of the USArray Transportable Array is available at http://www.earthscope.org/usarray/array_design/transportable.php

Acknowledgments

We thank Harley Benz and David Simpson for comments that helped improve this manuscript and George Randall and Harley Benz for discussions of array processing. This work was supported in part by the U.S. National Science Foundation (NSF) under grants EAR-0125595 and EAR-0453884 (T.L.) and the U.S. Geological Survey under award 05HQGR0174 (C.J.A.). USArray is supported by NSF as part of the EarthScope project under Cooperative Support Agreement EAR-0323309. The maps were generated using the GMT plotting software package, and we used SAC2000 (Lawrence Livermore National Laboratory) and Robert B. Herrmann's GSAC seismogram analysis tool.

References

Douglas, A. (1998), Making the most of recordings from short-period seismometer arrays, *Bull. Seismol. Soc. Am.*, *88,* 1155–1170.

Lay, T., J. Hernlund, E. J. Garnero, and M. S. Thorne (2006), A post-perovskite lens and D" heat flux beneath the central Pacific, *Science*, *314*, 1272–1276.

Moschetti, M. P., M. H. Ritzwoller, and N. M. Shapiro (2005), California surface wave tomography from ambient seismic noise: Tracking the progress of the USArray transportable network, *Eos Trans. AGU*, *86,* Fall Meet. Suppl., Abstract S31A-027.

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Satellite Observations of New Volcanic Island in Tonga

PAGES 37, 41

A rising volcanic plume from an unknown source was observed on 9–11 August 2006 in the Vava'u Island group in the northernmost islands of Tonga [*Matangi News Online,* 2006]. On 12 August, the crew on board the yacht *Maiken*, sailing west from Vava'u to Fiji, encountered "a vast, many miles wide, belt of densely packed pumice" floating on the water (F. Fransson personal communication, 2006). Later, the crew sailed south and discovered that the source of the pumice was a newly erupting submarine volcano near Home Reef (18.991°S, 174.767°W) (Figure 1a).

The submarine Home Reef volcano last erupted in 1984, creating a small, temporary island, 1500 meters long × 500 meters wide [*Smithsonian Institution,* 1984]. The 1984 eruption also produced large amounts of pumice that rafted away with the currents, and over the following year the floating pumice traveled to beaches as far away as Fiji and Australia [*Smithsonian Institution,* 1985; *Bryan et al.,* 2004]. With time, these ocean-voyaging pumice fragments can have far-reaching ecological effects as a transportation mechanism for some marine organisms [*Bryan et al.,* 2004].

The characteristics of the current eruption are similar to those of the 1984 eruption: a volcanic plume breaching the sea surface, extensive pumice rafts, and the formation of a new island [*Smithsonian Institution,* 2006]. In addition, satellite observations of Home Reef indicate water discoloration and increased sea surface temperatures. Discolored seawater caused by the precipitation of silicon dioxide, aluminum oxide, and iron oxide particles often is present around active volcanic islands and seamounts where hydrothermal fluids mix with cooler seawater [*Urai and Machida,* 2005].

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Home Reef Observations

The first local observations of the new island were recorded on the Web log of the *Maiken* crew on 12 August 2006, who noted that the new island was "…one mile in diameter and with four peaks and a central crater smoking with steam and once in a while an outburst high in the sky with lava and ashes" (Figure 2b). After these initial observations were reported, data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the Terra satellite and MODIS onboard the Aqua satellite were used to pinpoint the timing of the eruption, locate and measure the new island at Home Reef, measure temperature and color changes in the water around the island, and measure the extent of the floating pumice rafts.

The ASTER instrument measures radiance in 14 spectral channels from the visible-near infrared/short-wave infrared (VNIR/SWIR) to the thermal infrared (TIR) wavelength region [*Yamaguchi et al.,* 1998]. The three VNIR channels acquire data between 0.556 and 0.807 microns and have 15-meter spatial resolution; the five TIR channels acquire data between 8.287 and 11.289 microns and have 90-meter spatial resolution. The MODIS instrument measures radiance in 36 spectral channels from the VNIR/SWIR to the TIR region with spatial resolution varying between 250 and 1000 meters per pixel [*Salomonson et al.,* 1989]. Only the 250-meter-resolution VNIR channels (0.645 and 0.859 microns) were used in this study.

Interpreting the Satellite Data

ASTER data acquired before August 2006 show no evidence of an island at Home Reef, confirming that any volcanic island that had formed there previously—from the 1984 Home Reef eruption [*Smithsonian Institution,* 1984]—had been eroded away. The first ASTER image of the new island was acquired on 4 October 2006, about 8 weeks after the recent eruption (Figure 1a). By this time, the new island at Home Reef was 900 × 400 meters (~0.28 square kilometers), elongated in a northeast-southwest direction, and about 90 kilometers southwest of the Vava'u Islands. Nighttime TIR ASTER data from 28 October suggest that the island was smaller in size, based on a smaller thermal feature, and daytime images from 12 and 14 November showed the island had decreased in size to 0.16 square kilometers (Figure 1e).

There was a visible discoloration of the water around the island in the daytime ASTER scenes. On 4 October, the discoloration was more intense and widespread, and was drifting away from the island with the currents toward the north and east (Figure 1a). The brightest area of the discolored water plume extended about 1 kilometer off the northeastern shore. The eastern limb of the drifting discoloration could be detected approximately 14 kilometers away.

On 12 and 14 November, the discolored water could be detected only adjacent to the island; however, partly cloudy conditions may have concealed the discoloration plume drifting with the currents. The blue/green discolored areas in the water were interpreted to be volcanic materials (ash and/or mineral precipitates) suspended in shallow (<10 meter) water because (1) the texture of surface waves was superimposed on the discolored areas and (2) ASTER channel 3 (0.807 microns) radiance does not penetrate the water surface, which is why the ASTER false-color image using channels 3-2-1 as R-G-B produces the colors observed in Figure 1a. The brightest areas were presumably where this material was more concentrated and shallower; the discoloration fades to darker blue as it drifts away from the source. Similar to studies by *Urai and Machida* [2005], the observed blue/green discoloration adjacent to the new island could be indicative of iron and aluminum oxides precipitating from the mixing of hydrothermal waters with cooler seawater.

On 4 October, ASTER TIR temperature data identified an anomalous thermal plume associated with the visibly discolored water (Figure 1c). The maximum temperature

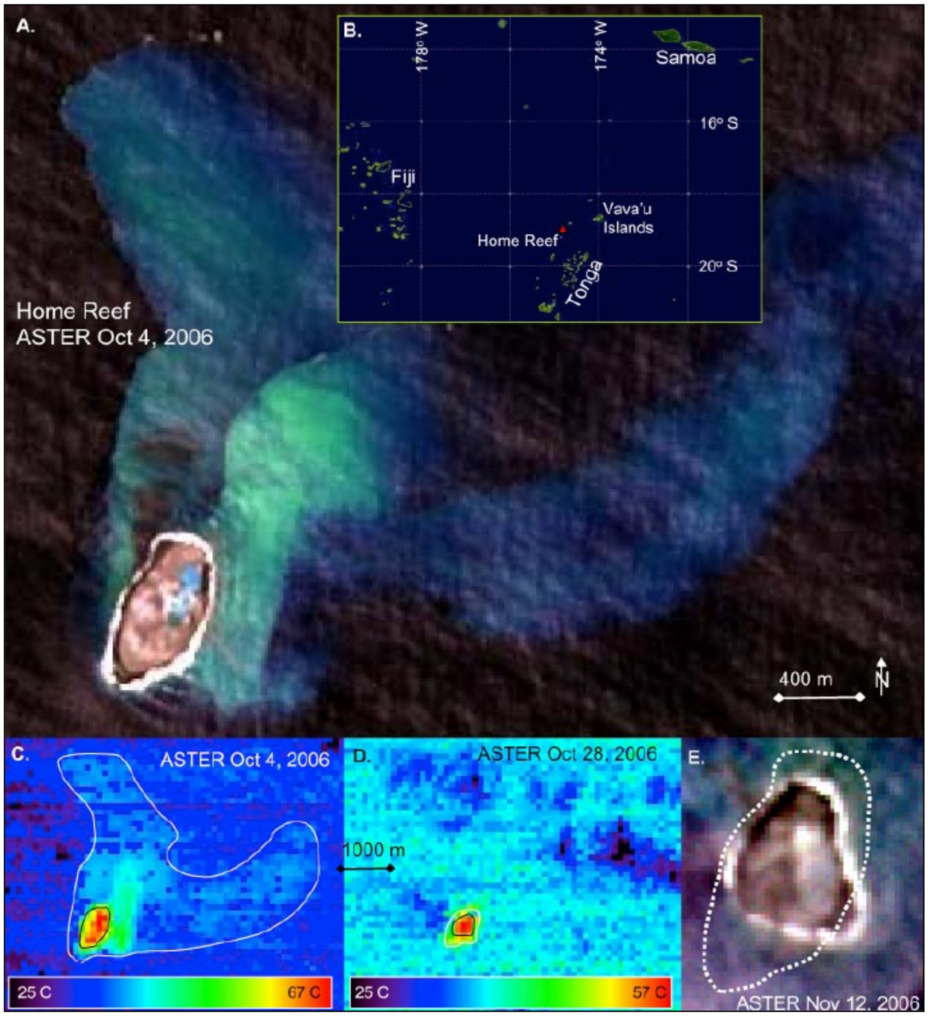

Fig. 1. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images of the new island at Home Reef. (a) On 4 October 2006 (channels 3-2-1 as R-G-B). The island was about 900 × 400 meters, and the discoloration around the island was due to turbulent mixture of volcanic debris and hydrothermal precipitate in the shallow water. (b) General location map showing 2° latitude/longitude grid. (c) On 4 October 2006 (TIR temperature image). (d) On 28 October 2006 (TIR temperature image). In both temperature images, the scale bar is in degrees Celsius, the island perimeter is outlined in black, and anomalously warm water is outlined in white. (e) On 12 November 2006 (channels 3-2-1 as R-G-B), the dotted line shows the size of the island from 4 October. North is up in all images.

(integrated over a 90-meter pixel) was in the center of the island (67°C), due to the presence of a warm crater lake, fumaroles, and fresh volcanic island material heated by the Sun. The subpixel temperature components of the hottest pixel were calculated using the dual-channel method of *Rothery* [1998] modified for ASTER TIR channels. Assuming a 27°C background temperature, the hottest subpixel temperature components, likely from active fumaroles, were approximately 200°C and covered about 8% of the pixel area. Surrounding the island, sea surface temperatures were as high as 40°C adjacent to the island, which was about 13°C higher than the ambient sea surface temperature (27°C); the average temperature of the thermal plume was about 30°C.

By 28 October, the temperature data showed a smaller island (with a maximum temperature of 57°C), and no significant thermal plume in the water (Figure 1d). This was interpreted to reflect diminished volcanic-hydrothermal activity after 4 October. Absolute temperatures from 14 November were not accurate due to thin cloud cover; however, like the nighttime data from 28 October, there was evidently no thermal anomaly outboard of the island mass itself.

Analysis of daytime MODIS images indicated that the eruption started after 1319 LT on 7 August and before 1017 LT on 8 August. The MODIS scene acquired at 1017 LT on 8 August is partly cloudy, but shows a plume that originates from the Home Reef area and a small area of pumice next to the plume source. Possibly, the plume breached the sea surface and started to deposit floating pumice fragments on the water before an island formed, and also before any water discoloration was detectable. Several susequent MODIS scenes clearly showed the appearance of the new island, the eruption plume, water discoloration, and large rafts of floating pumice fragments that had accumulated on the sea surface (Figure 2a).

Water discoloration first appeared adjacent to Home Reef on 10 August. An airborne eruption plume was present between 8 and 16 August. Large rafts of floating pumice fragments were first detected on 8 August, but the first MODIS data to show the large extent of the pumice deposits were on 11 August (Figure 2a, green). Over the next 2 weeks, the pumice rafts traveled with ocean currents, and as of 28 October, stringers of pumice were located just 50 kilometers off the coast of the easternmost islands of Fiji, approximately 300 kilometers west of Home Reef (Figure 2a, red). The area of the pumice rafts was calculated to be at least 1600 square kilometers and assuming a 10-centimeter thickness, corresponds to an erupted volume of at least 0.16 cubic kilometers.

Importance of Satellite Monitoring

This study demonstrates the significant value of multisensor and multispectral satellite data spanning the VNIR through the TIR wavelength regions for monitoring volcanic activity in remote regions. On 8 August 2006, the submarine volcano Home Reef erupted and within days had created a new island in the Tongan arc with a central crater lake of warm water. The combination of MODIS and ASTER data was critical for making important observations of this remote eruption. High-spatial-resolution ASTER data measured changes in the size of the island, water discoloration, and surface temperatures. High-temporal-resolution MODIS data determined the timing and duration of the eruption, the distribution of water discoloration, and the extent and volume of pumice rafts as they drifted away.

Future satellite monitoring will help determine how long the island takes to erode back down to below sea level, monitor the extent of the thermal anomaly and water discoloration indicative of continued activity, and track the pumice rafts as they drift toward the islands of Fiji and beyond.

Acknowledgments

The research described in this paper was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA as part of the Earth Observing System Mission to Planet Earth program. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not imply endorsement by the United States or the Jet Propulsion Laboratory. The MODIS data used in this study were acquired as part of the NASA Earth Science Enterprise. The algorithms were developed by the MODIS science teams. The data were processed by the MODIS Adaptive Processing System and Goddard Distributed Active Archive Center, and are archived and distributed by the

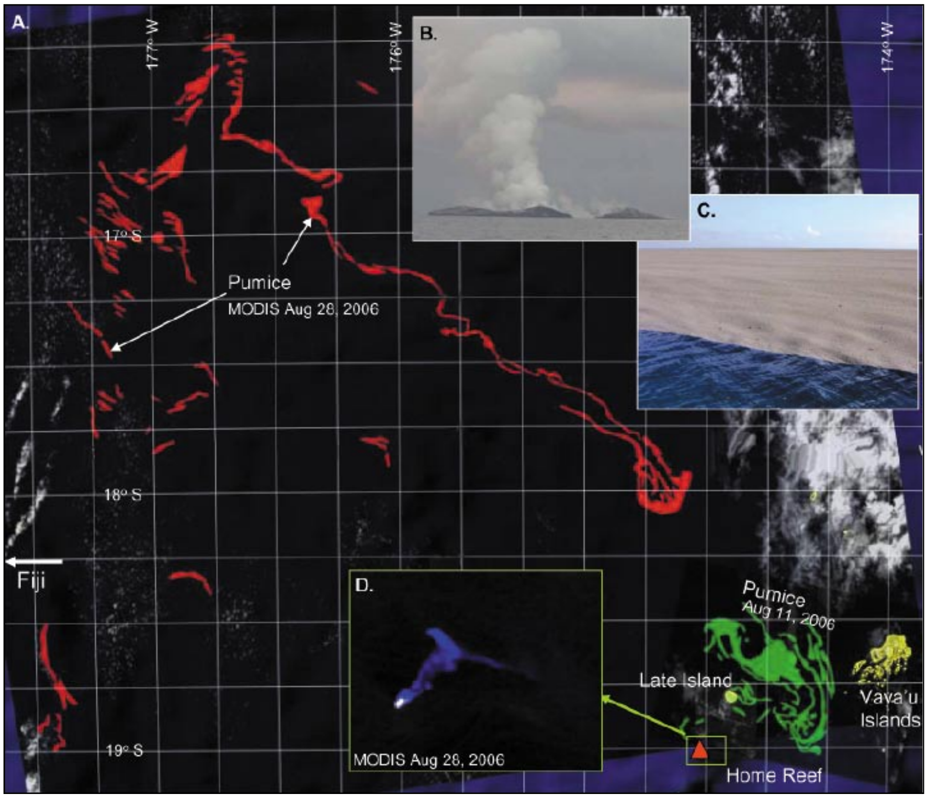

Fig. 2. (a) Extent of pumice rafts measured by the Moderate Resolution Imaging Spectroradiometer (MODIS) as of 11 August (shown in green) and 28 August 2006 (shown in red). Photographs of (b) new Home Reef island from about 3 kilometers away and of (c) floating pumice, taken by the yacht crew on 12 August 2006 (courtesy of F. Fransson). (d) Discolored water drifting away from Home Reef observed by MODIS on 28 August 2006.

Goddard DAAC. Thanks to the Smithsonian Institution Global Volcanism Program and the volcano listserv staff at Arizona State University for sharing information and supporting the open dialog between numerous scientists studying this eruption. Special thanks to Fredrik Fransson and the crew of the *Maiken* for their excellent observations and photographs of the pumice rafts and new island.

References

Bryan, S. E., A. Cook, J. P. Evans, P. W. Colls, M. G. Wells, M. G. Lawrence, J. S. Jell, A. Greig, and R. Leslie (2004), Pumice rafting and faunal dispersion during 2001–2002 in southwest Pacific: Record of a dacitic submarine explosive eruption from Tonga, *Earth Planet. Sci. Lett., 227,* 135–154.

Matangi Tonga Online (2006), New island emerges in Tonga, 6 Nov. (Available at http://www.matangitonga.to/article/tonganews/disasters/new_island061106.shtml)

Rothery, D. A., P. W. Francis, and C. A. Wood (1988), Volcano monitoring using short wavelength infrared data from satellites, *J. Geophys. Res., 93*(B7), 7993–8008.

Salomonson, V., W. Barnes, P. Maymon, H. Montgomery, and H. Ostrow (1989), MODIS: Advanced facility instrument for studies of the Earth as a system, *IEEE Trans. Geosci. Remote Sens., 27*(4), 145–153.

Smithsonian Institution (1984), Home Reef, *Sci. Event Alert Network Bull., 9*(2), Global Volcanism Program. (Available at http://www.volcano.si.edu/world/volcano.cfm?vnum=0403-08=&volpage=var#sean_0904)

Smithsonian Institution (1985), Home Reef, *Sci. Event Alert Network Bull., 10*(3). (Available at http://www.volcano.si.edu/world/volcano.cfm?vnum=0403-08=&volpage=var#sean_0904)

Smithsonian Institution (2006), Home Reef, *Global Volcanism Network Bull., 31*(11). (Available at http://www.volcano.si.edu/reports/usgs/index.cfm?content=archive&volcano=homereef)

Urai, M., and S. Machida (2005), Discolored seawater detection using ASTER reflectance products: A case study of Satsuma-Iwojima, Japan, *Remote Sens. Environ., 99,* 95–104.

Yamaguchi, Y., A. B. Kahle, H. Tsu, T. Kawakami, and M. Pniel (1998), Overview of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), *IEEE Trans. Geosci. Remote Sens., 36*(4), 1062–1071.

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Connecting the Sun to the Heliosphere

PAGES 37, 42

To better understand the processes that connect the Earth environment to the Sun, NASA's Living With a Star program must address questions that cut across traditional science disciplines. To meet this challenge, the Targeted Research and Technology component of Living With a Star has developed an innovative strategy to focus research on the most complex science targets. The targets are drawn up each year by a panel of senior scientists. These targets are then publicized, and individual researchers can propose solutions. NASA then selects teams of researchers through a peer-review process for each targeted effort. This contrasts with other NASA programs in which individual and independent programs are selected for study.

T. H. Zurbuchen

This article reports on the science motivation and approach of one key team selected in September of 2005 to address the following major question: What determines the topology and evolution of the magnetic fields that stretch from the surface of the Sun to the outer boundary of the heliosphere?

Heliospheric Magnetic Field

The heliosphere is a teardrop-shaped bubble of hot gas, or plasma, in interstellar space that extends from the Sun to beyond 100 times the Sun-Earth distance (100 astronomical units (AU)). It is inflated by the solar wind and threaded by magnetic fields that affect the electrical environment of Earth and all the planets.

Events in the Earth's space environment are dominated by what happens at the inner heliospheric boundary, the solar corona. The spectacular observations of the Sun and its million-degree corona obtained by decades of ground-based observatories and by the Solar and Heliospheric Observatory (SOHO) and other spacecraft have attracted the attention of specialist and lay audiences alike. Yet, relatively little is known about the fundamental processes taking place within the corona.

One important reason that such issues have not been addressed is that it is not currently possible to measure the magnetic fields in the solar corona directly. In the mid-1970s, the two Helios spacecraft, developed by Germany and the United States to study the Sun, came within 0.29 AU, or 62 solar radii (R_S), of the Sun. This is the closest approach yet, but it is not close enough: The solar wind is heated and accelerated within 5 R_S, and the supersonic solar wind decouples from the Sun at 10–20 R_S (the so-called Alfvén radius, where the speed of transverse waves in the magnetized plasma equals the solar wind speed itself). Helpful optical and radio wave observations of solar wind components in the corona exist, but they usually