

# OTH-B Coordinate Registration Experiment Using an HF Beacon

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*Abstract* – Over-the-horizon backscatter (OTH-B) radars provide long range, wide area surveillance by reflecting radio waves off the ionosphere. Estimates of the ionospheric reflection heights of the radar signals are used to convert from radar coordinates to ground coordinates for target detection and tracking. This paper describes the results of an experiment using an HF beacon to eliminate bias errors in the coordinate registration (CR) process.

## INTRODUCTION

Over-the-horizon backscatter (OTH-B) radars operate in the 5 to 30 MHz frequency range to detect and track targets beyond the line of sight over wide areas by reflecting high frequency (HF) radio waves via the ionosphere. The energy received back by the radar is Doppler processed to distinguish the moving aircraft targets from the stationary surface returns. The exact ground location of these targets is determined by a process called coordinate registration (CR). In order to perform the CR task, optimally, the radar operators need to know the structure of the ionosphere accurately, i.e., the virtual height at which the propagating ray reflects at the midpoint. Any inaccuracy in determining this height will cause an error in the predicted ranges of the targets.

A relatively simple solution to this problem is the use of beacons within the region of interest. Beacon signals provide a calibration point to correct the CR process in real-time. To determine the feasibility of using beacons, a series of experiments was conducted in 1993 using the US Air Force OTH-B East Coast Radar System (ECRS). This paper presents the results of these experiments.

## EAST COAST RADAR SYSTEM

### System Description

The transmit system, receive system, and operations center of the ECRS are located in Moscow, Columbia Falls, and Bangor, Maine, respectively. The system consists of three independent radars, referred to as Segment 1, 2, and 3, as shown in Figure 1.

For each segment, the transmit system contains six separate 12-element subarrays, each optimized to cover a different portion of the HF band. Targets are illuminated by 7.5° wide transmit beams which are electronically step-scanned across the 60-degree azimuth coverage area. Each receive system provides the same 60 degrees of coverage as the corresponding transmit segment. The receive array contains 246 monopoles which are divided into three sub-bands covering the HF band [1].

### Surveillance Capability

The ECRS receive system provides eight “barrier” beams and three “interrogate” beams, simultaneously, for each segment shown in Figure 1. The barrier beams, consisting of triads of 2.5-degree azimuth sub-beams at fixed 7.5-degree increments, are independently positionable in range. The interrogate beams are similarly steerable in 2.5-degree steps, but are capable of providing higher azimuth resolution. During normal operations one to three interrogate beams may be used in addition to the standard complement of eight barrier beams [1].

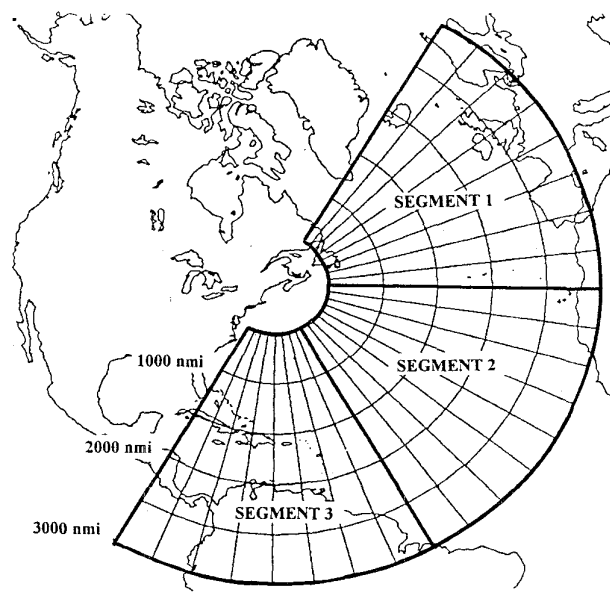


Figure 1. Coverage area of the East Coast Radar System.

The coordinate registration (CR) process develops a virtual height data base of the mid-path reflection points, maintains a real-time model, and establishes coordinate conversion tables for converting the radar slant range and the apparent arrival azimuth into ground range and coning-corrected azimuth to determine the ground locations of the targets detected. The radar tracking depends greatly on the accuracy of the CR process, since tracking is done only in ground coordinates. The CR database uses mainly height information from vertical sounders located inside or near the coverage area. Additional techniques available for CR use the terrain features in backscatter ionograms and pilot position reports from aircraft with precision navigation (PNAV) equipment.

#### *Vertical Incidence Sounders*

The ECRS has available a number of vertical sounders for environmental assessment, located both "on-site" and remotely. The on-site quasi-vertical sounder equipment is collocated with the radar transmit and receive sites. Data from the remote sounders provide proximal estimates of the required downrange ionospheric virtual heights for the slant range to ground range conversion data base. Ionospheric parameters for other regions of the OTH coverage area are also estimated from the height measurements provided by these remote sounding sites, since vertical sounders cannot be placed at every required location. This spatial separation between the surveillance regions and the locations of these sounder sites is a source of inaccuracy in slant range to ground range conversion [2].

#### *Backscatter Ionogram Terrain Features*

Backscatter ionograms are obtained by using oblique sounding equipment, collocated with the radar transmit and receive sites, to linearly sweep across the operating band of the radar and receive the returned signals. These signals provide information about what frequencies can be used to operate the radar at certain ranges. Sometimes, the backscatter ionograms contain intense returns from terrain features within view of the radar. Using a list of known terrain features stored in the radar database, these observations can then be used to determine the virtual height values to be included in the CR process. This conversion is accurate to within the definition in range of the terrain feature. However, the availability of terrain features may be lacking in regions of interest.

#### *Precision Navigation Updates*

All large commercial airliners are required by the FAA to have precision navigation (PNAV) equipment on-board that provides high accuracy navigation data during the entire flight. The presence of this equipment is identified on flightplans that are in the ECRS database. The pilot position report updates provided to the FAA are also forwarded to the ECRS nearly instantaneously, and are used to test the validity of the CR tables in the surveillance area of the radar. Any differences between the correlated radar tracks and the PNAV messages are applied as refinements to the CR process. However, aircraft equipped with PNAV equipment are not always present in all the areas under surveillance. Therefore, other methods are needed for the CR process.

#### *Beacon Assisted CR Technique*

The limitations of current CR techniques maybe overcome by employing HF beacons, which can provide calibrated radar signal returns from within or near the surveillance area. Since these signals travel through similar ionospheric ray paths as the echoes from the targets, they will be subject to the same propagation effects caused by temporal changes in layer height. Also, azimuth deviations induced by layer tilts and multiple target echoes due to multi-mode propagation will be similar. The beacons are relatively simple and can be easily installed. To what extent this method will work is the subject of this report.

#### *Experiment Setup*

OTH radar data were collected during a number of experimental campaigns, using an aircraft specifically equipped for gathering highly accurate groundtruth data while being tracked. This option was selected over using targets of opportunity, since groundtruth data is required with a resolution commonly not available from commercial or military target flight plans, even if they provide regular updates. The aircraft flew over a number of predetermined, round-robin, radial paths in the vicinity of Puerto Rico. Each path was well within the coverage area of the ECRS, and within the desired range of the HF beacon (Figure 2). The aircraft available was a Piper Aztec, which has dimensions commonly associated with targets of interest. Each of the flight legs was approximately 160 nmi in length, matching a flight time of about one hour for either the inbound or outbound leg. A number of legs were selected both to the north (labeled Ba, Ca, and Da in Figure 2) and to the south (labeled B, C, and D in Figure 2) of Puerto Rico.

The target aircraft was equipped with on-board PNAV Global Positioning System (GPS) equipment, and HF communication equipment, to provide accurate location updates and flight coordination during the tests at various checkpoints along each of the flight paths. These location updates were important to verify the track acquisition of the Piper Aztec, in particular in the vicinity of Puerto Rico, since the air traffic environment is very dense with many other targets flying at about the same speed. The Piper Aztec was at times being redirected by air traffic controllers to avoid other traffic or weather from the planned radials. The GPS groundtruth track data were recorded once every second, providing a temporal location resolution much better than that of the ECRS, which is updated once every 90 seconds. The radar track data were collected using the normal operational data recording process, taking pertinent data from both the detection and tracking (DT) and the correlation and identification (CI) track history files. The DT track history format provides data in the slant range domain, while the data in the CI format is provided in the ground coordinate domain.

The beacon consisted of SRI International electronics connected to a log-periodic antenna to provide wide frequency coverage. This beacon receives the signal, stores and amplifies it, and then retransmits it by

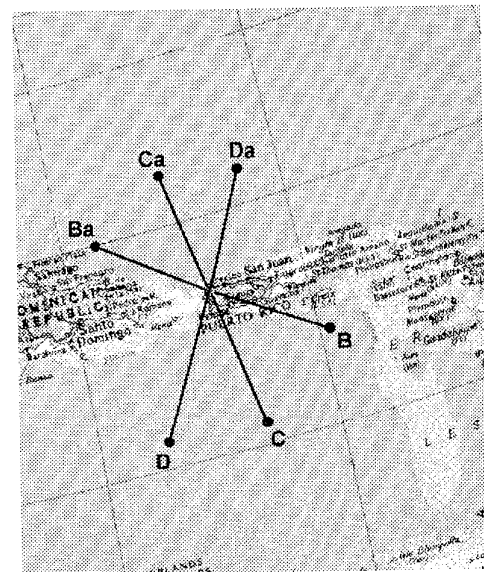


Figure 2. Coordinate Registration Experiment Setup.

switching rapidly between transmit and receive modes [3]. Because of the nature of these tests the beacon was left with no attenuation in the amplification loop. Any large signal source, such as the ECRS, impinging upon this beacon will produce a very strong return signal causing significant sidelobes in both the range and azimuth signal processing done by the radar. The beacon track data points were collected manually at the ECRS operations center since it does not have the ability to maintain a track on non-moving targets. A procedure was developed whereby the operator would force the radar to initiate a track at regular intervals.

The most useful data, collected during the August/September period, will be the focus of this analysis. The experiment dates, periods, and the flight path radials are listed in Table 1, where the notation Ca - Da indicates that the initial round-robin radial to point Ca and back was immediately followed by a second round-robin to Da.

Table 1. Data Collection Periods and Flight Paths

Date	Time	Flight Radials
31 Aug 93	1951 - 2340	Ca - Da
1 Sep 93	2010 - 0013	Ca - Da
2 Sep 93	2000 - 0005	Ca - Da
9 Sep 93	2100 - 0100	Ca - Da
10 Sep 93	2122 - 0100	Ca - Da
11 Sep 93	2105 - 0106	C - D

Data Description

Using the ECRS radar track data (RTD) and the GPS groundtruth data (GTD), a coordinate registration offset (CRO) was determined as follows:

$$CRO = RTD - GTD \tag{1}$$

This calculation is the actual offset between the radar ground track coordinates and the groundtruth target location; it is this offset that will be reduced by using the beacon as a calibration point. The offsets are due to the inability to model the short-term spatial variations in the ionospheric electron density profile, causing both range and azimuth variations as the signals propagate towards and back from the target.

The beacon bias (BB) was determined by subtracting the radar calculated beacon track data (BTD) from the actual beacon groundtruth location (BGL) as follows:

$$BB = BTD - BGL \tag{2}$$

The beacon bias was used to obtain a corrected coordinate registration offset (CCRO) with the bias error produced by the time-varying ionosphere subtracted out as follows:

$$CCRO = (RTD - BB) - GTD \tag{3}$$

The offsets calculated from (1) and (3) were plotted in scatter plots, similar to the one shown in Figure 3, with (1) along the vertical axis and (3) along the horizontal axis, for comparison. In this figure, the 45 degree line is the line of no improvement with points falling above this line representing improvements, and those falling below the line indicating unwanted degradations introduced by the application of the beacon bias correction. The closer a point is to the 45 degree line, the smaller the improvement or degradation. The axes in Figure 3 are given in normalized units. The data are segregated with respect to range (Figure 3a) and azimuth (Figure 3b) to show the difference between beacon-assisted corrections in latitude and longitude. For the nearly south-looking radar-to-target geometry used here, latitude and range are interchangeable as are longitude and azimuth.

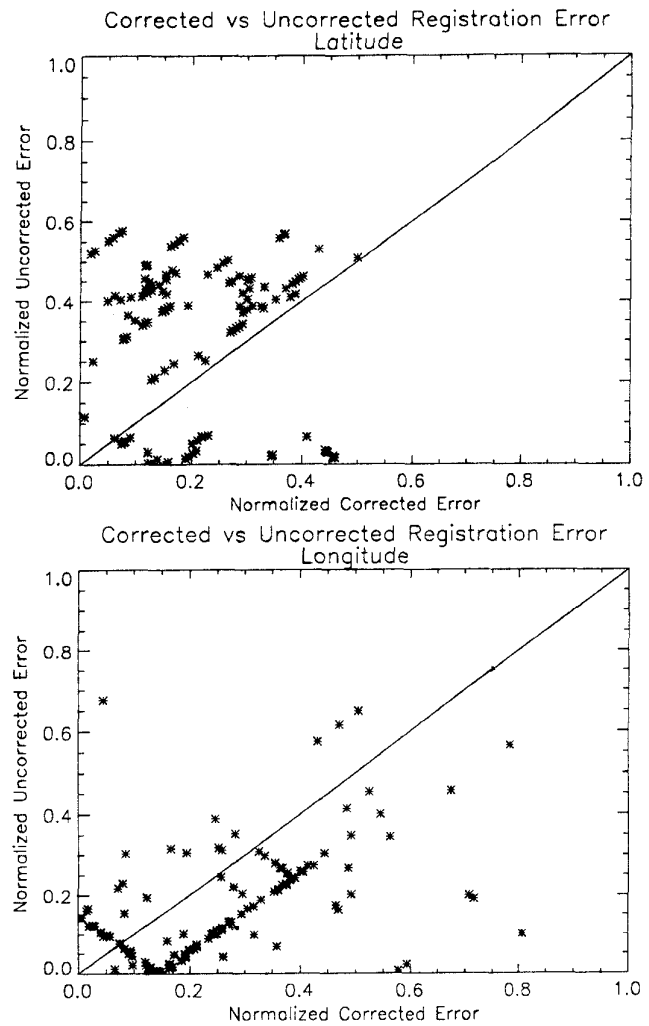


Figure 3. Scatter Plots Displaying Uncorrected Error vs. Corrected Error for (a) Latitude (Range) and (b) Longitude (Azimuth) for Sept. 1, 1993.

RESULTS

Table 2 lists the median offset values for all the range and azimuth data collected during each day's mission identified in column 1. In columns 2, 3, 5, and 6 the uncorrected and corrected median offsets (labeled Unc. and Corr., respectively) were normalized by the same factor used Figure 3. Improvement factors (labeled Imp.) for both range and azimuth were calculated in columns 3 and 4, respectively, by taking the ratios of the uncorrected and corrected medians.

Table 2. Median Uncorrected and Corrected Offset Values

Date	Range Offset			Azimuth Offset		
	Unc.	Corr.	Imp.	Unc.	Corr.	Imp.
31 Aug 93	.17	.26	.65	.14	.32	.44
1 Sep 93	.39	.19	2.05	.13	.25	.52
2 Sep 93	.50	.28	1.79	.15	.26	.58
9 Sep 93	.27	.18	1.50	.10	.18	.56
10 Sep 93	.21	.19	1.11	.12	.21	.57
11 Sep 93	.28	.14	2.00	.10	.13	.77

The best improvement in CR range offset occurred on September 1, when the range accuracy was doubled, while the worst data correspond to August 31. From Table 2, we conclude that the beacon bias correction process was successful in correcting for offsets in range but produced degraded azimuth results. The latter may have been caused by system error in interpolating the beacon crossrange location with sufficient accuracy due to spilling of the unattenuated beacon signals into adjacent azimuth beams. The map displayed in Figure 4a shows the estimated location of the beacon as manually initiated by the operators with the variance in the estimated crossranges high in comparison to the estimated downrange variance. This is also borne out by in Figure 4b, which displays the estimated range (latitude) and azimuth (longitude) beacon biases as a function of track sample (approximately proportional to time-of-day) for September 1.

#### CONCLUSIONS

These experiments demonstrated that using a beacon in conjunction with an OTH radar can significantly improve the CR process, since the majority of the data show improved range accuracy. Similar improvements are anticipated for the crossrange accuracy when using a beacon with attenuated echo signal strength.

#### REFERENCES

- [1] G.S. Sales, *OTH-B Radar System: System Summary*. PL-TR-92-2134, Phillips Laboratory, Hanscom AFB, MA, May 1992.
- [2] G.S. Sales, *High Frequency (HF) Radiowave Propagation*. PL-TR-92-2123, Philips Laboratory, Hanscom AFB, MA, April 1992
- [3] A.C. Phillips and K.L. Ford, *SRI Single-Antenna Repeater*. TR-22, SRI International, Menlo Park, CA, May 1973.

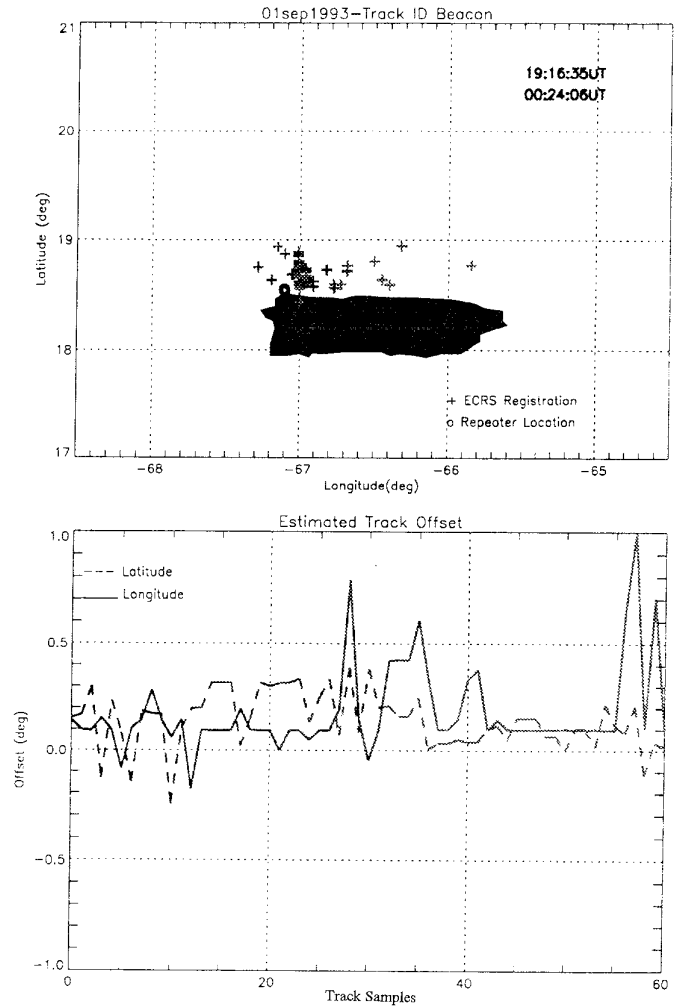


Figure 4. Plots of (a) Estimated Beacon Locations and (b) Estimated Beacon Biases for Sept. 1, 1993.