are shown as an area with a very bright color by the intense backscatter.

[Double bounce scattering]
Scattering caused by re-reflection of forward scattering reflected on the ground by a structure facing the direction of microwave irradiation. It is observed as an extremely intense backscatter.

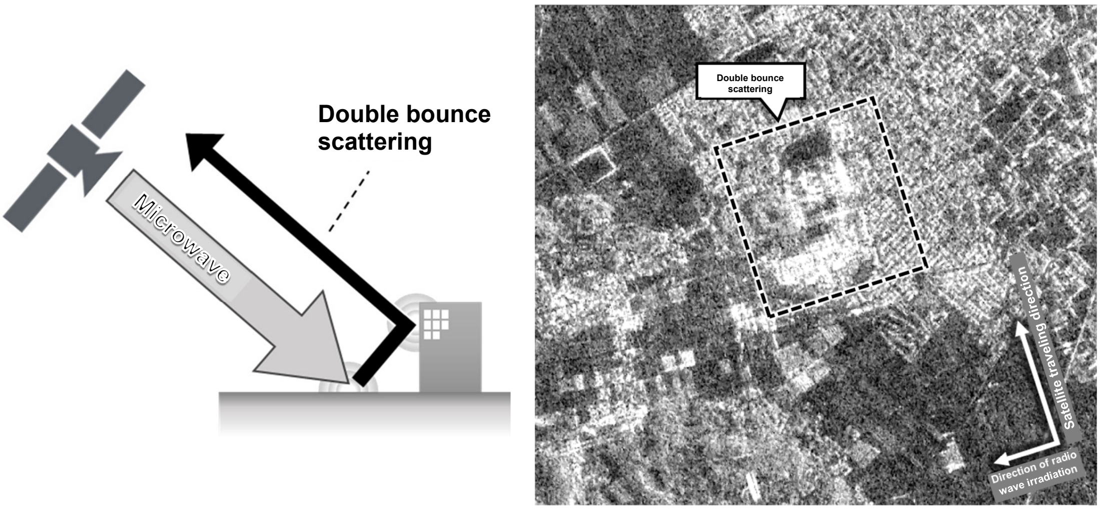


Fig.-1.3 Concept of double bounce scattering (left) and an example of a SAR intensity image showing double bounce scattering (right)

1.4 Volume scatter

In the case of ground objects having complex a stereoscopic structure such as trees and plants with complicated branches and leaves, scattering occurs in all the directions within the stereoscopic structure. The scattering mode such as this is called "volume scatter."

The point of difference from normal scattering is that, since scattering occurs in all the directions as a result of reflections in various places while microwaves pass through the stereoscopic structure, the situation of scattering is vague as compared with the reflection on a uniform surface. In addition, the backscatter intensity does not change greatly even when irradiation is performed in different directions, when the effects of topography are excluded.

[Volume scatter]

Scattering caused by reflections in various places while microwaves pass through a complex stereoscopic structure.

In a volume scatter, the backscatter intensity is lower than that with a structure, and is identified visually as a vague image.

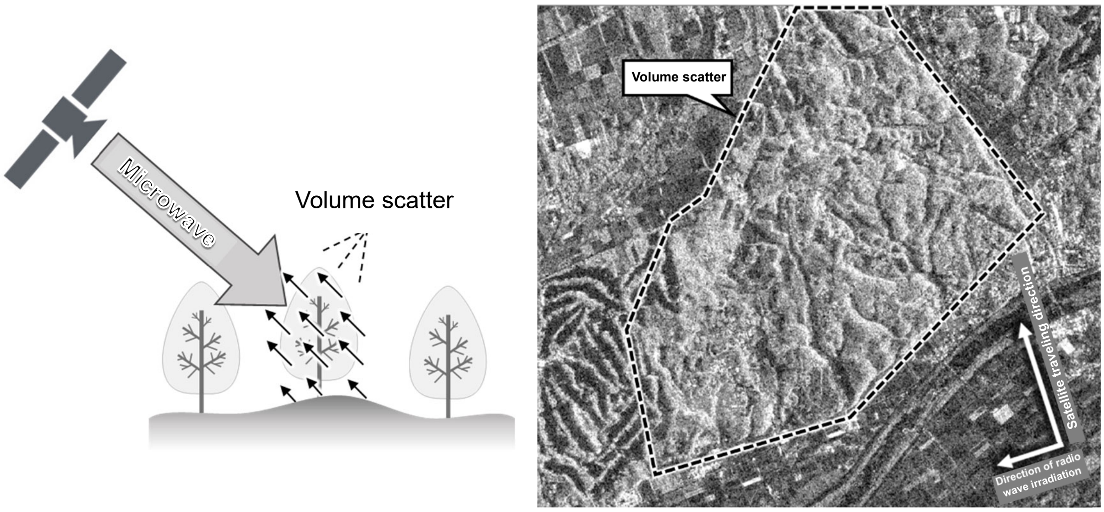


Fig.-1.4 Concept of volume scatter (left) and an example of a SAR intensity image showing volume scatter (right)

1.5 Relationships with the local incidence angle

The backscatter intensity depends on, in addition to the smoothness of the scattering surface, the angle of incidence on the scattering surface (hereinafter called the "local incidence angle").

As shown in Fig.-1.5, generally there is a tendency that the greater the local incidence angle, the smaller the backscatter intensity. The local incidence angle greatly affects a smooth scattering surface, as compared with a rough scattering surface. In a volume scatter that is dominant in a forest, changes in the backscatter intensity according to the local incidence angle are small [6].

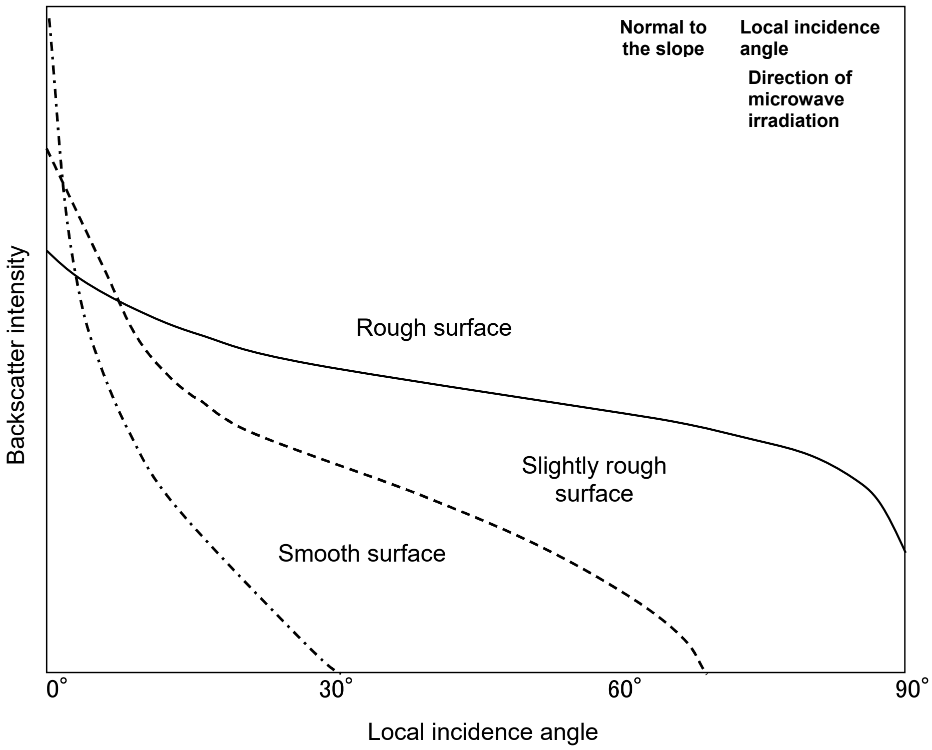


Fig.-1.5 Relationships between backscatter intensity and incidence angle relative to roughness of the scattering surface

2. Changes in the scattering of SAR during a disaster

2.1 Concept of changes in the scattering of SAR during a disaster

In this chapter, the concept of changes in the scattering of SAR during a disaster will be shown.

Changes in the scattering of SAR during a disaster are the results of comparison between the backscatter intensity of SAR observed before the disaster and that after the disaster, and they can roughly divided into the following 2 types.

- When the backscatter intensity after the disaster increases as compared with that before the disaster
- When the backscatter intensity after the disaster decreases as compared with that before the disaster

When understanding changes in the scattering of SAR, a wide variety of complex factors must be considered, but it is difficult to consider all the effects accurately.

And during the initial response to a disaster, the results of survey based on the changes in the scattering of SAR need to be utilized speedily, and therefore interpretation that has been simplified to a certain extent is required.

For this reason, in this material, the effects of various types of scattering have been modelled as follows (hereinafter called the "scatter change model").

Note that in part of the changes in the scattering of SAR during a disaster, artificial effects such as inundation of rice paddies, deforestation, etc. may be included [1)]. In the scatter change model, assuming that the probability of changes in the scattering of SAR is the highest as a result of the occurrence of the disaster, the changes in the scattering of SAR during a disaster shall be considered without distinguishing the artificial effects.

2.2 Scatter change model of SAR during a disaster

It has been described that the types of SAR scattering include backscatter, forward scatter, double bounce scatter, and volume scatter, and a specific scattering is dominant according to land utilization and land cover. Therefore, it is considered that the changes in the scattering of SAR during a disaster show the situation of disaster damage to a certain extent.

The scatter change model in which the backscatter intensity increases after the disaster shall be classified into the following 2 types.

(a) Occurrence of a scattering surface

A scatter change when the roughness of the scattering surface has increased as a result of inflow, onto a smooth scattering surface with a weak backscatter, of another scattering body due to the disaster. Since scattering appears that intensifies the backscatter after the disaster, it is called the "occurrence of a scattering surface."

(b) Occurrence of double bounce scattering

A scatter change when there is a height difference as a result of a disaster and double bounce scattering has newly occurred. Since double bounce scattering that intensifies the backscatter after the disaster, it is called the "occurrence of double bounce scattering."

Note that if a volume scatter occurs, the backscatter intensity increases, but in this material, assuming that the frequency of such occurrence is low as the change caused by a disaster, it is not shown in the scatter change model.

The scatter change model in which the backscatter intensity decreases after the disaster shall be classified into the following 3 types.

(c) Disappearance of a scattering surface

A scatter change when the smoothness of a rough scattering surface where backscatters are dominant has increased as a result of the disaster. Since the backscatter before the disaster is lost, it is called the "disappearance of a scattering surface."

(d) Disappearance of a volume scatter

A scatter change when the smoothness of a scattering surface where volume scatters are dominant has increased as a result of the loss of the scattering body due to the disaster. Since the backscatter due to a volume scatter before the disaster is lost, it is called the "disappearance of a volume scatter."

(e) Disappearance of double bounce scattering

A scatter change when a height difference is lost as a result of a disaster and double bounce scattering is lost. Since the intense backscatter due to double bounce scattering before the disaster is lost, it is called the "disappearance of double bounce scattering."

Also, in the case of specific land utilization or land cover, the backscatter intensity varies with the local incidence angle. Namely, it is considered that if the local incidence angle changes as a result of a topographical change, etc. due to the disaster, changes in the scattering of SAR occur.

The model in which scattering changes as a result of a topographical change, etc. due to the disaster shall be the following.

(f) Deformation of a scattering surface

A scatter change when the local incidence angle changes as a result of a topographical change, etc. due to the disaster. Since the backscatter is changed by the topographical change, etc., it is called the "deformation of a scattering surface."

3. Explanations of examples of SAR scatter changes during a disaster

The features of changes in the scattering of SAR and precautions are explained concerning the examples of A) to L) below during a disaster in recent years.

A) Deposition of sediment on farmland or roads

A-1 Torrential Rainfall in July 2018 (Yasuura District, Kure City)

A-2 Torrential Rainfall in July 2018 (Takaya JCT)

A-3 2018 Hokkaido Eastern Iburi Earthquake (Takaoka District, Atsuma Town)

A-4 [Exception] Deposition of fine particle sediment

B) Floating of floodwood, etc.

B-1 Northern Kyushu Torrential Rainfall in July 2017 (Terauchi Dam)

B-2 Torrential Rainfall in July 2020 (Yatsushiro Sea)

C) Inundation caused by channel blockage (natural dam)

C-1 Northern Kyushu Torrential Rainfall in July 2017 (Ono District, Hita City)

C-2 2018 Hokkaido Eastern Iburi Earthquake (Hidaka Horonai River)

D) Water seepage/flood

D-1 Torrential Rainfalls in Kanto and Tohoku in September 2015 (Kinugawa River)

D-2 Heavy Rainfall Associated with the Seasonal Rain Front in July 2017 (Omonogawa River)

D-3 2019 East Japan Typhoon (Chikumagawa River)

D-4 [For reference] Inundation of rice paddies

E) Bridge collapse caused by flooding

E-1 2016 Kumamoto Earthquake (Aso Ohashi Bridge)

E-2 Torrential Rainfall in July 2020 (Fukami Bridge)

E-3 [For reference] New bridge construction

F) Failure on a forest slope (horseshoe shape)

F-1 2016 Kumamoto Earthquake (Seta District, Ozu Town)

F-2 Northern Kyushu Torrential Rainfall in July 2017 (Otoishigawa River)

F-3 [Exception] Failure on a grassland slope

F-4 [For reference] Deforested land

F-5 [For reference] Quarry

G) Failure on a forest slope (thin and long shape)

G-1 Northern Kyushu Torrential Rainfall in July 2017 (Toho Village, Mt. Hoshu)

G-2 Torrential Rainfall in July 2018 (Yasuura District, Kure City)

H) Failure on a bare land slope

H-1 Torrential Rainfall in July 2020 (Amehatagawa River)

H-2 Torrential Rainfall in July 2020 (Matsuno District, Kuma Village)

I) Deposition of sediment on residential land

I-1 Northern Kyushu Torrential Rainfall in July 2017 (Shozugawa River)

I-2 Torrential Rainfall in July 2018 (Sozugawa River)

J) Collapse of a building or structure

J-1 2016 Kumamoto Earthquake (Mashiki Town)

K) Ashfall

K-1 Eruption of Mt. Kusatsu-Shirane in 2018

L) Moving down of a pyroclastic flow

L-1 Eruption of Mt. Kuchinoerabu in 2015

A) Deposition of sediment on farmland or roads

[Explanations of scatter changes]

When sediment is deposited on farmland or roads, the backscatter intensity after the disaster increases.
Such places are shown in cyan on intensity difference SAR images.

Microwaves irradiated from SAR are subjected to scattering on a flat ground surface without undulations such as farmland or paved roads in which forward scatters are dominant. For this reason, the backscatter intensity before the disaster decreases. If sediment flows into farmland or roads, etc. due to a disaster, the deposited sediment facilitates the backscatter of microwaves, and therefore the backscatter intensity after the disaster increases [1), 7)]. Based on such changes in the scattering of SAR, places where sediment deposited on farmland or roads, etc. may be identified.

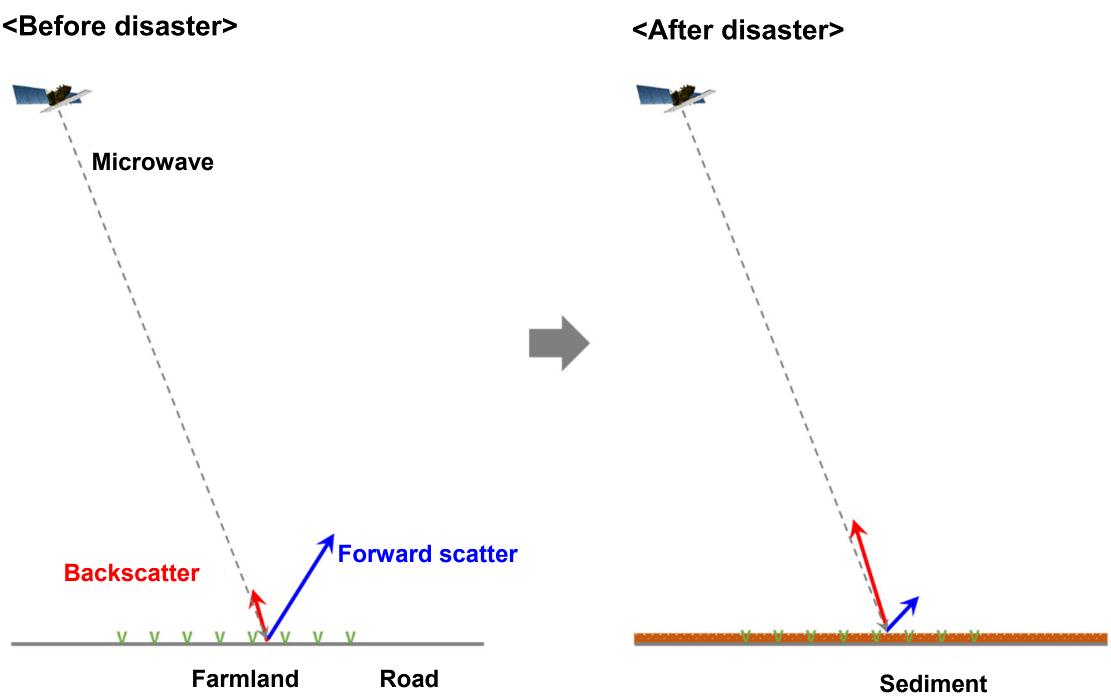
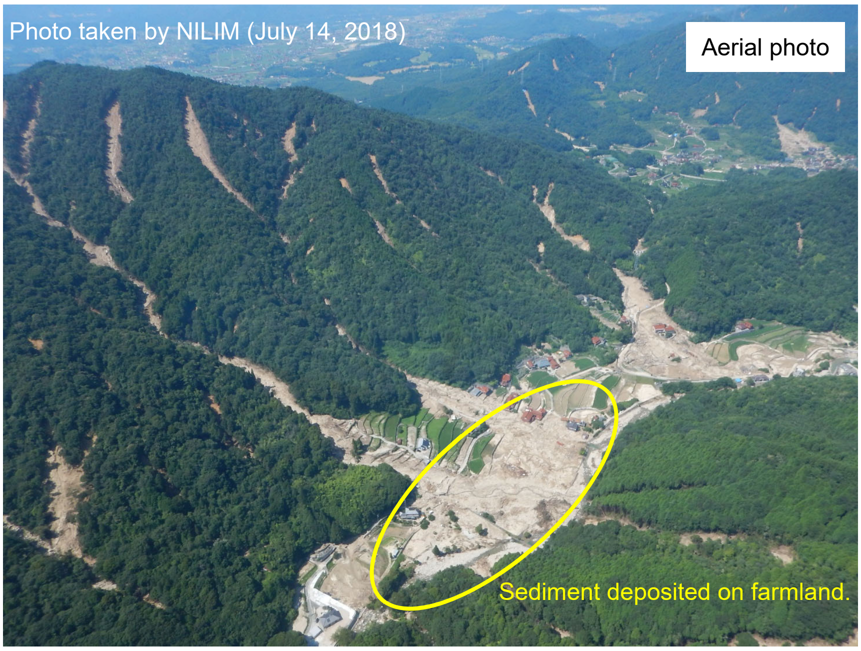


Fig.-3.1 Concept concerning scatter changes when sediment is deposited on farmland or roads

[Precautions]

- The ground surface needs to be smooth before the disaster, such as farmland or paved roads.
- When the road width is great such as that on a truck road, the visibility of scatter changes is high.
- Under specific conditions, the backscatter intensity may decrease after the disaster (for details, see P. 15).

A-1 Torrential Rainfall in July 2018 (Yasuura District, Kure City)



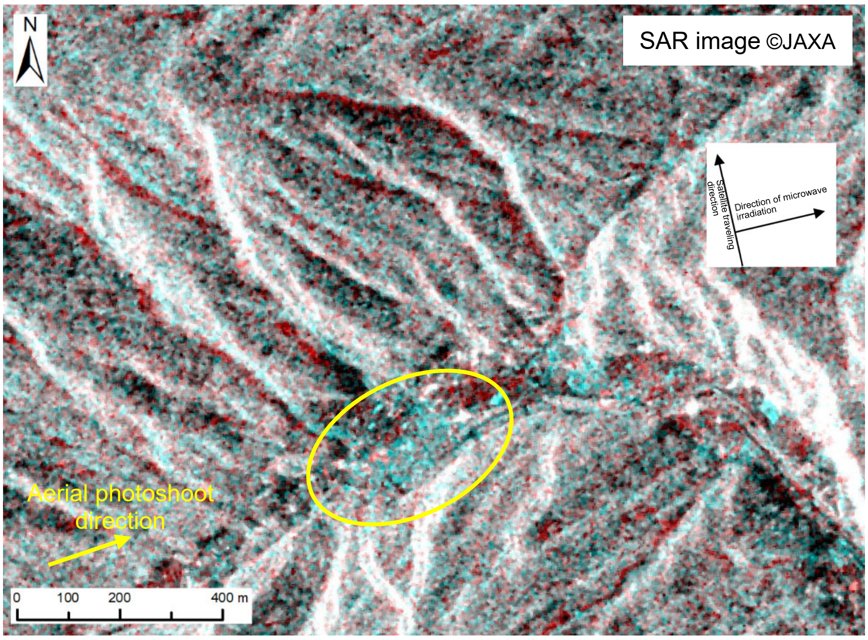


Fig.-3.2 Aerial photo (top) and intensity difference SAR image (bottom)

(Kure City, Hiroshima Prefecture)

As a result of the deposition of sediment in places that were used as farmland such as rice paddies, the backscatter intensity after the disaster increases. The places are shown in cyan on the intensity difference SAR image.

A-2 Torrential Rainfall in July 2018 (Takaya JCT)

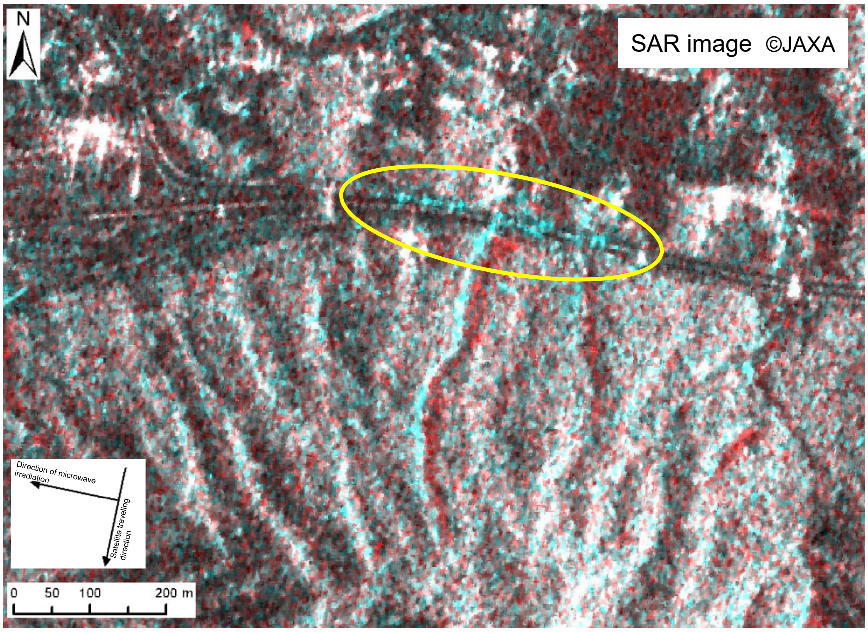


Fig.-3.3 Site photo (top) and intensity difference SAR image (bottom)

(Higashihiroshima City, Hiroshima Prefecture)

As a result of sediment deposition on roadways in the vicinity of the Takaya JCT of the Sanyo Expressway, the backscatter intensity after the disaster increases. The places are shown in cyan on the intensity difference SAR image.

A-3 2018 Hokkaido Eastern Iburi Earthquake (Takaoka District, Atsuma Town)

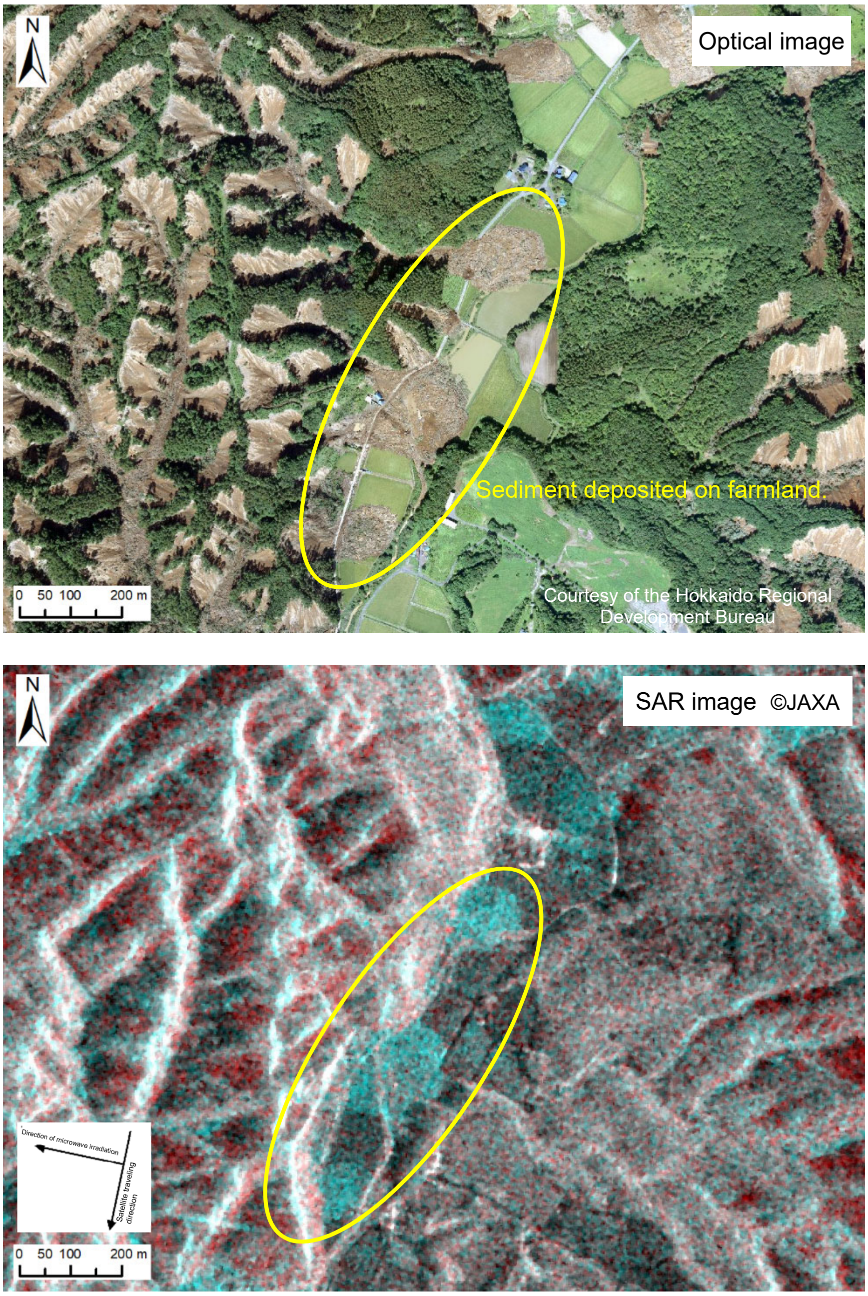
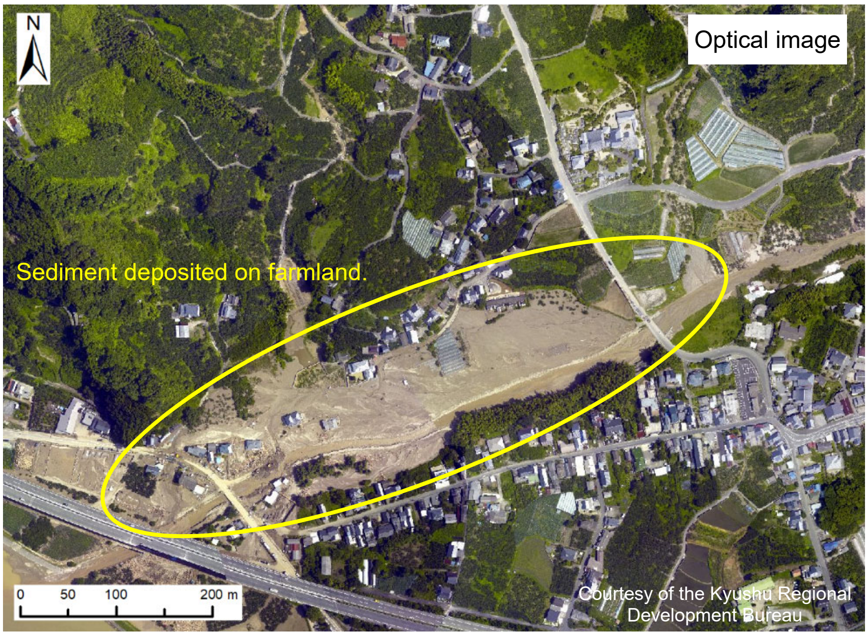


Fig.-3.4 Optical image (top) and intensity difference SAR image (bottom)

(Atsuma Town, Yufutsu County, Hokkaido Prefecture)

As a result of sediment deposition on places that were used as farmland such as rice paddies, the backscatter intensity after the disaster increases. The places are shown in cyan on the intensity difference SAR image.

A-4 [Exception] Deposition of fine particle sediment



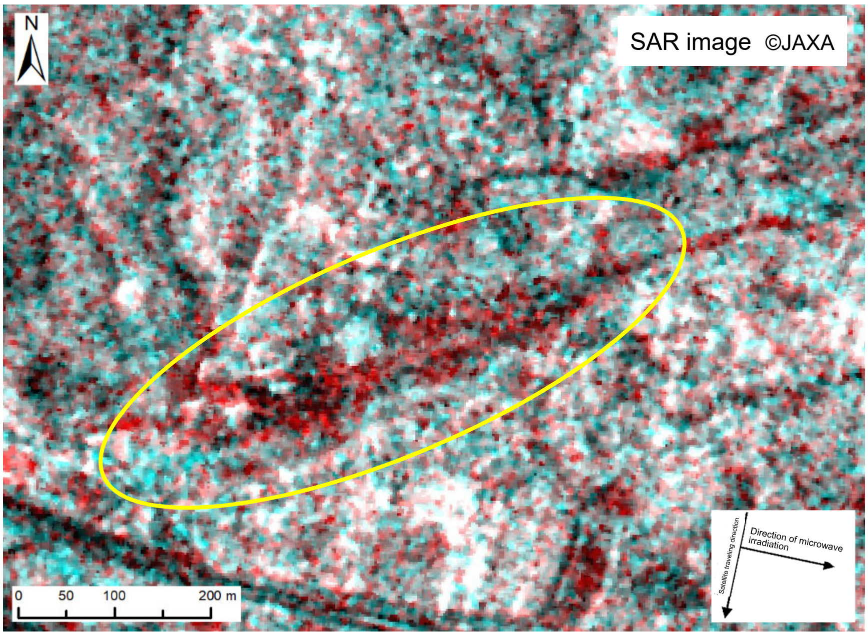


Fig.-3.5 Optical image (top) and intensity difference SAR image (bottom)

(Asakura City, Fukuoka Prefecture)

When fine particle sediment is deposited as a result of a flooding, etc., the places become a flatter ground surface without undulations as compared with that before the disaster, and therefore the backscatter intensity after the disaster decreases. In this case, the places are show in red on the intensity difference SAR image.

B) Floating of floodwood, etc.

[Explanations of scatter changes]

When floodwood, etc. floats, the backscatter intensity after the disaster increases.
The places are show in cyan on the intensity difference SAR image.

Microwaves irradiated from SAR are subjected to scattering on a still water surface like a water area in which forward scatters are dominant. For this reason, the backscatter intensity before the disaster considerably decreases. If floodwood, etc. floats due to a disaster, the floating object facilitates the backscatter of microwaves, and therefore the backscatter intensity after the disaster increases [7)]. Based on such changes in the scattering of SAR, the distribution of floating floodwood, etc. may be identified.

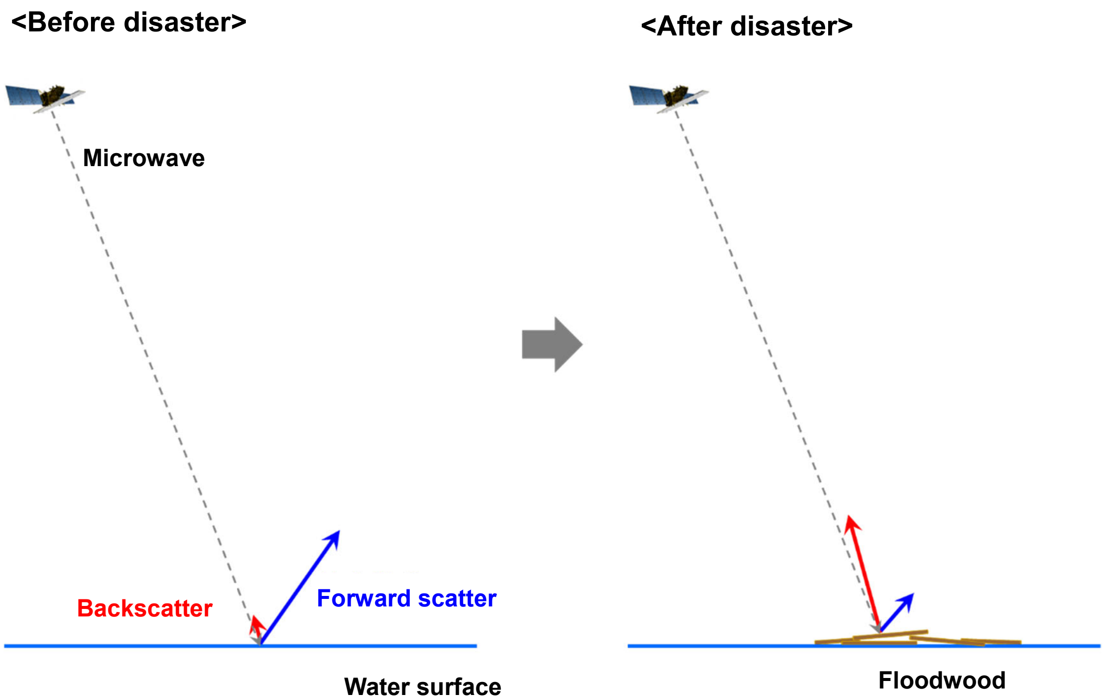


Fig.-3.6 Concept concerning scatter changes when floodwood, etc. floats

[Precautions]

- After a lapse of time from the observation after the disaster, the floating objects may be moved by a current.
- When floating objects are distributed in a wide area from before the disaster or when plants grow on the water surface, it is difficult to identify the distribution.
- The scatter changes may be wrongly identified as those caused by waves in places with fast-flowing currents.

B-1 Northern Kyushu Torrential Rainfall in July 2017 (Terauchi Dam)

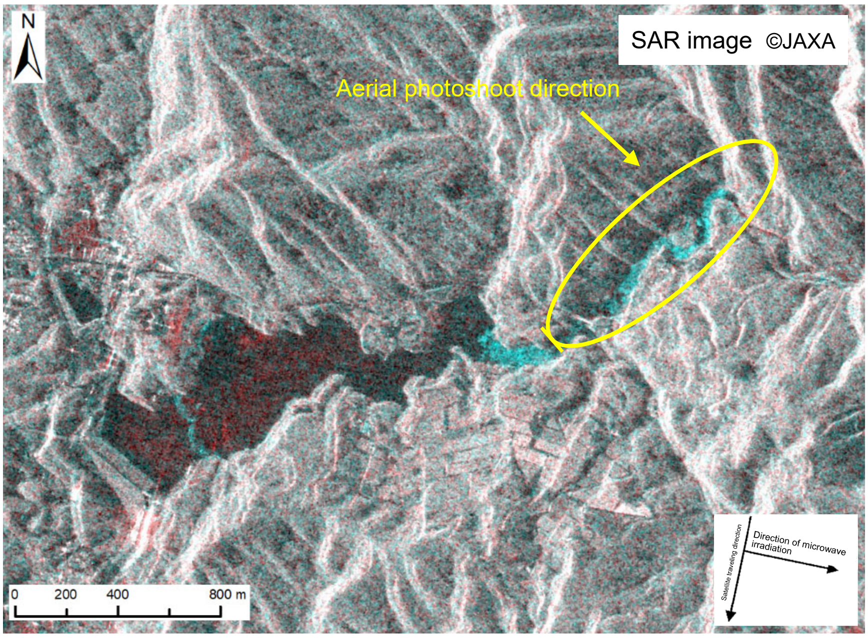


Fig.-3.7 Aerial photo (top) and intensity difference SAR image (bottom)

(Asakura City, Fukuoka Prefecture)

As a result of the floating of floodwood, etc. on the water surface of the Terauchi Dam, the backscatter intensity after the disaster increases. The places are shown in cyan on the intensity difference SAR image.

B-2 Torrential Rainfall in July 2020 (Yatsushiro Sea)

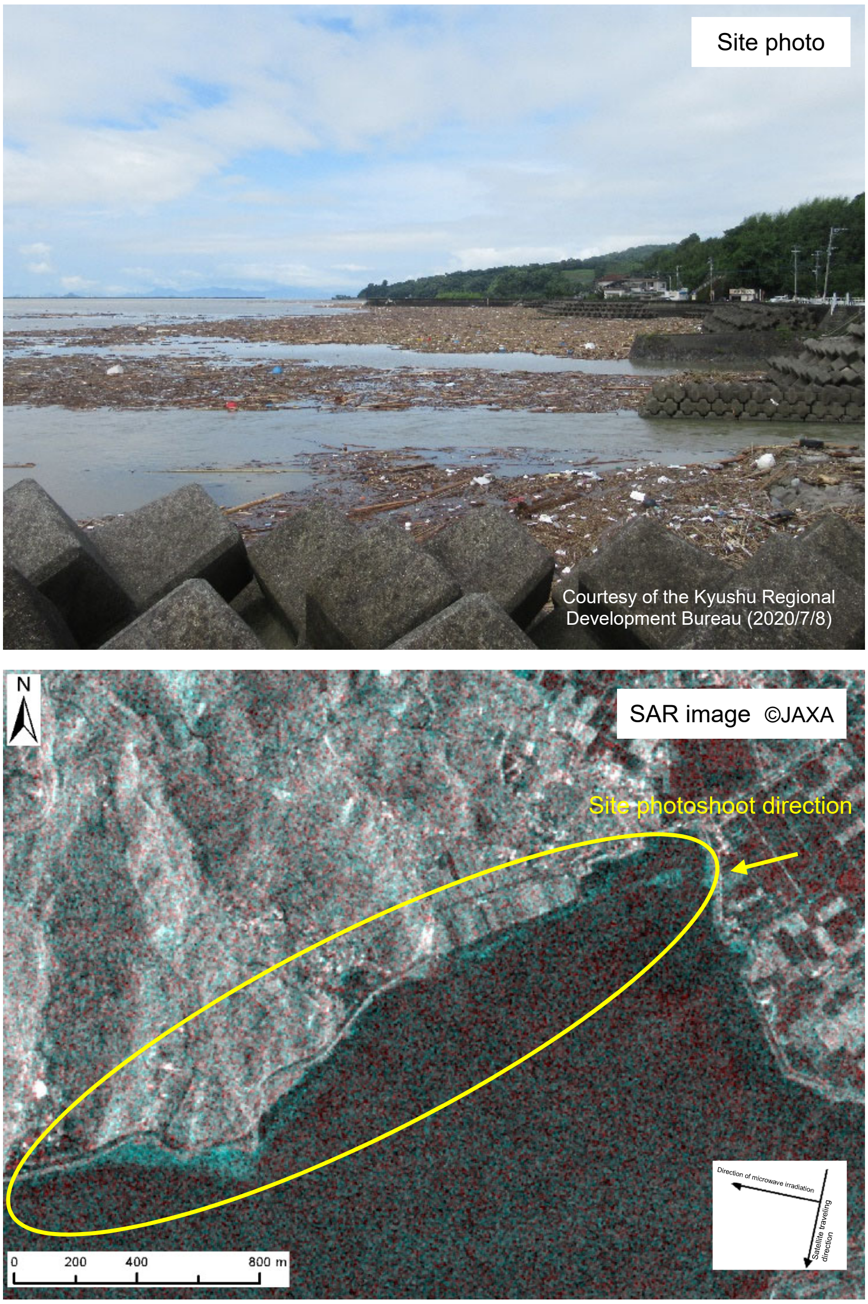


Fig.-3.8 Site photo (top) and intensity difference SAR image (bottom)

(Uki City, Kumamoto Prefecture)

As a result of the floating of floodwood, etc. along the coast of the Yatsushiro Sea, the backscatter intensity after the disaster increases. The places are shown in cyan on the intensity difference SAR image.

C) Inundation caused by channel blockage (natural dam)

[Explanations of scatter changes]

If inundation occurs as a result of channel blockage, the backscatter intensity after the disaster decreases conspicuously.
The places of inundation are shown clearly in red on the intensity difference SAR image.

Microwaves irradiated from SAR are subjected to backscatters according to the shape of the ground surface around the channel, etc. and the degree of dents and projections. For this reason, the backscatter intensity before the disaster shows a certain degree of greatness. If an inundated area is formed by blockage of the channel by sediment, etc. due to the disaster, the water surface of the inundated area facilitates the forward scatter of microwaves, and therefore the backscatter intensity after the disaster considerably decreases [8]. Based on such changes in the scattering of SAR, the places of inundation caused by the channel blockage may be identified.

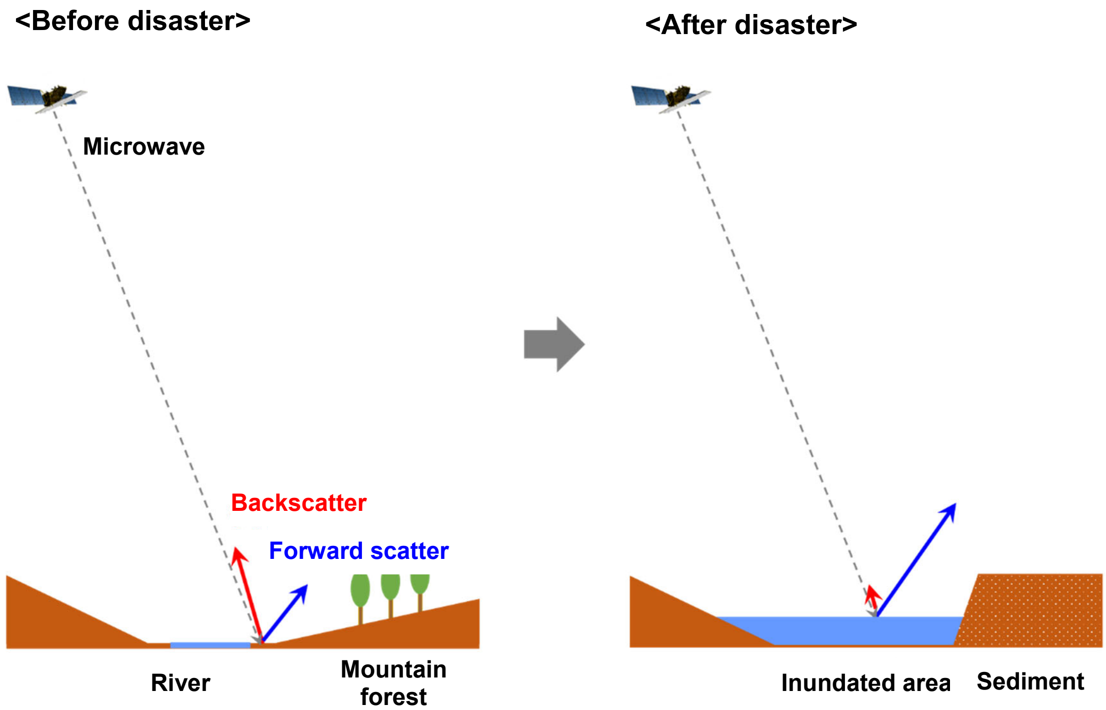


Fig.-3.9 Concept concerning scatter changes when an inundated area has been formed by channel blockage

[Precautions]

- If water seepage or a flood occurs in surrounding areas, scatter changes are assimilated, resulting in a lack of visibility.
- If the archived image is the one taken during a drought period, it may be wrongly identified as inundation in a reservoir facility.

C-1 Northern Kyushu Torrential Rainfall in July 2017 (Ono District, Hita City)

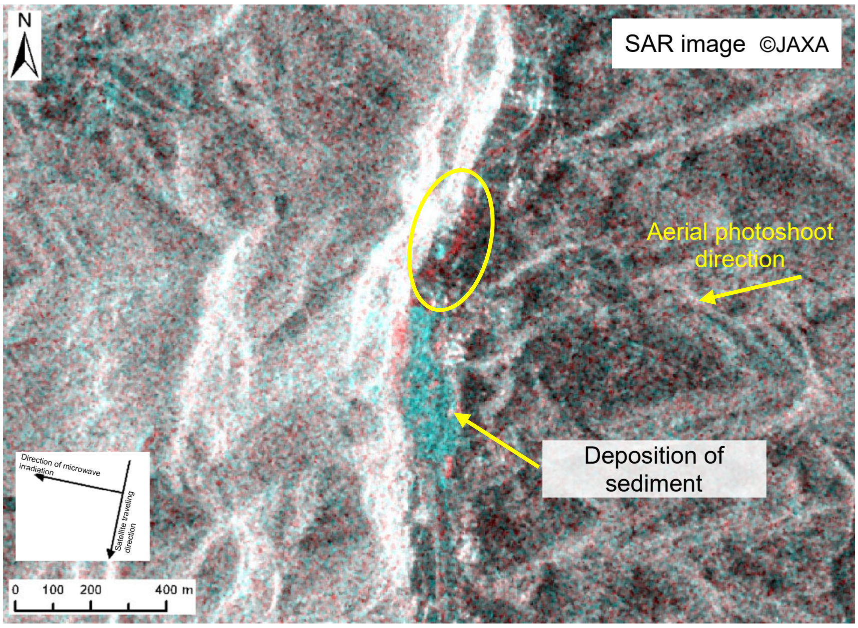


Fig.-3.10 Aerial photo (top) and intensity difference SAR image (bottom)
(Hita City, Oita Prefecture)

As a result of the formation of inundated areas due to the deposition of sediment in the channel, the backscatter intensity after the disaster decreases. The areas are shown in red on the intensity difference SAR image.

Also, in the places where sediment has been deposited in the channel, the backscatter intensity after the disaster increases, and therefore the places are shown in cyan on the intensity difference SAR image.

C-2 2018 Hokkaido Eastern Iburi Earthquake (Hidaka Horonai River)

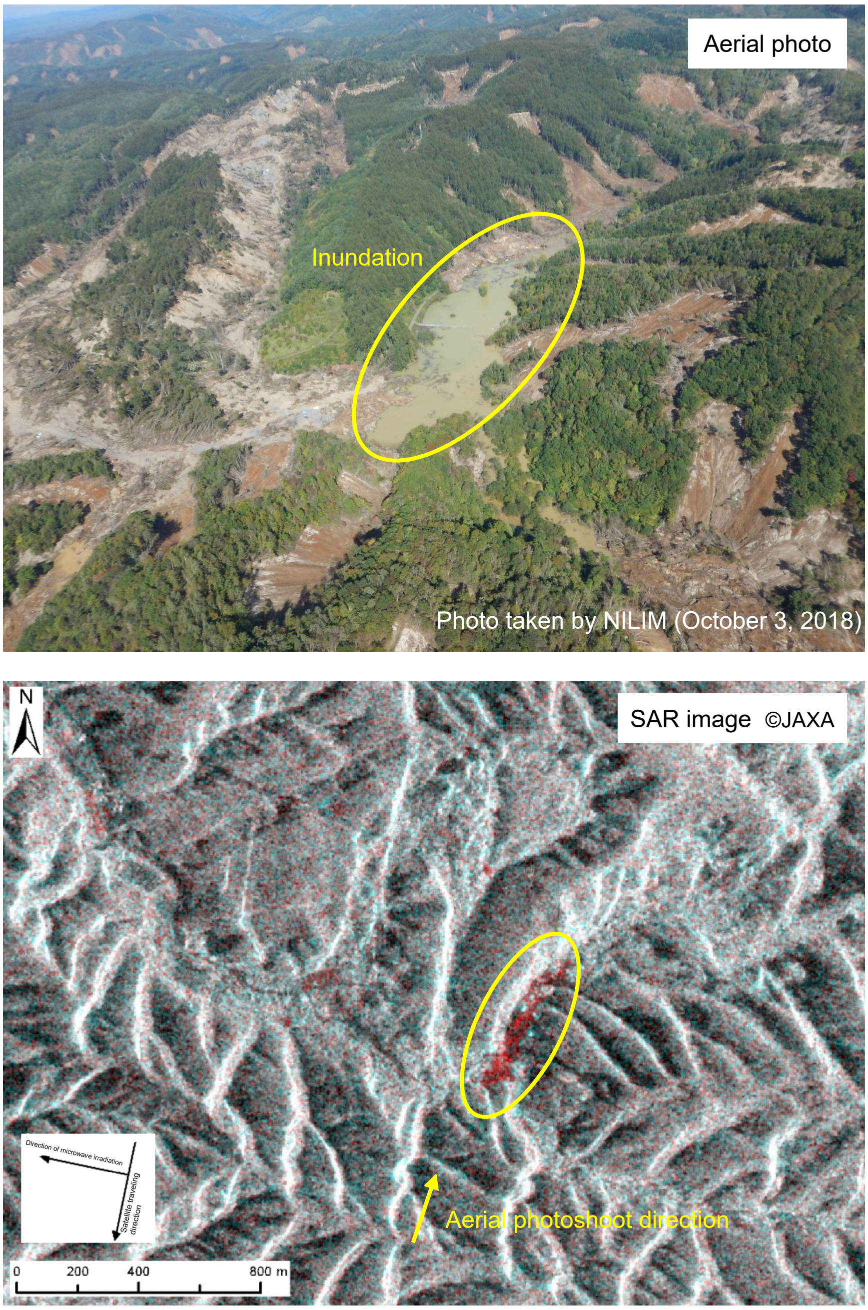


Fig.-3.11 Aerial photo (top) and intensity difference SAR image (bottom)

(Atsuma Town, Yufutsu County, Hokkaido Prefecture)

As a result of the formation of inundated areas due to the deposition of sediment in the channel, the backscatter intensity after the disaster decreases. The areas are shown in red on the intensity difference SAR image.

Note that the rate of formation of the inundated areas was slow, and regarding the archived image as well, monitoring was done by using the archived image after the disaster, and therefore there are no changes in the places where sediment was deposited in the channel.

D) Water seepage/flood

[Explanations of scatter changes]

If water seepage or a flood occurs, the backscatter intensity after the disaster decreases conspicuously.
The places are shown clearly in red on the intensity difference SAR image.

Microwaves irradiated from SAR are subjected to backscatters according to the shape of the ground surface around the channel, etc. and the degree of dents and projections. For this reason, the backscatter intensity before the disaster shows a certain degree of greatness. If water seepage or a flood occurs due to the disaster, the water seepage surface facilitates the forward scatter of microwaves, and therefore the backscatter intensity after the disaster considerably decreases [8]. Based on such changes in the scattering of SAR, the range of water seepage or a flood may be identified.

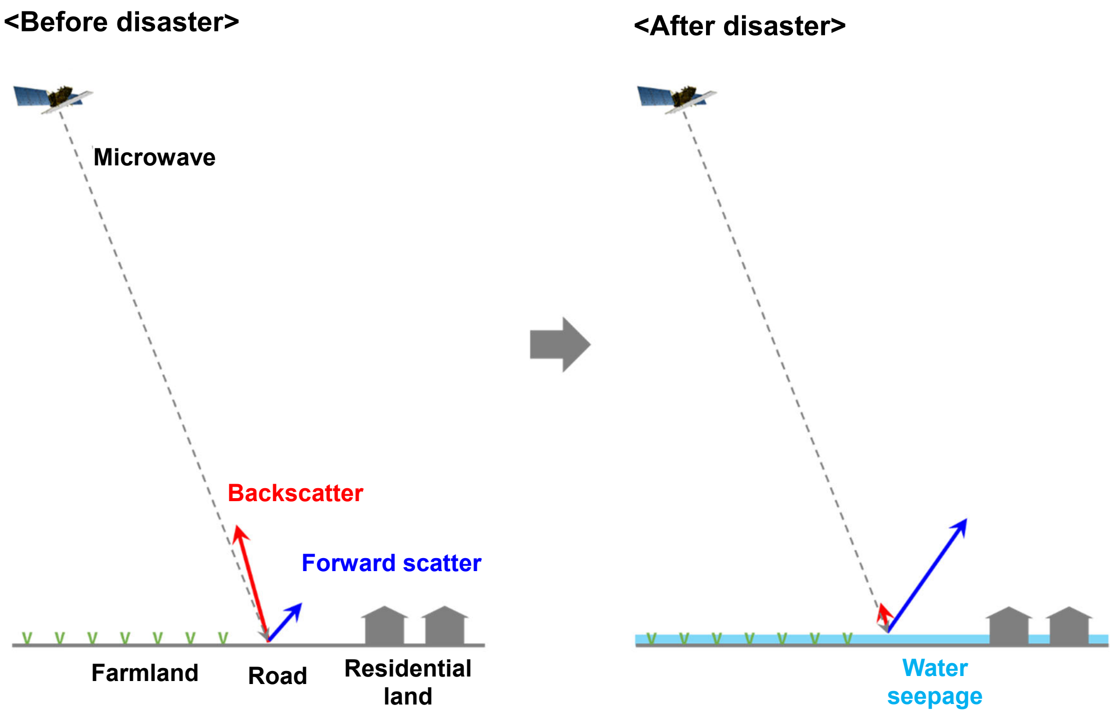


Fig.-3.12 Concept concerning scatter changes when water seepage or a flood has occurred

[Precautions]

- If rice paddies are inundated, scatter changes are assimilated, resulting in a lack of visibility (for details, see P. 26).
- When observation after the disaster has been made after a lapse of time, the range may be different from the maximum water seepage range.

D-1 Torrential Rainfalls in Kanto and Tohoku in September 2015 (Kinugawa River)

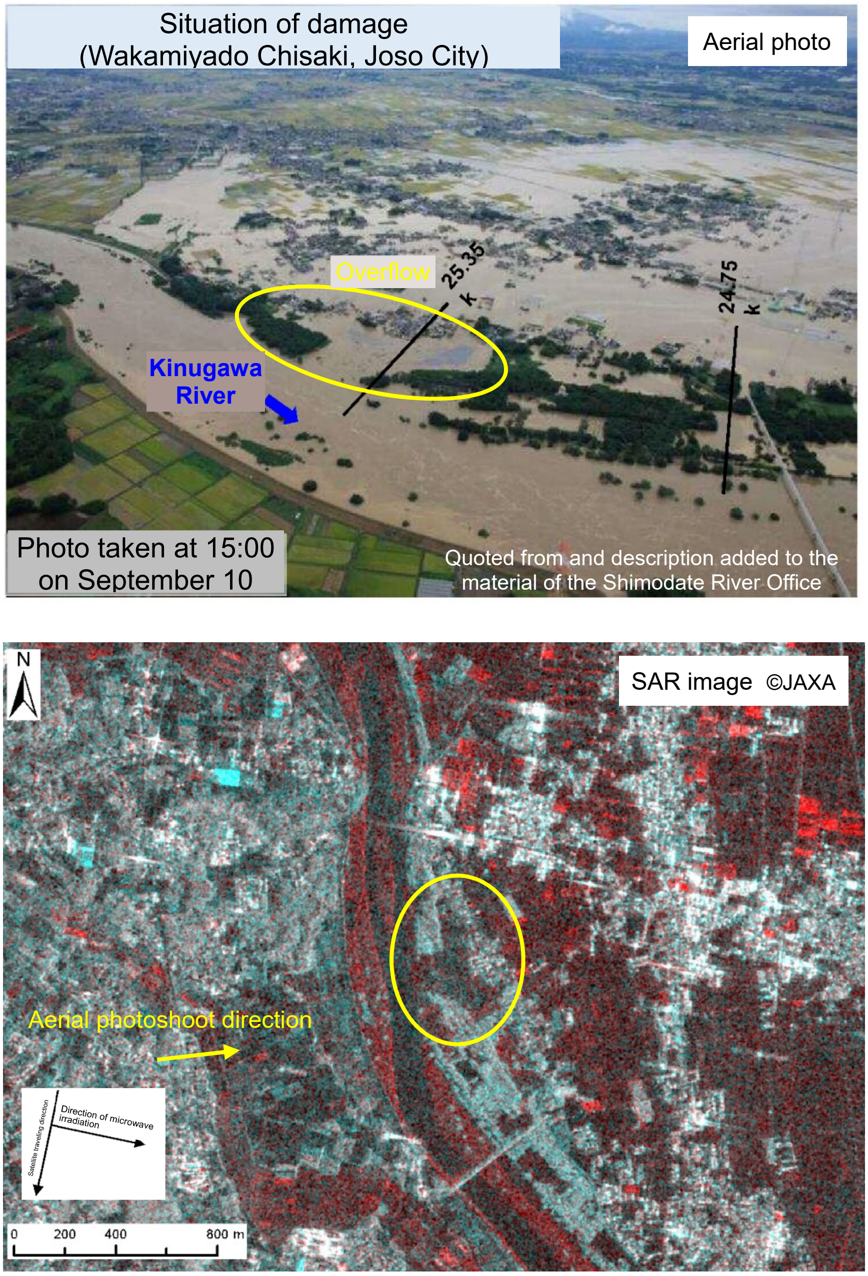
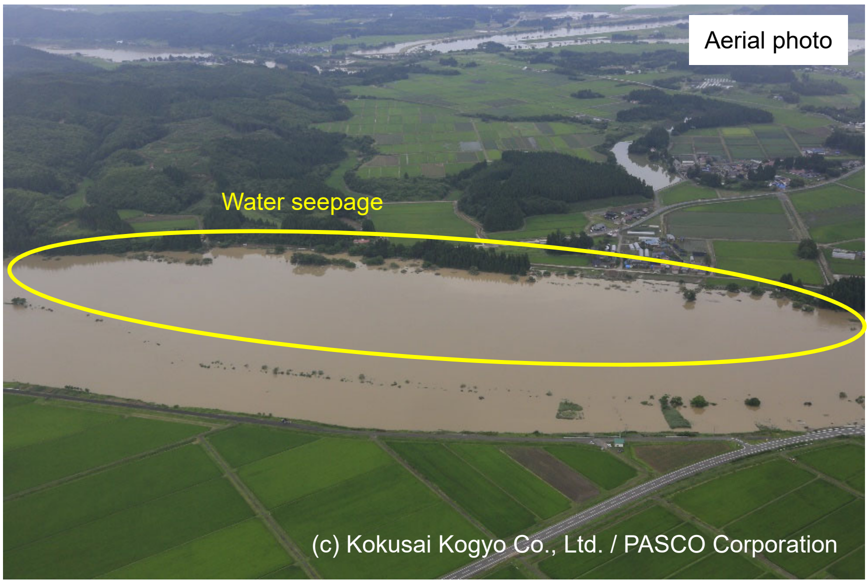


Fig.-3.13 Aerial photo (top) and intensity difference SAR image (bottom)

(Joso City, Ibaraki Prefecture)

In the range of water seepage along the Kinugawa River, the backscatter intensity after the disaster decreases. The range is shown in red on the intensity difference SAR image.

D-2 Heavy Rainfall Associated with the Seasonal Rain Front in July 2017 (Omonogawa River)



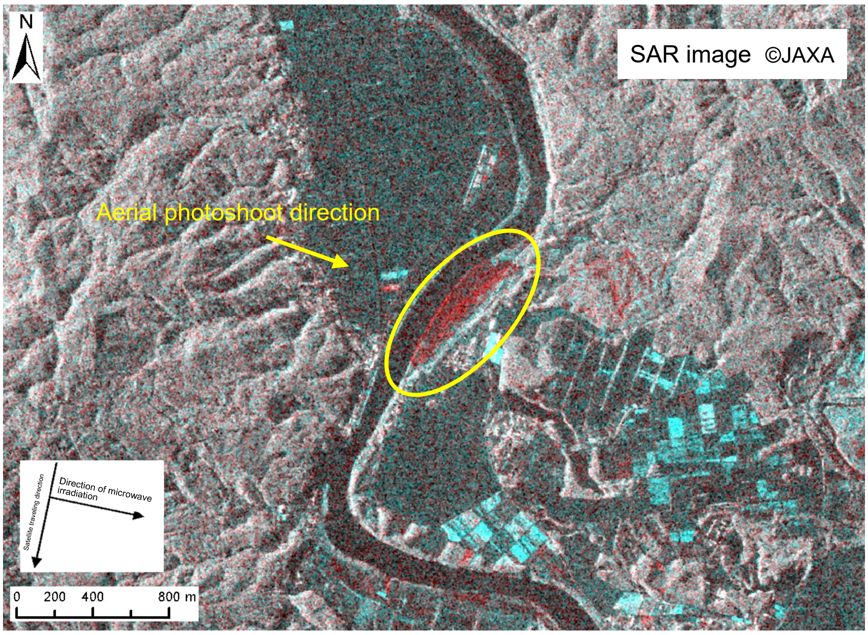
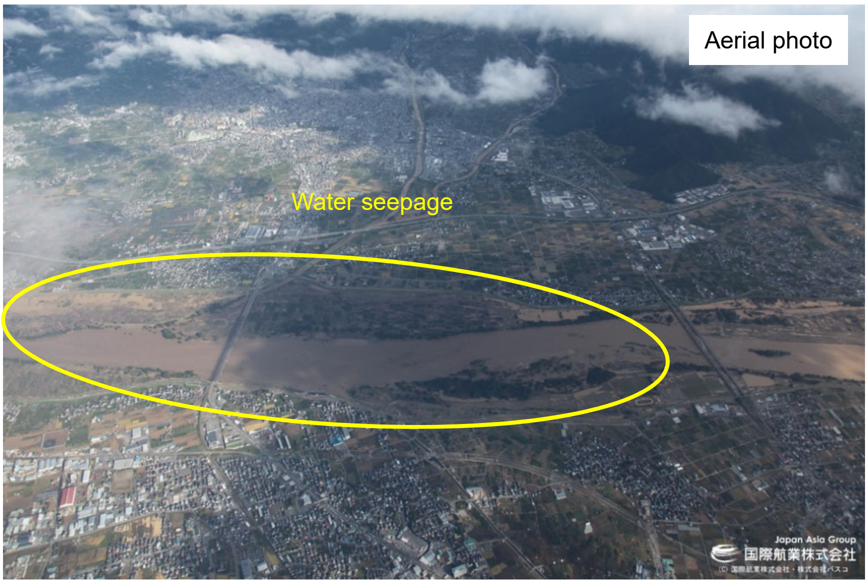


Fig.-3.14 Aerial photo (top) and intensity difference SAR image (bottom)

(Akita City, Akita Prefecture)

In the range of water seepage along the Omonogawa River, the backscatter intensity after the disaster decreases. The range is shown in red on the intensity difference SAR image.

D-3 2019 East Japan Typhoon (Chikumagawa River)



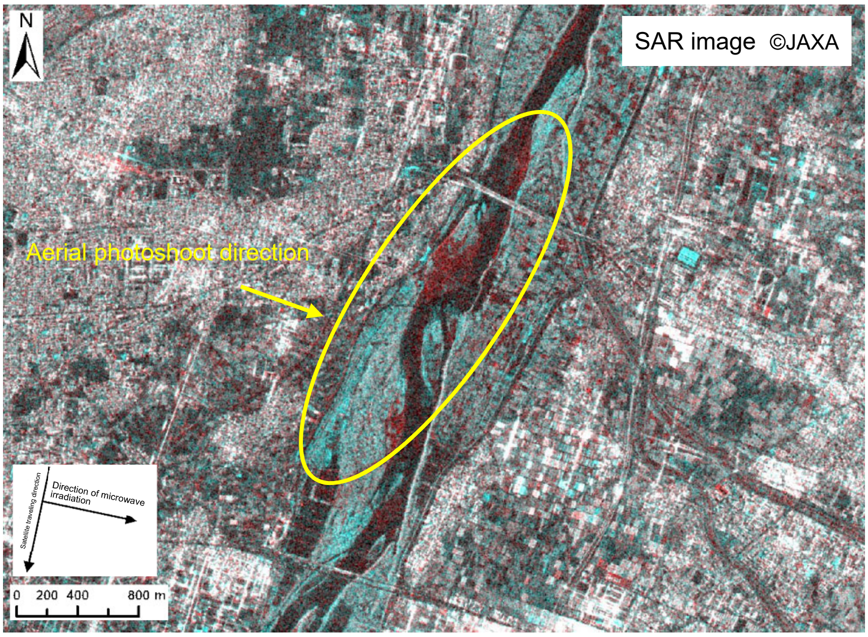


Fig.-3.15 Aerial photo (top) and intensity difference SAR image (bottom)
(Nagano City/Suzaka City, Nagano Prefecture)

In the range of water seepage along the Chikumagawa River, the backscatter intensity after the disaster decreases. The range is shown in red on the intensity difference SAR image.

Also, in the range where water seepage has disappeared, the backscatter intensity after the disaster increases due to deposition of sediment and floating objects, and the range is shown in cyan on the intensity difference SAR image.

D-4 [For reference] Inundation of rice paddies

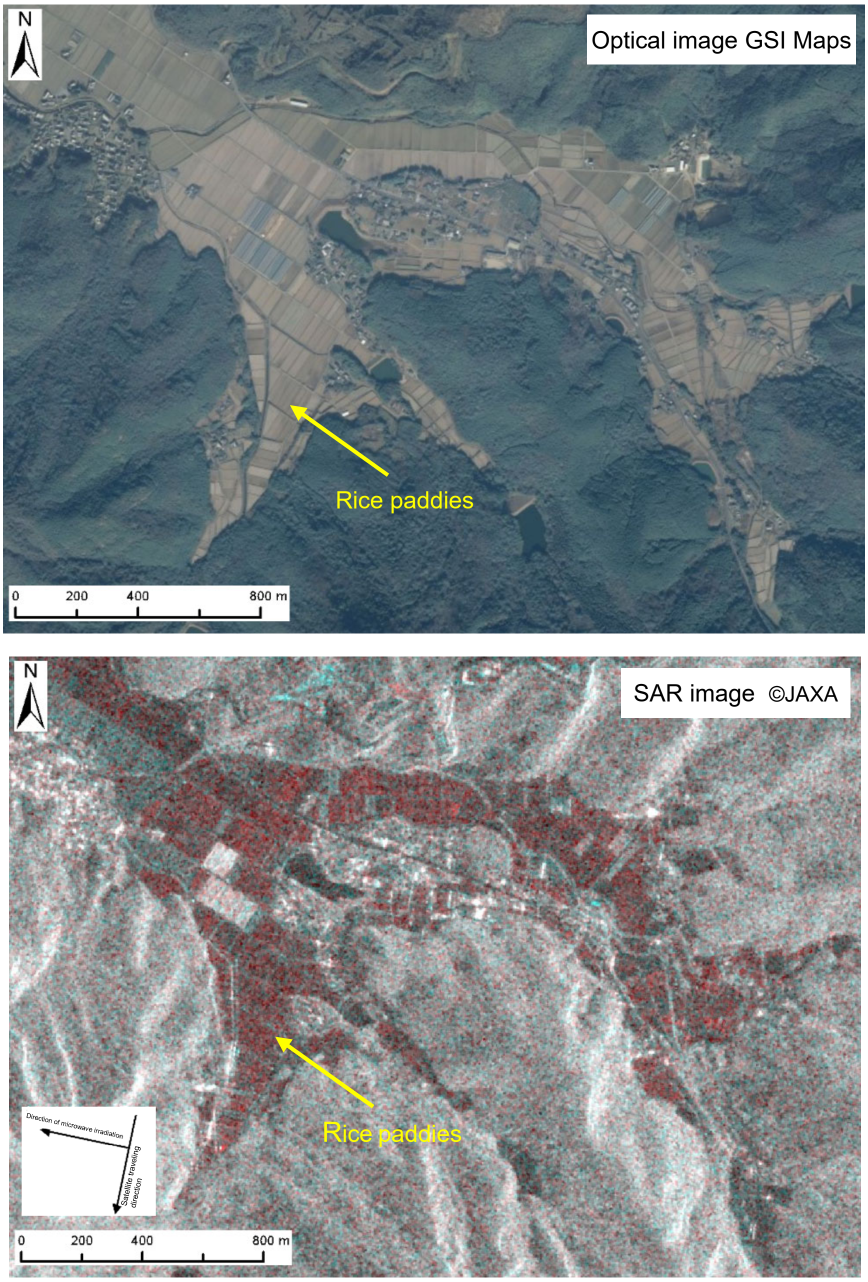


Fig.-3.16 Optical image (top) and intensity difference SAR image (bottom)

(Usa City, Oita Prefecture)

When rice paddies are inundated, the backscatter intensity after the disaster decreases. They are shown in red on the intensity difference SAR image.

The inundation is likely to be wrongly identified as water seepage, etc., image interpretation needs to be performed after having checked the period of observation of the archive image to be used.

E) Bridge collapse caused by flooding

[Explanations of scatter changes]

When a bridge is collapsed by flooding, the backscatter intensity after the disaster decreases conspicuously.
The place is shown clearly in red on the intensity difference SAR image.

Microwaves irradiated from SAR are subjected to backscatters according to the shape and direction of the bridge. For this reason, the backscatter intensity before the disaster shows a certain degree of greatness. If a bridge is collapsed by flooding due to a disaster, the backscatters of microwaves are lost, and therefore the backscatter intensity after the disaster considerably decreases [9]. Based on such changes in the scattering of SAR, the place of the bridge collapse by flooding may be identified.

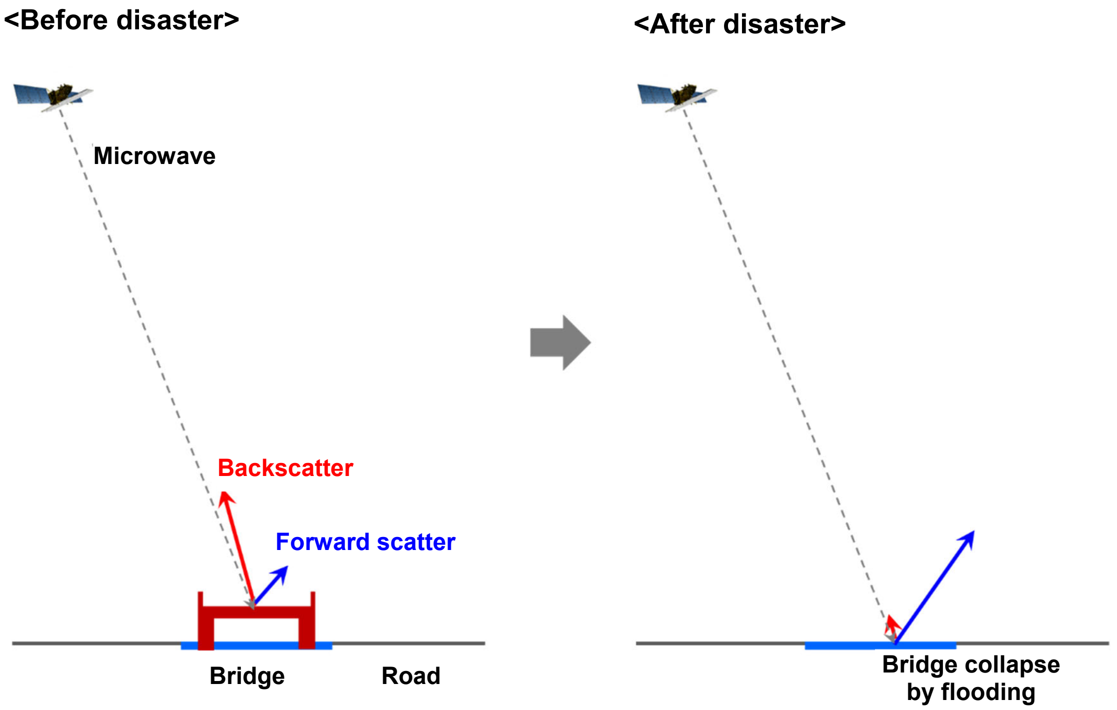


Fig.-3.17 Concept concerning scatter changes when a bridge has been collapsed by flooding

[Precautions]

- If water seepage or a flood occurs in surrounding areas, scatter changes are assimilated, resulting in a lack of visibility.

E-1 2016 Kumamoto Earthquake (Aso Ohashi Bridge)

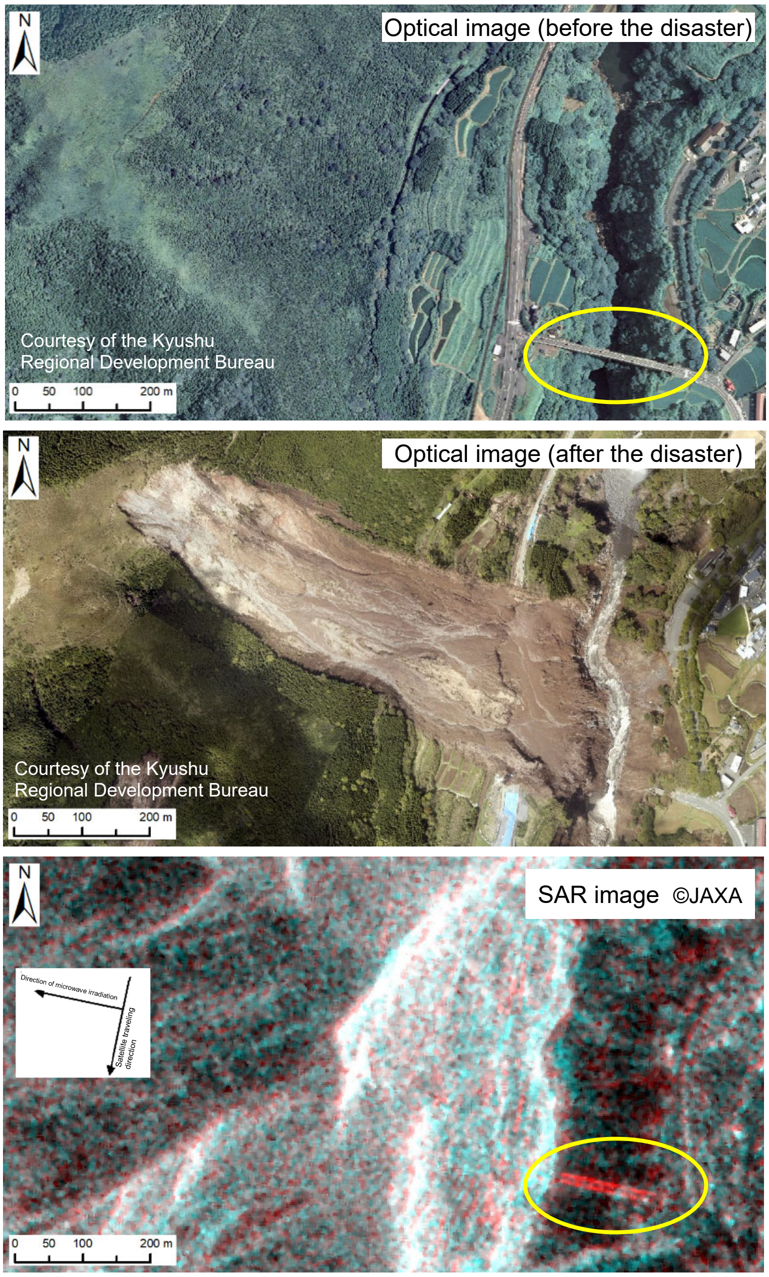


Fig.-3.18 Optical images (top: before the disaster, middle: after the disaster) and intensity difference SAR image (bottom)

(Minamiaso Village, Aso County, Kumamoto Prefecture)

As a result of the collapse of the Aso Ohashi Bridge caused by flooding due to a slope failure, the backscatter intensity after the disaster decreases. The place is shown clearly in red on the intensity difference SAR image.

E-2 Torrential Rainfall in July 2020 (Fukami Bridge)

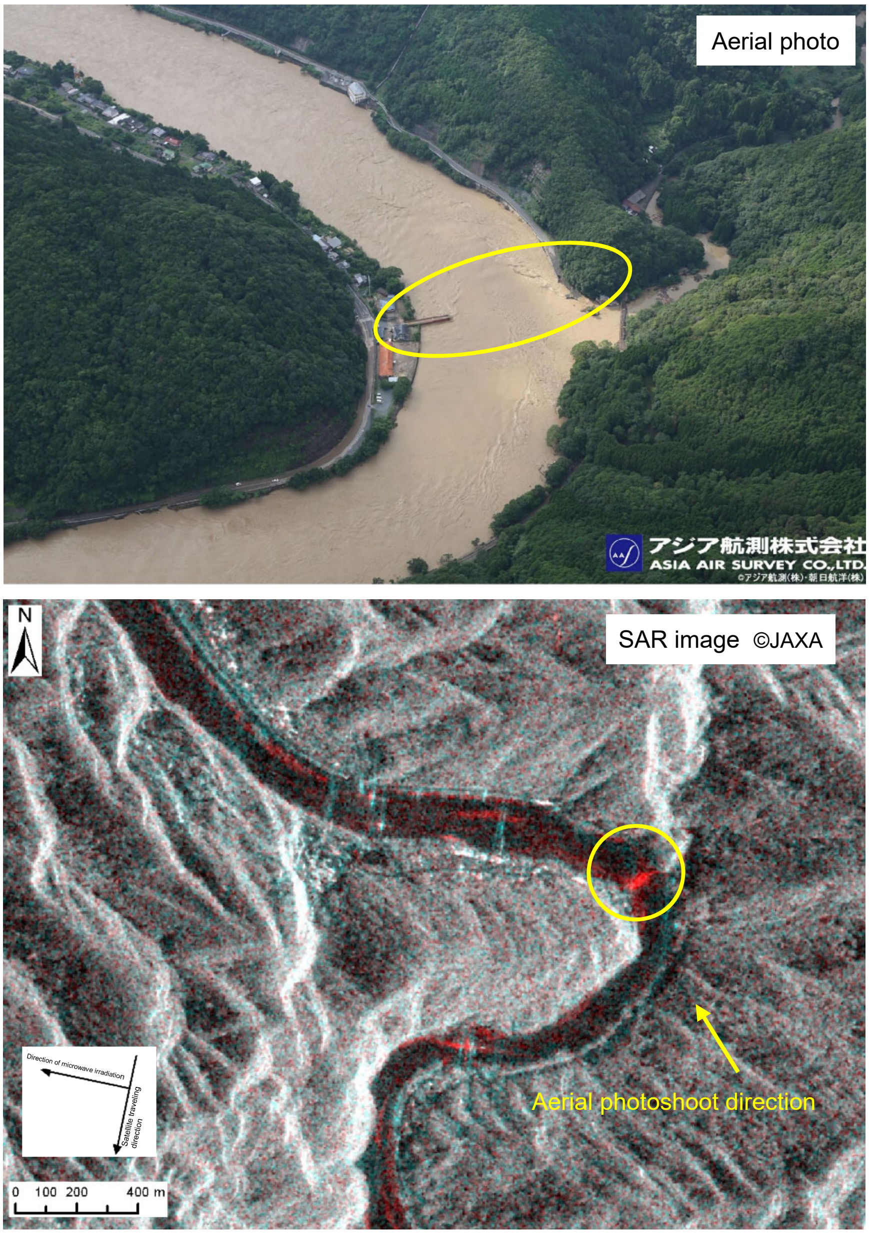
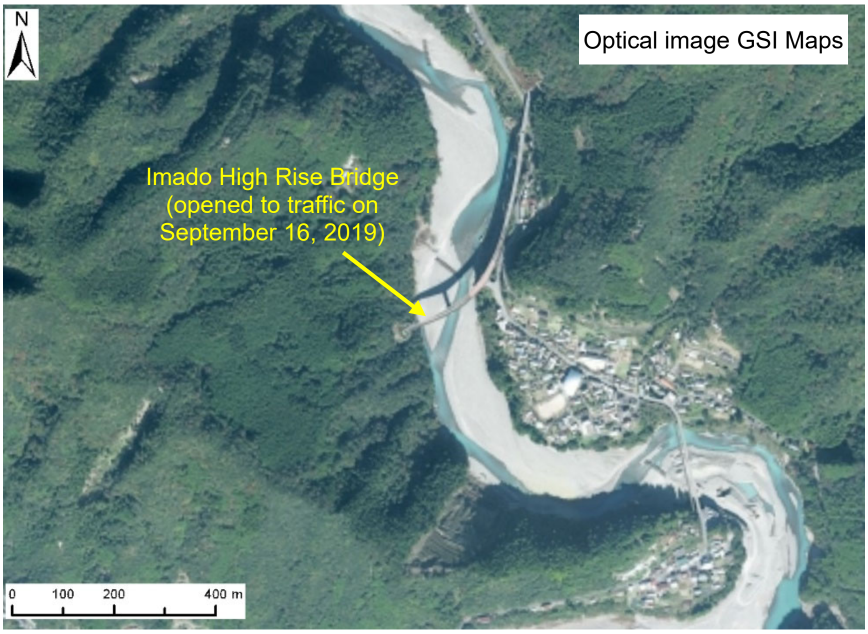


Fig.-3.19 Aerial photo (top) and intensity difference SAR image (bottom)

(Yatsushiro City, Kumamoto Prefecture)

As a result of the collapse of the Fukami Bridge caused by overflow of the Kumagawa River, the backscatter intensity after the disaster decreases. The place is shown in red on the intensity difference SAR image.

E-3 [For reference] New bridge construction



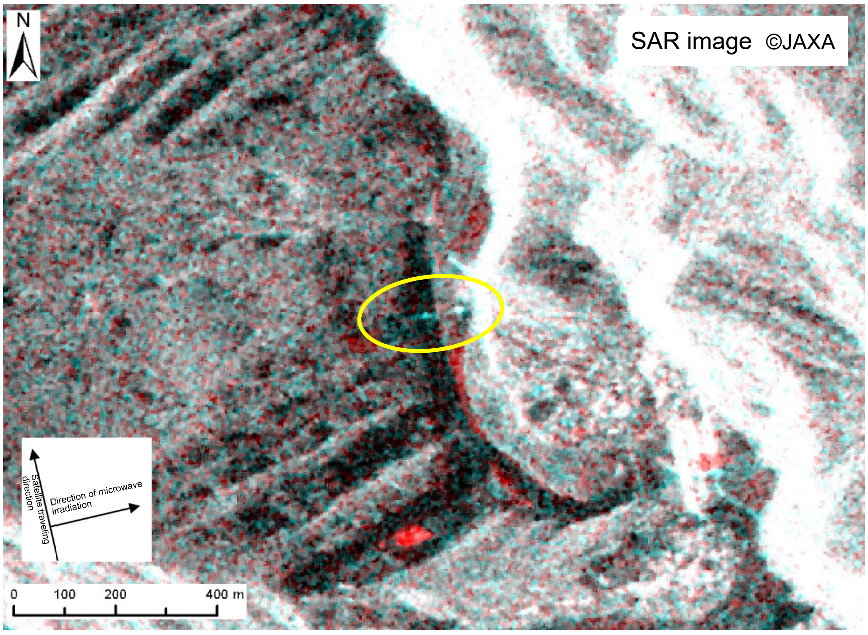


Fig.-3.20 Optical image (top) and intensity difference SAR image (bottom)

(Totsukawa Village, Yoshino County, Nara Prefecture)

When a bridge has been newly constructed, the backscatter intensity after the construction increases. The place is shown in cyan on the intensity difference SAR image.

F) Failure on a forest slope (horseshoe shape)

[Explanations of scatter changes]

When a horseshoe shaped failure occurs on a forest slope, the backscatter intensity after the disaster decreases.
The place is shown in red on the intensity difference SAR image.

Microwaves irradiated from SAR are subjected to volume scatters occurring at forests. For this reason, the backscatter intensity before the disaster increases. When a forest is lost as a result of a slope failure caused by the disaster, forward scatters of microwaves are dominant, and therefore the backscatter intensity after the disaster decreases [1), 7)]. Also, as a result of the slope failure (topographical change), the local incidence angle changes, and the backscatter intensity after the disaster slightly decreases. Based on such changes in the scattering of SAR, the place where a failure occurred on the forest slope may be identified.

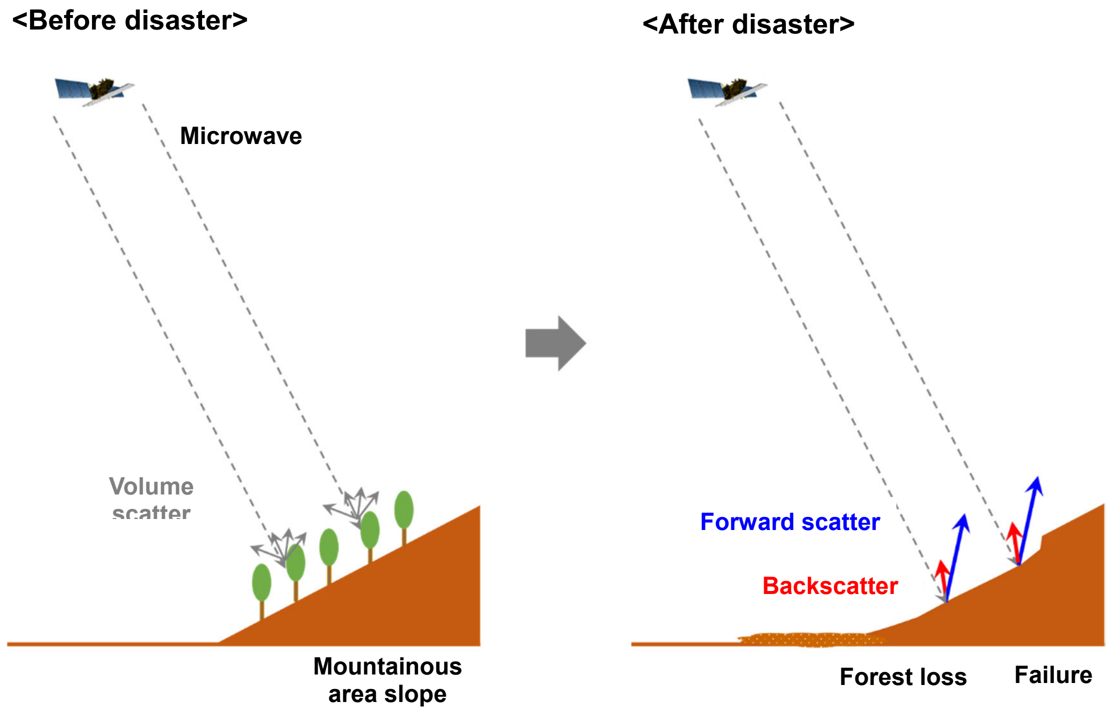
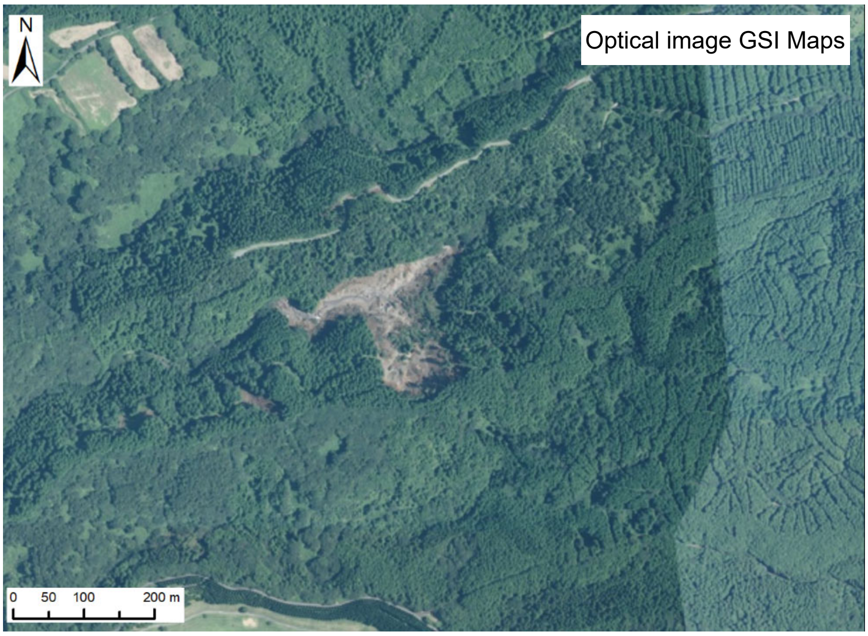


Fig.-3.21 Concept concerning scatter changes when a horseshoe shaped failure has occurred on a forest slope

[Precautions]

- Under specific conditions, the backscatter intensity may increase after the disaster (for details, see P. 34).
- The failure is likely to be wrongly identified as artificially modified land such as deforested land (for details, see PP. 35-36).

F-1 2016 Kumamoto Earthquake (Seta District, Ozu Town)



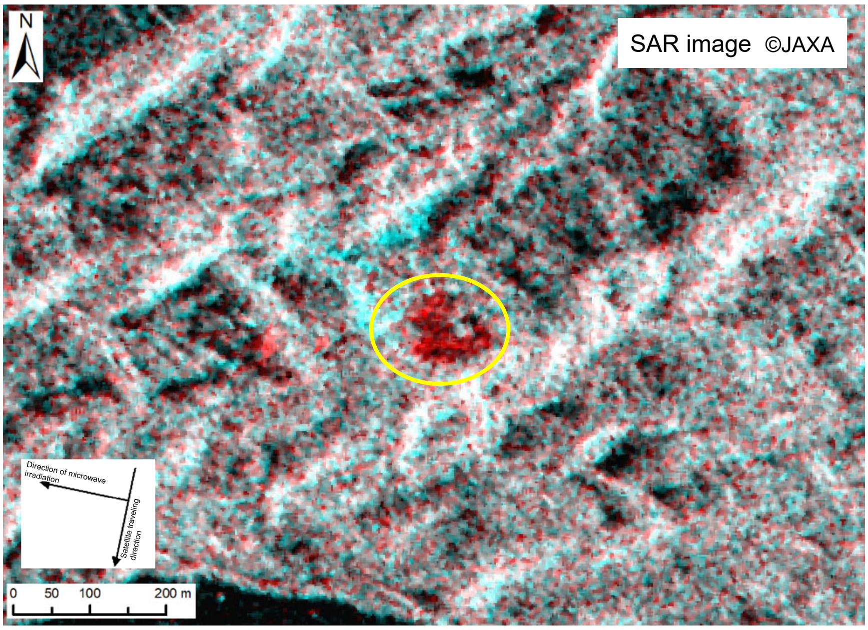


Fig.-3.22 Optical image (top) and intensity difference SAR image (bottom)

(Ozu Town, Kikuchi County, Kumamoto Prefecture)

As a result of occurrence of a horseshoe shaped failure on a forest slope, the backscatter intensity after the disaster decreases. The place is shown in red on the intensity difference SAR image.

F-2 Northern Kyushu Torrential Rainfall in July 2017 (Otoishigawa River)

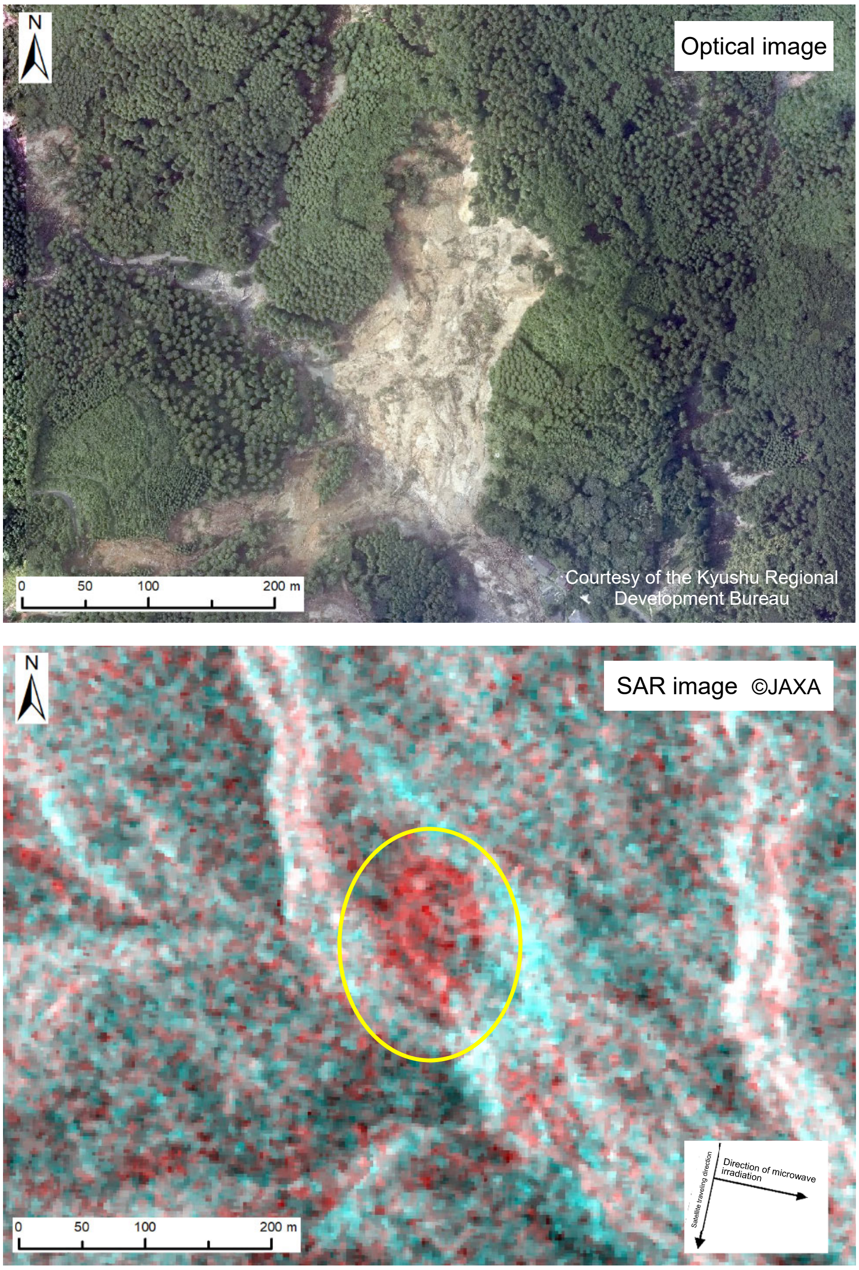


Fig.-3.23 Optical image (top) and intensity difference SAR image (bottom)

(Asakura City, Fukuoka Prefecture)

As a result of occurrence of a horseshoe shaped failure on a forest slope, the backscatter intensity after the disaster decreases. The place is shown in red on the intensity difference SAR image.

F-3 [Exception] Failure on a grassland slope

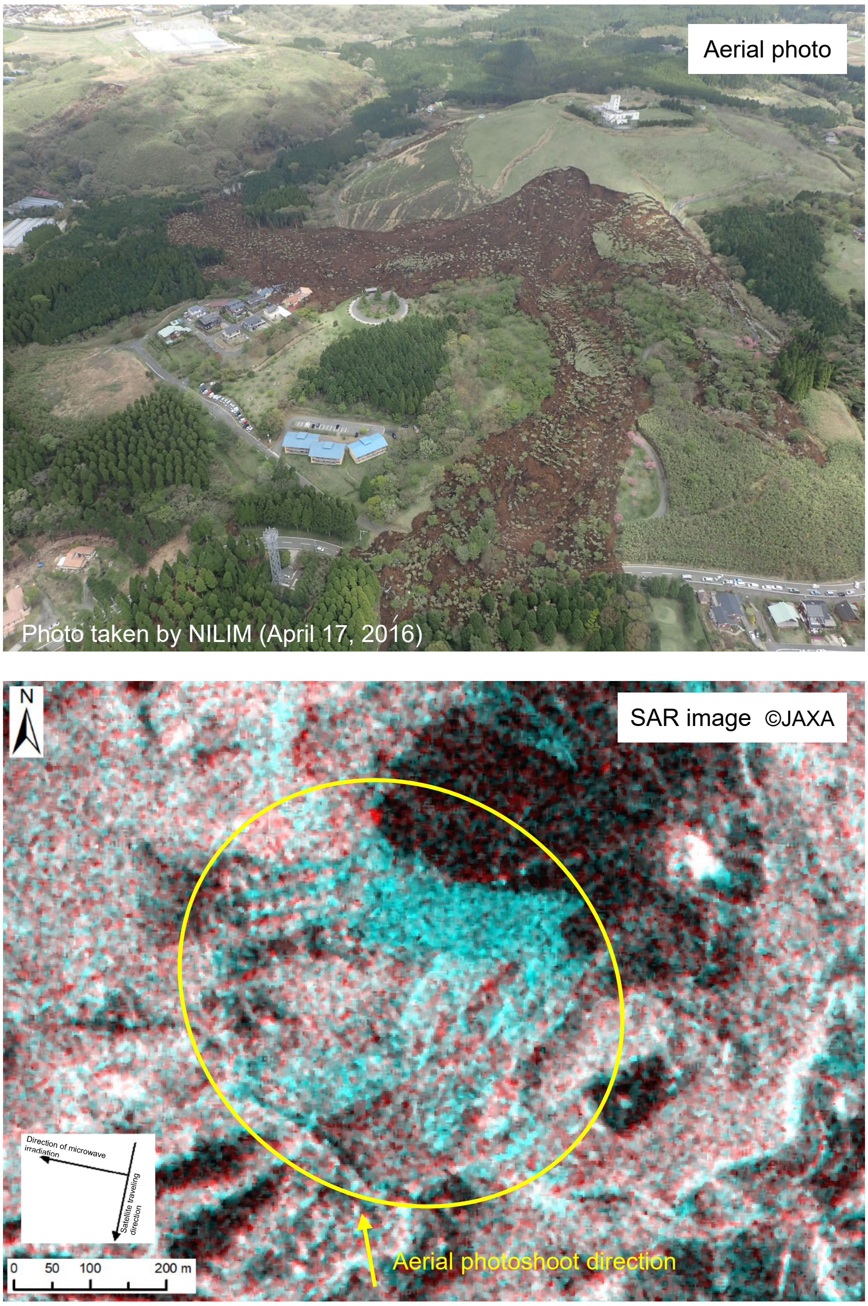


Fig.-3.24 Aerial photo (top) and intensity difference SAR image (bottom)

(Minamiaso Village, Aso County, Kumamoto Prefecture)

When a failure has occurred on a grassland slope, sediment exposed on the ground surface makes the backscatter of microwaves dominant, and therefore the backscatter intensity after the disaster increases [10]. In this case, the place is shown in cyan on the intensity difference SAR image.

F-4 [For reference] Deforested land

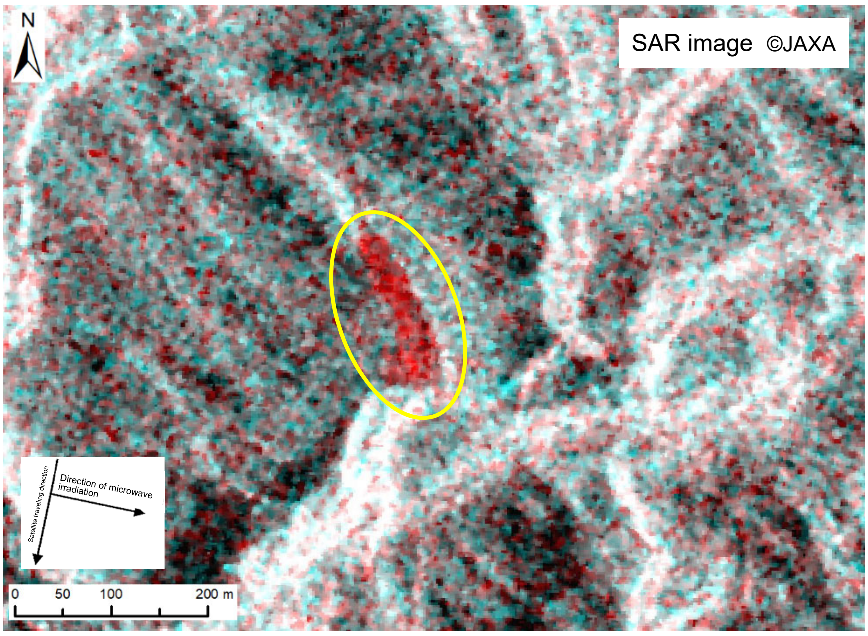


Fig.-3.25 Optical image (top) and intensity difference SAR image (bottom)
(Hita City, Oita Prefecture)

If deforestation is done on a forest slope, the backscatter intensity decreases [11]. The place is shown in red on the intensity difference SAR image.

Since deforestation is likely to be wrongly identified as a failure on a forest slope, image interpretation needs to be performed after having checked the optical image immediately before the disaster.

F-5 [For reference] Quarry

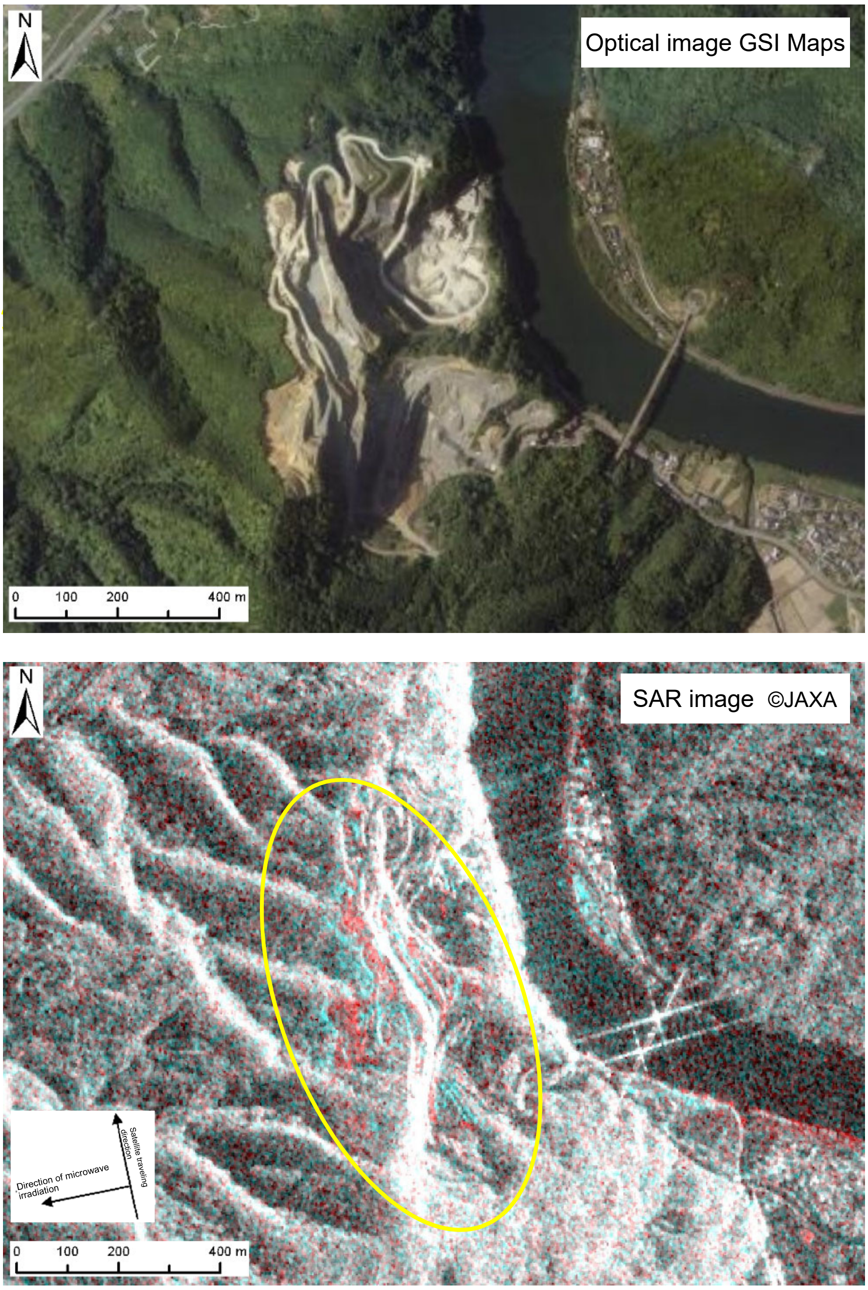


Fig.-3.26 Optical image (top) and intensity difference SAR image (bottom)

(Yatsushiro City, Kumamoto Prefecture)

If quarrying is done within a forest slope, the backscatter intensity changes. The place is shown in red or cyan on the intensity difference SAR image.

Since quarrying is likely to be wrongly identified as a failure on the forest slope, image interpretation needs to be performed after having checked the optical image.

G) Failure on a forest slope (thin and long shape)

[Explanations of scatter changes]

If a thin and long shaped failure occurs on a forest slope, in the eroded part the backscatter intensity after the disaster decreases, and around a steep cliff the backscatter intensity after the disaster increases.
On the intensity difference SAR image, the eroded part is shown clearly in red, and the areas around the steep cliff are shown in cyan.

Microwaves irradiated from SAR are subjected to volume scatters occurring at forests. For this reason, the backscatter intensity before the disaster increases. When a forest is lost as a result of a slope failure caused by the disaster, forward scatters of microwaves are dominant in the eroded part, and therefore the backscatter intensity after the disaster decreases [1), 7)], and double bounce scattering of microwaves occurs around a steep cliff, and therefore the backscatter intensity after the disaster increases. Also, as a result of the topographical change, the local incidence angle changes, and the backscatter intensity after the disaster slightly decreases. Based on such changes in the scattering of SAR, the place where a failure occurred on the forest slope may be identified.

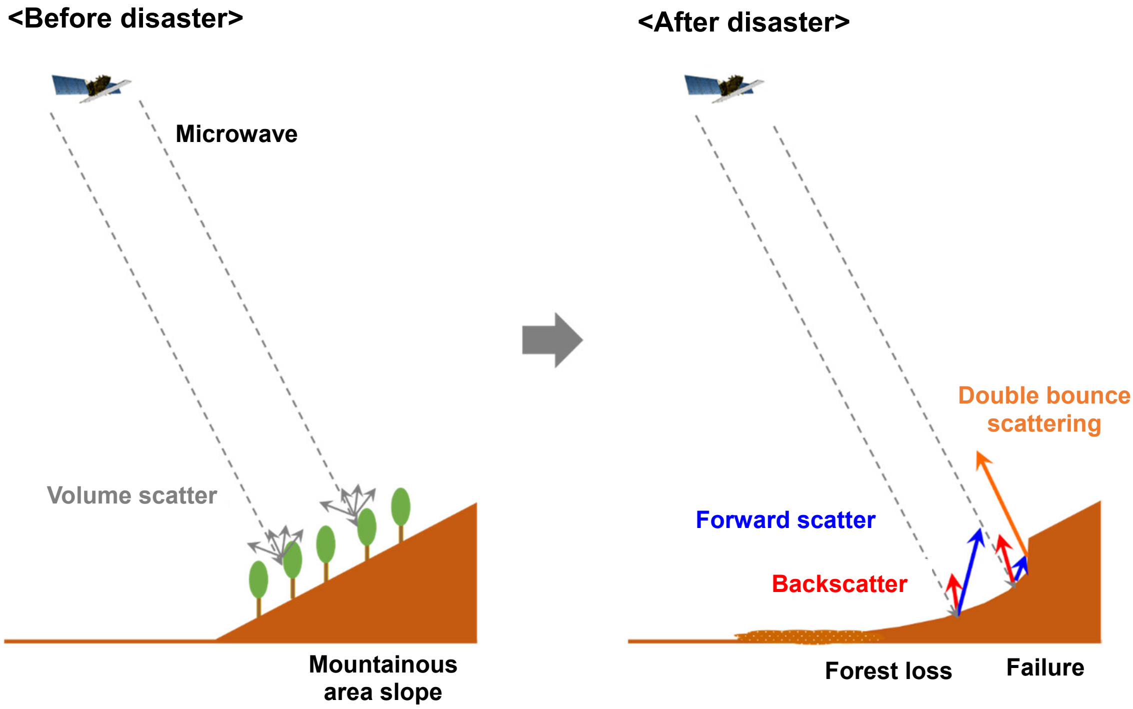


Fig.-3.27 Concept concerning scatter changes when a thin and long shaped failure has occurred on a forest slope

[Precautions]

- The failure is likely to be wrongly identified as artificially modified land such as deforested land (for details, see PP. 35-36).

G-1 Northern Kyushu Torrential Rainfall in July 2017 (Toho Village, Mt. Hoshu)

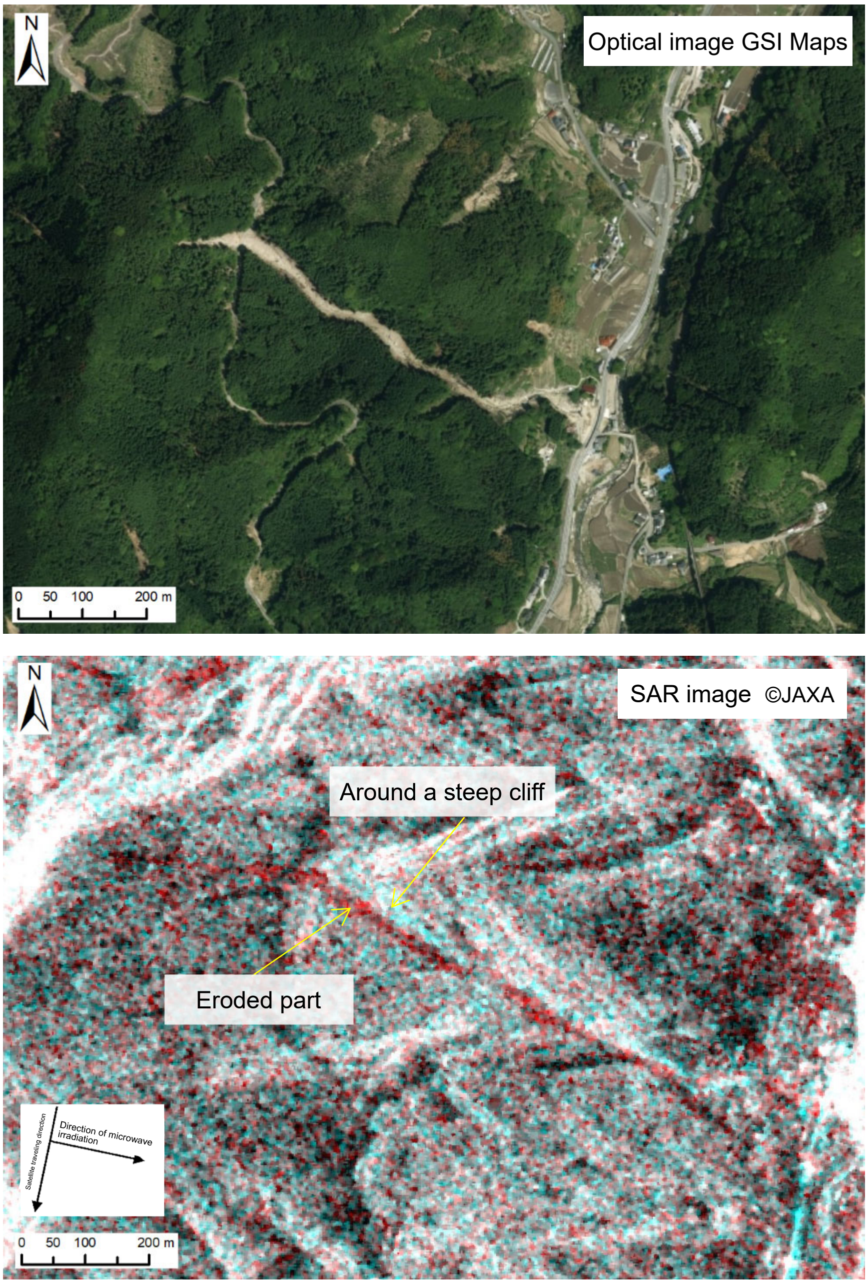
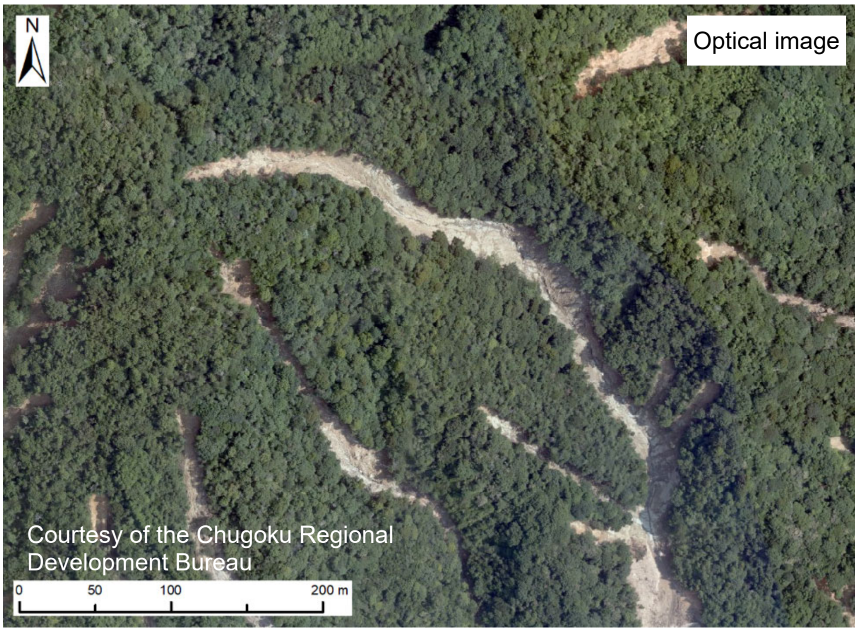


Fig.-3.28 Optical image (top) and intensity difference SAR image (bottom)

(Toho Village, Asakura County, Fukuoka Prefecture)

As a result of occurrence of a thin and long shaped failure on a forest slope, in the eroded part the backscatter intensity after the disaster decreases, and around a steep cliff the backscatter intensity after the disaster increases. On the intensity difference SAR image, the eroded part is shown in red and the areas around the steep cliff are shown in cyan.

G-2 Torrential Rainfall in July 2018 (Yasuura District, Kure City)



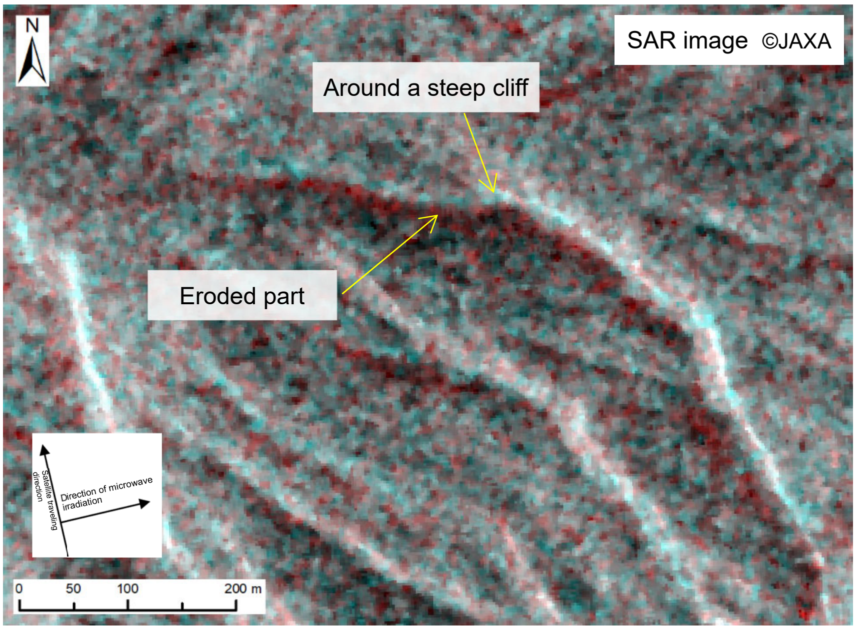


Fig.-3.29 Optical image (top) and intensity difference SAR image (bottom)

(Kure City, Hiroshima Prefecture)

As a result of occurrence of a thin and long shaped failure on a forest slope, in the eroded part the backscatter intensity after the disaster decreases, and around a steep cliff the backscatter intensity after the disaster increases. On the intensity difference SAR image, the eroded part is shown in red and the areas around the steep cliff are shown in cyan.

H) Failure on a bare land slope

[Explanations of scatter changes]

If a failure occurs on a bare land slope, the backscatter intensity after the disaster slightly decreases.
On the intensity difference SAR image, the place is shown in light red.

Microwaves irradiated from SAR are subjected to scattering in which forward scatters are dominant on the bare land slope. For this reason, the backscatter intensity before the disaster decreases. When a slope failure is caused by the disaster, as a result of the topographical change, the local incidence angle changes, and the backscatter intensity after the disaster slightly decreases. Based on such changes in the scattering of SAR, the place where a failure occurred on the bare land slope may be identified.

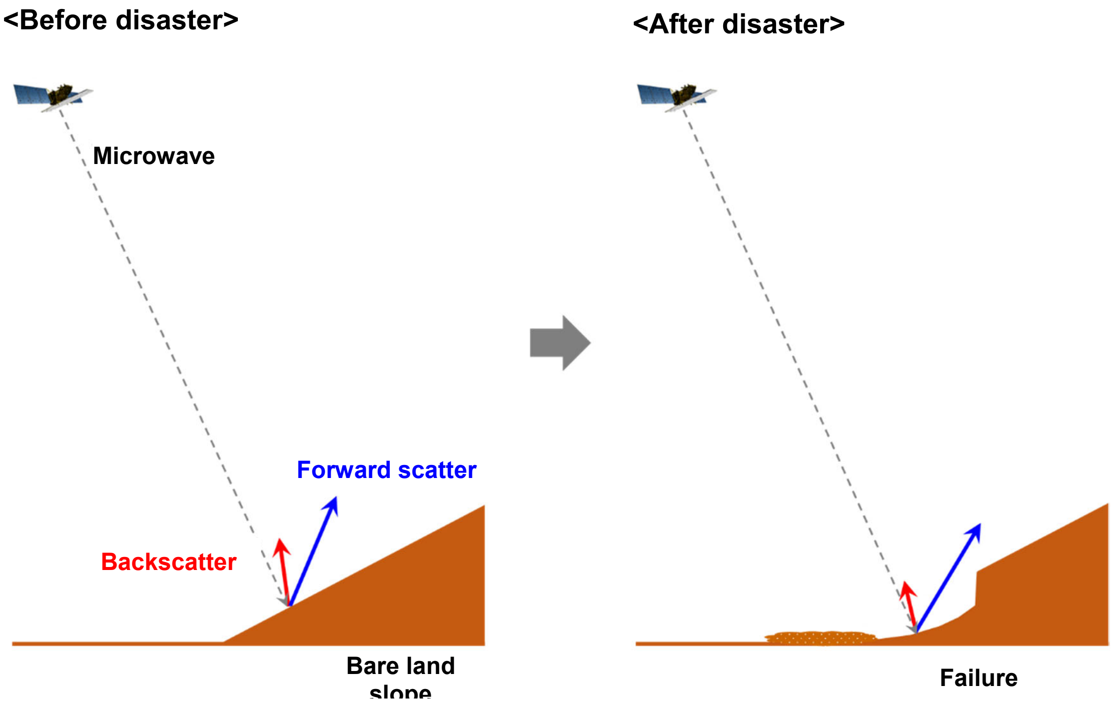


Fig.-3.30 Concept concerning scatter changes when a failure has occurred on a bare land slope

[Precautions]

- Scatter changes are small, resulting in a lack of visibility.
- The failure is likely to be wrongly identified as artificially modified land such as deforested land (for details, see PP. 35-36).

H-1 Torrential Rainfall in July 2020 (Amehatagawa River)

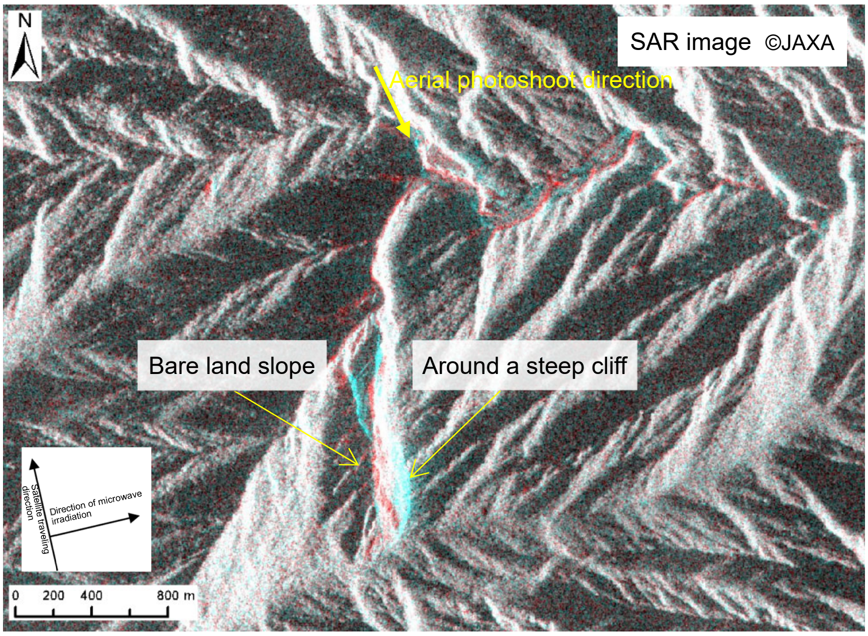


Fig.-3.31 Aerial photo (top) and intensity difference SAR image (bottom)

(Hayakawa Town, Minamikoma County, Yamanashi Prefecture)

As a result of occurrence of an expanded failure on a bare land slope that is an existing failure land, the backscatter intensity after the disaster slightly decreases. On the intensity difference SAR image, the place is shown in light red.

Also, since double bounce scatters occur around a steep cliff where the expanded failure has occurred, the backscatter intensity after the disaster increases, and on the intensity difference SAR image, the place is shown in cyan.

H-2 Torrential Rainfall in July 2020 (Matsuno District, Kuma Village)

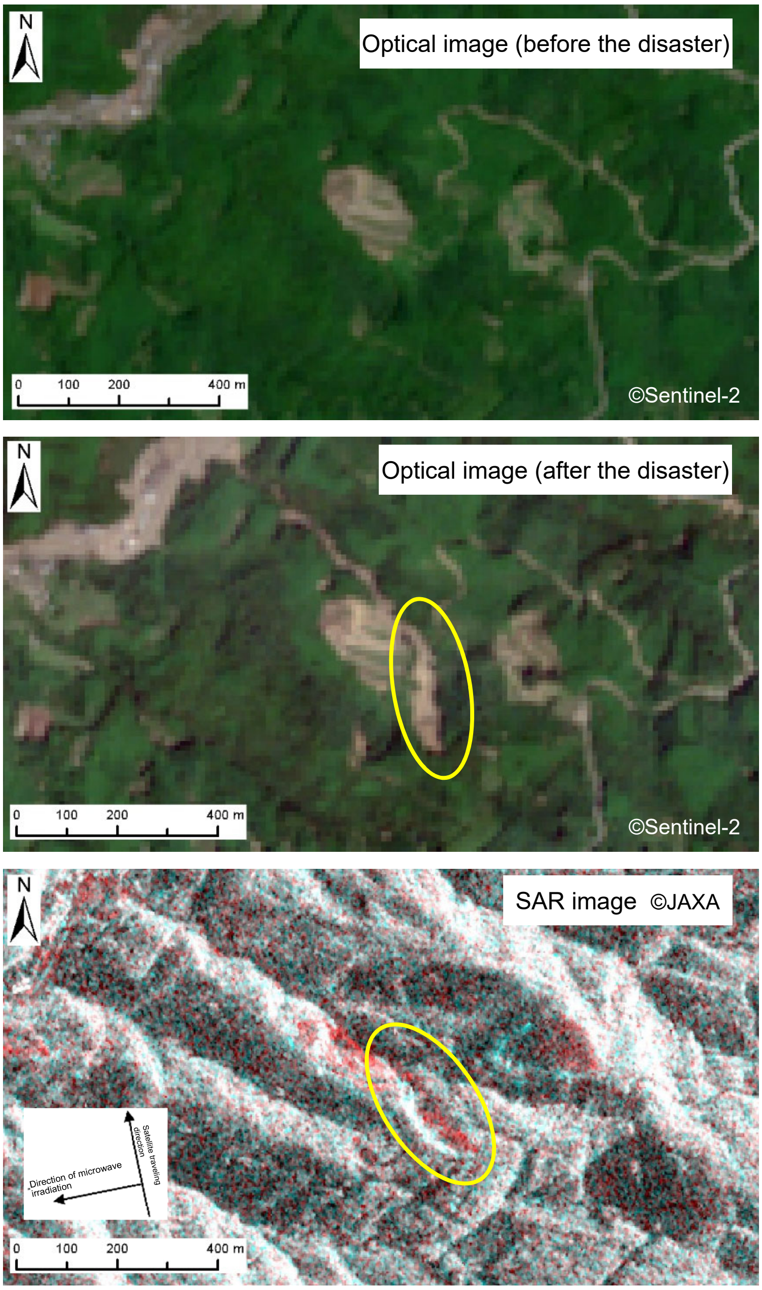


Fig.-3.32 Optical image (top: before the disaster, middle: after the disaster) and intensity difference SAR image (bottom)

(Kuma Village, Kuma County, Kumamoto Prefecture)

As a result of occurrence of a failure on a bare land slope that is a deforested land, the backscatter intensity after the disaster slightly decreases. On the intensity difference SAR image, the place is shown in light red.

I) Deposition of sediment on residential land

[Explanations of scatter changes]

When sediment is deposited on residential land, the backscatter intensity after the disaster slightly decreases.
On the intensity difference SAR image, the place is shown in light red.

Microwaves irradiated from SAR are subjected to double bounce scattering on residential land. For this reason, the backscatter intensity before the disaster becomes very high. When sediment is deposited by the disaster on residential land, the double bounce scattering of microwaves weakens, and the backscatter intensity after the disaster slightly decreases. Based on such changes in the scattering of SAR, the place where sediment was deposited on the residential land may be identified.

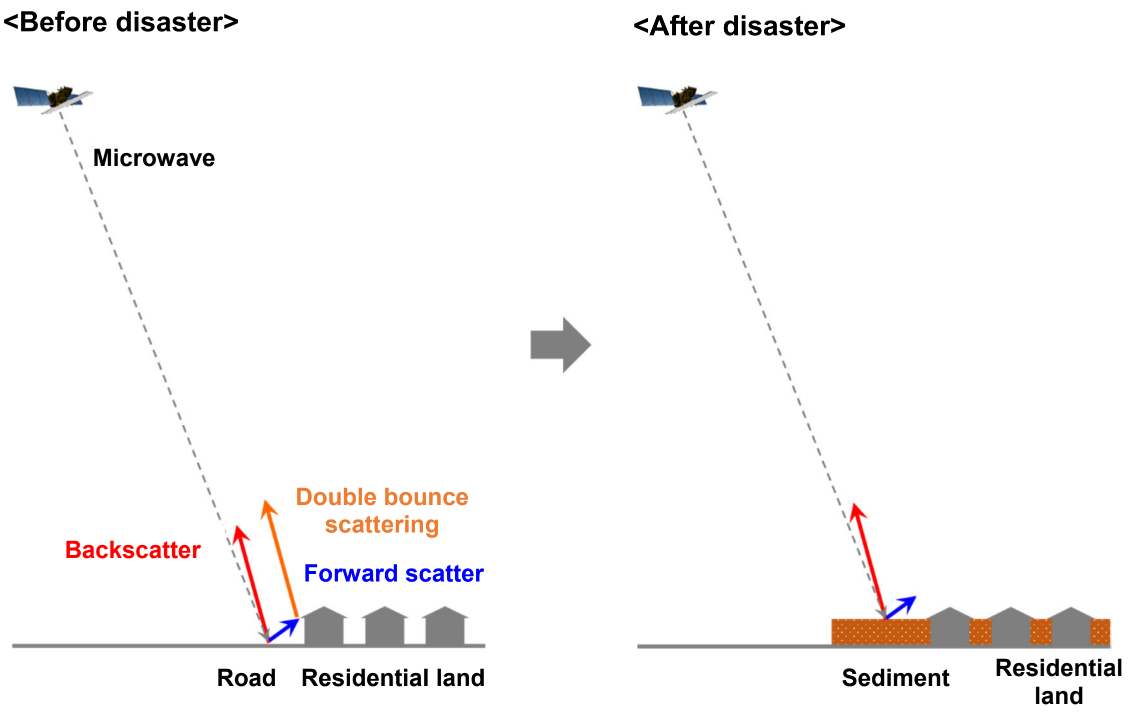
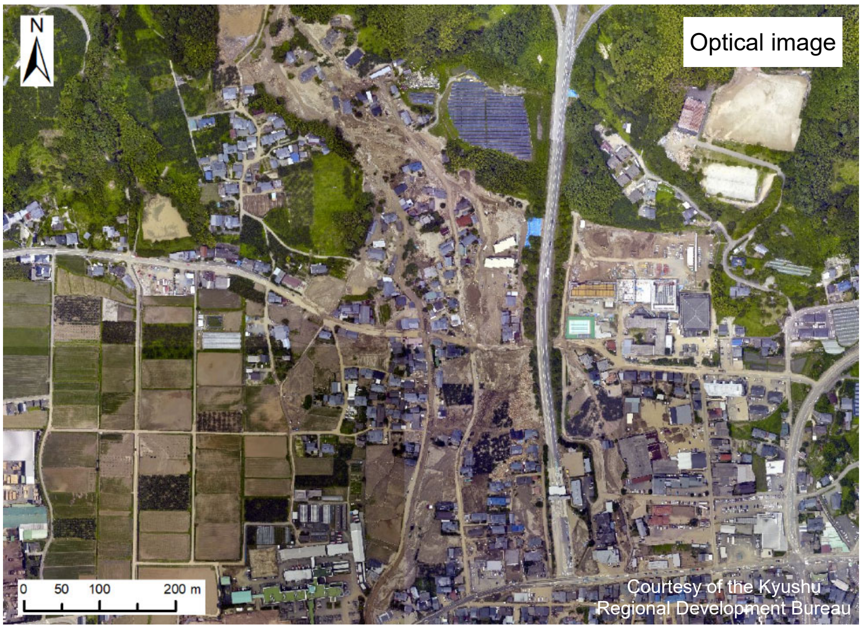


Fig.-3.33 Concept concerning scatter changes when sediment has been deposited on residential land

[Precautions]

- Scatter changes are small, resulting in a lack of visibility.

I-1 Northern Kyushu Torrential Rainfall in July 2017 (Shozugawa River)



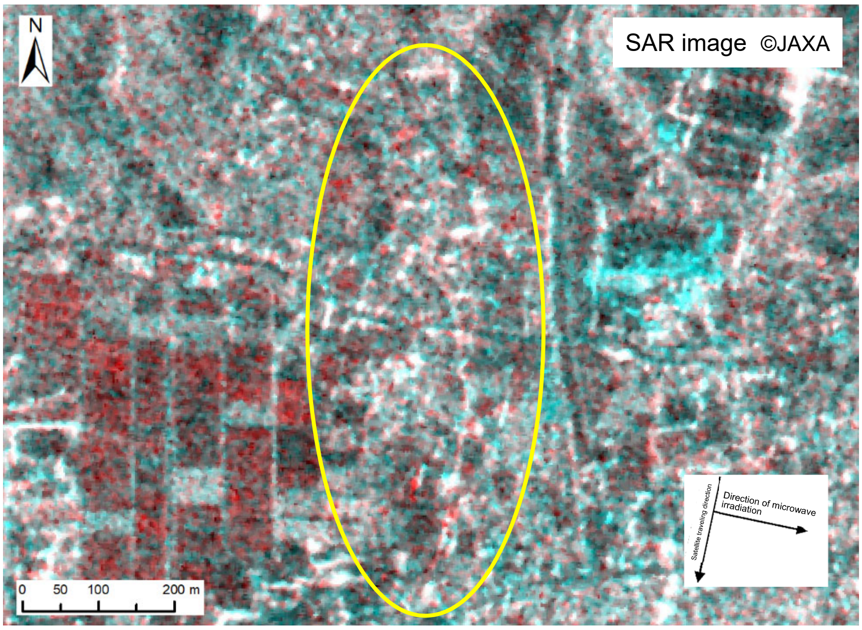
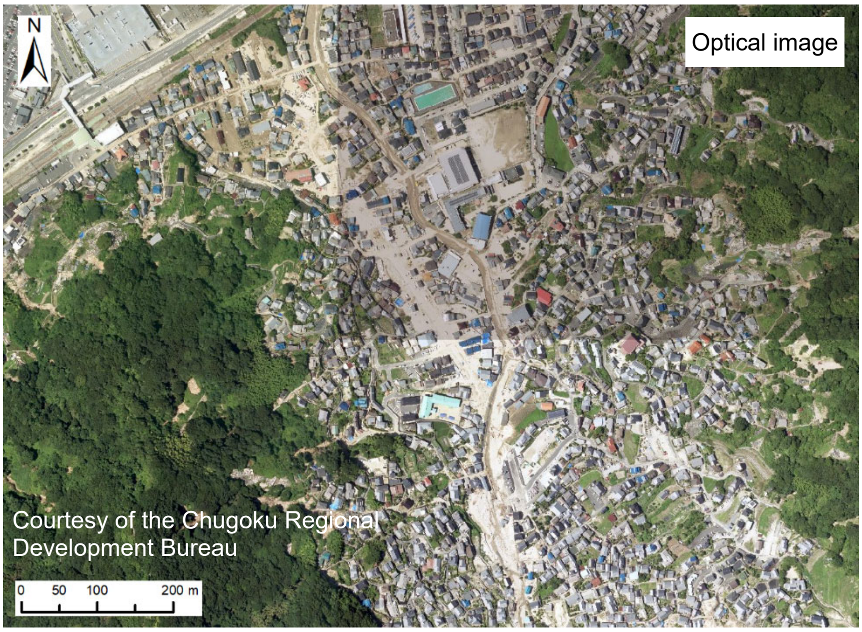


Fig.-3.34 Optical image (top) and intensity difference SAR image (bottom)

(Asakura City, Asakura County, Fukuoka Prefecture)

As a result of deposition of sediment on residential land, the backscatter intensity after the disaster slightly decreases. On the intensity difference SAR image, the place is shown in light red, but since scatter changes are small, it results in a lack of visibility.

I-2 Torrential Rainfall in July 2018 (Sozugawa River)



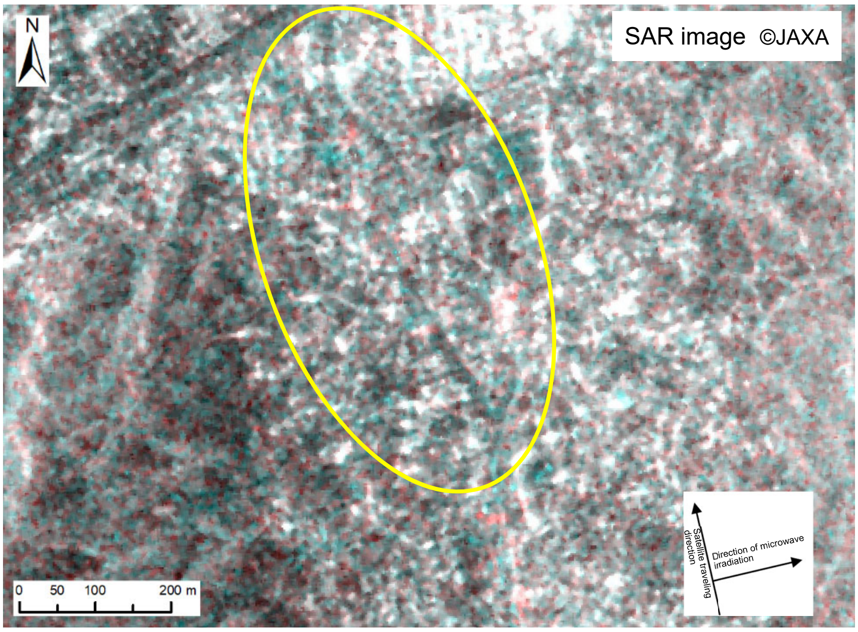


Fig.-3.35 Optical image (top) and intensity difference SAR image (bottom)

(Saka Town, Aki County, Hiroshima Prefecture)

As a result of deposition of sediment on residential land, the backscatter intensity after the disaster slightly decreases. On the intensity difference SAR image, the place is shown in light red, but since scatter changes are small, it results in a lack of visibility.

J) Collapse of a building or structure

[Explanations of scatter changes]

> When a building or structure collapses, the backscatter intensity after the disaster slightly decreases.
> On the intensity difference SAR image, the place is shown in light red.

Microwaves irradiated from SAR are subjected to double bounce scattering on residential land. For this reason, the backscatter intensity before the disaster becomes very high. When a building or structure is collapsed by the disaster, the double bounce scattering of microwaves weakens, and the backscatter intensity after the disaster slightly decreases [12)]. Based on such changes in the scattering of SAR, the areas where the building or structure collapsed may be identified.

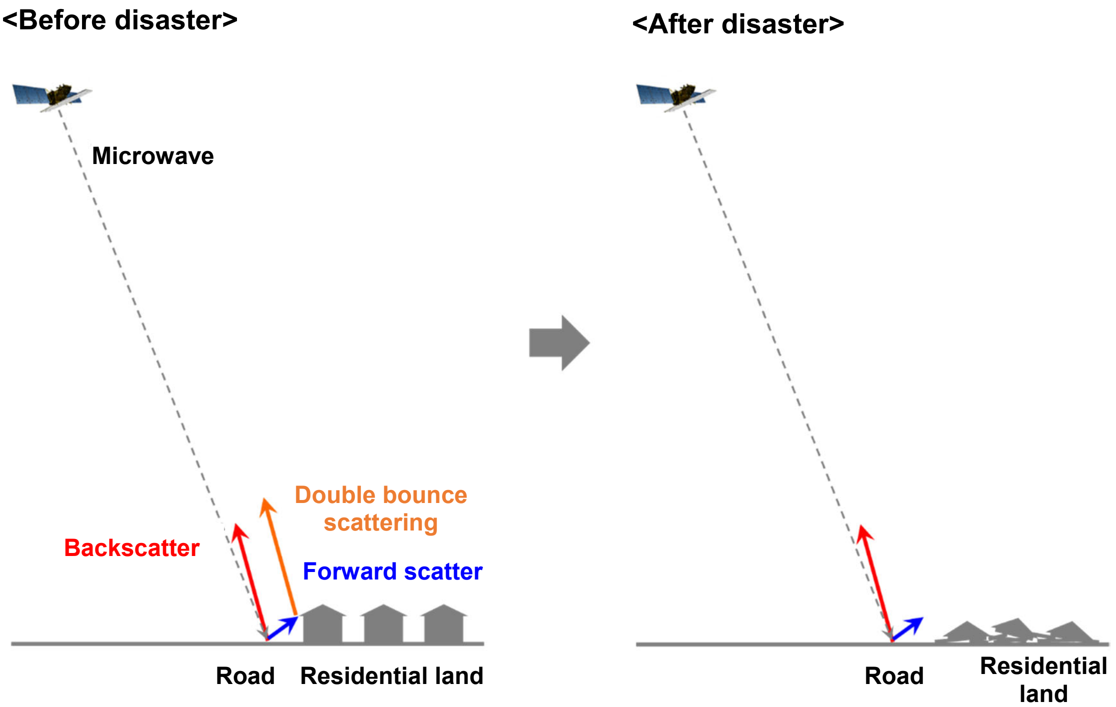


Fig.-3.36 Concept concerning scatter changes when a building or structure has collapsed

[Precautions]

- Scatter changes are small, resulting in a lack of visibility.
- Spatially a lack of visibility occurs unless multiple buildings or structures are collapsed.

J-1 2016 Kumamoto Earthquake (Mashiki Town)

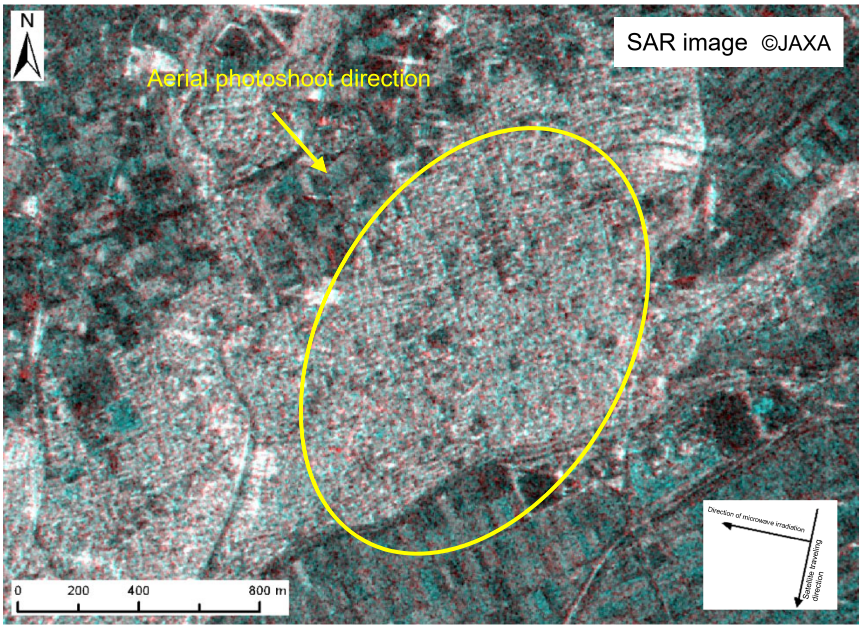


Fig.-3.37 Aerial photo (top) and intensity difference SAR image (bottom)

(Mashiki Town, Mashiki County, Kumamoto Prefecture)

As a result of collapse of a building caused by the earthquake, the backscatter intensity after the disaster slightly decreases. On the intensity difference SAR image, the place is shown in light red, but since scatter changes are small, it results in a lack of visibility.

K) Ashfall

[Explanations of scatter changes]

In the range of ashfall, the backscatter intensity after the disaster slightly decreases.
On the intensity difference SAR image, the place is shown in light red.

Microwaves irradiated from SAR are subjected to backscatters according to the shape of the ground surface around the crater and the degree of dents and projections. For this reason, the backscatter intensity before the disaster shows a certain degree of greatness. When volcanic ashes are deposited by an eruption, the ground surface becomes flatter without undulations than before the eruption, and the backscatter intensity after the disaster slightly decreases [13]. Based on such changes in the scattering of SAR, the range of ashfall may be identified.

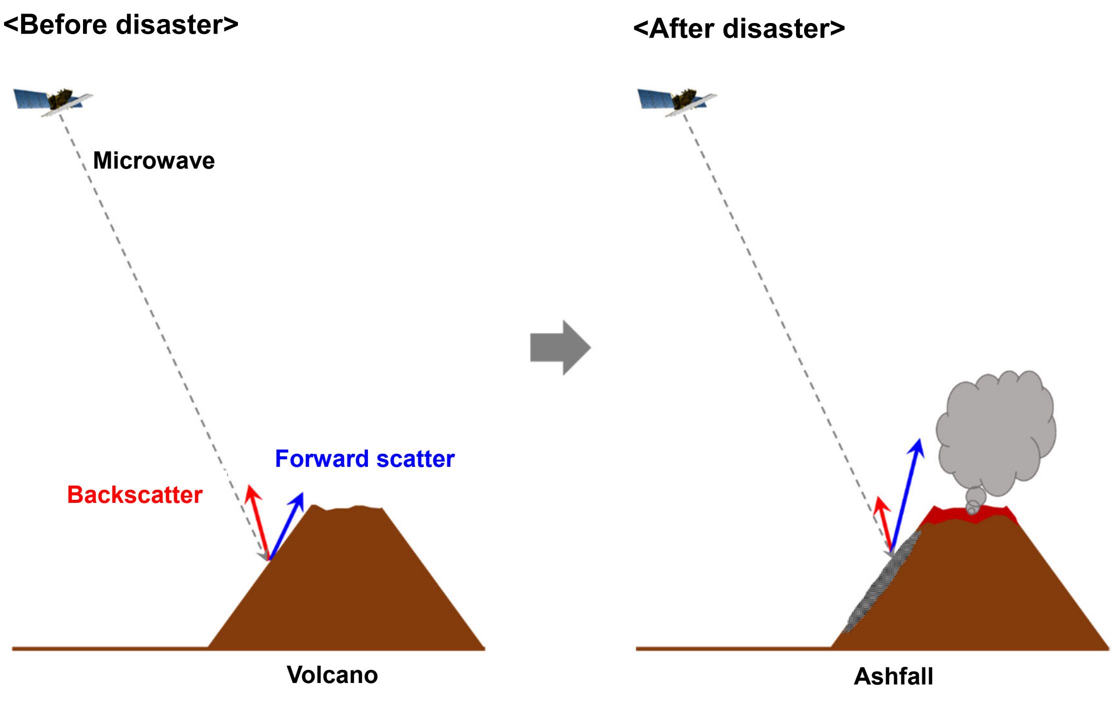
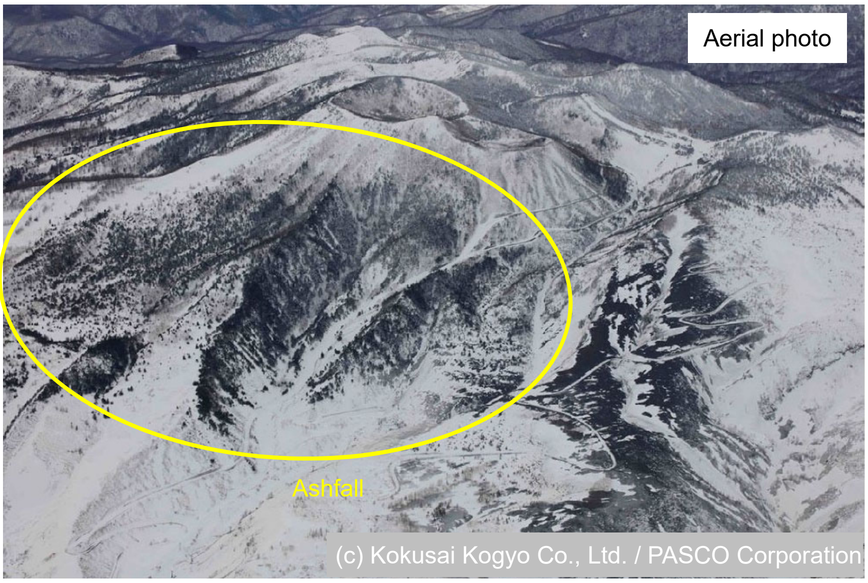


Fig.-3.38 Concept concerning scatter changes during ashfall

[Precautions]

- Since examples are scarce, there are unknown portions about the tendency of scatter changes.

K-1 Eruption of Mt. Kusatsu-Shirane in 2018



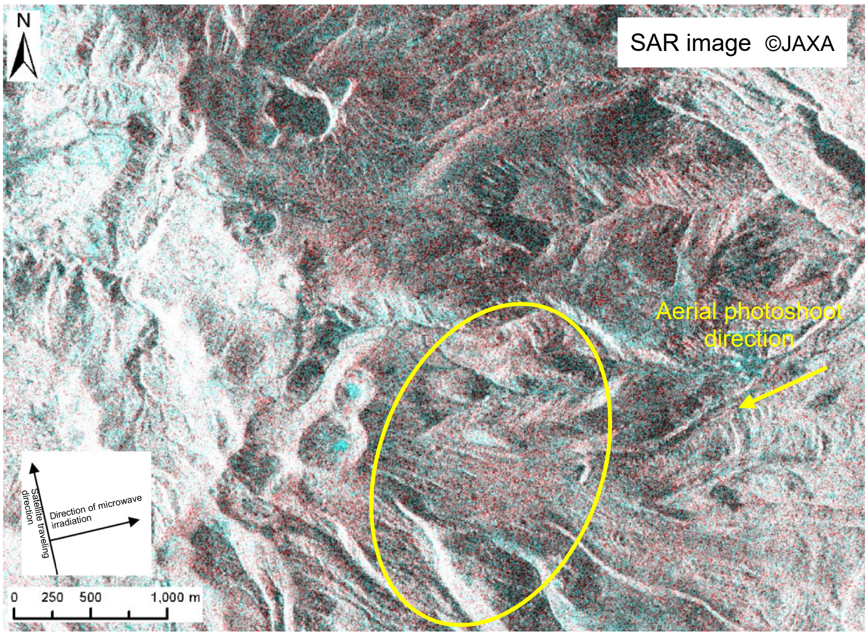


Fig.-3.39 Aerial photo (top) and intensity difference SAR image (bottom)

(Tsumagoi Village/Kusatsu Town, Agatsuma County, Gunma Prefecture)

As a result of ashfall around the crater caused by the eruption, the backscatter intensity after the disaster slightly decreases. On the intensity difference SAR image, the place is shown in light red.

However, in this example, it is considered that the influence of snow accumulation is included to a certain extent.

L) Moving down of a pyroclastic flow

[Explanations of scatter changes]

> In the range where a pyroclastic flow has moved down, the backscatter intensity after the disaster decreases.
> On the intensity difference SAR image, the place is shown in red.

Microwaves irradiated from SAR are subjected to volume scatters in the forests around the crater. For this reason, the backscatter intensity before the disaster increases. When a pyroclastic flow occurs and the forests are burnt and lost, the backscatters of microwaves are lost, and therefore the backscatter intensity after the disaster decreases. Based on such changes in the scattering of SAR, the range of the pyroclastic flow that has moved down may be identified.

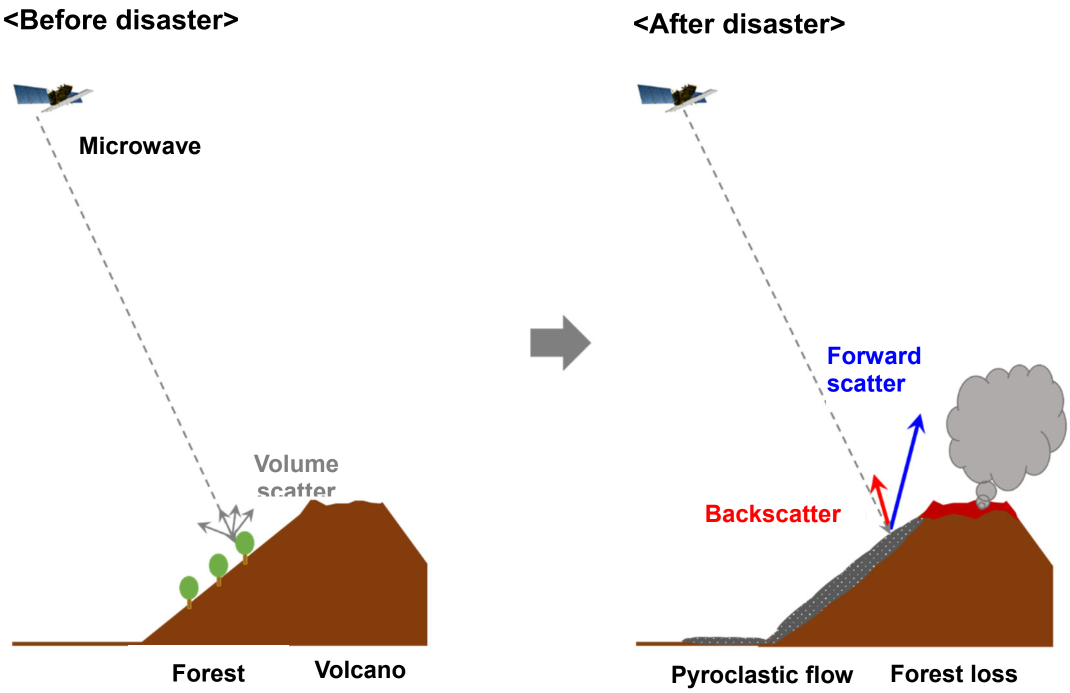


Fig.-3.40 Concept concerning scatter changes when a pyroclastic flow has occurred

[Precautions]

- It is necessary that there is vegetation such as forests around the crater.
- Distinction from the deposition of volcanic ash is difficult.
- Since examples are scarce, there are unknown portions about the tendency of scatter changes.

L-1 Eruption of Mt. Kuchinoerabu in 2015

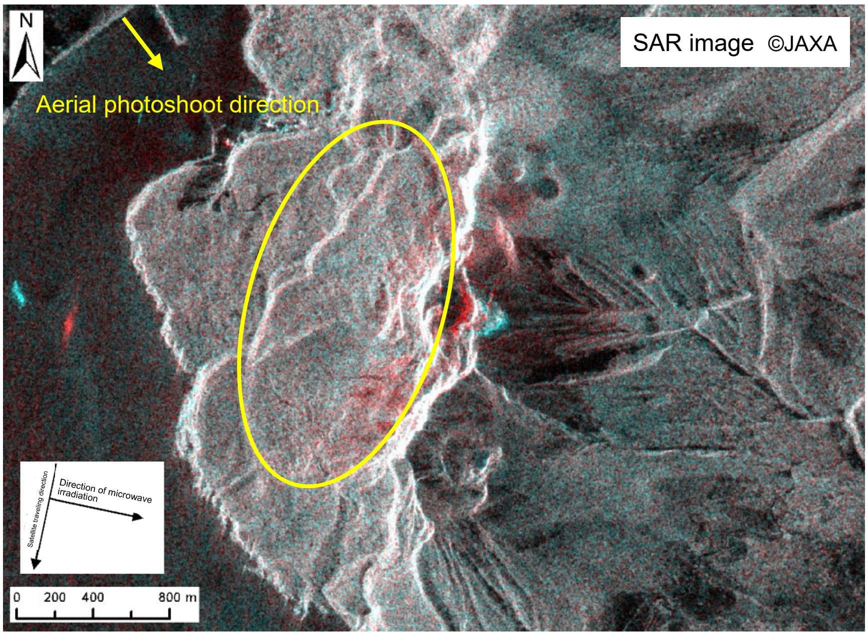


Fig.-3.41 Aerial photo (top) and intensity difference SAR image (bottom)

(Yakushima Town, Kumage County, Kagoshima Prefecture)

As a result of occurrence of the pyroclastic flow, the backscatter intensity after the disaster decreases. On the intensity difference SAR image, the place is shown in red.

4. Procedures for image interpretation survey on the basis of SAR scatter changes during a disaster

4.1 Tendency of SAR scatter changes during a disaster

Table-4.1 lists SAR scatter changes during a disaster of which explanations of examples were given in the preceding chapter.

In A) Deposition of sediment on farmland or roads, and B) Floating of floodwood, etc., where a scattering surface is generated, the backscatter intensity after the disaster increases, and the visibility on the intensity difference SAR image is high. Also, since the two phenomena occur in different places, there is a low possibility that SAR scatter changes are assimilated and are wrongly identified. For this reason, they are phenomena that are detected easily from the SAR scatter changes during a disaster.

In C) Inundation caused by channel blockage (natural dam), D) Water seepage/flood, and E) Bridge collapse caused by flooding, where a scattering surface disappears, the backscatter intensity after the disaster decreases conspicuously, and the visibility on the intensity difference SAR image is high. However, since these phenomena occur around a channel, there is a possibility that SAR scatter changes are assimilated and distinction of each phenomenon will be difficult.

In F) Failure on a forest slope (horseshoe shape), G) Failure on a forest slope (thin and long shape), and L) Moving down of a pyroclastic flow, where a volume scatter disappears, the backscatter intensity after the disaster decreases, and the visibility on the intensity difference SAR image is relatively high. In particular, G) Failure on a forest slope (thin and long shape) also has features that double bounce scatters occur as well, which is a phenomenon that is easily detected from SAR scatter changes during a disaster.

On the other hand, in I) Deposition of sediment on residential land, J) Collapse of a building or structure, where double bounce scatters disappear, and in H) Failure on a bare land slope, and K) Ashfall, where the scatter surface is deformed, the backscatter intensity after the disaster slightly decreases, and scatter changes on the intensity difference SAR image are not clear. It is considered that there is a low possibility that these phenomena can be detected from SAR scatter changes during a disaster.

Table-4.1 List of SAR scatter changes during a disaster

Phenomenon	Scatter change model						Backscatter intensity after the disaster	Intensity difference SAR image
	(a) Occurrence of a scattering surface	(b) Occurrence of double bounce scattering	(c) Disappearance of a scattering surface	(d) Disappearance of a volume scatter	(e) Disappearance of double bounce scattering	(f) Deformation of a scattering surface		
A) Deposition of sediment on farmland or roads	○						Increase	Cyan
B) Floating of floodwood, etc.	○						Increase	Cyan
C) Inundation caused by channel blockage (natural dam)			○				Decrease conspicuously	Clear red
D) Water seepage/flood			○				Decrease conspicuously	Clear red
E) Bridge collapse caused by flooding			○				Decrease conspicuously	Clear red
F) Failure on a forest slope (horseshoe shape)				○		○	Decrease	Red
G) Failure on a forest slope (thin and long shape)		○		○		○	Increase/Decrease	Cyan/Red
H) Failure on a bare land slope						○	Decrease slightly	Light red
I) Deposition of sediment on residential land					○		Decrease slightly	Light red
J) Collapse of a building or structure					○		Decrease slightly	Light red
K) Ashfall						○	Decrease slightly	Light red
L) Moving down of a pyroclastic flow				○			Decrease	Red

4.2 Procedures for the image interpretation survey of sediment disasters by means of SAR images

There are a wide variety of SAR scatter changes related to sediment disasters, and **Table-4.2** shows the viewpoints of SAR scatter changes on the basis of the characteristics of each phenomenon, and precautions when conducting the image interpretation survey of sediment disasters by means of SAR images.

[Slope failure]

A failure on a forest slope has a high visibility of SAR scatter changes, and a failure on a bare land slope lacks the visibility of SAR scatter changes. Also, as shown in PP. 35-36, a failure on a forest slope is often wrongly identified as artificially modified land such as deforested land, and attention needs to be paid to the fact that, as shown in P. 34, when a failure occurs on a grassland slope, the SAR scatter changes are reversed.

For this reason, before starting image interpretation of sediment disasters by means of SAR images, it is desirable to check the situation of forest operation in the land to be surveyed and the distribution of quarries and grassland slopes from optical images, etc.

[Deposition of sediment]

Deposition of sediment on farmland, roads, channels, etc. has a high visibility of SAR scatter changes, and deposition of sediment on residential land lacks the visibility of SAR scatter changes. Also, attention needs to be paid to the fact that, as shown in P. 15, when fine particle sediment is deposited, the SAR scatter changes are reversed.

It is desirable to conduct image interpretation, on the basis of the characteristics of collapsing soil beforehand from the geology of the land to be surveyed and the situation of disaster damage in the past, while checking the land utilization of the places where deposition of sediment is expected to occur.

[Natural dam]

In general, inundated areas that have been formed by a natural dam have a high visibility of SAR scatter changes. However, in rivers with a small flow rate, inundated areas may lack visibility due to small-scale inundated areas, etc. Also, as shown in PP. 23-26, attention needs to be paid to the fact that, the inundated areas are assimilated with scatter changes due to water seepage, flooding, and inundation of rice paddies, thus resulting in a lack of visibility. In addition, it is desirable to check the distribution of inundation facilities (dams, reservoirs, etc.) from optical images, etc. beforehand.

Table-4.2 List of SAR scatter changes during a disaster

Phenomenon	Place with a high visibility of SAR scatter changes	Place with a lack of visibility of SAR scatter changes	Phenomenon that is likely to be wrongly identified	Phenomenon that shows exceptional SAR scatter changes
Slope failure	Forest slope	Bare land slope	Artificially modified land such as deforested land	Failure on a grassland slope
Deposition of sediment	Farmland, roads, channels, etc.	Residential land	–	Deposition of fine particle sediment
Natural dam	–	River with a small flow rate	Water seepage, flooding, inundation of rice paddies	–

4.3 Other precautions

First, invisible areas occur on SAR images resulting from the principles of observation of SAR [1]. Therefore, it needs to be understood that SAR scatter changes during a disaster may be included in the invisible areas and may not be identified visually.

Next, in order to interpret SAR scatter changes appropriately, diverse and complicated factors need to be considered. In this material, explanations were given by using a scatter change model so that simplified interpretation can be made even in a survey with high emergency during initial response to a disaster.

Also, this material was created based on limited types of phenomena and a limited number of examples after commencement of the operation of ALOS-2. For this reason, as a result of accumulation of observation data hereafter, there is a possibility that exceptional SAR scatter changes that are different from the examples shown in this material will be confirmed.

In particular, flexible utilization is desired, bearing in mind the fact that SAR scatters during a disaster may change irregularly.

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Parameters of the intensity difference SAR images

Drawing number	Date & time of observation	Off nadir angle [°]	Orbit direction	Direction of microwave irradiation
Fig.-3.2	2018/03/17 2018/07/21	32.4	Northbound	Satellite traveling direction, right
Fig.-3.3	2015/04/19 2018/07/08	48.0	Southbound	Satellite traveling direction, right
Fig.-3.4	2018/08/23 2018/09/06	32.4	Southbound	Satellite traveling direction, right
Fig.-3.5	2017/04/29 2017/07/07	29.1	Southbound	Satellite traveling direction, left
Fig.-3.7	2017/04/29 2017/07/07	29.1	Southbound	Satellite traveling direction, left
Fig.-3.8	2020/06/08 2020/07/06	32.4	Southbound	Satellite traveling direction, right
Fig.-3.10	2017/06/12 2017/07/10	32.4	Southbound	Satellite traveling direction, right
Fig.-3.11	2018/09/20 2018/10/04	32.4	Southbound	Satellite traveling direction, right
Fig.-3.13	2015/08/13 2015/09/10	35.4	Southbound	Satellite traveling direction, left
Fig.-3.14	2015/06/30 2017/07/25	44.7	Southbound	Satellite traveling direction, left
Fig.-3.15	2015/06/16 2019/10/15	42.7	Southbound	Satellite traveling direction, left
Fig.-3.16	2017/06/12 2017/07/10	32.4	Southbound	Satellite traveling direction, right
図-3.18	2016/03/07 2016/04/18	32.4	Southbound	Satellite traveling direction, right
Fig.-3.19	2020/06/08 2020/07/06	32.4	Southbound	Satellite traveling direction, right

Drawing number	Date & time of observation	Off nadir angle [°]	Orbit direction	Direction of microwave irradiation
Fig.-3.20	2015/02/25 2019/10/30	29.1	Northbound	Satellite traveling direction, right
Fig.-3.22	2016/03/07 2016/04/18	32.4	Southbound	Satellite traveling direction, right
Fig.-3.23	2017/04/29 2017/07/07	29.1	Southbound	Satellite traveling direction, left
Fig.-3.24	2016/03/07 2016/04/18	32.4	Southbound	Satellite traveling direction, right
Fig.-3.25	2017/04/29 2017/07/07	29.1	Southbound	Satellite traveling direction, left
Fig.-3.26	2017/10/13 2020/10/31	42.7	Northbound	Satellite traveling direction, left
Fig.-3.28	2017/04/29 2017/07/07	29.1	Southbound	Satellite traveling direction, left
Fig.-3.29	2018/03/17 2018/07/21	32.4	Northbound	Satellite traveling direction, right
Fig.-3.31	2018/05/30 2020/07/08	42.7	Northbound	Satellite traveling direction, right
Fig.-3.32	2017/10/13 2020/10/31	42.7	Northbound	Satellite traveling direction, left
Fig.-3.34	2017/04/29 2017/07/07	29.1	Southbound	Satellite traveling direction, left
Fig.-3.35	2018/03/17 2018/07/21	32.4	Northbound	Satellite traveling direction, right
Fig.-3.37	2016/03/07 2016/04/18	32.4	Southbound	Satellite traveling direction, right
Fig.-3.39	2014/11/05 2018/01/24	44.7	Northbound	Satellite traveling direction, right
Fig.-3.41	2014/11/14 2015/05/29	29.1	Southbound	Satellite traveling direction, left

TECHNICAL NOTE of NILIM
No.1159 April 2021

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