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Surface Wind Measurements from Satellites - A Comparison of SEASAT Scatterometer Data with JASIN Surface Winds.

by

D. Offiler, Met O 19

January 1982

Met O 19
(Satellite Meteorology Branch)
Meteorological Office
London Road
BRACKNELL
Berks RG12 2SZ

Surface Wind Measurements from Satellites - A Comparison of SEASAT Scatterometer Data with JASIN Surface Winds

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Summary

This report describes the data used in, and results of a comparison of wind vector measurements from the SEASAT-A Satellite Scatterometer (SASS) with JASIN ship and buoy winds observed during July to September, 1978. Overall standard deviations of the differences in speed were found to be 1.7 m/s and in direction 17 degrees, well within the SASS design goal of 2 m/s and 20 degrees. Data have also been analysed with respect to radar polarisation, swath position etc, and two case studies are presented showing the SASS performance on a larger scale.

A comparison of the JASIN platform winds have been studied to assess the surface measurement data quality, both between platforms at coincident times ("inter-platform comparison") and from observation to observation within the time-series for each platform ("intra-platform comparison").

1. Introduction

SEASAT-1 was launched on 26 June 1978 and prematurely failed on 10 October 1978. This experimental oceanographic satellite had an orbit height of nearly 800 km and an inclination of 108 degrees - ie its maximum latitude was 72 deg N and S - and its orbit was not sun-synchronous. It carried five science instruments. four of them microwave: a radar altimeter, wind scatterometer, synthetic aperture radar, microwave radiometer, and a visible/infra-red radiometer. A general account of the SEASAT-1 mission and instruments is contained in a special issue of Science, 29 June 1979.

The SEASAT-A Satellite Scatterometer (SASS) was designed to measure the surface wind vector over the ocean to an accuracy of ± 2 m/s or 10 per cent (whichever is greater) and ± 20 degrees in direction. In order to validate the actual accuracies of all the instruments, a special oceanographic exercise, the Gulf of Alaska Experiment (GOASEX) was undertaken, involving several oceanographic vessels and an aircraft carrying a similar scatterometer. (Science, 1979, NASA, 1980a)

Coincidentally, the Joint Air-Sea Interaction (JASIN) experiment was conducted in the North Atlantic during July to September, 1978, within the lifetime of SEASAT and when all of its instruments were functioning correctly. This high spatial and temporal set of surface observations provides a reasonable range of meteorological conditions and of a sufficiently high quality to assess the performance of the SASS.

This report will compare the two methods of wind vector measurement, independently of the validation undertaken jointly by the Jet Propulsion Laboratory, Pasadena (USA) and the Institute of Oceanographic Sciences, Wormley (UK) (NASA, 1980b, Guymer et al, 1981, Jones et al, 1981).

2. The SASS data

A description of the measurement of winds by scatterometry, including the principle of measurement and the SASS instrument characteristics, is given in Annex 1. Briefly, the scatterometer emits a polarised beam of microwave radiation and measures the backscattered energy from a defined area of the ocean (about 50 x 50 km).

The backscatter level is dependent on wind speed and direction. Both wind parameters may be deduced by making two orthogonal backscatter measurements, one as the satellite approaches and the other, a few minutes later, as it recedes. The SASS provided winds in a swath about 500 km wide either side of the sub-satellite track. Within these areas, the harmonic nature of backscatter with wind direction leads to ambiguities in the interpretation of the data, providing up to four possible estimates ("solutions") of wind speed and direction. Near nadir, there is no dependence of backscatter on wind direction, and only a speed estimate is possible.

All the SASS wind data used in this study were produced by the Jet Propulsion Laboratory (JPL) using calibrations and corrections obtained from the special aircraft scatterometer under-flights during GOASEX, measurements over the Amazon forest, where backscattering is believed to be isotropic (Bracalente et al, 1980) and validated using GOASEX surface data (NASA, 1980a). The new "SASS-1" algorithms converting the measured radar backscatter to wind vector incorporate this post-launch information. Data from the microwave radiometer (SMMR) have been used by JPL to estimate atmospheric attenuation at the SASS frequency (14.6 GHz) in order to correct the backscatter measurements. The latter have been partly validated using JASIN data, but otherwise the algorithms have not been tuned to JASIN, which remain essentially an independent validation set of surface observations.

All SASS data for the period and area of JASIN (15 July to 15 September, 1978 and 55-65°N, 5-20°W) were supplied by JPL including all solutions of speed (referenced to a height of 19.5 m) and direction at specified geographical locations. Note that although the wind is given at a point, it actually represents a spatial average over typically a 50 x 50 km cell centred on that point. Near nadir measurements, where wind direction cannot be retrieved, have not been used in this study.

3. The JASIN data

The Institute of Oceanographic Sciences (IOS) has collated the JASIN data and made available for this study time series sets of hourly observations (following WMO procedures) from the ships Meteor, Hecla, John Murray and Gardline Endurer, 15-minute autologged data from buoys W2 and B1, and 1-minute autologged data from the ship Tydeman. Only data measured every 15 minutes from Tydeman have been used in this SASS comparison study. The WMO winds are an average over 2 minutes, the autologged data are averaged over the same period as the sampling interval, except for buoy B1, which uses a spot direction and average speed.

By comparing the data from each platform with buoy W2, and using W2 as a standard, IOS have applied corrections to the data (Macklin and Guymer, 1980). As supplied, the winds relate to the anemometer height of each platform - ranging from 2.5 m asl for buoy B1 to 23 m for Meteor (Royal Society, 1979). These wind speeds have been adjusted to a common height of 19.5 m, assuming neutral stability, using the procedure suggested by Pierson (1978). Halberstam (1980) considers that this approach is also valid for unstable cases (ie as long as the Richardson number, $Ri < 0.21$). These adjusted JASIN winds are now comparable to the given SASS observations, and are the speeds used throughout this study.

The period of coverage of each platform, mean daily wind speed and direction during JASIN and inter- and intra-platform comparison studies are given in Annex 2.

4. The SASS/JASIN comparison procedure

4.1 Colocations

The first stage in comparing Satellite and in-situ winds was to identify pairs of observations which were coincident within limits of time and distance. Such pairs are referred to as "colocations".

For each SEASAT pass over the JASIN area, SASS measurement 'points' were colocated with JASIN wind observations for each platform separately. Using the JASIN observation nearest in time to the satellite pass (ie a time difference no greater than ± 30 minutes for the WMO observations and ± 7.5 minutes for the autologged data), all SASS points within a 60 km radius of the platform were noted. There were 132 passes with swaths that provided colocations with at least one JASIN platform, resulting in a total of over 3300 SASS points, with an average of about eight points per 60 km radius circle. Each of these eight or so cases is taken to be a colocation pair, although of course they do not form an independent set. Figure 1 shows a typical SASS swath and the JASIN colocations (for 01Z) on 28 August 1978.(An alternative analysis, using the average SASS winds over the 60km area, is presented in Annex 3).

Wind speeds in the comparison set ranged from less than 0.5 m/s to about 18 m/s, and all directions are represented.

4.2 Removal of anomalous cases

Several anomalous SASS/JASIN pairs of observations have been removed, prior to compiling the statistics.

- About a dozen cases were removed when the (WMO) JASIN observation was clearly in error in direction or speed when compared with those of nearby platforms or with their own time series. These all appear to be coding errors.

- For one pass, a small patch of SASS points (5 cases) showed very high speeds of 12-22 m/s compared with three close JASIN observations of about 4 m/s. This anomaly, probably associated with thunderstorm activity, is discussed in Section 6.1.

- One SASS point, colocated with several platforms, appears to have the solution in the 'correct' quadrant missing: neighbouring SASS measurements did have such a solution.

Several other cases showed speed differences of several metres per second, which were due to strong gradients across the JASIN area. However, these winds have been left in the colocation set.

A total of 3284 SASS/JASIN colocation pairs of wind estimates remain.

4.3 Choice of SASS solution

As previously mentioned, the SASS-1 wind retrieval algorithms produce up to four solutions of wind direction at each point from the two orthogonal backscatter measurements. These solutions, one in each quadrant (referenced to North), have slightly different speeds. Before these winds can be compared with JASIN, the 'correct' solution must be chosen. For the purposes of this study, the solution closest in direction to that of the JASIN observation has been taken, in a similar manner to other studies.

A second method, taking all solutions within a specified sector of the JASIN direction has also been tried for comparison - see Annex 3.

5. Comparison results

5.1 Overall results

The mean and standard deviation of the (SASS-JASIN) differences in speed and direction and the vector differences were first calculated for each platform separately, and then with all data together. These results are set out in Table 1. (The term "standard deviation of the difference" is abbreviated to "SDD" in the following). It can be seen that:

- Comparison of direction with buoy B1 shows a large variance and bias. This is not unexpected given the problems with this buoy - see Annex 2, Section A2.2. Since the winds from this platform seem unreliable, B1 has not been used for the rest of this comparison study.

- The speeds from Tydeman and Hecla show larger SDDs than the other platforms, but not enough to warrant their exclusion.

- Overall, the SASS agrees with JASIN to about 1.7 m/s and 17 degrees, well within the SASS design goal of 2 m/s and 20 degrees. These statistics include cases when the wind speed was below 4 m/s, the lower design limit of the SASS range with the required accuracy. There is no overall significant bias in speed or direction. Excluding Tydeman and Hecla reduces the speed SDD to just over 1.5 m/s.

- 62 per cent of all cases were within 2 m/s and 20 degrees (design goal 46 per cent) and $>$ 98 per cent within 5 m/s and 50 degrees. (d.g. 97 per cent).

- There was no correlation between differences in speed and differences in direction - i.e. there is no evidence that a positive speed difference is associated with a positive (or negative) direction difference.

The average time difference of the SASS and JASIN nominal observation times is about 10 minutes; allowing for an estimated natural wind variability of 0.6 m/s and 9 degrees over a ten minute period (Annex 2, Section A2.3), the SDD of SASS from the 'true' wind would be about 1.6 m/s and 14 degrees.

More detailed statistics using all data are given in the form of scatter diagrams for SASS vs JASIN speed and direction in Figures 2 and 3, histograms of SASS-JASIN speed and direction in Figures 4 and 5, a scatter diagram of speed differences vs direction differences (Figure 6) and a histogram of vector differences (Figure 7).

5.2 Dependence of results on various parameters

Further analysis has been done to determine the effects of various parameters on the SASS retrieval accuracy, as measured by the SDD in speed and direction and vector differences. All colocations were used, except for data from B1, divided according to the parameter under investigation. Three types of parameter were examined: SASS instrument (polarisation and incidence angle), surface conditions (wind speed and direction) and colocation criteria (space and time differences).

- Polarisation. Analysis of SASS winds obtained with both backscatter measurements using horizontal or vertical polarisation or mixed (Table 2) shows that V-pol may be marginally better in speed (and in vector difference) and H-pol slightly worse in direction, though these SDD differences are not statistically significant.

- Incidence angle. An analysis with respect to beam incidence angle range, measured from the vertical, shows (Figure 8), a significant trend to smaller SDD, in both speed and direction, in going from 25 ($\pm$5) degrees to 35 degrees and then increasing again towards the maximum angle of 60 degrees (ie the outside edge of the swath). This might be anticipated, as at shallow angles, the sensitivity of the backscatter to wind is smaller, and at larger angles the level of backscatter becomes smaller and so more difficult to measure within noise.

  However, in all regions the SDDs are within 2 m/s and 20 degrees, and there is no significant bias in speed or direction.

- Wind speed. The variation in SDD with JASIN wind speed range is shown in Figure 9. At speeds below 4 m/s (the lower design limit of SASS), retrieval SDD remains good, but there is a larger bias of nearly 1 m/s. (There is evidence that below 3 m/s, W2 reads low by 1 m/s (Guymer, personal communication)). The differences in direction are bigger, probably because at low speeds, conventional wind vanes often do not record a representative average direction, especially when the averaging period is short.

  In the range 12-16 m/s, there is a large increase in speed SDD. Of the 130 cases (14 individual JASIN observations), 83 are colocations with Tydeman: from Annex 2, this ship's anemometer is suspected to be over-speeding in high winds ($>$ 10 m/s). If Tydeman is excluded, SASS tended to produce higher winds than JASIN by 2-3 m/s in this category, with the speed SDD reduced to about 2.1 m/s.

- Wind direction. The variation in retrieval SDD with JASIN wind quadrant is shown in Figure 10. The quadrant 90-180 degrees shows a higher SDD in both speed and direction. There is a weak correlation ($r = 0.17$) between the two differences (ie a positive speed difference is linked with a positive direction difference), but there is no consistent trend with any other parameter. Since this SDD shows a statistically highly significant difference from those of the other quadrants, there may be some problem in wind retrieval with the particular combination of wind direction and SASS viewing geometry in this sector.

This anomaly may be related to the findings of Halberstam (1981), who has reported that correlation in SASS backscatter with surface measured wind speed was smaller in certain cases in a combined GOASEX and JASIN dataset. The correlation coefficient was smallest when the SASS radar beam was 90 degrees to the wind direction (crosswind), at low or high incidence angles and for horizontal polarisation.

Changing the class boundaries shows that this anomaly lies between wind directions 60 and 180 degrees. Outside this sector, SDDs are below 1.6 m/s and 16 degrees.

- Distance from JASIN platform. Figure 11 shows how the retrieval accuracy varies with the SASS distance from the point JASIN measurement, remembering that the SASS winds relate to a nominal 50 x 50 km area. The speed SDD shows that the 'accuracy' falls off with increasing distance but direction accuracy is marginally, though not significantly improved, from 18 to 17 degrees. The vector differences are essentially constant. These variations are probably due to gradients over the JASIN colocation areas.

- Time difference from JASIN observation. The effect of measurement time difference on the wind retrieval (for the hourly reporting WMO ships only) is given in Figure 12. The speed SDD increases beyond about 20 minutes, but all other changes are non-significant, although it appears that the first 8 minute period is worse than the second. Note that the SASS fore and aft cell measurements may be up to 3 mins apart (the mean time has been used here) and the JASIN WMO observations may be made up to 10 mins before the reporting hour.

6. Synoptic Examples

6.1 4 August: Thunderstorm case.

There was only one occasion during the JASIN period when the wind speeds measured by SASS were clearly in error by more than 10 m/s. This occurred during orbit 557 at 2314 GMT on 4 August 1978, near the southern vertex of the JASIN Triangle. This swath for horizontal polarisation is shown in Figure 13, together with the nearby JASIN observations for 23 GMT, other surface measurements taken at midnight and the analysis (based on the Central Forecasting Office midnight subjective analysis). SASS values ranged from 6 m/s to 22 m/s (with vertical polarisation measurements less than 10 m/s), while JASIN measured wind speeds were about 4 m/s, with little variation before and after the satellite pass. At 23 GMT, Meteor reported light drizzle, with thunder during the previous hour.

A more detailed investigation by IOS and JPL shows that other nearby JASIN ships Discovery and Shackleton also reported thunderstorm activity, with Discovery logging heavy rain just after the pass. Their analysis of the SASS backscatters showed high values in this area, coincident with deep clouds seen in the SEASAT VIRR imagery, both during the previous pass $1\frac{1}{2}$ hours earlier. Radiosonde observations indicated potentially unstable air behind the surface occlusion. (Guymer et al, and Guymer, personal communication). It seems likely, therefore, that the SASS measurements were affected by a thunderstorm associated with deep convection on the occlusion, and may have several causes:

- SASS was operating correctly and measuring locally high winds, eg due to gust fronts/down-draughts from the convecting cell(s).

- Large precipitation meteors caused increased sea-surface roughness, invalidating the backscatter-wind speed relationship.

- Raindrops, usually thought to attenuate microwaves, were large enough to cause additional backscatter, with possibly some contribution from a 'bright band'.

- Radio frequency interference (RFI) from lightning discharge.

The last possible cause is unlikely as each beam measurement, taken several minutes apart, showed a similar increase in backscatter. The SASS also Doppler filters the return signal for range-gating and in addition detects passive radiation at the same frequency to reject background thermal noise. On the first point, there was no evidence in data sampled every minute that there were any large gusts. Considering the possible rainfall rate ($\gtrsim$ 20 mm hr^{-1}?) and convection cell dimensions ($\sim$ 5 km deep and some 10 km^2), either of the other two possible causes, or a combination of both, could have been responsible for the anomalous SASS winds - ie affected directly or indirectly by rain.

6.2 31 August: cold front case.

This case demonstrates the usefulness of satellite-derived winds because of their density of measurements over a swath. Figure 14 shows the synoptic situation at 00 GMT on 31 August 1978, and Figure 15 the wind field, both from the 10-level model objective analysis on the 100 km grid. Fronts have been manually added according to the Central Forecasting Office subjective analysis. The low pressure area over Iceland had been moving north-eastwards, bringing its associated fronts over the JASIN area by midnight.

SEASAT orbit 930 passed just south of Iceland at 0050 GMT, enabling the port swath of the scatterometer to measure winds across JASIN, as shown in Figure 16. Also marked are the observations (at 0100 GMT) and analysis. Meteor's winds had veered by 30 degrees during the previous hour and Tydeman's by 50 degrees in the following hour, showing the cold front to be between them. In this case the surface frontal zone shows clearly in the SASS winds as a line of cells with only two solutions, marking the transition between the wind directions either side of the front.

With experience, synoptic features such as fronts, and especially low pressure centres, can be positioned accurately even with the present level of ambiguity. Subjective analysis of the wind field has been successfully demonstrated by meteorologists working experimentally on SASS data in the United States (NASA, 1980b).

7. Conclusions

As other studies have shown (mainly using Gulf of Alaska data) the SASS instrument met its design goal of measuring near-surface wind vectors to 2 m/s and 20 degrees (rms). Using JASIN data, this analysis has confirmed that overall, and in nearly all sub-categories, SASS was well within these limits. A comparison between the conventionally observed data platforms indicates a variability of a similar size to that between the two systems: the SASS measurements therefore show that they are at least as 'accurate' (on the average) as this special surface data.

However, it should be noted that the comparison of the direction measurements involved a prior estimate of the true wind direction in order to select one of the four possible solutions. (For comparison, Annex 3 presents an alternate analysis based on taking all solutions within a sector of the JASIN wind direction. For wind speeds $\geq$ 4 m/s, and directions within $\pm$ 30 degrees of JASIN, the SDDs were 1.6 m/s and 15 degrees). Future scatterometers, such as the one proposed for the European oceanographic satellite ERS-1 (due for launch 1987) are likely to be able to resolve this ambiguity without reference to such external data over much of the swath.

The two case studies presented have also demonstrated some of the strengths and weaknesses of satellite-measured winds.

8. Acknowledgements

I would like to thank David Lame and Dale Boggs of JPL, Pasadena for help and advice on the processing of SASS data and for supplying the SASS products, and also to Trevor Guymer of IOS, Wormley for the JASIN data and for much of the information on the 4 August thunderstorm case.

References

Bracalente, E.M., D.H. Boggs, W.L. Grantham and J.L. Sweet (1980): The SASS scattering coefficient σ^o algorithm. J. Oceanic Eng., Vol OE-5, No. 2, April 1980, pp 145-154.

Guymer, T.H., J.A. Businger, W.L. Jones and R.H. Stewart (1981): Anomalous wind estimates from the SEASAT scatterometer. Nature (to be published 1981).

Halberstam, I. (1980): Some considerations in the evaluation of SEASAT-A scatterometer (SASS) measurements. J. Phys. Ocean., Vol 10, April 1980, pp 623-632.

Halberstam, I. (1981): Verification studies of SEASAT-A satellite scatterometer (SASS) measurements. J. Geophys. Res., Vol 86, No. C7, 20 July 1981, pp 6599-6606.

Jones, W.L., D.H. Boggs, E.M. Bracalente, R.A. Brown, T.H. Guymer, D. Shelton and L.C. Schroeder (1981): Evaluation of active microwave remote sensing of oceanic wind vector: Results of the SEASAT-JASIN Workshop. Nature (to be published 1981).

Macklin, S.A. and T.H. Guymer (1980): Inter-platform comparisons of JASIN WMO observations. (Unpublished manuscript) JASIN News, No. 15, January 1980, pp 5-9.

NASA (1980a): SEASAT Gulf of Alaska Workshop II report. Jet Propulsion Laboratory, Pasadena, No. 622-107, January 1980.

NASA (1980b): SEASAT JASIN Workshop report. Vol 1: Findings and conclusions. Jet Propulsion Laboratory, Pasadena, No. 80-62, December 1980.

Pierson, W.J. (1978): Verification procedures for the SEASAT measurements of the vector wind with the SASS. Cuny Institute of Marine and Atmospheric Sciences, City College, New York. January 1978. (Report to JPL contract 954411)

Royal Society (1979): Air-Sea Interaction Project: Summary of the 1978 field experiment. London.

Science (1979): Special issue on preliminary results from SEASAT. Vol 204, No. 4400, 29 June 1979.

Table 1. Mean and Standard Deviation of (SASS-JASIN) differences in wind speed and direction, and vector differences* for each JASIN platform

	Meteor	Hecla	John Murray	Gardline Endurer	Buoy W2	Buoy B1	Tydeman	All	excl B1
N	454	446	301	351	574	560	598	3284	2724
$\bar{S}$	-0.04	-0.11	0.21	0.43	0.41	0.91	-0.70	0.15	-0.01
σ_S	1.47	1.83	1.50	1.54	1.50	1.61	1.83	1.71	1.69
$\bar{D}$	0.88	5.37	1.55	-0.87	-2.38	-9.68	3.10	-0.60	1.27
σ_D	17.36	17.19	16.90	15.97	17.62	24.94	17.69	19.35	17.42
$\bar{V}$	2.24	2.70	2.26	1.98	2.27	3.24	2.65	2.52	2.37
σ_V	1.24	1.72	1.13	1.15	1.39	2.07	1.67	1.61	1.46

KEY:

N	No of cases		
$\bar{S}$	mean	speed difference	(m/s)
σ_S	s.d.		
$\bar{D}$	mean	direction difference	(deg)
σ_D	s.d.		
$\bar{V}$	mean	vector difference*	(m/s)
σ_V	s.d.		

* Vector difference $V = (U_S^2 + U_J^2 - 2U_SU_J\cos(D_S - D_J))^{\frac{1}{2}}$

subscript S denotes SASS wind, J for JASIN

Table 2. Mean and Standard Deviation of (SASS-JASIN) differences in wind speed and direction and vector differences by SASS beam polarisation

	Both beams Horizontal	Both beams Vertical	Mixed	All Cases
N	612	929	1183	2724
$\bar{S}$	0.03	-0.11	0.04	-0.01
σ_S	1.72	1.61	1.73	1.69
$\bar{D}$	0.66	1.58	1.33	1.27
σ_D	18.25	17.22	17.15	17.42
$\bar{V}$	2.51	2.23	2.41	2.37
σ_V	1.59	1.27	1.52	1.46

KEY: As Table 1.

Figure 1. SASS swath and JASIN observations - sample colocations.

JASIN observations for 0100 GMT : winds shown conventionally, in knots.

(SASS winds: length of line is proportional to speed - see scale at bottom left.)

SASS retrievals are numbered for reference.

M = Meteor
H = Hecla
JM = John Murray
GE = Gardline Endurer
T = Tydeman

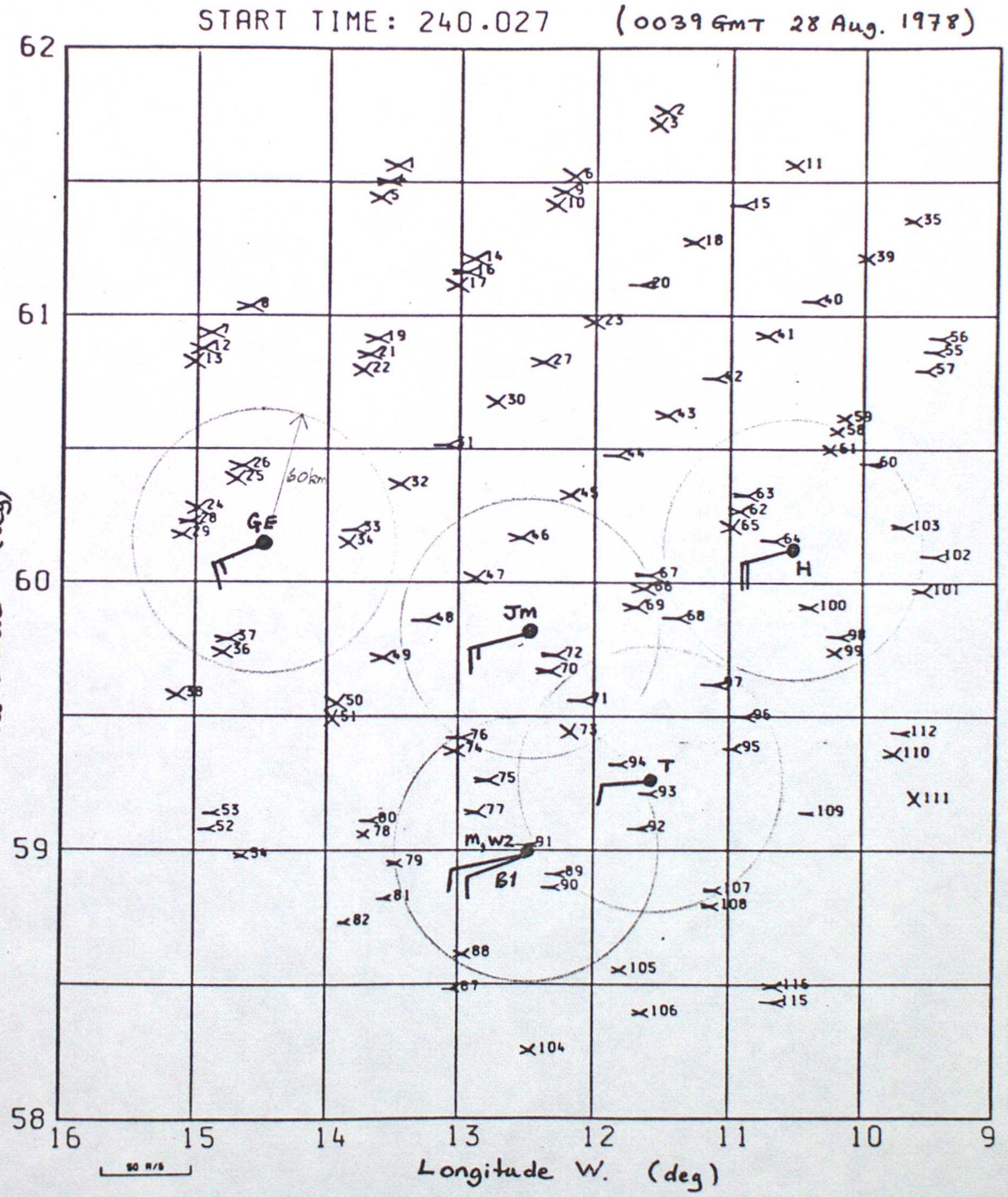
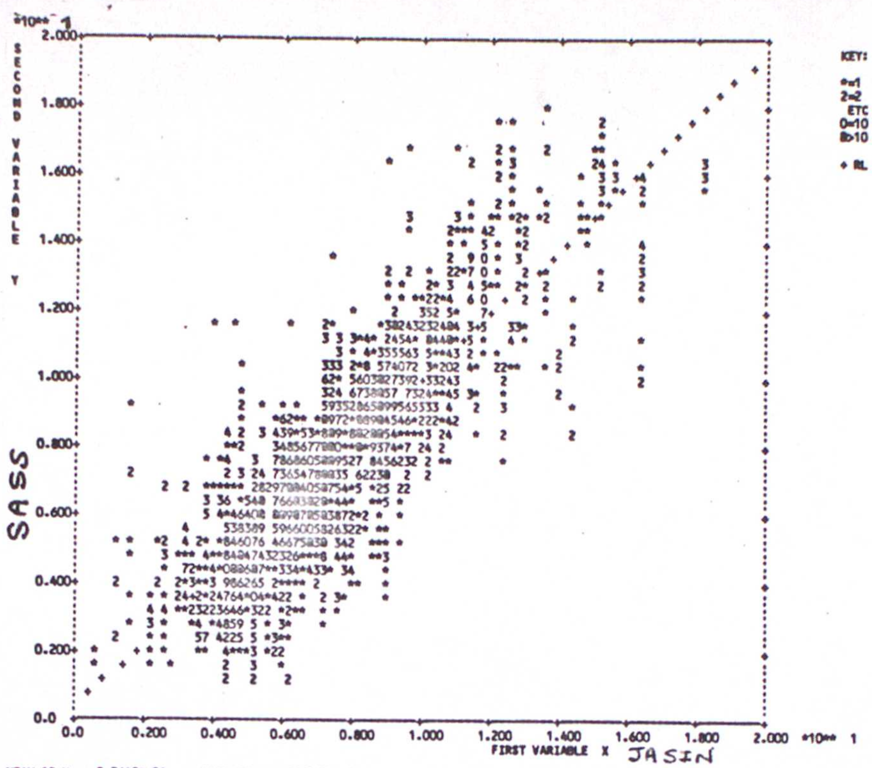
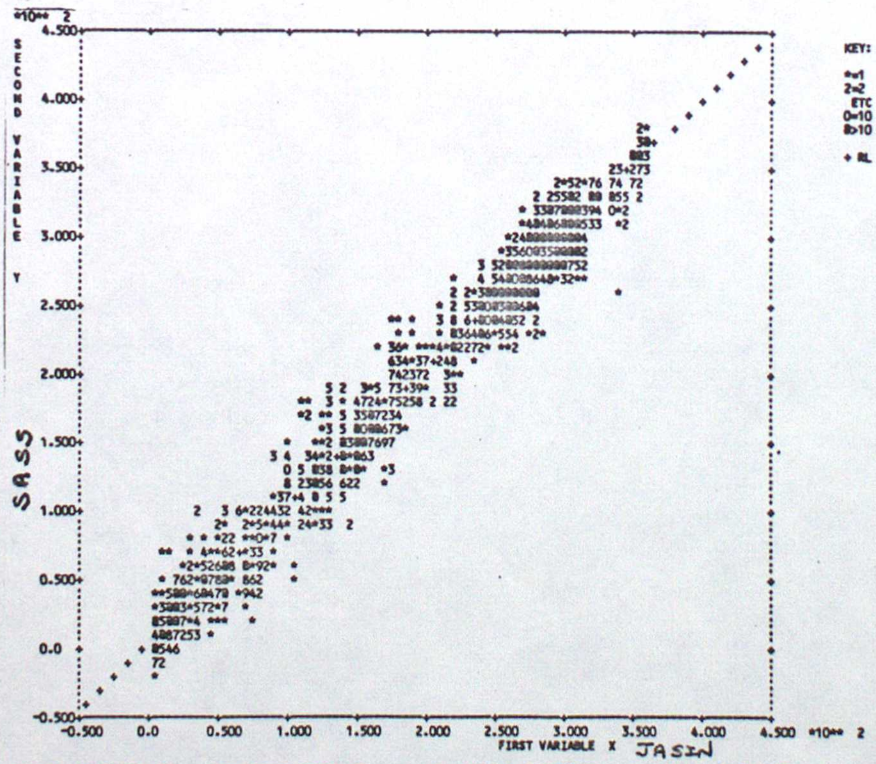


Figure 2. SASS vs. JASIN wind speeds (m/s)



MEAN OF X = 0.7615E+01 MEAN OF Y = 0.7602E+01 S.D. OF X = 0.2705E+01 S.D. OF Y = 0.3111E+01
REGRESSION LINE (Y ON X) - Y = M*X + C - M = 0.9672E+00 C = 0.2373E+00
CORRELATION COEFFICIENT = 0.841 NO. OF CASES: 2724

Figure 3. SASS vs. JASIN wind directions (deg)



MEAN OF X = 0.1998E+03 MEAN OF Y = 0.2011E+03 S.D. OF X = 0.1018E+03 S.D. OF Y = 0.1026E+03
REGRESSION LINE (Y ON X) - Y = M*X + C - M = 0.9928E+00 C = 0.2686E+01
CORRELATION COEFFICIENT = 0.985 NO. OF CASES: 2724

Figure 4. SASS-JASIN wind speed differences (m/s)

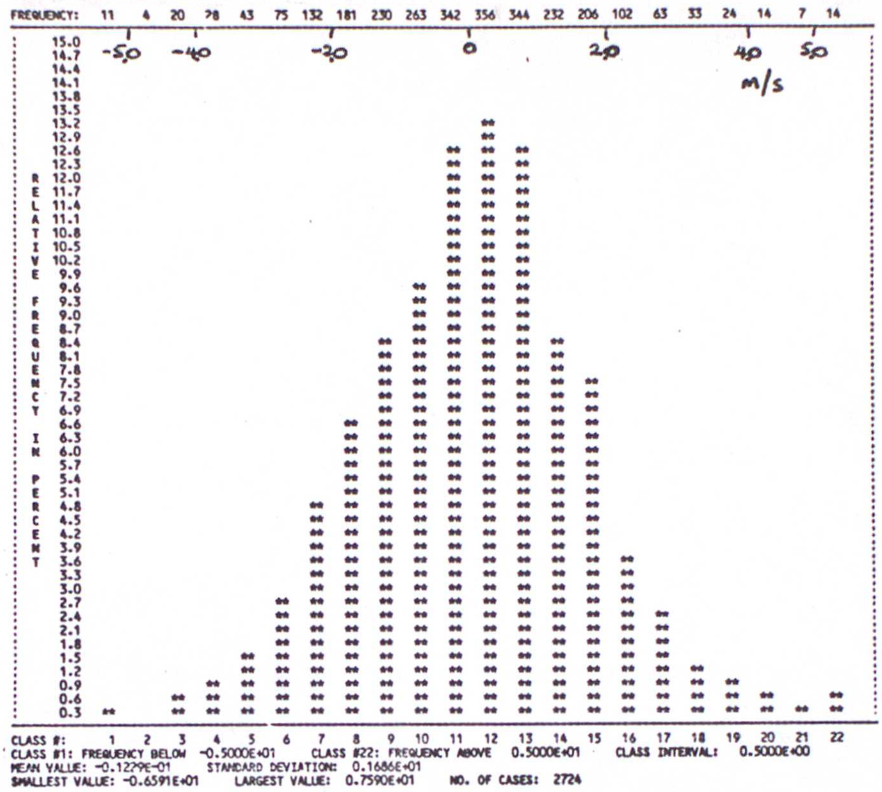


Figure 5. SASS-JASIN wind direction differences (deg)

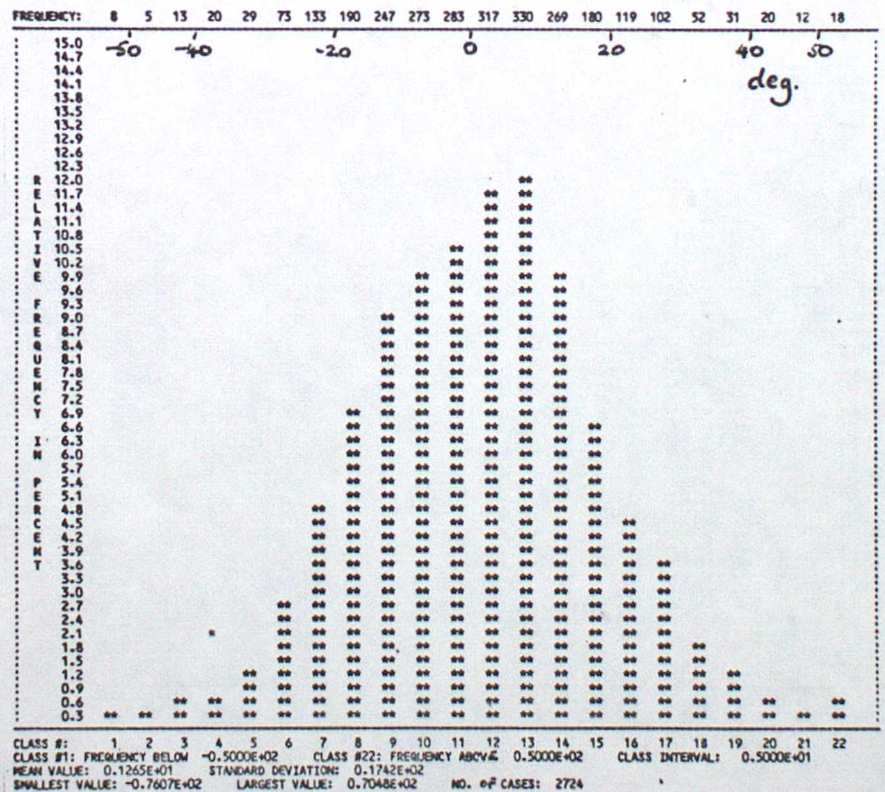
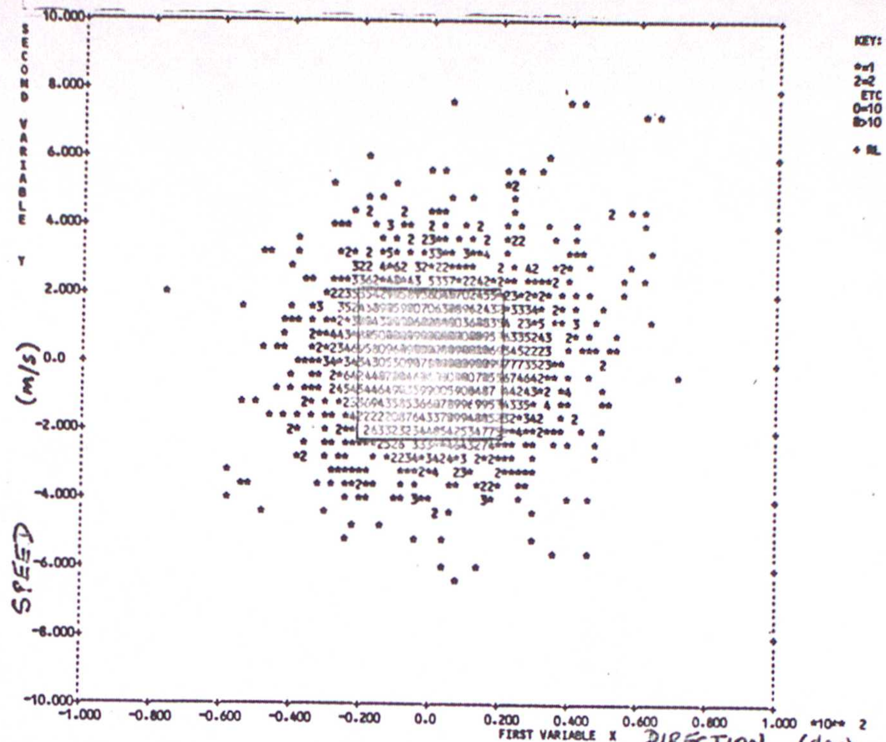
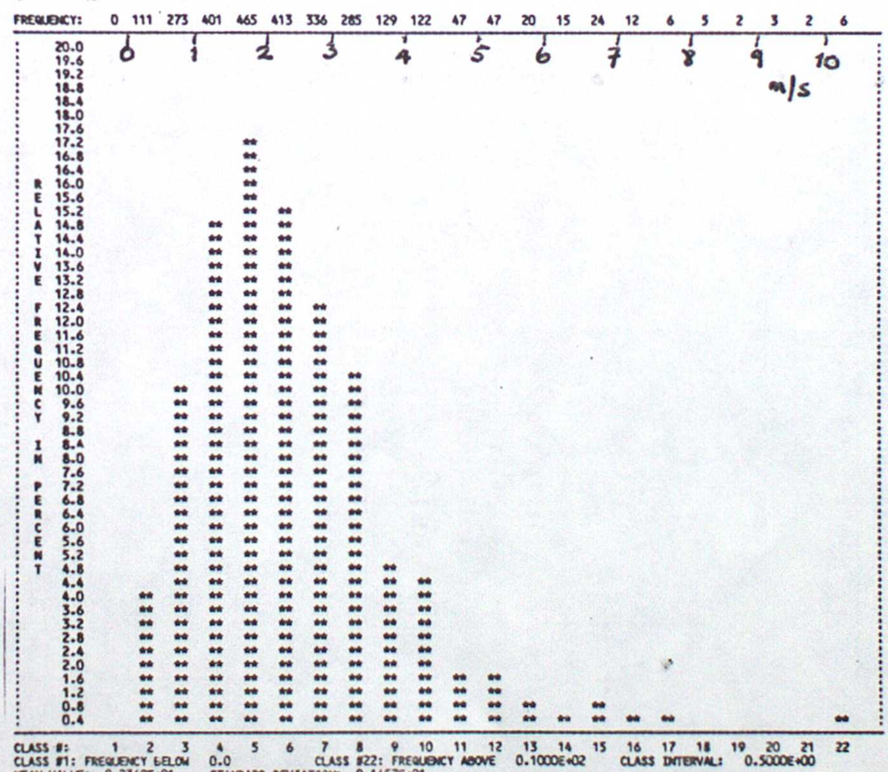


Figure 6. SASS-JASIN wind speed differences vs. direction differences



MEAN OF X = 0.1265E+01 MEAN OF Y = -0.1229E-01 S.D. OF X = 0.1742E+02 S.D. OF Y = 0.1686E+01
REGRESSION LINE (Y ON X) - Y = M*X + C - M = 0.6765E-03 C = -0.1315E-01
CORRELATION COEFFICIENT = 0.007 NO. OF CASES: 2724

Figure 7. SASS-JASIN vector wind differences (m/s)



CLASS #1: FREQUENCY BELOW 0.0 CLASS #22: FREQUENCY ABOVE 0.1000E+02 CLASS INTERVAL: 0.5000E+00
MEAN VALUE: 0.2369E+01 STANDARD DEVIATION: 0.1457E+01
SMALLEST VALUE: 0.2561E-01 LARGEST VALUE: 0.1405E+02 NO. OF CASES: 2724

Figure 8. Standard Deviations of SASS-JASIN wind speeds, directions and vector differences vs. SASS incidence angle range.

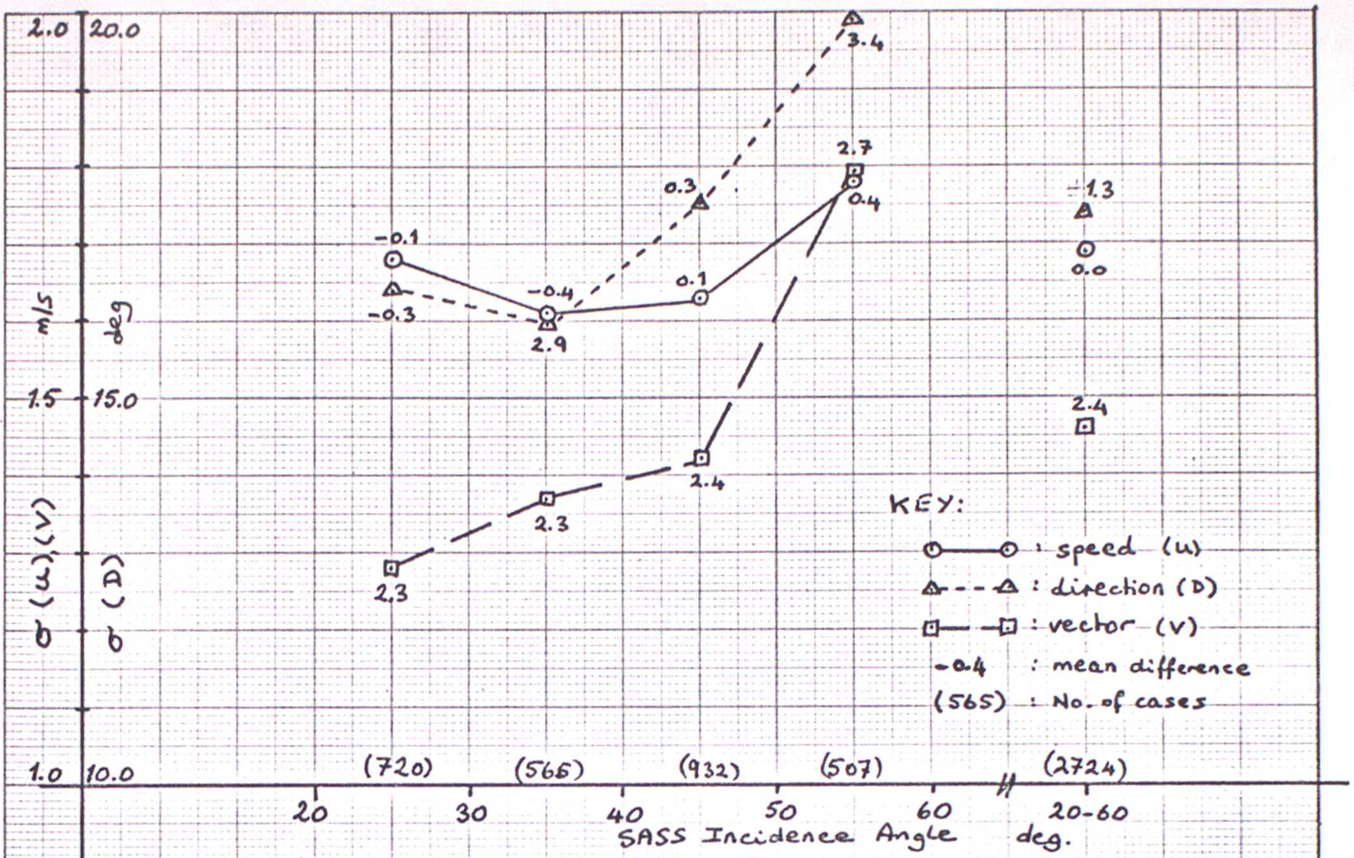


Figure 9. Same as Fig. 8 vs. JASIN wind speed range.

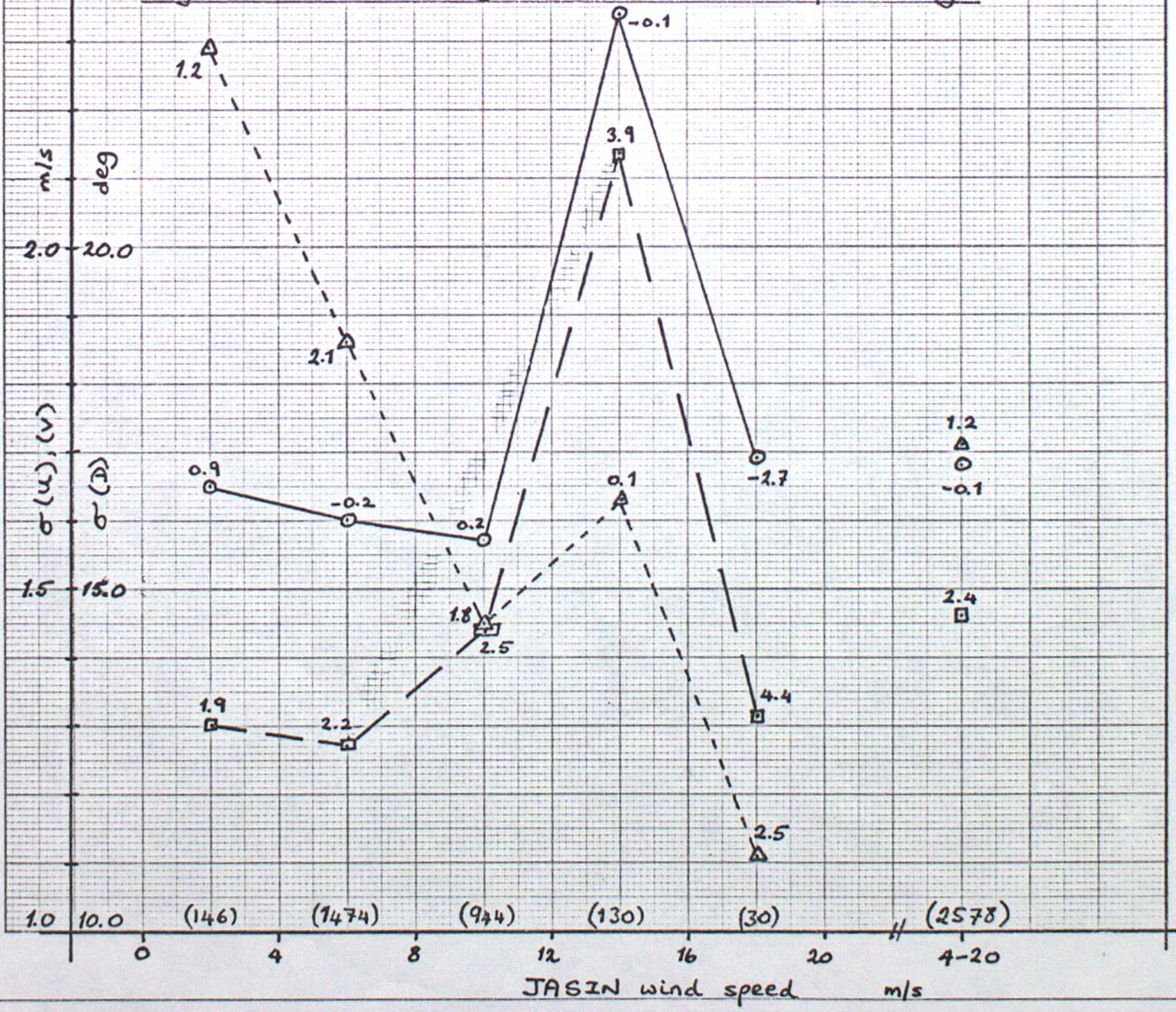


Figure 10. Same as Fig 8. vs. JASIN wind direction range.

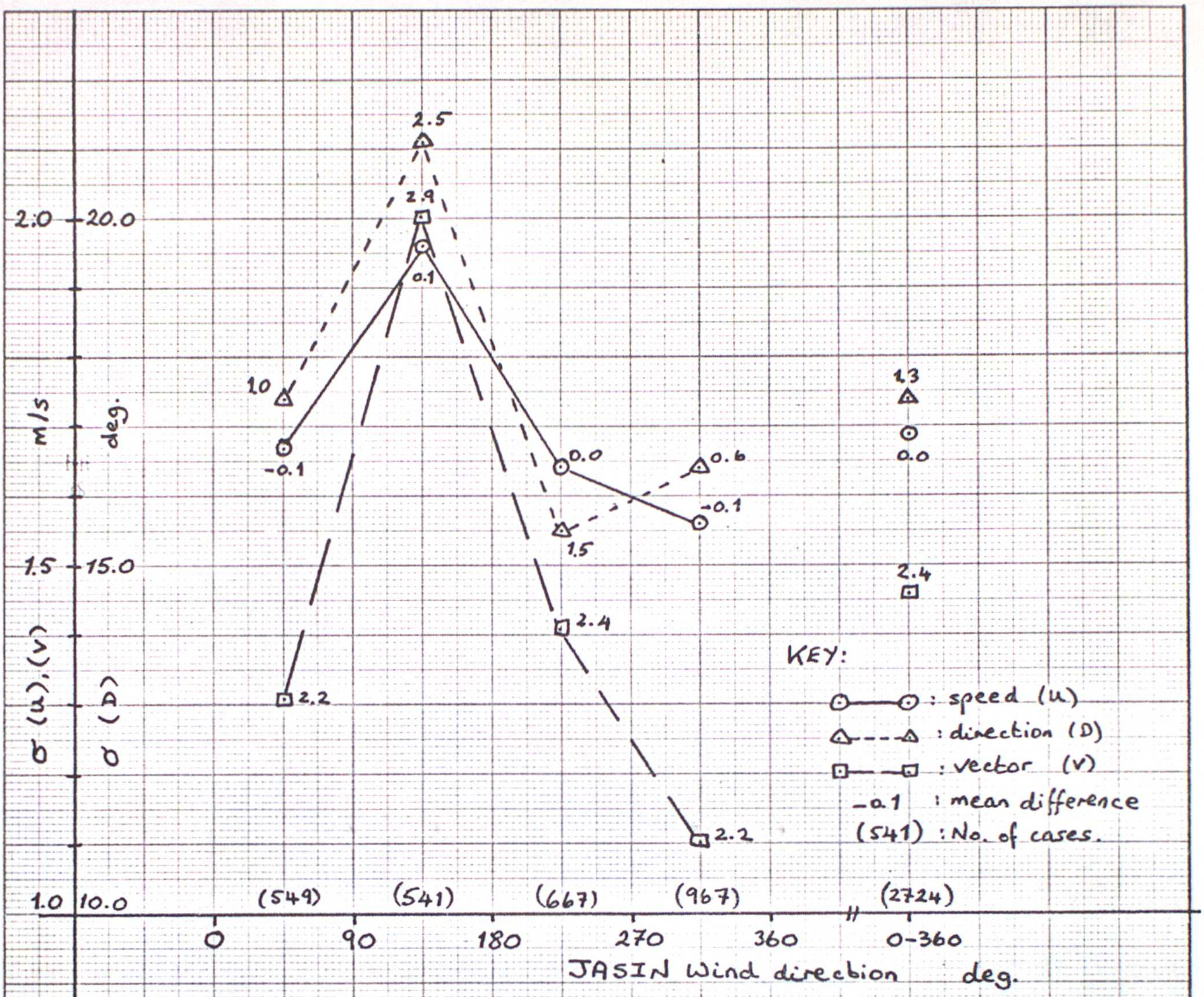


Figure 11. Same as Fig 8. vs. distance apart of centre of SASS cell from JASIN platform.

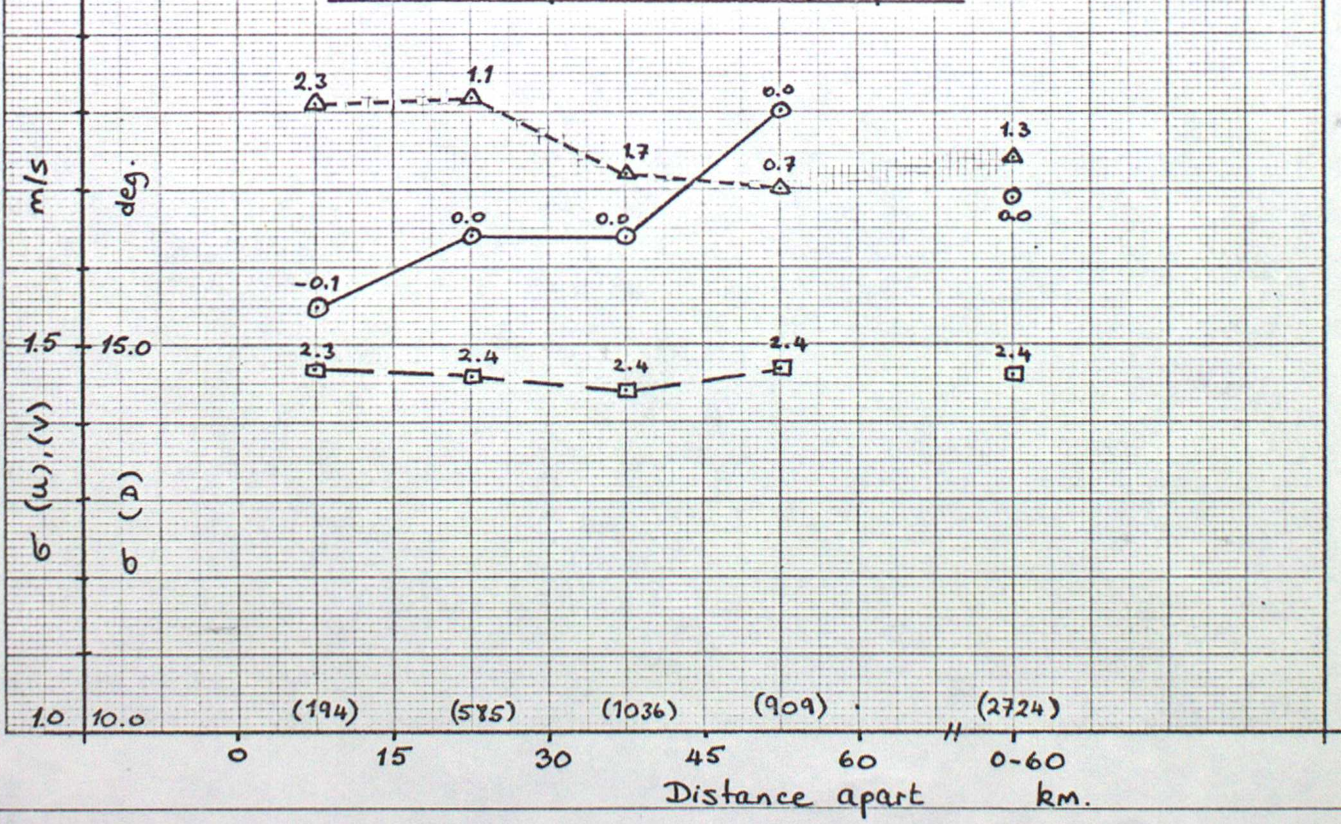


Figure 12. Same as Fig. 8 vs. time difference of SASS (mean time) and JASIN observations for WMO reporting ships only.

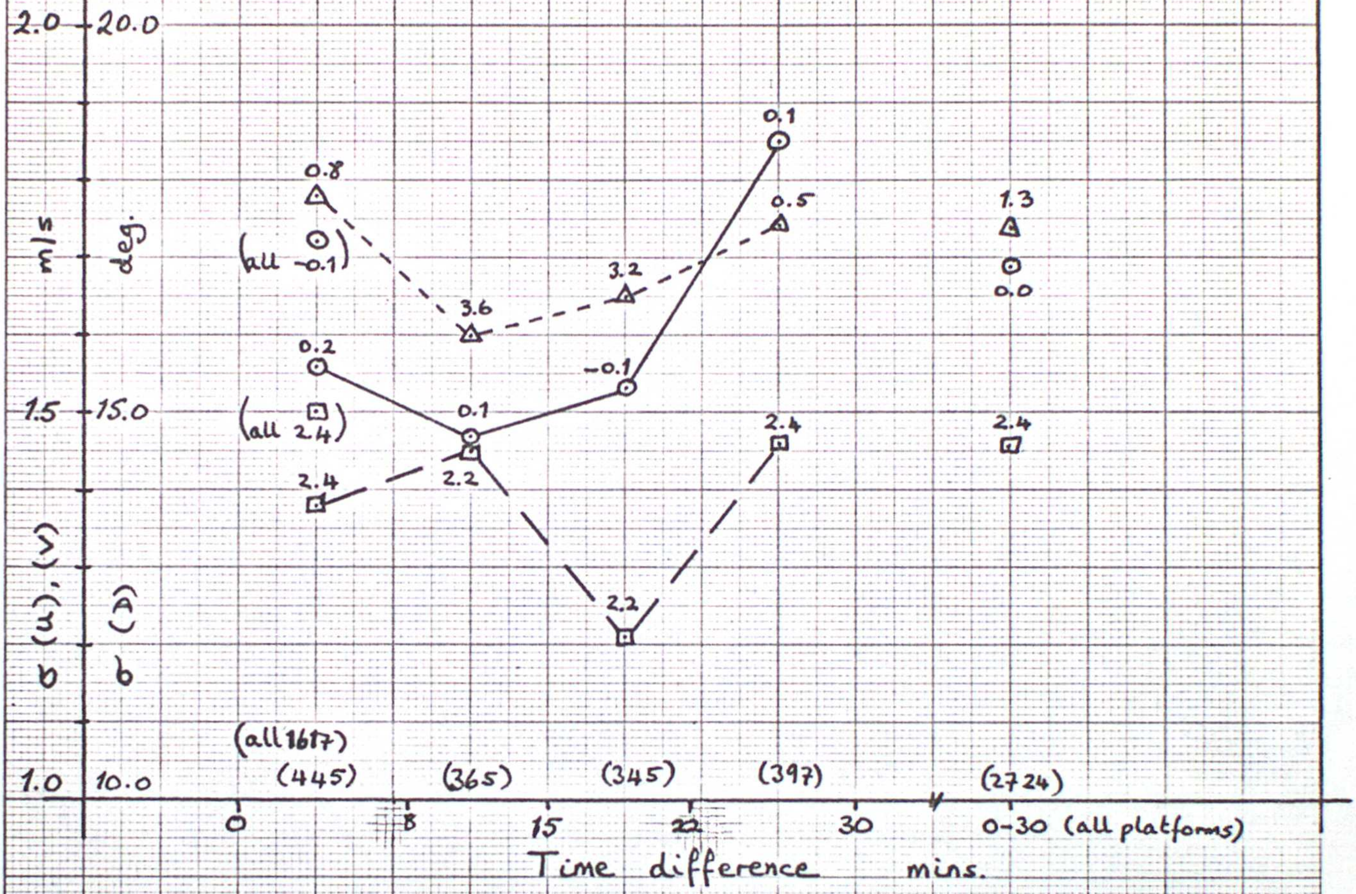
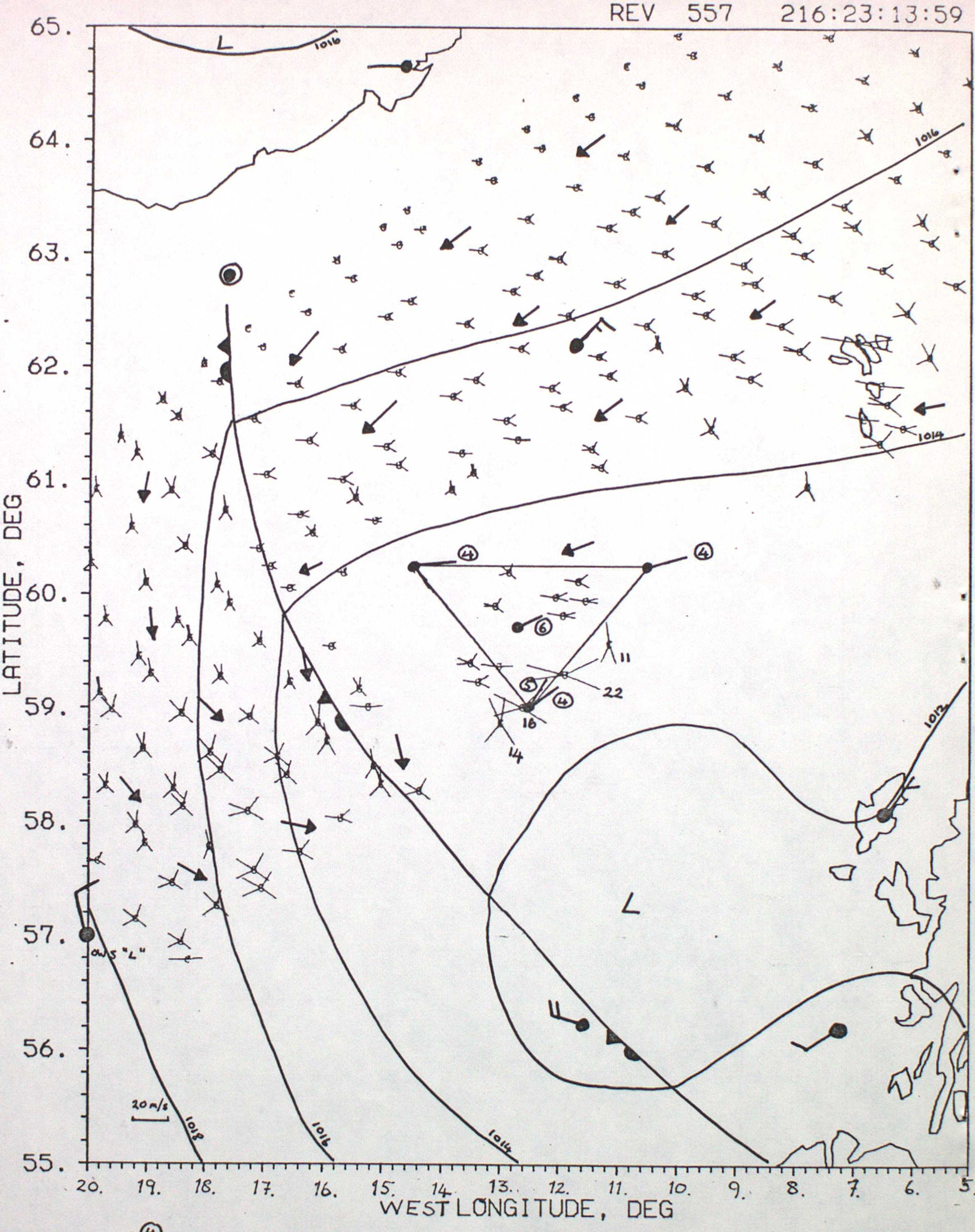


FIGURE 13. SASS ANOMOLY 4TH AUGUST 1978. (H POL)

REV 557 216:23:13:59



④ – JASIN wind direction and speed in m/s at 23Z : – other obs. at 00Z 5th.

← – General wind flow at the surface : 22 – SASS wind speed in m/s

Figure 14.

MSL PRESSURE

00Z 31/8/78

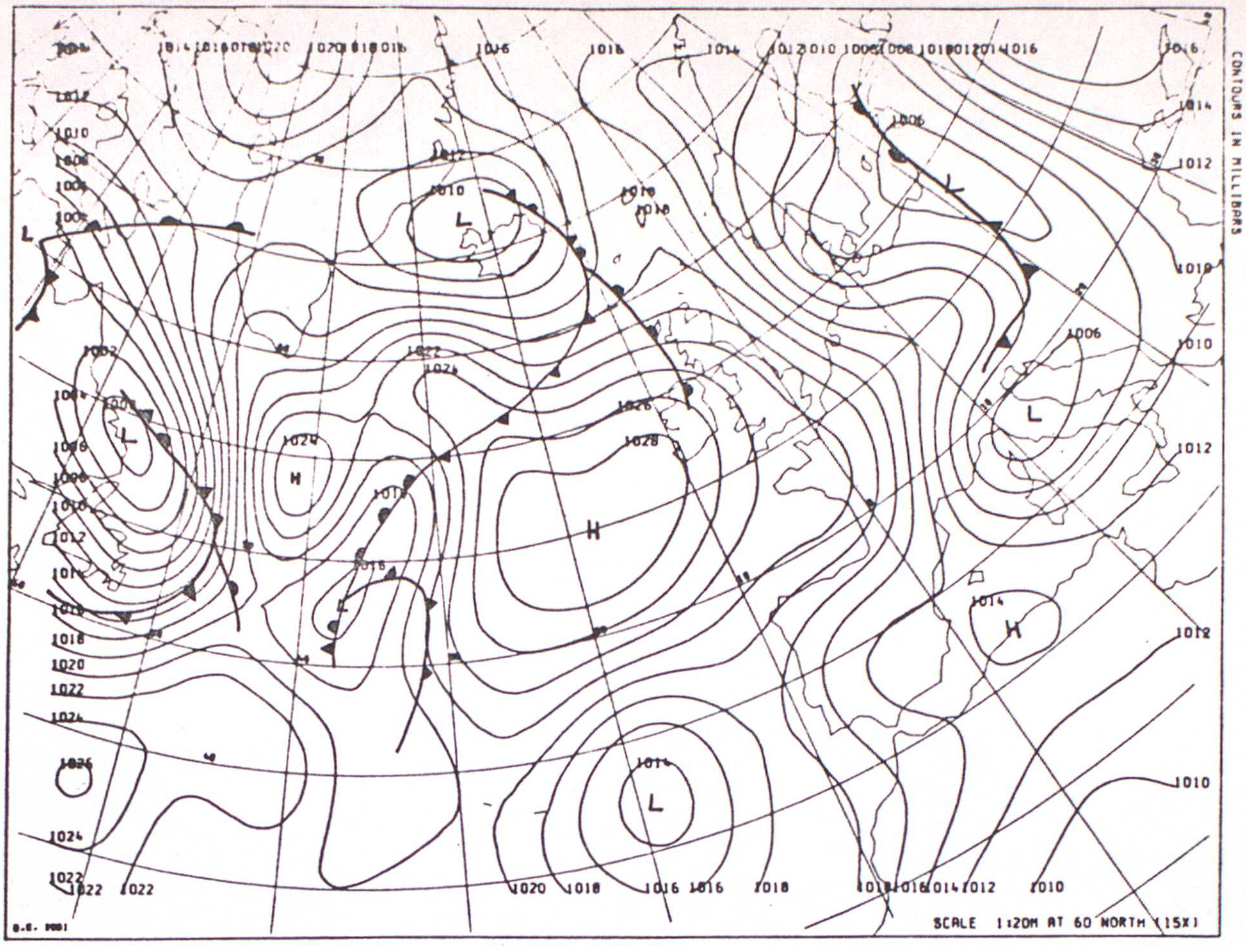


Figure 15

1000MB VECTOR WIND

00Z 31/8/78

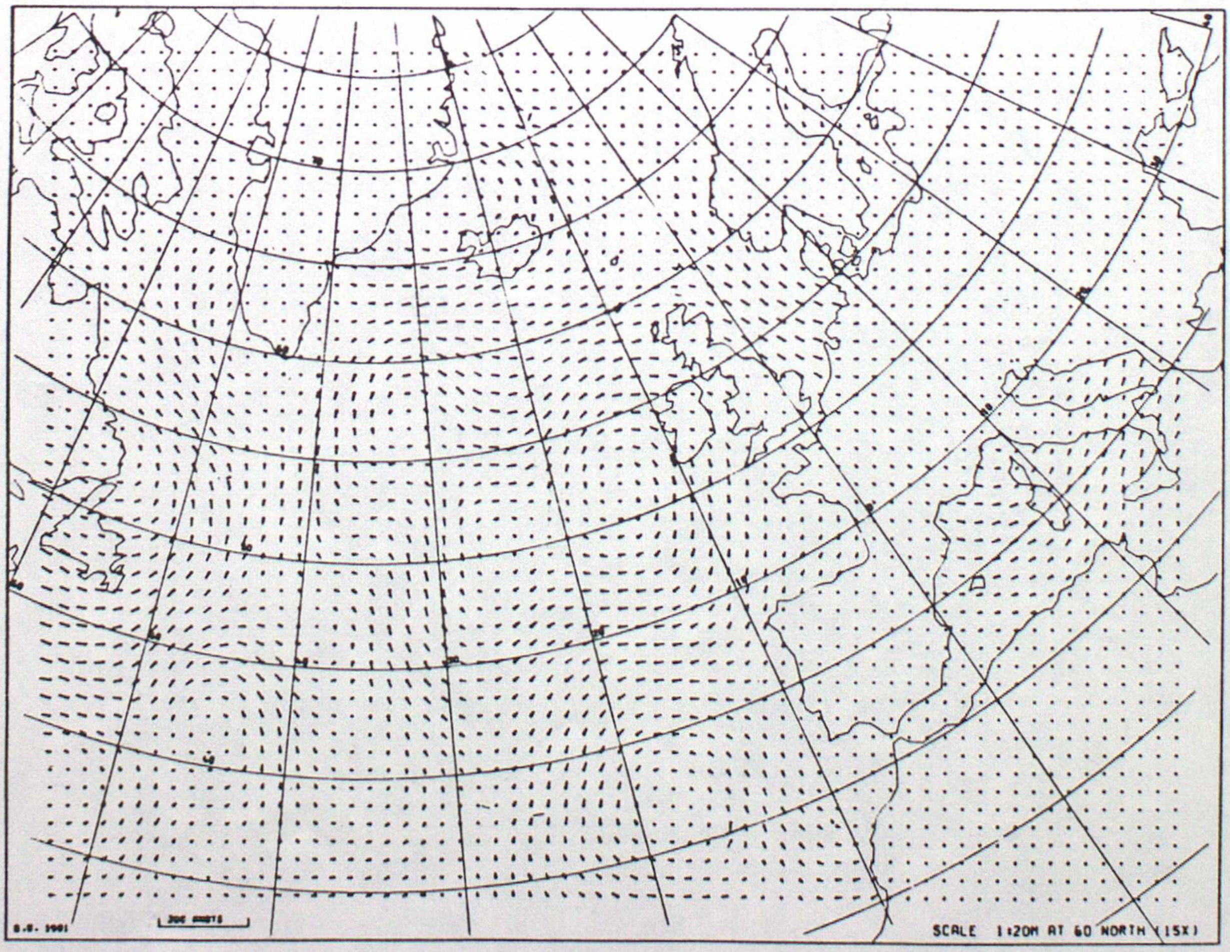
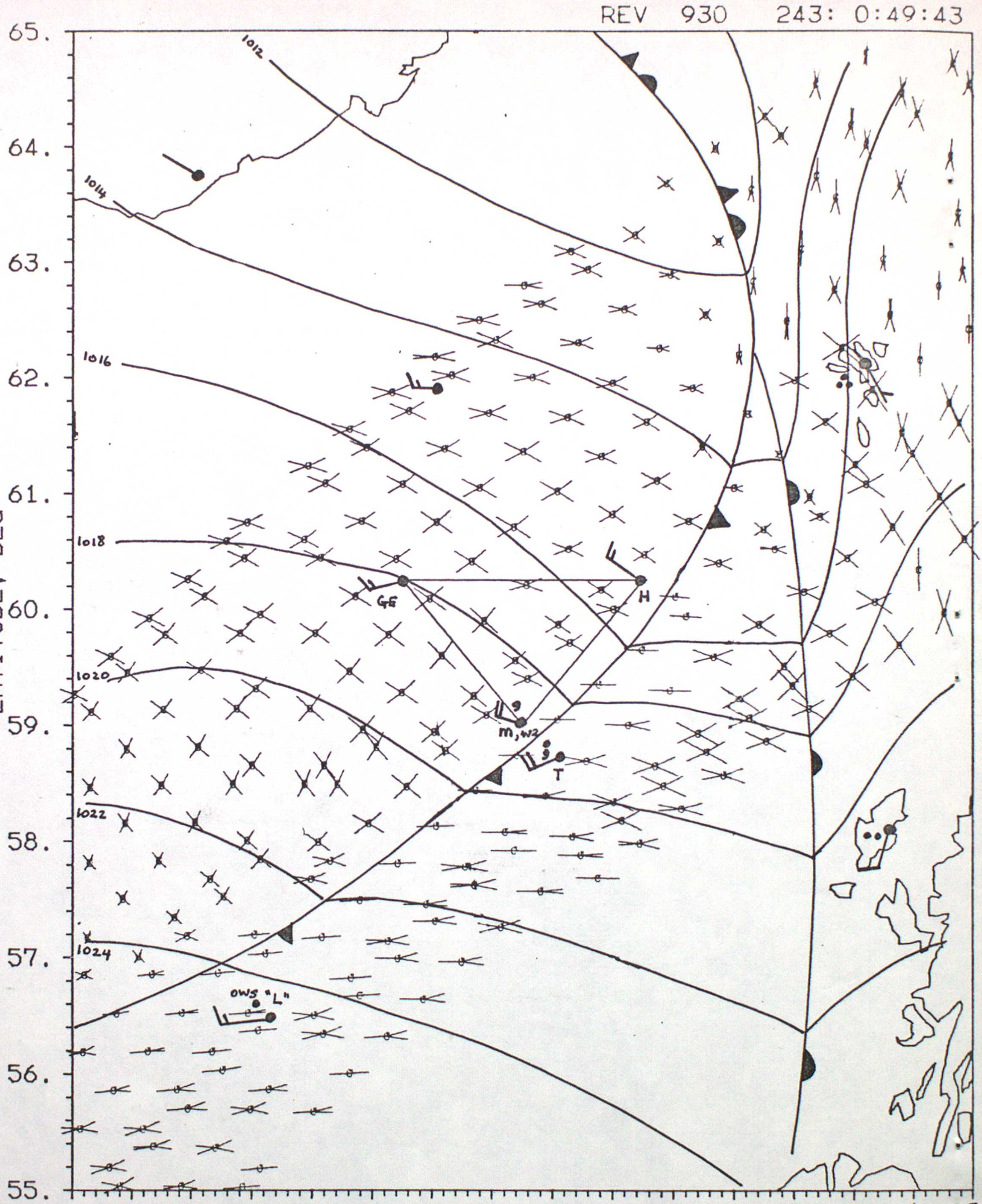


FIGURE 16. COLD FRONT 31st AUGUST 1978 (V POL)



Annex 1

A1. Background to the SASS wind measurements

A1.1 Principle of measurement

The basic measurement of 'wind' scatterometers is the level of backscattered microwave radiation from the (ocean) surface.

Backscattering is due to in-phase reflections from a rough surface; for incidence angles (measured from the vertical) of greater than about 20 deg, backscattering occurs when the Bragg condition is met:

$$\Lambda \sin\theta_i = n\lambda/2$$

where Λ is the surface roughness wavelength, λ is the radar wavelength, θ_i the incidence angle and n = 1,2,3.... For first order Bragg scattering (n = 1), and at microwave frequencies ($\lambda \sim$ 1 cm), Λ corresponds to small capillary waves superimposed on the larger gravity waves. These capillary waves are generated by the instantaneous wind at the ocean surface.

The level of backscatter from an object is usually expressed as the Radar Cross-Section (RCS or σ) which is defined as "the area intercepting that amount of power which, when scattered isotropically, produces an echo equal to that received from the object" (Long, 1975). For extended targets, such as the sea surface, the backscatter is expressed as the Normalised Radar Cross-Section (NRCS or σ°), which is the RCS per unit area. In terms of other known or measureable radar parameters,

$$= \frac{64\pi^3 R^4}{\lambda^2 L_s G_o^2 (G/G_o)^2 A} \frac{P_R}{P_T}$$

where R is the slant range to the target of area A, λ is the radar wavelength, L_s includes atmospheric and system losses (attenuation), G_o is the peak antenna gain, G/G_o the relative gain in the target direction, P_T the transmitted power and P_R the received power. This is often referred to as the Radar Equation. (σ° is usually expressed in decibels ie σ° (dB) = 10 $\log_{10}\sigma^\circ$).

Experimental evidence from wind-wave tanks and scatterometers mounted on static platforms, aircraft and satellites measuring over the ocean show that σ° increases with surface wind speed, decreases with incidence angle and is also dependent on the beam azimuth angle relative to the wind direction. It is generally lower for horizontal polarisation than vertical and the dependence of σ° on radar frequency seems to be small over the range 5-20 GHz (Krishen (1971), Jones and Schroeder (1978), Jones et al (1978), Ross and Jones (1978)).

Figure A1.1 is a plot of combined Skylab and aircraft scatterometer data of vertical polarisation σ°, against relative wind direction for various windspeeds, at 30° incidence angle. Direction 0° corresponds to looking upwind, 90° crosswind and 180° downwind. Note that the downwind peak is slightly lower than the upwind peak. An empirical σ° model function can be fitted to these curves of the form:

$$\sigma^\circ = a_o\,(U, \theta_i, P) + a_1(U, P)\cos\phi + a_2\,(U, P)\cos 2\phi \quad \text{dB}$$

where a_o, a_1 and a_2 are found by regression and are proportional to $\log_{10}U$, U being the wind speed, ϕ the relative direction and P = horizontal or vertical radar polarisation.

By measuring σ° at more than one ϕ, it is possible, in principle, to deduce the wind speed and direction using such a σ° model (Jones et al, 1978). (The σ° model is based on experiments which measured the wind at different heights above the surface from ships and buoys. These observations were all referred to a neutrally stable atmosphere at 19.5 m, so this is the deduced scatterometer wind 'height', though σ° is actually dependent on the surface friction velocity, U_*)

A1.2 The SASS instrument

The SEASAT scatterometer used two fore and two aft radar beams, directed 45° either side of the subsatellite track, as shown in Figure A1.2. For cells near nadir, the σ° variation with ϕ vanishes, and only speed can be deduced. Beyond about 55° incidence angle, the radar return is too small to permit accurate wind deduction except for high winds ($>$ 25 m/s). This results in a useful swath of about 500 km wide either side of the subsatellite track.

Due to spacecraft movement, the Doppler-shifted returns can be used to divide the swath into smaller cells, the σ°'s being measured simultaneously in each cell from each beam in rotation. A measurement in the forward beam is followed a few minutes later by one from the rearward beam at the same geographical location. This results in a pair of orthogonal σ°'s (at one polarisation) at each nominal 50 x 50 km cell, from which the wind speed and direction may be deduced. Unfortunately, the harmonic nature of the σ° model allows a four-fold ambiguity in the solution for direction, each direction having a slightly different speed (Bracalente et al, 1980).

For further details of the SASS instrument, see Grantham et al (1975, 1977) and Johnson et al (1980).

References

Grantham, W.L., E.M. Bracalente, W.L. Jones, J.H. Schrader, L.C. Schroeder (1975): An operational satellite scatterometer for wind vector measurements over the oceans. NASA TM X72672, March 1975.

Grantham, W.L., E.M. Bracalente, W.L. Jones, J.W. Johnson (1977): The SEASAT-A Satellite Scatterometer. IEEE J. Oceanic Eng., Vol OE-2, No. 2, April 1977, pp 200-206.

Jones, W.L., L.C. Schroeder, J.L. Mitchell (1977): Aircraft measurement of the microwave scattering signature of the ocean. IEEE Antennas and Propag., Vol. AP-25, No.1, January 1977, pp 52-61.

Jones, W.L., L.C. Schroeder (1978): Radar backscatter from the ocean: dependance on surface friction velocity. Boundary Layer Met., Vol. 13, Nos. 1, 2, 3 and 4, January 1978, pp 133-149.

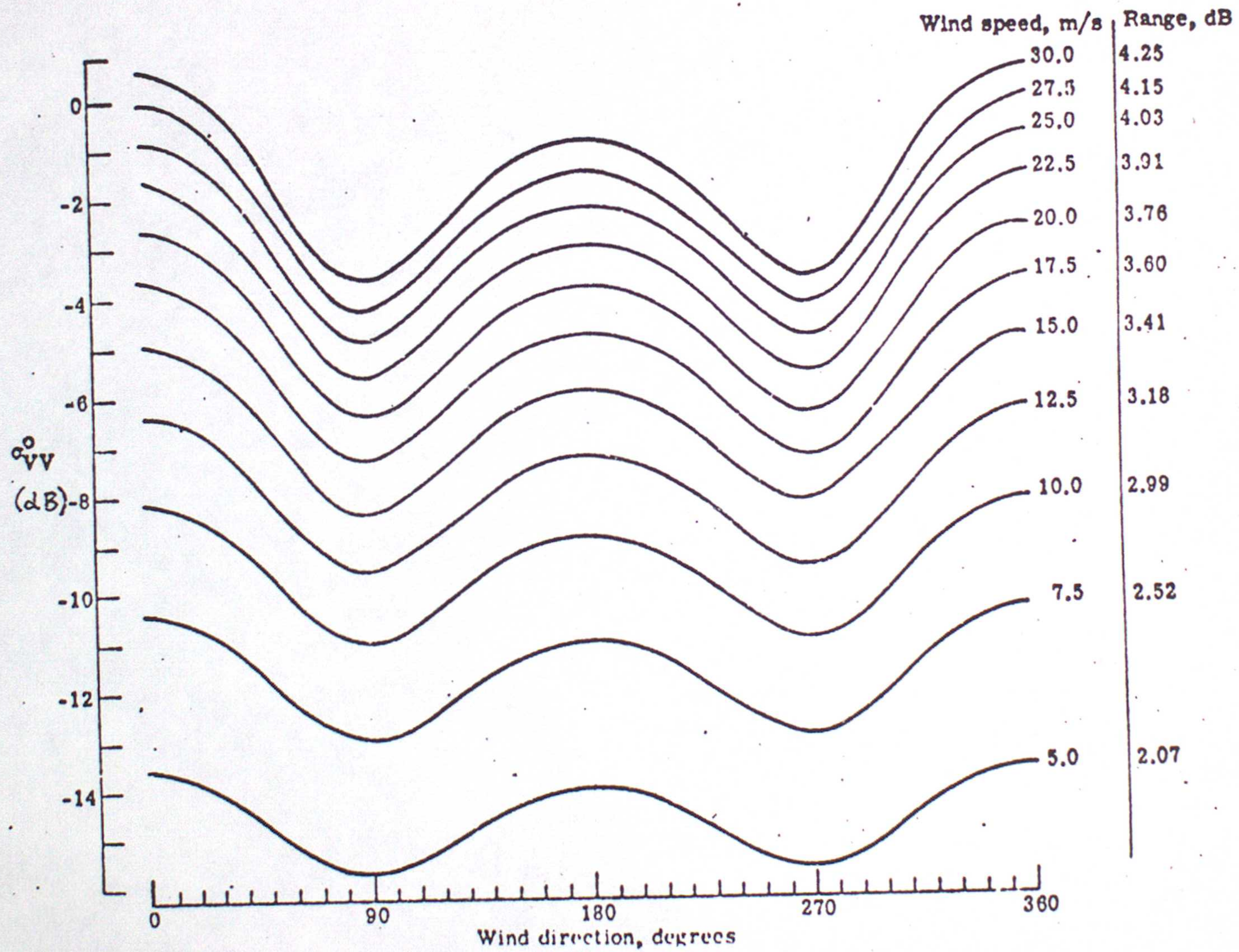
Jones, W.L., F.J. Wentz, L.C. Schroeder (1978): Algorithm for inferring wind stress from SEASAT-A. J. Spacecraft and Rockets, Vol. 15, No. 6, November/December 1978, pp 368-374.

Johnson, J. W., L.A. Williams, E.M. Bracalente, F.B. Beck, W.L. Grantham (1980): SEASAT-A Satellite Scatterometer Instrument Evaluation. IEEE J. Oceanic Eng., Vol. OE-5, No. 2, April 1980, pp 138-144.

Krishen, K., (1971): Correlation of Radar Backscattering Cross Sections with Ocean Wave Height and Wind Velocity. J. Geophys Res., Vol. 76, No. 27, pp 6528-6539.

Long, M.W. (1975): Radar Reflectivity of Land and Sea. Lexington Books, Lexington, Mass., USA.

Ross, D., W.L. Jones (1978): On the relationship of radar backscatter to wind speed and fetch. Boundary Layer Met., Vol. 13, Nos. 1, 2, 3 and 4, January 1978, pp 151-163.



(a) σ^o_{VV} vs. wind azimuth angle.

Figure A1.1 Scattering coefficient dependence on wind azimuth angle at $\theta_i = 30^o$.

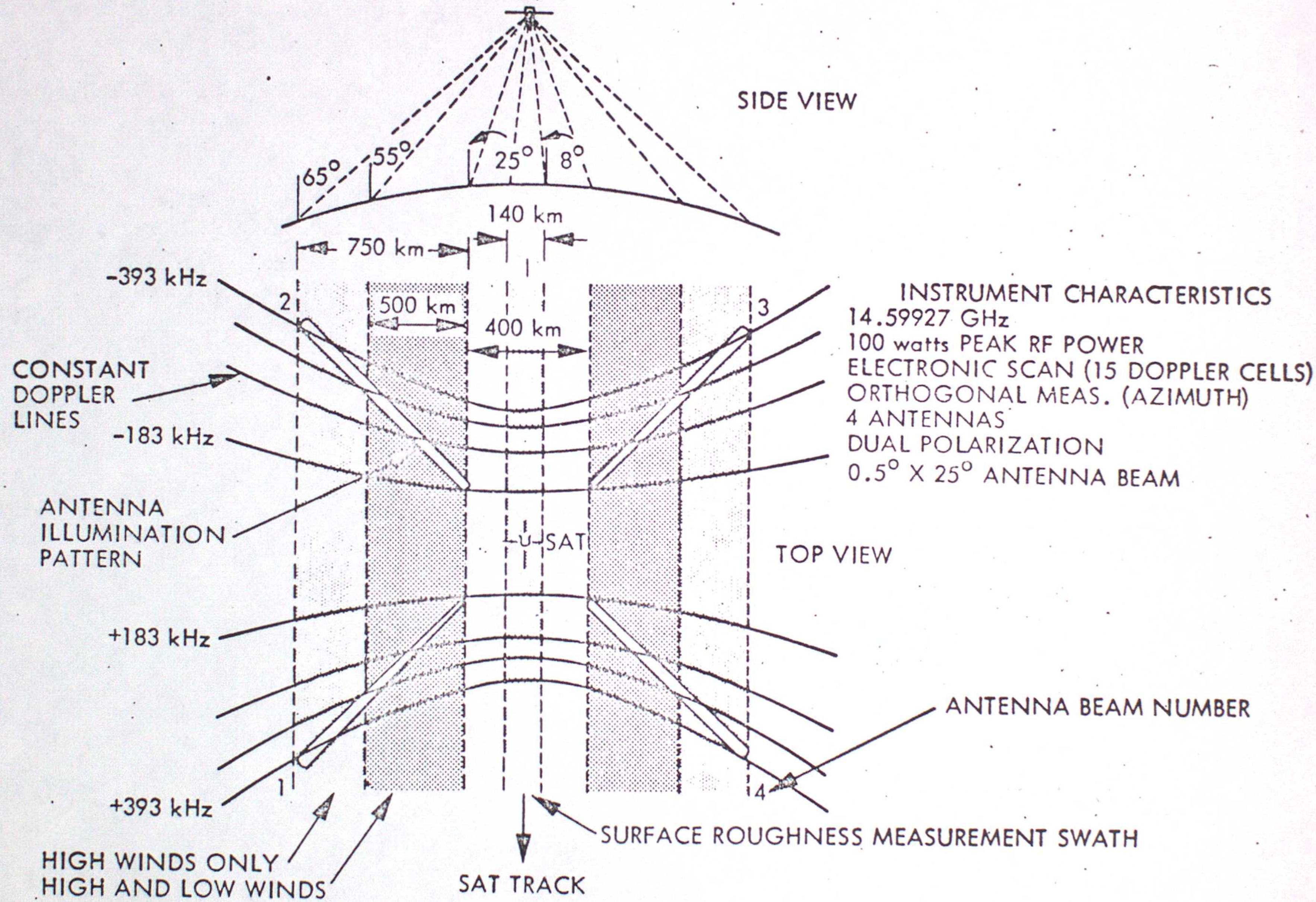


Figure A1.2 Scatterometer Ground Pattern and Swath

Annex 2

A2. Variability in the JASIN wind observations

A2.1 Coverage and conditions

The periods of coverage for each JASIN platform are depicted in Figure A2.1, together with the intercomparison days when the platforms shown were close together. Although during these periods the ships' positions were not available in the supplied datasets, meteorological information was given and the Royal Society (1979) report on JASIN lists the times of day when the ships were being compared.

The daily mean wind speed and direction, combined from all available platforms, is shown in Figure A2.2. Single wind observations ranged from near calm to about 20 m/s, and all directions, though most frequently from SW to NW.

Of the 48 days when at least one of the four WMO reporting ships was in the area, some form of precipitation was observed on all but one day.

A2.2 Inter-platform comparison of JASIN winds

In order to compare instrumentation, the WMO-reporting ships (Meteor, Hecla, John Murray and Gardline Endurer) occasionally spent a few hours within a kilometre of each other during the scheduled and unscheduled intercomparison periods (ICPs) shown in Figure A2.1.

For winds $>$ 1 m/s measured during these periods, the mean and standard deviation of their differences have been calculated for each ship pair, and are given in Table A2.1. Overall, the WMO hourly reporting ships, with 2 minute averaging, agree to about 1.7 m/s and 21 deg., or in vector terms, a mean vector difference of 2.6 m/s with standard deviation 2.0 m/s. Part of this variance is due to the data being recorded only to the nearest knot ($\sim$ 0.5 m/s) and 10 deg. There were several isolated cases where the differences appeared to be about 90 or 180 degrees, and a few others with differences of several metres per second. These cases, which are likely to be coding errors (some of which were corrected by IOS) have been rejected in this analysis.

Apart from the ICPs, several of the platforms came close together during parts of the experiment (eg the southern vertex of the JASIN Meteorological Triangle (59°N, 12° 30'W) was station for Meteor, with buoys W2 and B1 in the Fixed Intensive Array (FIA) moored within 5 km). Tydeman had no fixed station and came near several other platforms. For all those occasions when platforms were within 60 km of each other, the mean and standard deviation of their wind differences were calculated as before, and are presented in Table A2.2. A starred box denotes that those two ships only came within 60 km during the ICPs: for these the statistics are repeated from Table A2.1.

Overall the platforms agree to about 1.5 m/s and 20 degrees (vector mean difference 2.9 m/s, standard deviation 2.0 m/s). One or two points arise from these statistics:

- Meteor's wind speeds seem to be about 1 m/s too low, though this difference does not appear in the ICP data.

- Buoy B1's directions have a high bias (which varied during the JASIN period from about 5° to 25° and back).

- Tydeman's 1 minute averaged winds appear more variable than the other platforms particularly for speed. There is a suggestion that Hecla's speeds are also more variable. This is confirmed in Section A2.3 below.

Further analysis shows that for speeds > 10 m/s, Tydeman's winds are biased high by nearly 2 m/s against other platforms, and also shows a higher (2.3 m/s) standard deviation. It is possible that this anemometer overspeeds.

A2.3 Intra-platform comparison of JASIN winds: Surface wind variability

In order to investigate the natural variability of surface winds over the ocean during the JASIN experiment on the timescale of about one hour, the auto-standard deviations of speed and direction differences from hour to hour have been calculated - i.e. the standard deviations of $(U_T - U_{T+\tau})$ and $(D_T - D_{T+\tau})$ - with τ = 1 hr, for each platform and in addition τ = 15 minutes for the autologged platforms (buoys W2 and B1, Tydeman). Only data in continuous runs of at least one hundred hours have been used. The results are presented in Table A2.3 and show that:

- Tydeman's windspeeds show as much variability over 15 mins as do the other platforms over an hour, and supports the findings in Section A2.2. This is probably due to Tydeman's anemometer having a significantly smaller averaging time than the others: its original sampling interval being every minute, averaged over the minute.

- Hecla's speeds also seem more variable than the rest.

- Gardline Endurer's wind direction shows greater variability than the other platforms.

- The overall variability from hour to hour is about 1.4 m/s and 21 deg., or 0.9 m/s and 13 deg. over 15 minutes. The average time difference for all the SASS/JASIN colocations was about 10 minutes: an estimate of the wind variability on this time scale would be about 0.6 m/s and 9 deg.

In the GOASEX validation studies, the Error Analysis Sub-panel found that "..... random turbulence effects with averaging times and distances (or areas) corresponding to anemometer averaging times and SASS cell dimensions actually cause the [estimated] winds at the locations involved to differ by amounts comparable to the kinds of differences being found in the comparison of the [GOASEX] comparison data set and the SASS winds" (NASA, 1980).

References

NASA (1980): SEASAT Gulf of Alaska Workshop II Report. Jet Propulsion Laboratory, Pasadena. 622-107. January 1980.

Royal Society (1979): Air-Sea Interaction Project: Summary of the 1978 Field Experiment. London.

Table A2.1. Mean and Standard Deviation of JASIN platform pair difference in wind speed and direction during special Intercomparison Periods

PLATFORM: (2 across, 1 down)	METEOR	HECLA	JOHN MURRAY	GARDLINE ENDURER
METEOR	m/s deg.	30 -0.0 1.5	24 -0.1 1.3	32 0.1 1.6
HECLA	30 -3.3 12.3		166 0.1 1.8	19 0.7 2.1
JOHN MURRAY	24 11.1 25.7	166 -3.5 21.6		19 0.5 1.2
GARDLINE ENDURER	32 -2.5 20.0	19 -0.8 19.3	19 5.5 25.7	

KEY:

Number of cases
mean) of difference s.d.)

(calculated as Platform 1 - Platform 2)

The top half of the table shows speed differences, the lower half direction differences.

All speeds adjusted to 19.5 m neutral stability.

Table A2.2 Mean and Standard Deviation of JASIN platform pair difference in wind speed and direction, when less than 60 km apart

2 PLATFORM: 1	METEOR	HECLA	JOHN MURRAY	GARDLINE ENDURER	BUOY W2	BUOY B1	TYDEMAN
METEOR	m/s deg.	* 30 -0.0 1.5	87 -0.9 1.5	* 32 0.1 1.6	592 -1.0 1.3	550 -1.0 1.2	281 -1.0 2.3
HECLA	* 30 -3.3 12.3		148 0.2 1.9	* 19 0.7 2.1	—	—	—
JOHN MURRAY	87 4.8 16.0	148 -4.4 18.2		* 19 0.5 1.2	89 -0.2 1.3	89 -0.2 1.2	23 -1.2 1.3
GARDLINE ENDURER	* 32 -2.5 20.0	* 19 -0.8 19.3	* 19 -5.5 25.7		—	—	—
BUOY W2	592 3.0 12.2	—	89 -5.5 14.7	—		2000 0.0 0.8	1132 -0.3 2.0
BUOY B1	550 16.5 23.0	—	89 -7.8 16.3	—	2000 15.6 19.1		972 -0.5 1.8
TYDEMAN	281 -3.2 21.5	—	23 -2.5 11.3	—	1132 -5.1 18.7	972 -21.5 24.6	

KEY:

Number of cases
mean) of difference s.d.)

(Calculated as Platform 1 - Platform 2)

A '*' denotes data during intercomparison periods only (< 2 km apart)

The top half of the table shows speed differences, the lower half direction.

Wind speed > 1 m/s

All speeds adjusted to 19.5 m neutral stability.

Table A2.3 Auto-standard deviation* of wind speed and direction of each JASIN platform

	Meteor	Hecla	John Murray	Gardline Endurer	Buoy W2	Buoy B1	Tydeman	All
N (60)	690	658	141	660	913	862	1162	5086
$\sigma_S(60)$	1.15	1.40	1.05	1.27	1.14	1.03	1.84	1.36
$\sigma_D(60)$	16.51	21.13	18.16	29.56	17.53	21.08	22.57	21.54
N (15)	-	-	-	-	3653	3449	4538	11640
$\sigma_S(15)$	-	-	-	-	0.66	0.59	1.24	0.92
$\sigma_D(15)$	-	-	-	-	8.61	15.42	14.69	13.34

KEY:

N (60)	No. of cases	)	
$\sigma_S(60)$	speed s.d.	)	τ = 1 hour
$\sigma_D(60)$	direction s.d.	)	
N (15)	No. of cases	)	
$\sigma_S(15)$	speed s.d.	)	τ = 15 minutes
$\sigma_D(15)$	direction s.d.	)	

* s.d. of $(U_T - U_{T+\tau})$ and $(D_T - D_{T+\tau})$

Only continuous data runs of $\geqslant$ 100 hrs used, and then combined.

All speeds adjusted to 19.5 m neutral stability.

Figure A21 Data availability of SASS and JASIN ship/buoy observations

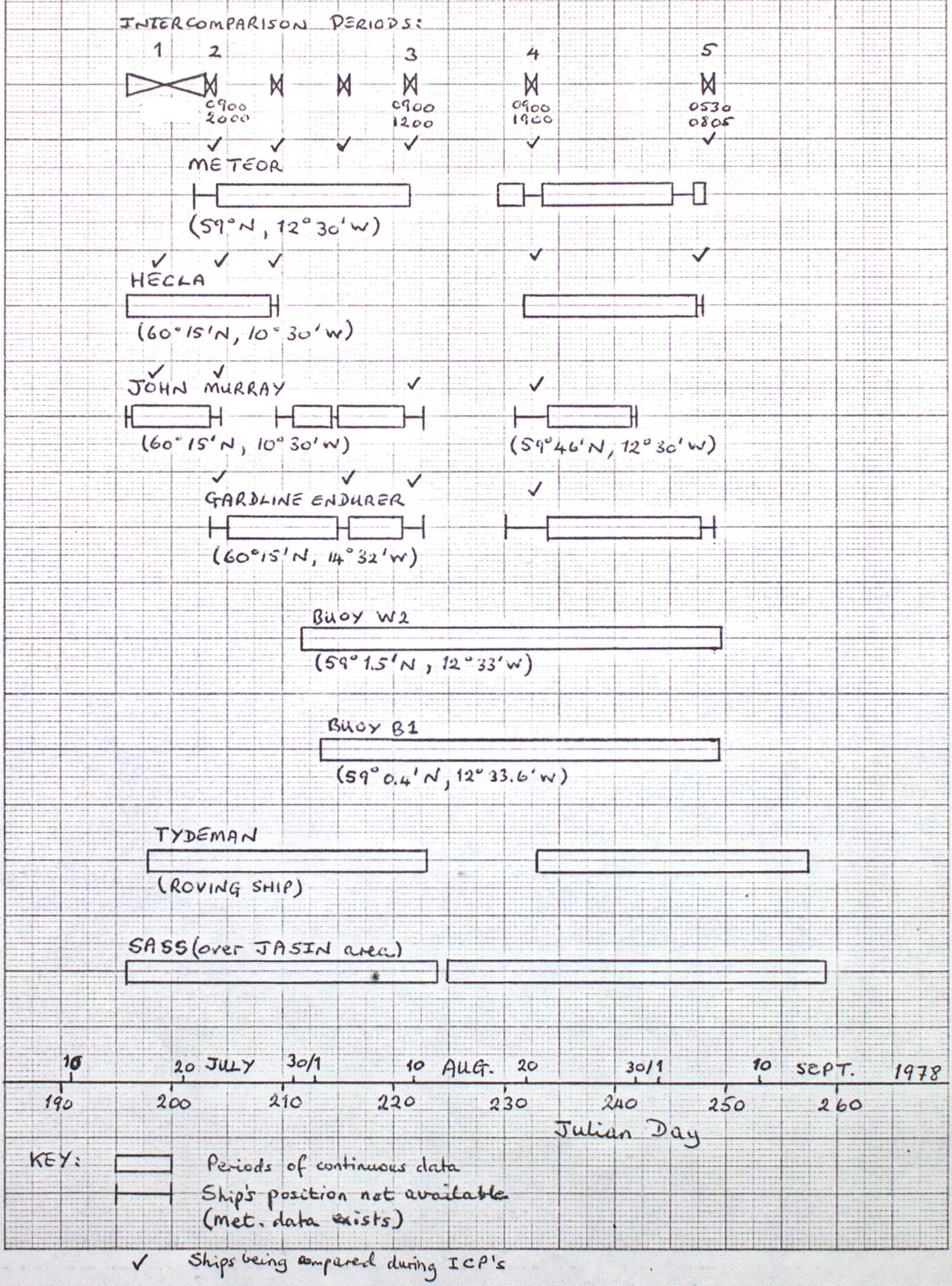
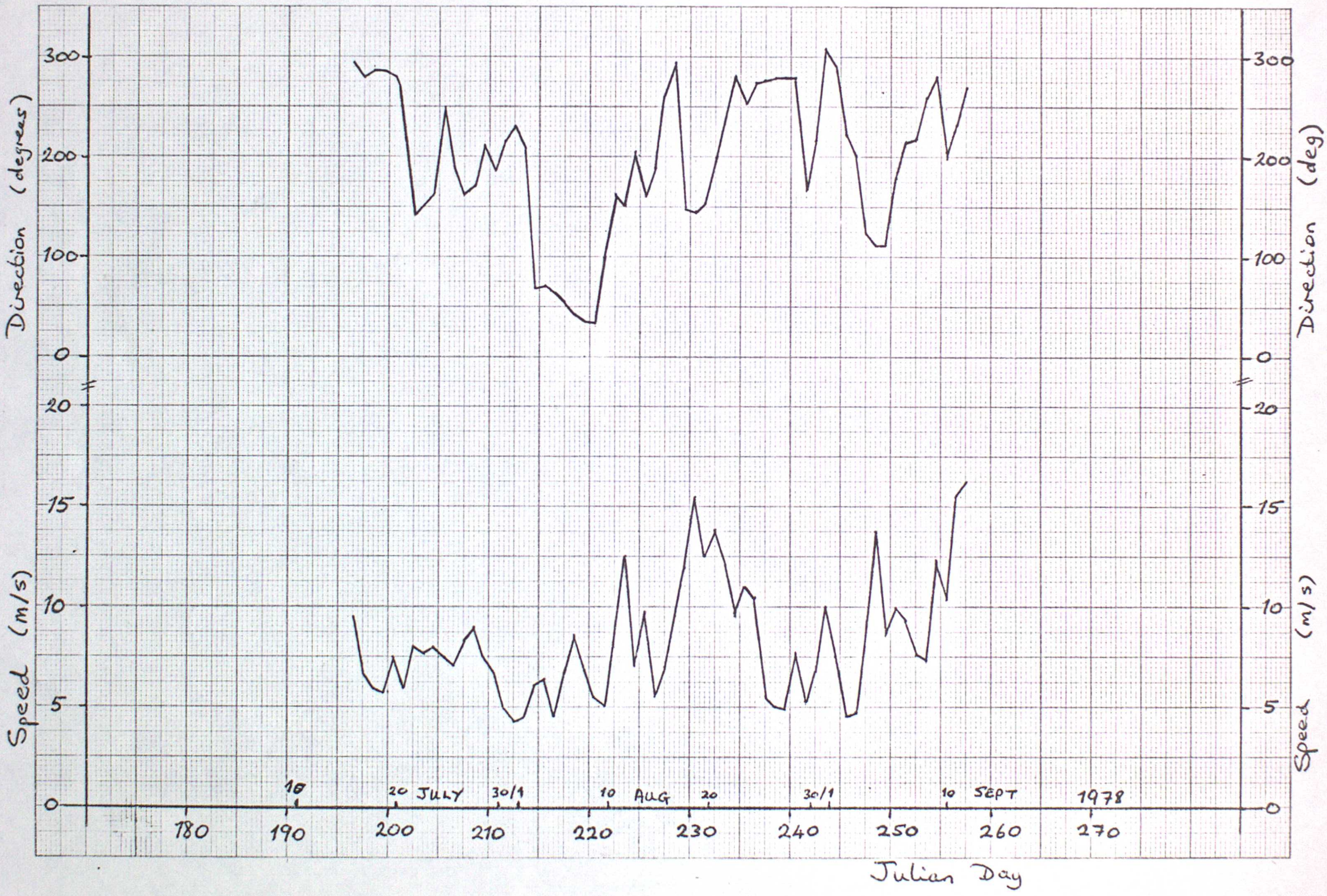


Figure A2.2 JASIN Daily Averages of Wind Speed and Direction (all available platforms combined)



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Annex 3

A3. Alternative analyses of SASS winds

A3.1 Averaged SASS winds

When using grid point numerical models, an average wind about the grid point may be a more appropriate input than several related estimates. In this section, all SASS wind measurements (with solutions chosen by the 'nearest to JASIN direction' criteria) within the 60km radius and 30 (or 7.5) minutes about each JASIN observation have been averaged. No weighting has been applied for distance or time differences, but all polarisations have been included.

Scatter diagrams of SASS-JASIN wind speed and direction are given in Figures A3.1 and A3.2 respectively. SDDs were 1.5 m/s in speed and 14 degrees in direction, with very little bias in either.

The average number of SASS measurements per JASIN observation is about 8: if all the SASS winds were independent and their differences from JASIN normally distributed, one might expect the averaged wind SDDs to be reduced by a factor of $1/\sqrt{8}$ (ie to 0.6 m/s and 6 degrees) from those of the individual cases. This has not occured because the eight or so measurements about one JASIN observation show small standard deviations, but a fairly constant difference from the JASIN wind speed or direction. It is these (normally distributed) 'biases' from idividual JASIN winds that form the major contribution to the overall SDDs.

A3.2 Choice of SASS solution

Objective removal of ambiguous solutions has been demonstrated using external data (Yu and McPherson, 1979), and most other analyses have (or will) also use surface data or derived wind fields to choose one of the four SASS solutions.

In the main body of results, the choice of SASS solution as the 'correct' one was made by taking the SASS direction closest to that of the JASIN observation. In a possible future operational environment, such an in-situ surface measurement is very unlikely to be available for any given area of ocean: an analysed (or forecast) wind field only may be available, with its own uncertainty in direction. It may be more appropriate to allow all scatterometer solutions that lie within some limits of direction, and treat them as separate, though conflicting wind vector estimates (perhaps also averaging all these over some area).

In order to compare these two approaches, statistics have been prepared, varying the limits within which solutions will be taken. Results of SDDs are tabulated in Table A3.1 for both the 'closest' and 'all' SASS solutions within $\pm 90^{\circ}$ and $\pm 45^{\circ}$ of the JASIN observation, and in addition, 'all' solutions within $\pm 60^{\circ}$ and $\pm 30^{\circ}$. Only (JASIN) speeds greater than 4 m/s have been used.

The effect on wind speed retrieval is negligable, since all four possible solutions have similar speeds. Allowing 'all' solutions within $\pm 30^{\circ}$ (in practice, at most only 3 solutions lie within $\pm 90^{\circ}$ and only 1 or 2 within $\pm 45^{\circ}$) gives a comparable direction SDD to that using the 'closest' only solution within 45°.

However, future wind scatterometers are expected to reduce the level of ambiguity by using two polarisations simultaneously, giving four radar measurements per cell instead of the two for SASS. Simulations suggest that about 70% of cells will have a unique solution and by spatial consistency tests, the correct solution in most of the other cells may be determined, without reference to any external data.

References

Yu, T-w and R.D. McPherson (1979): Surface pressure analysis using scatterometer-derived wind data from the Seasat-A satellite. Fourth conference on numerical weather prediction, October 29-November 1, 1979, pp 351-355. AMS, Boston.

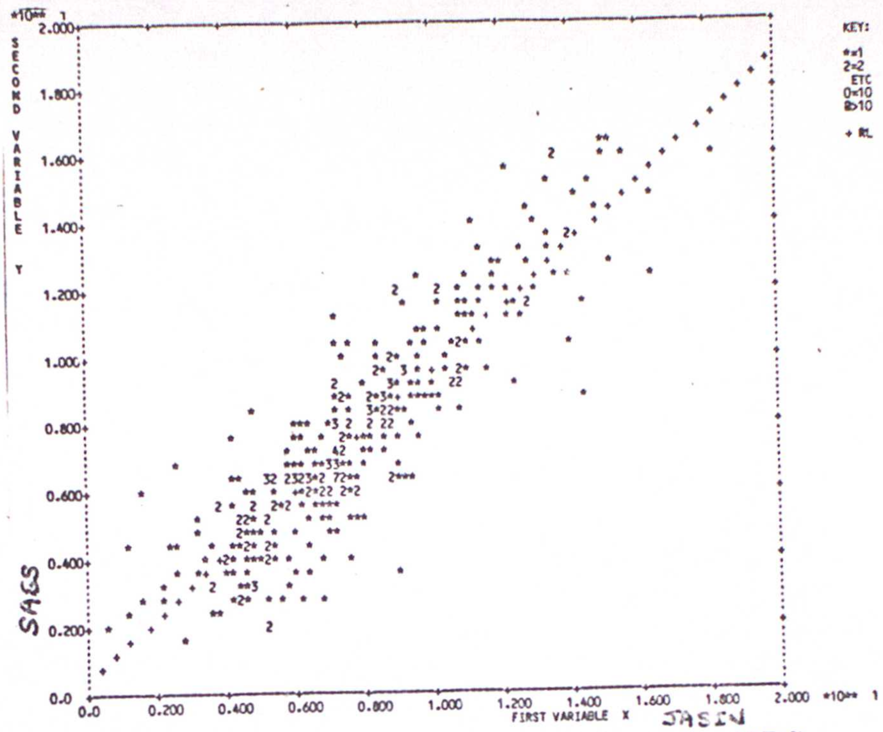
Table A3.1. Mean and standard deviation of (SASS-JASIN) wind speed and direction difference and vector difference, for both closest only and all solutions within specified limits of JASIN direction.

	closest only within		all solutions within			
	± 90°	± 45°	± 90°	± 60°	± 45°	± 30°
N	2580	2542	4569	3680	3278	2718
$\overline{S}$	-0.06	-0.07	-0.10	-0.10	-0.09	-0.10
σ_S	1.68	1.65	1.68	1.66	1.63	1.62
$\overline{D}$	1.28	0.90	-0.35	-1.24	-0.62	0.24
σ_D	17.22	15.94	40.84	26.11	20.76	15.16
$\overline{V}$	2.41	2.34	4.42	3.25	2.80	2.34
σ_V	1.48	1.35	3.44	2.24	1.73	1.28

KEY:

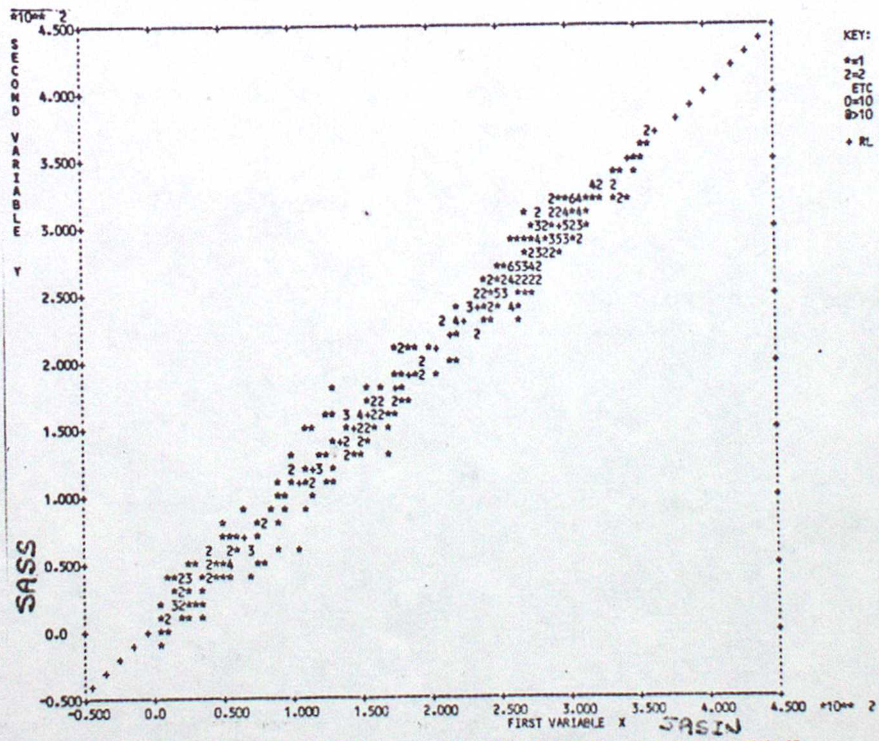
N	No. of cases		
$\overline{S}$	mean	speed difference	(m/s)
σ_S	s.d.		
$\overline{D}$	mean	direction difference	(deg.)
σ_D	s.d.		
$\overline{V}$	mean	vector difference	(m/s)
σ_V	s.d.		

Figure A3.1 Averaged SASS vs. JASIN wind speed (m/s)



MEAN OF X = 0.7711E+01 MEAN OF Y = 0.7455E+01 S.D. OF X = 0.3055E+01 S.D. OF Y = 0.3177E+01
REGRESSION LINE (Y ON X) - Y = M*X + C - M = 0.9232E+00 C = 0.3372E+00
CORRELATION COEFFICIENT = 0.888 NO. OF CASES: 344

Figure A3.2 Averaged SASS vs. JASIN wind direction (deg.)



MEAN OF X = 0.1961E+03 MEAN OF Y = 0.1973E+03 S.D. OF X = 0.1018E+03 S.D. OF Y = 0.1020E+03
REGRESSION LINE (Y ON X) - Y = M*X + C - M = 0.9931E+00 C = 0.2602E+01
CORRELATION COEFFICIENT = 0.991 NO. OF CASES: 344