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Satellite Trials
ARGOS trial 1994

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Resume
In the period January-March 1994, the Directorate of Fisheries carried out a trial of the ARGOS MAR90 system on board F/F Johan Hjort. During this period, the vessel was for the most part located in the Barents Sea.

An important part of the trial was the comparison between positioning based on GPS and positioning by means of ARGOS. The trial has given results which may indicate that the algorithm used by ARGOS for position determination is not the optimum for position determination of fast-moving objects.

Topic words
ARGOS, satellite system, tracking, the Barents Sea

Distribution

CONTENTS

1. INTRODUCTION

The Directorate of Fisheries is required by Parl. Bill no. 1 (1993-94) to conduct further trials into the use of information technology for surveillance of fishery activities (tracking) at sea based on satellite systems, as well as catch reporting via satellite.

During the first half of 1991, the Directorate of Fisheries carried out its first tracking trials using the ARGOS system. Subsequently, further trials were carried out in order to ascertain the degree to which tracking by satellite can indicate the prior fishery activities of a vessel (ARGOS 1993), and also trials of transmission of bit-mapped messages via satellite for quota control purposes (ARGOS/INMARSAT-C 1993). INMARSAT-C is also used by the Directorate of Fisheries in other connections.

In cooperation with the Institute of Marine Research, equipment for a new trial was mounted on board F/F Johan Hjort (910 gross tonnage/64.4 m.l.length) in the middle of January 1994. This vessel was selected because at this time she was about to begin a two months' expedition in the Barents Sea.

The main purpose of the trial was to test the positioning accuracy and degree of coverage of the EUTELTRACS system. However, this voyage also provided us with the opportunity of testing the positioning accuracy of the ARGOS system in the same manner. An ARGOS MAR90 transmitter was therefore also installed on board the vessel. This gave us the opportunity of the parallel testing of three positioning systems, all of which may be of interest for the tracking of fishing vessels by means of satellite.

The ARGOS system has its best coverage performance in the polar regions, being based upon satellites in polar orbit. Previous trials have shown that the system is simple to install and reasonably robust in use.

The Directorate of Fisheries wishes to thank the Institute of Marine Research, Instrument Section, for their kind assistance during the trial.

2. ARGOS

The ARGOS system has been used for tracking fishing vessels since the end of the 1980s. Within this field, the system is possibly best known from the Pacific Ocean area, where ARGOS was used from 1989 till 1992 to ensure that fishing vessels kept outside closed areas while drift-net fishing [1]. In European waters, the system, as seen from a fishery aspect, is best known from its use in the Dutch regulation of beam-trawling. Here, also, it is mainly a question of distinguishing between activities inside and outside given areas.

The system is based on the use of satellites in low polar orbits. It makes use of the American NOAA satellites of the TIROS type. A satellite of this type passes each of the poles 14 times every 24 hours. This allows up to 28 locations pr. day with two satellites and up to 42 locations pr. day with three satellites in operation. For each new passage, the satellite will follow a longitude of about 25° further to the west. When the satellite passes over a given point on earth, it will be able to read signals from transmitters 2.500 kilometers to each side of the satellites earth projection. It thus covers a belt with a total width of 5.000 kilometers [2].

ARGOS will in the course of 1994 offer a new combined ARGOS/GPS platform specifically developed for surveillance of fishery activities. The new unit will be able to report GPS based positions in addition to offering the traditional ARGOS positioning. This platform, however, was not available at the time of our trial. Our test is therefore based on the traditional ARGOS MAR90 transmitter, which until now has been the one normally used onboard fishing vessels.

The type of transmitter used during the trial, MAR90, transmits a short message every 120 seconds. If this message is read by a passing satellite, the satellite can, by means of the Doppler shift effect, calculate the position of the transmitter. As a consequence of technical characteristics, such as frequency stability and number of readings, the position will be calculated with varying degrees of accuracy. Accuracy is usually divided into four classes, from the best, class 3, to the worst, class 0. An outline of these classes is given in Appendix 1.

Please note that accuracy of measurement is given for 66% of the observations, and that this relates to each of the axes. A hypothetical circle comprising the area in which 66% of the observations having a certain degree of quality are to be found will therefore have a radius which is greater than the axis deviation. The radius will be equal in size to the length of the hypotenuse of a right-angled triangle where the catheti are equal to the maximum deviation of latitude and longitude. If the measurement deviation is maximum 150 meters, then the length of the radius will, correspondingly, be 212 meters.

There is also another matter which it may be of interest to mention. Division into classes of quality is partly dependent upon the number of readings over a period of time. For classes 3 and 2, this will be five measurements during at least 7 minutes. The MAR90 transmitter emits a signal every second minute. A vessel travelling at a speed of 10 knots will, however, move 300 meters a minute. ARGOS reports back one position and one point of time for each position determination, even if this position at 'best' is calculated from a background of measurements over 7 minutes.

3. THE TRIAL

3.1 Technical factors

For the Directorate of Fisheries' trial January - March 1994, two satellites were used, a practice which has long been standard. These satellites are respectively 'D' and 'H'.

Table 1 gives the expected number of position determinations per 24 hours with two satellites in relation to the degree of latitude on which a platform is situated. During the active part of the expedition period, F/F Johan Hjort did not move south of 68° north. Most of the time the vessel was in the area of 70°-72° north. For two short periods during trip no. 1, the vessel was slightly to the north of 75° north. This indicates the extremities of latitude during the period covered by our test.

Table 1 - PASS FREQUENCY / source [2]			
Ptt	Number of passes per 24 hours		
latitude	Minimum	Mean	Maximum
0°	6	7	8
±15°	8	8	9
±30°	8	9	12
±45°	10	11	12
±55°	16	16	18
±65°	21	22	23
±75°	28	28	28
±90°	28	28	28

During the trial, a mobile station of the type MAR90AB with Id.no. 13863 was used. The Directorate of Fisheries obtained its data from the French processing centre in Toulouse over X.25 PAD, accessed by means of standard modem connection.

The equipment was mounted on board the vessel in Tromsø 1994-01-17, and the trial was completed in Bergen 1994-03-20. During the trial period, F/F Johan Hjort made in all 5 excursions to the Barents Sea. Charts of these excursions are shown in Appendix 2.

F/F Johan Hjort has also 2 sets of GPS equipment on board for position determination. One of these sets is connected to the ship's echo sounder. The vessel's position is continuously logged on board in machine-readable form as WGS-84. This log is active so long as the vessel is carrying out research work. Normally the log is not active when the vessel is in port.

The vessel's position from GPS is logged every 5th minute, as degrees with three decimals. The position is, however, also logged in connection with a number of special tests. This entails an improvement in the total frequency of position determination logged from GPS, in total an average of 3.1 minutes. From a total of 23.376 measure intervals during the testing period, 75% of these were less than 5 minutes.

The GPS equipment used for logging during this expedition was of the type Trimble Navigation GPS/Loran 10X, No. 11433-31, serial no. 2950A00609.

The vessel's typical behaviour during an expedition of the type covered by our analysis will be long periods of steaming at relatively high speed, around 11 knots. These periods are followed by shorter periods of sample taking, during which the vessel lies almost motionless. Such motionless periods may last for about 20 minutes. On an average, there may be intervals of approximately 3 hours between these tests. At times the vessel may also carry out trawl hauls. Speed may then be reduced to around 3 knots [3].

3.2 Method

Other properties of the ARGOS system, especially message transmission, but also degree of coverage, have previously been tested by the Directorate of Fisheries. Our aim with regard to this test was, therefore, to pay special attention to the accuracy of position determination from ARGOS MAR90 seen in relation to GPS.

If one has no absolute positions to which one may relate one's measurements, then accuracy of position must take the form of a deviation analysis. We have chosen to measure the deviations in relation to normal GPS. It is customary experience that a GPS position of today has a maximum deviation of 100 meters in relation to actual position. Many would consider a deviation of 50 meters to be a normal average result. One must, however, be aware of the fact that the deviations within the GPS system are, without correction, 'random'. Thus, with regard to a mobile unit, one cannot draw reliable conclusions as to the accuracy of any one reading.

For the purposes of our trial, it was not possible to obtain simultaneous measurements by simple means. This is a point of great importance for a mobile platform. A vessel travelling at a speed of 5 knots will cover a distance of 150 meters in one minute. If the speed is 10 knots, the distance covered will be 300 meters.

During most of the time covered by our trial, F/F Johan Hjort had a speed of at least 10 knots. If measurements are not simultaneous, then the vessel will have changed position between the two measurements to be compared. However, attention should be drawn to the fact that this movement may also have an effect which may partly compensate a possible measurement error, given that the time difference is small proportionate to the measurement errors and the speed of the platform.

In our analysis, we have chosen to take the individual position determinations as our point of departure, and to compare these with the GPS position which is nearest in time. The point of time reported by ARGOS is based on one type of calculation of average. Upon approaching CLS/ARGOS, we were informed that both the satellites report exact correct time for the observations which are included in the calculations. The point of time of the position determinations are reported to the users in hour-min.-sec. UTC, and position as WGS-84.

Clock time in the vessel's GPS-log is taken from a UNIX work station. Check measuring in Bergen 1994-04-21 showed that this clock was about 3 min. 3 sec. slow.

For the purposes of our analysis, we have therefore compensated for this discrepancy.

Corresponding calculations regarding simultaneous position determinations from EUTELTRACS would indicate that this is the correct manner of approach [4].

3.3 Position determination

Positions are reported in degrees to three decimal places. The distance between the given positions from ARGOS and GPS are automatically calculated as the length of the hypotenuse using standard trigonometry based on measured differences of longitude and latitude. For the sake of simplification, approximate formulas have been used to calculate the extent in meters of the minutes of latitude and longitude on the individual degrees of latitude. Results from calculations based upon this formula work are shown in Appendix 3, in comparison with calculations based on the international ellipsoid. As can be seen from this table, error is greatest with regard to latitude, up to 2 meters compared to 1.859 meters round

70° North. This error is infinitesimal, a little over a thousandth, and is insignificant in that it is only applied to the difference in position. This difference is merely a fraction of a geographical minute.

The calculations are carried out on a PC using own program in FORTRAN-77 [5].

3.4 Measurement results

Before examining the result tables, one must realize that the accuracy of an ARGOS measurement is usually given in relation to each of the axes, and for 66% of the measurements. The maximum deviation for 66% of the measurements will then approximate the hypotenuse of a right-angled equal-sided triangle where the length of the catheti is the maximum deviation.

Table 2 - MEASUREMENT DEVIATION 66%		
Class	Axis error	Distance
3	150 m	212 m
2	350 m	495 m
1	1.000 m	1.414 m

It is this distance which we wish to check. The measurement results are given in Table 3 - Table 5.

Table 3 gives measured deviation between position determination by means of ARGOS and GPS where the time discrepancy is not more than ±0.5 minutes. The results are distributed in precision classes, see column 1. Number of measurements is given in column 2, and thereafter average measured latitude and longitude for these observations. Further, average time difference between measurements is given in minutes. Then comes the average distance between the two positions, in the line for class 3 equating 708 meters, and finally the average deviation in measured latitude and in measured longitude.

Table 3 - TIME DIFFERENCE ±0.5 MINUTES											
Class	Quant.	Av. position N	E	±Time	±Distance		±Long.		±Lat.	
3	31	71.14	35.53	0.2	708	m	474	m	439	m
2	202	71.86	33.96	0.3	1769	m	1153	m	1130	m
1	42	72.30	34.92	0.2	2771	m	1881	m	1611	m
Total	275	71.85	34.28	0.3	1802	m	1188	m	1126	m

It can be seen from Table 3, that gathered from 275 measurements with minimal time discrepancy, an average distance of 1.802 meters has been registered between the positions given on the basis of measurements from ARGOS and GPS. The best coincidence, 708 meters, is, as expected, registered in class 3. But the number of observations, 31 in all, is comparatively small.

In the line for class 2, the number of observations is greater, and the average distance is put at 1.769 meters. One can also see that there is a markedly greater average distance in class 2, and, as is to be expected, even greater in class 1. Taking Appendix 1 as point of departure, one may expect proportional accuracy between class 3 and class 2 to be of the size of 350/150, that is 2,33. Between class 2 and class 1 a proportion of 1.000/350 may be expected, that is to say 2,86.

If, for a moment, we allow ourselves to consider the GPS measurements in our trial as a kind of key, we can see in the first place that the measured deviations in Table 3 are greater for all the three classes than those one would normally have expected from ARGOS-related factors alone.

We see also that the realized proportions between the measurements are somewhat different, namely 1.769/708, thus 2,5 (2,33) and 2.770/1.769, thus 1,57 (2,86). But we have few observations both in class 3 and class 1.

It could therefore be desirable to attempt to expand the selection somewhat, even though the average time discrepancy would thus be increased.

Table 4 - TIME DIFFERENCE ±1.0 MINUTES											
Class	Quant.	Av. position N	E	±Time	±Distance		±Long.		±Lat.	
3	63	71.15	34.05	0.5	738	m	482	m	481	m
2	405	71.81	34.36	0.5	1735	m	1115	m	1110	m
1	74	71.99	35.06	0.5	2468	m	1666	m	1493	m
Total	542	71.76	34.42	0.5	1719	m	1116	m	1089	m

Table 4 contains 275 measurements with time discrepancy ±0.5 minutes and in addition 267 measurements with time discrepancies between ±0.5 and ± 1 minute. A further 355 measurements are included in Table 5.

Table 5 - TIME DIFFERENCE ±2.0 MINUTES										
Class	Quant.	Av. position N	E	±Time	±Distance		±Long.		±Lat.	
3	117	71.33	34.63	1.0	810	m	524	m	516	m
2	664	71.86	34.22	0.9	1693	m	1096	m	1079	m
1	116	72.06	34.75	0.8	2556	m	1789	m	1466	m
Total	897	71.82	34.34	0.9	1689	m	1111	m	1056	m

As F/F Johan Hjort has, for the most part, been in motion, it is only to be expected that the average distance between the ARGOS and GPS positions will increase at around the same pace as the time discrepancy. If we keep solely to the observations in class 3, we see that the average measured distance between the positions has increased from 708 to 738 meters during 0.3 minutes from Table 3 to Table 4, that is to say with a speed equivalent to about 100 meters a minute.

From Table 4 to Table 5, the average distance has increased from 738 to 810 meters while the time difference has increased by an average of 0.5 minutes. Thus, in this case the speed is equivalent to about 140 meters a minute.

Even though one should not read too much into these calculations, they would, if correct, imply that the measurement error caused by the vessel's movement between times of measurement for ARGOS and GPS could be equivalent to somewhat over 20 meters average distance in Table 3.

3.5 Satellite differences

Two satellites, D and H, were active for ARGOS during this trial. It may be of interest to see if these two satellites have given essentially different measurement results. In order that the number of observations shall be reasonably large in the different groups, our point of departure here has been a maximum time difference of ±1.0 minute between the measurements.

Table 6 - OBSERVATIONS FROM DIFFERENT SATELLITES TIME DIFFERENCE ±1.0 MINUTES

Class	Quant.	Av. position N	Av. position E	±Time	±Distance	±Long.	±Lat.
3 D	33	71.26	32.12	0.6	797 m	590 m	460 m
3 H	30	71.03	36.17	0.4	674 m	365 m	505 m
2 D	210	71.85	34.09	0.5	1670 m	1067 m	1076 m
2 H	196	71.80	34.61	0.5	1799 m	1162 m	1143 m

From the measurements in quality class 3, it appears that satellite H has given a somewhat shorter average distance compared with the GPS measurements. Please note that the average time difference is also less here.

But if we go further and consider quality class 2 where the number of observations is greater, then a contrary indication is received. Here, the average time difference is also approximately the same. Since the difference in average distance is small in this group, one is therefore unable to find any indication of satellite-based differing measurement results in Table 6.

As our trial took place over a period of time, the situation arose where, for orbit-technical reasons, the two satellites at times gave grounds for their own position determinations of our platform at about the same time. Those instances of such occurrences which fall within an interval of approximately one minute are given in Table 7.

In extreme cases, two measurement errors will either be able to add themselves to a large sum or to completely or partly cancel each other out. The norm will most probably be partly addition and partly counteraction.

In our introductory comments we said that the vessel's maximum speed would move the platform approximatly 300 meters in one minute. But it may be that this movement takes place in the same direction as the vector in a possible measurement error, then the vessel will be moving at full speed more or less towards the first measurement point, so that it will be nearer this point at the next measurement (see also pt. 3.4).

In Table 7 there are three instances where the time difference between the ARGOS measurements are two seconds or less, namely 1994-01-26 16:11 hours, 1994-02-07 10:17 hours and 1994-02-17 01:36 hours. The distance between the points is here from 2 km. to 3,2 km. This is not what one would normally expect for class 2 with 66% accuracy at 495 meters, even in cases where one is unusually unlucky.

The last registration in Table 7 is from the harbour area in Vadsø.

Table 7 - SAME POSITION MEASURED FROM TWO SATELLITES						
Sat	Class	Date	Time	Mean position N	E	Distance
H	2	1994-01-26	16:11:56	75.559	27.448	
D	2	1994-01-26	16:11:58	75.422	27.344	3264 m
H	2	1994-01-26	17:53:54	75.457	27.488	
D	2	1994-01-26	17:54:52	75.455	27.501	427 m
D	2	1994-01-27	02:29:33	74.348	27.107	
H	2	1994-01-27	02:30:30	74.341	27.145	1385 m
H	2	1994-01-27	04:09:33	74.238	27.405	
D	2	1994-01-27	04:10:33	74.241	27.386	666 m
H	2	1994-01-27	10:53:17	74.198	29.544	
D	2	1994-01-27	10:54:13	74.199	29.542	127 m
D	2	1994-01-27	12:32:21	74.421	29.667	
H	1	1994-01-27	12:33:15	74.457	29.841	6852 m
H	2	1994-02-07	10:17:49	73.003	43.000	
D	2	1994-02-07	10:17:50	73.017	43.041	2055 m
D	2	1994-02-17	01:36:32	70.652	44.371	
H	2	1994-02-17	01:36:34	70.660	44.420	2020 m
H	2	1994-02-28	11:01:55	70.071	29.737	
D	3	1994-02-28	11:02:53	70.070	29.734	160 m

3.6 Stationary vessels and vessels in motion

One of the problems with our comparative measurements has been that we have not had position determinations at two identical points of time. In some cases, however, the GPS log has also been in action while the vessel was lying alongside the quay, so that possibilities have arisen for parallel registrations also for stationary platforms. One such possibility arose in Vadsø harbour from 1994-01-31, 13:00 hours to 1994-02-01, 18:45 hours. During this period, ARGOS made 23 registrations in all. These are summarized against GPS in Table 8. The time difference is of no importance when the vessel is lying motionless, and in order to obtain a reasonable number of observations, the point of departure here has been a difference of ±2 minutes.

Table 8 - TIME DIFFERENCE ±2.0 MINUTES VADSØ HARBOUR							
Class	Quant.	Av. position N	E	±Time	±Distance	±Long.	±Lat.
3	7	70.07	29.74	1.0	149 m	98 m	96 m
2	8	70.07	29.74	1.1	378 m	200 m	251 m
1	2	70.07	29.75	0.9	650 m	209 m	613 m
Total	17	70.07	29.74	1.0	316 m	159 m	229 m

Table 9 - TIME DIFFERENCE ±1.0 MINUTES 70.000° - 70.999°							
Class	Quant.	Av. position N	E	±Time	±Distance	±Long.	±Lat.
3	28	70.55	31.18	0.5	541 m	426 m	263 m
2	146	70.62	32.81	0.5	1576 m	1021 m	970 m
1	20	70.58	33.94	0.5	2454 m	1609 m	1561 m
Total	194	70.60	32.69	0.5	1517 m	996 m	929 m

Table 9 shows the average results for all position deviations in the interval 70° - 70.9°. The time difference has been set at ±1 minute. The table also includes positions from Vadsø harbour, in class 3 (4 positions), class 2 (3) and class 1 (1). Most of the deviations, though not all, therefore apply to vessels in motion.

A comparison between Table 8 and Table 9 gives indications that deviation measurement is affected by whether or not the platform has been in motion. There may be several reasons for this result. Errors in time specifications could be one possible reason. However, trials we have carried out with other clock corrections give no evidence that this could be the cause here.

4. CONCLUSIONS

Our trials indicate deviations in position determinations greater than those one normally would have expected.

We can determine that the average deviation measured between the positions, here at best approximately 700 meters, must be apportioned between at least four factors:

1) Measurement error ARGOS
2) Measurement error GPS
3) Measurement error TIME
4) The vessel's movement between measurements

Our trials indicate that the first factor is the most important, and the measurement error is due to the vessels relatively swift motion.

Be aware that the speed of the research vessel has on the average been rather higher than that of a fishing vessel.

ARGOS MAR90 gives one position and one point of time as a result of several measurements during a period of approx. 7 minutes. It would seem appropriate to investigate as to whether the algorithm used for this purpose is the optimal for platforms in relatively swift motion, or whether the algorithm is adapted to relatively stationary objects.

A more thorough investigation could take its point of departure in differential GPS or in new combined ARGOS/GPS transmitters which are now under development.

5. OTHER MATTERS

The Institute of Marine Research has kindly placed F/F Johan Hjort at the disposal of the Directorate of Fisheries for the accomplishment of further trials with satellite systems. It has therefore been determined that the trials will continue for a further 12 months from and including April 1994.

The existing ARGOS equipment has therefore remained installed on board the vessel, and data will be available later for analyses from these expeditions also.

After the conclusion of our trial we have been informed by ARGOS that a new version of the positioning algorithm has been developed by CLS. The new locationing will be operational from approximately mid June.

The new locationing algorithm should especially be of benefit when locating platforms in motion, such as vessels in route.

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March 1994

APPENDIX 1

Source: ARGOS User Manual

LOCATION CLASSES

The location classes are defined as follows:

	Required conditions	Accuracy (1)
CLASS 3	- At least seven minutes between first and last messages of pass, - At least five messages received, - very good oscillator stability, - very good géométric configuration.	location accuracy 150m (1 st. dev.) (2) (1) on each coordinate (2) varies with sunspot activity
CLASS 2	- At least seven minutes between first and last messages of pass, - At least five messages received, - good oscillator stability.	location accuracy 350m (1 st. dev.)
CLASS 1	- At least four minutes between first and last messages of pass, - At least four messages received, - reasonable oscillator stability.	location accuracy 1km (1 st. dev.)
CLASS 0* 	- At least two messages received during pass.	quality of obtained results to be determined by user; depends on oscillator stability and geometric configuration satellite/transmitter

The stated accuracies are achieved for over 66% of results.

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APPENDIX 2

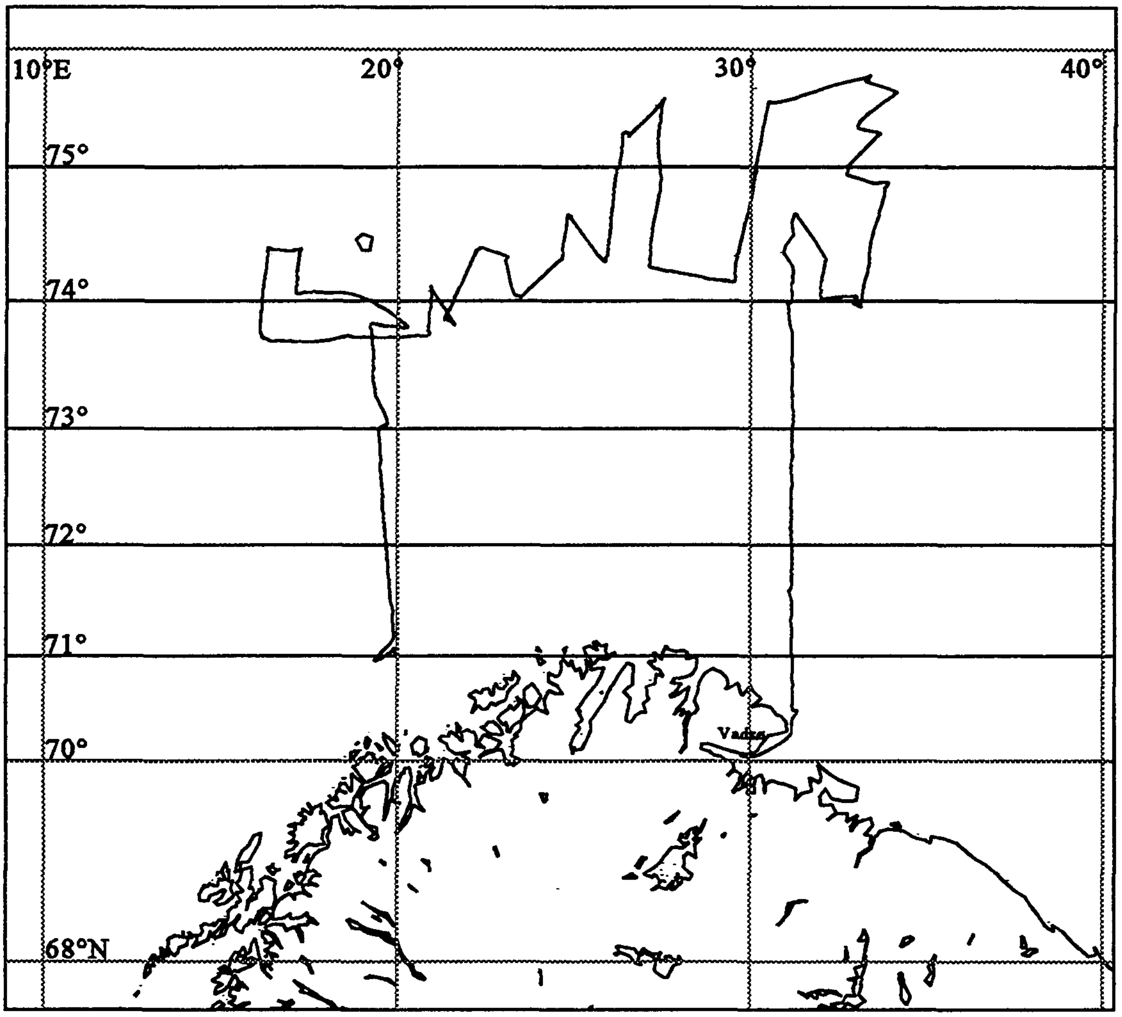

Figure 1 Trip no. 1: January 21 - January 31, 1994

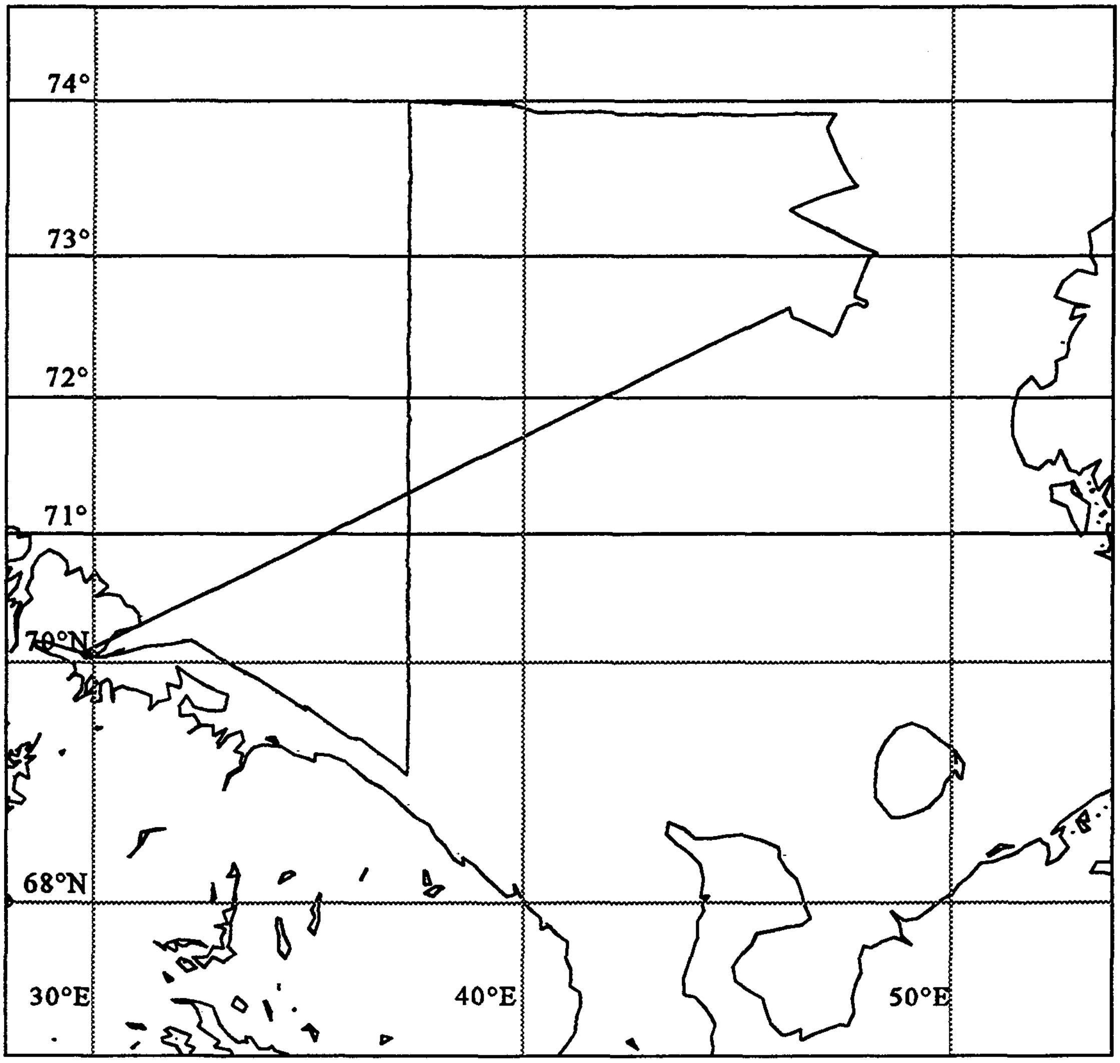

Figure 2 Trip no. 2: February 1 - February 11, 1994

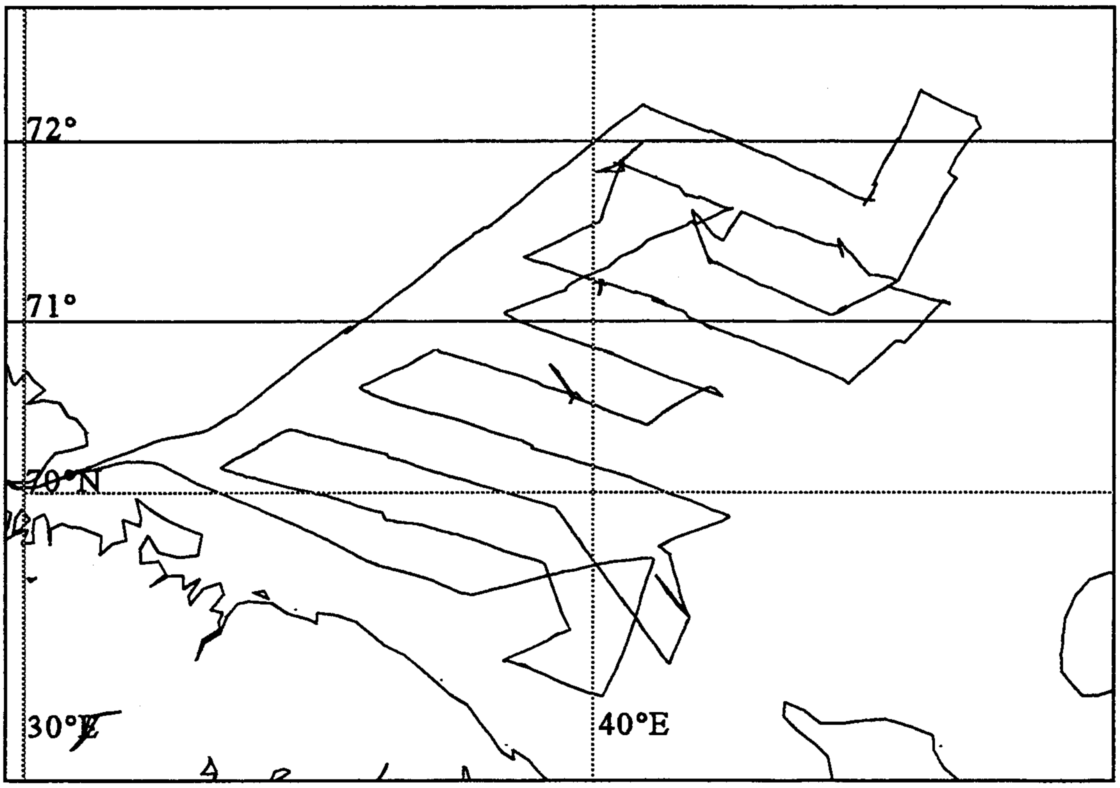

Figure 3 Trip no. 3: February 11 - February 27, 1994

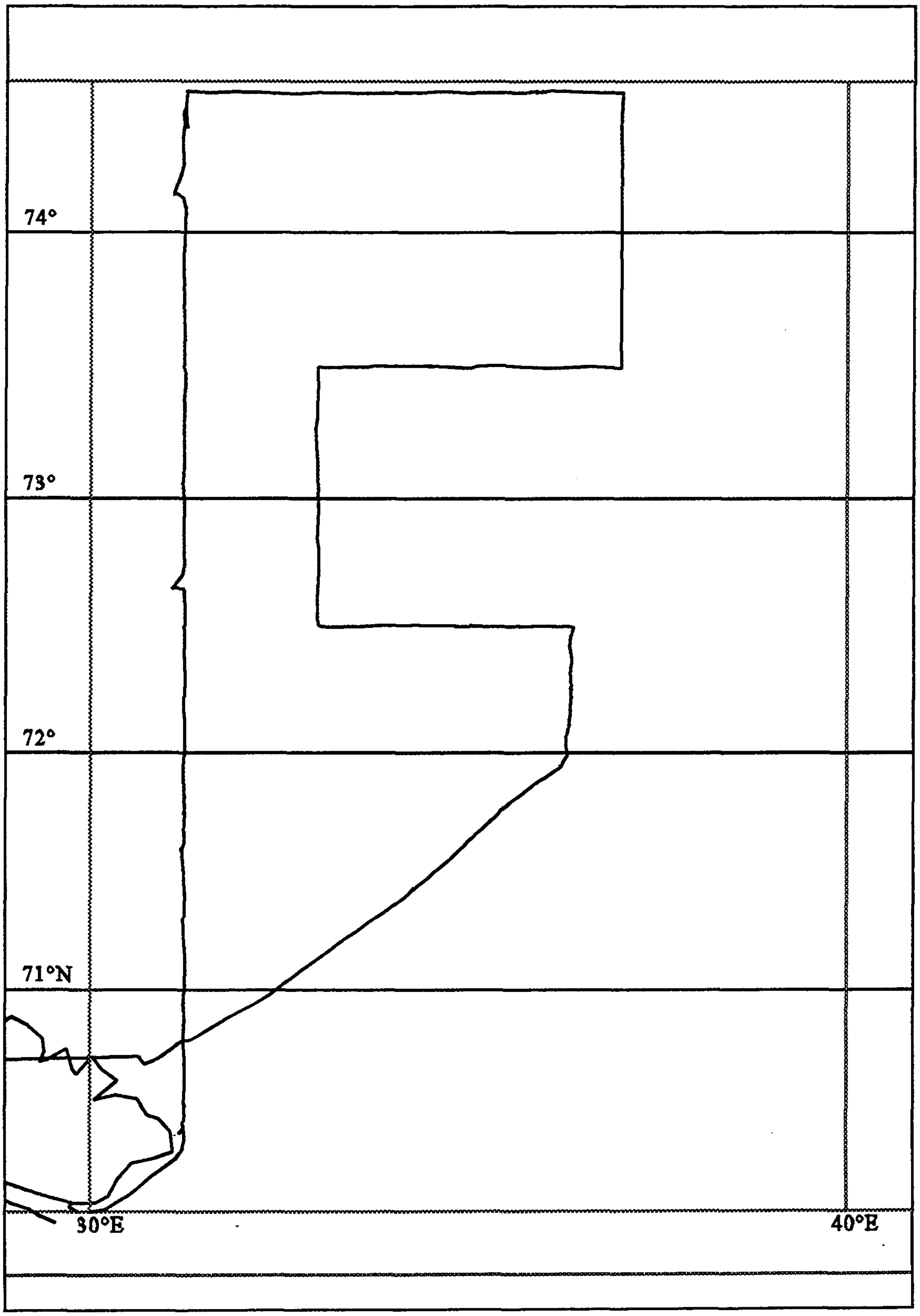

Figure 4 Trip no. 4: February 28 - March 6, 1994

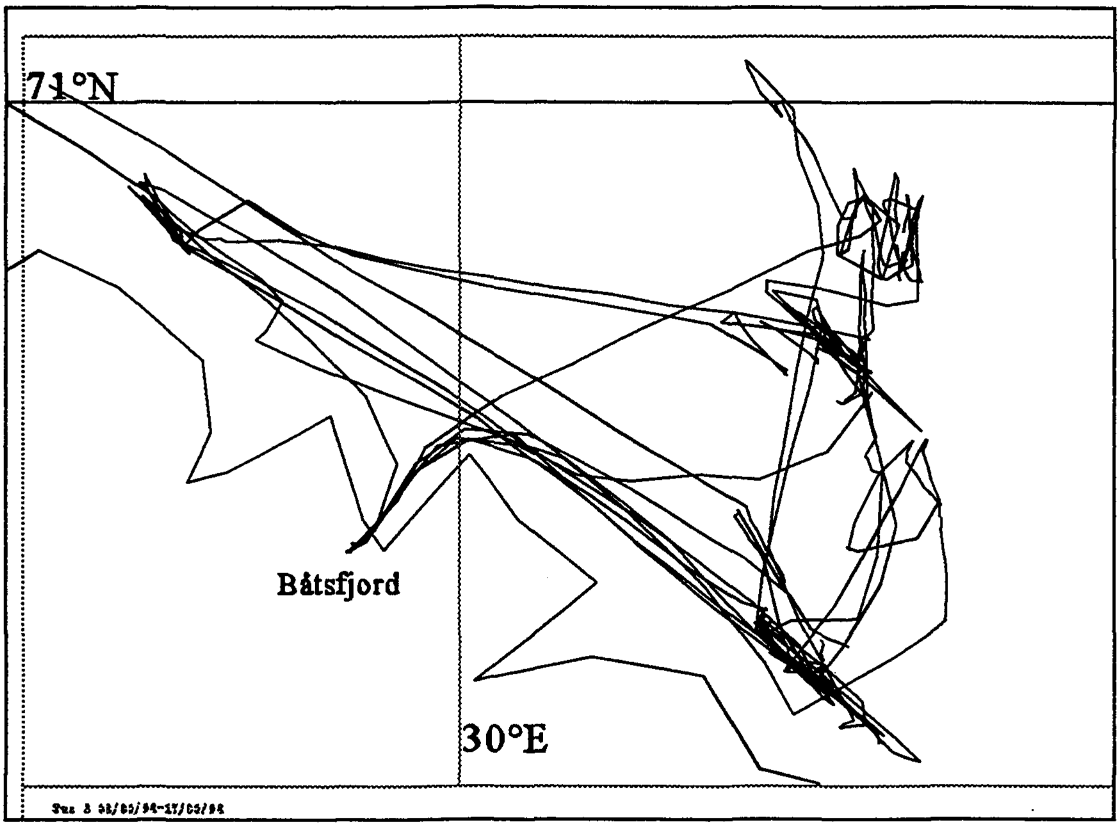

Figure 5 Trip no. 5: March 8 - March 17, 1994

APPENDIX 3

LATITUDE	CALCULATION		ELLIPSOID	
degree	lat.min	long.min	lat.min	long.min
2	1843.3	1854.4		
4	1843.7	1851.2		
6	1844.2	1845.7		
8	1844.6	1837.9		
10	1845.0	1827.9	1843.5	1827.4
12	1845.4	1815.7		
14	1845.8	1801.2		
16	1846.3	1784.6		
18	1846.7	1765.7		
20	1847.1	1744.8	1845.1	1744.2
22	1847.5	1721.7		
24	1847.9	1696.5		
26	1848.4	1669.2		
28	1848.8	1639.9		
30	1849.2	1608.6	1847.6	1608.2
32	1849.6	1575.3		
34	1850.0	1540.1		
36	1850.5	1503.0		
38	1850.9	1464.1		
40	1851.3	1423.4	1850.7	1423.3
42	1851.7	1380.9		
44	1852.1	1336.8		
46	1852.6	1291.0		
48	1853.0	1243.7		
50	1853.4	1194.8	1853.9	1195.0
52	1853.8	1144.4		
54	1854.2	1092.7		
56	1854.7	1039.6		
58	1855.1	985.3		
60	1855.5	929.7	1857.0	930.0
62	1855.9	873.0		
64	1856.3	815.2		
66	1856.8	756.5		
68	1857.2	696.7		
70	1857.6	636.2	1859.5	636.5
72	1858.0	574.8		
74	1858.4	512.8		
76	1858.9	450.1		
78	1859.3	386.8		
80	1859.7	323.1	1861.1	323.2
82	1860.1	259.0		
84	1860.5	194.5		
86	1861.0	129.8		
88	1861.4	65.0		
90	1861.8	0.0		