Synergistic Use of Satellite Volcano Detection and Science: A Fifteen Year Perspective of ASTER on Terra *(#GC51E-0479)*

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INTRODUCTION:

The success of ASTER observations of active volcanic processes early in the Terra mission gave rise to a funded NASA program designed to both increase the number of ASTER datasets following an eruption and the science potential of that data. The urgent request protocol (URP) system as it later came to be known grew out of this initial study and has now operated since 2004 in conjunction with (and the support of) the Alaska Volcano Observatory, the University of Alaska Fairbanks, the University of Hawaii, the USGS Land Processes DAAC, and the ASTER science team [1,2]. The University of Pittsburgh oversees this rapid response/ sensor-web system, which until 2011 had focused solely on the active volcanoes in the North Pacific region (Figure 1). Since that time, the URP has been expanded to operate globally with the AVHRR and MODIS monitoring streams. Now ASTER VNIR/TIR data are being acquired at numerous erupting volcanoes around the world (Figure 2). This program relies on the increased temporal resolution of AVHRR/MODIS 3-5 µm mid-infrared data to trigger the next available ASTER observation, which results in new data as frequently as every 1-5 days.

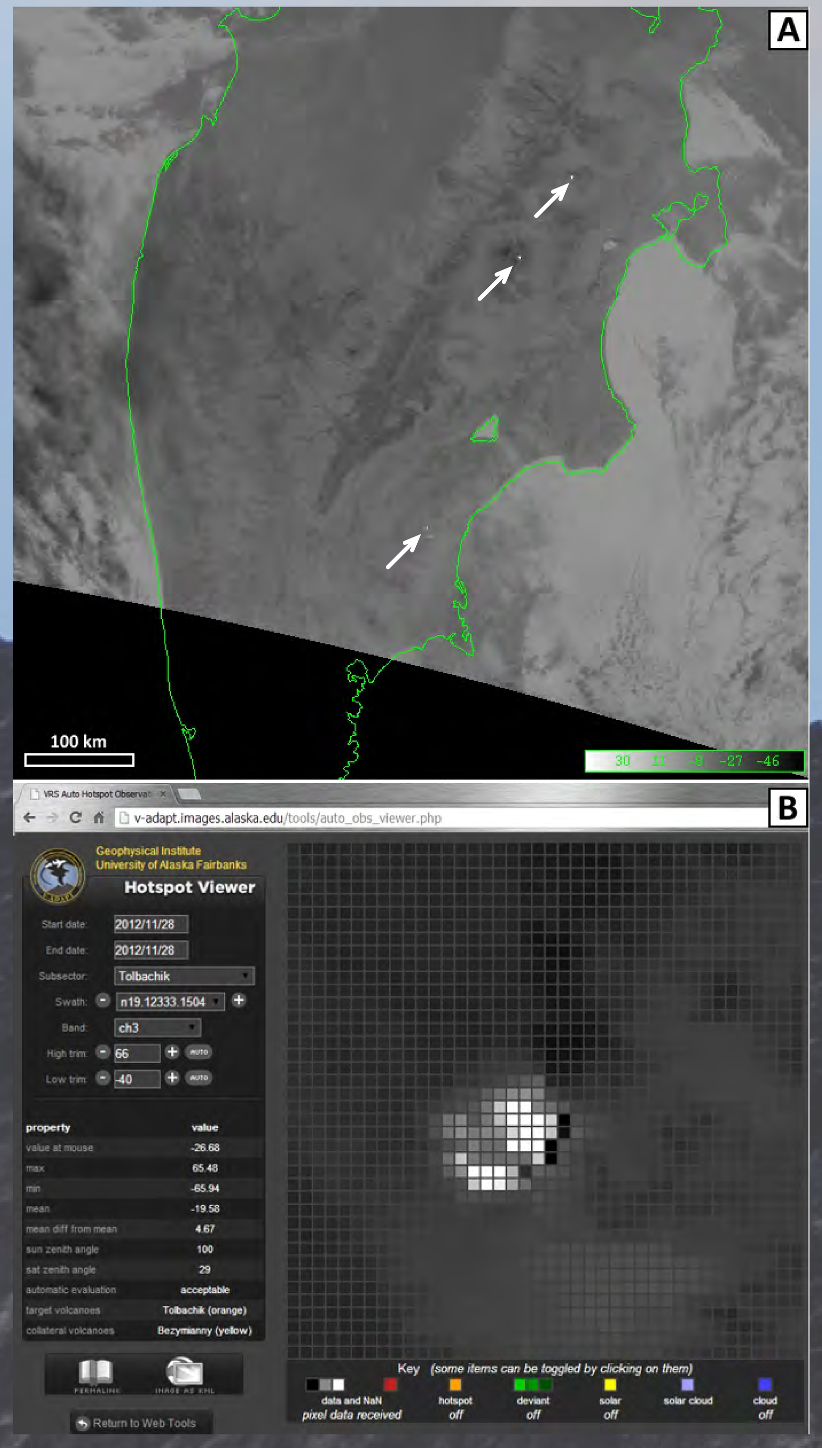

Figure 1: AVHRR data of Kamchatka, Russia shown with tools developed at the University of Alaska Fairbanks. *(A)* Subset of the band 3 (3.9 µm) AVHRR image acquired on 22 Nov 2009 at 20:02 UTC with 3 hotspots denoted by white arrows. *(B)* Hotspot Viewer web interface showing a 40 by 40 pixel area of a band 3 AVHRR image acquired on 28 Nov 2012 15:04 UTC and centered over Tolbachik volcano, Russia following the start of the large fissure eruption. This detection triggered the ASTER URP system and data were acquired 4 days later.

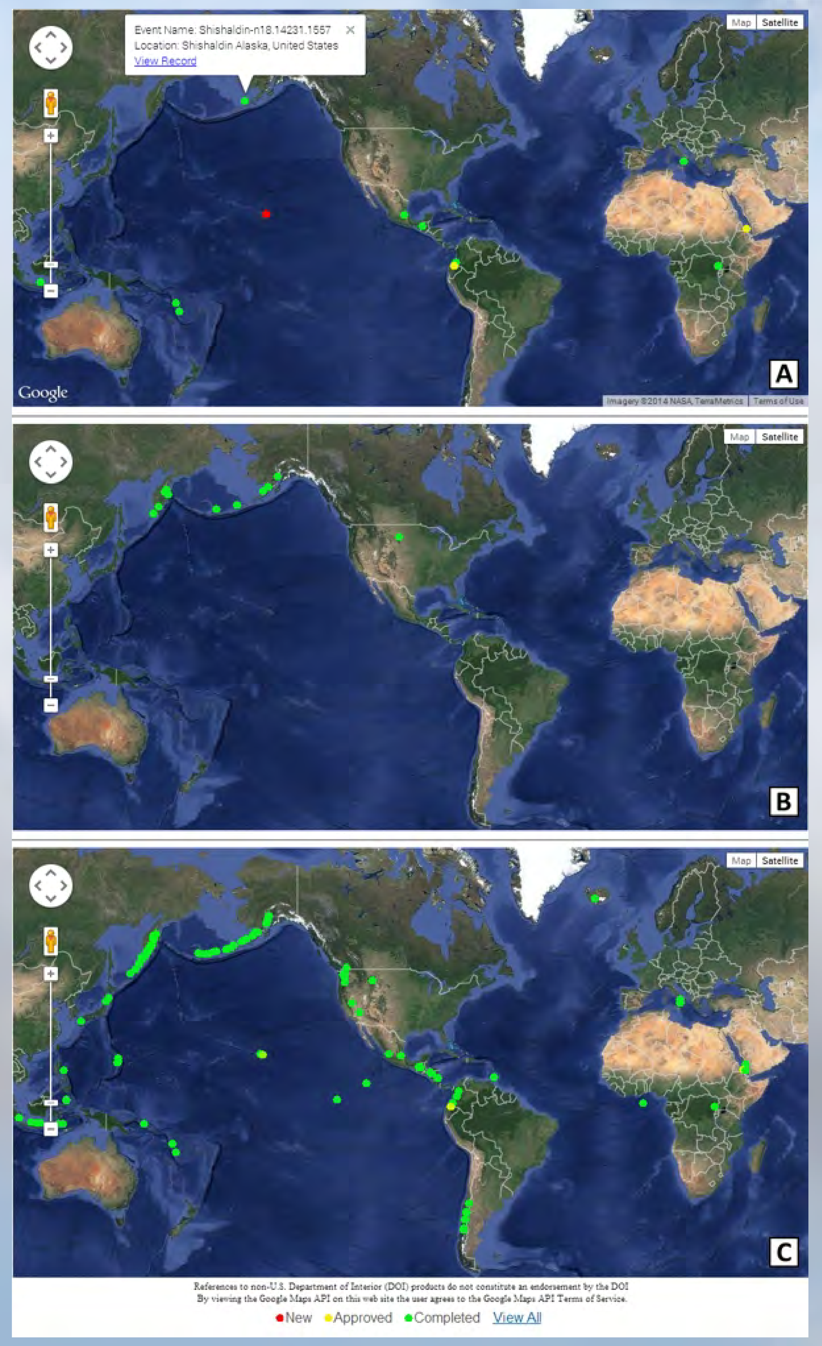

Figure 2: Google map web interface developed at the LP DAAC to ingest and track URP requests [3]. Displayed here are the URP acquisitions over time. *(A)* Recent URP targets over a two-week period with new requests shown in red, approved/scheduled requests in yellow, and acquired data in green. Each target is an active link displaying relevant information and a nested link to more detailed information and the acquired data. *(B)* All URP data acquired from 1 Jan 2004 – 31 Dec 2005 prior to the time when the URP system was fully automated. *(C)* All URP data acquired from the start of the automated URP system (1 Jan 2006 to 31 Aug 2014).

For many eruptions, the URP has increased the observational frequency by as much 50%. The data have been used for operational response to new eruptions and longer-term scientific studies such as capturing detailed changes in lava domes/flows, pyroclastic flows, and lahars [4,5]. These data have also been used to infer the emplacement of new lava lobes, detect endogenous dome growth, and interpret hazardous dome collapse events [6-8]. The emitted TIR radiance from lava surfaces has also been used effectively to model composition, texture and degassing [9]. Now, this long-term archive of volcanic image data is being mined to provide statistics on the expectations of future high-repeat TIR data such as that proposed for the NASA HyspIRI mission [10]. In summary, this operational/ scientific program utilizing the unique properties of ASTER and the Terra mission has shown the potential for providing innovative and integrated synoptic measurements of geothermal activity, volcanic eruptions and their subsequent hazards globally.

OPERATIONS:

The URP program has been operating as part of the ASTER sensor's operational scheduling since 2004. It has been responsible for over 2000 additional scenes of active volcanoes during that time, which is approximately one new scene every 2 days (Table 1). This is a vast improvement from the original nominal volcano observation strategy of between 4 and 18 images per year (one image every 90 to 20 days, respectively) for each of the world's active/potentially active volcanoes depending on the activity level [11].

year	URP phase	days per scene	scenes per month	% volcano observations
2004 – 2005	#1 *(manual)*	5.5	5.5	21.6%
2006 – 2010	#2 *(AVHRR)*	2.3	13.1	40.0%
2011 – 2014	#3 *(MODIS)*	1.3	23.6	61.0%

Table 1: Summary of ASTER volcano acquisitions over the past decade from the initial phase of the URP program until present. Each new phase is cumulative meaning that by phase 3, all triggering mechanisms (manual, AVHRR and MODIS) are operating concurrently. In the current phase, the URP program is now responsible for 61% of all the expedited scenes acquired by ASTER resulting in a new volcano scene every 1.3 days on average.

The ASTER instrument currently acquires 60 km scenes that contain 3 spectral channels in the VNIR region (0.52 – 0.86 µm) and 5 in the TIR region (8.13 – 11.65 µm), with resolutions of 15 m/pixel and 90 m/pixel, respectively. The nominal observation frequency is 16 days at the equator, decreasing to 4-5 days at higher latitudes. However, the complexity of scheduled observations, variable gain settings and off-axis pointing commonly impose a complex prioritization of targets. Therefore, it is rare to observe a given volcano even at the nominal 16 day temporal resolution.

The URP was designed to improve the number of observations by using automated detections from lower spatial/higher temporal resolution sensors (e.g., AVHRR and MODIS). Requests are now commonly scheduled rapidly following a detection trigger and observed as quickly as 1-2 days after that. However, the number of these rapid-response observations are limited to approximately 30 per month and the URP must adhere to that constraint.

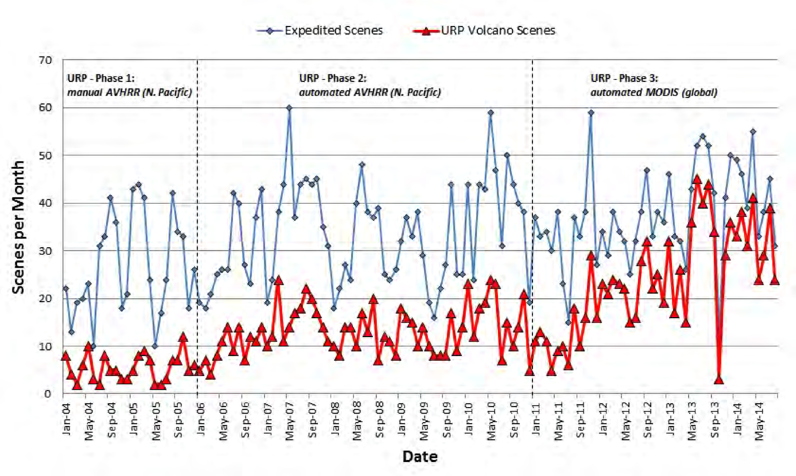

Figure 3: Total ASTER expedited scenes (blue line) and URP scenes (red line) per month beginning at the start of the URP project in 2004 and showing its three phases. During those phases the URP data increased from an average of 21.6% to 40.0% to 61.0% of the total expedited data collected by ASTER attesting to the success of the URP project.

The URP has been funded by NASA from 2004 until 2018 and to date has grown through 3 distinct phases: (1) manual triggering; (2) automated triggering using AVHRR data in the Northern Pacific region; and (3) automated triggering using MODIS data globally [2]. As each new phase was brought online, the number of scenes per month has increased from 5.5 to 23.6, and the time between each of these scene has decreased from 5.5 to 1.3 days (Table 1, Figure 3).

EXPANSION:

The initial URP design took advantage of an established satellite monitoring effort by the Alaska Volcano Observatory (AVO) and the University of Alaska Fairbanks (UAF) that operated in the north Pacific region [3]. That monitoring system was already well-established and had the software tools needed to rapidly scan AVHRR data for thermally-elevated pixels from the Northern Kurile Islands, Kamchatka, the Aleutian Arc and south to the northern Cascades. NASA funding established this program, allowed several field campaigns to Kamchatka, and produced data that became the foundation for several graduate degrees and numerous papers [4-6, 8-9].

In 2010-2011, phase 3 of the URP system was undertaken and involved a considerable expansion in both the scope of coverage and the volume of data returned from ASTER. The URP implementation was integrated into the MODVOLC system [12]. However, a constraint was placed on the number of monitored volcanoes because of the expected high volume. Ten volcanoes were initially chosen based on their prior activity levels, which was then expanded to 18 currently (Table 2). This list is dynamic and changes to accommodate new activity such as the eruptions in Iceland in 2010 and 2014 (Figures 4 and 5).

volcano	country	volcano	country
Ambrym	Vanuatu	Popocatepetl	Mexico
Cordon Caulle	Chile	Reventador	Ecuador
Erta Ale	Ethiopia	Ruiz	Columbia
Etna	Italy	Sakura Jima	Japan
Kilauea/Pu'u O'o	USA	Santa Maria	Guatemala
Nyamuragira	DR of the Congo	Semeru	Indonesia
Nyiragongo	DR of the Congo	Stromboli	Italy
Pacaya	Guatemala	Tungurahua	Ecuador
Paluweh	Indonesia	Yasur	Vanuatu

Table 2: Monitored volcanoes in phase 3 of the ASTER URP project using the MODVOLC system as the triggering mechanism.

RESULTS:

The data acquired by the URP program have been used to observe numerous volcanic processes, validate lower resolution data, and provide science never before possible. For example the TIR emissivity and temperature data were used to map the composition and particle size in ash plumes (Figure 4), monitor small-scale changes in lava flow advance (Figures 5-6), and resolve different pyroclastic flow initiation mechanisms (Figure 7).

As the ASTER sensor approaches its fifteenth year in orbit, there is a growing desire to test new ideas and observation strategies, as well as to use the vast data archive to plan future mission concepts. The URP program will be central to many of these plans.

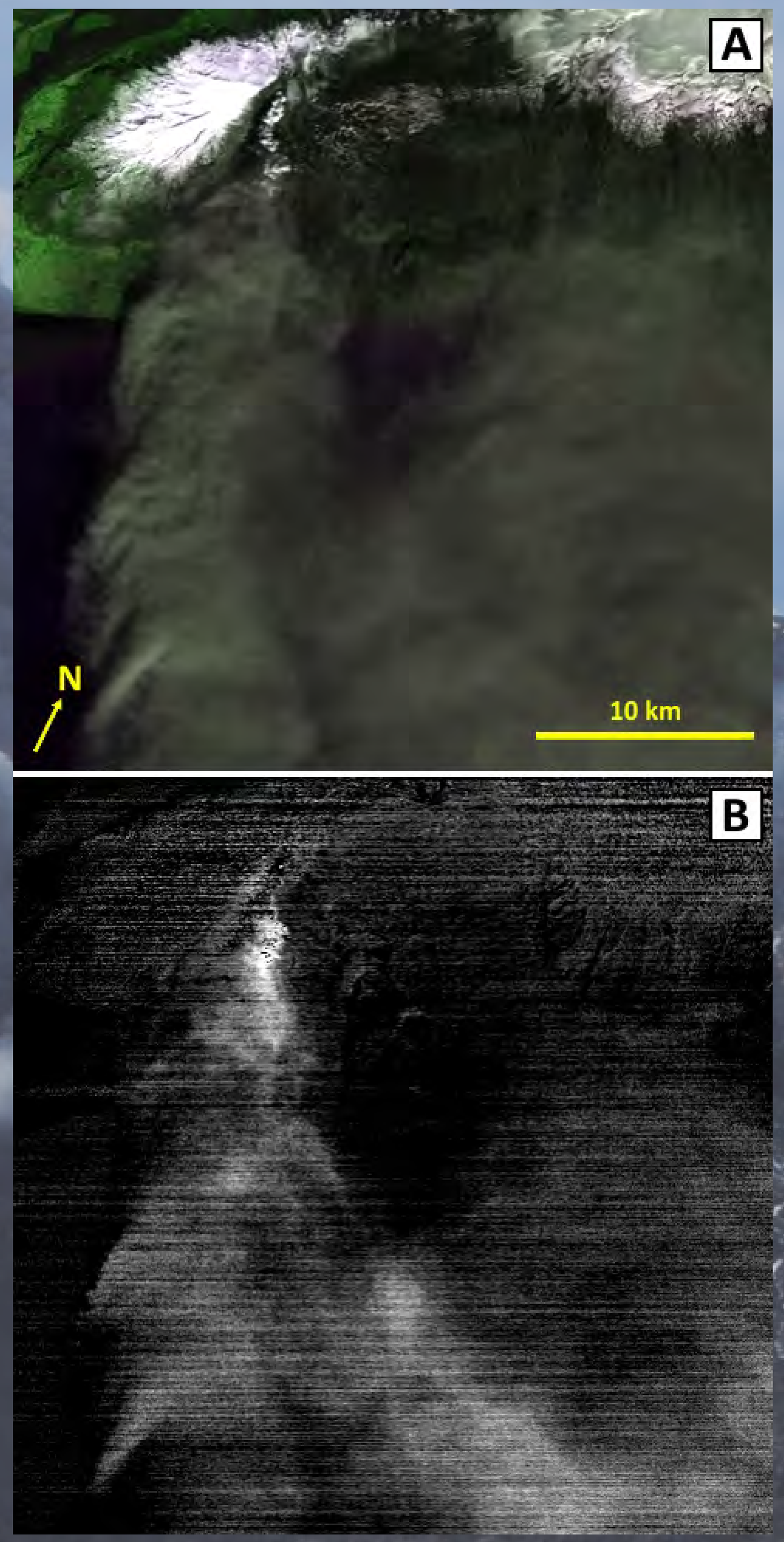

Figure 4: ASTER URP data of the 19 April 2010 eruption of Eyjafjallajökull, Iceland showing the proximal plume. *(A)* VNIR false color image. *(B)* Linear spectral deconvolution result of the TIR data for a 5 µm andesitic glass end-member varying from approximately 80% (white) to 0% (black).

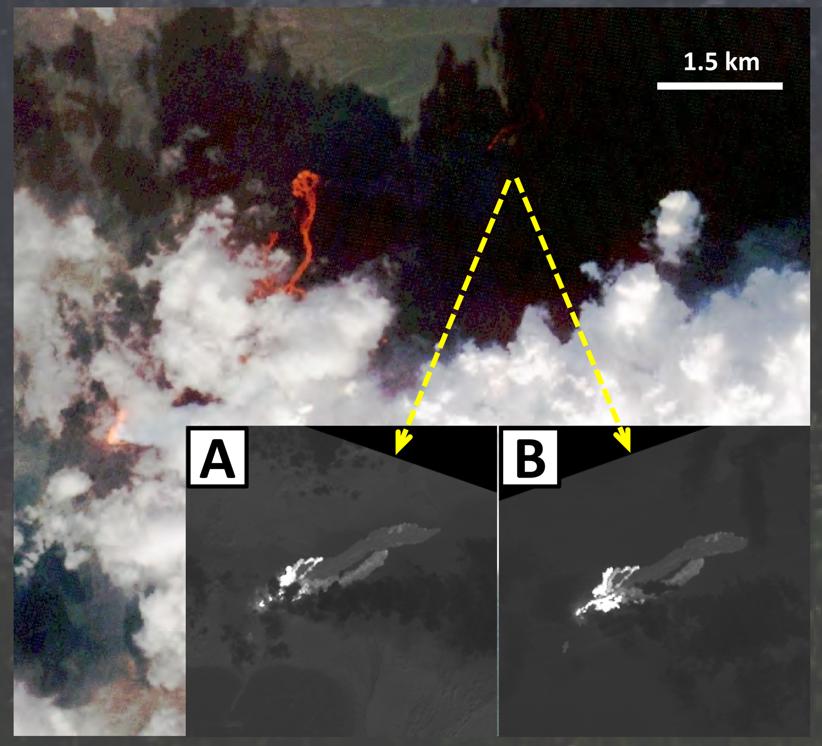

Figure 5: ASTER URP data of the 23 Sept 2014 eruption of Bardarbunga, Iceland showing the new lava flows. The background VNIR daytime data show two active flows (the large one flowing north and a smaller on the plume shadow). *(A)* TIR daytime data of the shadowed flows. *(B)* TIR nighttime data of the same flows acquired 9.75 hours later.

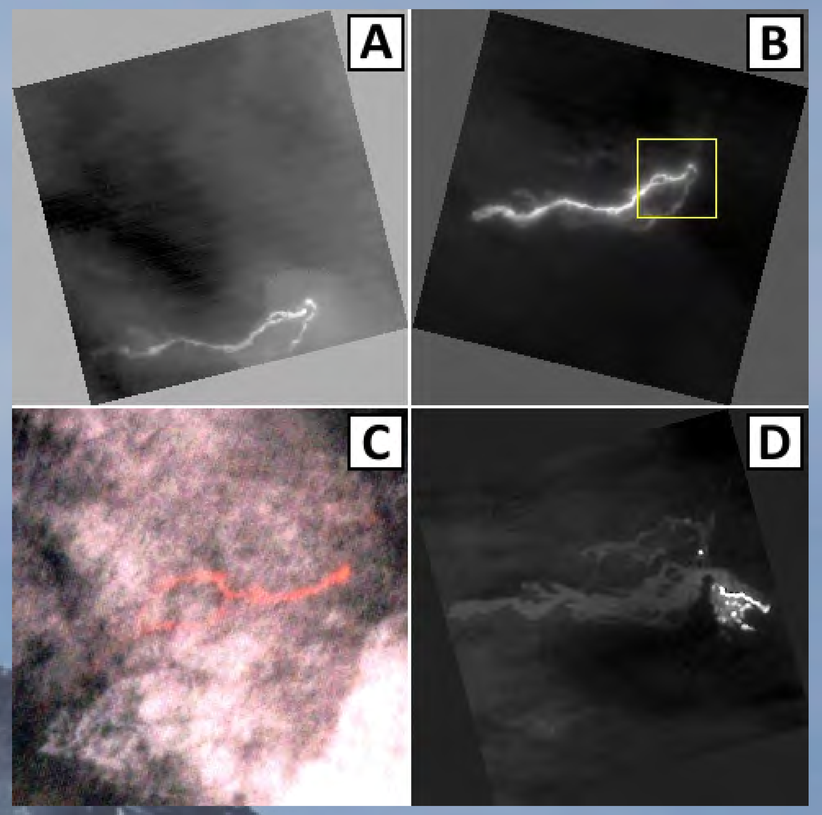

Figure 6: Examples of ASTER URP data for the 2012-2013 Tolbachik eruption, Russia. *(A)* The first clear TIR image (night) acquired on 2 Dec 2012. *(B)* Daytime TIR image acquired 13.5 hours later with slightly less cloud cover. The yellow box indicates the area shown in (C). *(C)* VNIR image collected at the same time as (B) showing the incandescent flow through the clouds. *(D)* Nighttime TIR image acquired six months later (5 Jun 2013) near the end of the eruptive phase and showing the entire cooling flow field. The effusion rate and cumulative flow area were both calculated from the time series over 6 months. Each image is 18 km^2 (north up).

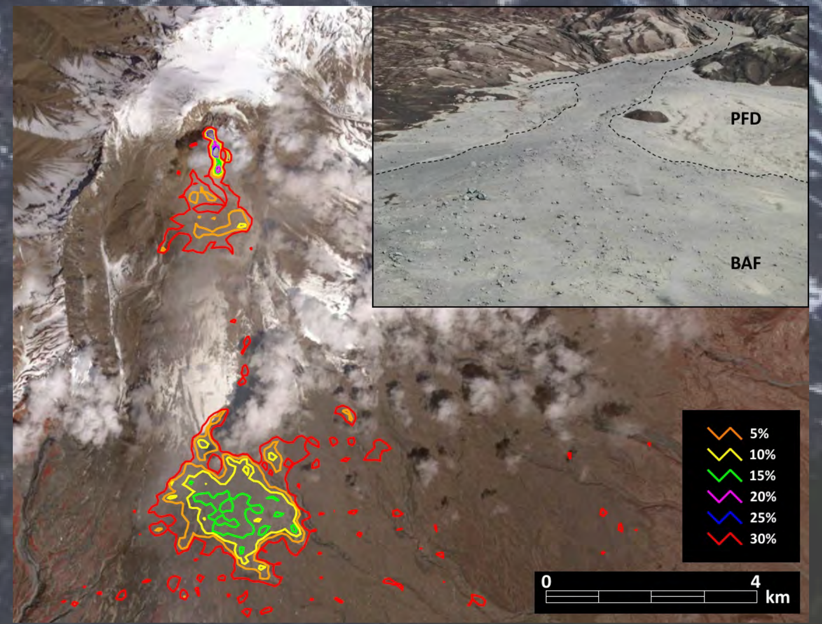

Figure 7: Flow deposit mapping on Shiveluch volcano, Kamchatka, with ASTER URP data. VNIR image (base) acquired on 4 June 2004 overlain with vesicularity contours derived from the TIR emissivity collected at the same time. The annotated inset picture (from O. Girina) was taken several days prior to the ASTER image and shows the pyroclastic flow deposit (PDF) covered by a later block and ash flow (BAF) deposit. These can be seen in the vesicularity data.

REFERENCES:

[1] Ramsey, M.S., Harris, A.J.L., *J. Volcanol. Geotherm. Res., 249,* 217-233, 2013.

[2] Ramsey. M.S., in *"Detecting, Modelling and Responding to Effusive Eruptions"*, (in review), 2015.

[3] Duda, K.A., Ramsey, M., Wessels, R., Dehn, J., in *"Geoscience and Remote Sensing"*, ISBN 978-953-307-003-2, 473-496, 2009.

[4] Carter, A.J., Ramsey, M.S., *Remote Sens. 2(11), doi:10.3390/ rs2112571, 2571-2583,* 2010.

[5] Ramsey, M.S., Wessels, R.L., Anderson, S.W., *Geol. Soc. Amer. Bull.,* doi:10.1130/B30580.1, 2012.

[6] Rose, S.R., Ramsey, M.S., *J. Volc. Geotherm. Res., 184,* 367–380, 2009.

[7] Ramsey, M.S., Dehn, J., *J. Volc. Geotherm. Res., 135,* 127-146, 2004.

[8] Carter, A.J., Ramsey, M.S., *Rem. Sens. Environ., 113,* 2142-2151, 2009.

[9] Wessels, R.L., Schneider, D.J., Coombs, M.L., Dehn, J., Ramsey, M.S., in *"The 2006 eruption of Augustine Volcano, Alaska"*, U.S.G.S. Prof. Paper #1769, 527-553, 2010.

[10] Ramsey, M.S., *2012 HyspIRI Science Symposium*, Greenbelt, MD, 2012.

[11] Pieri, D., Abrams, M., *J. Volcanol. Geotherm. Res., 135*, 13-28, 2004.

[12] Wright, R., Flynn, L.P., Garbeil, H., Harris, A.J.L., Pilger E., *J. Volcanol. Geotherm. Res., 135*, 29-49, 2004.