Effect of Turbidity, Temperature and Salinity of Waters on Depth Data from Airborne LiDAR Bathymetry

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Abstract. The influence of seawater parameters cannot be ignored when conducting bathymetric LiDAR (Laser Induced Detection and Ranging or Light Detection and Ranging) surveys such as turbidity, temperature, and salinity. Turbidity affects the attenuation diffusion coefficient of the green laser is penetrating the air column. The comparison of LiDAR bathymetric depth with Secchi disk depth is used as a reference in determining the effect of turbidity. The results are in locations with primarily clear water the ability of LiDAR can penetrate up to 7m, while in turbid waters up to 3m. On average, the ability of the green laser LiDAR bathymetry can penetrate the waters of 1.5-2 times the depth at the location of this study around the bay of Lampung, Indonesia. Other water parameters are temperature and salinity. These parameters are used to calculate the refractive index value of water. The different temperature and salinity values in a water column can result in differences in the accuracy of the bathymetry LiDAR depth of 4-6mm. The influence of water column parameters can be a concern in planning and processing airborne LiDAR altimetry (ALB) surveys.

1. Introduction

Current technological developments make it possible to conduct water depth surveys or bathymetry using remote sensing. One of the remote sensing technologies that can be used for bathymetry surveys is Airborne LiDAR (Laser Induced Detection and Ranging or Light Detection and Ranging) Bathymetry (ALB). The use of LiDAR bathymetry is carried out by aircraft. The advantage of LiDAR bathymetry is that it can obtain data at shallow depths (<15m) which are difficult to achieve by bathymetric surveys using acoustic sensors such as single-beam or multi-beam echosounders [1]. The broad LiDAR sweep makes data fast and effective compared to acoustic sounding.

LiDAR Bathymetry is an active sensor that uses a light source that emits itself, not from the reflection of sunlight. The system works by comparing the characteristics of the transmission signal and its reflection, namely the difference in pulse propagation time, wavelength, and reflection angle [2]. LiDAR transmits laser pulses from the sensor transmitter to the reflected bottom plane to be received back through the receiving sensor. The distance of the sensor to the reflected plane is calculated from the
length of time the laser pulse travels back to the receiving sensor. In general, LiDAR Bathymetry uses two wavelengths of light, namely green and infrared to detect surface and bottom waters [3]. Green laser is used because it can penetrate water to the bottom. Infrared rays are used to reduce the distance detected by green laser because infrared rays cannot penetrate the surface of the water. Figure 1 describes the laser propagation when it is emitted and received back by the sensor. The green line represents the green laser pulse while the red line represents the infrared pulse.

Figure 1. Laser pulse propagation on LiDAR bathymetry

The propagation of a green laser is identified to determine the depth of the waters. LiDAR bathymetry by transmitting a laser to the surface of the water at an angle of 22° to the axis of the nadir. When the laser hits the surface of the water, some of the laser waves are reflected and refracted in all directions and some will penetrate the water. The laser beam that penetrates the water is about 98% of the total initial energy and will be refracted in a direction close to the standard line due to changes in the density of the air medium with water [4]. The laser light beam will continue to propagate in the water until it hits the bottom of the water and is reflected in all directions and one of the beams is reflected towards the angle of incidence. The ray of light that reflects towards the angle of incidence then continues its propagation journey and penetrates the boundary of the water and air medium. In this condition, the light beam will be refracted from the standard line and propagate on a path line in the same direction as when it was first transmitted and received back in the sensor by the wave receiving unit.

The laser transmits 3,000 pulses of data per second and each laser pulse consists of two rays, namely infrared with a wavelength of 1,064 nm and 532 nm for green light. It should be noted that the two laser sensors are independent, information related to the offset between the two sensors is essential to know to minimize errors to get good observation data [5]. LiDAR bathymetry measurements produce a wide footprint with a diameter of ~2 meters and can penetrate the bottom of the water to a depth of 2-3 Secchi depths [6].

The light waves received back by the sensor will be read in the form of a waveform. The accepted waveform should ideally consist of two distinct wave peaks. The first peak represents the energy reflected from the surface of the water, while the second peak represents the energy reflected from the bottom of the water. The backscatter signal time, slope, and amplitude provide water depth, diffuse attenuation in the water column, and water properties [7]. Figure 2 is an example of a full waveform received by a single signal sensor. The signal explains its propagation when transmit by the transmitter and then hits the water surface which forms the first peak then through the water column until it hits the bottom surface which forms the second peak. dark blue color describes the backscatter as the laser travels through the water column.
There are no specified water quality requirements for ALB surveys but instead suggested values indicating the transparency. One indicator of water column quality is turbidity, temperature, and salinity. Turbidity, a dynamic indicator of water quality, is mainly determined by suspended matter concentration in the water column. Turbidity causes light beams to scatter in the water column where particle size, shape, and composition may all affect its amplitude. Salinity and water temperature are considered to create the required refraction values calculated in the LiDAR bathymetry equation for each diverse survey location. Because LiDAR bathymetry depth-measuring capability is limited to shallow bodies of water, calculating a single refractive index value for the entire water column is generally adequate. Users of other ALB systems with deep channel ratings may need to account for differences in the temperature because of variation in density and should do so based on in situ measurements taken concurrently with ALB surveys.

In this research, the depth value is obtained from the results of bathymetry LiDAR processing carried out by the Indonesian Geospatial Information Agency. Depth data has been done to reduce sensor errors, significant clean noise, and pre-processing. Further data will be processed at the post-processing stage used in this research analysis. The purpose of this study was to obtain the effect of turbidity, temperature, and salinity of the waters on the depth value generated from the bathymetric LiDAR.

2. Methodology
The method used in this study is to compare the depth data from the bathymetric LiDAR processing with water turbidity, temperature, and salinity data. The turbidity of the water will be compared from several locations with differences in water clarity and then the penetration ability of the bathymetric LiDAR will be seen. Then, different values will be used for temperature and salinity to process cloud lidar bathymetry data points using the Leica Lidar Survey Studio software. The results of point cloud processing with differences in temperature and salinity are then compared to determine their effect on water depth value.

2.1. Sensor and Study Area
Bathymetric lidar data were obtained from a coastline survey using Airborne Lidar Bathymetry conducted by the Indonesian Geospatial Information Agency (BIG). The survey aims to produce data on three types of coastlines on a large scale. The Airborne LiDAR bathymetry survey was conducted on the southern coast of Lampung in the Sunda Strait, Lampung Province - Indonesia at the coordinates 5.423830° to 5.934868° and 105.107767° to 105.855827°. The ALB system uses a Leica Chiroptera 4x sensor with 2 lasers, namely an infrared laser (500 kHz) for land topography mapping and a green laser (35 kHz) for bathymetry mapping with a penetration depth of up to 25m below sea level. The flight
height used during bathymetry measurements is approximately 500 m above ground level with an interval of 250 - 300 m flight lane. On the other hand, the acquisition of ground topography at an aircraft altitude of 1,100 m above ground level with a flight lane interval of 750 m. Side lap used is 20-30%.

The survey process was carried out in December 2020 with a daily acquisition capacity of 157 km per day. LiDAR measurements were tied to the Indonesia National Geodetic Control Network using the SRGI2013 coordinate system with vertical reference using an ellipsoid. The location sampled in this study corresponds to the number of turbidity surveys that have been conducted. Each research location has a different acquisition time, including SD18 & SD19 on 9 December, SD20 on 10 December, SD1 & SC2/SC3 on 13 December, SD2 on 15 December, and finally SD3 on 16 December.

![Coverage of the bathymetric LiDAR survey](image)

**Figure 3.** Coverage of the bathymetric LiDAR survey

| Characterization               | Sensor Specification                                      |
|-------------------------------|----------------------------------------------------------|
| Bathymetric capability        | 140,000 points/second green, full waveform               |
| Operation altitude            | 400 – 600 m above Ground Level                           |
| Depth range                   | \( D_{\text{max}} = 2.7/k \)                             |
| Scanner pattern               | Oblique scanner                                          |
| Field of view                 | ±14° front/back, ±20° left/right                         |
| Swath width                   | 70% of AGL                                               |
| Point density                 | 5 points/m\(^2\)                                         |
| Accuracy                      | 0.15 m (2\(\sigma\))                                    |

Table 1 describes the specifications of LiDAR Bathymetry used in this study. Where \( k \) is the diffuse attenuation coefficient. Depth penetration formula is valid for the diffuse attenuation coefficient in the interval 0.1 < \( k \) < 0.3, but data is normally captured for \( k \) < 1.0. Depth penetration is subject to several
other parameters aside from the diffuse attenuation coefficient \( k \). For this specification, a normal sea-state and 15% sea-bed reflectance have been assumed. Accuracy and point density stated in the table is acquired at 400 m AGL, 60 m/s aircraft speed. The 2\( \sigma \) value represents the 95% confidence interval, the 1\( \sigma \) value represents the 68% confidence interval. Typically, the RMSE value is equal to 1\( \sigma \) accuracy value, or half of the 2\( \sigma \) accuracy value.

In theory the bathymetric LiDAR Equation can be expressed as seen below in Equation (1) [9].

\[
P(2t, FOV) = S(t) \cdot \hat{Z}(t) \cdot \hat{F}(t, FOV), \quad t > t_0
\]

\[
S(t) = \frac{P_0 \eta \beta_\pi (1-\rho)^2 e^{-2\tau_a A_{rec} \cos^2(\theta)}}{n(2\pi n_w + v(t-t_0) \cos(\varphi))^2}
\]

\[
\hat{Z}(t) = e^{-2K_d v(t-t_0)}
\]

\[
\hat{F}(t, FOV) = \frac{1}{2} \Psi^2 e^{-2b_f v(t-t_0)} \int_0^{\infty} \left[ x + \sqrt{1 + x^2} \right] x \exp \left[ -\frac{x^2 m^2}{4} (r_0^2 + R_0^2 + \theta^2 + \Psi^2) \right] dx
\]

\[
\Theta = \frac{D_{IV}}{2} \gamma; \quad \Psi = \frac{FOV}{2} \gamma; \quad \gamma = \frac{H}{v(t-t_0)} + \frac{1}{n_w}
\]

where,

- \( t_0 \) is the time the pulse hits the water (s)
- \( P_0 \) is the peak transmitted pulse power
- \( \eta \) is the optical conversion efficiency
- \( \beta_\pi \) is the backscattering coefficient
- \( \rho \) is the surface reflectance
- \( \tau_a \) is the optical thickness of air
- \( A_{rec} \) is the area of the receiver aperture
- \( \theta \) is the off-nadir angle in air (degree)
- \( \varphi \) is the refracted off-nadir angle in water
- \( H \) is the flying altitude of the aircraft (m)
- \( n_w \) is the index of refraction of water
- \( v \) is the velocity of the pulse in water (m/s)
- \( K_d \) is the diffuse attenuation coefficient
- \( FOV \) is the field of view of the receiver
- \( DIV \) is the divergence of the transmitted pulse
- \( m \) is the water type optical index
- \( r_0 \) is the radius of initial beam cross-section
- \( R_0 \) is the radius of the receiver aperture
- \( b_f \) is the forward scattering coefficient in water

Although these equations can seem rather daunting at first glance, it is relatively straightforward upon closer examination. \( S(t) \) describes the return signal due to reflection and backscattering at a given time \( t \), while accounting for the reduction in solid angle subtended by the airborne receiver as the pulse travels farther away from the aircraft (deeper into the water). \( \hat{Z}(t) \) is simply Beer-Lambert’s Law, accounting for the round-trip exponential decay in optical signal through the water column. Finally, \( \hat{F} \), the subject of this chapter, is the FOV loss factor. The multiplication of these three terms results in the optical return signal at time \( 2t \) (complete round-trip time), \( P(2t, FOV) \), produced by bathymetric LiDAR systems [10]. In equation (1) Water column quality, the most significant limitation for ALB surveys, is impact the depth-measuring capability of an ALB system.
2.2. Bathymetry Data Processing
Bathymetric LiDAR data processing is significantly different from and more demanding than topographical LiDAR data processing. The LiDAR bathymetry data have been calibrated before post-processing, combining sensor-sensor data and pre-processing (initial classification of cloud points). After that, post-processing is using the Leica LiDAR Survey Studio (LSS) software. In general, this processing is used to classify point clouds as bathymetry. Figure 4 is the initial data from the bathymetric LiDAR point cloud which will be processed by waveform to produce a bathymetric point classification.

![Figure 4. Sample of LiDAR bathymetry pre-processing data](image)

Post-processing is analyzing the waveform of each point cloud obtained. The point cloud that is used as an indication as bathymetric data is that which has two peaks in its waveform. The first peak is when the laser hits the water surface, then the second peak is when the laser hits the bottom of the water. In the waveform, several parameters are determined as shown in the figure 5, such as:

- Backscatter thresholds start (A)
- Backscatter threshold slope (B)
- Min amplitude threshold (C)
- Max amplitude threshold (D)

![Figure 5. Waveform parameter for bathymetric point analysis](image)
The waveform parameters must pass the threshold through the first peak and cut the second peak as a bathymetric point. The analysis was carried out on many samples point clouds to get the best waveform model parameter values. Then these parameter values can be applied to all point clouds to classify them as bathymetric points. In addition, post-processing also includes the value of water parameters, namely salinity, and temperature which generate a refractive index value. As we know, the bathymetric LiDAR equation requires an index of refraction in determining the classification of bathymetric points.

To validate the results of the bathymetry points obtained, a GPS survey was conducted as comparison data. GPS survey using the Real-Time Kinematic (RTK) method with one base and one rover. The RTK method used is absolute, where this method does not require a reference point where the position is known and simply uses one receiver [11]. In advance to compare both data, they must be in the same geoid reference. The geoid model used in this research is EGM2008 geoid model. To obtain the EG2008 geoid model from the ellipsoid are as follows:

$$H = h - N$$

Where $H$ is the geoid elevation, $h$ is the ellipsoid elevation and $N$ is the undulation [12]

2.3. Water Turbidity, Temperature and Salinity Data

Information on the turbidity of the waters can be obtained by observing using a Secchi disk for water clarity condition. Secchi Disk is a weighted, 20-centimeter (eight-inch) disk, usually painted white or alternating black and white quadrants. It is lowered into a water body until it can no longer be seen directly above [13]. Figure 6 shows the secchi disk observation at the SD2 location. The weight of the disk is essential to ensure the disk hangs straight when there is a current or tidal flow. The Secchi depth also explains ALB survey expectations regarding where one can expect to survey depths of 1.5–3 times, depending on the ALB system. Leica Chiroptera 4x is rated at 1.5 times the Secchi depth. Figure 7 is the location of the secchi disk observation and the area where the bathymetric lidar data will be processed.

![Figure 6. Water clarity observation using Secchi disk](image-url)
**Figure 7.** Water clarity observation location which is the research location

**Table 2.** Result of water clarity observation

| Id   | Latitude      | Longitude      | Secchi Depth (m) | Turbidity     |
|------|---------------|----------------|------------------|---------------|
| SD3  | -5.773889°    | 105.170833°    | 3.3              | Clear         |
| SD2  | -5.579167°    | 105.204722°    | 3.1              | Clear         |
| SC3  | -5.465000°    | 105.266111°    | 0.35             | Turbid        |
| SD1  | -5.470000°    | 105.320000°    | 2.6              | Mostly Clear  |
| SD20 | -5.743889°    | 105.586944°    | 0.8              | Mostly Turbid |
| SD19 | -5.835722°    | 105.645988°    | 1.35             | Mostly turbid |
| SD18 | -5.850833°    | 105.765833°    | 0.4              | Turbid        |

This LiDAR bathymetry survey does not carry out temperature and salinity observations. Initial processing of bathymetric LiDAR data uses only the default values provided by the software. These values are the temperature at 20°C and salinity at 0 ppt. Therefore, it is necessary to process lidar bathymetry again to produce point cloud data using temperature and salinity data closest to the values at the survey time. Temperature and temperature data uses secondary data obtained from the Copernicus Marine Service website. ([https://marine.copernicus.eu/](https://marine.copernicus.eu/)). The Copernicus Marine Service (or Copernicus Marine Environment Monitoring Service) is the marine component of the Copernicus Programme of the European Union. It provides free, regular, and systematic authoritative information on the state of the Blue (physical), White (sea ice) and Green (biogeochemical) ocean, on a global and regional scale. It is funded by the European Commission (EC) and implemented by Mercator Ocean International. Temperature and salinity are taken from global ocean physics analysis and monthly forecast data from. The results of the analysis were carried out from 1950 to 2020 and for data taken in December 2020, the result is seen in Figure 8. Additional information that in December 2020 at the survey location, the rainy season had started but data acquisition was carried out when the weather was quite good and it is not raining.
The bathymetry LiDAR requires data on the optical index of refraction of seawater \((n_w)\) for depth calculations. The optical index of refraction is one of the critical inherent optical properties of seawater. This value is obtained from the temperature and salinity values of the waters. McNeil used the A&H data to obtain an empirical equation for the refractive index of seawater as a function of wavelength, temperature, salinity, and pressure \[14\].

\[
n_w(S, T, \lambda) = 1.3247 - 2.5 \times 10^{-6}T^2 + S(2 \times 10^{-4} - 8 \times 10^{-7}T) + \frac{3300}{\lambda^2} - \frac{3.2 \times 10^{-7}}{\lambda^4} \tag{9}
\]

Where \(S\) is the salinity in parts per thousand (‰), \(T\) is the temperature in degrees Celsius, and \(\lambda\) is the wavelength in nanometers. For studies of the upper mixed layer of the ocean, we can focus our attention on the index of refraction of seawater at atmospheric pressure. Specifically, pressure effects down to <100 m are small \[15\].

Besides comparing the point cloud, this paper also tests the vertical/depth accuracy. A vertical accuracy test was conducted to determine the vertical accuracy of airborne measurements. Vertical accuracy test can be done by calculating RMSE according to the equation below,

\[
RMSE = \sqrt{\frac{\sum(Z_{\text{data}}(i) - Z_{\text{check}}(i))^2}{n}} \tag{10}
\]

then calculate the vertical accuracy test such as the equation below,

\[
Vertical\ accuracy = 1.6499 \times RMSE \tag{11}
\]

Vertical accuracy is determined by comparing the coordinates of vertical data and check point data (data with reference altitude truth) \[16\]. The check point data using GPS RTK from the survey on the field.

3. Result and Discussion

Our first step will determine the accuracy of the vertical value of depth resulting from the bathymetric LiDAR processing. The point cloud used is the bathymetric point classification. The processing results are generated using the default values of temperature and salinity. Two locations have field validation point values in the research area, namely the Mutun Beach and the Bagus Beach in Lampung Province. Mutun beach has 137 validation points, while Bagus beaches have 134 validation points.
Figure 9. All point clouds (left) and only bathymetric points (right) on the Mutun beach

Figure 9 describes a full point cloud then a point cloud which only displays point bathymetry data. After that, the bathymetric points are overlaid with GPS survey validation points from the field to get the difference value. Then look for the vertical accuracy of the two locations using equation (11). Then the results obtained on the Mutun beach have an accuracy of 28cm while on the Bagus beach it has an accuracy of 48cm as shown in table 2. This accuracy are used to describe the vertical accuracy or depth produced by LiDAR bathymetry in the area of interest of this study. As the information on the density of bathymetry points, bathymetry points result in an average of about 5-7 points per square meter.

| Information                        | Mutun Beach | Bagus Beach |
|------------------------------------|-------------|-------------|
| Number of validation points        | 137 points  | 134 points  |
| The average of the difference values | 0.028m      | 0.085m      |
| RMSE                               | 0.168m      | 0.291m      |
| Vertical accuracy                  | 0.281m      | 0.480m      |

3.1. Result of the effect of turbidity in the water
Water turbidity is measured using a Secchi disk tool. Water turbidity is obtained by measuring the depth of the Secchi disk from the water surface until the disk is not visible from the water surface by observers. The turbidity survey locations used are seven locations in the area of interest (AOI). The location selection has various water conditions from clear to cloudy. The survey result is the Secchi depth which is the average between the depth when the disc is visible again, and when the disc is starting to become invisible. The Secchi depth is used to compare the penetration ability of the green laser LiDAR in the water. LiDAR penetration depth data seen from the cross section at the secchi disk observation location as shown in figure 10. The results of comparing the Secchi disk values and the results of the LiDAR bathymetry are shown in the table 3 below.
Figure 10. Cross-section sample of LiDAR bathymetry data on a Secchi disk survey site sample

Table 4. Results of comparison of bathymetric LiDAR depth penetration

| Id  | Turbidity   | Secchi Depth (m) | Average LiDAR Max Depth (m) |
|-----|-------------|------------------|-----------------------------|
| SD3 | Clear       | 3.3              | 7.45                        |
| SD2 | Clear       | 3.1              | 7.13                        |
| SC3 | Turbid      | 0.35             | 3                           |
| SD1 | Mostly Clear| 2.6              | 6.33                        |
| SD20| Mostly Turbid| 0.8              | 3.81                        |
| SD19| Mostly turbid| 1.35             | 4.80                        |
| SD18| Turbid      | 0.4              | 3.07                        |

Figure 11 Depth difference comparison chart
Clear waters generate penetration depths of up to 7.45m while the LiDAR capability can reach up to 3m on average for turbid waters. The table also illustrates that the penetration depth of the green laser decreases when the water conditions become cloudy. At the SD3 location, the LiDAR capability is 2 x Secchi depth while at the SC3 location it can be up to 7.5 x Secchi depth. This brief analysis is caused by Secchi disk observation near the coast or onshore while the maximum depth achieved by LiDAR is further on the offshore. This condition allows differences in water clarity between nearshore and offshore, which makes the difference in the penetration ability of LiDAR. Leica Chiroptera 4x sensor in the survey in this research area can penetrate green lasers up to 1.5-2 x Secchi depth.

The results obtained to follow the theory that the turbidity of the water affects the penetration depth of the green laser LiDAR bathymetry. The results of the penetration comparison between clear and cloudy water areas have a difference of up to 4m. Turbidity causes light beams to scatter in the water column where particle size, shape, and composition may all affect its amplitude [17]. Therefore, turbidity will affect the attenuation diffusion coefficient of the green laser so that it affects the pattern and increases backscatter noise. Another analysis found that in locations where the water column is turbid, it is close to river mouths or estuary. So, before conducting a survey using a bathymetric lidar, it is recommended to conduct a preliminary survey of the turbidity of the minima waters using a Secchi disk. The preliminary survey can explain ALB survey expectations regarding where one can expect to survey depths of 1.5–2 times, depending on the ALB system.

![Figure 12. SC 20 location close to the river estuary](image)

3.2. Result of Effect of Water Temperature and Salinity

The default value of LiDAR bathymetry depth processing usesa temperature value of 20°C and salinity of 0ppm. This value describes the waters at cool temperatures and freshwater conditions. Using equation (9), the refractive index of the water is 1.3369. To determine the effect, other processing is carried out using custom values of temperature and salinity. Temperature and salinity values were obtained to approximate the water conditions during the survey in December 2020, temperature value of 29.6°C and salinity of 32.8ppm. With this value, the water refraction index is 1.3419. The results of the comparison of bathymetric points at several locations are presented in the table below.
Table 5. The depth difference between the two water conditions

| Location | Max depth different (m) | Average depth different (m) |
|----------|-------------------------|----------------------------|
| SD3      | 0.004                   | 0.0032                     |
| SD2      | 0.016                   | 0.0105                     |
| SC3      | 0.011                   | 0.0098                     |
| SD1      | 0.014                   | 0.0102                     |
| SD20     | 0.006                   | 0.0043                     |
| SD19     | 0.022                   | 0.0171                     |
| SD18     | 0.014                   | 0.0073                     |

The results explain as in table 4 that the resulting difference has a small value between the two water conditions. Different temperature and salinity value can give different depths on the order of cm, which is about 1-3 cm. The relatively small value is also likely because the bathymetric LiDAR data has been corrected such as lever arm and boresight calibrations. In addition, if it is associated with water clarity conditions, waters with clear water have more negligible effect on temperature and salinity differences than cloudy waters.

The vertical accuracy test was also carried out again with different temperature and salinity values to determine the effect on accuracy. The result is that the difference in the accuracy value on the Mutun beach is 4mm while on the Bagus beach it is 6mm as shown in table 5. The difference in the accuracy value is on mm, which is small for some depth data purposes.

Table 6. Comparison of vertical accuracy in two conditions of temperature and salinity

| Information                | Mutun Beach | Bagus Beach |
|----------------------------|-------------|-------------|
|                            | Default     | Custom      | Default     | Custom      |
| Average difference value   | 0.029m      | 0.028m      | 0.087m      | 0.085m      |
| RMSE                       | 0.170m      | 0.168m      | 0.295m      | 0.291m      |
| Vertical Accuracy          | 0.281m      | 0.277m      | 0.486m      | 0.480m      |
| Accuracy Difference        | 0.004m      |             | 0.006m      |             |

Temperature and salinity influence the depth value from the bathymetric LiDAR. During the ALB survey, it is advisable to observe the salinity and temperature. In case there are no observations, the information taken from other marine information providers is secondary data at postprocessing. The use of appropriate values for temperature and salinity can increase the accuracy of the depth values obtained.

4. Conclusion

The water column parameters, specifically turbidity, temperature, and salinity, influence the bathymetric LiDAR depth. Turbidity will affect the penetration ability of green laser LiDAR bathymetry. In locations with good water clarity, the penetration of LiDAR in this study was up to ±7m, while in turbid waters up to ±3m. Temperature and salinity will affect the depth value obtained from the processing. The difference in the accuracy of the depth validation values using different temperature and salinity conditions is up to 4mm and 6mm.
The condition of the water column influence can be a concern in the survey of Airborne LiDAR Bathymetry survey. Turbidity surveys can be helpful for survey planning so that an estimate of the depth can be obtained at that location. Observation of temperature and salinity is needed for post-processing LiDAR bathymetry to make the depth data more accurate. In addition to direct observations, this information can also be obtained from marine information providers. If the survey area is large, it will be a challenge in surveying water conditions such as restricted areas, weather, and dangerous natural conditions.

To maximize the results of this research, further research is needed on the effect of turbidity, temperature, and salinity on the bathymetric LiDAR depth data. Secchi disk data can use more data and for observations taken at locations farther from the shoreline. In addition, it can also test the accuracy with a validation point at a water depth of about 3-7m. The depth data can be obtained using acoustic sensors such as single beam or multibeam echosounder.

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