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TECHNICAL NOTE

A ONE MONTH EVALUATION of REAL-TIME QuikSCAT, and OTHER SATELLITE DERIVED OCEAN SURFACE WIND DATA

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List of Abstracts, Reports, Articles, etc. by members of the Branch. The numbers are referred to as OPC Contribution Numbers from Number 1 to 110 and as OMB Contribution Numbers from Number 111 and greater.

No. 1. Burroughs, L. D., 1987: Development of Forecast Guidance for Santa Ana Conditions. National Weather Digest, 12, 7pp.

No. 2. Richardson, W. S., D. J. Schwab, Y. Y. Chao, and D. M. Wright, 1986: Lake Erie Wave Height Forecasts Generated by Empirical and Dynamical Methods -- Comparison and Verification. Technical Note, 23pp.

No. 3. Auer, S. J., 1986: Determination of Errors in LFM Forecasts Surface Lows Over the Northwest Atlantic Ocean. Technical Note/NMC Office Note No. 313, 17pp.

No. 4. Rao, D. B., S. D. Steenrod, and B. V. Sanchez, 1987: A Method of Calculating the Total Flow from A Given Sea Surface Topography. NASA Technical Memorandum 87799, 19pp.

No. 5. Feit, D. M., 1986: Compendium of Marine Meteorological and Oceanographic Products of the Ocean Products Center. NOAA Technical Memorandum NWS/NMC No.68, 93pp.

No. 6. Auer, S. J., 1986: A Comparison of the LFM, Spectral, and ECMWF Numerical Model Forecasts of Deepening Oceanic Cyclones During One Cool Season. Technical Note/NMC Office Note No. 312, 20pp.

No. 7. Burroughs, L. D., 1987: Development of Open Fog Forecasting Regions. Technical Note/NMC Office Note, No. 323, 36pp.

No. 8. Yu, T. W., 1987: A Technique of Deducing Wind Direction from Satellite Measurements of Wind Speed. Monthly Weather Review, 115, 1929-1939.

No. 9. Auer, S. J., 1987: Five-Year Climatological Survey of the Gulf Stream System and Its Associated Rings. Jour. Geophy. Res., 92, 11, 709-726.

No. 10. Chao, Y. Y., 1987: Forecasting Wave Conditions Affected by Currents and Bottom Topography. Technical Note, 11pp.

No. 11. Esteva, D. C., 1987: The Editing and Averaging of Altimeter Wave and Wind Data. Technical Note, 4pp.

No. 12. Feit, D. M., 1987: Forecasting Superstructure Icing for Alaskan Waters. National Weather Digest, 12, 5-10.

No. 13. Sanchez, B. V., D. B. Rao, and S. D. Steenrod, 1987: Tidal Estimation in the Atlantic and Indian Oceans. Marine Geodesy,10, 309-350.

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No. 16. Yu, T. W., 1988: A Method for Determining Equivalent Depths of the Atmospheric Boundary Layer Over the Oceans. Jour. Geophy. Res., 93, 3655-3661.

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No. 18. Feit, D. M., 1987: An Operational Forecast System for Superstructure Icing. *Proc. Fourth Conference Meteorology and Oceanography of the Coastal Zone*, 4pp.

No. 19. Esteva, D. C., 1988: Evaluation of Preliminary Experiments Assimilating Seasat Significant Wave Height into a Spectral Wave Model. Jour. Geophy. Res., 93, 14,099-14,105.

No. 20. Chao, Y. Y., 1988: Evaluation of Wave Forecast for the Gulf of Mexico. *Proc. Fourth Conference on Meteorology and Oceanography of the Coastal Zone*, 42-49.

I. INTRODUCTION

The QuikSCAT satellite (NASA) was launched into a polar orbit in June 1999 with a SeaWinds scatterometer on board to provide ocean surface wind vectors. The data from the sensor were made available in "real-time" for operational use since February 2000, through Central Operations of the National Centers for Environmental Predictions (NCEP). These wind vector data are processed at a 25 km nominal resolution across a 1800 km swath (72 cells). The design of SeaWinds uses a scanning radar which is different from earlier scatterometers, which used fixed stick antennas. There are two spot beams with HH and VV polarization, which operate in the Ku band (14.6 GHz) at angles of approximately of 46 and 54 degrees, respectively, which scan the ocean surface to a distance of 700 km and 900 km from nadir (figure 1) and provides four different backscatter measurements (two fore and two aft) per target cell. The radar measures the backscatter which is dependent upon the roughness elements of the ocean surface. The roughness of the ocean surface is related to wind stress from which wind speed and direction can be deduced. Figure 2 summarizes the characteristics of current satellites European Remote-sensing Satellite (ERS-2), the Special Sensor Microwave/Imager (SSM/I) series and QuikSCAT, that provide "real-time" ocean surface winds. QuikSCAT has the capability for providing a much larger aerial coverage (1800km swath) of the ocean surface than ERS-2 (500 km swath). And, QuikSCAT has the capability for providing wind vector data through a higher range of wind speeds than the SSM/I which is also limited to only wind speed retrievals.

For each new satellite system that enters the NCEP operational environment, a period of evaluation is required before the data can be used at NCEP. The specified requirements of accuracy for ocean surface wind measurements are that the RMS should be less than 2m/s for wind speeds up to 20 m/s or 10% for wind speeds above 20 m/s, and 20 degrees for directions for all weather conditions. Past experiences at validating and preparing new satellite retrievals for use at an operational center, NCEP, have demonstrated that careful inspection of the new "fast-delivery" data is required (Gemmill, et al. 1999). Quality control problems must be determined and the adequacy of the transfer function under all weather conditions must be validated.

Because the design of QuikSCAT is new to operational meteorology, there are several concerns about the accuracy of the wind vector retrievals from radar backscatter measurements that need to be addressed. Further, backscatter in the Ku-band will be affected by atmospheric attenuation due to rain and cloud liquid water, as well as distortions at the ocean surface due to rain. And, there is the well-known liability for scatterometers in general, the inversion process from backscatter measurements to a wind vector is not unique, and may provide up to four solutions.

For each solution, a Most Likelihood Estimate (MLE) is calculated and then the solutions are ranked with the highest MLE first, and in a descending order of MLE for the others. However, selecting the wind vector based on the highest MLE does not always provide the "best" wind. The MLE often fails to discriminate correctly between two wind vectors opposite to each other, and a wrong wind vector is ranked first. Experience with the ERS-1 scatterometer demonstrated the problem with the MLE (Rufenach, 1998). A quick calculation demonstrates that even if the data were almost perfect, it takes only one wind direction reversal in nine to give an RMS error of 60 degrees. A common technique to improve the selection of the "best" wind vector has been the application of an ocean surface wind field as auxiliary (background) information which is used to re-rank the solutions. For QuikSCAT data, a 6-hour forecast ocean surface wind field from NCEP's global numerical weather forecast model is used to provide the background winds. The first re-ranked solution in this process is called the "nudged" solution. Obviously, if the background wind field contains serious errors, so would the selected "nudged" satellite wind vectors. Techniques have been proposed and developed for determining the "best" satellite derived wind field based on the consistency of the satellite wind retrievals by themselves (i.e. Stoffelen and Anderson, 1997).

2) EVALUATION of OCEAN SURFACE WIND DATA

This evaluation is made to determine and understand the characteristics (strengths and limitations) of the QuikSCAT ocean surface wind vector data, so that the data may be used to its fullest potential. This evaluation is performed in two parts: 1) the standard buoy, model and satellite collocation match up comparisons at a given locations, and 2) a satellite and model match up comparison by cell location across the swath. In addition, the standard buoy, model and satellite collocation match up comparisons are made for the NCEP reprocessed ERS2 scatterometer wind vector retrievals and also, NCEP neural network SSM/I wind speed retrievals from four satellites, F11, f13, f14 and F15, in order to make inter-comparisons of wind data quality between other operational satellite systems.

a) Buoy, Satellite and Model Analysis Evaluations

Satellite wind data are collocated four times a day at 00,06,12,18 UTC with buoy wind data that are within +/- three hours temporally and with 50km spatially. Model surface wind analysis wind data is valid at the same time of the buoys, but is interpolated to the collocated satellite location measurement. For this study, only buoys that are more than 100km from the coast and report a wind that is equivalent to 10 m above the sea level are used. This greatly reduces the number of buoys used, but their accuracy is more assured. An implicit assumption is that the buoy measurements are close to "truth." The dates for the match ups are from April 10, 2000 through May 10, 2000.

Figures 3-12 are a series of scatter plots of satellite retrievals against the buoy data for speed and direction, for various categories of cell location and rain flags (Huddleston and Stiles, 2000). Figures 3-4 are plots for speed and direction, respectively, for all the data. For wind speed data, the dashed diagonal line is the perfect fit line, and the solid diagonal lines above and below are the 2 m/s RMS error lines. Although the bias between the satellite and buoy data is close to zero, and the RMS is 1.6 m/s there are a number of satellite wind speeds that are well outside the 2 m/s error zone. For direction data, the dashed diagonal line is the perfect fit line, with the 20 degree error line above and below, 180 degree error line also above and below. The directions also show an acceptable RMS of about 25 degrees (for wind speed above 3.5 m/s), but the scatter is well outside the 20 degree error envelope. "Nudging" seems to have worked well, as there is no indication in the Quikscat data of the 180-degree error.

Figures 5-6 are for the situation where the edge cells (only one antenna) are excluded and the probability of rain is given as zero. Now most of the extreme satellite wind speeds are not present, and the bias is slightly negative m/s and the RMS is 1.3 m/s But, there is also an exclusion of the higher wind speeds (> 15 m/s). The directions improve only slightly. Wind direction RMS errors are less than 25 degrees.

Figures 7-8 are for again no edge data, but for the probability of rain greater than zero but less than 0.1, which is labeled here as light rain. The speed bias is now slightly above zero and the RMS increases to 1.5 m/s, but still quite acceptable. The RMS for wind direction is now just below 20 degrees.

Figures 9-10 are for no edge data, but for the probability of rain from 0.1 to 1.00, which is labeled as moderate rain. These data are obviously not useful, since the influence of rain increases the speed bias to +3.9 m/s, and the RMS to 6.6 m/s, while the direction RMS is increased to 32.0 degrees.

Figures 11-12 are for retrievals where the rain probability could not be determined, which includes all the edge data because there is only one antenna, but occasionally for interior swath data for other reasons. The speed bias for these data is only slightly high (+0.2 m/s), and its RMS is 1.8 m/s, but the RMS for direction is now 33.0 degrees which is too large for reliable use.

Table 2 summarizes the results presented in the above scatter plots. The top part of the table presents the mean and maximum wind speeds and number of data points for the buoy and quikscat data for the various categories of data. The bottoms part of the table presents the bias and RMS differences between the satellite and buoy data. The table suggests that the edge data and data with probability of rain in the range of 0.1 to 1.0 should be excluded.

Table 3 is included to compare the quikscat data with other ocean surface wind data. Here we present the wind speed data retrieved from SSM/I and wind vector data from ERS2. The SSM/I wind speed data used here were derived using neural networks (Krasnopolsky et al, 1999), and the ERS2 winds are the NCEP reprocessed winds (Gemmill et al, 1999). The QuikSCAT retrievals are presented for the two categories, 1) no edge data and there is no rain and 2) no edge data and there is only light rain. Using QuikSCAT data from both categories, the wind speeds are comparable to the SSM/I and ERS2. One unfortunate limitation to the validation of the ERS data in this region is that when approaching the north American continent the scatterometer mode is turned off and the SAR mode is turned on, so that wind comparisons with buoys are not always possible. This table shows that the quikscat wind speed data are slightly better than the SSM/I and ERS-2 data, and the wind direction data are slightly better than the ERS-2 scatterometer data.

b) Satellite and Model Analysis Evaluation

The other part of the evaluation is to collocate model analyses four times a day at 00,06,12,18 UTC by interpolating an analysis directly to each of the satellite cells across the swath, but only within +/- 45 minutes of the analysis. The QuikSCAT data are extremely dense, so the time window was reduced to conserve storage, but this should have little effect on the results. Even though wind field analyses by themselves are not real observations, such as those provided by the anemometers on board ships and buoys, it is generally accepted that they most often provide a reasonably accurate description of the wind field and its characteristics. Hence, it is possible to use the information from the analyzed wind fields to examine the quality of satellite wind retrievals across the swath which would not be possible to do with buoy measurements. In the later case, an exceedingly long period of time would be required to assemble a large enough collocated data base to compute reliable statistics. And, even with an adequate data base, buoys cannot represent the true relative nature from cell to cell because the cell matchups will be from different buoys at different times. Figures 13-24 are a series of plots comparing satellite and model wind speed and direction data across for each cell the swath.

Figures 13-14 show the comparisons of the first choice of the MLE for all the wind vector retrievals. These data show that there is a problem of speeds on the outer edges of the swath, but the rest of the swath has accurate wind speeds, although the accuracy decreases slightly near nadir. But, it is clear that the MLE is not a reliable measure to be used to obtain the correct direction. As expected, the selection problems of direction from the outer edges and near nadir are clearly evident. And, even at its best, the RMS of 60 degrees based on MLE over the rest of the swath is not acceptable.

Figures 15-16 show the comparisons for all the "nudged" retrievals. Wind speeds are improved along the edges, and there is a dramatic improvement of directions across the swath, close to 20 degrees, as opposed to 60 degrees with MLE solution.

Figures 17-18 show the comparisons for the "nudged" retrievals, but only for where the probability of rain is zero. These retrievals do not include edge data. Cells 1-8 and cells 65-72 are on the edges of the swath which are scanned with just one antenna, so no rain probability is determined. For the interior cells, cells 9-64, the wind speed data have a slight negative bias of -0.5 m/s and RMS of near 1.5 m/s. The direction RMS differences are now around 23 degrees except near the outer cells of the inner antenna.

Figures 19-20 show the comparisons for the "nudged" retrievals, where the probability of rain is greater than zero but less than 0.1, and again excluding the edge data. The speed bias is slightly positive and the RMS differences are near 1.5 m/s, and they tend to be slightly higher near nadir and close to the edge of the inner antenna, but the wind direction RMS is less than 20 degrees.

Figures 21-22 show the comparisons for the "nudged" retrievals, where the probability of rain is greater than 0.1 to 1.0, and excluding the edge data. Here again the contamination of the retrievals as a result of rain is obvious. The speed biases are well above 2.0 m/s and the RMS is above 4.0 m/s. Directional errors are in the 30-degree range.

Figures 23-24 show the comparisons for the cells where the probability of rain was not calculated or given. Most of this data comes from the outer edge of the swath. Occasionally, the probability of rain is not calculated for other portions of the swath. The direction errors are high for the outer edge, and there is a large variation in errors along the inner portion of the swath.

3) CONCLUSION

Based on this initial one-month evaluation, the "fast-delivery" QuikSCAT "nudged" ocean surface wind vector retrievals more than meet the specification for "operational" use at NCEP. This is especially true for wind speeds under most conditions, and also for wind directions provided that certain data are excluded from use. To insure that ocean surface wind vectors retrievals are of the highest quality, it is recommended that retrievals be excluded from: 1) from the outer 200km edges of the swath, or 2) from where the probability of rain is greater than 0.10, or 3) from where the probability of rain is not computed.

ACKNOWLEDGMENTS:

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QuikSCAT VIEWING GEOMETERY
TWO ANTENNAE at 54 & 46 Degree INCIDENT ANGLES
SWATH 1800 km
LIMITATIONS:
OUTER EDGES - ONLY ONE SCANNING ANTENNA
NADIR - SMALL LOOK ANGLES

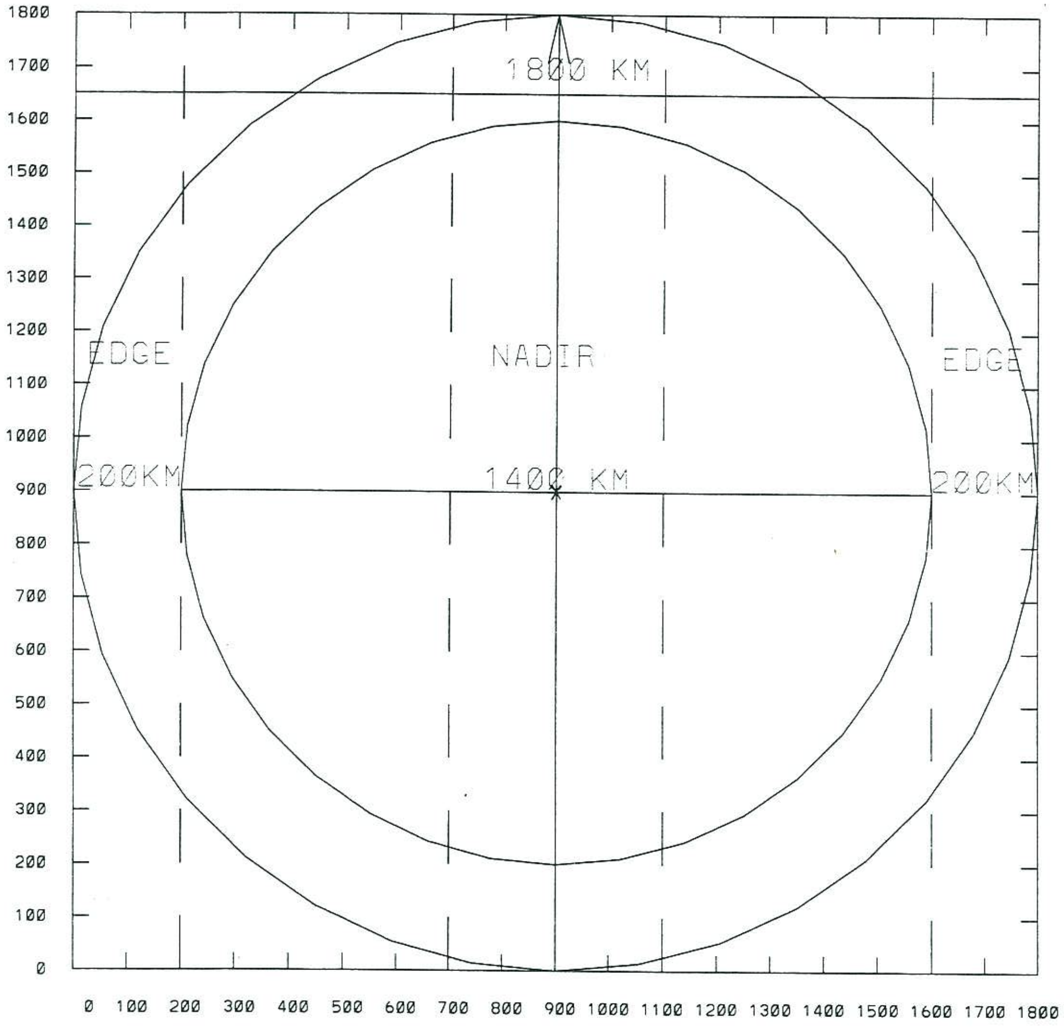

Figure 1

FIGURE 2

SATELLITE OCEAN SURFACE WIND SPECIFICATIONS FOR VARIOUS PLATFORMS.

- POLAR ORBITER (~ 102 MINUTES)

- TWICE DAILY AREAL COVERAGE
(ONE ASCENDING & ONE DESCENDING ORBIT)

SATELLITE	DMSP - SSM/I f11,f13,f14,f15	ERS-1/2	QuikSCAT
SENSOR	PASSIVE MICROWAVE	ACTIVE MICROWAVE	ACTIVE MICROWAVE
ANTENNA/ MEASUREMENT	7 CHANNELS / BRIGHTNESS TEMPERATURE	THREE ANTENNA / SIGMA-0	TWO ANTENNA / SIGMA-0 (2-POL)
ANTENNA/ MODE	SCANNING	1-SIDED	SCANNING
FREQUENCY/ BANDS	19 (H,V), 22 V 37 (H,V), 85(H,V) GHz	5.3 GHz / C-band	14 6 - GHz / KU-band
SWATH	1392 km	500 km	1800 km
No. of CELLS	64	19	72
FOOTPRINT	25 km	50 km	25 km
SPEED RANGE	3-25 m/s	4-24 m/s	3-30 m/s
SPEED ACCURACY	2 m/s, & for > 20 m/s (10%)	2 m/s, & for > 20 m/s (10%)	2 m/s, & for > 20 m/s (10%)
DIRECTION ACCURACY	No Directions	+/- 20 DEG	+/- 20 DEG
ALGORITHM	GWS & NN3	CMOD4	NSCAT

OCEAN SURFACE WIND MATCH-UP STATISTICS

QSCAT FIX BUOY

SPEED m/s

ALL DATA

Number of data points= 8907

BIAS,RMS SPEED = -.01 1.60

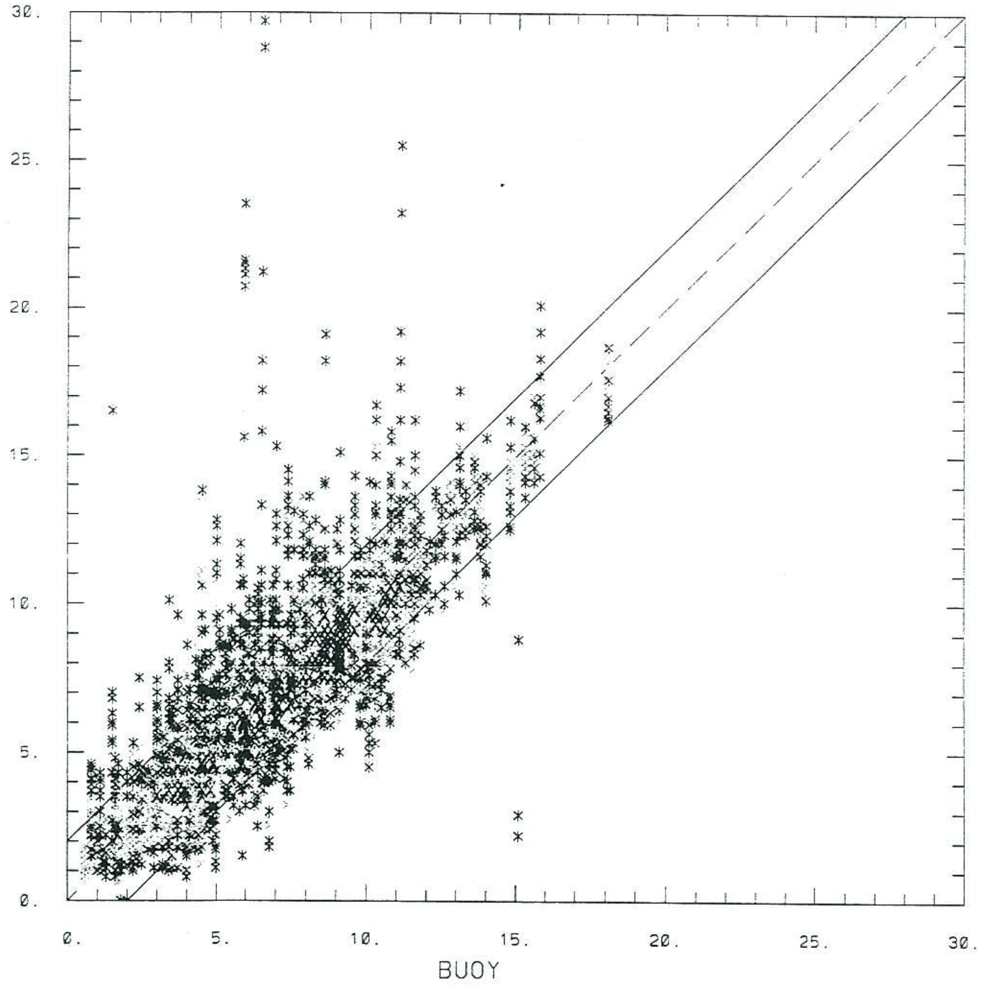

Figure # 3

OCEAN SURFACE WIND MATCH-UP STATISTICS

QSCAT FIX BUOY

DIRECTION degrees

ALL DATA

Number of data points= 8005

BIAS,RMS DIRECTION = 4.0 24.2

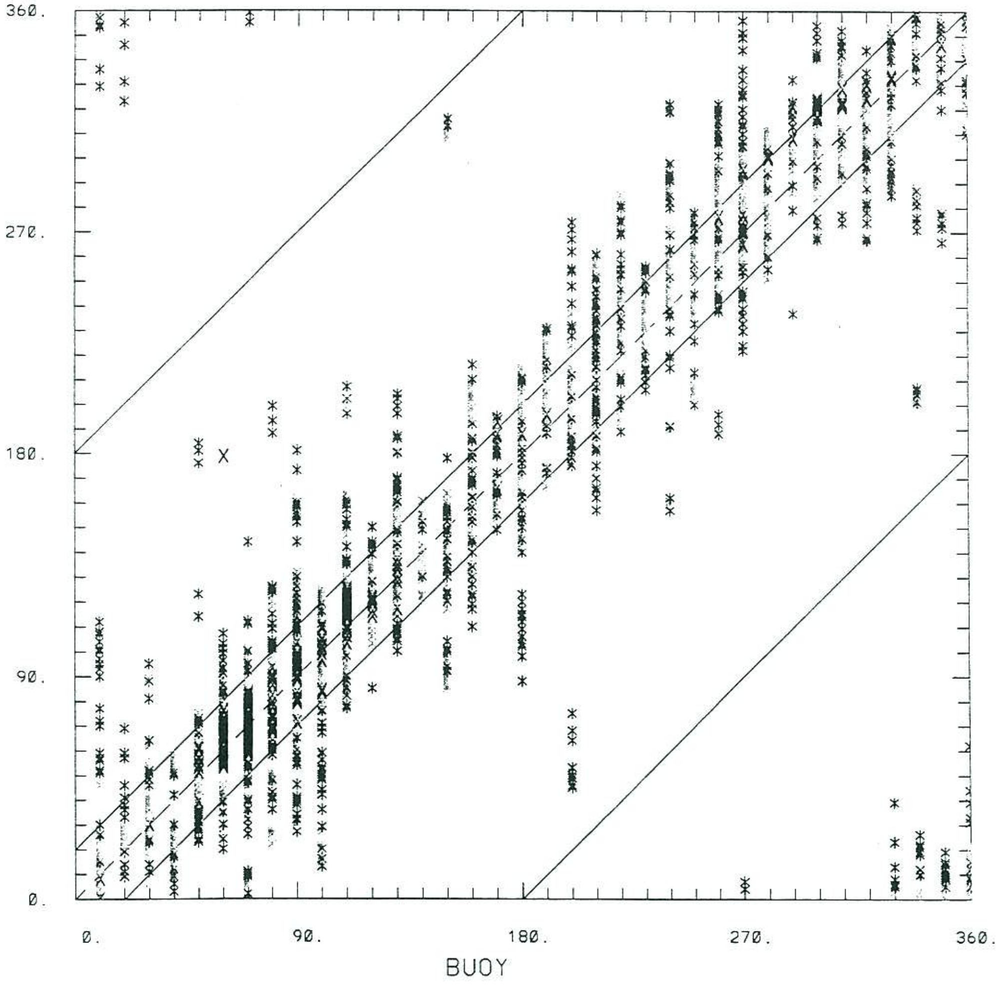

Figure # 4

OCEAN SURFACE WIND MATCH-UP STATISTICS
QSCAT FIX BUOY
SPEED m/s
NO RAIN, NO EDGES
Number of data points= 5261
BIAS,RMS SPEED = -.21 1.24

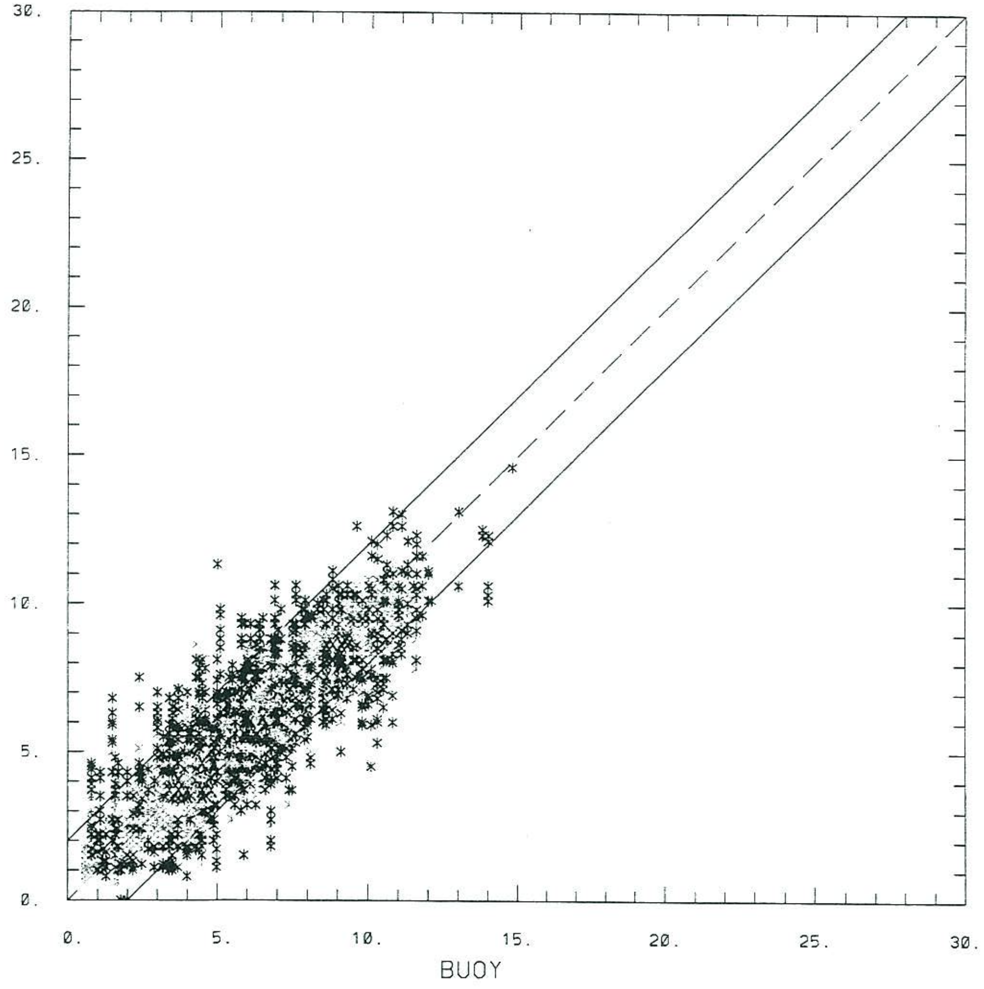

Figure # 5

OCEAN SURFACE WIND MATCH-UP STATISTICS
QSCAT FIX BUOY
DIRECTION degrees
NO RAIN, NO EDGES
Number of data points= 4555
BIAS,RMS DIRECTION = 3.6 22.9

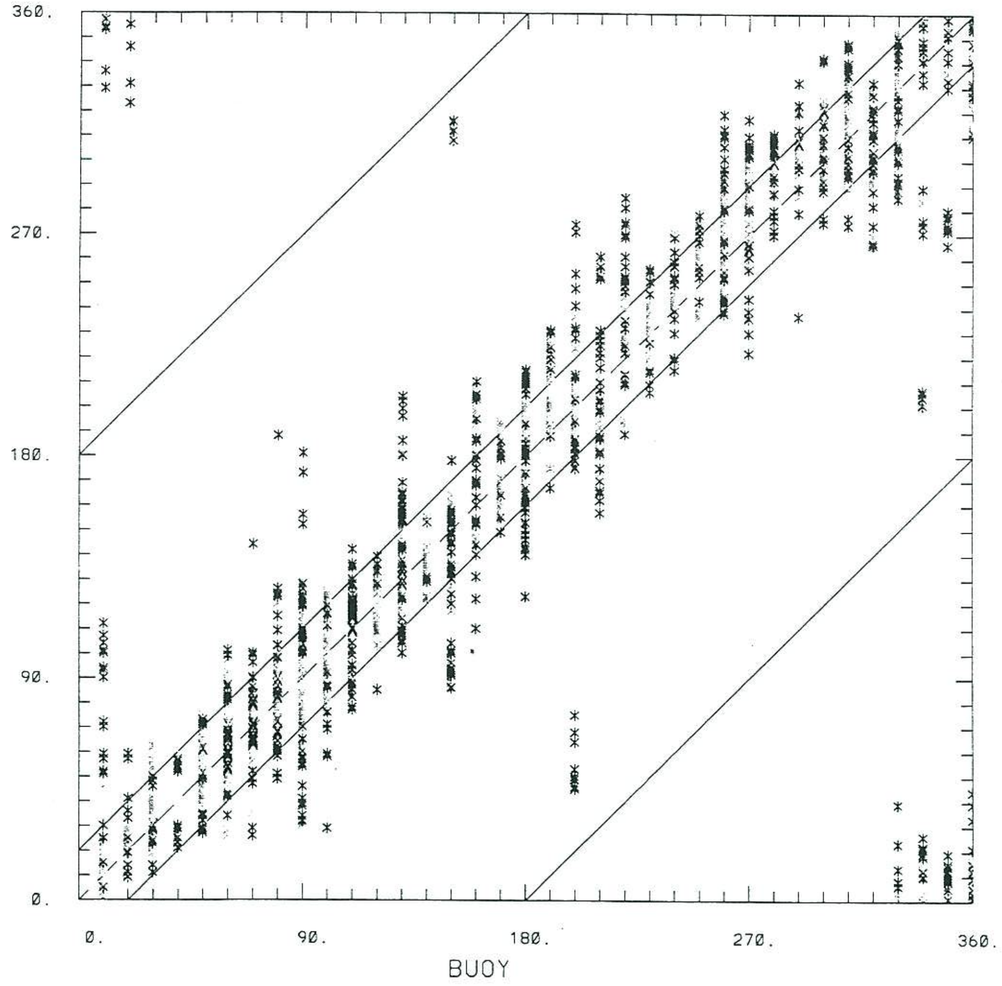

Figure # 6

OCEAN SURFACE WIND MATCH-UP STATISTICS
QSCAT FIX BUOY
SPEED m/s
Light RAIN, NO EDGES
Number of data points= 2034
BIAS,RMS SPEED = .12 1.48

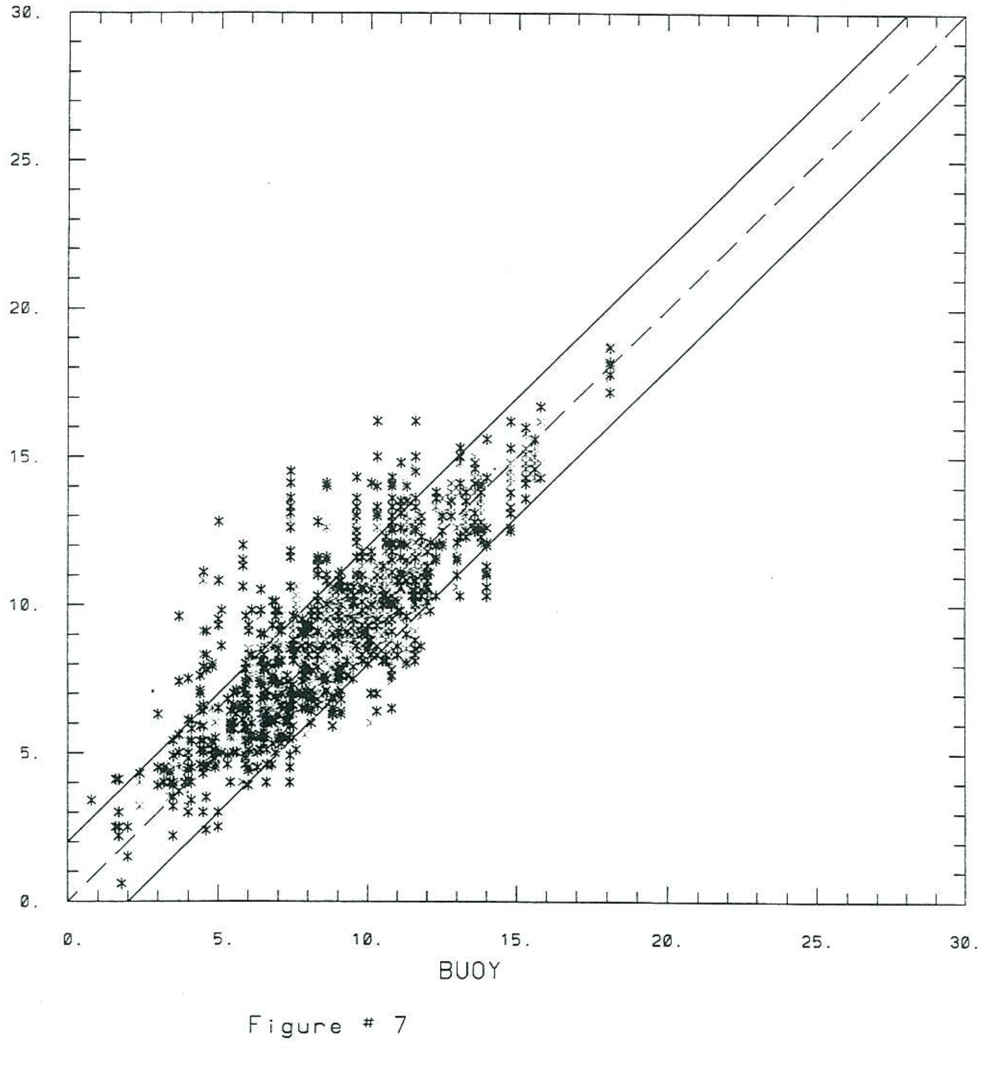

Figure # 7

OCEAN SURFACE WIND MATCH-UP STATISTICS
QSCAT FIX BUOY
DIRECTION degrees
Light RAIN, NO EDGES
Number of data points= 2005
BIAS,RMS DIRECTION = 5.3 20.1

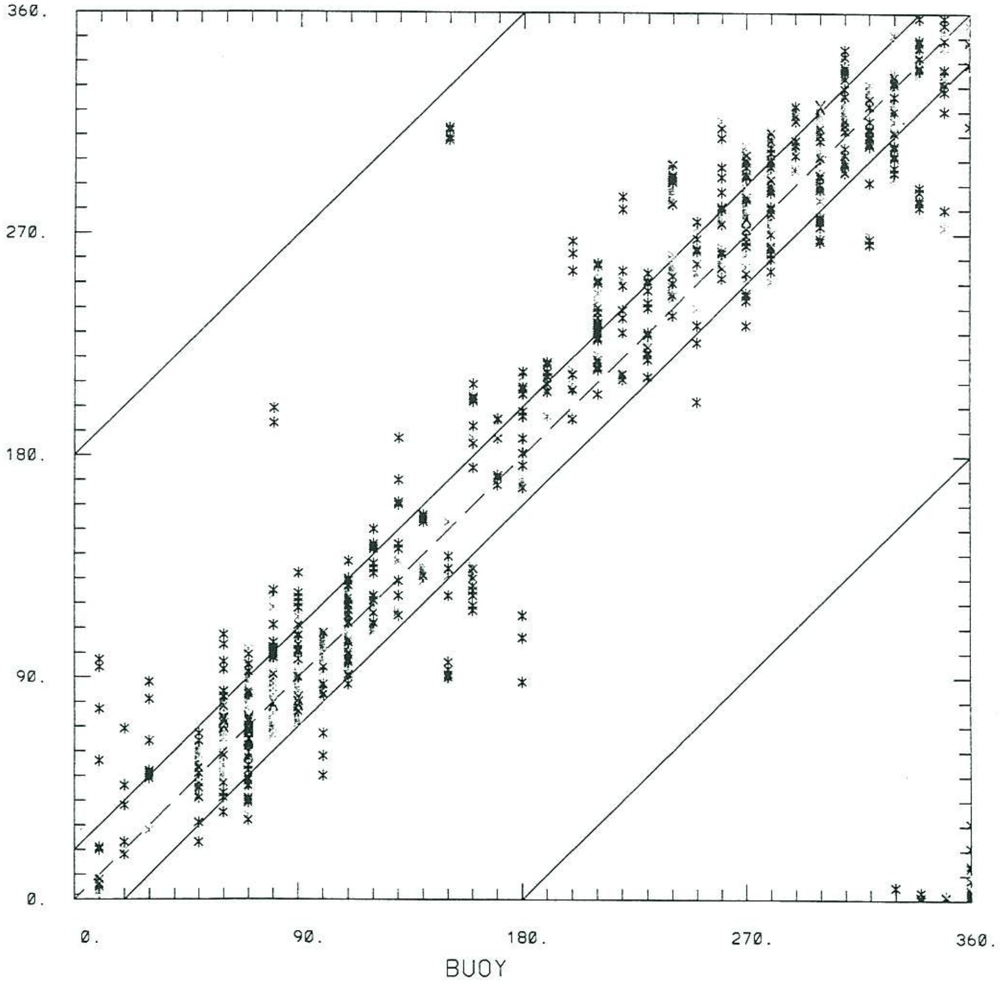

Figure # 8

OCEAN SURFACE WIND MATCH-UP STATISTICS

QSCAT FIX BUOY

SPEED m/s

Moderate RAIN, NO EDGES

Number of data points= 126

BIAS,RMS SPEED = 3.79 6.56

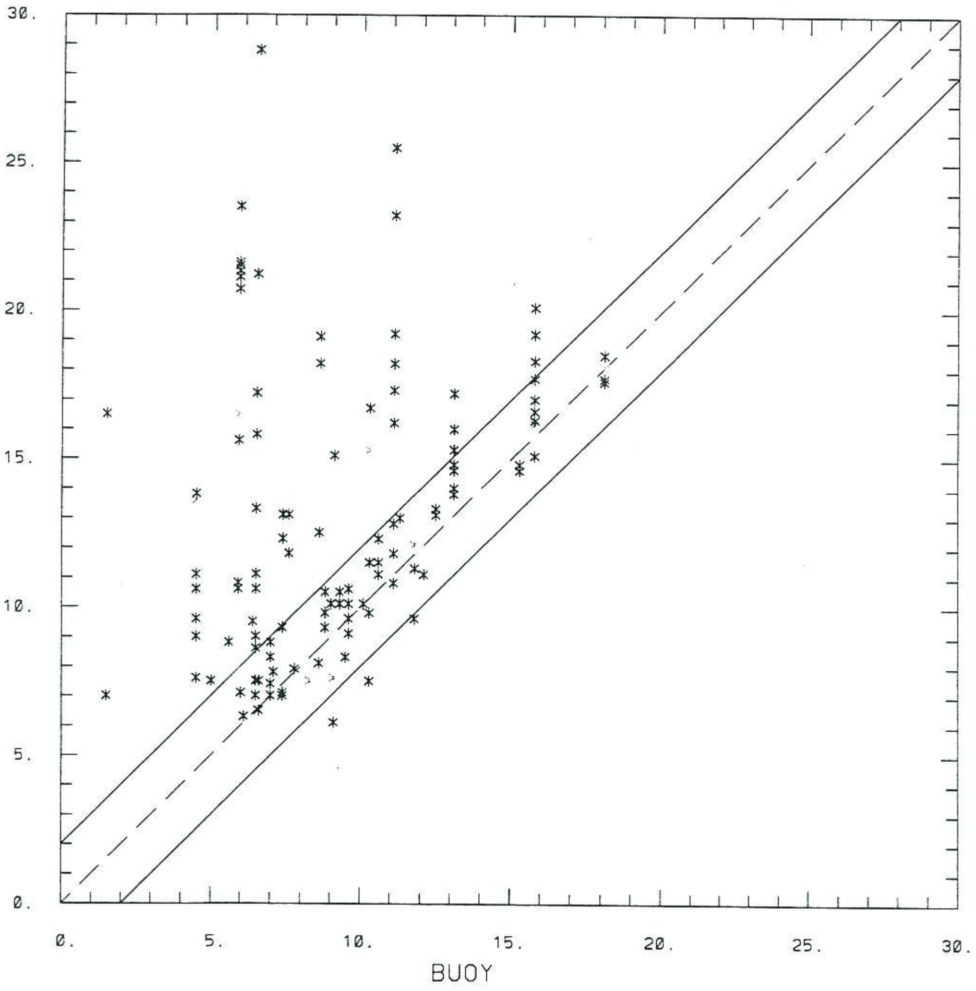

Figure # 9

OCEAN SURFACE WIND MATCH-UP STATISTICS
QSCAT FIX BUOY
DIRECTION degrees
Moderate RAIN, NO EDGES
Number of data points= 123
BIAS,RMS DIRECTION = 1.4 31.6

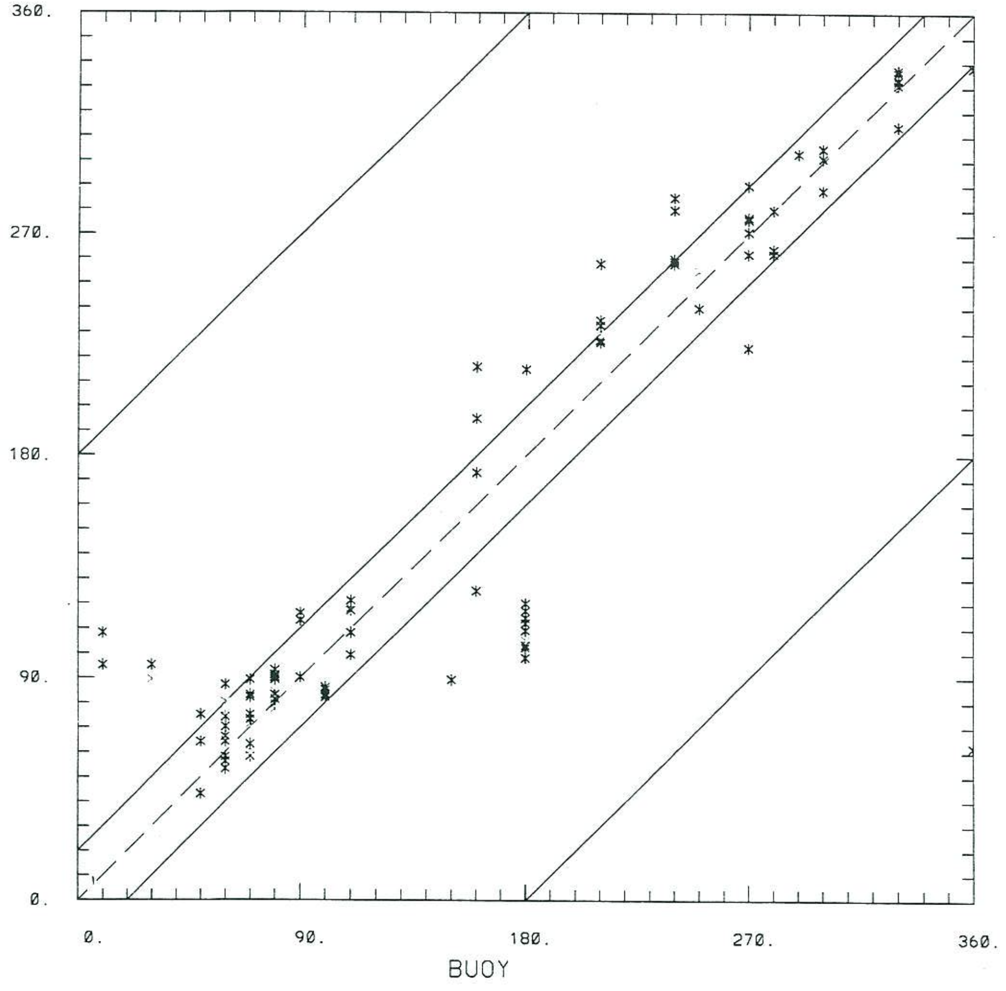

Figure #10

OCEAN SURFACE WIND MATCH-UP STATISTICS
QSCAT FIX BUOY
SPEED m/s
RAIN FLAG NOT DETERMINED, and EDGES

Number of data points= 1486

BIAS,RMS SPEED = .18 1.80

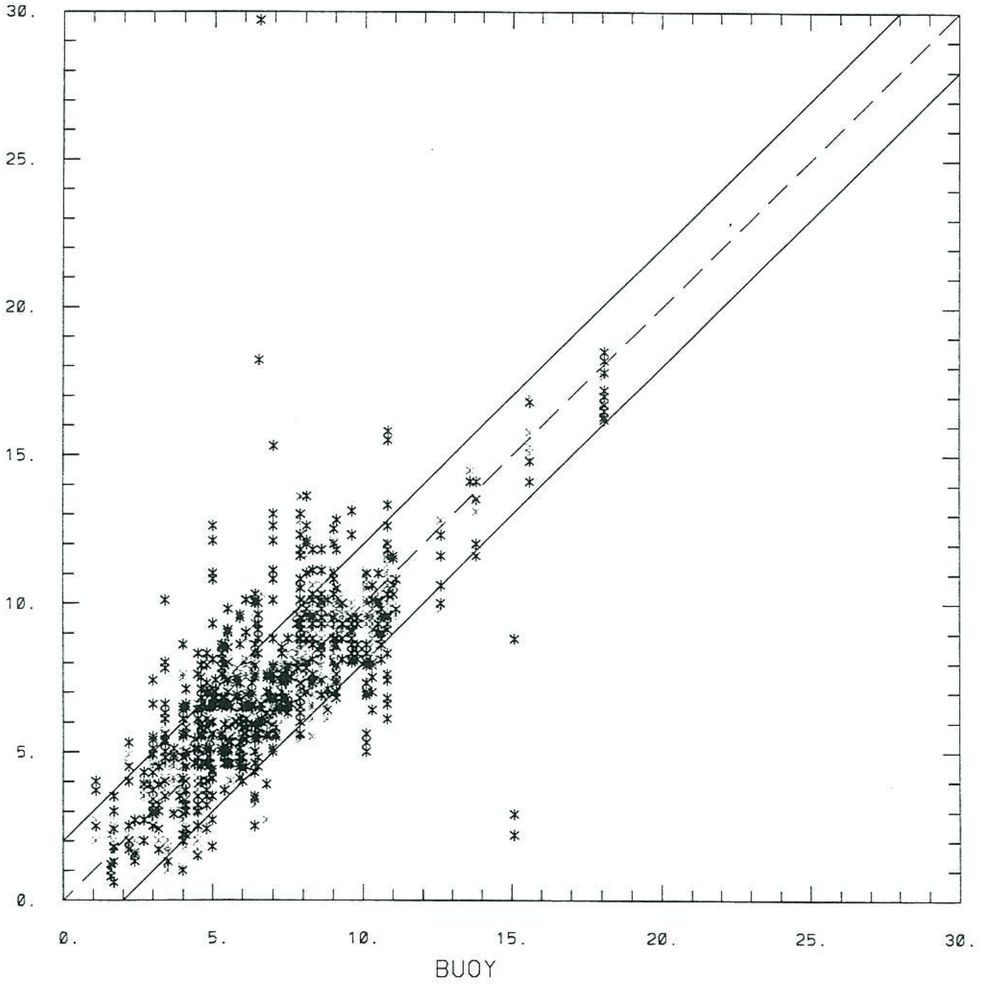

Figure #11

OCEAN SURFACE WIND MATCH-UP STATISTICS
QSCAT FIX BUOY
DIRECTION degrees
RAIN FLAG NOT DETERMINED, and EDGES
Number of data points= 1322
BIAS,RMS DIRECTION = 3.7 32.3

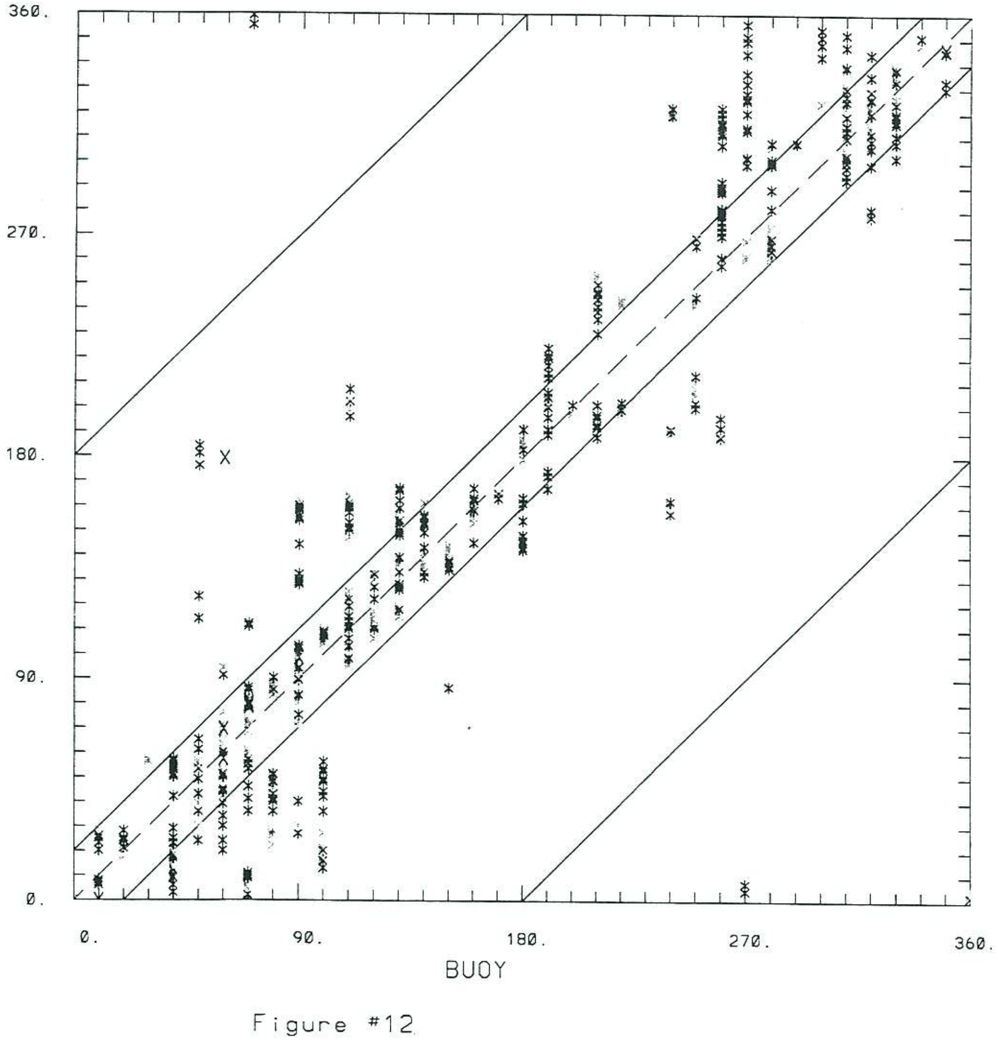

Figure #12

QSCAT vs MODEL ANL -- by CELL NUMBER -
SPEED DIFFERENCES (m/s)
ALL DATA AVN ANL MLE

Number of data points 4230778

Swath RMS = 1.93

Swath BIAS = .05

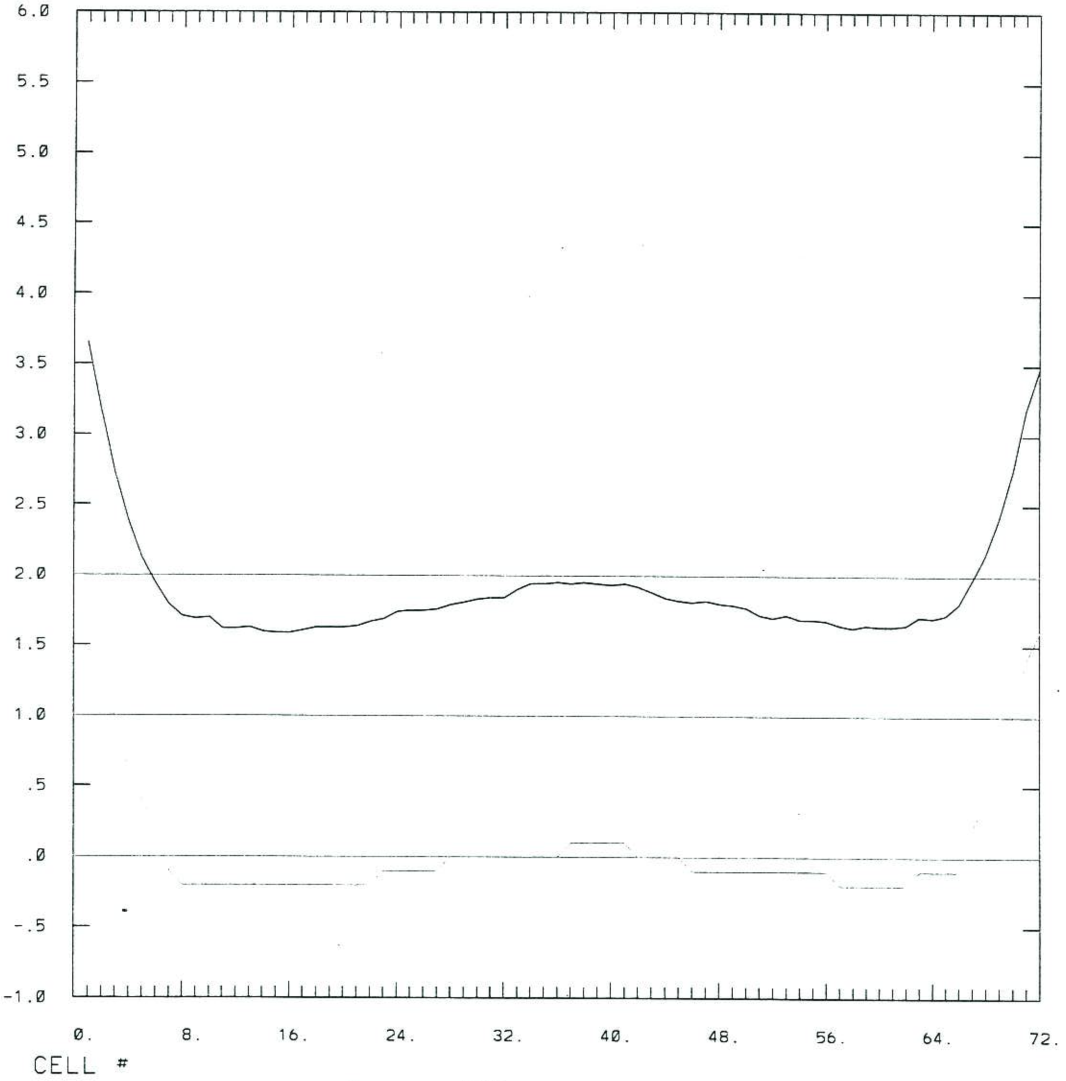

Figure #13

QSCAT vs MODEL ANL -- by CELL NUMBER -
DIRECTION DIFFERENCES (Degrees)
ALL DATA AVN ANL MLE

Number of data points 4230778

Swath RMS =71.54

Swath BIAS = .19

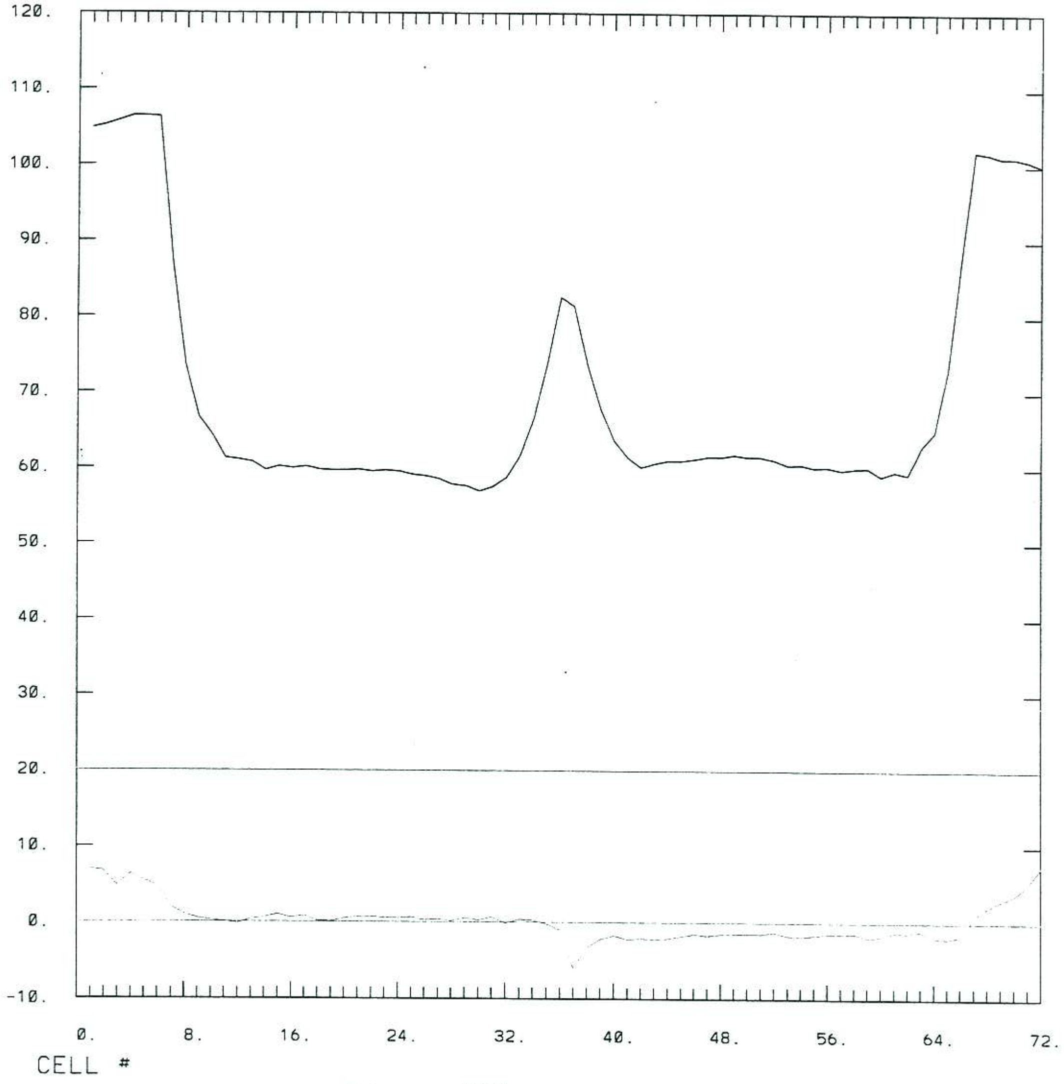

Figure #14

QSCAT vs MODEL ANL -- by CELL NUMBER -
SPEED DIFFERENCES (m/s)
ALL DATA AVN ANL NUDGED

Number of data points 4230778

Swath RMS = 1.75
Swath BIAS = -.21

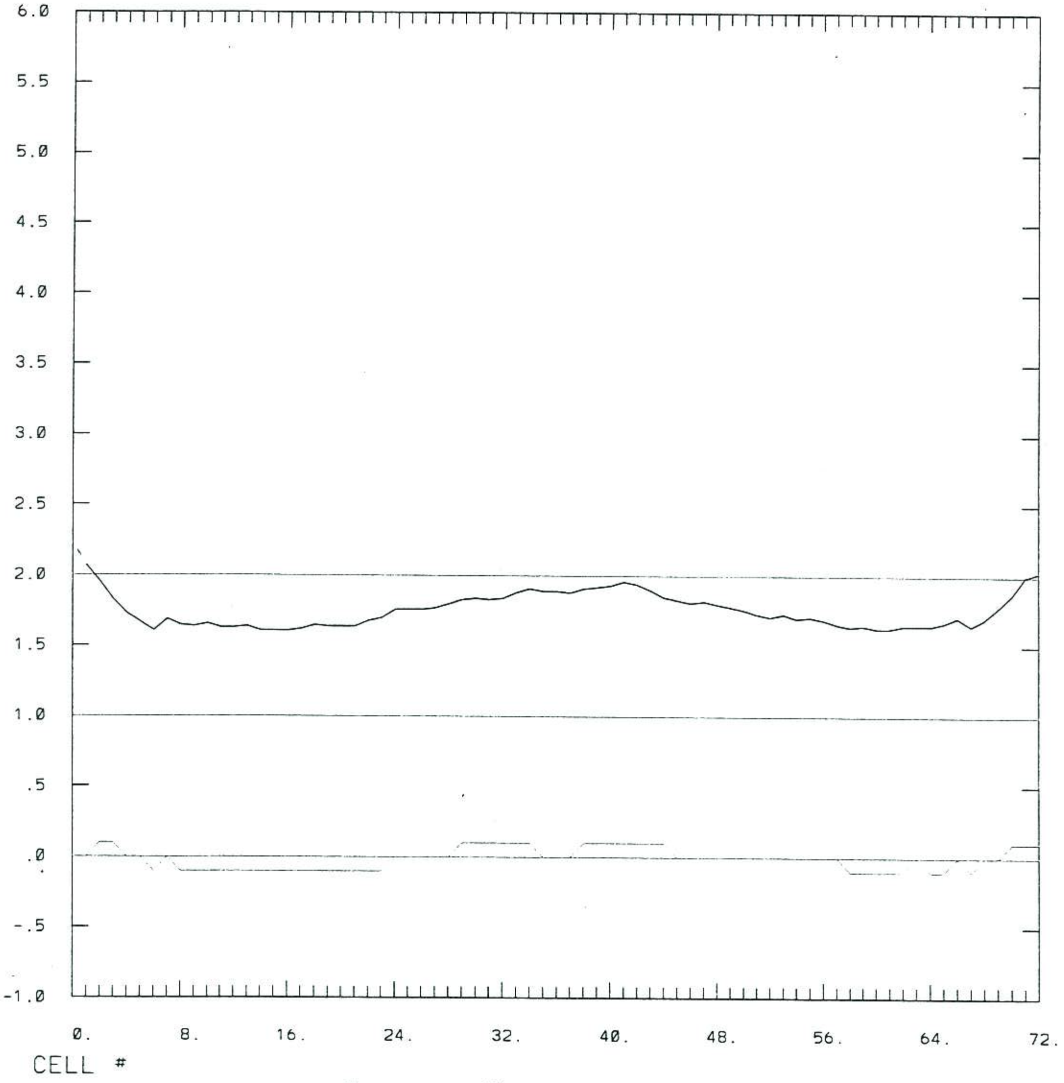

Figure #15

QSCAT vs MODEL ANL -- by CELL NUMBER -
DIRECTION DIFFERENCES (Degrees)
ALL DATA AVN ANL NUDGED

Number of data points 4230778

Swath RMS =22.68

Swath BIAS = -.91

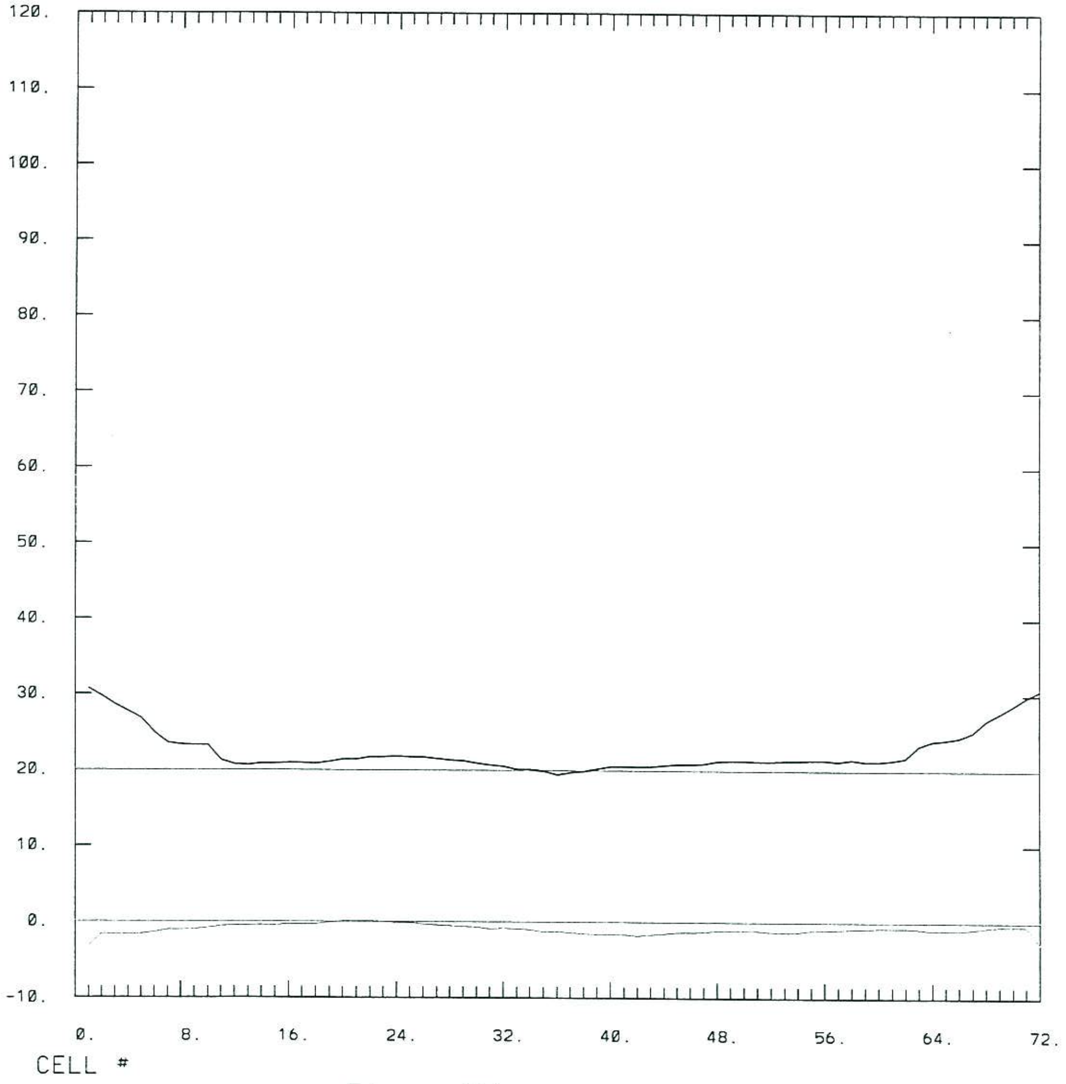

Figure #16

QSCAT vs MODEL ANL -- by CELL NUMBER -
SPEED DIFFERENCES (m/s)
NO RAIN AVN ANL NUDGED

Number of data points 1570344

Swath RMS = 1.41

Swath BIAS =-.43

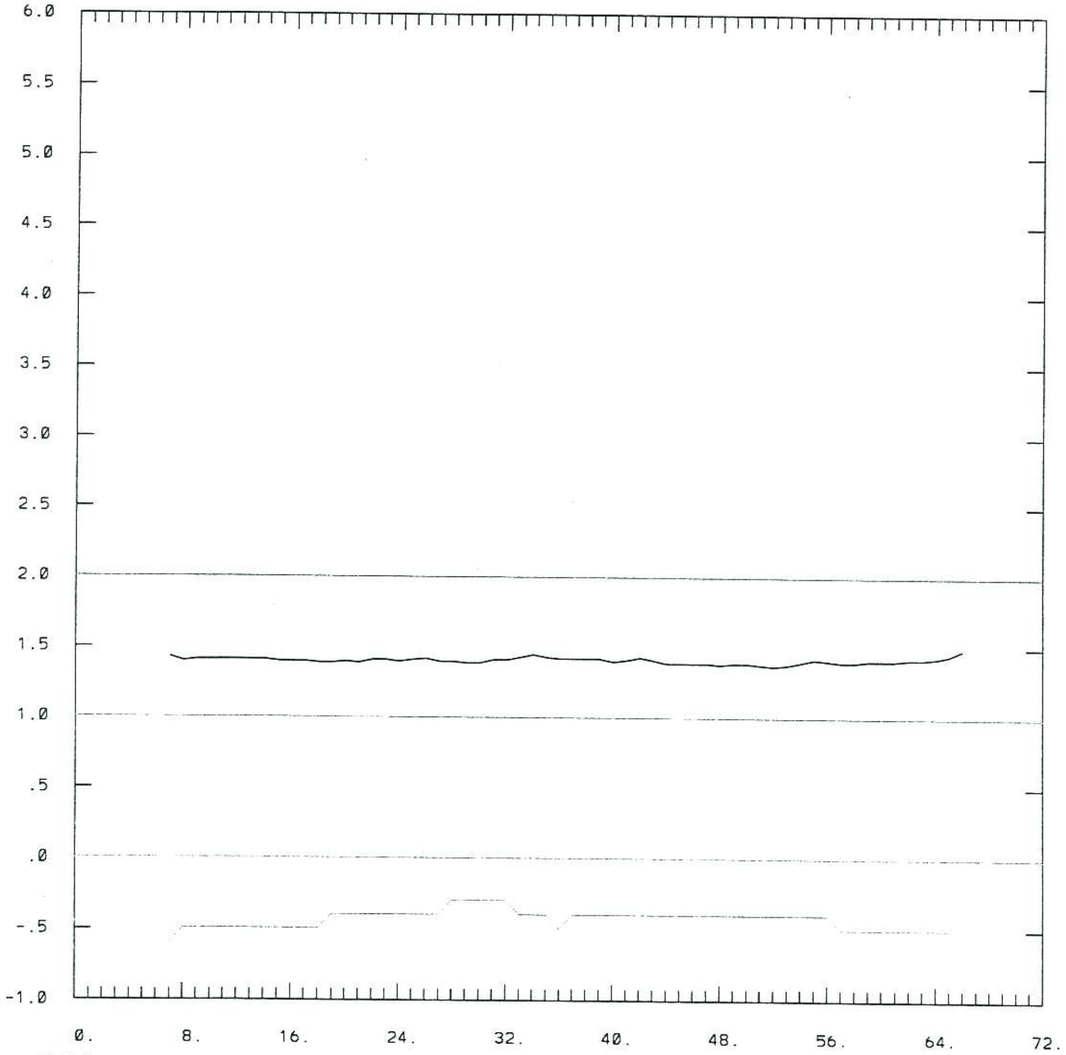

Figure #17

QSCAT vs MODEL ANL -- by CELL NUMBER -
DIRECTION DIFFERENCES (Degrees)
NO RAIN AVN ANL NUDGED

Number of data points 1570344

Swath RMS =23.48

Swath BIAS = -.45

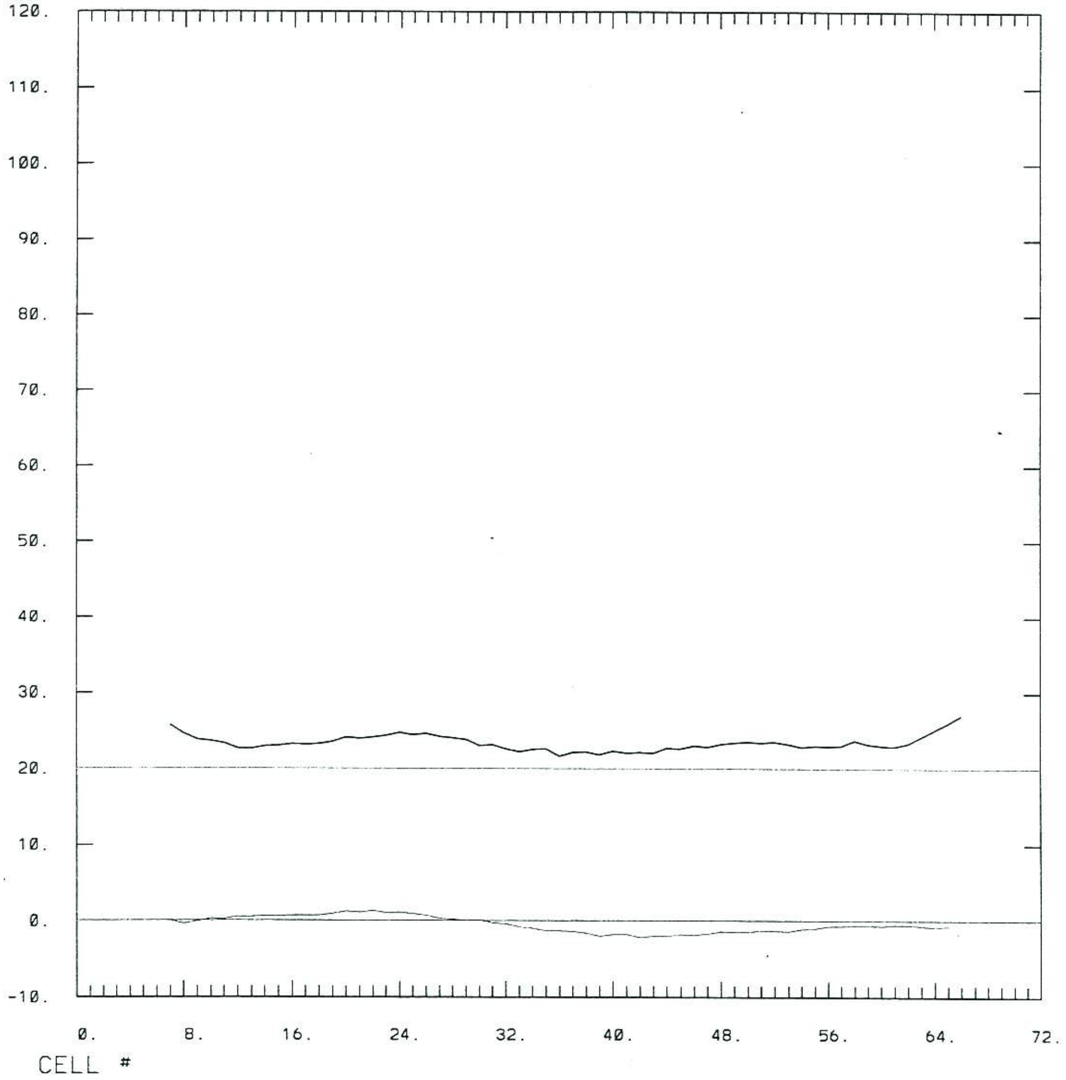

Figure #18

QSCAT vs MODEL ANL -- by CELL NUMBER -
SPEED DIFFERENCES (m/s)
Lt RAIN AVN ANL NUDGED

Number of data points 1686831

Swath RMS = 1.53

Swath BIAS = .12

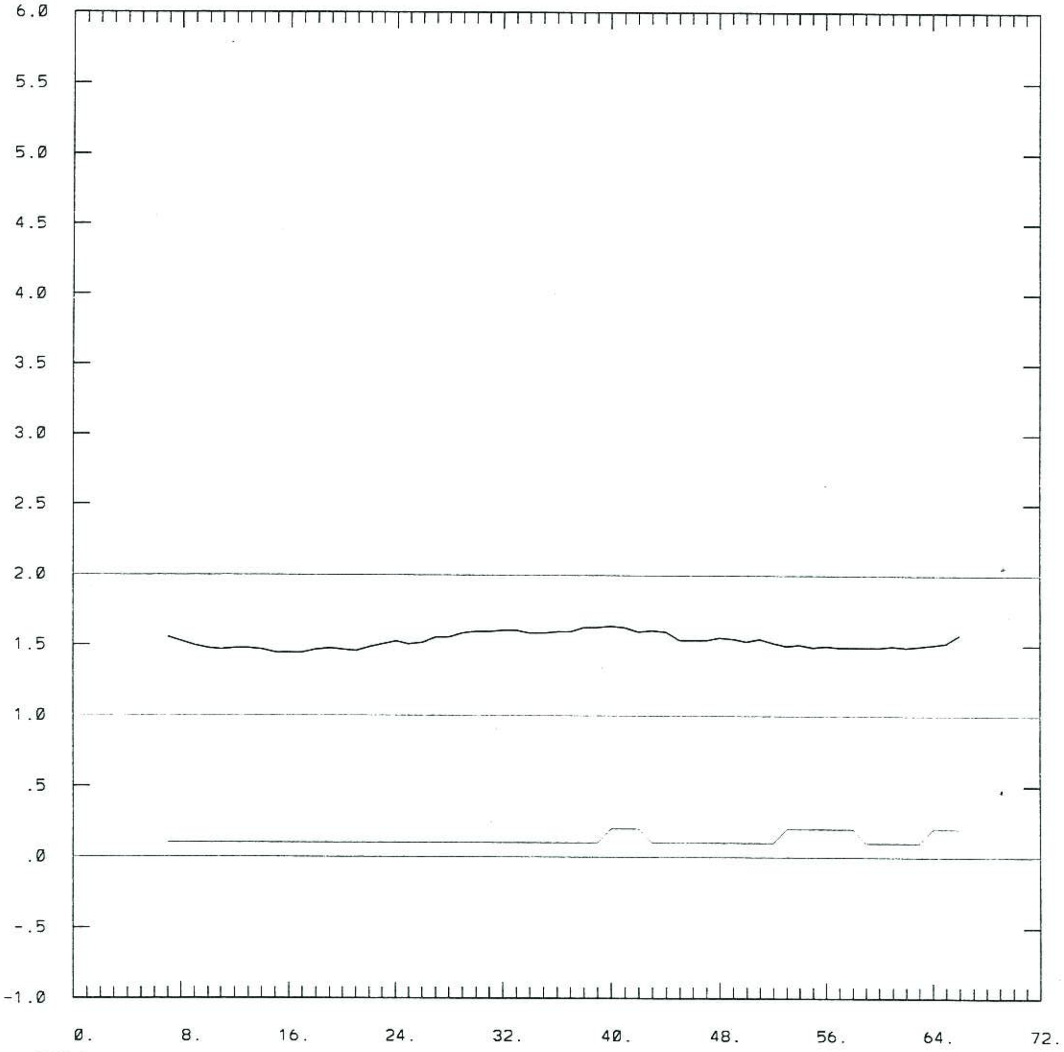

Figure #19

QSCAT vs MODEL ANL -- by CELL NUMBER -
DIRECTION DIFFERENCES (Degrees)
Lt RAIN AVN ANL NUDGED

Number of data points 1686831

Swath RMS =18.04

Swath BIAS =-1.15

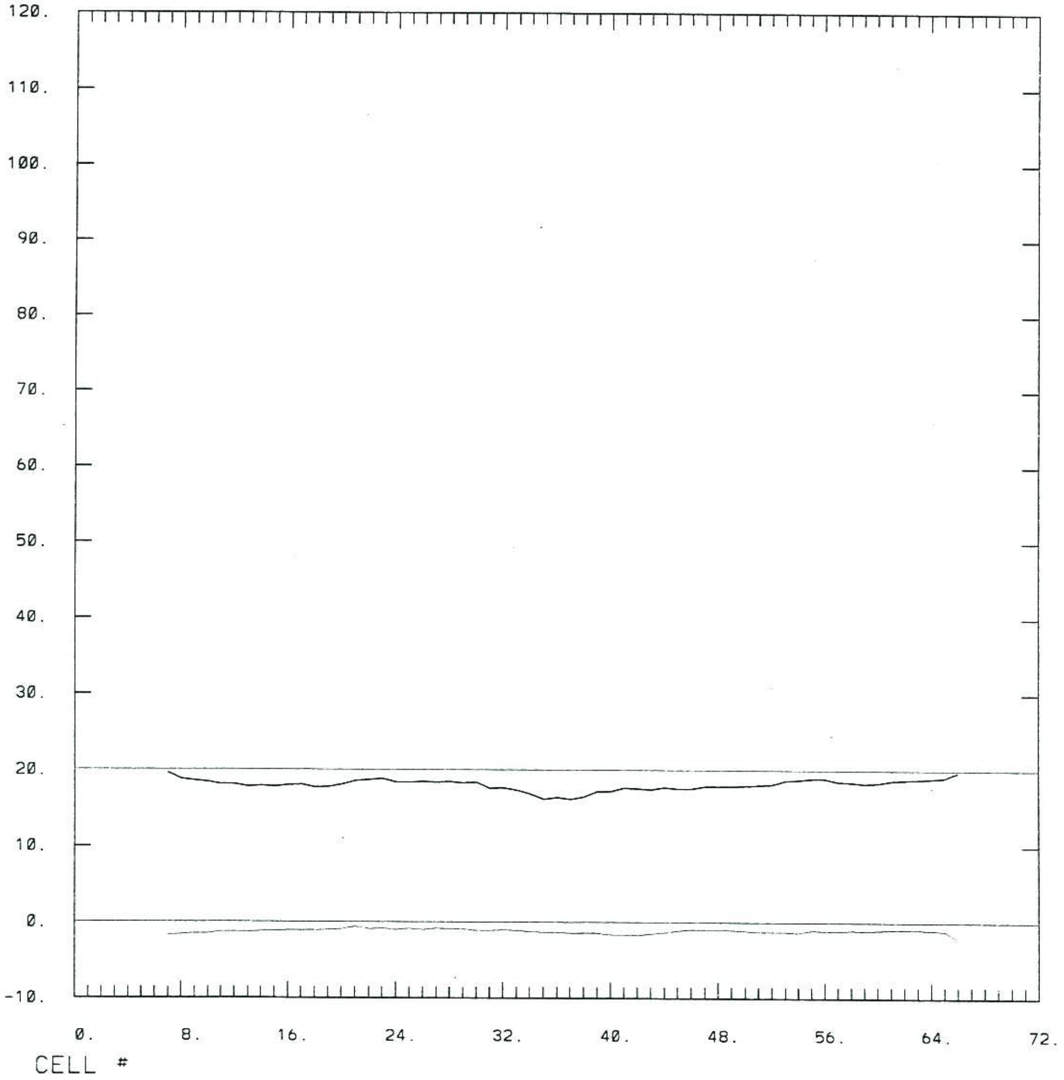

Figure #20

QSCAT vs MODEL ANL -- by CELL NUMBER -
SPEED DIFFERENCES (m/s)
MOD RAIN AVN ANL NUDGED

Number of data points 150725

Swath RMS = 4.57
Swath BIAS =2.69

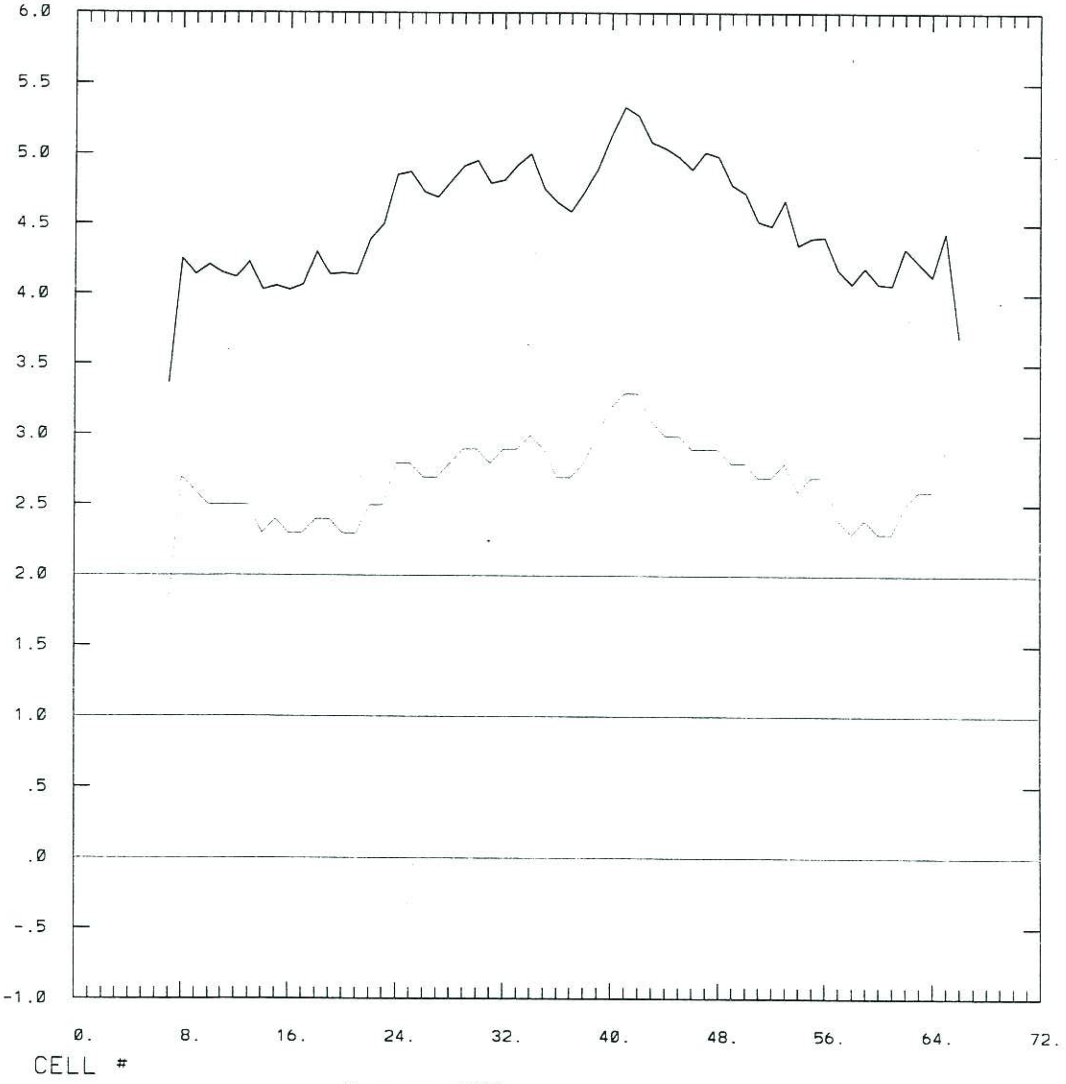

Figure #21

QSCAT vs MODEL ANL -- by CELL NUMBER -
DIRECTION DIFFERENCES (Degrees)
MOD RAIN AVN ANL NUDGED

Number of data points 150725

Swath RMS =30.56

Swath BIAS = -.29

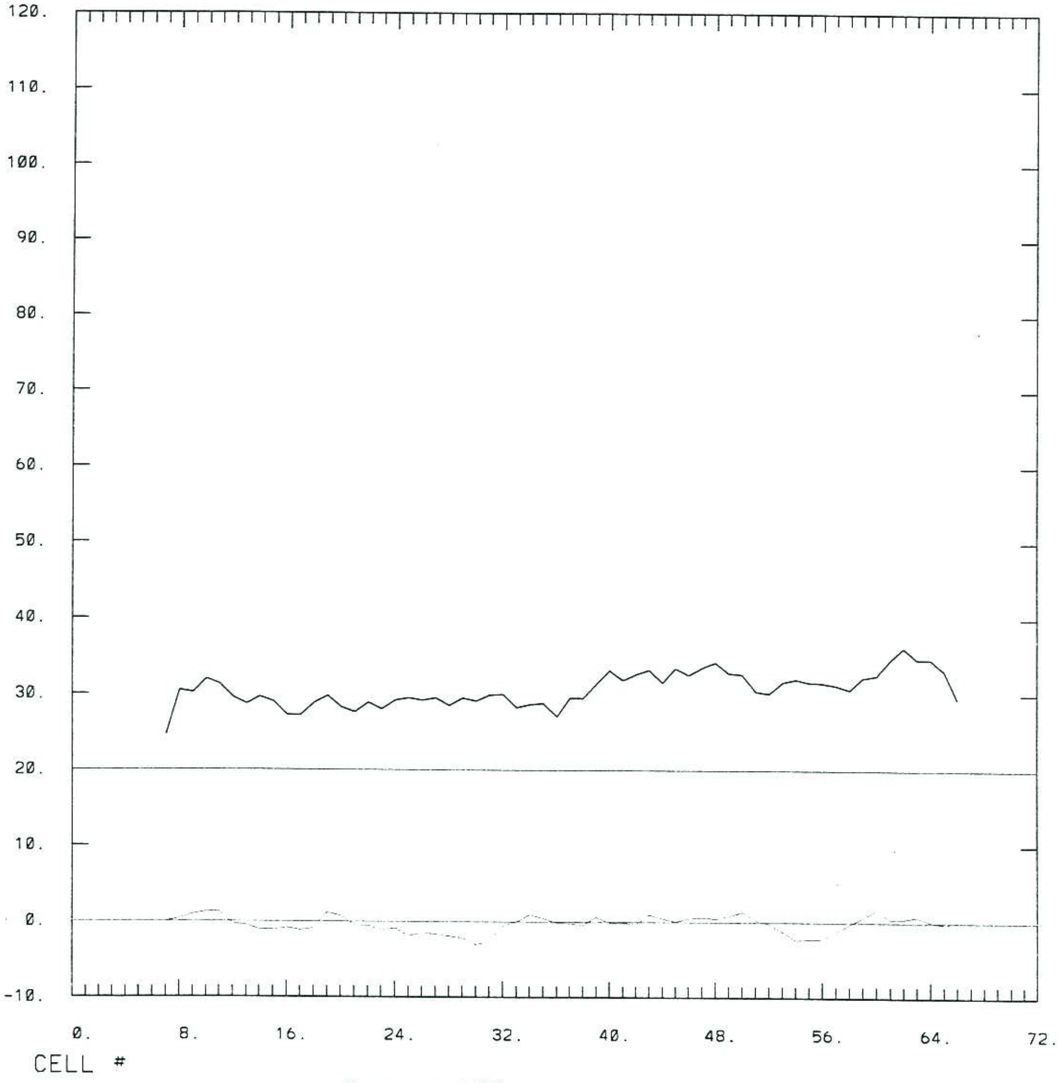

Figure #22

QSCAT vs MODEL ANL -- by CELL NUMBER -
SPEED DIFFERENCES (m/s)
NO R FLG   AVN ANL   NUDGED

Number of data points   822878

Swath RMS = 1.64

Swath BIAS = .04

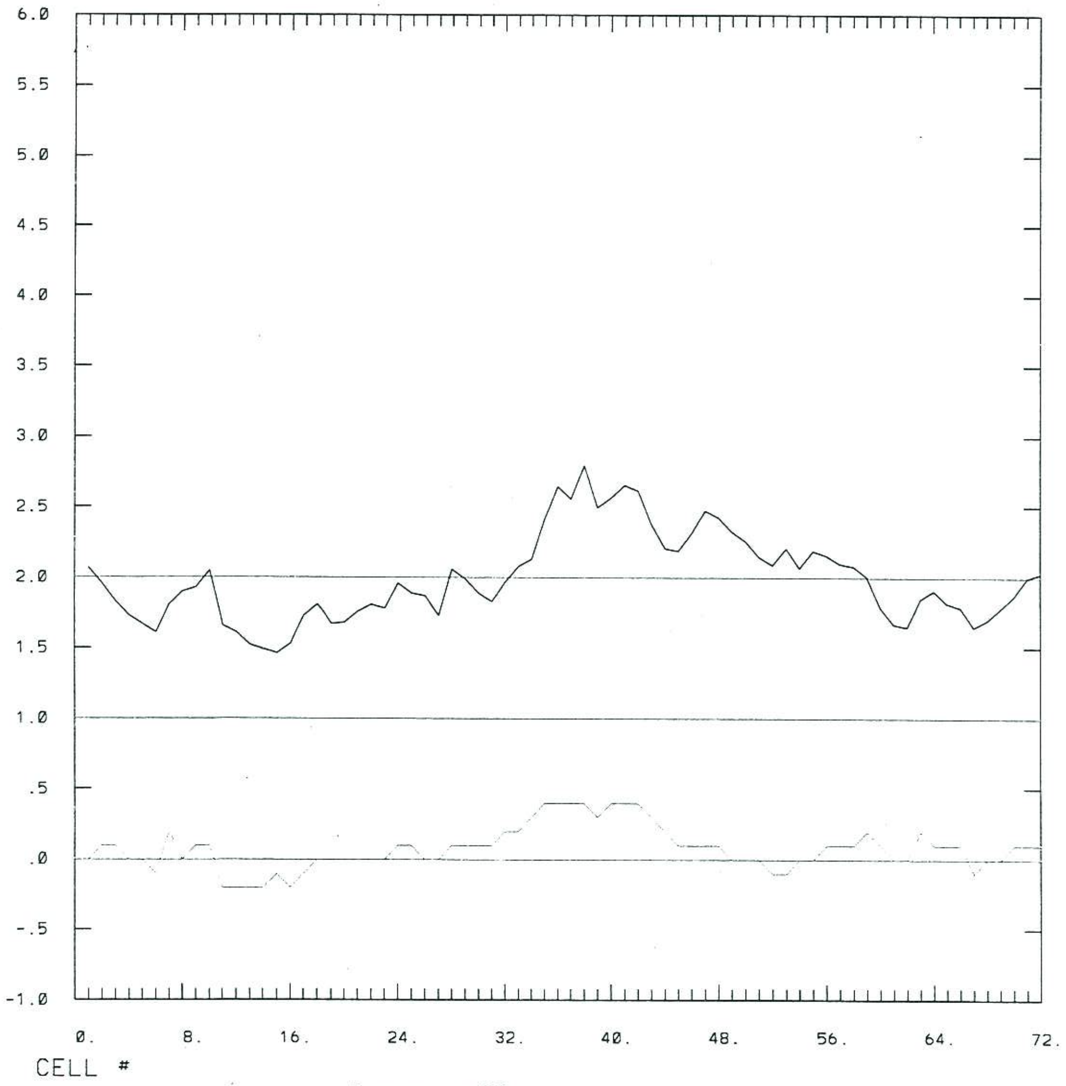

Figure #23

QSCAT vs MODEL ANL -- by CELL NUMBER -
DIRECTION DIFFERENCES (Degrees)
NO R FLG AVN ANL NUDGED

Number of data points 822878

Swath RMS =27.92

Swath BIAS =-1.32

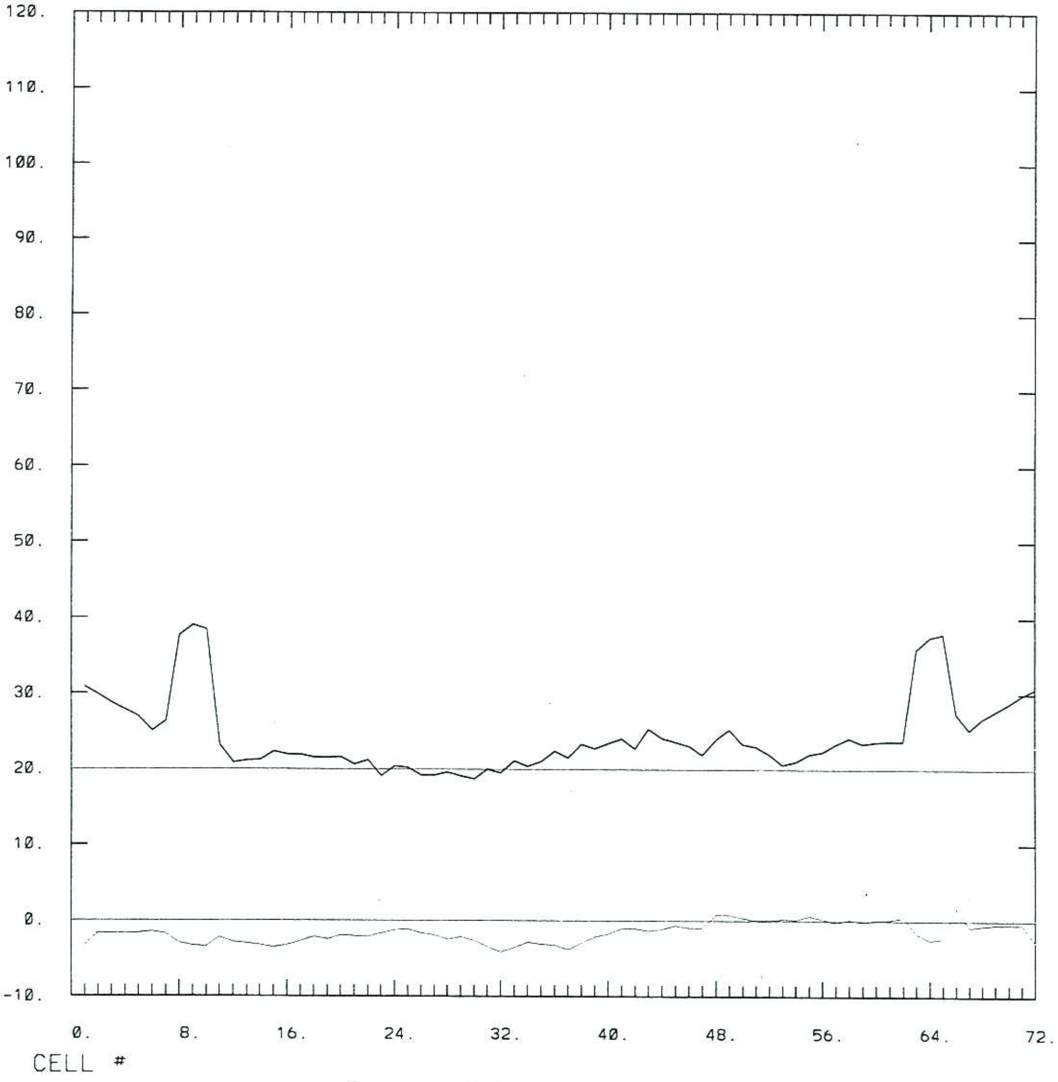

Figure #24

Table 1) Satellite vs Fixed Buoy Winds Speed and Direction Comparisons
April 11, 2000 - May 10, 2000

Collocation windows: time < +/- 3 hrs and space < 50km.
ONLY off-shore buoys > 100km
Satellite speed for direction > 3.5 m/s

SSM/I F11, F13, F14, F15 Wind Speed Neural Networks
NCEP Reprocessed wind vectors
QSCAT Wind Vectors, 1) no rain (Rain Probability = 0), no edge retrievals and
2) light rain (Rain Probability < 0.1), no edge retrievals.

	F11	F13	F14	F15	ERS2	QSCAT
Av Spd S	6.8	7.4	6.7	7.2	7.1	6.0 (9.1)
Av Spd B	6.5	6.9	7.4	7.2	7.5	6.2 (9.0)
Mx Spd S	15.5	18.3	19.2	19.6	20.2	14.6 (18.9)
Mx Spd B	18.1	18.1	18.1	17.7	17.7	14.8 (18.1)
Number of Satellite	2216	8155	6438	8098	1021	5216 (2034)

	F11	F13	F14	F15	ERS2	QSCAT
SPEED						
BIAS	0.30	0.52	-0.76	0.02	-0.36	-0.21(0.12)
RMS	1.86	1.70	1.88	1.67	1.80	1.24 (1.48)
Number	2216	8155	6438	8098	1021	5216 (2034)
DIRECT'n						
BIAS					4.8	3.6 (5.3)
RMS					24.9	22.9 (20.1)
Number of Satellite					970	4555 (2005)

Table 2). QuikSCAT vs Fixed Buoy Winds Speed and Direction Comparisons
April 11, 2000 - May 10, 2000

Collocation windows: time < +/- 3 hrs and space < 50km.
ONLY off-shore buoys > 100km
Satellite speed for direction > 3.5 m/s
Rain Probability (RP) (0 to 100% or not given)

	All Data	No rain, No edges RP = 0	Lt Rain No edges 0<RP<0.1	Mod Rain No edges 0.1<RP<1.	Edges or Msg Rain Prob	
Av Spd S	7.0	6.0	9.1	13.4	7.1	
Av Spd B	7.0	6.2	9.0	9.5	7.0	
Mx Spd S	34.1	14.6	18.9	34.1	29.7	
MX Spd B	18.1	14.8	18.0	18.1	18.1	
Number of QuikSCAT	8907	5261	2034	126	1486	

	All Data	No rain, No edges RP = 0	Lt Rain No edges 0<RP<0.1	Mod Rain No edges 0.1<RP<1.	Edges or Msg Rain Prob	
SPEED						
BIAS	-0.01	-0.21	0.12	3.79	0.18	
RMS	1.60	1.24	1.48	6.56	1.80	
Number	8907	5261	2034	126	1486	
DIRECT'n						
BIAS	4.0	3.6	4.8	1.4	3.7	
RMS	24.2	22.8	12.1	31.5	32.3	
Number	8006	4555	2005	124	1322	

Table 3). QuikSCAT Swath vs AVN analyses for Winds Speed and Direction Comparisons
April 11, 2000 - May 10, 2000

Collocation windows: time < +/- 0.75 hrs
Satellite speed for direction > 3.5 m/s
Rain Probability (RP) (0 to 100% or not given)
Summary over swath where valid

	All Data MLE	All Data Nudged	No rain, No edges RP = 0	Lt Rain No edges 0<RP<0.1	Mod Rain No edges 0.1<RP<1.	Edges or Msg Rain Prob
SPEED						
BIAS	0.05	-0.1	-0.4	0.12	2.69	.04
RMS	1.93	1.75	1.41	1.53	4.47	1.84
-------------	-------------	-------------	-------------	-------------	-------------	-------------
DIRECT'n						
BIAS	0.2	-0.9	-0.4	-1.1	-0.3	-1.3
RMS	71.5	22.7	23.5	18.0	30.6	27.9
Number	4230778	4230778	1570344	1686831	150725	822878

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