NASA SCP Arctic and Antarctic Ice Extent from QuikSCAT, 1999-2009, Version 2

USER GUIDE

How to Cite These Data

As a condition of using these data, you must include a citation:

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National Snow and Ice Data Center

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1 DETAILED DATA DESCRIPTION

This data set provides sea ice extent for the Arctic and Antarctic in Scatterometer Image Reconstruction (SIR) binary image format, along with ASCII text files containing latitude and longitude coordinates along the sea ice edge, and browse images of SIR files in Graphics Interchange Format (GIF) format. Ancillary products include daily-averaged total sea ice extent in ASCII format. Estimates of sea ice extent were produced from daily-averaged QuikSCAT sigma-0 measurements and extend from 19 July 1999 to 31 December 2009.

QuikSCAT obtains 12 individual radar normalized backscatter (sigma-0) measurements, called slices, for each footprint as it scans over a 1800 km wide swath. Slices are typically 4 to 6 km long by 20 km wide. The summed measurements of the slices are called egg measurements. The effective resolution and shape of each egg measurement is approximately 20 by 30 km, depending on the antenna beam and instrument mode. This data set contains both slice and egg images for each day.

The Microwave Earth Remote Sensing (MERS) group at Brigham Young University (BYU) developed a SIR-with-filtering (SIRF) algorithm that combines forward- and aft-looking sigma-0 measurements to produce enhanced-resolution backscatter images over various azimuth angles. The polarization ratio, incidence angle dependence, and the sigma-0 estimate error standard deviation were used to discriminate between sea ice and ocean. Sea ice extent was estimated for both slice and egg images. The nominal pixel resolution of the slice images is 2.225 km with an estimated effective resolution of approximately 4 km. Egg images have a nominal pixel resolution of 4.45 km with an estimated effective resolution of approximately 8 to 10 km.

1.1 Format

1.1.1 SIR Images

The SIR image format was developed by BYU-MERS to store images and corresponding geolocation information. A SIR file contains at least one 512-byte header with information necessary to read the remainder of the file, and projection information to geolocate the data. Headers also contain scale factors to convert floating-point data to integers. The header is followed by image data and additional zero padding to ensure the file is a multiple of 512 bytes long. Pixel values are generally stored in 4-byte float arrays, with most significant byte (MSB) order. Grid size varies between hemispheres and between egg and slice images, but not within an egg image for a specific year. See the Section 2.0 Software and Tools for tools that read SIR files.

The array index (n) of the (i,j)th pixel is given by:

$n = (j-1)*Nx + i$

Where:

i is horizontal location
j is vertical location
Nx is horizontal dimension of the image

Ocean areas outside of the estimated sea ice extent are set to a "no data" value of 0.

1.1.2 ASCII Ice Extent

For each SIR image, a corresponding ASCII text file (designated by an .ie extension) gives latitude and longitude pairs representing the contour points of the estimated sea ice edge. These values were obtained by computing the coordinates of each pixel along the edge of the corresponding binary ice mask. Longitude values range from -180 to 180. Multiple contours are separated by a "0 0" entry.

1.1.3 Browse Images

Daily browse images of sea ice extent from SIR images are provided in GIF format.

1.1.4 Ancillary Ice Extent Products

Daily total sea ice extent for Arctic and Antarctic egg and slice images are provided to support investigations of interannual variability and trends in sea ice cover. File names are as follows:

- quev_daily_extent_1999-2009.n
- qusv_daily_extent_1999-2009.n
- quev_daily_extent_1999-2009.s
- qusv_daily_extent_1999-2009.s

The "n" file extension represents the Arctic, and the "s" represents the Antarctic. Data are in ASCII text format, with columns for year, day of month, total number of pixels with at least 15% ice, and total ice extent (km2). In computing total ice extent, pixels must have an ice concentration of 15% or greater to be included; thus, total ice extent is computed by summing the total number of pixels with at least 15% ice concentration multiplied by the area per pixel. These files include all data, including bad data values.

1.2 File and Directory Structure

Data files, browse images, ancillary files, and tools to read the data are available via FTP. Files are organized as follows:

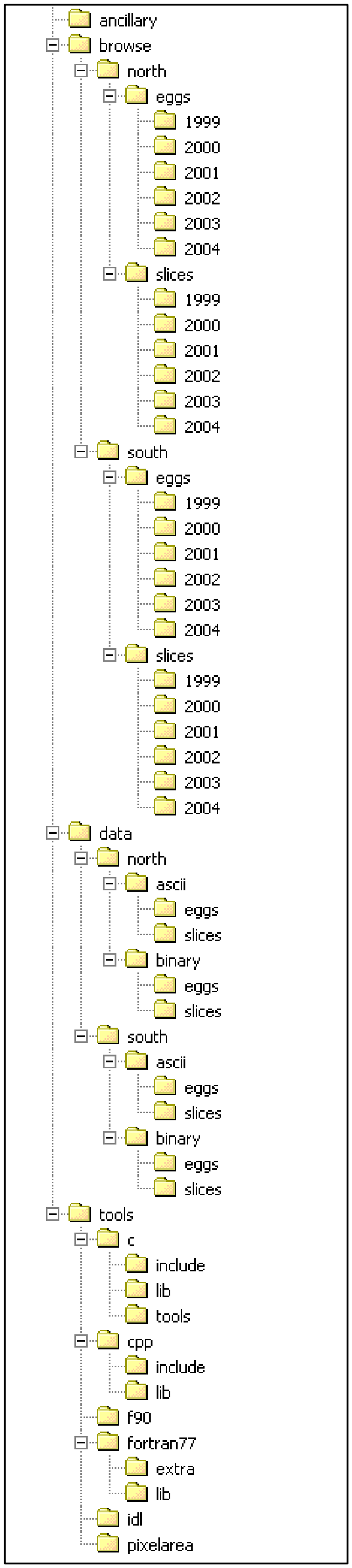

Figure 1. File Organization

Use binary mode to transfer SIR binary images, and ASCII mode to transfer the ASCII ice extent files. The data files are gzipped. Yearly files are also provided as tar files within each "eggs" or "slices" data directory.

1.3 File Naming Convention

The file naming convention for SIR and ASCII data files is as follows:

sens-a-regyr-dy1-dy2.sir.fff

Refer to Table 1 for the file name variable names and descriptions.

Table 1. File Naming Convention

Variable	Description
`sens`	A four-character sensor name: quev = QuikSCAT egg outer beam (vertical polarization) qusv = QuikSCAT slice outer beam (vertical polarization
`a`	Image type code for the "A" image (sigma-0 in dB, typically at 40° incidence)
`reg`	A three-character region indicator: Ant = Antarctica Arc = Arctic
`yr`	The two-digit year (such as 99, 00, 01, etc.)
`dy1`	The first day of data used to make the image, expressed as a three-digit Julian date
`dy2`	The last day of data used to make the image, expressed as a three-digit Julian date
`sir`	Indicates the SIR algorithm reconstruction technique
`fff`	A file extension that indicates the file type: imsk.mask is a SIR-formatted file with a binary ice mask ie is an ASCII sea ice extent file

The data files are provided in gzipped format for download, and therefore include an additional .gz file extension.

Yearly files are also provided as tar files within each "eggs" or "slices" data directory. These yearly tar files use the following naming convention:

sens-a-regyr-sir.tar

Refer to Table 2 for the tar file name variable names and descriptions.

Table 2. Tar File Naming Convention

Variable	Description
sens	A four-character sensor name: quev = QuikSCAT egg outer beam (vertical polarization) qusv = QuikSCAT slice outer beam (vertical polarization
a	Image type code for the "A" image (sigma-0 in dB, typically at 40° incidence)
reg	A three-character region indicator: Ant = Antarctica Arc = Arctic
yr	The two-digit year (such as 99, 00, 01, etc.)
sir	Indicates the SIR algorithm reconstruction technique
tar	The file extension indicating a tar file.

1.4 Spatial Coverage

Arctic Images

Southernmost Latitude: 60° N

Northernmost Latitude: 90° N

Westernmost Longitude: 180° W

Easternmost Longitude: 180° E

Antarctic Images

Southernmost Latitude: 90° S

Northernmost Latitude: 52° S

Westernmost Longitude: 180° W

Easternmost Longitude: 180° E

QuikSCAT is in an approximately four-day repeat orbit. While the satellite covers 95% of the Earth's oceans in one day, the frequency of swath coverage is highly dependent on latitude, with the most frequent passes near the poles. All of the product area is covered at least once a day. It takes a minimum of two days to provide complete coverage of the rest of the Earth's surface.

The nominal pixel resolution of the slice images is 2.225 km with an estimated effective resolution of approximately 4 km. Egg images have a nominal pixel resolution of 4.45 km with an estimated effective resolution of approximately 8 to 10 km. The effective resolution depends on the number of sigma-0 measurements and their overlap, orientation, and spatial locations.

1.4.1 Spatial Resolution

The SIR images are in a polar stereographic projection. The lower-left corner of an image represents the origin. The geographic location of a given pixel corresponds to its lower-left corner.

1.5 Temporal Coverage

Data extend from 19 July 1999 to 31 December 2009. Table 3 lists the dates for which data are missing.

Table 3. Missing Dates

Year	Arctic Slices	Arctic Eggs	Antarctic Slices	Antarctic Eggs
2001	Days 132, 133, 189	Days 132, 133, 178, 189	Days 132, 133, 189	Days 132, 133, 175, 189
2002	N/A	N/A	Day 091	N/A
2005	N/A	N/A	Day 40	Day 55
2006	Day 197	Day 197	Day 197	Day 197
2008	Days 332, 333	Days 332, 333	Days 332, 333	Days 226, 332, 333
2009	Days 328 – 365	Days 328 – 365	Days 328 – 365	Days 328 – 365

1.5.1 Temporal Resolution

Arctic and Antarctic SIR images and ASCII ice extent files were produced on a daily basis.

1.6 Parameter

1.6.1 Parameter Description

This product contains daily sea ice extent.

1.6.2 Sample Data Record

The following output is from the first several lines of "qus_s_2000_001.ie," a sample ASCII ice extent file. The two values are latitude and longitude contour points along the estimated sea ice edge. Multiple contours are separated by a "0 0" entry.

0.000	0.000
-119.085	-88.729
-117.834	-88.721
-117.015	-88.730

-117.441	-88.748
0.000	0.000
-118.270	-88.739
-119.085	-88.729
0.000	0.000
-116.600	-88.712
-116.196	-88.693
-115.804	-88.675
-114.627	-88.665
-113.820	-88.674
-113.004	-88.682
-113.358	-88.701
-112.521	-88.709
-111.674	-88.716
-110.817	-88.724
-109.951	-88.731

The following screen capture from IDL 6.0 shows a sample binary masked ice extent image of Antarctica from 06 August 2003. Click on the thumbnail for a larger image.

0 = water
1 = ice
2 = land

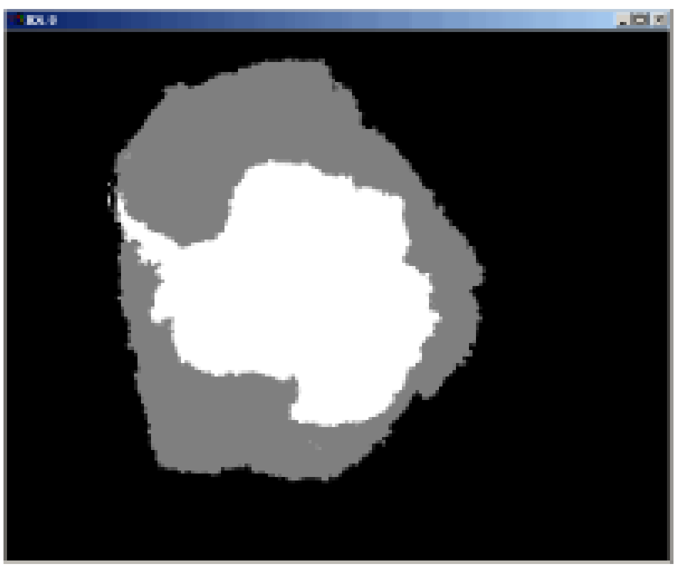

Figure 2. Sample masked ice extent image of Antarctica, 2003-08-06

The following output is from "daily_extent_1999-2004.n," a sample daily averaged ice extent ancillary file.

Table 4. Sample Daily Averaged Ice Extent Data

Year	Day	Number of Pixels	Ice Extent
1999	200	187920	3.85E+06
1999	201	426016	8.73E+06
1999	202	426197	8.73E+06
1999	203	417813	8.56E+06
1999	204	419403	8.59E+06
1999	205	419664	8.60E+06

2 SOFTWARE AND TOOLS

Interactive Data Language (IDL), C, and Fortran programs are provided that read and display SIR image data. Pixel area files are also provided to accompany Arctic and Antarctic egg and slice images. Other IDL and MATLAB programs are available from BYU-MERS.

The following tools are available from the "tools" directory.

The IDL, C, and Fortran programs were written by BYU-MERS and redistributed at NSIDC for user convenience. Please read the README files provided with each set of programs for instructions on using them. Other IDL and MATLAB programs are available from BYU-MERS. The IDL, C, and Fortran code may be copied and modified so long as (1) original or modified code is not redistributed for profit and (2) acknowledgement is made that the original code was obtained courtesy of David G. Long at the Microwave Earth Remote Sensing Laboratory at Brigham Young University.

2.1 Interactive Data Language (IDL) Programs

loadsir.pro: Simple IDL program to read and display SIR files. Use the following command at the IDL prompt to display a SIR file in a 512 by 512 window:

```
loadsir,'filename.sir.mask',array,info
sirimage=congrid(array,512,512)
tvscl,sirimage
```

2.2 C and C++ Programs

Code is provided to read SIR files using C and C++. Utilities are also provided to convert SIR images to other file types (BMP and GIF).

2.3 Fortran Programs

Code is provided to read SIR files using Fortran 77 and Fortran 90. Utilities are also provided to convert SIR images to other file types (byte).

2.4 Pixel Area Files

NSIDC developed the following grids (in SIR format) to determine the area of a given pixel for the ice extent SIR files:

quev_n_pixelarea.sir: Pixel area file for Arctic egg images
quev_s_pixelarea.sir: Pixel area file for Antarctic egg images
qusv_n_pixelarea.sir: Pixel area file for Arctic slice images
qusv_s_pixelarea.sir: Pixel area file for Antarctic slice images

2.5 Quality Assessment

Sea ice extent images were manually checked for spatial and temporal consistency. NSIDC noticed some inconsistencies in the ice extents from QuikSCAT. Slice images appear much noisier than egg images in the Arctic, particularly in 2003 and 2004.

Antarctic ice extents should match well between QuikSCAT and Special Sensor Microwave/Imager (SSM/I) using a 30% ice concentration threshold, but a preliminary analysis shows they match well even with a 15% threshold. In the Arctic, SSM/I shows much greater winter ice extents compared to QuikSCAT.

The differences in arctic ice extent between SSM/I and QuikSCAT may relate to the physical properties of the ice, in the sense that QuikSCAT does not "see" the first-year ice as readily as it sees the more highly scattering multiyear ice. In the Antarctic--where pancake ice, frazil ice formation, and refrozen snow slush at the snow/ice interface are prevalent, scattering is sufficient enough to yield similar extent results between SSM/I and QuikSCAT scatterometer data.

3 DATA ACQUISITION AND PROCESSING

3.1 Theory of Measurements

Radar scatterometers transmit pulses of microwave energy toward the earth and measure the returned echo, or reflected energy. The magnitude of the returned echo depends on the electrical properties and surface roughness.

SIR images are created from QuikSCAT Level-1B measurements of the normalized radar backscattering coefficient (sigma-0). The radar equation, which relates the radar return energy to the transmitted energy from scatterometers and takes into account various electrical and geometric factors, is the basis for computing sigma-0. Estimates of sigma-0 are often noisy because of instrument thermal noise and radar signal fading effects. Ku-band sigma-0 response over polar regions is a function of surface roughness, water content, and ice type (Remund and Long 1998). See JPL (2001) for details of how sigma-0 is calculated from scatterometers.

Ku-band radar backscatter is very sensitive to the difference between ice and water. The ratio of horizontally and vertically polarized sigma-0 images, coupled with image error standard deviations, is used to discriminate between open ocean and sea ice using a maximum likelihood classifier. Residual classification errors are reduced through binary image processing techniques and sea ice growth and retreat constraint methods.

3.2 Data Acquisition Methods

QuikSCAT uses a 1 m diameter rotating dish antenna with two spot beams that sweep in a circular pattern. The antenna radiates microwave pulses at a frequency of 13.4 GHz, and uses a conically scanning pencil-beam method to rotate a single beam of pulses at multiple angles (JPL 2001). The antenna spins at a rate of 18 rpm, scanning two pencil-beam footprint paths at incidence angles of 46° (H-pol, inner beam) and 54° (V-pol, outer beam). QuikSCAT's viewing geometry is illustrated as follows:

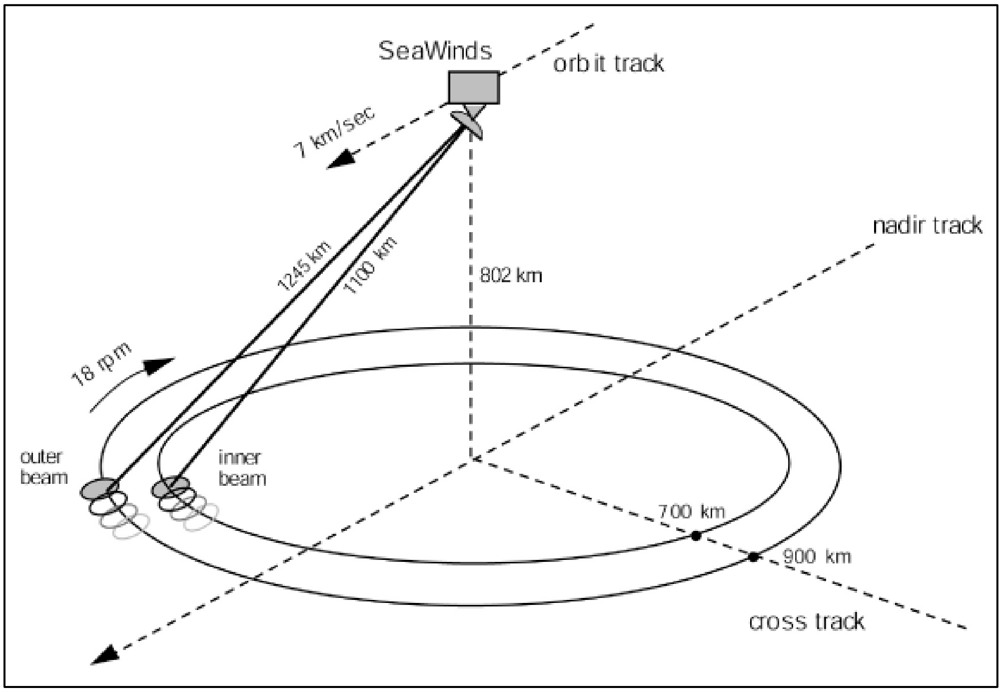

Figure 3. QuikSCAT Viewing Geometry. Image courtesy of Spencer, Wu, and Long (2000)

QuikSCAT obtains 12 individual radar normalized backscatter (sigma-0) measurements, called "slices," for each footprint as it scans over a 1800 km wide swath. Slices are typically 4 to 6 km long by 20 km wide. They are created by summing six Fast Fourier Transform (FFT) bins spaced over the center peak in the return echo spectrum. The summed measurements of the eight center slices are called "egg" measurements. The effective resolution and shape of an egg measurement is approximately 20 by 30 km, depending on the antenna beam and instrument mode. Egg images are produced using hardware aboard QuikSCAT from all of the slices, including those not down linked. BYU-MERS computes the spatial response function for each egg, as part of their process for creating images. The spatial response function is used in the image reconstruction algorithm that yields higher-resolution images. Refer to Section 3.3 Derivation Techniques and Algorithms.

The eight center slices used in an image have a finer resolution than the egg images produced onboard QuikSCAT, and are used to improve the resolution of the egg images. The slice and egg images were designed to overlay if the spatial resolution of the egg image pixel is doubled. The nominal pixel resolution of the slice images is 2.225 km with an estimated effective resolution of approximately 4 km. Egg images have a nominal pixel resolution of 4.45 km with an estimated effective resolution of approximately 8 to 10 km.

Although the egg images have a lower spatial resolution, they have less noise and are less sensitive to calibration errors than slice images (Long 2000).

3.3 Derivation Techniques and Algorithms

The QuikSCAT sea ice extent algorithm is based on the SIR with Filtering (SIRF) algorithm developed at BYU-MERS. The SIRF algorithm was originally developed to enhance Seasat scatterometer image resolution by combining data from multiple passes of the satellite (Long, Hardin and Whiting 1993) but has also been used with SSM/I radiometer data and European Remote Sensing (ERS) scatterometer data. Forward- and aft-looking sigma-0 measurements are combined to produce enhanced-resolution images over various azimuth angles. The images represent a nonlinear, weighted average of the sigma-0 measurements.

BYU-MERS created Arctic and Antarctic subsets and estimated sea ice extent for both slice and egg images. The polarization ratio, incidence angle dependence, and the sigma-0 estimate error standard deviation were used to discriminate between sea ice and ocean. Residual, misclassification noise was reduced using binary image processing techniques such as region growing, erosion, and dilation, resulting in a low-pass, filtered version of the sea ice extent edge. The resulting edge closely matches the 30% ice concentration edge calculated from the NASA Team algorithm, in the DMSP SSM/I Daily and Monthly Polar Gridded Bootstrap Sea Ice Concentrations product formerly distributed by NSIDC.

Ideally, egg and slice images should give the same area; however, the ice extent is computed independently for each image. Since the original measurements are somewhat different (slices are noisier than egg images), the results may be slightly different.

See Remund and Long (2000), Remund and Long (1999), Remund and Long (1998), and Long, Hardin, and Whiting (1993) for further details on the SIRF algorithm and how sea ice extent was estimated.

3.3.1 Version History

Table 5 outlines the processing and algorithm history for this product. Note: Versions are not indicated in file names.

Table 5. Description of Version Changes

Version	Date	Description of Changes
V02	March 2013	Updated data set through 2009; updated missing date information to reflect new temporal coverage Changed SIR images from 2-byte integers to 4-byte float arrays Changed browse image format from PNG to GIF
V01	August 2005	Original version of data

3.3.2 Error Sources

The following information is from Long (2000):

Forward- and aft-looking sigma-0 measurements are combined to produce imagery over various azimuth angles. The azimuth angles of the measurements over a given location vary with the pixel location and time, and may be further affected by missing or low-quality data. While most regions with sea ice exhibit little variation in sigma-0 with azimuth angle, sigma-0 in some regions (for example, East Antarctica) is dependent on the azimuth angle of the observations. Since sigma-0 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.

From multiple polarization sigma-0, sea ice extent is estimated using a classification scheme to separate sea ice from open ocean. High winds can make the ocean appear like ice, while surface melt conditions can make sea ice appear like ocean. Rapid ice edge motion can also lead to misclassification errors.

QuikSCAT suffered a power anomaly on 18 November 1999; the corresponding Arctic and Antarctic egg images are blank on this day, while the slice images are not. Since ASCII ice extent files are based on contour points along the ice edge, a substantial loss of data on a given day adversely affects the ice extent for that day. Algorithm classification errors may be evident on some days. For example, on 28 June 2003, a storm made the ocean appear as ice in one specific area.

See JPL (2001) for other possible sources of error in QuikSCAT observations.

3.4 Sensor or Instrument Description

The SeaWinds scatterometer flies on NASA's Quick Scatterometer (QuikSCAT) satellite. SeaWind's primary science objective is to acquire high-resolution, continuous, all-weather measurements of near-surface vector winds over the ice-free global oceans (Kramer 1994), but it has also proven useful for land and ice studies. Other characteristics are listed below:

Time period: 19 July 1999 to present
Polarizations: V-Outer/H-inner
Frequency: 13.4 GHz (Ku band)
Resolution: 25 x 30 km (egg), 25 x 6 km (slice)
Swath width: 1400 km/1800 km

4 REFERENCES AND RELATED PUBLICATIONS

The following references were used in this document:

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6 DOCUMENT INFORMATION

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