RETRIEVAL OF WATER CONSTITUENTS FROM MULTIPLE EARTH OBSERVATION SENSORS IN LAKES, RIVERS AND COASTAL ZONES

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ABSTRACT

Earth observation sensors collect valuable data of aquatic systems, which are further used for the retrieval of concentrations of water constituents such as suspended matter and phytoplankton. Different sensors deliver data with various spatial and temporal resolution ranging from 1 day to approximately a month in time and from 1km to 3m in space, high spatial resolution being connected with low temporal resolution and vice versa. In order to have detailed information on both spatial distribution of water constituents and their temporal variability, that is especially important for small aquatic objects like rivers and lakes, it is necessary to combine the data from several sensors. This creates certain problems as also spectral and radiometric resolutions of the sensors can be different.
The use of the modular image processing system MIP for the integration of data from different sensor is advantageous as it ensures standardized product outputs for a variety of satellite sensors such as MERIS, MODIS, SPOT, IKONOS, RapidEye. The processing chain of this system is automatically adapted to the sensor parameters as well as to the region specific inherent optical properties (SIOP) of the water basin. Various worldwide applications and time series for lakes, rivers and coastal areas are demonstrated and discussed.

Index Terms - Remote Sensing, Water Quality, Suspended Matter, Turbidity, Phytoplankton, Coastal, Lake, River, MODIS

1. METHODS

The algorithms of MIP are based on a coupled retrieval of atmospheric and water properties providing for the best fit of measured and model radiances in all spectral channels. The number of retrieved water species and final products depend on the spectral and radiometric resolution of the sensor. At least two parameters, namely suspended matter and atmospheric aerosol optical depth, are retrieved in addition to the automatic water detection. For higher number of channels also the absorbing water constituents such as Colored Dissolved Organic Material (CDOM) and phytoplankton can be derived.

MIP consists of a set of relatively independent modules each of which implements a physically distinct algorithm. The architecture of MIP in general is defined by the choice of iterative inversion of RTE as a basic line of processing scheme.

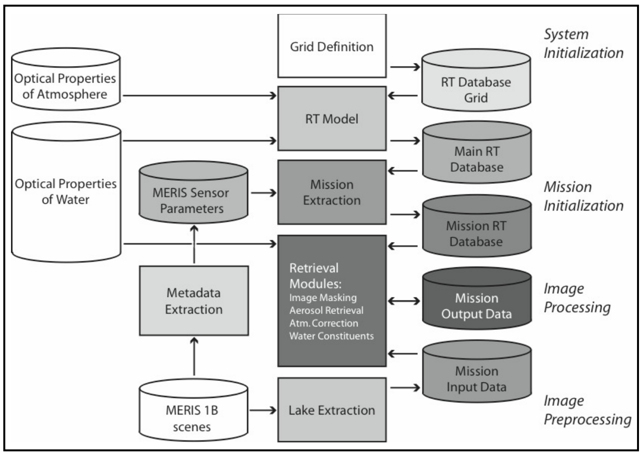

Figure 1 – Scheme of image and metadata preprocessing (lower workflows) and MIP processing (upper workflow), with the retrieval modules as consolidating element in the centre. Darker shad-ing indicates onward progress (from Odermatt 2008).

Atmospheric model of MIP is aimed at the regularization of the RTE inversion. Atmosphere is characterized by a comparatively low number of parameters and in the present version of MIP the model of the atmosphere follows the main features of that adopted in MODTRAN code [1].

The model of water composition serves the same aim as the model of the atmosphere. Scattering, backscattering and absorption coefficients of water bulk are expressed as a linear combination of corresponding location dependent normalized optical properties of water species with concentrations as weighting factors.

The requirements to RTE solver for modeling observations of water bodies in MIP are rather strict. The solution have to be obtained with high accuracy as only small part of total reflected radiance is reflected by water bulk and is in reality the useful signal. The RTE solver based on finite element method [3, 6, 7] is found to be the most appropriate for this purpose.

The retrieval of media properties, i.e. the inversion of RTE, is performed by fitting the simulated sensor channel radiances to those observed. The retrieved values give the minimum to the functional:

$$\min_{\tau} G(\tau) = \min_{\tau} \sum_{i=1}^{N_{ch}} w_i \left\{ L_i^{(0)} - L_i\left[\tau, \vec{c}(\tau)\right] \right\}^2 \qquad (1)$$

where $L_i^{(0)}$ = measured radiance in the i-th channel

N_{ch} = number of channels

τ = atmospheric optical thickness

w_i = user defined weight of the *i*-th channel

$L_i\left[\tau, \vec{c}(\tau)\right]$ = modeled radiance at sensor level

$\vec{c}(\tau)$ = vector of water constituent concentrations (chlorophyll, total suspended matter, yellow substance) retrieved from remote sensing data at fixed value of τ.

The last vector is calculated by minimizing the mean square difference between retrieved underwater reflectances corresponding to the given τ and those calculated for species concentrations $\vec{c}(\tau)$ according [2].

The results of radiative transfer modeling are stored in special MIP databases both with high spectral resolution and with channel responses of specific sensors. The high resolution database (main database) contains data for a reasonable interval of values of observation geometry parameters, such as solar angles, observation heights, view angles and azimuths, and also for different values of media parameters. Databases with modeled channel radiances (sensor databases) are calculated by averaging high resolution radiances from the main database with channel response functions as weights. This approach allows fast adaptation of the system to different sensors and variations of their parameters during the flight period.

MIP system was applied for processing of images of different satellite and airborne sensors and demonstrated stable and reliable performance [4,5,8,9,11].

2. APPLICATIONS

Various worldwide applications and time series from Lakes (e.g. Lake Sevan, Bodensee) over rivers (e.g. Ems, Mekong) up to Coastal areas (e.g. West-Australia, Vietnam and Chile) were processed. Satellite data from the sensors MODIS (250m, 500m and 1km resolution), MERIS (300m, 1km), SPOT 4+5 (10-20m), Landsat ETM (28m)and ASTER (15 m), QuickBird and IKONOS (3m) are used. The processing chain and inversion algorithm demonstrates robust performance and is also used for long term monitoring of industrial offshore activities with up to daily temporal resolution. In general, the number of retrievable parameters and the product quality depend on sensor characteristics (spectral resolution, radiometric sensitivity and calibration) and observation conditions (e.g. sun glitter existence).

A special attention in this case must be paid to the calibration of sensor channels as inaccuracies in calibration coefficients can result in artificial inhomogeneity of temporal trends. For producing quantitatively reliable retrievals the calibration of each sensor was investigated systematically in comparison with radiative transfer modelling results. E.g. for ASTER, we observed dominant differences of radiances between MODIS and ASTER especially in the NIR region, as also demonstrated by [10].

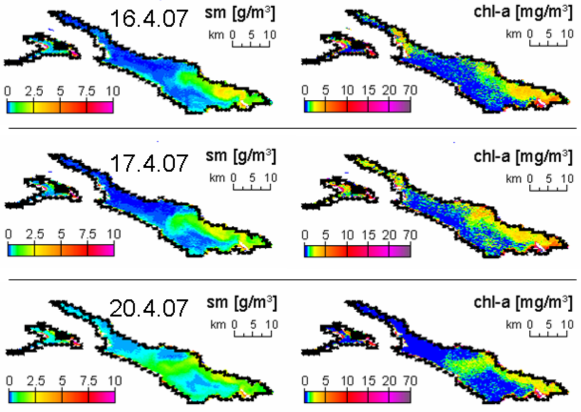

Figure 2 – Spatial distribution of suspended matter (SM) and Chlorophyll a (chl-a) in Lake Constance, calculated from MERIS 300m resolution data.

Essential for stable results is also the optimization of the regional Inherent Specific Optical Properties (SIOP), which describe the specific absorption and scattering properties of the water constituents and differ between e.g. turbid rivers and clear coastal waters.

Accuracy estimates therefore always depends on 1) spectral, radiometric resolution, calibration and stability of satellite sensors, 2) range and specific optical properties of water constituents, 3) atmospheric and sunglitter conditions.
Accuracy estimates therefore can be provided only in relation to a specific sensor, region and range of optical properties. Suspended matter and turbidity is usually the most uncritical parameter ([4,8,11] e.g. RMSE Lake Constance or at industrial offshore validation tests approx. 10-30%, correlation coeff. >0.8), while chlorophyll depends much more on sensor specifications and other in-water optical conditions of e.g. colored dissolved organic material (RMSE Chl approx. 30-70% for Lake Constance). For the Mekong we conducted two validation campaigns in 2008 and 2009 that improved the SIOPs, but we could not measure simultaneous ground truth with satellite recordings. However, the satellite products reflect largely the right range for turbidity and suspended matter, and are consistent between the retrieval with different sensors. Ongoing validation works from the latest campaign in 2009 will help to settle the physical description of the intermediate turbid Mekong river system and improve the results also for the small scale features.

The SIOPs could be optimized for all applications demonstrated here, but not for the extreme turbid river Ems. The so far unkown scattering coefficients of suspended matter are expected here much lower due to particle agglomeration than the used scattering coefficients derived for lakes and coastal areas. Therefore, the derived turbidity concentrations from ASTER for the river Ems obviously underestimate the real values. In this case, direct in situ measurements are necessary to optimize the SIOPs and the satellite based retrieval results.

3. CONCLUSION

The combined use of several sensors for monitoring of aquatic objects was found to be helpful and able to produce reasonable results. However, a special attention must be paid to the calibration as the difference in water species concentrations retrieved from the images of different sensors can result just from inaccuracies in calibration coefficients and lead to artificial inhomogeneity of temporal trends. Intercalibration with well calibrated sensors is applied and helps to overcome this challenge, but should be verified in long term time series in order to prove the systematical calibration differences.

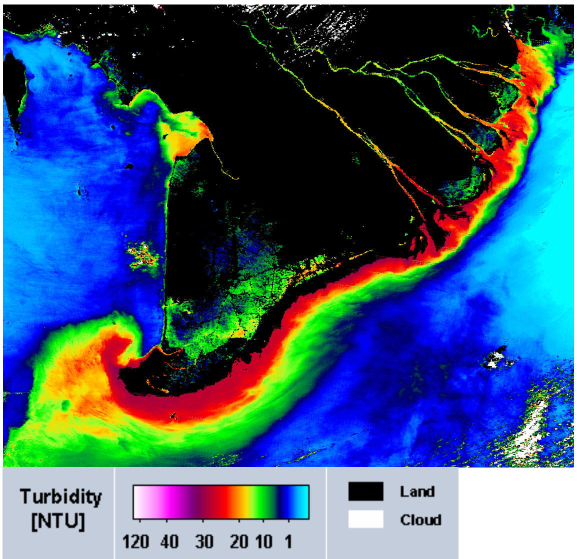

Figure 3 – Spatial distribution of turbidity and suspended matter in the Mekong delta from MODIS 250 m resolution. Jan 22, 2007.

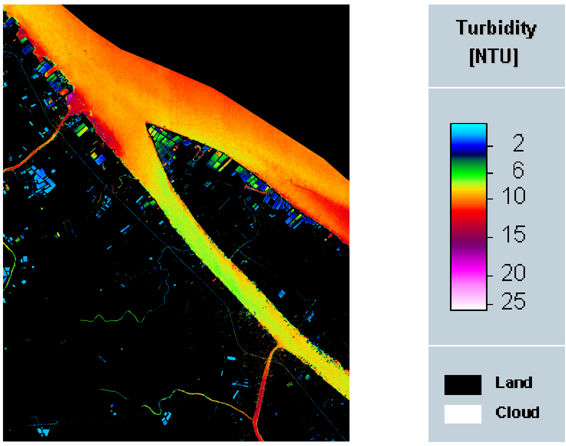

Figure 4 – Distribution of turbidity retrieved from QuickBird in the Mekong delta, January 27, 2007.

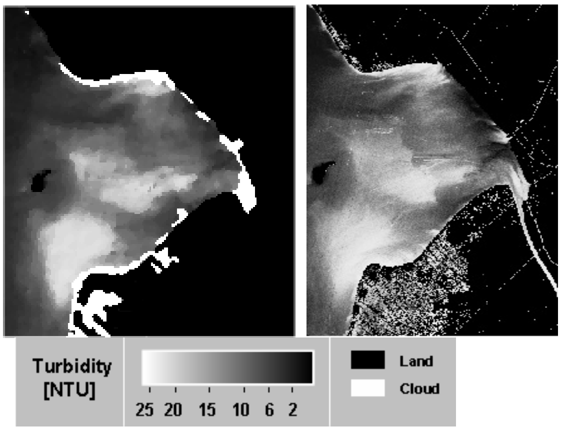

Figure 5 – Turbidity in Rach Gia Bay/Vietnam, retrieved from MODIS 250 m resolution (left) and SPOT5 (right) images, images recorded January 8, 2008, 3:10 UTC

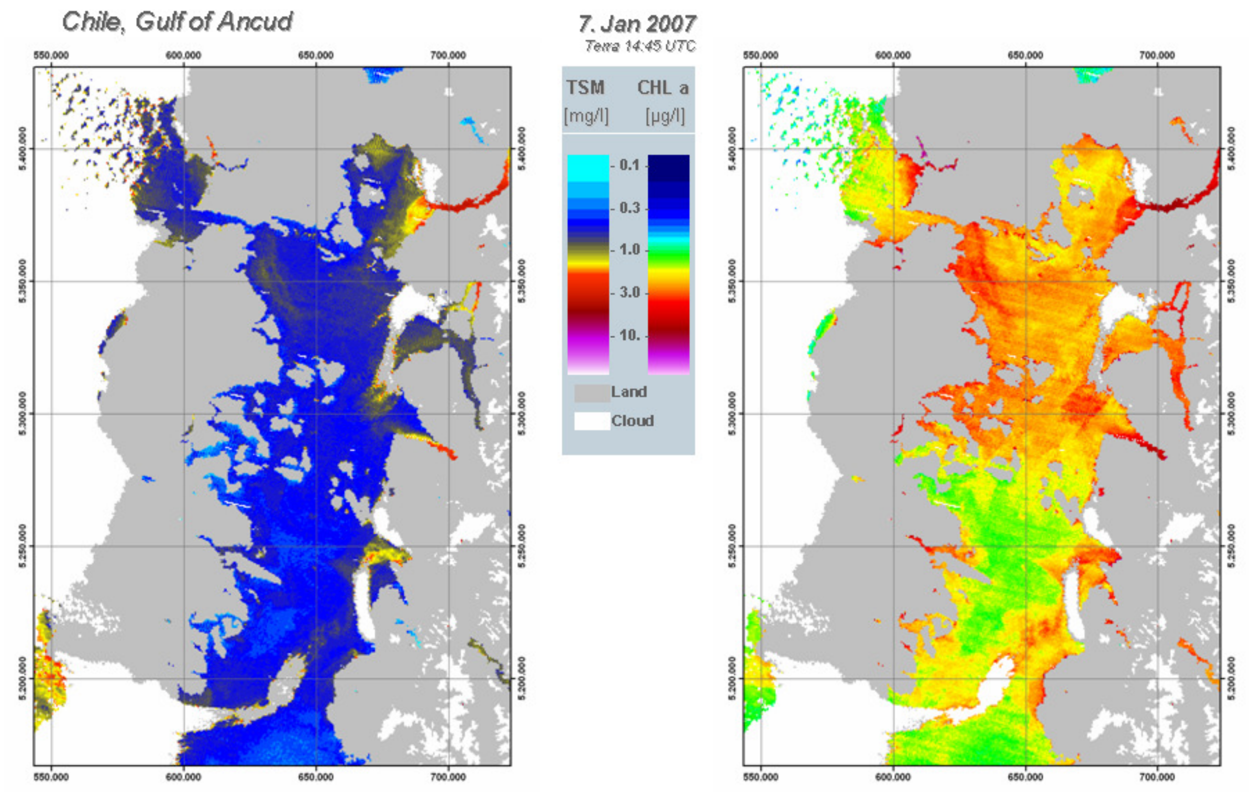

Figure 6 – Distribution of suspended matter and chlorophyll in the Gulf of Ancud/Chile near Chiloe: MODIS 500m

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