Early warning for volcanic activity investigated from the 2008 Chaiten eruption based on long-term observation by microwave radiometer

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Abstract

A microwave radiometer can observe thermal emission from the ground with less contamination by clouds than an infrared radiometer. However, because its spatial resolution is large, if an analysis method to compensate the disadvantage is developed, it should be more suitable to issue an alert for a volcanic activity in the early stage before an eruption. We have investigated an analysis method to detect local changes from the data of a satellite-borne microwave radiometer. We then applied this method for the Chaiten volcano in Chile, which was severely erupted in 2008. In this paper, the analysis results are presented.

1 Introduction

Volcano monitoring is one of the practical fields for remote-sensing technology. Monitoring of thermal anomalies on volcanoes by infrared radiometer and detection of slight land-surface deformations around volcanoes by interferometry of synthetic aperture radar (SAR) are good examples. However, an infrared radiometer is a little nervous for clouds which cover volcanoes, and interferometry of SAR also has a weakness that the time resolution becomes long in exchange for high spatial resolution. Meanwhile, focusing on microwave radiometer, we know it is less affected by clouds than infrared radiometer. Its time resolution is also higher than interferometry of SAR. Therefore, microwave radiometer can become a promising tool for volcano monitoring. But, a new methodology to compensate its large spatial resolution is essential. It was a serious problem.

We have investigated an analysis method to detect local and faint changes from the data of microwave radiometer [1, 2]. Our investigation stemmed from laboratory experiments which confirmed that rocks emit microwave energy when fractured [3]. This analysis method was originally developed to detect microwave signals generated by rock failures in association with an earthquake. Using our analysis method, we have already detected characteristic microwave signals emitted from the land surface in association with some large earthquakes [2, 4, 5]. We believe that these detection cases strongly indicate that our analysis method has the capability to detect local and faint microwave signals emitted from the land surface.

Since thermal anomalies on volcanoes should be reflected in microwave signals as well, we expect that our analysis method can detect such volcanic themal anomalies. Additionally, considering the advantage that microwave radiometer is less affected by clouds, anomalies of land surface temperatures (LST) around a volcano before eruption is likely to be detected. Therefore, we modified our analysis method for volcano monitoring, and applied it to a volcanic eruption case. This paper presents the details of the modified analysis method and the analysis results.

2 Analysis method

We analyzed the data of the Advanced Microwave Scanning Radiometer for Earth-Observation System (AMSR-E) aboard the Aqua satellite. We use brightness temperatures of vertically and horizontally polarized signals at 18.7 GHz (T_{18V} and T_{18H}) since they are relatively sensitive to LST.

The basic concept of the analysis method in [1] is maintained. We first define a 0.2-square-deg area in latitude and longitude centered on a volcano as a target area, and investigate time variations of T_{18V} and T_{18H} during the entire observation period (from June 1, 2002 to Feb. 28, 2011) with respect to as many points as possible in the target area. Therefore, we apply an improved linear-interpolation algorithm to all observation points in the target area at 0.01° (1 km) intervals in latitude and longitude. Thus, each distribution of T_{18V} and T_{18H} for the target area (scene) during the entire observation period consists of 441(=21 × 21) points, and time-series data of T_{18V} and T_{18H} are obtained with respect to these points.

We then calculate a difference of T_{18V} and T_{18H} at two points (ΔT_{18V} and ΔT_{18H}), and remove fluctuations by common causes from ΔT_{18V} and ΔT_{18H} to extract only the difference of the fluctuation by the specific cause. Actually, four points (reference points, RP) are defined for 441 points (target points, TP) in each scene (on the northern, southern, eastern, and western sides), and the number of combinations of TP and RP in each scene becomes 1,764. Distances of all combinations of TP and RP are fixed to 0.05° (half of the spatial sampling interval of AMSR-E).

Additionally, the following new value S_{18} is introduced in order to simplify the detection of a simultaneous increase of ΔT_{18V} and ΔT_{18H} at TP:

$$S_{18} \equiv \begin{cases} \sqrt{{\Delta T_{18V}}^2 + {\Delta T_{18H}}^2} & (\Delta T_{18V} > 0 \ , \ \Delta T_{18H} > 0) \\ 0 & (\text{otherwise}) \end{cases} \tag{1}$$

Eventually, we obtain time variations of S_{18} for 1,764 combinations of TP and RP in the target area during the entire observation period. As indicated by Eq. (1), S_{18} takes a value greater than zero only when both ΔT_{18V} and ΔT_{18H} are greater than zero. Therefore, we assume that S_{18} follows gamma distribution, and investigate when a cumulative probability $P(s \leq S_{18} \leq \infty)$ (s : S_{18} calculated in each observation) becomes less than 0.26%. The cumulative probability 0.26% is corresponding to $P(-\infty \leq x \leq \mu - 3\sigma) + P(\mu + 3\sigma \leq x \leq \infty)$ for a random variable x which follows normal distribution $\mathcal{N}(\mu, \sigma^2)$. We then count the number of combinations whose S_{18} values met this condition in each observation during the entire observation period.

3 Analysis results

We focused on the volcano Chaiten in the south of Chile (42.833°S, 72.646°W). Figure 1 depicts the location of Chaiten. This volcano was quiet since the observation by AMSR-E started in June 2002, but had a major eruption in May, 2008. Lively volcanic activity was ongoing until 2010. Therefore, we expected that features in the active phase of this volcano is definitely extracted from the data of AMSR-E by our analysis method.

Figure 3 depicts the time variation of the number of combinations whose S_{18} values' cumulative probabilities became less than 0.26%. According to Fig. 3, the number of combinations becomes largest in the period of the eruption in May, 2010 and May, 2008. Meanwhile, it should be noted that this number begins to increase from May, 2007 though it is before the eruption. This is just an initial finding but has possibilities that LST anomalies are detected around Chaiten before the eruption. We are currently verifying this analysis result in detail.

References

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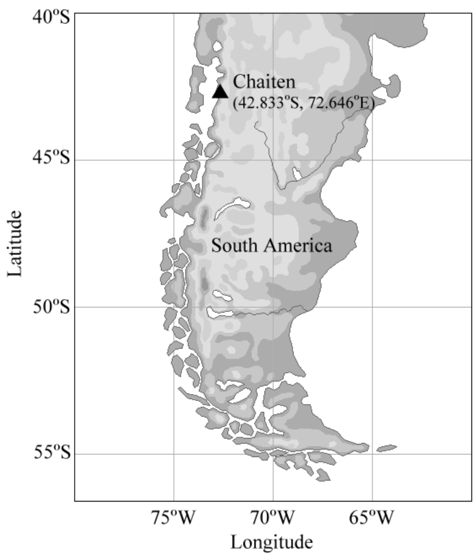

Figure 1: Location of the volcano Chaiten

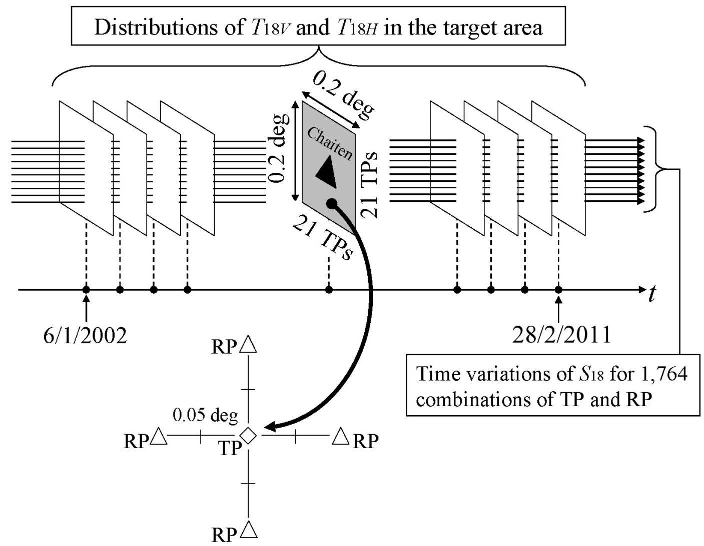

Figure 2: Extraction of 1,764 combinations of two points from each scene

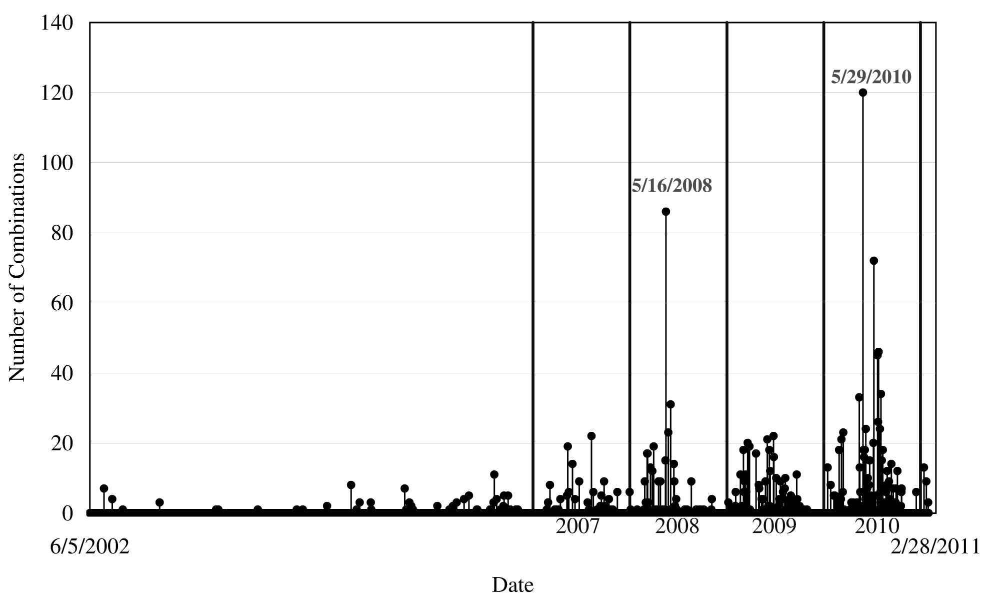

Figure 3: Time variation of the number of combinations whose S_{18} values' cumulative probabilities become less than 0.26%