LIMITATIONS OF THE APPLICATION OF THE MERIS ATMOSPHERIC CORRECTION

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ABSTRACT

The atmospheric correction of MERIS is working well for open ocean waters and shows acceptable performance also over coastal waters. However, this is valid only under conditions of standard aerosols, not exceptionally scattering particles in the water, good illumination conditions and free of disturbances from the coast or clouds. Unfortunately, these conditions are not always prevailing, and particularly over Northern European waters, which are ecologically and economically very important, they are often not met and the atmospheric correction fails.

The MERIS atmospheric correction consists of two parts: the Case 1 water atmospheric correction and an extension to this method for Case 2 waters. The algorithm is providing water leaving reflectance and accompanying flags. On average, more than 50% of the water pixel of a MERIS RR scene cannot be atmospherically corrected. The main reasons are residual clouds, high aerosol optical thickness, sea ice or sun glint, or a failure of the atmospheric correction. The main reasons are not always prevailing, and particularly over Northern European waters, which are ecologically and economically very important, they are often not met and the atmospheric correction fails.

1. INTRODUCTION

The MERIS atmospheric correction over water has been improved from the early days of the instrument. With the second reprocessing, a generally good performance has been achieved. However, the method basically relies on the assumption that the measurement in the near infrared (NIR) part of the spectrum is solely caused by the atmosphere. This assumption is not always fulfilled and its exploitation requires a highly precise measurement in the NIR. Measurements in the coastal zone, particularly in Northern areas, do not always provide best preconditions for such measurements. For example, between November and February the sun is very low and often exceeds a sun zenith angle of 65° where the plan-parallel assumption, which is used in the algorithm, reaches its limits. During the summer months, the sun glint limits the usage of large portions of the MERIS swath. Clouds often cover large parts of the area. Close to the shore, the environment effect is becoming very important because of the fragmented shape of the coast. The atmospheric correction of MERIS reaches here its limits, and it is very important to know these limits and to start a process to improve the atmospheric correction in order to overcome limitations where possible.

2. MERIS ATMOSPHERIC CORRECTION

The atmospheric correction of MERIS consists of two parts: the ocean atmospheric correction developed by Antoine and Morel [1], which is applicable for Case 1 waters and an extension to this method which covers Case 2 waters developed by Aiken and Moore [2]. The Case 1 water atmospheric correction assumes that only chlorophyll in the water determines the water leaving reflectance, and no water leaving reflectance exists in the NIR bands. MERIS measurements in bands 12 (779nm) and 13 (865nm) are used to identify an aerosol, which would produce these reflectances under the given illumination and viewing conditions. The matching aerosol is a mixture of two so called bracketing aerosols, which are closest to the measurements. A test band 3 (510nm), where the chlorophyll absorption is at its minimum and the water leaving reflectances can be assumed independent of the actual chlorophyll concentration, is used to double check if the selected aerosol model is valid when it is used to extrapolate the path radiance from the NIR into the visible spectral range. In Case 2 waters suspended sediments and yellow substance contribute to the water leaving reflectance, and neither the assumption of negligible signal in the NIR nor the constant signal at 510nm are valid. The extension of the atmospheric correction for Case 2 waters consists of simultaneous retrieval of the water leaving reflectance and the atmospheric path radiance in bands 10 (709nm), 12 (779nm) and 13 (865nm). Using these retrieved surface reflectances, the water leaving reflectance also in band 3 (510nm) is estimated. The water leaving reflectances in these 4 bands (3, 10, 12, 13) are then subtracted from the measured reflectances, so that the assumptions of the Case 1 water atmospheric correction are fulfilled. Since the transition from clear Case 1 water to sediment
loaded Case 2 water is smooth, switching of the Case 2 atmospheric correction extension, when a certain threshold is exceeded, would cause visual artefacts in the water leaving reflectance images. On the other hand, the physics of the Case 2 waters atmospheric correction algorithm causes a negligible correction term (water leaving reflectance in the 4 considered bands) in Case 1 waters. It has therefore been decided to apply the Case 2 atmospheric correction to all water pixels. However, recent investigations [3] have shown that the effect of the Case 2 atmospheric correction extension in Case 1 waters could be responsible for an overcorrection under certain circumstances. This is currently under investigation by the MERIS Data Quality Working Group.

The MERIS atmospheric correction is resulting in water leaving reflectances in 13 bands, namely all MERIS spectral bands except band 11 (761nm) and band 15 (900nm), which are placed in oxygen (band 11) and water vapour (band 15) absorption bands. The reflectances are accompanied by several flags characterising the performance of the atmospheric correction:

**Cloud flag**: a pixel has been identified as a thick cloud, so that no exploitable signal from the water surface has reached the sensor.

**PCD_1_13**: The Product Confidence Flag for all the reflectances. This is a summary flag, which, when turned on, indicates that the atmospheric correction has failed for at least one of the bands. During processing, several circumstances can occur which cause this flag. Due to lack of available space for all internal flags, the details why the PCD is raised are not available in the Level 2 product, except for three, namely the ice-haze flag, the uncorrectable sun glint flag and the out-of-aerosol data flag. These three flags and negative reflectance are the main reasons for raising the PCD_1_13 flag. I.e., the difference between PCD_1_13 and the sum of the three above flags are a good indication of pixels where a negative reflectance occurred.

**Ice-haze flag**: this indicates that the measured radiance at the sensor is too high to be used in the inversion process. This can be caused by ice on the water or, in the atmosphere, by a cirrus cloud or very high aerosol optical thickness. The ice-haze flag triggers the PCD_1_13 flag.

**Uncorrectable sun glint flag**: This flag is raised if calculated reflectances, using the wind speed as input, reach a certain threshold. In these cases the signal cannot be corrected for the sun-glint contribution. The uncorrectable sun glint flag triggers the PCD_1_13 flag.

**Out-of-aerosol database flag**: The Case 1 atmospheric correction algorithm was not able to find 2 aerosol models in its database, which fit with the measured signal in the NIR. The out-of-aerosol data base flag triggers the PCD_1_13 flag.

Figure 1 shows an example of a MERIS product, where the flags have been overlaid over the image of the surface reflectance in band 2. The PCD_1_13 is not explicitly shown in this image, however, the sum of all pixels shown in red, orange, brown and blue give the area flagged by PCD_1_13. It is typical that the cloud flag identifies a small portion of bright pixels, while a large portion is masked by the ice-haze flag. This is a consequence of the fact that the cloud flag is dedicated to identifying only those pixels which are suitable for further processing by the cloud properties retrieval algorithms. On the other hand, the ice-haze flag identifies those cases, which too cloudy to be used for water processing.

![Figure 1. MERIS scene of the southern North Sea, with the following flags overlaid: yellow: cloud; red: negative reflectances; orange and brown: ice-haze; blue: out-of-aerosol database](image-url)

The blue pixels are those where the atmospheric correction could not find a proper aerosol. The red masked pixels are those which are the difference between PCD_1_13 and the glint, ice-haze and out-of-aerosol database flags. These pixels have one or more negative reflectances. The latter cases, namely out-of-aerosol database and negative reflectances, are typically prevailing in a fringe around the coastline. Not existing in this case is the uncorrectable sun glint flag. In general, it can cover up to half of the image.

A statistical analysis of 692 products has been performed in order to study the frequency of PCD_1_13. 587 of these products or 84.8% have the PCD_1_13 raised for 50% or more of all water pixels. The ice-haze flag is the main cause of the PCD_1_13: it is raised in 361 products (52%) for 50% or more pixels, which are PCD_1_13 flagged. In 80% of the products it contributes at least 20% to the PCD_1_13 pixels. The
uncorrectable glint flag is the second important cause: in 243 cases or 35% of all products, it is raised for more than 50% of the PCD_1_13 flagged pixel. The out-of-aerosol database flag is statistically unimportant: it is raised in only 8 products for more than 1% of the water pixels. However, these pixels are located close the coast so that its importance for the coastal zone is larger than expressed by this statistical result.

3. LIMITS OF THE ATMOSPHERIC CORRECTION

In the previous section it has been shown that the causes of unsuccessful atmospheric correction are mainly high scattering from the surface (sun glint, ice) or from the atmosphere (residual clouds, high aerosol optical thickness). Both are natural phenomena and are not primarily an algorithmic problem of the atmospheric correction. Even though these causes explain 50% - 80% of the PCD_1_13 pixels in many cases, there are still a significant number of pixels where the atmospheric correction cannot be performed successfully. In the following sections some of these reasons shall be investigated.

3.1. Sub-pixel heterogeneity

The size of a MERIS RR pixel is 1.2km x 1.2km. This is an area where the spatial heterogeneity of the surface within one pixel can cause a spectral mixture which is difficult to handle by the atmospheric correction. The heterogeneity can be a mixture of land and water surfaces in the coastal zone, cloudy and non-cloudy areas at a cloud edge, semi-transparent clouds or foam or white caps on the water surface. Figures 2 – 4 present an area in the Baltic Sea in reduced resolution (Figure 2) and Full Resolution (Figure 3) which has been used to study the effect of sub-pixel heterogeneity.

The cloud the covers the right part of the image is largely not classified as a cloud but is flagged by the ice-haze flag (Figure 4). However, there is still a fringe around the cloud, which is significantly brighter than the surrounding water but not flagged. Some pixel at the top left edge of the cloud are flagged by PCD_1_13, indicating here a negative reflectance. This top-left area is where the cloud shadow lies on the water surface, as can be seen in the magnification (Figure 5). The water leaving reflectance spectrum is shown at three locations: (1) clear ocean, (2) cloud shadow, (3) cloud shadow, PCD_1_13 flagged.
Figure 5: Magnification of the top-left part of the cloud. Yellow: cloud flag; orange: ice-haze flag; red: negative reflectance. The 3 pins identify the pixel where the spectrum is shown in Figure 6.

Figure 6: Water leaving reflectance spectra at the 3 pixel indicated in Figure 5.

The spectra are shown in Figure 6. The effect of the cloud shadow is clearly visible: the spectrum is decreasing and is becoming negative with decreasing distance towards the cloud. The spectrum of pixel (2) is not flagged and will probably result in an overestimation of the chlorophyll concentration.

A similar effect can be observed in the patchy cloudy area in the lower part of the image, marked with “sub-pixel cloudiness” in Figure 3. This is an area where small clouds and associated cloud shadows disturb the image. Some pixels are flagged by the ice-haze flag (Figure 7, yellow pixels), but other pixels are probably too bright due to sub-pixel cloudiness but not flagged (e.g. pixel no. 5), and for others the atmospheric overcorrects resulting in a negative reflectance (red pixels). Pixel no. 4 is an undisturbed pixel, while pixel 6 is in the cloud shadow and too dark, but not flagged. The spectra are shown in Figure 8.

To certain extend the small clouds and sub-pixel cloudiness is interpreted as an increased aerosol optical depth, as shown in Figure 9. Therefore the water leaving reflectance spectra, e.g. as shown in Figure 8, are still reasonable, however, the aerosol product is quite wrong in these cases.

Figure 7: Magnification of the lower middle part of Figure 3, marked as “sub-pixel cloudiness”.

Figure 8: Water leaving reflectance spectra at the 3 pixel indicated in Figure 7.

3.2. Coastal issues

The sub-pixel heterogeneity can particularly be studied in coastal areas, where small islands or the coast lead to mixed pixels. This has been studied in a MERIS scene of the Swedish Fjord area near Stockholm. Figure 10 shows an overview of the area and Figure 11 and 12 magnifications of the area, which show in detail individual pixels in Full Resolution (grey scale figure of band 13). The area is characterised by a fragmented coastline, little islands and even large and small rocks in the water. Figure 11 shows the complicated land – water distribution: in green are shown the land pixel according to the Level 1 a priori classification.
Figure 9: Aerosol optical depth of the section shown in Figure 7.

In orange are pixel masked, which have a spectrum where band 12 is larger than band 10; a test which is also used in the Level 2 processor for the land/water reclassification. These large differences in the grey scale image of band 13 (Figure 12) show that most pixel are not pure water pixel but affected by a land surface. At the pixel where the pin is located in Figure 11, a ground truth measurement made by the University Stockholm is available. Figure 14 shows the 9 spectra of the 3x3 pixel neighbourhood around this pixel. All spectra are very close in the visible part of the spectrum but differ in the bands > 700nm. Most distinct from the other spectra is pixel (2,3), which is left of the central pixel and which is classified as land by the land test. It is worth noting that the land spectrum does not differ in the visible bands significantly from the water spectrum. Figure 14 picks out 2 important cases: the clear water spectrum is represented by pixels (1,2) and (3,2), while pixels (2,1) and (2,2) show a significant increase in the NIR bands, which is probably due to a mixture of land and water portions in the pixel.

The mixed spectra still are dark and decrease steadily with increasing wavelengths. Therefore, they are not classified as land spectrum but still as water spectrum. The atmospheric correction interprets the increase of the radiance in the NIR as due to aerosols. However, different from an increase in aerosols optical thickness, the mixed land-water spectrum does not increase in the visible. Consequently, the interpretation as aerosol leads to an overcorrection in the visible bands. This overcorrection might be so strong that negative reflectances result.
If not, it will be interpreted as a too high chlorophyll concentration or yellow substance absorption, because both have an absorbing effect in the blue bands. Finally, it should be reminded here that this investigation was made on a FR image. In RR, 4x4 of these pixels are averaged. In this particular case, the resulting pixel cannot be further interpreted. However, this investigation should demonstrate, what happens in coastal areas, where land and water portions contribute to individual pixels, which is always true in both, FR and RR coastal images.

In addition to the land-water mixed pixel problem, the atmospheric correction in the coastal zone is also complicated by the variety of possible aerosols and by the so-called adjacency effect or environmental effect. Due to scattering of radiance from land surfaces by aerosol particles into the path of light, which is measured over water surfaces, an artificial increase of the signal can be observed. Figure 15 is an example of a coastal scene (FR), where the radiances is comparably constant over the open ocean but is decreasing when the coast is approached and is constantly decreasing inside the Fjords. The spectra at 4 locations are shown in Figure 16. Pixel 1 is in the open sea. It is a typical spectrum with high absorption due to Chlorophyll. Pixel 2 is in the mouth of the Fjord. Even though it is not far from Pixel 1, the spectrum is constantly decreased across the whole spectrum. This trend is kept for pixels 3 and 4, which are deeper inside the Fjord. The spectrum of Pixel 4 is negative for bands 1-3.

4. CONCLUSIONS

The MERIS atmospheric correction is mainly limited by three factors, which are of natural origin: residual cloud coverage, surface reflectance from sun glint and scattering from high aerosol concentrations. Another...
An important source for raising the PCD_1_13 is an overcorrection leading to negative reflectance. This can be caused by sub-pixel effects, cloud shadow or the adjacency effect. Some of these problems could be solved by an extension of the atmospheric correction scheme. For example, the sun glint reflectance or the adjacency effect could be modelled and a correction could be developed. Also the mixed pixel problem, semi transparent clouds and sub-pixel cloudiness should be correctable. Since these problems accumulate in the coastal zone, which is ecologically and economically very important, it is worth to address these problems in the near future.

5. REFERENCES

