Estimating AOD using a Quad-Modal Size Distribution

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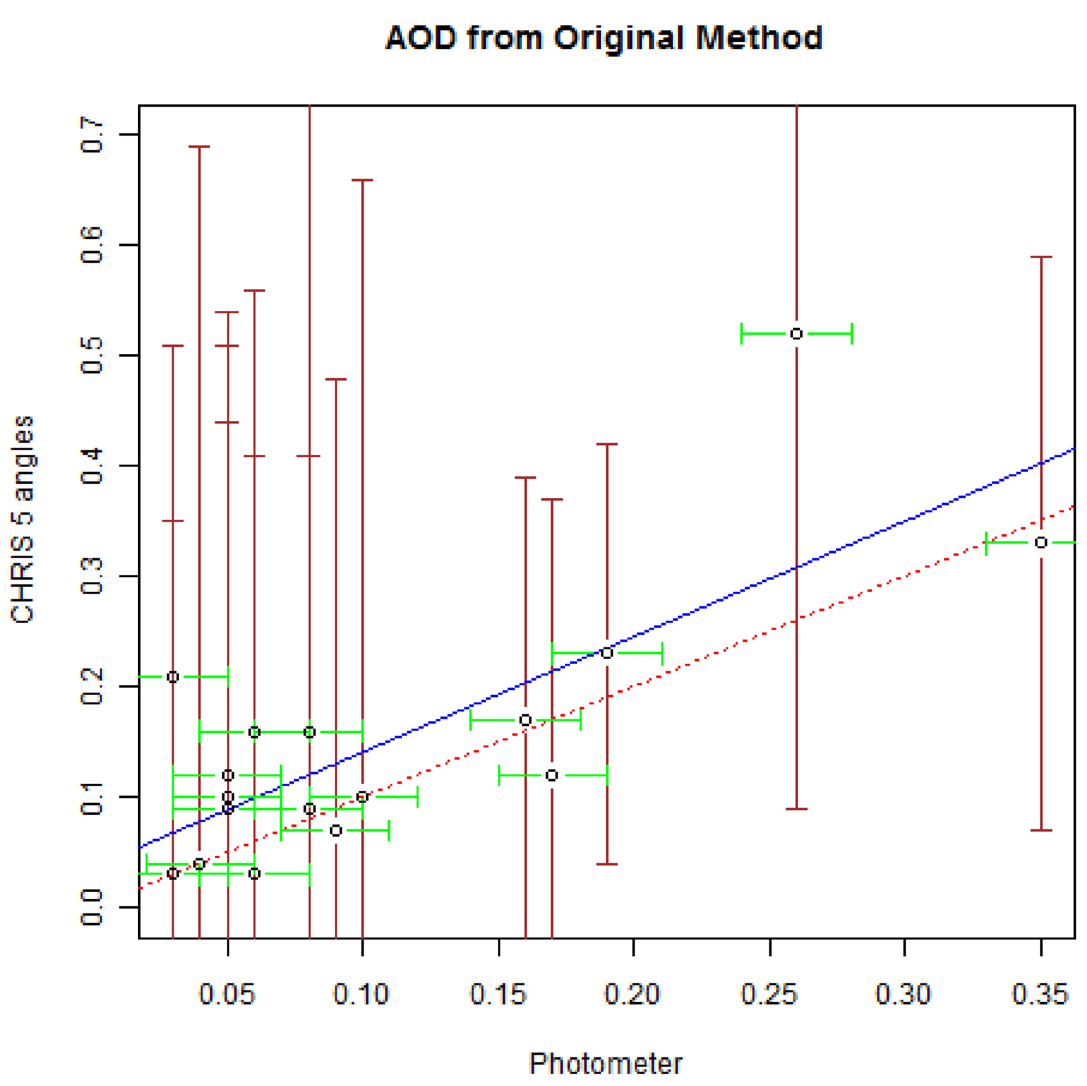
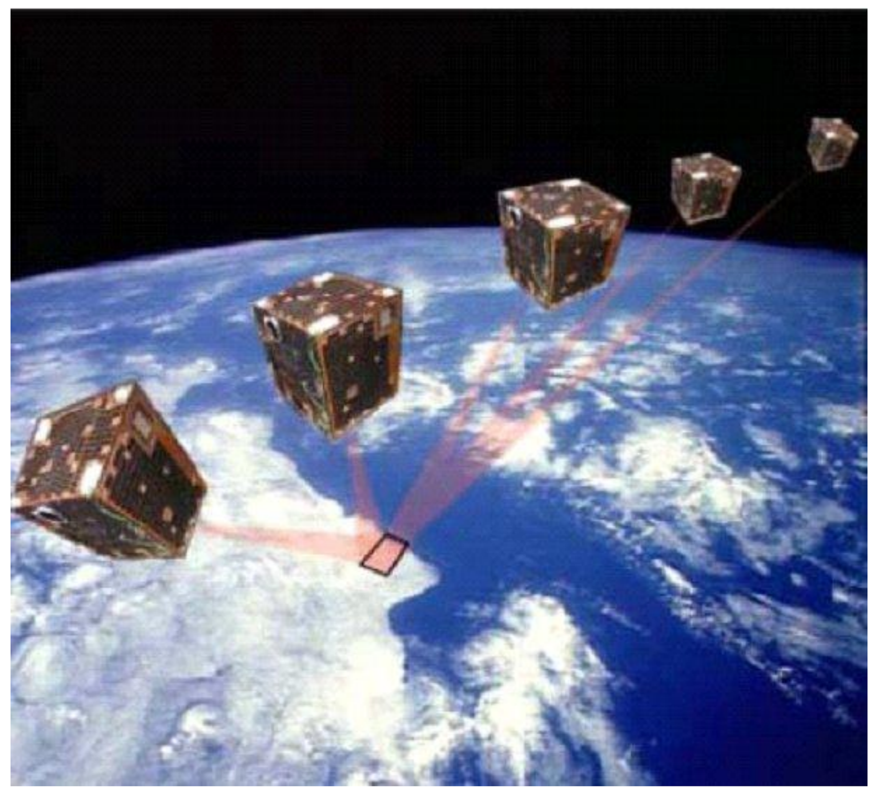
Abstract

A method has been developed to estimate Aerosol Optical Depth (AOD) and Single Scattering Albedo (SSA) over land surfaces using high spatial resolution, hyperspectral, multi-angle CHRIS/PROBA images. The Compact High Resolution Imaging Spectrometer (CHRIS) instrument is mounted aboard the Project for On Board Autonomy 1 (PROBA-1) satellite, and provides up to 62 bands. The PROBA satellite was launched by ESA in October 2001 and allows pointing to obtain imagery from five different view angles within a short time interval. The method uses inversion of a coupled surface/atmosphere radiative transfer model, and includes a general physical model of angular surface reflectance. An iterative process is used to determine the optimum value of the aerosol properties providing the best fit of the corrected reflectance values for a number of view angles and wavelengths with those provided by the physical model. This method of estimating AOD has previously been demonstrated on data from the Advanced Along-Track Scanning Radiometer (AATSR), and is extended here to the spectral and angular sampling of CHRIS/PROBA and the additional aerosol property. The values obtained from these observations are validated using ground based sun-photometer measurements. Results from 23 image sets show an RMS error of 0.09 in AOD at 550nm using standard 6S models. Results from 19 image sets show an RMS error of 0.21 in SSA for the estimates at 868 nm, an RMS error of 0.21 at 672 nm and 0.18 at 442 nm. Estimates of AOD from the extended method using a quad modal size distribution show an RMS error of 0.07.

Fig 1. Comparison of CHRIS Estimates from Original Method with Photometer values .





Extended Method for Estimating AOD

The AOD estimates from the original method using standard 6S models (Vermote et al, 1997) are displayed in Fig 1. That method is described in Davies et al. (2010) and is developed here for estimating AOD and SSA from CHRIS data as represented by an optimal set of atmospheric parameters (Press et al, 1992), namely the AOD and a mix of aerosol components. Previously the method had one unknown being input to the retrieval process - AOD. Here the method is developed to input four unknowns to the retrieval process – AOD and three components of aerosol mixture (the fourth component is derived because all four must add up to 100%). A full grid of mixture values is used in a LUT based approach. The values for the real and the imaginary indices of refraction are listed in Tables 1 and 2 respectively. The values for the radius and standard deviation are listed in Table 3. The retrieval process iterates through all the values in the grid, and the mix with the best fit is the solution. The results are validated by calculating the SSA associated with each mix and comparing with AERONET measurements (see Fig 3). A sensitivity study identifies the most suitable mix interval for the LUTs and also investigates whether there is enough information content in the data at varying AOD values to solve four unknowns (see Fig 2). The AOD estimates from the extended method are displayed in Fig 4. One of the CHRIS images is displayed in Fig 5.

Table 1: Real index of refraction values (r_n) for each wavelength (λ)

Component	λ (μm) 0.350	λ (μm) 0.400	λ (μm) 0.412	λ (μm) 0.443	λ (μm) 0.470	λ (μm) 0.488	λ (μm) 0.515	λ (μm) 0.550	λ (μm) 0.590	λ (μm) 0.633
Dust-Like	1.530	1.530	1.530	1.530	1.530	1.530	1.530	1.530	1.530	1.530
Water Soluble	1.530	1.530	1.530	1.530	1.530	1.530	1.530	1.530	1.530	1.530
Oceanic	1.385	1.385	1.382	1.382	1.382	1.382	1.381	1.381	1.377	1.377
Soot	1.750	1.750	1.750	1.750	1.750	1.750	1.750	1.750	1.750	1.750
	λ (μm) 0.670	λ (μm) 0.694	λ (μm) 0.760	λ (μm) 0.860	λ (μm) 1.240	λ (μm) 1.536	λ (μm) 1.650	λ (μm) 1.950	λ (μm) 2.250	λ (μm) 3.750
Dust-Like	1.530	1.530	1.530	1.520	1.520	1.400	1.400	1.400	1.220	1.270
Water Soluble	1.530	1.530	1.530	1.520	1.520	1.510	1.510	1.510	1.420	1.452
Oceanic	1.376	1.376	1.372	1.372	1.359	1.359	1.334	1.334	1.334	1.398
Soot	1.750	1.750	1.750	1.750	1.770	1.770	1.810	1.810	1.810	1.900

Table 2: Imaginary index of refraction values (r_i) for each wavelength (λ)

Component	λ (μm) 0.350	λ (μm) 0.400	λ (μm) 0.412	λ (μm) 0.443	λ (μm) 0.470	λ (μm) 0.488	λ (μm) 0.515	λ (μm) 0.550	λ (μm) 0.590	λ (μm) 0.633
Dust-Like	8.0E-03	8.0E-03	8.0E-03	8.0E-03	8.0E-03	8.0E-03	8.0E-03	8.0E-03	8.0E-03	8.0E-03
Water Soluble	5.00E-3	5.00E-3	5.00E-3	5.00E-3	5.00E-3	5.00E-3	5.00E-3	6.00E-3	6.00E-3	6.00E-3
Oceanic	9.90E-9	9.90E-9	6.41E-9	6.41E-9	6.41E-9	6.41E-9	3.70E-9	4.26E-9	1.62E-8	1.62E-8
Soot	0.460	0.460	0.450	0.450	0.450	0.450	0.450	0.440	0.430	0.430
	λ (μm) 0.670	λ (μm) 0.694	λ (μm) 0.760	λ (μm) 0.860	λ (μm) 1.240	λ (μm) 1.536	λ (μm) 1.650	λ (μm) 1.950	λ (μm) 2.250	λ (μm) 3.750
Dust-Like	8.0E-03	8.0E-03	8.0E-03	8.0E-03	8.0E-03	8.0E-03	8.0E-03	8.0E-03	9.00E-03	1.10E-02
Water Soluble	6.00E-3	7.00E-3	7.00E-3	1.20E-2	1.20E-2	2.30E-2	2.30E-2	2.30E-2	1.00E-2	4.00E-3
Oceanic	5.04E-8	5.04E-8	1.09E-6	1.09E-6	2.43E-4	2.43E-4	8.50E-4	8.50E-4	8.50E-4	2.90E-3
Soot	0.430	0.430	0.430	0.430	0.460	0.460	0.500	0.500	0.500	0.570

Fig 2. Sensitivity Study: Validating the Mix using SSA

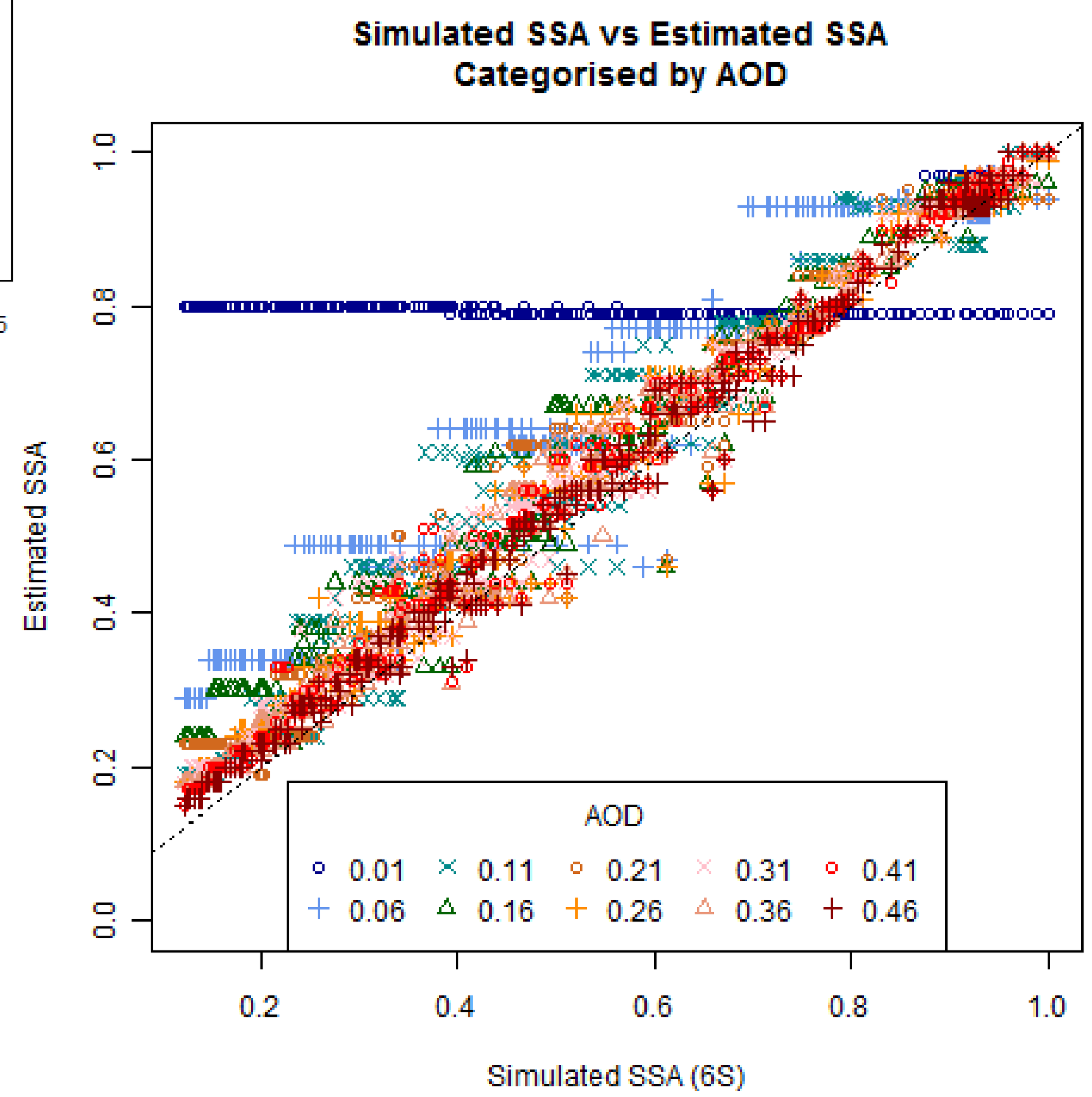


Fig 4. Comparison of CHRIS Estimates from Extended Method with Photometer values .

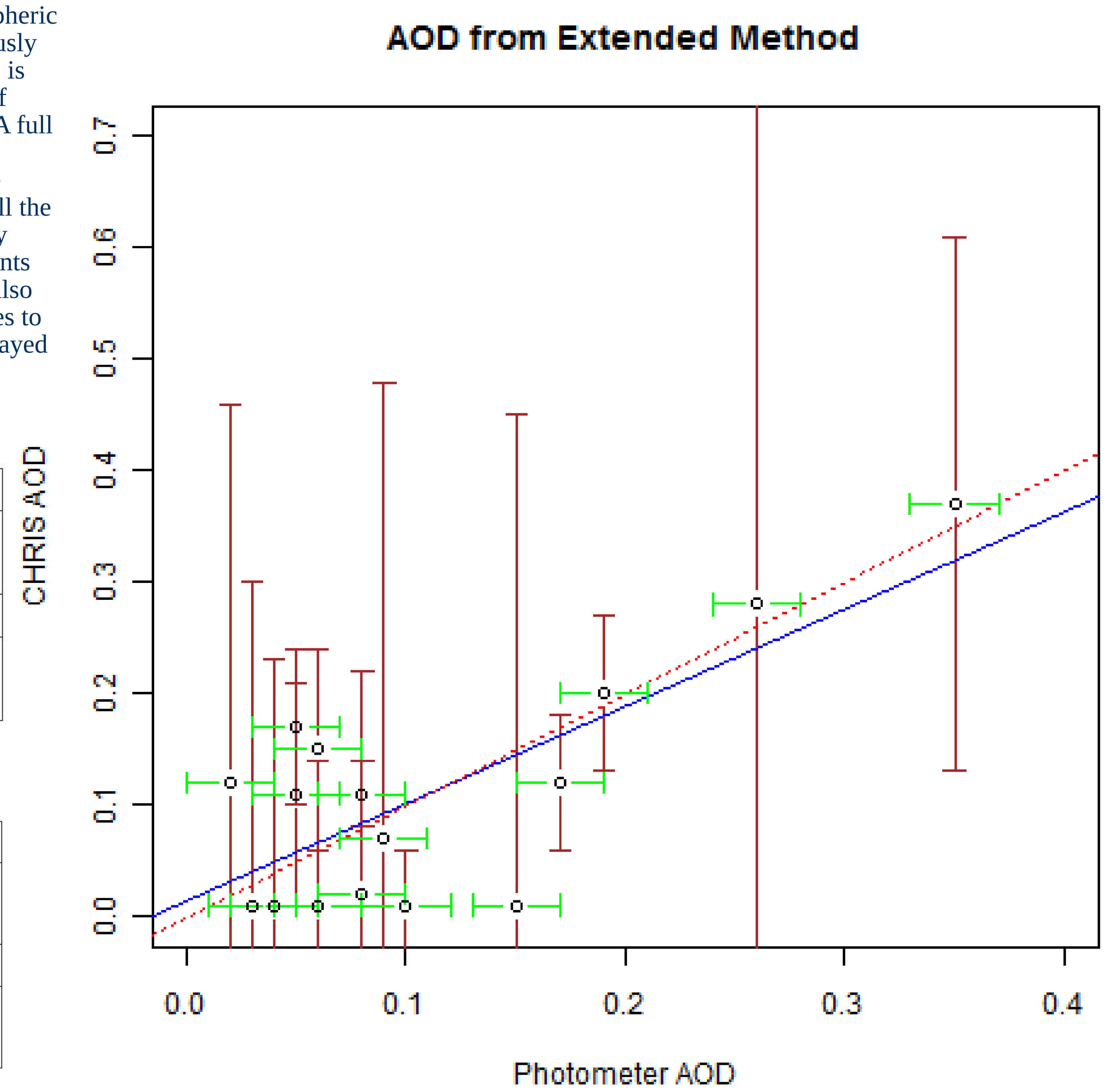


Table 3. Size Assumptions (Kahn et al., 2001)

Component	σ	r_M
Dust-Like (coarse)	2.60	1.90
Water Soluble (sulfate)	1.86	0.07
Oceanic	2.51	0.350
Soot	2.00	0.012

Fig 3. Comparison of CHRIS SSA estimates with AERONET measurements for AOD(440) > 0.2

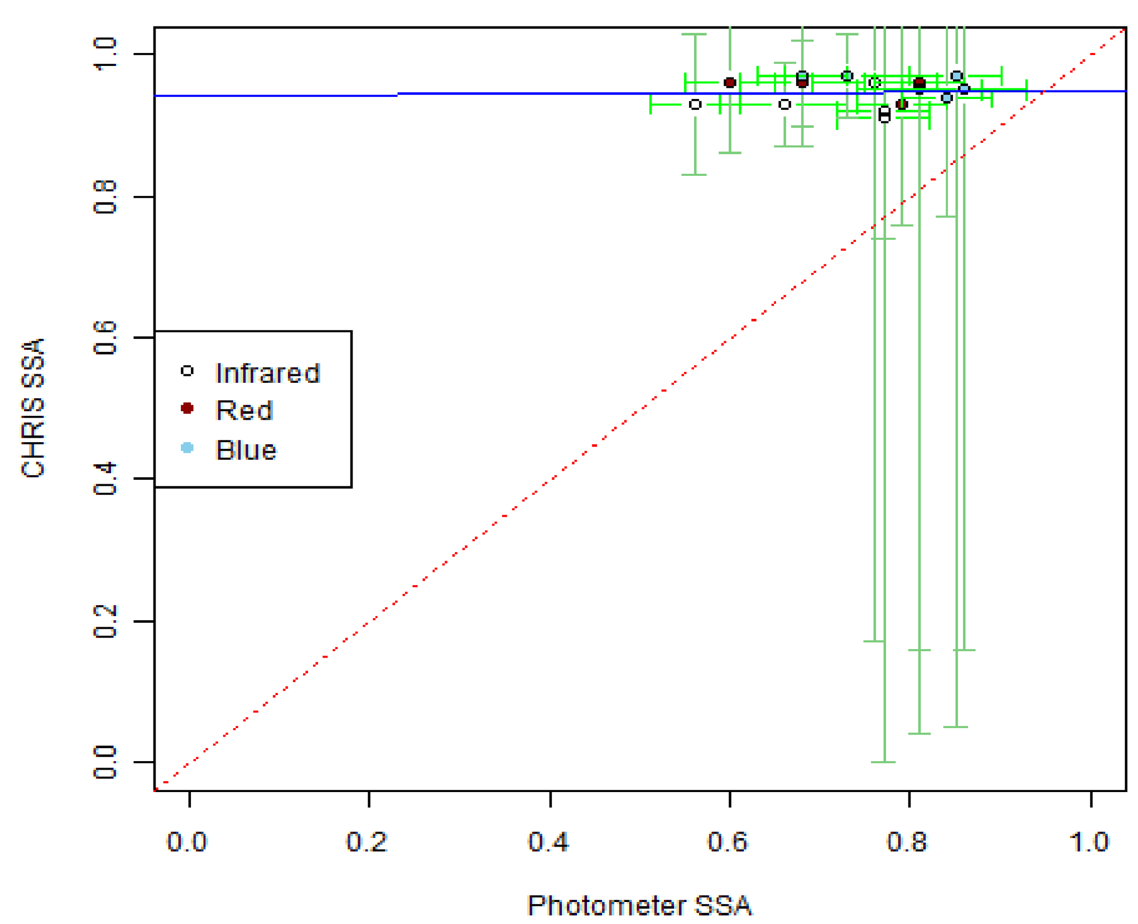
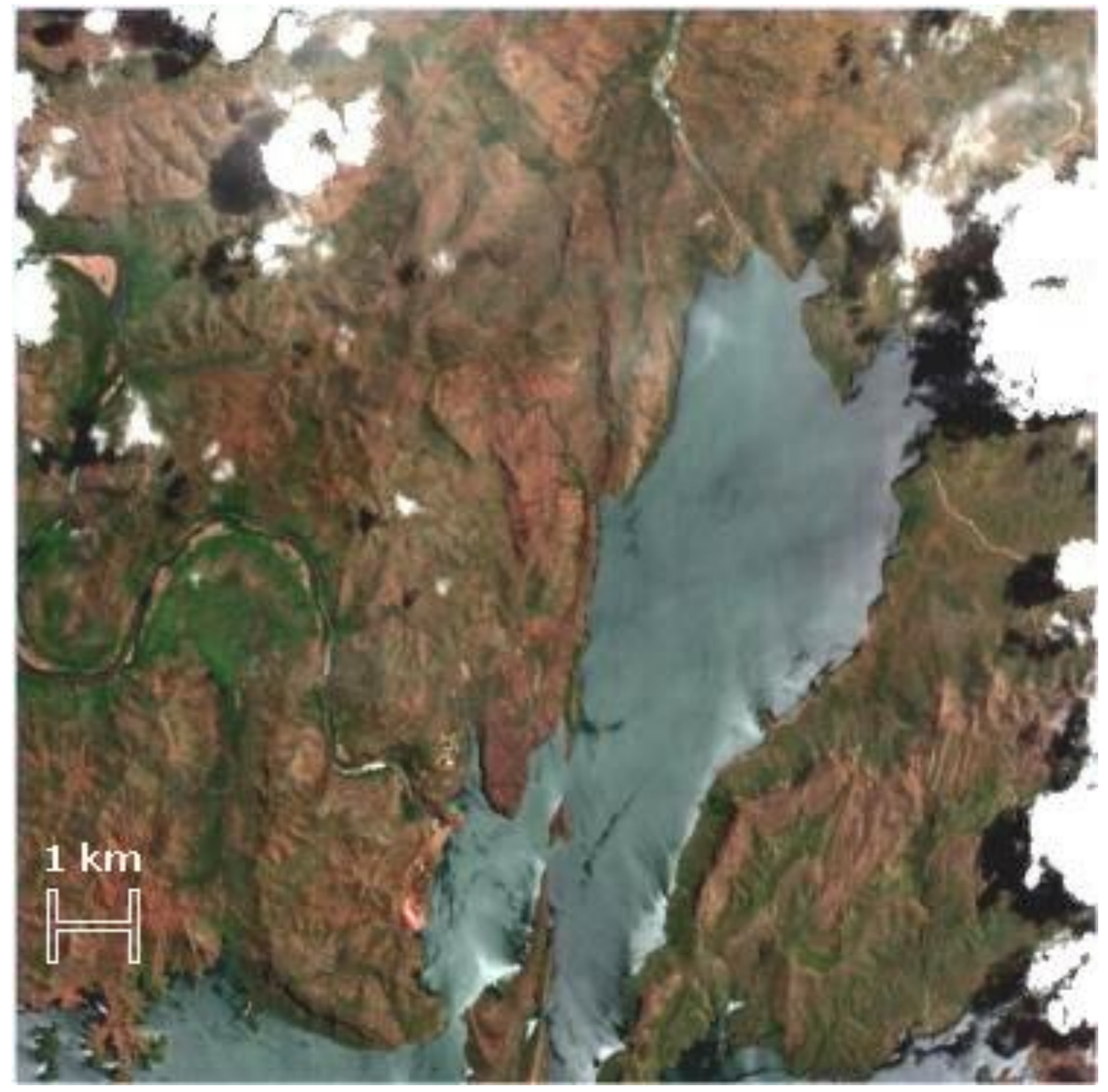


Fig 5. True Colour Nadir CHRIS image of Lake Argyle, Australia.



Conclusions

A method for estimating AOD, SSA and their uncertainties from CHRIS/PROBA images has been developed and tested on nineteen image sets from five sites. The method varies the mix of aerosol components in a quad modal size distribution. Results show an RMS error of 0.21 in SSA for the estimates at 868 nm with an r^2 of 0.03, 0.21 at 672 nm with an r^2 of 0.02 and 0.18 at 442 nm with an r^2 of 0.04. Further screened, the results for image sets where the value of τ_{440} > 0.2 did not produce a better result with an RMS error of 0.23 with an r^2 of 0.01. Results from simulated data show an RMS error of 0.13 in SSA with an r^2 of 0.83 from 2890 TOA radiance sets. When the estimates for AOD values of 0.01 are excluded the value of r^2 is 0.96 with an RMS error of 0.07.

Estimates of AOD from this extended method with four unknowns and a quad modal size distribution were compared to the AOD estimates using the standard 6S models with one unknown. The results were similar to the previous estimates with an RMS error of 0.07 and r^2 of 0.63 for the extended method, compared to 0.09 and 0.68 respectively for the previous method.

The results for the retrieval of SSA show that the method does not work for this dataset. This is probably due to the assumptions of correlation between the aerosol properties made in the simulations and LUT not being found in the test dataset. The sample size is low and further research is recommended to examine the method with a dataset that has higher AOD and to use different size distribution assumptions and choices of values for the refractive indices.

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References: Davies W.H.; North P. R. J.; Grey W.M.F.; Barnsley M.J. (2010). *Improvements in Aerosol Optical Depth Estimation Using Multiangle CHRIS/PROBA Images.* IEEE Transactions on Geoscience and Remote Sensing, vol. 48, no. 1, January 2010. **Kahn, R.A.;** Banerjee, P.; & McDonald, D. (2001). Sensitivity of multiangle imaging to natural mixtures of aerosols over ocean. Journal of Geophysical Research, 106(D16), 18219–18238. **Press, W H;** Teukolsky, S A; Vetterling, W T; Flannery, B P (1992). *Numerical Recipes in C: The Art of Scientific Computing(2nd Edition).* CAMBRIDGE: CAMBRIDGE UNIVERSITY PRESS.. **Vermote, E F;** Tanre, D; Deuze, J L; Herman, M; Morcrette, J, (1997). *Second Simulation of the Satellite Signal in the Solar Spectrum,6S: an overview*, / IEEE Transactions on Geoscience and Remote Sensing, 35(3)/ , 675-686, 1997.