Aerosol optical properties and the aerosol refractive index archive

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1 Abstract

Traditionally the atmospheric physics department at the University of Oxford has applied optimal estimation techniques for the retrieval of atmospheric properties of gases; temperature, pressure and volume mixing ratio from satellite measurements. This poster describes the latest novel application of these techniques in deriving aerosol optical properties in laboratory experiments. In addition we are compiling a list a web based refractive index data base from published refractive index data. We describe this effort and indicate how you can contribute to this community resource.

2 Aerosol Refractive index Archive

Our experience shows that finding and collating the refractive index's that are relevant for atmospheric modeling and remote sensing is time consuming. In addition it is difficult or impossible to obtain tabulated data for some of the older publications. A suitable electronic location for new data was also required. The Aerosol Refractive index Archive, ARIA, has been launched to reduce the effort of the community and provide a central location for refractive index data. The data base can be found at [1].

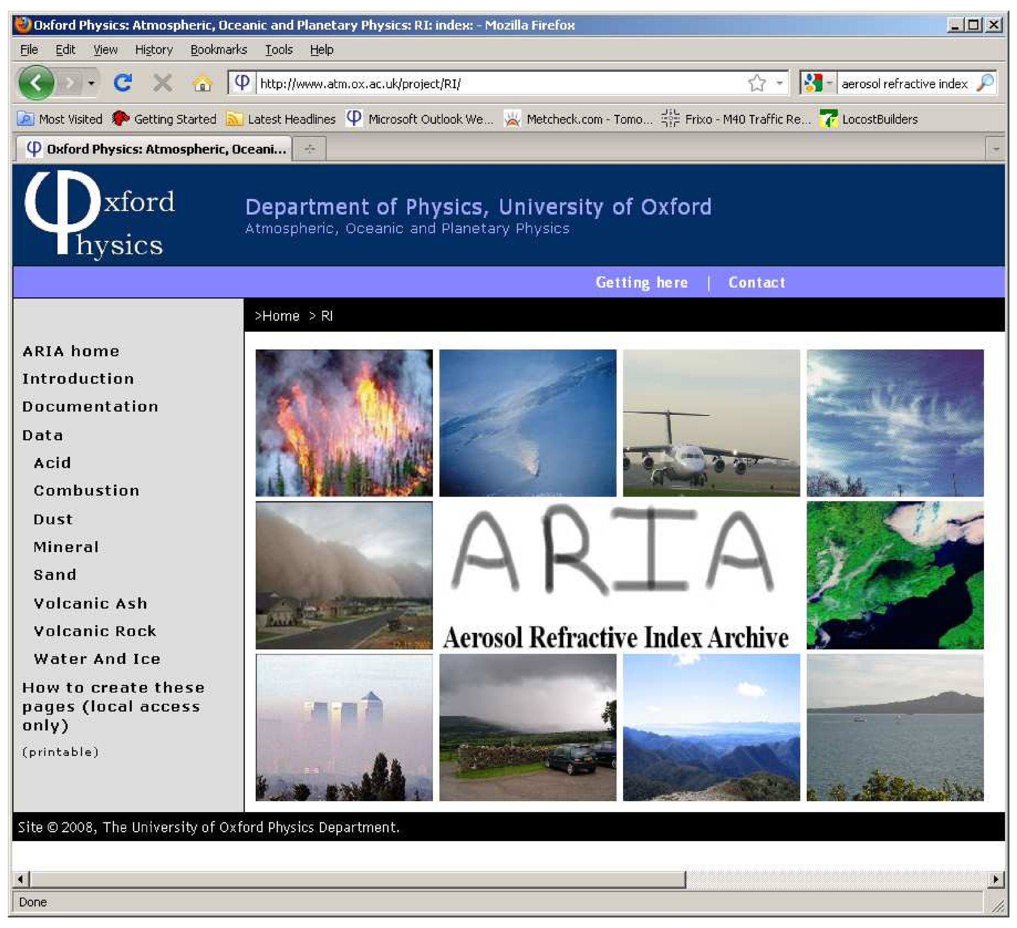

Figure 1: ARIA home page [1]

A simple human readable file format and file naming convention has been defined and documented. IDL and Matlab example read routines can be downloaded. Additional fields are available to provide information, for example the original citation in the files which is automatically displayed on the web database. We also provide fields for uncertainty of both the imaginary and real parts of the refractive index where these are available.

The database allows quick look plots of the data to enable the users to quickly look at the data on-line.

The database can be download as a whole or just sections (for example you might want only the Saharan dust section).

In-addtion we also provide links to our IDL code for calculating light scatting parameters using Mie theory.

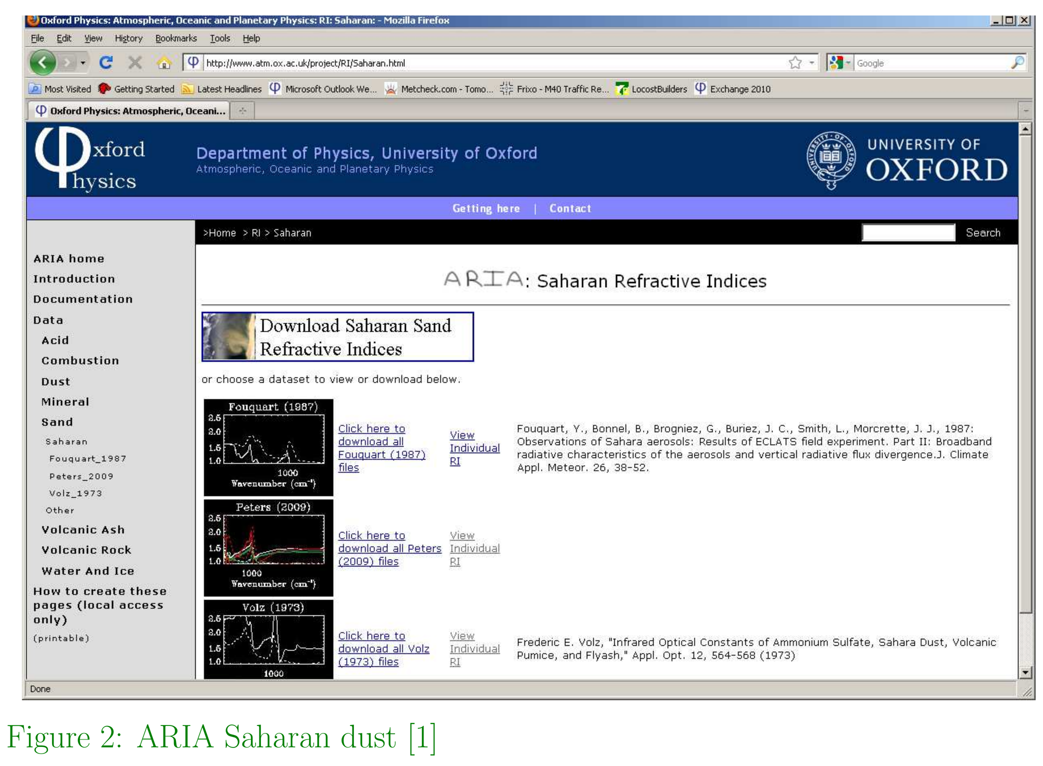

Figure 2: ARIA Saharan dust [1]

The database is now "live" but is still under development and we would welcome you input and comments on the current database and how it could be improved.

2.1 We need your contributions

To make the database more useful we need the *user community to contribute aerosol refractive index data.* In addition we would welcome *your comments and suggestions for improvements to the database.*

3 Oxfords new refractive index data

In this section we outline the our new method to derive the refractive index of real dispersed aerosols in a test cell. Current work includes Saharan dust, volcanic ash, sea-salt and black carbon aerosols.

3.1 Optimal estimation; a generic method

- Measurements $\mathbf{y}$ are related to the state $\mathbf{x}$, by physics. This is represented by the forward model $\mathbf{F}(\mathbf{x})$:

$$\mathbf{y} = \mathbf{F}(\mathbf{x})$$

- We need to invert our measurements to find the state, (i.e. refractive index, and particle size). We also us the best knowledge of the solution $\mathbf{x_a}$ before the measurement was made:

$$\mathbf{x} = \mathbf{F}^{-1}(\mathbf{y}, \mathbf{x_a})$$

- To do this we minimise the cost function to find the state $\mathbf{x}$:

$$\mathbf{\Phi}(\mathbf{x}) = (\mathbf{x} - \mathbf{x_a})^{\mathbf{T}}\mathbf{S_{xa}}(\mathbf{x} - \mathbf{x_a}) + (\mathbf{y} - \mathbf{F}(\mathbf{x})^{\mathbf{T}})\mathbf{S_y}^{-1}(\mathbf{y} - \mathbf{F}(\mathbf{x}))$$

- And we find:

$$\hat{\mathbf{x}} = \mathbf{x_a} + \mathbf{S_{x_a}}\mathbf{K_x^T}\mathbf{S_y^{-1}}(\mathbf{y} - \mathbf{F}(\hat{\mathbf{x}}))$$

where $\mathbf{K_x} = \frac{\partial \mathbf{F}}{\partial \mathbf{x}}$

- Which is solved by the Levenberg-Marquardt algorithm (Gauss-Newton and the gradient descent iteration methods).

3.2 Method

The extinction cross section is related to the optical transmission by:

$$T(\lambda) = \exp^{-\beta(\lambda)x}$$

Where:
T Transmission.
β Volume extinction coefficient.
x Measurement path length.

The volume extinction coefficient is given by:

$$\beta(\lambda) = \int_0^\infty \sigma_{ext}(r, m, \lambda) n(r) dr$$

Where:
σ_{ext} Extinction coefficient.
r Particle radii.
m Particle complex refractive index.
λ Wavelength.
$n(r)dr$ Number of particles between radii r and $r + dr$.

Hence to obtain the extinction coefficient, σ_{ext} we require the measurements of the optical transmission, T as well as the particle distribution, $n(r)$. The forward model $\mathbf{F}(\mathbf{x})$ represents the transmission of the cell, and the size distribution and refractive index the state $\mathbf{x}$.

3.3 Experimental setup

Figure 3 outlines the basic configuration of the experiments undertaken. The aerosol is generated (the generation method is chosen based on the aerosol type) then introduced to the small aerosol cell. The aerosol cell has optical windows fitted, allowing the aerosol absorption to be measured via the Fourier Transform Spectrometer, FTS. Particle size distribution of the aerosol is then determined using techniques insensitive to particle refractive index, and the aerosol vented into a fume cupboard. The configuration also included a water bath to allow the relative humidity to be controlled.

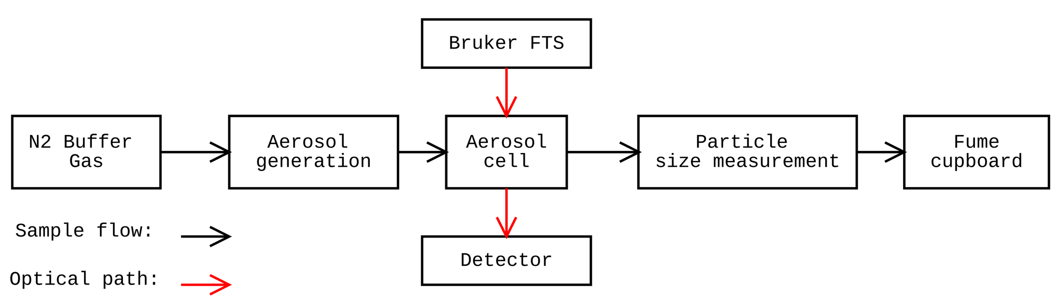

Figure 3: Simplified diagram of experimental configuration.

The MSF small aerosol cell has an optical path length of 30 cm. Future work will use a new multi-pass cell. Spectral intensity measurements are made using a Bruker FTS. Future measurements will include the UV and visible region measured simultaneously using a separate spectrometer. Measurements of the detected intensity are obtained with and without the aerosol to calculate the transmission spectrum, $T(\lambda)$.

3.4 Results: Refractive index

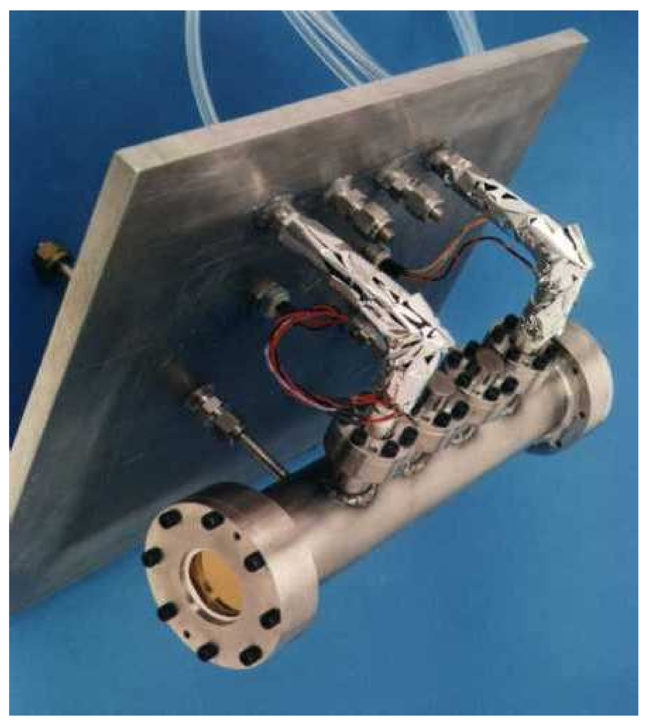

Figure 4: The small aerosol cell.

The method describe by Thomas [3] has been used to retrieval the refractive index of the aerosol from the measured absorption spectra. An example fit is shown in figure 5, complete with the associated refractive index in figure 6.

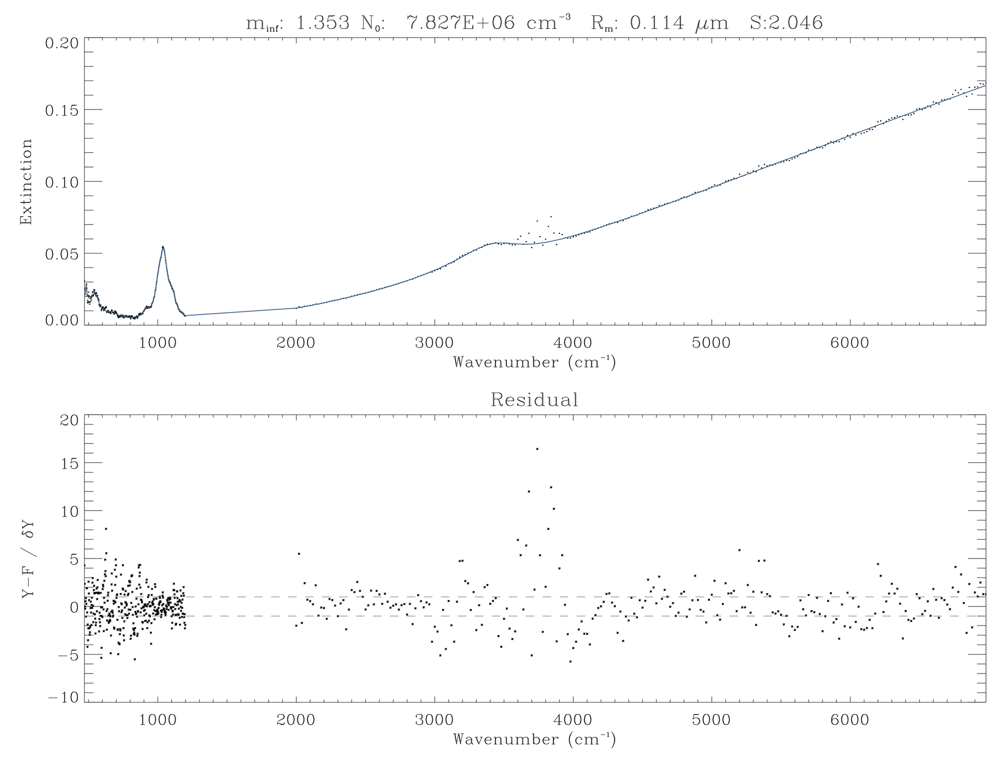

Figure 5: Top: Measured spectra (dots) and fitted spectra (lines). Bottom: residual.

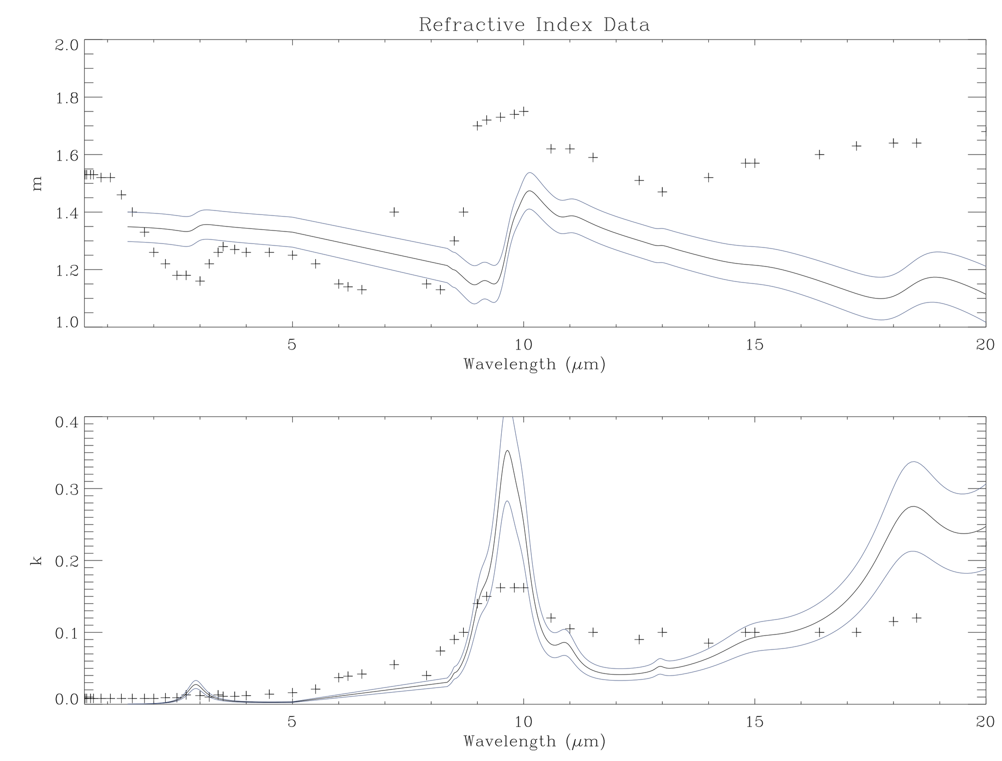

Figure 6: Inverted complex refractive example for Cape Verde dust (black line). Blue line indicates estimated uncertainties. Crosses show the existing published data [2]

4 Conclusions

A new database ARIA is now on-line with a collection of published refractive index's. With the communities contribution of refractive index data a useful resource for atmospheric models and remote-sensing can be built up. New infrared Saharan dust refractive index data has also been shown using oxfords new method. In the coming year this data and additional volcanic ash refractive index data will be published and available via ARIA.

5 Acknowledgments

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[1] ARIA home page. `http://www.atm.ox.ac.uk/project/RI/`.

[2] Eric P. Shettle and Robert W. Fenn. Models for the aerosols of the lower atmosphere and the effects of humitdity variations on their optical properties. Technical Report AFGL-TR-79-0214, Air Force Geophysics Laboratory, September 1979.

[3] Gareth E. Thomas, Stephen F. Bass, Roy G. Grainger, and Alyn Lambert. Retrieval of aerosol refractive index from extinction spectra with a damped harmonic-oscillator band model. *Applied Optics*, 2005.