



Constrained Lidar Ratios for Volcanic Ash and Sulfate Layers in the Stratosphere from CALIOP Version 4.10 data

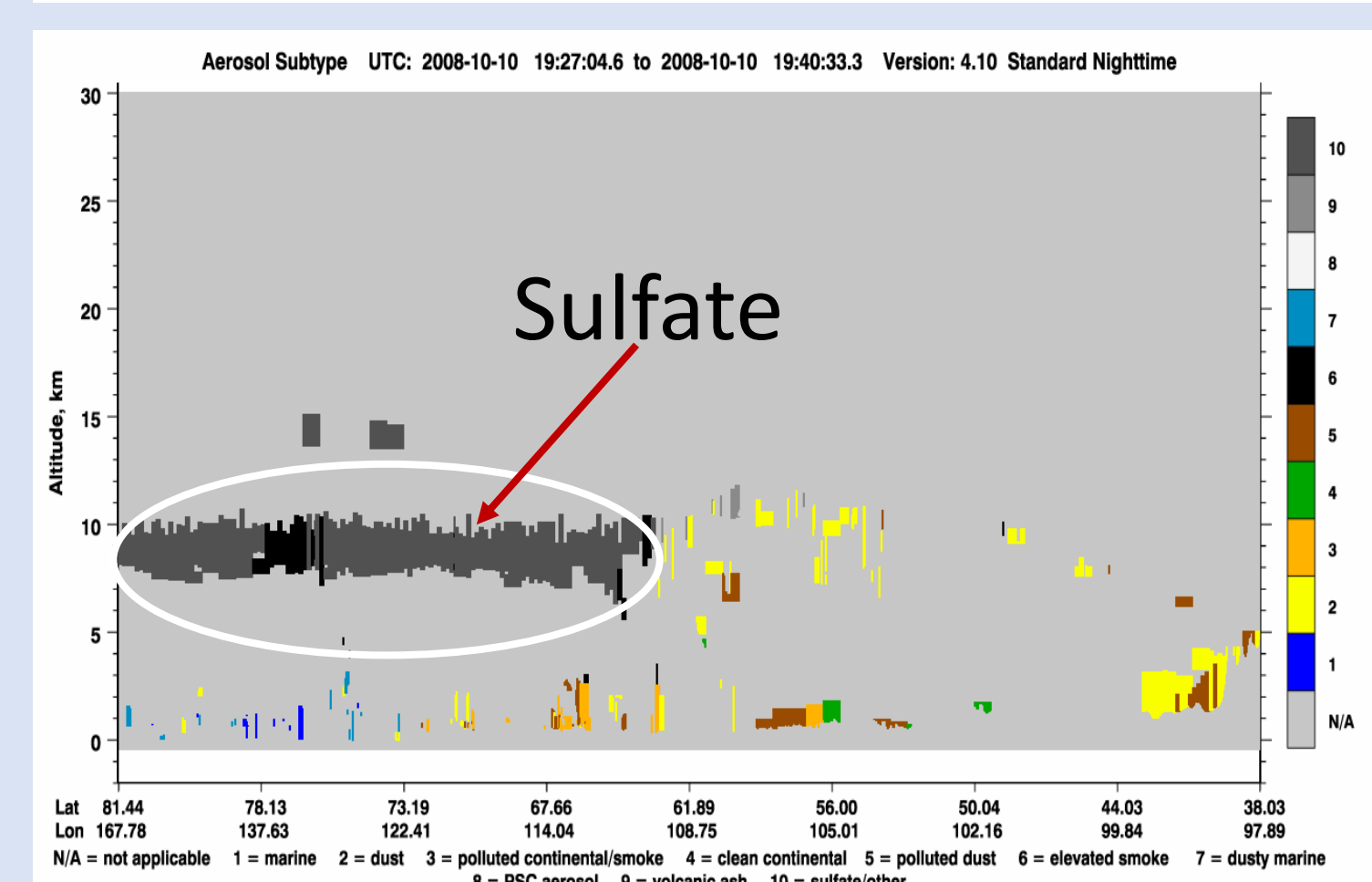
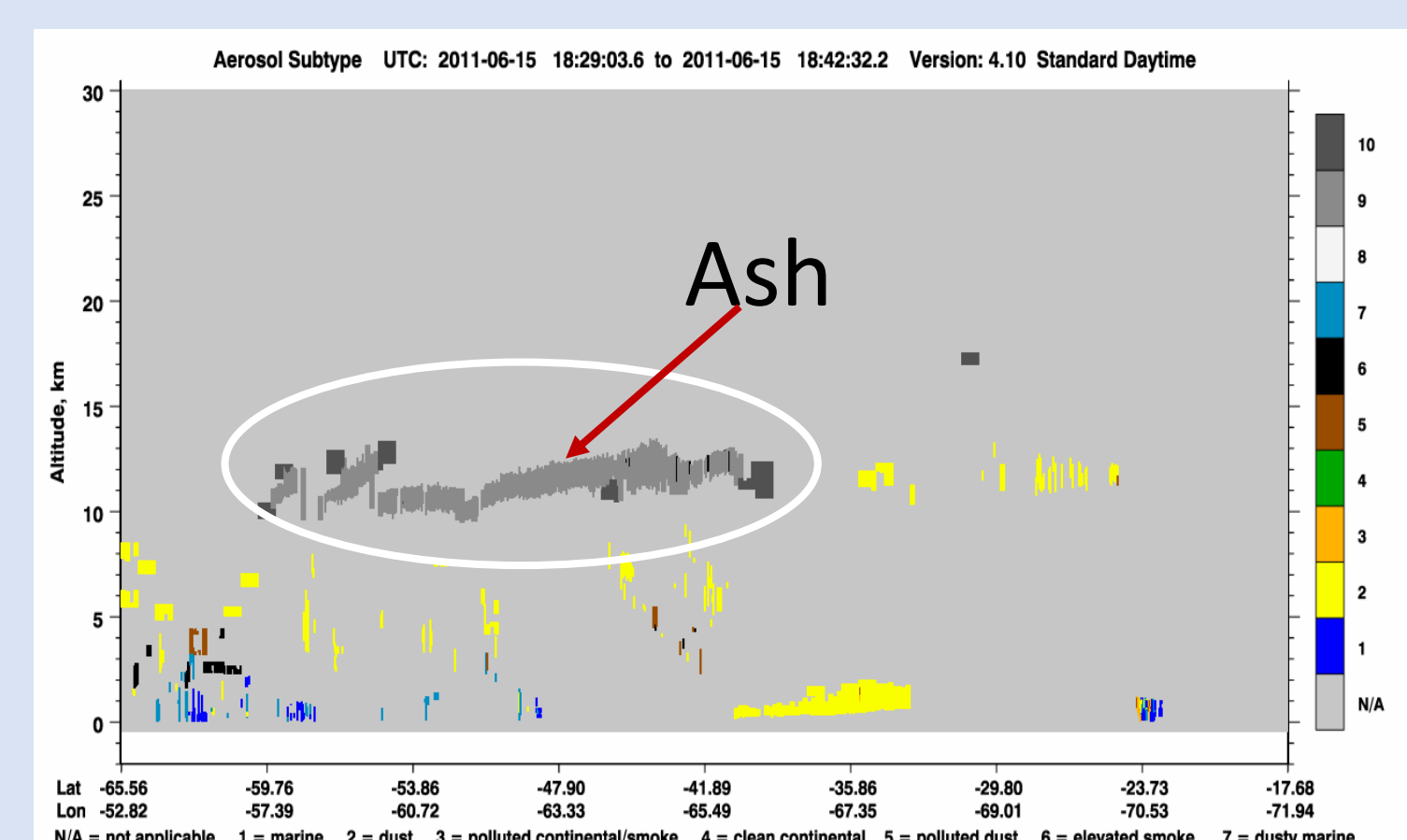
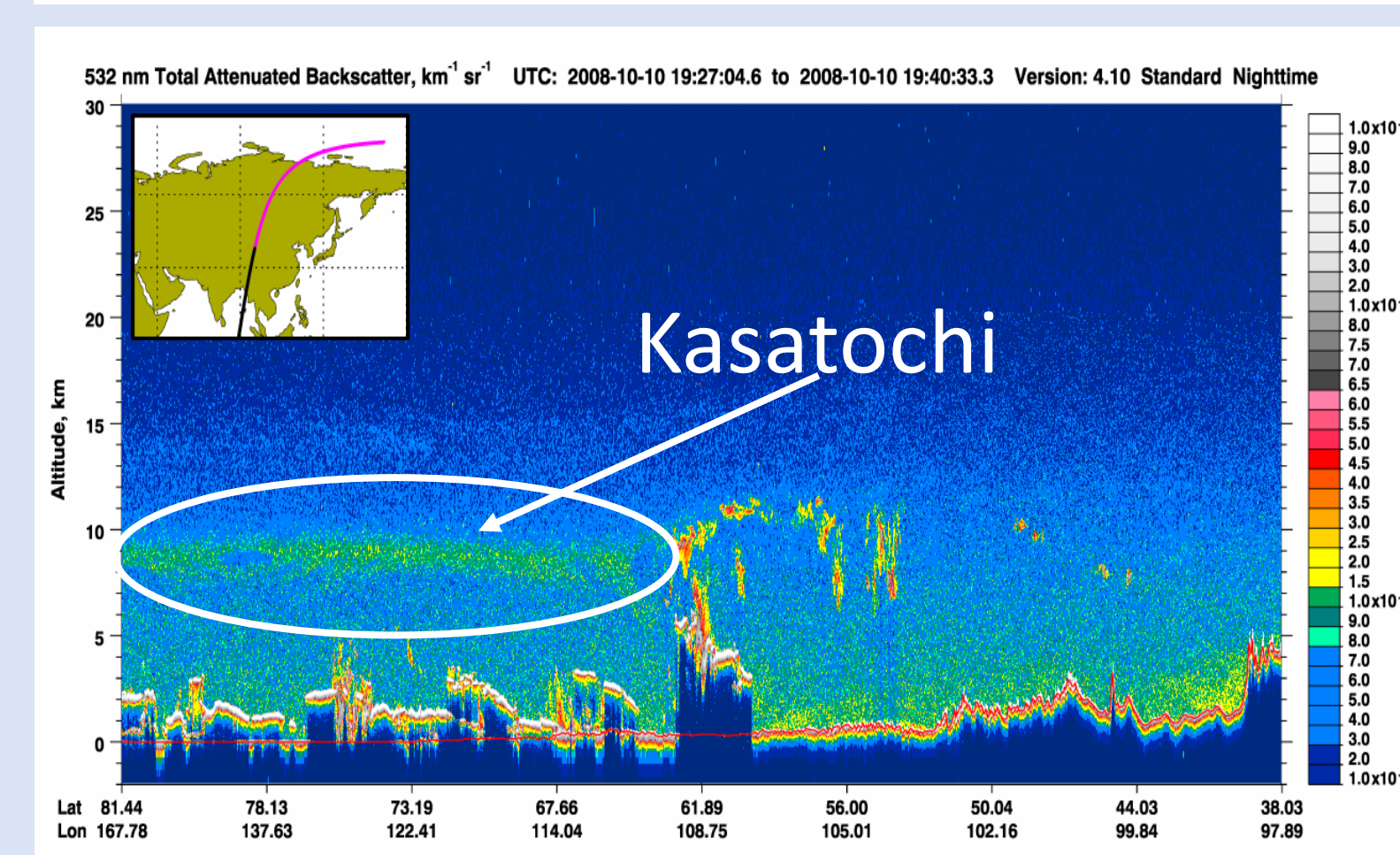
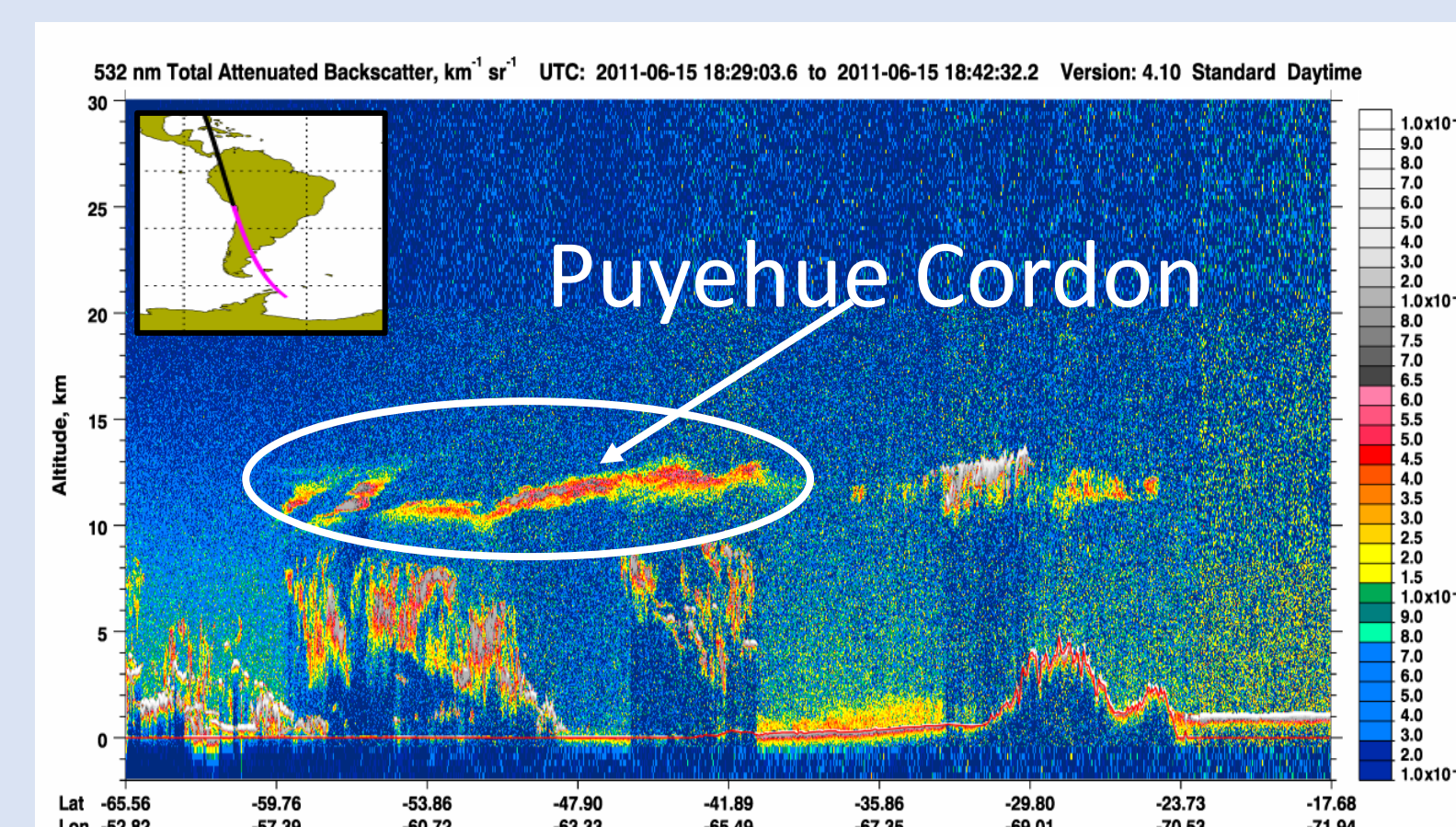
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Examples of Volcanic ash and Sulfate Layers in CALIOP Version 4 (V4) data



• Total attenuated backscatter (left) and aerosol subtype (right) from a volcanic layer (Puyehue Cordon Caulle) classified as “ash” in CALIOP version 4 (V4) data.

• Total attenuated backscatter (left) and aerosol subtype (right) from a volcanic layer (Kasatochi) classified as “sulfate” in CALIOP V4 data.

Constrained Retrievals in CALIOP V4 data

- Lidar ratios are required to retrieve the extinction profiles in CALIOP algorithm.
- Unconstrained retrievals:** A default lidar ratio is used depending upon the aerosol subtype.
- Constrained retrievals:** The lidar ratio (S) is retrieved from the measured two way transmittance (T^2), when clear air is found both above and below the layer for at least 2.5 km:

$$T^2 = \langle R'_b \rangle / \langle R'_a \rangle \quad (1)$$

$$S = (1 - T^2) / 2\psi' \quad (2)$$

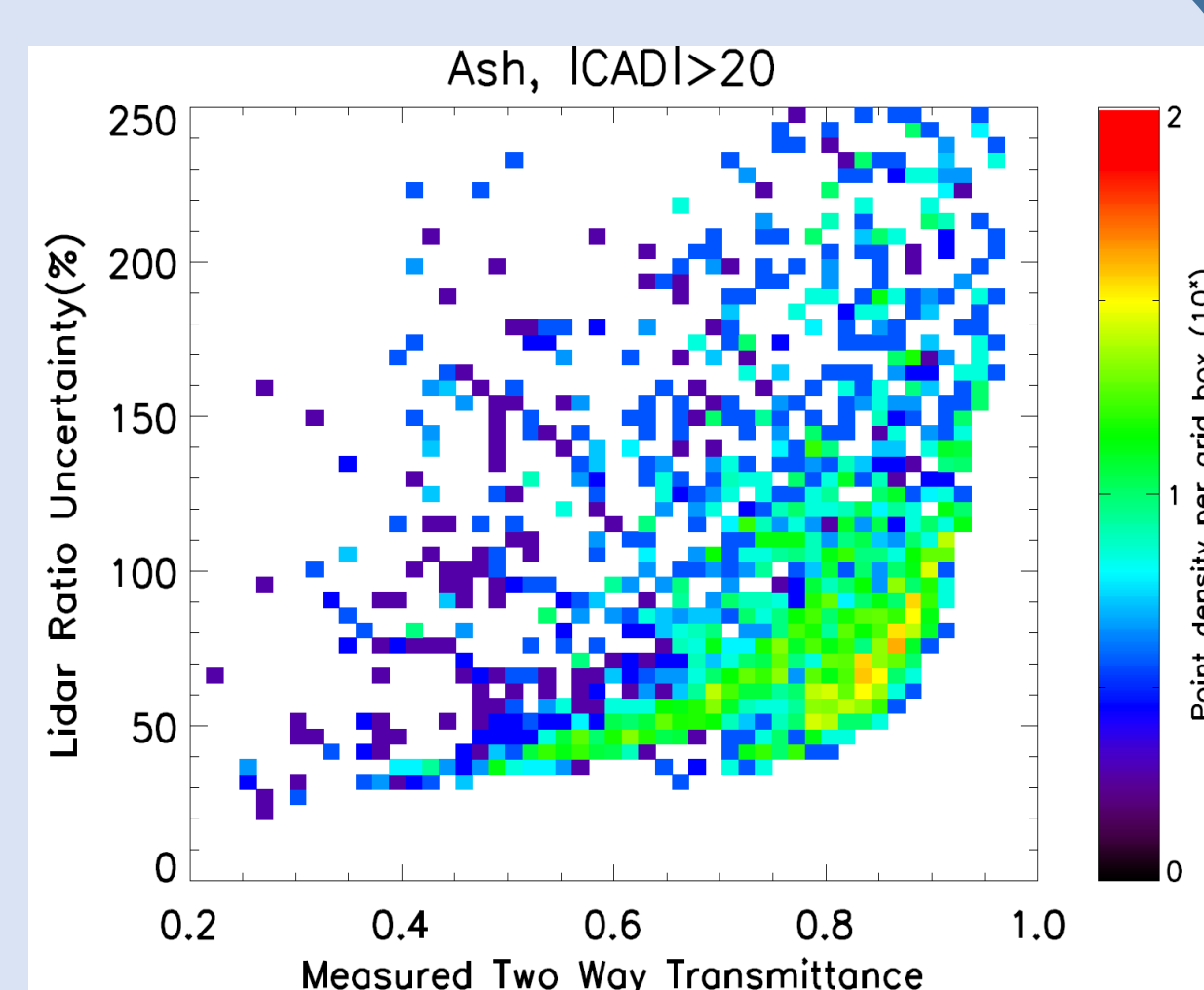
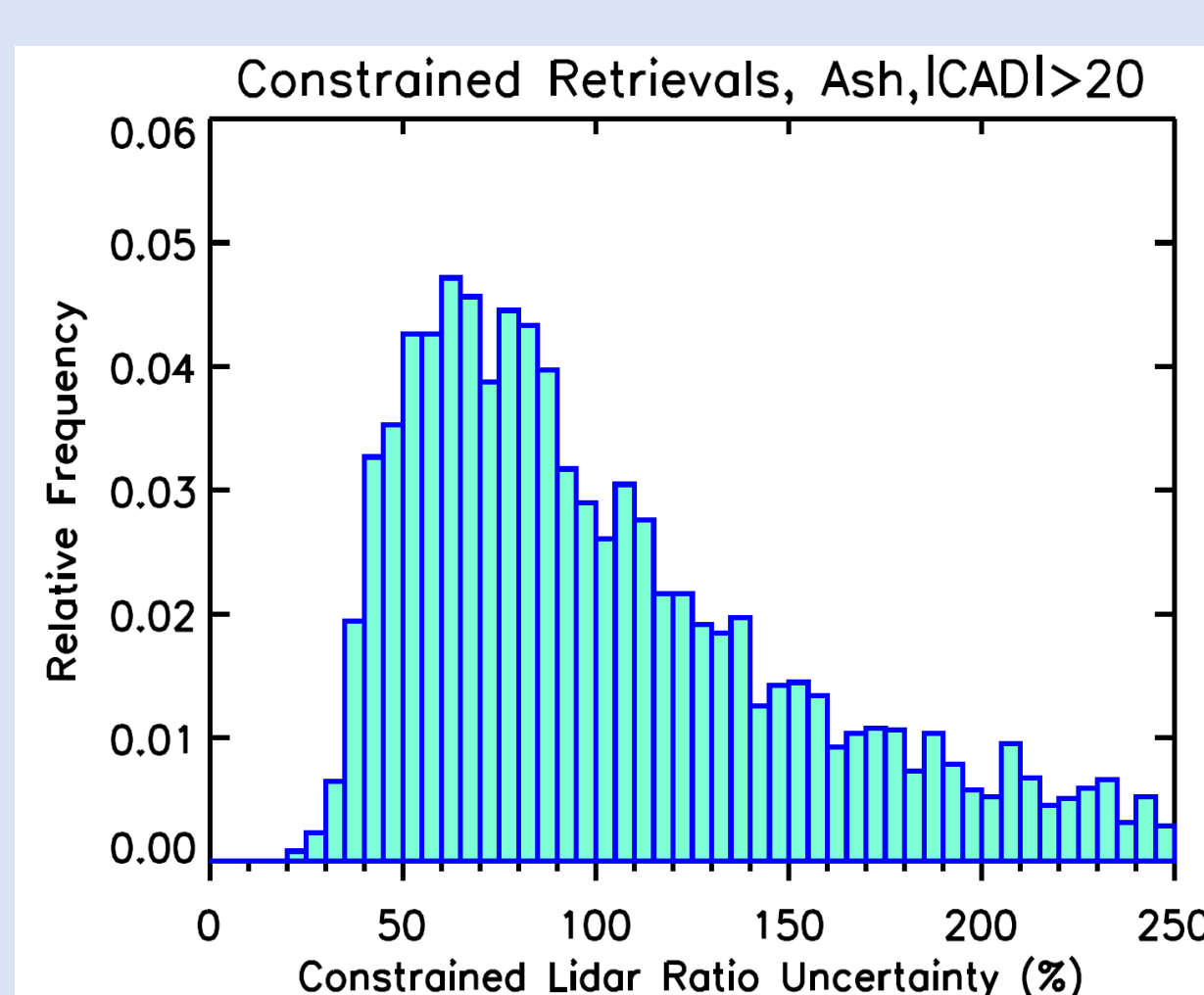
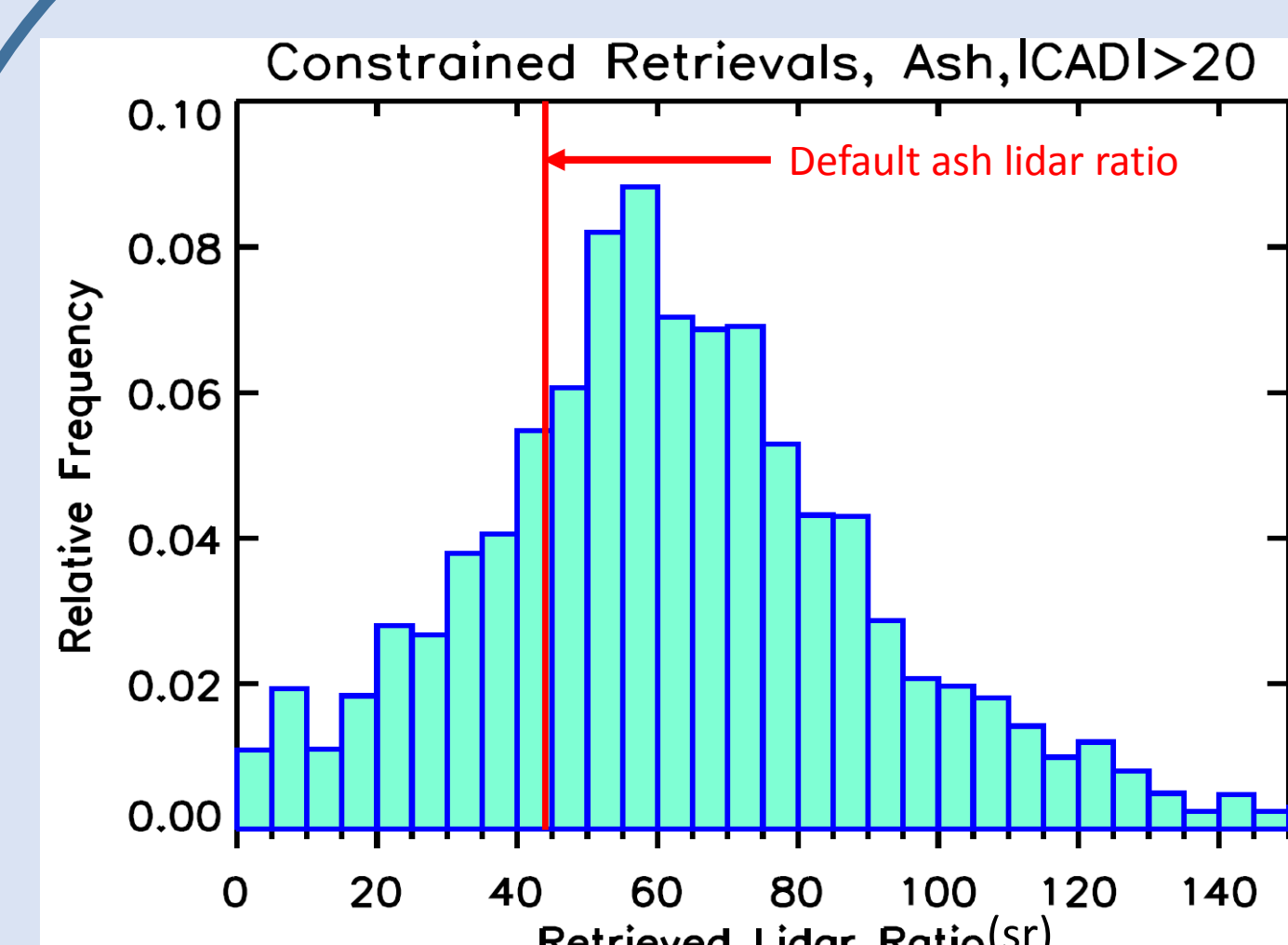
where $\langle R'_b \rangle$ and $\langle R'_a \rangle$ are the mean attenuated scattering ratios below and above the layer respectively, and ψ' is the layer integrated attenuated backscatter. A multiple scattering factor of 1 is assumed.

- Many more constrained retrievals in V4 than in earlier versions: Young et al., ACP, 2018, <https://doi.org/10.5194/amt-11-5701-2018>. In general, constrained lidar ratios are expected to be more representative (but also noisier) than the unconstrained cases, hence accuracy of the unconstrained lidar ratios can be assessed using the constrained ones.
- If the lidar ratios from the constrained retrievals (S_n) are significantly different from the default lidar ratios (S_0), then the estimated optical depths (τ_0) for the unconstrained cases are likely to be biased low or high. A correction can be made to the optical depth (τ_n) for the unconstrained retrievals using the equation:

$$\tau_n = -0.5 * \ln(1 - (S_n/S_0) * (1 - \exp(-2\tau_0))) \quad (3)$$

- No correction is made to the constrained retrievals, for which the optical depths are measured directly.

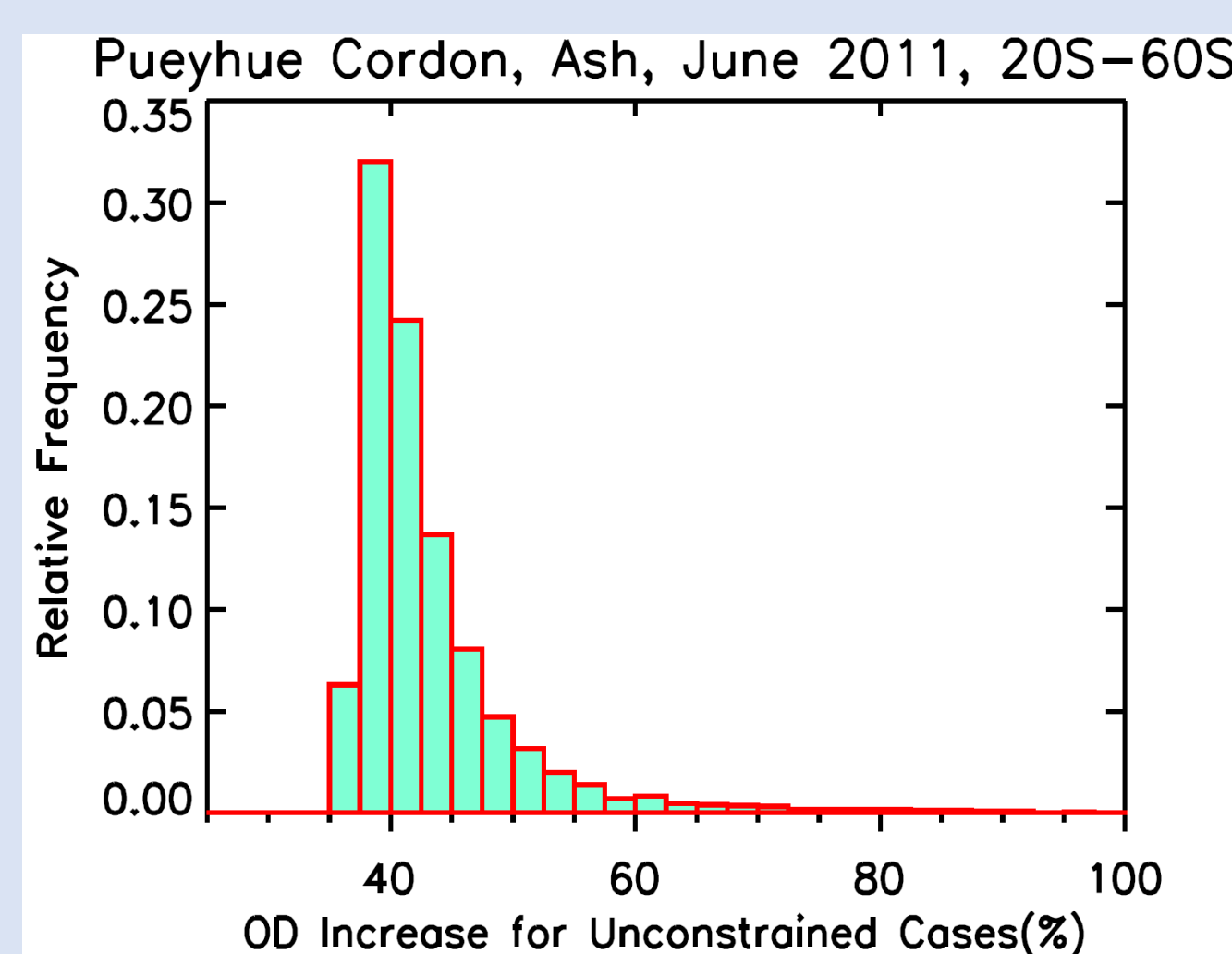
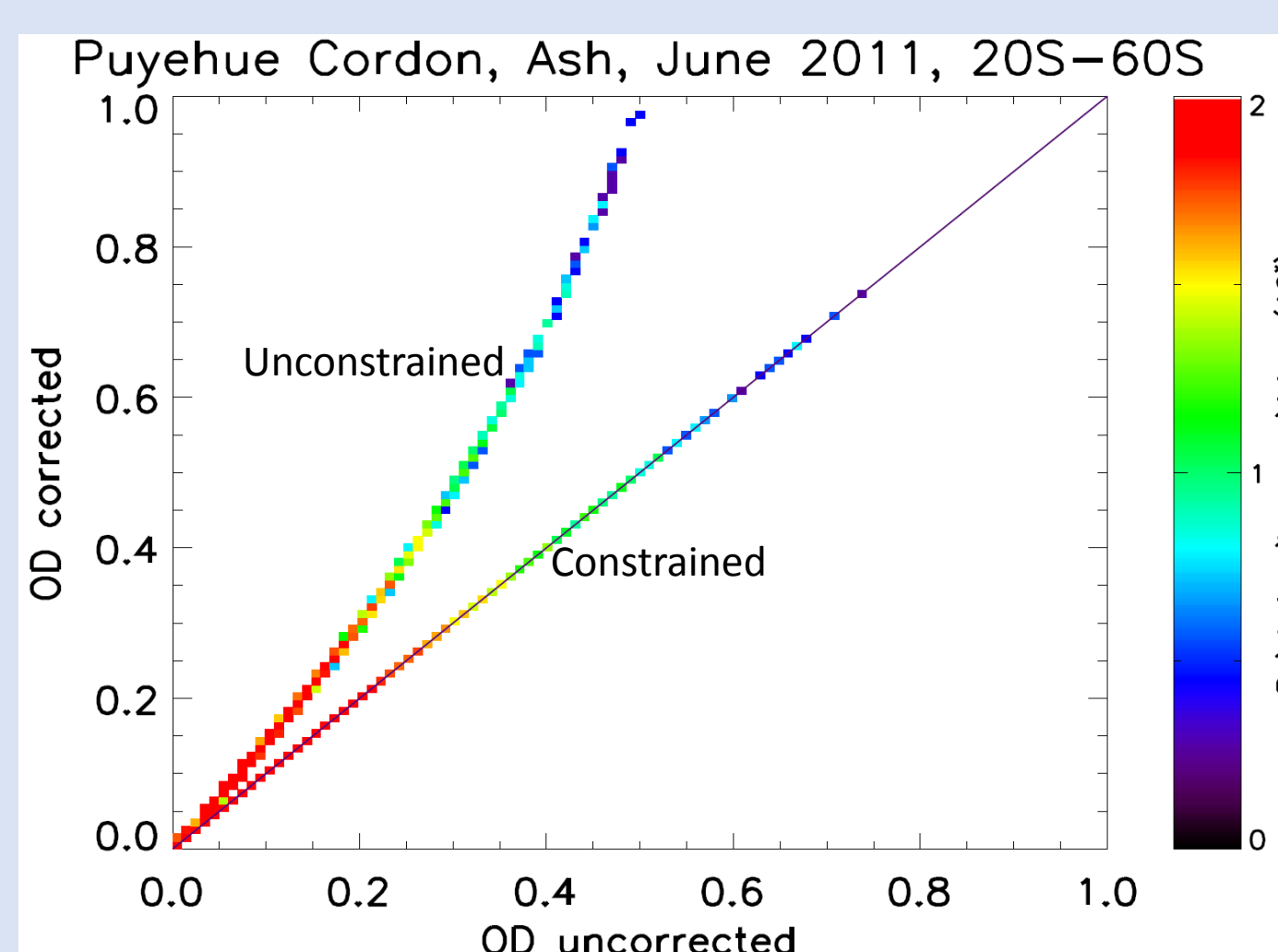
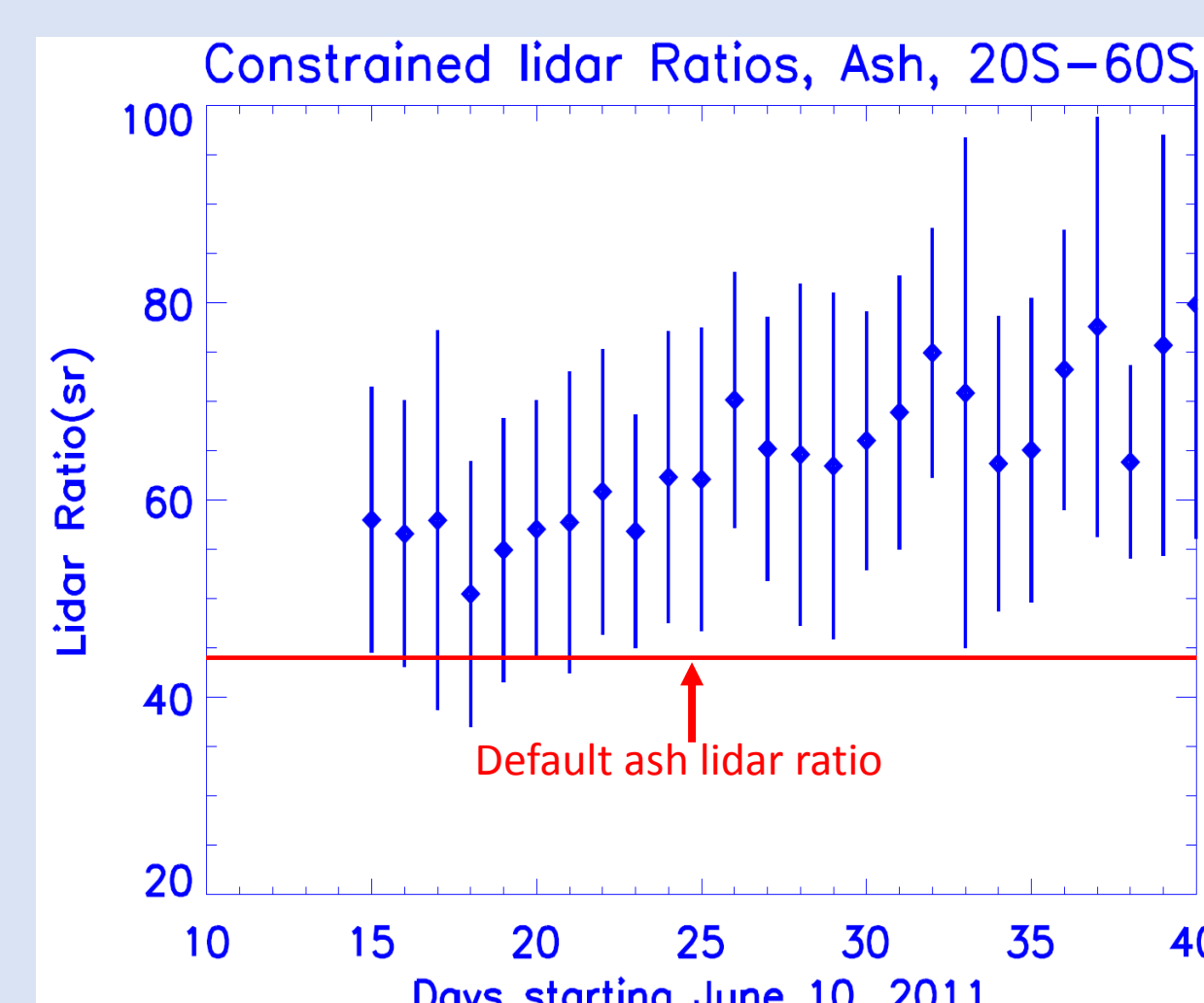
Constrained Retrievals of Volcanic ash Layers



• Lidar ratios retrieved from “ash” layers (~30% of all layers) from Puyehue Cordon Caulle, Kelud, Sarychev and Calbuco volcanoes. The median value of 61 sr is significantly larger than the default value for ash (44 sr). Data with medium and high confidence cloud - aerosol discrimination (CAD) scores ($|CAD| > 20$) were included.

• Fractional uncertainties in the retrieved lidar ratios of volcanic ash. These uncertainties are related to measurements and thus have a larger spread than those for unconstrained cases, which are assigned based on estimates of natural variability (Young et al., 2018).

• Lidar ratio uncertainties increase sharply for tenuous layers with high transmittance.

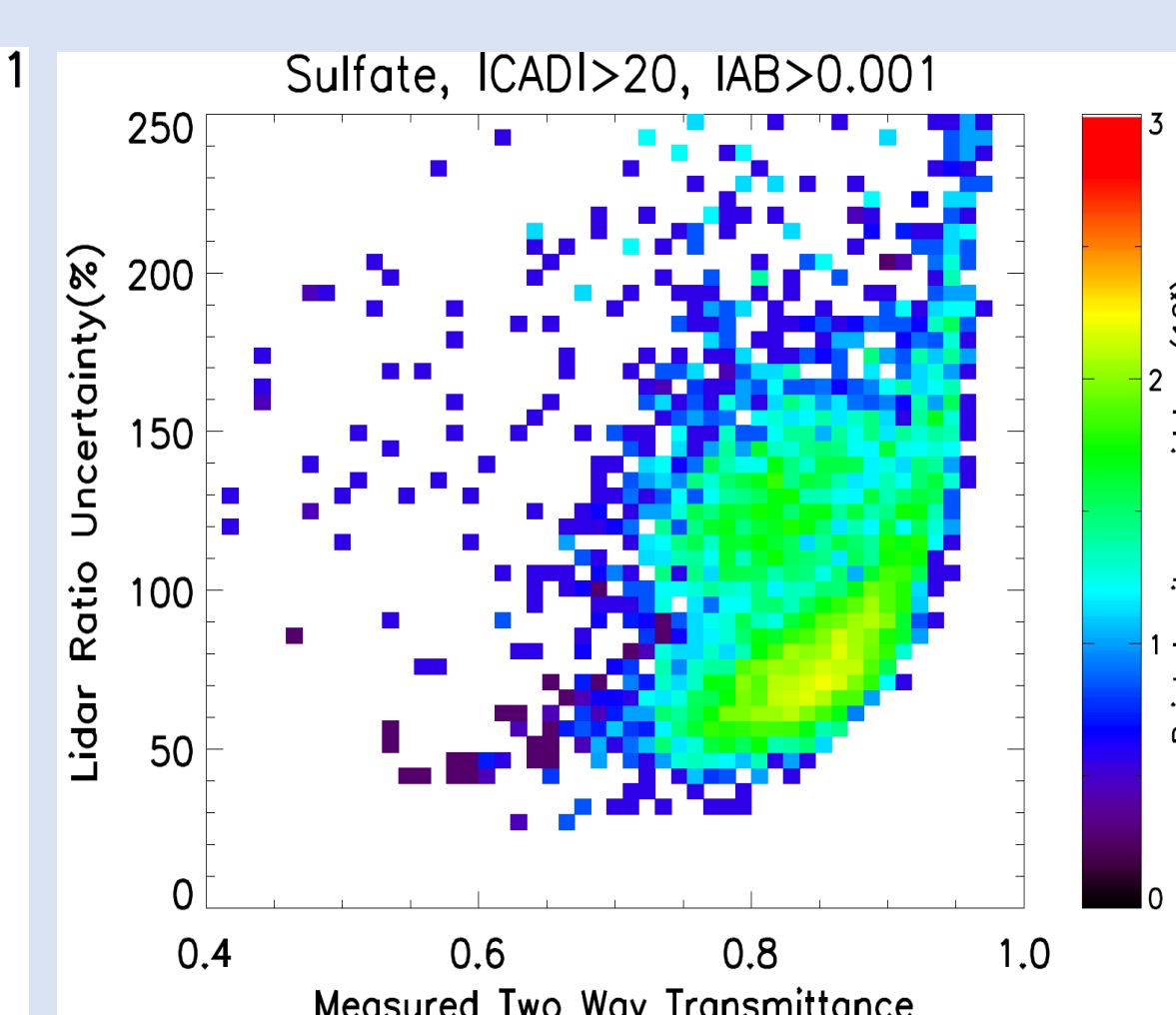
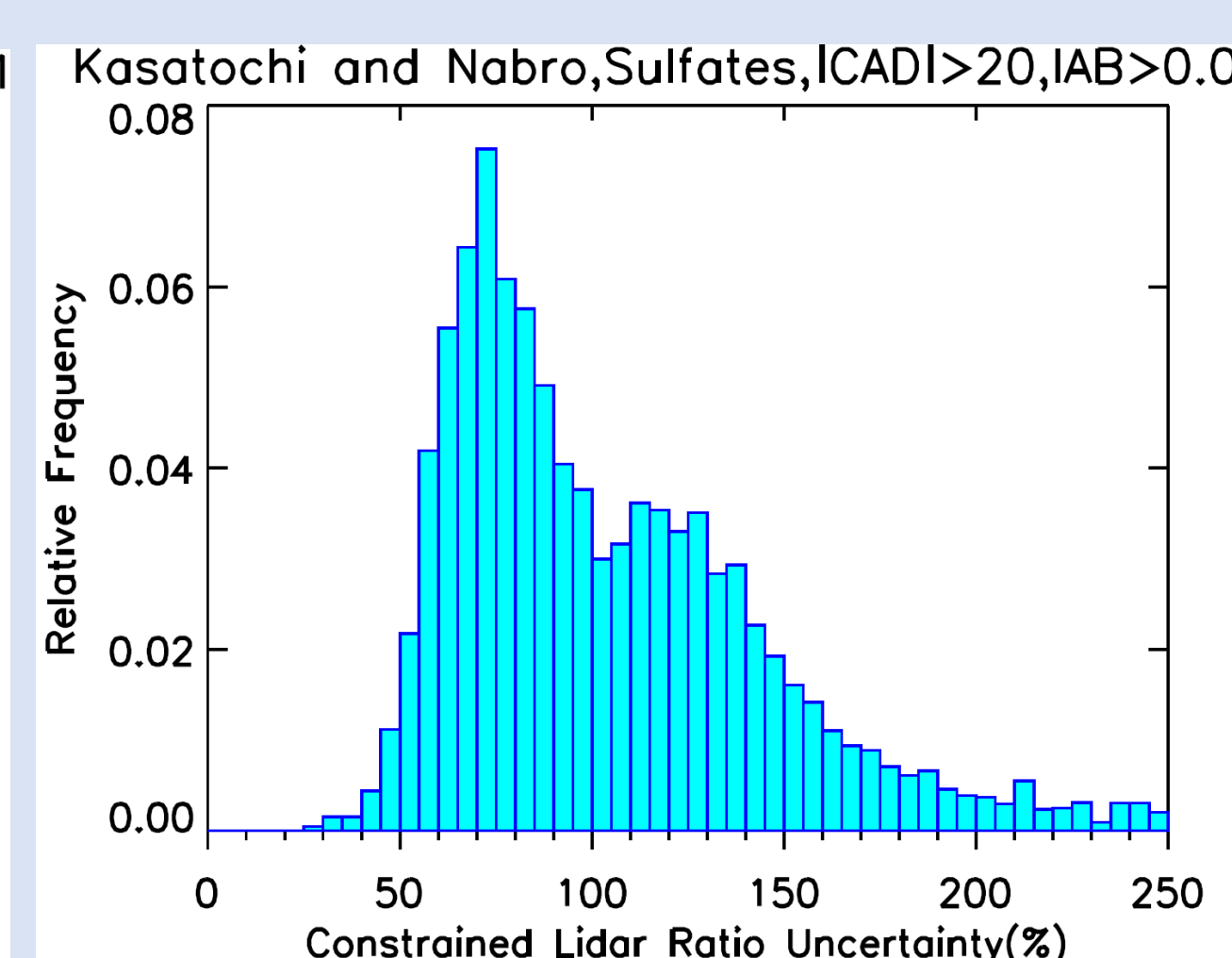
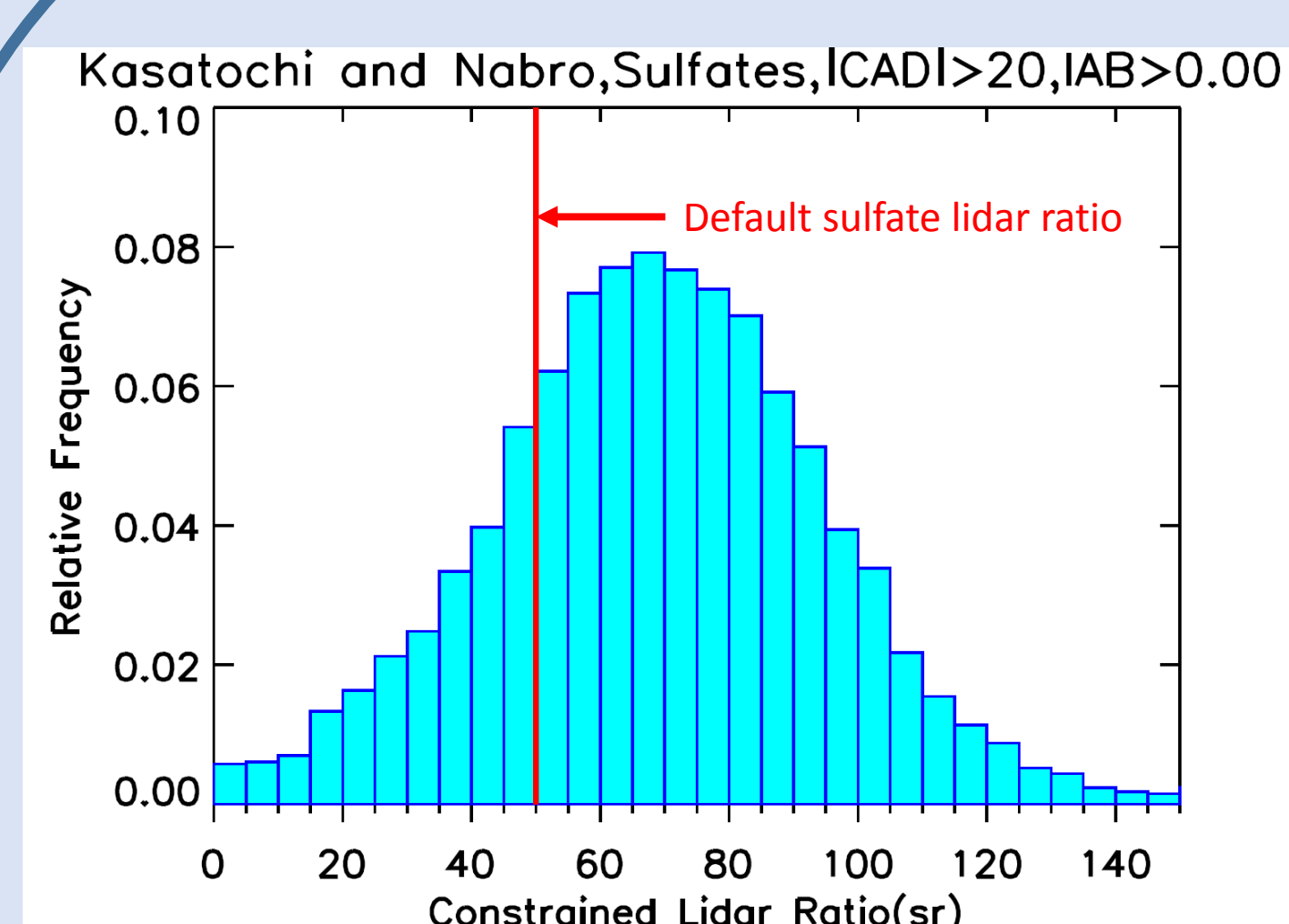


• Lidar ratios retrieved from ash layers for Puyehue Cordon Caulle volcano show a clear departure from the default lidar ratio used for unconstrained cases.

• Comparison of retrieved optical depths (OD) using lidar ratio from constrained retrievals (60 sr) versus default lidar ratio (eqn 3) for ash layers from Puyehue Cordon Caulle for June 2011.

• Optical depths for the unconstrained retrievals increase significantly using the median lidar ratio from the constrained cases for Puyehue Cordon Caulle.

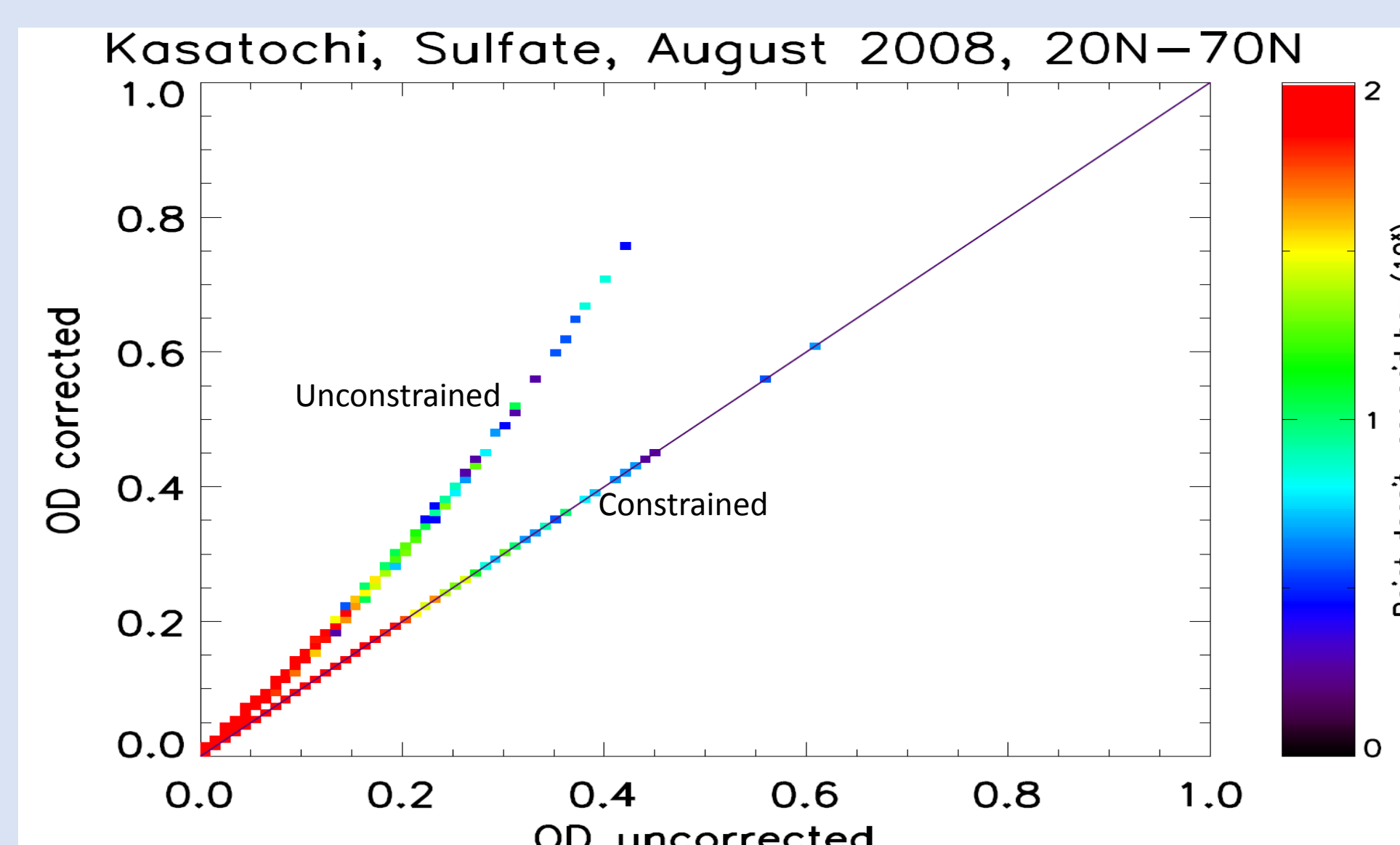
Constrained Retrievals of Volcanic Sulfate Layers



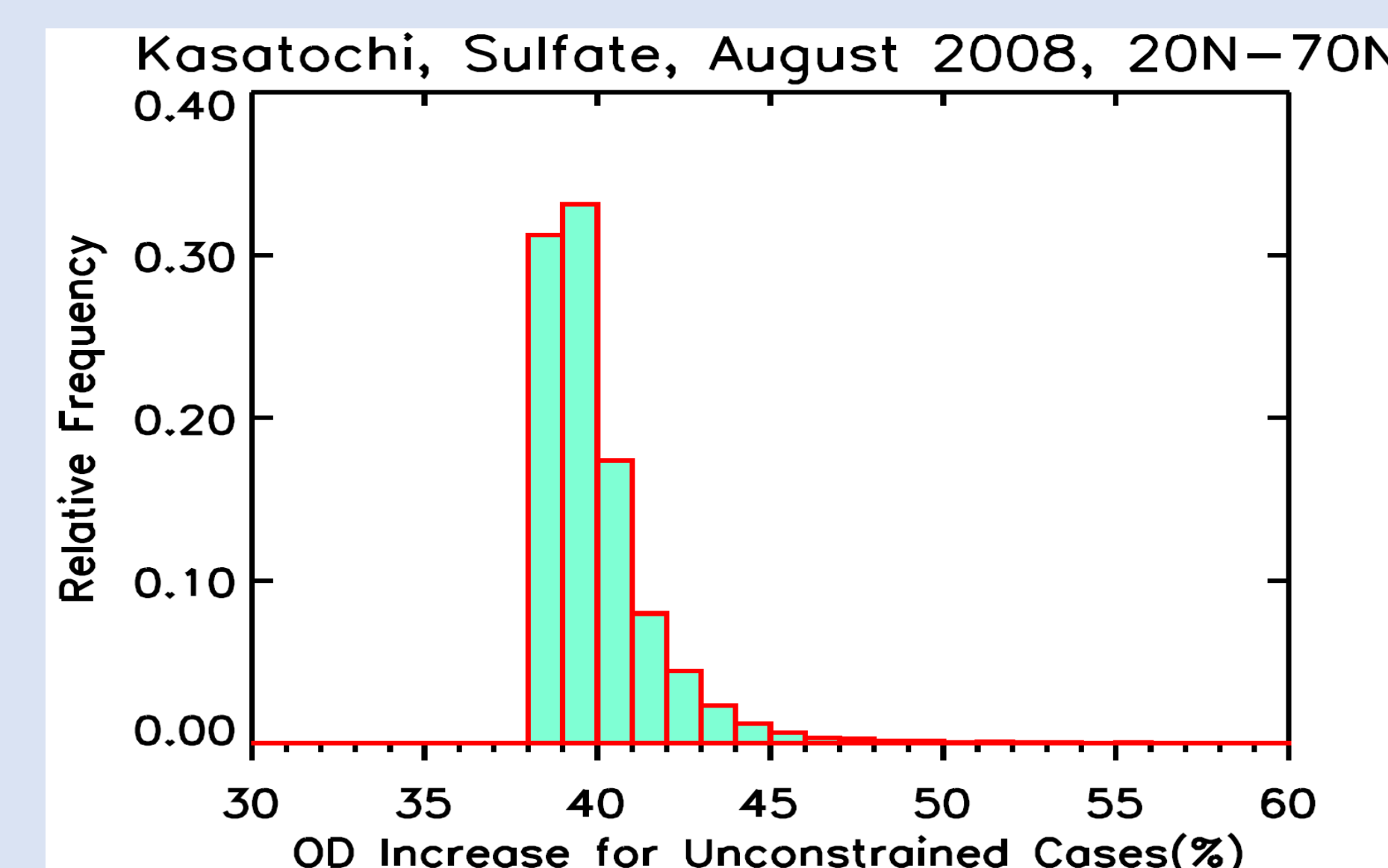
• Lidar ratios retrieved from sulfate layers (36% of all layers) from Kasatochi and Nabro volcanoes. The median value is 69 sr. The red line indicates the lidar ratio (50 sr) used as default for sulfate. Data with $|CAD| > 20$ and integrated attenuated backscatter (IAB) $> 0.001 \text{ sr}^{-1}$ were included.

• Fractional uncertainties in the retrieved lidar ratios for volcanic sulfate layers. The apparent second peak near 120% is due to thin layers with very low IAB ($\sim 0.001 \text{ sr}^{-1}$)

• Lidar ratio uncertainties increase sharply for tenuous layers with high transmittance.



• Comparison of retrieved optical depths (OD) using lidar ratio from constrained retrievals (69 sr) versus default lidar ratio (eqn 3) for sulfate layers from Kasatochi for August 2008.



• Increase in optical depths for unconstrained cases when the median lidar ratio from constrained retrievals is used.