Environment Canada
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Atlantic Region / Région de l'Atlantique

AE-ATN-88-04

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Atlantic Region

Technical Notes

88-004(N)

EVALUATION OF SSM/I DATA FOR THE PERIOD JANUARY TO MARCH 1988

by

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Abstract

SSM/I (Special Sensor Microwave/Imager) data from the Defence Meteorological Satellite Programme has been used to derive wind speeds at the one metre level over the ocean. Evaluation of SSM/I wind data for operational use has shown it to be generally unreliable in light winds. In the presence of liquid precipitation, winds are greatly exaggerated. The results appear to be reasonable in unstable flow. SSM/I data can also be used to derive rain rate, cloud cover and water vapour. These products were also assessed and found to perform poorly, apparently recognizing only liquid precipitation and clouds containing liquid water and failing to identify frozen precipitation and clouds containing ice crystals or snow.

1.0 INTRODUCTION

During the period January 21 to March 30 1988 charts showing satellite derived surface winds over the sea were received at the Newfoundland Weather Centre (NWC) so that they could be evaluated for operational use.

The winds were derived using SSM/I (Special Sensor Microwave/Imager) data from the DMSP (Defense Meteorological Satellite Programme) satellite.

Briefly, SSM/I receives polarized radiation in 3 different frequencies all centred near 1 cm wavelength. By cross matching the 3 wavelengths and the differences between the vertically and the horizontally polarized radiation within each band sea surface winds can be estimated. Nominally the winds are designated as being at one metre above sea level (ASL) but the sensors are actually responding to capillary wave action and reflect instantaneous changes in the sea skin. (It should be noted that SSM/I is not sensitive to what is normally regarded as "sea state", i.e. wind waves and swell.)

The developers of SSM/I made some modifications to the surface wind algorithms during the course of the experiment.

SSM/I estimates average wind speed over each 40 km square. This information was received at NWC in chart form on difax. The chart scale was 1:7.5 million to match the surface analysis performed at NWC. A few charts were not received but no attempt was made to remedy this as sufficient charts had been received to perform an assessment of the product. As it was, there was insufficient time to perform a complete survey of the charts that were received.

Subsequently a series of charts of SSM/I data were received by mail at NWC. These charts, which were at a smaller scale, displayed data for wind, cloud coverage, rain rate, and water vapour. On these charts wind was contoured at 10 knot intervals, cloud at intervals of 2 oktas, rain rate in mm/h and water vapour at 2 cm intervals (indicating the total rainfall possible if all the water vapour through the depth of the atmosphere was condensed out).

Generally 2 difax charts were received each day valid around 0800Z and 2200Z. The time of reception at NWC could be as much as 12 hours after the valid time, which meant that the charts could not be used in real time. This delay was due largely to the experimental nature of the program and it is understood that if the product were to become operational the delay could be considerably reduced.

Charts were received for both the North Atlantic and the North Pacific Oceans but only the Atlantic charts were studied at NWC. The area covered depended on the actual path covered by the satellite within the window defined by the East Coast of North America and longitude 20 degrees West and between latitudes 40 degrees North and 65 degrees North.

2.0 EVALUATION

Two approaches to evaluation were made. First a subjective one, where the general pattern on the SSM/I chart was compared to that on the nearest comparable surface analysis. The second approach was objective where ship reports were extracted from the analyzed surface charts which bracket the time of the SSM/I data (i.e., the charts for the synoptic hours before and after the time of the SSM/I pass) and these were compared with the values indicated on the SSM/I charts.

2.1 THE SUBJECTIVE APPROACH

Evaluation of this product is not simple. The first problem is timing. As already noted, most SSM/I passes were around 0800Z and 2200Z with the actual times varying between 0735Z and 1008Z and between 2048Z and 2301Z. They can therefore be as much as 3 hours away from the nearest main synoptic analysis available at NWC. The isotach gradient on SSM/I charts is frequently very sharp, which makes time differences of this magnitude very significant when attempting to compare the SSM/I charts with surface analyses, especially when dealing with systems that move across the area at up to 50 knots.

The second problem is the surface analysis itself. The main reason for interest in a product such a SSM/I is because there is a great sparsity of surface data over the ocean, and that its main value would be in assisting in the production of a reliable analysis. Therefore there is a degree of uncertainty in the surface analysis which raises questions as to the validity of using it to evaluate the accuracy of SSM/I.

Lack of time available for this project has meant that not all of the charts could be compared prior to the preparation of this report. All of the available charts for January and February and the latter half of March were examined. The findings proved reasonably consistent and are presented here despite the lack of completeness.

In this approach each chart was contoured at 10 kt intervals and compared with the nearest surface analysis by means of a light-table overlay. A brief description of the synoptic situation was noted from the analysis. Initially each ship report was extracted and a comment made upon how well it compared with SSM/I data but this was found to be too time consuming and was not continued through the study.

2.1.1 RESULTS

From the survey of the charts the following points appear reasonably consistently.

1. In a west to northwest unstable flow SSM/I seems to give reasonable results, with winds about half the geostrophic gradient, as one might expect considering the 1 metre reference level.

2. Where SSM/I indicates an area of less than 10 knots it nearly always appears to be too extensive. Usually this occurs in an area of high pressure or a ridge where light winds are expected. However the area of less than 10 knots generally extends well east and west of the analysed slack gradient. With an inversion probably developing in the southerly flow west of a ridge one may expect winds at the sea surface to be considerably less than the measured gradient but to the east the flow is more likely to be unstable and stronger winds would be expected.

3. The problems caused by liquid precipitation are well known to the developers of SSM/I. In most cases where there is rain, SSM/I will give winds stronger than and frequently very much stronger than one would expect from the surface analysis or than observed by nearby ships.

The problem is further complicated because it seems that liquid precipitation may cause this affect at times when SSM/I is unable to detect that rain is falling. Hence simply cross checking with the SSM/I rain rate chart may fail to resolve the uncertainty.

The problem may be exacerbated if wet snow, with consequently larger droplets, is mixed in the precipitation. (A possible example of this being Feb 11 0756Z near 50 N 41 W.) It may also be interesting to see if fog or drizzle droplets have any similar effect, particularly in the Atlantic Region where those elements frequently occur.

On cross checking one often finds a closer correspondence between SSM/I winds and other SSM/I products (cloud, rainfall, water vapour) than one finds between SSM/I winds and winds derived from surface analyses. In fact the product may be beneficial in aiding frontal and precipitation analyses.

4. Some of the greatest problems facing an analyst in the Atlantic Region are small lows or frontal waves which develop on the Gulf Stream and move northeast over our southern marine areas. From satellite imagery it is difficult to assess whether these features are relatively open with light winds or whether there is in fact a small area of strong circulation associated with them. In most

cases there will be (liquid) precipitation in these features and therefore SSM/I will indicate winds up 50 or 60 knots no matter what the circulation really is.

2.2 THE OBJECTIVE APPROACH

Ships reports were extracted from the nearest surface analysis both before and after SSM/I valid times. For the same positions SSM/I winds were extracted from the difax charts and water vapour, cloud cover, and rainfall rate were extracted from the smaller scale SSM/I charts.

Comparisons between ship data and SSM/I data must be treated with caution because there are several sources of error which must be considered.

1. Time difference between the observation and the SSM/I value can be as much as 3 hours. This is especially important when low pressure systems are moving rapidly across the region.
2. The very strong isotach gradients exhibited by SSM/I makes interpolation between SSM/I values very difficult.
3. There are well known errors common to ship reports such as the difficulty in measuring wind speed from a moving vessel, errors in coding both position and wind speed, etc. These errors may be exaggerated if reports from the same ship are used twice (once before and once after SSM/I valid time).
4. Most ship anemometers are around 20 metres ASL and rig anemometers are around 80 metres ASL consequently one would expect reports from ships and rigs to give higher windspeeds than estimated by SSM/I at one metre ASL.
5. Ship reports are rounded to the nearest 5 knot value before being plotted on the synoptic chart. This can change the report by as much as 3 knots which may be significant when comparing with SSM/I values.
6. Ship reports are observations taken at a single point, but SSM/I data is representative of a 40 km square area.

Only a certain degree of quality control was possible with the ship data. Ships reports which appeared obviously incorrect were rejected, for example ships reporting winds over one hundred knots and reports that did not agree reasonably well with others in the vicinity.

Two statistical methods were applied to this data. First the data was divided into classes so that simple comparisons could be made. Second some of the data was run through a micro-computer statistics package to examine correlations.

2.2.1 RESULTS FROM COMPARISONS

In normal circumstances one would expect SSM/I winds, which are nominally for one metre ASL to be less than ship reports. Therefore one would have doubts where SSM/I wind is greater than or equal to ships wind. In January this occurred 24.4 percent of the time, 31.2 percent in February and 19.7 percent in March. The lower value in March may reflect some improvements made to the algorithms used in the production of SSM/I winds. This would imply that 70 to 80 percent of the time SSM/I is either reasonable or possibly too low. The occasions when SSM/I winds were greater than observed winds were compared with other SSM/I data. It was found that in general one half to three quarters of these occurred when SSM/I reported a rain rate of more than 0.1 mm/h and water vapour greater than 2 cm.

A matrix of wind differences (ships winds minus SSM/I winds) was generated as shown in Table 1. It was grouped according to SSM/I indicated winds of 0 to 9 knots, 10 to 19 knots, 20 to 29 knots, 30 to 39 knots and 40 knots or greater. Ships winds are expected to be greater than the SSM/I value so a larger range was used for the first positive (i.e. column one) value than any other category. In other words it was judged that a ships wind of not more than 15 knots greater than SSM/I wind could be regarded as a hit, and that cases where SSM/I wind was not more than 10 knots greater than the ships wind may also be regarded as a reasonable estimate.

From examination of the tables the problem of SSM/I winds of less than 9 knots can be seen. Although it is not apparent in January, in February one third and in March about one fifth of the cases would appear to have been too low.

The categories 10-19 knots and 20-29 knots appear to be reasonably well handled. The problem with stronger winds is also apparent from the table. The worst case is February when 43 reports of SSM/I winds are more than 11 knots higher than ships winds for SSM/I estimates over 40 knots and of these a half are more than 21 knots higher than the ships value. Also in March about one half of the SSM/I estimates in the greater than 40 knots category are more than 11 knots higher than the ships winds.

TABLE 1. Comparison between SSM/I and ships winds.

January 21 - January 31

SSM/I	Ships wind minus SSM/I wind (154 cases)					
	0-15	16-25	>26	-1 to -10	-11 to -21	<-21
0-9	22	3	0	0	0	0
10-19	44	3	0	8	0	0
20-29	35	3	0	13	2	0
30-39	9	0	0	3	3	3
>40	2	0	0	0	1	0

February 1 - February 29

SSM/I	Ships wind minus SSM/I wind (804 cases)					
	0-15	16-25	>26	-1 to -10	-11 to -21	<-21
0-9	169	69	11	7	0	0
10-19	160	32	6	33	3	0
20-29	86	6	1	52	16	5
30-39	35	1	0	27	16	6
>40	3	1	0	15	21	22

March 1 - March 30

SSM/I	Ships wind minus SSM/I wind (954 cases)					
	0-15	16-25	>26	-1 to -10	-11 to -21	<-21
0-9	209	50	8	16	0	0
10-19	264	52	11	38	0	0
20-29	129	27	2	33	7	1
30-39	37	5	8	19	14	2
>40	4	6	0	2	6	4

2.3 STATISTICAL PACKAGE.

The following information was fed into a micro-computer statistical package :

wind	- ships wind
SSM/I	- SSM/I estimate of wind speed
diff	- the difference between ships wind and SSM/I wind
wv	- SSM/I derived water vapour
cc	- SSM/I derived cloud cover
rr	- SSM/I derived rainfall rate
temp	- ships temperature
dew pt	- ships dew point
sst	- ships sea surface temperature
stab	- temp minus sst - an indication of stability

The statistics package was unable to handle all of the data at one time, so it was divided into the following periods: January 21 to February 14, February 15 to February 29 and March 2 to March 7. Unfortunately, due to lack of time and computer problems we were unable to run the data for the whole of March. The resulting correlation matrices are shown in tables 2 through 4.

After eliminating the parameters which least correlated with wind, e.g., temperature factors, reduced correlation matrices were developed and are produced in tables 5 through 7.

Multiple regression analysis was also performed upon the data with the results displayed in tables 8, 9 and 10. In the first case (table 8) SSM/I wind was treated as the dependent variable with the predictors being ships wind, SSM/I water vapour, SSM/I rain rate and SSM/I cloud cover. The second and third cases held the difference (ships wind minus SSM/I wind) as the dependent variable and used the remaining SSM/I products (water vapour, cloud cover and rain rate) as predictors together with ships wind in table 9 and with SSM/I wind in table 10.

TABLE 2. Correlation Matrix for January 21 to February 14. (530 cases)

	ssmi	wind	diff	wv	rr	cc	temp	dewpt	sst	stab
ssmi	1.00	.41	.58	.56	.42	.64	.35	.39	.32	.08
wind	.41	1.00	-.46	.14	.09	.16	.04	.07	.05	-.26
diff	.58	-.46	1.00	.38	.26	.46	.32	.33	.25	.13
wv	.56	.14	.38	1.00	.66	.76	.52	.56	.36	.28
rr	.42	.10	.26	.66	1.00	.64	.27	.30	.16	.19
cc	.64	.16	.46	.76	.64	1.00	.46	.51	.34	.21
temp	.35	.04	.32	.52	.27	.46	1.00	.93	.79	.38
dewpt	.39	.07	.33	.56	.30	.51	.93	1.00	.70	.39
sst	.32	.05	.25	.36	.16	.34	.79	.70	1.00	-.23
stab	.08	-.03	.13	.28	.19	.21	.37	.39	-.23	1.00

TABLE 3. Correlation Matrix for February 15 to February 29. (465 cases)

	ssmi	wind	diff	wv	rr	cc	temp	dewpt	sst	stab
ssmi	1.00	.52	.68	.78	.59	.48	.09	.16	.04	.02
wind	.52	1.00	-.26	.32	.19	.16	-.03	.01	-.10	.14
diff	.68	-.26	1.00	.60	.50	.41	.14	.18	.13	-.08
wv	.78	.32	.60	1.00	.68	.58	.22	.29	.16	.01
rr	.59	.19	.50	.68	1.00	.34	.05	.09	.01	.04
cc	.48	.16	.41	.58	.34	1.00	.17	.25	.09	.07
temp	.10	-.03	.14	.22	.05	.17	1.00	.90	.77	.13
dewpt	.17	.01	.18	.29	.09	.25	.90	1.00	.64	.21
sst	.04	-.10	.13	.16	.01	.09	.77	.64	1.00	-.44
stab	.02	.14	-.08	.01	.04	.07	.13	.21	-.44	1.00

TABLE 4. Correlation Matrix for March 2 to March 7. (187 cases)

	ssmi	wind	diff	wv	cc	rr	temp	dewpt	sst	stab
ssmi	1.00	.65	.36	.63	.58	.45	.01	.06	-.10	.19
wind	.65	1.00	-.47	.37	.22	.29	-.19	-.14	-.15	.05
diff	.36	-.47	1.00	.23	.38	.12	.25	.25	.07	.16
wv	.63	.37	.23	1.00	.69	.70	.17	.15	.07	.11
cc	.58	.22	.38	.69	1.00	.46	.31	.33	.12	.20
rr	.45	.29	.12	.70	.46	1.00	-.03	-.02	.01	-.04
temp	.01	-.19	.25	.17	.31	-.03	1.00	.88	.73	.14
dewpt	.06	-.15	.25	.15	.33	-.02	.88	1.00	.55	.26
sst	-.10	-.15	.07	.07	.12	.01	.73	.55	1.00	-.55
stab	.19	.05	.16	.11	.20	-.04	.14	.26	-.55	1.00

TABLE 5. Reduced correlation matrix. Jan 21- Feb 14 (530 cases)

	SSM/I	wind	wv	rr	cc
SSM/I	1.00	.42	.55	.39	.64
wind	.42	1.00	.17	.11	.14
wv	.55	.17	1.00	.64	.74
rr	.39	.11	.64	1.00	.58
cc	.64	.14	.74	.58	1.00

TABLE 6. Reduced correlation matrix. Feb 15- Feb 29 (465 cases)

	SSM/I	wind	wv	rr	cc
SSM/I	1.00	.50	.74	.56	.53
wind	.50	1.00	.30	.16	.17
wv	.74	.30	1.00	.70	.63
rr	.56	.17	.70	1.00	.40
cc	.53	.17	.63	.40	1.00

TABLE 7. Reduced correlation matrix. Mar 2 -Mar 7 (187 cases)

	SSM/I	wind	wv	rr	cc
SSM/I	1.00	.58	.67	.57	.60
wind	.58	1.00	.30	.19	.12
wv	.67	.30	1.00	.70	.71
rr	.56	.19	.70	1.00	.52
cc	.60	.12	.71	.52	1.00

MODEL FITTING RESULTS

TABLE 8. SSM/I as dependent variable.

	Jan 21 - Feb 14 (477 cases)	Feb 15 - Feb 29 (465 cases)	Mar 2 - Mar 7 (187 cases)
Constant	4.23	-0.14	-1.37
wind	0.38	0.40	0.45
wv	1.01	3.42	1.08
rr	-0.37	0.49	1.83
cc	2.61	1.69	1.16

TABLE 9. Difference as dependent variable.

	Jan 21 - Feb 14 (477 cases)	Feb 15 - Feb 29 (465 cases)	Mar 2 - Mar 7 (187 cases)
Constant	3.71	-0.26	-1.54
wind	-0.61	-0.60	-0.54
wv	0.99	3.44	0.95
rr	-1.21	1.53	1.74
cc	2.73	0.49	1.19

TABLE 10. Difference as dependent variable.

	Jan 21 - Feb 14 (477 cases)	Feb 15 - Feb 29 (465 cases)	Mar 2 - Mar 7 (187 cases)
Constant	-14.23	-14.27	-13.45
SSM/I	0.51	0.49	0.23
wv	-0.30	0.10	-1.05
rr	-1.04	1.50	1.65
cc	1.33	0.35	1.36

2.3.1 RESULTS FROM STATISTICAL PROGRAMME.

The following points emerge and are in agreement with the findings already documented. SSM/I winds show higher correlations with rain rate, cloud cover and water vapour than with ships winds. The difference between SSM/I winds and ships winds also correlates highly with these parameters.

The worst period is perhaps Feb 15 to Feb 29 (Table 6) where SSM/I has a correlation coefficient of .74 with water vapour but only .50 , with ships wind.

The best correlation between ships wind and SSM/I wind is .58 in March, the worst is January 21 to February 14 where it is only .42. The higher value in March may be due to improvements made during the course of the experiment or it may be due to the small size of the sample analyzed (in March).

The multiple regression analysis indicates similar findings. In almost every example the dependent variable (both for SSM/I wind and for the difference between the ships wind and the SSM/I wind) is found to change more with a change in SSM/I's other products than with anything else.

3.0 CONCLUSIONS FROM SSM/I WIND DATA.

SSM/I surface wind algorithms appear to work well in the absence of liquid precipitation and in unstable flows. Generally in these cases there is already reasonable confidence in the surface analysis, though the SSM/I data may help to identify areas of stronger and areas of weaker flow, which might have otherwise been smoothed out by the analyst.

The SSM/I surface wind algorithms do not seem very reliable in handling the transition from very light winds to stronger ones and little faith can be placed on the large areas it displays of less than 10 knots.

In areas where there is already greatest uncertainty in the surface analysis it seems that little confidence can be placed on SSM/I wind data. The high correlation between SSM/I winds and the other SSM/I parameters of rain rate, cloud cover, and water vapour, is a major problem and must be eliminated before SSM/I wind data can be used by the operational meteorologist.

4.0 EVALUATION OF SSM/I CLOUD, RAIN RATE AND WATER VAPOUR DATA.

It was felt that SSM/I may give valuable assistance in analysis of cloud and precipitation and thereby indirectly assist in locating frontal systems as well. To this end a brief evaluation of SSM/I's other products, namely rain rate, water vapour and cloud cover, was performed.

First the same ship reports which were used in evaluating SSM/I winds were compared with SSM/I data. As previously noted, these reports can be as much as 3 hours before or after the SSM/I pass. It was felt that for SSM/I to be regarded as correct it should indicate the following minimum criteria when a ship reports precipitation :- cloud cover greater than 4 oktas, rain rate greater than 0.1 mm/h and water vapour greater than 2 cm. The latter two classes are the first step up from the minimum that SSM/I displayed. Only reports from ships of rain, snow and showers (rain and/or snow) were used. Drizzle was excluded. Roughly 1800 ships reports were used.

The results are not impressive. In January SSM/I indicated the minimum criteria on 5 of the 31 occurences of precipitation. In February there were 29 successes out of 133 cases and in March the score was 33 out of 164 .

Precipitation was further broken down into the following types :- rain, snow, rain and snow mixed, rain showers, snow showers, and showers of rain and snow mixed. Over the whole period there were 74 reports of snow, none of which SSM/I managed to show. Of the 77 reports of snow showers SSM/I managed to show only 3. SSM/I did fare better with rain and scored 3 out of 7 in January, 22 out of 35 in February and 23 out of 53 in March. This data is displayed in table 11.

The rigs on the Northern Grand Banks (approximately 46.5N 48.5W) provide hourly reports made by certified weather observers. A second evaluation using data from this single location was also performed. Comparisons with GOES Infra Red satellite imagery were also performed. In these cases there are no problems of time differences between the SSM/I data and the rig or satellite data as the rig reports are made hourly and GOES images are received every half hour.

The results are displayed in table 12 and again they are not impressive. There are 17 occasions when precipitation was reported but SSM/I identified only 3 of them. It is significant to note that these three cases were all rain. In January and February the skies were almost always overcast or at least broken but SSM/I only indicated more than 0-2 oktas on 2 occasions and those 2 were 2 of the 3 rain cases previously mentioned. SSM/I fared a little better in March indicating 2 to 4 oktas or more 16 times out of a possible 25.

Windspeed was actually not too bad. Generally it was lower than observed wind speed as it should be when compared with reports at 80 m ASL and it was markedly so in strong southerly winds. However it was stronger than reported for the 3 cases where it identified rain. In fact in these cases rig winds were of the order of 40 to 50 kt and SSM/I winds were of the order of 50 to 60 kt which initially appears impressive until one considers the height of the rig anemometers and what they should be reporting if there were indeed 50 to 60 kt winds at 1 m ASL.

A few sample GOES IR pictures were compared more broadly with SSM/I products. Examination of GOES imagery gave similar findings to those already noted. Large areas of cloud shown on GOES pictures are missed completely by SSM/I. SSM/I indicates cloud over southern and eastern parts of the coverage but usually much less over northern areas which again tends to suggest its "blindness" to ice/snow clouds. An example of this is seen in figures 1 and 2. Figure 1, the SSM/I cloud picture for January 30 at 0856Z shows cloud only over the southeastern area of its coverage. The corresponding GOES IR satellite photo shows that there was cloud over the whole area of SSM/I coverage.

At times SSM/I appears to either displace the cloud or else only see part of it, specifically those parts which contain water droplets. An example of this is shown in figures 3 and 4. There is a very close resemblance between the shapes of the SSM/I cloud pattern (fig 3) and the GOES IR satellite photo but a careful examination of the two figures reveals that the back edge of the cloud in the SSM/I depiction is about 4 degrees of longitude further east over the Northern Grand Banks than that shown on the GOES photo.

5.0 CONCLUSIONS ON SSM/I MOISTURE DATA.

SSM/I depiction of cloud and rainfall rate does not appear to be at all reliable. In the cases examined temperatures were typically near or below zero celsius and precipitation which SSM/I failed to depict was in the form of snow. Yet SSM/I seems to be able to indicate areas of liquid precipitation well. It would appear that it is actually "blind" to ice particles and may only "see" clouds or precipitation that contains liquid. If this is the case then it seem that SSM/I data may well be useful in determining precipitation type. Otherwise it appears that its cloud, water vapour and rain rate information is as unreliable as its wind data.

Table 11. SSM/I data compared with ships reports of precipitation.

Precipitation type	January SSM/I	January ship	February SSM/I	February ship	March SSM/I	March ship
rain	3	7	22	35	23	53
snow	0	12	0	38	0	24
rain/snow	0	0	1	0	1	1
rain shower	2	2	5	23	7	45
snow shower	0	7	1	35	2	35
rain/snow shower	0	3	0	2	0	6
all precip	5	31	29	133	33	164

TABLE 12. Observations from rigs on Hibernia (46.5N, 48.5W) compared with SSM/I data.

Time (UTC) (*)	Wind Dir Speed (kts)	Wx	Cld	T (C)	DP (C)	Wind Speed (kts)	Cld Cover (kts)	Rain Rate mm/h	Water Vpr. cm
	RIG OBSERVATIONS					SSM/I DATA			
JAN									
222231	26040	–	SC10	1	-2	20-30	0	0-.1	0-2
230831	31018	–	SC8	-2	-5	10-20	0	0-.1	0-2
240831	12005	–	SC4	-3	-8	0-10	0	0-.1	0-2
300831	35024	SW--	SC10	-5	-10	10-20	0	0-.1	0-2
302231	31027	SW-	SC9	-6	-11	10-20	0	0-.1	0-2
310831	27023	–	SC9	-4	-7	10-20	0	0-.1	0-2
FEB									
012231	21037	F	F 10	1	1	20-30	0-2	0-.1	0-2
020831	27020	F	F 10	0	0	10-20	0	0-.1	0-2
040931	30023	SW--	SC6	-5	-10	0-10	0	0-.1	0-2
042131	30021	–	CU2CI1	-5	-10	0-10			
050931	11015	–	AS10	-3	-7	0-10	0-2	0-.1	0-2
052132	23042	F	SF3ST6	4	2	10-20	0	0-.1	0-2
060831	25035	SW--	SC10	-1	-5	10-20	0	0-.1	0-2
070831	36014	3/8S	S6ST4	-4	-5	10-20	0	0-.1	0-2
080931	30034	–	SC8	-6	-13	10-20	0	0-.1	0-2
092231	03017	–	OVC	-3	-8	10-20	0-2	0-.1	0-2
102131	08013	–	SC8AC2	-1	-6	0-10	0	0-.1	0-2
112131	30035	–	CU4SC5	-1	-5	10-20	0	0-.1	0-2
120931	31030	SW-	S5CU5	-7	-10	10-20	0	0-.1	0-2
122131	33030	–	SC8	-8	-14	10-20	0	0-.1	0-2
150931	27035	–	SC8	-2	-6	10-20	0	0-.1	0-2
160831	21026	–	SC7	-1	-2	0-10	0	0-.1	0-2
162231	20033	–	SC10	2	1	10-20	0-2	0-.1	0-2
182231	26029	–	SC9	-2	-5	10-20	0	0-.1	0-2
192231	01015	–	AC4CS6	-2	-5	0 -10	0	0-.1	0-2
202131	34014	–	SC9	-3	-7	0 -10	0	0-.1	0-2
210931	19010	–	AS5CS5	-3	-5	0-10	0	0-.1	0-2
212231	17050	R-F	F2 ST8	3	2	40-50	8	1-3.5	0-2
240931	20038	–	CS6	2	0	10-20	0-2	0-.1	0-2
250831	17042	R-F	F4 ST6	4	2	10-20	0-2	0-.1	0-2
260831	17044	R-F	OVC	5	5	50-60	8	3.5-7	>8
262231	13040	1/8F	W3X	4	4	10-20	0-2	0-.1	0-2
290931	32015	4F	OVC	0	0	10-20	0-2	0-.1	0-2

TABLE 12 (cont/d).

Time (UTC) (*)	Wind Dir Speed (kts)	Wx	Cld	T (C)	DP (C)	Wind Speed (kts)	Cld Cover (kts)	Rain Rate mm/h	Water Vpr. cm
	RIG OBSERVATIONS					SSM/I DATA			
MARCH									
040831	19021	–	OVC	2	0	20-30	8	0-.1	0-2
042231	31005	–	BKN	2	0	0-10	2-4	0-.1	0-2
050731	15030	OF	WOX	2	2	10-20	4-6	0-.1	0-2
060831	26031	–	BKN	-2	-8	10-20	0	0-.1	0-2
062131	28025	SW--	BKN	-3	-8	10-20	0	0-.1	0-2
072131	21023	–	-SCT	0	-3	0-10	0	0-.1	0-2
080831	17027	–	BKN	2	1	0-10	0-2	0-.1	0-2
082131	11043	R--F	OVC	4	2	30-40	6-8	0-.1	0-2
092231	06034	–	BKN	3	1	10-20	2-4	0-.1	0-2
100831	06020	6F	-BKN	2	1	0-10	2-4	0-.1	0-2
110831	23008	OF	WOX	-1	-1	0-10	2-4	0-.1	0-2
120931	20020	8SW-	OVC	1	-1	0-10	0-2	0-.1	0-2
122231	23019	SW--	BKN	-2	-7	10-20	0	0-.1	0-2
140831	28013	–	BKN	-3	-7	0-10	0	0-.1	0-2
142131	11015	–	OVC	-1	-7	10-20	6-8	0-.1	0-2
152231	07024	–	OVC	-1	-2	10-20	4-6	0-.1	0-2
160931	18030	1/2F	OVC	3	3	0-10	4-6	0-.1	0-2
162131	18029	–	SCT	2	0	10-20	0	0-.1	0-2
170931	21034	3S-F	OVC	0	0	20-30	2-4	0-.1	0-2
180931	31034	–	OVC	-2	-5	20-30	2-4	0-.1	0-2
190831	29026	–	SCT	-2	-7	0-10	0	0-.1	0-2
200931	16043	5RF	OVC	4	4	40-50	8	3.5-7	>8
202031	26047	–	BKN	1	-2	20-30	0	0-.1	0-2
210831	26035	–	OVC	-1	-6	10-20	0	0-.1	0-2
212231	25031	6SW-	OVC	-1	-1	10-20	0	0-.1	0-2
232131	31025	S--	OVC	-1	-4	20-30	2-4	0-.1	0-2
280831	29024	–	SCT	3	2	0-10	2-4	0-.1	0-2
300831	07031	1/8F	W2X	3	3	10-20	4-6	0-.1	0-2
302231	03027	1/8F	W2X	2	2	0-10	4-6	0-.1	0-2

(*) Time of GOES IR satellite picture

Rig observations taken from Sedco 710 and Bowdrill 3

REFERENCES

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Smith, S.D. 1981: Factors for adjustment of wind speed over water to a 10 meter height. Bedford Institute of Oceanography Report Series BI-R-81-3.

SSM/I CLOUD COVER Orbit 3167 January 30, 1988 (Day 030). GMT 08:43 - 08:56

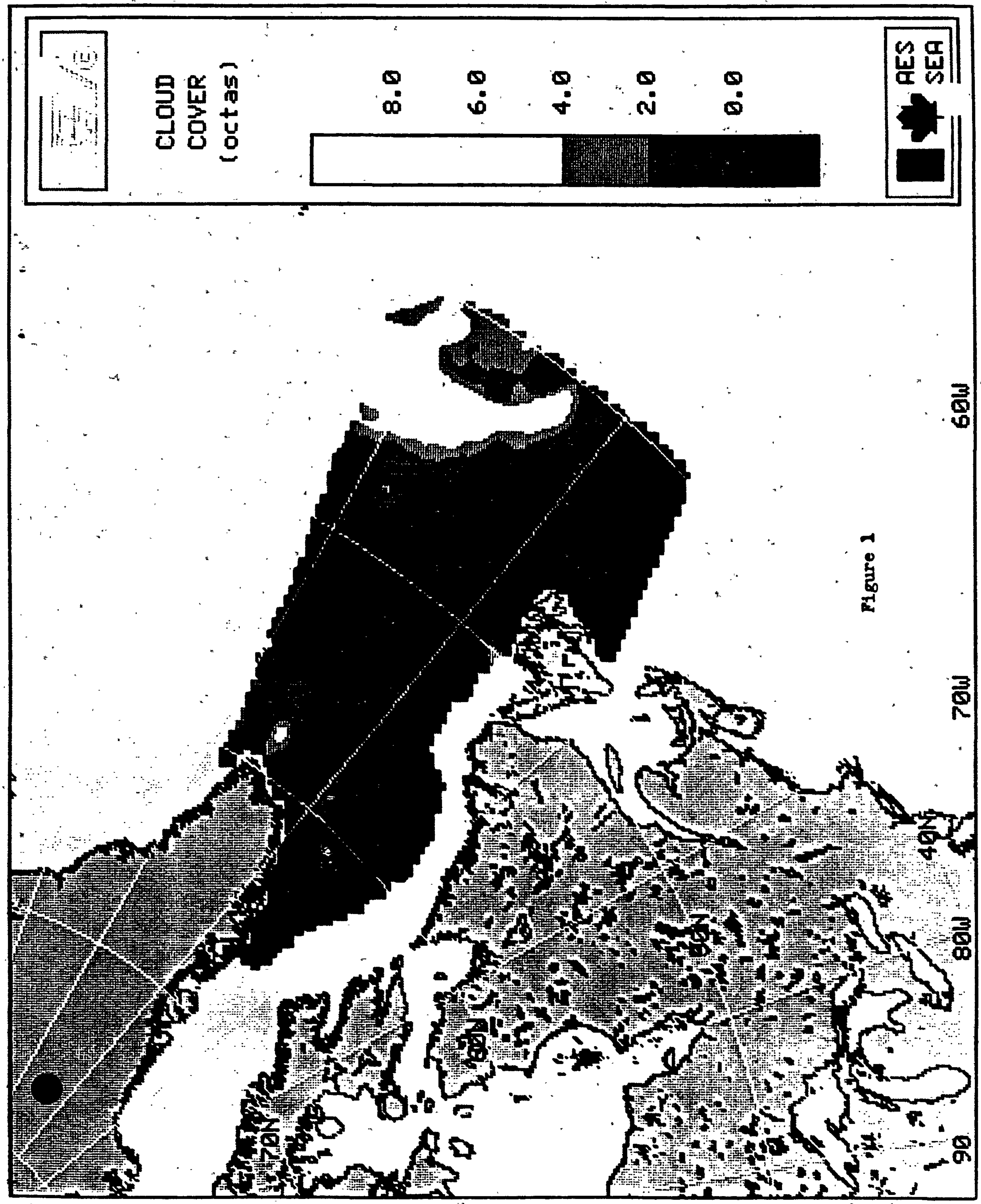

Figure 1

Ph.D. Associates Inc. AES

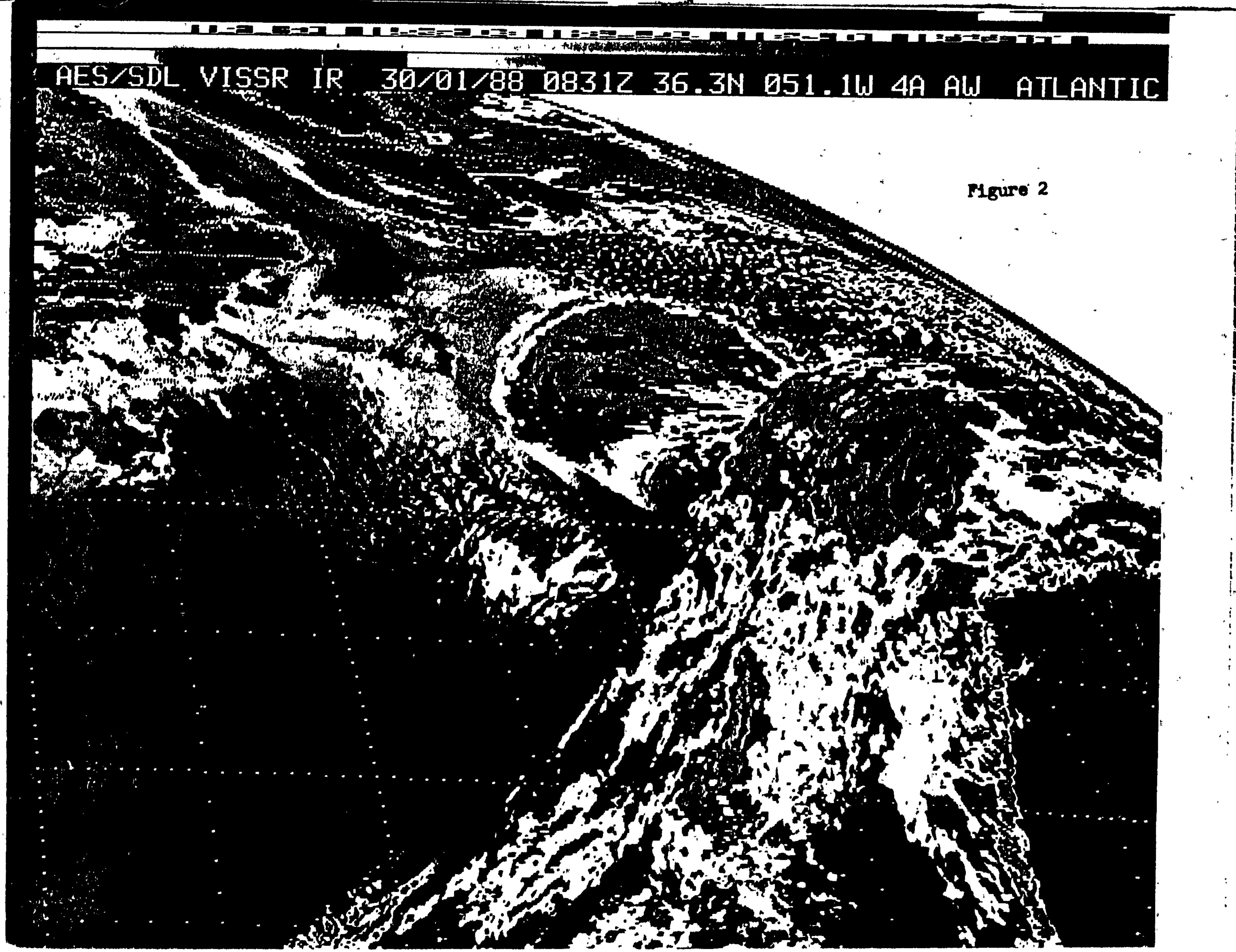

Figure 2

SSM/I CLOUD COVER Orbit 3259 February 5, 1988 (Day 036) GMT 21:20 - 21:34

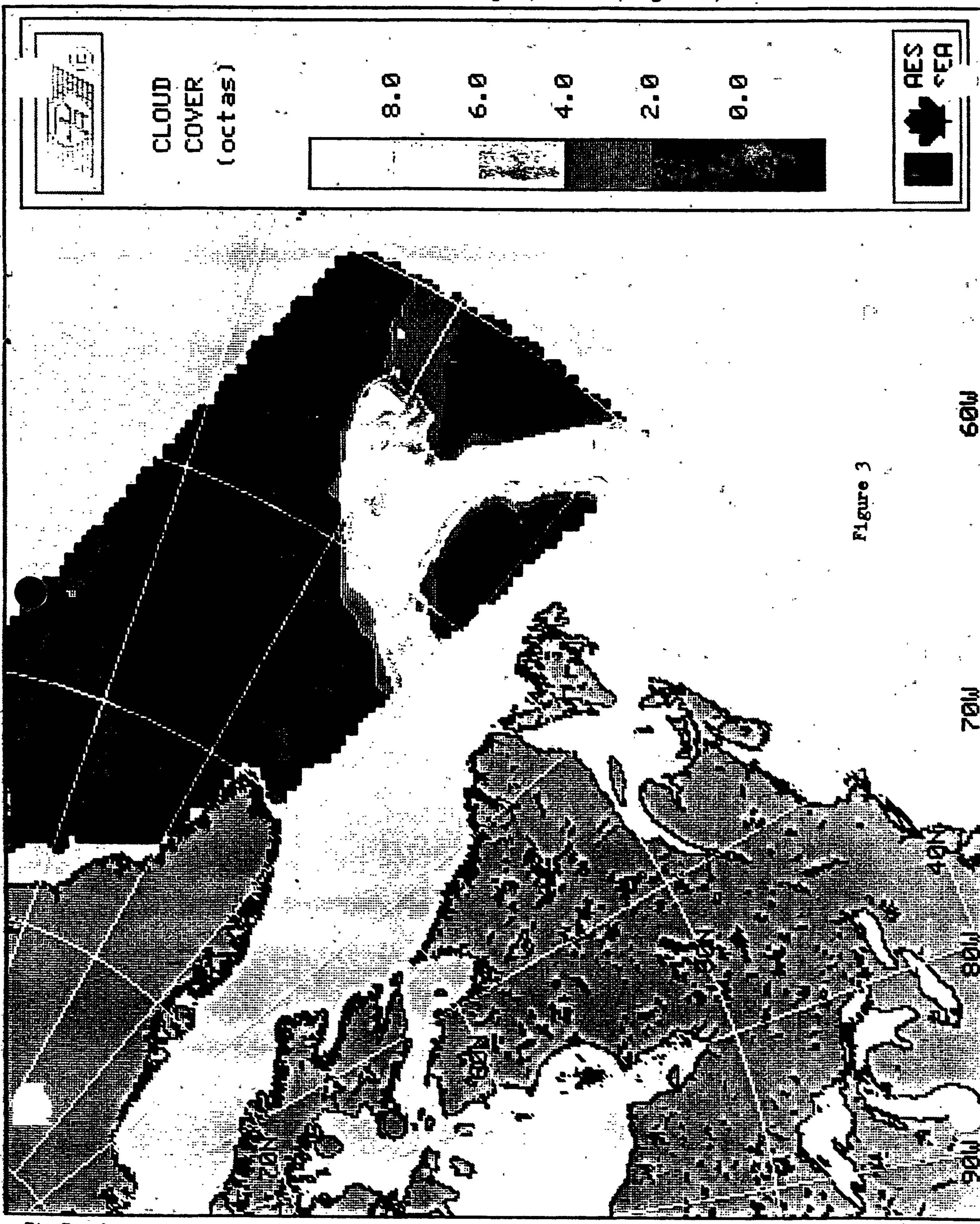

Figure 3

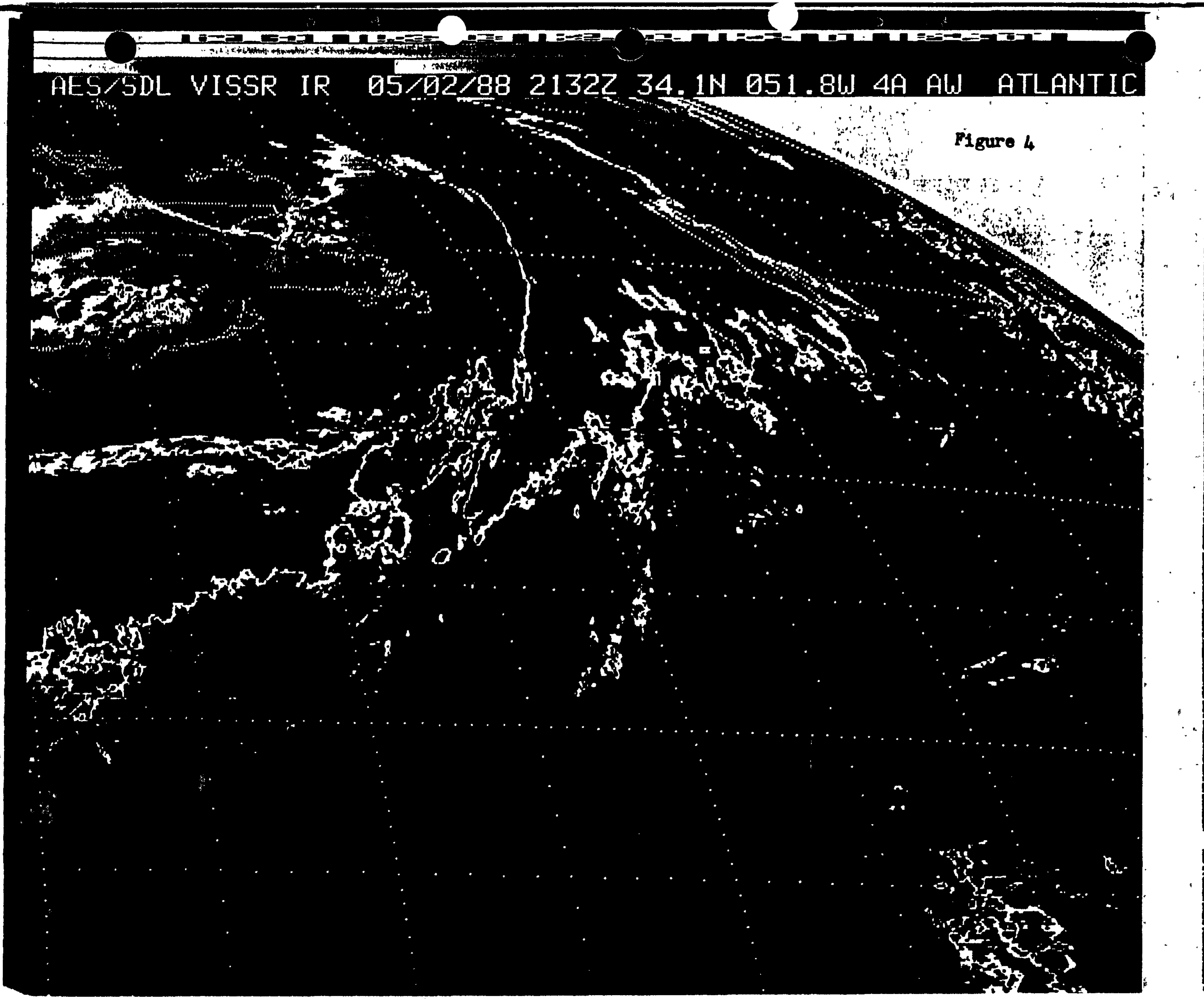

Figure 4