Optical Properties of Volcanic Dust

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Abstract

It is increasingly recognized that light-absorbing impurities deposited on a surface can reduce its albedo and lead to increased absorption of solar radiation. Natural dust can travel substantial distances in the Earth's atmosphere from its original source. It affects all climatic zones from the tropics to the poles and it may have a regional or global impact on air quality and human health. In the Arctic, a rapid increase in temperature compared to the global change, known as Arctic Amplification, is closely linked to snow albedo feedback. Furthermore, recent studies detail an extreme climate change scenario in the history of our planet that lead to catastrophic cascading events and global mass extinction triggered by atmospheric soot injections. Therefore, knowledge of optical properties of dust particles is important for improved climate models and dust effect studies. Here we report detailed results of multi-angular polarized measurements of light scattered by volcanic sand particles obtained with the FIGIFIGO goniospectrometer (Peltoniemi et al. 2014). The design concept of this custom made instrument has a well designed user friendly interface, a high level of automation, and an excellent adaptability to a wide range of weather conditions during field measurements. The foreoptics is connected to an ASD FieldSpec Pro FR 350-2500 nm spectroradiometer by an optical fiber. A calcite Glan-Thompson prism is used as a polarizer, covering the full spectral range with better than 1% accuracy. The samples studied in this work were collected from the Mýrdalssandur area in Iceland (in March 2016) and from the Villarica area in Chile (in July 2019). Following established FGI practices in laboratory conditions samples are further divided into the following categories: (1) natural volcanic sand, (2) sieved volcanic sand (dust) where the size of the particles is less than 250 μm, including dry and wet sample condition, and (3) a fine-grained powder of milled volcanic sand measurable also as aerosol. The potential use of the results from our measurements are diverse, including their use as a ground truth reference for Earth Observation and remote sensing studies, estimating climate change over time, as well as measuring other ecological effects caused by changes in atmospheric composition or land cover.

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PRESENTED AT:

GONIOSPECTROMETER (FIGIFIGO)

The Finnish Geodetic Institute Field Goniospectrometer (FIGIFIGO) is an instrument that gathers reflectance data from multiple viewing directions of studies' samples (Figure 1).

The design concept of this custom made instrument has a well designed user friendly interface, a high level of automation, and an excellent adaptability to a wide range of weather conditions during field measurements. The foreoptics is connected to an ASD FieldSpec Pro FR 350-2500 nm spectroradiometer by an optical fiber. A calcite Glan-Thompson prism is used as a polarizer, covering the full spectral range with better than 1% accuracy.

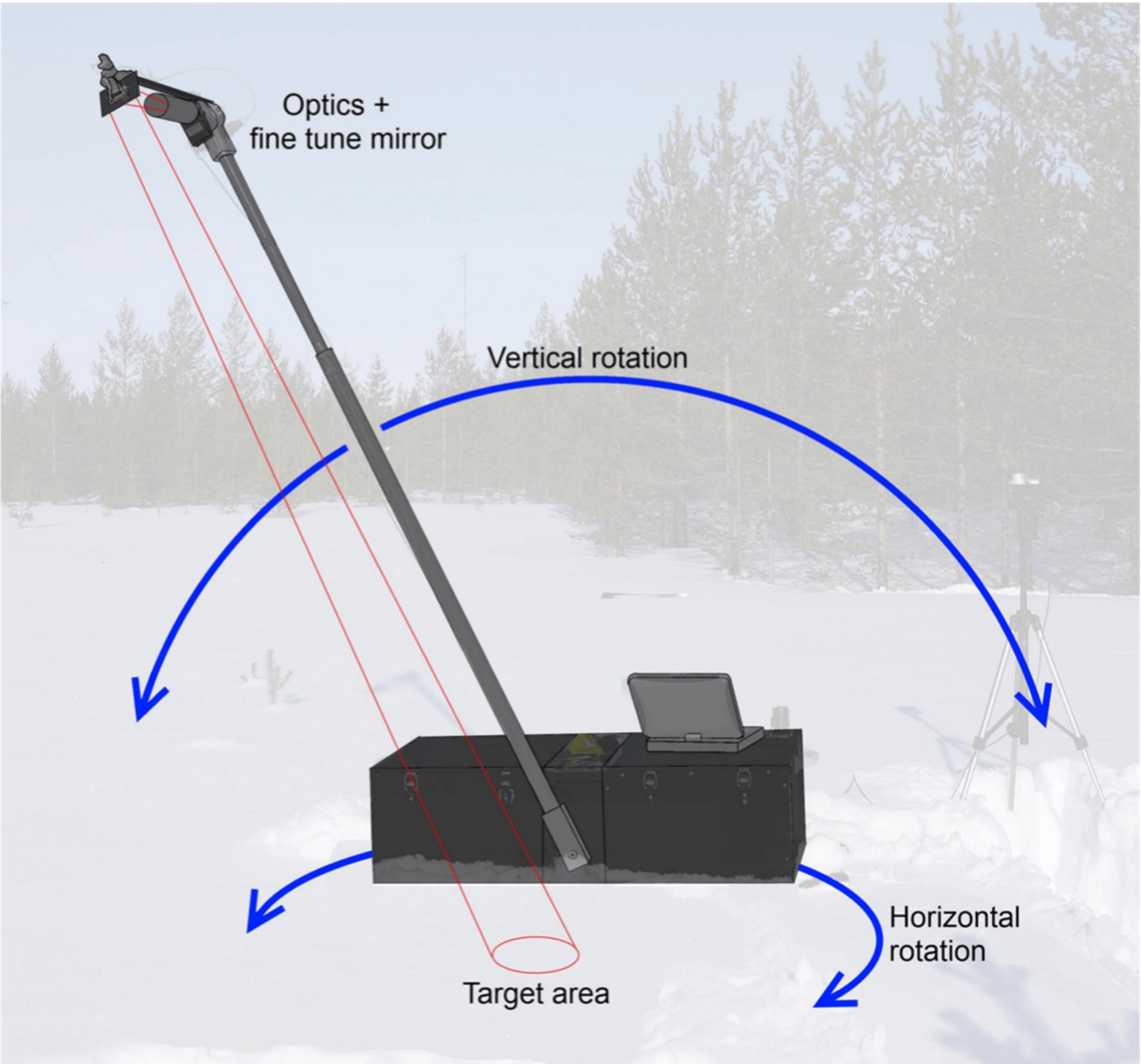

Figure 1

FIGIFIGO is equipped with an ASD FieldSpec Pro FR optical fiber spectroradiometer (350-2500 nm), which is housed inside a rugged casing along with lead acid batteries, electronics, and an electric motor (Figure 1). The optics is placed on an optical rail perpendicular to the arm (Figure 2). This rail is connected to a machined aluminum block, which connects the rail and the arm. At the other end of the rail, there is a fine-tune mirror at an angle of 45° to the optical rail. The mirror is computer controlled and can be tilted around two axes by about ±10°. The measurement starts by tilting the arm to the maximum measurement angle, and then follows a selected measurement sequence. Angles over 80° are possible but not practical, as the arm could hit the ground, and the elongation of the field of view would cause the spectra to be collected from outside the target area. A set of polarizing optics can be used to measure targets at different orientations. Calibration is done by accounting for the actual illumination conditions using a Labsphere Spectralon reference panel. The system measures the current GPS position and time, and calculates the Sun zenith and azimuth angles.

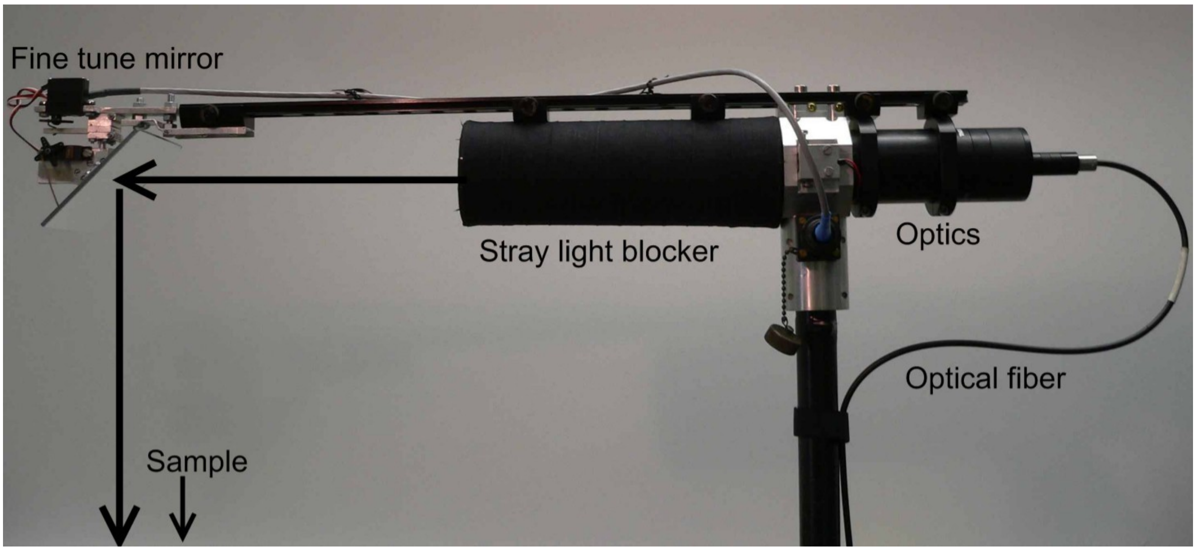

Figure 2

On the top of the measurement arm, all the parts are attached to the horizontal optical rail. It allows easy manipulation with any component and assures correct alignment. The fine-tune mirror corrects the parallax error caused by different heights of the sample and the arm axis. The stray-light blocker prevents light entering from the surroundings under field conditions. The arm is tilted by the motor to a starting predefined angle once the measurement starts, and then starts to drive at constant angular velocity to the same angle at the other side of the arc, while the spectrometer is constantly collecting spectra.

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SAMPLES

The volcanic sand samples studied by our team were collected from the Mýrdalssandur area in Iceland (March 2016) and from Llaima volcano in Conguillío National Park, Chile (July 2019).

Collecting samples at Llaima Volcano, Chile

Closeup of volcanic sand

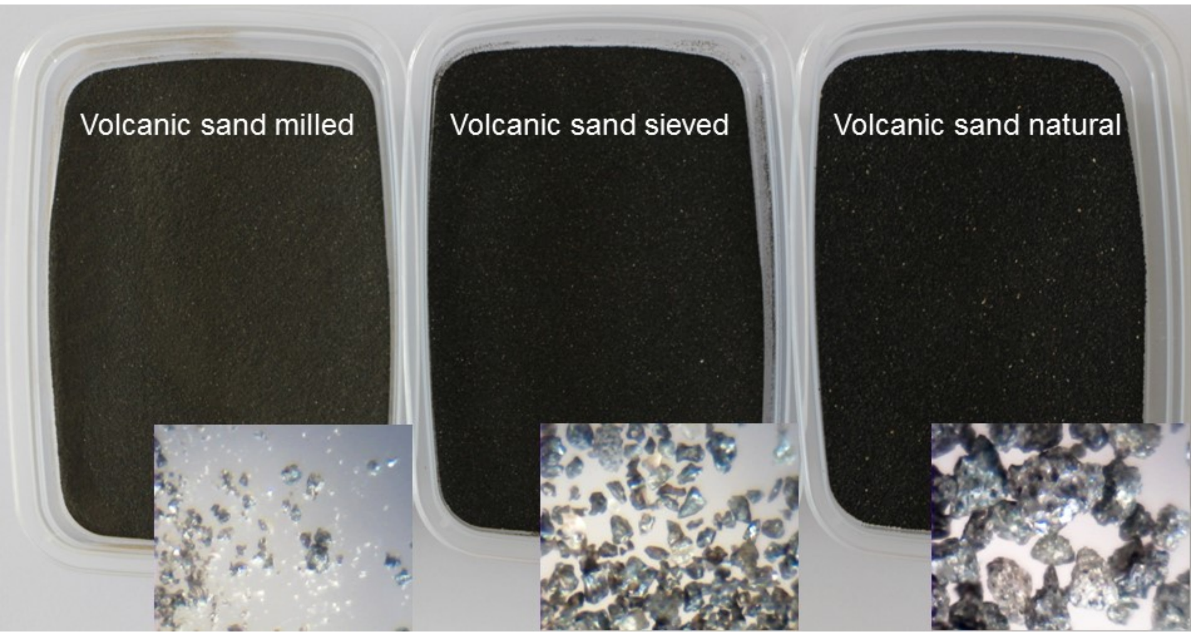
RESULTS

Following established FGI practices in laboratory conditions samples were divided into the following categories (Zubko et al. 2019):

(1) natural volcanic sand

(2) sieved volcanic sand (dust) where the size of the particles is less than 250 µm, including dry and wet sample condition

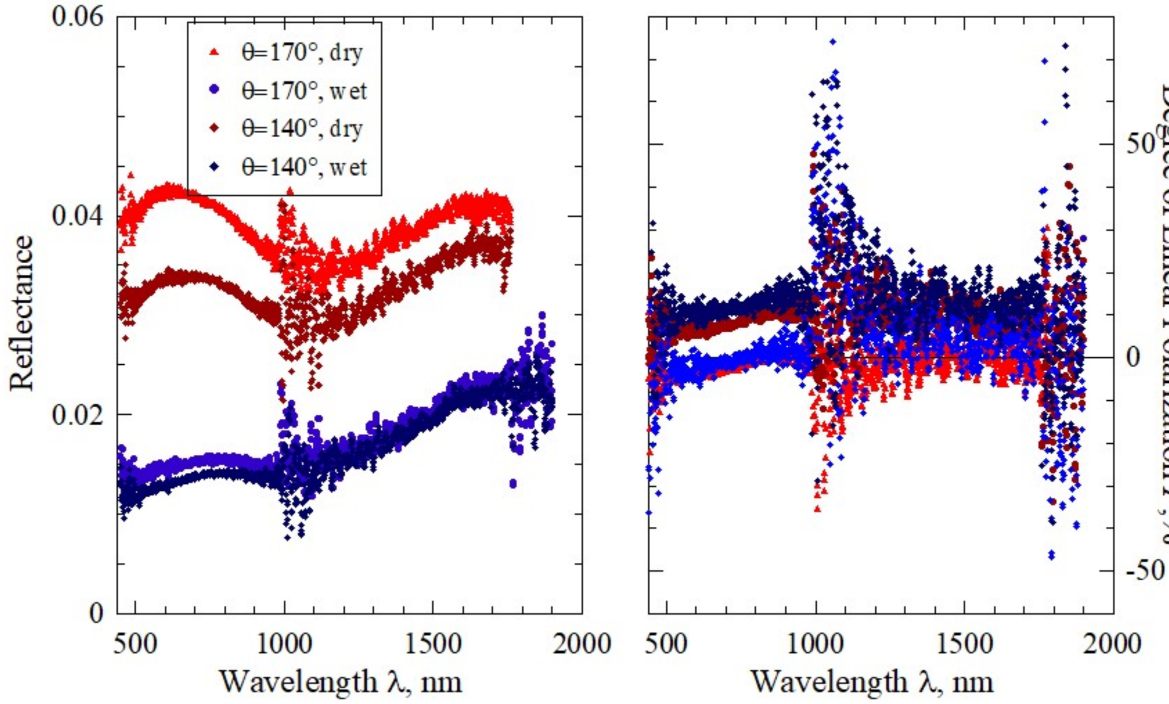
(3) a fine-grained powder of milled volcanic sand measurable also as aerosol.



Separated particle size of sample

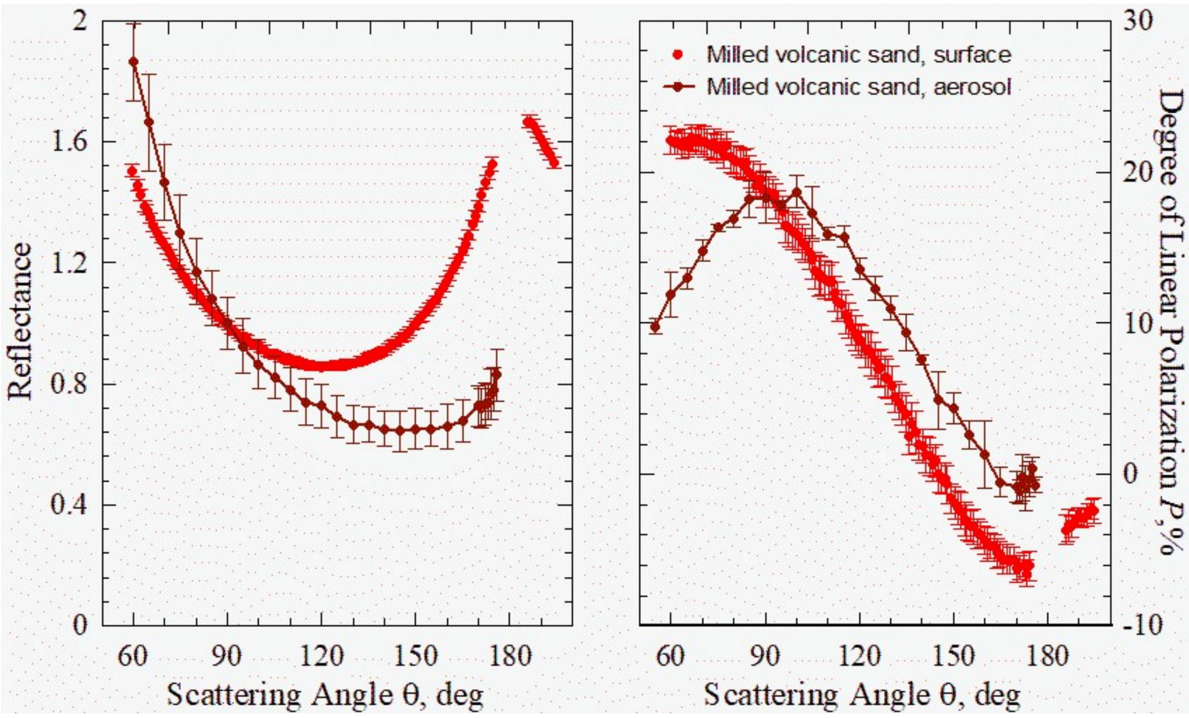
In the laboratory conditions the sample is deposited on the surface by uniform sprinkling particles on a black substrate with a layer of 0.8 - 1 cm thick. In addition to the standard measurement routine using FIGIFIGO (see e.g. Peltoniemi et al. 2015) and due to the dark appearance of volcanic sand, the laboratory measurements were taken in the principal plane with 25 repetions for each sample with the aim to improve the signal-to-noise ratio. The principal plane geometry corresponds to when the surface normal lies within the scattering plane.

Reflectance and degree of linear polarization as function of wavelength of sieved wet and dry volcanic sand particles deposited on the surface.



measured by FIGIFIGO

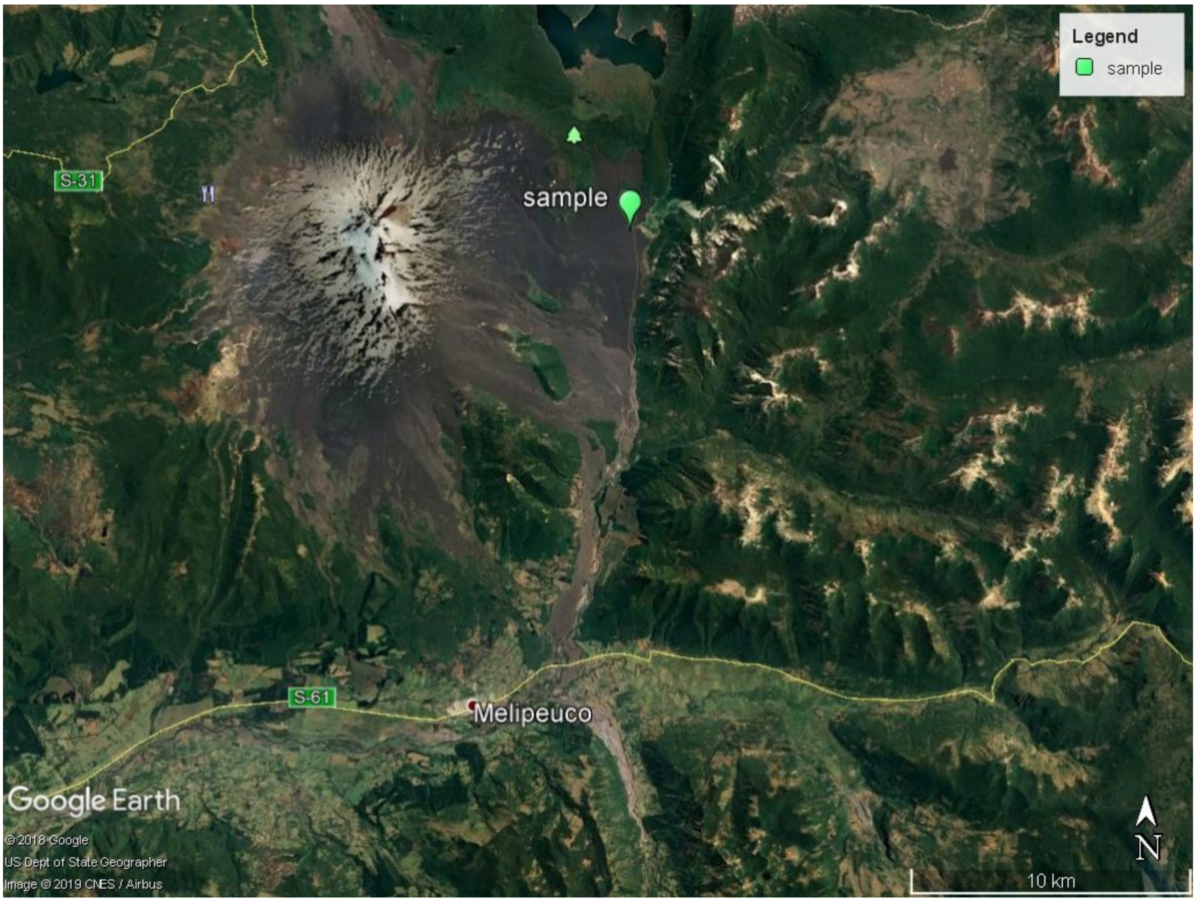
The scattering angle dependence of the normalized reflectance and degree of linear polarization obtained for the surface and aerosol of the milled volcanic sand.



measured by FIGIFIGO

DISCUSSION

Particle size-distribution strongly affects reflectance and polarization of sand. FIGIFIGO measurments help in ground truth reference for Earth Observation and remote sensing studies.



Aerial image showing contrast between volcanic land surfaces

Water content of sand increases its polarimetric response considerably (Zubko et al. 2019). At some scattering angles the response is nearly the same as the natural sand, which consists of larger particles. This observation may have important implications for remote-sensing observations of regions and changing climate.

Llaima Volcano

Small sand particles in an aerosol state help determine solar energy fates and biotic health. A positive feedback loop can occur when surface albedo is reduced by less snow cover which in turn increases solar absorption, surface tempreatures, and causes even less snow cover. Alternatively, when there is less snow cover, aerosolized particles from wind can be blown into the atmosphere changing the atmosphere temperature and blocking solar energy from reaching the surface have a cooling effect.

Conguillio National Park

Sorry but time is up!

ABSTRACT

It is increasingly recognized that light-absorbing impurities deposited on a surface can reduce its albedo and lead to increased absorption of solar radiation. Natural dust can travel substantial distances in the Earth's atmosphere from its original source. It affects all climatic zones from the tropics to the poles and it may have a regional or global impact on air quality and human health. In the Arctic, a rapid increase in temperature compared to the global change, known as Arctic Amplification, is closely linked to snow albedo feedback. Furthermore, recent studies detail an extreme climate change scenario in the history of our planet that lead to catastrophic cascading events and global mass extinction triggered by atmospheric soot injections. Therefore, knowledge of optical properties of dust particles is important for improved climate models and dust effect studies. Here we report detailed results of multi-angular polarized measurements of light scattered by volcanic sand particles obtained with the FIGIFIGO goniospectrometer (Peltoniemi et al. 2014). The design concept of this custom made instrument has a well designed user friendly interface, a high level of automation, and an excellent adaptability to a wide range of weather conditions during field measurements. The foreoptics is connected to an ASD FieldSpec Pro FR 350-2500 nm spectroradiometer by an optical fiber. A calcite Glan-Thompson prism is used as a polarizer, covering the full spectral range with better than 1% accuracy. The samples studied in this work were collected from the Mýrdalssandur area in Iceland (in March 2016) and from the Villarica area in Chile (in July 2019). Following established FGI practices in laboratory conditions samples are further divided into the following categories: (1) natural volcanic sand, (2) sieved volcanic sand (dust) where the size of the particles is less than 250 μm, including dry and wet sample condition, and (3) a fine-grained powder of milled volcanic sand measurable also as aerosol. The potential use of the results from our measurements are diverse, including their use as a ground truth reference for Earth Observation and remote sensing studies, estimating climate change over time, as well as measuring other ecological effects caused by changes in atmospheric composition or land cover.

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FIGIFIGO

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