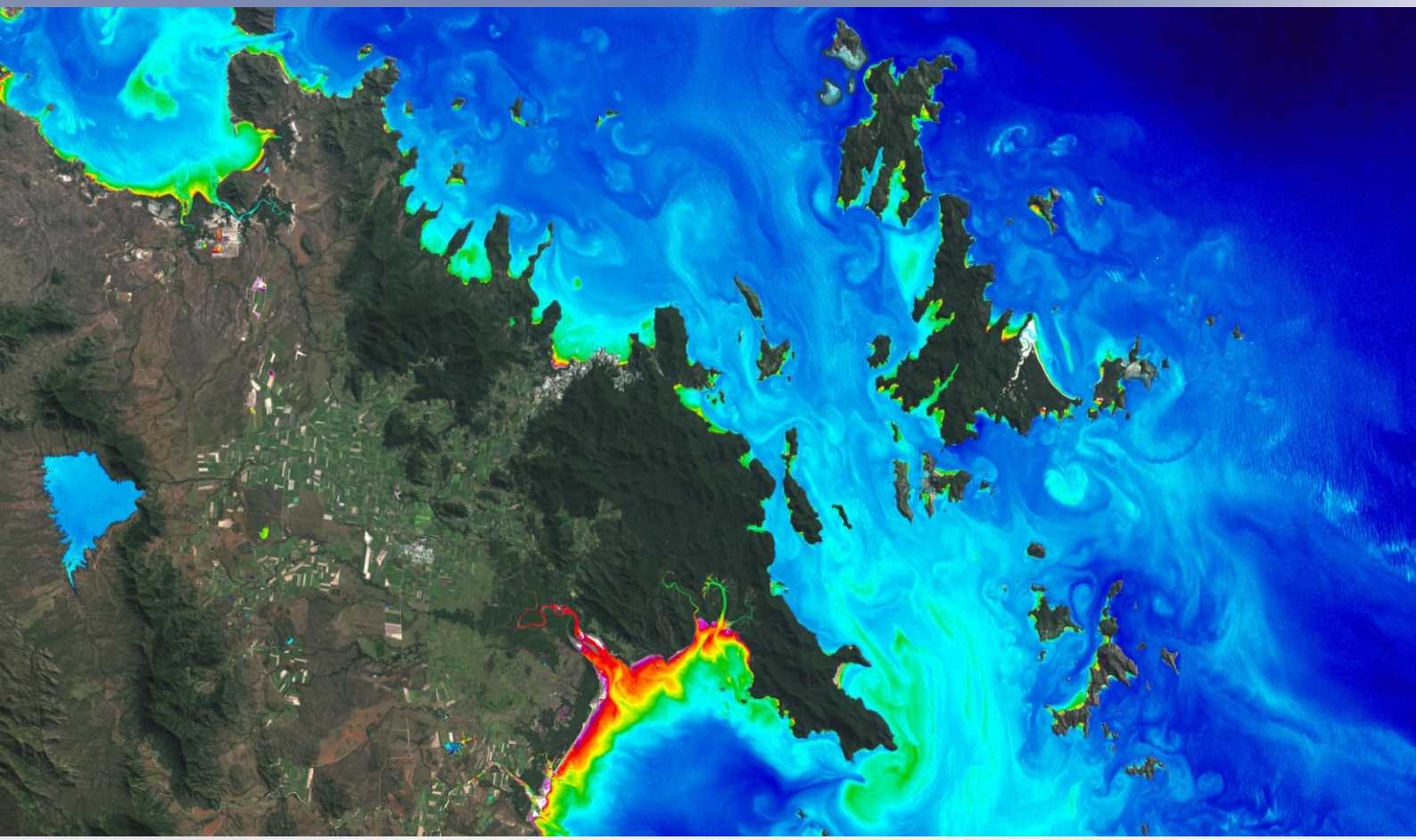
Water Quality Monitoring Australia
EOMAP



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Executive Summary

In light of the various marine and coastal issues facing Australia, which include the management of marine environments and the increase in both near-shore and offshore-development activities, a standardized, quantitative and near-real time monitoring approach is required for Australian waters. A good example of such an application is continuously monitoring the location and extent of dredging and dumping sediment plumes in the water, over a particular area of interest.

EOMAP GmbH & Co.KG now offers state-of-the-art, medium and high resolution water quality monitoring products for whole of Australia, in near real time. These satellite-derived products are jointly produced with Landgate, Western Australia's primary provider of land information and geographic data.

With physics-based inversion algorithms running through a standardized processing chain, the Modular Inversion and Processing System MIP produces digital map products of Australian Water Quality at 30 and 500 m horizontal resolution. This physics-based and sensor-independent retrieval of the water products ensures that the measures are inter-comparable both Australia- and world-wide. In fact EOMAP is also already generating products for other continents using the same harmonized production systems, while taking into account variations in specific optical properties for these waters.

These water quality data products are offered firstly on a subscription basis, where power users such as environmental managers, engineers, and scientists can ingest them directly into their systems for analysis and monitoring. However, we have also decided to make our water turbidity product freely accessible to everyone, for two important areas of the Australian Marine Jurisdiction. With our web-based eoApp Australia, any user is able to monitor the turbidity and visibility of the water in these areas. Finally, we also offer the option of setting up, together with the commercial subscriptions, customised, and secure eoApps for viewing and interpreting the data products.

The following document is intended to introduce and describe the project, the products and the technology.

For even more information, please visit www.eomap.com

Project partners

EOMAP GmbH & Co. KG

Landgate

EOMAP eoWaterQuality Monitoring Australia- Overview

EOMAP, in partnership with Landgate, is now operationally producing daily water quality products for whole of Australia at 500m horizontal resolution . Satellite data from the MODIS Aqua and Terra (NASA) platforms are delivered directly from Australian receiving stations to Landgate's server systems, where the imagery - handled by the EOMAP Workflow System (EWS) - is instantly processed through EOMAP's proprietary Modular Inversion Processor (MIP).

The standard output from this operational processing is digital maps of turbidity and chlorophyll-a concentrations. Other products available include visibility, total suspended matter and dissolved organic concentrations. Further to this, a range of ancillary aquatic environment parameters and quality control products are also routinely generated. These are discussed in further detail in the next section.

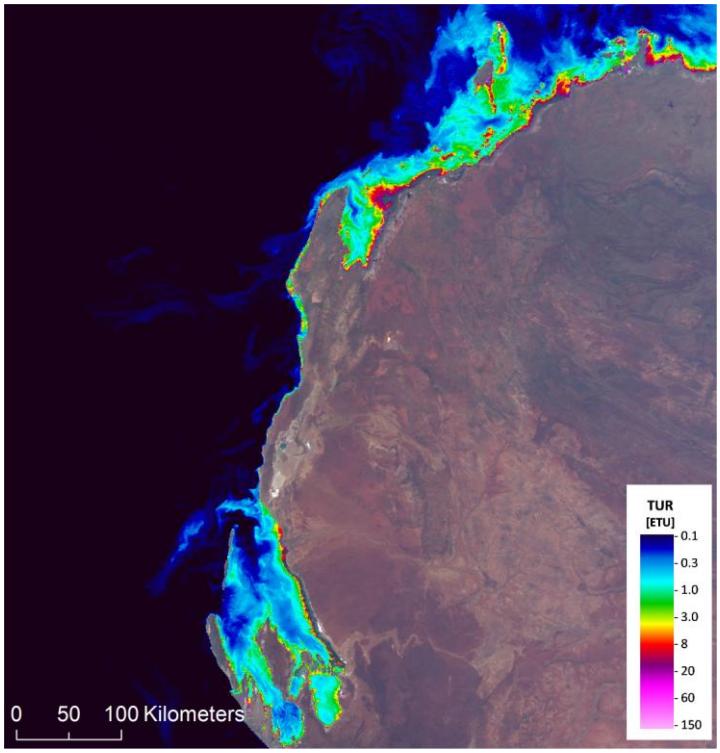


Figure 1: Standard EOMAP 500m turbidity product west Australia June 06, 2014, using MODIS Aqua satellite data (processing © EOMAP, data © NASA)

Higher spatial resolution eoWaterQuality products are also available, notably 30m products from the Landsat 7 and 8 sensors, 5 m products from the RapidEye sensor and 2m resolution products from the WorldView-2 sensor.

Furthermore, the capability exists to generate these standardised water quality products going back to 2000 for MODIS data and to 1984 for Landsat data. In other words, the EOMAP algorithms allow for the creation of time series for quantitatively-based change detection and trend analysis.

Currently, operationally processed prodcuts from two areas are freely accesible through the web-based **eoApp Australia** data visualiser: Abbot Point and the Grear Barrier Reef in Queensland and Ningaloo Reef and Barrow Island in West Australia (*Figure 2*).

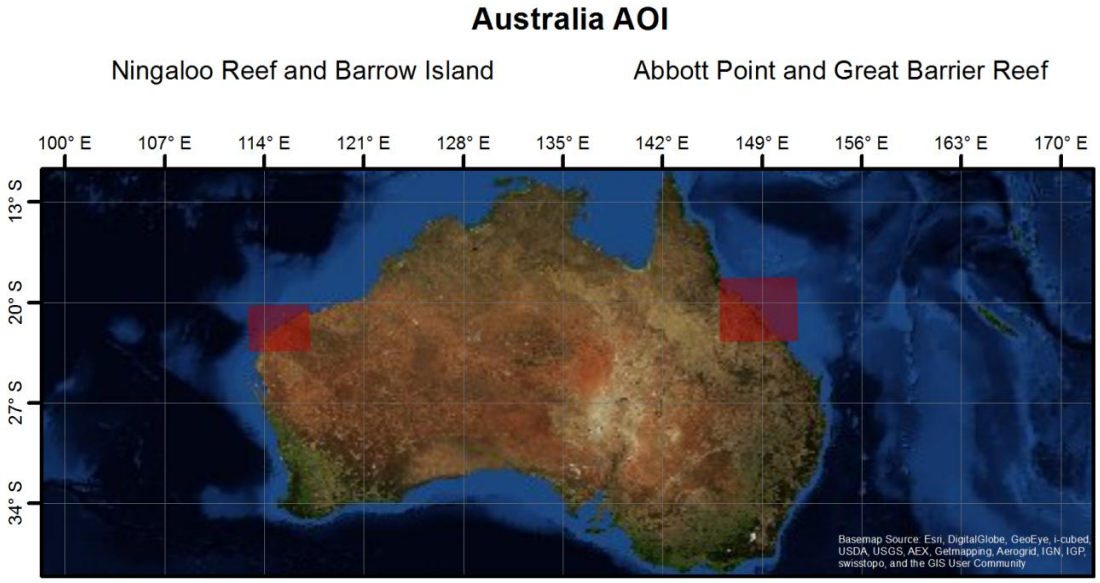


Figure 2: Overview of the Australian areas currently accessible with the eoApp Australia, displayed as red rectangles

For all other regions in Australia and further areas worldwide, you can visit our online store www.eomap.com/store or contact us via info@eomap.com.

Technical background and product information

Water bodies have specific reflectance characteristics (spectra) based on the concentration of its optical active constituencies. Optically active water components include suspended matter, phytoplankton and their different absorbing pigments, detritus, and dissolved coloured organic matter, called Yellow Substances or Gelbstoff. With the knowledge of these characteristics it is possible to retrieve quantitative values of the concentrations of water constituents, based on the data measured by the satellite sensors, see *Figure 3*.

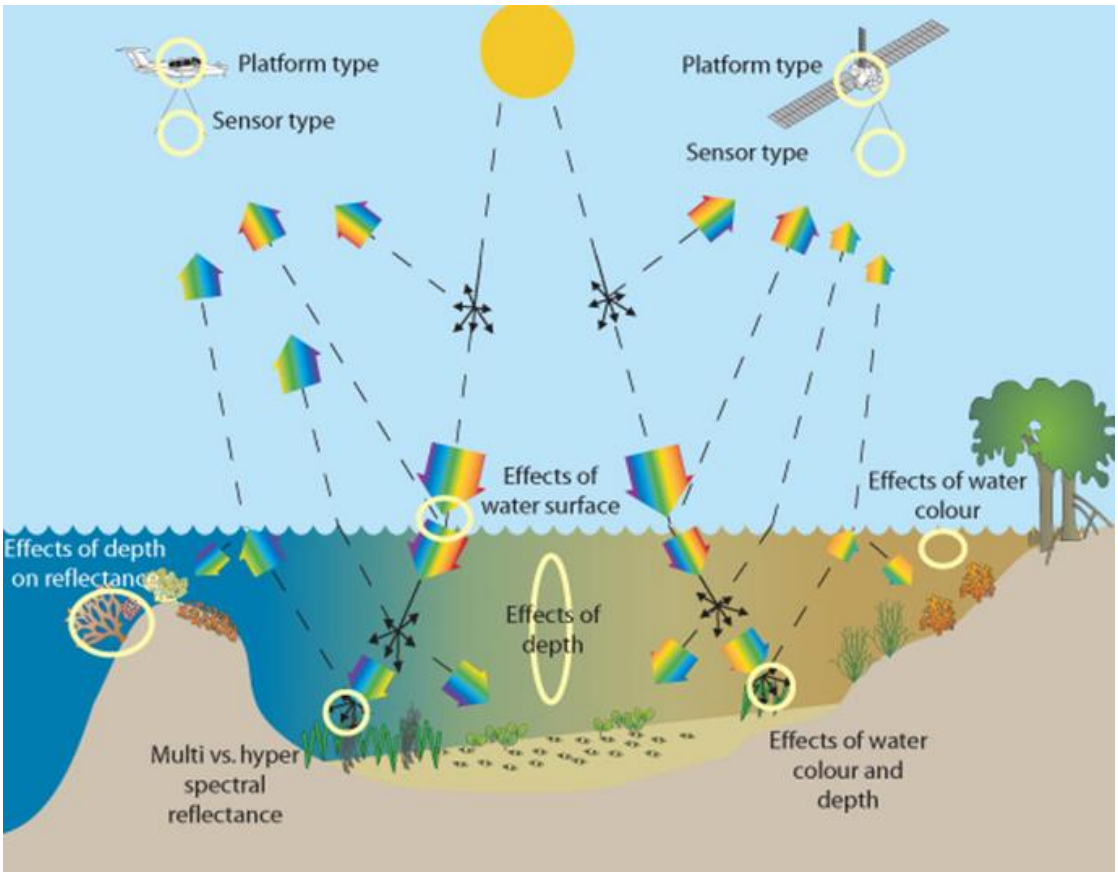


Figure 3: Schematic illustrating the path of the sunlight signal, interacting with the atmosphere, water column and seafloor, and finally being measured by a space-borne or airborne sensor. Image courtesy of the Centre for Spatial Environmental Research, University of Queensland.

EOMAP and German Aerospace Center (DLR) scientists have over the past 20 years developed a unique physics-based Modular Inversion and Processing System (MIP), which include all the relevant processing steps to guarantee a robust, standardised and operational processing of water quality parameters from satellite data (Heege 2014, Heege & Fischer 2004)). Importantly, physics-based methods require no known information of the study area, and can therefore be applied independent of satellite type and study area.

The MIP architecture systematically handles the independent properties of sensor parameters and specific optical properties, as well as the radiative transfer relationships (at 1nm spectral resolution) in the main data base, and furthermore manages the uptake of the individual algorithm modules. This allows for an automatic adaptation of the retrieval modules to the specific sensor properties and optical conditions of the target area.

Within the current operational processing at Landgate, a set of products are generated from daily recorded MODIS satellite images. These and other optional products cover the major parameters for evaluation of the ecological status of the water bodies and include:

- Turbidity (TUR) is a key parameter of water quality and is linearly related to the backward scattering of light of organic and inorganic particles in water. It is linearly related to TSM (Total Suspended Matter) at low to moderate turbidity values.
  The measurement unit is Earth Observation Turbidity Unit (ETU), which is similar to Formazine Turbidity Unit (FTU). Turbidity is determined by the backward scattering of light between 450 to 800nm, which is physically retrieved using satellite data. The geometrical properties of the in situ measurement device and wavelength used may differ in comparison to the satellite product. For example, the standard FTU determination is based on the measurement of light scattered within a 90° angle from a beam directed at the water sample.

  Note: As the shape, size and spectral characteristics of particles vary, the exact relationship between scattering and turbidity may vary across both location and time (e.g. when the phytoplankton species composition changes).

- Chlorophyll-a (CHL) is a pigment included in phytoplankton cells and serves as proxy for algae in natural waters. The EOMAP Chlorophyll product is related to the spectral absorption of the blue and red bands of the satellite sensor. The measurement unit is micro grams per litre (µg/l).

  Note: The differentiation between inorganic, organic and Chlorophyll absorption is limited by the spectral resolution and radiometric sensitivity of a given satellite sensor. As it happens, high spatial resolution sensors typically feature lower spectral resolution and radiometric sensitivity. This is why EOMAP offers a harmonized, or standardised, Chlorophyll-a_{max} (CHM) indicator for a range of sensors. This indicator is based on the derived, harmonized information of in-water turbidity, in-water organic absorption and spectral characteristics of each water body. Caution should be exercised with the interpretation of chlorophyll concentrations for areas with increased concentration of CDOM, e.g. close to river plumes. A naturally occurring adaptation of the phytoplankton pigments to the light conditions as well as different taxa has an impact on the regional relation between phytoplankton absorption and the satellite-retrieved value.

- Total Suspended Matter (TSM) is essentially related to the total scattering of particles in the water column and is therefore linearly related to Turbidity at low to moderate values (see above). Consistent small spatial differences of Total Suspended Matter of less than 0.2 mg/l can be detected for low to medium concentration ranges. TSM has a large influence on ecology in the water column as it reduces e.g. the light availability with negative effects on plants and animals.

  Note: The relation between scattering and TSM is in most cases regional constant, but can vary with particle size distribution. Therefore, regional calibration of TSM to the total scattering coefficients may improve the accuracy for quantitative TSM estimates.

- Visibility (SDD) or transparency indicates the clarity in the water column. The related measure of Secchi Depth (measured with a Secchi disk) is a common parameter in water quality analysis. Visibility is related to the euphotic zone in the water and is a useful

information source for divers. The EOMAP visibility product is derived from the in-water scattering properties, which are converted using the natural logarithm and an empirical retrieved coeffienct and expressed in metres (m).

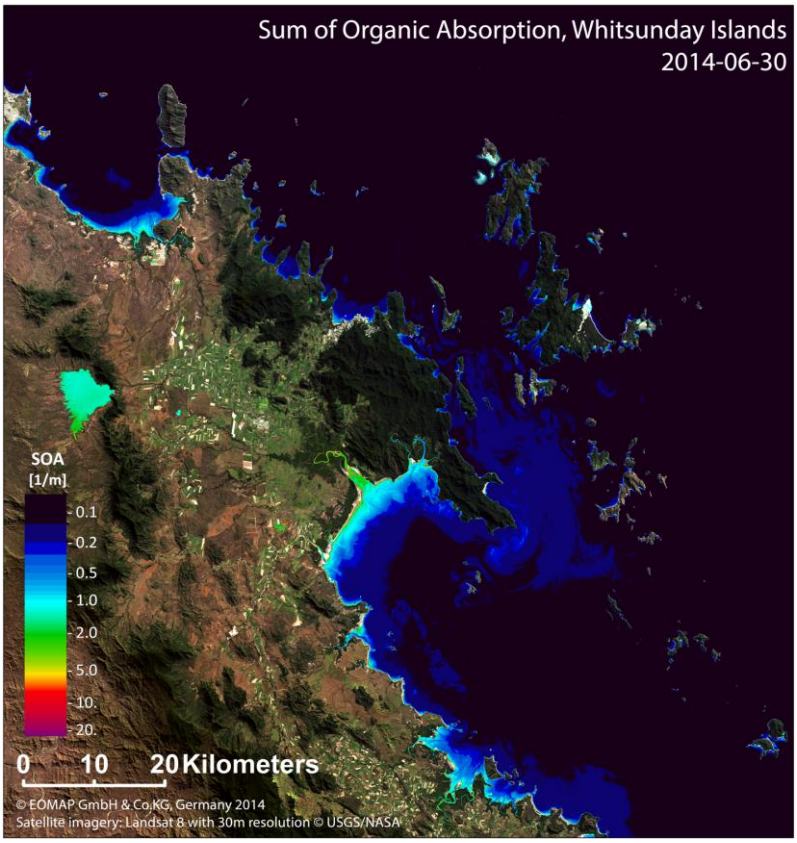


Figure 4: Example Sum of organic absorption product of eastern Australia using Landsat 8 data (processing © EOMAP, data © USGS/NASA)

- Total absorption (ABS) is retrieved from the absorption of light by particulate and dissolved organic and inorganic matter. The relative contribution of inorganic absorptions varies for changing SIOPSs, which are monitored within the retrieval algorithms.

- Sum of organic absorption (SOA) is retrieved from the absorption of light by particulate and dissolved organic matter.

- Z90 (Z90) indicates the water depth from which 90 % of the reflected light comes from.

- Total Quality Image (QUT) of EOMAP's MIP processor quantifies the overall quality of each pixel from low to high.

- EOMAP Quality Coding (QUC) visualize the processor internal quality check with defined indicators (e.g. sunglint, shallow water risk), classified into no quality concerns, quality warning and bad quality. The EOMAP Quality Decoder Plugin for Quantum GIS is a user-friendly visualization tool for the product.

- RGB composite images represent the area of interest either in "true colour" or "false colour" mode combining predefined bands, depending on the used sensor and the user specifications.
- DIV is the ratio between total absorption and total scattering of water constituents at 550nm. Zones of increased DIV can be interpreted as zones of increased organic production or increased dissolved organic and nutrient inflows, independent on absolute concentrations.

The dominant sources of error for satellite-based water quality retrieval are shallow water areas where the seafloor is affecting the satellite signal. Using bathymetry layers as additional input, recent EOMAP technologies are now capable of accounting and correcting for these sources of error. These methods are still in the development phase and will be applied as standard once testing and validation have been completed.

A demo data set with all generated products can be downloaded here:

- Demo data 500m and Demo data 30m

Further products, such as bathymetry for optically shallow water areas or atmospherically corrected subsurface reflectance imagery are also retrieved within the EOMAP processing chain and available upon request. For request, please contact info@eomap.com.

You can find showcase projects on www.eomap.com or consult our recent publications:

- Heege et al. (2014) : Operational multi-sensor monitoring of turbidity for the entire Mekong Delta, International Journal of Remote Sensing, Volume 35, Issue 8
- Kiselev et al. (2014, accepted): Sensor independent adjacency correction algorithm for coastal and inland water systems. Remote Sensing of Environment

Validation and Quality control of EOMAP water quality products

Comparisons of EOMAP's satellite derived products with in situ measurements are used to check and validate the water quality outputs. Further to this, the EOMAP processor's internal retrieval controls also provide continuous feedback on the quality of the products. Both, the validation as well as the EOMAP's own processor internal retrieval control shall help to evaluate product quality and to understand the harmonized nature of the products. Overall, the satellite-derived eoWaterQuality products deliver consistent products in long-term tests for the most relevant parameters, namely turbidity and related suspended matter and chlorophyll-a content.

Figure 5 a) and b show the comparison between a decade of in situ measurements by the International Water Protection Commission IGKB for Lake Constance, and EOMAP's satellite-retrieved Chlorophyll (from MERIS) and suspended matter (from MERIS and Landsat-7). *Figure 5* a) shows that the automated quality control measures generated for the remote sensing products are capable of differentiating between critical (orange) and good (green) measurements,. The quality measure of each pixel is calculated by taking into account several factors such as sunglint, solar angle, spacecraft angle, AOT influence, shallow water, transition zones, residuum of the retrieval, processor warnings and concentrations at the upper limit of the range.

The quantitative comparison of products from different satellite sensors is demonstrated in *Figure 5* b) for Lake Constance and *Figure 5* c) for the much smaller lake Walchensee. Consistent turbidity

measurements from MERIS and Landsat 7 have been retrieved, which match well with the in situ measurements, where available.

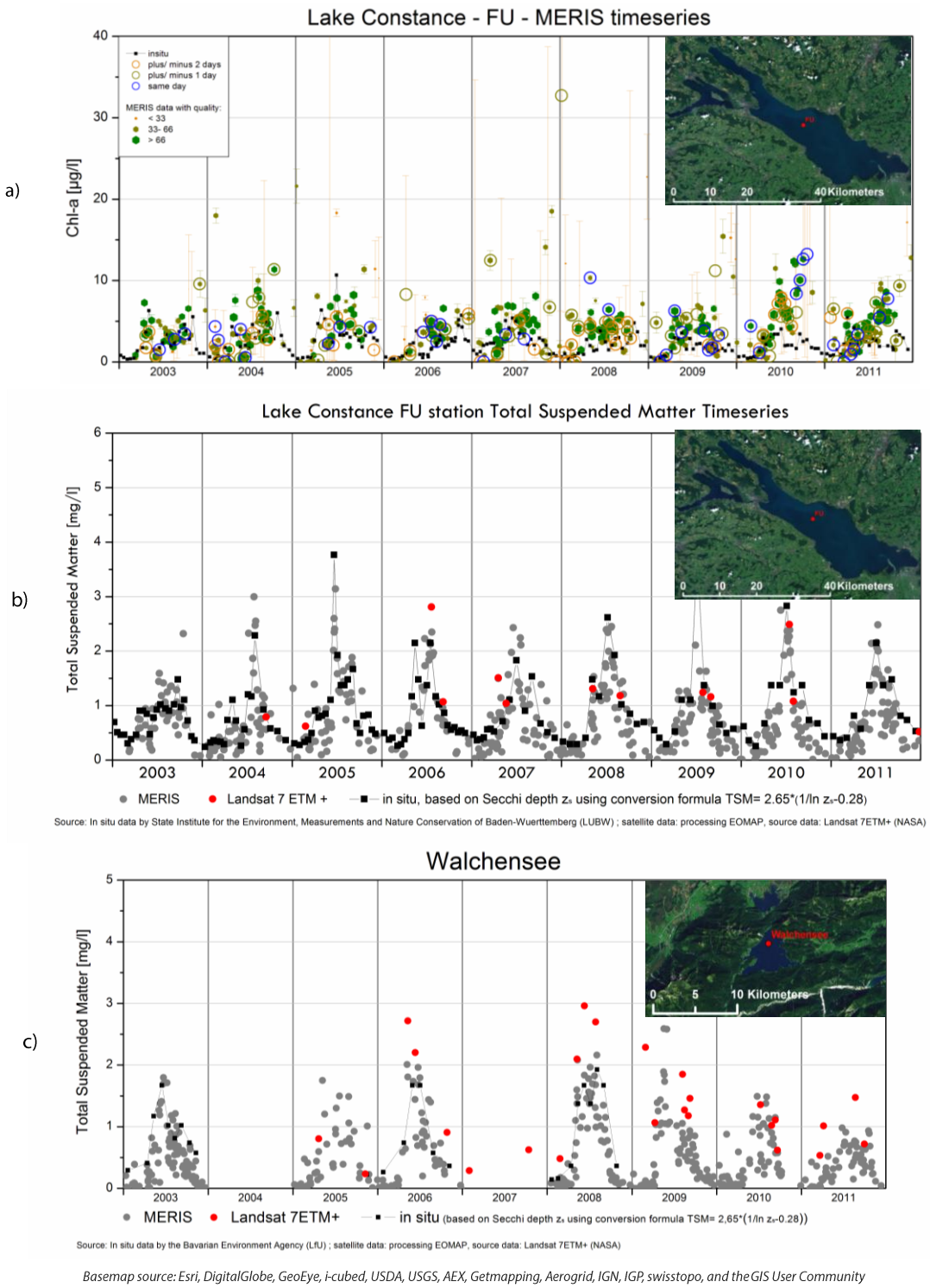


Figure 5: Time series of Chl-a and TSM from satellite data, processed with the EOMAP MIP and in situ data at the FU station Lake Constance and lake Walchensee, using MERIS (a) and MERIS and Landsat data (b) and c)). In situ measurements were kindly through the BOWIS –Lake Constance Water-Information-System provided by IGKB and LfU. The validation was conducted during the FP7-EU funded FRESHMON project.

Another validation example is shown in Figure 6 displaying turbidity values as derived from MODIS, Landsat and RapidEye as well as from the in situ measurements, where the MODIS values are calculated from the monthly median. It reveals that MODIS-derived turbidity follows very well the seasonal trends, and even more importantly, delivers quantitative values in good alignment with the in situ turbidity measurements (where highly mixed pixels have been filtered out). The high resolution satellite turbidity estimates (the value on the date where Landsat or RapidEye data were available) also follow the seasonal trend well.

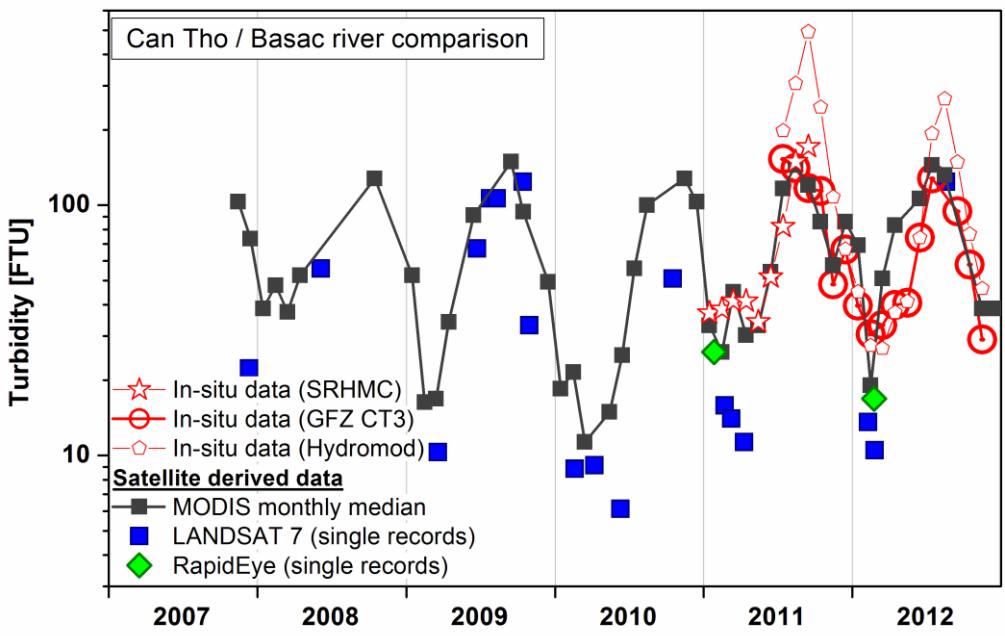
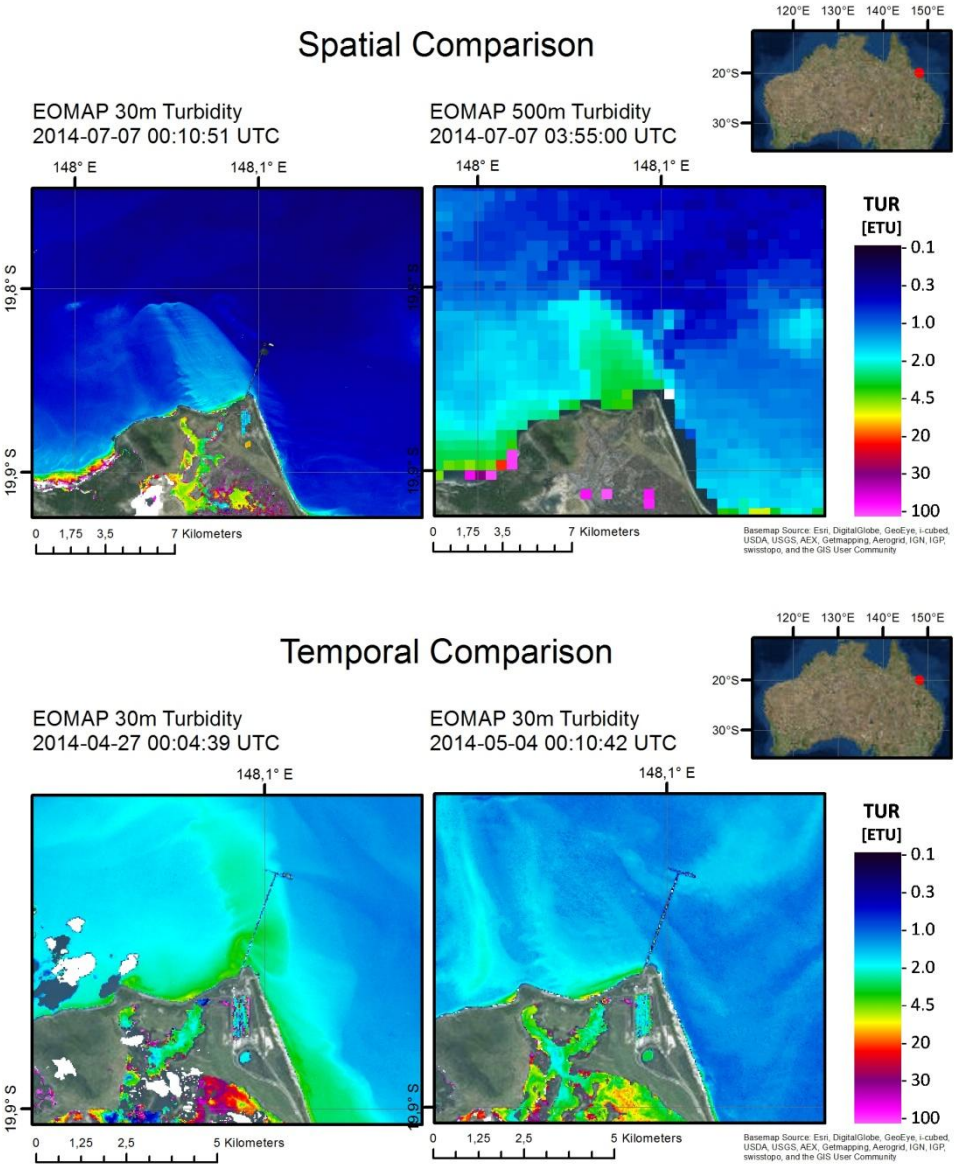


Figure 6: A comparison of monthly median MODIS (black), Landsat (blue), RapidEye (green) and in situ measurements (red), taken from Heege et al. (2014).

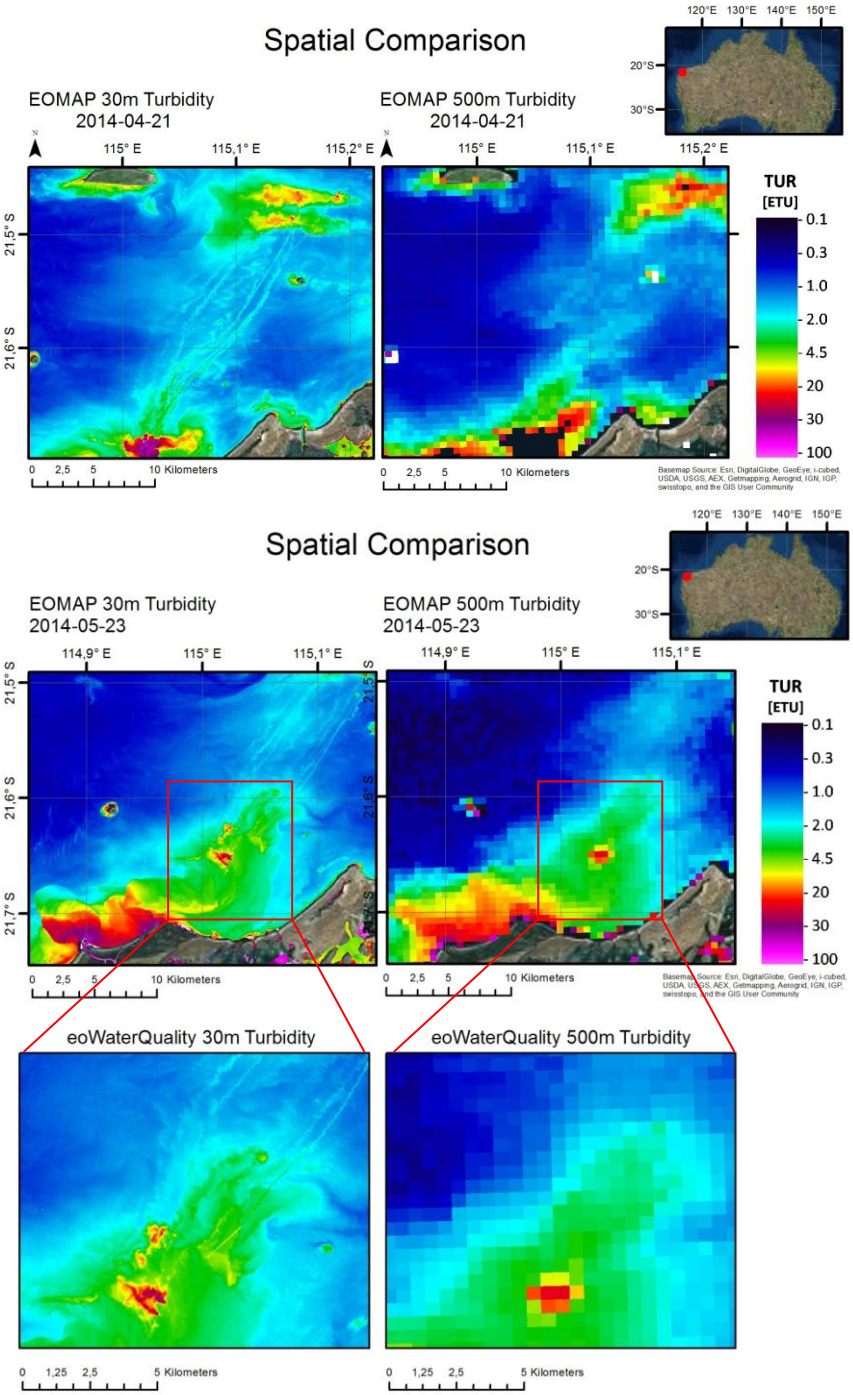
High vs. medium resolution water quality mapping

The following examples illustrate the effect of spatial resolution of the water quality data. Here, 500 m (standard) and 30 m data are shown for two locations: Abbott Point in east Australia (*Figure 7*) and the area east/south of Thevenard Island in north-western Australia ().In order to express the differences of having a 500m product and a 30m product, you can see the example of Abbott Point in east Australia (*Figure 7*) and the area east/south of Thevenard Island in north-western Australia (*Figure 8*).



Basemap source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 7: EOMAP Turbidity product for Abbot Point using 500m data from MODIS (NASA) and 30m data from Landsat 8 (USGS/NASA)



Basemap source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 8: Spatial and temporal comparison of Turbidity 30m and 500m north west Australia derived from Landsat 8 (30m) t and MODIS Aqua (500m) data

The 500m products have the advantage of providing imagery up to twice a daily, whereas the 30m product can identify small-scale features and important details. For dredging plume monitoring, both the temporal and spatial considerations are important.

Application Example: dredging plume monitoring

Dredging operations support new pipeline laying activities and the shipping channel expansions. In 2007, for a new development project, the Australian Oil & Gas company Woodside Energy sought a water quality monitoring solution to satisfy regulatory requirements for pipeline dredging operations. EOMAP implemented a cost effective satellite-based turbidity mapping solution, where operationally-generated, digital maps were delivered on a regular basis. The coastal water monitoring area is located in North Western Australia and water turbidity products were provided on average every two days for more than two years for an area of approximately 1000 sqkm. These data sets complemented the localised, point-based environmental monitoring strategy of Woodside's PLUTO LNG development project with spatially resolved distribution maps.

The large size of the required water quality monitoring area (~1000 sqkm) needed to be scanned at regular intervals, allowing for a high frequency monitoring during dredging operations. The extent and location of the dredging plume had to be detected and quantified consistently, in terms of turbidity, at an adequate spatial resolution. The evolution of the plumes, their potential impact on adjacent coastal areas, and the impact of natural factors such as re-suspension due to tidal currents and storms needed to be quantified for the environmental assessment. Conventional methods using in situ sensors of turbidity allow a point wise, vertically resolved measurement of turbidity and suspended solids, but unlike satellite-based technologies, they do not offer an area-wide coverage, with - importantly - a clear and objective classification of natural and anthropogenic turbidity sources. Increasing the number of in situ sensors increases the initial investment cost, the regular maintenance cost and, together with conventional airborne monitoring, also increases health and safety risks substantially.

Physics based retrieval algorithms ensure the consistent and operational generation of quantitative water quality maps. Additionally, flexible client-defined temporal and spatial resolutions (e.g. high resolution satellite) and back-up solutions can be implemented if satellite sensor independent processing technologies are applied. These requirements were fulfilled with the established EOMAP processing technology. For this monitoring program, various other remote sensing sources were integrated for verification, using the hyperspectral airborne HYMAP sensor and the multispectral satellite sensors IKONOS, RapidEye, MERIS, MODIS Terra and Aqua. The products showed consistent and well calibrated turbidity data, comprising spatial resolutions between 3 and 250 meters and a sampling frequency of up to two records per day. On average, a quality controlled turbidity map from one of the MODIS satellites was delivered every two days, for a total of over 420 scenes.

In *Figure 9*, an example time period of the water quality monitoring is shown. Next to potential dredge activity impacts, also strong easterly winds combined with a low tide effect can create anomalous observations across the entire monitoring area. This could lead to the increased turbidity (red colours) as seen on 2009-11-20 (see *Figure 9*), see also for further examples Woodside, 2010.

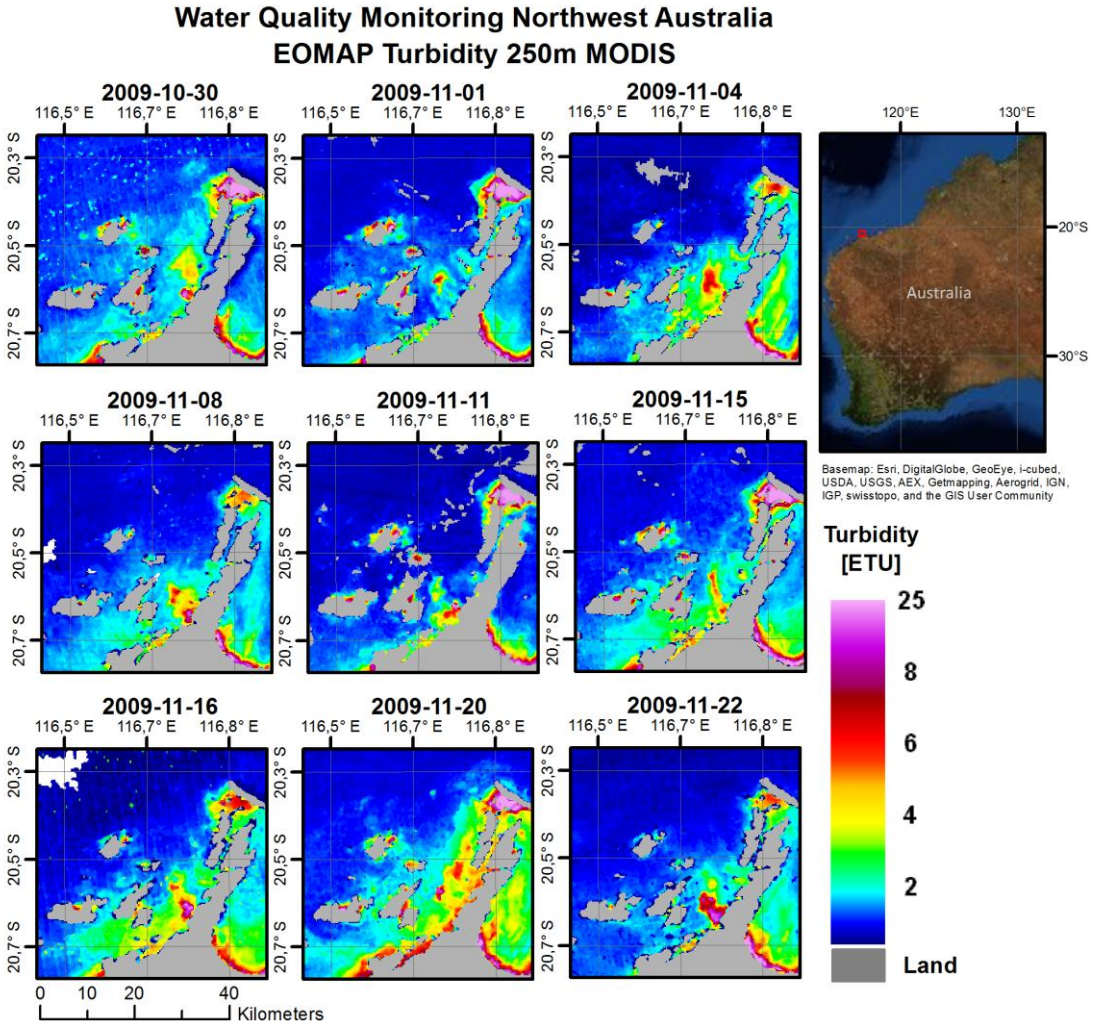


Figure 9: Example of EOMAP water quality monitoring with MODIS Aqua and Terra (© NASA) for the time period 2009-10-30 to 2009-11-22 in Northwest Australia. For more examples of this project, see Woodside, 2010

The cost saving for this project alone, when compared to an aerial monitoring solution, was in the order of 1 million AUD. Reliable and robust quantitative map products avoided any delays in the dredging operation, which in its cost impact is not being included here, but could easily equal the same amount. In addition, HSE risks were avoided completely, since no field operations were required and furthermore no environmental impacts were generated using the satellite monitoring solution.

Due to the direct cost savings, the return of investment for this project is already a multiple. In addition, this new methodology can now be utilized at even lower cost for any future dredging projects in Woodside, where a familiarisation of the satellite monitoring approach allows to easily extending new mapping and monitoring solutions in unrelated areas.

It should be noted that additional optical satellite-retrieved map products can complement these water quality services for various offshore applications. Examples would be water depth mapping and sea floor classification in shallow areas, as well as natural slick and oil spill mapping.

Please see for reference also Woodside, 2010 (earth.eo.esa.int/workshops/gasoil2010/Hausknecht.pdf).

EoApp Australia

The **eoApp Australia** is a free, web-based tool for viewing EOMAP data in Australian waters. Two areas have been selected for free visualisation of EOMAP water quality data feeds: Abbott Point with an adjoining section of the Great Barrier Reef, and Barrow Island with the nearby Ningaloo Reef .

The data products being shown are turbidity, visibility and satellite-derived reef bathymetry (topography) of the Great Barrier Reef. The water quality products are generated on a daily basis and are visible on the eoApp for the last three days. Monthly means are calculated as well, and are displayed from the last three months, e.g. for April, May and June 2014.

As an example, you can see the monthly mean of the Turbidity concentration for the north-western AOI in *Figure 10*.

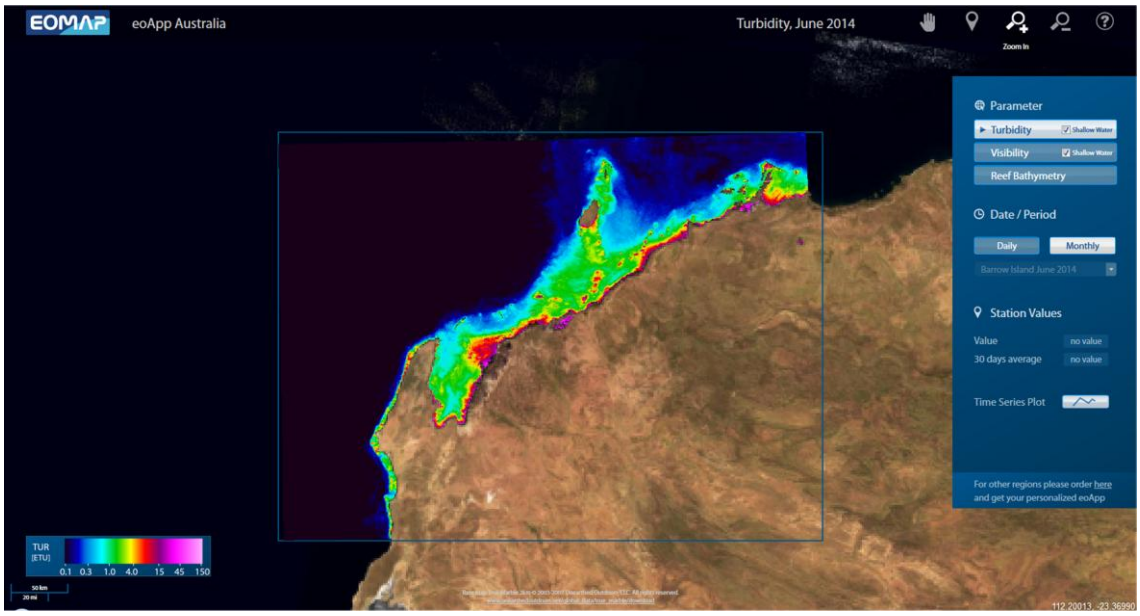


Figure 10: Screenshot of the eoApp Australia, showing eoWaterQuality Turbidity monthly mean product June 2014 for Ningaloo Reef to Barrow Island

The monthly means are generated from all available records within the time frame of one month. For instance, for Turbidity in January 2014 a total number of 63 scences (satellite image captures) have been processed.

Values of the past 30 days and calculated monthly mean values from January 2014 on can been accessed after setting a virtual station location of interest and activating the “time series plot” function.

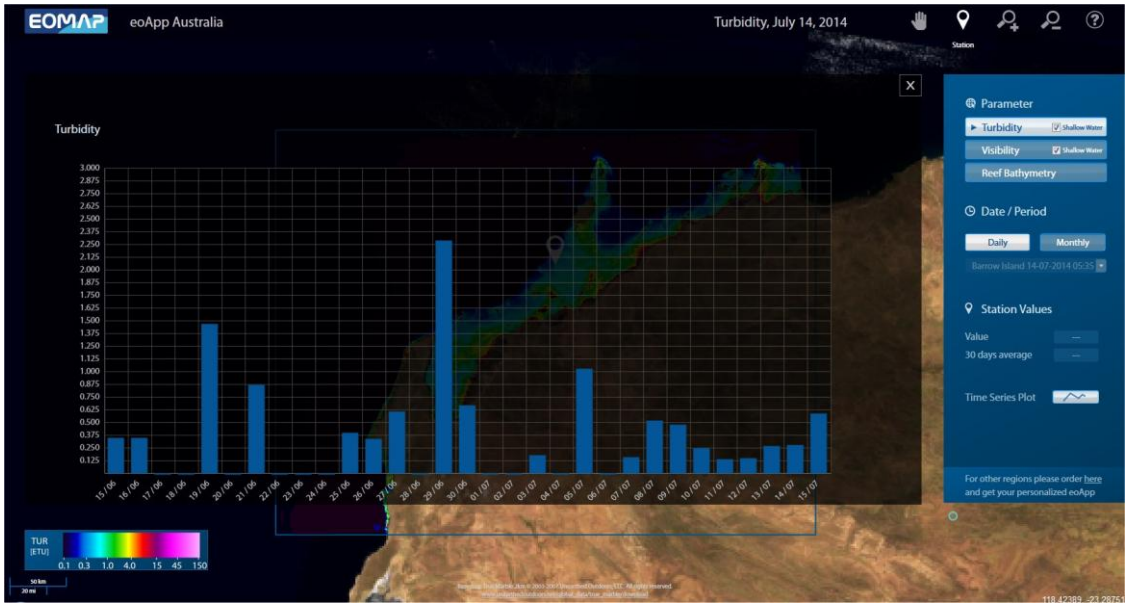


Figure 11: Screenshot of the eoApp Australia, showing time series plot for eoWaterQuality Turbidity for Ningaloo Reef to Barrow Island from 15-06-2014 to 15-07-2014

In Summary

EOMAP and Landgate have together implemented a satellite imagery-based system for near real time monitoring of important environmental water quality parameters for all Australian waters. This system is now operational and producing the full suite of water quality products as described in this document. We offer subscription-based feeds to these products, intended for agencies, private industry, and the research community. For more information on this, please contact us.

The turbidity and visibility in the water column are important and intuitive parameters for monitoring the effects of e.g. dredging, river plumes, or land run-off. Through our publicly available **eoApp Australia**, we have enabled monitoring of these parameters for two important coastal areas of Australia.

As always, we welcome your questions, comments and suggestions.

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Kiselev et al. (2014, accepted): Sensor independent adjacency correction algorithm for coastal and inland water systems. Remote Sensing of Environment

Image first page: Turbidity Whitsunday Islands from 2014-06-30 using Landsat 8 data, © processing EOMAP, © satellite data USGS/NASA

Disclaimer

Earth observation data are in general recorded under changing environmental conditions. EOMAP value adding software corrects for most relevant environmental conditions. However, with respect to the physical nature of the remote sensing method the achievable product quality can differ due to varying observation angles, varying atmospheric(-), surface(-) and in-water conditions or changing sensor raw data quality with each scene. Therefore, EOMAP cannot take any responsibility caused by the usage and interpretation of the remote sensing products. Of course, EOMAP will undertake all possible efforts to assure a constant product quality.

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