VALIDATION OF MERIS-REFLECTANCE FROM FERRIES

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ABSTRACT

Mounted on ferries covering most of the Norwegian coast we have sets of optical sensors mounted. Each set consist of two radiance sensors (one viewing at the surface of the sea, one at the sky) and one irradiance sensor (in addition to GPS-sensor a computer controlling the system). The collected data are used in calculating radiance reflectance which is also one of the MERIS-products. It is shown that the systems, which only requires maintainance on weekly or longer intervals, hardly are affected by deposits of salt or airborn particles.

If the ferry follows an optimal transect combined with a carefull choice of observing angles (to avoid ship shaddow on the sensors footprint as well as sun-glint from the surface) it is shown that data can be collected most of the day, including during satellite passage. Then there is the satellite coverage and cloud conditions that limits the number of possible match-ups, not the ship-time which usually is the limiting factor. Our result shows typically 20% deviation between between radiance reflectance determined from MERIS and our own data.

1. INTRODUCTION

Traditional optical satellite data for marine areas are validated with in situ measurements made from a research vessel. When a validation campaign is planned the vessel is usually ordered months in advance based on the daily satellite coverage of the area of interest. On the validation day or days the scientists then install their equipment on the ship, sail out, and do their measurements. In theory such an approach may work fine, but in practice there is one factor the scientists have no influence on: the weather. In waters around Norway cloudiness is rather normal, consequently the probability of good satellite data on a give day is quite moderate.

To significantly increase the number of match between in situ measurements and satellite data at favorable conditions we have chosen to use ferries as the platform with scientific instruments running automatically. With a continuously running ferry this will at least in principle result in in situ measurements everytime there is satellite data under favorable weather conditions.

In this paper we will present some of the results from the ongoing validation of normalized surface reflectance from the sensor MERIS.

2. SOME THEORY

The parameter to be studied here is the product “normalized surface reflectance” from MERIS which is defined as

\[ \rho'_u(\vartheta, \varphi, \lambda) = \pi \frac{L_u(\vartheta, \varphi, \lambda)}{E_d(\lambda)} \]  

(1)

Where \( \rho'_u \) is the normalized surface reflectance also called “MERIS reflectance”, \( L_u \) is the component of upward radiance in air with origin in the sea (i.e. no light reflected at the surface of the sea is included), and \( E_d \) is the downward irradiance in air. The two former components depend on nadir angle \( \vartheta \) and azimuth angle \( \varphi \), all three depend on the wavelength of the light \( \lambda \).

For validation based on measurements from a research vessel \( E_d \) is usually measured in air while \( L_u \) is calculated from measurements of nadirradiance below the surfac (which are extrapolated to the surface, then the waterleaving part is determined from the refractive index of water). This gives the right hand side of equation (1) which is compared with the reflectance given by MERIS.

On a continuously moving platform as the ferry subsurface measurements for determining \( L_u \) are for obvious reasons impossible. Instead radiance is measured above surface with a downward viewing radiancemeter. However, this measures not \( L_u \), but the sum of this and the downward direct and diffuse light reflected at the surface, i.e. \( L_u + L_{u}^{\text{diff}} \). To estimate the latter addend of this sum it has been common to measure the downward diffuse radiance at the
nadirangle \((\pi - \vartheta)\); assuming this is the radiance reflected into radiance meter (or proportional to it) we get

\[
L_{ur}^{\text{refl}}(\vartheta, \varphi, \lambda) = r_L L_d(\pi - \vartheta, \varphi, \lambda) \tag{2}
\]

For a flat surface \(r_L\) takes the value of 2\%, with a wind roughened surface the value of 2.8\% has been determined for an overcast sky.

As we later will see none of these values of \(r_L\) gives result we beleive in. This is because the reflected light do not only consist of \(L_d(\pi - \vartheta, \varphi)\) but due to the rough surface the entire upper hemisphere. consequently \(L_{ur}^{\text{refl}}\) is dependent on \(L_d(\Omega)\) (which depend on the solar elevation); additionally \(L_{ur}^{\text{refl}}\) do also depend on the direction of viewing and wind speed. Such a functionality is far more complicated than what is the scope of this paper, we search instead for a much simpler solution and presume that \(L_d(\Omega)\) is better correlated with \(E_d\) than \(L_d(\pi - \vartheta, \varphi)\), thus we write

\[
L_{ur}^{\text{refl}}(\vartheta, \varphi, \lambda) = r_E E_d(\lambda) \tag{3}
\]

Where \(r_E\) has the dimension \(sr^{-1}\) and is independent on wavelength but will vary amongst the measured spectras.

To determine \(r_E\) we presuume that due to the high absorption coefficient of the water \(L_u\) is zero somewhere on the wavelength interval 800-900 nanometres. With the observed values of upward radiance and downward radiance it is then straightforward to find the value of \(r_E\) for each measurements.

On the ferry the radiance meters are mounted in fixed angles relative to the ship. As a consequence of this the azimuth angle between the sun and the radiance meter depends on the suns position as well as the course of the ship. Here we will not go into details but mention that the measurements are filtered for shadow of the ship at the footprint of the radiance sensor, azimuthal angles less than 90 degrees between the viewing direction and sun and finally solar elevation less than 30 degrees.

### 3. DESCRIPTION OF THE SYSTEMS

#### Technical

We are using radiance and irradiance sensors from the German company TriOS. On two ships we have running systems, ‘Color Festival’ in the Skagerrak and ‘Trollfjord’ along the norwegian from 60ºN to the russian border. Each set consist of one irradiance sensor (for downward irradiance) and two radiance sensors, two for upward and two for downward radiance. These 5 sensors are together with a GPS receiver connected via an interface box to a computer which records the data.

For ocean colour data to be used it is an absolute “krav” that the footprint is not disturbed by the ship, this relates both to wakes and the shadow of the ship. Additionally the azimuth angle between the sun and the sensor should ideally be 135º to minimise the sunglint. Given this together with the route of the ferries we have chosen to install our sensors in the following way: At ‘Color Festival’ the downward viewing sensors are mounted slightly forward at the starboard and port side (which is optimal with a ship heading northward during daytime). Figure 1 shows where which of the sensor gives “good” data. The route of ‘Trollfjord’ is more complicated but we have ended up with the sensors at the port side of the ship forward and aft viewing respectively.

It should also be mentioned that the ships navigation radar is a source of problems; the electronics of the system easily gets disturbed or even knocked out of the electromagnetic radiation, care must therefore be taken both with the sensors as well as the cabeling which may work as antennas.
Maintainance and stability

Regularly the sensors have been cleaned and checked with a field calibrator. The results of the checks have shown that the sensors are radiometrically stable, and that any remains of dust or salt deposits affect the measurements to a very little degree. One example of this is given in Figure 2 where all the field calibrator measurements made over a period of time of 18 months for one of the downward viewing sensors are shown. In the figure checks made both before and after cleaning are plotted, between the maximum and minimum spectras (which are not from the same day) the difference is at most 18%. This is most probably not caused by sea salt deposits only; the construction of the field calibrator gives the distance between the light source and the receiver only in the order of one centimetre which makes it extremely sensitive to small differences. Our impression is therefore that the radiometric measurements are always better than 10% and probable around 5% is the normal.

Regularity

As the system is left unattended on the ship it can not be expected to be running hundred percent of the time. Obviously will there be no data when the ship is out of service (e.g. for maintenance on a ship yard), but software failures happens both in the controlling hardware as well as in the recording computer. Our experience is that the system is up and running approximately 300-330 days a year which we find satisfactory.

4. RESULTS

The choice between $L_d(\pi - \theta, \varphi)$ and $E_d$

As described earlier it is common to determine the water leaving radiance by subtracting a given fraction of $L_d(\pi - \theta, \varphi)$ from the measured upward radiance. Here we will briefly show an example illustrating our choice of using the downward irradiance when correcting for surface reflection.

In Figure 3 the spectras of $\rho_w$ are presented, the solid curve shows the MERIS-data while the other curves are from our measurements made with the system within the same pixel. For the dotted curves the coefficient $r_L$ in equation (2) has been set to 2.8% as recommended for rough sea surface, in the dashed curves expression (3) has been used where the coefficient $r_k$ has been determined assuming there exist a “black” wavelength at 800 nm or higher.

Figure 2 Spectral response from one of the downward viewing radiance meters illuminated with the field calibrator. The graphs presented cover data from 18 months and readings before and after cleaning are shown.

Figure 3 Spectra of MERIS-reflectance made 20060321. The solid curve is from the MERIS-scene, dotted are calculated from the ‘Color Festival’ data using $L_d(\pi - \theta, \varphi)$ to correct for the surface reflectance, in the dashed curves $E_d$ measurements have been applied.

Transects

We will now present the results of the measurements made 20060321 which was a clear day over Skagerrak (Figure 4) where we particularly observe the high reflectance near the danish coast.
Figure 4 RGB image over Skagerrak from 20060321 with the transect drawn.

The values of MERIS-reflectance from this day determined from MERIS as well as from our ferry measurements are presented here. Figure 5 shows the determined reflectances for all the pixels that are flagged as water and with no sunglint. Observe that there is a general good agreement until approximately 59°N which is where the Oslofjord narrows and the MERIS-data are disturbed by the adjacency effect.

Figure 5 Transect of MERIS-reflectance. Values from MERIS are drawn as lines, those determined from the ferry data as marks.

To view the relative difference in \( \rho_w \) determined from MERIS and our system we calculated 
\[
\left[ \rho_w(\text{ferry}) - \rho_w(\text{meris}) \right] / \rho_w(\text{meris})
\]
for all pixels where the quality flag of this product (i.e. PCF_1_13) has not been raised. The result of this is plotted in Figure 6 (note this plot do not cover the same range in latitude as Figure 5) and the median values at the different bands in Table 1. The well know problem in the MERIS-processing with over-correction of path radiance at the shortest wavelength is evident as it is the only one where MERIS seems to overestimate. If we not exclude pixels with the PCD_1_13 flag raised the relative difference becomes at 413 nm around 5%, for the bands covering the range 443-509 it becomes in the order of 10% while it for 560 nm and upwards is more or less unchanged.

Figure 6 Relative difference in MERIS-reflectance from the satellite and ferry measurements.

<table>
<thead>
<tr>
<th>Band (nm)</th>
<th>Relative Difference [%]</th>
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</thead>
<tbody>
<tr>
<td>413</td>
<td>-17%</td>
</tr>
<tr>
<td>443</td>
<td>16%</td>
</tr>
<tr>
<td>490</td>
<td>30%</td>
</tr>
<tr>
<td>509</td>
<td>20%</td>
</tr>
<tr>
<td>510</td>
<td>32%</td>
</tr>
<tr>
<td>560</td>
<td>112%</td>
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<tr>
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<td>100%</td>
</tr>
<tr>
<td>665</td>
<td>45%</td>
</tr>
<tr>
<td>681</td>
<td>45%</td>
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</table>

Finally in Figure 7-Figure 9 we show how the reflection coefficient \( r_E \) varies with the latitude of the ship, the solar zenith angle and finally the azimuth angle between the ship and sun. The plots clearly shows that the reflection coefficient do not depend in any simple way – which is a result of

Figure 7 The reflection coefficient \( r_E \) as function of latitude.
Our experience is that maintenance even as seldom as monthly gives data of acceptable precision.

Correction of diffuse and direct radiation reflected at the surface is difficult. We have used the downward irradiance together with a “black wavelength” assumption and obtained realistic results – but also these need validation.

For further use of this method to validate MERIS-reflectance we plan to estimate the term $I_{u \theta}^{\text{ref}}$ based on measurements of radiance from the upper hemisphere together with the wind direction.

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**5. CONCLUSION**

Autonomous instrumentation onboard ships of opportunity increase the amount of field observations significantly relative to traditional platforms like research vessels. For validation of optical satellite data which requires clear sky condition this is a particular useful supplement.

The route of the ship and the placement of the sensors are very important to maximise the number of high quality recordings.