

REPORT BY THE TASK TEAM ON SOT IRIDIUM PILOT PROJECT

APPENDIX A (PART 1) Iridium Pilot Project Report – Real-time Data Collection Performance, Amundsen AVOS

APPENDIX B (PART 2) Iridium Pilot Project Report – Position Data Accuracy, Amundsen AVOS

APPENDIX A

REPORT BY THE TASK TEAM ON SOT IRIDIUM PILOT PROJECT – PART 1

Iridium Pilot Project Report – Real-time Data Collection Performance Amundsen AVOS

Performance analysis, results and illustrations by:

Champika Gallage, Standards Officer, Marine Networks

Contributors: Dale Boudreau, A/Manager National Marine Networks

Chris Marshall, Manager National Marine Networks

Yvonne Cook, Former LCM Surface Networks

Weather and Environmental Monitoring Directorate

Meteorological Service of Canada (MSC), Environment Canada

1.0 Background

It has become apparent that the present INMARSAT telecommunication service does not perform well for VOS and AVOS (Automated VOS) travelling in northern areas (i.e. north of 55°N). A large percentage of AVOS data is not transmitted in real-time, which reduces the amount of expected data in already very data sparse regions. The current hypothesis is that the INMARSAT satellite footprint does not adequately cover the Polar Regions, as it is a geosynchronous satellite positioned over the equator. As ships travel north, they are further and further away from the satellite. This is compounded by signal attenuation caused by weather (e.g. clouds and precipitation), as well as terrain, due the low angle of the satellite signal.

To address the above issue, as well as other issues such as data throughput, reliability, cost-effectiveness, etc., an action item came out of the SOT meetings in Geneva, Switzerland April, 2007 to establish an Iridium Task Team to evaluate and demonstrate the operational use of Iridium technology for the real-time collection of VOS data. The Canadian marine program, a participating member of the project, offered a prototype Iridium-based Automatic Voluntary Observing Ship (AVOS) system onboard the Canadian Coast Guard (CCG) research vessel, Amundsen. This report summarizes the results of the pilot project based on data transmissions from the Amundsen from July 2007 – November 2008.

To supplement the Amundsen results, *Annex 1* contains a summary for a previous pilot project initiated by Canada using the ship Nunakput in the summer of 2006. Furthermore, **Météo-France** and NOAA are also participating in the Iridium Pilot Project and have provided a brief update on their findings in terms of operability and cost. A summary of their work is in *Annex 2* and *Annex 3*.

2.0 Purpose & Scope

The purpose of the pilot project is to determine whether Iridium communication is a reliable replacement for the INMARSAT communications, which is currently being used on the AVOS ships travelling to the Canadian Arctic. This document will report on the findings of data availability, and provide a comparison between position data from the Iridium communications equipment and the position data extracted from each AVOS observation sent from the ship. It is important to note that the ship's observer is capable of augmenting AVOS weather observations, but not position data associated with the observation.

3.0 Design

The Amundsen was selected, as its intention was to travel to the Canadian arctic during the winter of 2007-2008 and remain frozen into the ice pack, and gather data in support of the International Polar Year project. The Canadian arctic is a data sparse area, which does not have consistent, reliable coverage through standard INMARSAT communications, which the rest of the AVOS network enjoys in

the more southern latitudes.

Data receipt from the Amundsen commenced July 11, 2007 while travelling in the St. Lawrence River. The ship continued down the St. Lawrence River, along the south coast of Québec, north along the east coast of Labrador and continued into the Hudson Bay, making cargo drops along way to the various northern ports. It then continued its journey towards the western Arctic, eventually spending some time in the eastern Beaufort Sea before cruising back through the Canadian Arctic waters and returning to Québec City along the St. Lawrence River in November of 2008 (see Figure 1).

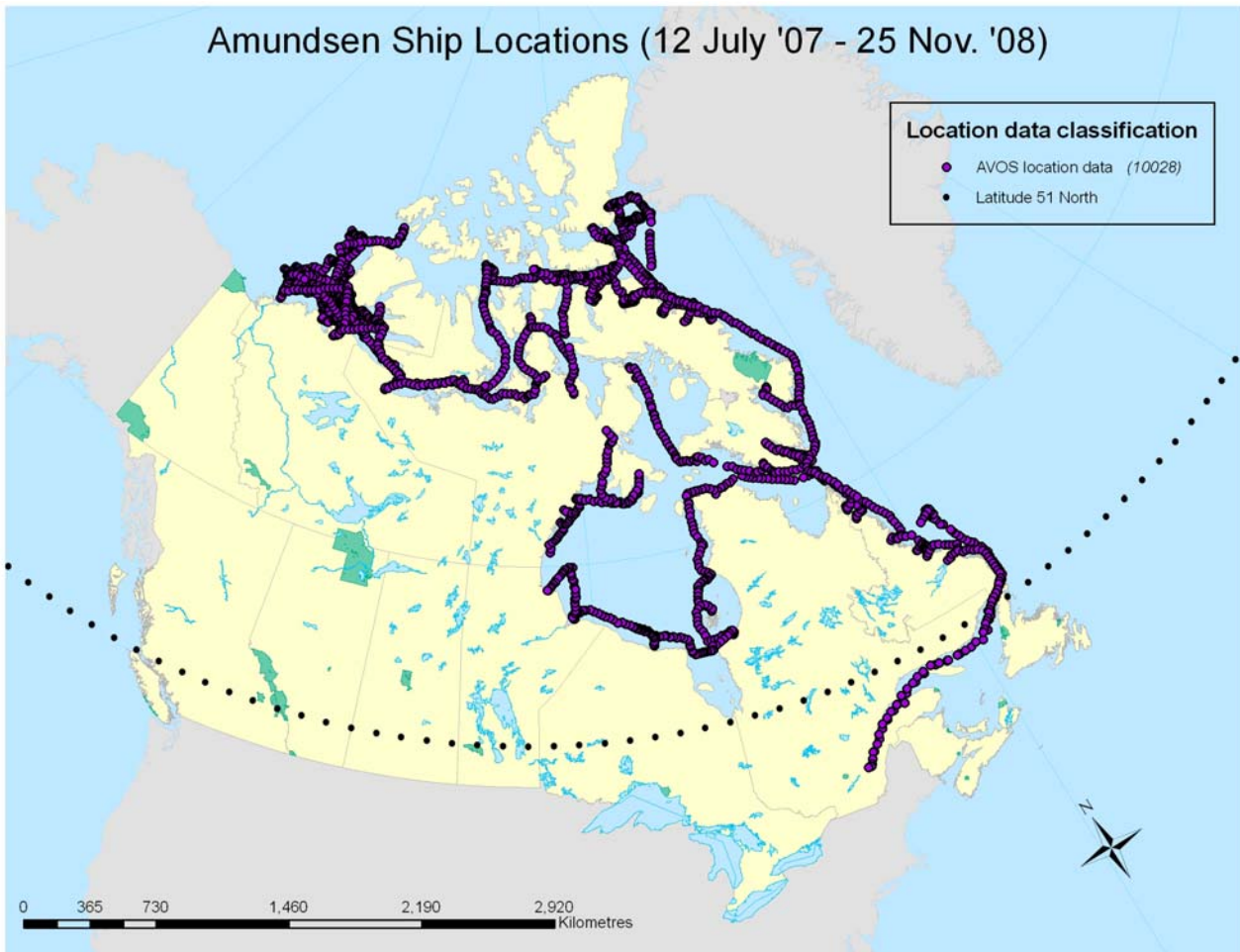


Figure 1. AVOS position data from July 12, 2007 to November 25, 2008

Stratos <http://www.stratosglobal.com/> provided the Iridium transmitter licensing and an account, as well as 5 email address destinations for the received observations. The number of observations transmitted from the AVOS over a period of 24 hours is dependant on its position off the coast of Canada.

4.0 Equipment

Comprised a modified AVOS system including standard data acquisition unit and sensor suite, prototype Iridium communications kit installed by Axys Technologies Inc., bridge PC for manual augmentation of automatic weather observations, UPS and standard Environment Canada Marine tilt pole. See Table 1 for more detail.

Table 1. Equipment on Amundsen belong to Environment Canada

DESCRIPTION	SENSOR SPECS/MODEL #S	Serial Number
-------------	-----------------------	---------------

Air Temp/RH	Rotronics MP101A-T7, Probe 0.1V, T-7 (-40>+60)	40326
Radiation Screen for Air Temp/RH	ROSMP41002; Natural Aspiration Shield for MP101A	N/A
Water Temperature	AXYS Water Temperature - HATS, c/w 2m cable	190
Barometer, Pressure (1)	Vaisala PTB210B1T1B, TTL, 500-11003	80530012
Anemometer, RM Young 05103	RM Young 05103	
Iridium Transceiver Unit	Sailor ST4120	5737336
GPS Antenna	Garmin GPS Receiver, Model GPS-36	81120586
Compass and Ships Gyro	KVH Fluxgate Compass, Model Autocomp1000	050300340
UPS for AVOS Bridge PC	APC SU700X93	
AVOS Sentinel	EC Basic System	AVI100500
Bridge PC	Poseidon 150/P4	M960200118

5.0 Analysis

5.1 Overview

10028 observations, collected from July 12, 2007 to November 25, 2008, were analysed. MS excel was used for processing data and ArcView V9.2 was used to plot the data. The number of observations expected from AVOS while a vessel is underway is dependant on the following criteria:

The AVOS system transmits at one of three intervals depending on position.

1. One Hour Transmissions (HLY) in Data Sparse Areas (two areas)

1. Northern Canada Data Sparse region defined as: West of 50°W, East of 170°W and North of 51°N
2. Antarctic Data Sparse Region defined as: South of 50°S

2. Three Hour Transmissions (EPD) inside North America 200 Mile Zone (South of 51°N)

3. Six Hour Transmissions (FPD) for the remainder of the world

The following is an example of the received Iridium message in email format:

From: sbdservice@sbd.iridium.com[SMTP:SBDSERVICE@SBD.IRIDIUM.COM]
Sent: Thursday, September 27, 2007 11:05:24 PM
To: Hung, Derek [Ontario]
Subject: SBD Msg From Unit: 300003000926000 Auto forwarded by a Rule

MOMSN: 19
MTMSN: 0
Time of Session (UTC): Fri Sep 28 03:05:20 2007 Session Status: 00 - Transfer OK Message Size (bytes): 93

Unit Position: Lat = 74.429912 Long = -91.735705 CEPradius = 3

Sample of an attachment received together with the above message:

BBXX CGDT 28034 99744 70919 46/// /3113 11033 21046 40074 58005 7//// 8//// 22223 01000 2////

Data received from Amundsen ship was analyzed in two different streams

1. Data availability
2. Iridium position data accuracy

5.2 Data availability

A key assumption is that the ship was underway at all times during the analysis period and was not in "Hove to" mode at any time.

Data availability was calculated based on the maximum number of data points possible during the period under consideration.

Based on the above assumption, the maximum number of data expected during 12 July 2007, and 25 November 2008 is 11113 and the total number of data received during the same period is 10028. This shows 90% data availability during the specified period.

Data availability in the Arctic region, i.e. north of 51^o, was considered separately. The Amundsen was sailing in the Arctic region (North of 51^o) from July 28, 2007 to October 13, 2008. The maximum number of observations expected during this period was 10636 and 9558 messages were received, maintaining the data availability in Northern regions at 90% (see Figure 1).

5.3 Missing observations

There were some identified and unidentified reasons for missing data. A log was maintained to capture the details of all missing data events during the trial period. According to the service provider, the missing data were a result of the AVOS not attempting a transmission. Upon further investigation by Environment Canada and shipboard staff, in some cases, the AVOS did create an observation but did not attempt to transmit a message. In other cases, the AVOS system had been powered down or was non-responsive. This was confirmed by checking the error message file onboard the AVOS bridge computer. Axyx Technologies, the AVOS system manufacturer, is investigating the problem. In some cases, data were not available due to loose connections in the system. This is due to the high amount of vibration associated with ice breaking activities.

6.0 Telecommunication costs

6.1 AVOS Scenarios

There are both ongoing communication charges, as well as one-time implementation costs that need to be assessed to determine the cost-effectiveness of Iridium technology for the Canadian AVOS fleet.

Charges for ongoing communication costs have been obtained from 3 different Iridium VARs (Value Added Resellers). It is anticipated that improved pricing may be possible via “bulk” or multi-year data contracts resulting from a competitive bid process.

Table 2. Sample one-time and ongoing costs based on VAR survey

Description of item	Unit cost (USD)*
<i>(One-time costs)</i>	
Iridium SBD transmitter	\$500
Integration of Iridium transmitter with existing AVOS WM100 system (AXYS quotation)	\$1500
Iridium account set-up fee	\$50
<i>(Ongoing communication costs)</i>	
Monthly account fee	\$16
Per message SBD charge (assumes 100 Byte messages)	\$0.13/message

* Information utilized in costing model (U.S. Dollars)

Table 3. Communications cost estimate for Iridium equipped AVOS

Scenarios	Number of observations per year per ship	Annual Cost* for 1 ship
1 Observations every hour (assumes ship transmits every hour) - This is theoretical maximum possible cost. Would never occur, as ships do not spend 100% of the year at sea.	8760	\$1,331
2 Observations every 3 hours (assumes observations available every 3 hours year round)	2920	\$572
3 Observations every 6 hours (assumes observations available every 6 hours year round)	1460	\$382
Estimates based on actual AVOS Observation Counts		
4 Review of AVOS observation count over past 3 years suggests that maximum number of obs is 400-600/month. Extrapolated over an entire year results in ~6000 obs. This should be considered a liberal estimate (high end) for costing purposes. Note that the Amundsen reported ~6200 observations last year via Iridium, with data transmitted each hour.	6000	\$972
5 A much more realistic number of observations is likely in range of 1500-3000 (even with hourly data transmission)	3000	\$582
6 The past 12 months saw AVOS report nearly 70,000 observations from 43 ships, so the total cost for one year per ship would be about:	1650	\$407

* Information utilized in costing model (U.S. Dollars)

For the Canadian AVOS fleet, this would result in savings of over 60% based off the amount currently

budgeted for the INMARSAT telecommunication solution. In addition, it is apparent that even with hourly transmission from all AVOS in all locations, the annual cost will be less than what is presently paid for INMARSAT, with the added benefit of much better performance in Arctic waters, and more frequent observations in other areas.

6.2 One time costs (retrofitting existing AVOS)

Table 4 provides an estimate of the costs associated with retrofitting the existing AVOS network with Iridium transmitters. Note that the salary and O&M costs associated with deploying the systems have not, been considered in this estimate. Additional details would be required regarding the complexity of the on-ship installation and testing.

Table 4. Costs of retrofitting AVOS

Item	Unit cost	Cost* for 44 AVOS
Iridium transmitter	\$500	\$22,000
Retrofit if existing AVOS payload to Iridium (work to be done by AXYS)	\$1,500	\$66,000
Iridium account activation	\$50	\$2,200
Total	\$2,050	\$90,200

* U.S. Dollars

6.3 Duplication of Communications Costs

Should Canada decide to proceed with deployment of Iridium for the AVOS network, it must be understood that until the implementation is complete, it will be necessary to pay both annual INMARSAT charges, along with new Iridium charges. This would likely be an issue for 2 concurrent fiscal years, depending on the speed of the Iridium transmitter deployment schedule.

6.4 Summary of cost estimates

Based on the estimates presented in the preceding tables, an AVOS network equipped with Iridium transmitters offer a more cost effective solution that the current INMARSAT service. Depending on the scenario, selected, annual cost savings are in the range of \$20,000 to \$40,000 USD. This would equate to a 2-3 year payback on the initial investment of \$90,000 (to equip current AVOS with Iridium). As noted above, there would also be a "bow wave" of costs due to required duplication during the system implementation, which may extend the payback closer to 4 years depending on the time required to deploy Iridium on all AVOS.

7.0 Other benefits of Iridium

In addition to improved data reception rates at high (Southern and Northern hemisphere) latitudes, and potential cost savings, the Iridium communication solution also offers the following benefits:

- capability for 2-way communications, allowing for direct connection with hardware on AVOS to assist with troubleshooting and diagnostics. Our current platforms do not support this, however the next generation AVOS payload will offer this functionality;
- processing of FM13 SHIP messages will be directly handled by The Canadian Metrological Centre (CMC) in Canada, removing the dependency on NOAA;
- the option for IP data routing means there would no longer be the requirement to decode binary satellite messages directly; and
- the Iridium solution allows more control of AVOS data routing, which is important as Coast Guard continues to be concerned with release of complete AVOS reports to the public.

8.0 Risks and challenges of adopting Iridium

- Dependency on American-based commercial satellite provider for both data reception and processing. Note, however, this dependency is also an issue with current INMARSAT AVOS.
- All MSC AVOS data will be routed through the Iridium data centre before delivery to CMC. Could be security concerns from CCG and others.
- No guarantee that SBD data costs will remain at current rates; price increases are likely over time.
- Integration of Iridium transmitter may lead to an increase in data outages as any initial bugs are worked out. Lessons learned from pilot project on Amundsen should help mitigate this.

9.0 Conclusions

Based on the analysis carried out on Amundsen data received from 12 July 2007 to 25 November 2008, the following conclusion can be made.

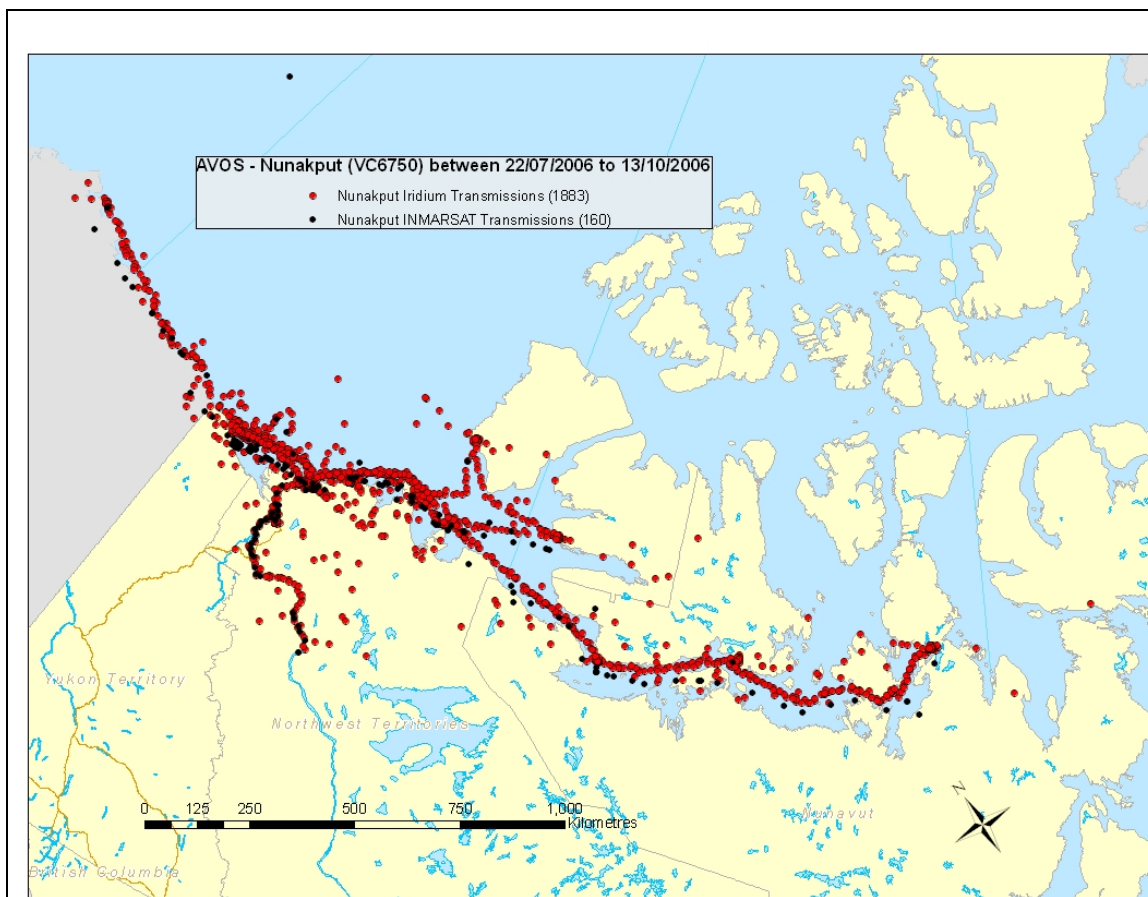
Iridium transmissions are reliable in Canadian Arctic. This was concluded based on 90 % data availability. The 10% data unavailability was mostly due to problems that were unrelated to Iridium transmissions. Therefore, it is fair to conclude that iridium transmission in Canadian Arctic is near perfect.

Additionally, the Iridium Pilot Projects have demonstrated a significant *improvement in reliability* of communications in Northern waters. In addition to improved performance, there are *significant cost savings* versus the current INMARSAT arrangement Canada has with NOAA. Cost savings will continue be realized with Iridium even if the frequency of AVOS observations is increased to hourly in all areas.

ANNEX 1

Nunakput Iridium Pilot Project Summary

Following the identification of data reception problems in Northern waters, a trial of Iridium communications was conducted in the summer of 2006. The Nunakput (VC6750) was equipped with an Iridium transmitter to operate in parallel with the standard INMARSAT system on the AVOS. The Iridium transmitter was not integrated into the AVOS, and was configured to send hourly position using the SBD (short burst data) service provided by Iridium. The resulting data allowed for a side-by-side comparison of the two systems, and a means to evaluate how well the Iridium transmitter performed in the Northwest Arctic. The following map provides a plot of the INMARSAT messages received, as well as the Iridium position reports during the nearly 2-month trial.



Note: The Iridium transmitter was not connected to a GPS, so position reports were based on estimates provided by Iridium, meaning that in some cases the position can be wrong by many hundreds of kilometres. Each Iridium message is accompanied by a score, which rates the confidence in the position report. In our AVOS applications, a GPS is utilized, so the Iridium position reports are not being used in the observation data.

Summary of Nunakput Trial:

- The INMARSAT system on Nunakput reported **160** observations during the 83 days of the trial;
 - The Iridium transmitter delivered **1883** messages during this time;
 - A limitation of the trial is that it was not possible for the Iridium transmitter to stop sending reports while the AVOS was in “hove to” mode (i.e. in port and not transmitting). In addition, it is not possible to know if there were other technical problems with the AVOS, which limited the number of observations delivered;
 - Position data derived from Iridium was not nearly as accurate as that obtained using GPS technology or the ship’s navigational equipment (INMARSAT reports);
 - Main conclusion—the Iridium transmitter delivered 92% more messages than the INMARSAT system.
-

ANNEX 2

Summary of the *Météo-France* Iridium Trial

Update provided by: *Pierre Blouch, **Météo-France***
E-SURFMAR Programme Manager
*Centre de **Météorologie** Marine, France*

Since Iridium Short Burst Data (SBD) demonstrated its ability to efficiently report drifting buoy data, developments are underway at **Météo-France** to use this communication system on Baros (basic) and Batos (complex) ship-borne Automatic Weather Stations (AWS).

Twelve Baros stations have been built. These are only reporting hourly pressure measurements. A first prototype (BARFR00) correctly worked on a trawler from October 2007 to August 2008. It reported 4690 observations in all and it was removed after the trawler was sold. By mid-February, four Baros AWS were in operation on E-ASAP ships (call signs are BAREUxx) and eight others were ready to be installed. Although equipping E-ASAP ships is a priority, E-SURFMAR recently invited NMS from Southern Europe to recruit ships, which could host a Baros.

The Baros data format is 15 bytes long, which includes the observation time, the ship's heading and speed, the GPS latitude and longitude, the sea level pressure and its tendency over the past three hours.

As for Iridium drifting buoys, the data from Baros are received at **Météo-France** through emails within a few of minutes after transmission. They are then uncompressed, coded accord to WMO formats and put onto the GTS in real-time (FM13-SHIP for the moment, FM94-BUFR soon). **The timeliness is excellent.**

Work is ongoing at **Météo-France** to interface an Iridium SBD modem to a Batos AWS instead of the INMARSAT-C transmitter. The data format will be the same as that used by the INMARSAT-C data reporting (DR) service (32 bytes), allowing a complete FM13-SHIP data set to be reported. Although the length of the binary reports was limited to these 32 bytes with INMARSAT, the limitation will be higher with Iridium SBD. **Having, more reportable parameters is desirable**, e.g. wind gust, salinity, CO2 pressure, irradiances, etc.

Communication costs were already low with INMARSAT-C DR (~0.15 € per report), but **with Iridium SBD the costs can be lowered** further to as much as 50% of INMARSAT.

ANNEX 3

Summary of the NOAA/AOML-USA Iridium Trial

Update provided by: Derrick Snowden
NOAA Climate Program Officer, Climate Observation Division
Silver Spring, MD USA

NOAA/AOML has been experimenting with using Iridium telecommunications to transmit Ship of Opportunity data to shore. This particular usage differs from the applications reported on by the DBCP Iridium Pilot Project in that the typical XBT and TSG message size is much larger than the typical data buoy message or weather message. This increased size, necessitates using a different communications protocol with different performance characteristics. For example, the size of an XBT message is approximately 2.5 Kb and a typical drifting buoy message is closer to 100 bytes. Drifting buoy messages are typically sent using the Iridium Short Burst Data (SBD) protocol. For XBT and TSG messages, AOML has been experimenting with the Direct Internet Connection protocol. The Direct Connection protocol is a dial-up internet connection similar to a terrestrial landline dial-up service in which connection to an Internet Service Provider is negotiated through a modem. The Direct Connection protocol provides for larger data throughput, which allows for the transmission of XBT and TSG messages as attachments to email.

The expected cost to transmit an XBT profile is approximately 1.50 USD and is based entirely on the advertised throughput of the Iridium data system. The actual cost, including taxes, overhead and monthly service fees, is between 2 and 5USD. This large variation in costs per profile is mainly due to difficulties in maintaining the internet connection during the transmission of the relatively large XBT file.

During the course of this experiment, we have learned several things that may help lessen the cost of the per profile transmission rate including:

- Configuring the data collection software to attempt transmission only when the signal strength is full
- Keeping the cable run between the Iridium modem and antenna as short as possible. We have built a weatherproof package with a 6" connecting low loss cable, and, are researching future off-the-shelf options for an integrated modem/antenna package. Our original installations had 60' cable runs and we had many unnecessary retransmission attempts due to signal degradation.
- Power cycling the Iridium modem at least once per day. Again, there are now hardware options where this function is built into the system. On our shipboard systems, we currently have digital timers that automatically power cycles the systems.
- Ensuring that Windows auto update is off on any computers connected to an Iridium transmission system.

We work with NAL Research as our Iridium service provider. They provided us with several months of detailed call logs, allowing us to observe the actual record of transmissions going through Iridium. Unfortunately, this service was temporary and we no longer have access to the detailed call logs. AOML recommends that anyone considering using Iridium in a somewhat experimental fashion should negotiate with the Iridium Service Provider to receive detailed logs containing information about each transmission that is crucial for troubleshooting.

We anticipate that the actual cost for an XBT transmission, including overhead and flat fees will not fall lower than \$2.00 USD.

APPENDIX B

REPORT BY THE TASK TEAM ON SOT IRIDIUM PILOT PROJECT – PART 2

Iridium Pilot Project Report – Position Data Accuracy Amundsen AVOS

Analysis by:

*Champika Gallage, Standards Officer, Marine Networks
Weather and Environmental Monitoring Directorate
Meteorological Service of Canada, Environment Canada*

Background: For accurate drifting buoy position, a GPS unit is required, which can add significantly to the overall cost. It has been suggested that this requirement can be eliminated if the Iridium-determined position is found to be of sufficient accuracy. Although this is not a concern for ship data since the precise ship location is used, for drifting buoys the possibility of eliminating the GPS requirement is very significant. The Iridium Pilot Project provided the opportunity to investigate the feasibility of using the Iridium-derived position rather than the surface-based GPS since AVOS is essentially a buoy on a ship. This report merely analyses the data and presents the results. It does not make any specific judgements on whether the Iridium position is of “sufficient accuracy” since that will need to be determined by the various client communities.

Iridium position data accuracy: Position data obtained from the Iridium message (Figure 1) was compared against corresponding position data extracted from the AVOS message. Distance between the two respective position data points was calculated based on the formula in Appendix A. Data points extracted from the AVOS were considered as the reference and a 20 km radius was used as an acceptable distance between two respective position data points. Table 1 shows a sample of a distance analysis between two data sets. Iridium position data not within the 20 km agreement radius with the AVOS position data have their rows highlighted in yellow for the given sample in Table 1.

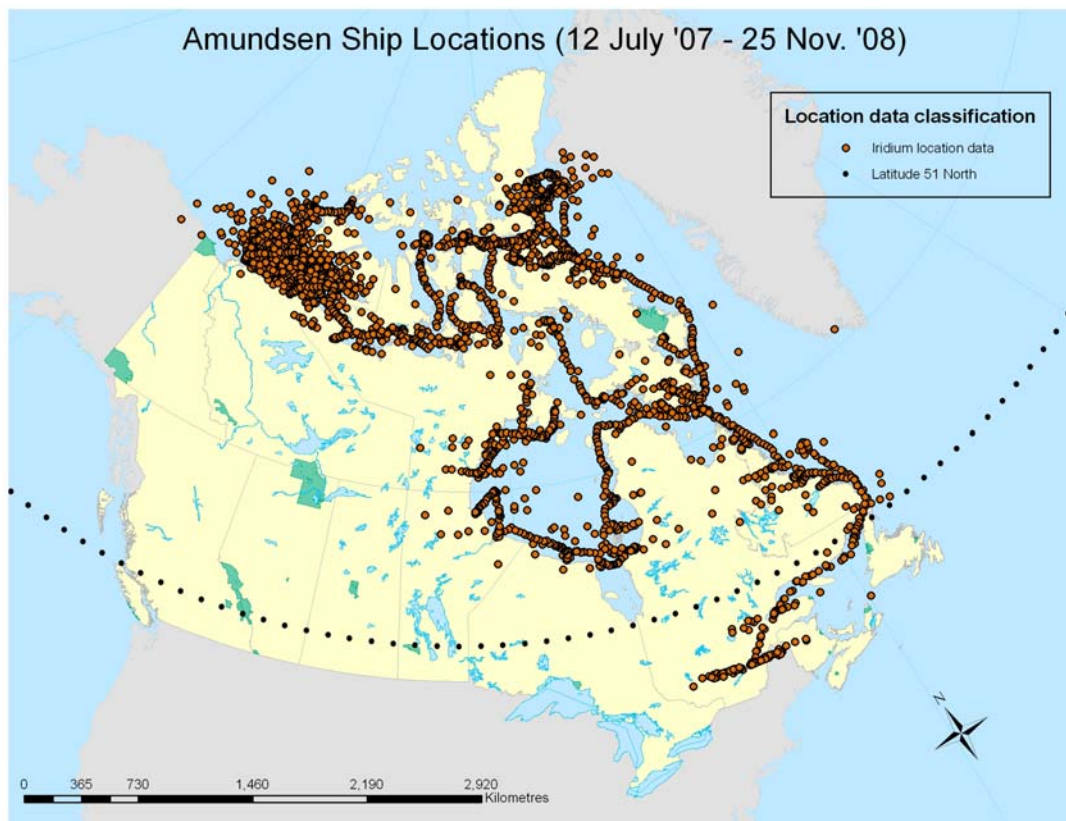


Figure 1. Iridium position data July 12, 2007 to November 25, 2008

Table 1. Distance analysis between AVOS and Iridium position data points (sample)

Date	Year	Time	<i>Position from AVOS Message</i>		<i>Position from IRIDIUM Message</i>		CEP radius	Point-to point distance
			Latitude	Longitude	Latitude	Longitude		
Sun Jul 29	2007	0:05:20	51.5	-56.4	51.5	-56.4	3	0.0
Sun Jul 29	2007	1:05:21	51.7	-56.1	51.7	-55.3	99	55.0
Sun Jul 29	2007	2:05:18	51.8	-55.8	51.8	-55.8	2	0.0
Sun Jul 29	2007	3:05:22	51.9	-55.6	52.0	-56.6	166	69.3
Sun Jul 29	2007	4:05:20	52.1	-55.3	52.1	-55.3	2	0.0
Sun Jul 29	2007	5:05:17	52.3	-55.3	52.3	-53.4	140	128.9
Sun Jul 29	2007	6:05:17	52.5	-55.3	52.6	-55.2	6	13.0
Sun Jul 29	2007	7:05:18	52.7	-55.3	52.8	-53.0	179	154.8
Sun Jul 29	2007	8:05:25	52.9	-55.3	53.0	-55.3	4	11.1
Sun Jul 29	2007	9:05:18	53.2	-55.3	53.2	-55.3	5	0.0
Sun Jul 29	2007	10:05:19	53.4	-55.2	53.4	-55.2	3	0.0
Sun Jul 29	2007	11:05:19	53.6	-55.3	53.6	-55.3	3	0.0
Sun Jul 29	2007	12:05:18	53.8	-55.4	53.8	-55.4	6	0.0
Sun Jul 29	2007	13:05:18	53.9	-55.6	54.0	-55.7	7	12.9
Sun Jul 29	2007	14:05:27	54.2	-55.7	54.2	-55.7	2	0.0
Sun Jul 29	2007	15:05:19	54.3	-55.9	54.3	-55.8	5	6.5
Sun Jul 29	2007	16:05:24	54.5	-56.1	54.6	-56.1	2	11.1
Sun Jul 29	2007	17:05:32	54.7	-56.3	54.6	-67.1	30	692.6
Sun Jul 29	2007	18:05:20	54.9	-56.4	54.9	-56.4	3	0.0
Sun Jul 29	2007	19:05:22	55.1	-56.6	55.1	-56.6	3	0.0
Sun Jul 29	2007	20:05:24	55.3	-56.7	55.3	-56.7	5	0.0
Sun Jul 29	2007	21:05:22	55.4	-56.7	55.4	-56.8	5	6.3

APPENDIX B, p. 3

Sun Jul 29	2007	23:05:24	55.8	-57	55.8	-57.1	3	6.2
Mon Jul 30	2007	0:05:27	55.9	-57.2	56.0	-57.1	6	12.7
Mon Jul 30	2007	1:05:22	56.2	-57.3	56.2	-58.0	73	43.2
Mon Jul 30	2007	2:05:25	56.3	-57.4	56.3	-57.4	4	0.0
Mon Jul 30	2007	3:05:20	56.3	-57.4	56.2	-55.6	128	111.5
Mon Jul 30	2007	4:05:23	56.4	-57.5	56.5	-57.5	2	11.1
Mon Jul 30	2007	5:05:17	56.6	-57.6	56.7	-57.7	32	12.7
Mon Jul 30	2007	6:05:20	56.8	-57.7	56.8	-57.6	2	6.1
Mon Jul 30	2007	7:05:18	56.6	-57.5	56.5	-57.6	4	12.7
Mon Jul 30	2007	8:05:19	56.3	-57.4	56.3	-57.4	3	0.0
Mon Jul 30	2007	9:05:18	56.5	-57.4	56.5	-57.5	4	6.1
Mon Jul 30	2007	10:05:18	56.7	-57.6	56.7	-57.5	6	6.1
Mon Jul 30	2007	11:05:18	56.9	-57.6	56.8	-57.6	8	11.1
Mon Jul 30	2007	12:05:19	56.7	-57.5	56.6	-57.4	2	12.7
Mon Jul 30	2007	13:05:24	56.5	-57.3	56.4	-57.3	1	11.1

All Iridium position data not within a 20 km radius of AVOS position data are displayed in Figure 2. Out of 10028 Iridium position data points received, 1522 or 15% are not within a 20 km radius of AVOS position data. The results also show that 66% of data were received while the Amundsen ship was underway in the Beaufort Sea, an area covering latitudes 68° to 75° and longitudes -110° to -145°.

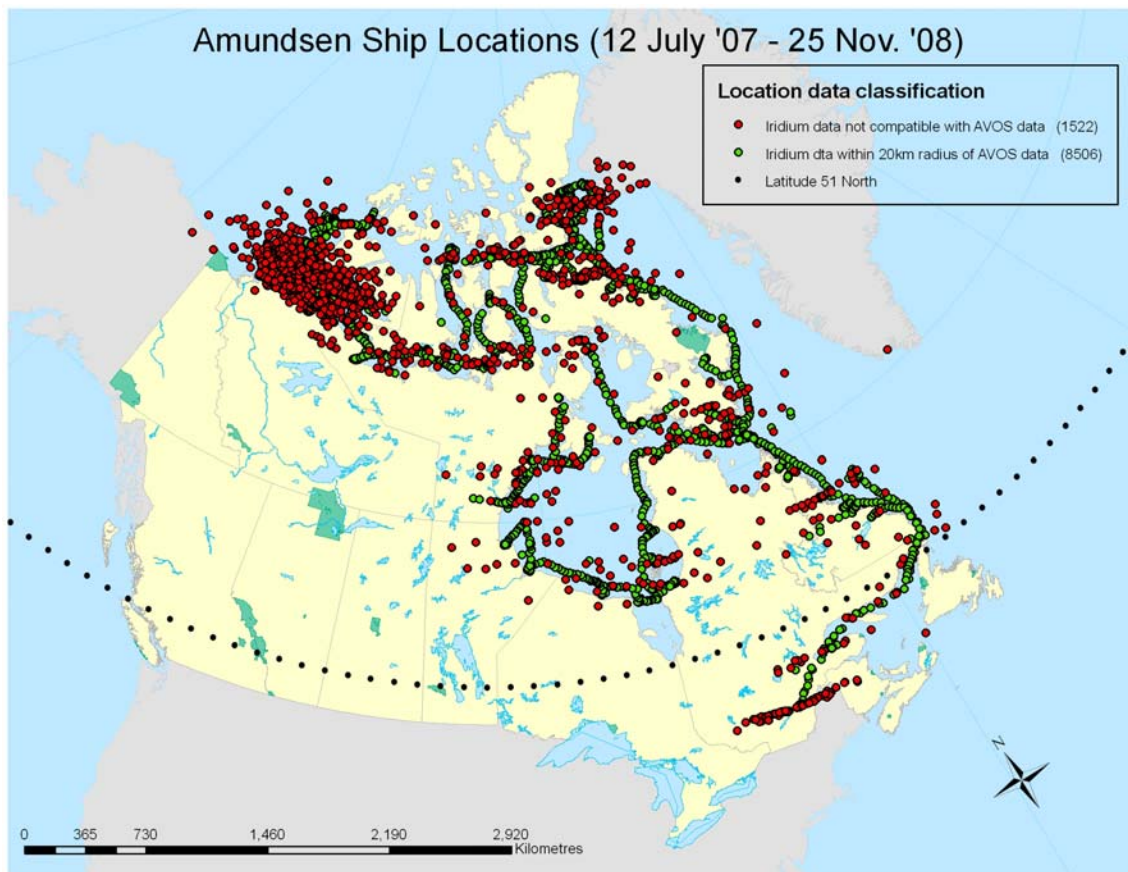


Figure 2. Compilation of AVOS and Iridium position data (from July 12, 2007 to November 25, 2008)

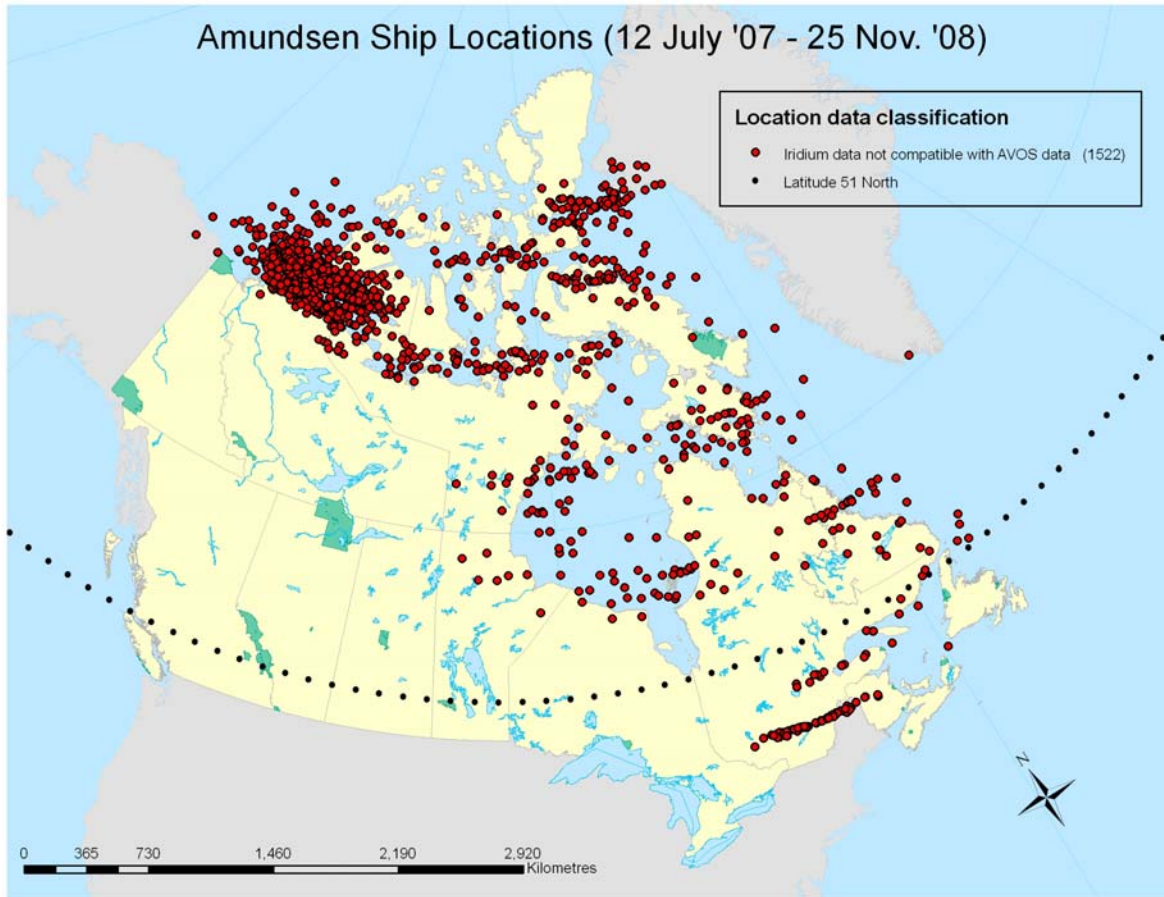


Figure 3. Iridium position data differing with respective AVOS position Data

Figure 3 shows all the position data not compatible with AVOS position data. Error data concentration in Beaufort Sea area is due to the Amundsen ship being in that area most of its sailing time.

Analysis were carried out to discover any relationships/trends between Position distance error and Latitudinal value (Figure 4), or Longitudinal value (Figure 5).

According to Figure 4 & 5, there is no detectable relationship (or trend) between distance error and longitudinal values or latitudinal values. Data concentration in Figure 4 & 5 (circled data points) is because Amundsen ship spent 66% of its time in the Beaufort Sea area (Figure 2 & Figure 3).

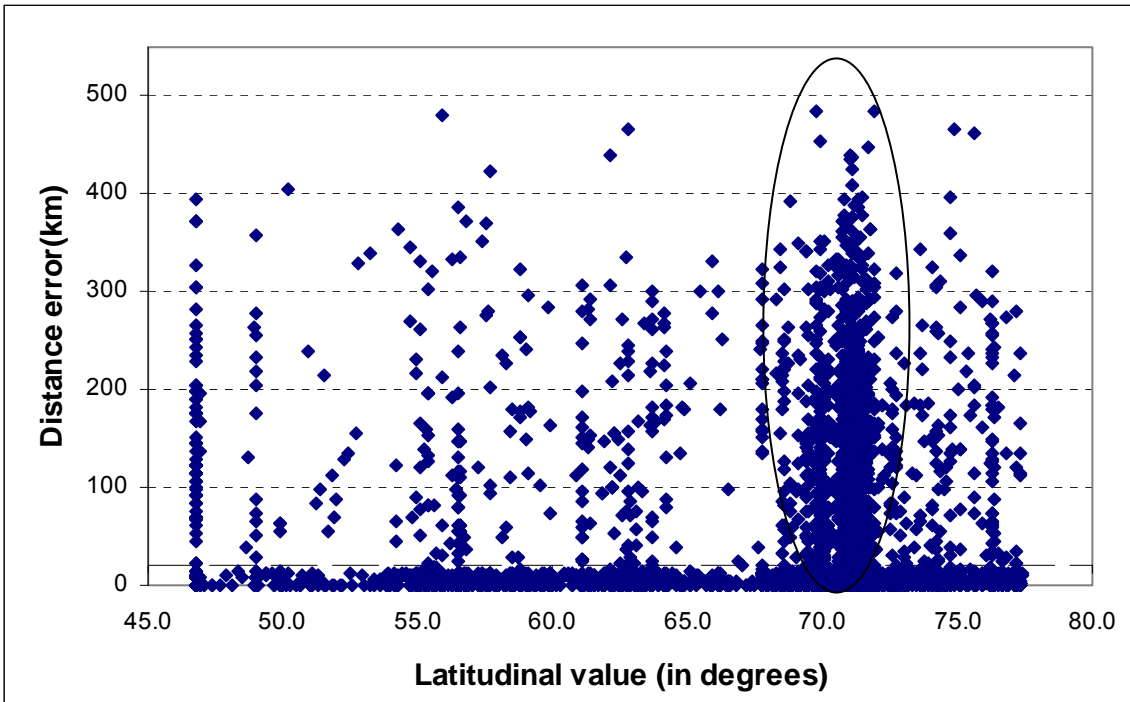


Figure 4. Relationship between Latitudinal value (degrees) and distance error (km) between AVOS position and Iridium position data

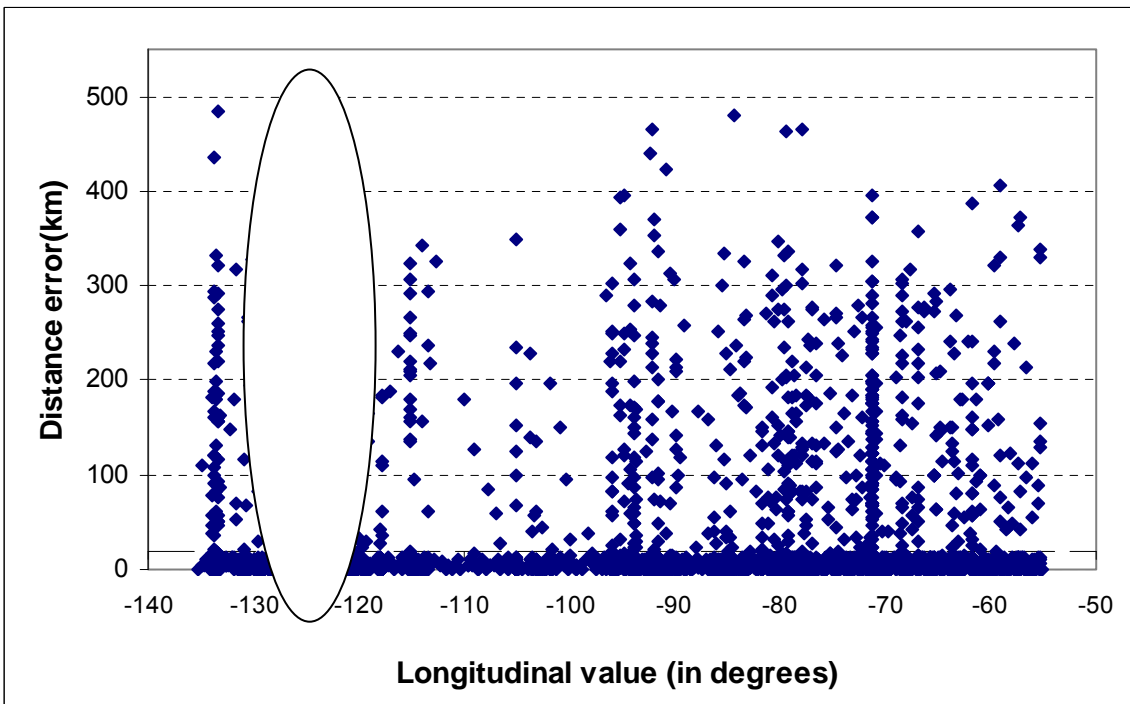


Figure 5. Relationship between Longitudinal value (degrees) and distance error (km) between AVOS position and Iridium position data

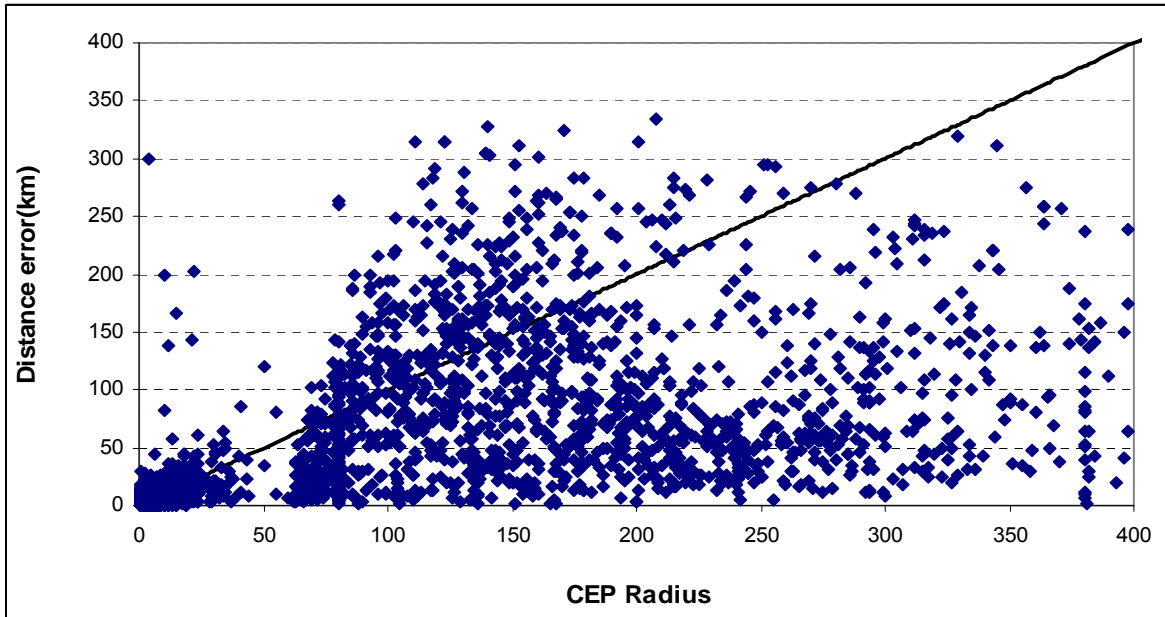


Figure 6. Relationship between CEP radius and distance error (km) between AVOS position and Iridium position data

Definition of Circular Error Probable (CEP) radius: CEP radius is the value of the radius of a circle, centred at the actual position that contains 50% of the position estimates.

Figure 6 shows the relationship between CEP radius and position distance error. According to Figure 6, it is clear that more than 50% of position distance error data falls below 50% of CEP radius. This suggests that CEP radius is a more pessimistic value.

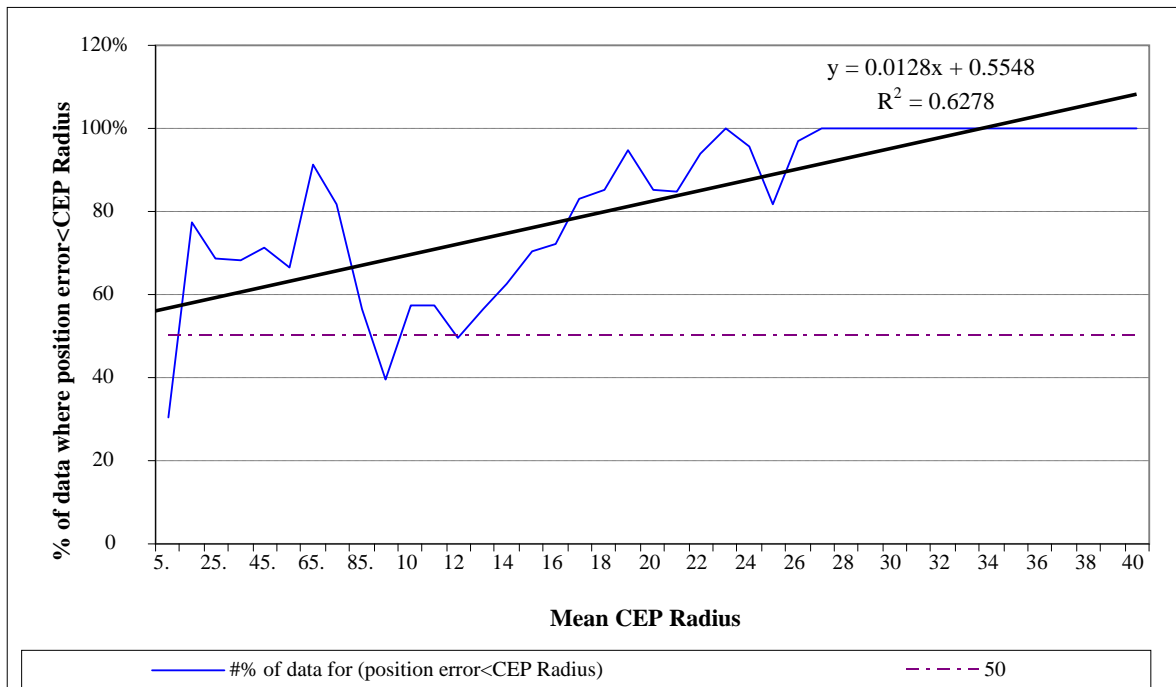


Figure 7. Relationship between mean CEP radius and % # of position error data less than CEP radius

Figure 7 (see Appendix B for data) shows the relationship between % number of position error data that is less than CEP radius and the mean CEP radius. According to the definition of CEP radius, the plotted data should closely follow the 50% data line. However, the actual data in Figure 8 shows a trend of above the 50% level, with values increasing gradually with increasing mean CEP radius. This

also confirms that CEP radius is an overestimation of position error data. The degree of overestimation is high when CEP radius increases.

Conclusion

- Based on the definition of CEP, the CEP radius for these data is a pessimistic value when analyzed against real position error data. This means that more than 50% of position estimates lie within the CEP radius. The number of data points lying within the CEP radius gradually increases with increasing CEP radius.
- Although the majority of the time the Iridium position is a close approximation of the actual location, outliers are commonly seen and this technique may not be appropriate for most drifting buoy applications. More study is required, but these preliminary results suggest that the GPS sensors will still be necessary for most drifting buoy applications pending improvements in satellite positioning technology and algorithms.

Annex 1: Point to point distance calculation in km

Annex 2: CEP radius analysis with regard to actual position distance error

ANNEX 1**Point to point distance calculation in km*****Length of 1 Degree of Longitude***

If the Earth were perfectly spherical in shape, the distance between one degree of latitude would be constant everywhere on the Earth's surface. However, because of the slight flattening of the Earth at the poles, the length of one degree of latitude varies slightly with distance from the Equator, but averages approximately 111 km.

At Latitude	Length of 1 Degree of Latitude
0 - 1	110.567 km
39 - 40	111.023 km
89 - 90	111.699 km
Average	111 km

Since meridians of longitude converge at the poles, the distance between one degree of longitude varies from approximately 111 km at the Equator to 0 km at the poles. At any latitude, the width of 1 degree of longitude can be calculated by multiplying the width of 1 degree of longitude at the Equator by the cosine of the latitude.

At Latitude	Length of 1 Degree of Longitude
0	111.321 km
15	107.553 km
30	96.448 km
45	78.849 km
60	55.802 km
75	28.903 km
90	0 km

Great Circles

A great circle is defined by the intersection of a sphere with a plane passing through the centre of the sphere. Great circles have the following properties:

- great circles bisect the sphere, i.e. divide the sphere into two equal hemispheres
- intersecting great circles bisect each other
- arcs of great circles represent the shortest route between two points on the surface of the sphere

The Equator is a great circle and all meridians of longitude are arcs of great circles. An infinite number of great circles are possible since a plane passing through the centre of the Earth can be placed at any angle relative to the Equator, and not just north-south or east-west.

Great Circle Distances

The great circle distance, between two points is often difficult to measure on a globe and, in general, cannot be measured accurately on a map due to distortion introduced in representing the approximate spherical geometry of the Earth on a flat map. However, great circle distances can be calculated easily given the latitudes and longitudes of the two points, using the following formula from spherical trigonometry:

$$\cos D = (\sin a)(\sin b) + (\cos a)(\cos b)(\cos P)$$

where:

D is the angular distance between points A and B

a is the latitude of point A

b is the latitude of point B

P is the longitudinal difference between points A and B

In applying the above formula, south latitudes and west longitudes are treated as negative angles. Once **cos D** has been calculated, the angle **D** can be determined using the ARCCOS function available on scientific calculators or in spreadsheet software such as Microsoft Excel. Note that these functions may expect angles measured in radians rather than degrees. Since π radians equal 180 degrees, you can convert degrees to radians by multiplying with $\pi/180$ or convert radians to degrees by multiplying by $180/\pi$.

ANNEX 2**CEP radius analysis with regard to actual position distance error****(Assumption: CEP radius is in km)**

CEP radius	CEP Radius (mean)	# % of data for (position error < CEP Radius)
1-10	5.5	30.57%
11-20	15.5	77.47%
21-30	25.5	68.52%
31-40	35.5	68.18%
41-50	45.5	71.43%
51-60	55.5	66.67%
61-70	65.5	91.18%
71-80	75.5	81.82%
81-90	85.5	56.34%
91-100	95.5	39.62%
101-110	105.5	57.33%
111-120	115.5	57.35%
121-130	125.5	49.40%
131-140	135.5	56.58%
141-150	145.5	62.67%
151-160	155.5	70.51%
161-170	165.5	72.22%
171-180	175.5	82.86%
181-190	185.5	85.11%
191-200	195.5	94.83%
201-210	205.5	85.42%
211-220	215.5	84.91%
221-230	225.5	93.75%
231-240	235.5	100.00%
241-250	245.5	95.45%
251-260	255.5	81.82%
261-270	265.5	97.14%
271-280	275.5	100.00%
281-290	285.5	100.00%
291-300	295.5	100.00%
301-310	305.5	100.00%
311-320	315.5	100.00%
321-330	325.5	100.00%
331-340	335.5	100.00%
341-350	345.5	100.00%
351-360	355.5	100.00%
361-370	365.5	100.00%
371-380	375.5	100.00%
381-390	385.5	100.00%
391-400	395.5	100.00%
401-410	405.5	100.00%

CEP radius data of up to 410 were taken into consideration. There are only 40 CEP radius values above 410, ranging from 416 to 996.