NOAA Technical Memorandum NMFS

FEBRUARY 1996

CALIBRATION OF RADAR ALTIMETER READINGS USED IN AERIAL PHOTOGRAMMETRY OF EASTERN TROPICAL PACIFIC DOLPHINS 1992 AND 1993

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NOAA-TM-NMFS-SWFSC-226

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

NOAA Technical Memorandum NMFS

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Abstract

Radar altimeter readings, applied in aerial photogrammetric studies of eastern tropical Pacific (ETP) dolphins, are corrected for bias with calibration coefficients derived from simple linear regression of true altitude against digital radar altimeter data. Aerial photogrammetry is used to define biological parameters (i.e., length frequency distributions and seasonality of calving) for dolphin populations subjected to mortality in the ETP purse-seine fishery for yellowfin tuna (*Thunnus albacares*). Findings from such studies are applied in devising management plans for dolphin conservation. During dolphin population surveys in 1992 and 1993, estimates of true altitude were determined photogrammetrically in calibration experiments using vertical aerial photographs of known size targets. To test if the bias in radar altimeter readings was consistent during each survey, calibration coefficients for separate experiments were tested for equality using analysis of covariance (ANCOVA). ANCOVA revealed that slopes were similar but y-intercepts differed significantly. Accuracy and precision tests using dolphin-sized targets (206.0 and 182.9 cm) revealed that target lengths, estimated photogrammetrically with the separate calibration coefficients, averaged within 1.2% (for 1992) and 3.4% (for 1993) of true lengths. Results indicated that, despite the significant y-intercept effects, radar altimeter performance was consistent within years. Minimal within-treatment variance probably increased the ANCOVA's power to detect small between-treatment differences in y-intercepts. Also, differences in the range of altitudes sampled between calibration experiments affected variance in the placement of regression lines at y-intercepts. The most accurate estimates of true target lengths came from calibration coefficients derived from regression data that were pooled within years. The radar altimeter calibration equation for 1992 was $y = -7.982 + 0.987x$, $r^2 = .994$; the calibration equation for 1993 was $y = -15.757 + 0.994x$, $r^2 = .99$ (where y represented true altitude and x represented radar altimeter readings). Using these equations, dolphin sized targets were estimated within 0.07% of true target length for 1992 and within 0.43% of true length for 1993. Ninety-five percent CL averaged ± 1.1 cm for 1992 and ± 2.6 cm for 1993. The variability in calibrated altimeter readings introduced a very small error in the true length (derived photogrammetrically) of a dolphin image (i.e., for a 200 cm dolphin photographed between 211-241 m altitude, the 95% CL was $< \pm$ 1.0 cm). Results of accuracy and precision tests indicated that experimentally derived regression coefficients were effective in correcting bias in radar altimeter readings.

Introduction

Researchers at the National Oceanic and Atmospheric Administration (NOAA), Southwest Fisheries Science Center (SWFSC) used aerial photogrammetry in the eastern tropical Pacific Ocean (ETP) to derive body length-frequency information for the pantropical spotted dolphin, *Stenella attenuata*; the spinner dolphin, *S. longirostris*; the striped dolphin, *S. coeruleoalba* and the common dolphin, *Delphinus delphis* (Perryman and Lynn, 1993, 1994). With the exception of *S. coeruleoalba*, each of these species have sub-species or geographic populations within the region that have been described based on differences in biological parameters, including average differences in body length-frequency distributions (Perrin, 1990; Perrin and Reilly, 1984; Perrin et al., 1985, 1994). Because these populations experience different degrees of exploitation in the ETP purse-seine fishery for yellowfin tuna (*Thunnus albacares*; Allen, 1985), management efforts are directed towards conservation at the population level (Wade and Gerrodette, 1992; DeMaster et al., 1992; Dizon et al., 1994). Aerial photogrammetry is used, therefore, as an analytical tool to estimate life history parameters and identify dolphin populations. Results from these biological studies are applied to conservation management.

The altitude from which an aerial photograph of a dolphin is taken is factored into determining the photograph scale for calculating the true size of the dolphin image (see Ghosh, 1988). Digital altitude readings, taken from commercially available radar-altimeters, typically show a consistent bias with changes in altitude (Davis et al., 1983; Koski et al., 1992; Best and Ruther,1992; Perryman and Lynn, 1993, 1994) and, in at least one system, readings over land are different than readings taken at sea (unpubl. data, SWFSC). Workers agree that bias in altimeter readings may introduce statistically significant error in aerial photogrammetric studies of cetaceans (Koski et al, 1992). For these reasons, it is important that radar-altimeter readings be compared and calibrated with true altitude on a regular basis during photogrammetry field efforts. This paper describes a system designed at the SWFSC to estimate true altitude at sea. Linear regression coefficients (Sokal and Rohlf, 1981), describing the relationship between radar-altimeter readings and calculated true altitude, are then used to calibrate the bias in the radar-altimeter readings. In addition, the accuracy and precision of the photogrammetric method is tested using known size photography targets and calibrated altimeter readings.

Materials and Methods

During a 90-day ETP dolphin population survey in 1992, radar-altimeter readings were compared and calibrated against true altitude on 8 August, 23 September and 26 October. During a 1993 dolphin survey radar calibration exercises were completed on 23 July, 15 August, 11 September, 7 and 17 October. True altitude was calculated photogrammetrically from vertical aerial photographs of two known size targets (or "calibration targets") floating at the sea surface. Photographs were taken with Kodak Aerial Plus-X 3404 (126 mm or 5 inch format) film loaded in a Chicago Aerial Industries KA-76 aerial reconnaissance camera. The camera had a fixed 152 mm (6 inch) lens and featured "forward-motion-compensation" (FMC) whereby the film in the camera was advanced along a stationary platen (while the shutter was open) at the same rate and direction as the image recorded by the camera (Smith, 1968). FMC helps to eliminate photograph image "blur" resulting from the forward movement of the aircraft. Aerial photographers adjusted camera f-stop (to 4.0 or 5.6) and shutter-speed (range: 1/1500th to 1/2000th s) based on ambient light conditions. The camera was mounted vertically from a Hughes 500-D helicopter which was stationed aboard the NOAA research ship *David Starr Jordan*. To facilitate the simultaneous recording of altimeter-readings with camera exposures of the calibration targets, an electronic "Tattletale™" analog to digital signal converter was interfaced with the radar altimeter (AA-300 series radio altimeter, Honeywell, Inc.), aerial camera, and a lap-top computer.

Each calibration target was constructed using six, 3.1 m (10.0 ft) sections of commercially available white PVC pipe (5.1 cm or 2 inch diameter, schedules 40 and 80 thickness); the sections were filled with insulation foam for flotation. Prior to each calibration exercise, pipe sections were screwed together (using standard PVC threaded fittings) and target lengths were measured and recorded. Targets were then towed away from the research ship by an inflatable boat so that radar-altimeter signals, processed during camera exposures of the calibration targets, would not be influenced by the research ship's superstructure. The camera exposure cycle rate was programmed for 80% film image overlap, i.e., 80% of the area photographed in one frame was photographed again in the next successive frame. Successive exposed photographs over the calibration targets were recorded as a completed "photo-pass". Multiple photo-passes were taken over the calibration targets between the altitudes of 110 - 310 m (360 - 1017 feet).

After film development, image lengths of calibration and other targets were measured on a video-image analysis system (VIA; Gilpatrick and Lynn, 1994). The VIA was comprised of a

Cohu CCD video-camera linked to a Bausch and Lomb dissection microscope; video images were stored on a frame-grabber board installed in a Macintosh IIci computer. Calibration and other target imagery were displayed and measured on a high resolution 40.6 cm (16 inch) video-monitor; image and numerical data processing were done with the computer software NIH Image 1.41[1]. The precision of dolphin aerial photograph images measured repeatedly by three readers using this system was evaluated by Gilpatrick and Lynn (1994): dolphin images averaging 185.9 cm were measured with 95% confidence limits (CL) ± 1.2 cm (n = 90).

The "true" altitudes from which photographs of the calibration targets were taken were estimated from the scale factor relationship (Ghosh, 1988):

$$A = (I/O) * F \qquad (1)$$

where A = true altitude (in cms); I = known length of the calibration targets (in cms); O = measurement of the calibration target (in cms) in the photograph; and F = focal length (in cms) of the camera.

Linear regression equations describing A as a function of radar-altimeter readings (R) were then determined for each calibration experiment. To see if the bias in R remained constant (i.e. that the radar altimeter performed consistently) during each year, linear regressions were plotted and compared with each other and regression coefficients were tested for equality with analysis of covariance (ANCOVA; Sokal and Rohlf, 1981).

To further examine the performance of the radar altimeter within years and to describe the accuracy and precision of the photogrammetric method, known size targets (PVC pipes) were placed at the sea surface and photographed at various altitudes. Targets (182.9 and 206.0 cms) were designed to approximate the lengths of ETP dolphins; target lengths were estimated photogrammetrically (with eq. 2 below) using radar altimeter calibration equations from each experiment. Length estimates were then compared to the true target lengths. In 1992, a 182.9 cm (or 6 ft.) target was photographed at altitudes between 109.7 and 256.3 m (360 - 841 ft.). In 1993, a 206.0 cm (or 6.75 ft.) target was photographed between 125 - 310 m (410 - 1017 ft.) altitude.

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[1]Computer software was public domain provided by U.S. Government, National Institute of Health, Washington, D.C.

Lengths of dolphin sized targets were estimated photogrammetrically using the scale factor relationship:

$$I = (A/F) * O \qquad (2)$$

where, I = target length (in cms); A = true altitude as predicted from the calibration of R (in cms); F = camera focal length (in cms); and O = target photograph image measurement (in cms).

Results and Discussion

Comparison of linear-regressions within years

Linear regressions computed for A against R for the three calibration experiments in 1992 and the five calibration experiments in 1993 are presented in Figs. 1 and 2 respectively. For both years, the fit of data to the regression lines were very close (r^2 range = .995 - 1.0). ANCOVA results indicated no significant difference between slopes of the separate linear regressions in 1992 ($F_{.05, 2, 35} = 1.027$, $p = 0.369$) or in 1993 ($F_{.05, 4, 72} = 2.220$, $p = 0.051$). However, significant differences were detected in heights of the regressions lines at the y-intercepts for 1992 data ($F_{.05, 2, 37} = 13.100$, $p = 0.0001$) and 1993 data ($F_{.05, 4, 72} = 2.220$, $p = .0417$). ANCOVA analyses were conducted using "SuperAnova" computer software (Abacus Concepts, 1990).

Photogrammetry target tests

In 1992, when dolphin-sized targets (true length =182.9 cm) were estimated photogrammetrically at various altitudes with calibration equations from the separate experiments, target estimates ranged from 178.2 - 189.5 cm. Length estimates, when averaged for the separate experiments, fell within 2.6 cm (1.02 inches) or within 1.4 % of true length; 95% CL averaged ±1.2 cms (Tables 1). In 1993, using regression coefficients from the 5 separate experiments, photogrammetric estimates of the dolphin sized target (true length = 206.0 cm) ranged from 195.8 - 211.3 cm. Target estimates averaged for the separate experiments fell within 7.1 cms (2.8 inches) or within 3.4 % the true target length; 95% CL averaged ± 2.6 cm (Table 2).

Despite the ANCOVA's significant y-intercept effects, the accuracy and precision of the target test results (Tables 1 and 2) suggested that the radar altimeter performed with acceptable consistency within years. Because the fit of data to the respective regression lines was very close (i.e., r^2 values reflected that most of the total variance was explained by the regression terms), the significant effects could reflect increased statistical power in the ANCOVA due to minimal within-treatment variance. That is, the statistical models power to detect relatively small differences between-treatments in y-intercepts is increased due to minimal variance within-treatments (Yezerinac et al., 1992). Differences in the range of altitudes sampled between calibration experiments could also effect variability in the placement of the regression lines at the y-intercepts. For example, in Fig. 2 the regression line for the 17-October-1993 calibration experiment was fit to data points between 150-270 m (the sampled range of altitudes). For the other experiments (Fig. 2), the regression lines were fit to data points lying within and outside of this range. Visual examination of the parallel regression lines (Figs. 1 and 2) and results of the target length estimates (Tables 1 and 2) suggest that differences between regression lines were small and not indicative of systematic changes in the performance of the radar altimeter within years.

Calibration equations derived from linear regression of data pooled within years

When data from the separate exercises were pooled (within years; Figs. 3 and 4), calibration equations derived from simple linear regression provided target length estimates that averaged very close to the true target lengths. For 1992 the target estimates averaged 181.6 ± 1.1 cms (95% CL; Table 1a); for 1993, the target estimates averaged 205.1 ± 2.62 cms (Table 2a). Because this method provided the most accurate estimates of true target lengths, the calibration equations derived from pooled regression data (within years) were used to correct bias in radar altimeter readings for the respective survey years.

For 1992, the radar altimeter calibration equation was:

$$y = -7.982 + 0.987\,x \qquad (3).$$

For 1993, the radar altimeter calibration equation was:

$$y = -15.757 + 0.994\,x \qquad (4).$$

Where y was the true or calibrated altitude and x represented the radar altimeter reading.

Precision of radar altimeter readings

For each year, the fit of data to the common regression lines was good (1992: $r^2 = 0.99$, n = 41; 1993: $r^2 = 0.99$, n = 81; Figs. 3 and 4). For 1992, the mean calibrated altitude (mean value for y in Fig. 3) with 95% CL was 241.4 m ± 0.65 m (or 792.4 ft ± 2.9 ft). For 1993, the mean calibrated altitude (mean value for y in Fig. 4) with 95% CL was 211.8 m ± 0.98 m (or 695 ft ± 3.2 ft). Based on these confidence levels, the variability in calibrated altimeter readings introduces a very small error in the true length (derived photogrammetrically) of a dolphin image. For a 200 cm dolphin photographed at an altitude of 241 m in 1992, the 95% CL translates to ± 0.5 cm of the estimated dolphin length. In 1993, the 95% CL on mean altitude would translate to ± 0.9 cm for a 200 cm dolphin photographed at 211 m altitude.

Between-year bias in radar altimeter readings

For each year, the y-intercept values (-7.982 m for 1992; -15.757 m for 1993) for pooled linear regression data indicated there was a positive bias in the radar-altimeter (i.e., the radar-altimeter overestimated the distance from the helicopter to the calibration targets at the sea surface). Based on practical experience, differences between years in radar altimeter bias was likely attributable to reconfiguration of radio equipment or electrical grounding systems or both. In small aircraft, installation changes in these systems can promote small changes in background voltage detectable in the aircraft's metal structure. In the described photography system, even small changes in voltage effect analog to digital data signal processing (e.g, a change of 0.004 volts analog signal results in a 0.33 m or 1.0 ft change in the digital altimeter reading). This, however, is not problematic provided the performance of the radar altimeter/camera systems are monitored for consistency and are calibrated on a regular basis during field sampling efforts.

Previous studies: Accuracy and precision tests using small targets

Koski et al. (1992) photographed ground targets measuring 300 cm using 70 mm format cameras mounted vertically from a fixed winged aircraft. Target lengths, estimated photogrammetrically, averaged 293.2 cm ± 7.1 cm (95% CL). Perryman and Lynn (1993), in 1990, using the same helicopter and photographic system described in this paper, photographed a 191.5 cm ground target (illustrated dolphin figure); photogrammetric estimates averaged 191.8 cm ± 0.9 cm (95% CL). Accuracy and precision of photogrammetric length estimates reported in this study are similar to those reported by Perryman and Lynn (1993) and slightly better than results reported by Koski et al. (1992).

Conclusion

Results indicate that the calibration method described is an effective method for "at sea" estimation of true altitude. Calibrated altimeter readings provided accurate and precise photogrammetric estimates of dolphin sized photography targets. Calibration during each aerial photography field effort is recommended to reduce the error in estimating size of cetaceans from photographs.

Acknowledgements

This manuscript was improved from comments by Wayne L. Perryman, Robin L. Westlake and Susan Chivers. Thanks to Joyce Sisson for enthusiastic support in towing through the surf (behind a surfboard) the proto-type calibration targets at Scripps pier. Thanks to Chico Gomez and Jim Elledge of the NOAA ship *David Starr Jordan* and Chuck Oliver and Dave Holts of the SWFSC for skilled small boat handling during calibration exercises. Much of the field methodology was developed by Wayne L.Perryman. Thanks to Tim Gerrodette, Chief Scientist of the Population of *Delphinus* Stocks (PODS) surveys, for supporting radar altimeter calibration exercises at sea. Robin L. Westlake, Morgan S. Lynn and Wayne L. Perryman provided support in all field aspects of this study at sea and in La Jolla. Thanks to the crew of the NOAA ship *David Starr Jordan* ; special thanks to the ship's commanding officer Lt. Herb Kirsch. Precision flying during calibration experiments was provided by helicopter pilots Lt. Steve Pape, Tom Gates and Dave Gardiner from NOAA's Aircraft Operations Center (AOC) in Tampa, Florida. Thanks to AOC helicopter mechanic Ron Helgeson for "flight-ops" support.

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Table 1. Accuracy and precision of photogrammetrically determined length estimates of a 182.9 cm photography target. Estimates were made using altitude calibration coefficients from experiments completed during a 1992 dolphin survey.

Calibration experiment dates	Altitude calibration equations (in meters)	Target length (true)	Target Ln estimates (mean)	Length estimates Range (cm)	95% CL
8-Aug.-1992	y = -13.541+ 1.013 x	182.9 cm	181.5 cm	(178.2-184.2)	± 1.1 cm
23-Sept.-1992	y = -7.588 + 0.987 x	182.9 cm	180.3 cm	(176.2-183.4)	± 1.1 cm
26-Oct.-1992	y = - 4.442 + 0.981 x	182.9 cm	184.3 cm	(179.0-189.5)	± 1.4 cm

Table 1a. Accuracy and precision of photogrammetrically determined length estimates of a 182.9 cm photography target. Estimates were made using altitude calibration coefficients derived from linear regression data that were pooled for experiments completed during 1992 (above).

Calibration experiment dates	Altitude calibration equation for 1992 (in meters and feet)	Target length (true)	Target Ln estimates (mean)	Length estimates Range (cm)	95% CL
8-Aug through 26-Oct.-1992	in meters: y = -7.982 + 0.987 x in feet: y = -26.187 + 0.987 x	182.9 cm	181.6 cm	(177.5-184.2)	± 1.1 cm

Table 2. Accuracy and precision of photogrammetrically determined length estimates of a 206.0 cm photography target. Estimates were made using altitude calibration coefficients from experiments completed during a 1993 dolphin survey.

Calibration experiment dates	Altitude calibration equations (in meters)	Target length (true)	Target Ln estimates (mean)	Length estimates Range (cm)	95% CL
23-July -1993	y = -22.319 + 1.026 x	206 cm	204.4 cm	(201.7 - 210.3)	± 1.8 cm
15-Aug.-1993	y = -11.792 + 0.996 x	206 cm	207.3 cm	(204.0 - 211.3)	± 1.4 cm
11-Sept.-1993	y = -17.859 + 1.000 x	206 cm	203.0 cm	(200.2 - 209.1)	± 1.8 cm
7-Oct.-1993	y = -11.901 + 0.987 x	206 cm	204.9 cm	(201.6 - 209.1)	± 0.6 cm
17-Oct.-1993	y = -14.051 + 0.961 x	206 cm	198.9 cm	(195.8 - 204.2)	± 2.6 cm

Table 2a. Accuracy and precision of photogrammetrically determined length estimates of a 206.0 cm photography target. Estimates were made using altitude calibration coefficients derived from linear regression data pooled for experiments completed during 1993 (above).

Calibration experiment dates	Altitude calibration equation for 1993 (in meters and feet)	Target length (true)	Target Ln estimates (mean)	Length estimates Range (cm)	95% CL
23-July through 17-Oct.-1993	in meters: y = -15.757 + 0.994 x in feet: y = -51.695 + 0.994 x	206 cm	205.1 cm	(202.9 - 209.9)	± 2.6 cm

Figure 1. Linear regressions computed for true altitudes (y) against radar altimeter readings (x) for calibration exercises conducted on August 8, September 23 and October 26, 1992.

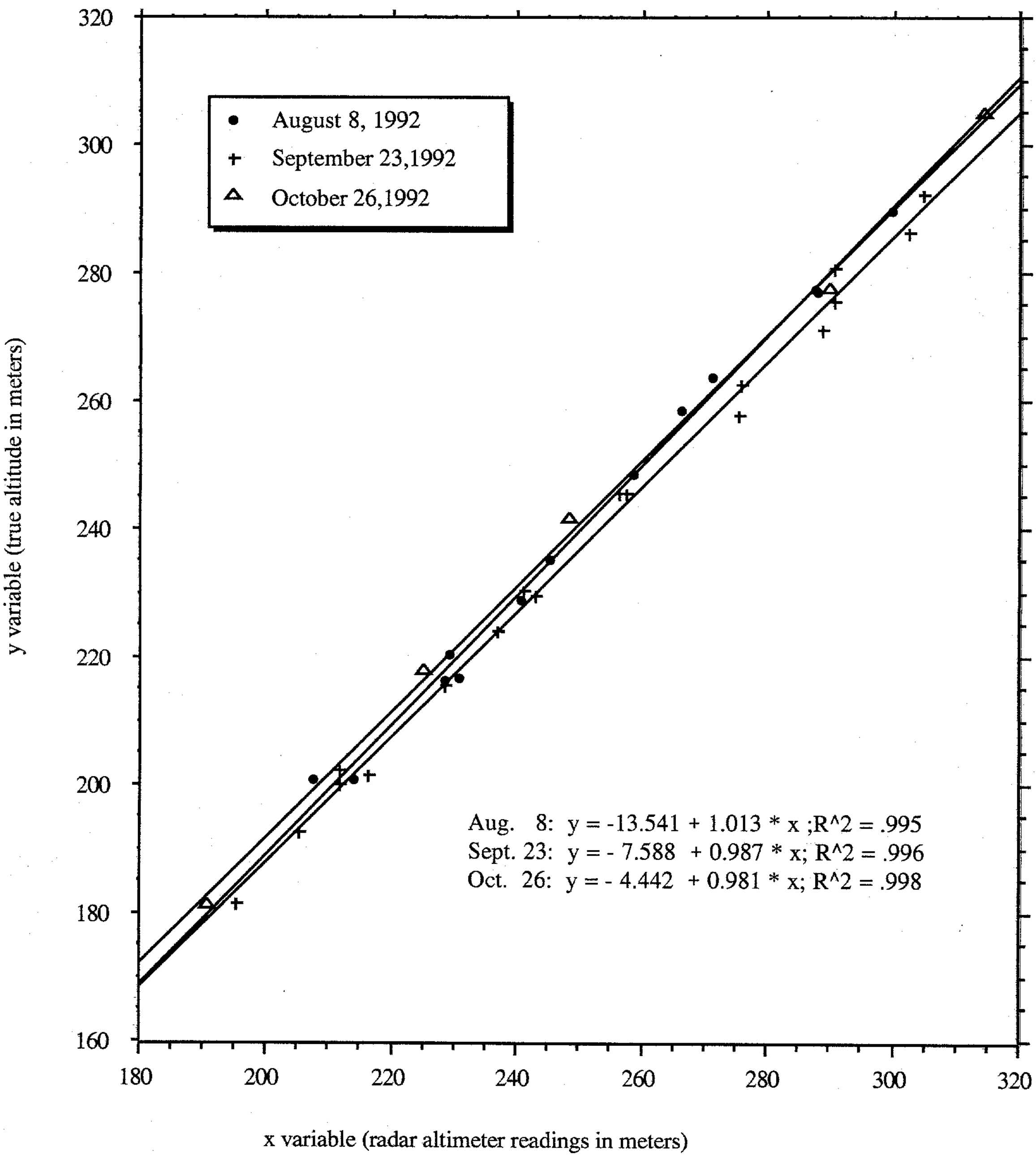


Figure 2. Linear regressions computed for true altitudes (y) against radar altimeter readings (x) for calibration exercises conducted on July 23, August 15, September 11, October 7 and October 17, 1993.

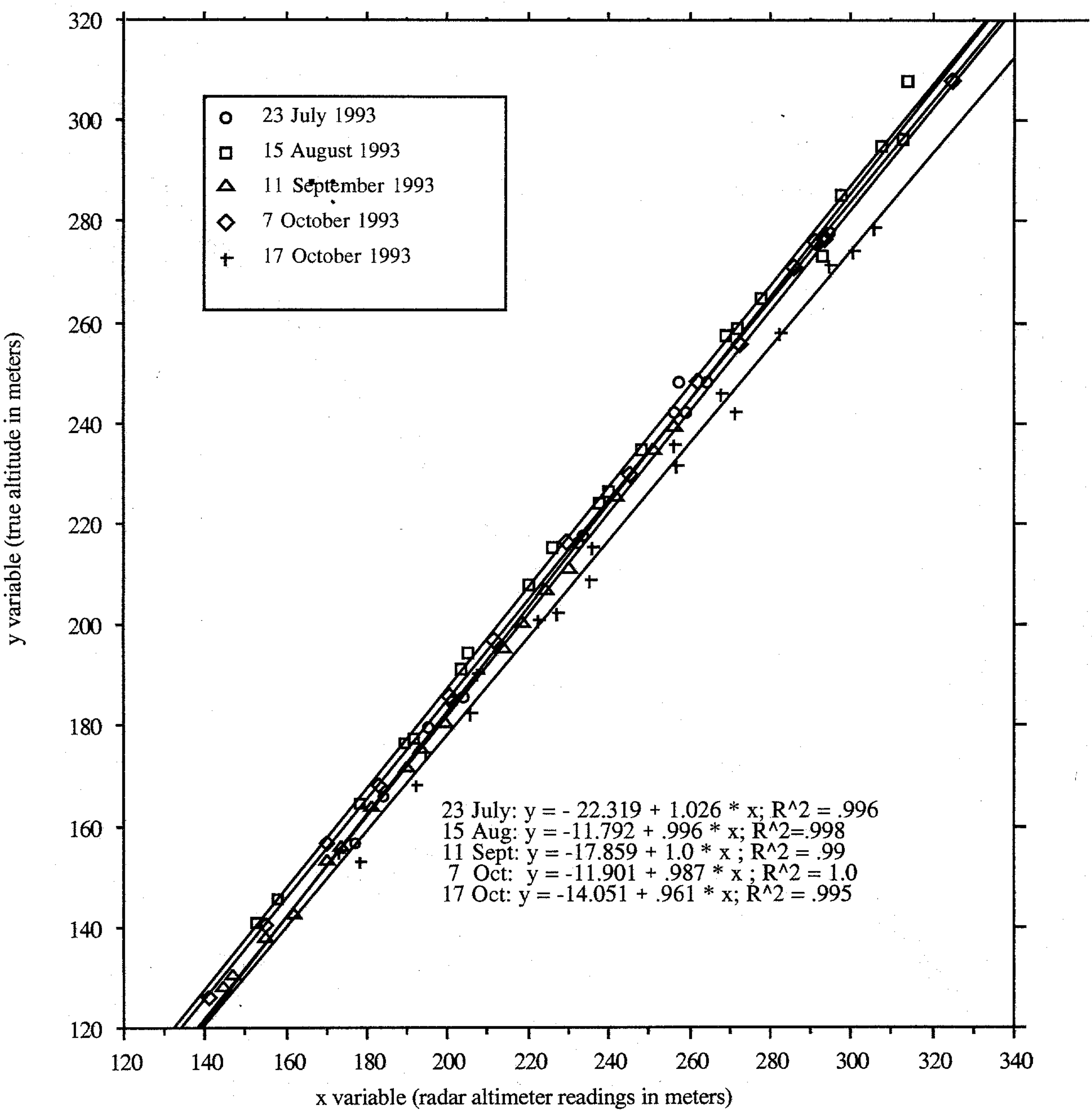


Figure 3. Linear regression computed for true altitude (y) against radar altimeter readings (x) for pooled data from the three altimeter calibration exercises in 1992. Regression coefficients were used in 1992 to calibrate radar altimeter data used in determining photographic scale for photogrammetric analyses of dolphin populations. The 95% confidence limits (CL) for the mean y altitude value of 241.4 m are ± 0.65 m (or 792.4 ft ± 2.9 ft).

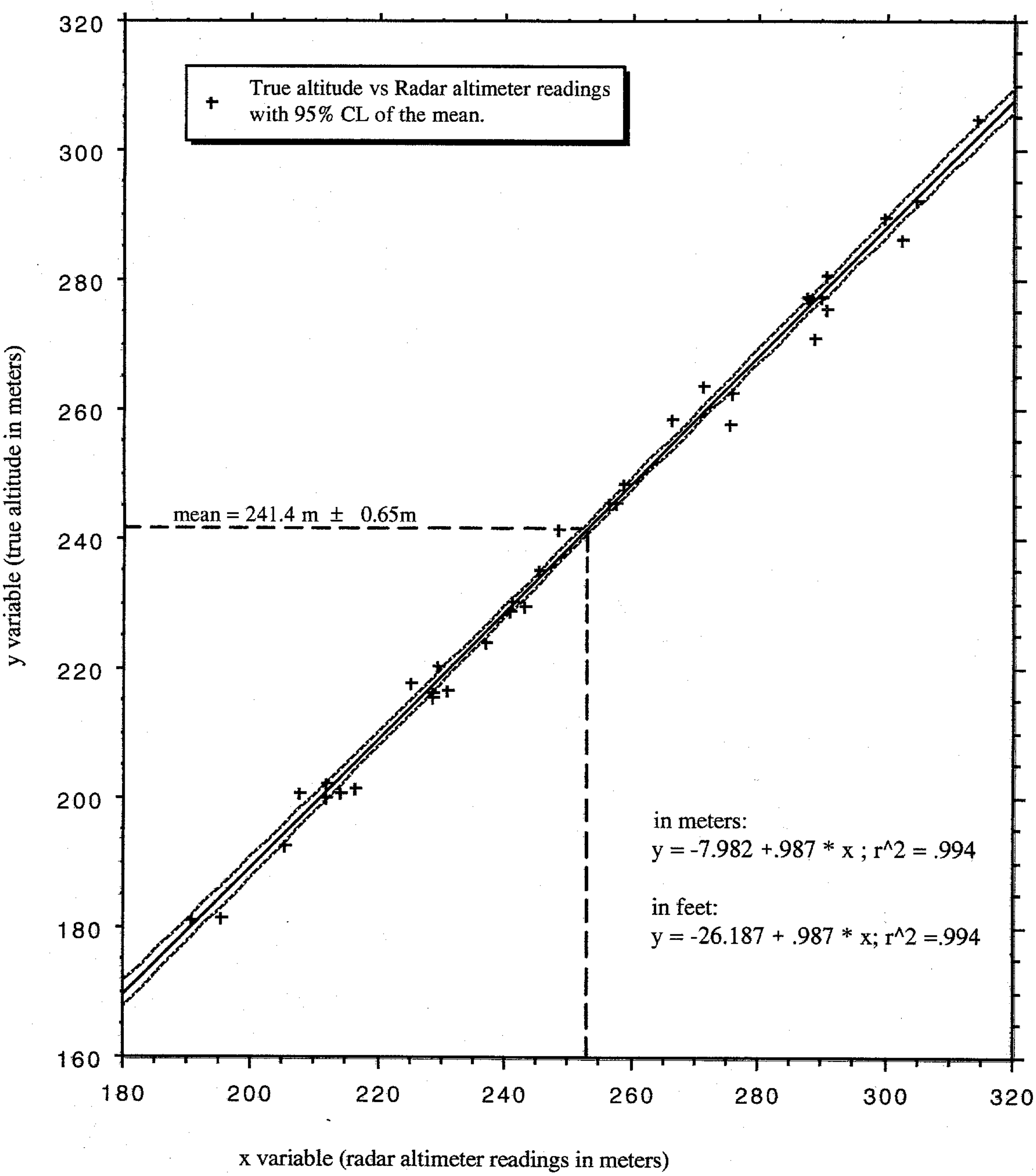
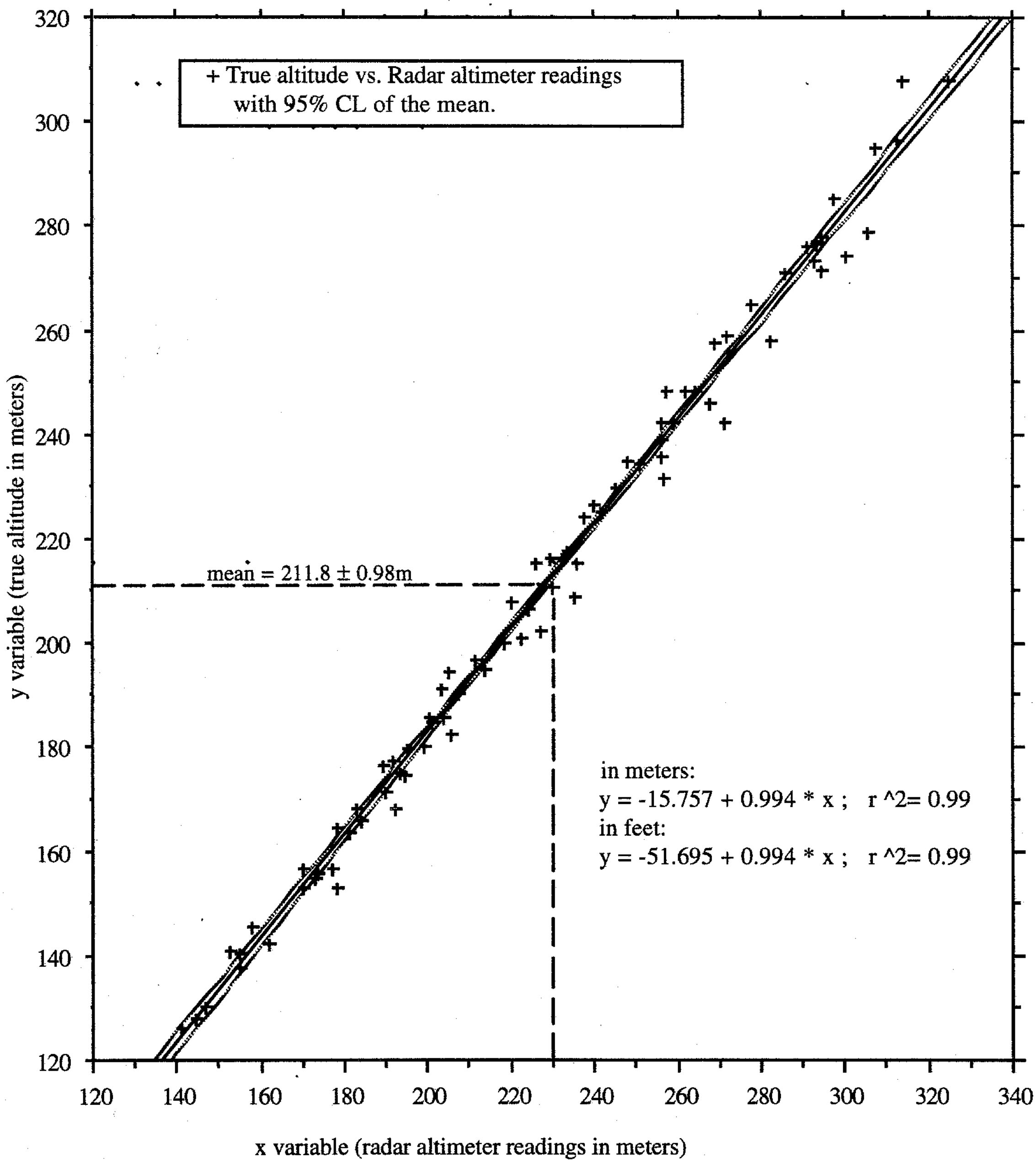


Figure 4. Linear regression computed for true altitude (y) against radar altimeter readings (x) for pooled data from the five altimeter calibration exercises in 1993. Regression coefficients were used in 1993 to calibrate radar altimeter data used in determining the photographic scale for photogrammetric analyses of dolphin populations. The 95% confidence limits (CL) for the mean y altitude value of 211.8 m are ± 0.98 m (or 695 ft ± 3.2 ft).



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