

UHF SYLEDIS FOR COASTAL SURVEY POSITIONING

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ABSTRACT

UHF positioning systems are intermediate between groundwave HF radio aids, such as Argo and Hi-Fix, and line-of-sight systems, such as Mini-Ranger III and Trisponder. The Canadian Hydrographic Service conducted tests along the coast of Nova Scotia in 1982/83 which showed that UHF propagation velocity is unaffected by the terrain that the signal passes over, that UHF Syledis is effective to about 100 km over water and low-lying land, and that low pressure weather systems reduce Syledis performance. This paper will describe test procedures and results, and the subsequent CHS experience with Syledis in the first year of operational use in 1983.

1. INTRODUCTION

Trans-horizon UHF propagation is a complex process involving elements of diffraction, refraction, and tropospheric scattering. It would also appear to be poorly understood by hydrographers and navigators in general, judging by the variety of interpretations that are encountered. However, it is significantly different from microwave propagation in that it extends two to three times beyond the line of sight, and from HF propagation in that it appears to be unaffected by landpath or skywave effects. Hence, UHF propagation offers potential benefits for coastal

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surveys along indented coastlines where microwave systems would be too often blocked by headlands and islands, and where HF systems would encounter inaccuracies because of unpredictable over-land phase lags.

UHF radio positioning was introduced to marine use in the 1960s, when the earlier VHF Shoran system was modified by Decca Surveys Ltd to allow it to operate at UHF frequencies (LAURILA, 1976). However, UHF systems were not widely evident at sea until the mid-1970s when advances in electronics and signal processing led to the development of the Syledis positioning system by Sercel Electronics of France (NARD and LAURENT, 1975). Since that time, the Syledis has gained acceptance for precise positioning applications, particularly in support of oil exploration activities [i.e. COX and BISHOP (1981); MORGAN (1983)]. In addition, a number of other UHF positioning systems have entered the market and become fairly well known in recent years, including the UHF Trisponder, the Maxiran, and the Trident.

The Syledis employs a sophisticated spread spectrum correlation technique which allows it to recover accurate range information from relatively long, low-power modulated pulses. The effect is to compress a 66.66 μ s pulse, generated at 20 watts, to a much shorter 0.52 μ s pulse, with an equivalent power of 2 500 watts, by matching the elements of a pseudo-random code sequence transmitted by the shore beacon with an identical reference code generated within the mobile. The finite length of this code sequence (66.66 μ s) introduces an ambiguity of 10 kilometres into the range measurement. The system operates by time-sharing transmissions on a single user-selectable frequency between 420-450 MHz, and considerable flexibility is allowed for in configuring chains in either circular or hyperbolic modes. At present, two versions of the Syledis are available, the MR3 and the SR3, both having the same basic accuracy and measurement scheme. Both versions were tested by the Canadian Hydrographic Service (CHS), which subsequently opted for the SR3. This is a more up-to-date and compact receiver offering a built-in CRT and microprocessor with a number of useful navigation and quality-control functions. Particularly useful is a digital output of signal reserve in dB, which can be used to flag potential reception problems. The MR3 provides only an indirect indication of signal quality through an analog meter graduated in Automatic Gain Control (AGC) units.

In an effort to evaluate the usefulness of UHF Syledis for coastal hydrography, the CHS embarked on a three-part test program in the winter of 1982/83. The CHS contracted with Canadian Engineering Surveys Co. Ltd., an Edmonton, Alberta, company having several years experience with Syledis in the Beaufort Sea, for equipment and technical assistance.

The tests, consisting of a two-week sea trial, a series of range observations at known points on land, and a six-week monitoring test, brought out two limitations of the Syledis : that signal attenuation and horizontal reflections can result in large ranging errors when working in the shadow of land and in confined waters, and that low pressure weather systems reduce system performance. However, the tests also showed that the Syledis is capable of 5 m to 10 m ranging accuracies (1 sigma) out to three times line of sight (los) over water and low terrain, and that it can be used effectively in the shadow of low-lying islands or headlands provided they are not very high or steep.

These results prompted the CHS to purchase a Syledis chain, and subsequent operations in the Belcher Islands of Hudson Bay gave a clear demonstration of its effectiveness for coastal hydrography.

2. TEST OBJECTIVES

The main questions to be addressed by the test program were :

1. Is reception reliable at three times line of sight (about 100 km) in coastal waters where signal attenuation due to mixed land-sea transmission paths and land shadowing are common ?
2. Are ranging errors incurred by propagation velocity variations on mixed surface transmission paths ?
3. Does signal diffraction or attenuation when working in the shadow of land features have an effect on ranging accuracy ?
4. What effect do horizontal reflections from nearby cliffs and hillsides or vertical reflections from the water's surface have on ranging accuracy ?
5. What effect do antenna gain patterns have on ranging accuracy ?
6. To what extent do variations in the weather influence system performance ?
7. Can signal strength be used to warn of possible ranging errors due to the above sources ?

3. CHAIN INSTALLATION AND CALIBRATION

The test area, depicted in Figure 1, was a 100 km stretch of indented Nova Scotia coastline west of Halifax. To cover this area, three Syledis stations were established on headlands at Western Head, Ovens Point, and Prospect. Each station consisted of a 12 dB omni-directional antenna mounted on a 15 m to 20 m lightweight aluminium tower, and utilized two 12V dc batteries and a float charger connected to a local 110V ac source for power. The one exception was the Western Head installation, which was first mounted atop a lighthouse and later moved to a tower set up at the nearby Mersey site.

The chain calibration was performed in two parts, in keeping with procedures recommended by Working Group 414b of the *Fédération Internationale des Géomètres* (FIG) (COOPER, 1979; RIEMERSMA, 1979). Initially, a short baseline (183 m) calibration was conducted prior to chain installation in order to accurately establish the transmission delays associated with the various system components. These were then confirmed by a field calibration conducted after the chain was installed for the purpose of checking station coordinates and verifying that the propagation velocity assumed by the Syledis was in fact appropriate for local conditions. The two calibrations agreed to within 5 m, and the short baseline results were subsequently applied in the field tests. No significant systematic effects which might indicate an error in calibration were detected.

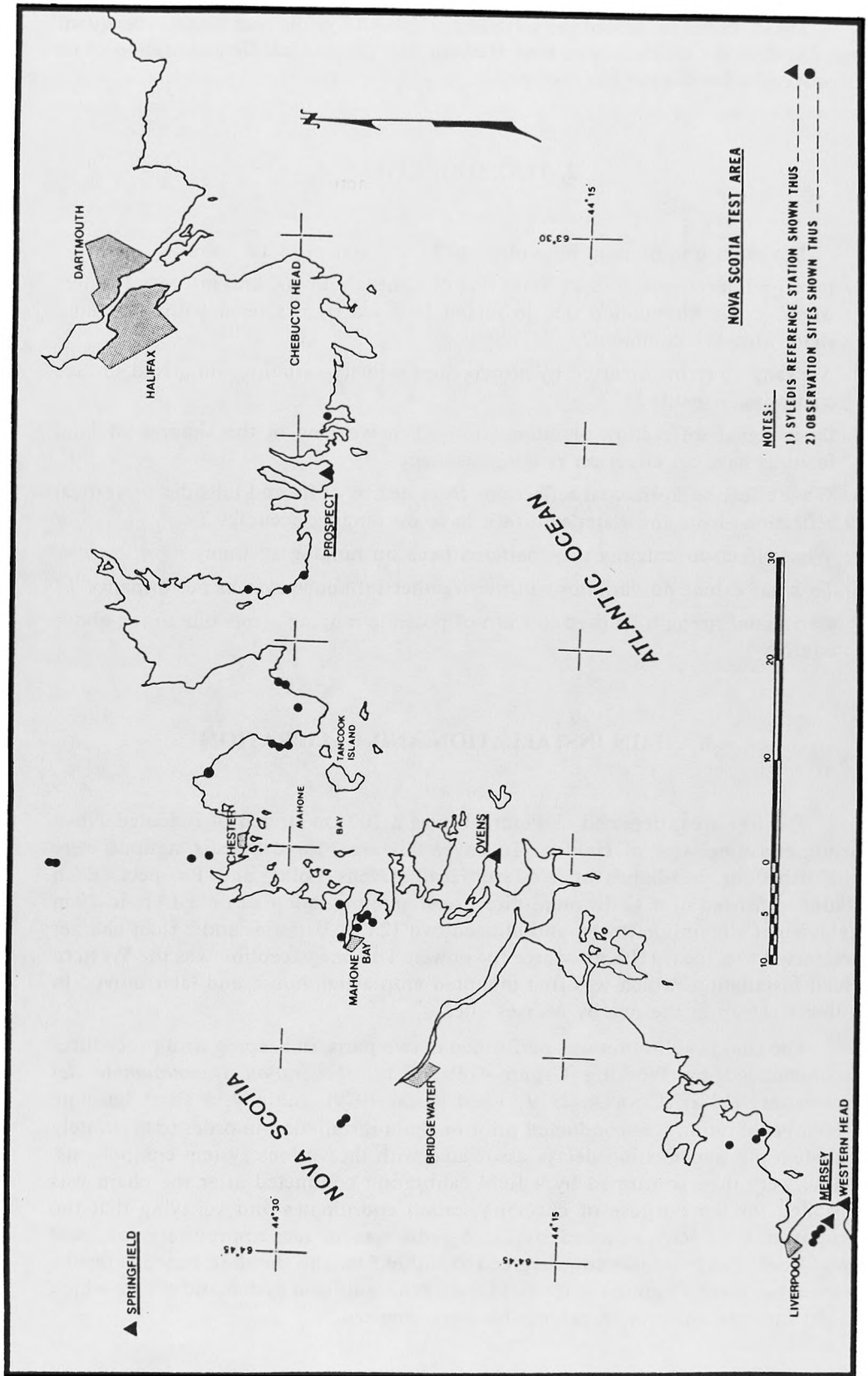


FIG. 1

Sercel specifies approximate transmission delay figures for a variety of antenna and cable types in its technical literature. These are quite accurate, and can serve as an effective blunder check when used to pre-compute approximate delays prior to calibration. In our case, delays predicted on the basis of these figures agreed to within two metres with those determined by short baseline calibration. However, Sercel does warn that actual transmission delays may vary, depending on the age and condition of the antennas and cables actually used. In addition, their list is not all-encompassing and there are many antenna and cable types for which no such figures are available and which can only be determined by field testing.

As part of the calibration exercises, a baseline test was conducted to determine the influence of antenna directivity on ranging accuracy. In this test, a highly directional 7-element Yagi antenna, mounted on a Syledis beacon, was rotated through a 360° arc and the variations in range over a known 20 km baseline distance were recorded. The result, as depicted in Figure 2, is such that large (5 m to 15 m) ranging errors were encountered outside the main 3 dB lobe of the antenna. A similar test with omni-directional antennas was later conducted as part of the sea trials and resulted in no significant effects being found.

These results illustrate that the type of antenna used can have a significant effect on UHF system performance. Directional antennas can be used to substantially increase coverage within a specified sector and to blank out potential reflectors around a beacon site. However, they do have a bearing-dependent delay pattern and must be carefully calibrated and pointed so that the work area falls within the main beam lobe of the antenna. Conversely, omni-directional antennas present no such delay variations, but are more sensitive to localised reflection errors from surrounding terrain.

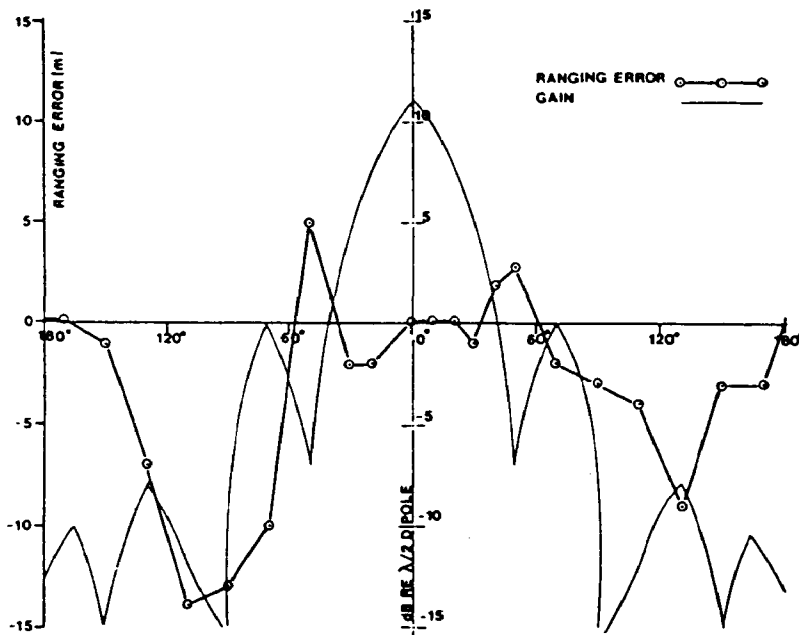


FIG. 2. — Bearing-dependent ranging error in a Yagi directional antenna.

4. SEA TRIALS

Sea trials were conducted aboard the CHS vessel CSS *Maxwell* in Halifax Harbour and its approaches, and in the Mahone Bay area from 9-26 November 1982. Test lines were run in Mahone Bay among 20 m to 30 m high islands, mostly tree covered, and off Chebucto Head, a 30 m granite cliff with 100 m hills close inland. A differential mode of investigation was employed in which the *Maxwell* was sailed from open, unobstructed waters to close in under headlands, cliffs, or islands where anomalous effects might be expected to occur. The influence of the potential error source was then determined by comparing, over the course of the manoeuvre, the observed Syledis ranges with ranges predicted on the basis of Miniranger III position fixing and computed in real time on the CHS BIONAV integrated navigation system. In this fashion it was hoped that differential effects as small as 5 m to 10 m might be detectable.

Since the Miniranger III is of the same order of accuracy as the Syledis, considerable care was required in calibration and subsequent operations to reduce the influence of errors in the Miniranger III control wherever possible. Reference stations were located so as to provide the best possible ranging geometry, ranges were kept short to minimize signal attenuation and the incidence of range holes, and signal levels were continuously monitored as a means of identifying anomalous ranges. Even so, it was clear that the procedures employed in the sea trial would not allow us to fully investigate Syledis ranging accuracy, and as a result they were later supplemented with a series of range observations at known survey control points on land. However, the use of Miniranger III did prove adequate for detecting the occurrence of gross ranging errors, and provided a comparative indication of accuracy relative to the system now used by the CHS for coastal hydrography.

The sea trials showed that the Syledis can be effective for surveying along indented coastlines, but that signal attenuation and horizontal reflections can significantly reduce system performance in the shadow of land features and in confined inland waters.

Figure 3 illustrates the influence of land shadowing on ranging stability for a test line run off Chebucto Head. Syledis ranges and signal levels (AGC) were recorded from the shadowed Ovens and Prospect stations as the *Maxwell* steamed from the open waters 6 km due east of Chebucto Head, westward to within 300 m of the headland. The result was a significant decrease in the stability of the Ovens range, 65 km distant, while the Prospect range, 25 km away, remained largely unaffected. In both cases, the attenuation due to land shadowing caused a significant reduction in signal strength, cutting the Prospect signal in half (40 to 20 AGC units), and reducing the Ovens signal to almost nil (20 to 1 AGC units). The Western Head station, some 115 km distant, was extremely erratic over the entire exercise, unlocking completely 500 m off the headland, and has been omitted from the figure for clarity.

Signal attenuation due to land shadowing seemed to have the added effect of making the system more sensitive to signals reflected from nearby terrain features.

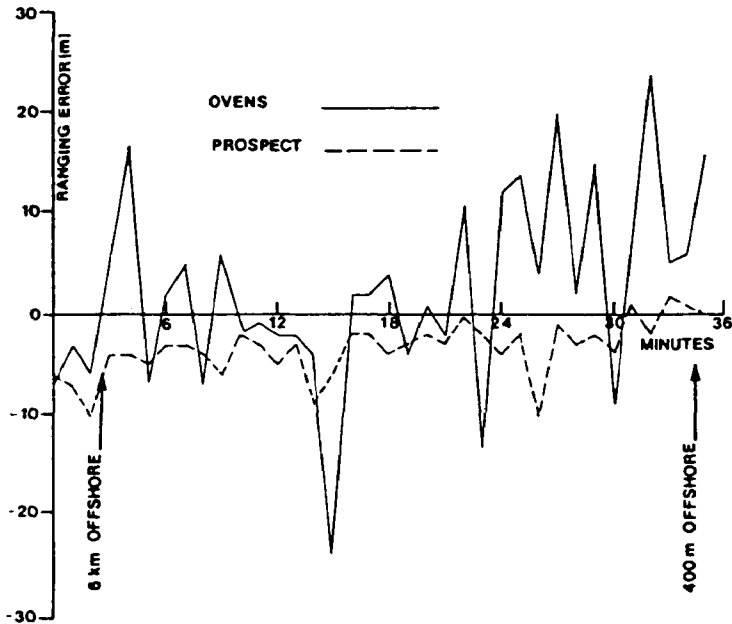


FIG. 3. — Effect of land shadowing on ranging stability.

Most often these errors were transient in nature, seldom having a duration of more than a few minutes, and varying from 10 metres to several tens of metres in magnitude. However, in cases of extreme shadowing, the Syledis was observed to “track” reflected signals for longer periods of time and over considerable distances (i.e., several hundred metres). As might be expected, more distant stations with less available signal reserve appeared to be more sensitive to such disturbances, but excursions in otherwise strong and stable ranges were not uncommon.

Figure 4 depicts a typical ranging error possibly due to shadowing or reflections. In this case, the *Maxwell* was drifting in the shadow zone east of 30-metre high Tancook Island in Mahone Bay when the Western Head range (65 km, 2.1 los) was observed to deviate over a four-minute period to a maximum error of about 50 metres. Ranges simultaneously recorded from the similarly shadowed Ovens station, 20 km distant, remained unchanged.

Two similar errors, also possibly reflection induced, are shown in Figure 5. This time the errors were encountered off Chebucto Head, again while the *Maxwell* was steaming from open waters to close in under the headland. Both were on the Ovens channel (65 km, 1.9 los). The first, a 110 m range error, was encountered while still 4 km offshore. The second and much smaller of the two, occurred within 500 m of the headland and reached 40 m in magnitude. Again, the similarly shadowed Prospect (26 km) and Western Head (115 km) ranges were not affected.

Hence, system performance varied over the test area depending on the degree of land shadowing encountered. The system proved very effective among the relatively low islands (20 m to 30 m) in and around Mahone Bay where ranges seldom exceeded 60 km to 70 kilometres. In addition, ranges exceeding three times line of sight, Sercel’s quoted maximum operating range, were regularly observed in

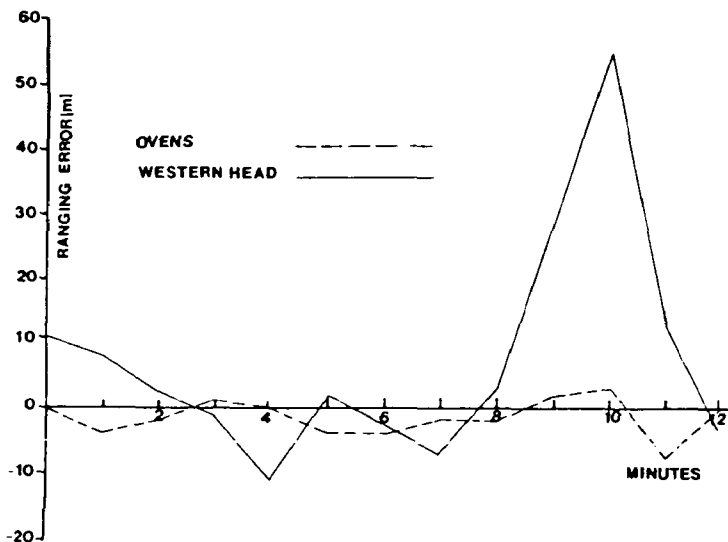


FIG. 4. — Syledis ranging error in shadow of Tancook Island.

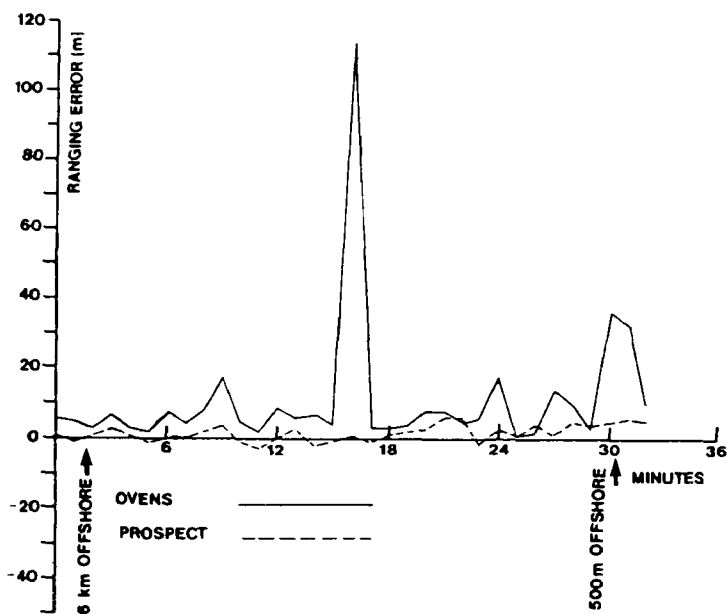


FIG. 5. — Syledis ranging errors in shadow of Chebucto Head.

Halifax Harbour and off Chebucto Head (the maximum range observed was in the order of 135 km). However, their reliability varied according to the weather conditions and the degree of land shadowing. System range and stability often suffered in rain and fog, and in confined inland waters, as evidenced during operations in Halifax Harbour where reflections and signal loss were frequent, and where ranging was seldom reliable even at relatively short ranges of 20 to

30 kilometres. Certainly reflections can be a serious problem in such areas. Redundant lines of position would appear to be a necessity, and signal strength recordings are highly recommended. Surprisingly, no instances of range holes due to vertical reflections from the water's surface were noted.

Generally, performance in coastal waters will be somewhat degraded in comparison with offshore situations. However, coverage of two to three times line of sight, typically 60 km to 90 km, can still be expected. This extended range and the system's ability to work in the shadow of low-lying land features, can offer a substantial advantage over microwave ranging for coastal hydrographic applications.

5. BASELINE TRIALS

Phase two of the evaluation consisted of a series of range observations taken at 28 survey control points distributed throughout the test area from Prospect to Western Head (Figure 1). The purpose of these observations was twofold: to determine if the influence of mixed land-sea propagation paths resulted in significant (i.e., greater than 5 m) propagation velocity errors, and to further investigate the sensitivity of the Syledis to reflections induced by local terrain features.

Range observations were recorded at each point over a 10 minute to 20 minute period, and reduced to a set of mean ranging errors and standard deviations for each of the three Syledis reference stations. A notation indicating the magnitude and stability of signal strength over each observation period was manually recorded at each site. The ranges observed varied from 2 km to 90 km in length, and comprised a variety of land-sea propagation paths.

The results are depicted in Figures 6 and 7. Some 50 % of the mean ranging errors fall within 5 m of the known baseline distances, 70 % within 10 m, and 80 % within 15 m; there is no distance-dependent trend in the means. The standard deviations of the means consistently fall within the 3 m to 5 m level out to 80 km where they then increase sharply to the 10 m to 15 m level. It is interesting to note

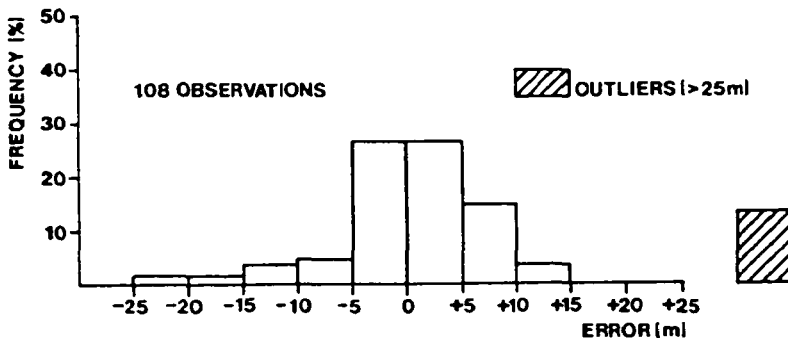


FIG. 6. — Distribution of mean ranging errors.

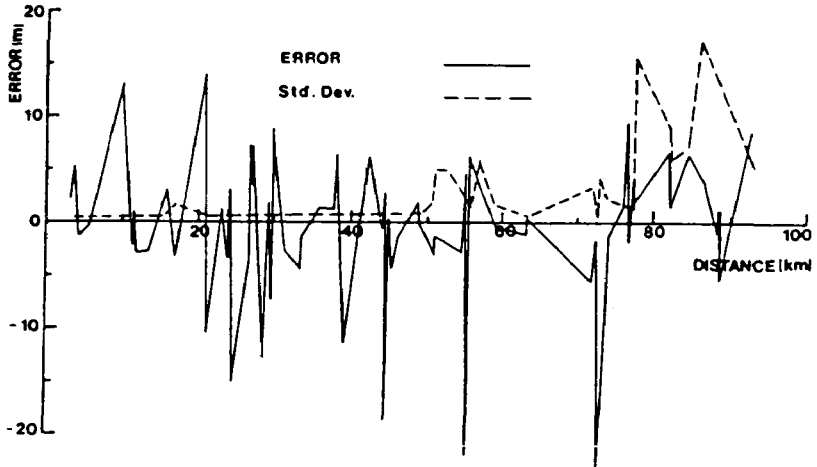


FIG. 7. — Mean ranging error and standard deviation versus distance.

that the errors are more or less evenly distributed about a zero mean, an unexpected result in that propagation, multipath, and attenuation effects tend to delay the signal, hence leading to a positive bias. In this case, it appears that the distortion of the signal also plays an important role, in that it degrades the basic resolution of the correlation measurement technique so as to create an equal opportunity for negative errors. On occasion these were observed to be as large as -30 metres. However, no trend appears in the data which would indicate a systematic error due to propagation velocity or signal attenuation effects.

Local terrain features seem to have a significant effect on ranging accuracy. Fully 36 % of the ranging errors fall between 5 m and 30 m. Most of these can be associated with the presence of powerlines, trees, buildings, earth banks, etc., in the immediate vicinity (i.e., within 50 m) of the observation site. They also appear to exert a random influence from site to site, so that when multiple sites in one general area are grouped together the mean error scatter is reduced.

Such is the case in Figure 8. Here, an attempt was made to reduce the influence of the local terrain by gathering the observations into ten regional groups, based on their clustered distribution along the coast (Figure 1). It was hoped that the propagation and attenuation effects would be similar for closely spaced points (i.e., 1 km to 2 km apart) and that any error variation between them would therefore be primarily due to the random influence of local terrain reflections. To some

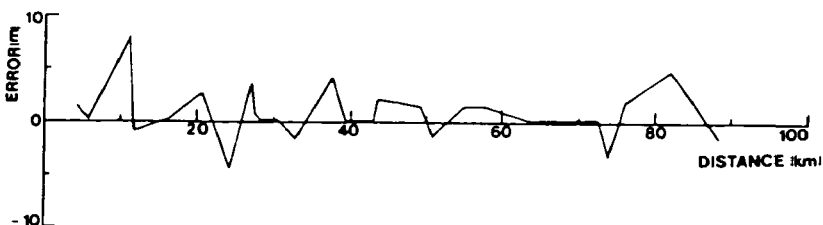


FIG. 8. — Ranging error versus distance : grouped observation sites.

extent this does appear to have been the case, such that the error scatter for readings grouped by location is about half (5 m) that found for the individual observations.

Based on these results, it does appear that the Syledis is capable of 5 m to 10 m ranging accuracies (1 sigma) out to three times line of sight under favourable conditions. However, local multipath effects can have a significant influence on ranging accuracy. Unfortunately, these are not always detectable from signal strength observations.

6. STATIC MONITORING

The final phase of the evaluation was aimed at investigating the influence of weather on system performance by monitoring one 41 km and three 86 km to 88 km baselines over a six-week period in December 1982 and January 1983. Accordingly, a monitoring station was established at the Prospect site and the two existing all-water legs to Ovens (41 km, 1.0 los) and Western Head (88 km, 2.1 los) were augmented by a third all-land segment to Springfield (86 km, 1.2 los) in the Nova Scotia interior (Figure 1). A fourth baseline was established three weeks into the monitoring test when the Western Head station was moved to the nearby Mersey site some 2 km to the north.

The baselines were monitored for a five-minute period twice hourly, and the readings obtained reduced to plots of mean ranging error, standard deviation, and reserve signal level (dB) versus time for each station. Regional weather data for the observation period was taken from weather analysis charts produced four times daily by Environment Canada, and consisted of temperature, pressure, precipitation, cloud cover and wind information. Given this data base, it was hoped that some qualitative assessment of the influence of changing patterns on Syledis performance might be realized.

As was the case in the sea trial, ranging stability appeared particularly sensitive to the presence of fog or heavy precipitation, probably due to the attenuation of signal levels. The largest variations in stability were recorded in January, when storm fronts bearing warm, moist air moved into the region and supplanted clear and extremely cold high pressure conditions. During these periods, the pressure typically dropped some 30 mb in 24 hours, the temperature rose from -15°C to $+5^{\circ}\text{C}$, and fog, rain and freezing rain conditions prevailed.

The effect on the Ovens station was detectable but minor, being largely limited to an increase in mean error scatter from 2-3 m to 3-5 m, together with a corresponding increase in standard deviation and no significant variation in signal levels. Surprisingly, the Western Head and Springfield stations exhibited markedly different levels of stability during these periods of inclement weather, despite being roughly equivalent distances from the Prospect monitor (Figure 9). Typically, the error scatter for the Western Head station averaged 2 m to 3 m during stable weather periods, increasing to 10 m to 15 m or greater during the passing of the storm fronts described above. Western Head signal levels also fluctuated during

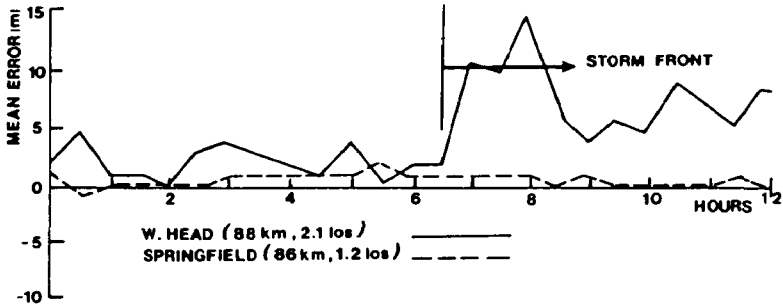


FIG. 9. — Relative performance of Springfield and Western Head baselines during winter storms.

these periods, but not as much as might be expected, 2 dB to 5 dB being a typical variation. However, the Springfield station was largely unaffected, varying at most from 1 m to 2 m during fine weather to 2 m to 5 m under poor conditions. While part of this difference can probably be attributed to variations in siting, equipment, and transmission paths, in large part it appears to be related to the elevations of the stations themselves and the radio horizons they dictate. In fact, the Springfield station, at just beyond line of sight, exhibits a degree of stability roughly equivalent to that of the Ovens station, just within line of sight, despite being approximately twice the range. In turn, both of these stations are far more reliable than Western Head at just over twice line of sight.

To ensure that the magnitude of the weather influences observed at Western Head were indeed typical of what could be expected at twice line of sight under local conditions, and not due to some problem at the site itself, the station was shifted to a tower installation at the nearby Mersey site, some 2 km to the north, and monitoring was resumed. Virtually, the same result was obtained and no improvement in stability over that exhibited by the Western Head installation was noted. Hence it would appear that low pressure weather conditions, particularly fog and rain, can significantly influence system performance at twice line of sight.

Sercel recommends keeping stations low to avoid possible signal loss during periods of atmospheric inversion. However, it may be preferable in areas where such inversions are rare to extend the horizon somewhat by selecting stations of slightly higher elevation. If our results are indicative of what to expect, the resulting improvement in ranging stability could more than compensate for the occasional inversion problem.

7. BELCHER ISLANDS SURVEY

The test results prompted the CHS to purchase a Syledis chain, and to use it in a hydrographic survey in the Belcher Islands of Hudson Bay in September 1983. The extent of the survey area is depicted in Figure 10. Miniranger III was utilized for positioning in Eskimo Harbour at a scale of 1:10,000 and the Syledis for positioning at 1:50,000 in the 10 km by 110 km corridor extending northwest from Eskimo Harbour into Hudson Bay. The Syledis was selected for positioning in the corridor for its specified accuracy, well within the 50 m required for a

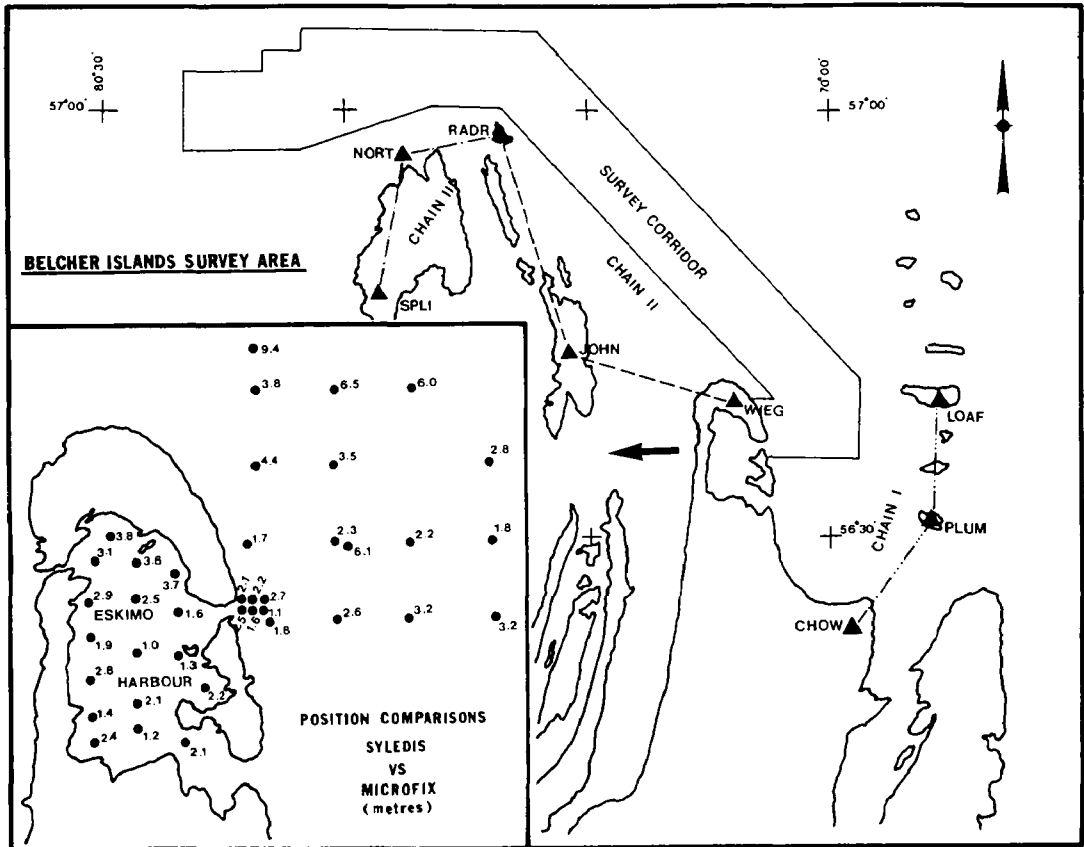


FIG. 10

1:50,000 survey, and because its operating range would simplify coverage, particularly in the northwestern leg of the corridor which extended beyond line of sight from the islands.

Three Syledis chains were required to cover the corridor and to allow for three ranges with acceptable geometry everywhere. The three stations, which were moved from chain to chain as required, each consisted of a lightweight omnidirectional whip antenna mounted on a 10 m aluminium mast, and were powered by two 12V dc batteries kept charged by a thermal electric generator. Sounding operations were carried out by the Canadian Coast Guard vessel *Sir William Alexander* and two 10 m nelson launches, each equipped with a Syledis SR3 receiver. Sounding lines were run in an east-west direction with a spacing of 225 m, and check lines perpendicular to these every 2 500 m. The navigation firmware supplied with the SR3 was used for guidance and data acquisition along the lines and proved to be a handy and efficient tool for line running.

Calibrations were performed upon the initial set up of chain I, and were repeated upon shifting the beacons to their chain II and chain III locations. In each case, the chains were calibrated by range comparison with a Microfix 100C, a range-bearing microwave system having a specified accuracy of 1.5 cm 3 ppm and

a maximum operating range of 60 kilometres. Surprisingly, shifts in the calibration constants between chains of several metres (i.e., 1 m to 8 m) occurred, possibly due to the influence of the terrain surrounding the stations themselves or to variations in equipment installation. This result illustrates the importance of a field calibration after the chain is installed in the field, even in those instances when a pre-calibration has been performed at a base camp or test range prior to installation.

In the chain I area, Syledis-Microfix comparisons were made at 39 locations, 17 of which were within Eskimo Harbour itself and in the shadow of hills extending from 40 m to 70 m in elevation (Figure 10). Each of the Syledis stations was approximately 27 km from harbour centre and all were blocked by the intervening hills with the exception of station Chow, which had a clear path to a small area in the north end of the harbour. Positions were taken along both sides and down the centre of the harbour, two or three being recorded at each location. The mean difference within the harbour was 2.2 m, with a maximum of 4.6 m, and there were no indications of bad fixes due to shadowing or reflections from the nearby hillsides. Hence the Syledis system could well have been used to survey the harbour at 1:10,000 and been easily within the positioning accuracy required. Outside the harbour the mean difference was slightly higher, at 3.3 m, partially due to the influence of the Microfix which was experiencing heat wave problems over the longer ranges to the northern points. However, the agreement demonstrated with this more precise ranging system was generally excellent.

Over the 56 days that the Syledis was on the air, approximately one day was lost due to system problems. One receiver developed a fault and had to be replaced, and water leaked into the cables initially installed on chain I, necessitating a change to a heavier type of cable and connector. The corridor survey itself took 15 days and comprised some 5 740 km of survey lines and 200 shoal investigations. In short, the range and reliability of the Syledis over the course of the survey demonstrated that a good deal of work can be accomplished in a short time with the system.

8. CONCLUSIONS

The Syledis positioning system does indeed appear to have characteristics that are intermediate between microwave and HF systems, and the experience gained in the first year of CHS operation shows that it can be an effective tool for coastal hydrography.

Within line of sight, the system is capable of 2 m to 5 m ranging accuracies (1 sigma) and appears to exhibit little or no sensitivity to range holes. Beyond the horizon, ranging accuracies of 5 m to 10 m can be achieved out to three times line of sight over water or low-lying land with no apparent loss of accuracy due to over-land transmission paths. However, performance at extended range (i.e., beyond twice line of sight) is strongly weather dependent, and the presence of rain or fog can significantly reduce system range and stability.

The system can be used effectively in the shadow of islands or headlands, albeit with caution, and providing these are not very high or steep. Signal attenuation due to land shadowing can significantly reduce operating range and

signal stability beyond 60 kilometres. Horizontal reflections can be a frequent source of ranging error in confined waters or whenever the direct signal is weak due to extended range or signal blockage. Reflected signals can cause transient ranging errors of several tens of metres or, in severe cases when the reflection completely overrides the direct signal, longer term errors of several hundred metres or more. Hence redundant lines of position would appear to be an absolute necessity, especially in harbour areas, and careful signal monitoring is strongly recommended.

Finally, care must be exercised in the selection and placement of antennas. The rule of thumb here is to select an antenna appropriate to your application, bearing in mind that directional antennas have transmission delay characteristics that are bearing dependent, and that omni-directional antennas are more sensitive to localised reflection problems. Transmission delays, if possible, should be determined over a relatively short range in a clear flat area to reduce the possibility of error due to propagation or local terrain influences. This should be followed by a field calibration after the chain is installed to detect potential control errors, local reflection problems, and to verify that the velocity of propagation assumed in the Syledis is correct for the work area.

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