Neural-network approach to hyperspectral data analysis for volcanic ash clouds monitoring

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Abstract

In this study three artificial neural networks (ANN) were implemented in order to emulate a retrieval model and to estimate the volcanic ash Aerosol optical Depth (AOD), particle effective radius (reff) and cloud height from volcanic eruption using hyperspectral remotely sensed data. ANNs were trained using a selection of Infrared Atmospheric Sounding Interferometer (IASI) channels in Thermal Infrared (TIR) as inputs, and the corresponding ash parameters retrieved obtained using the Oxford retrievals as target outputs.

The retrieval is demonstrated for the eruption of the Eyjafjallajökull volcano (Iceland) occurred in 2010. The results of validation provided root mean square error (RMSE) values between neural network outputs and targets lower than standard deviation of corresponding target outputs, therefore demonstrating the feasibility to estimate volcanic ash parameters using an ANN approach, and its importance in near real-time monitoring activities, owing to its fast application.

A high accuracy has been achieved for reff and cloud height estimation, while a decreasing in accuracy was obtained when applying the NN approach for AOD estimation, in particular for those values not well characterized during NN training phase.

Neural Network Approach

ANN can be seen as mathematical models for multivariate non-linear regression or functional approximation (Krasnopolsky et al., 1995).

Relationship between input space (the space of the data) and an output space is searched using training samples: $\mathbf{y} = \varphi (\mathbf{x}, \mathbf{w})$ : vector of independent variables, $\mathbf{w}$ : free adjustable parameters

$$\mathbf{x} = \sum_{i=1}^{n} a_{i} x_{i}$$

$$\varphi (\mathbf{x}) = \sum_{i=1}^{n} a_{i}$$

$$\mathbf{w} = \sum_{i=1}^{n} \sigma (\mathbf{w})$$

Neural Networks
- Inverse modeling;
- Multi Layer Perceptron (MLP);
- Back Propagation algorithm (BP);
- Early stopping using cross validation (Train, Test and Val set).

Topology
- NN retriever (105 inputs), IASI channels in 8.4 – 14.7 microns spectral range)
- outputs: AOD, reff, cloud height

Retrieval with IASI:

A NN has been built for each parameter that is to be retrieved. The neural networks for the quantitative estimation of the parameters associated with volcanic ash were trained using example results from retrievals carried out using an optimal estimation (OE) technique (Rodgers, 2000). The OE retrieval method analyses brightness temperature spectra from IASI and the NN uses the corresponding spectral data as inputs. Assuming a single infinitely thin ash cloud and combining this with the output from the radiative transfer model RTTDV, the OE algorithm produces probable values for the ash AOD, particle effective radius, cloud height and surface temperature, which are the target outputs of the NN.

Results:

AOD – histogram for dataset used for AOD NN training phase. It put in evidence how values higher than 1 are statistically not well represented.

Reff – histogram for dataset used for reff NN training phase. It put in evidence how values higher than 5 microns are statistically not well represented.

Cloud height – histogram for dataset used for height NN training phase. Tails of distribution describe upper troposphere altitudes and are statistically not well represented.

IASI

The Infrared Atmospheric Sounding Interferometer (IASI), on board both the MetOp-A and MetOp-B platforms, is a Fourier transform spectrometer covering the mid-infrared (IR) from 645-2760 cm$^{-1}$ (3.62-15.5 mm) with a spectral resolution of 0.5 cm$^{-1}$ (apodised) and a pixel diameter at nadir of 12km. These characteristics allow global coverage to be achieved twice daily for each instrument and make IASI a very useful tool for the observation of larger aerosol particles (such as desert dust and volcanic ash) and the tracking of volcanic clouds.

References


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