Inter-comparison of atmospheric correction algorithms for MODIS: Evaluation with emphasis on coastal waters

Thomas Schroeder [1], Bouchra Nechad [2], Kevin Ruddick [2], Roland Doerffer [3], Michael Schaale [4], Vittorio Brando [5], Arnold Dekker [5]

1 CSIRO Land and Water, Environmental Earth Observation Program, GPO Box 2583, Brisbane, QLD 4001, Australia
2 Management Unit of the Mathematical Models of the North Sea, Royal Institute for Natural Sciences, 100 Gudlledelle, B-1200, Brussels, Belgium
3 GKSS Research Centre, Institute for Coastal Research, Max Planck Strasse 1, D-21502, Geesthacht, Germany
4 Freie Universität Berlin, Department of Earth Sciences, Institute for Space Sciences, Carl-Heinrich-Becker-Weg 6-10, D-12165 Berlin, Germany
5 CSIRO Land and Water, Environmental Earth Observation Program, GPO Box 1666, Canberra, ACT, Australia

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Objective Accurate atmospheric correction (AC) is a prerequisite for quantitative ocean color remote sensing and remains a challenge above optically complex coastal waters due to the difficulty of separating the atmospheric path radiance from the water-leaving radiance. Atmospheric correction algorithms have been extensively validated alone but rarely been inter-compared. The performance of six atmospheric correction methods were compared for the Terra and Aqua Moderate Resolution Imaging Spectroradiometers using shipborne above water reflectance measurements.

Algorithms **(1)** The standard near-infrared (NIR) AC [Ref. 1], **(2)** the shortwave-infrared (SWIR) AC [Ref. 2], **(3)** the NIR-SWIR switching AC method [Ref. 3] all three (1-3) as implemented in SeaDAS version 6.1 **(4)** the MUMM turbid water plugin [Ref. 4] **(5)** CSIRO's Artificial Neural Network AC [Ref. 5] and **(6)** the MOD09 land surface AC algorithm [Ref. 6].

In-situ data In-situ above-water reflectance data were collected by MUMM, GKSS and CSIRO during various cruises between 2001 and 2008 (Tab. 1). In total 837 reflectance spectra were obtained during these campaigns and combined into a data base, which was subsequently used for match-up analysis.

MUMM used a system of three TriOS-RAMSES hyper-spectral spectro-radiometers to simultaneously collect above-water measurements of the down-welling irradiance (E_d), the upwelling radiance (L_{SEA}), and the sky radiance (L_{SKY}). Conversion into reflectance then followed the REVAMP protocols. CSIRO measured the above water reflectance with only one TRiOS radiance sensor from subsequent L_{SEA}, L_{SKY} measurements during absolute clear sky conditions along with indirect E_d measurements obtained from radiance measurements of a Spectralon 99% reflectance panel. Further processing was in accordance with MUMM. GKSS deployed the SIMBADA hand-held field radiometer to obtain above water-reflectance from subsequent L_{SEA} and sun radiance L_{SUN} measurements.

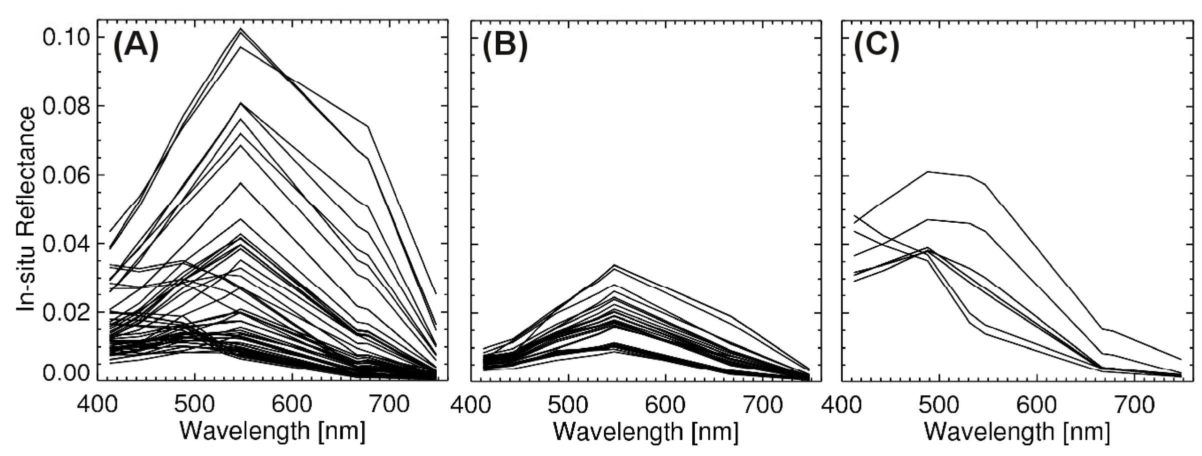

Figure 1: Variability of in-situ match-up spectra collected by MUMM (A), GKSS (B) and CSIRO (C). Data interpolated to MODIS bands.

Institution	Time period	Sampling locations	Campaigns/ stations	Match-ups Terra/Aqua
MUMM	18.06.2001-31.07.2008	Belgian coast, English Channel, Celtic Sea, Portuguese and Spanish coast	59/751	32/26
GKSS	23.04.2003-06.08.2003	North Sea	2/66	17/16
CSIRO	20.09.2007-23.04.2008	Great Barrier Reef	2/20	3/7

Table 1: Location and dates of the MUMM, GKSS and CSIRO field campaigns during which above water-reflectance data was collected and associated match-ups within ±3h of the satellite overpass. See maps in Fig. 2 for sampling locations.

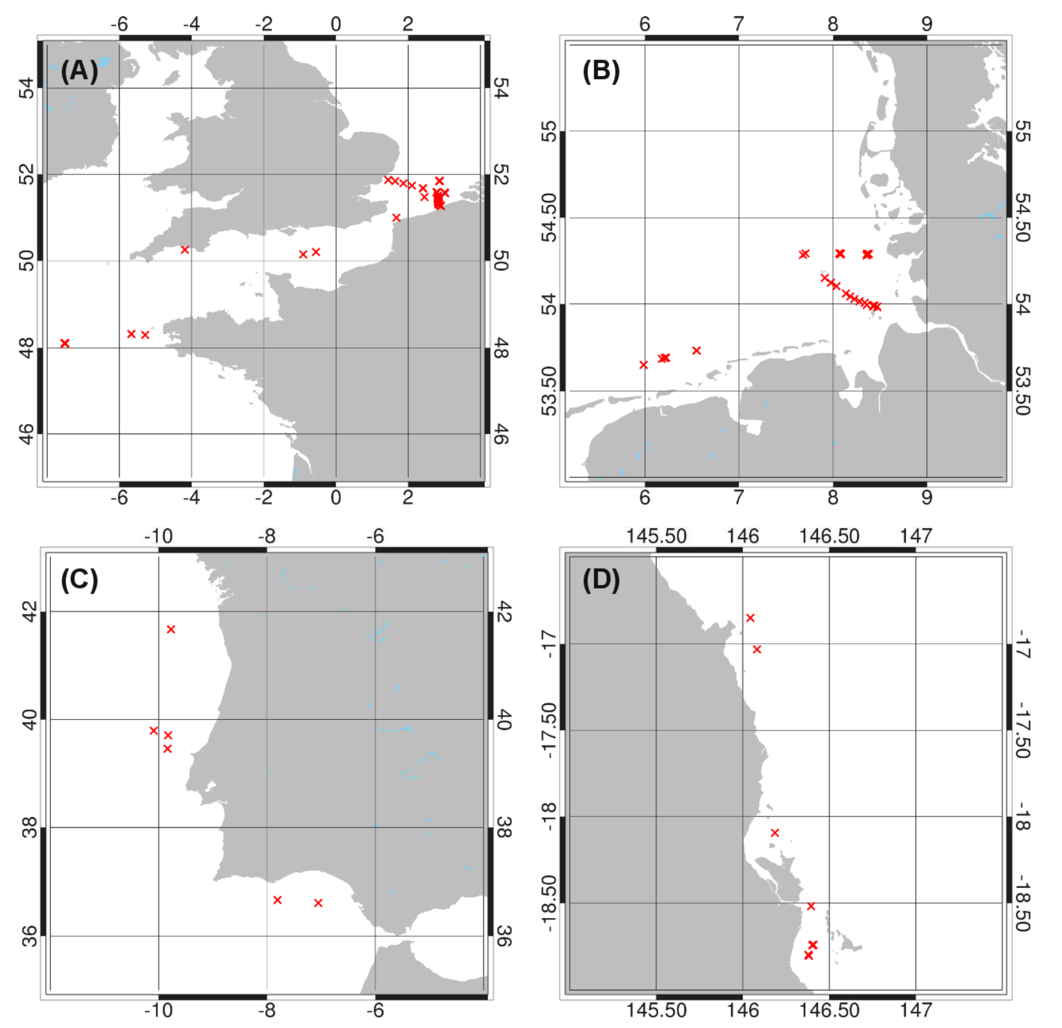

Figure 2: Match-up locations of the in-situ data at a maximum time difference of ±3 h to the Terra and Aqua over passes. Panel (A,C) measurements performed by MUMM (Celtic Sea, English Channel, Belgian, Portuguese and Spanish coast), (B) by GKSS (North Sea) and (D) by the CSIRO (Great Barrier Reef).

Match-up analysis The accuracy of the atmospheric correction algorithms was assessed by match-up analysis, extracting 3x3 satellite pixels from the processed MODIS images at the location of the in-situ measurements and comparing the median with the in-situ reflectance spectra within a maximum time window (T) of ±3 hours to the satellite overpasses. A valid match-up required the location difference to be less than 0.01 degree in both latitude and longitude dimensions. To enable algorithm inter-comparison only a single match-up data set (i.e. the same set for all algorithms) was extracted by applying a common set of flags for quality control and exclusion of erroneous and out-of-range pixels. In detail, we flagged land, cloud/ice, or high sun glint in addition to high sun angles above 75 degrees and observer zenith angles above 60 degrees using the Level 2 flags provided by SeaDAS. A valid match-up required all nine pixels of the match-up area to be valid (unflagged).

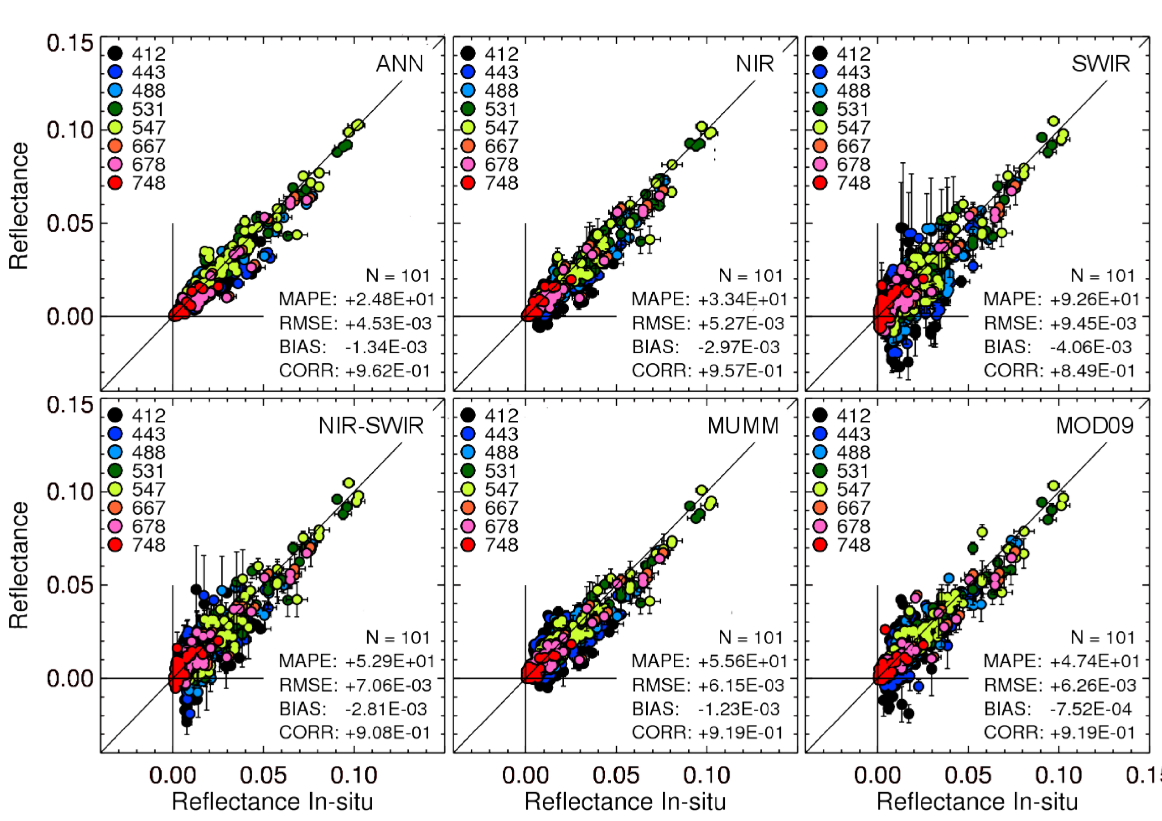

Figure 3: Scatter plots of in-situ versus satellite estimated reflectance for each AC method at a maximum time difference of ±3 hours to the Terra and Aqua overpasses.

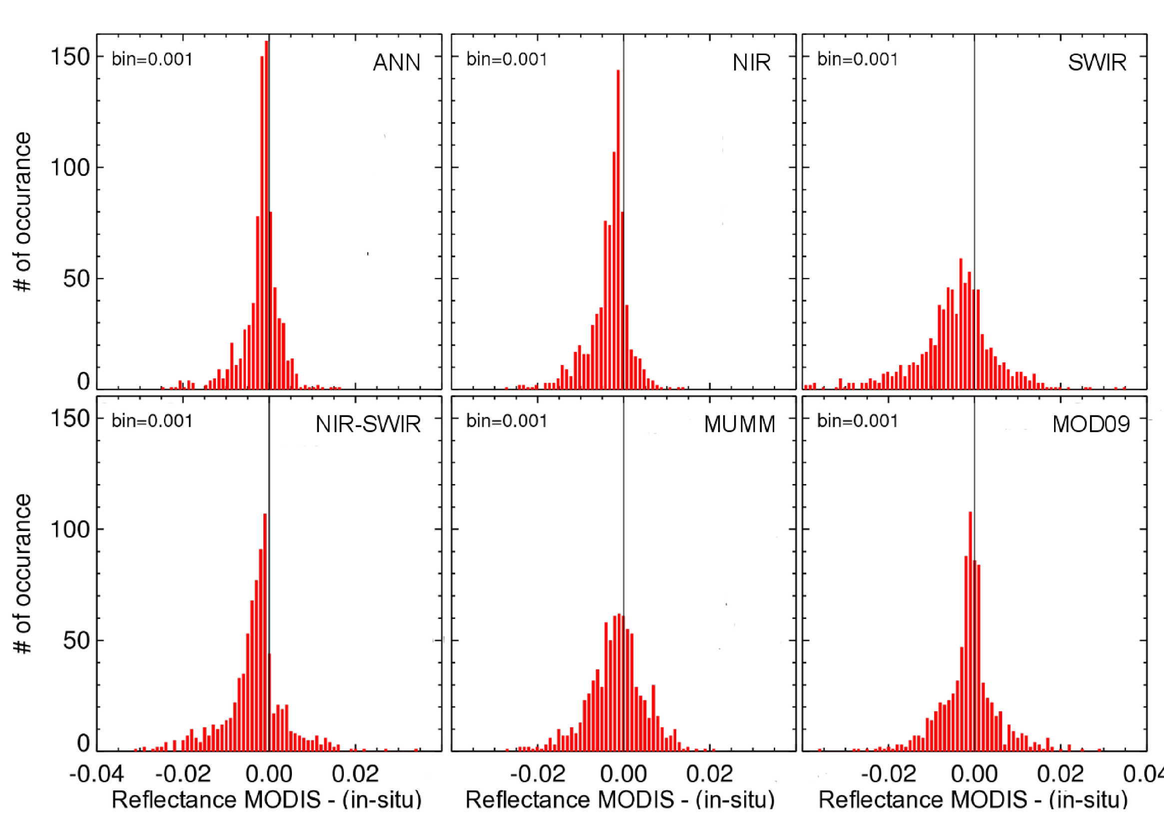

Figure 4: Histograms of the absolute difference between in-situ and satellite retrieved reflectance for each AC method at a maximum time difference of ±3 hours to the Terra and Aqua overpasses.

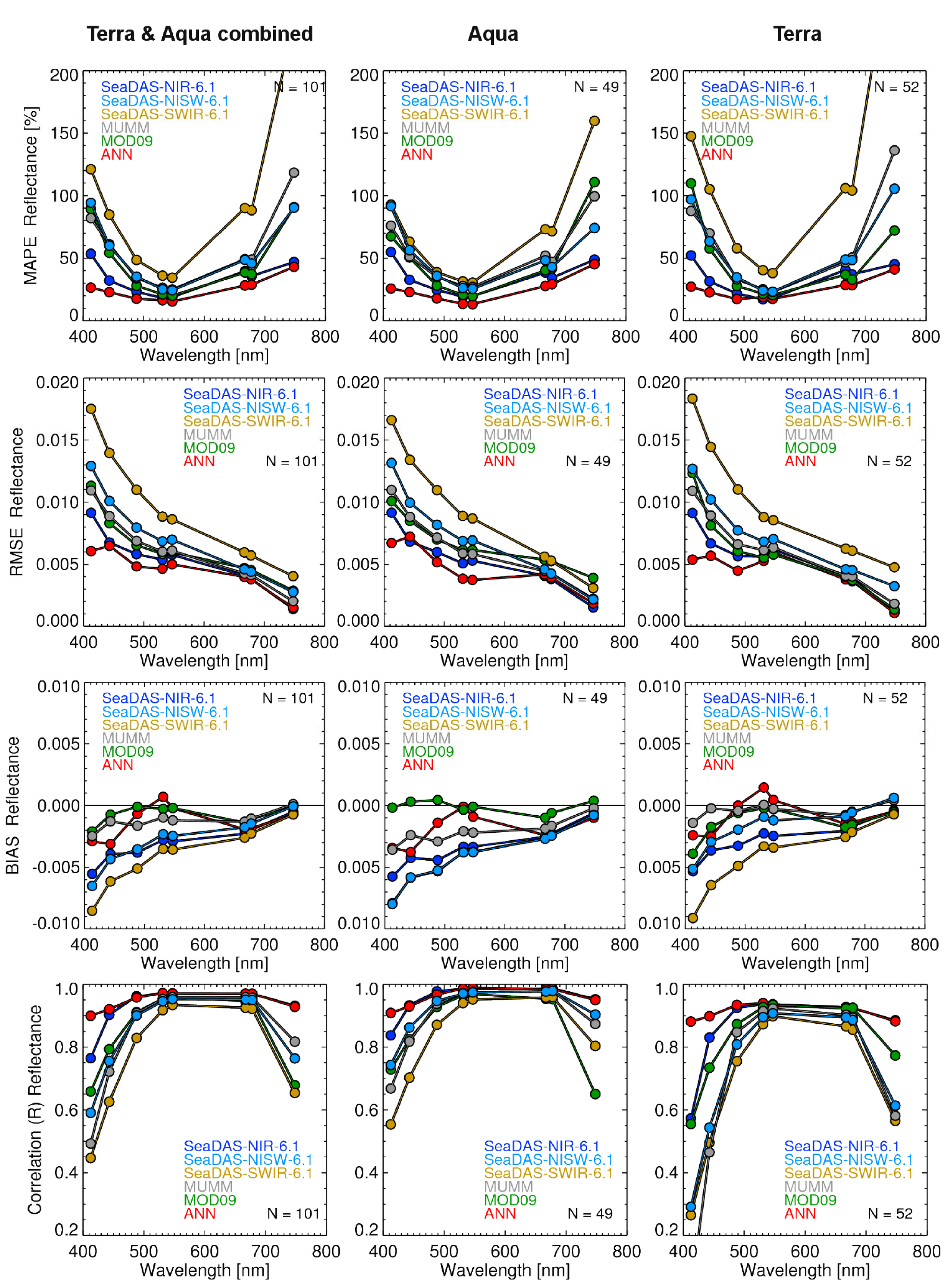

Figure 5: Spectral match-up statistics at a maximum time difference of ±3 hours between in-situ and satellite observations for MODIS Terra and Aqua combined (left column), Aqua only (centre column) and Terra only (right column).

Results

- ANN showed distinctly better results at 412.5 nm (MAPE 26%) than the algorithms that extrapolate aerosol reflectance from the NIR or SWIR to the shorter wavelengths.
- Standard NIR correction showed second best performance and was the most accurate SeaDAS v6.1 algorithm compared in this study.
- Least accurate results were obtained with the native SWIR correction that produced noisy outputs due to the low signal-to-noise of the SWIR bands.
- However good results were obtained from SWIR on a case by case basis and above the recommended turbidity threshold.
- Switching from native SWIR to NISW reduced the overall retrieval errors.
- MOD09 AC algorithm showed relatively good agreement with the in-situ reflectance data analyzed in this study even though it was developed for land applications.
- Unphysical negative reflectance data were retrieved by all algorithms except for Aqua NIR within T±1 hour and the ANN algorithm.
- Future inter-comparison studies should include synthetic data, which would allow a more comprehensive performance assessment by testing for specific and atmospheric conditions algorithm limitations.
- A free copy of the ANN code can be obtained from the principle author.

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GKSS FORSCHUNGSZENTRUM in der HELMHOLTZ GEMEINSCHAFT
Freie Universität Berlin
Management Unit of the North Sea Mathematical Models, Royal Institute of Natural Sciences

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[1]CSIRO Land and Water, Brisbane, QLD 4102, Australia
[2]Management Unit of the North Sea Mathematical Models, 100 Gulledelle, B-1200 Brussels, Belgium
[3]GKSS Research Centre, Institute for Coastal Research, Geesthacht, Germany
[4]Freie Universitaet Berlin, Department of Earth Sciences, Institute for Space Sciences, Berlin, Germany
[5]CSIRO Land and Water, Canberra, ACT 2601, Australia

ABSTRACT

This study aims at evaluating the performance of six atmospheric correction algorithms for the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the Terra (EOS AM) and Aqua (EOS PM) satellites. Algorithm performance was assessed by match-up analysis, comparing satellite estimates of spectral above water remote sensing reflectance with in-situ measured reflectance data. The in-situ measurements were collected by MUMM, GKSS and CSIRO, predominately in European and Australian coastal waters, during various field campaigns between 2001 and 2008. In detail, we compared three SeaDAS (v6.1) implemented atmospheric correction methods – the standard near-infrared (NIR) correction, the shortwave-infrared (SWIR) algorithm and the NIR-SWIR switching algorithm, along with the MUMM turbid water plug-in and CSIRO's Artificial Neural Network (ANN) approach. Further, we included the MOD09 land surface reflectance algorithm to evaluate its performance for coastal application. All algorithms were compared using the same match-up data set by applying a common set of flags for quality control and exclusion of erroneous and out-of-range pixels. Several band averaged and spectrally resolved error statistics were computed at different time steps (±1-3 h) to the satellite over passes including different match-up area sizes – for Terra/Aqua combined and for each sensor separately. Aqua performed overall better than Terra using the SWIR, NIR-SWIR, MOD09 and MUMM algorithms, whereas both sensors showed similar good results from the application of the NIR and ANN methods. Overall best performance was obtained with the neural network approach, followed by the standard NIR correction. Least accurate results were found with native SWIR processing, which resulted in noisy outputs due to the low signal-to-noise of the SWIR bands and improper filtering for below threshold turbidity indices. Nevertheless, good results were obtained from SWIR on a case by case basis. Switching from native SWIR to NIR-SWIR reduced the overall retrieval errors. More detailed results will be presented.

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