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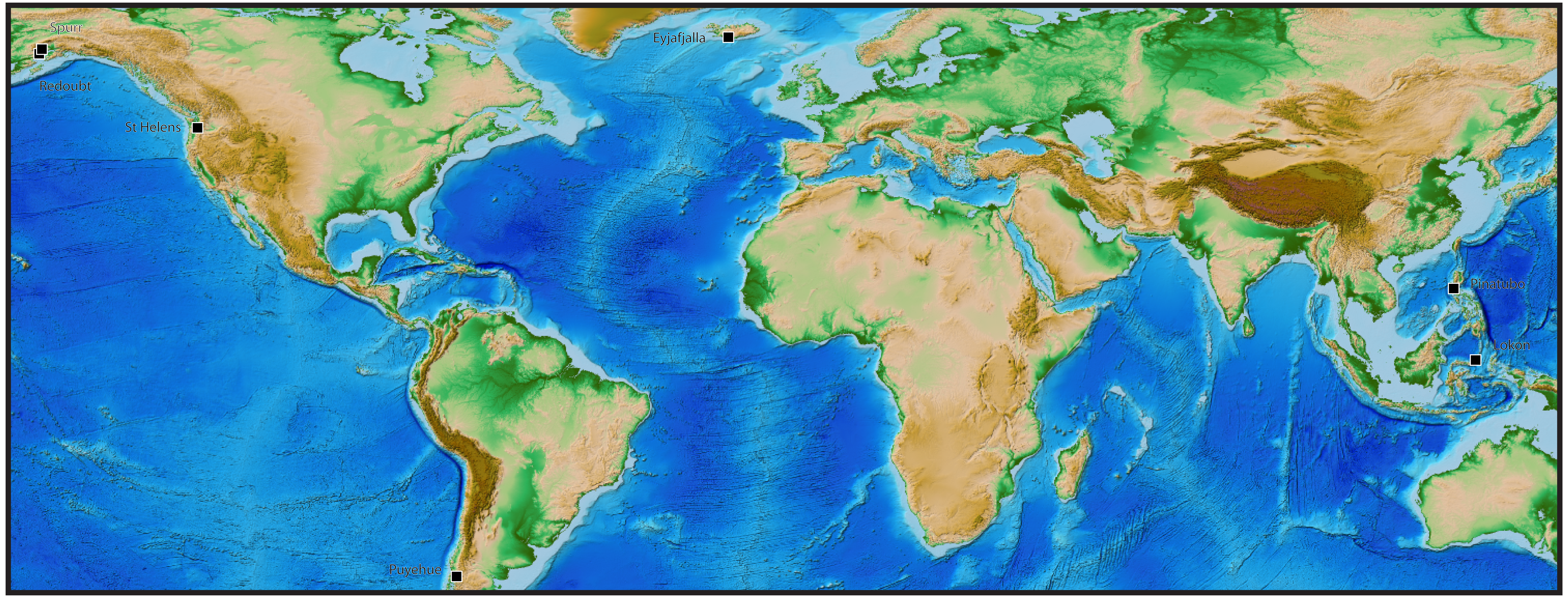

Figure 1. Map showing locations of the Volcanoes participating in this study.

Volcanic ash optical model for satellite remote sensing

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Volcanic eruptions release ash in the atmosphere that may be transported over great distances. These particles impact atmospheric radiation transfer by absorbing, emitting and scattering electromagnetic radiation. While in the atmosphere, dust particles may interfere with aviation activities causing considerable economic losses. Remote detection and global monitoring of ash clouds is therefore of great interest.

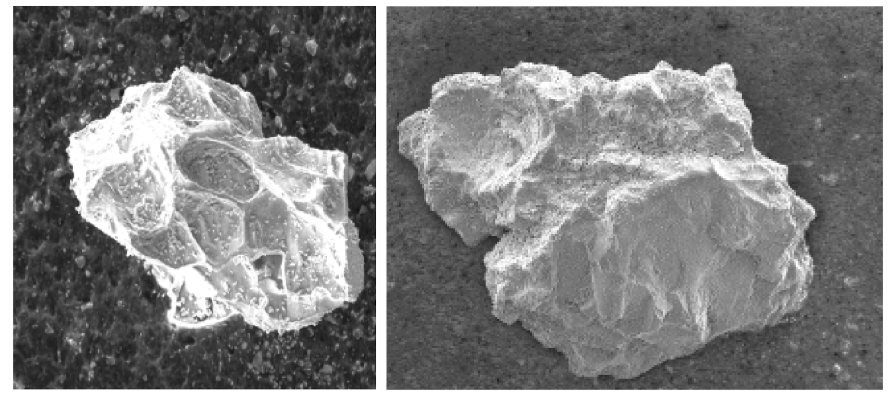

Figure 2. SEM images of Volcano ash particles from St. Helens (left) and Redoubt Volcanos. [3]

Volcanic dust particles are irregularly shaped and can be substantially porous (Figure 2). However, when modeling optical properties, simpler model geometries may provide adequate performance. We are using ellipsoidal model particles to mimic the measured scattering properties of volcanic dust. This approach has been previously shown to work well for the mineral dust in terrestrial and Martian atmosphere [1, 2]. Porosity is accounted for by using the effective medium approximation.

To validate the approach we use laboratory measurements, [3], from several volcanic dust samples with varying porocity as a reference: Pinatubo (Philippines), Eyjafjalla (Iceland), Puyehue (Chile), St. Helens (USA), Spurr (USA), Lokon (Indonesia) and Redoubt (USA). The laboratory data consist of the full scattering phase matrix, the size distribution, estimate for the refractive index and some electron microscope images of the particles.

Stokes vectors are used to describe the state of the electromagnetic radiation. Scattering matrix relates the Stokes vectors for incident and scattered radiation. In this case only six of the scattering matrix elements are non-zero and independent:

$$\begin{pmatrix} I_{sc} \\ Q_{sc} \\ U_{sc} \\ V_{sc} \end{pmatrix} \propto \begin{pmatrix} P_{11} & P_{12} & 0 & 0 \\ P_{12} & P_{22} & 0 & 0 \\ 0 & 0 & P_{33} & P_{34} \\ 0 & 0 & -P_{34} & P_{44} \end{pmatrix} \cdot \begin{pmatrix} I_{in} \\ Q_{in} \\ U_{in} \\ V_{in} \end{pmatrix}$$

In Figure 3 fitting results are shown for three of the Volcanoes considered: Eyjafjalla, Puyehue, and St. Helens. Shape distribution of ellipsoids has been fitted simultaneously for all scattering matrix elements. In the case of phase matrix P_{11}, a considerable improvement can be seen in the model (black line) when compared with the solution given by spherical particles (blue curve). The fit for linear polarization P_{12} is decent, but the ellipsoids face difficulties in trying to replicate the depolarization element P_{22}.

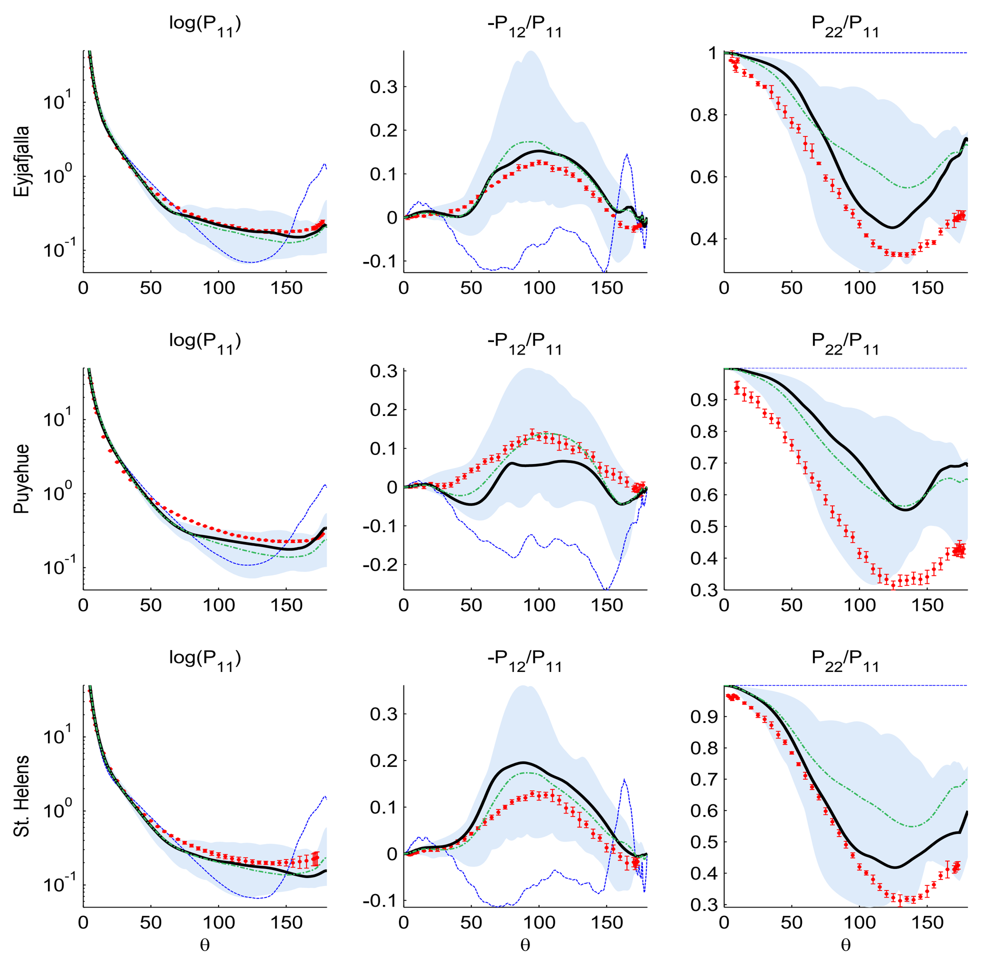

Figure 3. Measured values are plotted in red, the ellipsoidal best-fit model results are shown in black, equiprobable distribution of ellipsoids gives the green curve, and spheres (Mie - solution) result in the blue line. The light blue area on the background spans the reach of all the other ellipsoidal shapes, besides sphere. Light wavelength for Eyjafjalla and Puyehue cases is 647 nm, while for the other samples, including St. Helens on the third row, it is 632.8 nm.

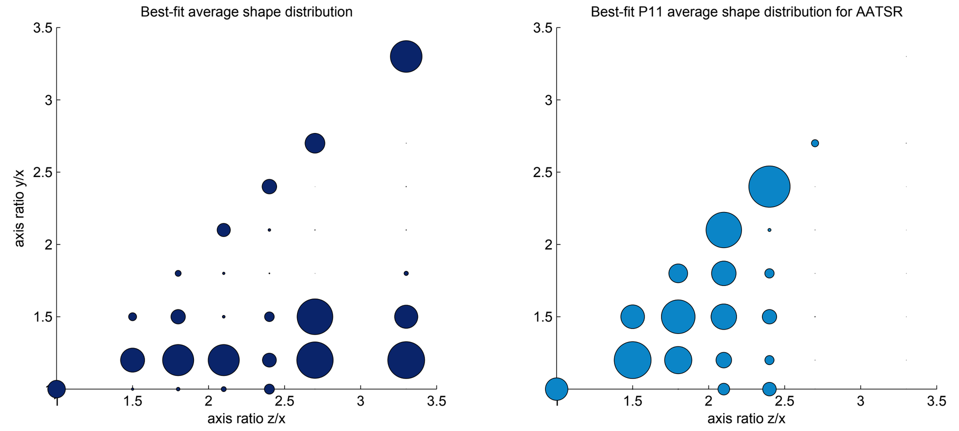

Figure 4. Best-fitting shape distributions for ellipsoidal model particles. On the fit for the whole scattering matrix is shown, whilst on the right only the phase function has been fitted for the angle range measured by AATSR.

Figure 4 shows the best-fit shape distributions averaged over all samples. Shown are both the fitting results for the whole scattering matrix (left), and the P11 element (right). In fitting the phase function, only the angle span typical for AATSR (Advanced Along Track Scanning Radiometer) measurements (50 - 170°) has been considered. These results will be used to compute the Finnish Meteorological Institutes AATSR algorithm look-up tables for ash.

Ellipsoids provide a good model for various different volcanic dusts, and likely works for modeling future eruption products as well.

References
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