Application of Singular Vector Decomposition for mineral dust retrieval from IASI over land and ocean

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Introduction

Satellite remote sensing in the thermal infrared (TIR) enables to observe mineral dust separated from other aerosols, also over bright surfaces such as deserts. Using TIR only, dust retrieval becomes independent of solar illumination and thus provides twice daily observations from polar orbiting spacecraft. Many applications, e.g. aerosol-cloud interactions research, can clearly benefit from such observations (Klüser and Holzer-Popp, 2010).

Nevertheless TIR remote sensing of dust faces other limitations such as surface emissivity, gas absorption (e.g. water vapour, ozone) and sensitivity to the atmospheric profile. The high spectral resolution of TIR sounders like the Infrared Atmospheric Sounding Interferometer (IASI) can be exploited to reduce these limitations.

The Optical Properties of Aerosols and Clouds database (OPAC: Hess et al., 1998) provides information about dust spectral extinction in the TIR for four different size distributions of dust (hereafter: dust types). The OPAC coarse mode type is linearly mixed with the mineral transported type to achieve better retrieval performance.

Data

IASI spectra in 8µm-12µm are stored into 42 bins with the maximum high-resolution brightness temperature representing the bin value. Thus strong gas line absorption effects on the reduced-resolution spectrum are avoided. Then the baseline temperature T_{base} is determined as the maximum brightness temperature of the reduced spectrum. After some initial cloud avoidance tests (T_{base} threshold, imaging subsystem IIS variance and spectrum shape scoring) the reduced spectrum is transformed into *equivalent optical depth* τ_{eqv}:

$$L_{obs}(\lambda) = e^{-\frac{\tau_{eqv}(\lambda)}{\cos(\Theta_v)}} B_\lambda(T_{base}) \qquad (1)$$

For τ_{eqv} observations of several days (March 11-17,2009) over Northern Africa and Arabia (land and ocean, day and night) a Singular Vector Decomposition is performed leading to singular vectors v_i, of which the first i=1,6 vectors are used for the retrieval (Fig.1).

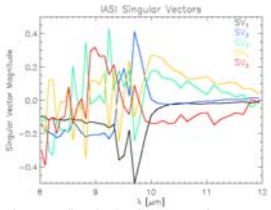

Fig. 1: Leading six Singular Vectors of IASI τ_{eqv} spectra.

Retrieval Method

The weights of the singular vectors (v_i) in the observed spectrum are

$$w_i = \frac{\sum_\lambda v_i(\lambda)\tau_{eqv}(\lambda)}{\sqrt{\sum_\lambda \left(\tau_{eqv}(\lambda)\right)^2}} \qquad (2)$$

The reduced τ_{eqv} spectrum (avoids strong surface contributions)

$$\tau_{sv}(\lambda) = \sum_{j=3}^{5} w_j \cdot v_j(\lambda) \qquad (3)$$

is projected onto the four OPAC dust types (scaled to $AOD_{10\mu m}$=1):

$$AOD_{type} = \sum_\lambda \left[AOD_{opac,type} \cdot \tau_{sv}(\lambda)\right] \qquad (4)$$

The OPAC dust types are weighted by:

$$\frac{1}{\varphi_{type}} = a\cos\left(\frac{AOD_{type}}{\sqrt{\sum_\lambda \left(AOD_{opac,type}(\lambda)\right)^2}\sqrt{\left(\tau_{sv}(\lambda)\right)^2}}\right) \qquad (5)$$

Statistical correction for leading two v_i contribution with the standardized projection of τ_{sv} spectra for leading onto lagging v_i (P_w) and signed variance between AOD_{opac} and leading v_i τ_{sv} (s_{var})

$$c_{[1,2]} = s_{var} \cdot \sum_{type}(\varphi_{type} \cdot P_w \cdot AOD_{type}) \qquad (6)$$

leads to calculation of 10µm first guess AOD:

$$AOD_{10\mu m} = \sum_{type}(\varphi_{type} \cdot AOD_{type}) + c_{[1,2]} \qquad (7)$$

Effective dust emission temperature T_{dust} is estimated by inverting

$$L_\uparrow(\lambda) = e^{-AOD_\lambda} B_\lambda(T_{surface}) + (1 - e^{-AOD_\lambda})\varepsilon_{dust} B_\lambda(T_{dust}) \qquad (8)$$

The inversion is done with the assumption of $T_{surface}$ being represented by T_{base}. Then the τ_{eqv} spectrum is corrected for the estimated dust emission contribution and the above retrieval steps are repeated once more. Based on the OPAC database and the weights of the dust types $AOD_{10\mu m}$ is transferred to 0.5µm. Dust particle effective radius R_{eff} is determined from the weighting of the OPAC dust types given the assumptions of the OPAC log-normal size distributions. Effective dust emission temperature is also a direct by-product of the retrieval (eq. 8).

The intrinsic retrieval uncertainty is built from the three independently estimated uncertainties of dust type speciation, T_{dust} estimation and impact on AOD, and the leading-v_i correction. It is given in percent.

The only *a priori* knowledge to be exploited is the dust extinction spectra from OPAC. It is moreover assumed that the singular vectors are representative for the region (Klüser et al., 2011).

Results and Evaluation

Four months (Feb, May, Aug, Nov 2009) of IASI dust observations over Northern Africa and Arabia are used for comparison with coarse mode AOD from 23 AERONET stations (Fig..2).

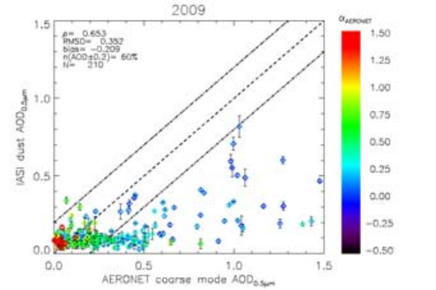

Fig. 2: Comparison of IASI $AOD_{0.5\mu m}$ with AERONET coarse mode AOD for 23 stations over four months of 2009. Error bars represent intrinsic retrieval uncertainty.

IASI underestimates AERONET coarse mode AOD, but correlates quite reasonably given the differences in observations methods and spectral ranges. Despite the tendency to underestimate AOD, dust episodes are well captured by the IASI retrieval (Fig. 3, Fig. 5).

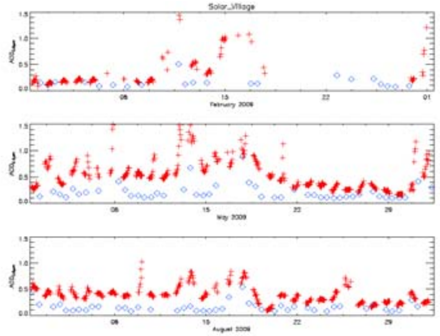

Fig. 3: Time series of IASI and AERONET AOD over Solar Village (KSA) for Feb, May, Aug 2009.

Sensitivity of the retrieval to internal and external parameters has been tested by correlating the deviation from AERONET with the respective parameter (Tab. 1).

	AOD	Δd	Δt	σ²(IIS)	R_{eff}	T_{dus}t	Θ_v
ρ_{lin}	-0.27	+0.08	-0.14	-0.09	-0.35	-0.14	+0.14
ρ_{rank}	-0.23	+0.11	-0.15	-0.16	-0.32	-0.19	+0.10

Tab. 1: Correlation of IASI error with AOD, distance (Δd), time deviation (Δt), imaging subsystem variance (σ²(IIS)), R_{eff}, T_{dust}, Θ_v

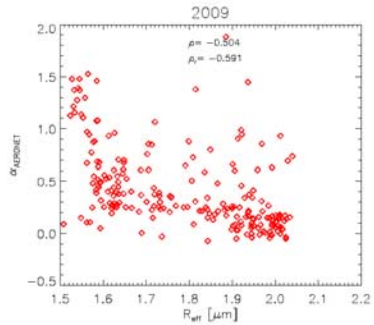

Fig. 4: Comparison of IASI retrieved dust effective radius with AERONET Ångström exponent α.

Although it provides no proper evaluation of the R_{eff} retrieval, Fig. 4 gives evidence that the retrieved R_{eff} really can be regarded as indicative for dust particle size estimation.

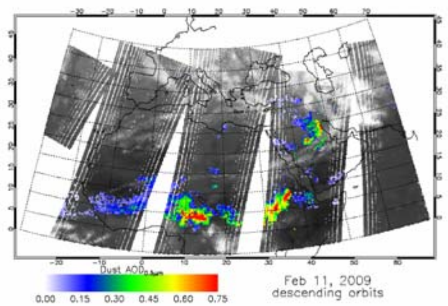

Fig. 5: Daytime IASI dust observation over Arabia and in Bodélé Depression and the Sahel-Soudan belt (11 Feb 2009).

Summary

Singular Vector Decomposition of IASI spectra in the 8-12µm band allows for mineral dust observation over land and ocean including bright desert areas, independent of solar illumination. The twice daily dust retrieval provides AOD, dust particle effective radius, effective dust emission temperature and the intrinsic retrieval uncertainty.

The retrieval compares reasonably well with AERONET, while it tends to underestimate coarse mode AOD. Dust episodes are well captured by the method over ocean, over vegetated areas and over desert.

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