

Comparison of sea-level measurements using microwave radar and subsurface pressure gauge deployed in Mandovi estuary in Goa, Central West Coast of India

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Abstract- Data from the radar and an absolute pressure gauge collected from Verem, Goa over a period of one year- January, 2009-May, 2010 is used to carryout the comparative studies. The root mean square difference between the estimated sea level using radar and pressure gauge with atmospheric pressure correction is ~ 2.6 cm. The harmonic analysis over the two time series produces similar residuals and tidal constituents. The results from the study indicate the importance of concurrent measurement of atmospheric pressure along with sub-bottom absolute pressure gauge. The radar gauge has advantages over other type of gauges with regard to easy installation, maintenance and also sea level measurements are absolute and could be given precedence in future applications.

at several locations on the Indian coasts & Islands is described in detail by Prabhudesai et al., (2010).

I. INTRODUCTION

The information about mean sea level and its variability along the coastal locations is essential for practical as well as scientific studies. However, witness to the recent disastrous consequences of Japan Tsunami (11th March, 2011), the impact of powerful December 2004 global tsunami (Titov *et al.*, 2005, Joseph *et al.*, 2006, Prabhudesai *et al.*, 2008) and the historically known vulnerability of the Indian coasts to storm surges (Joseph and Prabhudesai, 2005). The need of real-time reporting of sea-level, sea-state, and surface meteorological information has become all the more important for multi-hazard monitoring and warning purposes.

Considering the importance of the sea level variability, the National Institute of Oceanography (NIO) has established an Integrated Coastal Observation Network (ICON) along the coastal and Island locations of India as shown in Fig.1a (<http://inet.nio.org>). The in-house designed and developed Internet-accessible real/near-real time reporting cellular based sea-level, sea-state, and surface meteorological (Met) stations

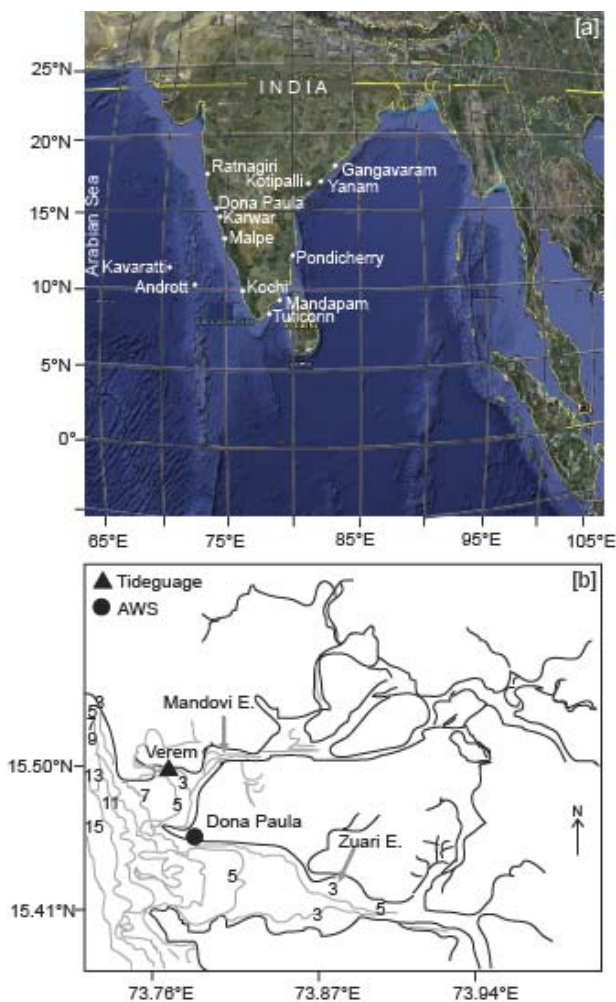


Fig. 1 Map showing the [a] network of near real-time reporting sea level and surface meteorological systems along the coast of India and [b] the study region, Verem, Goa, India.

In this paper, we present the results of the field measurement from the sub-bottom pressure and radar gauge from Verem Goa, India from January, 2009 to May, 2010 (Fig. 1b). The study is to compare; sea level measurements from the radar and pressure gauge and to evaluate the impact of atmospheric pressure in estimating the sea level using sub-bottom pressure gauge. In section-II, we briefly describe the theory of pressure and radar gauge systems; section-III describes the means and data and section-IV describes the results of analysis

II. SEA LEVEL MEASUREMENT METHOD

The most common sea level measuring technologies are (IOC, 2006); A stilling well and a float, Pressure system, Acoustic system and Radar system. We will briefly describe the principle of operation of Pressure and Radar system in this section, as they are the used in the present study:

A. Pressure System:

These systems measures sub-surface pressure (Fig.2a) instead of sea level according to the law:

$$h = \frac{(p - p_a)}{\rho \times g} \quad (1)$$

where, h= height of sea level above the pressure sensor, p = measured sub-surface pressure, p_a = atmospheric pressure, ρ = water density and g= gravitational acceleration. Therefore, this system requires knowledge of local atmospheric pressure, density variations and the knowledge of the local gravity. The density ‘ ρ ’ is important in estuarine waters, where it may change during a tidal cycle or seasonally. In such cases, the density corrections need to be incorporated during post processing. However, in the locations where the water is well mixed, it can be considered constant.

B. Radar Gauges:

The radar sensor is positioned (Fig.2b) well above the highest expected sea level (also the highest expected wave to avoid damages to the unit) and measures the distance from this point to the water level. The radar gauge has many advantages over traditional systems (IOC, 2006), as it makes a direct measurement of sea level. The effects of density and temperature variations, even in the atmosphere, are unimportant.

The typical configuration of subsurface pressure sensors and, downward-looking microwave radars as incorporated in ICON are shown in Fig.2. The sea-level information is acquired using dedicated Linux based data loggers and

uploaded to an Internet server at 5 min intervals using GPRS cellular modems. The sensors and data loggers are powered from sealed lead acid batteries, which are charged through solar panels. The ICON provides graphical presentation of observed sea-level, predicted tide and residual sea-level over internet (<http://inet.nio.org>).

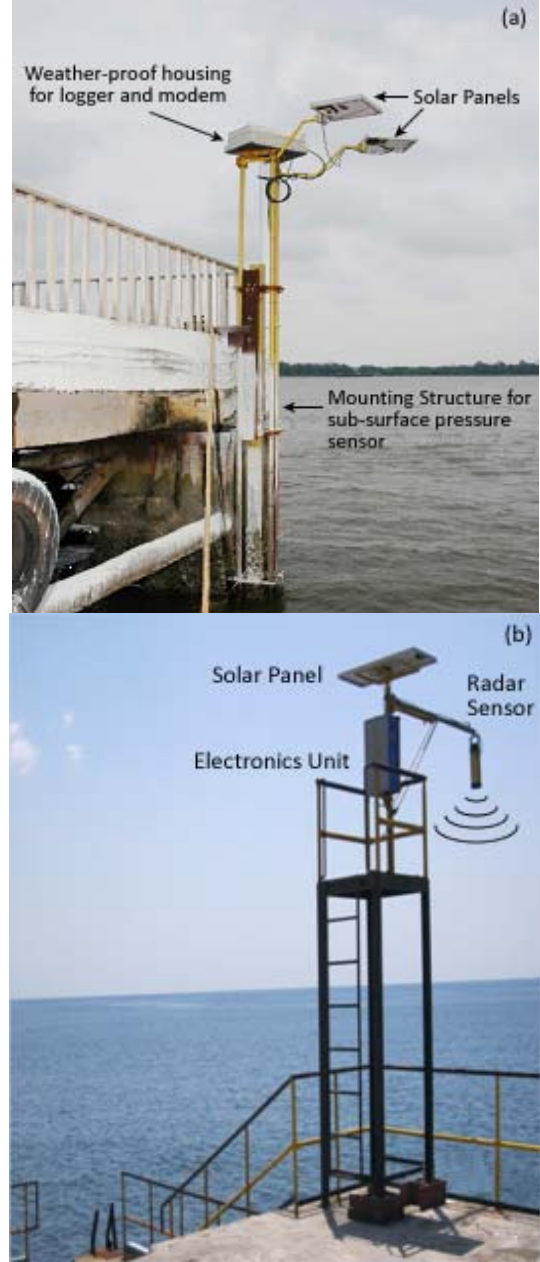


Fig. 2 Typical installations of [a] sub-bottom pressure gauge and [b] radar gauge.

III. DATA

Sea level data are collected at Goa (Fig.1b) using a real-time reporting pressure (Honeywell, Inc.) and radar (OTT,

Kalesto) tide gauge at Verem, near the mouth of the Mandovi estuary from January, 2009 to May, 2010. The tide-gauge instruments were described in detail by Prabhudesai *et. al.*, 2006. The data is sampled at 2 Hz frequency for five minute duration (600 samples), averaged and then recorded in the data-logger every five minute. The radar gauge samples are obtained 1 minute prior to the recoding interval over a 30 second window and then recorded every five minutes. Therefore, the measurements of radar gauge corresponding to the pressure gauge are in a narrow window of 30 second of the 4th minute of the recording duration of 5 minute. If there is no significant sea level variability within the 5 minute duration, then the two systems would report similar estimates. The atmospheric pressure is used from the Automatic Weather Station (AWS) installed on NIO building which is ~5 Km away from the tide gauge site. For comparisons, we have used the data every 10 minutes.

IV. RESULTS

The sea level measurements reported by the pressure gauge and radar gauge is shown in Fig.3 from January, 2009 to May, 2010 from Verem, Goa. Both the systems reported a tidal range up to 250 cm with fortnightly variation of spring and neap tide (Fig. 3a&b). The tides in the study region have

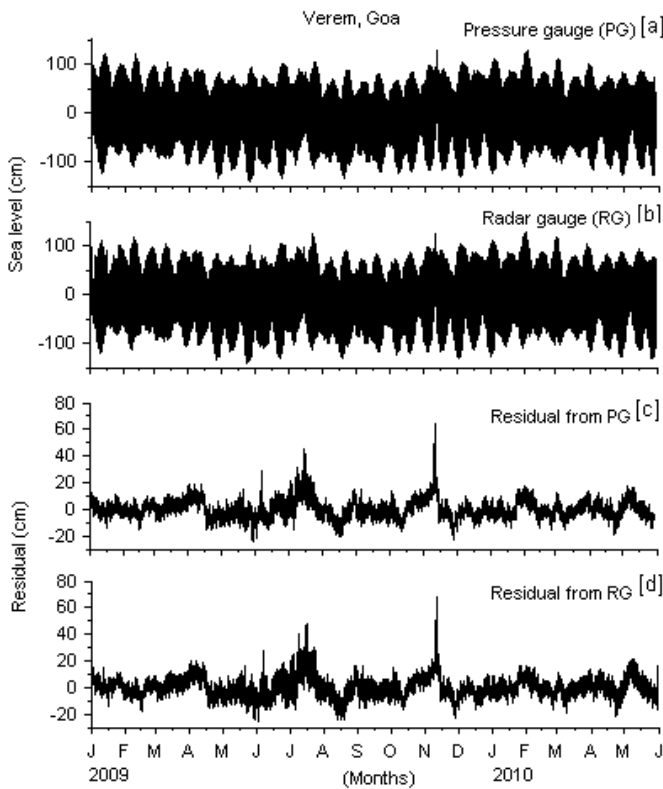


Fig. 3 Sea level measurements at Goa using [a] pressure gauge (PG), [b] radar gauge (RG) and respective residuals [c] from PG and [d] RG.

‘form number’ of 0.64, implying that the tides are mixed, mainly of semidiurnal nature (T.S. Murty and R.F. Henry, 1983). When the tidal signal was removed from the sea level records using the TASK [Bell *et. al.*, 2000] tidal analysis and prediction program, both the system produced similar sea level residuals (SLR) as shown in Fig. 3c&d. The monthly variability is shown in Fig. 4 with negligible difference. The high residual variability ($\sim 163 \text{ cm}^2$) seen in November, 2009 is the response of the sea level to the tropical cyclonic storm ‘Phyan’, which developed in winter in the south-eastern Arabian Sea and swept northward along the eastern Arabian Sea from 9–12 November, 2009 (Joseph *et. al.*, 2010).

Table 1 shows some of the main tidal constituents determined from the radar and pressure gauge during the study duration (also see Fig. 5). The main diurnal, semidiurnal tidal constituents are within $\pm 2 \text{ mm}$ in magnitude and within 1.5° in phase. However, exception is the annual (Sa) and semi-annual (Ssa) for which the amplitude (phase) differ by 10.7 mm (-3.2°) and 2.2 mm (11.8°) respectively. This could reflect to some extent the seasonal changes in density in the river and also due to the data series of ~ 1 year.

The atmospheric pressure variations are shown in Fig. 6a measured by AWS at Dona Paula, Goa (Fig. 1a). The atmospheric pressure anomaly shows annual cycle where the atmospheric pressure is low (high) during June-July (January). The atmospheric pressure variations are within $\pm 10 \text{ mb}$. The sea level estimates obtained using the sub-bottom pressure gauge may lead to over (under) estimations, if atmospheric corrections is not applied (inverse barometric effect $\sim 1 \text{ cm}/\text{mb}$). The sea level is first estimated from the pressure gauge without using measured atmospheric with $p_a = 1004.5 \text{ mb}$, $\rho = 1.020 \text{ gcm}^{-3}$ and $g = 980.665 \text{ cms}^{-2}$ (equation-1).

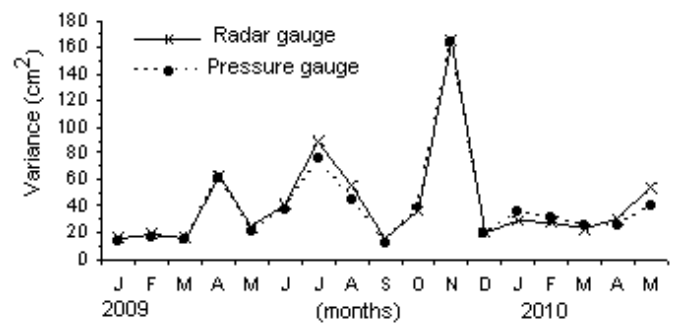


Fig. 4 Seasonal sea level residual variability at Verem Goa.

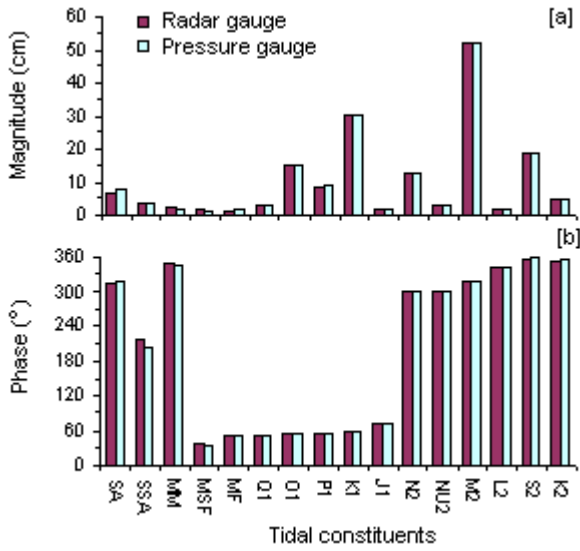


Fig. 5 Major tidal constituents at Verem, Goa obtained using radar and pressure gauge. [a] amplitude and [b] phase.

TABLE 1

MAJOR TIDAL CONTITUENTS OBTAINED FROM RADAR GAUGE (RG) AND PRESSURE GAUGE (PG) AT VEREM, GOA FROM JANUARY 2009-MARCH, 2010.

Tidal constituents	Time period (days)	Magnitude (cm)		Difference (mm)	Phase (°)		Difference (°)
		RG	PG		RG	PG	
SA	365.2	6.65	7.72	-10.7	312.96	316.15	-3.2
SSA	182.6	3.71	3.49	2.2	216.37	204.60	11.8
MM	27.55	2.06	1.68	3.8	347.24	345.86	1.4
MSF	14.77	1.33	1.15	1.8	38.08	31.38	6.7
MF	13.66	1.27	1.31	-0.4	53.11	51.64	1.5
Q1	1.12	3.02	2.98	0.4	52.77	53.02	-0.2
O1	1.076	14.82	14.75	0.7	55.52	55.56	0.0
P1	1.003	8.40	8.49	-0.9	56.48	56.14	0.3
K1	0.997	30.00	30.09	-0.9	58.72	58.94	-0.2
J1	0.982	1.71	1.71	0.0	71.07	71.78	-0.7
N2	0.527	12.14	12.20	-0.6	297.73	298.17	-0.4
NU2	0.526	2.41	2.34	0.6	301.75	302.80	-1.0
M2	0.518	51.94	51.77	1.7	320.08	320.43	-0.3
L2	0.508	1.48	1.40	0.8	343.55	343.42	0.1
S2	0.5	18.37	18.22	1.4	358.25	358.86	-0.6
K2	0.499	4.74	4.74	0.0	352.60	353.67	-1.1

The difference (d_0) between radar and pressure gauge (without measured atmospheric pressure correction) is shown in Fig. 6b with a variance of $\sim 16.1 \text{ cm}^2$. Fig. 6c shows the difference (d_1) between radar and pressure gauge with measured atmospheric pressure correction used in equation-1. The variance in the difference reduces to $\sim 7.0 \text{ cm}^2$. The root-mean-square difference (RMSD) for the difference with (d_1) and without (d_0) atmospheric pressure corrections is estimated to be 2.6 cm and 4.0 cm respectively as listed in Table. 2.

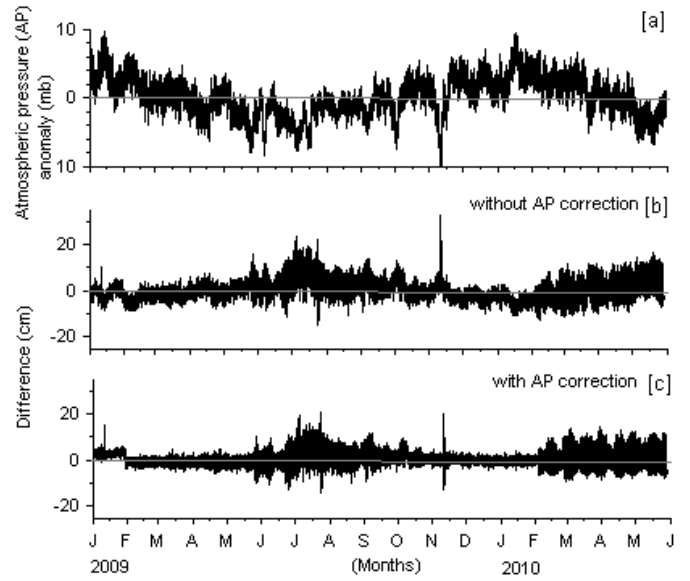


Fig.5 Time series of [a] atmospheric pressure (AP) anomaly (mb), [b] difference (d_0) between sea level estimated from radar and pressure gauge without measured atmospheric pressure correction and [d] difference (d_1) between sea level estimated using radar and pressure gauge with measured atmospheric pressure correction.

TABLE. 2

STATISTICAL INFERENCES FROM THE DIFFERENCE BETWEEN RADAR AND PRESSURE GAUGE.

Difference between sea level estimated using radar and pressure gauge	Variance (cm^2)	RMSD (cm)
d_0 , without atmospheric pressure correction	16.1	4.0
d_1 , with atmospheric pressure correction	7.0	2.6

V. CONCLUSION

This report has described a comparison of measurements from radar and pressure gauges from Goa, West Coast of India. The results obtained suggest that both the systems function well most of the time and produces similar tidal constituents. However, during rainy period the pressure gauge may under-estimated the sea level due to density variations. The importance of concurrent measured of atmospheric pressure along with the pressure gauge is emphasized.

The ICON is developed with simple supporting structure to mount the sensors, powered by solar energy and communicating data (using cellular modems) automatically at base server in NIO. With prior survey of the sites, the drawback of harsh environments and security aspects are minimized and we therefore, have been able to operate the network of such stations (see <http://inet.nio.org/>) successfully.

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