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Detecting Active Volcanism with Microwave Radiometry : Terrestrial Experience with SMAP and prospects for Venus

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Abstract

Microwave radiometry can sense surface and shallow subsurface temperatures even in the presence of thick clouds. This approach may be useful for detecting present-day volcanism on Venus, in particular since microwaves can sense near-subsurface heat from lava or ash whose optical surface has cooled. We present our experience with the powerful SMAP (Soil Moisture Active Passive) radiometer in attempting to detect volcanic signatures at Earth.

1. Introduction

Microwave radiometers have a long history in planetary exploration – indeed, the very first instrument sent by NASA to another planet was the microwave radiometer on Mariner II, intended to resolve the question of how warm was the surface of Venus. Dedicated microwave radiometer instruments have also flown to a comet (MIRO on ESA's Rosetta), the Moon (the multi-band instrument on the Chinese Chang-E 1 lunar orbiter) and most recently the Multiwavelength Radiometer (MWR) at Jupiter on the JUNO mission. Additionally, a microwave radiometer capability can be frequently added with minimal cost to radar instruments (as in Magellan or Cassini) or even the spacecraft telecommunications system (as on the New Horizons mission), although these implementations may not enjoy as high precision as a dedicated instrument.

Such radiometers measure the beam-averaged brightness temperature. A principal challenge, however, is that the long wavelength yields a large (tens of km) wide footprint for typical antennas. Thus, while a fresh lava flow might have a brightness temperature of several hundreds of Kelvin above its surrounds, the lava flow may have an area of only a few km^2, and thus the footprint dilution yields an antenna temperature increment of only a few K [1].

Offsetting this resolution effect is the fact that microwaves sense the temperature some centimeters or tens of centimeters (or even deeper) beneath the surface. Thus, even a lava flow that has crusted over and is no longer glowing in the visible or near-infrared may have a very high brightness temperature. This advantage, noted in [2] but possibly overstated, is particularly important on slowly-rotating Venus. A mapping spacecraft in a low polar orbit will only fly over a given low-latitude spot every half Venus day (i.e. at intervals of ~121) so on average, a 'new' lava flow would be ~2 months old by the time it is observed, which may frustrate near-infrared observations.

2. Terrestrial Observations

A useful exercise when contemplating planetary observations is to examine whether the same approach works at Earth. Microwave radiometers have been used for decades on Earth-orbiting satellites to measure surface and atmospheric conditions, notably snow/ice cover.

For the present purpose, a long wavelength is desired, to penetrate as deeply as possible. Also desired is as small a footprint as possible. These two factors require a very large antenna.

The SMAP (Soil Moisture Active Passive) satellite was launched in 2015, with the objective of combining L-band (1.41 GHz) radiometry with higher-resolution Synthetic Aperture Radar (SAR) imagery at a similar wavelength, to derive a high-resolution soil moisture product for hydrology and land-use studies. It flies in a 690km sun-synchronous orbit, revisiting sites every 2-3 days. The instrument mechanically scans a 6m deployed mesh antenna reflector to sweep a radiometer beam with an instantaneous footprint of 39x47km in a ~1000km wide swath. The radiometer measures the brightness temperature Tb in V- and H- polarizations with an incidence angle of 40 degrees. The JPL SAR system operated for several months before a low-voltage supply for the high-power amplifier failed. The radiometer continues to supply excellent data, however.

We have examined [3] SMAP data of the 2018 eruption of Kilauea on Hawaii which has been well-documented in-situ by the US Geological Survey, and via satellite infrared observations. By August 3, some 35km^2 of terrain had been covered by lava flows, including about 3.5km^2 of new land where lava entered the ocean.

Although this large eruption should have yielded an observable signature, if the new flows had a brightness temperature of hundreds of K, we have been unable to isolate a signature that corresponds to the eruption. The challenge is in part due to the proximity (few km) of the eruption to the ocean : seawater has a very high dielectric constant and thus a low brightness temperature (unlike land surfaces where the brightness temperature is close to the physical temperature, the sea has a brightness temperature 100K or so less than that). Thus the antenna temperature depends very sensitively on exactly how much of the footprint is filled by water. Even with careful location of the footprints, the resultant scatter of tens of K makes it impossible to detect a few K brightness temperature change due to erupted lavas.

We avoided this issue by examining an eruption inland in an arid region – the January 2017 Erta Ale eruption in Ethiopia. Here we found the scatter in the SMAP data considerably reduced, making it possible to detect a smaller signal. However, the eruption itself here was also rather smaller and we could not make a confident detection. It may be that more elaborate detection schemes are successful.

A different problem confronted us in observing the wider-area ash deposition from the 2018 Fuego eruption in Guatemala. Here the problem is the abundant radio frequency interference (RFI) from electronic equipment in the area, where spectrum discipline appears to be poor.

3. Summary and Conclusions

Just as volcanism on Venus should be theoretically possible in the near-infrared (noting that the atmospheric opacity blurs the emission seen from above the cloud tops over an area ~50km across), detection on Earth by microwave means should be possible. However, the problem is not instrument sensitivity as much as confounding variations in the background (just as putative infrared detections [4] on Venus may actually be due to cloud variations).

It may be that in due course a sufficiently voluminous eruption in an area with low background variations will allow us to make a detection with SMAP. Microwave methods are particularly effective at large-area detections, so large ash deposits may be easier to spot than lava flows. The presumed lack of RFI on Venus may mean that the technique is more effective there than on Earth.

Acknowledgements

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