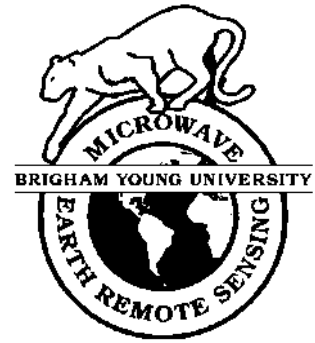


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**Microwave Earth Remote Sensing (MERS)  
Laboratory**

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# Improving Temporal Resolution of SIR Images Using Tandem Mission Data in the Polar Regions

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March 14, 2005

**Abstract**

## 1 Introduction

The SeaWinds instruments aboard QuikSCAT and ADEOS II are spaceborne scatterometers in near-polar sun-synchronous orbits. Because of their wide swath widths and orbit geometries these satellites each covered many areas in the polar regions multiple times a day, for the duration of the tandem mission. This high temporal sampling frequency in the polar regions provides a powerful tool for greater study of the ice caps. This tandem mission of SeaWinds aboard QuikSCAT, referred to as QuikSCAT, and SeaWinds aboard ADEOS II, referred to as SeaWinds, ran from JD 100 through JD 297 of 2003.

Currently, tandem data has been processed by the Scatterometer Image Reconstruction (SIR) algorithm to produce daily images of various standard regions worldwide. Individually, QuikSCAT and SeaWinds data is also processed into ascending pass-only, and descending pass-only images, in addition to daily images. Because these satellites have similar sun-synchronous orbits, but different local time of ascension, the combined dataset allows a greater temporal sampling frequency of the world than each satellite separately.

In the polar regions it has been shown [1] that the ascending and descending method of improving the temporal resolution of SIR images in the polar region does not meet its full potential. By using the local time of day to divide the QuikSCAT dataset into morning and evening images, greater temporal resolution is achieved. Extending this notion to the tandem mission, we show that images can be produced that improve the temporal sampling of the Arctic to three nearly uniformly-spaced samples daily. This improved temporal sampling provides useful data for the study of diurnal variations and other short-lived natural phenomena in the polar regions.

In this paper, we first give background on currently available images and their limitations in the polar regions. Then, we discuss how tandem—QuikSCAT and SeaWinds—images help improve temporal resolution. Finally, we propose a new set of images that take better advantage of the tandem mission data in the Arctic to provide three nearly uniformly separated images daily.

## 2 Background on Currently produced QuikSCAT, SeaWinds, and Tandem Images

In the currently available QuikSCAT and SeaWinds products, daily data is temporally separated into three images: daily, ascending pass-only, and descending pass-only. Tandem images that combine data from both satellites are also produced daily.

QuikSCAT and SeaWinds, and Tandem images are currently produced of various regions of the Earth's surface in several ways. The most simple images are produced by merely averaging measurements within each pixel's area. Gridded images produced by this method result in images with good signal to noise, but suffer from poor spatial resolution. Gridded image spatial resolution is limited by the dimensions of the antenna pattern: roughly 25km. Other images are produced using the Scatterometer Image Reconstruction (SIR) technique that greatly improves spatial resolution, but also introduces some extra noise. SIR images are created using both the full antenna footprint, resulting in 'Egg' images, and range filtered footprints, resulting in 'Slice' images. Both 'Egg' and 'Slice' images have variable effective resolution that depends on the number and orientation of measurements covering each pixel. The typical effective resolutions are on the order of 9km for 'Egg' images, 3–6 km for 'Slice' images.

In the production of SIR images, many auxiliary images are also produced. In this paper we are strongly concerned with the image produced by the SIR algorithm that estimates the time that each pixel was measured. This "time" image is referred to as the  $\mathbf{p}$  image [2].

In current ascending and descending images produced for QuikSCAT and SeaWinds, the temporal resolution is not as good as it could be at the polar extremes due to inadequate temporal separation and grouping of individual measurements. The causes of this loss are discussed in greater detail in [1], however a short description is given in following subsection.

### 2.1 Causes of Temporal Resolution Loss in Ascending/Descending Images

There are two main contributors to temporal resolution loss in ascending/descending images in the polar regions: swath overlap and day boundary effects.

A single satellite orbit can be separated into two parts, ascending and descending. By convention, a satellite is ascending when its velocity has some northward component, and descending when the converse is true. Sun-synchronous near polar orbiting satellites, such as QuikSCAT and SeaWinds, make this transition in close proximity to the poles. Because the satellites' sensor measures a swath that extends radially in all directions, there is a region that is covered by both the ascending pass and descending pass near the poles of

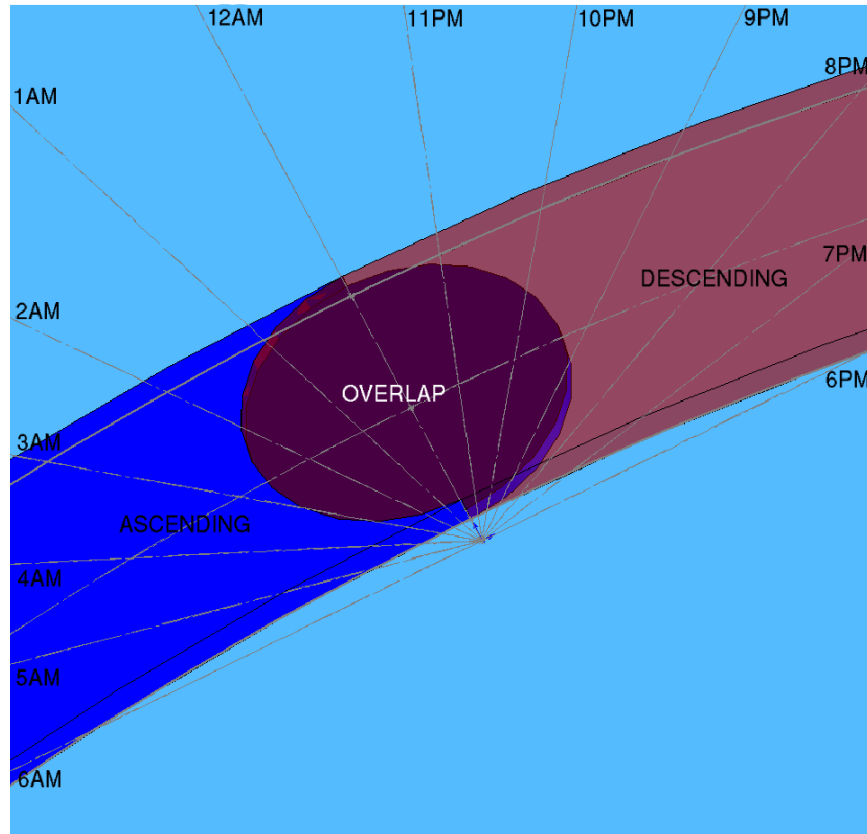


Figure 1: Diagram illustrating a QuikSCAT transition from ascending pass to descending pass in the Arctic. The lines radiating out from the center depict the local time zone boundaries. Note that there is significant overlap of the ascending and descending data. The SeaWinds ascending-to-descending transition occurs at roughly 4PM local time, 8 hours before QuikSCAT.

every orbit. Figure 1 is a diagram illustrating the swath overlap. This overlap is detrimental to temporal resolution, because temporally similar data is found in both ascending and descending images. Fortunately this swath overlap only effects polar regions, and only at high ( $> 74^\circ$  N or S) latitudes.

The effects of the day boundary are perhaps the most damaging to temporal resolution in the polar images. Because currently produced ascending and descending images use 24 hours of data, there are regions where the first few passes and the last few passes of this time period cover the same region. This day boundary-affected region is especially damaging to temporal resolution, because data separated by nearly twenty-four hours is averaged together. This effect is unavoidable in full coverage images with shorter than daily temporal resolution because of the satellites orbital and measurement geometries, however in the ascending and descending images it is poorly handled. In these images the region affected by the day boundary is very large, and its location changes from day to day.

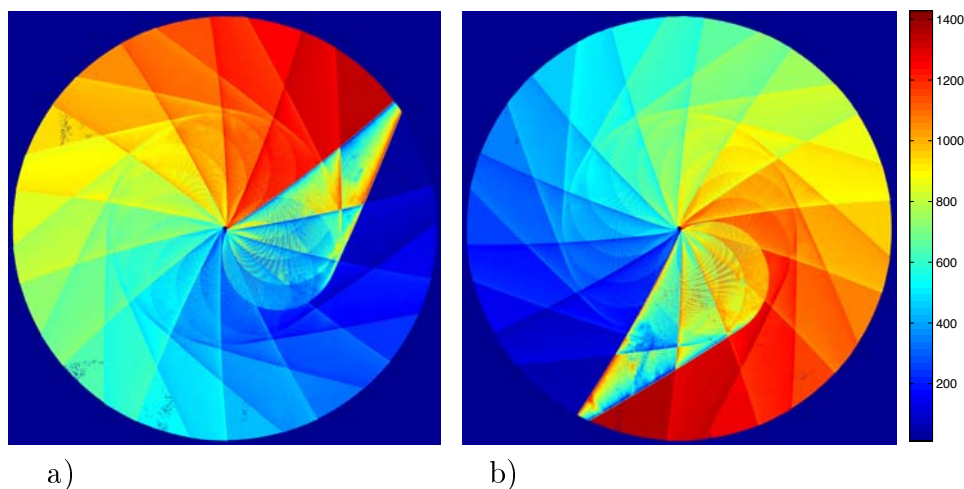


Figure 2: Ascending (a), and descending (b) QuikSCAT  $\mathbf{p}$  images from JD 258 2003. Note the area to the right of center in (a), and below center in (b), where the first several passes and the last several passes overlap.

### 3 Combined Look at QuikSCAT and SeaWinds Images

By combining the image-set of QuikSCAT and SeaWinds we should obtain higher temporal sampling frequencies than with either one separately. In practice, however, the usefulness of these images as independent samples, and the resulting temporal resolution, is not nearly as good as it could be for the polar regions. In this section, the combined image-set of ascending/descending images from QuikSCAT and SeaWinds and its temporal limitations is discussed.

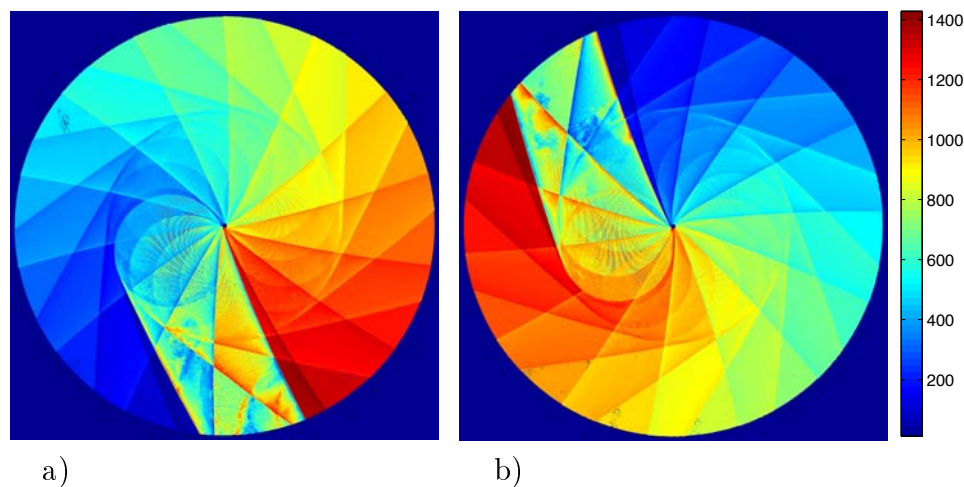


Figure 3: Ascending (a), and descending (b) SeaWinds  $\mathbf{p}$  images from JD 258 2003. Note the area to the right of center in (a), and below center in (b), where the first several passes and the last several passes overlap.

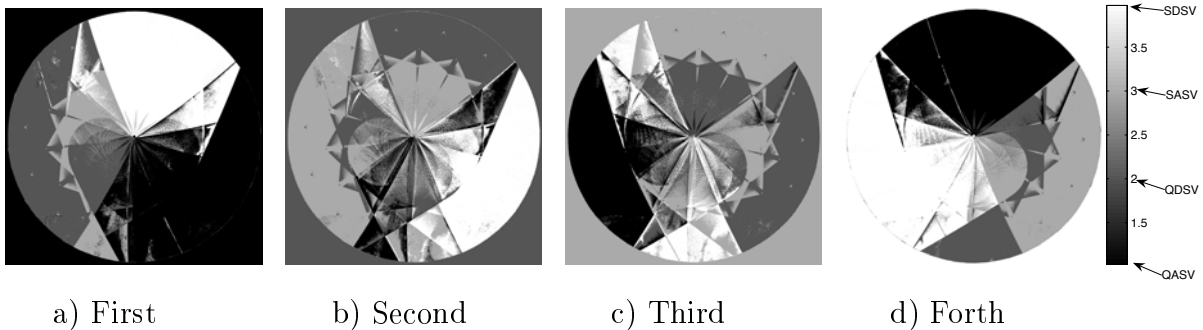


Figure 4: Chronological order the four QuikSCAT/SeaWinds ascending and descending images should be placed in, by pixel. Sequential order varies significantly based on the pixel, making proper chronological sequencing of the images difficult at best.

Figures 2 and 3 are QuikSCAT and SeaWinds  $\mathbf{p}$  images, respectively, from JD 258 2003. Figures 2a, and 2a are ascending images, and 3b, and 3b are descending images. From these images a few items should be noted:

1. The North pole is located at the center of the images.
2. The day boundary affected region is clearly visible as the region between the red and blue whose color varies. Its location differs in each image.
3. The combined day boundary affected region is a significant portion of the image.

Because the day boundary location is different for each image type, the chronological order in which the images should be placed varies from location to location. Figure 4 illustrates the problem with chronological sequencing of the images. As a result of the unclear chronological sequencing, using the four images in studies over large areas of the polar regions becomes complicated.

If we restrict the area of study to a single pixel, chronological ordering of the image pixels is simplified. However, we still must determine if the information provided is useful. Figure 5 shows the individual measurements of QuikSCAT and SeaWinds, and how their image values are arranged chronologically. Largely due to day boundary affects on the SeaWinds data, the image values shown in Figure 5b do not represent the measured data very well. This causes all four QuikSCAT/SeaWinds images to be closely grouped temporally in Figure 5c—often within 4–6 hours of each other. From Figure 5c we also note that the samples do not accurately follow the data, and do not exhibit temporal resolution better than that of each satellite separately.

Using the QuikSCAT/SeaWinds ascending and descending polar images as unique samples does not accurately portray the underlying data. Because of the effects outlined in [1], namely, swath overlap and day boundary effects, the resulting images have excess temporal variability, making some the images too closely correlated to be used independently. In the next section, an image-set is described which reduces the temporal variability, resulting in images that are temporally independent, and thus, more accurately describe the underlying physical features.

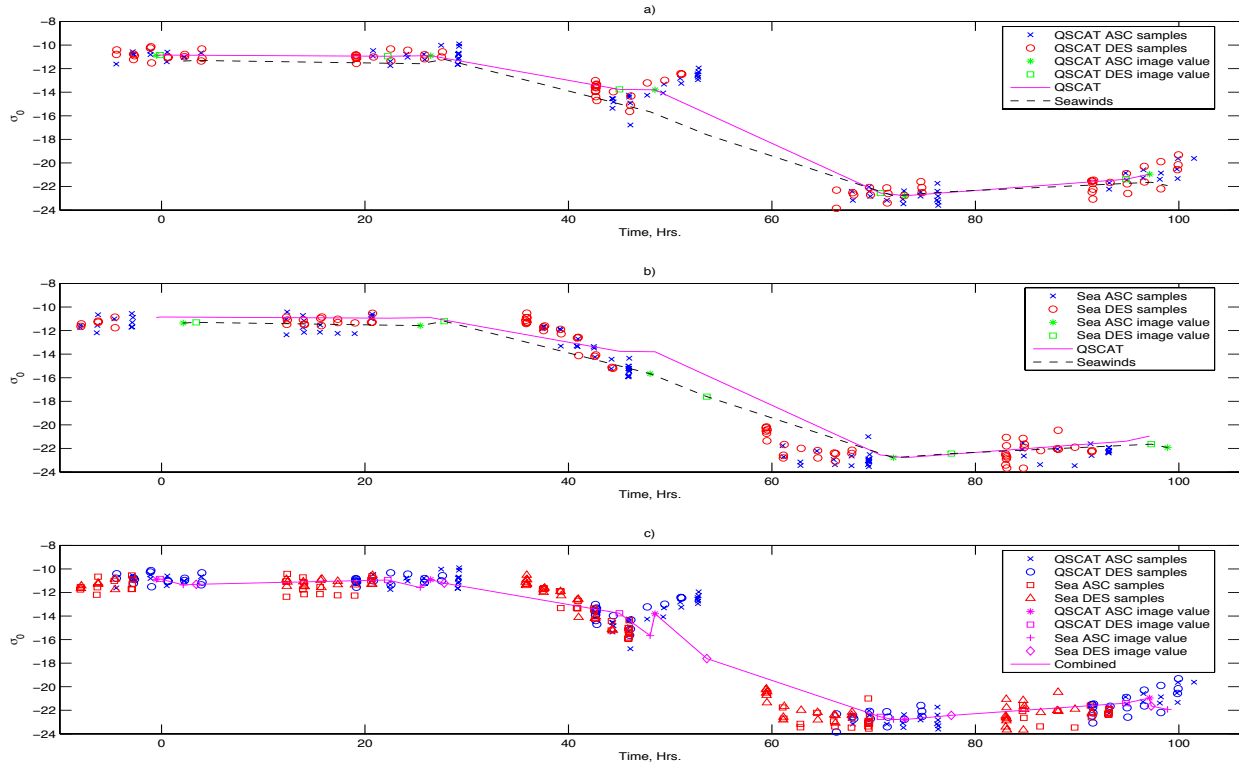


Figure 5: Graph showing individual measurements and image values for a particular pixel (84.0468 N 135.3773 W from JD 163 to JD 167 2003) for a) QuikSCAT ascending/descending, b) SeaWinds ascending/descending, and c) Combined QuikSCAT/SeaWinds. Note that at this location, SeaWinds suffers from day boundary effects, making its image values appear between groupings of data. The usefulness of these images at this pixel are questionable: all the samples are grouped within 6-10 hours of the day, and when chronologically ordered they do not follow the raw data well.

## 4 Morning, Midday, and Evening Tandem SIR Images

In an effort to decrease the temporal variability of measurements which compose polar images, a new method using both QuikSCAT and SeaWinds data has been developed. In these new images the data is separated by the local time of measurements at each pixel creating three images a day. Using local time of day rather than spacecraft and spacecraft motion provides means by which samples can be placed into images. By separating the data according to local time of day, we can guarantee that all temporally similar samples are grouped into the same image, and that temporal variability of measurements in each images is kept low.

Given that data used to create these new images comes from the tandem mission of QuikSCAT and SeaWinds, it would seem that 4 images a day should be possible in the polar regions. However, when we look at the times when actual samples are received in polar regions, we realize that QuikSCAT and SeaWinds have temporally similar measurements. In particular, from Figures 5, and 4 we see that the QuikSCAT ascending, and SeaWinds

descending images are always very closely spaced temporally in the polar regions, and that their individual measurements are closely grouped temporally as well. Because these images and their respective measurements are temporally similar, it is more reasonable to create three images instead of four in this region. Furthermore, dividing the data temporally into four images would result in images that do not have full coverage.

For the QuikSCAT only case, the logically intuitive approach placed the time boundaries at 12:00 AM, and 12:00 PM. This time boundary essentially divided each QuikSCAT pass into two equal parts, placing half of the data into each image as shown in Figure 6. Taking a similar approach, it is logically intuitive to place one time boundary at 12:00AM dividing QuikSCAT passes in half, one at 4:00 PM, dividing SeaWinds passes in half, and the third at 8:00 AM, a time when no measurements are recorded. These time boundaries result in three 8-hour images: morning (12:00 AM to 8:00 AM), midday (8:00 AM to 4:00 PM), and evening (4:00 PM to 12:00 AM). The placement of the time boundary, although placed somewhat arbitrarily, does have implications if they are moved away from these values. Figure 6 shows the local time boundaries in relation to the swath pass. Because the way local time boundaries slice through the swath data, improper placement of the boundary may cause visible anomalies along the temporal decision boundaries of each pass. The time boundaries placed at 12:00 AM, 8:00 AM, and 4:00 PM insures that the swaths are being sliced in a way that minimizes the potential for such anomalies. This also reinforces the justification for creating three images a day instead of four.

Figure 7 shows three consecutive days of raw QuikSCAT and SeaWinds data samples at a particular location (84.0468 N 135.3773 W), and the resulting morning, midday, and evening values. Individual passes are seen as vertical columns of data, because the measurements are separated at most by a few minutes. Contrast this figure with Figure 5, which shows the combined QuikSCAT/SeaWinds ascending and descending image dataset. This method, which uses the local time of day instead of a satellite and is motion to define the images, clearly exhibits improved sampling. The actual time separation between images does not deviate far from 8-hours, resulting in a near uniform sampling of the surface with three samples per day. This lowers the upper bound on signal frequencies that can accurately be represented without aliasing to those with periods shorter than 24 hours, making diurnal variations of the signal much more clear.

The sequencing problem described previously, and illustrated by Figure 4, is also eliminated by the new method. This is occurs because the effects of the day boundary on the images is moved to the same small location in the images. As a result, each pixel, regardless of its location in the image can be assured to follow a well defined chronological order.

Moving the day boundary affected region to a small defined location does have some negative repercussions. This anomaly may negatively affect certain studies of ice movement in this portion of the world, making it more difficult to track the ice's movement across this day boundary, without taking this into account.

## 5 Conclusions

Largely due to the loss of temporal resolution associated with the creation of ascending and descending polar images, the use of these images created for QuikSCAT and SeaWinds to-



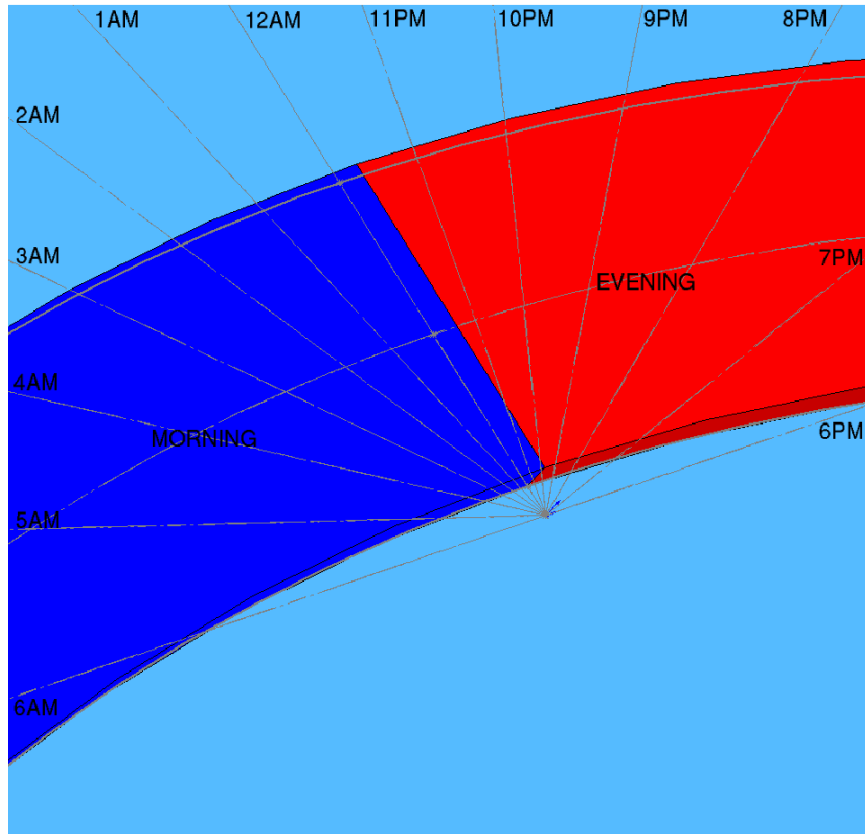


Figure 6: Diagram illustrating a QuikSCAT transition from morning pass to evening pass in the Arctic. The lines radiating out from the center depict the local time zone boundaries. Note that there is no overlap of the morning and evening data, and that the swath is divide into two nearly equal halves. Note that by placing a time boundary at 4:00 PM results in a similar diagram for SeaWinds passes. Contrast with Figure 1.

gether, does not provide improved temporal resolution. First, these images are difficult to use when time of day is required, or when a chronological order is needed, due to the day boundary effects of the individual images. Second, these images suffer from ascending-to-descending pass overlap. Together these issues increase the temporal variability of measurements in each images, and also decrease the separation times between images.

A new method, wherein polar images are created by separating the data according to the local time of the measurements, improves the temporal sampling by forcing temporally similar measurements from both satellites to be used. As a result the effect of swath overlap is eliminated, and the day boundary placed in the same location for each image. This drastically decreases temporal variability of pixel times in the region previously affected under the current method, increasing temporal resolution. In this new method, three images a day was chosen, because of a several hour long period time each day when both satellites swaths cover the same regions, making full coverage images possible for only three images a day. The resulting image-set provides three nearly uniform samples daily of the polar regions.

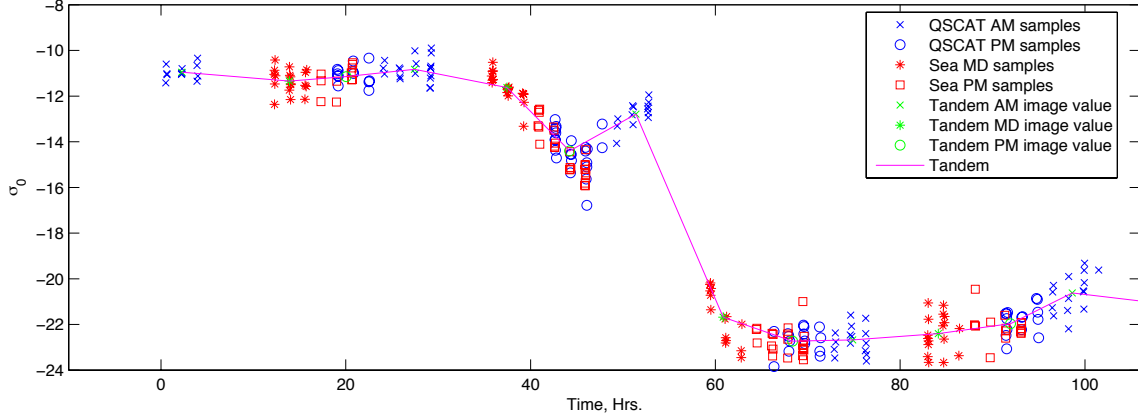


Figure 7: Graph showing individual measurements for a particular pixel (84.0468 N 135.3773 W from JD 163 to JD 167 2003) for QuikSCAT and SeaWinds, and the resulting morning, midday, and evening image values that result from applying the new time-of-day method to the Tandem data. Contrast with Figure 5. Note the near uniform, three daily samples that this method provides.

## References

- [1] Hicks, B. R. and Long, D. G. *Improving Temporal Resolution of SIR Images for QuikSCAT in the Polar Regions* MERS Technical Report 05-??, Microwave Earth Remote Sensing Laboratory, Brigham Young University, 2005
- [2] Watt, G., and Long D. G. *Temporal Average Estimate Algorithm for ERS-1/2* MERS Technical Report 97-07, Microwave Earth Remote Sensing Laboratory, Brigham Young University, 1997.