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# **NSCAT Twice-Daily SIR-Enhanced Scatterometer *EASE-Grid 2.0* Radar Backscatter**

**Algorithm Theoretical Basis Document**

**Version 1.0**

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# 1 Revision History

**Table 1:** *ATBD Revision History*

Revision	Date	Purpose
1.0	2023-01-05	Initial Version

**Table 2:** *Data Set Revision History*

Revision	Date	Purpose
1.0	2023-01-05	Initial Data Release

## 2 Acronyms and Abbreviations

**Table 3:** List of Acronyms and Abbreviations

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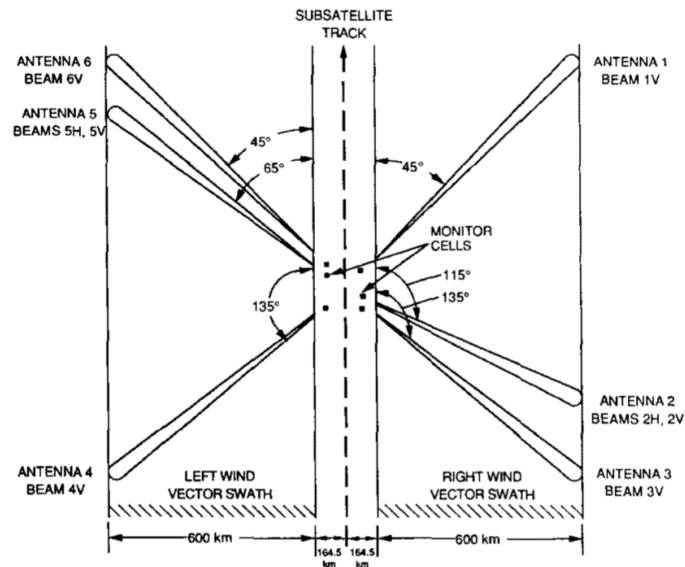
ADEOS	Advanced Earth Observing Satellite
ATBD	Algorithm Theoretical Basis Document
AVE	weighted AVeraging image formation algorithm
bSIR	Scatterometer Image Reconstruction using binary response function
BYU	Brigham Young University
CDR	Climate Data Record
CETB	Calibrated Passive Microwave Daily EASE-Grid 2.0 Brightness Temperature
CF	Climate and Forecast Metadata Conventions
DAAC	Distributed Active Archive Center
dB	decibel ( $10 \log_{10}$ )
DDP	Digital Doppler Processor
DIB	Drop-In-the-Bucket averaging (used to produce GRD products)
E2N	EASE-Grid 2.0, Northern Hemisphere Projection
E2S	EASE-Grid 2.0, Southern Hemisphere Projection
E2T	EASE-Grid 2.0, Temperate and Tropical Cylindrical Projection
EASE-Grid	Equal-Area Scalable Earth Grid (Original Definition)
EASE-Grid 2.0	Equal-Area Scalable Earth Grid Version 2.0
EASE2-M	EASE-Grid 2.0, Mid- and Low-Latitude Cylindrical Projection
EASE2-N	EASE-Grid 2.0, Northern Hemisphere Projection
EASE2-S	EASE-Grid 2.0, Southern Hemisphere Projection
EASE2-T	EASE-Grid 2.0, Temperate and Tropical Cylindrical Projection
EIA	Earth Incidence Angle
EOSDIS	Earth Observing System Data and Information System
ESDR	Earth System Data Record
FA	incidence-angle Fixed Azimuth modulation coefficients
FCDR	Fundamental Climate Data Record
GHz	GigaHertz
GRD	(Drop-In-the-Bucket) Gridding Method
ltod	local-time-of-day
MEaSURES	Making Earth System Data Records for Use in Research Environments
MHz	MegaHertz
MRF	Measurement Response Function
NASA	National Aeronautics and Space Administration
NSCAT	NASA Scatterometer
NOAA	National Oceanic and Atmospheric Administration

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## *Acronyms and Abbreviations*

NORAD	North American Aerospace Defense Command
NSIDC	National Snow and Ice Data Center
NetCDF	Network Common Data Format
PRF	Pulse Repetition Frequency
PSRF	Pixel Spatial Response Function
rSIR	radiometer version of SIR
SAR	Synthetic Aperture Radar
SASS	Seasat Scatterometer
SCP	Scatterometer Climate Record Pathfinder
SDR	Sensor Data Record
Sigma-0	normalized radar cross section or backscatter ( $\sigma^0$ )
SIR	Scatterometer Image Reconstruction
TBD	To Be Determined
TLE	Two-Line Element
UTC	Coordinated Universal Time
VA	incidence-angle Variable Azimuth modulation coefficients

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**Figure 1:** NSCAT observation swath. Nominally 25 km  $\sigma^o$  measurements are collected over two 75 km swaths separated by a nadir gap. Measurements are not collected over the central (nadir) gap (Long et al., 2019).

### 3 Purpose of this Document

NSCAT collected nominally 25 km resolution normalized radar cross section ( $\sigma^o$ ) from 6 different azimuth angles over two 600 km wide swaths with a 300 km gap. Two of the antennas were dual-polarized. NSCAT employed long, fan-beam antennas with narrow ( $\sim 7$  km) narrow beamwidths, see Fig. 1. Along-beam resolution was achieved using 5 ms continuous wave (CW) transmit pulses and multiple bandpass filters, implemented in a DDP, to achieve along-beam resolution via **the of the echo**. By varying the parameters of the DDP bandpass filters, the DDP maintained the measurement areas at fixed cross-track distances from the spacecraft nadir track, which overcame a key limitation of SASS (Long et al., 1988). The multiple beams provided azimuth diversity of the  $\sigma^o$  measurements, which is required to retrieve the surface wind (Ulaby and Long, 2014, Naderi et al., 1991).

While designed and optimized for ocean observation, NSCAT also collected  $\sigma^o$  measurements over land and ice. The observed  $\sigma^o$  depends on the surface roughness, geometry, and dielectric constant. These depend on the geophysical parameters of interest such as surface freeze/thaw state, snow and ice structure, moisture content, and vegetation characteristics, among others (Ulaby and Long, 2014). The NSCAT data set provides a unique “snapshot” of the Earth during its mission lifetime.

This CETB backscatter product exploits the NSCAT measurements to create a unique backscatter image data set that captures the state of the Earth during the NSCAT mission

## *Purpose of this Document*

(1996-1997). To exploit this data, we employ image reconstruction techniques to create daily and twice-daily enhanced resolution NSCAT radar images from the measurements. The new data set is provided to the science community to support cryosphere and climate studies.

## 4 Gridded and SIR-Enhanced NSCAT Product Description

### 4.1 Product Description

The NSCAT radar backscatter (*NSCAT*) product includes Level 1 gridded, twice-daily, radar backscatter data collected at 13.995 GHz for two radar channels (horizontal transmit-horizontal receive [HH] and vertical transmit-vertical receive [VV]). Data are gridded to the EASE-Grid 2.0 Azimuthal and Cylindrical projections (Brodzik et al., 2012, 2014), at two spatial resolutions, as described below. The *NSCAT* product is archived and distributed by the NSIDC DAAC (<https://nsidc.org/data/NSIDC-TBD/versions/1>).

Input data for the *NSCAT* v1.0 product are the NSCAT L1.5 Sigma0 files (Faist and Lee, 1997). Using the quality flags in the input data, only the highest quality measurements are included in *NSCAT* product. The data coverage is global for the period beginning 14 Sept 1996 (doy 258) through 28 June 1997 (doy 179). No calibration corrections were applied to the data (Tsai et al., 1999).

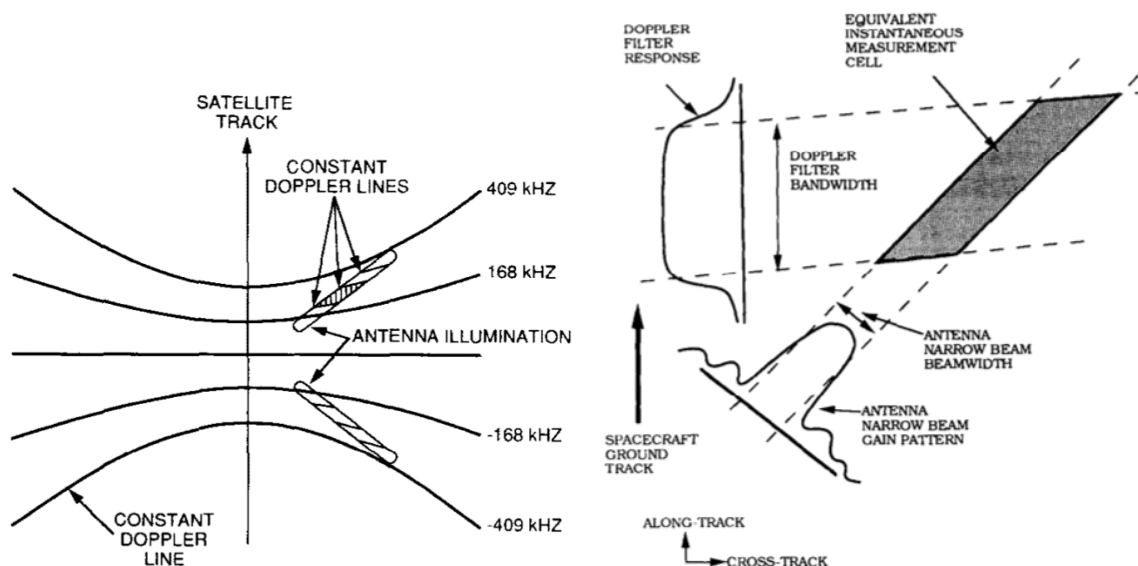
### 4.2 NSCAT Instrument

NSCAT flew as an attached payload on the ADEOS spacecraft, which was launched on 17 Aug 1996 from the Tanegashima Space Center, Japan and operated for approximately 9 months before the spacecraft power system failed due a detached solar array. ADEOS flew in a sun-synchronous 800 km circular polar orbit with an orbit inclination angle of 98.7° and a 10:30 AM local descending orbit equator crossing time.

The NSCAT instrument is described in Naderi et al. (1991), JPL (1997) with more detail on the DDP in Long et al. (1988). NSCAT is a fan-beam Doppler scatterometer (Ulaby and Long, 2014), like its predecessor the Seasat Scatterometer (SASS) (Johnson et al., 1980), though with a DDP instead of analog filters.

The NSCAT instrument employed six 3 m long fan-beam antennas deployed to provide three azimuth angle observations on each side of the spacecraft. The center antenna operated in dual polarization (HH and VV), while the other antennas used only VV polarization, see Fig. 1. Along-track resolution was provided by the narrow beamwidth of the antenna beams and the pulse timing. Along-beam resolution was provided via Doppler filtering, see Fig. 2.

The return echo was **Doppler filter** using the DDP into 25 measurement “cells”, one of which was designated the “monitor cell” and was adjusted to make measurements at a fixed 11° incidence angle. The Doppler center frequency and bandwidth of the other cells were adjusted to maintain the cells at a fixed cross-track distance from the spacecraft ground track throughout the orbit. The NSCAT swath and measurement geometry (Fig. 2) produced a 4-sided instantaneous 3-dB footprint for each pulse. A total of 25 sequential pulses were



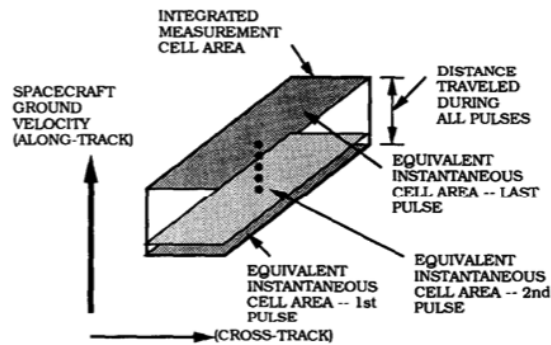
**Figure 2:** NSCAT measurement theory illustrations. (left) Intersection of the fan-beam footprint and iso-Doppler lines used to define the along-beam resolution. (right) Antenna pattern and Doppler filtering that define the individual  $\sigma^0$  measurement footprints for a forward-facing antenna.

issued on each of the 8 beams in sequence during the time it takes for the spacecraft to travel 25 km resulting in an along-track spacing of 25 km between measurements from the same azimuth angle (Naderi et al., 1991, Long et al., 1988).

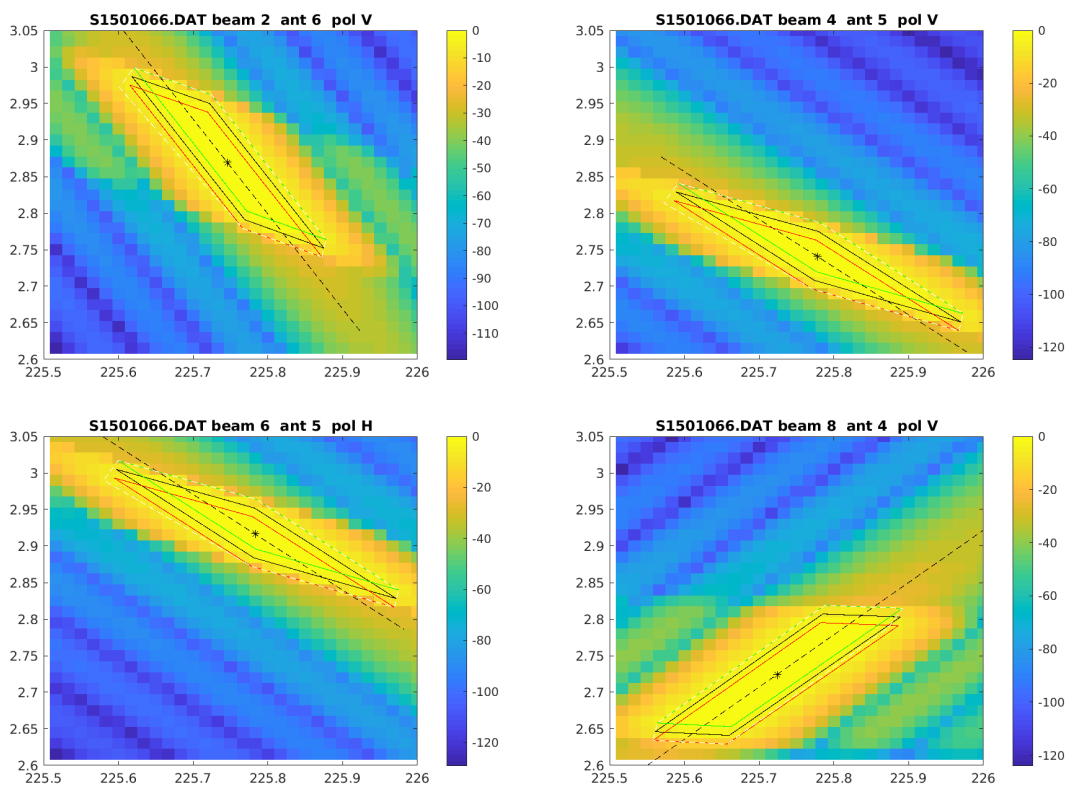
The 25 pulses were processed and summed into a single measurement. As shown in Fig. 3, this produces six-sided 3-dB footprints on the surface. Assigning 1 to areas within the 3-dB footprint and 0 outside results in a simplified *binary* description of the measurement's MRF. The *full response* includes the filter and antenna pattern rolloff. The full response minimizes coverage gaps, but is slightly smoother than the binary response when used in SIR or AVE. Examples of the full response for several NSCAT measurements are illustrated in Fig. 4. Image examples based on the full response and the binary response are shown in Section 6.

Note that while a radiometer's footprint is defined by the antenna pattern, the radar footprint is defined by the antenna pattern squared due to the two-way travel of the signal from radar to the surface (Ulaby and Long, 2014).

NSCAT collected return echo power measurements, which were converted into  $\sigma^0$  using the radar equation (JPL, 1997, Ulaby and Long, 2014). The nominal resolution of these measurements is described as 25 km, though the effective resolution varies over the swath and orbit. The  $\sigma^0$  value depends on the surface roughness, geometry, and dielectric constant (Ulaby and Long, 2014).



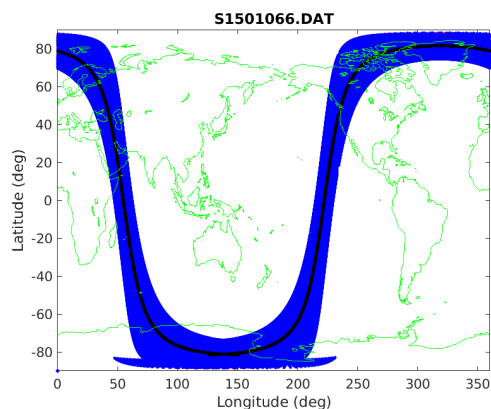
**Figure 3:** Illustration of the footprint when integrating multiple pulses into a single measurement (Long et al., 1993).



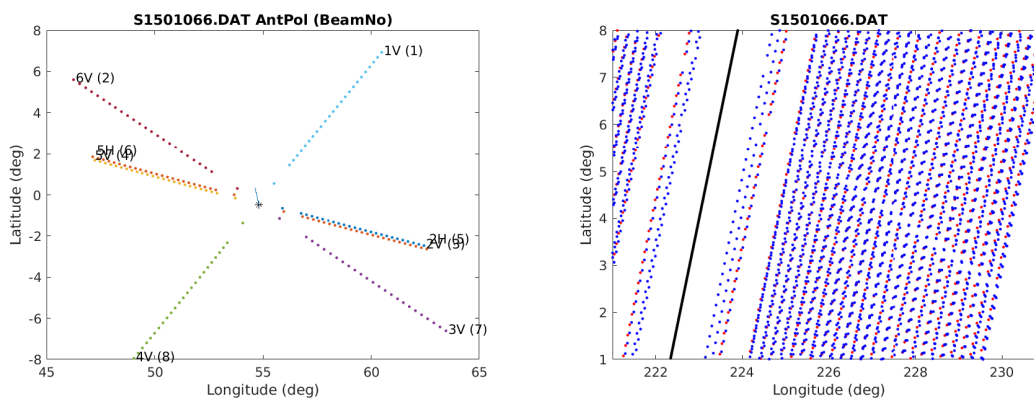
**Figure 4:** Arbitrarily selected examples of the full spatial gain pattern response of several mid-swath NSCAT  $\sigma^0$  measurements from different antenna beams. The dashed line shows the along-beam direction. The red, black, and green quadrilaterals show the instantaneous 3-dB footprint for the first, twelfth, and twenty-fifth pulses.



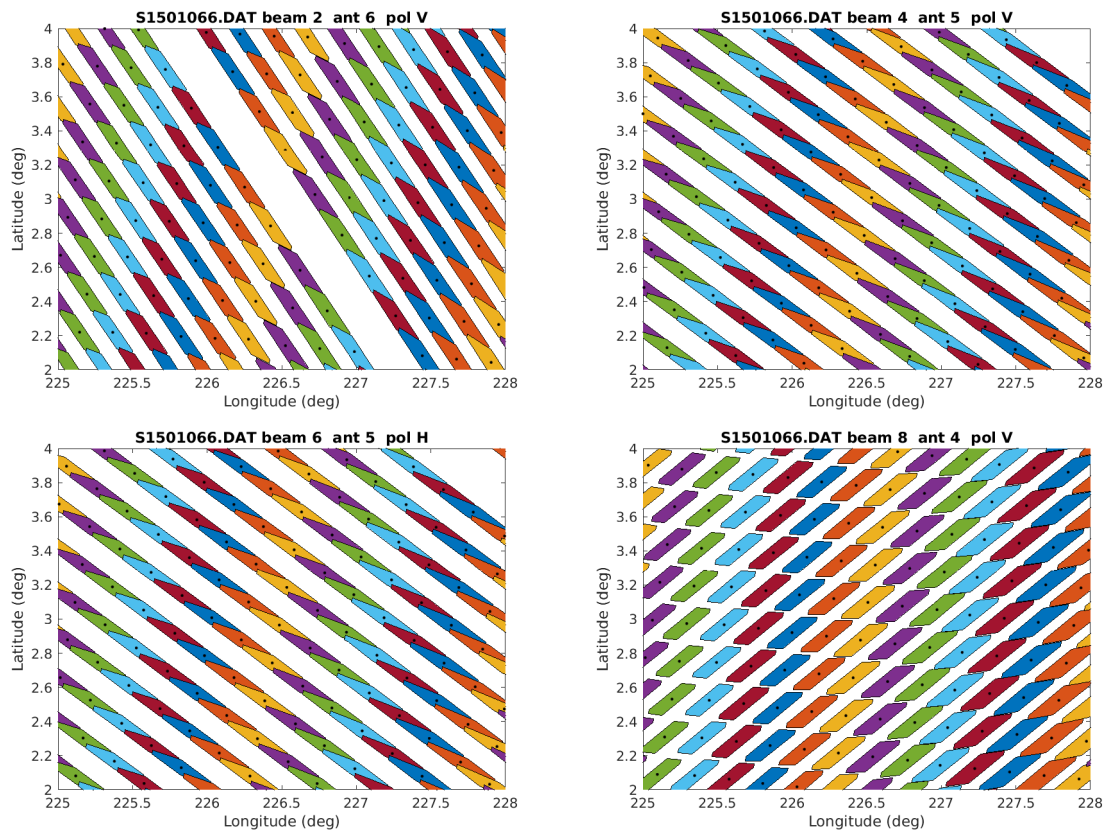
To better understand the spatial layout of the NSCAT  $\sigma^o$  measurements, Figs. 5–8 are presented. Figure 5 shows the positions of the centers of all the  $\sigma^o$  measurements from a single orbit pass. Preceding and succeeding orbits have a similar pattern, but are horizontally shifted. Figure 6 (left) shows the footprint locations for one beam cycle during an ascending orbit, while Figure 6 (right) shows the measurement centers for one side of a descending pass. Figures 7 and 8 show further zoom ins for each beam separately.



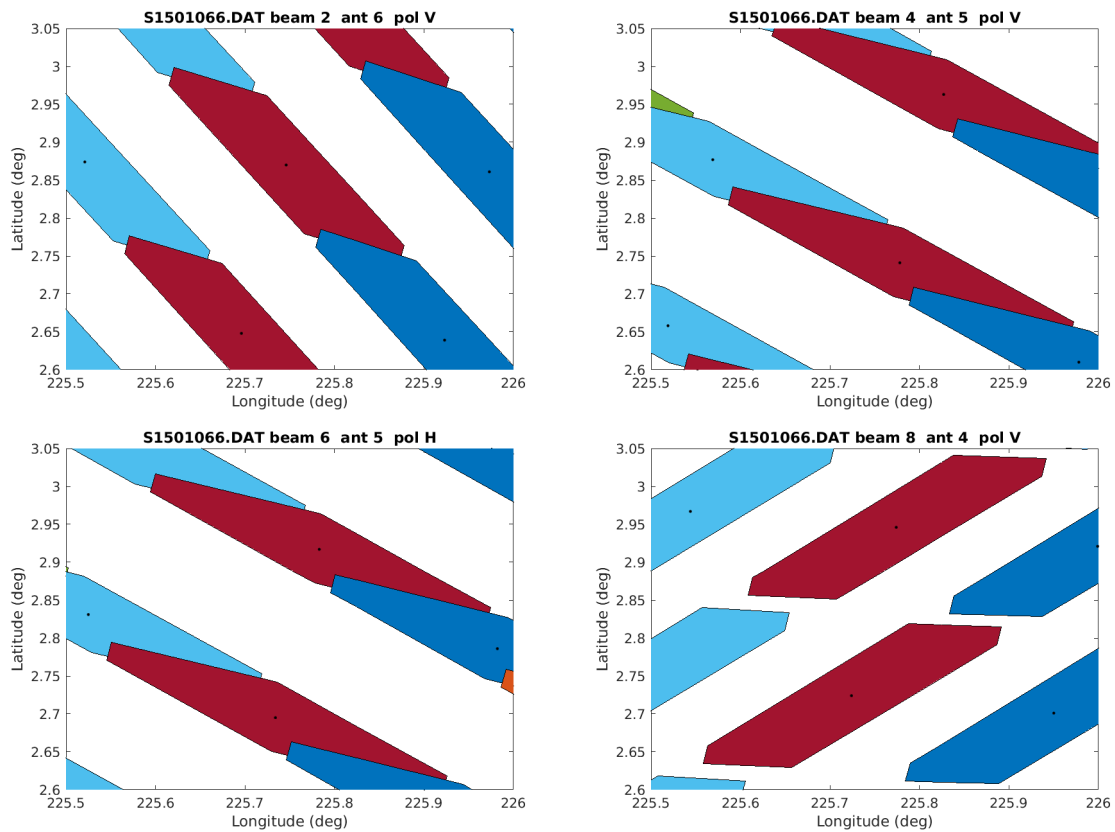
**Figure 5:** NSCAT  $\sigma^o$  measurement locations during a single orbit. Individual measurements cannot be resolved in this plot.



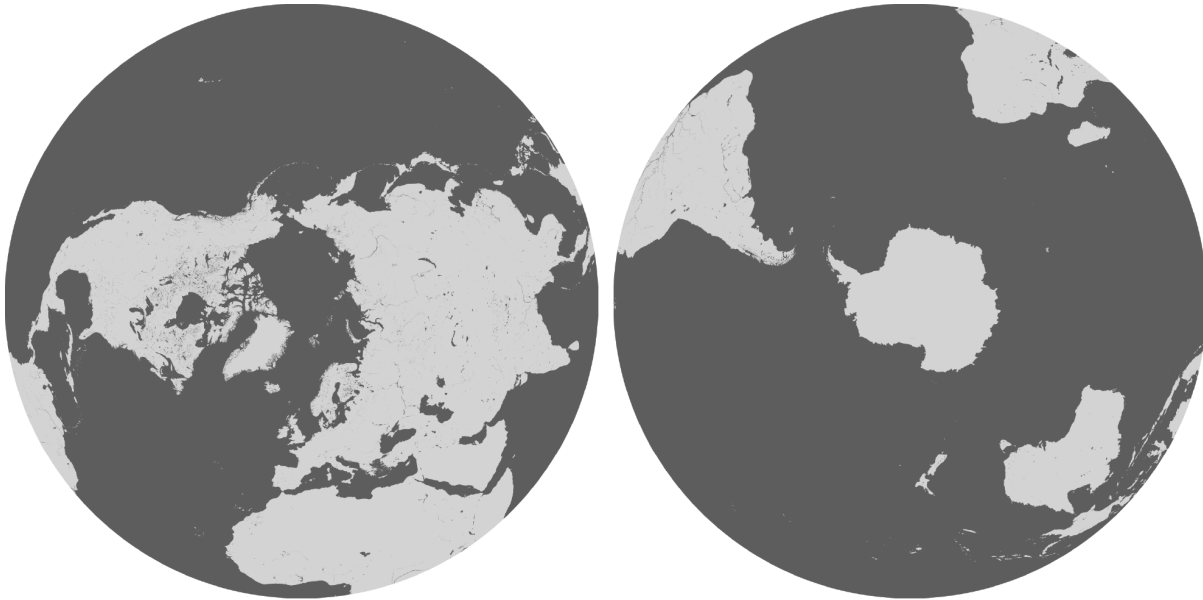
**Figure 6:** NSCAT  $\sigma^o$  measurement locations (left) for a particular antenna cycle during an ascending pass, and (right) for multiple pulse cycles zoomed in during a descending pass. Note that the center antennas are dual-polarization. The diagonal patterns are the result of missing  $\sigma^o$  measurements due to a calibration cycle, which are once per 100 antenna cycles. Each antenna beam is a different color.



**Figure 7:** NSCAT 3-dB  $\sigma^0$  measurement layouts for each beam. This is a zoom in of Fig. 6. Colors correspond to the along-beam measurement number. So, a particular color is a fixed cross-track distance from the spacecraft nadir track. These represent the binary response function.



**Figure 8:** NSCAT 3-dB  $\sigma^o$  measurement layouts for each beam. This is a zoom in of Fig. 7. Colors correspond to the along-beam measurement number. So, a particular color is a fixed cross-track distance from the spacecraft nadir track. These represent the binary response function.



**Figure 9:** Northern and Southern EASE-Grid 2.0 projection extents. Land-ocean mask from Brodzik and Knowles (2011).

The ADEOS spacecraft flew in a sun-synchronous circular polar orbit at an inclination of  $98.7^\circ$ , and an altitude of 900 km (JPL, 1997). During its mission lifetime, it had a 41 day exact repeat orbit and a 4 day near-repeat orbit, collecting  $\sigma^o$  measurements essentially continuously on both sides of the spacecraft ground track<sup>1</sup>. As described below, from these  $\sigma^o$  measurements twice-daily global images were created by (1) DIB gridding of the  $\sigma^o$  measurements on a 25 km grid and (2) applying the SIR algorithm to enhance the effective resolution of the data by exploiting the irregular patterns of measurement locations and signal oversampling (from overlaps in adjacent footprints and overlapping swaths). The SIR images are reported on a 3.125 km grid.

### 4.3 Grid Spatial Extent

Azimuthal NSCAT grids extend to the full Northern (EASE2-N) and Southern (EASE2-S) hemispheres, respectively, as described in Brodzik et al. (2012, 2014) (Fig. 9). The spatial extent of the equal-area cylindrical projections (Fig. 11 and Fig. 10) is defined to match the extent of compatible grids favored by two user communities: the Mid-Latitude (EASE2-M) grid, extending to  $\pm 85.0445664^\circ$  latitude, has been adopted by the SMAP user community; the Temperate and Tropical (EASE2-T) grid, limited to latitudes equatorward of

<sup>1</sup>A ground station was employed in New Mexico. During part of the mission, the instrument operation mode was altered over this area to optimize data collection at the ground station.



**Figure 10:** Cylindrical EASE-Grid 2.0 projection extents. Full extent coverage is EASE2-M, with horizontal red lines delineating the smaller latitudinal extent of EASE2-T grid. Land-ocean mask from Brodzik and Knowles (2011).

$\pm 67.1^\circ$ , is consistent with the original CETB products defined for similar scanning radiometers (Brodzik et al., 2021). See Appendix A Table 7 for grid specifications.

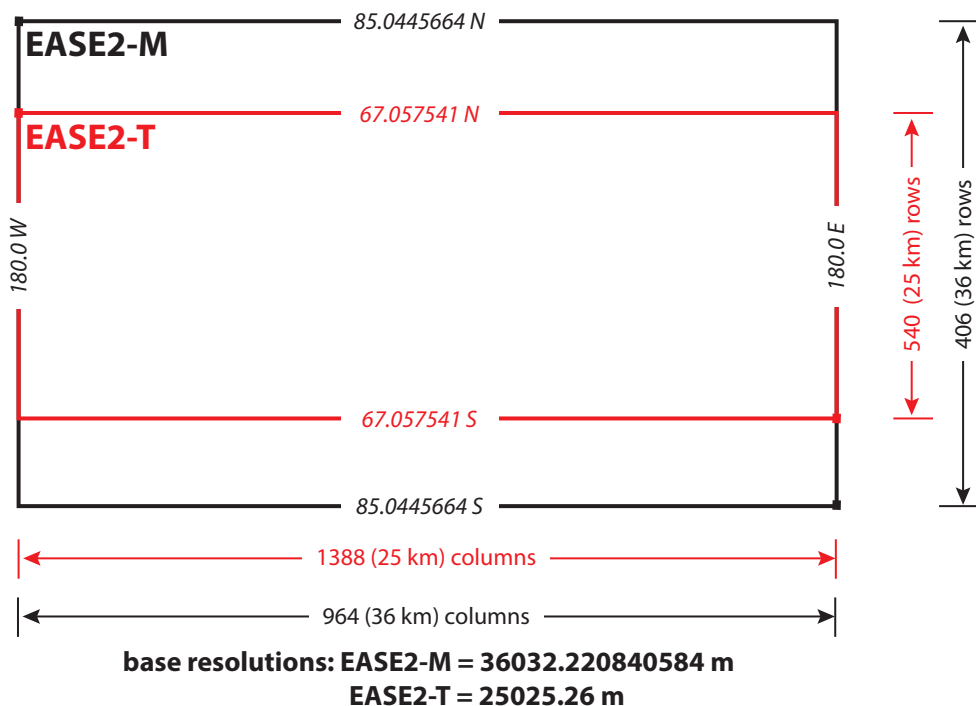
#### 4.4 Grid Spatial Resolution

NSCAT grid resolutions are defined relative to a 25km base resolution: 25 km grids and 3.125 km, which include EASE2-N, EASE2-S and EASE2-T grids that are compatible with the MEASUREs CETB data products (Brodzik et al., 2021). Nested resolutions relative to the CETB 25 km base grids are defined using exact divisors of 2, as illustrated in Figure 12. NSCAT projection extents, dimensions and grid cell size details are included in Appendix A. Grids used for NSCAT processing are included in Table 4.

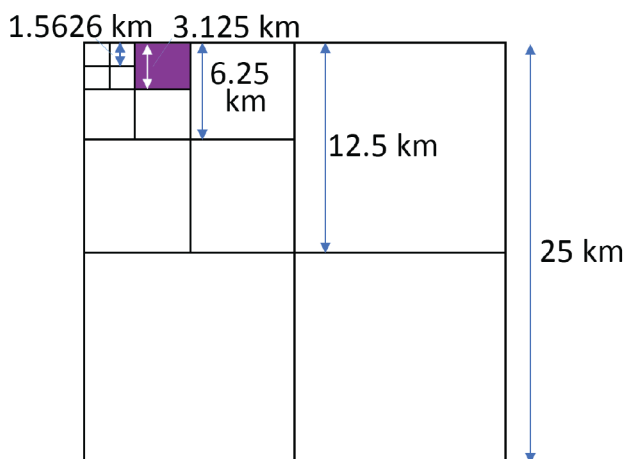
**Table 4:** NSCAT EASE-Grid 2.0 base grids produced, by projection and reconstruction algorithm. See Section 5 for GRD and sSIR reconstruction details.

EASE2-M	EASE2-N	EASE2-S	EASE2-T
n/a	25km (GRD)	25km (GRD)	25km (GRD)
n/a	3.125km (GRD/SIR)	3.125km (GRD/SIR)	3.125km (GRD/SIR)

4.4 Grid Spatial Resolution Gridded and SIR-Enhanced NSCAT Product Description



**Figure 11:** Relationship of EASE-Grid 2.0 cylindrical projection extents. EASE2-T extent is defined for compatibility with CETB products. (Difference in latitudinal extent is exaggerated, see Fig. 10 for actual difference in projected extent. (Brodzik et al., 2021).



**Figure 12:** CETB nested grids based on a 25 km base resolution cell. Only 25 km and 3.125 km divisions are used in NSCAT products (Long et al., 2019).

## 4.5 Data Products

The NSCAT data product at the NSIDC DAAC covers the period beginning 14 Sept (doy 258), 1996 through 28 June (doy 179) 1997. No calibration corrections were applied to the data. In creating a time series of times, a “moving average” approach was used with overlapping imaging periods, that start every mission day and extend through the desired 4- or 8-day period (or to the end of the mission, whichever comes first). Table 5 summarizes available NSCAT radar backscatter products, which are all in CETB-standard EASE-2 Grid projections.

**Table 5:** Available twice-daily NSCAT image products.

MRF Type	days	Algorithm	Pix. Res. (km)	Regions*	Polarizations	Size <sup>†</sup> N/S/T (MB)
	4,8	GRD	25	N,S,T	HH,VV	6/6/9
Binary	4,8	SIR	3.125	N,S,T	HH,VV	531/531/768
Full	4,8	SIR	3.125	N,S,T	HH,VV	531/531/768

\* Region code: N=Northern Hemisphere, S=Southern Hemisphere, T=Global

† Uncompressed size

## 5 Algorithm Description

### 5.1 Background

The *effective* resolution of an image is defined by the *pixel spatial response function* (PSRF), with the effective resolution is given by the dimension(s) of one-half power (3-dB) extent of the PSRF. In contrast, the *measurement* response function (MRF) describes the spatial characteristics of the *individual* measurements. For a radar, the MRF depends on the two-way antenna pattern, the modulation, and the signal processing. For both radars and radiometers, the PSRF depends on the MRF and the image formation algorithm. In linear image formation algorithm, the reported pixel value consists of the weighted sum of nearby measurements. In this case the PSRF is then the normalized weighted sum of the measurement MRF functions, including their spatial offset from the center of the pixel.

In creating the *NSCAT* backscatter image product, multiple measurements from different passes are combined into single pixel values. The resulting image pixels have an effective resolution slightly coarser than the pixel spacing since (a) the measurements are not all centered the same and (b) their MRFs can extend outside of the pixel area. The PSRF provides the tool for defining the effective pixel resolution.

The spacing of pixels is termed the “pixel posting” or the “posting resolution”. Note that the posting resolution is not the same as the *effective resolution* which is defined by the PSRF. In general, the effective resolution is coarser than the posting resolution (see (Long and Brodzik, 2016a)). In order to be compatible with the CETB data set, two posting resolutions are considered: 25 km and 3.125 km. See Fig. 13.

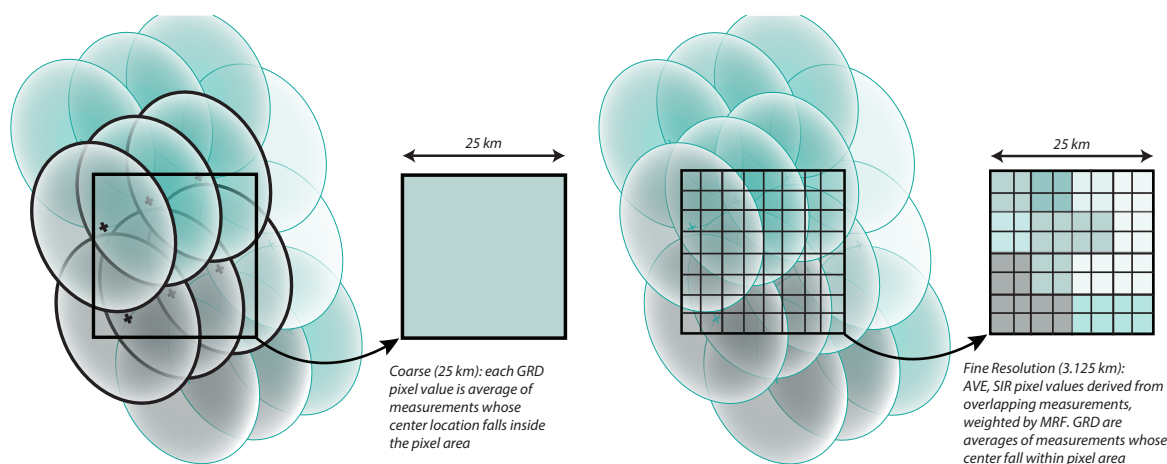
### 5.2 NSCAT Backscatter Image Products

The *NSCAT* backscatter products include both low-noise (low-resolution) coarse resolution GRD images and higher-noise (enhanced) fine-resolution (SIR) images. The various products have their advantages and disadvantages. The multiple images allow users the flexibility of choosing the appropriate images for their research application.

To create radar CETB-compatible products, different approaches are used for each resolution. For GRD images the source backscatter measurements are gridded onto to a 25 km grid using drop-in-the-bucket (DIB) techniques. In this approach, all the measurements whose center falls within a grid element are averaged into the reported value. For the 3.125 km product, the source measurements are processing using the AVE (the first iteration of SIR) and the SIR image algorithms. Along with each measurement’s MRF, the SIR algorithm exploits the irregular patterns of measurement locations and signal oversampling (from overlaps in adjacent footprints and overlapping passes).

Because the sensor was not designed as an imager, there are gaps between the measurements that must be filled by combining multiple passes over an extended imaging period.





**Figure 13:** Conceptual illustration of coarse 25 km (left) vs. high resolution 3.125 km (right) pixels. The ellipses represent the individual MRFs of the measurements. (The actual shapes are more complicated than this.) DIB is used for GRD imaging while AVE and SIR are used for high resolution images.

With a 4 day near-repeat cycle, two imaging periods are defined: 4 day and 8 day. Table 5 summarizes the image product types. Simple GRD images are created using drop-in-the-bucket (DIB) techniques at 25 km. In DIB, the measurements whose center falls within a given pixel area are averaged. AVE images use weighted averages where the weighting is the measurement MRF, which may vary from measurement to measurement. The SIR algorithm is employed for slice and footprint images on the 3.125 km pixel grid.

### 5.3 Radar Spatial Response and Image Reconstruction

The effective spatial resolution of an image product is determined by the spatial measurement response function (MRF) of the sensor and by the image formation algorithm used. The MRF is determined by the antenna gain pattern, the scan geometry (notably the antenna scan angle), and the signal processing, see Long et al. (1993), Long (2017). The goal in forming a  $\sigma^o$  image map is to estimate the backscatter properties of the surface from noisy measurements that employ (possibly variable) MRFs that sample the surface. Though simple to implement, DIB techniques ignore the MRF, which limits their effective resolution. Reconstruction techniques that use the MRF can provide much finer effective resolution.

Reconstruction processing techniques effectively assume the underlying signal (the backscatter) being sampled is band-limited, which is the only consistent assumption possible with sampled data. For reconstruction, the backscatter at each point of a fine-scale pixel

grid is estimated, producing a backscatter image or map. While the image is generated on a regular grid, the measurement locations and MRF are not aligned with the grid, and so the measurements form an irregular sampling pattern, which can complicate signal reconstruction.

An individual scatterometer backscatter measurement  $z_i$  can be modeled as the integral of the product of the MRF and the surface backscatter, i.e.,

$$z_i = \iint \text{MRF}_i(x, y; pp) \sigma^o(x, y, \theta, \phi_i, t, pp) dx dy + \text{noise} \quad (1)$$

where  $\text{MRF}_i(x, y; pp)$  is the spatial MRF of the  $i^{\text{th}}$  measurement at  $x, y$  and the surface  $\sigma^o$  depends on spatial location  $x, y$ , incidence angle  $\theta$ , azimuth angle  $\phi$ , time  $t$ , and polarization  $pp$ , i.e.,

$$\text{MRF}_i(x, y; pp) = \iint \frac{G_a^2(x, y; pp) G_p(x, y; pp)}{R^4(x, y)}. \quad (2)$$

where

$$X = \iint \frac{G_a^2(x, y; pp) G_p(x, y; pp)}{R^4(x, y)} dx dy. \quad (3)$$

where  $G_a(x, y; pp)$  is the effective two-way antenna gain at the surface at  $(x, y)$  for polarization  $pp$ ,  $G_p(x, y; pp)$  is the processor gain, and  $R(x, y)$  is the slant range from the radar to the surface. Note that the measurement is an average of  $\sigma^o$  in spatial coordinates as well as in azimuth and incidence angles.

Eq. 1 is discretized on the imaging grid to become

$$z_i = \sum_{j \in \text{image}} h_{ij} a_j + \text{noise} \quad (4)$$

where  $a_j$  is the backscatter at the center of the  $j^{\text{th}}$  pixel at  $(x_l, y_k)$  and  $h_{ij} = \text{MRF}(x_l, y_k; \phi_i)$  is the discretely sampled MRF for the  $i$ -th measurement evaluated at the  $j$ -th pixel center where  $h_{ij}$  is normalized so that  $\sum_j h_{ij} = 1$ . In practice, the MRF is negligible some distance from the measurement center, so the sums need only be computed over a small area around the pixel. Ignoring the noise, Eq. 4 can be written as the matrix equation

$$\vec{Z} = \mathbf{H} \vec{a} \quad (5)$$

where  $\mathbf{H}$  contains the sampled MRF for each measurement and  $\vec{Z}$  and  $\vec{a}$  are vectors composed of the measurements  $z_i$  and  $a_j$ , respectively. Even for small images,  $\mathbf{H}$  is large and sparse, and may be over-determined or under-determined depending on the number and locations of the measurements. Reconstruction of the surface  $\sigma^o$  is equivalent to inverting Eq. 5.

The iterative SIR algorithm (Early and Long, 2001, Long et al., 1993) is a particular reconstruction algorithm that is specifically developed for scatterometer image formation.

SIR approximates a maximum-entropy solution to an under-determined equation and a least-squares solution to an over-determined system. The first iteration of SIR is termed 'AVE' (for weighted AVErage) and provides a simple reconstruction estimate that is refined in later SIR iterations. The AVE estimate of the  $j$ -th pixel is given by

$$a_j = \frac{\sum_i h_{ij} z_i}{\sum_i h_{ij}} \quad (6)$$

where the sums are over all measurements that have non-negligible MRF at the pixel. The SIR iteration begins with an initial image  $a_j^0$  whose pixels are set to the AVE values defined in Eq. 6. Thereafter, the iterative equation for single-variate SIR is given by

$$a_j^{k+1} = \frac{\sum_i u_{ij}^k h_{ij}}{\sum_i h_{ij}} \quad (7)$$

where

$$u_{ij}^k = \begin{cases} \left[ \frac{1}{2p_i^k} \left( 1 - \frac{1}{d_i^k} \right) + \frac{1}{a_j^k d_i^k} \right]^{-1} & d_i^k \geq 1 \\ \frac{1}{2} p_i^k (1 - d_i^k) + a_j^k d_i^k & d_i^k < 1 \end{cases} \quad (8)$$

$$d_i^k = \left( \frac{z_i}{p_i^k} \right)^\lambda \quad (9)$$

where  $d_i^k = (s_i/p_i^k)^\lambda$  with  $\lambda = \frac{1}{2}$ . The factor  $d_i^k$  is the square root of the ratio of a measurement to its forward projection at the  $k^{\text{th}}$  iteration. The update term  $u_{ij}^k$  is a non-linear function of both  $d_i^k$  and the previous image  $a_j^k$ . The sigmoid-like non-linearity in Eq. 8 constrains the amount of change permitted during any one iteration, thereby minimizing the effects of noise Long et al. (1993). Though not used in this paper, a spatial median filter can be applied to the image between iterations to further reduce the noise Long et al. (1993).

For scatterometers, SIR is implemented in dB (Long, 2017, Early and Long, 2001, Long et al., 1993); i.e., the computation is done on  $10 \log_{10}(z_i)$  rather than on the linear-space value  $z_i$  as done in the radiometer version of SIR (Long and Brodzik, 2016a, Long and Daum, 1998). In considering the differences between linear and dB processing, recall the well-known fact that computing the arithmetic mean of values in dB is equivalent to computing  $10 \log_{10}$  of the geometric mean of the linear-space values (Wikipedia, 2016). With the measurements in dB, the reconstruction processing can be viewed as a form of weighted geometric mean filtering. Since it has been found that geometric mean filters are better at reducing Gaussian-type noise and preserving linear features than (linear) arithmetic mean filters (Pitas and Venetsanopoulos, 1986), some performance advantage to dB processing is expected and observed (Long, 2017). The linear and dB computations yield similar, but slightly different results, due to the varying signal-to-noise ratio (SNR) of the measurements and limited signal dynamic range (Long, 2017).

In practice, since the  $\sigma^o$  measurements are quite noisy, attempting full image reconstruction can produce excessive noise enhancement. In general, more iterations improve the signal and resolution, but also increase the noise level. To reduce noise enhancement and resulting artifacts, regularization can be employed, at the expense of resolution (Long and Franz, 2016, Early and Long, 2001, Long et al., 1993, Long, 2017). Regularization is a smoothing constraint introduced in an inverse problem to prevent extreme values or overfitting. Regularization results in partial or incomplete reconstruction of the signal (Long and Franz, 2016). It also creates a trade off between signal reconstruction accuracy and noise enhancement. SIR includes regularization achieved by prematurely terminating the iteration. Based on simulations and confirmed by analysis of actual data, 20-30 iterations provides a nice trade off result. We note that for a noisy sensor like a scatterometer, the results are not particularly sensitive to the precise value chosen, hence a fixed value can be selected. Selection of the number of iterations is based on simulation, see citeearly2001, Long et al. (1993) and Long (2017). For this product, a fixed (30) number of SIR iterations is employed for both binary and full response MRFs.

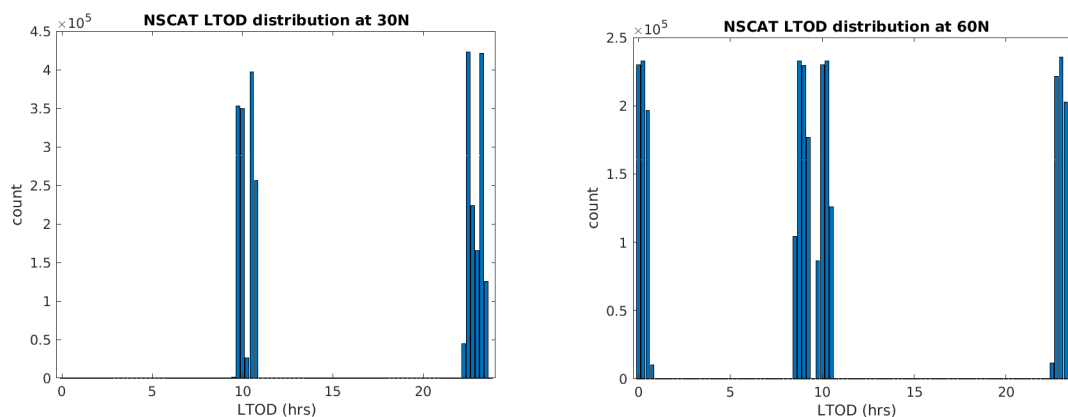
### 5.3.1 Local-Time-of-Day

As previously noted, the goal of image reconstruction is to estimate the surface  $\sigma^o$  from the sensor  $\sigma^o$  measurements. Measurements from multiple orbit passes over a narrow local time window are combined. When multiple measurements are combined, the resulting images represent a temporal average of the measurements over the averaging period. There is an implicit assumption that the surface characteristics remain constant over the imaging period. For both conventional-resolution (GRD) and enhanced-resolution (SIR) images.

The radar backscatter of a natural surface is a strong function of the state of the water it contains, i.e., frozen or thawed. As a result of the sun-synchronous orbit geometry, the radar observations at a given location on the earth fall within two narrow diurnal windows. At the equator, these correspond to the ascending and descending orbit passes. This can be exploited to provide twice-daily sampling. Thus, *NSCAT* images on the cylindrical *EASE-Grid 2.0* projections are separated by ascending and descending passes. A separate image ("both") product is also made that combines both which achieves between spatial coverage at the expense of temporal resolution.

Near the poles, the temporal windows widen to several hours but remain relatively narrow. Since surface temperatures can fluctuate widely during the day, daily averaging is not generally useful at these locations, since it smears diurnal temperature fluctuations in the averaged  $\sigma^o$ . However, it is reasonable to split the data into two distinct images per day, using intervals based on local-time-of-day (ltod), thereby only combining measurements with a similar ltod. This minimizes the fluctuations in the observed  $T_B$  at high latitudes due to changes in physical temperature from daily temperature cycling.

The *NSCAT* images on the azimuthal projections are separated into twice-daily, morning



**Figure 14:** Histograms of typical measurement *ltod* for NSCAT measurements falling within a  $1^\circ$  latitude band at (left)  $30^\circ$ – $31^\circ$  N and (right)  $60^\circ$ – $61^\circ$  N over one day. All measurements fall into essentially one of two narrow *ltod* time periods, centered at approximately 00:00 h and 10:00 h in the Northern Hemisphere. Although the center time varies with latitude, any point on Earth is observed at one of two times within  $\pm 90$  min.

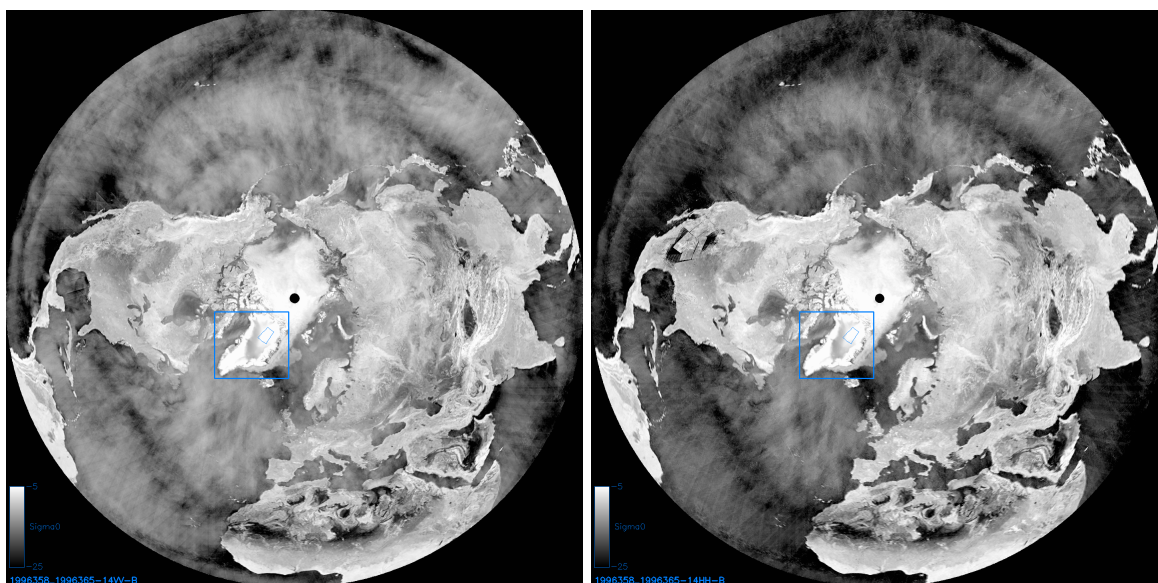
and evening passes based on observation *ltod*, in addition to images that combine the two. At low latitudes, which typically have few overlapping swaths at similar *ltod* in the same day, *ltod* division is equivalent to ascending/descending division. An ancillary data array is included in each file, to describe the effective time average of the measurements combined into the pixel for a particular day. This enables investigators to explicitly account for the *ltod* temporal variation of the measurements included in a particular pixel. A separate image ("both") product is also made that combines both which achieves greater spatial coverage at the expense of temporal resolution.

Histograms of the *ltod* of the sensor's measurements falling within two narrow latitude bands are shown in Fig. 14. For the NSCAT orbit, a natural division in the measurement *ltod* is at 00:00 and 12:00 h. For consistency with Long and Brodzik (2016b) and Brodzik et al. (2021), the NSCAT data are produced using this *ltod* division. Note how the *ltod* falls within one of two tight groups that correspond to the ascending and descending orbit passes, and that there are natural divisions in the measurement *ltod* at 00:00 and 12:00 hrs. Thus, the measurements provide twice-daily sampling. Note that when more than day's worth of data, the *ltod* division is maintained so that a multi-day morning image combines only morning observations.

## 5.4 Sample Data

Figures 15–17 present examples of 8-day product images for each polarization and region where all passes ('both') within the imaging period are combined. Swath-like artifacts

over the oceans are the result of significant temporal variation of surface  $\sigma^o$  due to wind changes during the imaging interval. Over the ocean high winds correspond to higher  $\sigma^o$  values while low winds correspond to low wind speeds. Additional data visualization are provided in later sections.

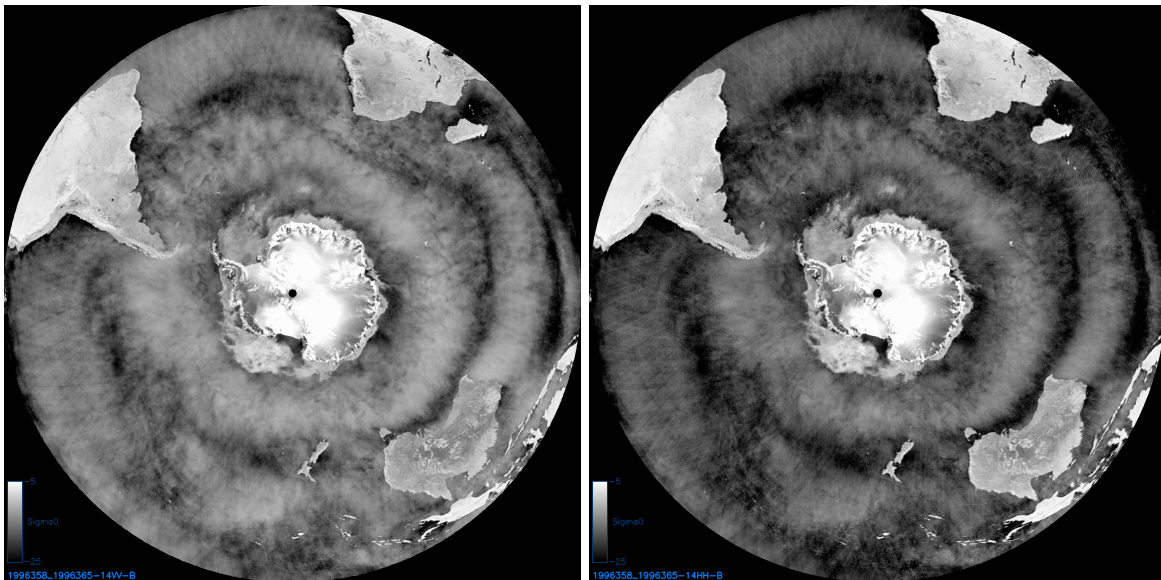


**Figure 15:** Visualizations of examples of 8-day (doy 351-358, 1996) NSCAT A ( $\sigma^o$  at  $40^\circ$  incidence angle) for (left) V-polarization and (right) H-polarization. Images have been reduced in resolution for presentation here. The large Greenland study area is outlined. See captions for Figs. 17 and 18.

**Table 6:** Study Sub Regions

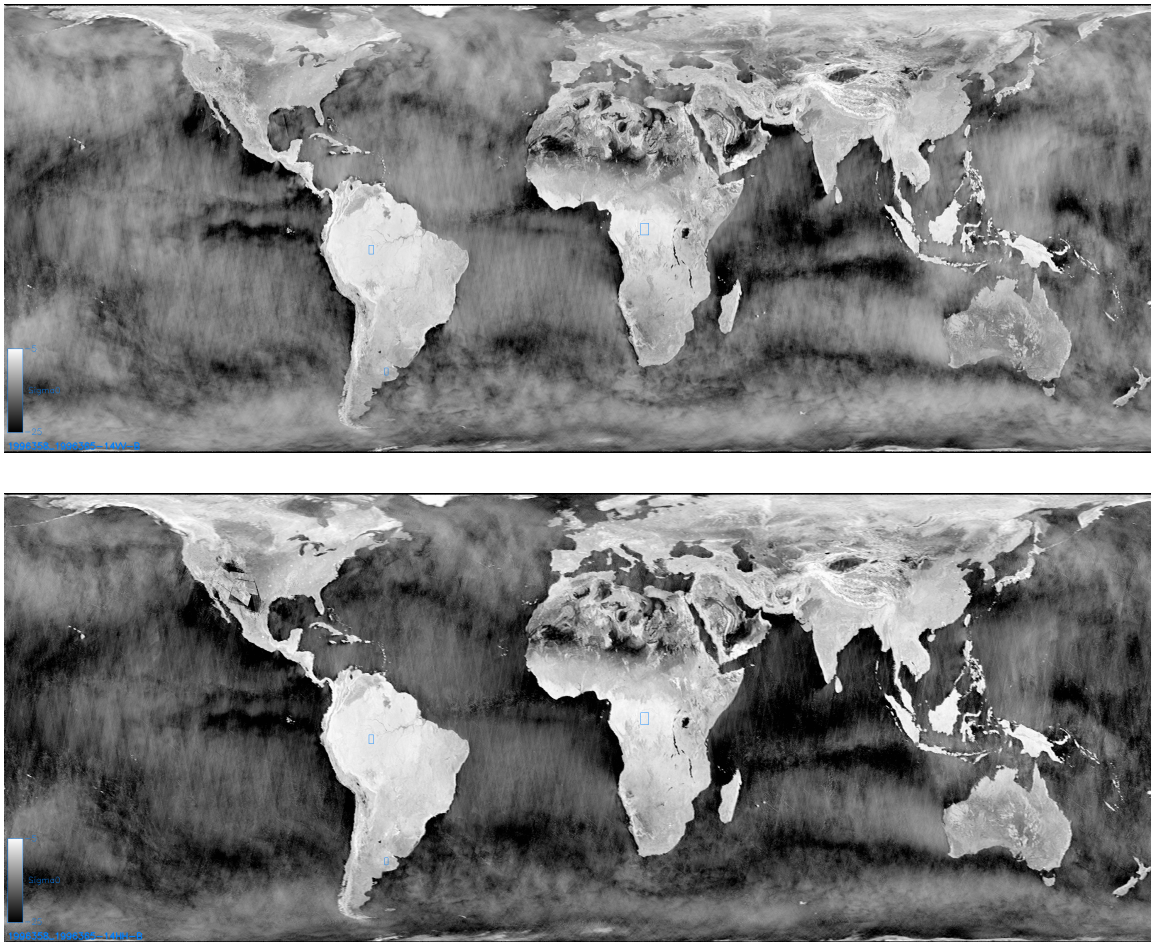
Region	Longitude		Latitude		$A_{HH}$ dB	$B_{HH}$ dB/deg	$A_{VV}$ dB	$B_{VV}$ dB/deg
	left	right	lower	upper				
Amazon	294	295.5	-6	-4	-7.12	-0.0684	-7.47	-0.0836
Congo	19	21.5	-1.5	1.25	-6.63	-0.0486	-7.08	-0.0677
Greenland (large)	317	328	75	79	-5.17	-0.1813	-4.32	-0.1347
Greenland* (small)	312	328	70	70.25	-	-	-	-
Pampas	299	300	-37	-35	-10.82	-0.1468	-11.53	-0.1359

\*Each small Greenland subregion spaced 2 deg of longitude has longitude extent 0.5 deg



**Figure 16:** Visualizations of examples of 8-day (doy 351-358, 1996) NSCAT A ( $\sigma^0$  at  $40^\circ$  incidence angle) for (left) V-polarization and (right) H-polarization. Images have been reduced in resolution for presentation here.



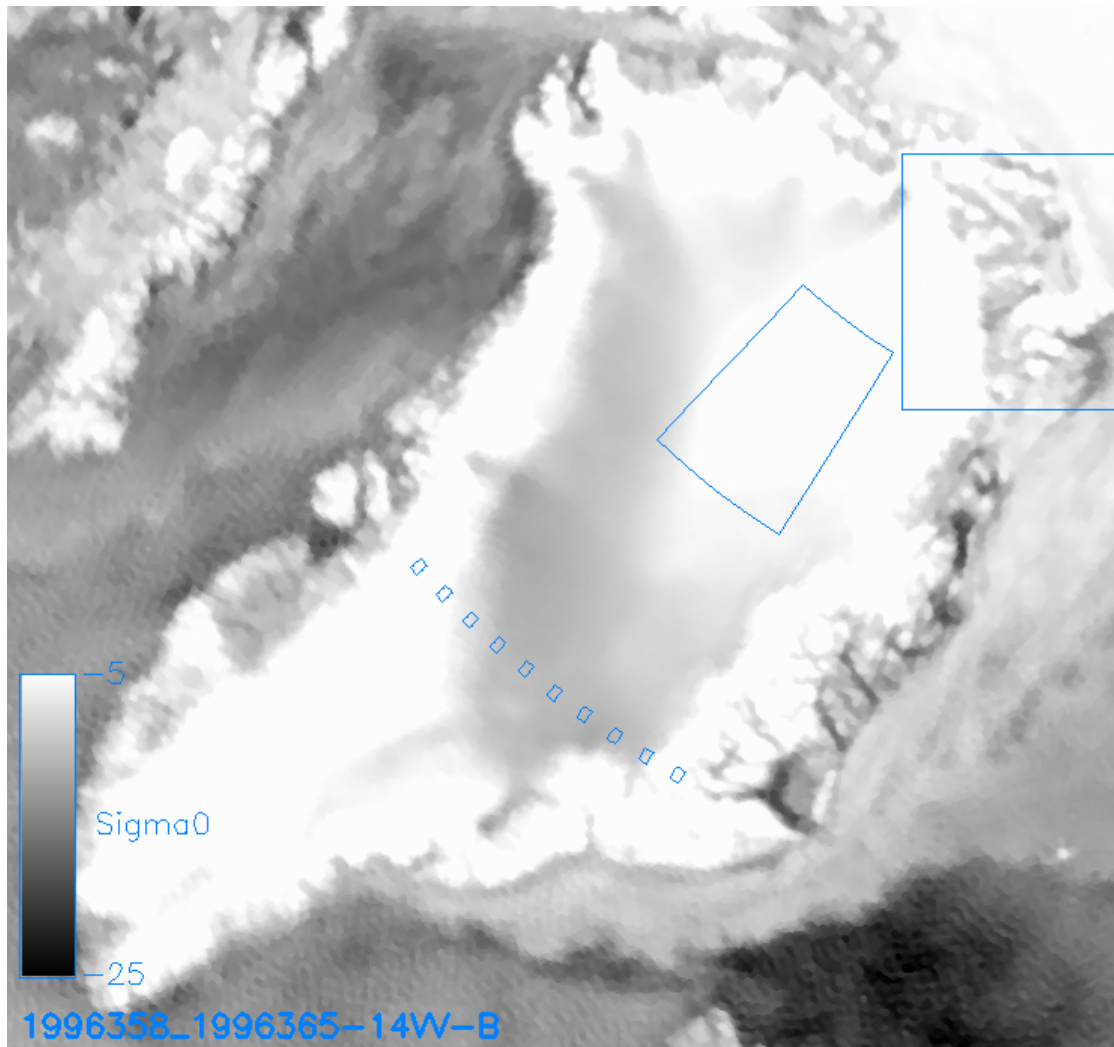


**Figure 17:** Visualizations of examples of 8-day (doy 351-358, 1996) NSCAT A ( $\sigma^0$  at  $40^\circ$  incidence angle) for (top) V-polarization and (bottom) H-polarization. Images have been reduced in resolution for presentation here. Blue boxes show study regions used later. The image artifacts in Western North America are from missing data resulting from instrument mode variations to support a ground calibration ground station in New Mexico.

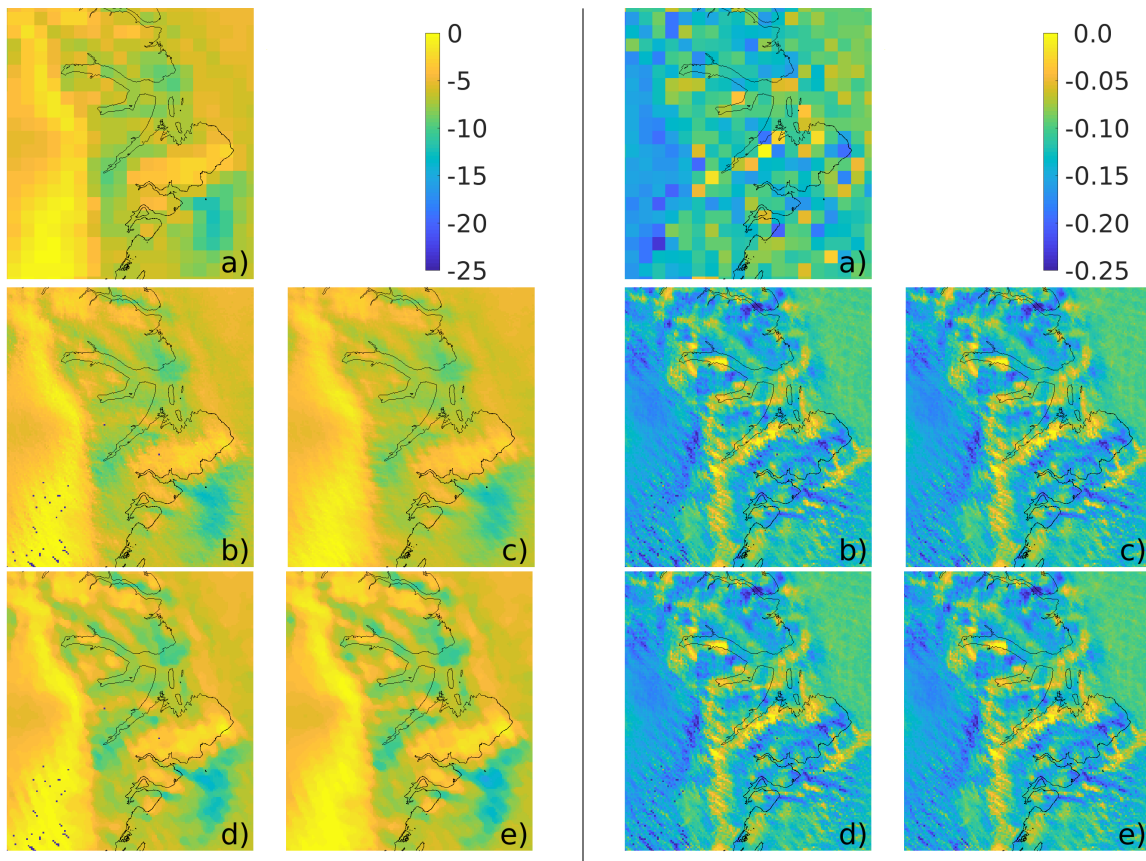


## 6 Measurement Modeling

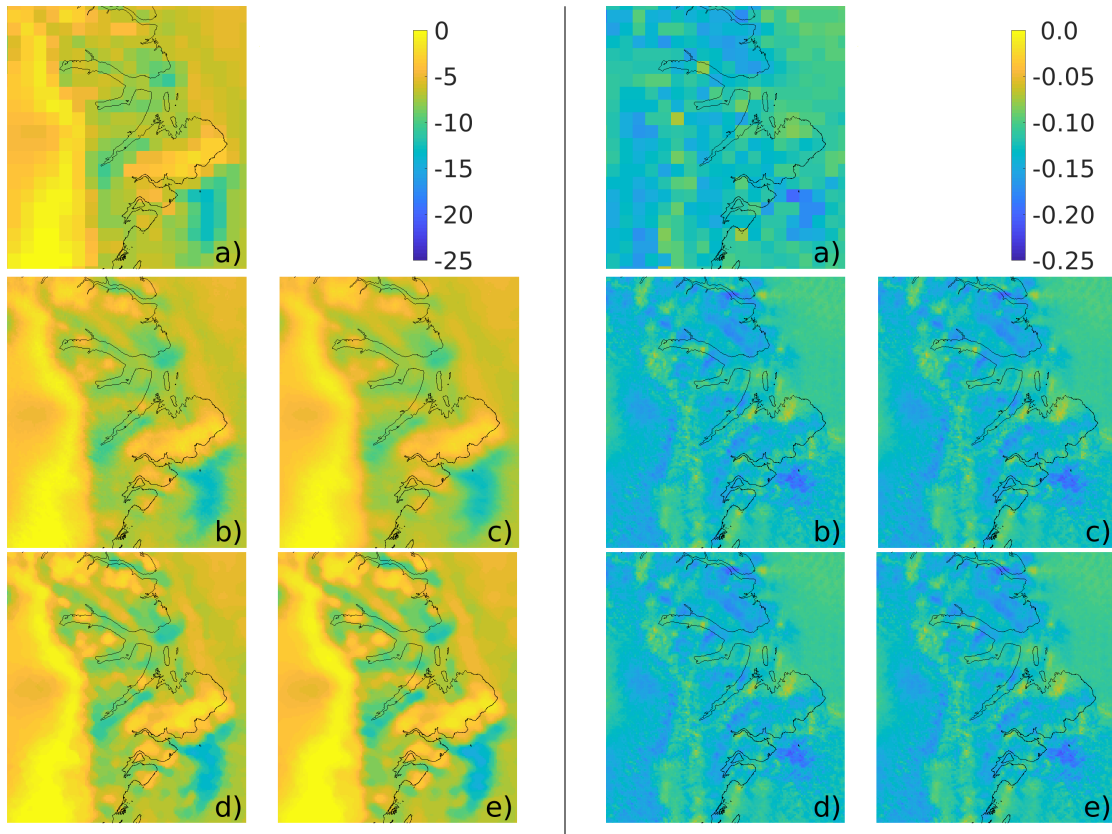
To dive deeper into the backscatter data and the performance of the imaging algorithms, we define a number of study regions in Greenland, see Fig. 18 and Tab. 6. The coastal region is employed to visualize the differences between the products at fine resolution in Figs. 19–24.



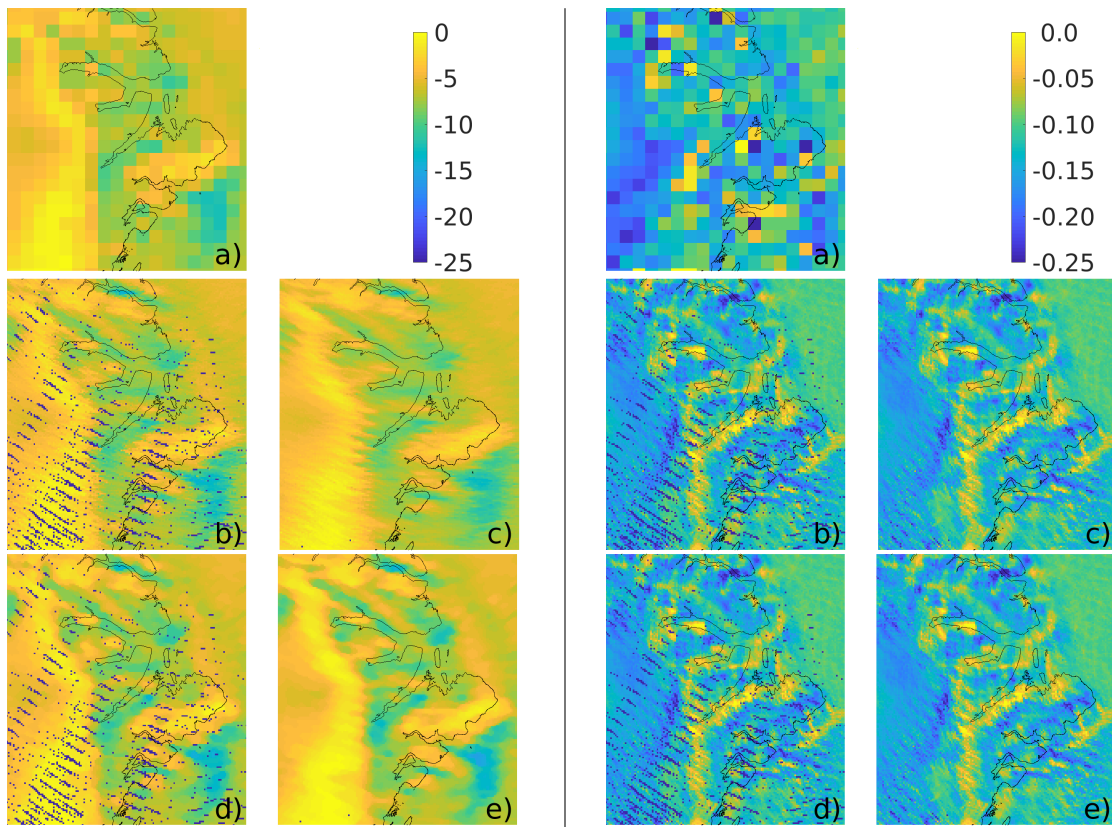
**Figure 18:** Sample 8 day both pass VV pol A image of the Greenland study area outlined in Fig. 15. Subregions considered in later figures are outlined, see Tab. 6.



**Figure 19:** Comparison of horizontal-polarization all-pass 8 day images for doy 346-353, 1996. (left side) A in dB. (right side) B in dB/deg. (a) 25 km pixel GRD image. (b) 3.125 km pixel binary response AVE. (c) 3.125 km pixel full response AVE. (d) 3.125 km pixel binary response SIR. (e) 3.125 km pixel full response SIR. Black spots in the binary response images are pixels not included in the binary response coverage. Texture artifacts result from limited measurement overlap and coverage during the imaging interval, which are more severe for H-pol.

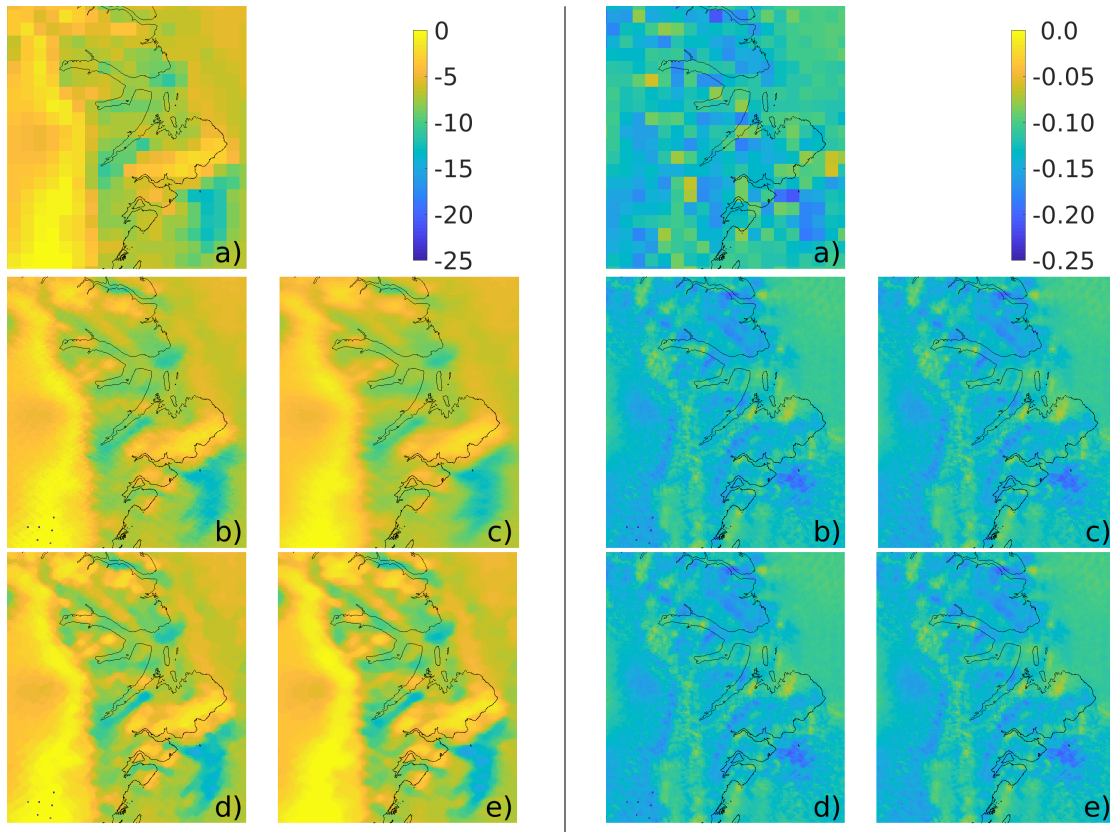


**Figure 20:** Comparison of vertical-polarization all-pass 8 day images for doy 346-353, 1996. (left side)  $A$  in dB. (right side)  $B$  in dB/deg. (a) 25 km pixel GRD image. (b) 3.125 km pixel binary response AVE. (c) 3.125 km pixel full response AVE. (d) 3.125 km pixel binary response SIR. (e) 3.125 km pixel full response SIR. Black spots in the binary response images are pixels not included in the binary response coverage. Texture artifacts result from limited measurement overlap and coverage during the imaging interval.

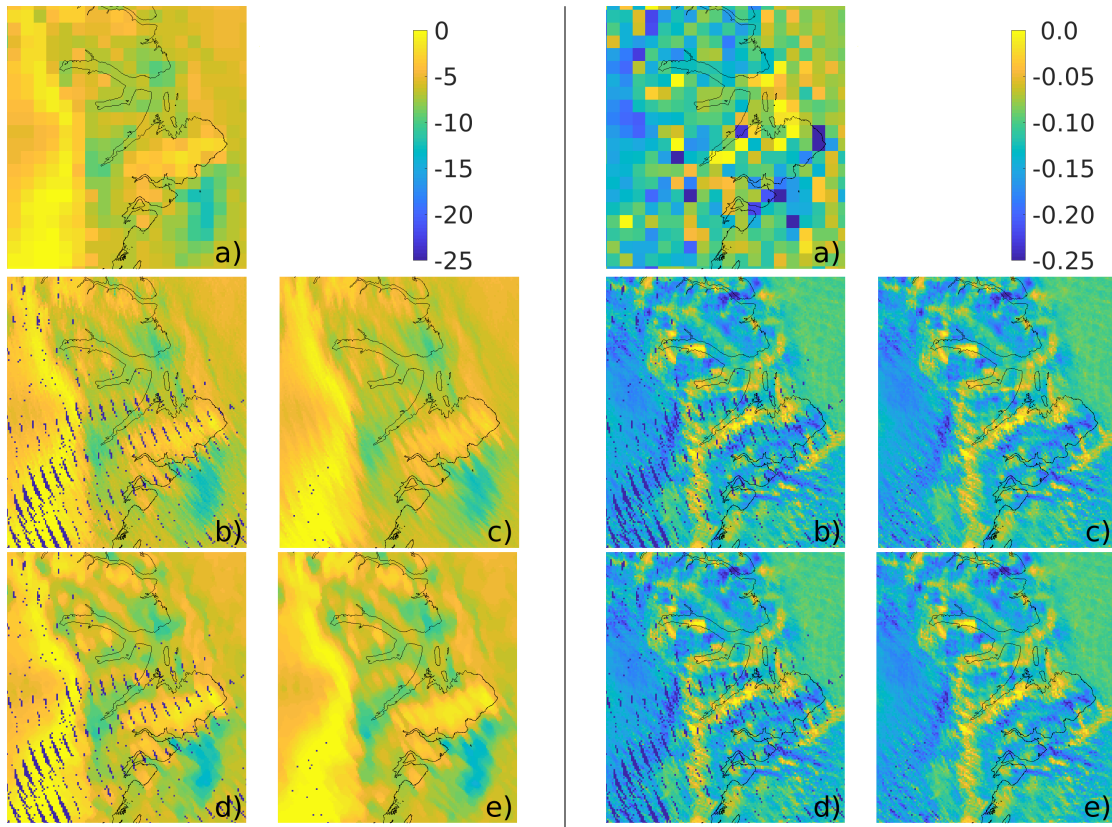


**Figure 21:** Comparison of horizontal-polarization evening-pass 8 day images for doy 346-353, 1996. (left side)  $A$  in dB. (right side)  $B$  in dB/deg. (a) 25 km pixel GRD image. (b) 3.125 km pixel binary response AVE. (c) 3.125 km pixel full response AVE. (d) 3.125 km pixel binary response SIR. (e) 3.125 km pixel full response SIR. Black spots in the binary response images are pixels not included in the binary response coverage. Texture artifacts result from limited measurement overlap and coverage during the imaging interval, which are more severe for H-pol.

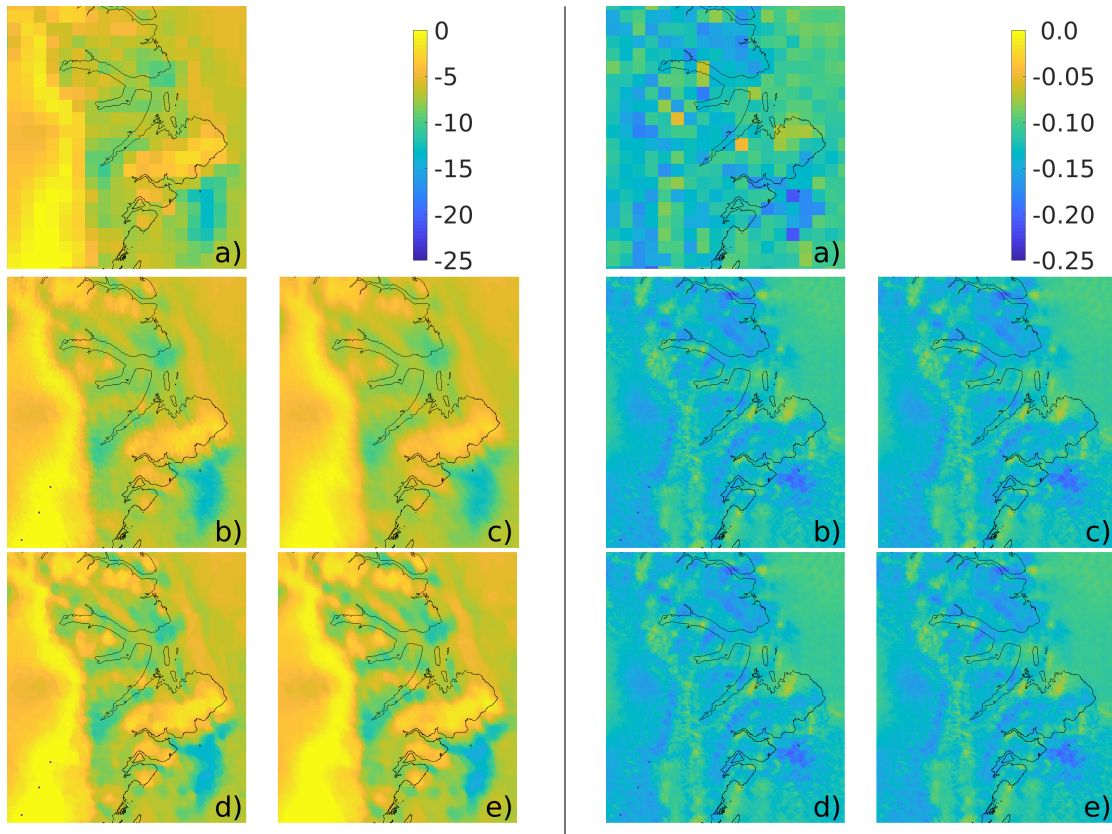




**Figure 22:** Comparison of vertical-polarization evending-pass 8 day images for doy 346-353, 1996. (left side) A in dB. (right side) B in dB/deg. (a) 25 km pixel GRD image. (b) 3.125 km pixel binary response AVE. (c) 3.125 km pixel full response AVE. (d) 3.125 km pixel binary response SIR. (e) 3.125 km pixel full response SIR. Black spots in the binary response images are pixels not included in the binary response coverage. Texture artifacts result from limited measurement overlap and coverage during the imaging interval.



**Figure 23:** Comparison of horizontal-polarization morning-pass 8 day images for doy 346-353, 1996. (left side)  $A$  in dB. (right side)  $B$  in dB/deg. (a) 25 km pixel GRD image. (b) 3.125 km pixel binary response AVE. (c) 3.125 km pixel full response AVE. (d) 3.125 km pixel binary response SIR. (e) 3.125 km pixel full response SIR. Black spots in the binary response images are pixels not included in the binary response coverage. Texture artifacts result from limited measurement overlap and coverage during the imaging interval, which are more severe for H-pol.



**Figure 24:** Comparison of vertical-polarization morning-pass 8 day images for doy 346-353, 1996. (left side) A in dB. (right side) B in dB/deg. (a) 25 km pixel GRD image. (b) 3.125 km pixel binary response AVE. (c) 3.125 km pixel full response AVE. (d) 3.125 km pixel binary response SIR. (e) 3.125 km pixel full response SIR. Black spots in the binary response images are pixels not included in the binary response coverage. Texture artifacts result from limited measurement overlap and coverage during the imaging interval.

## 6.1 Incidence Angle Effects

Over natural surfaces  $\sigma^\circ$  depends on the measurement incidence angle. Since NSCAT is a fan-beam system, it collects  $\sigma^\circ$  measurements over a range of incidence angles ranging from about  $15^\circ$  to  $60^\circ$ . The variation in incidence angle must be accounted for when combining multiple measurements. The incidence angle normalization  $\gamma^\circ = \sigma^\circ / \cos \theta$  where  $\theta$  is the incidence angle is sometimes used. However, the slope of this correction is strictly downward and since upward slopes are observed in some areas, this normalization is not used. Instead, following prior investigators (see Long et al. (1993) and references therein) a linear slope is used that is centered at  $40^\circ$ , i.e.,  $\sigma^\circ$  as a function of incidence angle is modelled according to

$$\sigma^\circ = A + B(\theta - 40^\circ) \quad (10)$$

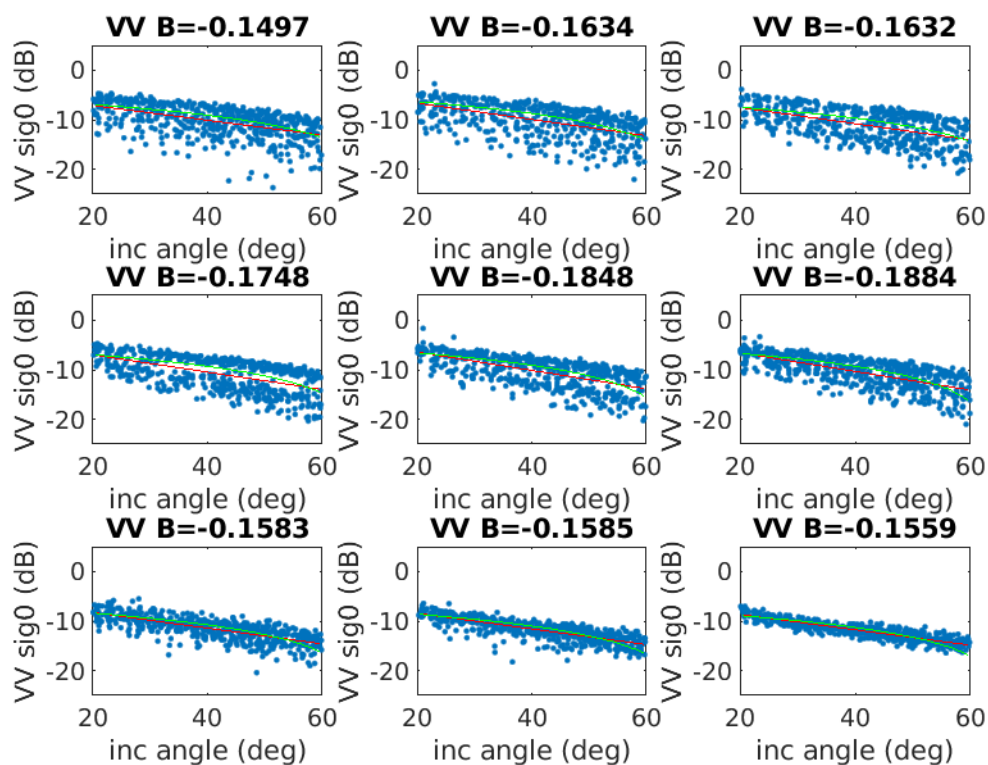
where  $A$  is  $\sigma^\circ$  at  $40^\circ$  incidence angle;  $B$  is the slope of  $\sigma^\circ$  versus incidence angle  $\theta$ . At each pixel, the model parameters  $A$  (the mean  $\sigma^\circ$ ),  $B$  (the normalized slope of  $\sigma^\circ$  versus incidence angle) are estimated from the backscatter measurements on a pixel by pixel basis.

Note that there is a variation (typically  $<1^\circ$ ) in incidence angle over the footprint of each measurement. Because the measurements integrate the echo return over the measurement MRF, only a single  $\sigma^\circ$ , mean incidence angle, and mean azimuth angle value is reported for an NSCAT measurement. The measurements essentially average the incidence and azimuth angle dependence over the MRF. While the *intra*-measurement angle variation is small, the *inter*-measurement the variation in incidence angle between measurements is much larger, and has a significant effect.

To explore this, some small ( $0.5^\circ$  longitude by  $0.25^\circ$  latitude) study regions are defined in the Greenland Ice Sheet, see Fig. 18. The regions are individually small enough to have nearly spatially constant scattering characteristics, but span the range of ice facies Long and Drinkwater (1994) over the ice sheet with a variety of mean  $\sigma^\circ$  values. Figures 25 and 26 shows the variation in incidence angle for measurements collected over each of these study regions during a 41-day interval. Noting the sloping dependence of  $\sigma^\circ$  (and  $\gamma$  with incidence angle. Linear least-squares (in both linear space and with  $\sigma^\circ$  in dB) fits of  $\sigma^\circ$  versus incidence angle are shown as solid lines. The coefficients of the the linear ( $\sigma^\circ$  in dB) fit are included in Tab. 6. In Fig. 26 scaled coefficients of the fits (in dB) are included as overprinted values. In each panel, the top line is linear fit with  $A$  (the mean value at 40 deg incidence angle) on the left and  $B$  (the slope) times 10 on the right. The second line shows the coefficients of the quadratic fit with  $A$  on the left,  $B$  times 10 in the center and  $C$  times 1000. The third line is the coefficients of the cubic fit with  $A$  on the left,  $B$  times 10 left of center,  $C$  times 1000 right of center and  $D$  times 10000 on the right where

$$\sigma^\circ = A + B(\theta - 40) + B(\theta - 40)^2 + C(\theta - 40)^3. \quad (11)$$





**Figure 25:** Vertically-polarized  $\sigma^o$  versus incidence angle for Greenland sub regions showing (red)  $\sigma^o$  in dB linear fit and (green)  $\sigma^o$  and (green)  $\sigma^o$  in normal space (not dB) linear fit to the data. Panel titles give the slope  $B$  in dB/deg for the  $\sigma^o$  in dB model. Because of the small sub region size, a long time interval spanning two orbit repeat cycles (82 days) from day 271 to day 353 was used. Refreezing of firn in areas some regions result in two different populations of data over long time interval.

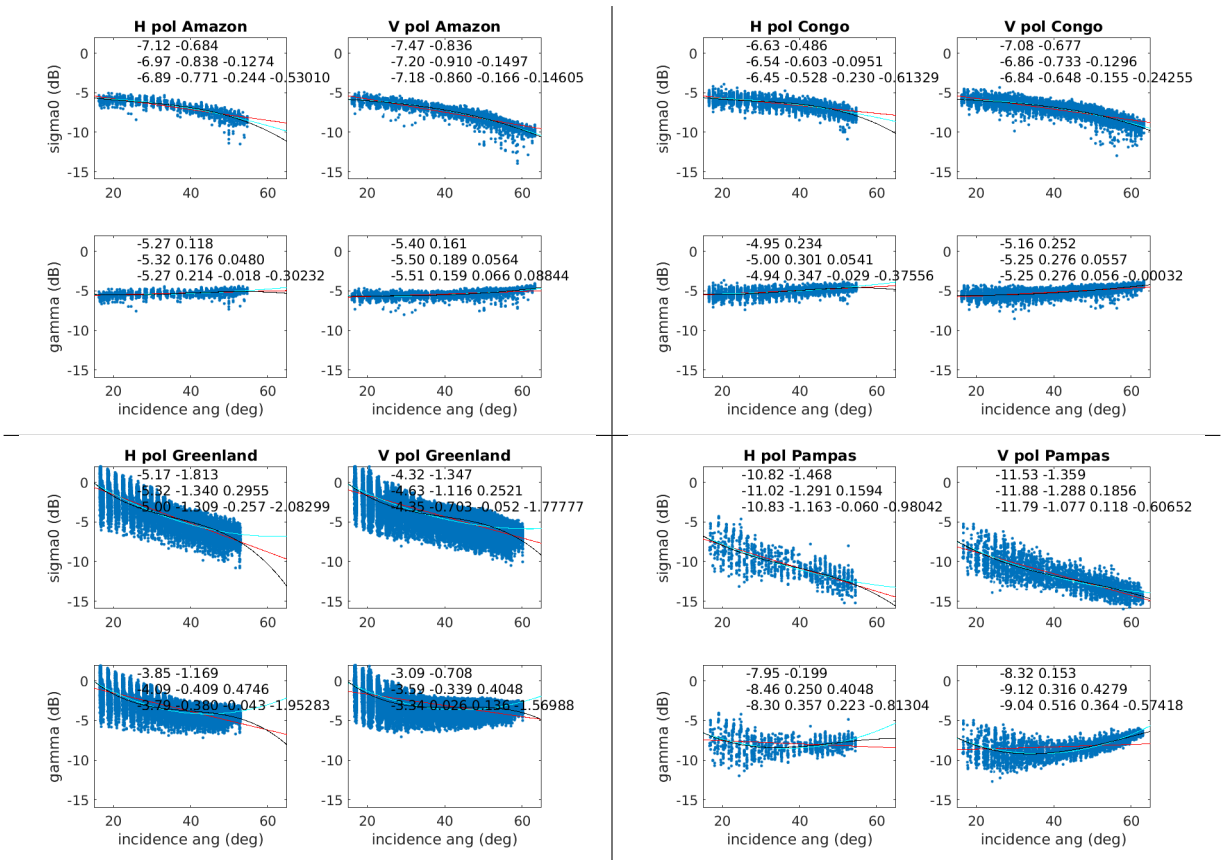


Figure 26:  $\sigma^o$  and  $\gamma$  versus incidence angle for four study regions of varying locations and size with different surface types showing (red) linear, (green) quadratic, and (black) cubic  $\sigma^o$  in dB versus incidence angle fits to the data. Data is from doy 271–353, 1997 all passes. See text regarding numbers on plot.

## 6.2 Azimuth Angle Effects

Periodic natural surfaces exhibit variations in  $\sigma^\circ$  with azimuth angle, including water waves Ulaby and Long (2014), Naderi et al. (1991), sastrugi and snow dunes (Long and Drinkwater, 2000, Lindsley and Long, 2016, Ashcraft and Long, 2006). The measured  $\sigma^\circ$  is thus a function of the azimuth direction from which the surface is observed. Scatterometers such as NSCAT are *designed* to make multi-azimuth observations over the ocean to exploit this effect for wind-driven wave in order to estimate the near-surface wind Naderi et al. (1991). However, these measurements intrinsically coarse since they must be made in a single pass. Unlike the ocean, land and ice features do not (generally) change as rapidly so observations from multiple passes can be combined.

Over the course of the orbit's repeat cycle each point on the surface can be observed at multiple azimuth angles. For example, as the spacecraft passes over a particular location within the swath, the location is first observed looking, then a short while later the same location is observed looking backward. Over the orbit repeat cycle, the ground track shifts so that the same location is observed from a different set of azimuth angles for each pass. The precise distribution of azimuth angles depends on the orbit latitude, with the narrowest range near the equator and the largest range at high latitudes.

Note that there is a trade off between the imaging time period, the spatial resolution, and the azimuth sampling. Short time periods provide better temporal resolution for tracking sea ice motion and rapid freeze thaw events. However, short time periods provide inadequate coverage and/or azimuth sampling to reliably estimate the azimuth angle variation, particularly when the data is divided by local time of day. Recalling that the orbit repeat cycle is near-repeat after 4 days, we choose  $N_d = 4$  and  $N_d = 8$  day imaging intervals ( $N_d$  in days<sup>2</sup>). The imaging intervals are chosen to overlap by  $N_d - 1$  days so they act like a  $N_d$  long moving average filter. Shorter  $N_d$  provides finer temporal resolution at the expense of reduced spatial coverage/resolution, including possible spatial artifacts in the reconstruction. These negative effects are reduced for the longer imaging intervals.

Note that a particular  $\sigma^\circ$  observation is an average of  $\sigma^\circ$  in spatial coordinates as well as in azimuth and incidence angles. Within a single measurement the azimuth angle span ( $<1^\circ$ ) for a particular measurement is small and can be neglected. The incidence angle span within a single measurement can be slightly larger ( $1-1.5^\circ$ ). The roll off of  $\sigma^\circ$  versus incidence angle, slightly biases the integrated measurement toward smaller incidence angles. This effect is neglected.

On the other hand, the variation in  $\sigma^\circ$  as a function of azimuth and incidence angles for different measurements is important and provides useful geophysical information. Incidence angle variation is considered in the previous section. Of course, the variation in  $\sigma^\circ$  as a function of azimuth enables wind retrieval over the ocean (Ulaby and Long, 2014,

---

<sup>2</sup>Imaging intervals are specified in days, but may include only morning or evening (or descending or ascending) passes depending on the ltod setting.

Meissner et al., 2017). Azimuth variation (sometimes termed ‘azimuth modulation’) can be observed over snow dunes and sastrugi (Long and Drinkwater, 2000, Ashcraft and Long, 2006, Lindsley and Long, 2016) and sand dunes in ergs<sup>3</sup> (Stephen and Long, 2007). As a result, significant azimuth variation in  $\sigma^\circ$  is common over the Great Ice Sheets (GI) of Greenland and Antarctica, but is only rarely observed elsewhere over large regions with the exceptions of ergs.

For fan-beam scatterometers, since each satellite pass observes a given point on the surface from a limited azimuth angle, the variation of  $\sigma^\circ$  with azimuth can lead to biases in the mean  $\sigma^\circ$  value and to imaging artifacts when multiple passes with different azimuth angle observations are combined. To deal with azimuth variation of  $\sigma^\circ$  on the GI, previous investigators, e.g., Long and Drinkwater (2000) Ashcraft and Long (2006), and Lindsley and Long (2016), have used a simple Fourier series model for the azimuth variation observed in  $\sigma^\circ$ . Two models have been considered. One (here termed ‘FA’) with fixed azimuth modulation coefficients and the other (here termed ‘VA’) with incidence angle-dependent azimuth modulation coefficients. The azimuth modulation models can be expressed as

$$\sigma^0 = A + B(\theta - 40) + M_1 \cos(\phi + P_1) + M_2 \cos(2\phi + P_2) \quad (12)$$

where  $\phi$  is the azimuth angle,  $M_1 = A_1$  and  $M_2 = A_2$  for the FA model, and  $M_1 = A_1 + R_1(\theta - 40)$  and  $M_2 = A_2 + R_2(\theta - 40)$  for the VA model where  $A_1$  and  $A_2$  are the mean azimuth modulation coefficients and  $P_1$  and  $P_2$  are the phase angles relative to north. Note that the model can be with  $\sigma^\circ$  in dB or linear space, though dB model have proven to be the most successful (Long and Drinkwater, 2000, Lindsley and Long, 2016).

Unfortunately, with a maximum of 6 azimuth angles, the NSCAT geometry is not very well suited for estimating the azimuth variation. Further, in the polar regions the incidence angle and azimuth angle of the observations at a given point may be coupled for fan-beam scatterometers, which greatly complicates azimuth dependence estimation (Long and Drinkwater, 2000). Thus, for this product azimuth dependence is ignored.

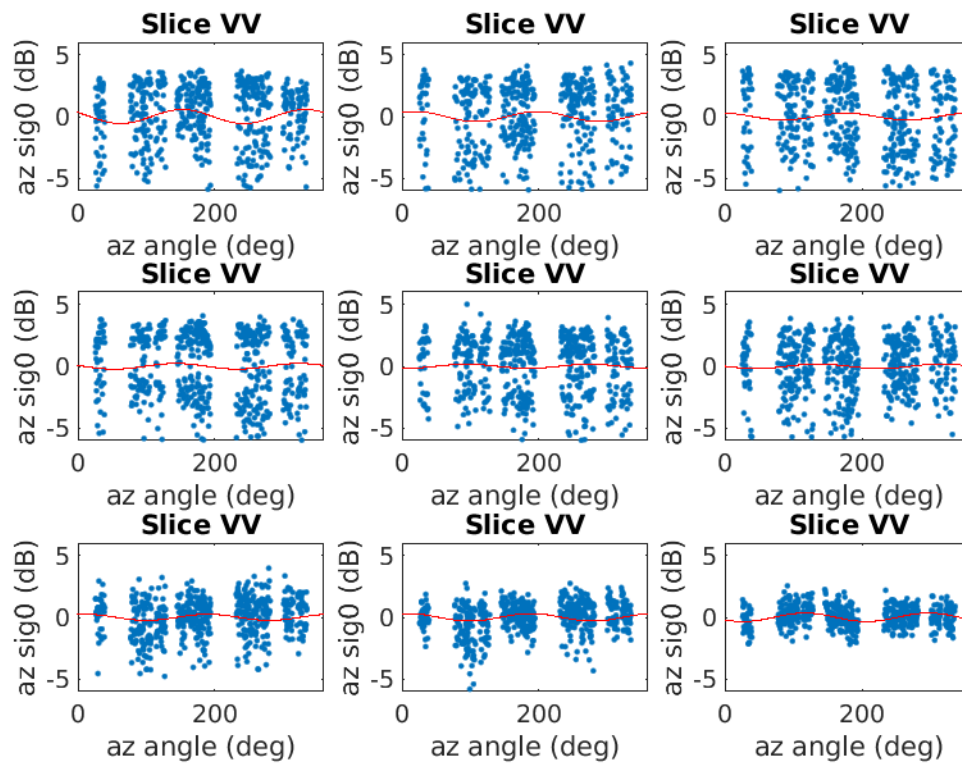
*TODO: consider adding azimuth images in the polar regions?*

### 6.3 Data Volume

Table 5 summarizes available CETB NSCAT radar products, which are all in CETB-standard EASE-2 Grid projections. In this table, “days” refers to the length of time used for image formation. Imaging periods overlap, with a new image started each day. Note that for ltoad images that in order to have the right number of morning or evening passes, the time period of the measurements actually used in the images may extend slightly outside the multi-day period. Individual file sizes vary due to internal file compression for each image type. See Section 4.5 for access details.

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<sup>3</sup>An erg landform is a large region or ‘sea’ of vegetation-free, wind-swept desert sand.



**Figure 27:**  $\sigma^o$  versus azimuth angle relative to north for Greenland subregions with 1st order azimuth modulation fit shown in red. Individual  $\sigma^o$  measurements have been corrected for incidence angle and adjusted to zero mean. The individual plots are for the sub regions with the larger Greenland study area.

## **7 Acknowledgements**

This work utilizes resources from the Brigham Young University Scatterometer Climate Record Pathfinder and University of Colorado Boulder Research Computing Group, which is supported by the National Science Foundation (awards TBD), the University of Colorado Boulder and Colorado State University.

## 8 References

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# Appendices

## A NSCAT Projections and Grids

**Table 7:** NSCAT 25 km product EASE-Grid 2.0 projections and grid dimensions, produced for compatibility with CETB ESDR data products (Brodzik et al., 2021).

Name	Projection	Resolution (km)	Cols	Rows	Latitude Extent	Longitude Extent
EASE2-T25km	Temperate and Tropical Cylindrical	25.0	2600	1388	±67.057 640 6°	±180°
EASE2-T3.125km	Temperate and Tropical Cylindrical	3.125	15750	11104	±67.057 640 6°	±180°
EASE2-N25km	Northern Lambert Azimuthal	25.0	720	720	0°–90°	±180°
EASE2-N3.125km	Northern Lambert Azimuthal	3.125	5760	5760	0°–90°	±180°
EASE2-S25km	Southern Lambert Azimuthal	25.0	720	720	–90°–0°	±180°
EASE2-S3.125km	Southern Lambert Azimuthal	3.125	5760	5760	–90°–0°	±180°

## B NSCAT Data Definition

### B.1 File Requirements

Following Brodzik et al. (2021), NSCAT product file requirements include:

- Output file format shall be acceptable for NSIDC DAAC to easily ingest to ECS
- File size maximum will be < 1 GB (larger files are allowed in ECS, but fast network speeds cannot always be assumed)
- Files will conform to netCDF-CF 1.6 conventions for all but the requirement that puts the lat/lon arrays into the file; however, we will include CF-compliant coordinate variables with projected coordinate locations
- Files should pass CF-compliance-checking for all but the lat/lon arrays (we used JPL compliance-checker)
- Each file will contain 1  $T_B$  array variable, with associated ancillary variables, possibly different ancillary variables for each gridding technique. We may have a practical limit on the number of ancillary variables to include, limited by maximum file size
- Each file of the same type (GRD or SIR) will contain the same file-level metadata for that type.
- We will follow the DRY (Don't Repeat Yourself) principle: Metadata will not be duplicated at multiple places in the same file
- DRY exception: Time values will be machine- and human-readable
- DRY exception: Some projection metadata may be in multiple forms (a proj4 string and/or a WKT string)
- Variable/attribute names will be CF-compliant whenever possible

The NSCAT .nc files work with gdal utility, *gdal\_translate*, to produce a geoTIFF version of each of the data variables <variable\_name> in the file, (details in Brodzik et al. (2018)), for e.g.:

```
$ gdal_translate -of GTiff -b 1 \
NETCDF:''cetb.nc':<variable_name> variable_name.tif
```

### B.2 Filename Convention

NSCAT data are distributed by the NSIDC DAAC (<http://nsidc.org/data/nsidc-TBD>).

Filenames are:

```
<product_id>-<grid_name>-<platform_sensor>-<yyyyddd>
-<channel_id>-<pass>-<algorithm>-<input_source>-<version>.nc
```

where parts of the filename are described in Table 8.

**Table 8:** NSCAT file naming convention

Part	Description	Values
<product_id>	NSIDC unique data product id	NSIDC-TBD
<grid_name>	EASE-Grid 2.0 grid id	See Table 7
<platform>	Satellite platform	ADEOS
<sensor>	Sensor name	NSCAT
<yyyyddd>	Date	4-digit year and 3-digit day-of-year
<channel_id>	Channel (frequency in GHz and polarization)	14 followed by polarization, one of: <ul style="list-style-type: none"> <li>• HH = horizontal-horizontal</li> <li>• VV = vertical-vertical</li> </ul>
<pass>	Pass direction (T grids) or ltod (N or S grids)	one of: <ul style="list-style-type: none"> <li>• B = Both (all measurements)</li> <li>• A = Ascending</li> <li>• D = Descending</li> <li>• M = Morning</li> <li>• E = Evening</li> </ul>
<algorithm>	Reconstruction algorithm	one of GRD or SIR
<version>	Version number	production version number

### B.3 File Content, v1.0

The following is a sample NetCDF `ncdump -h` utility output for a NSCAT v1.0 3.125 km SIR file. File-level metadata and processing details vary depending on projection, spatial resolution and processing details (method, input file list, etc.).

```
netcdf BYU-NSCAT-EASE2_S3.125km-ADEOS_NSCAT-1997119_1997126-14VV-M-SIR-v1.0 {
dimensions:
time = UNLIMITED ; // (1 currently)
y = 5760 ;
x = 5760 ;
variables:
double time(time) ;
time:standard_name = "time" ;
time:coverage_content_type = "coordinate" ;
time:long_name = "ANSI date" ;
```

```
time:units = "days since 1972-01-01 00:00:00" ;
time:calendar = "gregorian" ;
time:axis = "T" ;
time:valid_range = 0., 1.79769313486232e+308 ;
double y(y) ;
y:standard_name = "projection_y_coordinate" ;
y:coverage_content_type = "coordinate" ;
y:long_name = "y" ;
y:units = "meters" ;
y:axis = "Y" ;
y:valid_range = -9000000., 9000000. ;
double x(x) ;
x:standard_name = "projection_x_coordinate" ;
x:coverage_content_type = "coordinate" ;
x:long_name = "x" ;
x:units = "meters" ;
x:axis = "X" ;
x:valid_range = -9000000., 9000000. ;
char crs ;
crs:grid_mapping_name = "lambert_azimuthal_equal_area" ;
crs:longitude_of_projection_origin = 0. ;
crs:latitude_of_projection_origin = -90. ;
crs:false_easting = 0. ;
crs:false_northing = 0. ;
crs:semi_major_axis = 6378137. ;
crs:inverse_flattening = 298.257223563 ;
crs:proj4text = "+proj=laea +lat_0=-90 +lon_0=0 +x_0=0 +y_0=0 +ellps=WGS84 +datum=WGS84";
crs:srid = "urn:ogc:def:crs:EPSG::6932" ;
crs:coverage_content_type = "auxiliaryInformation" ;
crs:references = "[\"EASE-Grid 2.0 documentation: http://nsidc.org/data/ease/ease_grid2.\"";
crs:crs_wkt = "PROJCRS[\"WGS 84 / NSIDC EASE-Grid 2.0 South\", BASEGEODCRS[\"WGS 84\", D";
crs:long_name = "EASE2_S3.125km" ;
short Sigma0_ave(time, y, x) ;
Sigma0_ave:standard_name = "brightness_temperature" ;
Sigma0_ave:long_name = "SIR Sigma0" ;
Sigma0_ave:units = "1" ;
Sigma0_ave:_FillValue = -32768s ;
Sigma0_ave:valid_range = 0s, 32767s ;
Sigma0_ave:packing_convention = "netCDF" ;
Sigma0_ave:packing_convention_description = "unpacked = scale_factor*packed + add_offset
```

```
Sigma0_ave:scale_factor = 0.002f ;
Sigma0_ave:add_offset = -55.f ;
Sigma0_ave:grid_mapping = "crs" ;
Sigma0_ave:coverage_content_type = "image" ;
short Sigma0_slope_ave(time, y, x) ;
Sigma0_slope_ave:standard_name = "brightness_temperature" ;
Sigma0_slope_ave:long_name = "SIR Sigma0 slope" ;
Sigma0_slope_ave:units = "1" ;
Sigma0_slope_ave:_FillValue = -32768s ;
Sigma0_slope_ave:valid_range = 0s, 32767s ;
Sigma0_slope_ave:packing_convention = "netCDF" ;
Sigma0_slope_ave:packing_convention_description = "unpacked = scale_factor*packed + add_
Sigma0_slope_ave:scale_factor = 0.001f ;
Sigma0_slope_ave:add_offset = -2.f ;
Sigma0_slope_ave:grid_mapping = "crs" ;
Sigma0_slope_ave:coverage_content_type = "image" ;
short Sigma0(time, y, x) ;
Sigma0:standard_name = "brightness_temperature" ;
Sigma0:long_name = "SIR Sigma0" ;
Sigma0:units = "1" ;
Sigma0:_FillValue = -32768s ;
Sigma0:valid_range = 0s, 32767s ;
Sigma0:packing_convention = "netCDF" ;
Sigma0:packing_convention_description = "unpacked = scale_factor*packed + add_offset" ;
Sigma0:scale_factor = 0.002f ;
Sigma0:add_offset = -55.f ;
Sigma0:grid_mapping = "crs" ;
Sigma0:coverage_content_type = "image" ;
Sigma0:sir_number_of_iterations = 30 ;
Sigma0:median_filter = 1 ;
Sigma0:temporal_division = "Morning" ;
Sigma0:temporal_division_local_start_time = 5.f ;
Sigma0:temporal_division_local_end_time = 17.f ;
Sigma0:frequency_and_polarization = "14VV" ;
short Sigma0_slope(time, y, x) ;
Sigma0_slope:standard_name = "brightness_temperature" ;
Sigma0_slope:long_name = "SIR Sigma0 slope" ;
Sigma0_slope:units = "1" ;
Sigma0_slope:_FillValue = -32768s ;
Sigma0_slope:valid_range = 0s, 32767s ;
```

```
Sigma0_slope:packing_convention = "netCDF" ;
Sigma0_slope:packing_convention_description = "unpacked = scale_factor*packed + add_offs
Sigma0_slope:scale_factor = 0.001f ;
Sigma0_slope:add_offset = -2.f ;
Sigma0_slope:grid_mapping = "crs" ;
Sigma0_slope:coverage_content_type = "image" ;
short Sigma0_num_samples(time, y, x) ;
Sigma0_num_samples:long_name = "SIR Number of Measurements" ;
Sigma0_num_samples:units = "count" ;
Sigma0_num_samples:_FillValue = 0s ;
Sigma0_num_samples:valid_range = 1s, 255s ;
Sigma0_num_samples:grid_mapping = "crs" ;
Sigma0_num_samples:coverage_content_type = "auxiliaryInformation" ;
short Incidence_angle(time, y, x) ;
Incidence_angle:standard_name = "angle_of_incidence" ;
Incidence_angle:long_name = "SIR Incidence Angle" ;
Incidence_angle:units = "degree" ;
Incidence_angle:_FillValue = -1s ;
Incidence_angle:valid_range = 0s, 9000s ;
Incidence_angle:packing_convention = "netCDF" ;
Incidence_angle:packing_convention_description = "unpacked = scale_factor*packed + add_o
Incidence_angle:scale_factor = 0.01f ;
Incidence_angle:add_offset = 0.f ;
Incidence_angle:grid_mapping = "crs" ;
Incidence_angle:coverage_content_type = "auxiliaryInformation" ;
short Sigma0_std_dev(time, y, x) ;
Sigma0_std_dev:long_name = "SIR Sigma0 standard deviation" ;
Sigma0_std_dev:units = "1" ;
Sigma0_std_dev:_FillValue = -32768s ;
Sigma0_std_dev:valid_range = -32766s, 32767s ;
Sigma0_std_dev:packing_convention = "netCDF" ;
Sigma0_std_dev:packing_convention_description = "unpacked = scale_factor*packed + add_of
Sigma0_std_dev:scale_factor = 0.002f ;
Sigma0_std_dev:add_offset = 0.f ;
Sigma0_std_dev:grid_mapping = "crs" ;
Sigma0_std_dev:coverage_content_type = "auxiliaryInformation" ;
short Sigma0_time(time, y, x) ;
Sigma0_time:long_name = "Time of Day" ;
Sigma0_time:units = "minutes since 1997-04-29 00:00:00" ;
Sigma0_time:_FillValue = -32768s ;
```

```
Sigma0_time:valid_range = -32767s, 32767s ;
Sigma0_time:packing_convention = "netCDF" ;
Sigma0_time:packing_convention_description = "unpacked = scale_factor*packed + add_offset" ;
Sigma0_time:scale_factor = 1.f ;
Sigma0_time:add_offset = 0.f ;
Sigma0_time:grid_mapping = "crs" ;
Sigma0_time:coverage_content_type = "auxiliaryInformation" ;
Sigma0_time:calendar = "gregorian" ;

// global attributes:
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:title = "NSCAT Radar Twice-Daily SIRF-Enhanced EASE-Grid 2.0 Sigma0" ;
:id = "doi:TBD" ;
:summary = "Enhanced-resolution, gridded NSCAT Ku-band radar backscatter" ;
:project = "Scatterometer Climate Record Pathfinder" ;
:contributor_name = "David G. Long, NASA Scatterometer Climate Record Pathfinder" ;
:contributor_role = "Principal Investigator and Developer, Data Producer" ;
:citation = "D. G. Long\nNSCAT Twice-Daily SIRF-Enhanced EASE-Grid 2.0 Sigma0.\nVersion 1.0" ;
:license = "These data are freely, openly, and fully available to use without restriction" ;
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:comment = "Epoch date for data in this file: 1997-04-29 00:00:00Z" ;
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```



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:date_metadata_modified = "2022-12-31T06:57:46GMT" ;
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:acknowledgement = "This data set was created with funding from NASA Grant #TBD." ;
:processing_level = "Level 3" ;
:creator_name = "David Long" ;
:creator_type = "person" ;
:creator_email = "long@ee.byu.edu" ;
:creator_url = "http://www.scp.byu.edu" ;
:creator_institution = "Electrical and Computer Engineering Department\nBrigham Young Un
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:geospatial_lat_max = 0. ;
:geospatial_lon_min = -180. ;
:geospatial_lon_max = 180. ;
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}
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