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Estimating measurement errors in distance experiments using GPS

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ABSTRACT

This paper discusses the advantages and drawbacks of radar and gps as reference points for estimating measurement error for visual observations of marine mammals during line transect surveys with reference to the distance and angle experiments as conducted during the Norwegian minke whale sightings surveys. Radar and gps give very similar and consistent results but the convenience of the gps method makes it preferable to using the radar as a calibration reference.

KEYWORDS: DISTANCE EXPERIMENT, GPS, RADAR, ERROR SOURCE, SURVEY, MINKE WHALE, NORTHEAST ATLANTIC

INTRODUCTION

In shipborne surveys of northeastern Atlantic minke whales, sightings are made searching with the naked eye. Radial distance is estimated without any aid while the angle between the track line and the sighting is estimated from an angle board. Models and distributions of the errors in the measurements of radial distances and angles are parts of the procedure for estimating abundance of minke whales in the northeastern Atlantic (Schweder et al. 1997; Skaug et al. 2004). Distance and angle experiments as conducted during the Norwegian surveys are described in Schweder (1997). Visual measurements are checked against readings from the radar, but the precision of the radar readings is not known. This note investigates the precision by attaching gps-recorders to the buoy with radar reflector used in the distance and angle experiments.

DATA

The data for the experiments described here were collected in the following way: One buoy with radar reflector and gps-recorder was dropped in the sea. The vessel approached the buoy from approximately one nautical mile at crusing speed (10 knots) and frequently changed its course relative to the buoy. One observer was situated in the barrel equipped with a microphone connected to a computer-recording-system, which was also connected to a gps receiver. Following a signal from the cruise leader the observer estimated the distance (by naked eye) and angle (from angle board) to the buoy. The measurements were verbally recorded as a sound file on the computer together with the position and time from the attached gps. The gps data were recorded every 2 second throughout the sound recording.The gps receiver attached to the buoy also record time and position every 2 second.

The distance between the vessel and the buoy can then easily be calculated from the positional data received from the two different gps devices. Assuming a constant course under the recording of one sound file it is possible to calculate the course of the vessel from the first and last gps-recording through the sound file. Constant course of the vessel is achieved using an autopilot equipped with gyrocompass. It is possible to calculate courses from the first and second gps-recordings as well, but this gives a less precise estimate, because the two points are very close. Gps can give a course, but those are normally not accurate.

Knowing the position of the vessel and the buoy and the course of the vessel makes it easy to calculate the angle between the course line and the bearing to the buoy.

We have 91 distance and angle measurements recorded simultaneously from the observers and the radar. We have extracted the positions and courses of the vessel for all of these experiments together with the positions of the buoy as given by the buoy's gps.

SOURCES OF ERROR AND DIFFICULTIES

Radar

When the sea state is not optimal it is difficult to discriminate the signal from the buoy from the sea echo. This may cause the radar operator to miss the buoy's position. The reading from the radar are aided by operator determined distance rings and bearing lines on the radar.

Most modern radars have the possibility to lock on a target, but the signal from the radar reflector used on the buoy in the experiments described here is not strong enough to hold on to the target.

Measurements involving a human component will always contain misreadings.

Sweeping radars will have a delay between screen updates. Normally, radars operate at 20-40 rpm. This will cause problems at short distances and large angles.

The radar operator normally switch range on the radar during the experiment and we can expect different accuracies according to range. This possibility has not been investigated here.

A logistical problem associated with use of radars is that the radar antenna has to be located far away from the observation platform (for example barrel) to avoid harmful exposure to radiation.

Gps

Commercially available gps devices normally have a known accuracy of less than 50 m. In the near future this is expected to decrease to within a few metres.

Gps satellites are equipped with internal clocks, these clocks are drifting and causing error in position fixes in gps receivers. To correct for this a system called WAAS/EGNOS (http://www.esa.int/esaNA/GGG63950NDC_egnos_0.html) is under construction.

Up till quite recently only US military controlled all gps satellites but Russia is planning their own system called GLONASS (http://www.glonass-center.ru/frame_e.html) and EU is planning Galileo (http://europa.eu.int/comm/dgs/energy_transport/galileo/index_en.htm). Signals for all these systems can be received by ordinary gps receivers. Galileo is a modern system with much higher accuracy than the old US gps system.

Gps receivers can give wrong positions when switching from one satellite to another.

The spherical shape assumed for the Earth surface is only approximate and therefore calculations of distances as *arc lengths* also will be approximations. We use the formula from Beyer (1978).

Test of gps

To further investigate the precision of the gps we mounted one Garmin gps35-VHS (used on ship) on the roof of our office building and recorded positions every 2 second for half an hour. Recorded positions are shown in Figure 1. Without knowing the exact coordinates for the place where we mounted the gps we calculated a mean position from the recordings and used this approximation for the real coordinates. If we assume that the registrations of latitude and longitude are bivariate normal distributed with equal variance and no correlation, error is Rayleigh distributed with RMS as scale parameter. Upper part of

Figure 2 shows a histogram of the errors and the fitted Rayleigh distribution. Lower panel of Figure 2 shows cumulative functions of empirical error and the fitted Rayleigh distribution. The 95% and 50% quantiles are shown for the fitted distribution. The median or the 50% quantile is often called the Circular Error Probability (CEP). The plot also indicate that P(error<RMS) is just above 0.6 The quantiles, RMS and the mean form the model and the empirical data are summarized in Table 1.

ANALYSIS

The first step is to plot distance to object as measured from radar versus the corresponding distance from gps-calculations as shown in Figure 3. There is a strong linear relationship with correlation 0.9992 and 75% of the residuals within (–6.3, 4.8) metres. The regression equation is Gps = 0.99•Radar - 24.91, with slope significantly different from 1.

This indicates that the radar used in this experiment returns smaller distances than those corresponding to the gps calculations. According to the regression equation the radar would report 2000 metres while the gps would report 1955 meters. Looking at the quartiles of the differences (gps – radar), 75% of the differences are within (-41, -36) meters and the largest difference is –73 meters.

Without any further knowledge of the accuracy of the distance reading from the radar and the calculated distances from gps positions, we assume them to be equal and equal to σ^2. Looking at $Var(R_{gps}-R_{radar})$ we get an estimate of $\sigma = 9.53$ metre.

Figure 4 shows all observations of angles as recorded from radar and gps calculations. Figure 5 shows the same observations, however, observations greater than 270 degrees are transformed 360 degrees counterclockwise. A regression equation can then be calculated as Gps = 0.93•Radar - 0.62; the correlation is 0.9237 and with 75% of the residuals within (-1.9, 0.5) degrees.

Figure 4 shows one very apparent possible outlier. After investigating this observation (radar:336, gps:36) it is evident that the reason must be a misreading from the radar: Looking at the experiment before and after this one and looking at the track of the vessel, made this a probable explanation and thus we removed this observation in Figure 6.

Figure 5 also shows three smaller outliers with differences of –26, -15 and 10 degrees between gps calculations and radar readings. Those observations are all made at small distances (less than 300 metres). In this situation the bearing changes rapidly and even a small time lag in radar reading will result in a large error in angle reading. Therefore we also excluded these three observations when drawing Figure 6.

The data in Figure 6 gives a regression line Gps = 0.96•Radar - 1.36, with slope significantly different from 1, with a correlation of 0.9975 and 75% of the residuals within (-0.9, 0.9) degrees. The quartiles of differences (gps – radar) is (-2.3, 0.14) degrees and the largest difference is –6.6 degrees.Looking at $Var(A_{gps}-A_{radar})$, we get an estimate of $\sigma = 1.35$ degree.

CONCLUSIONS

This analysis shows a systematic difference in measurements from the radar used in these experiments and gps calculations: The radar reports slightly smaller distances and angles than the gps system, however, the difference is quite small, and the readings from the radar and the gps calculations are consistent. The accuracy of gps is well known and still improving. Attaching gps to a buoy is very easy and do not involve the hazel of operating a radar and thus exclude the human factor as one possible source of error.

We therefore recommend that gps are being used instead of radar for calibrating experiments of visual distance and angle estimates during surveys. Further we recommend that analyses of distance experiments include the variance inherent in the method used, whether radar or gps calculations, to account for noise in the calibration.

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Table 1 Empirical and predicted error-measurements for gps position fix.

Error	Empirical [m]	Model [m]
RMS	5.4	
Mean	4.3 (s=3.3)	4.8
CEP 50%	3.5	4.5
95 %	11.3	9.4

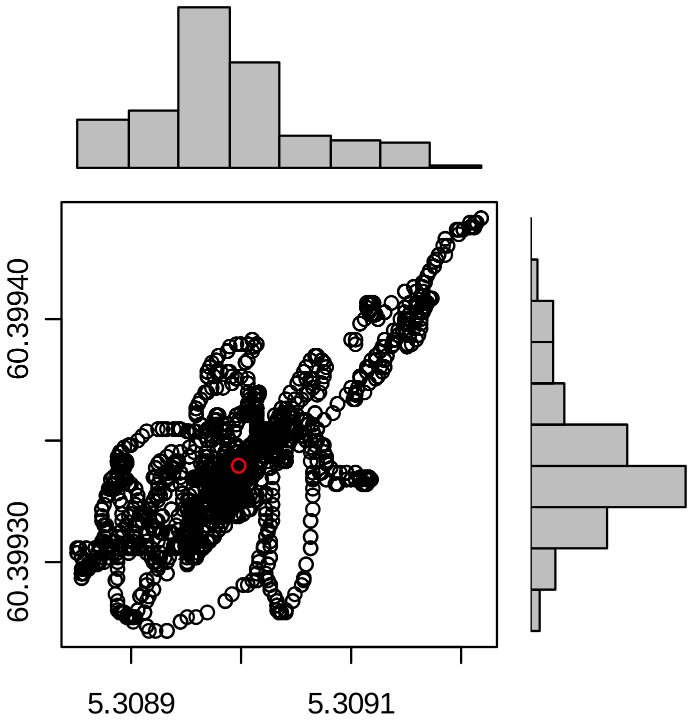

Figure 1. XY-plot of positions recorded from the applied gps receiver over 30 minutes with marginal histograms for latitude and longitude.

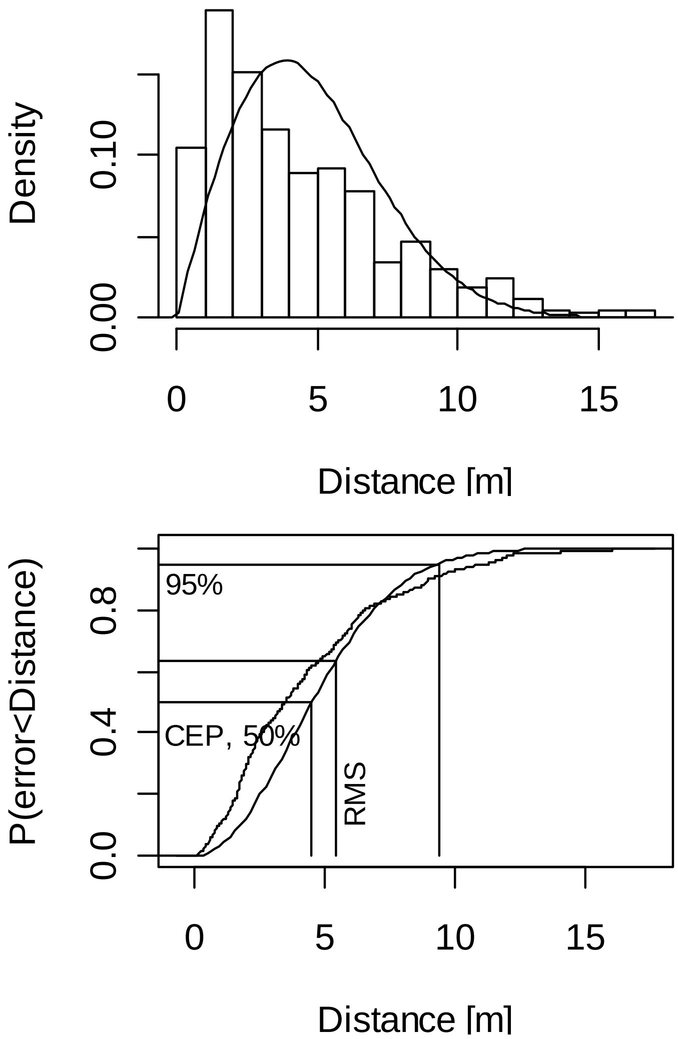

Figure 2. Upper panel: Histogram of errors and Rayleigh distribution. Lower panel: Cumulative function of empirical error and Rayleigh distribution.

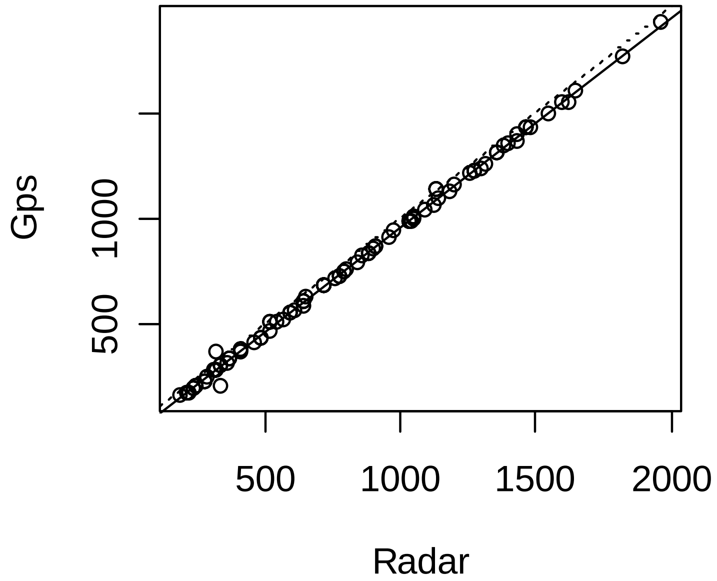

Figure 3. Distances to object as measured from radar versus gps calculations. The solid line is the regression, the dotted line represents y=x.

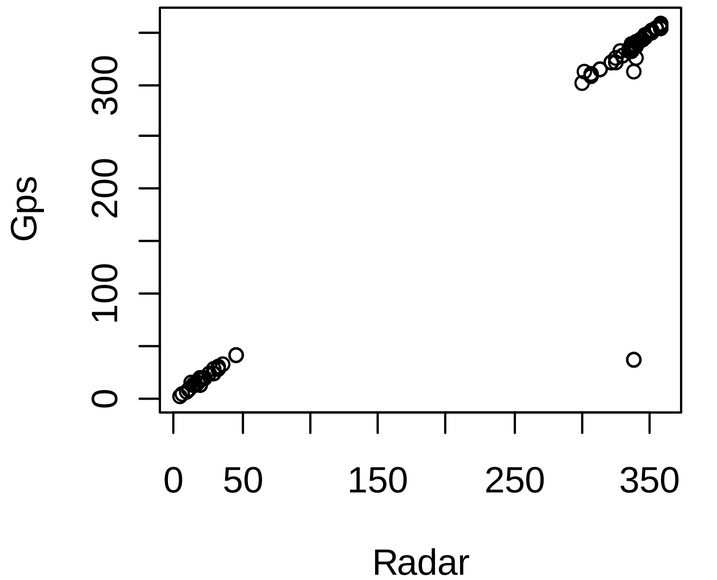

Figure 4. Angles as measured from radar and gps calculations. All observations are included with observations from starboard side in (0-90] and observations from port side in (270,360].

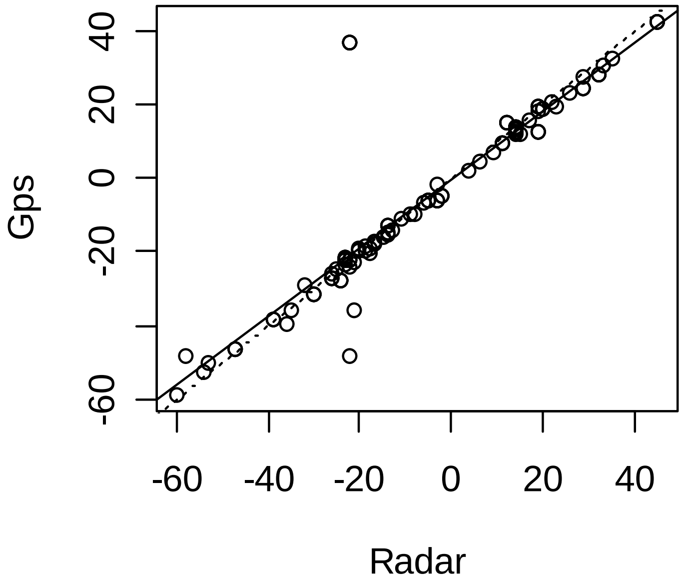

Figure 5. Angles as measured from radar and gps calculations with. all observations included. The data correspond to those in Figure 4 but with observations in (270,360] transformed to (-90,0]. The solid line is the regression, the dotted line represents y=x.

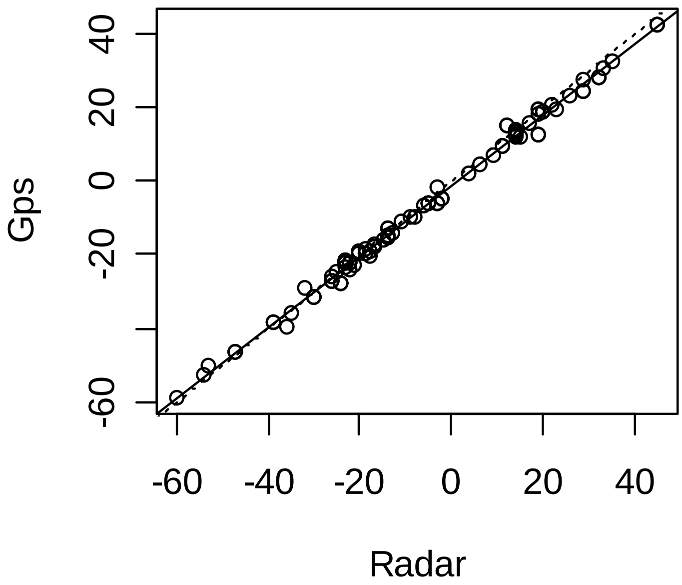

Figure 6. Angles as measured from radar and gps calculations with four outliers removed, as compared to the data in Figure 5. The solid line is the regression, the dotted line represents y=x.