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5200 Auth Road
CAMP SPRINGS, Maryland, 20746-4304

TECHNICAL NOTE:

COMPARISON OF RAIN QUALITY CONTROL PROCEDURES FOR "REAL-TIME" QUIKSCAT WIND RETRIEVALS

WILLIAM H.GEMMILL

MARINE MODELING AND ANALYSIS BRANCH
ENVIRONMENTAL MODELING CENTER

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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.

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ABSTRACT

QuikSCAT was launched in June 1999 to measure wind vectors over the ocean surface at 10m. This satellite introduced a new antenna design for measuring the wind field over the oceans in the Ku-band frequency (14.6GHz). This report summarizes an evaluation that has been performed to determine the impact of rain contamination on the wind retrievals and to determine an appropriate quality control (QC) method.

Various evaluations of QUIKSCAT data have revealed that there are several QC problems with the ocean surface wind retrievals. There is a loss of accuracy for data along the outer edges (200 km) of the swath. Also, the data are susceptible to rain contamination. Although only about 5% data are normally contaminated by rain, rain occurs where the weather situations are active (i.e., convergence zones, fronts, storms and hurricanes) and good quality wind data are needed to accurately analyze the meso-scale marine surface wind patterns associated with these systems. Unfortunately, there are no concurrent direct measurements of rain along the QUIKSCAT orbit, but algorithms have been developed to detect rain using QuikSCAT data. In this note two algorithms are investigated: the first is the "probability of rain" index developed by Huddleston & Styles (2000), which is based on onboard satellite measurements that are sensitive to rain and included in the QUIKSCAT retrieval data; and the other was developed by Portabella & Stoffelen (2002) based on the deviation of the Most Likely Estimate (MLE) of the selected vector from an expected MLE. The purpose of this comparison is to determine whether one can improve the QC of rain contamination the QUIKSCAT retrievals for numerical weather prediction.

1. INTRODUCTION

At National Centers for Environmental Prediction (NCEP), in-situ and satellite derived observations of varying quantity and quality are used by the global data assimilation systems provide numerical analyses for weather forecast models. It is customary practice to evaluate the timeliness of availability and the quality of new data sets before using them in operational models. The accuracy specifications for satellite ocean surface wind retrievals are:

1) the RMS speed errors should be less than 2 m/s for winds up to 20 m/s and no more than 10% for wind speeds above 20 m/s and,

2) the RMS errors for direction should be less than 20 degrees.

Data assimilation systems are based on a set of *apriori* mathematical formulations that are designed to minimize the errors between the first guess fields provided by a model and observations received in "real-time" in order to produce an accurate initial condition for a numerical forecast model. These procedures involve performing quality control (QC) of data and determining weights of the data before they are ingested into the analysis. The fewer the QC decisions the data assimilation system has to make, the better the chances that poor quality data will not influence the analysis. Or, to state it alternatively, the better the quality of the data, the better the quality of the analysis.

QuikSCAT was launched in June 1999 with a Ku-band (14.6 GHz) scatterometer on board, and ocean surface wind vector retrievals from it became available in "real-time" (within three hours of observation) for operational use at NCEP during February 2000. Assimilation of these data into the National Centers for Environmental Prediction (NCEP) operational Global Forecast System (GFS) was implemented on January 15, 2002 (Yu).

The design of the QuikSCAT antenna system is different than in previous scatterometers. QuikSCAT uses two antennas at different incident angles (46 & 54 degrees) to *scan* the ocean surface through 360 degrees of the azimuth. This design provides for two backscatter (σ°) measurements over a surface location from each antennae, one from the fore look and one from the aft look. Thus, for the two antenna design, there are a maximum of four (σ°) values at each location that can be used to retrieve wind vectors. There are certain regions across the swath where the accuracy will deteriorate. There are two such regions which are located along the outer 200km edges on opposite sides of the swath over which only one of the antennas is capable of retrieving radar backscatter measurements (two values), thus, limiting the accuracy of the retrieval. A third region is near nadir, where the separation between viewing angles and nadir are small resulting in less discrimination for determining wind direction.

As is well known, the wind retrieval inversion process that converts scatterometer radar backscatter measurements into a wind vector does not yield a unique solution, and can provide up to four vector solutions. The backscatter values are modeled: $\sigma_m = f(u,\chi)$, for given wind speeds (u) and wind directions (χ) relative to the motion of the satellite. To determine the u, χ from satellite retrievals of σ°, it is necessary to find the closest fits of the satellites retrievals of σ° to the geophysical model function σ_m by using the Most Likelihood Estimates (MLE) as defined by:

$$J = \sum_{I=1}^{N} (\sigma^\circ - \sigma_m)^2 / Var(\sigma_m)$$

where there are N (four or less) values of σ_m, and Var(σ_m) is the measurement error variance. A local minima of J with a given σ_m then corresponds to a wind vector solution u,χ. Unfortunately, there are more than one local minima (maybe up to four). So, the solutions are ranked in order by their MLE. The closer the MLE is to zero the higher the certainity of the solution, and the further away it is from zero, the less the certainty.

But the first ranked MLE wind vector solution is not always the "best" wind retrieval solution (Rufenach, 1998). Hence, an additional procedure is applied to reduce errors in the wind vector (direction) selection process. A background wind field, obtained from the 6-hour forecast from NCEP's global forecast model, is used to provide additional information in the vector selection. A median filter technique (Shaffer et al., 1991) is applied across the swath using a set of wind vectors in a 7X7 window centered at the cell of concern. It is a two-step process: 1) The 7X7 window is initialized with either first or second ranked wind vector solutions based on MLE solutions, whichever is closest to the background wind direction (JPL, 2000); and then 2) the median filter technique finds the median vector for the **center** cell of wind vectors in the window. The MLE solution that is closest to the median vector is the selected vector. The process is repeated until no solutions are changed. The selected vectors from the above median filtering process will be referred to as the *nudged* solutions. Although nudging can provide a relatively consistent meteorological wind field, the question exists of how much information in the nudged wind field is from the original scatterometer derived wind at a cell and how much is forced from the median filtering technique. And further, the more solutions available to chose from, the lower the skill is in the selection of the best retrieval (Stoffelen, et. al. 2000 and Krasnopolsky, 2001).

It is known that rainfall will affect the radar backscatter in the Ku band of QuikSCAT. The effect is made worse because of the large incident angles of the scanning antannae, which increase the path length of the QuikSCAT beam over past scatterometers. Recent studies have shown that wind speed errors are related to the rain rate and the wind speed itself (ie, Weissman et al., 2002). In that study, NWS radar, QuikSCAT and buoy data in close proximity were examined to determine the impact of rain on a QuikSCAT wind retrieval. The results are encouraging and have provided useful information on contamination. The radar backscatter signal is distorted due to increased atmospheric attenuation and scattering from rain falling through the atmosphere, and to increased ocean surface scattering from rain striking the ocean surface. In general, at low rain rates and wind speeds, the contamination comes from the increased ocean surface roughness, but at high rain rates contamination is due to increases in atmospheric scattering from the rain itself. Regions near and around storm centers and fronts are active weather areas, usually with moderate winds and rain. Since rain decreases the accuracy of the backscatter values, the accuracy of the wind vector (speed and direction) retrievals in and around storm centers and fronts will correspondingly decrease. Rainfall is normally characterized by small spatial scales with short time scales. Rain can move quickly and at the same time change its intensity. It is locally driven by horizontal convergence of moisture, usually along fronts and cyclonic systems, and in the tropics by individual convective elements and/or systems. Determining the impact of rain on a QuikSCAT wind retrieval is, therefore, a complex exercise.

Several algorithms have been developed to detect rain contamination. In fact, a probability of rain value (Huddleston and Stiles, 2000) is included as part of the retrieval data from the Jet propulsion Laboratory (JPL). It is based on a set of satellite derived parameters that are sensitive to rain. Also, Portabella and Stoffelen (2001, 2002) at the Koninklijk Nederlands Meteorologisch Instituut (KNMI) have recently developed a rain detection procedure based on determining the deviation of the observed MLE from the expected rain free MLE at each cell location. This evaluation has been made to determine the possibility of improving QuikSCAT retrieval QC for rainfall detection based on these two techniques referred to as JPL and KNMI throughout this note.

2. FIXED BUOY COMPARISON STATISTICS

A "real-time" buoy-satellite match-up data base has been assembled from September 12, 2002 to May 31, 2003 (about 8 ½ months). This data base collocates mid-latitude fixed buoy wind data with QuikSCAT wind retrievals four times daily; at 00, 06, 12, 18 UTC. Satellite data are collocated in time to be within +/- 3hours, and in space within 50km. Winds from fixed buoys are adjusted neutrally to 10 meters above the ocean surface, and the buoys are at least 100 km from land. This collocation space/time window is broader than the window of 30 min and 25 km used during the original calibration validation efforts, but was done to obtain a larger sample in some of the data sparse categories. This will no doubt degrade the absolute validation statistics to some extent. But comparisons can still be made in a relative sense.

1) Rain Influence

Satellite derived wind speed and direction vs. buoy wind speed and direction data are presented in sets of scatterplots. Figure 1, a & b are scatterplots for the entire matchup data set (excluding the outer 200 km edges of the swath). These pairs are given for speed (a) and for direction (b). The overall statistics show that QuikSCAT wind vector retrievals, when compared to buoys, are close to the wind specifications with a speed RMS of 2.04 m/s and direction RMS of 23.4 degrees (Table 1). These statistics are slightly poorer than the specification requirements, in part because of the broader time/space matchup windows used as explained above. It is obvious that there are many individual satellite retrieval outliers which exceed the buoy speed and direction values much more than the prescribed specification limits. Many of these retrievals may be contaminated by rain. At high wind speed (>20 m/s) there are relatively few observations (<0.5%) so that the reliability of those statistics may not be as accurate. Figures 2 through 6 are comparisons of retrievals for various JPL probabilities of rain values (no rain, 0<5%, 5-10%, 10-50%, and 50-100%).

For those retrievals that are rain free by JPL classification (probability of rain is equal to zero), most of the extreme outliers are not present. In this set, the speed bias is slightly positive at 0.15 m/s, and the RMS is 1.54 m/s. But, for directions, there is almost no improvement with the RMS being about 22.0 degrees. For the next three probability categories, 0<5%, 5-10%, 10-50%, (see Figures 3, 4, 5) the wind speed bias increases from 0.69 m/s to 1.39 m/s to 2.39 m/s and RMS increases from 1.99 m/s to 2.66 m/s to 3.69 m/s. For wind direction, the RMS increases from 21.5 to 27.0 to 34.1 degrees fo each of the 3 previous probability of rain categories. There is a large degradation on the wind retrieval accuracy as the probability of rain increases. Rain contamination is clearly evident when the probability is greater than 50% as seen in figure 6. The wind speed bias is 7.24 m/s and RMS is 8.70 m/s and the RMS of direction is 55.7 degrees. There are almost no wind speed retrievals less than 10 m/s. Obviously the satellite scatterometer is receiving most of the backscatter from the rain falling through the atmosphere.

All the data with a JPL probability of rain greater than zero, are assumed to be rain contaminated to some extent. For this data, the speed bias is1.21 and RMS is 2.99, and the direction RMS is 25.9 degrees, which obviously contain data with errors larger than the specifications. Yet some of the winds at the lower probability of rain were shown to be adequate. Unfortunately, if winds with only "no" probability of rain (JPL) were to be accepted, only 70.1% of QUIKSCAT wind could be used.

In order to increase the amount of wind retrievals available to the Global Forecast System, a rain flag was designed based on a threshold from the probability of rain, for which the influence of rain contamination would still be small. A probability of rain threshold of 10% was chosen, which is reasonable based on the above statistics. This threshold rejects about 5% of the data when using this probability to specify rain, the winds still easily meet the specifications with a speed BIAS of 0.32 m/s and RMS of 1.72 m/s and direction RMS of 22.0. This will be referred to as the EMC rain detection technique. The statistics for the rejected data clearly show the data are rain contaminated because of the large speed bias of 3.79 m/s and RMS of 4.32 m/s, and direction RMS of 41.4 degrees.

Statistics were also determined using the KNMI rain detection technique in comparison with the EMC technique. For accepted data (no rain), the speed bias is 0.32 and RMS is 1.73 m/s and direction is RMS 21.1. About 6% of the data are rejected, with statistics for KNMI similar to those of EMC. But it will be shown later that there are important differences.

The statistics for rain dependence are presented in Table 1 with statistical comparisons in four sections: 1) all the data, 2) by JPL categories, 3) by EMC (for no or yes rain contamination) and 4) by KNMI (for no or yes rain contamination).

2) Selection Rank

A fundamental problem with a scatterometer is that the inversion process (radar backscatter to a wind vector) does not yield a unique solution, and may yield up to four solutions. The solutions are then ranked in order of their Most Likely Estimate (MLE) values. However, it has been shown that the first ranked solution is not necessarily best direction solution. The reasons for this depend on the noise in the radar backscatter measured by the satellite, changes in geometry due to the cell location across the swath and rain. The final selection of the wind vector is obtained from any one of the available MLE solutions through the nudging process also described above.

The number of selected retrievals for each rank is shown in table 2. The first rank selected (rank 1) retrievals account for about 80% of the total. The error statistics (Table 3) reveal the importance rank of the selection as there is a degradation in the wind speed and direction accuracy the lower the selection rank. Only rank 1 selected vectors meet the accuracy specifications (Speed bias of 0.47 m/s, RMS of 2.04 m/s and Direction RMS of 23.4 degrees), whereas rank 2 & 3 are marginally poorer especially for wind directions. When a rank 4 vector is selected, there is a strong indication of rain contamination in many of the retrievals (Speed bias of 1.05 m/s, RMS of 2.88m/s and Direction RMS of 60.1 degrees).

3) Number of Solutions at a Cell

The number of wind vector solutions at a cell is shown in Table 4. In this sample there are no cells with just a single retrieval. And the number of solutions decreases from about 42% for two solutions to 25% for four solutions. The error statistics in Table 5 show that there is not much of a difference of wind direction accuracy (RMS) based on the number of wind vector solutions. Krasnopolsky and Gemmill (2001) estimated the no skill level (RMS) of a selected wind vector based on the number of vectors available (see last column of table 5), and the no skill level decreases with increasing number of wind solutions . Since there is little difference in the accuracy of wind direction, there is then a measured decrease in the skill of wind direction when more directions are available.

When 3 wind vectors are available at a cell, both speed and direction are slightly poorer (Speed Bias 0.56 m/s and RMS of 24.1 degrees), than for the cases when there are 2 or 4 vectors. available. But clearly, there is skill in most of the direction retrievals.

4) Speed Dependency

QuikSCAT wind speed estimates are good in the mid-speed range of 4 to 20 m/s (table 6). At low wind speeds (< 4 m/s), the bias and RMS are high (1.28 m/s & 2.31 m/s) and the direction RMS is 52.8 degrees. Throughout this note, if wind speeds are less than 4.0 m/s they are not included in wind direction statistics, although they are included in wind speed statistics. It is assumed that both the satellite retrievals and buoy measurements are poor at resolving wind direction at low wind speeds. RMS for directions for wind speeds above 8 m/s is consistent at 20. For wind speeds above 20 m/s, the low bias is uncertain as there are too few retrievals to substantiate its value, which can be seen from figure 1. For strong weather systems with high winds speeds, the selected directions appear to be close to the buoy data in terms of the specification.

4) Rain Flag Comparisons

Two rain flags are compared for rain contamination QC: 1) the EMC method, which is based on an extension of JPL probability of rain; and 2) the KNMI method, based on deviations of calculated MLE from expected rain-free retrievals. First, return to Table 1 (the bottom 4 categories) to see that the EMC method generates mean wind speeds of 8,4 m/s and RMS of 1.74 m/s and direction RMS of 23.2 degrees for the no rain cases, and 15.2 m/s, 5.60 m/s & 42.0 degrees, respectively, for the rain cases. A significant increase in the mean speed, and RMS difference in speed and direction fo the rain cases. The same table for KNMI provides mean wind speeds of 8.5 m/s and RMS of 1.77 m/s and directions RMS of 22.1 degrees for the no rain cases and 11.8 m/s, 4.71 m/s and 47.2 degrees, respectively, for the rain cases. Rain contamination is being detected in the general sense by both EMC and KNMI, but to what extent do they discriminate individually. Although the "no rain" statistics are similar for both methods, there are differences in the "rain" cases. KNMI detects more rain than EMC (6.7 vs. 4.6%, respectively) and EMC is rejecting more high wind speed data than KNMI. Plots, not shown, show that EMC consistently identifies more rain cell in storms than KNMI.

A 2-way contingency table of 4 categories is created to separate the observations into categories by the rain detection technique as: 1) no rain EMC vs no rain KNMI; 2) no rain EMC vs yes rain KNMI; 3) yes rain EMC vs no rain KNMI; and 4) yes rain EMC vs yes rain KNMI. Table 7 presents the number of the 2-way comparisions and percentages of the total of each category and Table 8 presents the error statistics for speed and direction. When both rain QC procedures agree (93%) the error statistics clearly suggest that the discrimination between no rain and rain is reliable.

When the two methods disagree (7.0 %), the interpretation is not so clear. But, the error statistics do indicate that these categories contain rain contamination. KNMI detects more rain in the EMC rain free cells (4.5% of the total) than EMC detects in the rain free cells of KNMI (2.5%). This suggests that KNMI may a better discriminator for rain contamination.

Another comparison of the agreement/disagreement between the KNMI and JPL algorithms for whether rain is detected or not is presented in Table 9. This table gives the percent of wind vector retrievals determined to be rain free by the KNMI technique in each category of rank selection and probability of rain. The trends in this table are clear: 1): the higher the rank selection, the higher the percent of acceptance by KNMI; and 2). the lower the probability of rain, the higher the percent of acceptance by KNMI. For rank 1 winds, with JPL no probability of rain (PR=0), the KNMI technique accepts 98.8% (almost perfect agreement) of those retrievals as rain free, whereas for rank 4 wind with a PR within 50-100%, the KNMI technique accepts only 5.3% as rain free (close to perfect agreement). As both the selected rank and the JPL probability of rain increases there is decreasing probability that KNMI will indicate rain free retrievals. There are two categories where there is a disagreement between JPL (reject) and KNMI (accept). That is for the probability of rain in the category of 10<PR<50, for both rank 1 (83.5% accept) and rank 2 (65.9% accept) selection. It can be seen that for the EMC method rain detection limit of 10% should be modified. For JPL with no probability (PR=0), all rank selections agree well over 50% with KNMI acceptance of no rain, but for the next category of rain 0<PR< 5% rank 4 selected winds, the KNMI acceptance of no rain is below 50%. For the rain category of

5<PR<10%, both rank 3 and 4 are below 50%.

4. CONCLUSIONS

The purpose of this note was to compare two rain detection algorithms for QuikSCAT ocean surface wind retrievals to determine their attributes. These algorithms were empirically derived with collocated data sets that were assembled the could relate satellite measured variables with rainfall. Since there are no concurrent rainfall data available along the full satellite orbit, it is not possible to determine directly whether the rain or no rain within a satellite measurement. One can only speculate on estimates.

The JPL probability of rain index is a good discriminator for the accuracy of wind retrievals. The higher the probability of rain (JPL) the worse is the wind retrieval accuracy. Rain contamination is especially severe when the probability of rain (JPL) is greater than 50%. But rain contamination is evident even as the probability of rain approaches 10%. The wind retrieval accuracies degrade as the selection rank increases. Only 1st rank data are totally acceptable. Rank 2 & 3 retrievals are marginal, Rank 4 selections clearly show the effects of rain on both wind speed and direction and should not be used. The wind retrieval accuracies are satisfactory for wind speeds between 4 m/s and 20 m/s. And there is a high bias at low wind speeds (< 4 /s), and a low bias at high wind speeds (> 20m/s), which is difficult to validate because of the small amount of data in this range.

KNMI discriminates rain better at high wind speeds than JPL, although KNMI does detect more rain at the lower speeds. The results show that for EMC rain detection that 10% is an adequate lower limit for the JPL probability of rain. When both the KNMI and EMC techniques agree (93 % of cells) on rain/no rain detection, the discrimination appears accurate. .

Finally, it is recommended that Table 10 should be used as a guide for accepting/rejecting QuikSCAT retrievals as a result of rain.

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	QuikSCAT MEAN SPEED	BUOY MEAN SPEED	SPEED BIAS	SPEED RMS	DIRECTION RMS	NUMBER/ %	PLOT Diagram Number
All WEATHER	8.47	8.00	0.47	2.04	23.4	82394 / 100.0	1
	JPL - PROBABILITY OF RAIN						
NO RAIN JPL	7.07	6.91	0.15	1.54	22.0	57761 / 70.1%	2
0<PR<5% JPL	10.92	10.23	0.69	1.99	21.5	18758 / 22.7%	3
5<PR<10% JPL	13.24	11.85	1.39	2.66	27.0	2255 / 2.7%	4
10<PR<50 JPL	14.15	11.76	2.39	3.69	34.1	2573 / 3.1%	5
50<PR<100 JPL	17.52	10.28	7.24	8.70	55.7	1047 / 1.3%	6
YES RAIN PR>0% JPL	11.75	10.54	1.21	2.88	25.9	24633 29.9%	
	EMC - RAIN FLAG						
NO RAIN PR<10% EMC	8.16	7.16	0.32	1.72	22.1	78774 / 95.6 %	
YES RAIN PR > 10% EMC	15.13	11.33	3.79	4.32	41.4	3620 / 4.4%	
	KNMI - RAIN FLAG						
NO RAIN KNMI	8.26	7.94	0.32	1.73	21.1	77124 / 93.6%	
YES RAIN KNMI	11.51	8.90	2.61	4.60	45.2	5270 / 6.4%	

Table 1. QuikSCAT vs buoy collocated match-up wind data by rain category The first 9 categories are based on using rain probabilities from JPL, the last two are based on the KNMI techniques. . With speed in m/s and direction in degrees. With speed in m/s and direction (for speeds > 4.0 m/s) in degrees. Bias = QuikSCAT - buoy. The space window was 50 km and +/- 3hours. There are 4 groupings of the data in this table. 1) are statistics for all the data; 2) are the statistics for a sequence for probability of rain categories, 3) are statistics for the EMC QC rain detection based on the probability of rain and the last 4) are the statistics for the KNMI rain detection technique.

RANK	Number / %
Total	82394 / 100.0%
1	64822 / 78.7%
2	14398 / 17.5%
3	2630 / 3.3%
4	494 / 0.5%

Table 2. Number of selected Wind Vectors and percentages by their rank.

	QuikSCAT MEAN SPEED	BUOY MEAN SPEED	SPEED BIAS	SPEED RMS	DIRECTION RMS	NUMBER/ %	
ALL *NUDGED* DATA	8.47	8.00	0.47	2.04	23.4	82394/ 100%	
RANK 1	8.53	8.15	0.38	1.90	20.7	64822/ 78.6%	
RANK 2	8.47	7.70	0.77	2.46	30.9	14398/ 17.5%	
RANK 3	6.99	6.22	0.77	2.54	37.6	2680 3.3%	
RANK 4	7.91	6.86	1.05	2.88	57.1	494/ 0.6%	

Table 3. QuikSCAT vs buoy collocated match-up wind data by rank of selection. With speed in m/s and direction in degrees. With speed in m/s and direction (for speeds > 4.0 m/s) in degrees. Bias = QuikSCAT - buoy. The space window was 50 km and +/- 3hours.

NWVA	Number / %
Total	8i2394/ 100.0%
1	0 / 0.0%
2	34721 / 42.2 %
3	27376 / 33.2%
4	20297 / 24.6 %

Table 4. Number of Wind Vectors Available (NWVA) and percentage at a cell; ie there were no cells with just one wind vector, and there were 34721 cells that had two wind vectors, and so forth

.

	QuikSCAT MEAN SPEED	BUOY MEAN SPEED	SPEED BIAS	SPEED RMS	DIRECTION RMS	NUMBER/ %	DIRECTION NO SKILL RMS*
ALL *NUDGED* DATA	8.47	8.00	0.47	2.04	23.4	82394/ 100%	
NWVA 1	----	----	---	---	---	0 / 100%	
NWVA 2	8.20	7.83	0.37	1.96	22.9	34721 / 42.1%	73*
NWVA 3	8.81	8.25	0.56	2.23	24.1	27376 / 33.3%	49*
NWVA 4	8.45	7.95	0.50	1.89	23.1	20297 24.6%	37*

Table 5. QuikSCAT vs buoy collocated match-up wind data by the number of wind vectors available (NWVA). With speed in m/s and direction in degrees. With speed in m/s and direction (for speeds > 4.0 m/s) in degrees. Bias = QuikSCAT - buoy. The space window was 50 km and +/- 3hours.

(*) The final column, direction no skill in degrees is presented from Krasnopolsky and Gemmill, 2001, Table 1, page 5.

	SPEED BIAS	SPEED RMS	DIRECTION RMS	NUMBER/ %
ALL SPEEDS	0.47	2.04	23.4	82394 / 100.0%
0<SPEED<4	1.21	2.31	[52.8]**	11080 / 13.4%
4<SPEED<8	0.49	1.91	27.3	32192/ 39.1%
8<SPEED<12	0.24	1.95	19.2	27191/ 33.0%
12<SPEED<20	0.28	2.28	20.4	11704 / 14.2%
SPEED>20	-1.71	3.29	21.9	227 / 0.3%

Table 6. QuikSCAT vs buoy collocated match-up wind data by buoy wind speed interval. With speed in m/s and direction in m/s and direction in degrees. Bias = QuikSCAT - buoy. At low wind speeds of < 4.0 m/s, wind directions are not included in the direction overall statistics. The space window was 50 km and +/- 3hours.

	KNMI NO RAIN	KNMI YES RAIN	TOTALS
EMC NO RAIN	75032 / 91.1%	3742 / 4.5%	78774 / 95..6%
EMC YES RAIN	2092 / 2.5%	1528 / 1.9%	3620 / 4.4%
TOTALS	77124 / 93.6%	5270 / 6.4%	82394 / 100.0%

Table 7. Two way contingency table for the comparison of the KNMI vs EMC rain detection methods in terms of percentages of agreements and disagreements between the two methods.

	NO RAIN - KNMI	YES RAIN - KNMI
NO RAIN - EMC	SPEED BIAS 0.27 RMS 1.65 DIRECTION RMS 23.0	SPEED BIAS 1.19 RMS 2.52 DIRECTION RMS 48.2
YES RAIN - EMC	SPEED BIAS 2.13 RMS 3.57 DIRECTION RMS 32.1	SPEED BIAS 6.07 RMS 7.58 DIRECTION RMS 58.8

Table 8.Evaluation of the KNMI vs EMC rain detection methods in terms of satellite vs buoy error statistics for agreements and disagreements between the two methods.

Probability of Rain-JPL	PR=0	0 <PR< 5	5<PR < 10	10<PR< 50	50 <PR<100
RANK 1	98.8	95.3	89.4	83.5	26.8
RANK 2	91.9	82.1	76.1	65.9	18.0
RANK 3	82.0	50.7	28.9	29.0	9.4
RANK 4	66.7	26.0	16.0	14.3	5.3

TABLE 9. The comparison between the percent of acceptance (no rain) of the wind retrieval by KNMI given the probability of rain (JPL) of a Quikscat wind retrieval and its selected wind vector rank,

Probability of Rain-JPL	PR=0	0 <PR< 5	5<PR < 10	10<PR< 50	50 <PR<100
RANK 1	Accept	Accept	Accept	Reject	Reject
RANK 2	Accept	Accept	Accept	Reject	Reject
RANK 3	Accept	Accept (?)	Reject	Reject	Reject
RANK 4	Accept	Reject	Reject	Reject	Reject

TABLE 10. Accept/reject QuikSCAT retrievals as determined by selection of rank and probability of rain based on Table 9 results. .

APPENDIX (A) presents the scatterplots of collocated buoy date vs QuikSCAT retrievals for speed (left) and direction (right) for various rain contamination using JPL probability of rain categories. Scatterplots were generated by finding the number of matched points in 0.1 m/s boxes for speed and 0.1 degree boxes for direction. Color coding for boxes with no matches is left blank, with 1 match is red, with 2-5 matches are green, with 6-10 matches are blue and greater than 10 matches are purple.

Figure 1, All interior swath data
Figure 2, No rain, PR=0% (JPL)
Figure 3, ?? rain, 0<PR<05% (JPL)
Figure 4, Light rain, 05<PR<10% (JPL)
Figure 5, Moderate rain, 10<PR<50% (JPL)
Figure 6, Heavy rain, PR>50% (JPL)

OCEAN SURFACE WIND MATCH-UP STATISTICS
QSCAT FIX BUOY

SPEED m/s DIRECTION degrees

ALL WEATHER ALL INTERIOR ALL ISWV

Number of data points= 82394 Number of data points= 71309
BIAS,RMS,MAX SPEED = .47 2.04 39.9 27.5 BIAS,RMS DIRECTION = 2.5 23.4

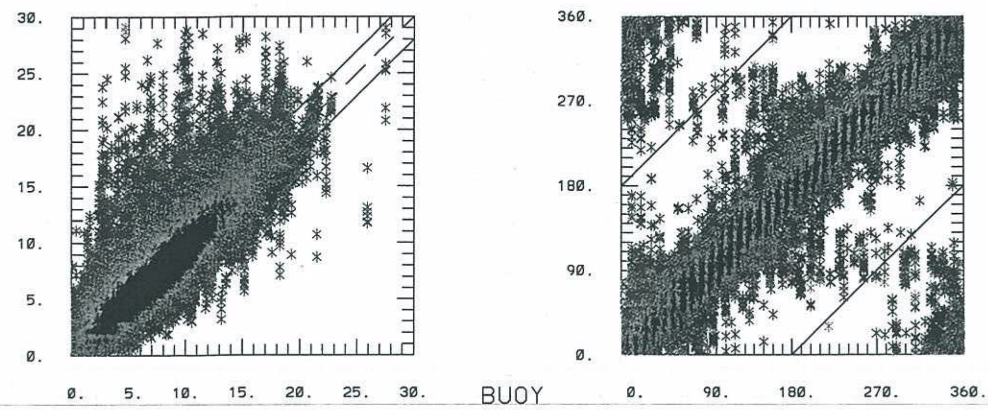

FIGURE # 1

DATES 20020912 20030531

JPL NO RAIN, PR=0% ALL INTERIOR ALL ISWV

Number of data points= 57761 Number of data points= 47519
BIAS,RMS,MAX SPEED = .15 1.54 26.9 22.3 BIAS,RMS DIRECTION = 3.0 22.0

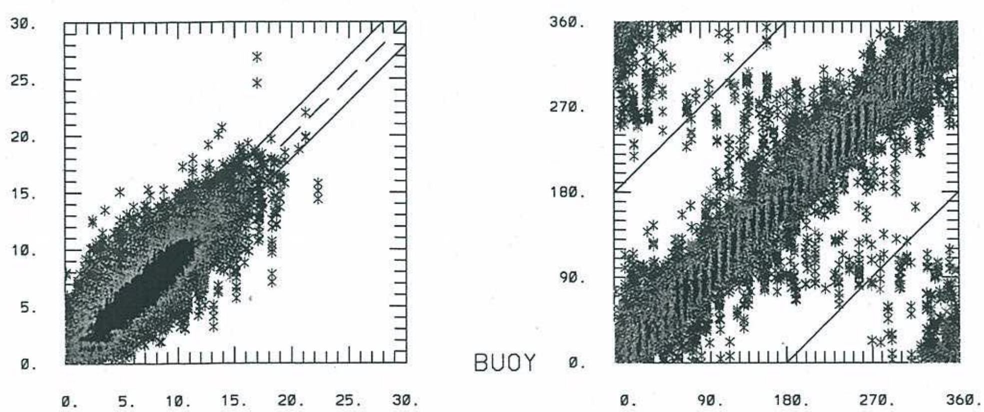

FIGURE # 2

OCEAN SURFACE WIND MATCH-UP STATISTICS

QSCAT FIX BUOY

SPEED m/s DIRECTION degrees

JPL ?? RAIN, Ø%<PR<5% ALL INTERIOR ALL ISWV

Number of data points= 18758 Number of data points= 18147

BIAS,RMS,MAX SPEED = .69 1.99 26.9 25.9 BIAS,RMS DIRECTION = 1.5 21.5

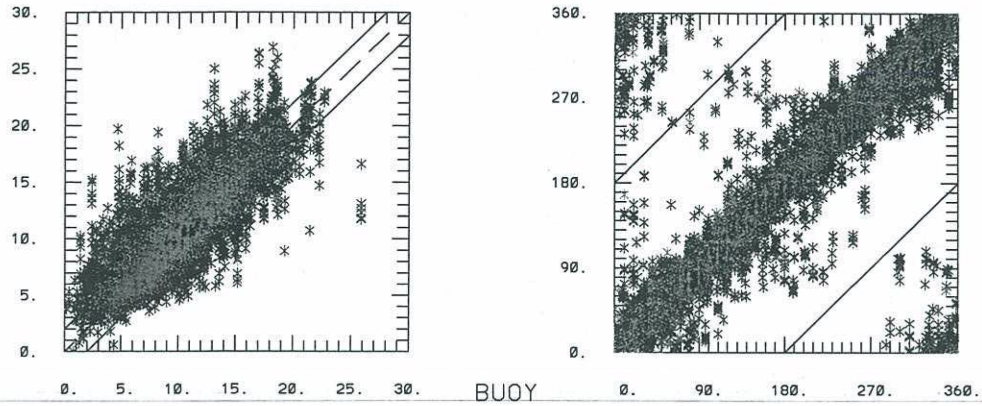

FIGURE # 3

JPL Light RAIN, 5%<PR<1Ø% ALL INTERIOR ALL ISWV

Number of data points= 2255 Number of data points= 2198

BIAS,RMS,MAX SPEED = 1.39 2.66 27.4 22.7 BIAS,RMS DIRECTION = .6 27.Ø

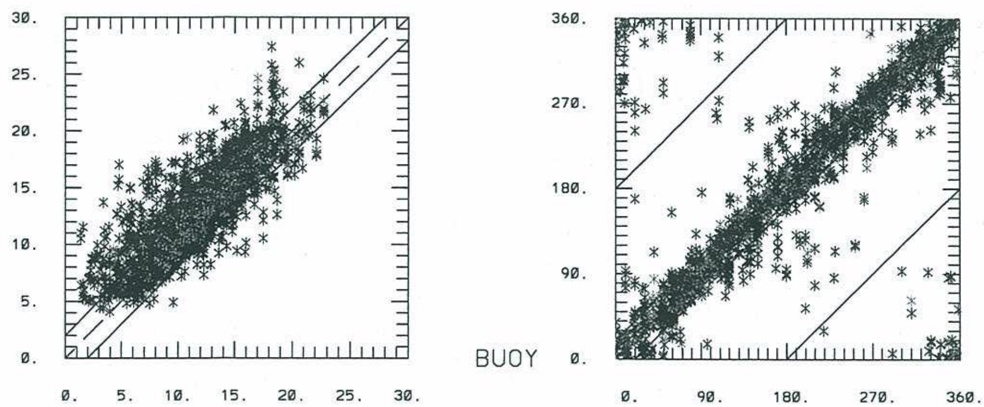

FIGURE # 4

OCEAN SURFACE WIND MATCH-UP STATISTICS
QSCAT FIX BUOY

SPEED m/s DIRECTION degrees

JPL Moderate RAIN, 10<PR<50%ALL INTERIOR ALL ISWV

Number of data points= 2573 Number of data points= 2473

BIAS, RMS, MAX SPEED = 2.39 3.69 25.1 22.7 BIAS, RMS DIRECTION = .4 34.1

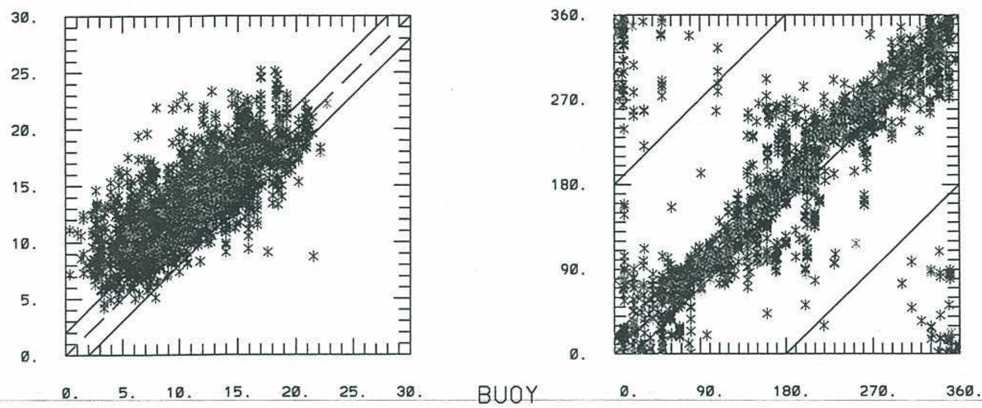

FIGURE # 5

JPL Heavy RAIN, 50%<PR<100 ALL INTERIOR ALL ISWV

Number of data points= 1047 Number of data points= 972
BIAS, RMS, MAX SPEED = 7.24 8.70 39.9 27.5 BIAS, RMS DIRECTION = 1.7 55.7

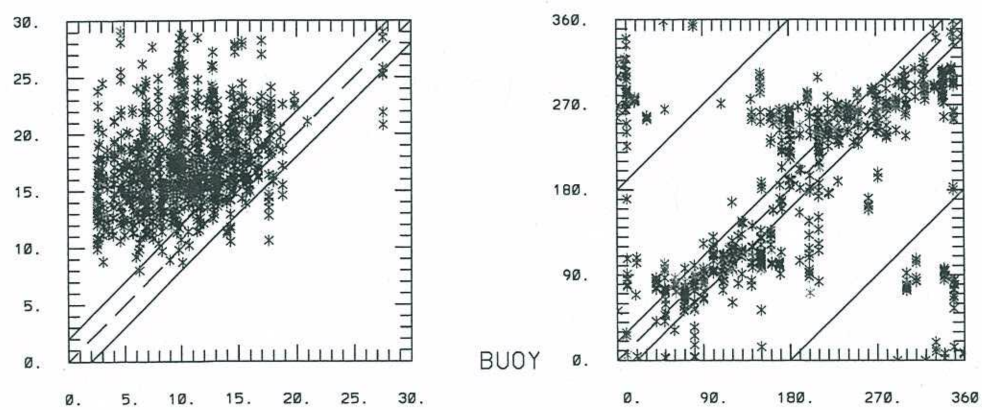

FIGURE # 6

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