Optical characterization of UV multispectral imaging cameras for SO_2 plume measurements

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Camera development

NILU's first spectral imaging camera for SO_2 plume monitoring (**Fig. 1**) was based on the Hamamatsu C8484 UV camera (1344 x 1024 pixels,12 bits) with high quantum efficiency in the UV region from 280 nm onward and a single filter in the absorption band of SO_2.

***Fig. 1**: Initial SO_2 camera*

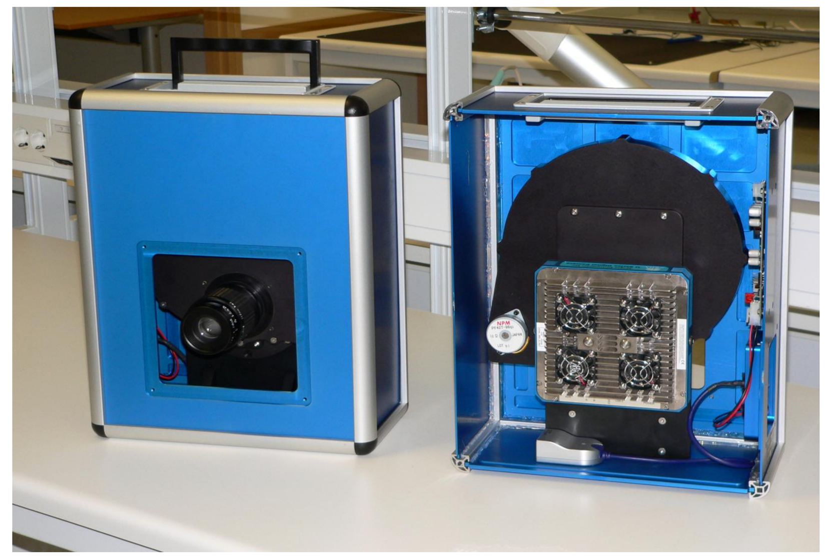

***Fig. 2**: Second SO_2 camera*

The heart of the second UV camera system (**Fig. 2**) is a cooled Alta U47 camera, equipped with two on-band (310 and 315 nm) and two off-band (325 and 330 nm) filters.

Our most recent system, called EnviCam II (see **Fig. 3**), utilizes again the un-cooled Hamamatsu camera for faster sampling (~10 Hz) and a four-position filter-wheel equipped with two 10 nm filters centered at 310 and 325 nm, a UV broadband view and a blackened plate for dark-current measurement. The cameras can be equipped with different lenses (e.g. 50 mm, C-mount, F/3.5). A co-aligned spectrometer provides a ~0.3nm resolution spectrum of about 1° within the field-of-view of the camera and the general overview of the scene is captured by an integrated webcam (FOV 160°).

***Fig. 3**: Field measurements using the most recent systems. Left: blue SO_2 camera at a 2850 m plateau at Mt. Etna. Right: golden SO_2 camera monitoring at Turrialba. The white cameras are NILU's IR cameras for volcanic ash and SO_2 monitoring.*

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Laboratory and field measurements

Custom made cylindrical quartz calibration cells with 50 mm diameter (**Fig. 4**), to cover the entire field of view of the camera optics, are filled in our laboratory with various amounts of gaseous SO_2 (typically between 100 and 1500 ppmm) (**Fig. 5** left panel). The cameras are characterized and calibrated in the laboratory (**Fig. 5** right panel) as well as in the field.

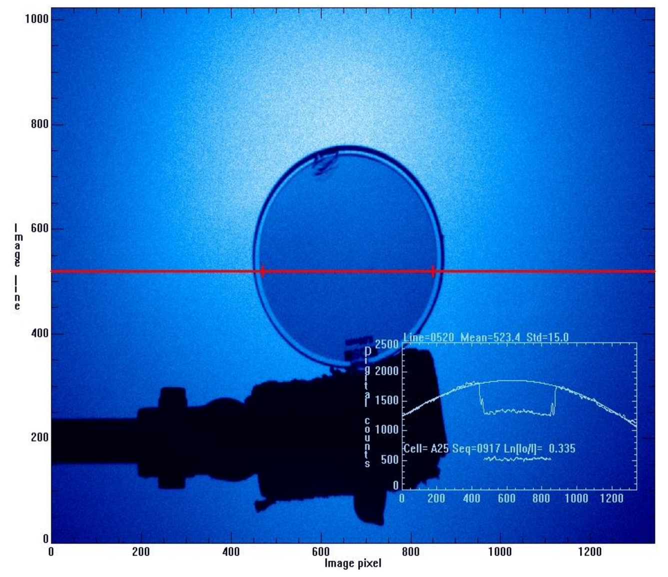


***Fig. 4**: Calibration cell*

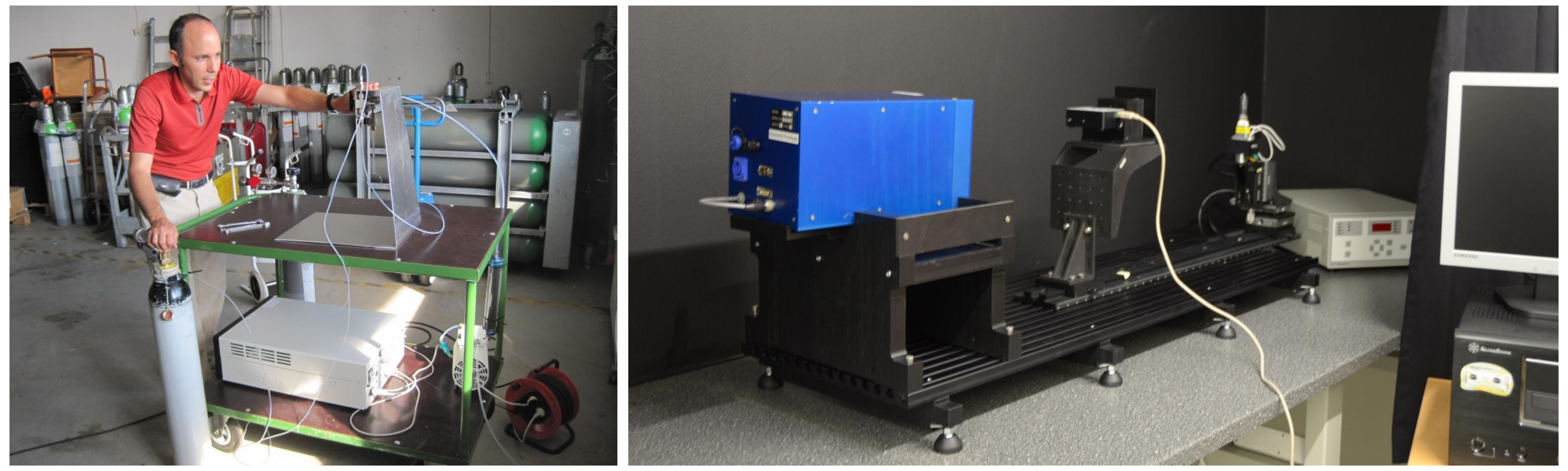


***Fig. 5** : Calibration cell gas filling line (left panel) and laboratory setup for characterization and calibration of the cameras (right panel).*

The newest system was tested for volcanic plume monitoring at Turrialba, Costa Rica in January, 2011, at Merapi volcani, Indonesia in February 2011, at Lascar volcano in Chile in July 2011 and at Etna/Stromboli (Italy) in November 2011.

Preliminary results from Turrialba, Jan. 2011

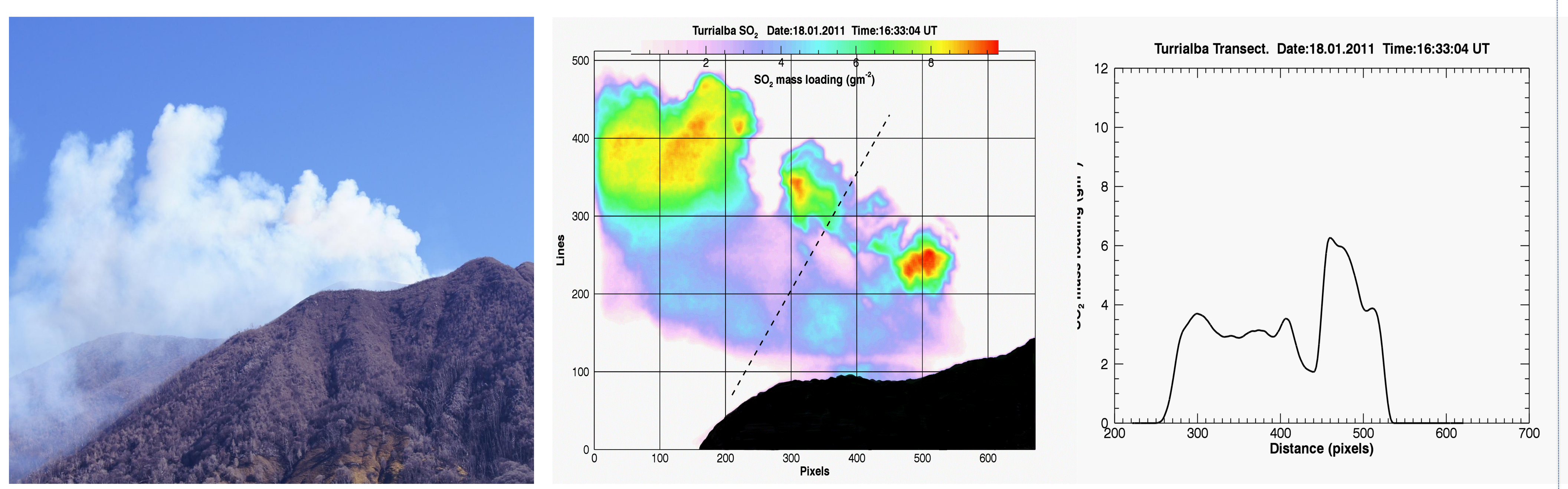
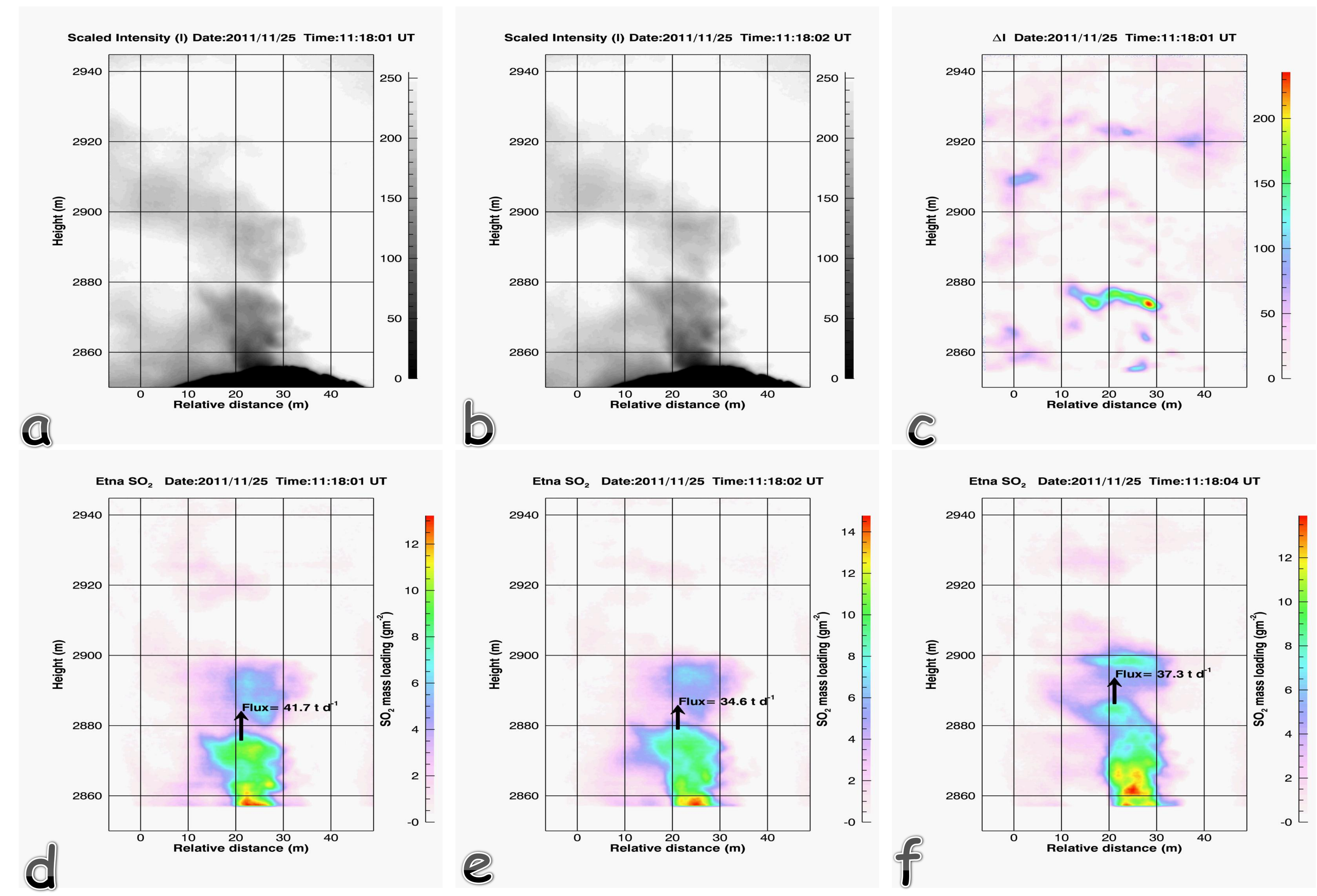


***Fig. 6** : Visual image of Turrialba outgasing (left panel), retrieved SO_2 mass loading (middle panel) and SO_2 mass loading along the marked transect (right panel)*

Preliminary results from Etna, Nov. 2011

***Fig. 7 (left)**: Visual image of vents*

***Fig. 8 (below)**: a/b: Two consecutive images (310 nm) of the vent, c: ratio of the two images, d-e: calculated SO_2 mass loadings and retrieved SO_2 fluxes.*



Estimates of SO_2 flux (t day^{-1}) were made at a small degassing vent near Torre del Filosofo on Mt Etna, during the recent activity in November 2011. The camera was approximately 1 km from the vent and pointing almost horizontally. Despite intermittent cloud cover the UV camera was able to determine mass loadings and fluxes.

By tracking "SO_2 thermals" using consecutive images (~1 Hz sampling was used) the vertical ascent rate was calculated (~3 ±1 ms^{-1}). The flux was then derived by integration of the SO_2 mass loading across the plume at the height of the thermal. Typical fluxes of 30-60 t d^{-1} were found over the period of the measurements (5-10 minutes) (see **Fig. 8**).

These preliminary results demonstrate the advantage of rapid sampling UV cameras for determining fluxes at active volcanic sites.