Diurnal Melt Detection on Arctic Sea Ice Using Tandem QuikSCAT and SeaWinds Data

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***Abstract*— The tandem mission of QuikSCAT and SeaWinds provides means for study of the diurnal variation of backscatter. Combined with a new method of temporally separating measurements based on the local time-of-day, a new dataset of images is generated using the Scatterometer Image Reconstruction (SIR) method. This new dataset has high spatial resolution as well as a nearly uniform temporal sampling period of 8 hours. This new time-of-day data imaging method is described, and applied to the maximum likelihood estimation of melt over Arctic sea-ice.**

I. INTRODUCTION

The tandem mission of QuikSCAT and SeaWinds, combined with a new method of temporally separating and processing the data into Scatterometer Image Reconstruction (SIR) images, enables an unprecedented temporal sampling of 3 high resolution images a day. The high sampling frequency permits the resolution of the diurnal cycle of backscatter (σ^o) and backscatter polarization ratio (PR). This method results in a nearly uniform 8 hr sampling period during the tandem QuikSCAT-SeaWinds mission.

This temporal separation method is referred to as the morning/midday/evening method because it considers the local time of day of the measurements when creating backscatter images. The local time of day of each measurement is used to separate the data into each image: morning-only, midday-only, and evening-only. This technique insures that only temporally similar data are used in the creation of each image. The morning/midday/evening method results in a nearly uniform 8 hr sampling period during the tandem QuikSCAT-SeaWinds mission, and sampling with 3–6 hrs better time separation than the current ascending/descending method at extreme latitudes.

First, we discuss the new method of temporally separating images, and show how this new method overcomes the problems associated with current ascending/descending images. We then develop and apply a maximum likelihood estimator that uses σ^o, PR, and a measure of diurnal variation at a selected location to detect sea-ice melt.

II. TEMPORAL SEPARATION: TIME-OF-DAY FILTERING

In the currently available scatterometer image products[1] (see Fig. 1), daily data is temporally separated into three images: daily, ascending pass-only, and descending pass-only. Ascending and descending pass-only images are produced to aid the study of diurnal variation and very short-lived natural phenomena. In lower latitudes where the local-time of day for measurements is relatively constant, this method nicely separates the data temporally into twice-daily images. The only trade-off in lower latitudes is a decrease in spatial coverage. Unfortunately, in high latitudes, ascending and descending QuikSCAT and SeaWinds images suffer from poor temporal resolution due to inadequate temporal separation. In this section we briefly outline this temporal resolution loss, and provide a solution.

The limitations regarding the temporal resolution of the current ascending and descending product are, in part, a result of ascending and descending pass overlap [2]. This overlap is a result of the instrument's measurement geometry. The SeaWinds instrument uses a conically scanning pencil-beam antenna. Each rotation of its parabolic reflector sweeps out a circle on the earth's surface centered around the nadir point of the satellite. This circle of measurements can be divided into two halves, forward-looking and aft-looking.

Figure 2 is a diagram showing how the measurements of a single pass are divided into ascending and descending passes. By convention the transition from ascending to descending and visa versa occurs at the northern and southern most point in the satellites' travel. The satellite approaching the point on the ground where the transition occurs measures forward of the transition point. After passing that transition point, the instrument continues to observe aft-looking. This creates a nearly circular region, where the forward-looking measurements are ascending, but the aft-looking measurements are descending. In this region the ascending and descending pass overlap. Because the ascending/descending overlap for each pass is closely located to the poles, it covers many lines of longitude and thus many local time zones. Since each pass suffers from this overlap, and as many as 8 consecutive passes cover a particular area on the ground, the entire region north of $\sim 73°$N suffers from the effects of this overlap. Essentially, the ascending/descending method assumes that the local-time of measurements is relatively constant across the swath; in the polar regions this is not the case, and results in degraded temporal resolution.

Along with the SIR σ^o images, a number of ancillary images are created, including images of the effective time the data was gathered for that pixel [4]. The difference between consecutive ascending and descending time images is shown in Fig. 3. In high latitude areas, where the ascending and descending pass overlap occurs, the ascending/descending images have very little time separation.

The effects of the day boundary also limit temporal resolution in ascending/descending images. The day boundary-affected region is the region of the image where data separated by nearly 24 hours is averaged together. Current polar SIR

[1] Found at `http://www.scp.byu.edu`

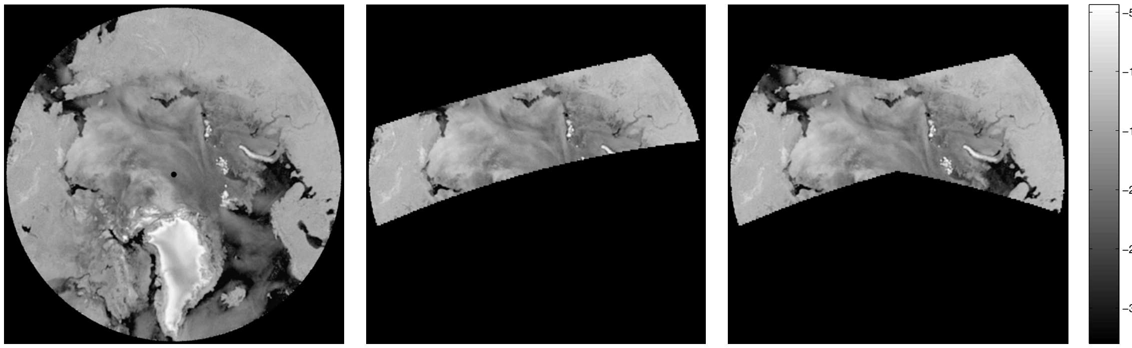

Fig. 1. From left-to-right: A typical one-day v-pol QuikSCAT SIR image of the Arctic which includes multiple passes, the same image masked to show the coverage of a single pass, and the same image masked to show the coverage of two consecutive passes.

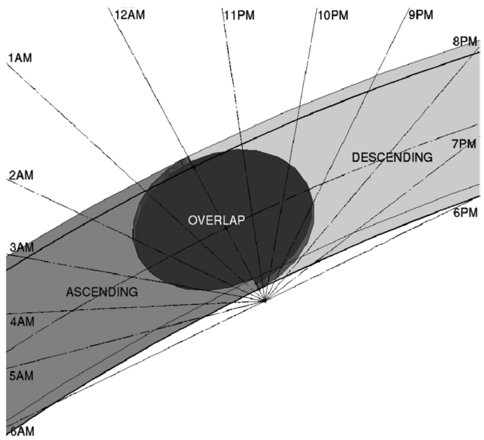

Fig. 2. Diagram illustrating the transition from ascending pass to descending pass in the Arctic. The lines radiating out from the center depict the local time zone boundaries. Note that there is significant overlap of the ascending and descending data.

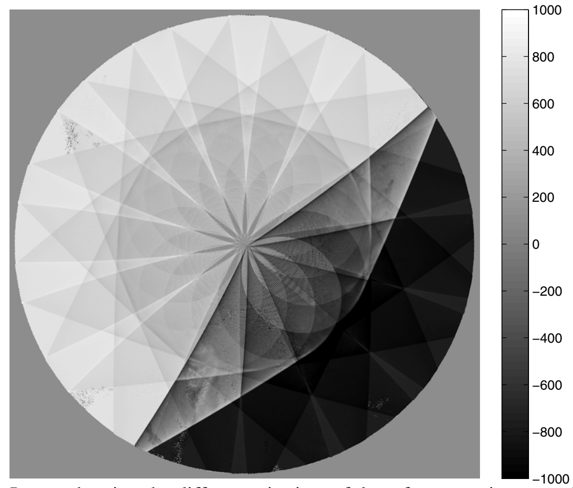

Fig. 3. Image showing the difference in time of day of consecutive ascending pass and descending. Time separation in minutes – descending first is positive.

images are created from one twenty-four hour time period. All valid data taken during the twenty-four hour period are used to create the images (see Fig. 1). We note there are significant portions of the Arctic and Antarctic where, due to the wide swath, the first several passes and the last several passes of each day cover the same area. Figure 3 shows the time between the ascending and descending images. The day boundary region is the elongated diamond shaped region to the right and below the center of the image. This region separates the portion of the image where the ascending precedes the descending in the bottom right of the image, and the portion where descending precedes ascending in the upper left of the image. This day boundary has poor temporal separation, however the temporal resolution in this region suffers even more due to measurements separated by as much as 24 hours being averaged together.

It should be noted that some day boundary effects are unavoidable in polar images made with shorter than daily temporal sample period because the satellite's sun-synchronous near polar orbit and wide swath. In the ascending and descending images, these day boundaries effect a large portion of the Arctic and Antarctic images. For the new proposed images this boundary is relegated to a small portion of the image in a predictable manner. Because there is such variation in local sample time across the wide swath of QuikSCAT and SeaWinds in the polar regions, a new method of separating the daily data can be accomplished by using the local times of the samples themselves rather than the direction of the spacecraft's motion. In this method, a particular local time of day is used to separate the data into distinct 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. We note that this method is only needed in the polar regions; in lower latitudes, the ascending/descending method, and the local-time of day method are equivalent.

Time-of-day filtering the data eliminates pass overlap, and limits the day boundary effect. Figure 4 shows a time series

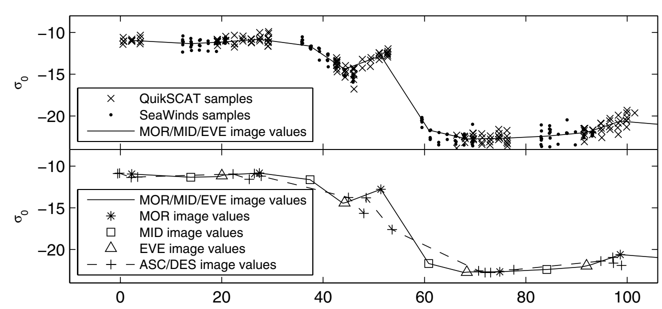

Fig. 4. A comparison of the ascending/descending method and time-of-day(morning/midday/evening) method at 84.0°N 135.4°W beginning JD 163 2003. Top: Individual σ^o measurements. Bottom: The time series of the morning/midday/evening and ascending/descending image values.

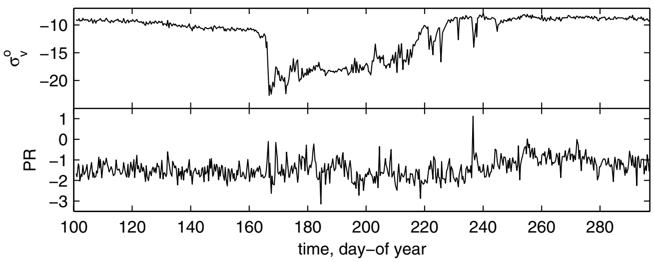

Fig. 5. V-pol backscatter and PR of multi-year ice at 84.0°N 135.4°W, for 2003.

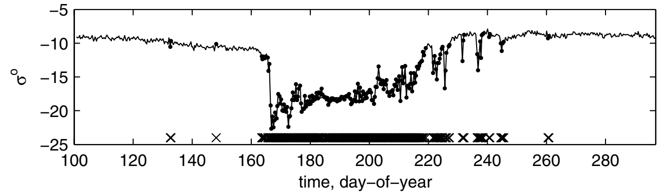

Fig. 6. Backscatter and the ice-state of mulit-year ice at 84.0°N 135.4°W. Melting is indicated by dots in the time series, and 'x's along the bottom.

comparison of the two methods. The local time boundaries are chosen to divide the measurements from each satellite equally into images. For QuikSCAT-only images we use 12:00AM and 12:00PM as the filter boundaries. For SeaWinds-only images we use time-of-day filter boundaries at 4:00AM and 4:00PM. For the tandem SeaWinds/QuikSCAT dataset, we create three images a day using 12:00AM, 8:00AM and 4:00PM as the time-of-day filter boundaries in the Arctic and 12:00PM, 8:00PM and 4:00AM in the Antarctic. By using these time boundaries, full coverage images are produced.

III. Melt Detection

The SeaWinds instrument on QuikSCAT/SeaWinds measures the backscatter, both h-pol and v-pol. For maximum likelihood estimation we use v-pol measurements, and the 'quasi' polarization ratio (PR),

$$PR = \sigma_V^o - \sigma_H^o, \tag{1}$$

where the values are in dB, as well as a measure of diurnal variation. The change in the dielectric constant due to the intrusion of melt water results in a substantial drop in σ^o, as well as a change in PR [1][3].

The Tandem image data, with increased temporal sampling and resolution, provide the means to discern the ice state with added information regarding the diurnal cycle. In the melted state, small changes in heat flux into or out of the ice have a marked effect on the backscattered return, leading to potentially rapid fluctuation in σ^o during the course of a day. Thus, σ^o, PR, and a measure of diurnal variation are reasonable indicators of melt. Using these, we perform classification using the maximum-likelihood (ML) ratio test [3]. We initialize the test by grouping data into frozen and melting categories by selecting data before day 150 and after 250 (for our study point in Fig. 5) as frozen and compute the mean and covariances. After the classification is performed, the new melt and non-melt classifications are used to recompute the mean and covariances of the ML parameters. Several iterations are used to allow the melt state estimate to converge.

As an illustration, the ML method is used to classify the melt at a particular location where multi-year ice (MYI) is found. The ML classification is performed on data at 84.0°N 135.4°W shown in Fig. 5. The results of this ML classification are shown in Fig. 6. Melt is predicted quite well, showing good agreement with dips in the backscatter, even late in the melt season when the frozen ice backscatter has increased above its mean winter value, and the short melt events drop σ^o by only several dB. We note that there are several false detections, the most obvious of which is seen near day 135: melt is detected, however no appreciable drop in σ^o is seen. Looking at the data, a small rise in the diurnal variation of backscatter occurs at day 135, coupled with a fluctuation in PR, for reasons unknown.

The ML classification method performed on various ice types exhibits varied success. In regions of MYI, the method is successful. In areas of first-year ice (FYI), this method's accuracy is decreased slightly because the winter backscatter is 6–10dB lower than MYI, making melt less distinguishable in the change in σ^o. However, by using the diurnal variation as a parameter in our ML estimate, even in these regions classification works fairly well. The regions that are most difficult to accurately detect melt using this method are regions where the winter backscatter changes significantly from season to season, i.e. regions where FYI becomes MYI or visa versa. This difficulty arises because this method requires significant differences in the mean and/or covariance between melt and non-melt. The algorithm attempts to accentuate the statistic differences between the data from the "melt" data and "non-melt" data, regardless of physical interpretation. In these areas, the ML method tends to place less emphasis on the differences in backscatter, and more on the diurnal variation and PR.

IV. Conclusions

The temporal resolution gained by the use of time-of-day filtered images is sure to improve the detection of melt in the polar regions, as well as the study of other phenomena. Using a simple ML estimator to detect melt provides a reasonable estimate of the melt condition, though further work is needed to improve and verify the effectiveness of this method in areas where the ice types changes, whether by transformation and/or by advection.

References

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