Extracting the Volcanic Ash Plume Elevation Model (PEM) from Landsat-8 Application to the 2014 Holuhraun (Iceland) Eruption

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In this study we introduce a method to restitute the volcanic gas/ash Plume Elevation Model (PEM) from optical satellite imagery.

As the volcanic plume is moving rapidly, conventional satellite based photogrammetric height restitution methods do not apply as the epipolar offset due to plume motion adds up to the one generated by the stereoscopic view. This is because there are time-lags of tens of seconds between conventional satellite stereoscopic acquisitions, depending on the stereo acquisition mode.

Our method is based on a single satellite pass. We exploit the short time lag and resulting baseline that exist between the multispectral (MS) and the panchromatic (PAN) bands to jointly measure the epipolar offsets and the perpendicular to the epipolar (P2E) offsets. The first are proportional to plume height plus the offsets due to plume velocity in the epipolar direction. The second, are proportional to plume velocity in the P2E direction only. The latter is used to compensate the effect of plume velocity in the stereoscopic offsets by projecting it on the epipolar direction assuming a known plume direction, thus improving the height measurement precision.

We apply the method to Landsat 8 data taking into account the specificities of the focal plane modules. We focus on the Holuhraun 2014 fissure eruption (Iceland). We validate our measurements against ground based measurements.

The method has potential for detailed high resolution routine measurements of volcanic plume height/velocity. The method can be applied both to other multi focal plane modules push broom sensors (such as the ESA Sentinel 2) and potentially to other push-broom systems such as the CNES SPOT family and Pléiades.

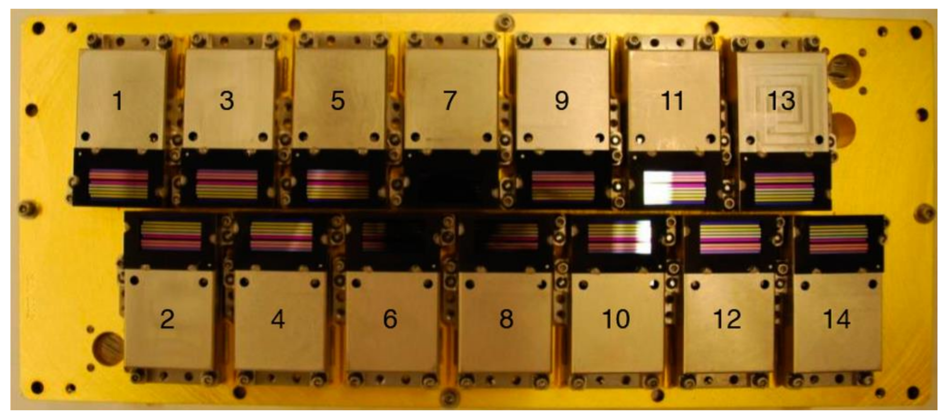

Figure 2. LANDSAT focal plane geometry
The Landsat 8 Operational Land Imager (OLI) is a push-broom (linear array) imaging system that collects visible, Near-InfraRed (NIR), and Short-Wavelength InfraRed (SWIR) spectral band imagery at 30-meter (15-meter panchromatic) ground sample distance (Storey et al., 2014). It collects a 190-kilometer-wide image swath from a 705-kilometer orbital altitude. The OLI architecture is described as follows by Knight et al. (2014) and Storey et al. (2014). The OLI detectors are distributed across 14 separate Focal Plane Modules (FPMs), each of which covers a portion of the 15-degree OLI cross-track field of view.

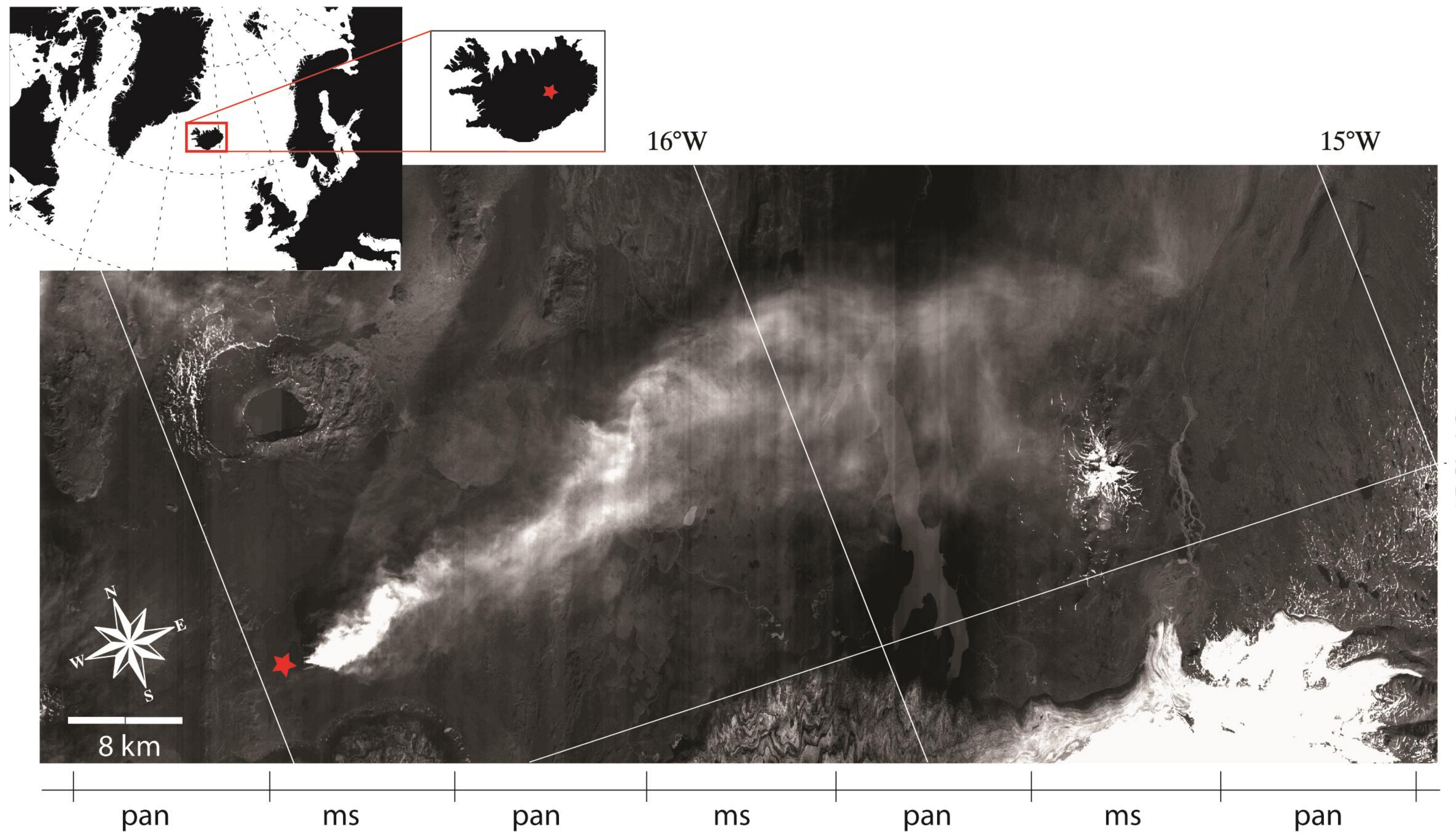

Figure 1. LANDSAT 8 IMAGES acquisition during the Holuhraun eruption
The study area. Holuhraun (Iceland) eruption site (red star) and the volcanic plume from Landsat 8. The data were acquired on 6 September 2014 at 12:25 UTC. We reconstructed this image from raw Landsat 8 data (courtesy of USGS). The image is made of alternate PAN-MS stripes from adjacent FPMs.

VALIDATION

The satellite derived plume height was validated using height estimates from images of a web camera located at Kverkfjöll (64°40.5'N, 16°41.4'W, 1730 m a.s.l.).

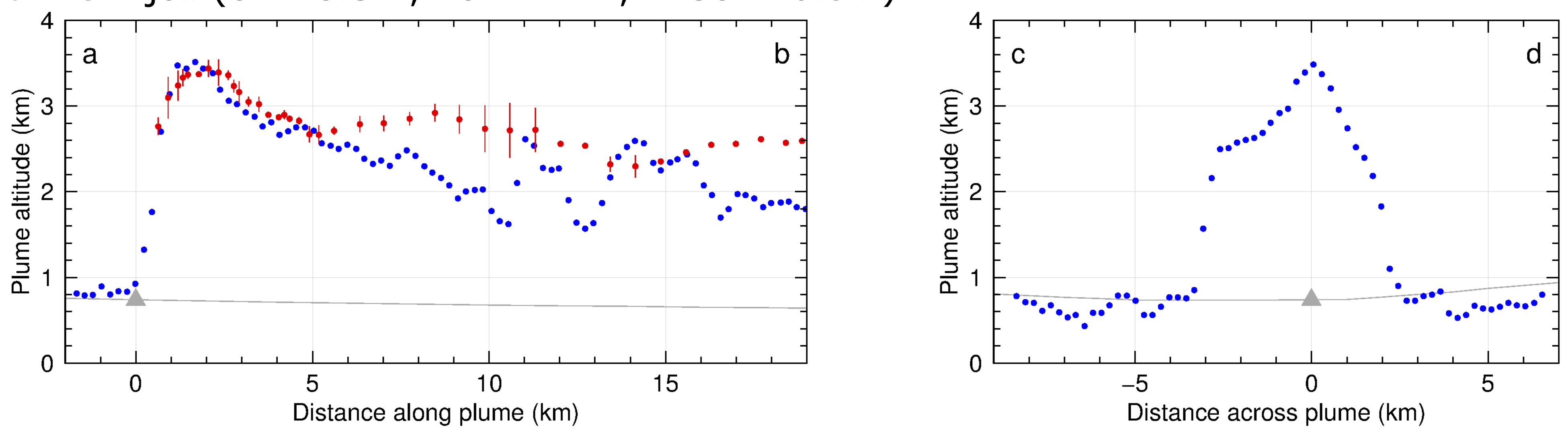

Figure 5. Validation with field observations
Along-plume elevation profile a-b (left) and across-plume elevation profile c-d (right) (see location in Fig. 4). The blue dots show the satellite derived plume height profile and the red show average of two ground camera observations at 12:20 and 12:30 UTC that we use for validation, and the red bars show range of the ground observations. The gray baseline shows the ground elevation and triangles the eruption site.

CONCLUSIONS

The comparison yields a good fit, which makes us confident about the potential use of our method in remote access areas. Moreover, the method has potential for automation given that the procedure is relatively straight forward and the only input is the spaceborne imagery and associated metadata. The produced PEM is consistent with ground observations for the first 7 km of the profile from the eruption site. The discrepancies are less than 150 m indicating that, in a range of a few km from the eruption site, our method appears to be accurate.

PUBLICATION

de Michele, M., D. Raucoules & Þ. Arason (2016), Volcanic plume elevation model and its velocity derived from Landsat 8, *Remote Sensing of Environment*, **176**, 219-224, doi:10.1016/j.rse.2016.01.024.

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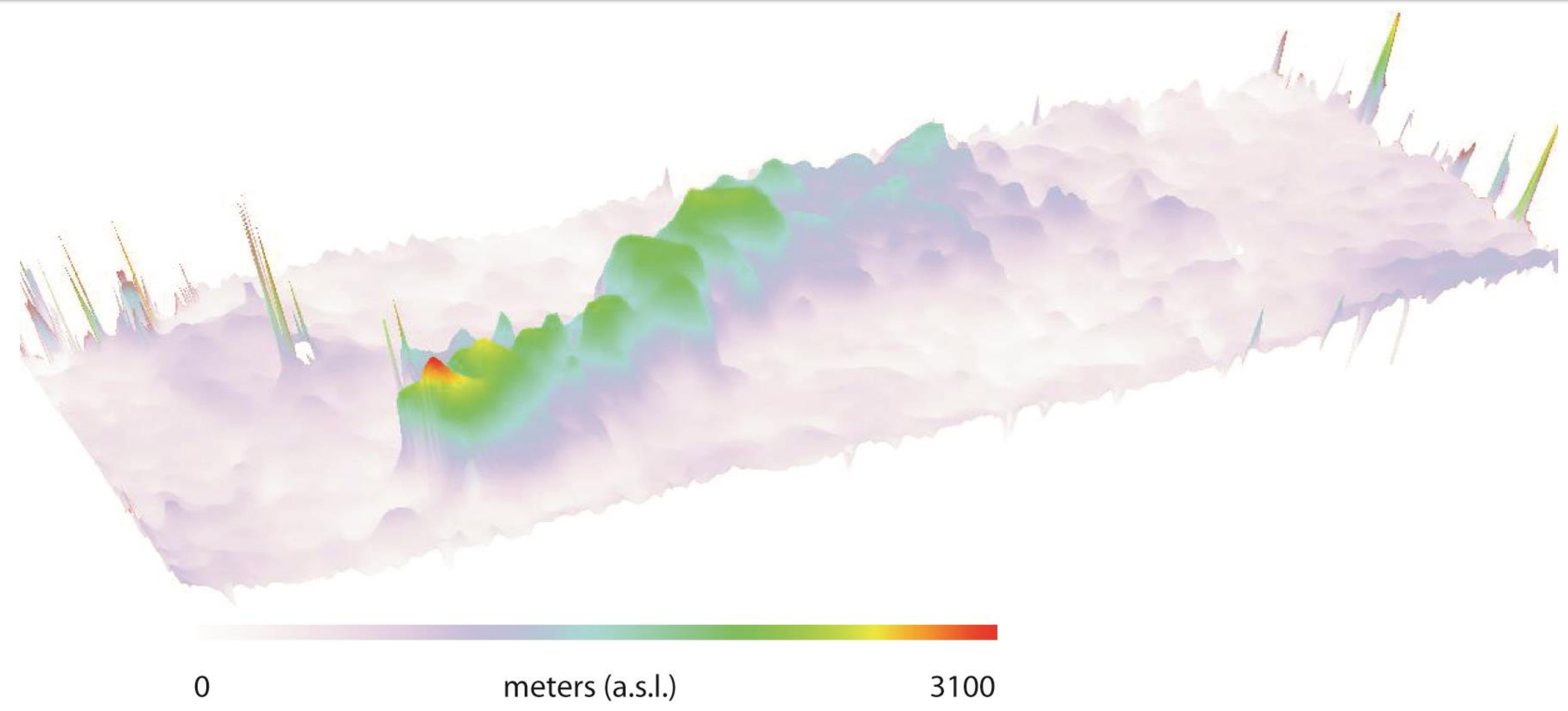

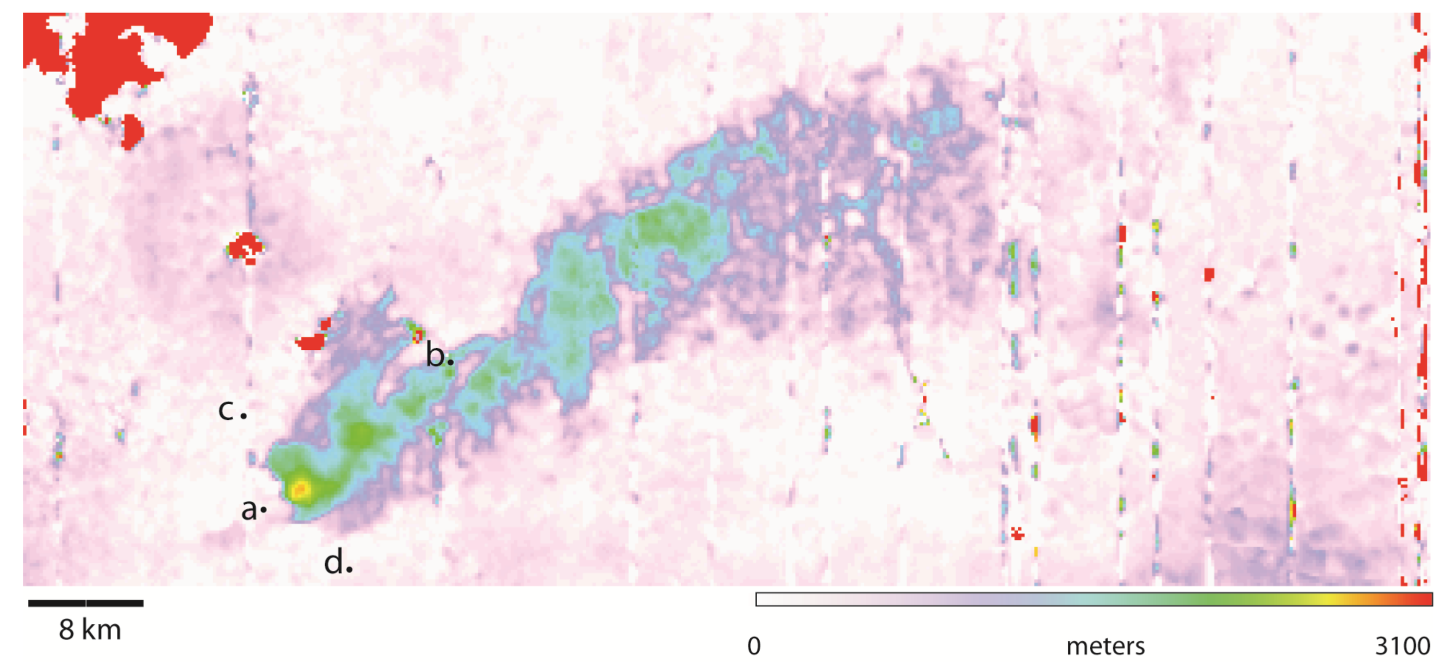

Figure 4. Results - The Plume Elevation Model (PEM)
The Holuhraun Plume Elevation Model on 6 September 2014 with a spatial resolution of 240 m per pixel. Location of the a-b and c-d elevation profiles in Fig. 5 are shown.

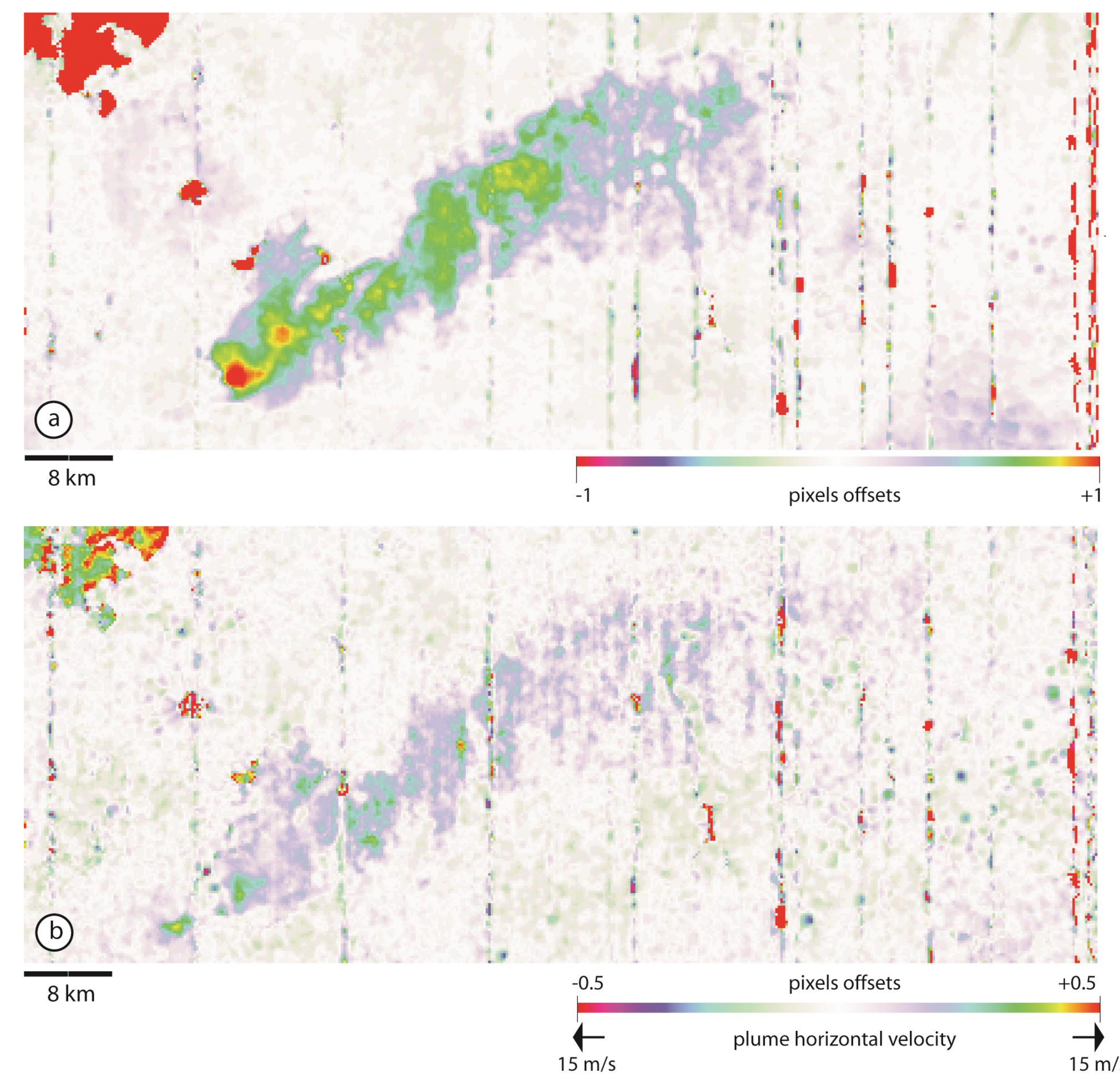

Figure 3. Cross correlation between PAN and MS bands
Pixel offsets from correlation analysis. a) offsets in the epipolar direction due both to parallax and plume velocity in the along-track direction. b) P2E offset due to horizontal plume velocity in the P2E direction.

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