End-to-end deep learning approach for the AOD-retrieval problem with MERIS data: a feasibility test

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Introduction

The aerosol optical depth (AOD) is a key parameter for aerosol research owing to its simplicity and suitability for aerosol column amount characterization. Global satellite monitoring is producing massive amounts of data which, owing to nowadays computer power, can be linked efficiently to ground measurements through machine learning. In this work, we lay out a satisfactory first attempt to retrieve the AOD at 550nm over land, using a deep neural network which learns from AODs found by Aerosol Robotic Network (AERONET) by associating them with observations collected by the Medium Resolution Imaging Spectrometer (MERIS) and no additional information. This serves as an experimental precursor for a planned multi-sensor-retrieval extending to a wider spectral and aerosol-information range.

Instruments & data reduction

MERIS is a push-broom imaging spectroradiometer, on board the Envisat mission (2002-2012), measuring radiance pixels at 68.5° field-of-view in 15 spectral bands in the visible and near-infrared wavelengths and a 1200m reduced ground spatial resolution (Full Res.: 300m). Here we use the L1b product which contains top of the atmosphere (TOA) reflectances.

Data size is further reduced to approx. 1/10 of the original resolution using a moving average.

The learning data are provided by the AERONET Level 2 (L2) product derived by the Spectral Deconvolution Algorithm (SDA)[1] and based on sun-photometer measurements.

Conclusion - outlook

- It is possible to retrieve the total $AOD < 1$ with satisfying accuracy (abs. err $= 0.085$) using a deep neural network. An one-day worth of MERIS data (1/3 orbit) takes $\sim$ 18sec in an Intel(R) Xeon(R) CPU E5-2620 v4 @ 2.10GHz for an AOD retrieval.
- Higher accuracy is feasible at lower AODs at the expense of higher ones, which makes it appealing for synergies with other instruments with complimentary expected retrieval behavior, e.g. infrared sensors.
- The approach can be used for a quantitative AOD retrieval over land for low to medium dust loads; inclusion of higher AODs still leave severe dust events out of reach pointing to actual instrument limitations.
- Performance could be improved by adding a critical assessment of the quality and distribution of the learning data and/or extending the training sets out of the dustbelt.
- A multi-sensor retrieval (ultimate goal) covering a larger range of the EM spectrum is envisaged to overcome such limitations.

References

[1] O'Neill, N. T., et al., Spectral discrimination of coarse and fine mode optical depth, J. Geophys. Res., Vol. 108, No. D17, 4559-4573, 10.1029/2002JD002975, 2003.

[2] Popp, T., Ensemble algorithms, Algorithm Theoretical Baseline Document, version 2.1 (29.04.2021), C3S, 2021.

Methodology

Associator	Spatio-temporal matching of MERIS reduced TOA reflectances with AERONET (L2) AODs from 231 stations in the dustbelt ($0 \leq latitude \leq 45$).
Preprocessor	Restrict to $0.01 < AOD < 1.01$.
Artificial Neural Network (ANN) Setup	Use of 14 features, decided by performing sensitivity tests: • Reflectances at 413, 443, 490, 560, 665, 709, 865, 885, 900 nm (9) • sun zenith/azimuth (2) • viewing zenith/azimuth (2) • Digital Elevation Model (1) • Data are normalized using standard score to counteract magnitude differences. • Use of gradient descent with L2 regularization. • Iteration break depends on min. absolute error & max. correlation coefficient.
Tuner	Grid search for training-parameter tuning: learning rate, hidden layers, nodes, activation functions, regularization parameter, etc.
Pretrainer	Preliminary training of the neural network (long run). Random split to several training & test sets: final model results from a median w.r.t. to absolute error.
Final trainer	Train for an augmented data-set with **transfer learning** using the Pretrainer.

The resulting neural network has 7 hidden layers with descending node number $\in [4, 56]$.

Results & performance

The resulting ANN is blindly trained (no restrictions) to a whole year of data (2011) and achieves a **mean** Pearson's/Spearman's correlation (rho_p/s) coefficient of 0.71/0.66, and a **mean** absolute error (abs_err) of 0.085 on the validation set. Fig. 1 (left): True vs retrieved AOD from a random **validation-set instance**. Fig. 1 (right): True vs retrieved AOD distribution of a whole year of **unknown (test) data** (2003); small inner plot (right): a different model (applied to same data) with even greater fidelity in smaller AODs.

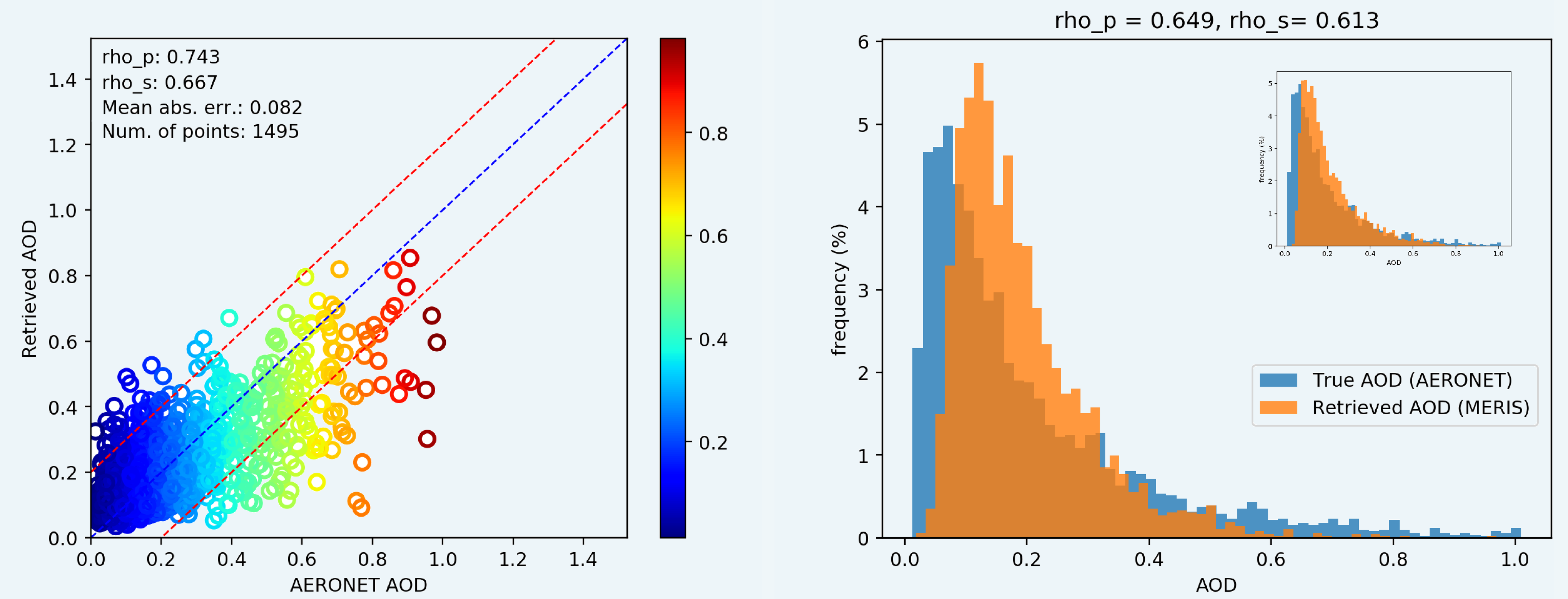

Figure 1: Left: True (AERONET-SDA) vs retrieved (MERIS-ANN) AOD. Right: True vs retrieved AOD distribution for the model used for Fig. 1 (left) and for a different model (small inner plot).

- <u>General performance of the ANN-based approach</u>

Here we calculate the mean AOD at 550nm for a period of a month (09, 2003) (Fig. 2 right) and contrast it to the Level 3 Monthly AOD product of the Advanced Along-Track Scanning Radiometer (AATSR)-ensemble algorithm[2] v. 3.0 (Fig. 2 left). The AATSR-retrieval serves merely as a guide for the strengths and weaknesses of the MERIS-ANN approach in the framework of this feasibility experiment and not as an actual comparison with this mature aerosol retrieval algorithm. Remarks:

– Similar patterns are observed in many areas over land in the maps, differing in intensity.
– Over ocean AOD is kept relatively but not negligibly small and its extent is clearly overestimated.
– AOD is retrieved with a mean abs. error of 0.088. Overall, the AOD-retrieval seems reasonable; no severe dust event reported to our knowledge during this period.

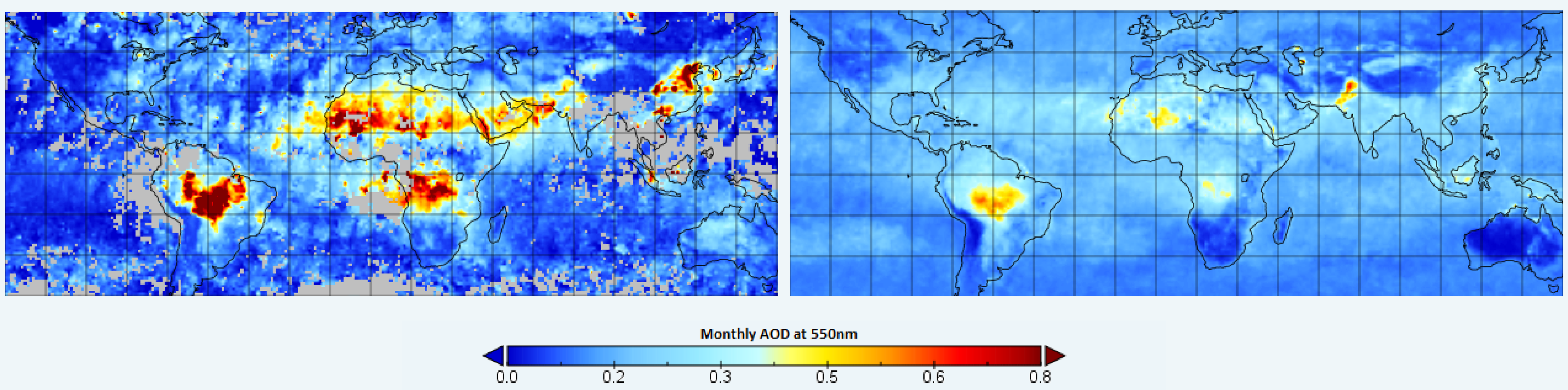

Figure 2: Georeferenced contour plots of the monthly mean AOD at 550nm found by the MERIS-ANN approach (right) and the AATSR-ensemble algorithm v. 3.0 (left).
∗∗*Note: the AATSR-product is color-scaled to the AOD range found by the MERIS-ANN approach for fast reference but it otherwise exceeds it by far (max* $AOD^{AATSR} = 2.1$*).*