Cross-Validation of Jason-1 and QuikSCAT Wind Speeds

S.H. Chan, R.R. Halterman, D.G. Long

Microwave Earth Remote Sensing Laboratory, Brigham Young University
459 CB, Provo, UT 84602, USA, email: chan@byu.net

Abstract— **Observing near-surface ocean winds is important to the understanding of global weather patterns. Wind speed information can be retrieved from σ° measurements made by Jason-1 and SeaWinds on QuikSCAT. Though co-located measurements from the two satellites generally agree, significant differences between the co-located measurements are occasionally observed, particularly associated with rain events. Co-located data from TRMM PR 2A25 and ECMWF is used to study the effects of rain on Jason-1. Key observations are discussed.**

I. Introduction

Near-surface ocean wind is a crucial element of sea-air interaction and global energy transport. Measuring these near-surface ocean winds has long been one of NASA's goals, as traditional methods such as buoys and ships fail to provide accurate global coverage. NASA's SeaWinds on QuikSCAT mission is designed to measure near-surface ocean winds [1].

NASA joins with the French Centre National d'Etudes Spatiales (CNES) in the Jason-1 mission, which also provides near-surface ocean wind speed measurements through a space-borne altimeter. Since altimeters are primarily used to measure surface heights, near-surface ocean wind measurement is only a secondary goal of Jason-1.

With the availability of multiple data sets, cross validation can aid in the understanding of data quality and consistency, and provide additional insight into related geophysical phenomena. Although co-located wind speed data from Jason-1 and QuikSCAT are generally in good agreement, at times wind speed data from the two missions differ significantly. Through spatial and temporal co-locations of Jason-1 and QuikSCAT wind measurements, these differences are studied. Many of these differences are found to coincide with rain events.

In order to better understand the effects of rain on both Jason-1 and QuikSCAT wind speed estimates, rain measurements from the Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR) 2A25 data set are co-located to provide a more accurate depiction of rain events. Understanding the rain effects on Jason-1 and QuikSCAT may aid in improving the accuracy of near-surface ocean wind measurements. In addition, near-surface ocean wind is influenced by storms, fronts, and other global weather patterns. Thus, increased understanding of near-surface ocean wind may enhance the understanding of these meteorological interests.

This paper presents observation and results from multi-sensor co-located data. Background information on the various satellites and rain complications is presented, followed by a description of the data co-location process. General observations and two detailed case studies precede conclusions.

II. Satellite background

Jason-1's primary goal is measuring ocean surface topography; however, near-surface ocean wind speed is also measured to aid in correcting altimetric measurements over the oceans. Due to the nadir looking nature of altimeters, an increase of wind speed is signified by a decrease of backscatter. The Poseidon-2 altimeter aboard Jason-1 (Jason-1) uses two channels at 13.575 GHz and 5.3 GHz. Only the 13.575 GHz (Ku band) is used in the current co-location study.

The Ku-band (13.402 GHz) QuikSCAT measures near-surface ocean wind vectors via dual pencil beam scans at 46.44° and $54.24^\circ(\pm 0.5^\circ)$ incidence angles. The L2B data from QuikSCAT used in the current study has 25 km resolution, and covers over 90% of the globe daily with a swath size of 1900 km. The dual beam QuikSCAT has both a horizontally polarized beam and a vertically polarized beam. However, the outer edge of the swath is only reached by one of the two beams. Measurements from these two beams can yield up to four wind vector estimates at each data point in the L2B data set through inverting the geophysical model function. A median filter-based ambiguity selection technique is used to select the most consistent wind estimate [2].

TRMM provides three dimensional rain data through the first satellite based precipitation radar. The PR operates in the Ku band (13.80 GHz) and scans the tropical regions of the Earth. With a horizontal resolution of approximately 4.34 km, three-dimensional rainfall measurements are made over a 247 km swath at 0° to 17° incidence angles [3].

A. Rain

Rain causes volumetric scattering and absorption, and modifies the ocean surface roughness and surface scatter. The effects of rain on the observed normalized radar cross section (σ°) are dependent on incidence angles and path lengths, and are therefore expected to be different for Jason-1 and QuikSCAT.

The fact that Jason-1 is nadir looking implies that its received σ° has fewer atmospheric effects from its path length. No thorough evaluation on how rain affects altimeter measurements has been performed according to [4]; however [4] refers to several sources suggesting that the effects are probably significant.

Since scatterometer wind measurements depend on surface, volumetric, and atmospheric effects, the σ° that QuikSCAT observes is changed in the presence of rain. Moreover, the incidence angles of QuikSCAT are greater than 45° and thus the integration path through the atmosphere is long, which implies that the atmospheric effects to the $\sigma°$ due to rain are more significant.

III. Data co-location

Data from Jason-1 and QuikSCAT between February and October 2002 are simultaneously co-located to aid in the study of wind speed differences between them. In order to overcome resolution differences between the two instruments, QuikSCAT wind measurements are bi-linearly interpolated to Jason-1 measurement cell locations. Temporal differences are restricted to within one hour of Jason-1's time stamps. Co-locating in this fashion yields nearly 1 million co-located data points. In order to obtain accurate measurements of rain, data from a third instrument, TRMM PR, is used. PR data is co-located both spatially and temporally to Jason-1 data in a similar fashion. Figure 1 illustrates the swath coverage and co-location of Jason-1, QuikSCAT, and TRMM. Jason-1's swath width is much narrower than QuikSCAT's counterpart; thus QuikSCAT wind field measurements can help put Jason-1 wind speed measurements into context. We note that unlike Jason-1, QuikSCAT provides wind direction information. It is fortunate that all three instruments use the Ku band so that cross comparisons are greatly simplified.

Spatially and temporally co-locating TRMM PR data with measurements from QuikSCAT and Jason-1 results in a limited number of co-location points, on the order of tens out of some 4000 data points per co-located Jason-1 revolution due to differences in orbital and observational geometries (Fig. 1). Relatively few Jason-1 passes are sufficiently co-located with QuikSCAT and TRMM to provide usable data. Thus the number of co-located data points is limited to approximately 11,000. In this paper, rain events are designated by TRMM PR rainrates, so most observations and figures are obtained from this triply co-located data set.

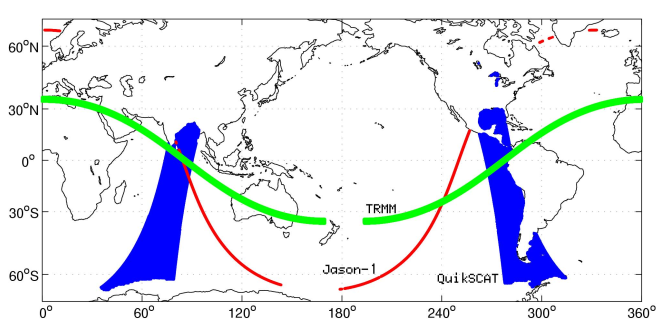

Fig. 1. An example of Jason-1, QuikSCAT, and TRMM orbit overlap. The orbit with the widest swath belongs to QuikSCAT. The swath with medium width belongs to TRMM, and the narrowest swath belongs to Jason-1.

IV. Observations

Within the triply co-located data set, QuikSCAT and Jason-1 wind speed estimates generally agree to within a bias of 1.52 m/s, with QuikSCAT wind speeds being higher. This data set is smaller and is limited to the tropics, where rain is abundant. The bias between co-located Jason-1 and QuikSCAT (TRMM PR data excluded) wind speeds is 1.30 m/s, with QuikSCAT wind speeds having a higher mean estimate. For the same data set, the ECMWF wind speeds are 0.38 m/s higher than the Jason-1 counterparts. Even after removing the biases, some large wind speed difference cases occur. In the majority of co-locations where Jason-1 and QuikSCAT wind speeds differ significantly, rain events are present as detected by TRMM PR. These cases are plotted with an "x" in Fig. 2.

QuikSCAT wind estimation is known to suffer from rain contamination [5]. [4] asserts that altimetry measurements are also sensitive to rain. Since QuikSCAT has a longer signal path due to larger incidence angles, it is expected that QuikSCAT is more affected by attenuation from rain than is Jason-1. Figures 3 and 4 compare the difference of Jason-1 or QuikSCAT wind speed and European Centre for Medium-Range Weather Forecasts (ECMWF) wind data to TRMM PR-derived rainrate. Co-located ECMWF wind speeds and TRMM PR rain appear to have a negligible relationship. Figures 3 and 4 suggest that TRMM rainrate is somewhat related to wind speed error in QuikSCAT and Jason-1. As expected, QuikSCAT wind speed error appears more severe.

Because of the high variability of rain events, observing them within a multi-sensor co-located data set requires greater restrictions on temporal proximity. Shortening the time window for temporal co-location significantly reduces the total number of storms available for examination. However, even in relatively poor temporal co-location cases where storm shifting becomes a greater factor, the wider swath contexts of QuikSCAT vector wind and TRMM rain permit the investigation of rain influences on wind speed estimation since displaced storms generally continue to lie within the swaths of these instruments for a reasonable period of time. Presented next are two sample rain events. The first is nearly simultaneously viewed by Jason-1, QuikSCAT, and TRMM, while the second has noticeable storm displacement.

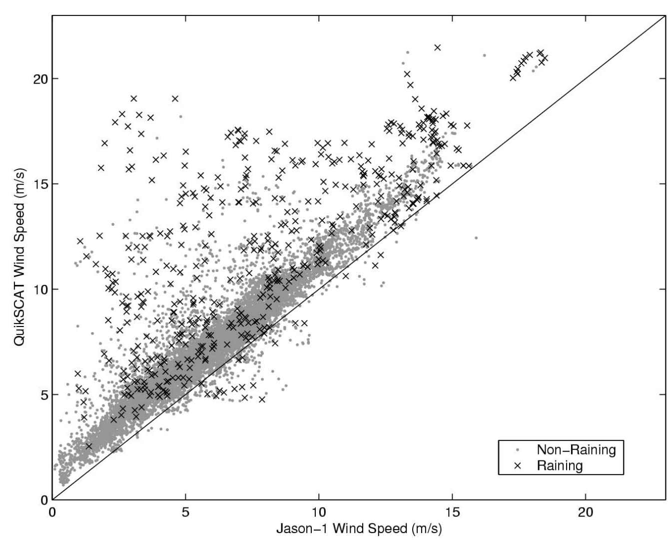

Fig. 2. A scatter plot of Jason-1 wind speeds wind speeds versus QuikSCAT L2B wind speeds for 11073 co-locations of Jason-1, QuikSCAT, and TRMM between February 11 and October 13, 2002. The rain information is from TRMM PR. A diagonal line is plotted for reference.

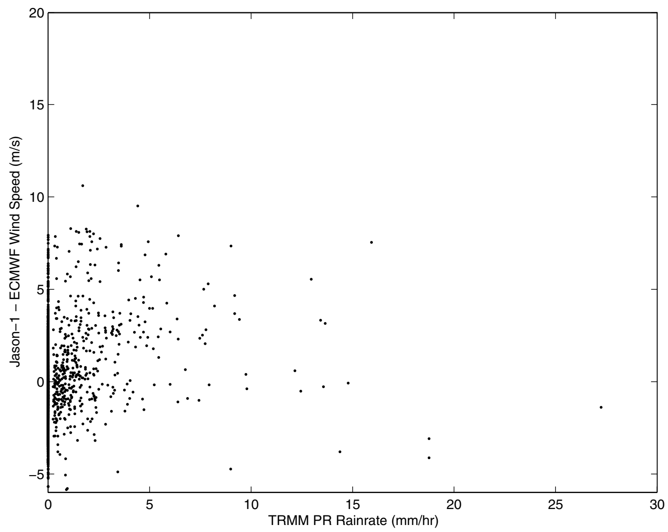

Fig. 3. A scatter plot of TRMM PR rainrates versus wind speed differences between Jason-1 and ECMWF for 11073 co-locations of Jason-1, QuikSCAT, and TRMM between February 11 and October 13, 2002.

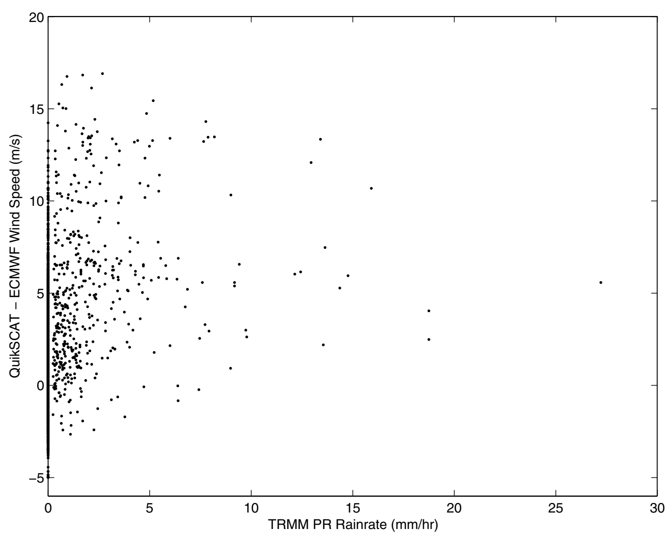

Fig. 4. A scatter plot of TRMM PR rainrates versus wind speed differences between QuikSCAT and ECMWF for 11073 co-locations of Jason-1, QuikSCAT, and TRMM between February 11 and October 13, 2002.

A. Case study 1: Small scale rain

Figure 5 represents a near-equatorial Jason-1, QuikSCAT, and TRMM co-located observation of small scale rain events. Making this case particularly useful, all sensor observations are within five minutes of each other. This is expected to alleviate some of the complications introduced by the high temporal variability of rain.

It is interesting to note that the sudden jump in Jason-1-derived wind speed near bin 16 is associated with a similar increase in QuikSCAT wind speed. Jason-1 flags this event as rain over an extended area; however, the nearest TRMM measurement cells show no rain present. Nevertheless, in the larger TRMM context for this case (Fig. 6), TRMM detects several small scale storms near the Jason-1 track, which reach rainrates exceeding 10 mm/hr. That TRMM detects no rain at its cells nearest Jason-1 measurement locations is perhaps an artifact due to the nature of small scale rain events. This is an example of TRMM rain context providing a clearer picture of the meteorological state.

The second rapid rise in Jason-1 wind speed near bin 45 coincides with a mirrored trend at the same bins in QuikSCAT. As is frequently the case, TRMM and Jason-1 detect rain in the cells of this wind speed anomaly. The greater variability of Jason-1 wind speed measurements manifests its higher spatial resolution relative to QuikSCAT. We note that ECMWF model winds appear unaffected by these small scale rains.

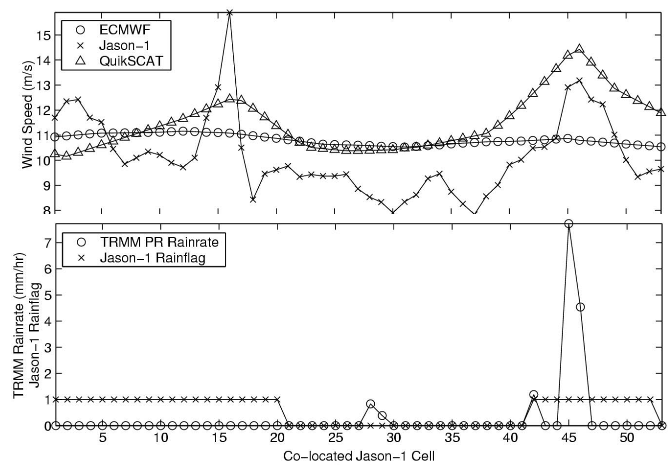

Fig. 5. Case study 1: A sample of Jason-1, QuikSCAT, and TRMM co-locations when the time differences are within five minutes. Jason-1 rainflag is one when rain is detected. (See Fig. 6.)

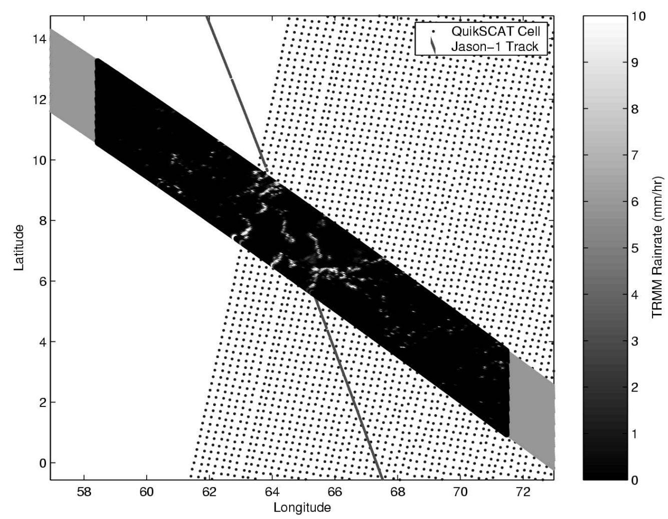

Fig. 6. Case study 1: TRMM PR rainrates and Jason-1, QuikSCAT, and TRMM co-locations with small scale TRMM rain. Dots indicate QuikSCAT L2B measurement locations.

B. Case study 2: Large storm

The time series from a noteworthy, near-equatorial, co-located observation of a large rain storm is depicted in Fig. 7. Notice the similarity in trends between TRMM rainrates and the satellite estimated winds, particularly Jason-1-derived wind speeds.

Jason-1 and TRMM data are co-located to within about five minutes, while QuikSCAT is approximately 30 minutes ahead. Storm shifting over time is evident in the relative lag of the Jason-1 and QuikSCAT curves. The Jason-1 rainflag suggests the existence of rain within every cell of this co-location series even though there are several TRMM estimates showing an absence of rain.

Co-location with wider swath instruments provides contextual insight. From the Jason-1 data alone, storm structure, magnitude, and directions may not be readily apparent. Figures 8 and 9 demonstrate the addition of QuikSCAT wind field and TRMM precipitation contexts to Jason-1 observations. Figure 9 shows TRMM rain covering an expansive area. Rainrates in excess of 10 mm/hr are detected near the Jason-1 observation track. The QuikSCAT wind field of Fig. 8 portrays regional QuikSCAT wind speeds up to more than 25 m/s. These context figures also reveal that the co-located series passes through the edge of a storm, bringing related complications into consideration.

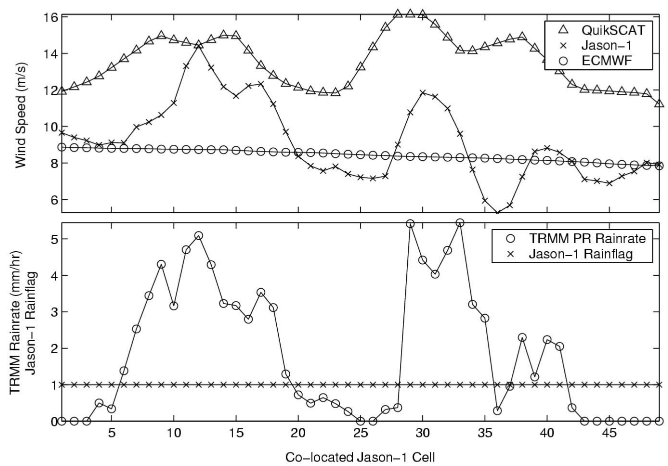

Fig. 7. Case study 2: A sample of Jason-1, QuikSCAT, and TRMM co-locations in the presence of a large storm. The time difference between Jason-1 and TRMM is about five minutes, between QuikSCAT and TRMM is about 29 minutes, and between QuikSCAT and Jason-1 is about 24 minutes. Jason-1 rainflag is one when rain is detected. (See Figs. 8 and 9.)

V. Conclusion

The wind speeds from QuikSCAT and Jason-1 are generally observed to be in good agreement, but when speed measurements from the two instruments differ significantly, they are often associated with rain events. A bias between Jason-1 and QuikSCAT wind measurements is also observed.

Acknowledgment

The authors express gratitude to CNES, JAXA, and NASA for providing the data used in the current study.

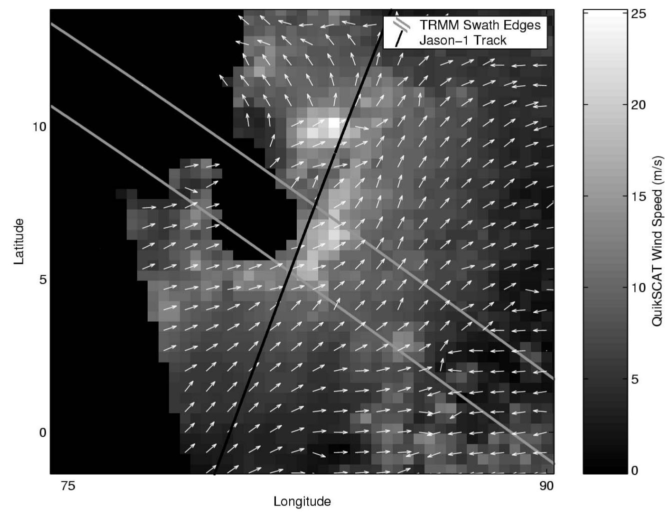

Fig. 8. Case study 2: QuikSCAT winds and Jason-1, QuikSCAT, and TRMM co-locations in the presence of a large storm. The arrows are QuikSCAT L2B wind directions (binned and interpolated). Gray scale background is QuikSCAT L2B wind speeds.

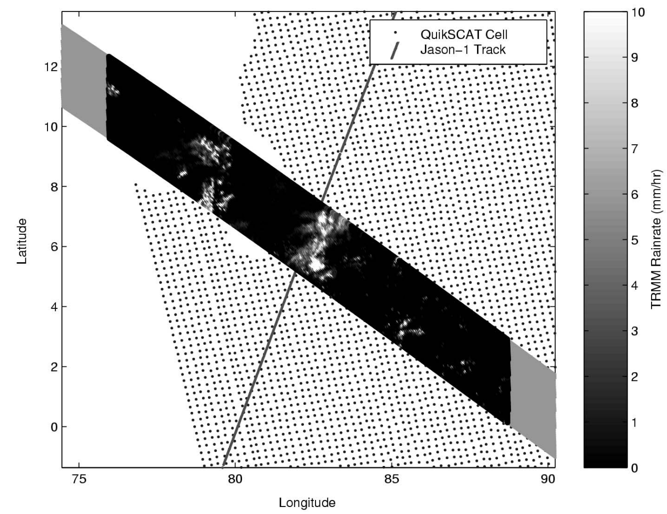

Fig. 9. Case study 2: TRMM PR rainrates and Jason-1, QuikSCAT, and TRMM co-locations in the presence of a large storm. Dots indicate QuikSCAT L2B measurement locations.

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