

# Preliminary results of algorithms to determine horizontal and vertical underwater visibilities of coastal waters

Suresh Thayapurath<sup>1\*</sup>, Shreya Joshi<sup>1</sup>, Madhubala Talaulikar, Erwin J.A. Desa<sup>2</sup>

<sup>1</sup>National Institute of Oceanography Dona Paula, Goa 403004, India.

\*[sureshnio@gmail.com](mailto:sureshnio@gmail.com), 919423061610

<sup>2</sup>Goa University, Goa 403004, India.

## ABSTRACT

Algorithms developed for underwater horizontal and vertical visibilities are presented. The algorithms have been developed to derive the underwater visibilities based on the contrast theory using the in-situ and Hydrolight derived optical parameters. Unlike many other algorithms on vertical visibilities, these algorithms have been developed using the photopic optical parameters. One of the important components in the contrast visibility relation is the coupling parameter, which has been modeled using the underwater average cosine. These algorithms for vertical and horizontal visibilities have been validated for the coastal waters of Goa with the measured and those derived from the ocean color data of OCM-2 and MODIS.

**KEYWORDS** : Algorithm, underwater visibility, horizontal visibility, vertical visibility, MODIS, OCM, optical properties

## 1. INTRODUCTION

Underwater visibilities are of importance for naval operations, divers in salvage operation, research studies of corals, underwater habitat and other related studies. The vertical visibility is observed with a white disk of 30 cm diameter looking at an angle of 0 degree or in the nadir direction normal to the surface of water and the horizontal visibility is the visibility inside the water looking at the target at 90 degree with respect to the nadir. These visibilities are functions of optical properties of water<sup>1</sup>. The simple measurement of the vertical visibility suggested by Fr. Pietro Angelo Secchi, an Italian astrophysicist in April 1865 using a disk lowered in water, is presently known as Secchi depth and has been used since long by the oceanographers. There have been many empirical relationships of vertical visibility and bio-optical parameters<sup>2,3,4,5,6,7</sup>. Though there are methods used to determine the vertical visibility or Secchi depth from the satellite data there are few methods available to determine horizontal visibility from the satellite data<sup>8,9</sup>.

Here we describe algorithms to determine both vertical and horizontal visibilities from the satellite data and their validations for the waters off Goa.

## 2. METHODOLOGY

The underwater visibility depends on four parameters - a radiation source (sunlight), a medium that the radiation travels through (water), an object or target and a sensor (our eye). Here we determine the luminous flux or the brightness of light as observed by the human eye, which is given in lumens per cross-sectional area per solid angle centered in the direction of viewing. (Lumens/m<sup>2</sup>/sr). The theory is based on determining the brightness contrast of the target in water with respect to the background. The contrast  $C$  (also known as Weber contrast) is defined as the normalized luminance or brightness with respect to the background.

$$C = \frac{I_T - I_B}{I_B} \quad (1)$$

where  $I_B$  is the luminance of the background and  $I_T$  is the luminance of the target. Luminance is analogous to brightness and is the photometric equivalent of radiance. The contrast theory of visibility has been developed using the radiative transfer and the visibility model based on the contrast of the target and the background, with some valid assumptions and empirical approximations<sup>1,10,11</sup>. The range of visibility  $Z$  in meters is given as

$$Z = \frac{\Gamma}{c + K_d \cos(\theta)} \quad (2)$$

where  $c$  is the beam attenuation coefficient (an inherent optical property of water),  $K_d$  is the diffuse attenuation coefficient (an apparent optical property of water) and  $\Gamma = -\ln(C_t)$  is the coupling parameter that is a function of limiting contrast of the eye and  $\theta$  is the viewing angle with respect to the nadir. For vertical viewing and finding vertical visibility  $\theta = 0^\circ$  and for horizontal visibility  $\theta = 90^\circ$ . The target is assumed to be darker than background; hence, the limiting contrast is a negative value. Contrast that leads to 50% probability of detection is called the threshold contrast and is identified as  $C_t$  and this depends on the lighting of the background and the angular size of the target. There is a limiting contrast for human, which are assumed to be reasonably constant<sup>12</sup>. Though the low value of  $C_t = 0.003$  is reported to be acceptable<sup>1,4</sup>, it is argued that the smallest value of  $C_t = 0.01$ <sup>13</sup>. The reported values of  $\Gamma$  are close to  $9^{1,2,3}$ .

The equation 2 is applicable for monochromatic light<sup>10</sup>. The diver or the observer views the target with the eye. The eye views spectral light with a weighting function known as the luminosity function of the eye and the maximum region known as the photopic region of eye is around 555 nm under adequate lighting conditions. Hence, for a human viewer the underwater vertical visibility (Equation 3) and horizontal visibility (Equation 4) were derived using the photopic optical properties as given here

$$\text{Vertical Visibility} = \frac{\Gamma}{c(v) + K_d(v)} \quad (3)$$

$$\text{Horizontal Visibility} = \frac{\Gamma}{c(v)} \quad (4)$$

These models are applicable for photopic equivalent of the radiometric optical properties and  $c(v)$  and  $K_d(v)$  are the photopic beam attenuation and diffuse attenuation coefficient respectively. Though the models use the photopic optical properties, most algorithms just use the radiometric optical properties of water. The algorithms described here finds the relationships between the photopic and radiometric optical properties to have some precise meaning to the underwater visibilities models based on contrast theory. The approach towards the formulations of the algorithms for the vertical and horizontal visibilities is given in Figure 1.

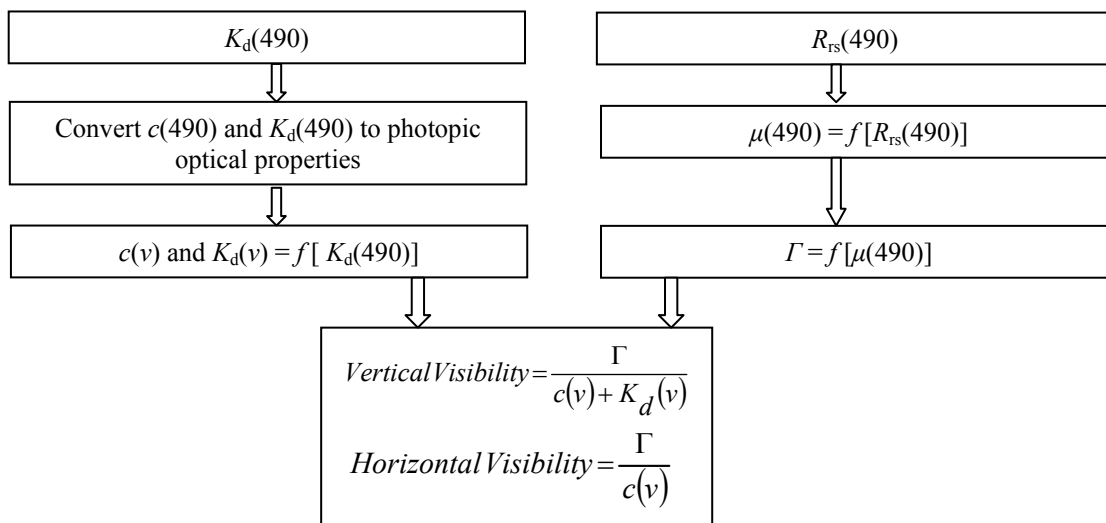


Figure 1. Approach towards the development of the visibilities algorithm

The algorithms require only two optical parameters,  $K_d(490)$  and  $R_{rs}(490)$ , both of which can be derived from the ocean colour satellite data. The  $R_{rs}(490)$  is available directly from the satellite data after atmospheric correction, while there are robust algorithms that can determine  $K_d(490)$  from the satellite data<sup>14</sup>. The algorithms have been developed using the apparent optical properties  $K_d(490)$  and  $R_{rs}(490)$  measured by an hyper-spectral radiometer of Satlantic make and the

beam attenuation at 490 nm was obtained from the in-situ measurements using AC-9 instrument of WetLabs make. The measurements were carried-out in the coastal of Goa.

The photopic values of beam attenuation,  $c(\nu)$  and diffuse attenuation coefficient,  $K_d(\nu)$  were derived from the radiometric value of  $K_d$  at 490 nm using Eq.5 and Eq. 6 respectively.

$$c(\nu) = 4.165667032 K_d(490) \tag{5}$$

$$K_d(\nu) = 0.1128015036 + (0.7266500607 K_d(490)) - (0.01974366444 * (K_d(490)^2)) \tag{6}$$

The underwater average cosine at 490 nm was calculated using the value of  $R_{rs}$  at 490 nm<sup>15</sup>.

$$\mu(490) = 0.2035 (R_{rs}(490))^{-0.223} \tag{7}$$

The coupling parameter  $\Gamma$  was found to be in the range 4.8 to 6.8 (Figure 2). Unlike most others who have assumed a constant value of  $\Gamma$ , considering the variations of this coupling parameter  $\Gamma$  it was modeled as a function of underwater average cosine at 490 nm (Eq. 8).

$$\Gamma = 10.17530547 \mu(490) \tag{8}$$

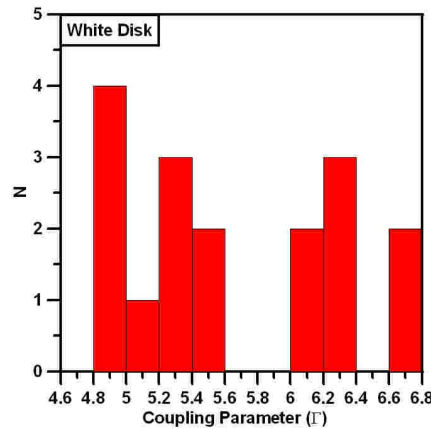


Figure 2. Histogram of  $\Gamma$ .

### 3. RESULTS AND DISCUSSION

#### 3.1 Validation using measured data

The measurements were carried out in the coastal waters off Goa. The target was a white disk of 30 cm diameter with Lambertian type surface. To measure vertical visibility, the disk was mounted on a line and lowered slowly down in the water till it disappeared. It was then slowly raised up till it appeared again. The depth of the water where the disk vanished and reappeared was measured as the vertical visibility depth (m). To measure horizontal visibility, the target disk was mounted at the centre of a large black square metal plate to avoid any reflection from the boat. The target mounted on the dark plate was placed at a depth of 2 m from the water surface. To determine the horizontal visibility, one end of a measuring tape was tied to the centre of the target while the other end was held by the diver who moved horizontally away from the target till it disappeared. Optical properties were measured of the same waters using profiling optical instruments. The optical parameters were averaged within the depth of vertical visibility and it was observed that there were no large variations in the water column of the optical properties. Hence the average was assumed to be close to the average within the satellite penetration depth of first optical depth,  $Z_{90}$ .

The measured vertical and horizontal visibilities compared well with the model (Figure 3).

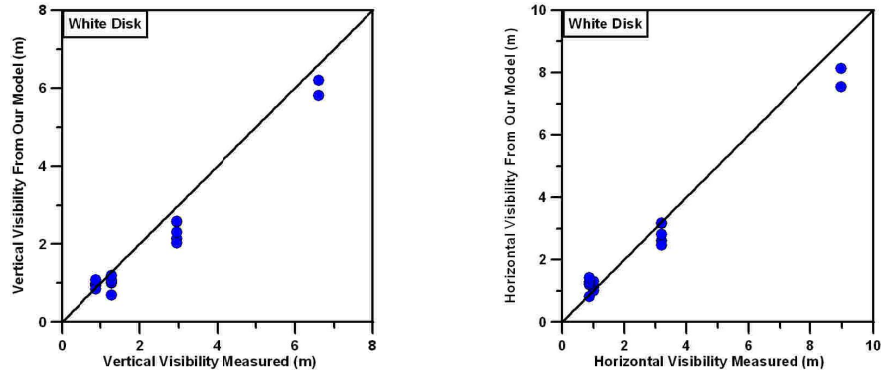


Figure 3. Comparisons of vertical (Left) and horizontal visibilities (Right) measured during validation as compared to those derived using the models.

The relationship between vertical visibility and horizontal visibility was found to be linear. The horizontal visibility was about 1.3 times the vertical visibility (Figure 4). For limiting case with pure water this factor would be about 2.0.

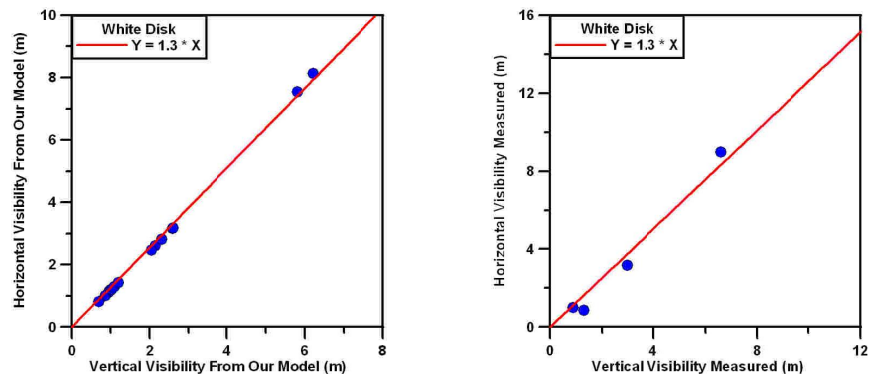


Figure 4. Relationship between vertical and horizontal visibilities using model (Left) and measured (Right)

### 3.2 Validation using the satellite data

The model was validated deriving the horizontal and vertical visibilities from the ocean color satellite data of MODIS and OCM-2 for the day of the validation experiment of 20 February 2015. The satellite data was processed using the software SeaDAS 7.2.

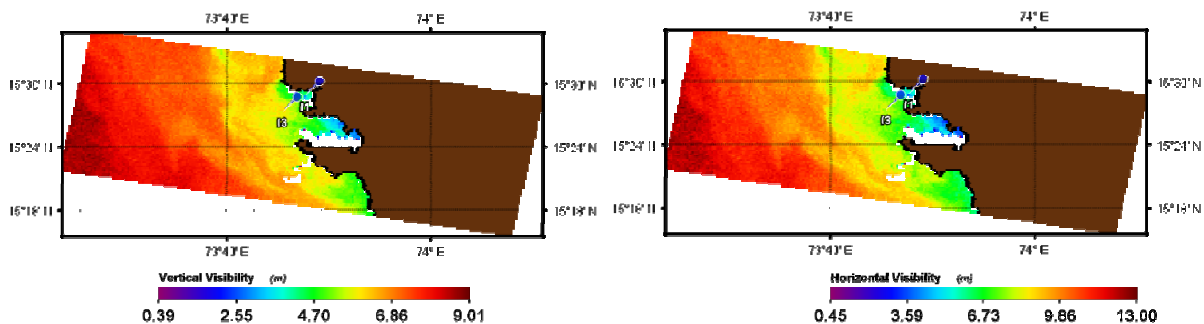


Figure 5. Vertical(left) and horizontal (right) visibilities derived from satellite data, OCM for 20 February, 2015

Table 1. Vertical and horizontal visibilities measured and derived from OCM-2 in the coastal waters off Goa

Vertical Visibility Measured (m)	Vertical Visibility from OCM-2 (m)	Horizontal Visibility Measured (m)	Horizontal Visibility from OCM-2 (m)
2.95	4.06	3.19	5.19
6.6	6.02	8.98	8.06

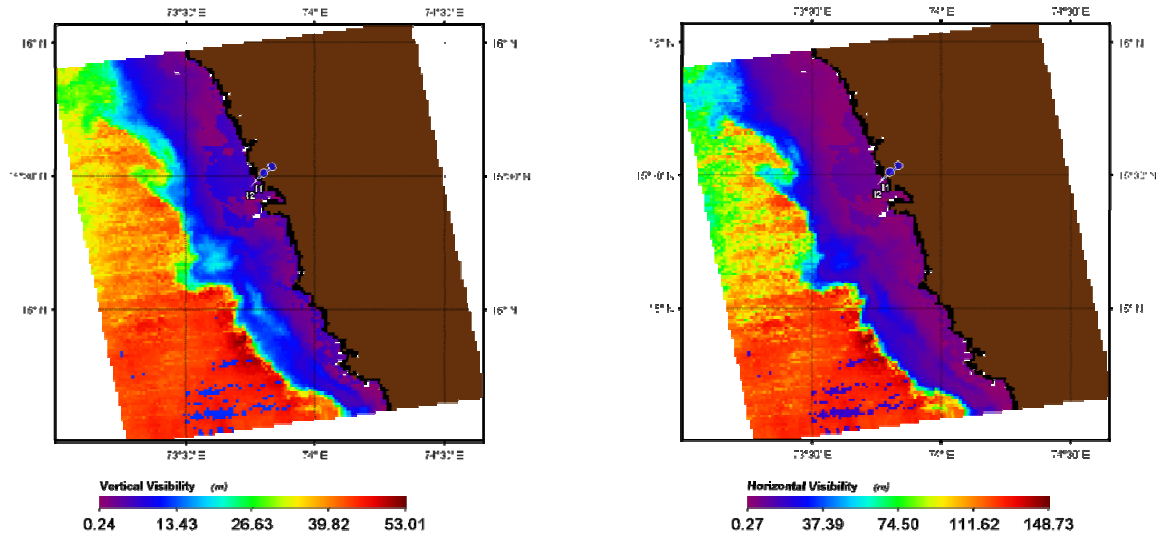


Figure 6. Vertical(left) and horizontal (right) visibilities derived from satellite data, MODIS for 20 February, 2015

Table 2. Vertical and horizontal visibilities measured and derived from MODIS in the coastal waters off Goa

Vertical Visibility Measured (m)	Vertical Visibility from MODIS (m)	Horizontal Visibility Measured (m)	Horizontal Visibility from MODIS (m)
2.95	3.83	3.19	4.82
6.6	5.76	8.98	7.56

The vertical visibilities derived in the low visibility coastal waters from the satellite data were over-estimated (37.6% from OCM-2 and 29.8% from the MODIS), while it was marginally underestimated in the high visibility coastal waters. (-8.8% for OCM-2 and -12.7% for the MODIS). Similar trends were also observed for the horizontal visibilities derived from the satellite, with overestimation of above 50% for the low visibility coastal waters and underestimated by (-10.24% for OCM-2 and -15.8% for MODIS) in the high visibility coastal waters.

## 4. CONCLUSION

- The models to determine vertical and horizontal visibilities of coastal waters performed well for a wide range of visibilities in the coastal and estuarine waters.
- The horizontal and vertical visibilities derived from the MODIS and OCM-2 satellite data provided very promising results. The errors were larger for lower visibility ranges as compared to the higher visibilities of coastal waters. This probably could be due to the errors in the optical parameters derived from the satellite.
- The model requires only two apparent optical parameters at 490 nm and is easy to implement.
- It uses the contrast model and does not relate the visibilities with any other parameters directly to provide any empirical relations. It is a function of optical properties alone. do not use any other parameters such as turbidity or chlorophyll
- Limiting contrast or coupling factor,  $I$  is derived using a model and is not considered as constant.
- The model uses the photopic values rather than radiometric values for the optical parameters.
- Models find an approximate relation between horizontal and vertical visibility for the coastal waters. Horizontal visibility  $\approx 1.3$  Vertical visibility.

Rooms for improvements

- The models need to be validated for various other coastal waters and also with larger data set.

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