# ON THE VARIABILITY OF OPTICAL PROPERTIES OF DESERT DUST

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## Summary

Deserts and increasing anthropogenic activities in arid regions of the earth are globally the strongest aerosol source producing mineral dust particles. An estimation of its influence on radiative forcing requires the existence of representative data to obtain the radiative properties of desert dust for the estimation of the climatic effects and for remote sensing.

Reviewing aerosol data on desert dust one finds size distributions with a wide range of sizes from 0.05 $\mu$m up to 100 $\mu$m in radius and number concentrations varying over almost three magnitudes and different mode structure. For the radiative transfer - as well as for the radiative forcing as well as for remote sensing - it is of interest, what is typical for desert dust and what are the equivalent changes in the climate-relevant optical aerosol parameters:

- *spectral aerosol optical thickness,*
- *aerosol phase function and*
- *single scattering albedo ?*

These optical parameters are determined either by direct optical measurements or - as in the majority of cases - indirectly by calculation from structural and chemical composition parameters as:

- *the structure of the aerosol size distribution,*
- *the chemical or mineral composition, determining the spectral refractive index (real and imaginary part) and*
- *the particle shape, determining the light scattering theory to be applied.*

Therefore here the very different structural and composition data are used to calculate the optical characteristics of desert dust and to compare them with measured and model data.

The main results are:

- The spectral aerosol optical thickness has in almost all cases a flat spectral slope in the wavelength range 0.3 - 1.4 $\mu$m. In this all considerations are confident (calculations, model data, measured optical thicknesses).
- Above the wavelength of 1.4 $\mu$m the spectral slope is increased in different ways, caused by structural and composition effects. Here remains a need for experimental confirmation.
- The aerosol phase functions show a wide variability in the range of 90 - 150 degree scattering angle, caused by the size distribution and particle shape effects. This produce an increased lateral scattering compared with the assumption of spherical particle shape. This effect increases with the amount of super-micron particles (relevant for $r \geq 4\mu$m) (sandstorm, duststorm events).
- Consequently lower asymmetry parameters will be obtained for size distributions with an increased amount of super-micron particles.

## Method

In order to obtain the climate-relevant optical parameters, the size distributions have to be transferred into optical parameters using spectral data of complex refractive index and an adequate light scattering theory:

- Using at first refractive indices for the mineral component from the OPAC data base (Optical Properties of Aerosol and Clouds, Hess et al., 1998).
- The light scattering theory is considered by either Mie-theory (for the assumption of spherical particle shape) and the semi-empirical theory of Pollack and Cuzzi, 1980 (for non-spherical particles).
- The parameters for the characterization of the non-sphericity of the particles by the semi-empirical scattering theory (surface roughness, border radius $r_{Border}$ between the small particle region (Mie-theory valid) and large particle region (additional transmission component characterize an increased lateral scattering)) are taken from the findings of combined sun- and sky-radiometer measurements from a campaign in West Africa (Senegal, 1995, c.f. von Hoyningen-Huene et al., 1999). Here the additional transmission component hadt to be considered for particles with radii $\geq 4\mu$m.

The size distributions originated from a compilation by Schütz, 1997, see Fig. 1, and can be considered as representative for various dust situations as: dust storm events, background situations and typical loadings within deserts of Central Asia, North America and the Sahara. For the referenced data different direct and indirect techniques of size distribution analysis are used with different sampling efficiencies, especially for coarse particles. (e.g. it is not reasonable that such strong dust events like in the case of the Tadjikistan size distribution, no particles in the size range of 10 $\mu$m should be existent).

## References

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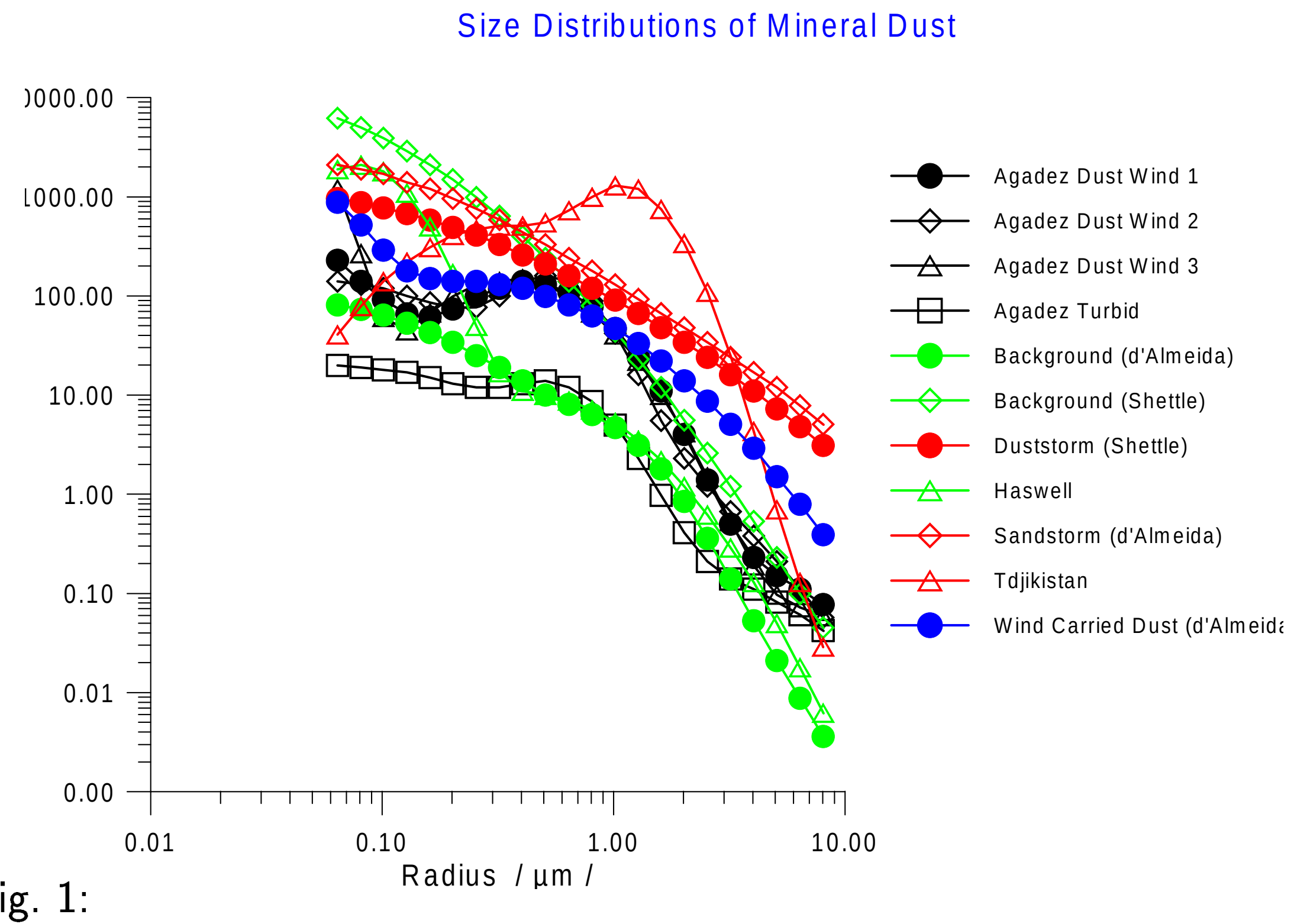

Fig. 1:
Aerosol Size Distributions of different desert dust situations compiled from literature by Schütz, 1997, showing the wide structural variability of desert dust.

## Results for the Optical Properties

The optical properties are calculated for a layer of 1 km vertical extension containing the aerosol of the size distributions $dN(r)/dlogr$ in Fig. 1. For the spectral optical thickness

$$\delta_A(\lambda) = \int_0^H \int_0^\infty \pi \cdot r^2 \, Q_{M/P}(r, \lambda, m, p) \cdot \frac{dN(r)}{dlogr} dlogr \; dh$$

and for the phase function

$$p_A(\theta, \lambda) = \int_0^H \int_0^\infty \pi \cdot r^2 \, F_{M/P}(r, \theta, \lambda, m, p) \cdot \frac{dN(r)}{dlogr} dlogr \; dh$$

is used with $Q_{M/P}$ - the extinction efficiencies for either Mie-theory or the theory of Pollack and Cuzzi or $F_M/P$ - the equivalent individual scattering functions for single particles.

## Spectral Optical Thickness

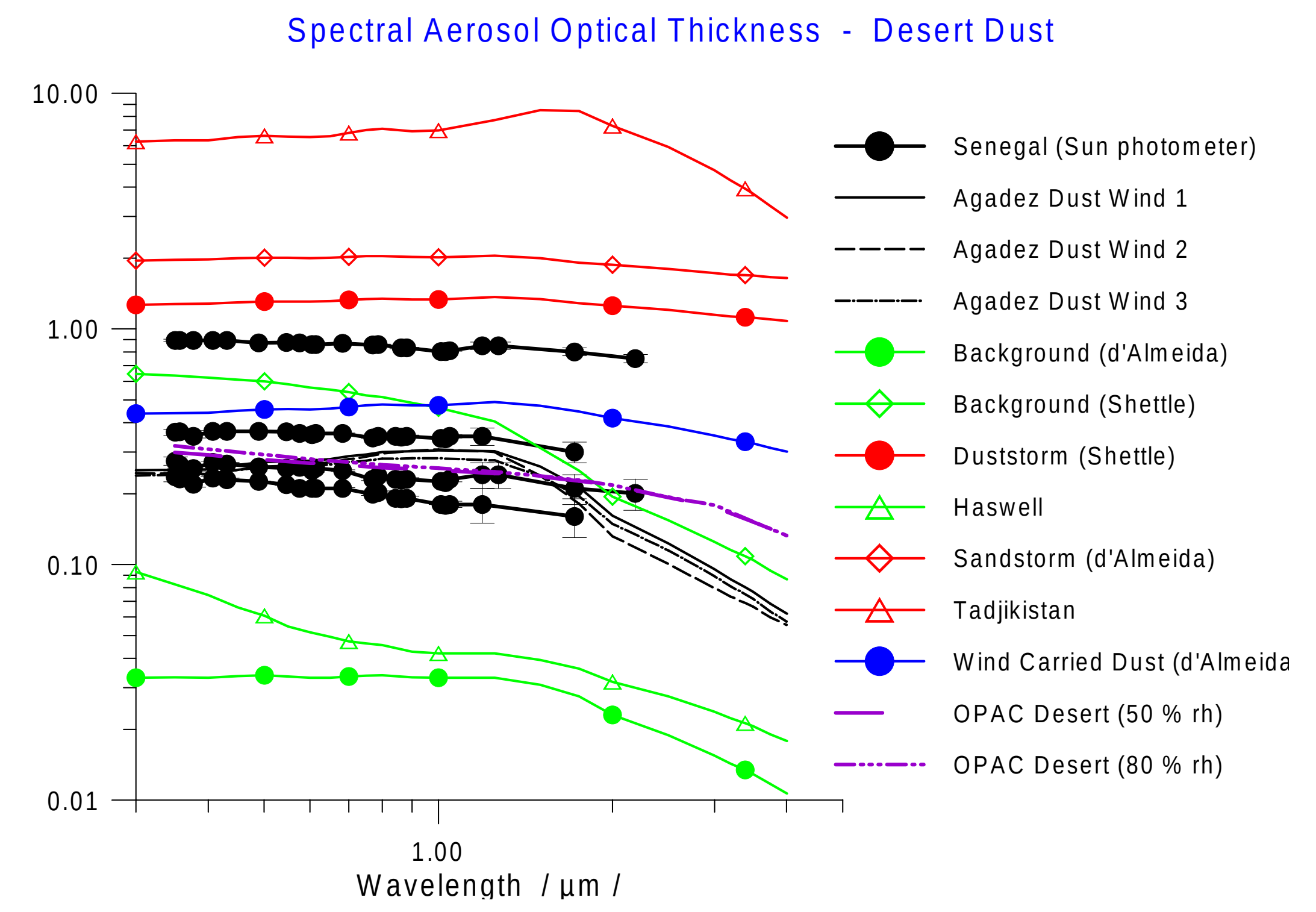

Fig. 2:
**Spectral Aerosol Optical Thickness** calculations from the size distributions in Fig. 1 in comparison with the model 'Desert' from OPAC, c.f. Hess et al., 1998 and sunphotometer measurements in West Africa (Senegal, c.f. von Hoyningen-Huene et al, 1999).

## Phase Function

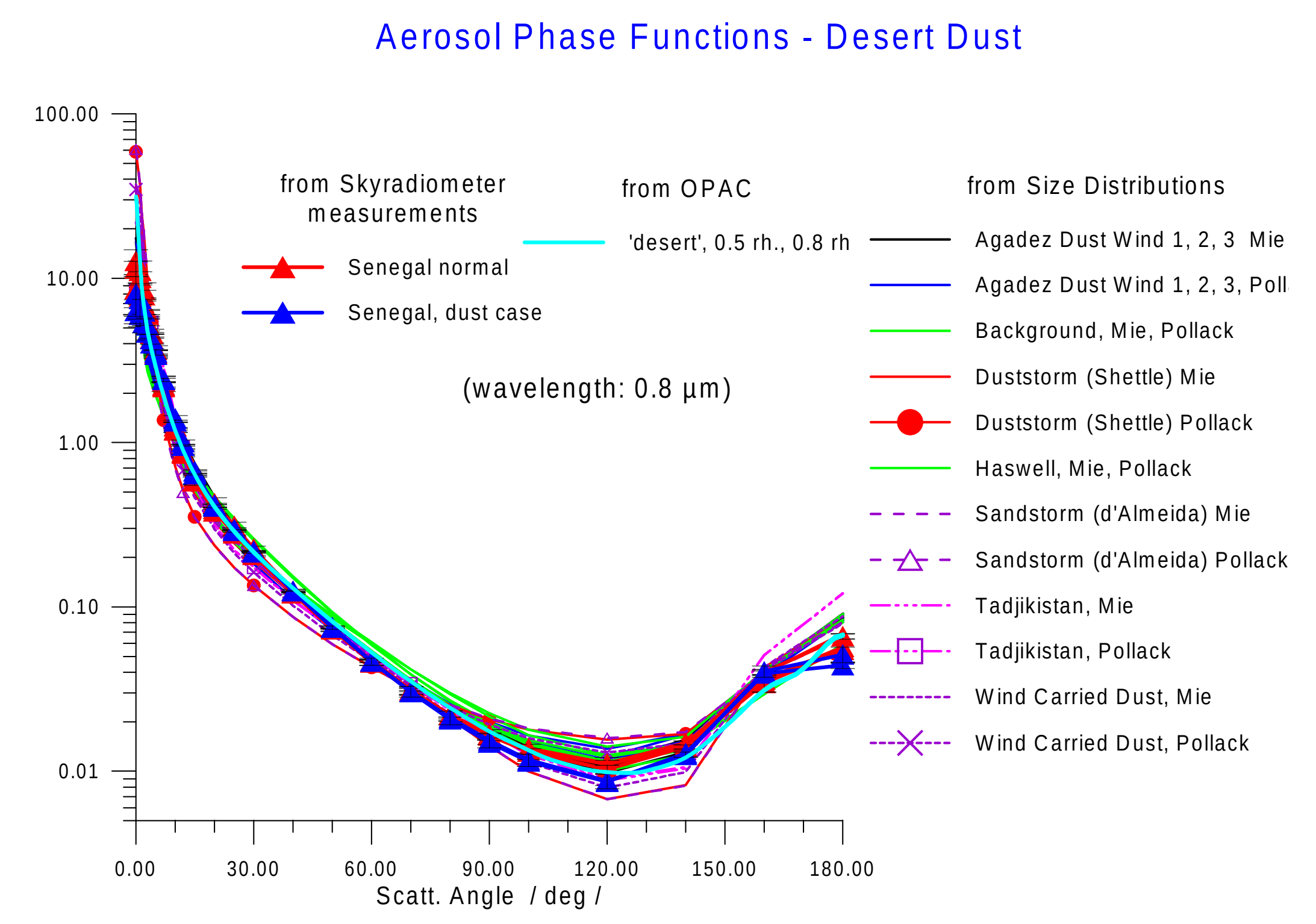

Fig. 3: Normalized aerosol phase functions for different desert dust cases from Fig. 1 in comparison with measurements and model data for the wavelength $\lambda = 0.8\mu$m. Obvious is the range of variability in the lateral scattering area between 90 and 150 degree scattering angle.

## Optical Aerosol Parameter

From spectral aerosol optical thickness the Angström turbidity parameter and from the phase functions the asymmetry parameter have been determined:

| Parameter | Asymmetry Parameter g(0.55) $\mu$m<br>Scattering Theory | | Angström Parameter 0.4 - 1.0 $\mu$m | |
|---|---|---|---|---|
| Size Distribution | Mie | Pollack | $\alpha$ | $\beta$ |
| Agadez Dust Wind 1 | 0.755 | 0.745 | -0.155 | 0.305 |
| Agadez Dust Wind 2 | 0.742 | 0.730 | -0.212 | 0.308 |
| Agadez Dust Wind 3 | 0.753 | 0.745 | -0.112 | 0.282 |
| Background (d'Almeida) | 0.766 | 0.756 | 0.015 | 0.033 |
| Background (Shettle) | 0.718 | 0.713 | 0.390 | 0.462 |
| Duststorm (Shettle) | 0.835 | 0.727 | -0.045 | 1.332 |
| Sandstorm (d'Almeida) | 0.831 | 0.721 | -0.021 | 2.012 |
| Haswell CO | 0.702 | 0.690 | 0.457 | 0.042 |
| Tadjikistan | 0.823 | 0.820 | -0.146 | 6.956 |
| Wind Carried Dust (d'Almeida) | 0.813 | 0.755 | -0.080 | 0.475 |
| | | | | |
| Senegal (Sunphotometer) | | | | |
| normal case | 0.729 | 0.709 | 0.092 | 0.321 |
| dust event | | | 0.051 | 0.663 |
| | | | | |
| OPAC Model | | | | |
| 'desert' - 0.5 rh | 0.741 | | 0.139 | 0.127 |
| 'desert' - 0.8 rh | 0.743 | | 0.189 | 0.129 |

Tab. 1: Calculated aerosol parameters - Asymmetry Parameter and Angström Turbidity Parameter ($\delta_A(\lambda) = \beta \cdot \lambda^{-\alpha}$) - in comparison with measurements (von Hoyningen-Huene et al., 1999) and model data (OPAC, c.f. Hess et al, 1998)
Scattering theories have been used: Mie-theory for spherical particles and the semi-empirical theory of Pollack and Cuzzi, 1980 for non-spherical particles. The parameters describing scattering by non-spherical particles have been taken from the sun- and skyradiometer measurements in Senegal 1995, c.f. von Hoyningen-Huene, 1999. The effect on increased lateral scattering rises up with the amount of particles with $r \geq r_{Border} = 4\mu$m.

## Satellite Retrievals of AOT

Aerosol phase functions obtained by the skyradiometer measurements in Western Africa (Senegal 1995, c.f. von Hoyningen-Huene et al., 1999) have been used to set-up Look-Up-Tables to retrieve spectral aerosol optical thickness form the eight SeaWIFS channels (0.412 - 0.876 $\mu$m). The application of these LUT's gives for cloud-free pixels estimations for the aerosol optical thickness and their parametrization in kind of the Angström power law: $\delta_A(\lambda) = \beta \cdot \lambda^{-\alpha}$. The retrieved $\alpha$ - spectral slope - is quite low as expected from Fig. 2. The optical thickness reaches in the center of the outbreak up to 2.7 quite comparable with the level of the sandstorm case of d'Almeida in Fig. 2.

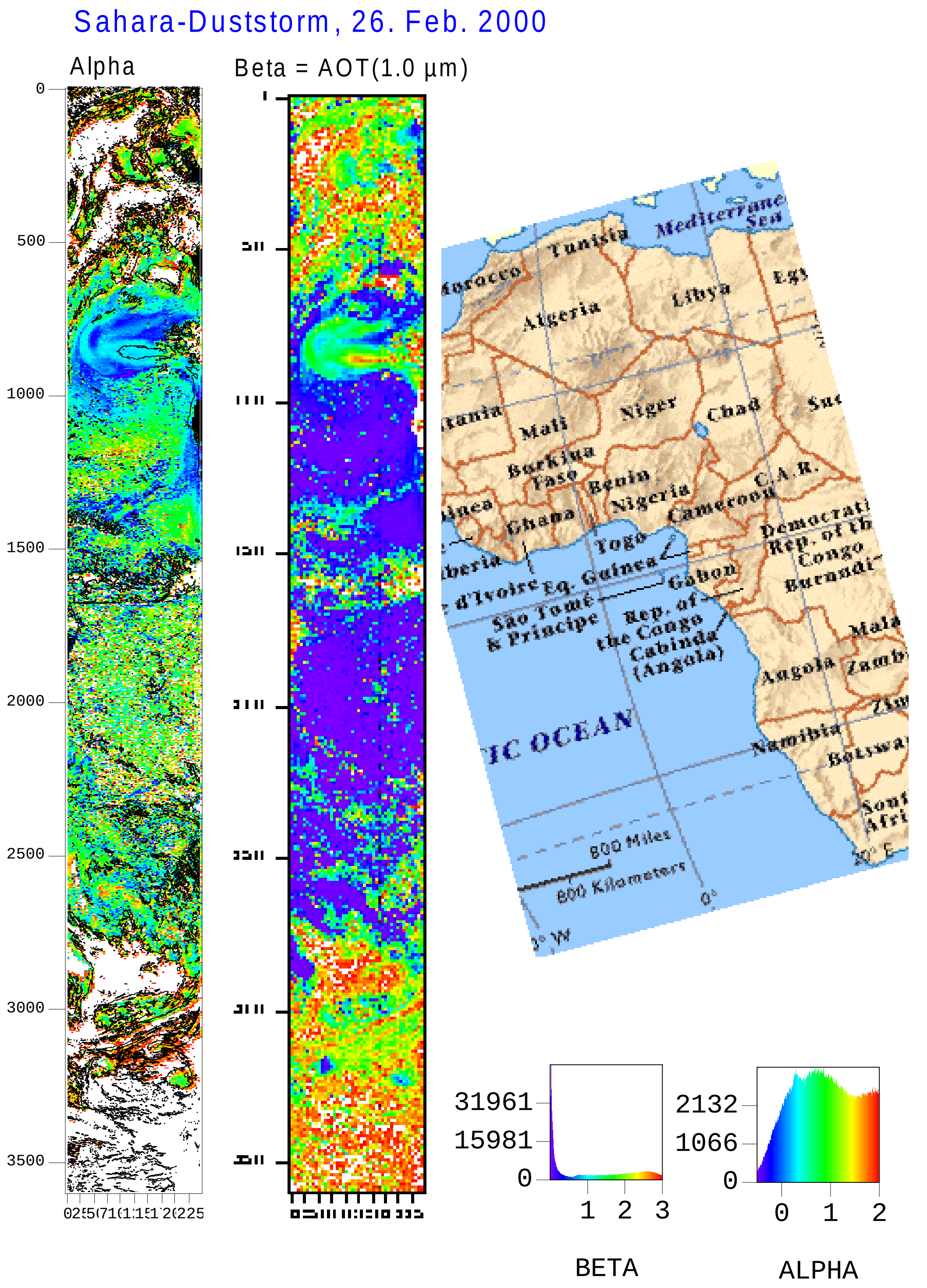

Fig. 4:
Retrieved Angström aerosol parameters $\alpha$ and $\beta$ for the SeaWIFS overflight of 26. Feb. 2000 with a strong desert dust outbreak.