Satellite Monitoring of Chlorophyll-a Concentration in the Water Bodies of the Dnieper and Don River Basins

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Introduction

The work presented here is a part of a larger project involving the use of remotely sensed data to investigate and understand the effects on the bio-physical characteristics of the water bodies in the Dnieper and Don River basins due to changes in the land use and land cover in the surrounding regions.

The specific objective was to estimate the concentration of chlorophyll-a (Chl-a) from **MODIS** and **MERIS** data using two-band and three-band spectral algorithms specially developed for turbid and productive Case II waters.

The data were processed with different atmospheric correction procedures available for MODIS and MERIS data. No one particular procedure was consistently and systematically better than the rest.

The results highlight promises as well as challenges in using satellite data for remotely monitoring such dynamic water bodies.

Spectral Algorithms

The basic spectral algorithm used is fundamentally a three-band NIR/Red model that has been formulated by isolating the absorption of light due to Chl-a (keeping the contributions from the other constituents in water at a minimum) and relating it to Chl-a concentration. The two-band algorithm is a special case of the three-band algorithm, wherein the contribution by the other constituents are considered negligible at the wavelengths considered and thus not factored out.

Three-Band Model: $\text{Chl-a} \propto \left(R_{\lambda_1}^{-1} - R_{\lambda_2}^{-1}\right) \times R_{\lambda_3}$

Two-Band Model: $\text{Chl-a} \propto \left(R_{\lambda_1}^{-1}\right) \times R_{\lambda_3}$

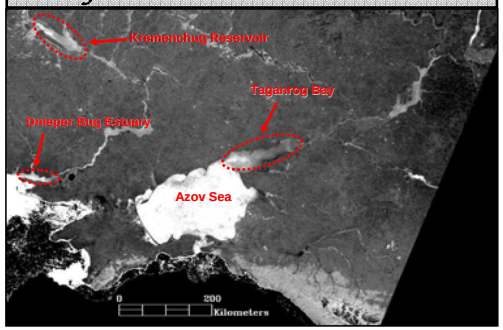
$\lambda_1 \sim 670$ nm - maximum of the red Chl-a absorption;
$\lambda_2 \sim 710$ nm - absorption by other constituents and minimal absorption by Chl-a;
$\lambda_3 \sim$ NIR region - scattering by all suspended matter.

For MODIS: $\text{Chl-a} \propto \left(R_{667}^{-1}\right) \times R_{748}$

For MERIS: $\text{Chl-a} \propto \left(R_{665}^{-1} - R_{708}^{-1}\right) \times R_{753}$

$\text{Chl-a} \propto \left(R_{665}^{-1}\right) \times R_{708}$

Study Area



Data

The *in-situ* data were collected by the field crews at the Southern Scientific Centre of the Russian Academy of Sciences, Rostov-on-Don, Russia and Institute for Environmental Quality, Kiev, Ukraine

Region	Date	No. of Stations	Data
Dnieper Bug Estuary	May 2003	29	Chl-a, Chemical Analysis
	Jul 2003	28	Chl-a, Chemical Analysis
	Aug 2003	32	Chl-a, Chemical Analysis
	Jun Jul 2004	26	Chl-a, Chemical Analysis
	Aug 2004	32	Chl-a, Chemical Analysis
	Sep 2007	26	Chl-a, Chemical Analysis
Azov Sea/ Taganrog Bay	Jun 2005	Ship-track	Fluorescence
	Jun-Jul 2006	13	Phytoplankton Biomass, Species Diversity, TSS
	Apr 2008	9	Chl-a
	Jun 2008	21	Chl-a, TSS
	Sep 2008	11	Chl-a, TSS
Kremenchug	May 2007	26	Chl-a, TSS

MODIS-AQUA and MERIS Full Resolution data acquired up to two days surrounding each date of *in-situ* data collection were used.

Data Processing

Level-1A MODIS AQUA data were downloaded from NASA's LAADS website and processed using the software SeaDAS to derive Level-2 reflectance products.

The MODIS data were processed using four different atmospheric correction procedures:

NIR Processing: Atmospheric correction by using the radiance at 748 nm and 869 nm for aerosol model selection

***SWIR Processing*:** Atmospheric correction by using the radiance at 1240 nm and 2130 nm for aerosol model selection

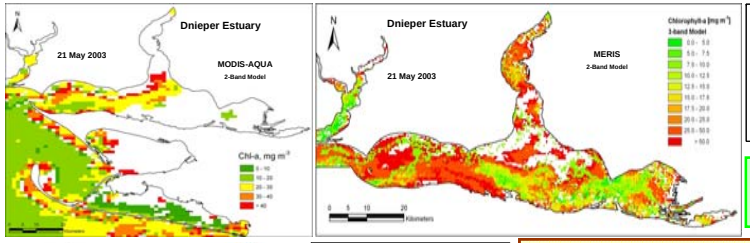
***MUMM Processing*:** A method proposed by Ruddick et al. (2000) wherein the assumption of zero water-leaving radiance in the NIR bands is replaced by the assumption of spatial homogeneity of the 748/869 reflectance ratio for aerosol and water reflectance within an image. This ratio calculated for aerosol and water reflectance is used to determine the aerosol model

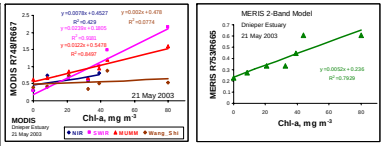
***Wang-Shi Processing*:** Same as the SWIR processing method but with different calibration coefficients for the SWIR bands

The MERIS data were obtained as Level-1 and Level-2 images from the European Space Agency. The Level-1 images were processed using the BEAM toolbox through the interface, VISAT.

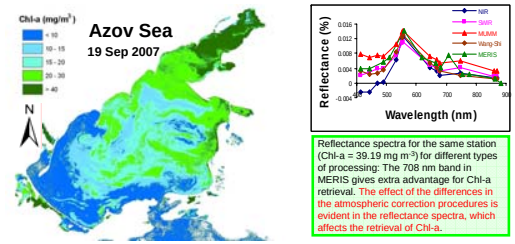
The MERIS data were processed using the default neural network procedure for atmospheric correction, which was developed from a broad training dataset chosen to be globally applicable for Case II waters, and also a special neural network procedure developed with a limited training dataset that was specifically targeted for coastal and inland waters. Both these types of processing are options available through VISAT.

Chlorophyll-a Estimation



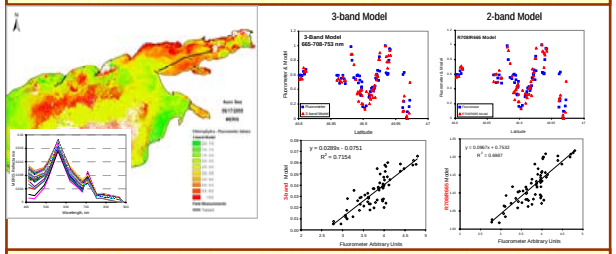


Chl-a vs. the two-band model for MODIS and MERIS data for May 2003: The results of SWIR and MUMM processing and MERIS were reasonably good; they explained the highest percentage of variation of Chl-a concentration. The results illustrate the sensitivity of the algorithm to differences in the type of data processing.

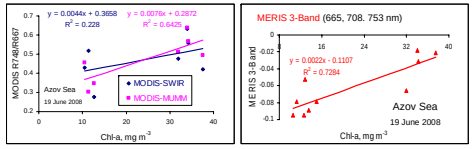


Reflectance spectra for the same station (Chl-a = 39.19 mg m^{-3}) for different types of processing: The 708 nm band in MERIS gives extra advantage for Chl-a retrieval. The effect of the differences in the atmospheric correction procedures is evident in the reflectance spectra, which affects the retrieval of Chl-a.

Chlorophyll Fluorescence Retrieval - MERIS



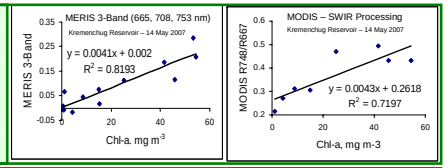
Chlorophyll fluorescence was measured continuously during the day along the transect shown in the map on 17 June 2005. The fluorometer readings were compared with different chlorophyll models using MERIS data acquired on the day of fluorescence measurement. Scaled fluorometer readings (Y_r-Y_{min})/(Y_{max}-Y_{min}) and model estimates are shown above.



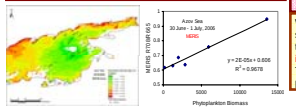
The plots above correspond to *in-situ* data collected on 18 and 19 June2008 and satellite images acquired on 19 June 2008. The figures illustrate a case where better results were retrieved from MERIS data compared to MODIS data. The higher spatial resolution of MERIS (260 m x 290 m) compared to MODIS (1 km x 1 km) and the availability of a band at 708 nm give MERIS data a significant advantage over MODIS data, especially for coastal and inland waters that are turbid and productive and not so spatially expansive.

Kremenchug Reservoir

The figures on the right show the results of Chl-a retrieval using MERIS three-band model and MODIS two-band model (with SWIR Processing). The data points shown correspond to *in-situ* data collected on 13 May 2007 and satellite images acquired on 14 May 2007.



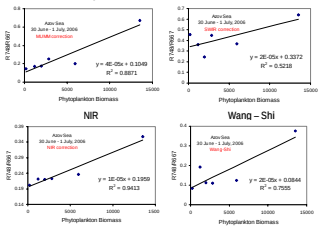
MERIS Biomass Estimation



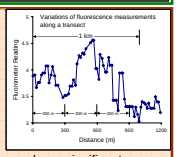
Since the reflectance at λ_3 (in NIR) is a multiplicative factor in the spectral algorithm, the algorithm *is very sensitive* to the magnitude of reflectance. Thus reliable atmospheric correction for accurate retrieval of R_{λ_3} is so critical. The spectral algorithm has been shown to consistently give reliable results for waters of widely varying bio-physical characteristics (Gitelson et al. 2008). Thus, any observed inconsistencies can be attributed to the problem of atmospheric correction. For the particular case shown on right, among the different atmospheric correction procedures for MODIS data, the retrievals from NIR processing gave the best comparison with phytoplankton biomass. Nevertheless, in assessing many different datasets, no one procedure stood out consistently better than the rest, thus rendering atmospheric correction an issue yet to be fully resolved for MODIS data.

MODIS Biomass Estimation - Different Atmospheric Correction Techniques

Water samples were taken on 30 June and 01 July, 2006 at stations shown in the map and phytoplankton biomass was determined. The two-band model was used for biomass retrieval from two MODIS images (29 and 30 June, 2006) and a MERIS image (01 July 2006). The MODIS and MERIS estimates were compared with measured phytoplankton biomass.



Key Conclusions



❖ The results were encouraging. However, problems persist due to two primary factors which pose a big hurdle in deriving reliable calibration coefficients for the spectral algorithm

- **Spatial heterogeneity in water within satellite pixels:** The point *in-situ* measurement may not be representative of the whole pixel area. The figure above shows significant variations of Chl-a fluorescence within each 300 m and 1 km lengths along a transect measured on the Azov Sea in 2005.
- **Time difference between in-situ and satellite observations:** Coastal and inland waters are very dynamic and the time lapse between the acquisitions of *in-situ* data and satellite data may result in actual changes in the bio-physical characteristics of water in-between the data acquisitions, which are not accounted for.

❖ *In-situ* data with measures of spatial variability within satellite pixel-areas that were collected truly simultaneously with satellite data will help better assess the accuracy of the NIR/Red spectral algorithm.

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