Recent Advances in Satellite Retrieval of Volcanic Ash Properties

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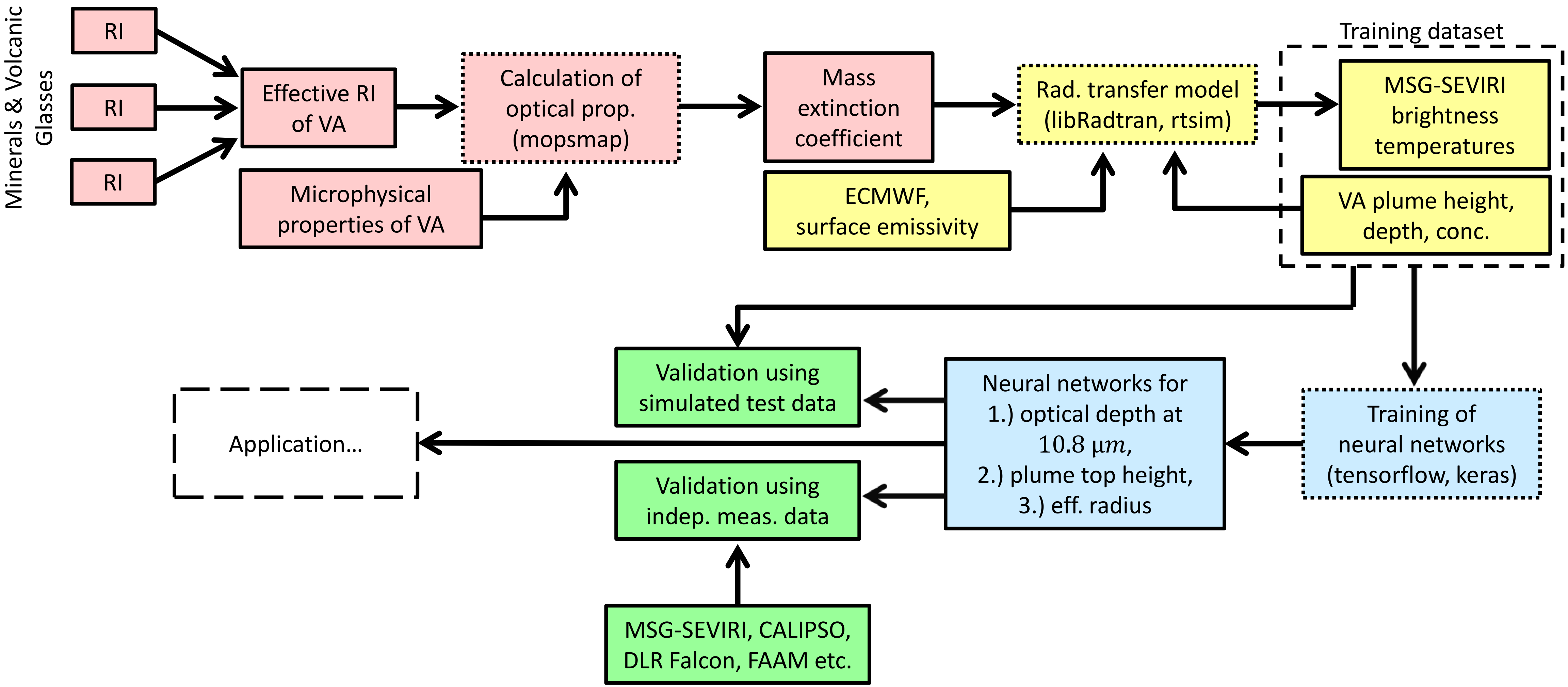
Overview


Minerals & Volcanic Glasses
RI
RI
RI
Effective RI of VA
Microphysical properties of VA
Calculation of optical prop. (mopsmap)
Mass extinction coefficient
ECMWF, surface emissivity
Rad. transfer model (libRadtran, rtsim)
Training dataset
MSG-SEVIRI brightness temperatures
VA plume height, depth, conc.
Validation using simulated test data
Application...
Validation using indep. meas. data
MSG-SEVIRI, CALIPSO, DLR Falcon, FAAM etc.
Neural networks for 1.) optical depth at 10.8 μm, 2.) plume top height, 3.) eff. radius
Training of neural networks (tensorflow, keras)

Complex Refractive Indices of Volcanic Ashes

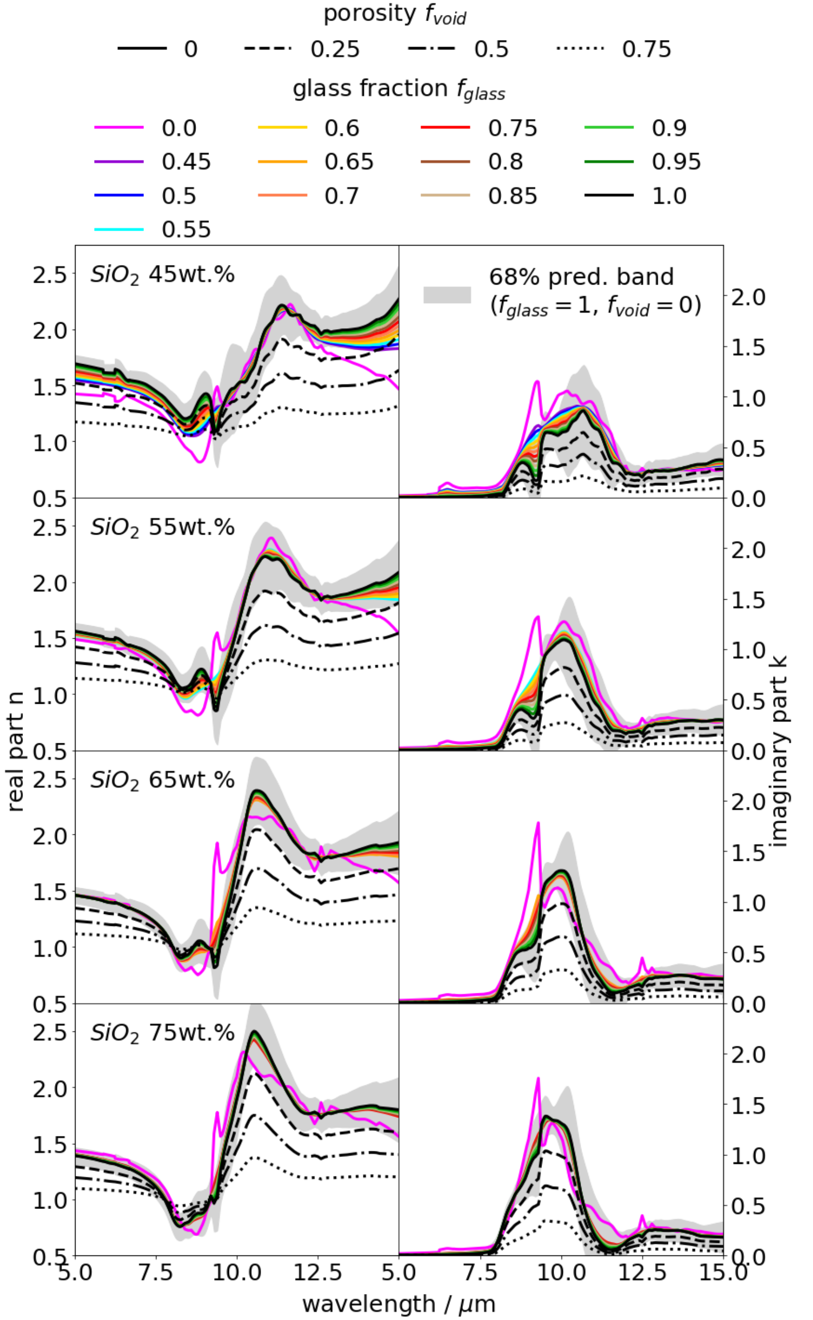
Refractive indices of volcanic ash exhibit large variability.
How big is the impact of silica content, glass-to-crystal fraction and porosity?

Volume weighted averaging of refractive indices for different bulk silica contents x_s:

$$m_{eff} = f_{void}\, m_{void} + (1 - f_{void})\, m_{volc}$$
$$m_{volc} = f_{glass}\, m_{glas} + \left(1 - f_{glass}\right) m_{min}$$
$$m_{min} = \sum_i f^i_{min}\, m^i_{min}$$

Now:
- bubble sizes mostly few microns (Sparks , 1978) → $f_{void} = 0$
- $f_{glass} \sim x_s$ but up to $f_{glass} = 1$ (Vogel et al., 2017, Heiken, 1974)
- $m_{void} = 1$ (Kylling et al., 2014)
- f^i_{min} e.g. from Jerram & Petford, 2011; m^i_{min} from literature
- m_{glass} problematic as $x_{s,bulk} \neq x_{s,glass}$ (Mackie et al., 2016) → calculated by difference from lab measured m_{eff} (Deguine et al., 2020)

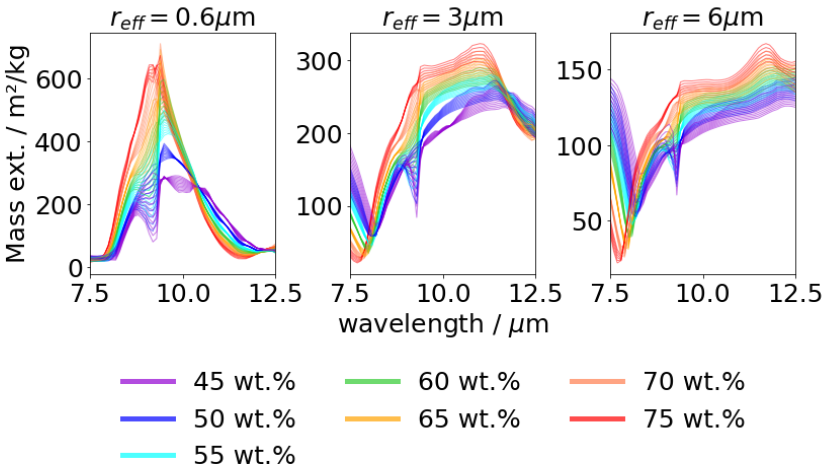
calculate possible refractive indices →



Piontek, Hornby, Voigt, Bugliaro, Gasteiger; submitted to J. Volcanol. Geotherm. Res.

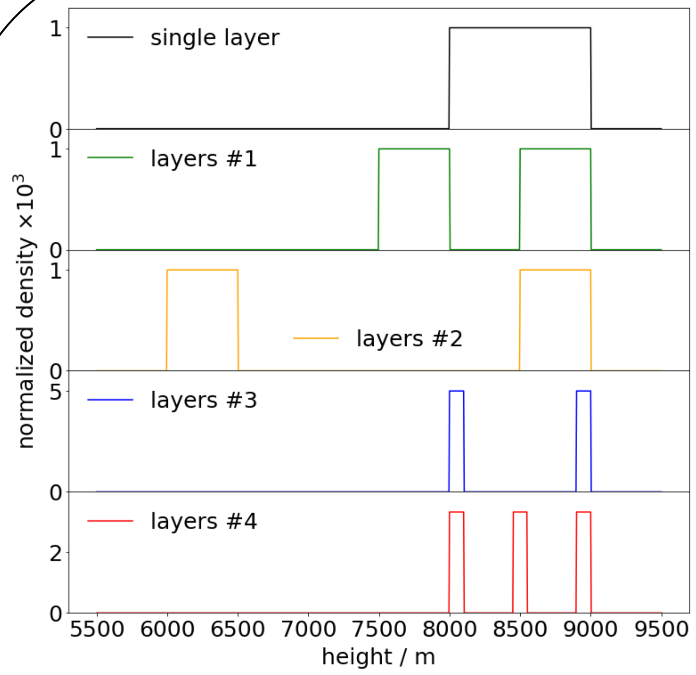
Result: Impact of
porosity
> silica content
> crystallinity

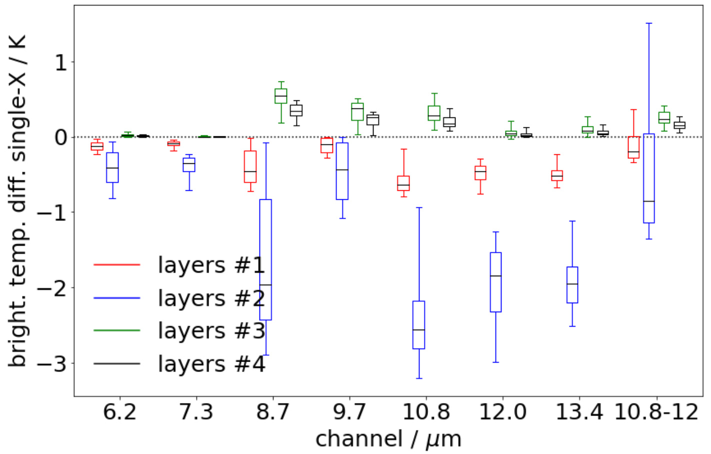
← calculate optical properties
spherical particles with log-normal size distribution, geom. std. dev. 1.5



Large variations due to eff. radius and composition
→ retrievable by satellite?

Macrophysical Volcanic Ash Plume Properties





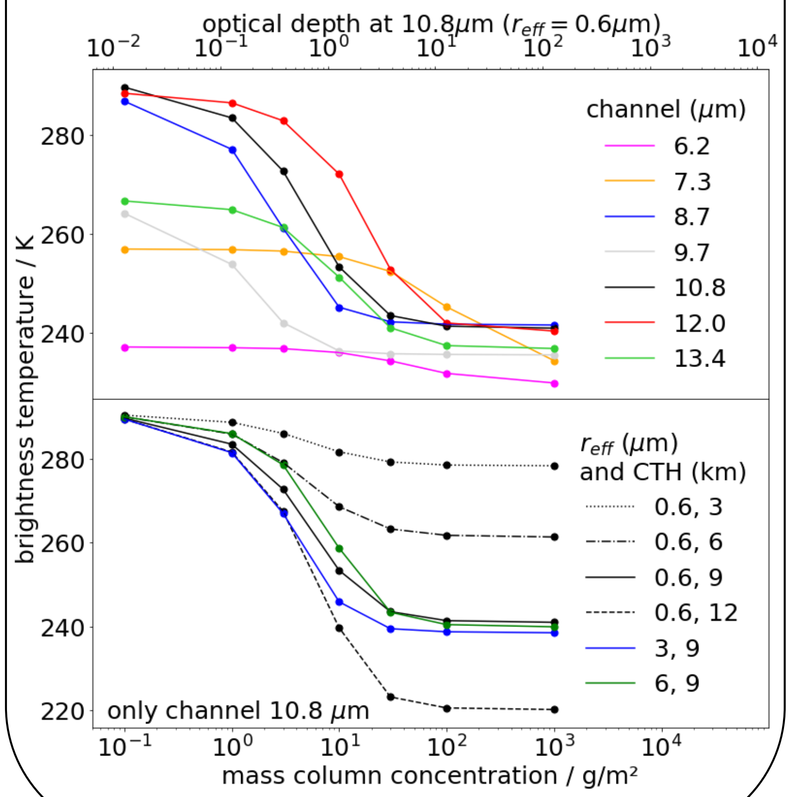
In our simulation we **assume single homogenous** volcanic ash layers. In reality however, aged ash plumes can consist of **multiple layers** with **non-uniform vertical profile**. Also the **thickness is not retrieved**. *How big is the uncertainty due to these factors?*

Compare uniform ash layer (CTH=9km, thickness=1km, load=10g/m², Eyjafjalla ash with r_{eff}=0.6µm) with different settings

Result: **profile negligible**, otherwise **variations up to ~4K** → introducing significant error in retrieval!

Check mass load dependence of the brightness temperatures using radiative transfer calculations

Result:
Retrievable loads: up to ~30g/m²
Higher sensitivity for larger cloud top heights



Paper in preparation…

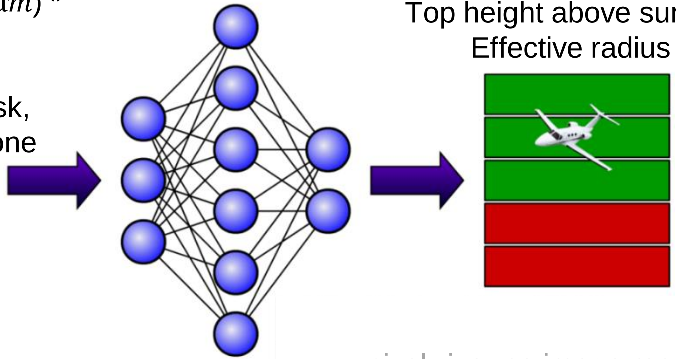
Creation of Artificial Neural Networks

From MSG SEVIRI:
IR channels $(6.2, 7.3, 8.7, 9.7, 10.8, 12.0, 13.4\ \mu m)$
Est. ash-free temp. $(8.7, 10.8, 12.0\ \mu m)$ *

From ECMWF:
Surface temperature, land/sea mask, total column water vapor/water/ozone

Auxiliary:
Latitude, longitude, day of year, hour of day, viewing zenith angle

Optical depth at $10.8\ \mu m$ *



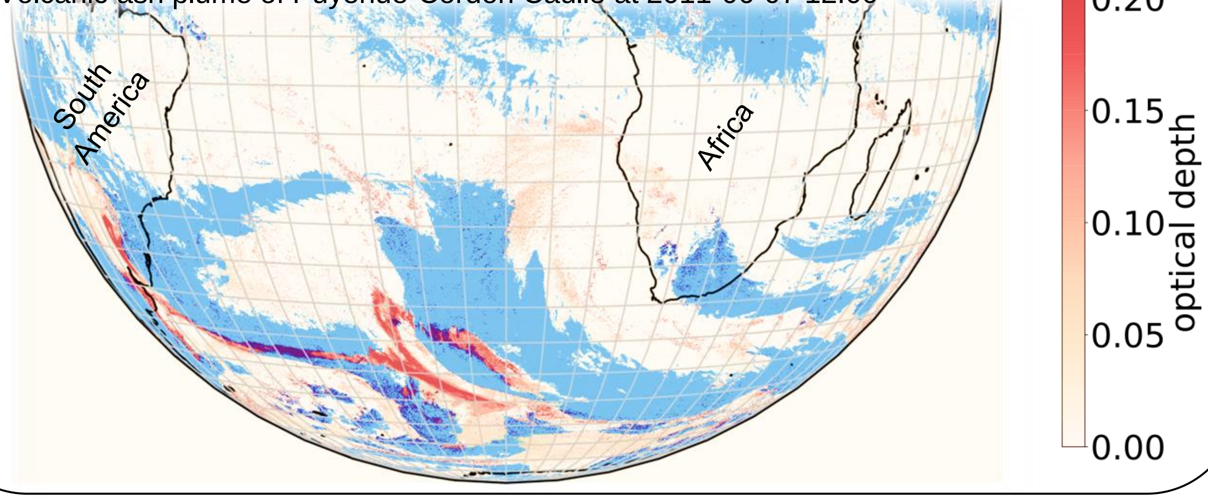
3x100 neurons

Optical depth at $10.8\ \mu m$
Top height above surface
Effective radius

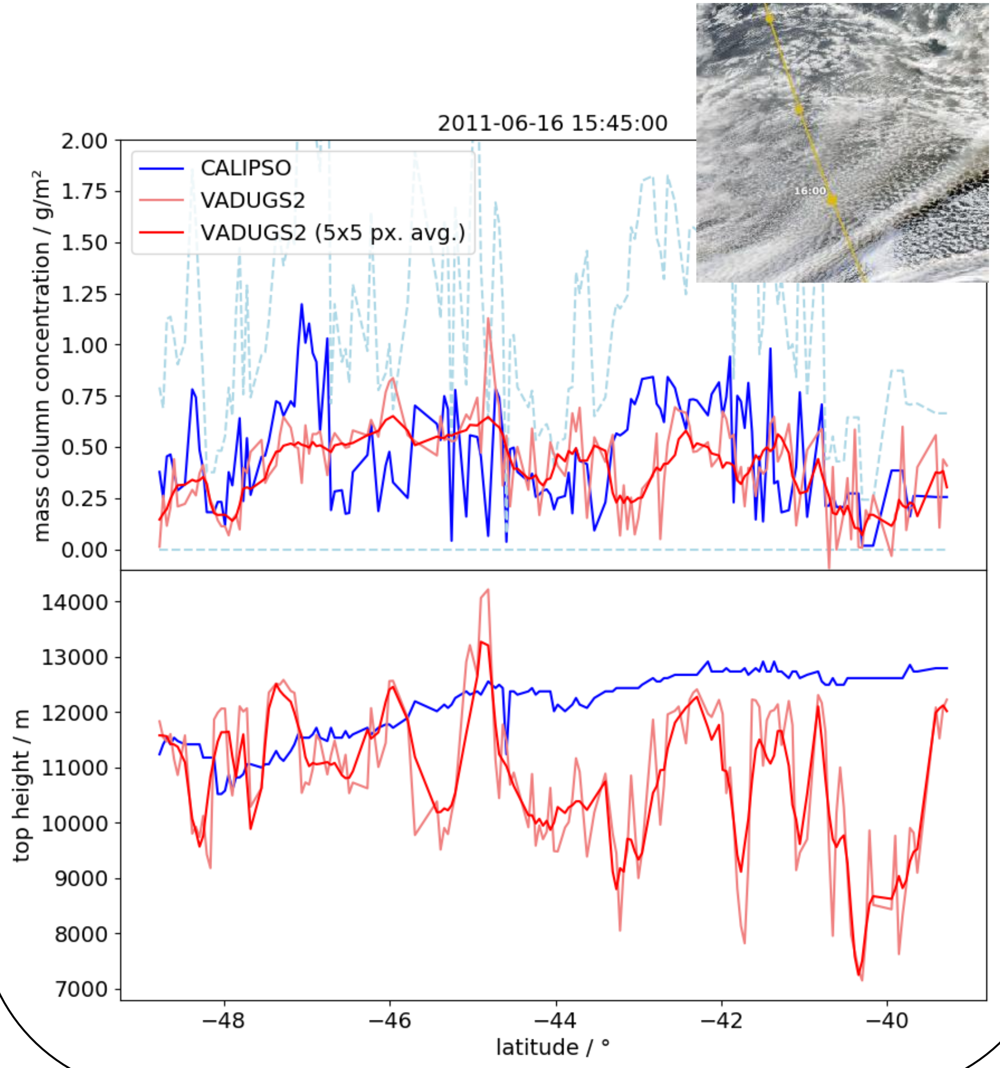
pixelwise, no image recognition

* only height and effective radius retrieval

Volcanic ash plume of Puyehue-Cordón Caulle at 2011-06-07 12:00

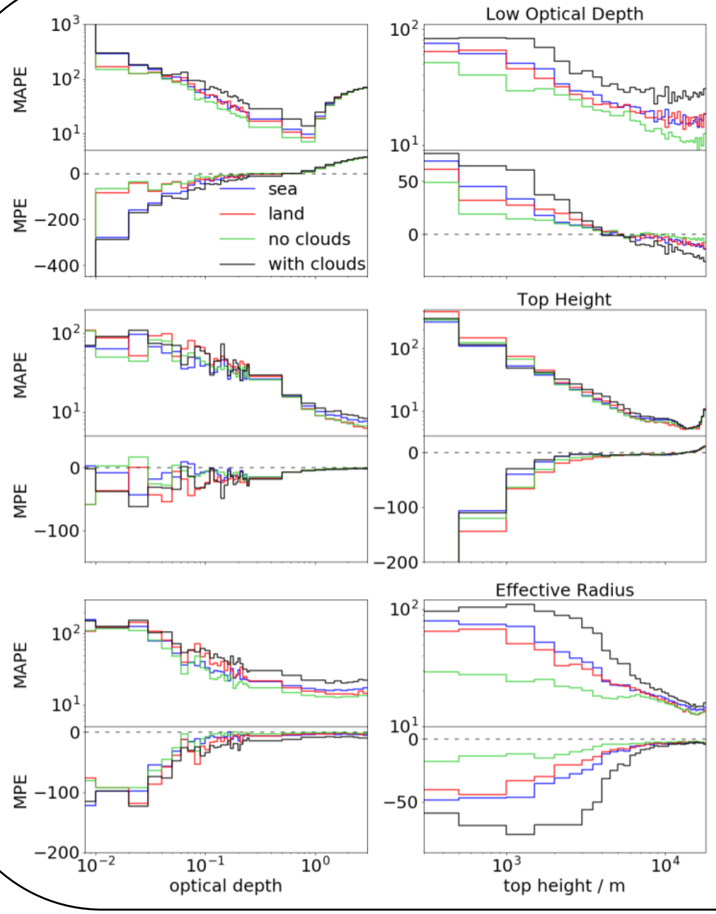


Here: comparison with CALIPSO retrievals of the Puyehue-Cordón Caulle ash plume above the Southern Atlantic (from Kar et al., WMO Intercomparison 2018).



Retrieval Performance

After training of neural networks: *How is the performance with respect to unseen simulated test data?*



Calculation of mean absolute percentage error (MAPE) and mean percentage error (MPE) between truth and prediction.

For optical depth=1, top height=10km:
~10 to 20% error

Result:

- **Decreasing error with increasing optical depth and top height**
- **Big influence of meteorological clouds (less: land/sea)**
- **Increase of error for high ash layers**

Generally: **~10 to 20% error**

Result:

- **Increased errors at deserts (Northern Africa, Arabian peninsula, Southern Africa)**
  → surface emissivity?
- **Increase of error with latitude for height retrieval**
  → Lowering of tropopause?