Coastal Erosion from Space

Coastal Erosion time series in Happisburgh (GB)

Coastal Erosion events:

in Nerja (Spain) in Kilkee (Ireland) in St Laurent mouth (Canada)

TSS Algorithm Theoretical Baseline Document

Ref: SO-TR-ARG-003-055-009-ATDB-ST

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Version and Signatures

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01	21/11/2019	-
	09/12/2019	Review
Prepared by	Christian Marchese	
Verification by		
Authorisation		

Acronyms

CDOM: Coloured dissolved organic matter

E_d: Downwelling irradiance

L_w: Water radiance

SPM: Suspended Particulate Matter

TSM: Total Suspended Matter

TSS: Total Suspended Solids

ρ_w: Water reflectance

Applicable and reference documents

Id	Description	Reference
AD-1	Requirement Baseline Document	SO-RP-ARG-003-055-006-RBD_v1.0_20190916
AD-2	Pre-processing ATBD	SO-TR-ARG-003-055-009-ATBD-PP

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1 Overview and Background Information

1.1 Product requirement

1.1.1 Information content quality and value

Total suspended solids (TSS) are an important biogeochemical parameter to monitor for both coastal and inland waters.

Total Suspended Solids (TSS) concentration also referred to as Total Suspended Matter (TSM) or Suspended Particulate Matter (SPM) in the literature, are usually particles that are larger than 2 microns found in the water column. Most suspended solids are made up of inorganic materials but organic particles (e.g., algae) from decomposing materials can also contribute to the TSS concentration. Overall, suspended solids include floating (although some particles can settle at the bottom of the body of water) or drifting sediment[1] in the water column. This means that TSS is a specific measurement of solid material per volume of water and thus reported in milligrams of solids per liter of water (mg/L).

It is thus possible for some streams to be characterized by the presence of suspended solids, a sudden increase or long-term changes in turbidity can be seen as an alarm bell. Excessive suspended sediment can impair water quality for aquatic life, for example by increasing nutrient pollution and preventing light from penetrating the water column. Moreover, settleable solids can impaired water bodies as well. For instance, if the sedimentation rate is high it can damage benthic habitats by altering structures that give fish an opportunity to rest, hide, feed or spawn.

In order to manage the coastal environment and related commercial and recreational activities, the monitoring of TSS require therefore continuous measurements over an appropriate period of time.

[1] Sediment is comprised of any solid material (e.g. from fine sand, silt, clay, to plankton and algae.) that can be transported by water, ice or wind.

1.1.2 Product order & delivery services*, incl. data formatting*

1.2 Quick Review – Feasibility

1.2.1 Satellite sensors and mission

Please refer to the pre-processing ATDB (ref: SO-TR-ARG-003-055-009-ATBD-PP)

1.2.2 Existing EO Products

Please refer to the pre-processing ATDB (ref: SO-TR-ARG-003-055-009-ATBD-PP)

1.2.3 Models

The presence of suspended solids in the water column increases turbidity and consequently reduces water clarity by creating an opaque, hazy or muddy appearance. As such, turbidity[2] is often used to indicate changes in the TSS concentration in water without providing an exact measurement of solids. Nowadays TSS measurements are used as an indicator of water quality.

Satellite remote sensing can be utilized as a tool for monitoring the sediments in coastal zones because capable of providing continuous, wide area, up-to-date information. Remote sensing data can thus dispense a rich source of invaluable information to investigate near-shore TSS spatial and temporal changes. Nowadays, remote sensing data have been used in various ways and across

[2] The turbidity of the water column may be affected by colored dissolved organic matter (CDOM), which is usually not included in TSS measurements.

diverse near-shore areas to assess the spatial-temporal changes in TSS. For instance, historical progress in the research of satellite-based suspended sediment concentrations from 1974 to 2005 is given in *Acker et al. (2005)*.

1.2.4 Auxiliary data

1.2.5 Currently known issues

1.3 Potential Solutions

1.4 Product Specifications

As previously noted, monitoring changes of total suspended sediment concentration (TSS) can be achieved from space-based optical sensors. TSS is a parameter with high variability (spatial and temporal) and can be therefore characterized by sudden increases as a consequence, for example, of strong erosion events. In this regard, Zhou et al. (2018) have demonstrated that for a sampling frequency of fewer than two observations per day, the relative error of TSS could be higher than 50%. With multiple coverage per days, error in the TSS monitoring can be mitigated.

Recently, Nechad et al. (2010) developed a single-band algorithm for TSM retrieval based on a reflectance model to multiple ocean colour sensors (i.e., multi-sensor approach). If the provided single band is chosen appropriately, its use gives a robust and TSM-sensitive algorithm. Overall, the algorithm is based on empirical relationships between spectral reflectance of the water column and TSS concentrations obtained from in situ data covering a wide range of turbidity in optically complex waters. Satellite reflectance are converted into TSS using the following equation:

$$TSS = A \times \frac{\rho_w}{\frac{1-\rho_w}{C}} + B \qquad [1]$$

were A, B and C, are the empirical coefficients and ρ_w is he water reflectance ($\rho_w = \pi$ Lw/Ed – were Lw is the water radiance and Ed is the downwelling irradiance at the water surface).

2 Algorithm Description

2.1 Data Processing outline

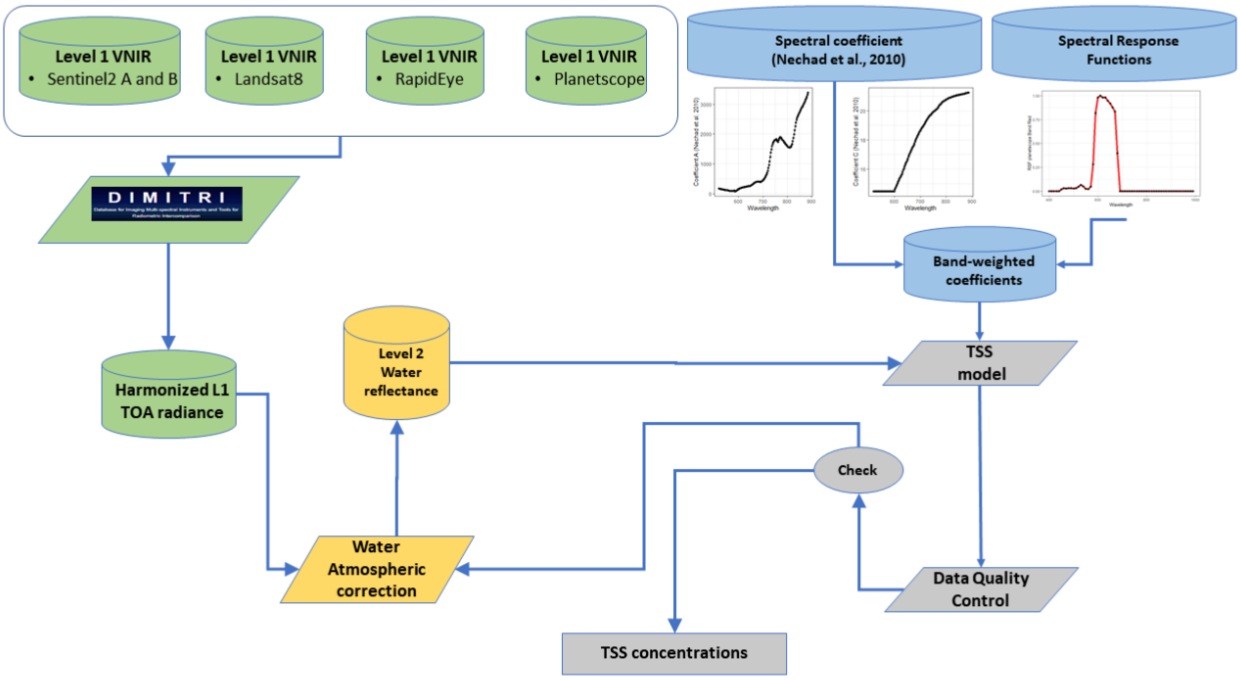

Figure 2.1: Workflow showing the different steps to determine TSS data

2.1.1 *Sketch of the computer program*

The workflow (Figure 2.1) shows the interconnection between the different steps to determine TSS using a multi-sensor approach and the model described in Nechad et al. (2010). The different steps can be resumed in the following way:

- The green boxes:
    - Level-1 images from different satellites sensors are used as input.
    - These Level-1 images are provided as input for DIMITRI[3] (the Database for Imaging Multi-spectral Instruments and Tools for Radiometric Inter-comparison). DIMITRI is

[3] DIMITRI, the Database for Imaging Multi-spectral Instruments and Tools for Radiometric Inter-comparison was developed with the approach and aims towards the goals of the Global Earth Observation System of Systems for an operational radiometric calibration

specifically used to obtain calibration coefficient in order to create harmonized Level-1 Top of Atmosphere (TOA) reflectance between all the selected sensors.

- The yellow boxes:
  - The atmospheric correction is performed on the harmonized Level-1 Top of Atmosphere (TOA) reflectance data by using the "dark spectrum fitting" approach in ACOLITE[4], which is a processor that allows simple and fast processing for coastal and inland water applications. The output of this step are Level-2 water reflectance data.
  - The Level-2 water reflectance data is therefore given as input to the TSS model (Nechad et al. 2010).

- The blue boxes:
  - The empirical coefficients A, B (see table 4 in Nechad et al. 2010) and C (see table 1 in Nechad et al. 2010) for wavelengths ranging from 520 nm to 885 nm are convoluted with the spectral response functions[5] to derive the band-weighted coefficients by using equation [15] in Nechad et al. 2010 (see Appendix).
- The grey boxes:
  - The band-weighted coefficients previously obtained are used in the equation [1] (see section 1.4) to convert satellite reflectance into TSS.
  - A data quality control (i.e., model output verification) is then performed on the model output. If the accuracy of the results is satisfactory the output data is then used to observe sediment transport and analyze the fate and distribution of suspended matter in riverine and coastal waters. Otherwise the whole procedure is repeated.

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system. DIMITRI user manual, references and other detailed information can be found at the following webpage: https://dimitri.argans.co.uk

[4] ACOLITE, is a processor that allows simple and fast processing for coastal and inland water applications. ACOLITE references and more detailed information can be found at the following webpage: https://odnature.naturalsciences.be/remsem/software-and-data/acolite

[5] The spectral response functions (SRFs) for each band of the sensor are provided as part of the satellite documentation.

2.1.2 Pre-requisite

2.2 Algorithm Input

2.3 Theoretical Description of the models in background of the procedure

2.3.1 Physical Description

2.3.2 Mathematical Description and calculation procedures

A detailed mathematical description and calculation procedures of the algorithm together with its calibration is reported in Nechad et al. (2010); see section 2 (theory) and section 4 (calibration) in Appendix.

2.3.3 Acceptance of the Models

2.4 Algorithm output

2.4.1 What you put in the files

2.4.2 How these files are managed.

2.5 Algorithm Performance Estimates

2.5.1 Test specification

The performance of the proposed model was recently tested to monitor TSS in the fluvial section of the St-Lawrence river (Québec, Canada) by using high resolution sensor (Landsat 8: 30 m – Sentinel 2: 10m) and very high-resolution sensor (PlanetScope: 3 m).

2.5.2 Test Datasets

Three specific images were used: Landsat 8 on October 2, 2017, Sentinel-2 on October 3, 2017 and PlanetScope on October 1, 2017. After atmospheric correction (Vanhellemont and Ruddick, 2018; Vanhellemont, 2019) was applied on the images, equation [1] was used to retrieve TSS from the red bands of the three sensors.

2.5.3 Verification

The comparison between the TSS obtained using the three different sensors, i.e., Landsat 8, Sentinel-2 and Planetscope, shows an excellent agreement (Figure 2.2a and 2.2b).

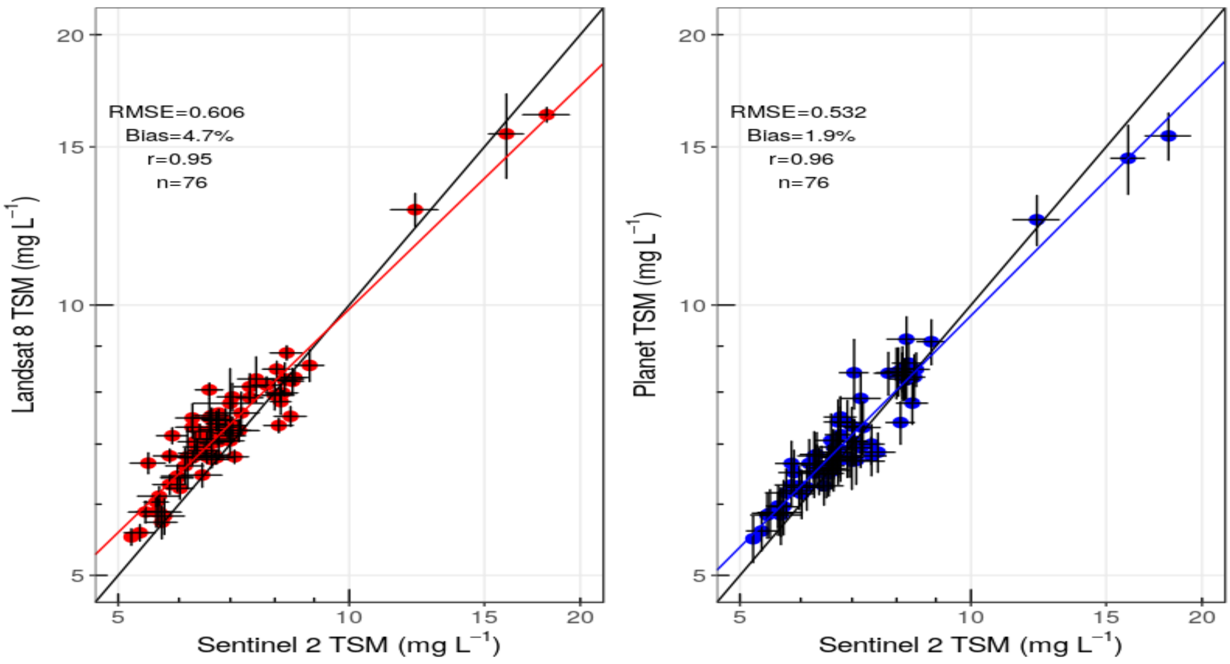

Figure 2.2: Relationship between a) Sentinel-2 TSM versus Landsat 80 TSM and, b) Sentinel-2 TSM versus PlanetScope TSM.

2.5.4 Practical Considerations

These results (Figure 2.2) clearly show the possibility to monitor efficiently TSS dynamics by using the aforementioned model and multi-sensor data. The use of data from different sensors dramatically increases the coverage to observe sediment transport and analyze the fate and distribution of suspended matter in riverine and coastal waters.

2.6 Products Validation

Value of the products in terms of accuracy, precision, reliability…

2.6.1 Test specifications

2.6.2 Test Datasets (identification & description)

2.6.3 Validation

2.6.4 Practical Considerations

on the discrepancies between expectations and test results: inputs (sensor effects, pre-processing, etc.), models, and procedures incl. QC

3 Conclusion

i.e. Roadmap for improvements

3.1 Assessment of limitations

Overall, the model developed by Nechad et al. 2010 provides a coherent and robust basis for multi-sensor mapping of TSM in turbid waters. The model performs unsatisfactory in phytoplankton-dominated waters and low TSS concentration, especially if compared to a multi-spectral inversion approach. The use model is therefore most suitable for moderately turbid waters. Additional error in TSS estimates due to CDOM absorption are relatively low when using the red spectral range. Finally, error in TSS estimates may also due to atmospheric correction errors in the satellite reflectance product.

3.2 Mitigation

4 References

Acker, J., Ouillon, S., Gould, R. and Arnone, R. (2005, 17–19 May 2005). Measuring marine suspended sediment concentrations from space: history and potential. Paper presented at the The 8th International Conference on Remote Sensing for Marine and Coastal Environments, Halifax, NS, Canada.

Nechad, B., Ruddick, K.G., & Park, Y. (2010). Calibration and validation of a generic multi-sensor algorithm for mapping of total suspended matter in turbid waters. Remote Sensing of Environment, 114/4, 854-866

Vanhellemont, Q. (2019). Daily metre-scale mapping of water turbidity using CubeSat imagery. Opt. Express 27, A1372-A1399.

Vanhellemont, Q., Ruddick, K. (2018). Atmospheric correction of metre-scale optical satellite data for inland and coastal water applications. Remote Sens. Environ 216, 586-597.

Zhou, Q., Tian, L., Wai, O.W.H., Li, J., Sun, Z., Li, W. (2018). Impacts of Insufficient Observations on the Monitoring of Short- and Long-Term Suspended Solids Variations in Highly Dynamic Waters, and Implications for an Optimal Observation Strategy. Remote Sensing 10, 345.

5 Appendix

End of Document