Assessment of atmospheric correction results by iCOR for MSI and OLI data on TSS concentration

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Abstract. Atmospheric correction is very important process to determine of land and ocean surface properties measured from satellite data, especially optical remote sensing satellite system, because passive satellite instruments will always be contaminated by the influence of the atmosphere. The result of this processing is the surface reflectance (sr) product, and it is a necessary process when quantitatively monitoring environmental quality parameters from space. The goal of this study is to assessing of the spectral remote sensing reflectance satellite (RS) by the image correction for atmospheric effects (iCOR) tools on total suspended solid (TSS) concentration from the MultiSpectral Instrument (MSI) sensor on-board Sentinel-2 and the Operational Land Imager (OLI) sensor on-board Landsat-8. Involvement of 25 in-situ TSS stations in Kendari bay waters is to assess the results of iCOR-S2 and iCOR-L8. An assessment of the sr results reduced to Rs(λ) on the MSI and OLI data respectively, affected the value of R2 where the highest value R2 = 0.665 is shown on red band OLI data. Meanwhile, the assessment of three TSS algorithms models is built on Rs(λ), all of them showed mean relative error (MRE) < 30% and were considered capable of defining TSS concentrations in the study area.

1. Introduction
Atmospheric correction (AC) is the process to retrieve the surface reflectance from remotely sensed imagery by removing the atmospheric effects (scattering and absorption) [1]. This process is very important to determine of land and ocean surface properties measured from satellite data, because passive satellite instruments will always be contaminated by the influence of the atmosphere [2]. This correction will have an impact on optical observations as well as being a fundamental preliminary steps for quantitative analysis from the optical remote sensing satellite (ORS) data [3]. The result of this
processing is the surface reflectance (sr) product [4]. While in the ocean colour remote sensing study, AC is a necessary process when quantitatively monitoring water quality parameters from satellite data [5]. Even, Reliable atmospheric correction is essential to support routine retrieval of optically active substance concentration from water-leaving reflectance [6]. The goal of the AC is to retrieve the spectral remote sensing reflectance satellite (Rs(λ)), defined as the ratio of water leaving radiance to the total downwelling irradiance just above the water surface [7]. This quantity Rs(λ) is critical for deriving the properties of optically active components of water, including the Inherent Optical Properties (IOPs), concentrations of chlorophyll a (Chl-a), and suspended particulate matter (SPM) including total suspended solid (TSS). However, the quality of Rs products has not been extensively assessed [8], and it is still a major challenge to carry out AC for turbid coastal waters [5].

Considering the importance of AC for optical satellite studies, international initiations such as the Atmospheric Correction Inter-comparison Exercise (ACIX) [4] summarize tools that can reduce sr products, including: ACOLITE, the Atmospheric CORrection (ATCOR/S2-AC2020), CORrection of the Atmosphere (CorA), Framework for Operational Radiometric Correction for Environmental monitoring (FORCE), the image correction for atmospheric effects (iCOR), Linear Etalon Imaging Spectral Array Atmospheric Corrector (LAC), the Land Surface Reflectance Code (LaSRC), Multi-sensor Atmospheric Correction and Cloud Screening (MACCS), SeaWiFS Data Analysis System (SeaDAS), and Sen2Cor. In addition to the above model, another model to obtain sr products is by Dark Object Subtraction (DOS), LOW Resolution TRANsmission code (LOWTRAN), Moderate-Resolution Atmospheric Radiance and Transmittance Model (MODTRAN), Transmittance functions, and Radiometric Terrain Correction (RTC’s) [9]. The another models that can also be used is the Second Simulation of a Satellite Signal in the Solar Spectrum-Vector (6SV) [10] based of the world wide web, which can be accessed on the page http://6s.ltdri.org/, the Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) [11], The Quick Atmospheric Correction (QUAC) [12] or user can be also ordering sr products via on the page https://espa.cr.usgs.gov.

Nowadays, the sr value of an optical imagery is more easily analysis by the presence of ACIX initiation. The iCOR for example, in addition to being the latest tool for atmospheric correction, iCOR is user-friendly and is based on open source so that it is possible for anyone to obtain it. The iCOR designed to work over inland, coastal or transitional waters and land, previously known as OPERA (OPERational Atmospheric correction). Although iCOR works over land and water, the primary focus will be the validation of coastal and inland waters [13]. Generally, the assessment of iCOR for inland and coastal waters shows reasonable results for Sentinel-2 (S2) and Landsat-8 (L8). The retrieved values are in line with ACOLITE results for the coastal, and also the ocean colour component of the Aerosol Robotic Network (AERONET-OC) stations. The iCOR is a software to atmospherically correct Earth observation data. It allows to correct imagery from atmospheric effects. The iCOR also corrects adjacency effects which could help to obtain improve the imagery quality at the water-land boundary. The iCOR atmospheric correction workflow is MODTRAN-5 based, and written in C++ [13]. This application is presented in the form of a plug-in that is installed into the Sentinel Application Platform (SNAP), this is an open source application that can be downloaded on the page https://remotesensing.vito.be/case/icor. A few basic versions as free plugins for SNAP toolbox include: iCOR-L8, iCOR-S2, and iCOR-SENTINEL-3-OLCI. Not only that, the iCOR also supports advanced versions for other sensors such as: Environmental Satellite Medium-Resolution Visible and Near-IR Spectrometer (Envisat MERIS), Project for On-Board Autonomy-Vegetation (PROBA-V), Airborne hyperspectral data, and Drone data.

This research was focused on the sr product from iCOR on the MultiSpectral Imager (MSI) sensor on-board Sentinel-2 and The Operational Land Imager (OLI) sensor on-board Landsat-8, which recording simultaneously on study area. The goal of this study is to assessing of sr Top of Atmosphere (ρToA) reflectance by iCOR to sr Bottom of Atmosphere (ρBoA) reflectance referred to as Rs(λ) on TSS concentration in Kendari bay waters.
2. Methods and data collection

2.1. Study area
The location and spatial distribution of sampling stations are in Kendari bay waters, Southeast Sulawesi, Indonesia. Astronomically, Kendari Municipality as the capital of Southeast Sulawesi Province is located in the southern of equator line between 3°54'40" dan 4°5'05" south latitude and stretching from west to east between 122°26'33" dan 122°39'14" east longitude. In terms of geographic position, Kendari Municipality has boundaries as follows, North: Konawe Regency; East: Kendari Sea; South: South Konawe Regency; West: South Konawe Regency. In terms of geographic location, Kendari Municipality is located in south east of Sulawesi Island. Its regional land is on the mainland of Sulawesi Island which around Kendari Bay. The total land area of Kendari Municipality is 271.76 km² or 0.7 percent of the land area of Southeast Sulawesi.

![Map of the Kendari bay waters and 25 sampling distributions of in-situ TSS](image)

**Figure 1.** Map of the Kendari bay waters and 25 sampling distributions of in-situ TSS

2.2. Data collection
The imagery in this study are red, green, blue, and near infrared (RGB+NIR) bands from Sentinel-2B MSI and Landsat-8 OLI, respectively, recorded on October 4, 2018 with the sensor ID:

- S2B_MSIL1C_20181004T021339_N0206_R060_T51MVR_20181004T054703
- LC08_L1TP_112063_20181004_20181010_01_T1
While the in-situ data for sea water 25 samples were collected to coincide with the acquisition of Sentinel-2B and Landsat-8 recording in Kendari bay waters. Furthermore, all samples were processed in the laboratory for the purpose of TSS concentration analysis.

### Table 1. In-situ TSS on Kendari bay waters

| Station | Latitude | Longitude | In-situ TSS (gm⁻³) |
|---------|----------|-----------|-------------------|
| Sta-01  | -3.9780  | 122.5347  | 450               |
| Sta-02  | -3.9712  | 122.5350  | 380               |
| Sta-03  | -3.9875  | 122.5425  | 510               |
| Sta-04  | -3.9864  | 122.5476  | 430               |
| Sta-05  | -3.9747  | 122.5412  | 440               |
| Sta-06  | -3.9698  | 122.5452  | 450               |
| Sta-07  | -3.9774  | 122.5498  | 370               |
| Sta-08  | -3.9829  | 122.5579  | 320               |
| Sta-09  | -3.9763  | 122.5617  | 300               |
| Sta-10  | -3.9704  | 122.5585  | 370               |
| Sta-11  | -3.9723  | 122.5690  | 380               |
| Sta-12  | -3.9799  | 122.5695  | 320               |
| Sta-13  | -3.9763  | 122.5779  | 360               |
| Sta-14  | -3.9769  | 122.5849  | 320               |
| Sta-15  | -3.9739  | 122.5895  | 350               |
| Sta-16  | -3.9780  | 122.5922  | 330               |
| Sta-17  | -3.9807  | 122.5985  | 320               |
| Sta-18  | -3.9764  | 122.6022  | 320               |
| Sta-19  | -3.9739  | 122.6076  | 310               |
| Sta-20  | -3.9766  | 122.6149  | 290               |
| Sta-21  | -3.9810  | 122.6203  | 300               |
| Sta-22  | -3.9878  | 122.6228  | 350               |
| Sta-23  | -3.9948  | 122.6209  | 240               |
| Sta-24  | -3.9943  | 122.6139  | 430               |
| Sta-25  | -3.9859  | 122.6071  | 350               |

2.3. Atmospheric correction using tools of iCOR

The tools of iCOR in this research are used to reduce the effects of the atmosphere on the imagery recorded by the MSI and the OLI sensors. This application is presented in the form of a plug-in that is installed into the Sentinel Application Platform (SNAP) version 6.0, this is an open source application that can be downloaded on the page [https://remotesensing.vito.be/case/icor](https://remotesensing.vito.be/case/icor).

2.4. Empirical algorithm models

The modelling of TSS algorithm in this study used the value of $R_a(\lambda)$ referred to as $\rho$BoA reflectance, in units of sr⁻¹. Each the sr product is processed using the iCOR-S2 and iCOR-L8 in platform SNAP. Furthermore, The TSS retrieval algorithm developed using the regression algorithm between the in-situ TSS concentrations and $R_a(\lambda)$ based on single-band using the regression of exponential function as in equation (1)’. From several combinations, the highest correlation between both variables indicated by the highest coefficient of determination (R²) was chosen as a retrieval algorithm. Coefficient of determination with $R^2 \geq 0.5$ can be concluded enough to assessing its result, even though $R^2 \approx 1$ is so perfect in a regression.

$$y = ae^{bx}$$

(1)

where, $y$ is the in-situ TSS concentration, $a$ is the slope of regression line, $x$ is the value of $R_a(\lambda)$, $b$ is the intercept and $e$ is an exponential function.
The iCOR is user-friendly, just by add file the metadata from each imagery to be processed in the SNAP tool. For MSI data, add naming convention: S2 *.xml file found in the *.SAFE folder and OLI data is: *_MTL.txt file. The plug-in of iCOR-S2 will be processing atmospheric effect on the MSI bands at 10m, 20m and 60m respectively. While in the iCOR-L8 will be processing atmospheric effect on the OLI bands (1 to 7). The AC process of both iCOR-S2 and iCOR-L8 each produces $R_s(\lambda)$ referred to $\rho_{BoA}$ reflectance. Its results are then used to developed the TSS algorithms.
Figure 3. Value of $R_{rs}(\lambda)$ from RGB+NIR on the MSI and OLI bands

The results of AC processed by iCOR tools on the RGB + NIR bands to the MSI and OLI data, respectively, it shows the maximum $R_{rs}(\lambda)$ values in OLI bands at 0.037 sr$^{-1}$ and the minimum at 0.008 sr$^{-1}$. This result is different from the MSI data (Figure 3) and (Figure 4), where the maximum $R_{rs}(\lambda)$ value in MSI$_{10m}$ bands is obtained at 0.064 sr$^{-1}$ and the minimum at 0.022 sr$^{-1}$. As for the its MSI$_{60m}$, the maximum $R_{rs}(\lambda)$ value is obtained at 0.060 sr$^{-1}$ and the minimum at 0.027 sr$^{-1}$.

Figure 4. Maximum and minimum the $R_{rs}(\lambda)$ values from the MSI dan OLI bands
3.2. Algorithm models

Technically, the TSS retrieval algorithm developed using the regression algorithm between the in-situ TSS concentrations and in-situ measured $R_{\text{s}}(\lambda)$ based on single-band and two-band ratios reflectance combinations [16]. But in this study, our focus to develop the TSS algorithm from information $R_{\text{s}}(\lambda)$ based on single-band from satellite sensors to maintain its authenticity $R_{\text{s}}(\lambda)$ in each of the MSI and OLI bands. In-situ TSS concentration and the $R_{\text{s}}(\lambda)$ were used as dependent and independent variable, respectively. From several combinations, the highest correlation between both variables indicated by the highest coefficient of determination ($R^2$) was chosen as a retrieval algorithm [16][17][18]. Coefficient of determination with $R^2 \geq 0.5$ can be concluded enough to assessing its result, even though $R^2 \approx 1$ is so perfect. The regression algorithm for TSS concentrations was shown in Table 2 and (Figure 5). Which is, high coefficient of determination ($R^2 \geq 0.5$) were shown in the algorithm based on the single-band of $R_{\text{s}}(\lambda)$. 

| Sensor  | $R^2$ from $R_{\text{s}}(\lambda)$ band | Algorithm models               |
|---------|--------------------------------------|--------------------------------|
| MSI10m  | 0.117 blue 0.309 green 0.456 red 0.308 | TSS = 186.71e^{16.593(\text{Red})} |
| MSI60m  | 0.135 blue 0.376 green 0.536 red 0.458 | TSS = 165.81e^{19.546(\text{Red})} |
| OLI30m  | 0.174 blue 0.487 green 0.665 red 0.379 | TSS = 257.57e^{21.56(\text{Red})} |

The TSS algorithms as shown Table 2 are models which built based on the highest $R^2$ value, where $R_{\text{s}}(\lambda_{\text{red}})$ MSI10m, MSI60m, and OLI shows the highest response: 0.456, 0.536, and 0.665, respectively, compared to blue, green, and NIR bands.

![Figure 5. The algorithm models of TSS](image-url)
3.3. TSS concentration

The materials of TSS are all particles in water measuring < 2 μm consist of volatile and fixed solids. However, based on its materials size different to suspended sediment concentrations (SSC), although both are classified as suspended solids [18]. Based on the ORS study, its material was very well responsive at the wavelength range of 400-800 nm. TSS concentration in the study area based on algorithm MSI and OLI is shown in Figure 6.

![Figure 6](image_url)

**Figure 6.** Maps of TSS distribution in Kendari bay waters; (a) Estimated-TSS from red band on MSI_{10m}, (b) Estimated-TSS from red band on MSI_{60m}, (c) Estimated-TSS from red band on OLI

TSS distribution based on Figure 6 shows TSS concentration from OLI and MSI_{60m} data has almost the same pattern, but both of them are different from TSS concentration of MSI_{10m} data. Thus, the authors conclude that the difference is influenced by its determination value.

3.4. Assessment of atmospheric correction

Atmospheric correction has a significant effect on the sr value of the material in water bodies. Its values are useful for various analyzes such as; coastal and marine ecology, water quality, and other ocean colour studies, even the $R_0(\lambda)$ value is also useful for terrestrial studies. We had processed the MSI data at 10m and 60m resolutions and OLI data at 30m resolution on the RGB+NIR bands respectively, using the iCOR-S2 and iCOR-L8 plug-ins involving 25 in-situ TSS. The result shows the value of $R_0(\lambda)$ at 60m resolution responds fairly well on in-situ TSS ($R^2 = 0.536$) compared to MSI data at 10m resolution ($R^2 = 0.456$). However, both of them showing the highest determination value on the red bands. Meanwhile, for OLI data is giving the maximum results $R^2 = 0.665$ and also the highest determination value was shown by the red band.

If observing at the maximum values of $R_0(\lambda)$ in Figure 4, results of MSI_{10m} has the highest value of 0.064 sr\(^{-1}\) compared to MSI_{60m} that only of 0.060 sr\(^{-1}\), while the OLI band showed the lowest value of 0.037 sr\(^{-1}\). The difference value of $R_0(\lambda)$ are allegedly due to the difference of pixel resolution, and if referred to other studies using the Sen2Cor method, conversion of ToA to BoA reflectance gives
uncertainties in surface reflectance up to 0.04 sr⁻¹ [19]. Thus, our temporary conclusion about the value of $R^2 < 0.5$ at the MSI_{10m} data, and the highest value $R^2 = 0.665$ at the OLI data are effect by the $R_{rs}(\lambda)$ values and the spectral resolution an imagery.

![Figure 7. The MRE and RMSE values](image)

The parameter is stated to be correlated or not through the coefficient of determination ($R^2$), the coefficient $R^2 \approx 1$ concludes that the parameter is very strong correlation, but even if $R^2 \geq 0.5$ is considered sufficient, while for evaluating the accuracy of the retrieval algorithm MRE is used. The MRE values less than 30% are considered good value and vice versa. the results of the assessment of the 3 algorithms as shown in Table 2 are shown in Figure 7, and the conclusion of the assessment of these 3 algorithms has an MRE < 30%. Meanwhile, the lowest RMSE value is shown in the OLI band (Figure 7). Thus, the overall assessment of processed by iCOR in SNAP tools generally works optimally on MSI and OLI data. The combined TSS estimates and in-situ results are shown in Figure 8.

![Figure 8. All of TSS concentration in Kendari bay waters](image)
4. Conclusion
Processing of AC on MSI data at 10\textsubscript{m} and 60\textsubscript{m} resolutions, and OLI data on the RGB+NIR band respectively, using the iCOR-S2 and iCOR-L8 plugins involving 25 in-situ TSS, shows the difference in both values its $R_o(\lambda)$. By observing the results of the value $R^2$ on the TSS response, our assessment is the results of iCOR-L8 that processed OLI data are better than iCOR-S2 on MSI data. The best accuracy of the TSS algorithms models is built on the value of $R_o(\lambda)$ is on the OLI data. However, all models from both MSI and OLI data showing MRE < 30%, and were considered capable of defining TSS concentrations in the study area.

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