Standard BYU QuikScat/Seawinds Land/Ice Image Products

David G. Long
Microwave Earth Remote Sensing Laboratory
BYU Center for Remote Sensing
Brigham Young University
459 Clyde Building, Provo, UT 84602
long@ee.byu.edu (801) 378-4383

Revision 2.0
September 28, 2000

Abstract

Following up on the successful NSCAT mission, the QuikScat/Seawinds scatterometer (Qscat) provides normalized radar cross section (σ^o) measurements of the Earth's surface at unprecedented coverage and resolution. While originally designed for wind observation, scatterometers have proven useful in a variety of land and ice studies. To further improve the utility of the data, resolution enhancement algorithms have been developed and applied to the data. These algorithms produce images of the surface σ^o at enhanced resolution (to better than 10 km). This report briefly describes a standard product suite of Qscat enhanced resolution image products developed and produced at the Brigham Young University (BYU) Microwave Earth Remote Sensing (MERS) Laboratory.

1 Introduction

Though the mission was cut short by the loss of the host spacecraft, the NASA Scatterometer (NSCAT) was an unqualified success. In addition to its primary wind observation mission, NSCAT has also had an impact on a variety of polar ice [9] and tropical vegetation [10] studies. In particular, NSCAT data is very effective in mapping the extent of sea ice [12]. It is clear that scatterometers will continue to play an increasingly important role in monitoring tropical vegetation and polar ice in the future.

As a follow-up/replacement for the NSCAT mission, the QuikScat/Seawinds scatterometer (Qscat) provides measurements of the near-surface ocean wind field with unprecedented coverage and resolution. Qscat makes dual polarization measurements of the normalized radar cross section (σ^o) at both vertical and horizontal polarization using a conically scanning pencil-beam antenna (see Fig. 1). The σ^o measurements have demonstrated application in land and ice studies (e.g., [1, 4, 5, 15, 14]). The Brigham Young University (BYU) Microwave Earth Remote Sensing (MERS) Laboratory has developed a standard set of Qscat land/ice image products for distribution. This report describes these products. Both conventional and enhanced resolution products are included in the product suite. The enhanced resolution products are produced with the aid of the Scatterometer Image Reconstruction (SIR) algorithm described below.

2 The Scatterometer Image Reconstruction Algorithm

NSCAT, launched in August of 1996 is a real aperture dual polarization Ku-band radar scatterometer designed to measure the σ^o of the Earth's surface. NSCAT made dual-polarization σ^o measurements over an incidence angle range of $17° - 55°$. Over the limited incidence angle range of $\theta \in$[20°, 55°], σ^o (in dB) is approximately a linear function of θ,

$$\sigma^o(\theta) = A + B(\theta - 40°) \tag{1}$$

where A and B are functions of surface characteristics, azimuth angle, and polarization. A is the incidence-angle normalized σ^o value at 40° incidence while B describes the dependence of σ^o on θ.

NSCAT produces nominally 25 km resolution σ^o measurements on a 25 km sampling grid. Not originally designed as an imaging sensor, the measurements are disjoint in the along-track dimension and vary somewhat in shape over the swath. Combining multiple passes and using the Scatterometer Image Reconstruction (SIR) with Filtering (SIRF) algorithm enhanced resolution images of the surface backscatter can be produced [3]. The SIR algorithm was originally developed to enhance Seasat scatterometer data[6]. The SIR algorithm has also been used with SSM/I radiometer [8] and ERS scatterometer data [7]. A number of improvements to the original SIR algorithm have been developed to optimize its performance for NSCAT [11]. The SIRF algorithm applied to NSCAT data produces both A and B images from the NSCAT σ^o measurements. The NSCAT SIRF image pixel resolution is nominally 4.45 km with an effective resolution of 8-10 km [3, 9, 10].

The SIR algorithm is based on a multivariate form of block multiplicative algebraic reconstruction. Combining multiple overlapping passes and robust performance in the presence of noise, it provides enhanced resolution measurements of the surface characteristics [2]. To provide a simple intuitive explanation of the idea behind SIR, consider the following. (The incidence angle dependence of σ^o is ignored in the following discussion.) More detailed discussions are contained in [6] and [2].

Let $f(x, y)$ be a function that gives the surface σ^o at a point (x, y). The scatterometer measurement system can be modeled by

$$z = Hf + \text{noise} \tag{2}$$

where H is an operator that models the measurement system (sample spacing and aperture filtering) and z represents the measurements of σ^o made by the instrument sensor. The set of measurements z are a discrete sampling of the function f convolved with the aperture function (which may be different for each measurement). A particular measurement z_i can be written as

$$z_i = \int\int h_i(x, y)dxdy + noise \tag{3}$$

where $h_i(x, y)$ is the measurement response (due, for example, to the antenna pattern and the Doppler filter response) of the ith measurement.

For resolution enhancement, we are interested in the inverse problem:

$$\hat{f} = \hat{H}^{-1}z \tag{4}$$

where $\hat{f}$ is an estimate of f from the measurements z. The inverse of the operator H, $\hat{H}^{-1}$, is exact only if H is invertible and the measurements are noise free, in which case $\hat{f} = f$. This represents a form of resolution enhancement since information in the sidelobes of the measurement response or aperture function is recovered in the inversion. In effect, this is what the iterative SIR algorithm does, producing images at a finer resolution than the original measurements [1]. It should be noted that SIR is a true resolution enhancement algorithm which extracts information from the sidelobes of the measurement response function to generate the final image product [2]; in effect, it is an inverse reconstruction filter optimized to minimize noise in the reconstructed image.

While the enhanced resolution A and B images are normally of the most interest, BYU also produces a number of ancillary image products along with the enhanced resolution images. These include non-enhanced images (i.e., A and B images produced at the intrinsic resolution of the sensor), low resolution browse images, and quality assurance image products.

3 Qscat

Unlike NSCAT which made σ^o measurements over a broad range of incidence angles, Qscat makes σ^o measurements at only two nominal incidence angles, 46° and 54.1°, corresponding to the inner and outer beams. The inner beam measurement is horizontal-polarization while the outer beam is vertical-polarization. Since it is undesirable to combine measurements from different polarizations, it is not possible to infer B from the Qscat σ^o measurements. Instead, a single-variate form of SIR similar to the type developed for radiometer applications [8] is used to generate enhanced resolution images of σ^o (which will be termed A_v and A_h) at each of the two polarizations and nominal incidence angles of the antenna beams.

Qscat σ^o measurements are reported in two forms: termed 'eggs' and 'slices' [17]. These differ in their spatial sizes and shapes. The nominal instantaneous Qscat antenna footprint is an ellipse. However, the on-board range-doppler processing incorporated within the instrument improves the resolution. Using the on-board processor, twelve individual σ^o measurements are obtained for each footprint, though only 8 are reported in the L1B data product. These individual measurements are termed 'slices'. The slices are typically 4-6 km long (depending on the instrument mode and antenna beam) by 20 km wide. The summed measurements of the 8 center slices are known as 'egg' measurements and are reported as a standard product. The effective resolution and shape of the egg measurement nearly matches the elliptical 3 dB antenna footprint (approximately 15 km by 25 km depending on the antenna beam and instrument mode). Although lower resolution, the egg measurements have less noise are less sensitive to calibration errors. Figure 1 illustrates the spatial response functions of eggs and slices while Fig. 2 illustrate the spatial overlap in the slices.

4 Standard Qscat Image Products

As implemented by BYU, a number of standard Qscat image products are produced. A description of these follow. The standard Qscat image set consists of both SIR enhanced resolution images, as well as non-enhanced images and a number of auxiliary data images. All image products are generated and stored in the BYU MERS **SIR** file format. Viewer and reader programs for the BYU MERS **SIR** file format are available on line from the BYU MERS web and anonymous ftp sites at URLs `http://www.mers.byu.edu/` and `ftp://ftp.cers.byu.edu/`, respectively. A standard file naming convention (described below) is used.

Two main divisions of Qscat data products are produced from the two types of σ^o measurements reported by Qscat: 1) slices and 2) eggs. Separate SIR resolution enhanced and non-enhanced images are produced from each type of σ^o measurement. The nominal pixel resolution of the

[1]Note that the image products are produced at a particular *pixel* resolution; however, the *effective* resolution of the images is typically coarser by a factor of 2 or depending on the number of available measurements, the spatial location distribution of the measurements, temporal variations in the surface, the size of the grid, etc.

slice-based SIR images is 2.225 km with an estimated effective resolution of ~ 4 km. Egg-based SIR images have a nominal pixel resolution of 4.45 km with an estimated effective resolution of $\sim 8-10$ km. Slice-based SIR images have a nominal pixel resolution of 2.225 km with an estimated effective resolution of ~ 5 km. A set of low-resolution (5 pixels/deg) global browse products are also produced.

Gridded image products are not resolution enhanced and are produced at pixel resolution of 5 times the nominal SIR resolution (11.125 km and 22.25 km for slices and eggs, respectively). Gridded images are created by accumulating all of the measurements whose center falls with a given grid element (pixel), i.e., by the "binning" or "drop in the bucket" method: for a given grid element A is generated by averaging all the measurements whose centers fall within the grid element. The resulting A values are temporal averages over the imaging time interval. Since part of the spatial response of the measurements fall outside of the grid elements (or, bins) the *effective* resolution of the gridded products is somewhat less than the grid sizes.

To aid in comparison of enhanced resolution and non-enhanced resolution products, selected gridded products are pixel replicated to produce images with the same number of pixels as the enhanced resolution products. These images are referred to as 'non' images. Figure 3 illustrates simulation results for non and SIR egg and slice images.

Standard products images are made over several standard regions identified by number, name, and a rectangular box in lat/long (see Table 1 and Figs. 4 and 5). Land images are typically produced in Lambert projection while polar images are produced in polar stereographic projection. A list of the standard image regions is given in Table 1. Polar images are based on one day's worth of data and are produced every day (see Fig. 4). Non-polar image products generally use four days of data. Non-polar images (other than the Bering Sea region) are land masked and have ocean pixels set to the no-data value (see Fig. 5). Figures 6 and 7 compare the resolution of the various products. Figure 8 shows a sample of the ancillary image products.

A standardized `SIR` naming scheme (described below) is used which has key information about the contents of the image file in the file name.

For a given region, the following list of SIR product files are produced for each beam. Similar products are also produced using the gridding algorithm. In addition to SIR enhanced resolution products, an 'em A' product is also produced using the SIR-related AVE algorithm (see [6]) which has intermediate resolution. Each product can be produced for both slices and eggs unless otherwise indicated. The SIR algorithm is used for egg processing while the SIR algorithm with filtering (SIRF) is used for slice processing. The product type is denoted by a one character type designator in the file name.

a: A value. σ^o value in dB. For QuikScat/Seawinds slices, the nominal reference incidence angles are H-pol (inner beam) 46° and V-pol (outer beam) 54.1°.

C: counts. The number of σ^o measurements which hit the pixel during the imaging interval. (produced for only slices)

E: mean reconstruction error in dB. The mean difference between each measurement which hits the pixel and its forward projection based on the final image estimate.

I: incidence angle standard deviation in deg. The standard deviation is over all the σ^o measurements which hit the pixel during the imaging interval.

J: mean incidence angle in deg. The mean is over all the σ^o measurements which hit the pixel during the imaging interval.

Region Name	Region Abreviation	Lower-Left Corner Latitude	Lower-Left Corner Longitude	Upper-Right Corner Latitude	Upper-Right Corner Longitude	Region Code Number
Antarctic	Ant	-90.0	-180.0	-52.0	180.0	100
Arctic	Arc	60.0	-180.0	90.0	180.0	110
Greenland	Grn	59.0	-74.0	84.5	-11.0	202
Alaska	Ala	50.0	-180.0	73.0	-130.0	203
Cntrl-Amer	CAm	5.0	-115.0	30.0	-57.0	204
North-Amer	NAm	25.0	-135.0	65.0	-50.0	205
South-Amer	SAm	-58.0	-83.0	15.0	-32.0	206
North-Afri	NAf	2.0	-20.0	40.0	65.0	207
South-Afri	SAf	-38.0	5.0	10.0	53.0	208
Siberia	Sib	50.0	60.0	75.0	180.0	209
Europe	Eur	35.0	-12.0	72.0	65.0	210
South-Asia	SAs	5.0	60.0	30.0	130.0	211
Chin-Japan	ChJ	25.0	60.0	55.0	150.0	212
Indonesia	Ind	-15.0	93.0	10.0	165.0	213
Australia	Aus	-48.0	110.0	-10.0	180.0	214
Bering Sea	Ber	50.0	135.0	75.0	-135.0	256

Table 1: Standard product regions. The products are produced in a local radius Lambert projection except for the Antarctic and Arctic regions (region numbers 100 and 110) which are produced in polar stereographic form.

p: time image (in minutes from the start of the imaging interval). The time value reports the effective time center of the measurements used to compute the image [16].

V: reconstruction std image (in dB). The standard deviation of the difference between each measurement which hits the pixel and its forward projection based on the final image estimate. Useful for evaluating temporal variation in the surface, azimuth modulation, etc.

A sample product listing of the standard products is contained in the Appendix. Table 2 gives the approximate file sizes for the egg-derived product files for each region. Slice-derived products are approximately 4 times larger.

Region Abreviation	Region Code Number	SIR/SIRF Image size (MB)	Gridded Image size (MB)	Region Name
Ant	100	7.5	3.0	Antarctic
Arc	110	4.7	1.9	Arctic
Grn	202	1.1	0.5	Greenland
Ala	203	1.0	0.4	Alaska
CAm	204	2.0	0.8	Cntrl-Amer
NAm	205	4.3	1.8	North-Amer
SAm	206	4.8	2.0	South-Amer
NAf	207	4.8	2.0	North-Afri
SAf	208	3.1	1.2	South-Afri
Sib	209	2.8	1.1	Siberia
Eur	210	3.2	1.3	Europe
SAs	211	2.5	1.0	South-Asia
ChJ	212	3.8	1.5	Chin-Japan
Ind	213	2.4	1.0	Indonesia
Aus	214	3.8	1.5	Australia
Ber	256	0.1	0.1	Bering Sea

Table 2: Approximate Qscat standard product file sizes for egg-derived products in MB for each region. Slice-derived products are approximately 4 times larger due to the higher resolution of the products.

5 User Notes

This section provides additional specific details regarding the generation and application of the standard Qscat products. SIR images are generated from Qscat L1B files.

In generating enhanced resolution images, the SIR algorithm combines σ^o measurements (only measurements from a single beam are combined) from multiple azimuth angles and (possibly) multiple orbit passes collected over the imaging period. The resulting images represent a non-linear weighted average of the measurements. There is an implicit assumption that the surface characteristics remain constant over the imaging period. The effective resolution depends on the number of measurements and the precise details of their overlap, orientation, spatial locations.

5.1 Quality flags and σ^o measurements used

Only σ^o measurements flagged as 'usable' in the Qscat L1B files are included in the processing. Note that the SIR algorithm forms images in dB space and thus excludes use of negative σ^o measurements. Since most land/ice areas have fairly large σ^o, relatively few measurements are excluded.

While 8 slice measurements per pulse are reported in the L1B file, the outer slices tend to more noisy than the inner slices and are more sensitive to calibration/balance problems. For this reason only the center 4 slices are currently used in slice image products.

5.2 Ascending/Descending

Ordinarily, both ascending and descending data passes are combined in creating the images. This, in effect, assumes that the surface is essentially the same for both ascending and descending passes, equivalent to assuming that the diurnal variation is small since ascending and descending passes are approximately 12 hours apart. However, some diurnal variations have been observed, particularly in the polar regions during peak melting periods. While the assumption of limited diurnal variation appears appropriate for most land surface, additional products will be produced for selected regions and time periods which use only ascending and descending data. The naming scheme reflects this.

5.3 Antenna azimuth angles

Note that due to the rotation of the antenna, the cross-track density of σ^o measurements varies with more measurements at the outer edges of the swath than at the swath center. As a result, swath edges are clearly visible in the count images.

Note that in producing the images the forward-looking and aft-looking measurements are combined and the resulting average is over the various azimuth angles of the measurements. The azimuth angles of the measurements hitting a given location vary with the pixel location and with time and may be further affected by missing or low-quality data. While most land and sea-ice regions exhibit little variation in σ^o with azimuth angle, σ^o in some regions (notably, parts of East Antarctica) is dependent on the azimuth angle of the observations. Since σ^o measurements from multiple azimuth angles may be combined, the resulting image value is sensitive to the azimuth angle distribution of the measurements. This effect can result in artifacts near the edge of the swath. In this area the σ^o measurements span a large range of azimuth angles. Thus, to improve the image quality, σ^o measurements in the outer edges of each beam's swath are not used to generate the SIR image products. σ^o measurements with antenna azimuth angles within $\pm 15°$ of orthogoal to the flight path are discarded prior to applying SIR. The $\pm 15°$ threshold was subjectively chosen based on a tradeoff of computation and image artifact reduction. While eliminating far swath σ^o measurements reduces the swath width somewhat, the swath width reduction is small and results in a substantial reduction in computational time required to generate the enhanced resolution images.

5.4 Coverage

QuikScat is in a near-four day repeat orbit. While 95% of the Earth's oceans are covered in one day, the frequency of swath coverage is highly latitude dependent with most frequent passes near the poles. (Note that while the V pol beam covers the exact poles, the H pol beam does not.) It takes a minimum of two days to provide complete coverage of the Earth's surface. For this reason, several days of data (typically 4, to obtain the maximum diversity) are used for non-polar regions. Some special products may use more or less than this.

5.5 Slice balancing and topographic effects

Currently, no special calibration correction is applied to the QuikScat L1B σ^o measurements. However, initial studies suggest that improved calibration can be obtained by so-called egg and slice balancing techniques. This may be applied later.

The X factor used in computing the σ^o measurement from the raw power measurements is somewhat dependent on the height of the surface. JPL's processing includes a correction factor to account for this. The correction is estimated to be accurate to within 0.15 dB. A correction is also applied for the measurement location. While the spatial response function is somewhat dependent on the surface height, this dependence is ignored in image formation.

5.6 Incidence angle correction

The observed variation in incidence angle of the σ^o measurements over a given region is very small, typically less than 0.1°. For comparison, over vegetated regions typically B[the variation in σ^o with incidence angle, see Eq. (1)] is ~ -0.13 dB/deg. For ice this may be as large as 0.25 dB/deg. (Over the ocean $\mathcal{B} \sim 1$ dB/deg.) Since only σ^o measurements from a given beam are combined and the egg incidence angle variation is small, incidence angle normalization is felt to be unnecessary at this time for egg images and no σ^o incidence angle correction is made; thus, the image A values correspond to the σ^o value at the beam incidence angle. For slice images, individual slice σ^o measurements are incidence angle corrected to the nominal reference angle using a Bvalue of ~ -0.13 dB/deg. The mean incidence angle (**I**) and the standard deviation (**J**) of incidence angles of the measurements for each pixel are reported.

6 BYU SIR File Format

The BYU-MERS `SIR` image format was developed by the Brigham Young University (BYU) Microwave Earth Remote Sensing (MERS) laboratory to store a variety of types and projections of EArth images along with the information required to earth-locate the image pixels.

A `SIR` format file consists of one or more 512 byte headers followed by the image data and additional zero padding to insure the file is a multiple of 512 bytes long[2]. The file header record contains all of the information required to read the remainder of the file and the map projection information required to map pixels to lat/long coordinates on the Earth surface. The image pixel values generally represent floating point values and may be stored in one of three ways. The primary method is as 2 byte integers (with the high order byte first), though the pixels may be stored as single bytes or IEEE floating point values. Scale factors are stored in the header to convert the integer or byte pixel values to native floating point units. The image is stored in row-scanned (left to right) order from the lower left corner (which is the origin of the image) up through the upper right corner. By default, the location of a pixel is identified with its lower-left corner. The origin of pixel (1,1) is the lower left corner of the image. The array index n of the $(i,j)^{th}$ pixel where i is horizontal and j is vertical is given by $n = (j-1) * N_x + i$ where N_x is the horizontal dimension of the image. The last pixel stored in the file is at (N_x, N_y).

The `SIR` file header contains various numerical values and strings which describe the image contents. For example, a no-data flag value is set within the header as well as the nominal display range and the minimum and maximum representable values. Optional secondary header records (512 bytes) can be used to store additional, non-standard information.

The standard `SIR` file format supports a variety of image projections including:

1. Rectangular array (no projection)
2. A rectangular lat/lon array
3. Two different types of Lambert equal-area projections which can be used in either non-polar or polar projections
4. Polar stereographic projections
5. EASE grid polar projection with various resolutions
6. EASE global projection with various resolutions

[2]This ensures that images can be transferred to and from all platforms without loss using binary ftp.

$SENS$	Sensor
ers1	ERS1 AMI scatterometer mode
ers2	ERS2 AMI scatterometer mode
FXXY	SSM/I FXX channel index Y
nsDP	NSCAT
qDEP	QuikScat/Seawinds
sasP	SASS
trmm	TRMM PR surface σ^o

Table 3: Standard sensor strings for `SIR` file names. Special symbols XX, Y, D, E, G, and P are defined in Tab. 5.

For the Qscat products described here, only the Lambert and polar stereographic projections are used.

Readers for the `SIR` file format are available in C, FORTRAN, Matlab, and IDL/PVWAVE. Viewer and reader programs are available on line from the BYU MERS web and anonymous ftp sites at URLs `http://www.mers.byu.edu/` and `ftp://ftp.cers.byu.edu/pub/sir`, respectively[3]. Documentation for these readers are located there. Sample files and various utility and display routines are also available. (Be sure to use binary ftp to transfer `.sir` files!)

A customized version of **`xv`** which reads `.sir` files and can convert images to other forms is also available on this site. Routines for display in Matlab and IDL/PV-Wave are available at the site. Adobe Photoshop can display the image data `.sir` file stored as two-byte integers. Read the file as 'raw', specify a 512 header and 16 bit data, and enter the image dimensions in pixels.

6.1 `SIR` Standard file name format

Where possible, a standardized file naming scheme for `SIR` format files, suitable for unix, vms, and windows 9X and above. The general naming scheme is:

$$SENS - T - \mathbf{REG}YR - DY1 - DY2.RCN$$

where $SENS$ is the four character sensor name in Table 3, T is the one character image type code given in Table 4, **REG** is a region identifier string, YR is a two digit year code, $DY1$ and $DY2$ are the three digit Julian day-of-the-year of the data used to make the image, and RCN is the reconstruction type file extension given in Table 6. A number of three character region identification strings are listed in Table 8. Special product files may use other longer strings for the region name. Optionally, additional file extensions may be appended to the standard name to denote a post-processed image (see Table 7).

[3]The reader code may be copied and modified and freely distributed so long as (1) original or modified code is not redistributed for profit and (2) acknowledgment is made that the original code was obtained from the Microwave Earth Remote Sensing Laboratory at Brigham Young University, Provo, UT.

References

[1] I.S. Ashcraft and D.G. Long, "SeaWinds Views Greenland," *Proc. Int. Geosci. Rem. Sens. Sym.*, Honolulu, Hawaii, 6-10 July, 200.

[2] D.S. Early and D.G. Long,"Enhanced Resolution Imaging From Irregular Samples," to appear, *IEEE Trans. Geosci. Remote Sens.*, 2000.

[3] J. Dyal and D.G. Long, "NSCAT Views the Earth," MERS Technical Report, # MERS 97-004, Brigham Young University, 21 Oct. 1997. Available on the web at `http://www.mers.byu.edu/Papers/mers_reports.html`

[4] D.G. Long and M.R. Drinkwater, "Azimuth Variation in Microwave Scatterometer and Radiometer Data Over Antarctica," *IEEE Trans. Geosci. Remote Sens.*, Vol. 38, No. 4, pp. 1857-1870, 2000.

[5] D.G. Long, "Land and Ice Applications of SeaWinds Data," *Proc. Int. Geosci. Rem. Sens. Sym.*, Honolulu, Hawaii, 6-10 July, 200.

[6] D.G. Long, P. Hardin, and P. Whiting, "Resolution Enhancement of Spaceborne Scatterometer Data," *IEEE Trans. Geosci. Remote Sens.*, vol. 31, pp. 700–715, 1993.

[7] D.G. Long, D. Early, and M.R. Drinkwater, "Enhanced Resolution ERS-1 Scatterometer Imaging of Southern Hemisphere Polar Ice," *Proc. Int. Geosci. Rem. Sens. Sym.*, Pasadena, California, 8-12 August, pp. 156–158, 1994.

[8] D.G. Long and D. Daum,"Spatial Resolution Enhancement of SSM/I Data," *IEEE Trans. Geosci. Rem. Sens.*, vol. 36, pp. 407–417, 1997.

[9] D.G. Long and M.R. Drinkwater, "Cryosphere Applications of NSCAT Data," *IEEE Trans. Geosci. Remote Sens.*, Vol. 37, No. 3, pp. 1671-1684, 1999.

[10] D.G. Long, "NSCAT Views Land and Ice," *Proc. Int. Geosci. Rem. Sens. Sym.*, pp. 1973-1975, Seattle, Washington, 6-10 July, 1998.

[11] Q.P. Remund and D.G. Long, "Optimization of SIRF for NSCAT," MERS Technical Report # MERS 97-003, Brigham Young University, 3 July 1997. Available on the web at `http://www.mers.byu.edu/Papers/mers_reports.html`

T (type)	Code Number	Description
a	1	A image (σ^o in dB at reference incidence angle)
C	8	counts or hits (measurements) per pixel
E	21	average reconstruction error image (dB)
I	7	incidence angle standard deviation (in deg)
J	9	average incidence angle (in deg)
m	0	mask image
p	11	pixel time estimate (min from start of image interval)
V	22	reconstruction error standard deviation image (dB)
x	3	longitude image (deg)
y	31	latitude image (deg)

Table 4: Selected standard type codes for `SIR` file names

Symbol	Valid Values	Definition
XX	10-14	DMSP platform identifier
Y	1-7	SSM/I channel number (19H, 19V, 22, 37H, 37V, 85H, 85V)
D	c,u,a,d	Ascending/descending indicator
		c: Both ascending and descending data used
		u: Both ascending and descending data used
		a: Ascending data only used
		d: Descending data only used
E	e,s	Ascending/descending indicator
		e: QuikScat egg σ^o measurements
		s: QuikScat slice σ^o measurements
P	h,v	Polarization

Table 5: Standard sensor string characters used in standard file naming scheme in Tab. 3.

RCN	Standard reconstruction technique
.sir	SIR or SIRF algorithm
.ave	AVE image algorithm
.non	non-enhanced
.grd	gridded
.brw	low resolution gridded browse image

Table 6: Standard reconstruction algorithm extensions for `SIR` file names

Extension	Description
.lmsk	land masked data image
.imsk	Ice masked image
.omsk	Ocean masked image
.dif	Difference image
.sr	Subregion extracted image
.ed	Manually edited image
.lmask	binary land mask image

Table 7: Standardized extra file extensions for `SIR` file names. These are optional.

REG	Code Number	Description
Ant	100	Antarctica
Arc	110	Artic
Grn	202	Greenland
Ala	203	Alaska
CAm	204	Central America
NAm	205	North America
SAm	206	South America
NAf	207	North Africa
SAf	208	South Africa
Sib	209	Siberia
Eur	210	Europe
SAs	211	South Asia
ChJ	212	China-Japan
Ind	213	Indonesia
Aus	214	Australia
Ber	256	Bering Sea

Table 8: Standard three character region abbreviation strings for `SIR` file names

[12] Q.P. Remund and D.G. Long, "Polar Sea Ice Extent Mapping Using Ku-Band Scatterometer Data," *J. Geophys. Res.*, Vol. 104, No. C5, pp. 11515-11527, 1999.

[13] Q.P. Remund and D.G. Long, "Sea Ice Mapping Algorithm for QuikSCAT and Seawinds," *Proc. Int. Geosci. Rem. Sens. Sym.*, pp. 1686-1688, Seattle, Washington, 6-10 July, 1998.

[14] Q.P. Remund and D.G. Long, "Iterative Estimation of Antarctic Sea Ice Extent Using SeaWinds Data," *Proc. Int. Geosci. Rem. Sens. Sym.*, Honolulu, Hawaii, 6-10 July, 200.

[15] H. Stephen and D.G. Long, "Study of Iceberg B10A Using Scatterometer Data," *Proc. Int. Geosci. Rem. Sens. Sym.*, Honolulu, Hawaii, 6-10 July, 200.

[16] G. Watt and D.G. Long, "Temporal Average Estimate Algorithm for ERS-1/2," MERS Technical Report, # MERS 97-07, Brigham Young University, 5 Aug. 1997. Available on the web at `http://www.mers.byu.edu/Papers/mers_reports.html`

[17] 'SeaWinds/QuikScat Users Guide", SeaWinds Project Office, Jet Propulsion Laboratory, Padadena, CA, 1999.

A Sample Qscat Product Listing

The following is a sample listing of the egg product files for the h pol beam. Similar products are produced for the v pol beam. Note that files with a `.non` extension contain the same data as the corresponding `.grd` file but the gridded data pixels have been replicated to produce images the same size as the `.sir` images. Browse (low resolution grided data) products have a `.brw` extension and are not land or ice masked. Selected products are also produced from slices, in which case the sensor prefix is 'qus' rather than 'que'.

Browse Products

```
queh-a-Glb99-001-001.brw
queh-V-Glb99-001-001.brw
queh-C-Glb99-001-001.brw
quev-a-Glb99-001-001.brw
quev-V-Glb99-001-001.brw
quev-C-Glb99-001-001.brw
```

Enhanced resolution and Grid Products

```
queh-C-Ala99-001-001.grd.lmsk
queh-C-Ant99-001-001.grd
queh-C-Arc99-001-001.grd
queh-C-Aus99-001-001.grd.lmsk
queh-C-Ber99-001-001.grd
queh-C-CAm99-001-001.grd.lmsk
queh-C-ChJ99-001-001.grd.lmsk
queh-C-Eur99-001-001.grd.lmsk
queh-C-Grn99-001-001.grd.lmsk
queh-C-Ind99-001-001.grd.lmsk
queh-C-NAf99-001-001.grd.lmsk
queh-C-NAm99-001-001.grd.lmsk
queh-C-SAf99-001-001.grd.lmsk
queh-C-SAm99-001-001.grd.lmsk
queh-C-SAs99-001-001.grd.lmsk
queh-C-Sib99-001-001.grd.lmsk
queh-E-Ala99-001-001.sir.lmsk
queh-E-Ant99-001-001.sir
queh-E-Arc99-001-001.sir
queh-E-Aus99-001-001.sir.lmsk
queh-E-Ber99-001-001.sir
queh-E-CAm99-001-001.sir.lmsk
queh-E-ChJ99-001-001.sir.lmsk
queh-E-Eur99-001-001.sir
queh-E-Eur99-001-001.sir.lmsk
queh-E-Grn99-001-001.sir.lmsk
queh-E-Ind99-001-001.sir.lmsk
queh-E-NAf99-001-001.sir.lmsk
queh-E-NAm99-001-001.sir.lmsk
queh-E-SAf99-001-001.sir.lmsk
queh-E-SAm99-001-001.sir.lmsk
queh-E-SAs99-001-001.sir.lmsk
queh-E-Sib99-001-001.sir.lmsk
queh-I-Ala99-001-001.grd.lmsk
queh-I-Ala99-001-001.sir.lmsk
queh-I-Ant99-001-001.grd
queh-I-Ant99-001-001.sir
queh-I-Arc99-001-001.grd
queh-I-Arc99-001-001.sir
queh-I-Aus99-001-001.grd.lmsk
queh-I-Aus99-001-001.sir.lmsk
queh-I-Ber99-001-001.grd
queh-I-Ber99-001-001.sir
queh-I-CAm99-001-001.grd.lmsk
queh-I-CAm99-001-001.sir.lmsk
queh-I-ChJ99-001-001.grd.lmsk
queh-I-ChJ99-001-001.sir.lmsk
queh-I-Eur99-001-001.grd.lmsk
queh-I-Eur99-001-001.sir.lmsk
queh-I-Grn99-001-001.grd.lmsk
queh-I-Grn99-001-001.sir.lmsk
queh-I-Ind99-001-001.grd.lmsk
queh-I-Ind99-001-001.sir.lmsk
queh-I-NAf99-001-001.grd.lmsk
queh-I-NAf99-001-001.sir.lmsk
queh-I-NAm99-001-001.grd.lmsk
queh-I-NAm99-001-001.sir.lmsk
queh-I-SAf99-001-001.grd.lmsk
queh-I-SAf99-001-001.sir.lmsk
queh-I-SAm99-001-001.grd.lmsk
queh-I-SAm99-001-001.sir.lmsk
queh-I-SAs99-001-001.grd.lmsk
queh-I-SAs99-001-001.sir.lmsk
queh-I-Sib99-001-001.grd.lmsk
queh-I-Sib99-001-001.sir.lmsk
queh-J-Ala99-001-001.grd.lmsk
queh-J-Ala99-001-001.sir.lmsk
```

queh-J-Ant99-001-001.grd
queh-J-Ant99-001-001.sir
queh-J-Arc99-001-001.grd
queh-J-Arc99-001-001.sir
queh-J-Aus99-001-001.grd.lmsk
queh-J-Aus99-001-001.sir.lmsk
queh-J-Ber99-001-001.grd
queh-J-Ber99-001-001.sir
queh-J-CAm99-001-001.grd.lmsk
queh-J-CAm99-001-001.sir.lmsk
queh-J-ChJ99-001-001.grd.lmsk
queh-J-ChJ99-001-001.sir.lmsk
queh-J-Eur99-001-001.grd.lmsk
queh-J-Eur99-001-001.sir.lmsk
queh-J-Grn99-001-001.grd.lmsk
queh-J-Grn99-001-001.sir.lmsk
queh-J-Ind99-001-001.grd.lmsk
queh-J-Ind99-001-001.sir.lmsk
queh-J-NAf99-001-001.grd.lmsk
queh-J-NAf99-001-001.sir.lmsk
queh-J-NAm99-001-001.grd.lmsk
queh-J-NAm99-001-001.sir.lmsk
queh-J-SAf99-001-001.grd.lmsk
queh-J-SAf99-001-001.sir.lmsk
queh-J-SAm99-001-001.grd.lmsk
queh-J-SAm99-001-001.sir.lmsk
queh-J-SAs99-001-001.grd.lmsk
queh-J-SAs99-001-001.sir.lmsk
queh-J-Sib99-001-001.grd.lmsk
queh-J-Sib99-001-001.sir.lmsk
queh-V-Ala99-001-001.grd.lmsk
queh-V-Ala99-001-001.non.lmsk
queh-V-Ala99-001-001.sir.lmsk
queh-V-Ant99-001-001.grd
queh-V-Ant99-001-001.non
queh-V-Ant99-001-001.sir
queh-V-Arc99-001-001.grd
queh-V-Arc99-001-001.non
queh-V-Arc99-001-001.sir
queh-V-Aus99-001-001.grd.lmsk
queh-V-Aus99-001-001.non.lmsk
queh-V-Aus99-001-001.sir.lmsk
queh-V-Ber99-001-001.grd
queh-V-Ber99-001-001.non
queh-V-Ber99-001-001.sir
queh-V-CAm99-001-001.grd.lmsk
queh-V-CAm99-001-001.non.lmsk
queh-V-CAm99-001-001.sir.lmsk
queh-V-ChJ99-001-001.grd.lmsk
queh-V-ChJ99-001-001.non.lmsk
queh-V-ChJ99-001-001.sir.lmsk
queh-V-Eur99-001-001.grd.lmsk
queh-V-Eur99-001-001.non.lmsk
queh-V-Eur99-001-001.sir.lmsk
queh-V-Grn99-001-001.grd.lmsk
queh-V-Grn99-001-001.non.lmsk
queh-V-Grn99-001-001.sir.lmsk
queh-V-Ind99-001-001.grd.lmsk
queh-V-Ind99-001-001.non.lmsk
queh-V-Ind99-001-001.sir.lmsk
queh-V-NAf99-001-001.grd.lmsk
queh-V-NAf99-001-001.non.lmsk
queh-V-NAf99-001-001.sir.lmsk
queh-V-NAm99-001-001.grd.lmsk
queh-V-NAm99-001-001.non.lmsk
queh-V-NAm99-001-001.sir.lmsk
queh-V-SAf99-001-001.grd.lmsk
queh-V-SAf99-001-001.non.lmsk
queh-V-SAf99-001-001.sir.lmsk
queh-V-SAm99-001-001.grd.lmsk
queh-V-SAm99-001-001.non.lmsk
queh-V-SAm99-001-001.sir.lmsk
queh-V-SAs99-001-001.grd.lmsk
queh-V-SAs99-001-001.non.lmsk
queh-V-SAs99-001-001.sir.lmsk
queh-V-Sib99-001-001.grd.lmsk
queh-V-Sib99-001-001.non.lmsk
queh-V-Sib99-001-001.sir.lmsk
queh-a-Ala99-001-001.ave.lmsk
queh-a-Ala99-001-001.grd.lmsk
queh-a-Ala99-001-001.non.lmsk
queh-a-Ala99-001-001.sir.lmsk
queh-a-Ant99-001-001.ave
queh-a-Ant99-001-001.grd
queh-a-Ant99-001-001.non
queh-a-Ant99-001-001.sir
queh-a-Arc99-001-001.ave
queh-a-Arc99-001-001.grd
queh-a-Arc99-001-001.non
queh-a-Arc99-001-001.sir
queh-a-Aus99-001-001.ave.lmsk
queh-a-Aus99-001-001.grd.lmsk
queh-a-Aus99-001-001.non.lmsk
queh-a-Aus99-001-001.sir.lmsk
queh-a-Ber99-001-001.ave
queh-a-Ber99-001-001.grd

queh-a-Ber99-001-001.non
queh-a-Ber99-001-001.sir
queh-a-CAm99-001-001.ave.lmsk
queh-a-CAm99-001-001.grd.lmsk
queh-a-CAm99-001-001.non.lmsk
queh-a-CAm99-001-001.sir.lmsk
queh-a-ChJ99-001-001.ave.lmsk
queh-a-ChJ99-001-001.grd.lmsk
queh-a-ChJ99-001-001.non.lmsk
queh-a-ChJ99-001-001.sir.lmsk
queh-a-Eur99-001-001.ave.lmsk
queh-a-Eur99-001-001.grd.lmsk
queh-a-Eur99-001-001.non.lmsk
queh-a-Eur99-001-001.sir.lmsk
queh-a-Grn99-001-001.ave.lmsk
queh-a-Grn99-001-001.grd.lmsk
queh-a-Grn99-001-001.non.lmsk
queh-a-Grn99-001-001.sir.lmsk
queh-a-Ind99-001-001.ave.lmsk
queh-a-Ind99-001-001.grd.lmsk
queh-a-Ind99-001-001.non.lmsk
queh-a-Ind99-001-001.sir.lmsk
queh-a-NAf99-001-001.ave.lmsk
queh-a-NAf99-001-001.grd.lmsk
queh-a-NAf99-001-001.non.lmsk
queh-a-NAf99-001-001.sir.lmsk
queh-a-NAm99-001-001.ave.lmsk
queh-a-NAm99-001-001.grd.lmsk
queh-a-NAm99-001-001.non.lmsk
queh-a-NAm99-001-001.sir.lmsk
queh-a-SAf99-001-001.ave.lmsk
queh-a-SAf99-001-001.grd.lmsk
queh-a-SAf99-001-001.non.lmsk
queh-a-SAf99-001-001.sir.lmsk
queh-a-SAm99-001-001.ave.lmsk
queh-a-SAm99-001-001.grd.lmsk
queh-a-SAm99-001-001.non.lmsk
queh-a-SAm99-001-001.sir.lmsk
queh-a-SAs99-001-001.ave.lmsk
queh-a-SAs99-001-001.grd.lmsk
queh-a-SAs99-001-001.non.lmsk
queh-a-SAs99-001-001.sir.lmsk
queh-a-Sib99-001-001.ave.lmsk
queh-a-Sib99-001-001.grd.lmsk
queh-a-Sib99-001-001.non.lmsk
queh-a-Sib99-001-001.sir.lmsk
queh-p-Ala99-001-001.grd.lmsk
queh-p-Ala99-001-001.sir.lmsk
queh-p-Ant99-001-001.grd
queh-p-Ant99-001-001.sir
queh-p-Arc99-001-001.grd
queh-p-Arc99-001-001.sir
queh-p-Aus99-001-001.grd.lmsk
queh-p-Aus99-001-001.sir.lmsk
queh-p-Ber99-001-001.grd
queh-p-Ber99-001-001.sir
queh-p-CAm99-001-001.grd.lmsk
queh-p-CAm99-001-001.sir.lmsk
queh-p-ChJ99-001-001.grd.lmsk
queh-p-ChJ99-001-001.sir.lmsk
queh-p-Eur99-001-001.grd.lmsk
queh-p-Eur99-001-001.sir.lmsk
queh-p-Grn99-001-001.grd.lmsk
queh-p-Grn99-001-001.sir.lmsk
queh-p-Ind99-001-001.grd.lmsk
queh-p-Ind99-001-001.sir.lmsk
queh-p-NAf99-001-001.grd.lmsk
queh-p-NAf99-001-001.sir.lmsk
queh-p-NAm99-001-001.grd.lmsk
queh-p-NAm99-001-001.sir.lmsk
queh-p-SAf99-001-001.grd.lmsk
queh-p-SAf99-001-001.sir.lmsk
queh-p-SAm99-001-001.grd.lmsk
queh-p-SAm99-001-001.sir.lmsk
queh-p-SAs99-001-001.grd.lmsk
queh-p-SAs99-001-001.sir.lmsk
queh-p-Sib99-001-001.grd.lmsk
queh-p-Sib99-001-001.sir.lmsk

Fig. 1 SeaWinds geometry. (left) Swath diagram. (center) Contour plots of the antenna illumination patterns for egg and slie measurements. (right) Enhanced resolution grid illustration with single slice.

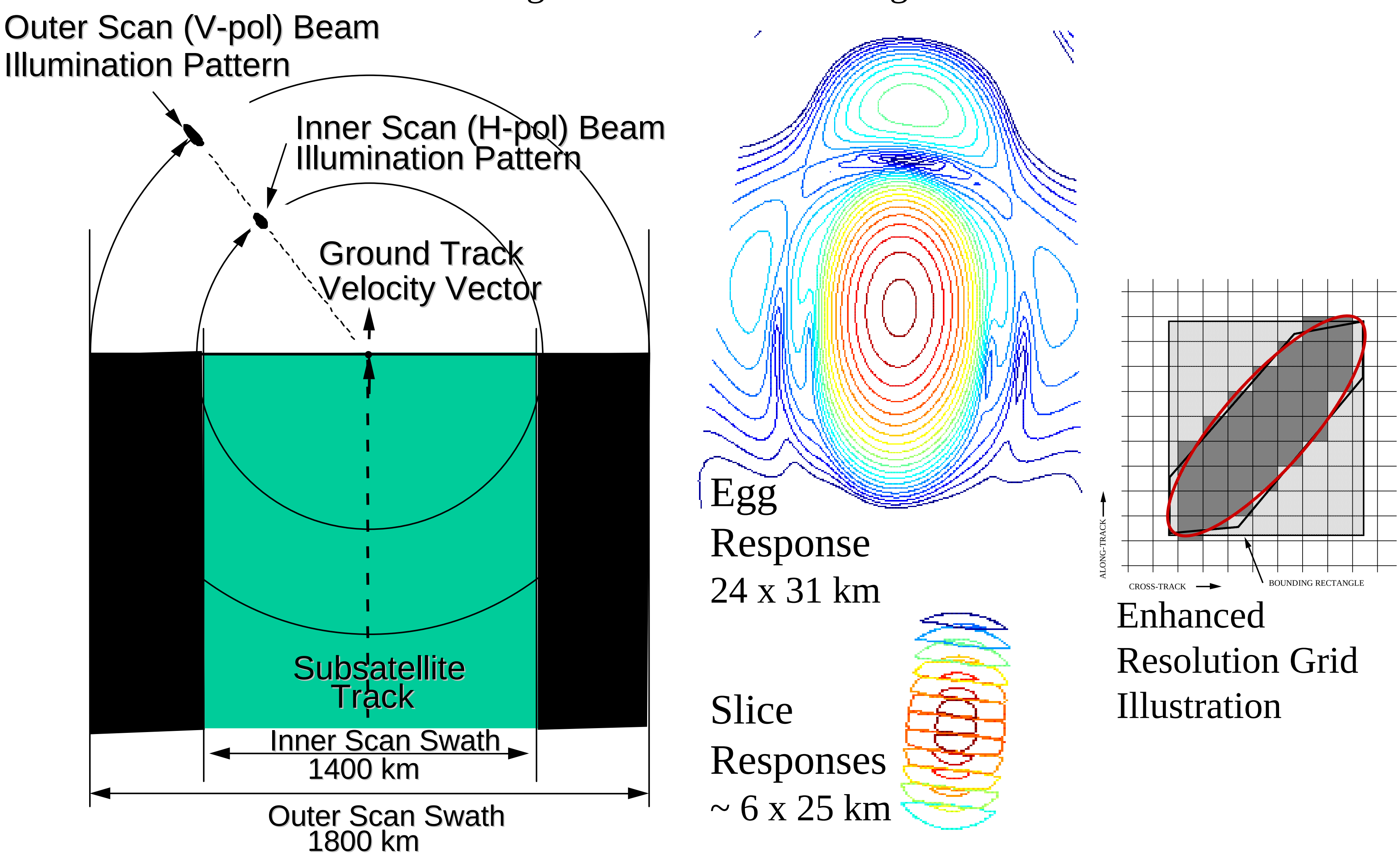
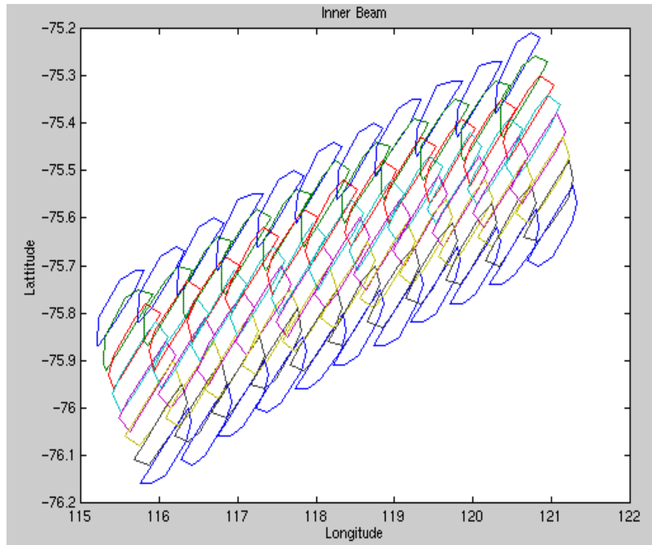
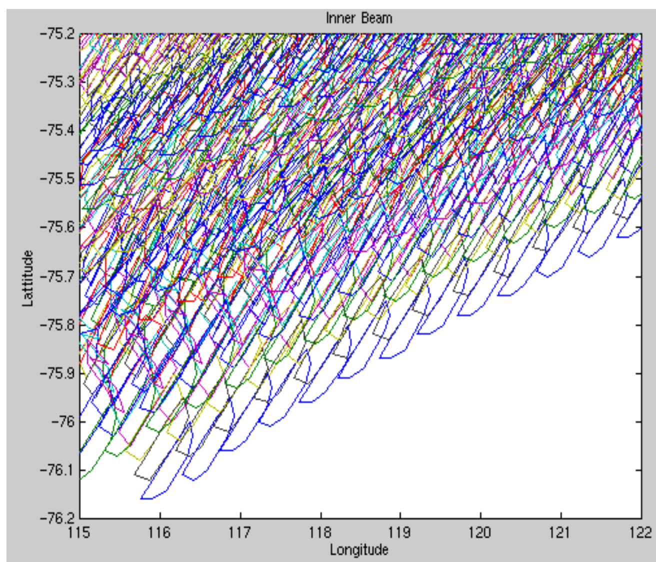


Fig. 2. Overlap of QuikScat slices for (top) a few consecutive pulses during a single antenna rotation and (lower) several antenna rotations





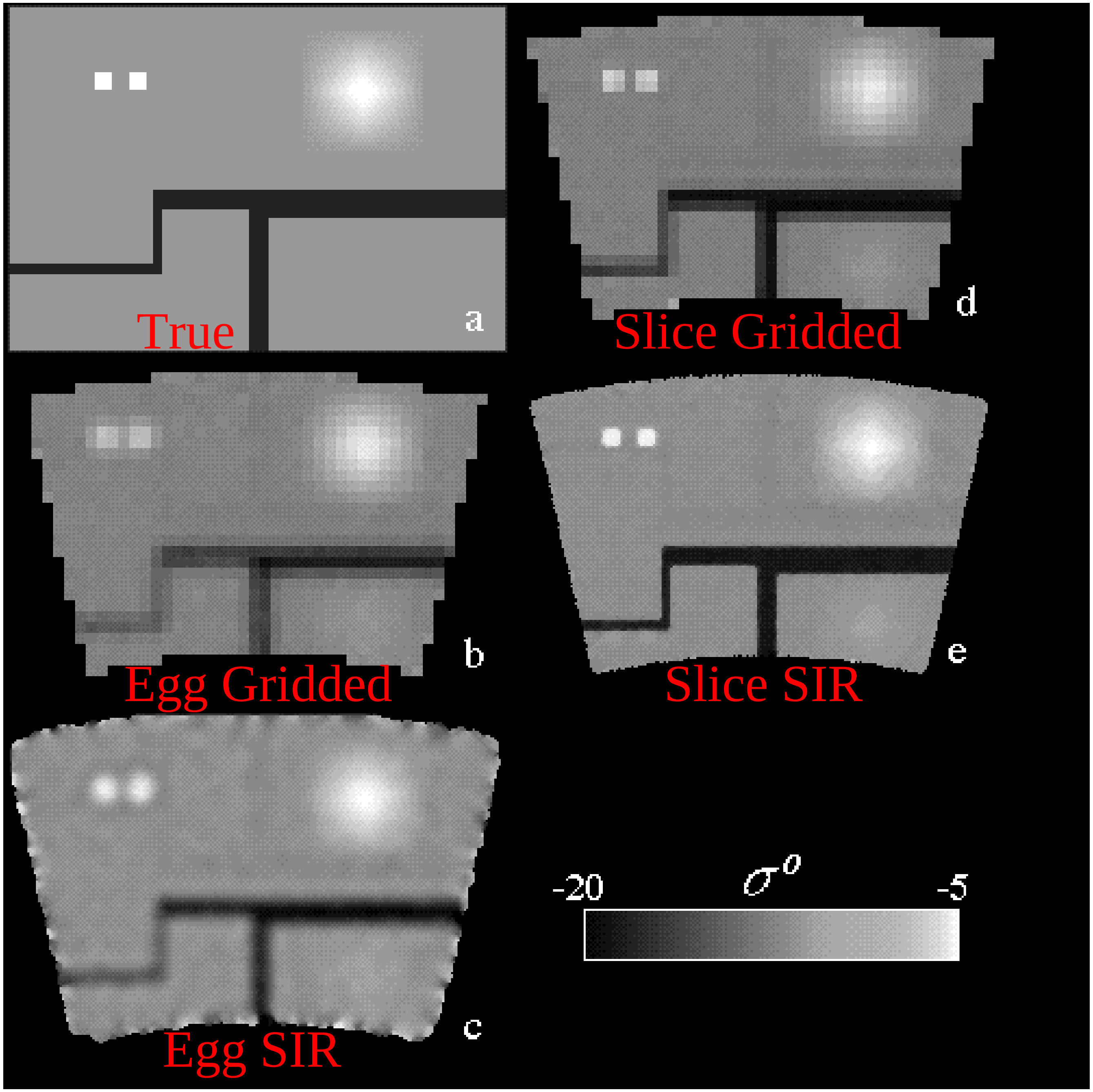


Fig. 3. SIR algorithm Simulation results. (a) Synthetic true image. (b) “drop in the bucket” grid image [non image] from eggs. (c) SIR image from egg measurements. (d) Grid image from slices [non image]. (e) SIR image from slices.

Fig. 4. Examples of polar region *A* images. These images have been ice masked.

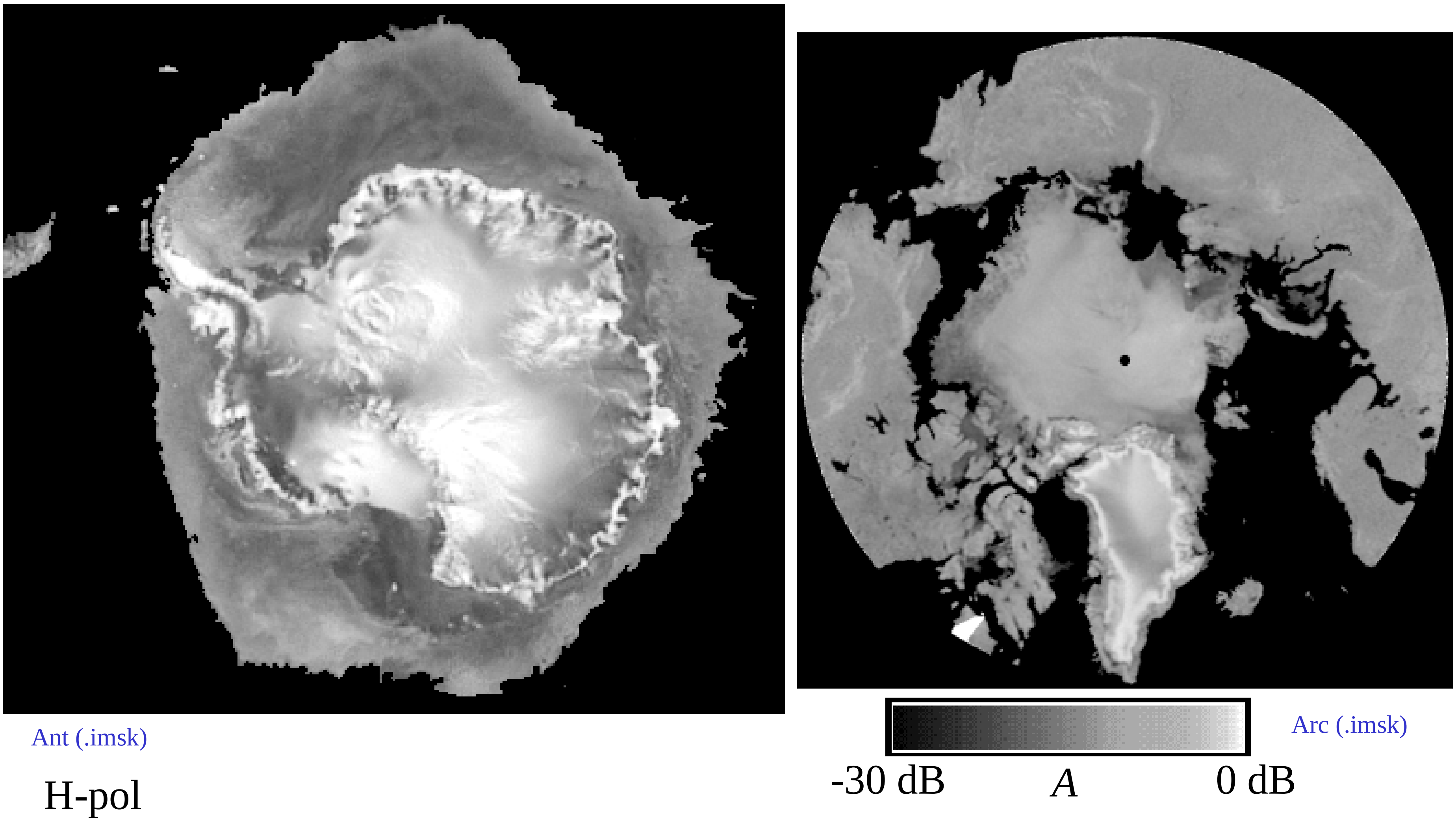


Fig. 5. Examples of QuikScat enhanced resolution land regions.
All images have been land masked. Red boxes are shown in greater detail in later figures.

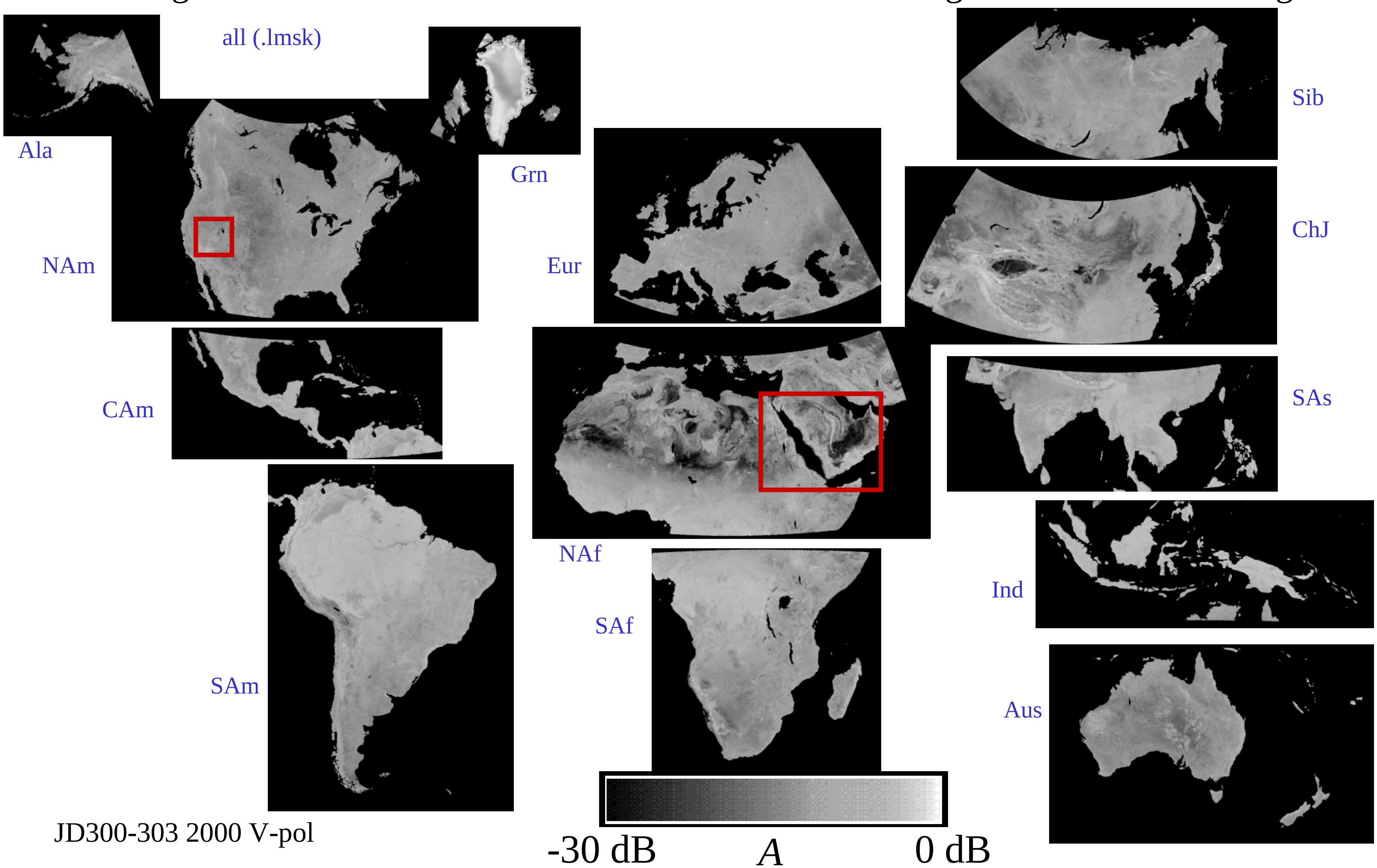


Fig. 6. Egg-based SIR enhanced-resolution image example.

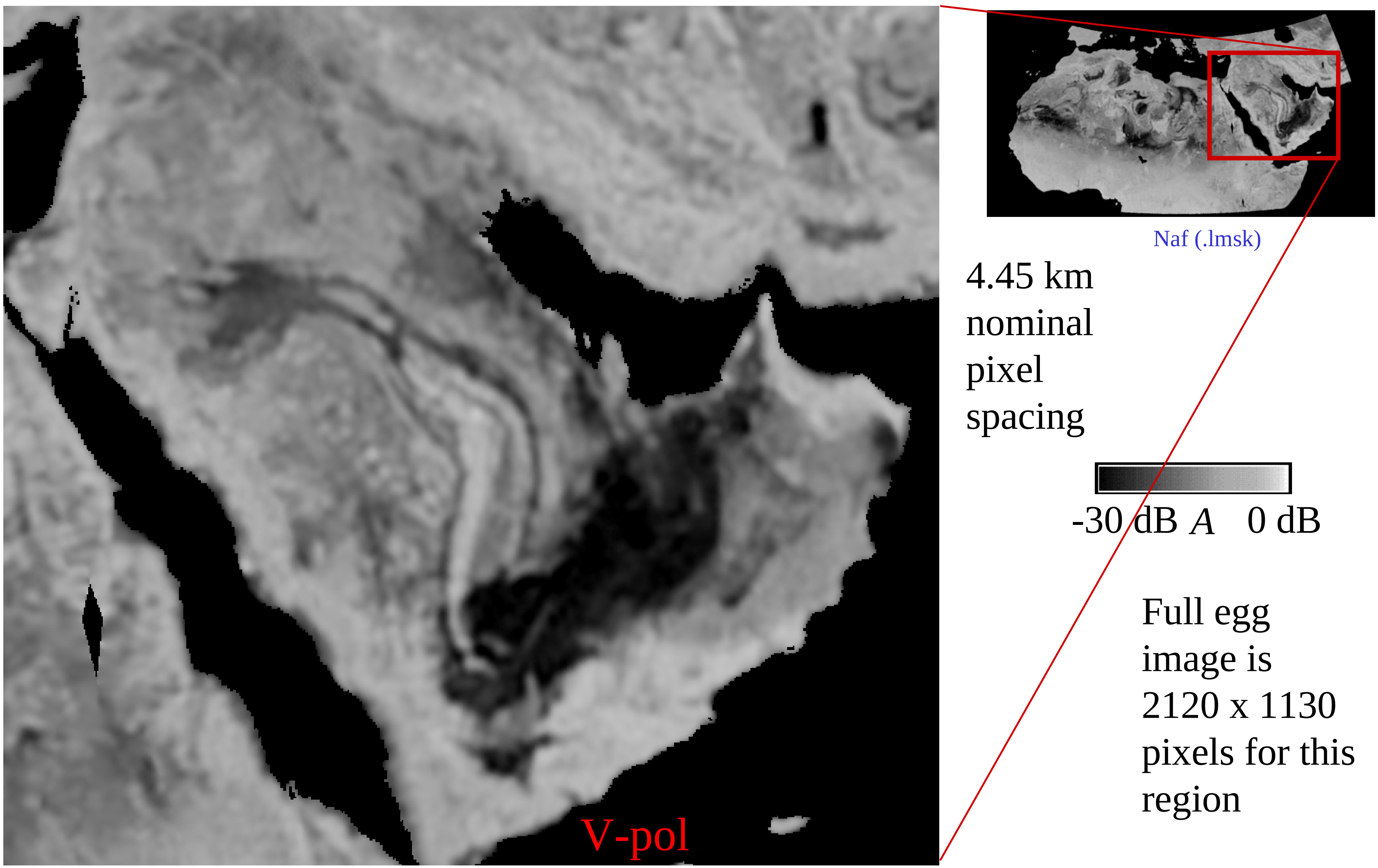


Fig. 7. Resolution comparison of various reconstruction types.

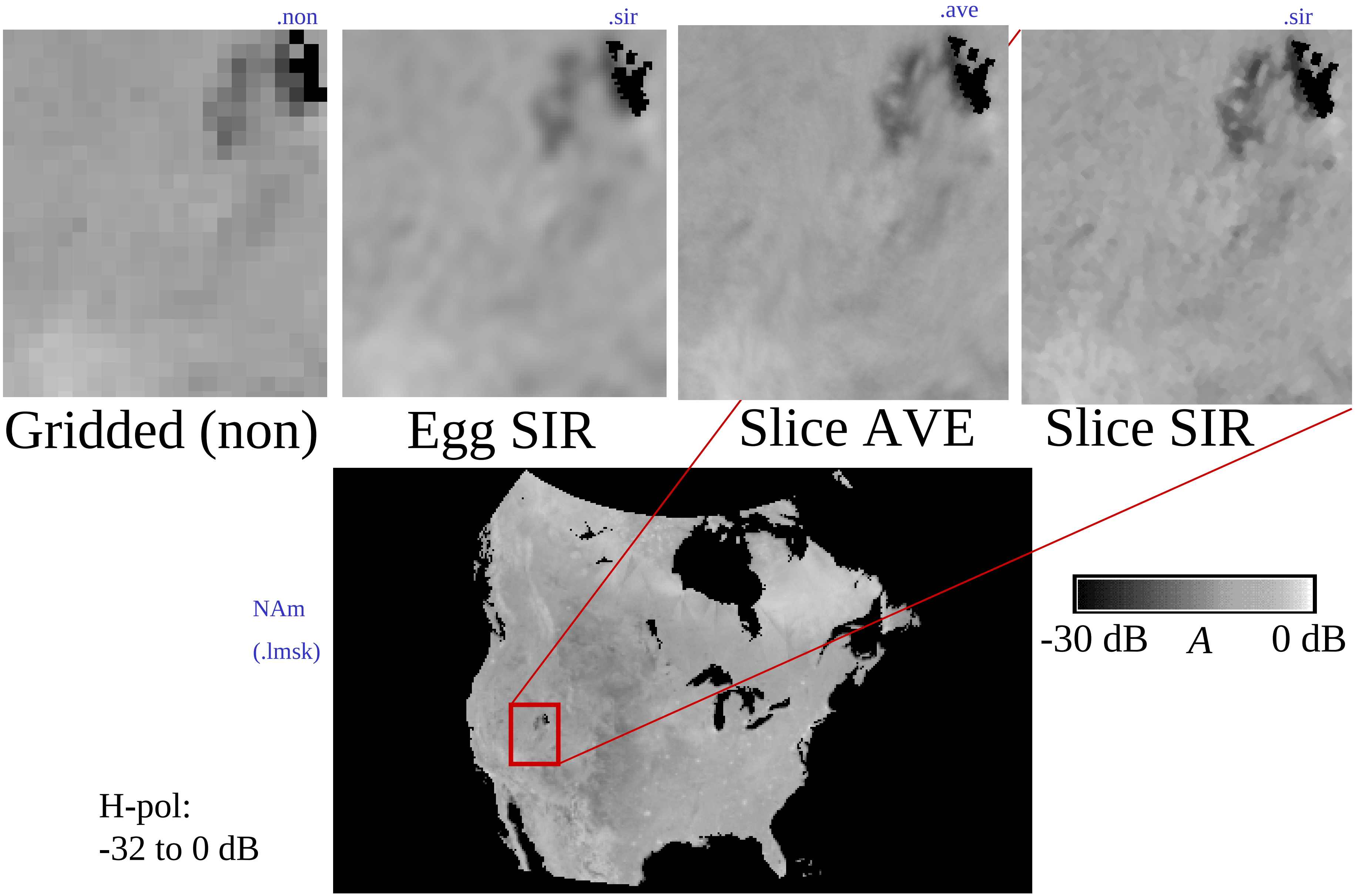


Fig. 8. Example ancillary products