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Evaluation of aerosol optical depth in IFS-GLOMAP

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Authors	Matthew Woodhouse (University of Leeds), Graham Mann (University of Leeds), Nicolas Bellouin (UK Met Office / University of Reading), Jean-Jacques Morcrette (ECMWF), Michael Schulz (Norwegian Meteorological Institute), Jan Griesfeller (Norwegian Meteorological Institute), Stefan Kinne (Max-Planck Institute for Meteorology)
Approved by	Olivier Boucher
Contact	info@gmes-atmosphere.eu

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Abstract

The IFS-GLOMAP aerosol scheme has been extended to include the RADAER aerosol optical depth (AOD) calculation. RADAER calculates monochromatic AOD at six wavelengths for each of the six optically-relevant aerosol modes with IFS-GLOMAP. This report compares fine-mode and total AOD calculated by RADAER online within IFS-GLOMAP with AERONET observations from around the world. Fine-mode AOD is reproduced very well in many regions (global bias = -6.3%, R = 0.617), but there is a significant low bias in total AOD (global bias =-27.1%, R = 0.689). The remote oceans suffer from a strong low bias, which may be accounted for by lack of DMS emissions in the present simulations with IFS-GLOMAP. Fine-mode and total AODs are reproduced very well in regions under strong anthropogenic influence.

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Introduction

As part of the MACC project, the aerosol microphysics module GLOMAP-mode (Mann et al., 2010) was incorporated in the ECMWF IFS model. The implementation of GLOMAP-mode in the IFS (referred to as IFS-GLOMAP) is described in MACC deliverables D G-AER 1.6, D G-AER 1.8 and D G-AER 4.1 (Woodhouse et al., 2011).

One of the development activities undertaken in MACC-II is the inclusion of the RADAER aerosol optical depth (AOD) calculation in IFS-GLOMAP. Calculating AOD online in IFS-GLOMAP is a prerequisite for the 4d-var data assimilation in the IFS, and an important step towards readying IFS-GLOMAP for operational use. AOD is also a useful metric when evaluating model performance.

This deliverable report describes the RADAER AOD calculation, and its implementation and evaluation in IFS-GLOMAP. The modelled AOD is evaluated in comparison to AERONET (http://aeronet.gsfc.nasa.gov/) observations compiled on the AeroCom website (http://aerocom.met.no/). Both the AERONET data and AeroCom interface are described in more detail in the MACC-II validation reports (e.g. Eskes et al., 2012).

The IFS-GLOMAP results in this report are from simulation b0zg, in IFS cycle 38r1. The IFS-GLOMAP configuration at the time of the simulations did not include dust. To facilitate a meaningful AOD comparison, dust AOD from a simulation (fuw5 in cycle 38r2) with the GEMS/MACC aerosol scheme is added to the IFS-GLOMAP AOD. The model results presented here are from January to December 2003, following one month of spin-up from zero aerosol. Neither the IFS-GLOMAP nor GEMS/MACC simulations included data assimilation.

The RADAER AOD calculation

The RADAER module for GLOMAP-mode is described in full in a UK Met Office technical note (Bellouin, 2011). RADAER uses look-up tables (LUTs) of pre-computed Mie values for several aerosol optical properties (scattering and extinction coefficients, asymmetry) to minimize computational cost at run time. The LUTs allow the monochromatic AOD to be calculated at six wavelengths (380 nm, 440 nm, 550 nm, 670 nm, 870 nm and 1020 nm) and cover all realistic combinations of each mode's mean radius and refractive index. At runtime, the refractive index from each mode is calculated (with reference to the fractional composition of each mode, including water content), and each mode's AOD is then returned after consulting the relevant LUT.

RADAER was developed for use in the HadGEM-UKCA composition-climate model (Bellouin et al., 2013) and can also calculate aerosol optical properties integrated across each of the shortwave and longwave spectral wavebands used in HadGEM. For the current RADAER implementation within IFS-GLOMAP, only the monochromatic AOD calculation is included.

AOD is calculated for each mode, excluding the nucleation mode (which is too small to be optically active). The aerosol is non-interactive with the radiation scheme in these simulations. The current implementation of RADAER in IFS-GLOMAP does not attempt to couple to the radiation scheme, though in future this is entirely feasible.

Implementation of RADAER in IFS-GLOMAP

At runtime, RADAER is initialized at the start of the simulation from the routine suphec.F90, alongside GLOMAP-mode. The LUTs are read in at this point and the data made available to the rest of the model through a module.

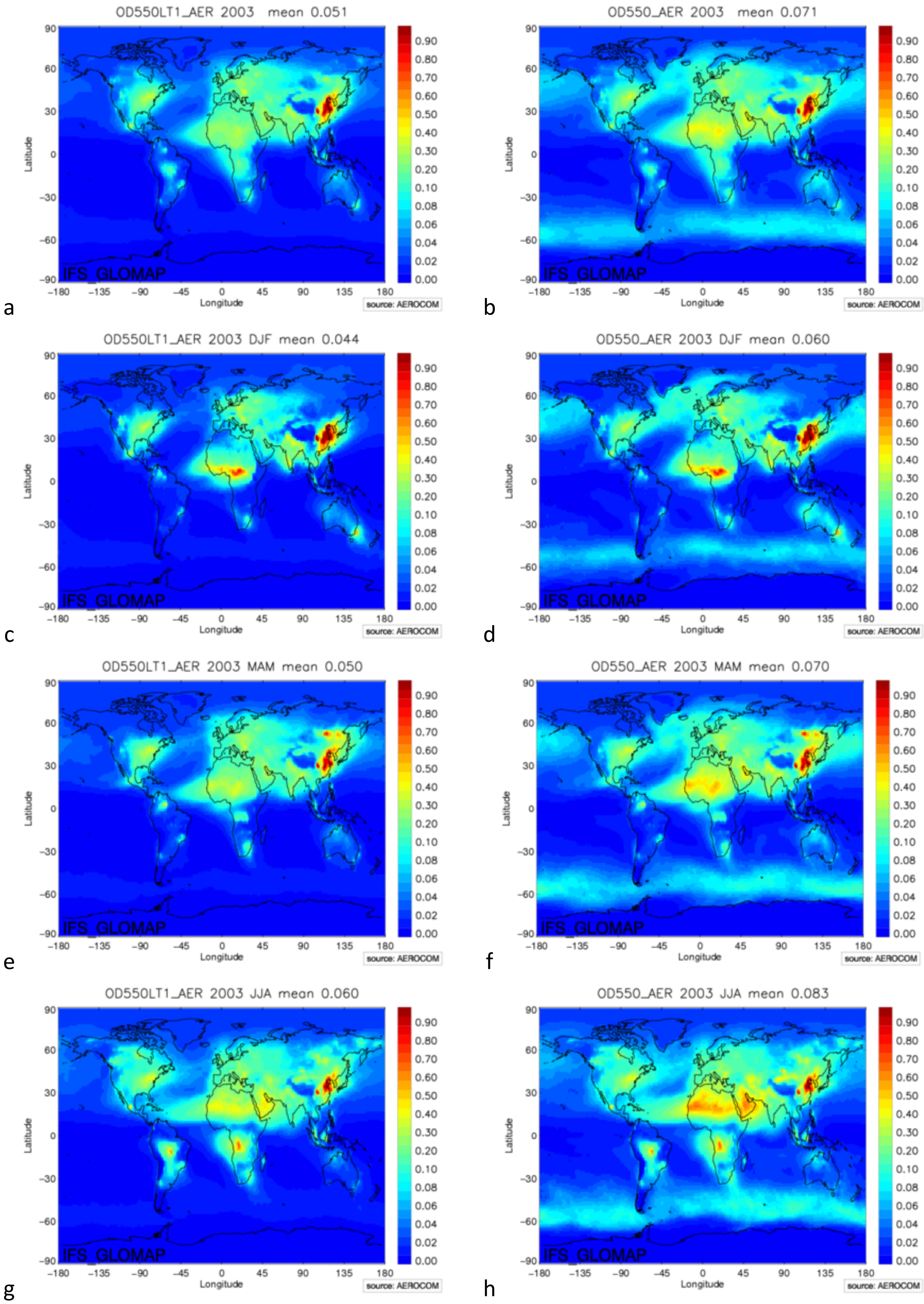
In IFS-GLOMAP, RADAER is called from GLOMAP-mode's interface routine 'ukca_aero_step_ifs.F90', immediately after the aerosol microphysics (and removal) have been calculated. Thus, RADAER is called at every time step.

Output from RADAER is currently passed back to the callpar routine, where it is outputted via the PEXTRA diagnostic. Output is available for each of the six modes (Aitken, accumulation, coarse, in soluble and insoluble distributions), at each of the six wavelengths noted above. Furthermore, both AOD due to extinction and absorption are output.

In contrast to the existing aerosol scheme (and derived AOD's), GLOMAP-mode has an internally-mixed representation of aerosol. The RADAER calculation accounts for this by calculating a volume-average refractive index and operating on this in the LUTs. Current MACC-II products include speciated AOD, for example dust AOD. Given the internally mixed nature of aerosol (both in GLOMAP and in the atmosphere), we have chosen not to calculate speciated AOD, only total AOD for each mode. Speciated AOD's could be diagnosed approximately based on the volume fraction composition in each mode. The sum of the speciated AOD's would not add up to the total AOD calculated in RADAER due to the internal mixing assumption.

AOD in IFS-GLOMAP

Annual and seasonal mean AOD's from IFS-GLOMAP are presented in Fig. 1. All figures in this report show AOD at 550 nm. Model 'fine-mode' AOD is calculated as the sum of the Aitken and accumulation modes (i.e. aerosol less than 1 µm in diameter).


OD550LT1_AER 2003 mean 0.051
OD550_AER 2003 mean 0.071
OD550LT1_AER 2003 DJF mean 0.044
OD550_AER 2003 DJF mean 0.060
OD550LT1_AER 2003 MAM mean 0.050
OD550_AER 2003 MAM mean 0.070
OD550LT1_AER 2003 JJA mean 0.060
OD550_AER 2003 JJA mean 0.083
Latitude
Longitude
90
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-180 -135 -90 -45 0 45 90 135 180
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IFS_GLOMAP
source: AEROCOM
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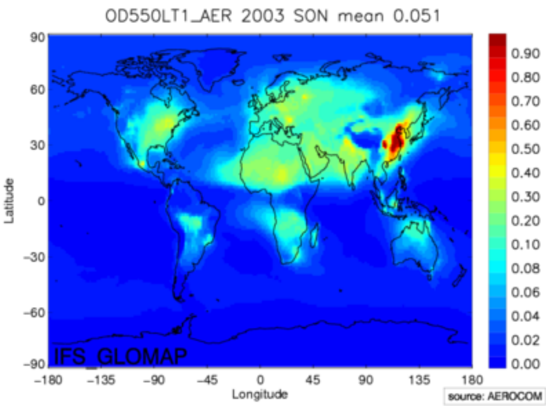
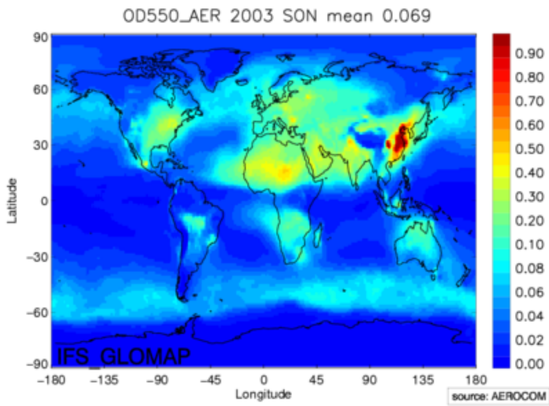


i



j

Fig. 1. Annual (top row) and seasonal mean AOD's for the fine-mode (left column) and total AOD (right column).

The highest AOD's in Fig. 1 are located over central eastern China, where values in excess of 0.8 are predicted. There are also anthropogenic peaks in AOD over western Europe and the eastern United States, which comes entirely from sub-micrometre particles, as expected. Natural dust emissions lead to AOD's of ~0.5 over north Africa, with fine-mode AOD's up to around 0.35. A clear seasonal cycle in AOD is apparent in regions with high biomass burning emissions (e.g. central Africa and the Amazon), also entirely from the fine-mode. The inclusion of secondary organic aerosol within the GLOMAP AOD will also add to the AOD in regions of strong biogenic volatile organic carbon (BVOC) emissions (e.g. boreal and tropical forest regions). A clear signal of sea-salt AOD is seen between 40 and 60°S, with AOD values peaking around 0.1, the majority of which is from coarse mode aerosol. Since DMS emissions are not included in these simulations, we expect fine-mode AOD to be strongly biased low in these simulations.

Comparison against AERONET AOD

The AOD derived from IFS-GLOMAP (including the GEMS/MACC dust) is compared against AERONET observations using the tools on the AeroCom II comparison website (http://aerocom.met.no/cgi-bin/AEROCOM/aerocom/surfobs_annualrs.pl), where the plots contained in this report are taken from.

Europe

Fig. 2 (a-f) shows annual time series of IFS-GLOMAP and AERONET AOD at three locations in Europe.

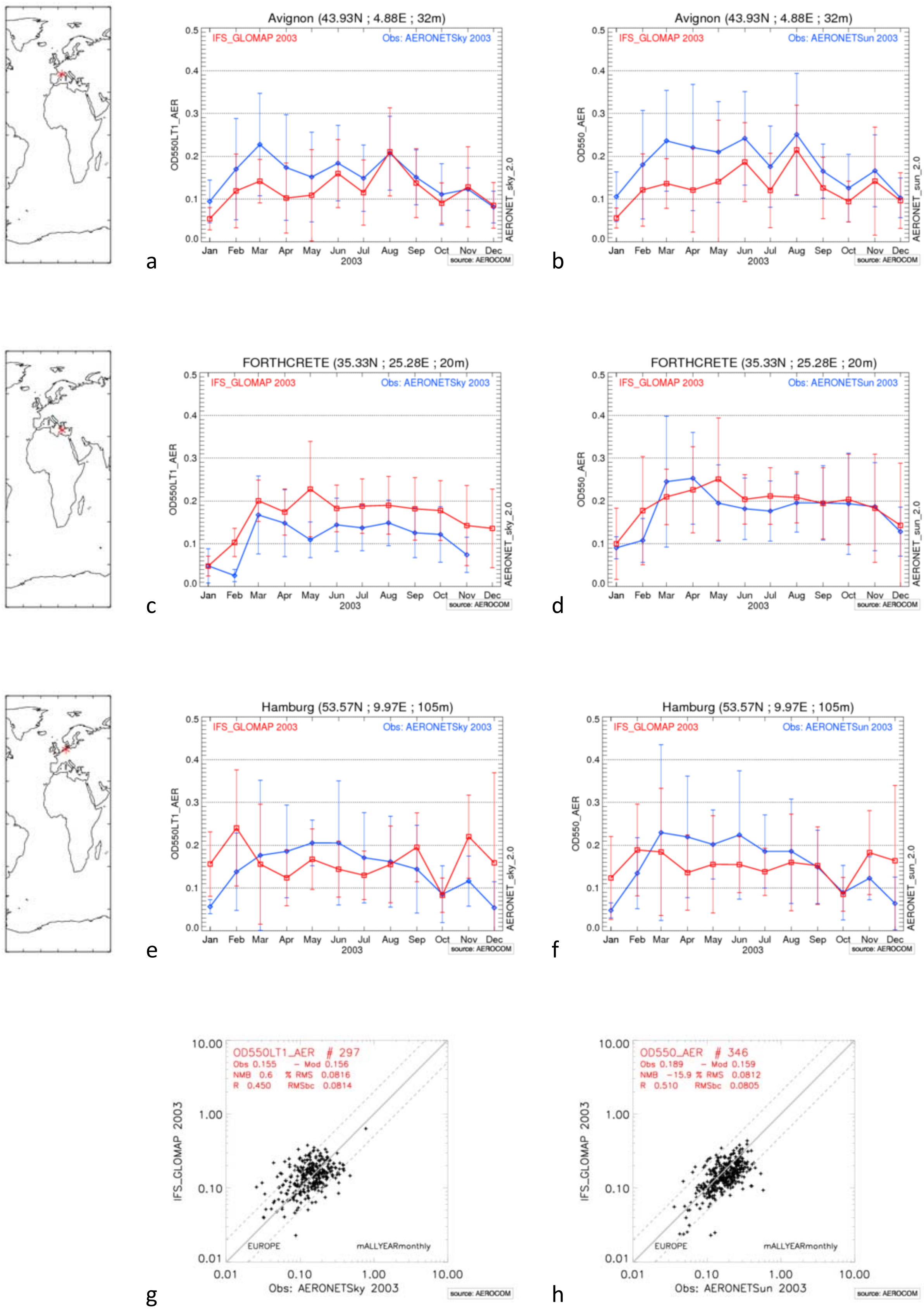


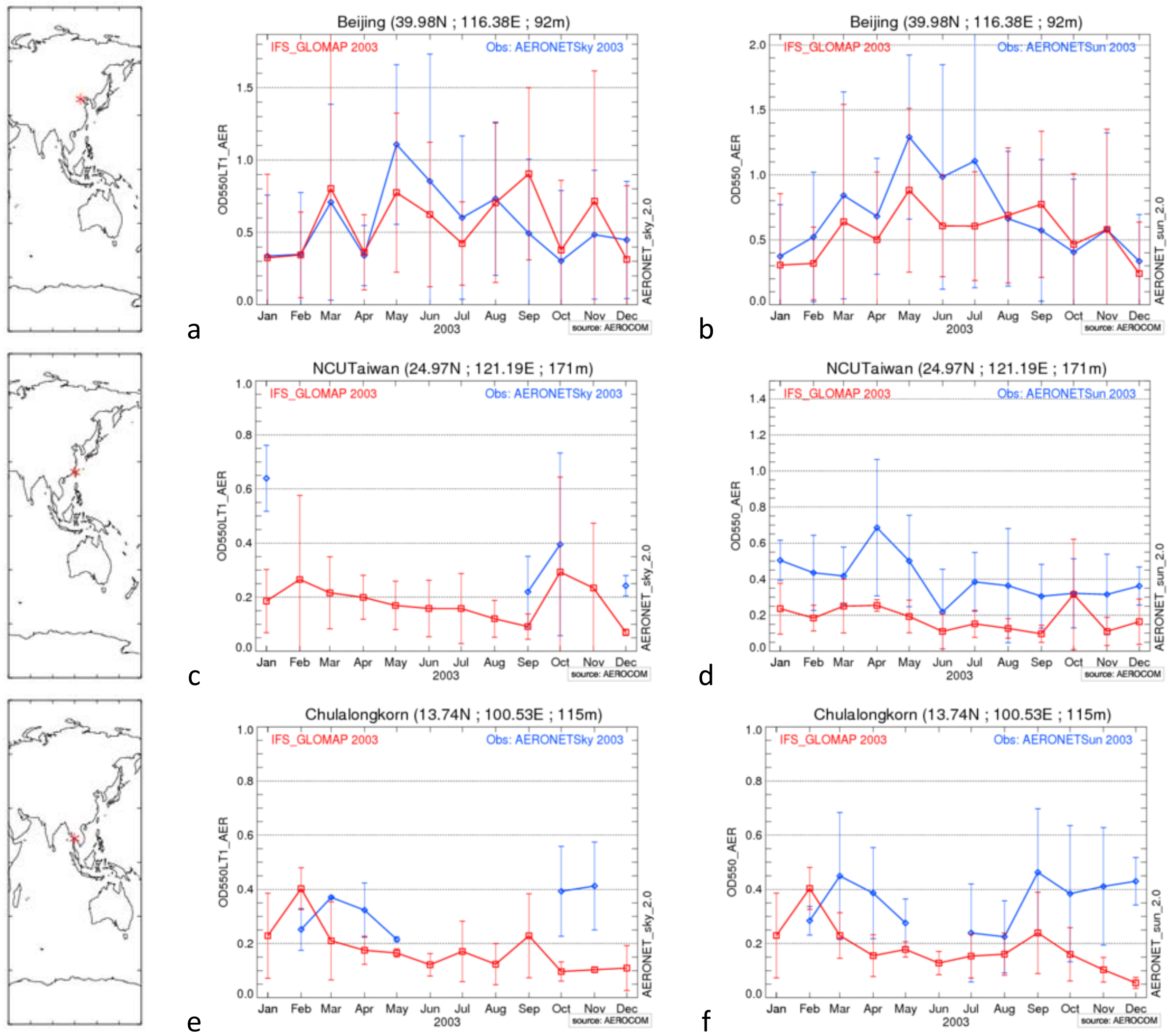
Fig. 2. (a-f) Comparison of IFS-GLOMAP AOD against a selection of AERONET AOD measurements within Europe. Fine-mode (left column) and total AOD (right column) are

presented. The maps on the left indicate the location of each AERONET site (g, h) Scatterplots showing the performance of IFS-GLOMAP against monthly mean AERONET measurement in Europe.

The comparisons in Fig. 2 are generally good, with the seasonal cycle and magnitude of the AOD broadly captured. The exception is Hamburg, where the model displays little seasonal cycle. The lack of a seasonal cycle at Hamburg may result from the simple oxidation scheme currently employed in IFS-GLOMAP, which follows a timescale conversion approach implemented by Morcrette et al. (2009). At Crete, there is too much aerosol in the fine mode, but the total AOD compares well, suggesting that there is too little coarse mode aerosol. Overall, the fine-mode normalized mean bias in Europe is very close to zero, although there is a large degree of scatter (R=0.45). Total AOD is biased 15.9% low (R=0.51), though the great majority of points lie within a factor of two of the observations.

Asia

Fig. 3 shows AOD comparisons for Asia.



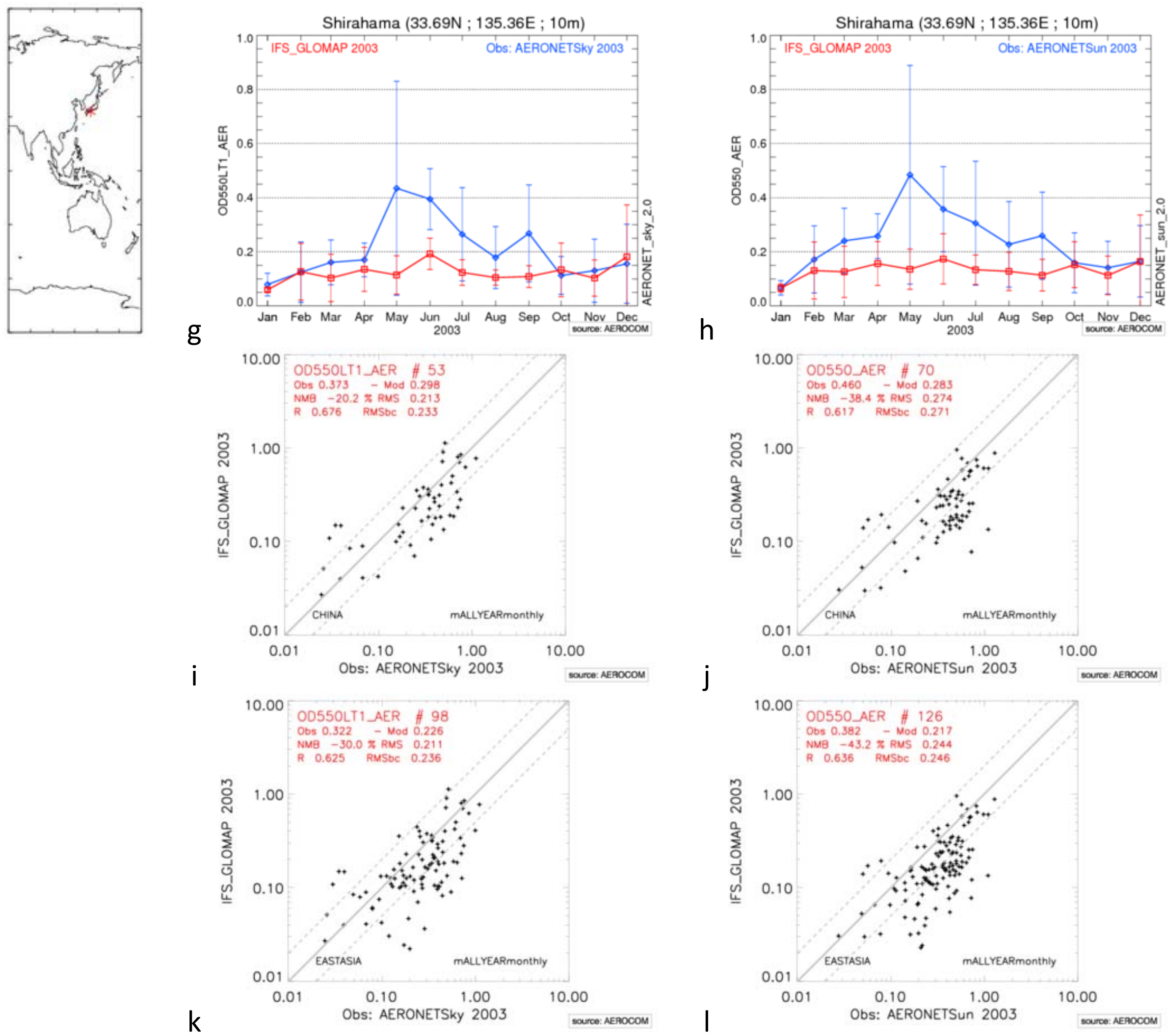
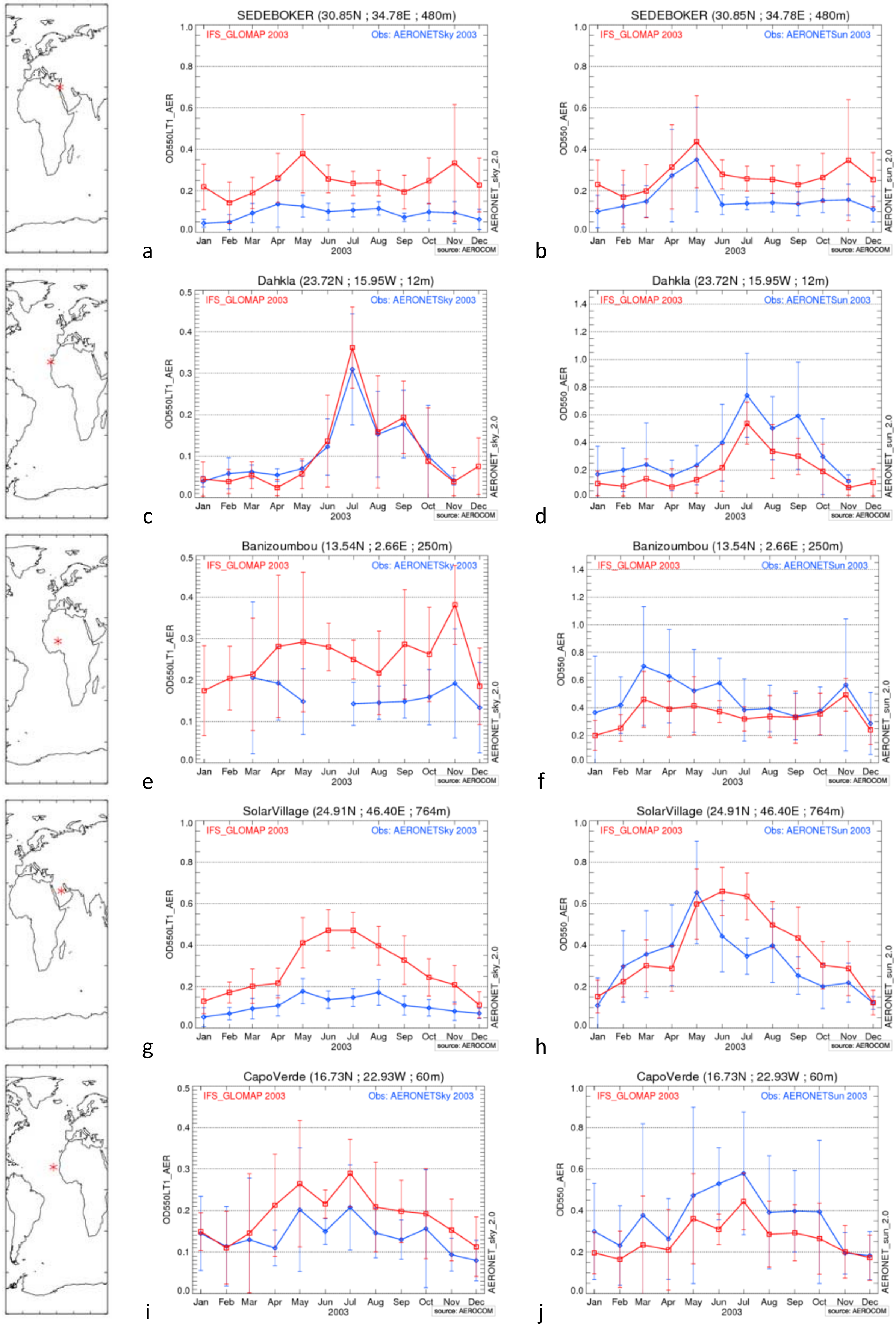


Fig. 3. As Fig. 2, but for Asian sites.

The high AOD's in Beijing are captured well by IFS-GLOMAP (Fig. 3). At the three other sites however (Taiwan, Chulalongkorn and Shirahama), a deficit in fine-mode AOD leads to a model underestimate in total AOD compared to the AERONET observations. IFS-GLOMAP does not capture the seasonal cycle at Shirahama, potentially due to the simplistic oxidation scheme currently employed. Significant low biases in both the fine-mode (-30%) and the total AOD (-43.2%) are apparent in the scatterplots summarizing the Asian comparisons (Fig. 3 i-l).

North Africa

Comparisons of AERONET and IFS-GLOMAP AOD for North Africa are shown in Fig. 4.


SEDEBOKER (30.85N ; 34.78E ; 480m)
IFS_GLOMAP 2003
Obs: AERONETSky 2003
Obs: AERONETSun 2003
Dahkla (23.72N ; 15.95W ; 12m)
Banizoumbou (13.54N ; 2.66E ; 250m)
SolarVillage (24.91N ; 46.40E ; 764m)
CapoVerde (16.73N ; 22.93W ; 60m)
OD550LT1_AER
OD550_AER
AERONET_sky_2.0
AERONET_sun_2.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2003
source: AEROCOM
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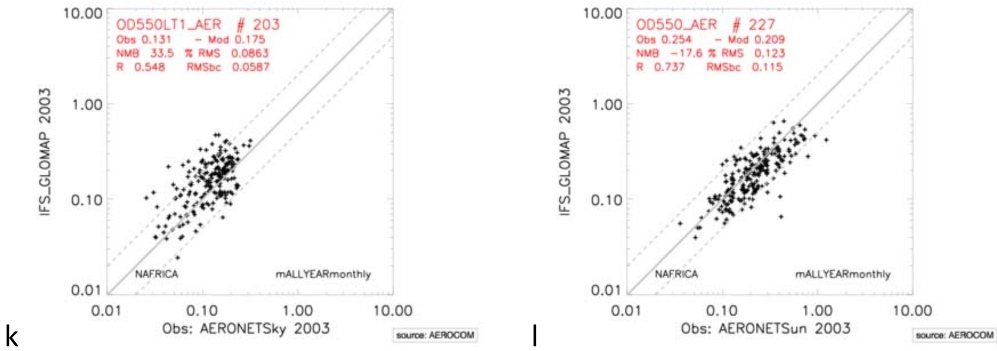
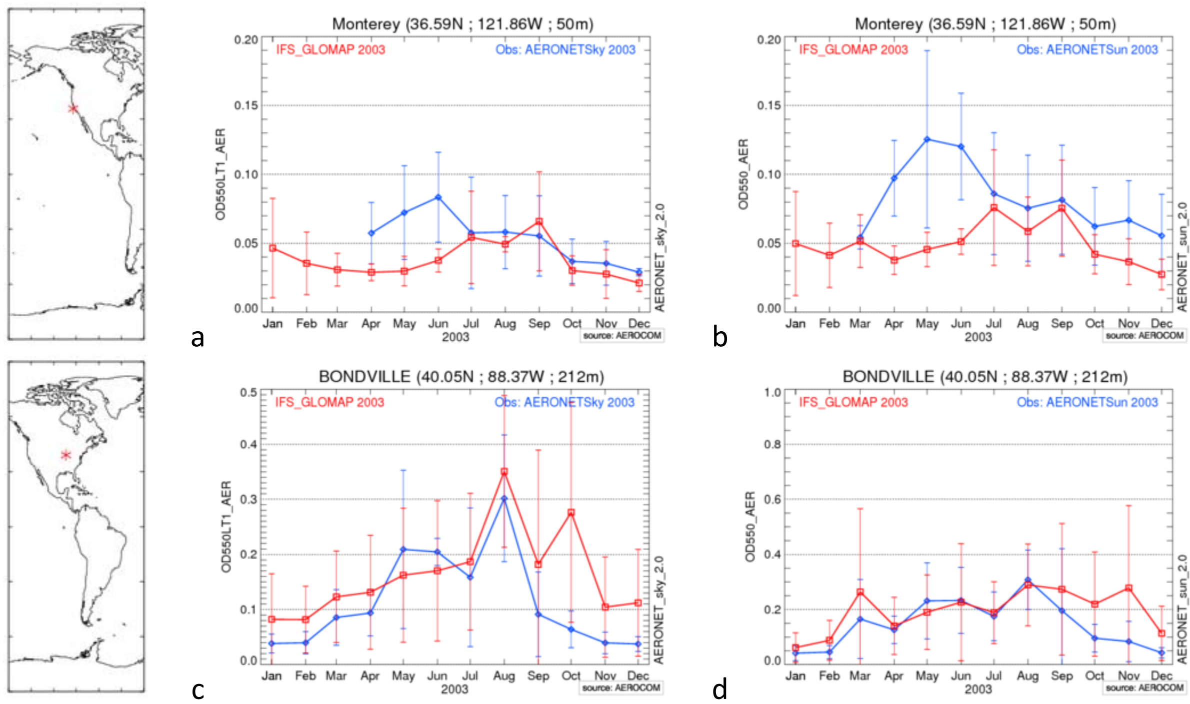


Fig. 4. As Fig. 2 but for North African sites.

AOD in the North African region (Fig. 4) is predominantly controlled by dust emission from the Sahara. Across most sites in this region, AOD is overestimated in the fine-mode, but underestimated in the coarse mode. This comparison suggests that the size distribution of the mineral dust emitted from the Sahara is incorrect, with too many small particles. No further analysis is undertaken, as has already been noted, dust AOD in these comparisons is taken from a simulation in the GEMS/MACC aerosol scheme (identifier fuw5), and not from IFS-GLOMAP.

North America

Fig. 5 shows comparisons of modelled and observed AOD for North America.



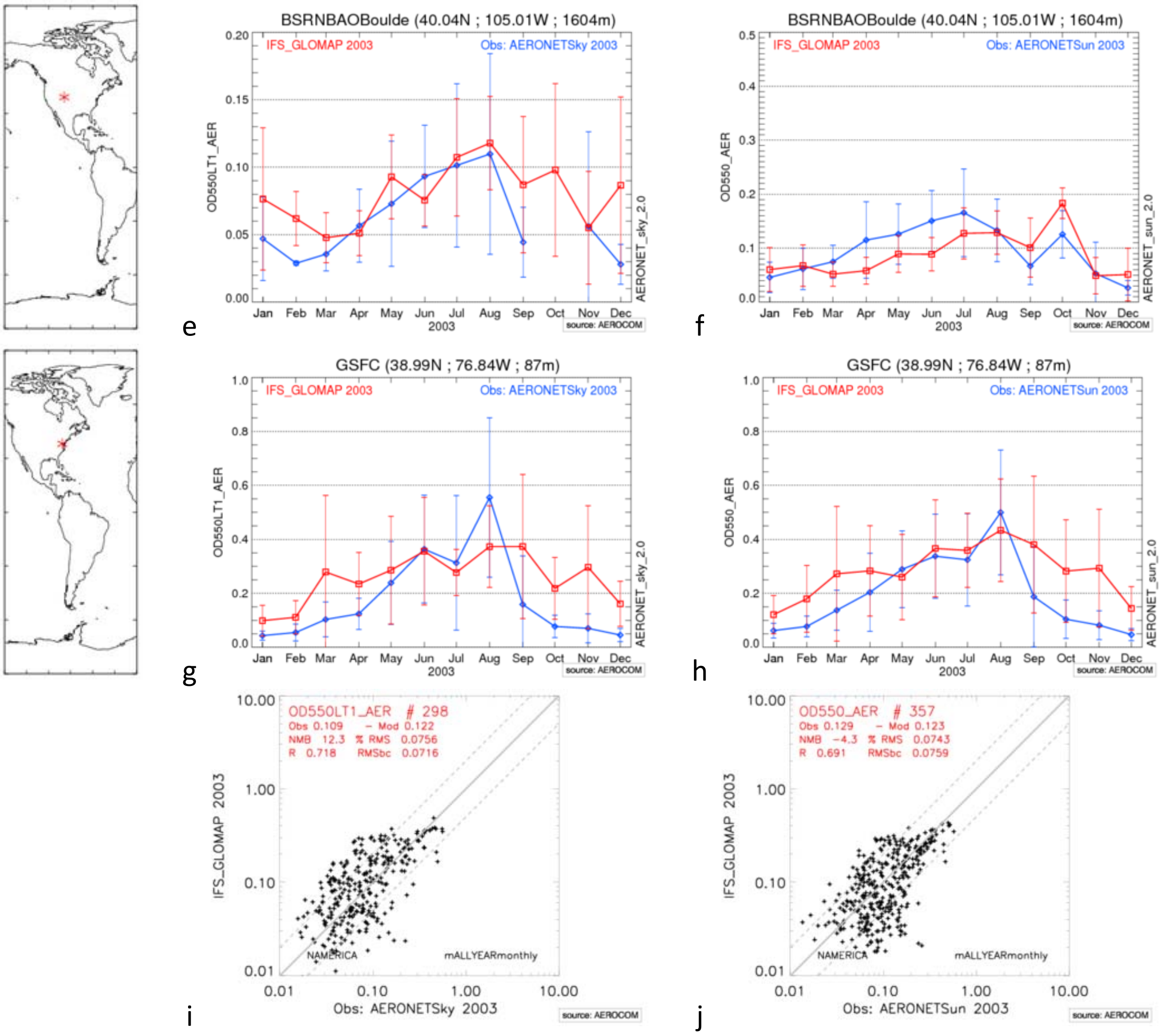


Fig. 5. As Fig. 2 but for North American sites.

The modelled AOD for North America compares well to the AERONET observations (Fig. 5), with biases of 12.3% and 4.3% for the fine-mode and total AOD respectively. The modelled seasonal cycle is weaker than that in the observations. At Monterey in particular, there is a peak in total AOD in May that is not picked up at all by the model. The May peak in Monterey may be due to nitrate aerosol, which is not currently simulated in IFS-GLOMAP.

South America

Observed and modelled AOD's for South America are shown in Fig. 6.

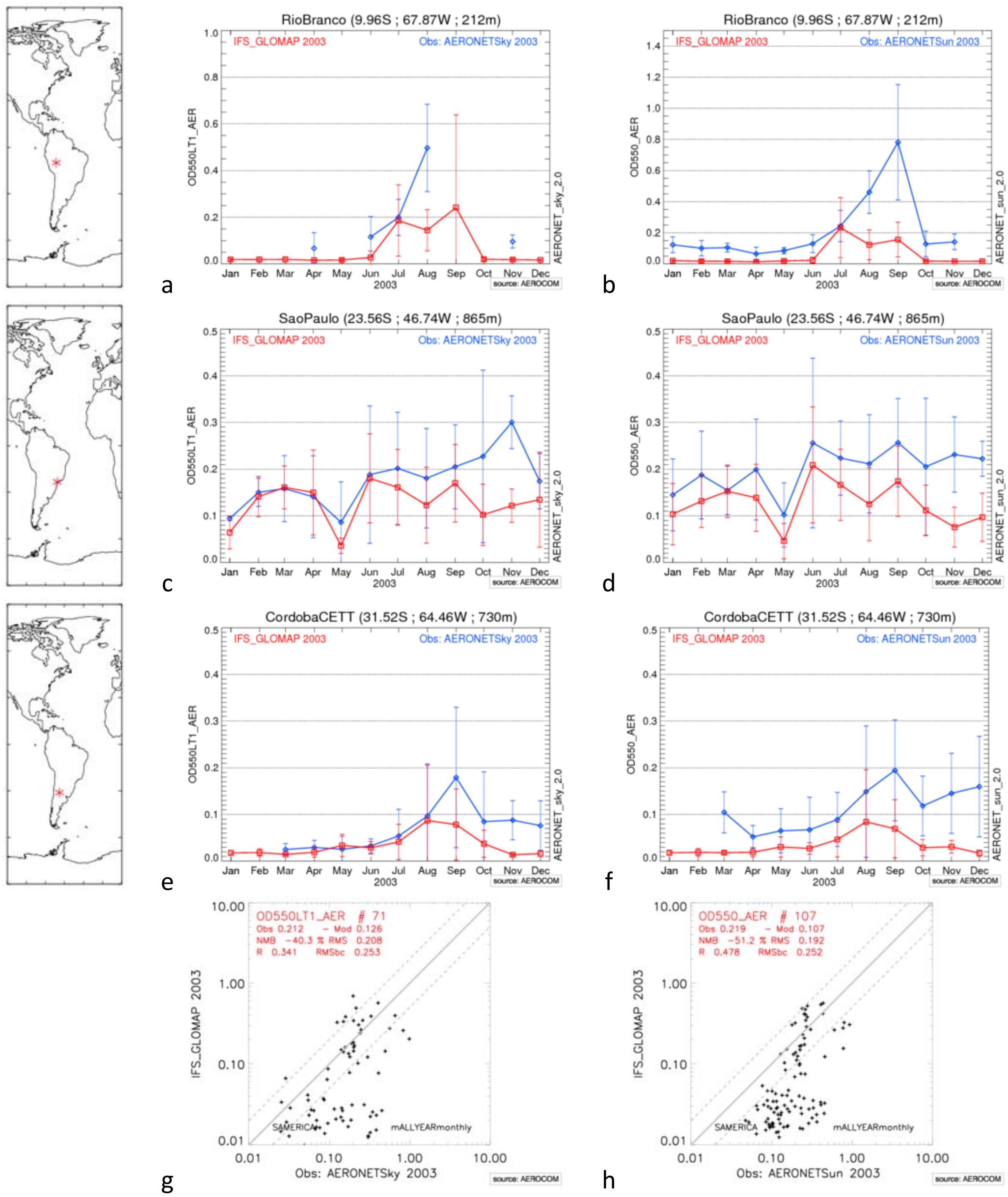


Fig. 6. As Fig. 2 but for South American sites.

There is a very clear low bias in South American AOD (Fig. 6); the biases for this region are -40.3% and -51.2% for fine-mode and total AOD respectively. The scatterplots (Fig. 6 g and h) hint at two distinct clusters of points. One cluster shows the model performing very well, and the second cluster shows a very low bias. When taken together with the comparisons at Rio Branco and Sao Paulo, the low bias may be due to a missing seasonal source.

Remote ocean

Fig. 7 presents AOD comparisons at several remote ocean sites.

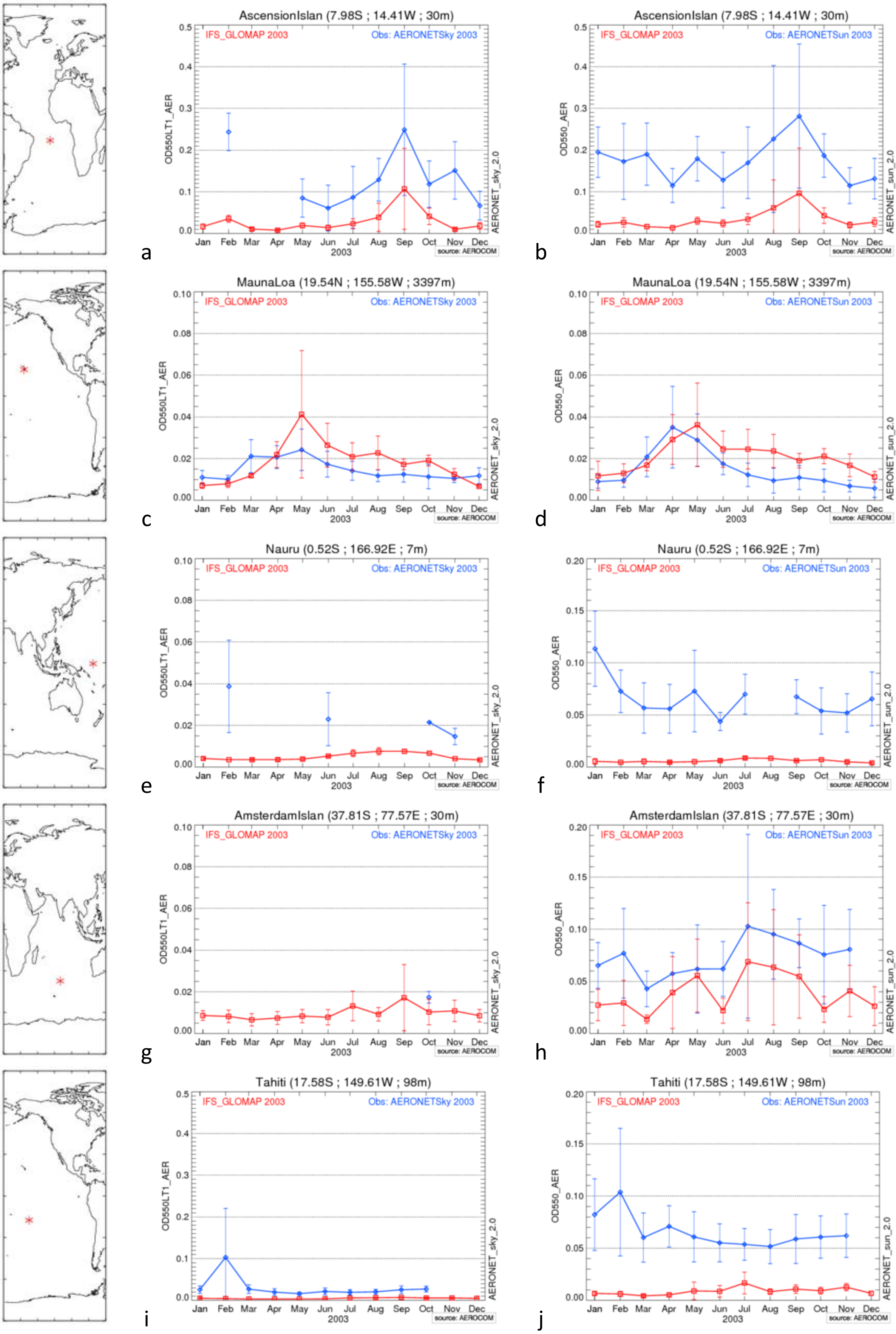


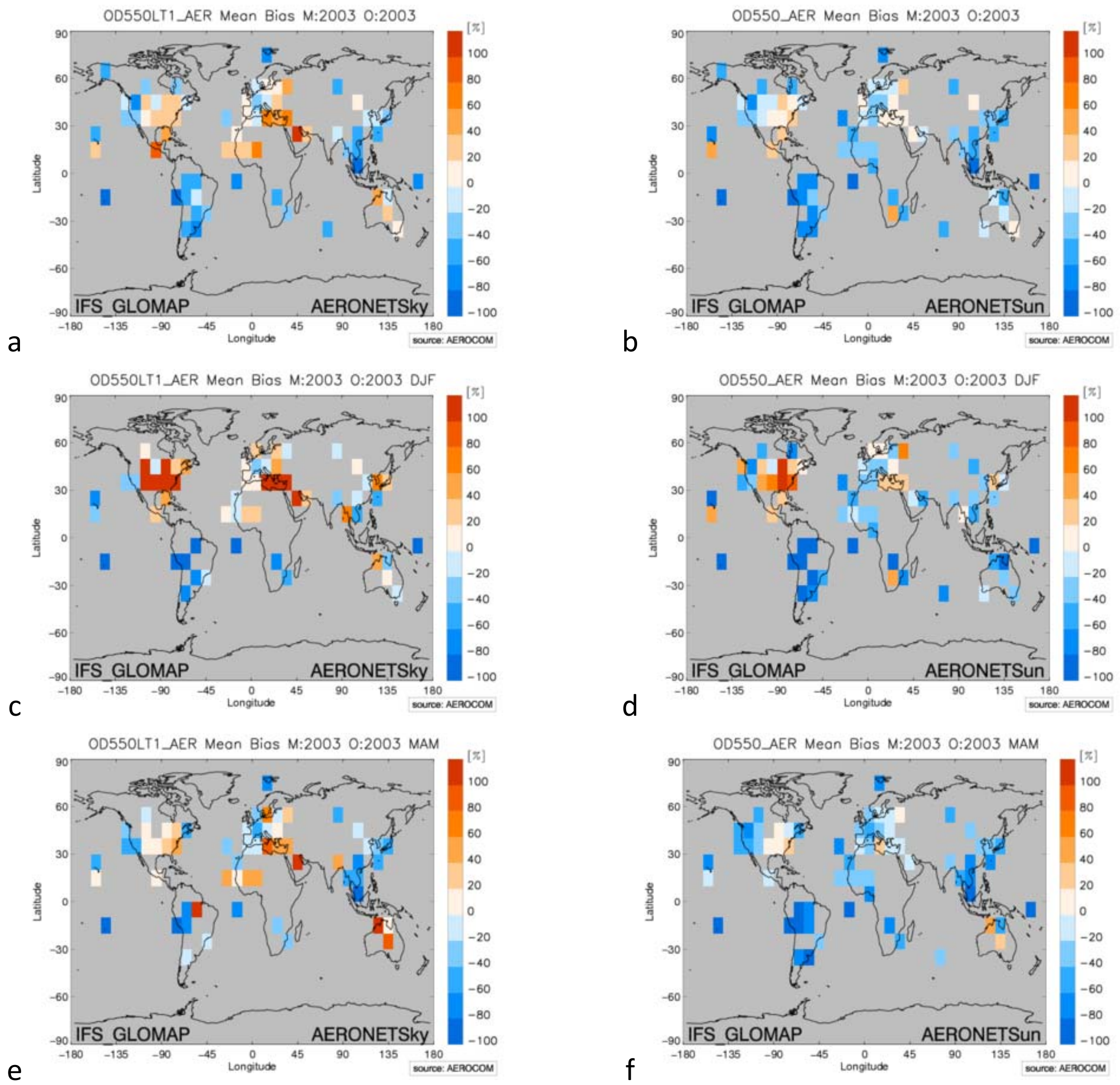
Fig. 7. As Fig. 2 but for remote ocean sites. Note that scatterplots are not available for this domain.

With the exception of Mauna Loa, the remote marine sites show a very low bias compared to AERONET observations (Fig. 7). The locations of these sites preclude a significant anthropogenic influence, so the low bias can be ascribed to either a missing natural source of aerosol (e.g. DMS, or too-weak sea-salt emissions), or overly vigorous removal of aerosol (e.g. nucleation scavenging). The current simulations lack DMS, but it is unlikely including DMS would increase the AOD enough to make IFS-GLOMAP comparable to the observations. Furthermore, with the exception of Nauru and Tahiti, IFS-GLOMAP does capture the seasonal cycle at some remote marine sites well, suggesting that the missing aerosol is not biogenic in origin.

It is worth stating that no tuning has been undertaken on the removal processes in IFS-GLOMAP. Further analysis of the sea-salt source and sinks is needed to determine why the model is underestimating marine aerosol.

Global performance

The AeroCom analysis also produces plots of the bias against AERONET meaned over limited area domains. These plots are shown in Fig. 8.



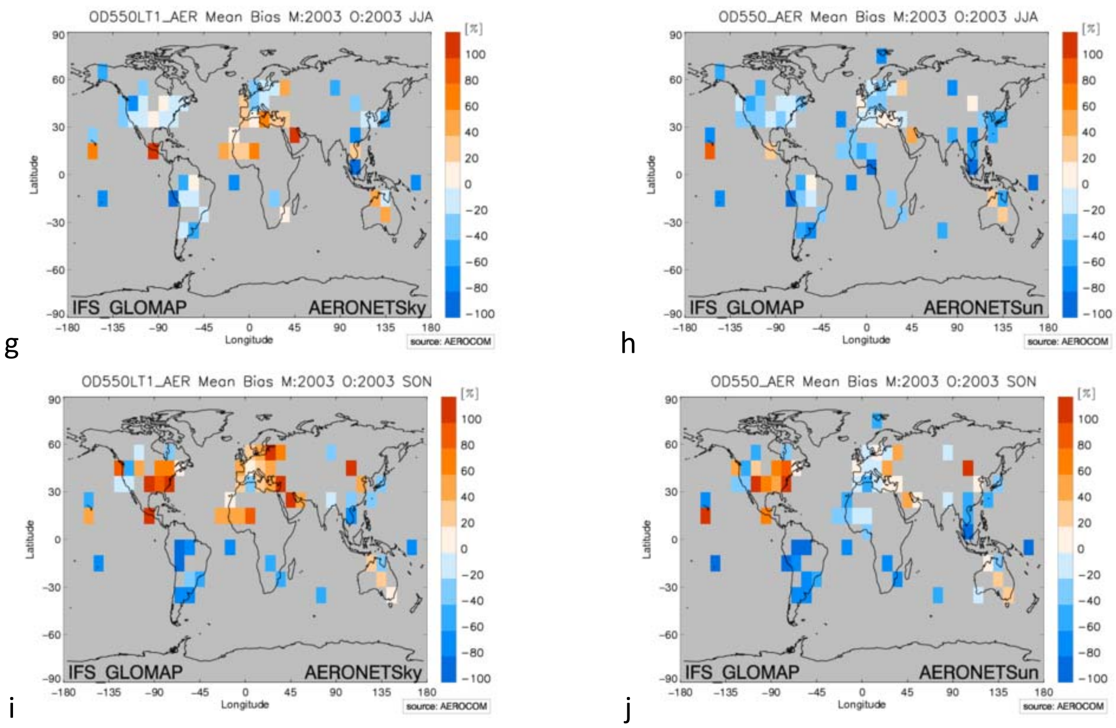


Fig. 8. Mean bias maps showing the performance of IFS-GLOMAP in comparison to AERONET observations. Fine-mode (left column) and total AOD (right column) are shown. Top row is annual mean, subsequent rows are seasonal means.

The underestimate of South American AOD is clear in the plots in Fig. 8 across all seasons. Also clear is the high bias in fine-mode AOD and low bias in coarse-mode AOD coming from North African mineral dust aerosol. South Africa is also subject to a low bias compared to the AERONET observations, across all seasons.

Comparing IFS-GLOMAP against all available measurements in North America reveals a high bias between September and February. A similar pattern is also noted in Europe. Asian AOD is generally underestimated throughout the year.

Global annual mean modelled and measured AOD's are shown in Fig. 9. The overall performance of IFS-GLOMAP in the fine-mode is very encouraging, with a bias of -6.3%. However, the total AOD bias is -27.1% suggesting a very large shortfall in the coarse AOD fraction. A significant portion of this shortfall clearly comes from the marine, South American and North African domains. The causes of this shortfall require a more detailed investigation.

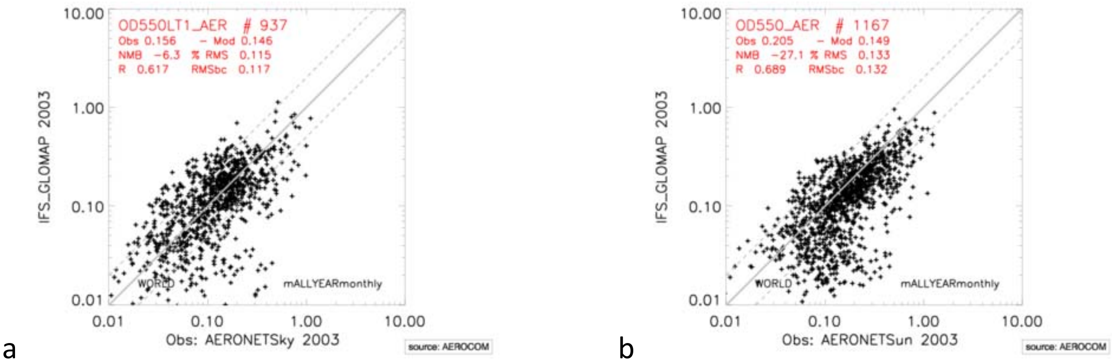


Fig. 9. Global scatter plots comparing IFS-GLOMAP and AERONET fine and total AOD.

Conclusions

This report evaluates the performance of the GLOMAP-mode aerosol scheme in the IFS model, making comparisons of modelled-derived AOD with observations from the AERONET network. Model performance is evaluated on a regional and global basis. As the current implementation of IFS-GLOMAP does not include dust emissions, dust AOD from a simulation with the existing GEMS/MACC aerosol scheme was included in this evaluation.

Globally, fine-mode AOD is reproduced well by the model. A significant low-bias is apparent in South America (Figs. 6g and 7a). The remote oceans also show a low bias in both fine-mode and total AOD, partially explained by the lack of DMS in these simulations, but perhaps also by overly vigorous removal.

Total AOD is biased significantly low. The underestimated marine aerosol will account for a significant part of this underestimate. The AERONET comparison over North Africa suggests a deficiency in modelled coarse mode dust AOD, partially compensated for by too-high fine-mode AOD. Over regions under strong anthropogenic influence (eastern US, Europe and Asia), both fine-mode and total AOD are reproduced well.

The complex nature of aerosol sources and processes makes disentangling the cause of a high or low bias in AOD very difficult. Deeper analysis examining specific sources and sinks, and comparison to in situ observations, will help to determine where the model can be improved upon. It is worth noting that no tuning has been done to any part of the model to make it specific to the IFS. The comparisons in this report are thus very encouraging.

In contrast to the existing GEMS/MACC model, RADAER does not calculate speciated AOD as the aerosol within any given mode is internally mixed. A surrogate for the speciated AOD could be derived, after making some coarse assumptions (assume each components AOD is proportional to the volume fraction of that component).

Development of IFS-GLOMAP is ongoing. In the near term, IFS-GLOMAP will be coupled with the C-IFS chemical scheme. This coupling will enable inclusion of a source of DMS, and also improve the seasonal representation of anthropogenic sulphate aerosol. The more complex chemistry associated with nitrate aerosol could also be simulated with coupled chemistry, leading to the inclusion of nitrate aerosol in IFS-GLOMAP simulations. Inclusion of dust will also be examined, though dust emission parameterizations are highly dependent on the host model land surface scheme.

Acknowledgements
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