Application and evaluation of the Oxford-RAL Retrieval of Aerosol and Cloud algorithm to MODIS data

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Introduction

The Oxford-RAL Retrieval of Aerosol and Cloud (ORAC) algorithm is an optimal estimation retrieval scheme for visible-IR imaging satellite radiometers. As part of the ESA Cloud_CCI project, the ORAC scheme has been applied to MODIS, AVHRR and AATSR data, using a set of "heritage channels" common to all three instruments. As MODIS (Aqua) is part of the A-Train formation of satellites, this has provided a wealth of validation and intercomparison data not previously available for assessing the ORAC algorithm. This poster provides a description ORAC, which is now publicly available as an open-source community algorithm, and presents results of comparisons of ORAC retrievals from all three instruments against CloudSat, Calipso and existing MODIS cloud products.

The ORAC algorithm

ORAC is an optimal estimation (OE) scheme for the retrieval of cloud and/or aerosol properties from visible/IR imaging radiometers. It was originally developed (as the Enhanced Cloud Processor [Watts et al. 1998]) for application to the SEVIRI instrument on board the second generation Meteosats, but has since been extended and adapted to work with a range of instruments including the Along Track Scanning Radiometers (ATSR-2 and AATSR) and the Advanced Very High Resolution Radiometers (AVHRR). The algorithm has been applied to the ATSR-2 and AATSR data to produce the 15 year "Global Retrieval of ATSR Cloud Parameters and Evaluation" (GRAPE) cloud and aerosol data set [Thomas et al., 2009, Thomas et al. 2010, Sayer et al. 2011, Poulsen et al. 2011].

In cloud-retrieval form, the algorithm uses a single-layer plane parallel forward model of cloud transmission, reflectance and thermal emission – with atmospheric temperature and transmission defined by ECMWF reanalysis and RTTOV – to predict the top-of-atmosphere radiances measured by a satellite instrument. The forward model also includes a BRDF model of the surface reflectance, based on a wind, chlorophyll and *Gelbstoff* driven ocean reflectance model over the sea, and the Ambrals BRDF model over the land.

The forward model is fit to satellite radiances (or reflectances/brightness temperatures) using the OE framework of Rogers [2000], providing estimates of:

- Cloud optical depth
- Cloud effective radius
- Cloud top pressure (plus height and temperature)

with the additional surface parameters of

- Surface temperature
- Surface reflectance

The use of an OE retrieval algorithm provides several distinct advantages:

- Full error characterisation and propagation is integral to the algorithm, providing pixel by pixel uncertainty estimates on the retrieved state.
- A rigorous and consistent method for the inclusion of *a priori* information on retrieved parameters is also integral to the algorithm.
- The retrieval produces a range of quality control information, including "cost" (a measure of the consistency of the assumed and retrieved parameters with the measurement and *a priori*), weighting functions (the sensitivity of each retrieved parameter to each measurement) and averaging kernels (the sensitivity of retrieved parameters to their true values).
- The algorithm simultaneously fits all retrieved parameters using all available measurements, thus ensuring optimal use of the information provided by the measurement.

The algorithm is in the process of being realised as a "community algorithm", freely available for download for registered users.

As part of the European Space Agencies Cloud_CCI (Climate Change Initiative) project the algorithm has now been applied to MODIS data for the first time, enabling comparison with similar cloud retrievals and the active CALIPSO and CloudSat sensors in the A-Train.

http://www.esa-cloud-cci.org Cloud_CCI website
http://proj.badc.rl.ac.uk/orac ORAC TRAC software archive

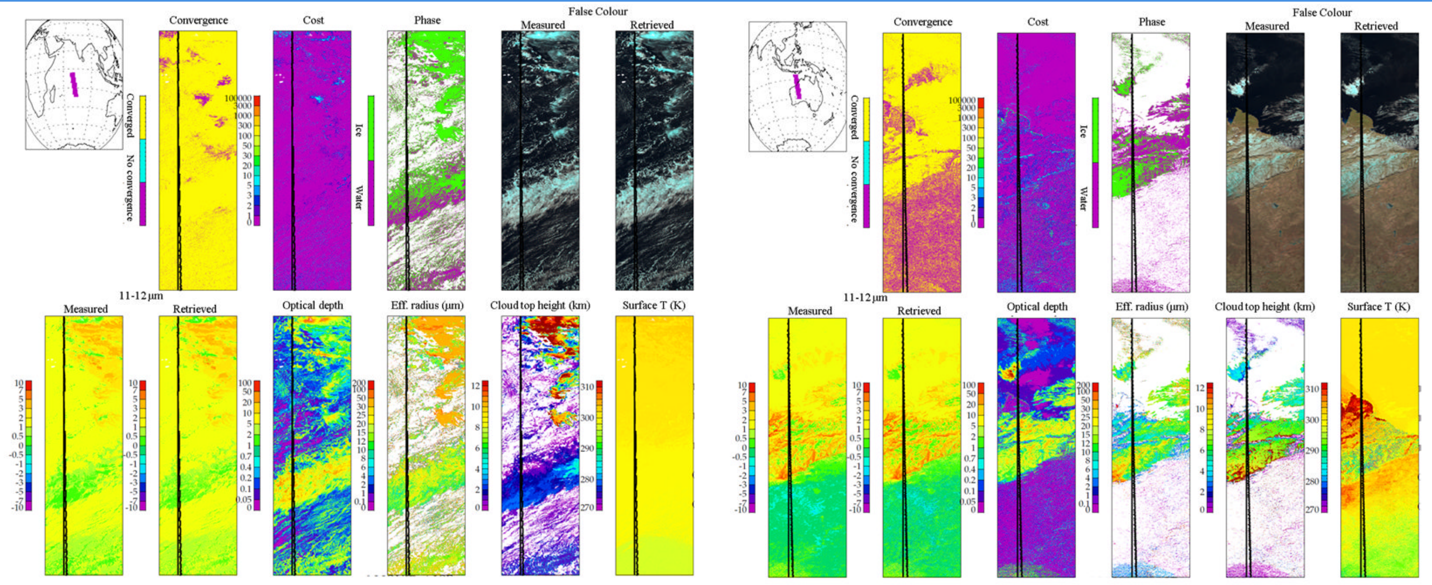


Figure 1: Example retrievals from ORAC applied to MODIS data. One scene is over ocean, whereas the other shows a challenging desert scene. Only "heritage channels" common between MODIS, AATSR and AVHRR have been used in the retrieval and only the central region of the swath has been processed, to provide colocation with CALISPO and CloudSat (tracks indicated by the black lines in the images). Cloud/clear masking was performed *a posteriori* using a simple optical depth threshold of 0.3

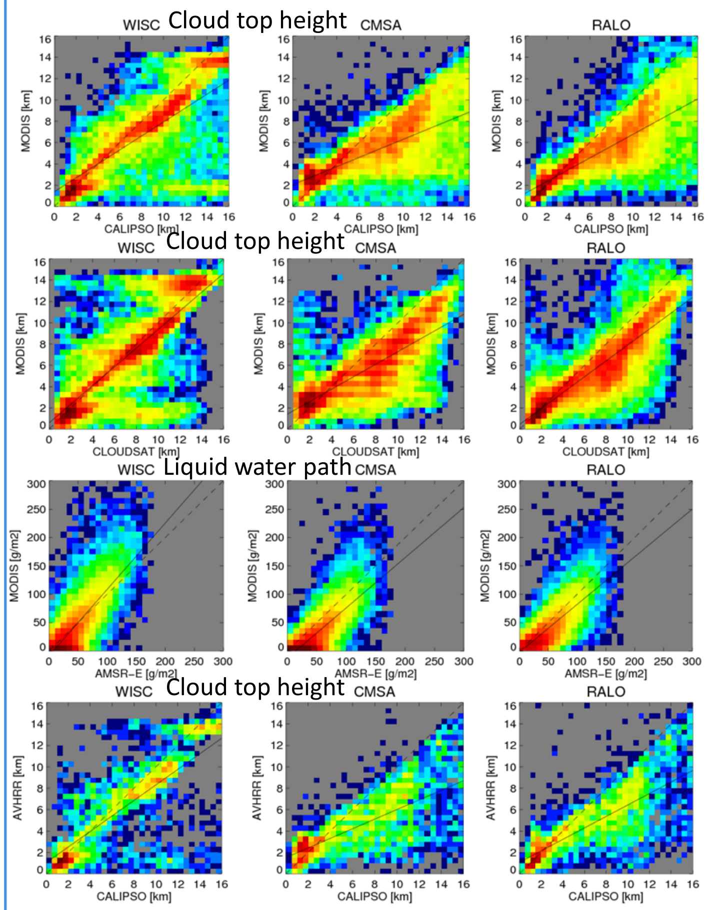


Figure 2: Comparisons of the three algorithms included in the Cloud_CCI round robin with CALIPSO and CloudSat cloud top height and AMSR-E liquid water path. The lower panels show a repeat of the CALIPSO comparison, but using AVHRR data rather than MODIS. The density of points is indicated by the warmth of the plot colour.

The three algorithms are:

- **WISC**: The Daytime Cloud Optical Microphysical Properties (DCOMP) algorithm used in deriving cloud properties for the PATMOS-X climatology [Walther et al. 2011].
- **CMSA**: The CM SAF algorithm combining the CPP (cloud physical properties) algorithm developed at KNMI and PPS (Polar Platform System) [Dybbroe et al. 2005a,b] cloud processing package developed by SMHI.
- **ORAC**: The algorithm discussed here.

An important distinction can be made between CM SAF and ORAC compared to the WISC results, as the latter uses a climatology based on CALIPSO data to provide *a priori* constraint on cloud height.

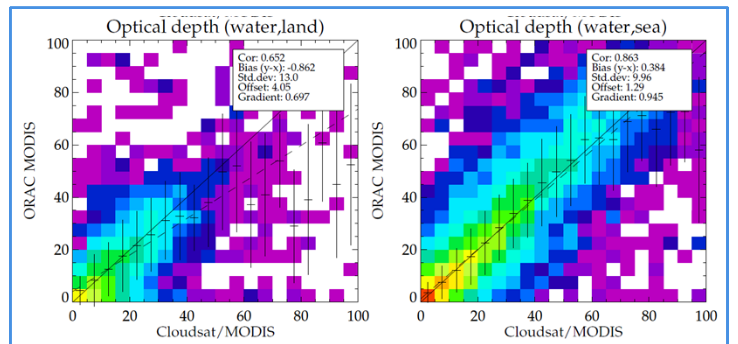
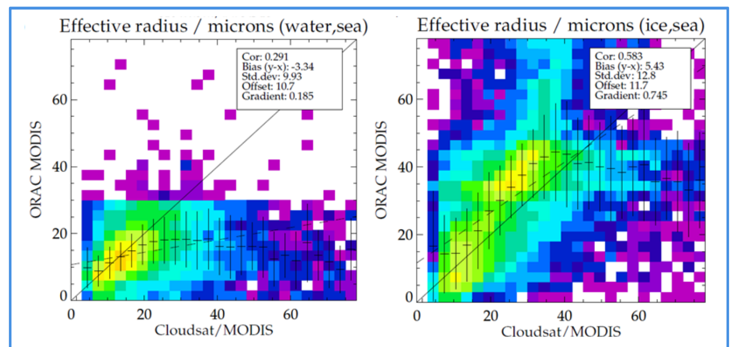


Figure 3: Comparisons of optical depth for water clouds between MODIS ORAC and the standard combined CloudSat-MODIS optical depth product (MOD06).



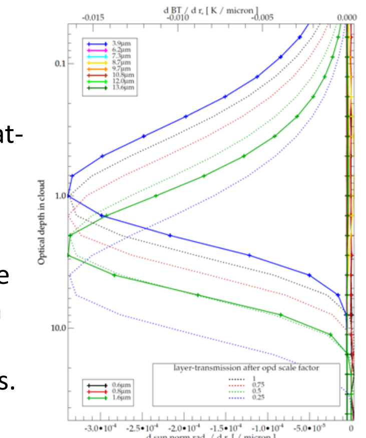


Figure 4: Comparisons of effective radius between MODIS ORAC and the standard combined CloudSat-MODIS product (MOD06).

The cut-off in ORAC water effective radius at 30 µm is due to the limited size range of the lookup tables used in the retrieval and will be addressed in future versions.

Comparisons of effective radius are greatly complicated by the differing penetration depths of different wavelengths into the cloud. Different instruments or algorithms are thus often sampling particle size at different vertical positions within clouds, making direct comparison difficult

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Cloud_CCI

The Climate Change Initiative (CCI) is a group of 11 projects being undertaken on behalf of ESA with the goal of using European satellite sensors to provide a set of Essential Climate Variables, as defined by the WMO Global Climate Observing System. ORAC is a central component of the Cloud_CCI project, as it will form the basis of a community algorithm which will be used to produce a prototype cloud ECV product. The AATSR instrument and it's predecessor ATSR-2 and follow on, the Sea & Land Surface Temperature Radiometer (SLSTR), will form the basis of the Cloud_CCI product and together offer an ongoing 16 year record of cloud properties; with better instrument calibration and orbital consistency than the AVHRR record.

Central to all CCI projects are round robin intercomparisons and evaluation of alternative algorithms that could form the basis of the ECV production. The Cloud_CCI round robin is on-going, and involves the three algorithms described in Figure 2. The approach taken in the Cloud_CCI round robin is to compare the three algorithms applied to a common set of "legacy channels" that are common between AVHRR, AATSR and MODIS (0.67, 0.87, 1.6 and/or 3.7, 11 and 12 µm) and compare these to cloud top height products from A-train active sensors (CloudSat and CALIPSO, which might be expected to provide more reliable estimates of height) and the Advanced Microwave Scanning Radiometer for EOS (AMSR-E), which provides reliable cloud water measurements.

Use of the A-train means that retrievals using MODIS provide the best intercomparisons, but results from AVHRR and AATSR (for limited orbital overlaps at high latitudes) also form part of the round robin exercise.

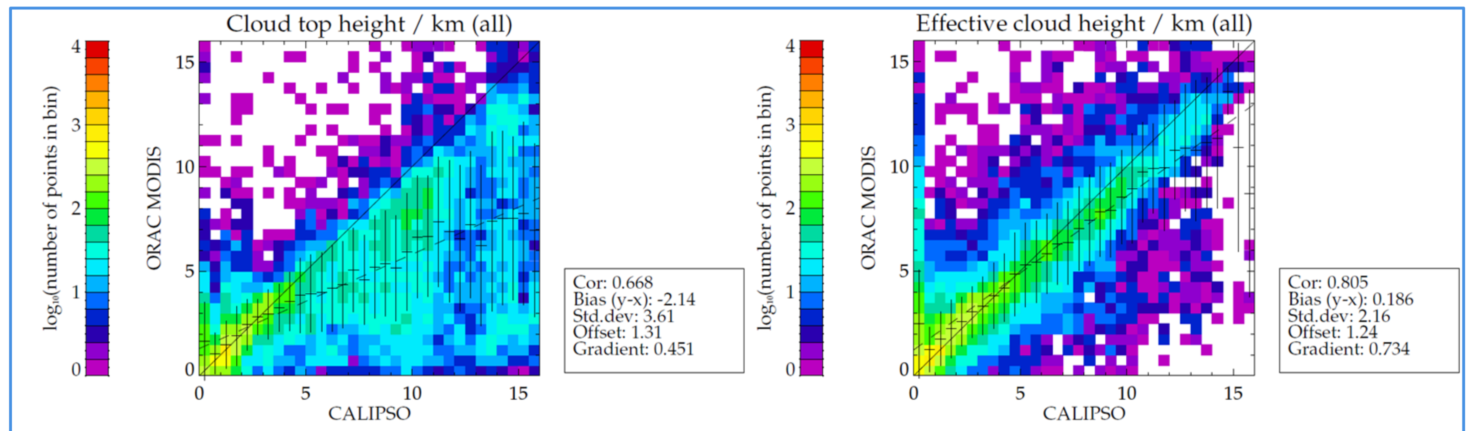

Figure 5: Penetration distance is also an issue when comparing cloud top height retrieved by CALIPSO, measuring in the shortwave, and thermal infrared based retrievals such as ORAC . Using the CALIPSO cloud layer optical depth, the effective thermal emission height can be estimated, which results in a substantial improvement in the correspondence the ORAC cloud top height. A similar correction can be applied to CloudSat heights, although it provides no noticeable improvement in the comparison with ORAC, suggesting that other error sources dominate in this case.

Conclusion

The application of the ORAC algorithm to the MODIS radiances has provided a great opportunity to compare it with comparable algorithms, as well as with the suite of A-Train sensors; and the Cloud_CCI round robin exercise providing a framework to fully exploit this opportunity. The algorithm is performing largely as expected and shows good agreement with the datasets compared against. The wealth of comparisons now available provide good scope for identifying and improving problem areas in the retrieval.

The round robin exercise has thrown up subtleties in comparing datasets and gaps in the available data, which are of relevance both to data comparison and using them for model comparison/validation. In particular, the radiative properties of the clouds themselves must be taken into account when comparing quantities such as cloud top height and effective radius, as retrieved values depend strongly on the methodology and spectral range used by each instrument and algorithm.

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