Demonstrating EO enabled assessment of sediment concentrations near offshore wind farms

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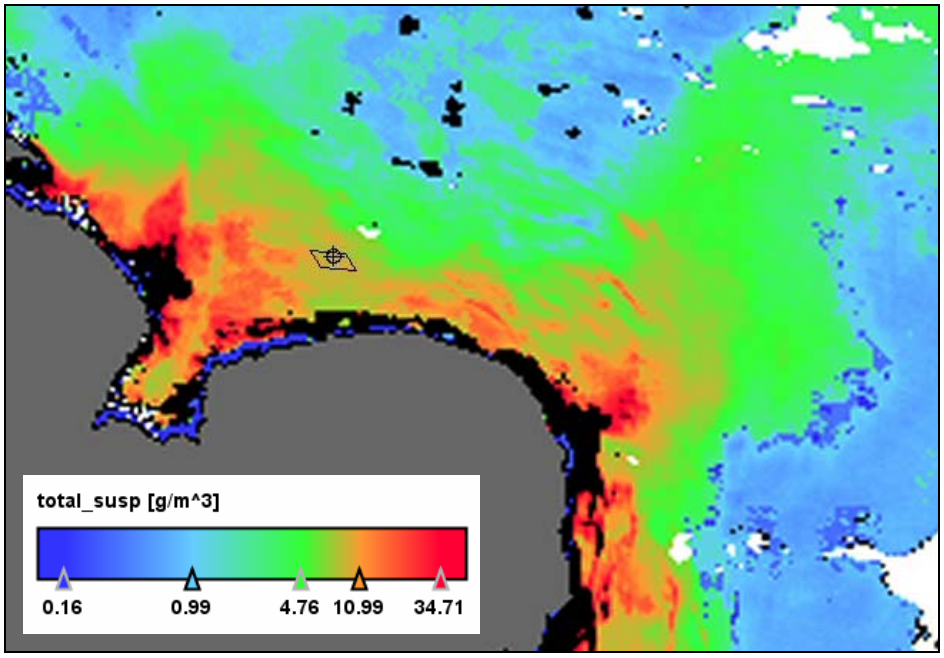

Abstract

The present study is a feasibility study on using earth observation data (EO) to assess changes in sediment concentrations around an offshore wind farm developed by the company Scira Offshore Energy Ltd (hereafter Scira). Offshore measurements were made from a buoy and an Acoustic Wave and Current meter (AWAC) sounding device around the study area during the period December 2004 to January 2005.
The EO data analyses are based on MERIS full resolution data from the ENVISAT satellite. Sediment concentration maps were produced and comparisons with the in-situ data showed a good agreement between EO TSM concentrations and in-situ TSM concentrations. However, only two good quality satellite images were available in December 2004 and it is therefore recommended for future studies and for operational purposes to compliment with data from more satellites, such as MODIS and SeaWiFS.
Sediment concentration maps from EO data have the advantage that they capture the spatial distribution of sediment concentrations. The combined use of EO data and in-situ measurements gives added value to the expensive in-situ measurements by placing these in their spatial context.
An interesting aspect of using EO assessed TSM is to use archive data to study the base line conditions. By analysing e.g. five years of monthly historical data, information can be obtained on the natural variability in TSM. Furthermore, EO derived TSM maps can be used as a part of the regular monitoring program during the time of operation of the wind farm. The main advantages and disadvantages of both EO and in-situ derived TSM concentrations are listed and discussed.

The work was executed by Scira as a Rapid Test Actions (RTA) under the European Space Agency (ESA) project “Earth Observation Responses to Geo Information Market Drivers – Offshore Wind Sector” undertaken by BMT Renewables Ltd contract No 17862/03/I-LG. The in-situ campaign was done by Gardline Environmental Ltd and the analysis of EO data, processing, analysis and comparison with in-situ data was done by Geographic Resource Analysis & Science Ltd (GRAS).

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Introduction

Existing methods to measure sediment concentration levels offshore involve either offshore recordings from instruments such as an Acoustic Wave and Current meter (AWAC) or boat measurements. Both are time consuming and resource demanding. These data can be of more value to the wind farm developers if they are combined with readily available information about sediment concentration maps produced from satellite earth observation data (EO).

The study had the objective to investigate if the offshore wind farm developer Scira Offshore Energy Ltd (hereafter Scira) would find the information from EO on sediment concentration maps useful. Scira is developing the Sheringham Shoal offshore wind farm (315 MW) which is planned for construction in 2008. As a part of the environmental impact studies Scira commissioned Gardline Environmental Ltd. to undertake offshore measurements around the Sheringham Shoal, off the Norfolk coast of England to get information on sediment concentrations at a specific location. This allowed a comparison of the two complementary data and information sources.

Specifically the winter months with their storms and sediment transport are of interest to the offshore wind farm developers. Seen from an EO point of view, this is the most difficult period because with

intensive cloud cover. Consequently, the study would address the feasibility of obtaining EO derived information on sediment concentrations during this period.

Progress has been made on the estimation of marine parameters from ocean colour remote sensing data. This includes the assessment of Total Suspended Matter (TSM). In this study ENVISAT MERIS full resolution (300 m) level 2 data was used to map the sediment distribution in the study area (Doerffer & Schiller, 1997). Unfortunately, only two good quality satellite images were available during December 2004

Satellite based estimation of TSM

The optical property of a water body is a function of the dissolved and dispersed substances and particles that are present in the water. EO data records reflected light in different wavelength intervals (called bands) and algorithms relate these measures of reflected light to the physical properties of the water (e.g. TSM). The satellite assessment of water quality can only be made from the part of the water column from where light are reflected back to the surface. This is know as the secchi depth, thus if the secchi depth is 10 m, the assessed TSM concentration will be an integrated value for the depth ranging from 0 – 10 meters, however, with a bias towards the surface, from where the most of the light is being reflected.

The individual satellite measurement that makes up an image is called a pixel and the size of the pixel determines the spatial resolution of the data. EO assessed TSM concentration is therefore an averaged value for the pixel area. The satellites orbiting Earth is only capable of capturing data at a certain time interval, known as the temporal resolution of the data. The temporal resolution of the EO data used in this study is normally one observation of a given point on the surface per day. Since cloud cover is a limiting factor when working with EO data the temporal resolution is often further reduced. Since the main EO data source used in this study is from MERIS, a description is given in the following section on the method used to derive TSM from ENVISAT MERIS data.

TSM from MERIS

MERIS data can be acquired from ESA as Level-1b and as Level-2 products in both full (FR) and reduced resolution (RR). The spatial resolution is 300 m for the FR and 1200 m for the RR data. Among the geophysical data delivered in the Level2 product is the Total Suspended Matter (TSM). TSM are defined as particulates ranging in size from less than 0.1 micrometer to 50 micrometers and are equally called Total Suspended Particulates (TSP). According to the product specifications TSM has an expected accuracy of 30%.

The TSM data are provided as concentrations in gm^{-3}. The product is derived by applying a scaling factor to the particle scattering (reflected light) at 442 nm, B_p (442) (m^{-1}). The scaling factor is 1.37 in the MERIS product, but may be adjusted to local conditions. Therefore,

$$TSM\ (g\ m^{-3}) = 1.37 * B_P\ (442\ nm)$$

Only few campaigns have attempted to validate the MERIS TSM product. One recent validation campaign, that equally included the validation of other geophysical MERIS products, suggested that the accuracy spans from up to ±75% when comparing with in situ data (Sörensen et al., 2003). Another study showed that when no confidence flags (possible error indications) were raised, MERIS over estimated TSM by 16% (Martinez et al., 2003). Consequently, it is too early to conclude on the accuracy of the TSM product.

Site description

The study area is located 11 nautical miles due north off the Norfolk coast (Weybourne/Sheringham) or 6 nautical miles due north of the Sheringham shoal (an area with water depths ranging from app. 2.5 – 10 meters). The geographic coordinates are 53° 08.5' N, 001° 09.0' E. The water depth of the area is app. 20 meters and the seabed in the area is dominated by a field of relatively small sand waves. The location is marked on Figure 3.

Data description

In- situ measurements

A number of in-situ measurements where conducted in the period from November 28th 2004 to February 3rd 2005 where a seabed mounted Nortek AWAC were deployed in the study area. Gardline Environmental Ltd deployed the AWAC and compiled the following results.

The AWAC was used to return acoustic backscatter intensities (ABSI). These ABSI values were related to total suspended matter (TSM) through a calibration. This was based on additional anchor station measurements with water samplings during a tidal cycle (13 hours). Hourly samples were collected at three different depths providing a total of 39 samples.

The TSM concentrations returned from the laboratory analyses of the water samples from the anchor station showed similar TSM concentrations throughout the water column, although a slightly higher concentration was detected near the seabed. The overall conclusion was that the water column was well mixed during the test period. The values of TSM concentrations ranged from 3 - 45 g/m^3 during the period with typical daily variation following the tidal cycle with amplitudes of app. 15 – 25 g/m^3.

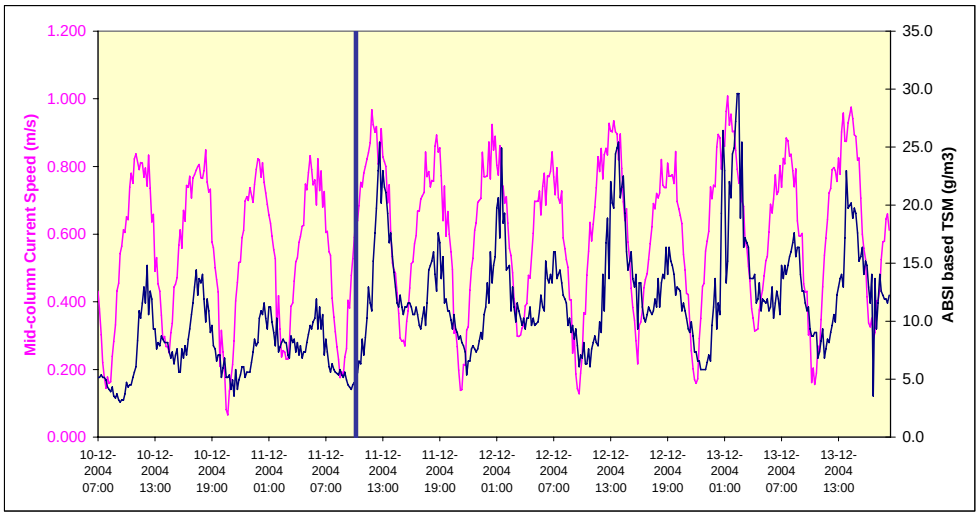


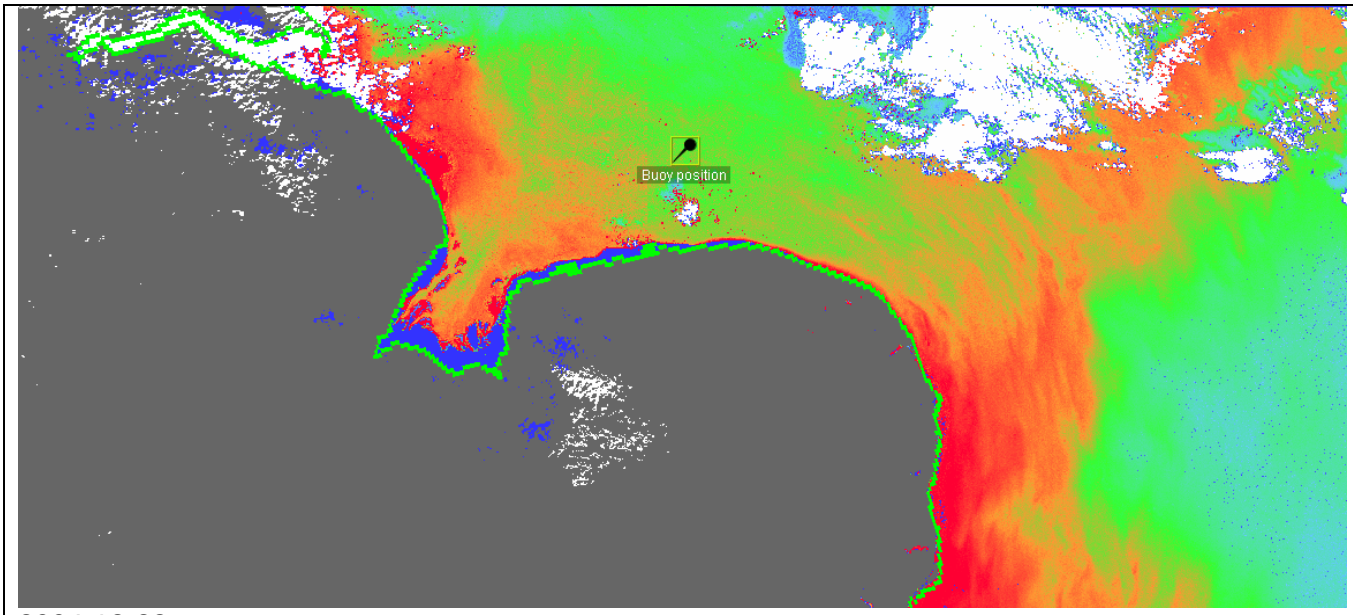
Figure 1: ABSI based TSM concentrations shown along with measured current speed in the mid-part of the water column. The tidal cyclus can clearly be observed. the time period is from 2004-12-11 07:00 to 2004-12-13 18:00. The vertical line indicate the time of comparison with EO data on 2004-12-11.

When the AWAC frame was recovered in February 2005 it was discovered that the AWAC was partially flooded. Also, a massive bio-fouling had occurred by whelks and whelk eggs covering the instruments. After inspections at Nortek it was found that data covering the period until the end of December were unaffected by this phenomenon, whereas data from the remaining period were affected. January data were therefore excluded from the study.

Figure 2: Recovered frame with whelks and whelk eggs covering the AWAC sensor.

MERIS data description

The ENVISAT MERIS data were made available through ESA. All archived scenes from the study period covering the AOI were examined through a visual inspection of the quicklooks. The search returned nine potentially suitable scenes in the period. However, a detailed analysis showed that only two scenes (2004-12-11, 10.13 UTC & 2004-12-23, 10.36 UTC) contained valid information. The rest were rejected due to failure of the TSM algorithm or due to cloud cover over the AOI.



2004-12-23

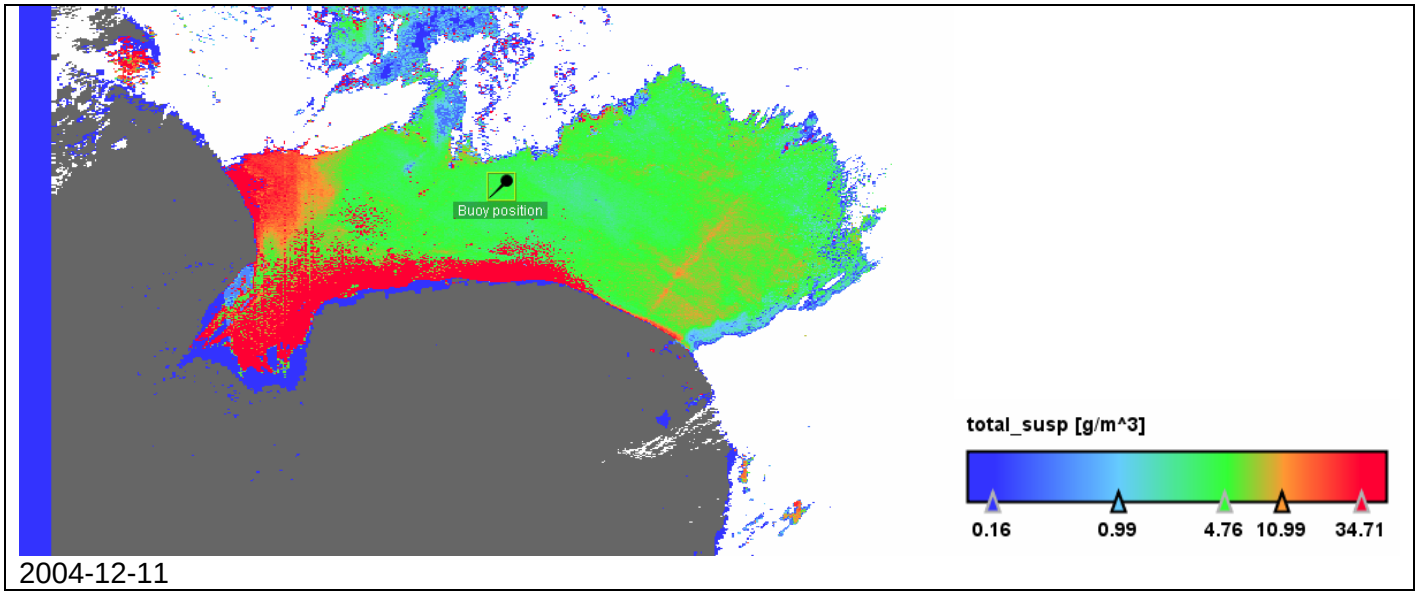
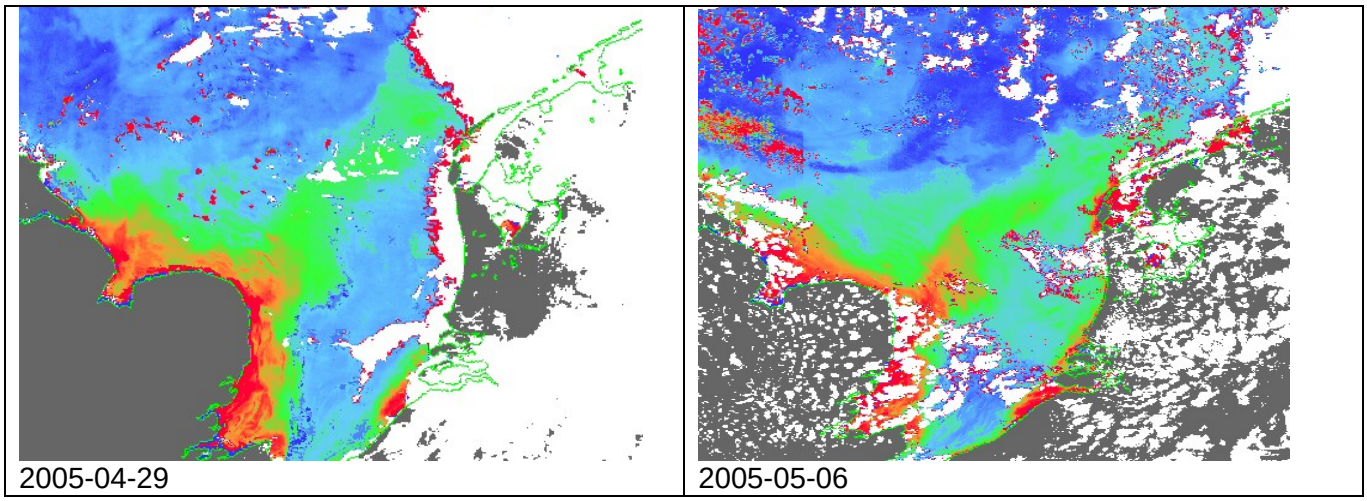


Figure 3: MERIS FR level-2 TSM maps covering the AOI. The color legend at the bottom right shows the concentration ranges. The location of the study area is marked with the black pin north of the Norfolk Coast, UK. The offshore wind farm will cover an area of 35 km^2 around this location.

In order to assess the general availability of EO data and the feasibility to produce TSM maps, the period from the end of April to the end of May 2005 was used as a case. Here five MERIS RR scenes were identified and processed. See figure 4.



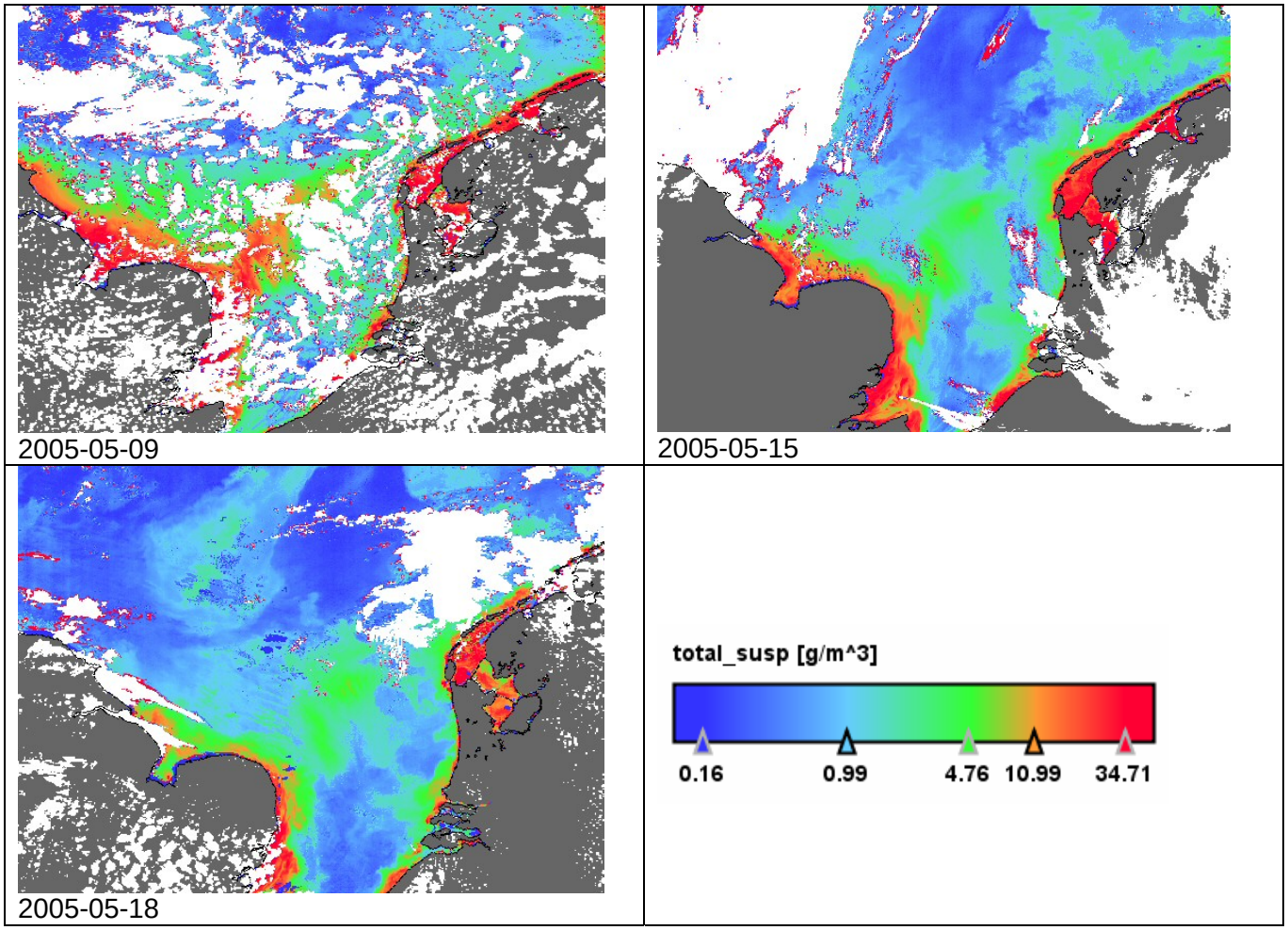


Figure 4: MERIS RR TSM from a 3 week period in May 2005. The overall distribution patterns of TSM are clearly visible and provide information about the dynamics in the area.

Data availability, cloud cover and MODIS TSM

As a consequence of the poor data coverage of MERIS data, the availability of MODIS data were examined in order to expand the dataset. Unfortunately, no TSM data were available at the exact position of the in-situ measurement due to cloud contamination or failure of the TSM algorithm. The MODIS data archives at NASA where studied to check if December 2004 was an extreme period in terms of cloud cover. This revealed that, based on data from 2002 and 2003, typically a number of 10 scenes were potentially available for December. From the experiences with the MERIS RR scenes it can be seen that not all 10 scenes may turn out to be useful when they are inspected in details and December 2004 did not appear to be an exceptional month with unusual cloud coverage for this particular area.

Comparison of in-situ measurements with EO derived TSM

The TSM algorithm described above is a general valid algorithm. Since local conditions may vary, it was anticipated that it would be necessary to calibrate the level-2 EO TSM product using the AWAC measurements. With only two valid EO data points this was not possible and a direct comparison has been made instead.

The general conditions on December 11 and 23 were examined by inspection of the in-situ data. Below is shown the tide levels and wind speeds for the two days where the comparisons were done. It can be seen that the tide is at or near the lowest point in the cycle with low tidal induced currents. The wind speed is measured to app. 5 knots on 2004-12-11 (general wind direction is SW) and to 30 – 35 knots on 2004-12-23 (general wind direction is W).

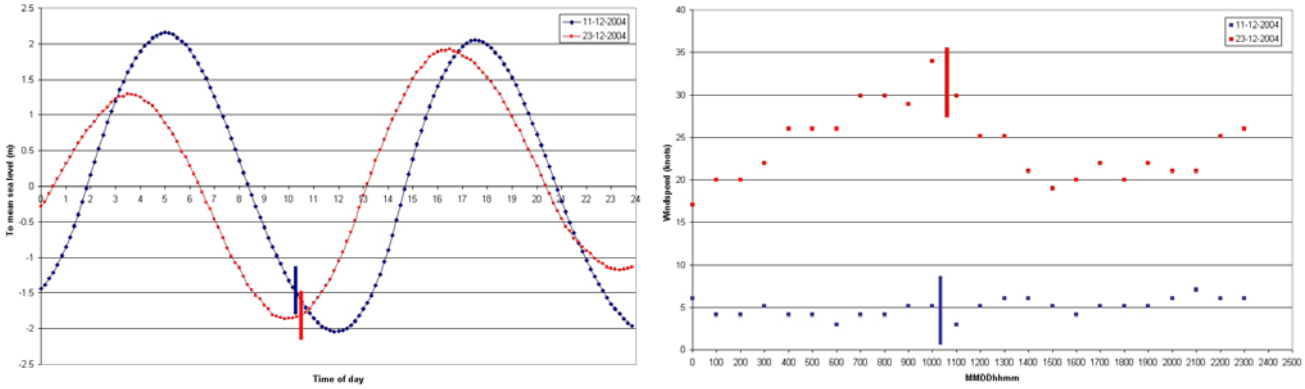


Figure 5: Left: Tide levels on the two days where the comparisons were made. The thick vertical lines in red and blue show the time of the EO data acquisition and for the in-situ data comparison. The x axis shows the time of the day. Right: Wind speed levels during the days where the comparisons were made. The thick vertical lines show again the time of the EO data acquisition and the match-up in-situ data. The horizontal axis indicates the time of the day.

From Figure 6 and table 1 it can be seen that the AWAC based TSM concentrations changes down through the water column. The satellite sensor records the total radiance leaving the water column and thus only returns a single value. As described above, the EO derived TSM value is therefore an integrated value for the concentration from the surface to a certain depth. An inspection of a secchi depth database available from the International Council for Exploration of the Sea (ICES), showed historical values for the area ranging from 4 to 15 meter (ICES, 2005; a description of the data set can be found in Aarup, 2002). An average secchi depth of 10 m was therefore chosen and consequently the AWAC TSM concentrations were averaged between 0 and 10 meter depth for 2004-12-11. The concentrations found in the upper part of the water column on 2004-12-23 are related the strong winds at that time (between 30 and 35 knots). This results in the creation of micro-bubbles due to near-surface aeration. These bubbles affect the AWAC recordings resulting in wrong and extreme TSM estimates. Due to the strong winds on that particular day well mixed conditions are expected down in the water column. The concentrations found at the depth range 5 – 12 meters are similar suggesting well mixed conditions, and an average TSM value has therefore been calculated for this depth range.

Table 1: ABSI based TSM concentrations in the water column at the EO data acquisition time. Concentrations are in g/m^3

Depth (m)	11-12-2004	23-12-2004
0	0.4	176.0
1	0.4	80.7
2	0.7	35.0
3	1.3	12.4
4	2.2	7.3
5	3.4	5.6
6	3.7	4.4
7	4.8	4.3
8	4.8	4.4
9	4.7	3.9
10	5.1	4.0
11	5.4	5.0
12	6.3	5.3
13	7.5	6.8
14	9.0	8.4
15	11.4	11.4
16	15.5	15.7

Figure 6: Estimated TSM derived from the ABSI recordings from the time of acquisition of the EO data. While the concentration at 2004-12-11 is gradually increasing down the water column towards the bottom a very high concentration level is found in the top four meters on 2004-12-23. The concentration is 176 g/m^3 at the surface according to the ABSI recordings.

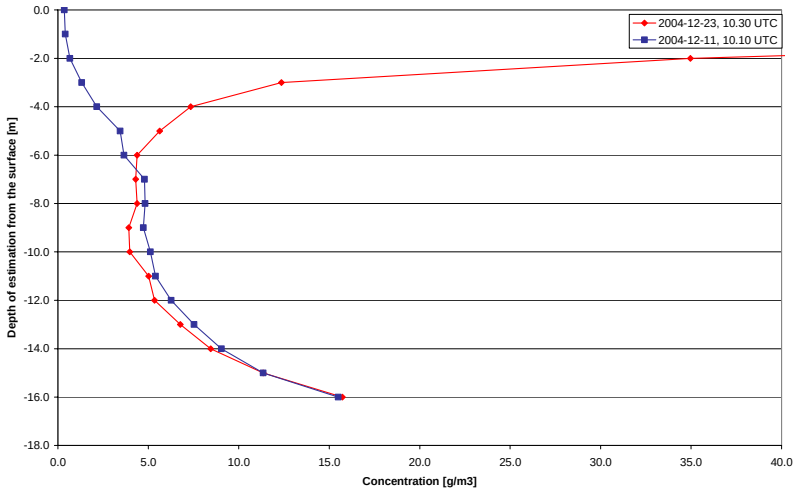


Table 2: Comparison between the EO derived TSM concentrations and the ABSI based TSM concentrations from the averaged part of the water column.

	EO MERIS TSM (g/m^3)	AWAC TSM (g/m^3)
2004-12-11 concentration	4.3 (10.13 UTC)	2.9 (10.10 UTC)
2004-12-23 concentration	6.5 (10.36 UTC)	4.6 (10.30 UTC)

From Table 2 it can be seen that there is a fair agreement between the EO derived TSM estimate and the ABSI based TSM estimate. Both EO results are overestimated compared to the AWAC estimated TSM. On December 11 the difference is 1.4 g/m^3 or close to 48 %. For December 23 the over estimation is 1.9 g/m^3 or close to 41 %. Though the estimation of TSM from EO is close to being 50% these estimates are still within the range (or very close for December 23) of the observations made by the AWAC.

Comparison – advantages/disadvantages

Although the EO data material in this study is rather limited and therefore not very conclusive, the present work shows that EO derived maps of TSM concentrations can be of potential use to the wind farm developers. Below are comparative advantages and disadvantages listed of using EO TSM maps.

EO based estimation of TSM

Advantage

- Large spatial coverage
- Flow patterns are visible and provide a better understanding of the sediment dynamics in the area compared to a point measurement
- Not dependent on external boat operator, buoy/AWAC operator etc, however, dependent on satellite data providers. It is expected that the present situation where difficulties were encountered to obtain MERIS will be improved in the future
- Data are available in near-real-time
- Low cost compared to in-situ measurements. A single EO TSM map from MERIS or MODIS data can be produced for less than 500 Euro. When ordering large quantities, the processing can be automated and the price reduced to an order of 100 Euro per TSM map.
- Archive data can be used to provide base line information about the dynamics of the area

Disadvantage

- Presence of clouds hinder EO data acquisitions
- Accuracy. The TSM algorithms are still not completely validated, regional differences may require regional algorithms. This will require local calibrations with local in-situ data in order to obtain improved accuracy
- EO estimates of TSM are only valid for the near-surface conditions and only for one observation per day (if cloud free). More EO data sources can be used, e.g. adding SeaWiFS data to the analysis. Using all available sensors, will limit the impact of clouds, and make acquisitions within the daily timeframe of 10:00 to 16:00 possible.
- Access to EO data. The process of getting access to EO data requires specialist knowledge

In-situ based estimation of TSM

Advantage

- Accurate measurement (if correctly calibrated)
- Continuous data logging with short time interval
- Provides depth profiles
- Well known method – no blockade due to lack of knowledge
- Possible to detect seabed flows of sediment
- Other in-situ data can be collected simultaneously

Disadvantage

- High cost. Approximately 22,000 Euro for deployment of an AWAC for two months.
- Single point measurement. May not be representative for the general conditions at the study site.
- Risk of human and/or bio disturbance or destruction ‘Bio-fouling’ (whelks)
- No warning if hardware fails/breaks – will only be noticed when the data is collected by the end of a measurement campaign.

Conclusion

The present study has shown that the EO derived TSM maps captures fairly well the TSM values as compared to in-situ data obtained from an AWAC device. However, clouds are a major problem resulting in only two days of match-up data being available for the area of interest during December 2004. For operational purposes, EO data from all available sources including MERIS, MODIS and SeaWiFS should improve the availability of data.

The combined use of EO data and AWAC measurements provides added value to the expensive in-situ measurements by placing these in their spatial context. Hereby the spatial representation of the AWAC data can be assessed.

An interesting aspect of using EO assessed TSM is to use archive data to study the base line conditions. By analysing e.g. five years of monthly data information about the natural variability in TSM can be obtained. Furthermore, EO derived TSM maps can be used as a part of the regular monitoring program during the time of operation of the wind farm.

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Acronyms

ABSI	acoustic backscatter intensities
AWAC	Acoustic Wave and Current meter
BMT	British Maritime Technologies
ESA	European Space Agency
EO	Earth Observations
FR	Full resolution
GRAS	Geographic Resource Analysis & Science
ICES	International Council for Exploration of the Sea
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectroradiometer
MODIS Aqua	One of two MODIS satellites (and instruments)
NASA	National Aeronautics and Space Administration
RTA	Rapid Test Action
SCIRA	Scira Offshore Energy Limited
SeaWiFS	Sea-viewing Wide-Field of view Sensor
TSM	Total Suspended Matter

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