# MERIS SURFACE PRESSURE AND CLOUD FLAG: PRESENT STATUS AND IMPROVEMENTS

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## ABSTRACT

This paper deals with the verification, consistency analysis and potential improvements of the surface pressure product. Pressure determination is based on the absorption in the Oxygen A band and is very sensitive to the spectral characterisation of MERIS. We describe how, thanks to programmable capability of MERIS, the spectral characterisation of MERIS was done using the pressure retrieval and what is the optimal location for the Oxygen absorption band. Some recommendations are given and exemplified for the improvement of the image quality of the product. The pressure is also used for classification purposes. We show the potential use of the pressure for the detection of thin clouds (cirrus) and/or high altitude dust transport over ocean.

**Keywords**: Surface Pressure, Oxygen Absorption, ENVISAT/MERIS, cloud detection.

## 1. INTRODUCTION

### 1.1 MERIS smile effect

MERIS is a programmable, medium-spectral resolution, imaging spectrometer operating in the solar reflective spectral range (400 nm to 900 nm). Fifteen spectral bands can be selected by ground command, with a programmable width and spectral location [1]. The scene is imaged simultaneously across the entire spectral range through a dispersing system, onto a CCD array. The programmed spectral width is obtained by summing the necessary number of CCD lines in the shift register. The CCD covers the spectral range with a nominal 1.25 nm spectral sampling interval. MERIS spectral bands are defined as the sum of one or more CCD detector pixel elements, with a Full-Width Half-Maximum (FWHM) equal to 1.25 nm and a Gaussian response function for each element. A spectral characterization of MERIS has been performed before the launch and spectral shifts have been observed, mainly due to the CCD integration with optics during the spatial registration. The CCD lines are tilted with respect to iso-wavelength line of the spectrum (smile effect) with a maximal spectral dispersion of about 1.5 nm.

### 1.2 Pressure Determination

In this spectral range (759 to 770 nm), the solar radiation measured at the top of the atmosphere depends mainly on the $O_2$ absorption and therefore on the surface elevation. The $O_2$ absorption can be achieved with space measurements from a two band ratio $R$, defined as the ratio of two reflectances measured in the oxygen A-Band and in a close non-absorbing channel respectively. When the scattering can not be neglected, there exists a pressure level defined as the apparent pressure $P_{app}$, where outgoing photons originate preferentially. The ratio $R$ is well correlated to the product $mP^2$, where $m$ is the air mass, and may be directly converted into a pressure using a polynomial regression [2, 3]. In the surface pressure product, a corrective factor that accounts for the coupling between absorption and scattering is applied to the ratio R. It depends mainly on surface reflectivity and air mass.

### 1.3 Scope of the paper

This paper aims at describing the effort done to verify and consolidate the surface pressure product and show the potential of the $O_2$ absorption channel for an improved cloud flagging over ocean. For that purpose we first summarize the work that has been done around the oxygen bands for the spectral calibration of MERIS and the optimization of the $O_2$ band settings. Then an analysis of the product quality is done and we give recommendations how to improve it mainly with regard to the smile effect.

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## 2. USING THE IN-FLIGHT SPECTRAL CALIBRATION EXPERIMENT

### 2.1 The spectral in-flight calibration

The goal of the in-flight spectral calibration is to retrieve the spectral shift (Δλ in nm) between the spectral response given in Fig. 1, and the actual one for each pixel in the across-track direction. The methodology is based on the determination of the surface pressure from the oxygen A band and is fully described in a recent paper [4].
The idea is to compute one surface pressure for each $O_2$ narrow channel shown in Fig. 1, for a given spectral shift Δλ and search for the optimal spectral shift that gives the minimum pressure dispersion.

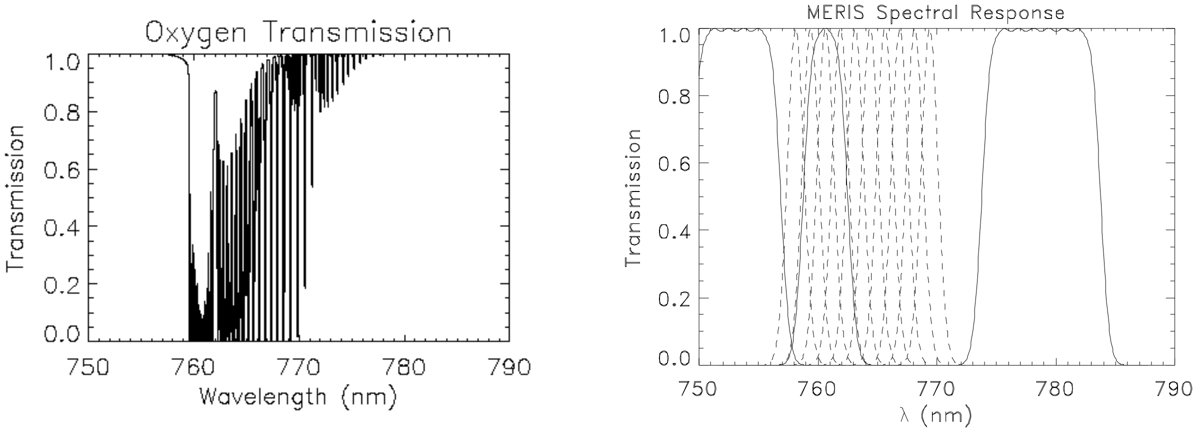


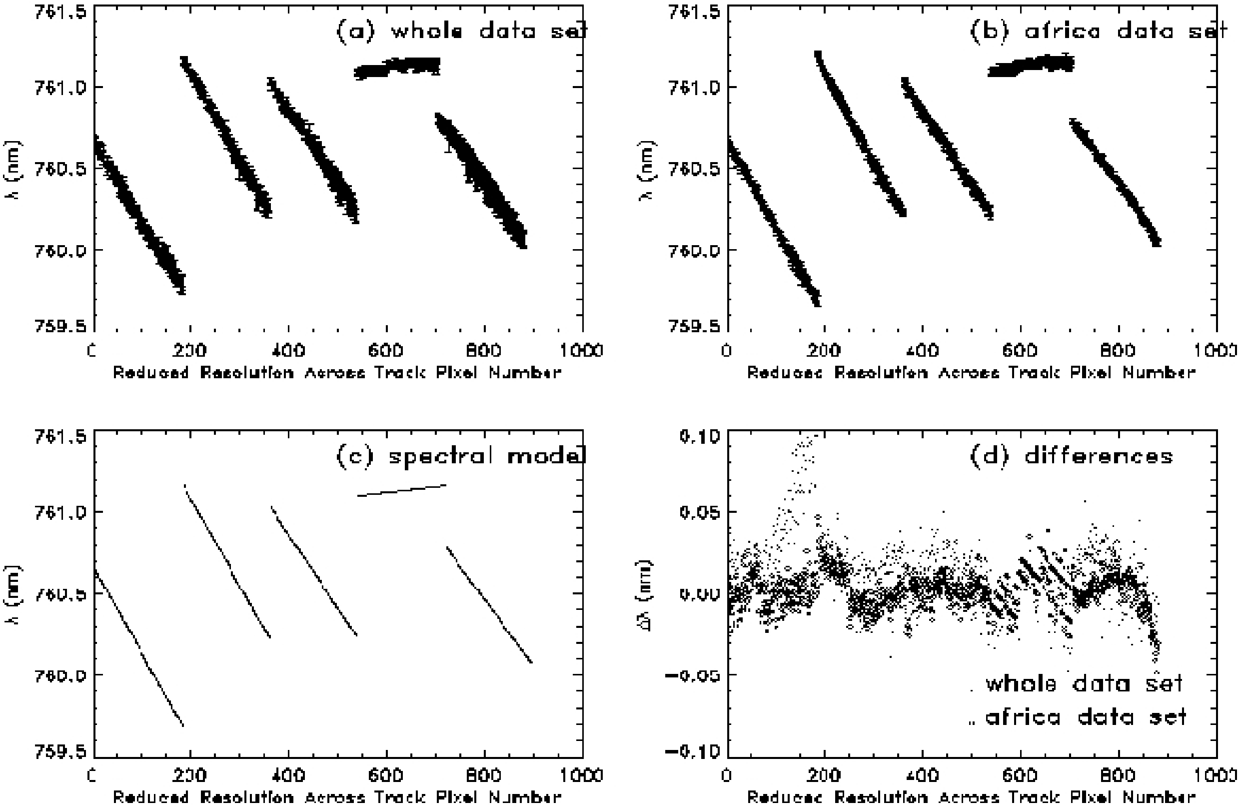
Fig. 1. MERIS spectral response and monochromatic atmospheric transmission for the $O_2$ absorption bands region. The dashed lines correspond to the 10 narrow channels within $O_2$ absorption bands used for this in-flight experiment. The full lines correspond to the broad channels of the nominal MERIS band setting.

Look-Up-Tables of polynomial regressions have been defined assuming realistic variations for the spectral shift (Δλ= ±1nm, with a step of 0.01 nm. From a theoretical point of view and using the MERIS spectral response, the use of a two band ratio would give a set of similar surface pressures under clear sky conditions. Consequently, the set of pressures can be calculated as a function of the wavelength shift using an iterative procedure. The spectral position of the MERIS bands will correspond to the best set of surface pressures, defined as the set with the minimal mean square deviation between the pressures. It can be noticed that $O_2$ channels can be outside the $O_2$ absorption band during the iterative procedure for extreme spectral shifts and can lead to large errors for the apparent pressure determination. The method has been then improved to avoid these numerical problems. The method could be named "Pressure Homogenization Method".
The algorithm described has been applied to the whole dataset and then the spectral shift vectors have been averaged. The result is given in Fig. 2 part a. This raw result can be improved if we choose a part of the Earth above land with good homogeneity and almost cloud free. This is for example the case for the orbit 519 over Africa's overpass in the south. The noise is low (the standard deviation for each pixel is of the order of 0.02 nm) and follows well a linear model as it was observed before launch. The differences between the retrieved spectral shift and the linear model are plotted on part c of Fig. 2. The main discrepancy with the linear model takes place at the end of the camera number 1, where the spectral shift is the lowest. This could mean that the calibration method becomes to be biased for such blue-shifted pixels. It is not a surprise since at that wavelength (around 759.7nm) we begin to be outside $O_2$ absorption lines and therefore non-linearity may occur. In part e we show the preliminary analysis of the fall spectral calibration campaign. The overall agreement between the two methods developed at Université du Littoral (UL) and Freie Universität Berlin (FUB) is excellent. There is a slight variation of the spectral location of camera 2 by ~0.1 nm between spring and fall. However, only fall campaign was fully radiometrically calibrated and this is probably the cause of this difference and not an instrument drift.

### 2.2 Optimisation of the $O_2$ band setting

From the spectral calibration campaign dataset we studied the optimal location of the $O_2$ absorption band by simulating the 3.75 nm wide channel (see Fig 1, in full lines) that is used in the operational mode for $O_2$ absorption measurement from 3 consecutives 1.25 nm narrow channels. We simply averaged those 3 channels as it is what is done onboard

MERIS. We did this for the nominal wavelength centre of the $O_2$ absorption channel at 760.625 nm and for two other configurations, i.e. at 761.875 nm (corresponding to a shift of 1 pixel/1.25 nm compared to nominal setting) and 763.125 nm (respectively 2 pixels/2.5 nm). In Fig. 3 we show the narrow channels measurements used for this simulation. The smile effect is clearly visible for each camera. For the 1st narrow channel, some part of the Field Of View (FOV) exhibits low absorption because it's getting out the $O_2$ absorption bands. The second channel is located at the absorption maximum while the fourth shows the lowest dispersion within the FOV. The central wavelength decreases when we go from right to left (from camera 1 to 5) and the absorption first increases (narrow channels 1 and 2) and then decreases for the narrow channels 3, 4 and 5. Transmission for each simulated broad channel is given in part b of Fig. 3. We can see that the combination that offers both the highest sensitivity to oxygen absorption and the lowest dispersion along the FOV and thus we gave the recommendation to shift the $O_2$ absorption band by 1.25 nm toward the red.



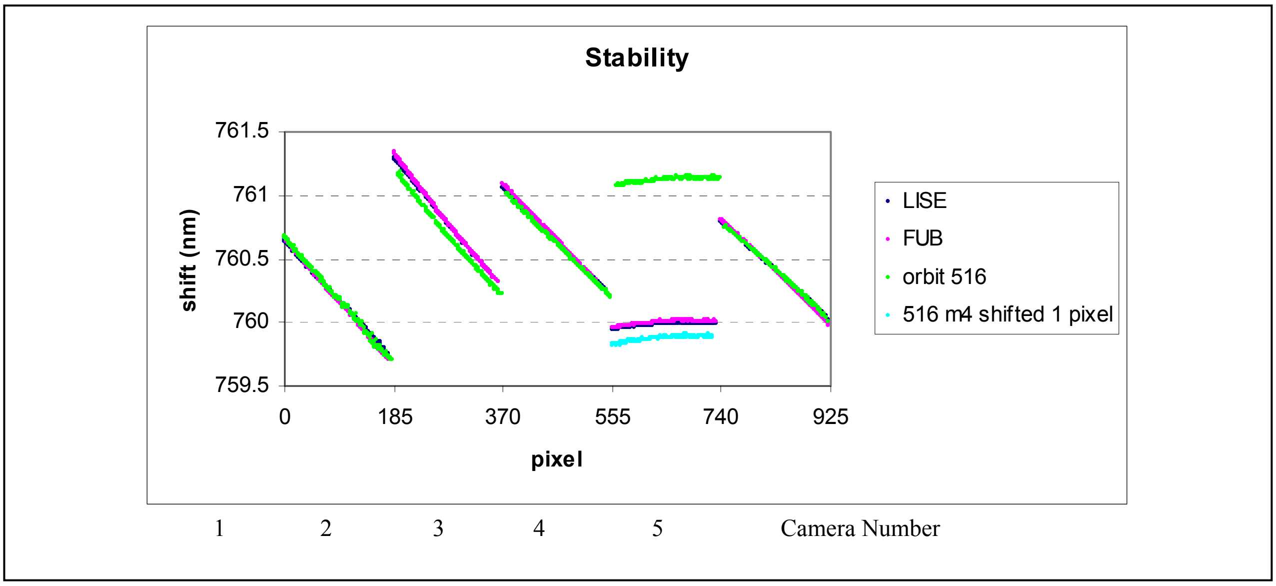
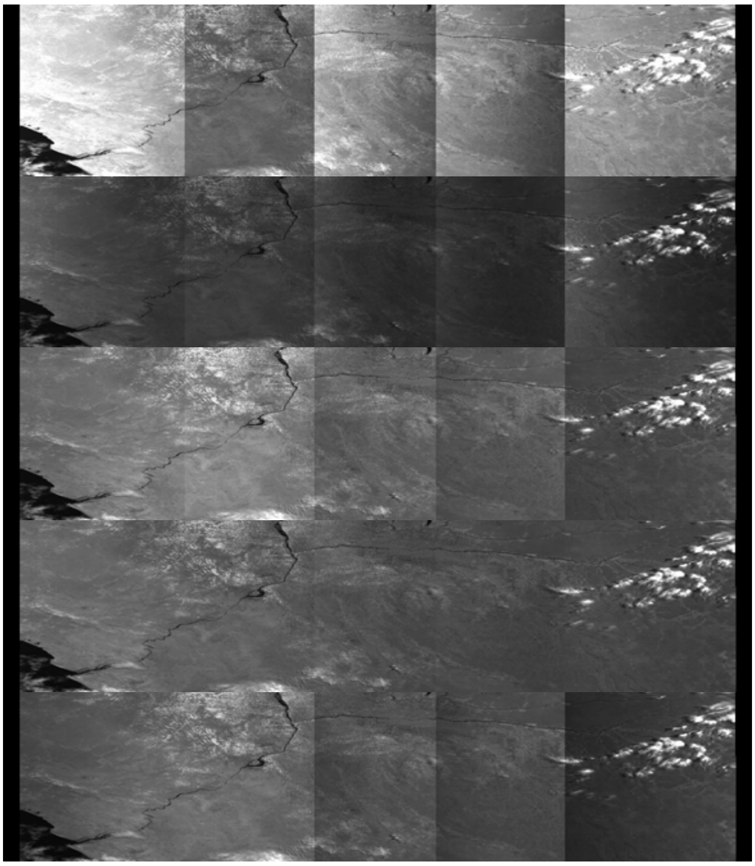


Fig. 2. Spectral characterisation of MERIS cameras in the $O_2$ bands spectral region after the first spectral calibration campaign (April 2002, orbits 512,513,515,516,519,520). (a) Wavelength centre mean and dispersion for the whole 6 orbits; (b) Same as plot **a** but for data acquired over Africa during orbit 519; (c) Spectral model used for the rest of the study based on a linear fit on the cleanest dataset acquired over Africa during orbit 519; (d) Differences between central wavelengths of dataset **a** and **b** and the spectral model. (e) stability of the spectral shift between spring (Orbit 516) and fall calibration campaign for two methods (Université du Littoral, LISE and Freie Universität Berlin, FUB). Note that camera 4 was shifted manually by 1.25 nm between the two campaigns. *[*figure (e), courtesy from L. Bourg, *ACRI* and R. Preusker, *FUB]*



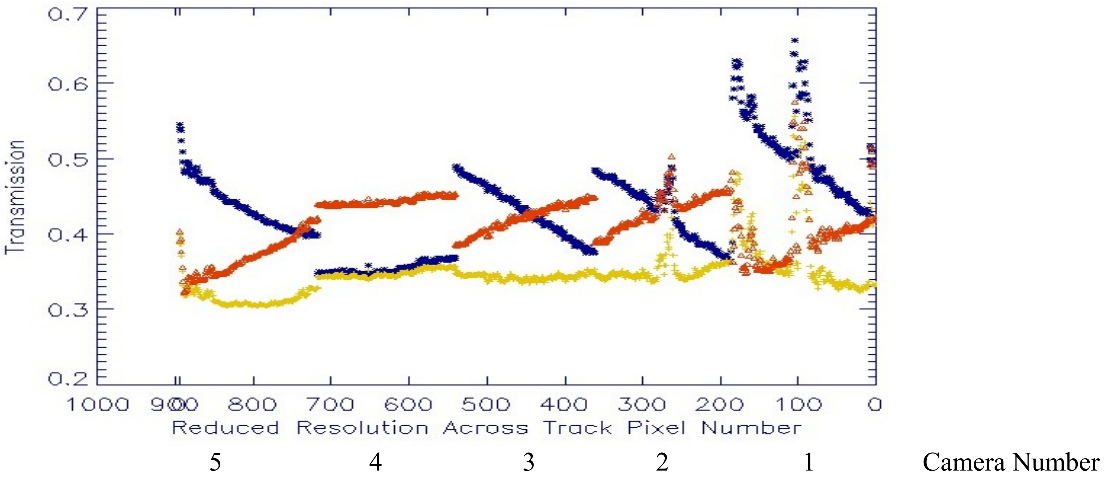


Fig. 3. (a) MERIS subscenes acquired during the first spectral calibration campaign (orbit 519) over Africa in 5 consecutives narrow (1.25 nm) channels (centered at 759.375, 760.625, 761.875, 763.125 , 764.375 nm). Camera 1 is on the right and the color scale ranges from 0 (black) to 100 W.m$^{-2}$.sr$^{-1}$.mm$^{-1}$ (white); (b) Transmission transect in the across-track direction for the middle of the scene and for 3 band settings simulated from the narrow channels 1,2 and 3 (blue:760.625nm), 2,3 and 4 (yellow:761.875nm), 3,4 and 5 (red:763.125nm). Rapid increases of the transmission correspond to cloud or ocean pixels.

## 3. PRESSURE PRODUCT QUALITY

The pressure product is now checked and some recommendations for the improvements of the algorithm are proposed.

### 3.1 The nominal algorithm: description and results

From the transmission *R* measured in the $O_2$ band, pressure is computed using a polynomial of order 6 for 21 sets of polynomials coefficients ($a_{ik}$) stored in LUTs and corresponding to 21 spectral shift in the range of ± 1 nm by steps of 0.1 nm. In addition, we introduce a corrective factor C that takes into account the coupling between absorption and scattering. Indeed the polynomials where computed for a purely absorbing atmosphere. At the moment C is stored in LUTs for several TOA apparent reflectance at 753 nm (from 0.05 to 0.6) and for several air masses (from 2 to 3.5). The spectral shift index which represents the polynomial number used for the pressure computation was built from the first spectral calibration campaign using the nearest neighbour approximation.

Fig. 4 is an example of the surface pressure one can get from level 2 MERIS data. The order of magnitude is correct and terrain elevation is well reproduced but the product is affected by wide stripes and exhibits strong inter camera gaps. The main cause for this effect is that the spectral shift precision is not high enough (0.1 nm). The $O_2$ nominal band setting enhances the impact of any spectral shift error onto the pressure product.

### 3.2 Recommendations to improve data quality

The way to include more accurately the spectral shift of each pixel S into the pressure computation is to compute two pressures with the polynomials corresponding to spectral shift index $S_1$ and $S_2 = S_1 + 0.1$nm with $S_1 < S < S2$ and then to interpolate linearly between these two pressures. We are just limited now by the accuracy of S itself that can be estimated to 0.02 nm (see Section 2.1) and ultimately by the coding precision of S (here 0.01 nm).

In Fig. 5 is displayed the same pressure image as in Fig.4 but obtained with an in-house program including interpolation and the results of the fall spectral calibration campaign. The improvement is obvious. The intercamera gaps are dramatically reduced (maximum around 20 hPa) and wide stripes are removed. There are still some residual narrow (pixel size) stripes in the image of low amplitude that could partly originate from the use of an experimental (a little bit noisy) spectral shift and not a linear model. The improvements shall be clearer with the recommended band setting.

## 4. THE PRESSURE PRODUCT FOR PIXEL CLASSIFICATION

### 4.1 Correction of the coupling between scattering and absorption

It appears that this corrective factor depends significantly on the spectral location and thus the spectral shift. This effect was not included in the first version of the ATBD. We computed this factor for several spectral shift (from 760.5 nm).

Results are given in Fig. 6. The order of magnitude of the variation of C in MERIS FOV is important (~0.03). For common targets with a surface reflectance around 20% in the red, considering C as constant in MERIS FOV may lead to several tens of hPa of relative error.

## 4.2. Pixel classification based on the surface pressure

The use of the surface pressure for pixel classification was coded in the ground segment for land but until now the quality of the product was not good enough and the pressure information was in fact switched off at this stage. The identification of clouds then relies mainly on a TOA reflectance threshold in the blue.

In Fig. 7 and 8 we give an example of all the information we may get from the surface pressure if it is calculated for all kind of targets in the pixel identification phase. We applied the algorithm described in Sec. 3 to a L1B image acquired over Horn of Africa in August 2002. Fig 7 shows the surface pressure and Fig 8 shows the TOA reflectance at 753 nm and the cloud flag as it is now and as it could be if one includes pressure information. This image contains several things. First of all the C corrective factor is not applied at the pixel classification stage. This correction is quite residual for bright surfaces which generally correspond to land surfaces. It is still the case over water in the high glint part of the image. The ocean surface is bright and we are close to ECMWF pressure. But, outside the strong sun glint spot, the ocean is dark and the photons backscattered originate from the atmosphere. The measured pressure corresponds then to the mean altitude of the atmospheric scatters. This usual situation over ocean is illustrated for a zone in the centre of the image corresponding to "case one" water in cloud free conditions. The pressure is then close to 700 hPa. If we want to use the O2 pressure for automatic classification, we certainly need to introduce C factor in this product.

In a demonstrative exercise, we can just have a visual inspection of the image in pressure to see if new cloud structure appears. It is clear that the L2 cloud flag missed some thin clouds/high aerosol in the south-eastern part of the image.

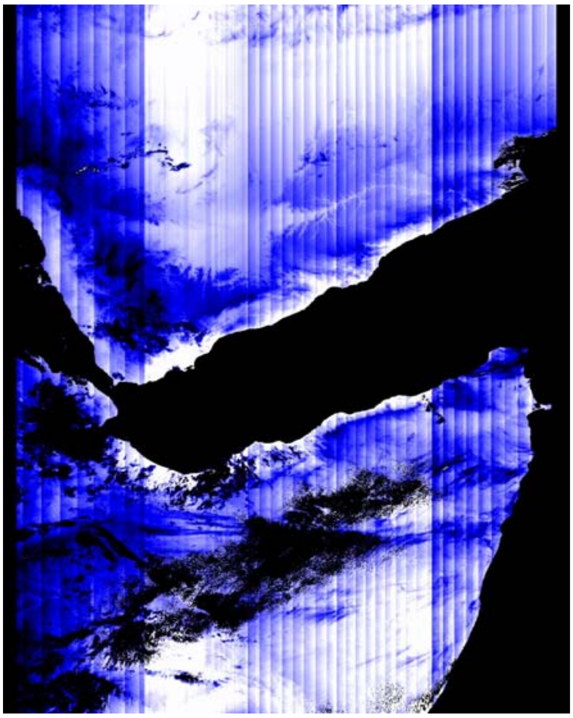


Fig. 4. Level 2 Surface Pressure computed with the nominal processing. Image acquired on 05 August 2002 over Horn of Africa. Color scale ranges from 750 hPa (black) to 1050 hPa (white). Over pixel classified as clouds (black) , No surface pressure is available

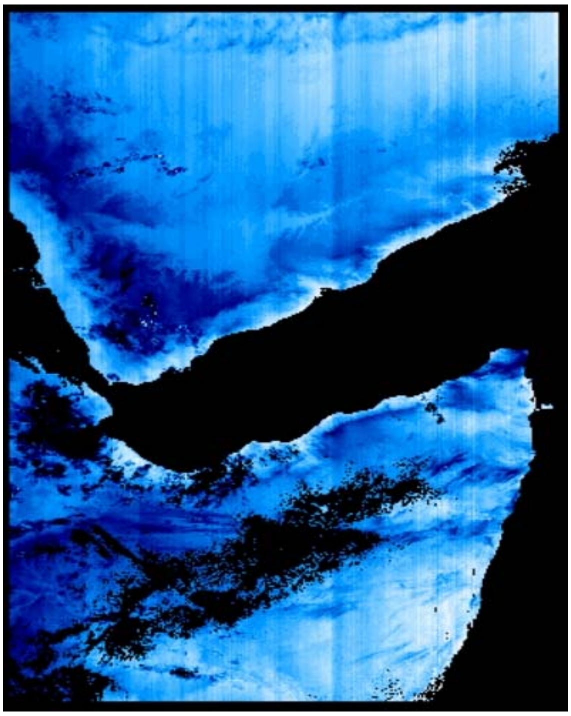


Fig. 5. Same as Fig. 4. but with the following improvements : (i) new spectral shift from fall campaign now defined at a resolution of 0.01 nm, (ii) computation of two pressures and linear interpolation as a function of spectral shift.

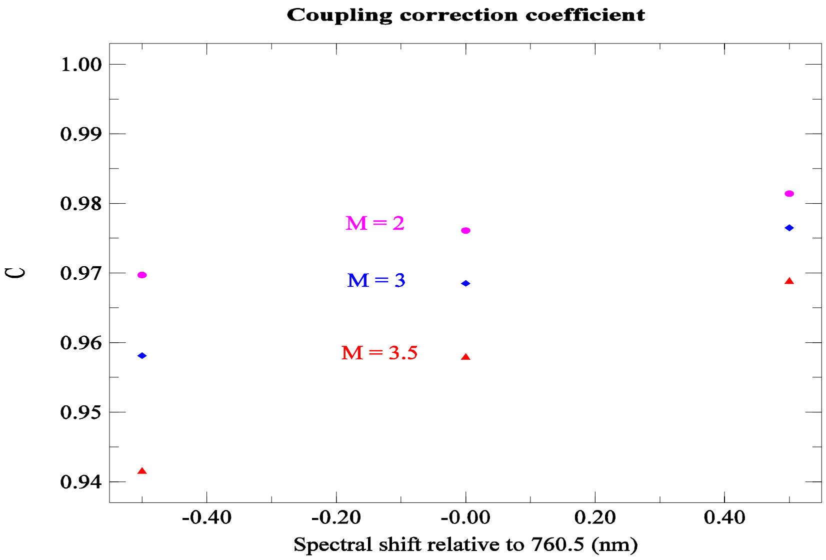


Fig. 6. Corrective factor that takes into account the coupling between absorption and scattering as a function of spectral shift and airmass for an atmosphere including aerosols with a visibility of 23 km and a surface of albedo 0.2

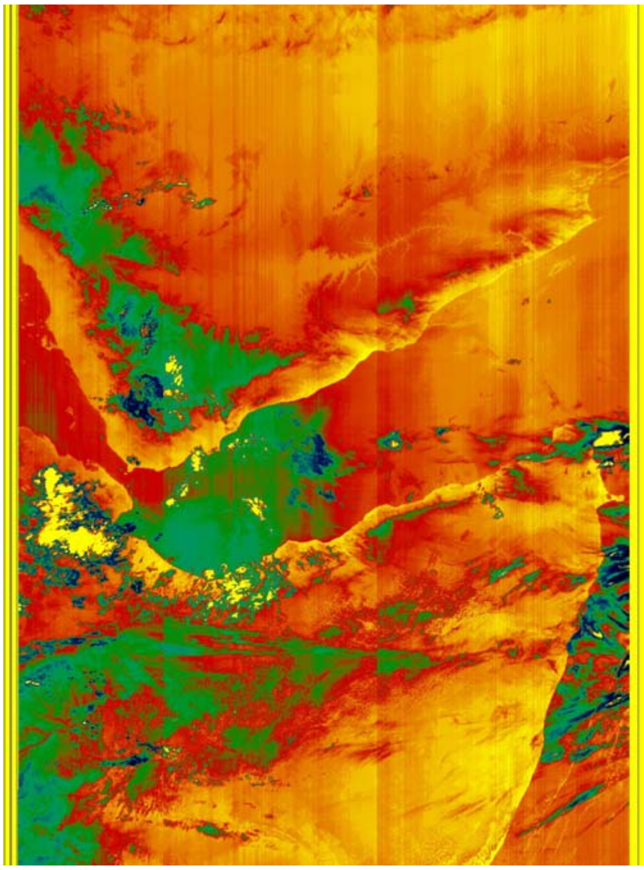


Fig. 7. Surface Pressure Image of Horn of Africa on 05 August 2002 computed whatever the target (cloud, land or ocean). The color scale ranges from black (650 hPa) to yellow (1050 hPa).

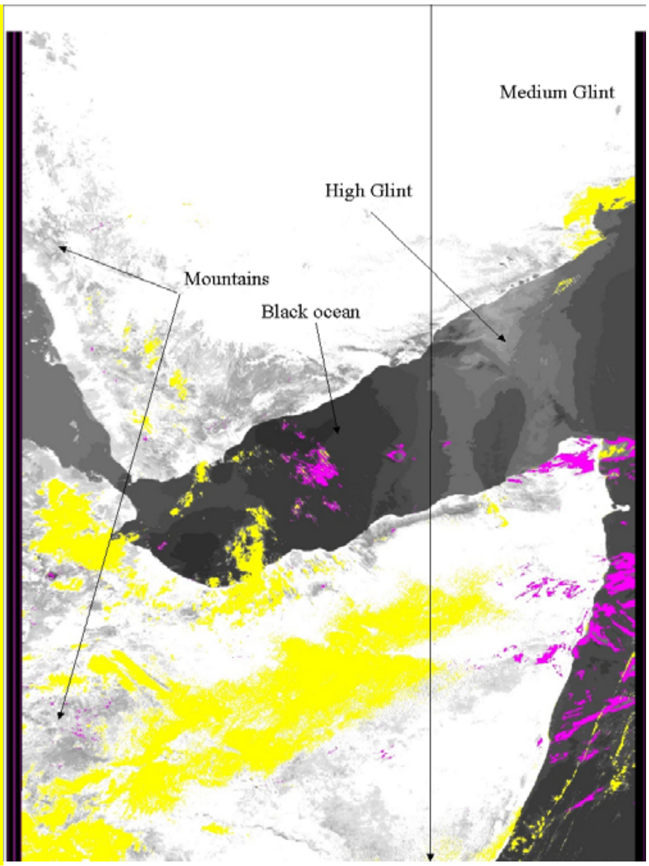


Fig. 8. Classification image of Fig. 7. Yellow corresponds to the level 2 cloud flag. Magenta corresponds to new pixels classified as clouds using the pressure difference between surface pressure using $O_2$ and ECMWF. The background image is the TOA reflectance at 753 nm.

They exhibit a strong signal in pressure (<700 hPa) whereas it was difficult to see them with a basic reflectance threshold neither in the blue nor in the red. Those high aerosols are seen also over land (900 hPa) and there is continuity across the coastline. As the terrain elevation is well reproduced by the surface pressure over land, the quantity to compute for the cloud flagging is the difference $\Delta P$ between the retrieved and the estimated surface pressure from ECMWF and Digital Elevation Model. With a simple criterion of classifying as clouds pixels for which $\Delta P$ exceeds a given threshold we detect easily new features.

## 5. CONCLUSION

The first part of the paper describes the results that were obtained during the spectral calibration campaigns using the "pressure derived from oxygen absorption" concept. On one hand, these experimental activities have been successful (unprecedented spectral calibration accuracy) and have proven the efficiency of the programmable capabilities of MERIS. On the other hand they were mandatory to understand how to improve the pressure product itself. It is shown in a second part that the surface pressure is greatly improved when we incorporate new spectral calibration results in conjunction with a more accurate spectral shift representation in the level 1B data.

The early attempts to correlate the surface pressure product with the surface pressure derived from ECWF and DEM data attached to the level 1B product gives encouraging results. The correction factors for the coupling between absorption and scattering LUTs have to be consolidated. The surface pressure has still improvements potential since we showed that the optimal location for the $O_2$ absorption band is 1.25 nm red-shifted compared to the present location. Finally the signal above water in the absorption band is very sensitive thin clouds, such as cirrus clouds, or to high aerosol transportations, even if such structure are not detected in the other bands. The detection of such events is very critical to validate the atmospheric corrections over water. We hope it could be used in the development of a consolidated cloud flag above water based on a pressure product corrected from the coupling between scattering and absorption.

## ACKNOWLEDGMENTS

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