National Snow and Ice Data Center

MODIS Mosaic of Antarctica 2003-2004 (MOA2004) Image Map

The MODIS Mosaic of Antarctica 2003-2004 (MOA2004) Image Map consists of two cloud-free digital image maps that show mean surface morphology and a quantitative measure of optical snow grain size on the Antarctic continent and surrounding islands using 260 orbit swaths from the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on board the NASA EOS Aqua and Terra satellites. The 260 orbit swaths used to create the 2003-2004 MOA Surface Morphology Image Map and the 2003-2004 MOA Grain Size Image Map were acquired 20 November 2003 through 29 February 2004 for the full spring-summer season. The 122 orbit swaths used to create the 2003 MOA Grain Size Image Map were acquired 1 November 2003 through 17 December 2003 for the shortened spring-only season. Vector data sets with the corresponding coastlines, ice sheet grounding lines, and islands are also provided.

Overview

Platform	Aqua/Terra Spacecraft (EOS PM-1/EOS AM-1)
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Spatial Coverage	Southernmost Latitude: 90° S Northernmost Latitude: 60° S Westernmost Longitude: 180° W Easternmost Longitude: 180° E
Spatial Resolution	This data set has two spatial resolutions: Grid scale of 750 m Grid scale of 125 m with an estimated resolution of 150 m to 200 m
Temporal Coverage	**2003 MOA Grain Size Image Map** 1 November 2003 through 17 December 2003 **2003-2004 MOA Surface Morphology Image Map & Grain Size Image Map** 20 November 2003 through 29 February 2004
Parameters	Surface Morphology Snow Grain Size
Data Format	• Mapx Map Projection Paramenters ASCII text file (`.mpp`) • Mapx Grid Parameters Definition ASCII text file (`.gpd`) • gzipped flat binary file for corresponding file (`.img.gz`) • ENVI header for corresponding *.img file (`.img.hdr`) • gzipped GeoTIFF for corresponding `*.img` file (`.tif.gz`) • ESRI Shapefiles (`.shp, .shx, .dbf, and .prj`) • ENVI Vector File (`*.evf`) • Generic Mapping Tools (GMT) Vector Files (`*.gmt`) • Keyhole Markup Language (KML) Vector Files (`*.kml`)
Metadata Access	View Metadata Record
Data Access	FTP MODIS MOSAIC of Antarctic (MOA) Map Server
Version History	In version 1.1, the original grain size image file, `moa750_r1_nds.img.gz`, was replaced with several new grain size image files with better resolution, and file names were changed to reflect the year for the data acquisition.

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Citing These Data

Data Citation

We kindly request that you cite the use of this data set in a publication using the following citation. For more information, see our Use and Copyright Web page.

Haran, T., J. Bohlander, T. Scambos, T. Painter, and M. Fahnestock 2005, updated 2013. *MODIS Mosaic of Antarctica 2003-2004 (MOA2004) Image Map*. Boulder, Colorado USA: National Snow and Ice Data Center. http://dx.doi.org/10.7265/N5ZK5DM5.

Literature Citation

The generation of this data set is discussed in the following article(s). Please acknowledge the use of this data set by referencing the following citation(s):

Scambos, T., T. Haran, M. Fahnestock, T. Painter, and J. Bohlander. 2007. MODIS-based Mosaic of Antarctica (MOA) Data Sets: Continent-wide Surface Morphology and Snow Grain Size. *Remote Sensing of Environment* 111(2): 242-257. http://dx.doi.org/10.1016/j.rse.2006.12.020.

1. Contacts and Acknowledgments

Investigators

Ted Scambos
National Snow and Ice Data Center
449 UCB, University of Colorado
Boulder, CO 80309-0449 USA

Terry Haran
National Snow and Ice Data Center
449 UCB, University of Colorado
Boulder, CO 80309-0449 USA

Mark Fahnestock

Institute for the Study of Earth, Oceans, and Space
University of New Hampshire
Morse Hall
8 College Road
Durham, NH 03824-3525 USA

Thomas Painter
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Jennifer Bohlander
National Snow and Ice Data Center
449 UCB, University of Colorado
Boulder, CO 80309-0449 USA

Acknowledgements

This work was supported by NASA grant NNG04GM10G, and by USGS funds supporting J. Bohlander (instigated by J. Ferrigno) during image selection and cloud clearing. The investigators also wish to thank R. Bindschadler, W. Abdalati, and J. Ferrigno for their interest and support initiating this project.

2. Detailed Data Description

NSIDC and the University of New Hampshire assembled a digital image map and snow-grain-size images of the Antarctic continent and surrounding islands called the MOA2004 Image Map. It provides a nearly-perfect cloud-free view of the ice sheet, ice shelves, and land surfaces. Two image data sets were compiled: a digitally smoothed red-light band 1 of MODIS image map, also called the MOA2004 Surface Morphology Image Map were the data were acquired 20 November 2003 through 29 February 2004; and two snow grain size images derived from normalized difference of calibrated band 1 and band 2 MODIS data, also called the MOA2004 Grain Size Image Map where the data were acquired 20 November 2003 through 29 February 2004, and the 2003 MOA Grain Size Image Map where the data were acquired 1 November 2003 through 17 December 2003.

Image data are available via FTP or through the MOA Image Map Server that can create manually-selected JPEG images, and permits on-the-fly zoom, a series of contrast stretches, and geolocated image delivery. Image data on the FTP site are provided as 16-bit images to preserve the radiometric content of the scenes; for the JPEG images, a variety of pre-processed contrast stretches are available.

Grain size cell values in the range of 10 through 1100 represent mean optical snow grain size in microns; values of 5 and 1105 represent grain size values outside this range, for example, some blue ice areas, or data for which a grain size could not be computed.

Format

The MOA2004 digital image maps are available at two spatial grid scales, 750 m and 125 m, and are provided as a gzipped flat binary 16-bit or 8-bit unsigned integer file (`.img.gz`) in little-endian byte order. Each `.img.gz` file has a corresponding gzipped GeoTiff (`.tif.gz`). file and a corresponding ENVI header file (`img.hdr`) in ASCII. Map projection parameter and grid parameter definition files (`.mpp`, `.gpd`) are also available.

Coastlines, ice sheet grounding lines, and islands are available in the following formats: shapefiles (`.shp`, `.shx`, `.dbf`, `.prj`), ENVI vector files (`.evf`); Generic Mapping Tools (`.gmt`), Keyhole Markup Language (`.kml`), and ASCII text files of point locations, with the exception of islands, which are not provided as a ASCII text file of point locations.

File and Directory Structure

MOA2004 Image Maps

The image maps and ancillary files are located in the `ftp://sidads.colorado.edu/pub/DATASETS/nsidc0280_moa2004/` directory. In this directory, there are three files: `Moa0125.gpd`, `Moa0750.gpd`, and `Moa.mpp`, and three folders: `envi`, `geotiff`, `and coastlines`. The `envi` folder contains the `.img.gz` and `.img.hdr` files, the `geotiff` folder contains the `.tif.gz` files, and the `coastlines` folder contains the `.shp`, `.shx`, `.dbf`, `.prj`., `.evf`, `.gmt`, `.kml`, and `.txt` files. Refer to Table 2 for the list of available files.

Where:

Variable	Description
YYYY	Denotes the acquisition period for a given grain size file, where YYYY can equal either: • 2003 for 1 November 2003 through 17 December 2003 • 2004 for 20 November 2003 through 29 February 2004.

*	Denotes that there are three format file extensions for each of these file types: `.img.gz`, `.tif.gz`, and `.img.hdr`.

Table 2. MOA2004 Image Maps and Ancillary Files

File Name	Description
`00README.txt`	ASCII text file containing an abbreviated explanation of the data available for download
`Moa.mpp`	Mapx Map Projection Parameters file
`Moa0125.gpd`	Mapx Grid Parameter Definition file for 125 m grid
`Moa0750.gpd`	Mapx Grid Parameter Definition file for 750 m grid
`moa125_YYYY_grn_v1.1*`	125 m weighted optical grain size image 16-bit unsigned integer little-endian flat binary
`moa125_2004_hct_v1.1*`	125 m count of MODIS scenes contributing to each `moa125_2004_hp1` grid cell 8-bit unsigned integer flat binary.
`moa125_2004_hp1_v1.1*`	125 m high-pass band 1 surface morphology image 16-bit unsigned integer little-endian flat binary
`moa125_2004_hwt_v1.1*`	125 m average weight applied to computed hp1 values to determine composited `moa125_2004_hp1` values 16-bit unsigned integer little-endian flat binary divide by 50000 to get true hwt decimal value.
`moa750_YYYY_gct_v1.1*`	750 m count of MODIS scenes contributing to each `moa750_YYYY_grn` grid cell 8-bit unsigned integer flat binary
`moa750_YYYY_grn_v1.1*`	750 m weighted optical grain size image 16-bit unsigned integer little-endian flat binary
`moa750_YYYY_gsd_v1.1*`	750 m standard deviation of unweighted optical grain size values contributing to each valid `moa750_YYYY_gmn` cell 16-bit unsigned integer little-endian flat binary a value of 1 indicates there were less than two valid contributing unweighted grain size values otherwise divide by 10 to get true gsd decimal value
`moa750_YYYY_gwt_v1.1*`	750 m average weight applied to computed grain size values to determine composited `moa750_YYYY_grn` values 16-bit unsigned integer little-endian flat binary divide by 50000 to get true gwt decimal value
`moa750_2004_hct_v1.1*`	750 m count of MODIS scenes contributing to each `moa750_2004_hp1` grid cell 8-bit unsigned integer flat binary.
`moa750_2004_hp1_v1.1*`	750 m high-pass band 1 surface morphology image 16-bit unsigned integer little-endian flat binary
`moa750_2004_hwt_v1.1*`	750 m average weight applied to computed hp1 values to determine composited `moa750_YYYY_hp1` values 16-bit unsigned integer little-endian flat binary divide by 50000 to get true hwt decimal value.

`All moa125_* files were created directly from 250 meter resolution swath data that were gridded to 125 meter resolution.`
`Each moa750_...._g* file was created by resampling the corresponding 125 meter file using a nearest neighbor algorithm.`
`Each moa750_...._h* file was created by resampling the corresponding 125 meter file using a drop-in-the-bucket averaging alogithm.`	

Coastlines, Grounding Lines, and Islands

The Antarctic coastlines, ice sheet grounding lines, and island files were derived from the MOA2004 surface morphology image and are located in the `ftp://sidads.colorado.edu/pub/DATASETS/nsidc0280_moa2004/` directory. Inside this directory, there is a `coastlines` folder. The `coastlines` folder contains the `.shp, .shx, .dbf, .prj, .evf, .gmt, .kml, and .txt` files. Refer to Table 3 for the list of available files.

Where:

Variable	Description
*	Denotes that there are up tp eight format file extensions for each of these file types (coastlines, ice sheet grounding lines, and islands):

File Extension	Description
`.txt`	ASCII text file containing WGS-84 latitude and longitude values. **Note:** .txt files are only provided for the coastline and grounding line data, not for the island data.
`.evf`	ENVI vector files for the Antarctic islands, coastline, and grounding line.
`.gmt`	Generic Mapping Tools Vector files for the Antarctic islands, coastline, and grounding line.
`.kml`	Keyhole Markup Language file.
`.dbf`	Shapefiles for the Antarctic islands, coastline, and grounding line.

.shx	
.prj	
.shp	

Table 3. Antarctic Coastlines, Ice Sheet Grounding Lines, and Island Files

File Name	Description
moa_2004_coastline_v1.1*	Point locations for Antarctic coastline including ice shelf calving fronts.
moa_2004_groundingline_v1.1*	Point locations for Antarctic grounding line.
moa_2004_islands_v1.1*	Point locations for Antarctic island coastlines and ice-covered island grounding lines.

File Size

The total size of the 750 m files is approximately 112 MB uncompressed.

The total size of the 125 m files is approximately 4 GB uncompressed.

Spatial Coverage

Southernmost Latitude: 90° S

Northernmost Latitude: 60° S

Westernmost Longitude: 180° W

Easternmost Longitude: 180° E

The mosaic includes all land areas and islands south of 60° S that are larger than a few hundred meters. Land areas north of 60° S and areas of ocean more than a few tens of kilometers from coastlines are masked with zero-fill.

Spatial Resolution

The input swath data from MODIS Bands 1 and 2 have a nominal resolution of 250 m; however, MOA uses a super resolution or data cumulation image stacking scheme to increase the resolution of the final product beyond that of individual MODIS scenes. The estimated resolution of the final surface morphology composite ranges between 150 m and 250 m, depending on the number of images that were stacked and how the images were weighted. See Compositing the Image Swaths via Data Cumulation for more details.

Projection

The 125 m grid images that make up the MOA2004 Image Map are provided in the Antarctic mapping projection recommended by the Scientific Committee on Antarctic Research (SCAR). This projection is identical to the Radarsat Antarctic Mapping Project Antarctic Mapping Mission 1 Synthetic Aperture Radar Image Mosaic of Antarctica, Version 2 data set with a 125 m mosaic.

- Projection: Polar Stereographic
- Spheroid: WGS-84
- Longitude of Central Meridian: 0°
- Latitude of True Scale: 71° S

Grid Description

Table 4 below lists the dimensions (in pixels) of the 125 m and 750 m product grids, and the location of the upper left corner of the upper left cell:

Table 4. Grid Dimensions

Dimension	Grid (px)		Upper left corner, upper left cell (m)
	125 m	750 m	
X	48333	8056	-3174450.0
y	41779	6964	2406325.0

Note: South Pole is not at the center of either of these grids.

Temporal Coverage

Swaths for the surface morphology and full spring-summer snow grain images were acquired 20 November 2003 through 29 February 2004. The preferred spring-only grain size mosaic was constructed from images that were acquired 1 November 2003 through 17 December 2003.

Acquisition times were restricted to between 0500 GMT and 1330 GMT to ensure that the sun is positioned to the upper right of the projection grid in all scenes across the entire continent. To maintain a roughly uniform solar elevation angle across the composite, images acquired close to the austral summer solstice were selected for the region near the 135° W longitude coastline; for images near the 45° E longitude coastline, the majority of the scenes were acquired late January through February.

Parameter Description

The MOA images report two parameters:

- surface morphology, derived from brightness variations in MODIS Band 1 red light images;
- snow grain size, inferred from the normalized difference radiance ratio of red to near-infrared light.

Surface Morphology

The surface morphology image required many processing steps, to create a seamless and uniform mosaic from the many images that were combined to generate single grid cell values. As such, the image values no longer have a clearly quantifiable relationship to the top-of-atmosphere, red light reflectances from which they were derived. Instead, the image provides a semi-quantitative but highly consistent representation of the surface shape and approximate reflectivity, as illuminated by the sun across all surface types for the entire continent.

Snow Grain Size

Pre-processing was reduced for the grain size mosaic. This approach sacrifices the seamlessness of the red-light image to produce a truer quantitative map of radiance ratios that can be used to approximate mean snow grain size in areas with dust-free, non-shadowed snow, firn, and ice.

The investigators derived lookup table values to correct for atmospheric effects and partially correct for bi-directional reflectance distribution function (BRDF) effects, using model runs of the Santa Barbara Discrete Ordinate Radiative Transfer (DISORT) Atmospheric Radiative Transfer (SBDART) software. The lookup tables were applied to image grids of radiance ratio and solar elevation to create images of snow optical grain size. These images were then composited to produce the final images using a similar weighting scheme to the surface morphology mosaic, favoring nadir-viewed scenes.

3. Data Access and Tools

Data is obtained through the Web-based map server that can create manually-selected JPEG images and offers features such as instantaneous zoom, a series of contrast stretches, and geolocated image delivery. See the MODIS Mosaic of Antarctica (MOA) Image Map Server User's Guide for more information.

Note: Visualizing the MOA2004 *.evf files require the use of ENVI 4.5+

You may also find the following resources and Web sites helpful when working with MOA:

- Mapx: Map Transformations Library
- The Generic Mapping Tools
- GeoTIFF

4. Data Acquisition and Processing

Theory of Measurements

The ability of Visible and Near-Infrared (VIS-NIR) satellite sensors, notably the Landsat series and the Advanced Very High Resolution Radiometer (AVHRR), to reveal previously unknown features of the Antarctic continent and its coastline was broadly recognized in the 1980s by glaciologists and cartographers. Later, a host of studies showed how careful processing of image radiometry could provide unprecedented information about the ice sheet surface revealing details of ice flow, sub-ice bedrock structure, and wind-related features in the interior of the ice sheet by detailed portrayal of the subtle surface morphology at the approximately 1 km spatial resolution scale of AVHRR (Orheim and Lucchitta 1988), (Bindschadler and Vornberger,1990), (Scambos and Bindschadler 1991) and (Seko et al. 1993). The U. S. Geological Survey created continent-wide mosaics using AVHRR (USGS 1991) and (USGS 1996). USGS and other groups then created regional ice feature image maps using Landsat (Ferrigno et al. 1994) and (Swithinbank et al.1988).

Recognizing that a red-infrared band combination can provide grain size information, Winther et al. (2001) used the VIS-NIR data from the USGS/Ferrigno AVHRR mosaics to generate an approximate estimation of total blue ice area for the Antarctic continent. This followed earlier experiments at mapping snow grain size and blue ice extent from space (Bourdelles and Fily 1993) and (Orheim and Lucchitta 1990).

The normalized difference band radiance ratio correlates with surface grain size because snow reflectivity decreases in the infrared as grain size increases (Warren 1982), (Fily et al. 1997) and (Painter and Dozier 2004). In detail, this reflectivity change is due to absorptive interactions between infrared light and ice crystal electronic structure. Decreasing reflectivity in the infrared region of the electromagnetic spectrum is the principal observable contributing to the capability to remotely determine snow grain size, and it is a function of the greater mean absorbing path length within a larger grain, that is, increased absorption with longer path length through the crystal structure. However, optical path within ice is also a function of grain shape: complex, feathery grains will have a small optical grain size even though individual grains may have a much larger maximum dimension. Moreover, smaller grain sizes have a larger single-scattering component off the crystal surface. For most albedo or energy balance investigations, optical grain size is the desired parameter, because the fundamental physics of the study concerns ice interacting with light.

Data Acquisition Methods

The MOA2004 image maps were composited from MODIS swaths acquired 1 November 2003 through 29 February 2004. Images were selected from a specific time window (05:30 to 13:30 UTC) to restrict solar illumination to a range of azimuths and to ensure that all scenes are illuminated from the upper right of the image projection; however, exceptions to this time window were made to gather Antarctic island data. Restricting the illumination in this manner results in a more seamless representation of mountains and topography across the continent. Unfortunately, the zone for which local noon is centered within the UTC time range for the Terra and Aqua satellite passes had a limited number of scenes available. The selected range of UTC times for image acquisition implies a broad range of local times across the continent. Over the northern West Antarctic coastline, the UTC range occurs during local midnight. This means that VIS-NIR images must be acquired around the time of the austral summer solstice to provide an acceptable solar elevation ranging from 3 degrees to 20 degrees. Yet, at the opposite side of Antarctica in Enderby Land, a near-solstice image selection would result in a solar elevation of 35 degrees to 45 degrees. High solar elevation reduces the amount of topographic detail in the MODIS scenes. To moderate this, the chosen images were those taken late in the summer (late-January through February) for the regions near 45° E longitude, reducing the solar elevation by about 10 degrees in this area. Mean solar elevation across the entire mosaic is 23.6° ± 7.7° (1 σ).

Derivation Techniques and Algorithms

Geolocation and Processing

Satellite image data swaths of Band 1 and Band 2 from MODIS Level-1B MOD02QKM (Terra) and MYD02QKM (Aqua) files, together with illumination and viewing angle data from Level-1A MOD03 and MYD03 files, were geolocated and resampled onto the projection grid using NSIDC's MODIS Swath-to-Grid Toolbox (MS2GT) software. The software interpolates the 1 km resolution latitude and longitude data from the Level-1A files to 250 m resolution and then resamples the Level-1B data to the grid using a forward elliptical weighted average (EWA) algorithm

(Greene et al. 1986).

Destriping of MODIS Image Data

The MS2GT algorithm was modified to remove striping artifacts incurred by the 40-detector whiskbroom scanner and the two mirror sides of the MODIS Band 1 and Band 2 sensor (Haran et al, 2002). These artifacts are a known problem with all Terra and Aqua MODIS Level-1B data at 250 m (MOD02QKM and MOY02QKM data). Inter-detector variations are as large as 1 percent or 50 Digital Numbers (DN) in the 12-bit MODIS data, contributing to distinct horizontal striping in contrast-enhanced images. This primary striping pattern appears to be caused by poor inter-detector calibration among the 40 detectors that constitute a single scan of the 250 m data. A secondary variation in brightness appears between successive 40-line scans that is due to mirror side effects in the double-sided MODIS scan mirror. A third artifact appears as an every-fourth-pixel brightness shift in detectors 28 and 29 (a stitching artifact in appearance). These three artifacts limit the usefulness of MODIS over ice sheet interior images, because they induce brightness variations as large or larger than the shading due to subtle topography.

To correct the problems caused by artifacts, investigators conducted a Lambertian solar zenith angle normalization on the swath data for both bands. Telemetry noise and line drops in the MODIS scenes, having the appearance of chads in the projected images, were reset to zero, that is, treated as masked cloud areas. Though the mosaic composite is nearly cloud-free, some areas of thin cloud and small fog or cloud patches exist.

Two composite images were created from the geolocated Band 1 and Band 2 images: a high-pass filtered Band 1 image composite, which emphasizes the surface morphology, and a normalized-difference band-ratio image, which provides semi-quantative information about mean surface grain size over snow and ice surfaces.

Cloud Masking

The geolocated swath images were manually masked to remove clouds, cloud shadows, fog, blowing snow, and heavy surface frost. To do this, the images were compared to the RAMP AMM-1 SAR mosaic image and to initial versions of the MOA composite to identify cloud, fog, and blowing snow areas. Refer to the RAMP Basics Web page. Investigators conducted cloud and surface artifact masking using the 750 m images. They then applied the same mask to the 125 m scenes. Some small cloud and fog features at less than 750 m scale were not masked, and in a few persistently cloudy areas, some thin cloud and cloud-shadow contaminated images had to be used to cover the enitre continent with multiple scenes.

The mosaic composite is nearly perfectly cloud-cleared. Some areas of thin clouds, cirrus cloud shadows, and fog or low-lying small clouds are present in the northeastern Ronne Ice Shelf, which was persistently cloudy throughout the 2003-2004 austral summer. In numerous areas, there are small patchy clouds at spatial scales of less than 1 km as a result of using a 750 m resolution image for the cloud clearing. More regionally, some areas are partly impacted by blowing snow, particularly in the East Antarctic.

Compositing the Image Swaths via Data Cumulation

Investigators created two composite images from the geolocated Band 1 and Band 2 images: a high-pass filtered Band 1 image composite, emphasizing the surface morphology; and a normalized-difference band-ratio image that provides quantitative information about mean surface grain size over snow and ice surfaces. The processing and assembly steps of these two composites is discussed separately.

High-Pass Filtered Surface Feature Composite

After cloud masking, the geolocated, destriped Band 1 images were high-pass filtered to reduce non-Lambertian illumination and to reset the mean grayscale range to a common value for compositing. Investigators set the filter size for the images to 511 x 511 pixels, or the ground equivalent of 64 km x 64 km. The mean brightness of these filtered images was set to the same value (the integer 16000) to match gray levels for compositing.

Investigators then applied a weighting scheme to the masked and filtered image swaths, creating a weight image for each gridded image that contains a scalar value for each non-masked pixel in the swaths. Weights for the pixels range from 0 to 50000. The weight was computed as the product of a fractional scan weight, a fractional mask weight, and a scale factor (50000). The scan weight was determined by the proximity to the nadir track, favoring near-nadir areas, and the mask weight by the proximity to an image edge or mask edge to feather the edges of the component images.

`wscan`, the scan weight image, is computed as follows:

```
Given:

  R = 6371 km; radius of circular Earth

  A = 725 km; altitude of circular satellite orbit

  seze; sensor zenith angle image

  seze_max = 66°; maximum sensor zenith angle

Computed:

  scan = asin(R / (R + A) * sin(seze)); scan angle image

  scan_max = asin(R / (R + A) * sin(seze_max)) = 55.1°; maximum scan angle

  cos_scan_max_sq = cos(scan_max) * cos(scan_max)

Then:

  wscan = [cos(scan) * cos(scan) - cos_scan_max_sq] / (1 - cos_scan_max_sq)
```

`wmask`, the mask weight image, is computed as follows:

```
Given:

  landmask; land mask image

  band1; cloud-masked Band 1 image

  mask_smooth_width = 43 pixels; boxcar average smoothing width

Computed:

  mask = band1;

  where band1 > 0,

        mask = 1

  where landmask = 0,
```

```
      mask = 0
  mask = smooth(mask, mask_smooth_width); IDL function SMOOTH
```

Then:

```
  wmask = (sqrt(mask) - sqrt(0.5)) / (1 - sqrt(0.5))
```

`weight`, the weight image, is then:

```
  weight = wscan * wmask * 50000
```

The high-pass filtered Band 1 and weight images were then combined using stacking techniques, also called image super-resolution or data cumulation. See Scambos et al. 1999 to improve spatial and radiometric detail beyond the 250 meter and 12-bit characteristics of single Band 1 and Band 2 MODIS images. This improvement in part is due to reduction of random image noise by cancellation and improvement of relative radiometric resolution by combining repeated measurements of the surface in the form of multiple digital images. The additional spatial resolution in the stacked image composite is a result of knowing the pixel center locations to a high precision (50 m), a precision that is smaller than the width of the pixel sample area (250 m).

Images were added to the mosaic with weighting applied according to the following scheme:

Given a set of n high-pass filtered Band 1 images (B_i) and a corresponding set of n weight images (W_i), compute the composited band image (B_c), composited weight image (W_c), and count image (N_c).

B_c, W_c, and N_c are initially all zero, and N_i is set to 1 for each pixel. Then, for each i from 1 to n, where B_i is not zero, and W_i is not zero:

$$N_{c\_old} = N_c$$

$$N_c = N_{c\_old} + N_i$$

$$W_{c\_0} = N_{c\_old} * W_c / N_c$$

$$W_{c\_1} = N_i * W_i / N_c$$

$$W_c = W_{c\_0} + W_{c\_1}$$

$$B_c = (W_{c\_0} * B_c + W_{c\_1} * B_i) / W_c$$

A set of n intermediate composites can themselves be composited into a single composite by setting the values of B_i, W_i, and N_i to the corresponding values of B_c, W_c, and N_c for each composite (in this case N_i is not set to 1), and then applying the given algorithm.

The image stacking allows multiple images to contribute to the representation of a single grid cell in the MOA composite. Image count ranges from 38 to 1; 98.53 percent of the imaged area is made up of six or more contributing images. Mean image count is 14.7. Areas of low image count are the northeastern and far northwestern Ronne Ice Shelf, which had persistent cloud cover throughout the summer of 2003-2004, the ice sheet region between the Executive Committee Range and Crary Mountains in West Antarctica, and the area between the Dome Fuji and Plateau Station camps in the East Antarctic Plateau. This area is in the region of local noon for the UTC time range; therefore, it has fewer near-nadir passes. Using the equations and models developed in Scambos et al. 1999, investigators infer that regions with five or more scenes contributing have resolutions of approximately 200 m or better ranging to a best resolution value of approximately 150 m for images composed of 10 or more scenes. Mean weight of the image pixels for the MOA grid cells is 30322, ranging from 4800 to 49980. A large region of lower weights (5000 - 9000) is centered on the South Pole, because all images are significantly off-nadir in this area.

In general, image quality is best in regions with high image counts and high composited weight.

Optical Mean Snow Grain Size

Two simple grain-size composite images were generated by applying a normalized difference algorithm to Band 1 and Band 2 of the composite scenes.

```
  (Band1 - Band2)/(Band1 + Band 2)
```

This ratio takes advantage of the decreasing reflectivity of snow in the infrared range, creating an image that is sensitive to grain-size variations (Warren 1982) and (Fily et al. 1997). To maintain a quantitative ratio, these images were not processed beyond geolocation, calibration, and destriping. Calibration is based on the information provided in the MOD02QKM and MYD02QKM files, as applied by the MS2GT software. The image is provided as a 16-bit unsigned integer image of optical mean snow grain size in µm.

A composite image of optical surface grain size was generated by applying a model-derived lookup table to images of normalized difference MODIS Band 1 (red light; 620 nm - 670 nm) and MODIS Band 2 (near-infrared; 841 nm - 876 nm) radiances and solar zenith angle:

$$G_{i,j} = (b1_{i,j} - b2_{i,j}) / (b1_{i,j} + b2_{i,j})$$

$$S_{i,j} = f(G_{i,j}, Z_{i,j})$$

$G_{i,j}$ represents a normalized radiance ratio image, $b1_{i,j}$ and $b2_{i,j}$ are the calibrated band radiance values at grid location (i, j) for the respective MODIS bands, $Z_{i,j}$ is the solar zenith angle image for each MODIS pixel in the scene, $f(G_{i,j}, Z_{i,j})$ is the lookup table, and $S_{i,j}$ is the optical grain radius image. The spring-only grain size image was constructed from 122 MODIS scenes acquired between 1 November and 17 December 2003. Calibration scale factors are provided in the MOD02QKM and MYDO2QKM data for the Terra and Aqua MODIS sensors, respectively.

Lookup table values for the grain size conversion were derived from runs of the Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART) software (Ricchiazzi et al. 1998). These lookup tables were then applied to the MODIS scenes to produce a corresponding set of grain size images. The grain size images were then composited together using the same weighting and compositing scheme as that used for the surface morphology image, except that in addition to masked areas, values of 5 or 1105 µm were treated as missing data. Values that led to unmodeled grain sizes, that is less than 10 µm or greater than 1100 µm, had the associated grain size value set to marker values of 5 µm and 1105 µm, respectively. Count and weight images for the grain size composites were slightly different from the corresponding surface morphology count and weight images because of these additional missing values. In cases where all images gave out-of-range grain size results, the grid cell value was set to either 5 µm or 1105 µm.

Runs of the SBDART software provided predictions of MODIS Top Of Atmosphere (TOA) Band 1 and Band 2 radiance values for a series of snow grain sizes (10 Âµm to 1100 Âµm in 10 µm increments) at a series of solar illumination solar zenith angles from 0 degrees to 89 degrees in 0.1 degree increments. Investigators provided SBDART with snow optical properties, that is, BRDF spectral reflectance information from a recent snow reflectance model (Painter and Dozier 2004), and created files (one for every 10 µm of grain size) that used the data to represent the reflecting substrate in the atmospheric radiative transfer model. Investigators held the sensor viewing angle at nadir for all SBDART evaluations. The weighting scheme favoring nadir-viewing conditions was appropriate to reduce off-nadir BRDF effects in the final optical snow grain size composite.

To validate the optical grain size scheme, researchers with the Antarctic Remote Ice Sensing Experiment used a field spectrometer to collect six surface-snow spectral measurements during three locally clear-sky days in October 2003 (Massom et al. 2006). MOA investigators averaged 60 separate spectra of snow (spectral range 0.4 to 2.5 µm), normalized to 40 interspersed spectra of an Etalon calibration target, and inverted the data to the optically equivalent grain-size radius using conversions developed by Nolin and Dozier (2000) with 50 µm - 100 µm grain radius uncertainties. The same sites were imaged by six MODIS scenes, five from the Terra platform and one from Aqua. In situ grain size radius ranged from 66 µm, for snow immediately following a storm accumulation, to 170 µm, for wet snow in warmer conditions. Comparing grain sizes predicted by the method used for these images with in situ measurements shows that, in general, the satellite algorithm underestimates grain size by 15 µm to 151 µm.

Validation data for the optical grain size measurement are shown in Table 5. Same-day sites are within 100 m of each other. SGS refers to Snow Grain Size.

Table 5. Validation Measurements of Normalized Difference Radiance Ratio and Optical Snow Grain Size

Site Locations	In Situ Solar Zenith (°)[2]	In Situ Optical Snow Grain Size (µm)	Satellite Scene[3]	Satellite Solar Zenith (°)[4]	Satellite Sensor Zenith (°)[4]	Satellite-Sun Rel. Azimuth (°)[4]	Satellite NDRR[1]	MOA Optical SGS (µm)[4]	Corrected Optical SGS (µm)[4]
04:48 3 Oct. 2003 Snow Site A 64° 36.55′ S, 117° 40.17 E	61.4	106 ± 50	Terra, 00:50 Terra, 02:30	69.2 62.6	30.7 50.6	66.5 109.2	0.264(2) 0.256(2)	87.4 ± 14 36.0 ± 5	85 70
05:26 3 Oct. 2003 Snow Site B 64° 36.55′ S, 117° 40.17 E	61.8	92 ± 50	Terra, 00:50 Terra, 02:30	69.2 62.6	30.7 50.6	66.5 109.2	0.264(2) 0.256(2)	87.4 ± 14 36.0 ± 5	85 70
04:00 7 Oct. 2003 Snow Site A (recent precip.) 64° 33.32′ S, 116° 34.90 E	60.3	66 ± 50	Terra, 00:25 Terra, 02:05	70.8 63.0	51.3 25.1	65.9 110.9	0.243(2) 0.258(3)	15 ± 5 34 ± 12	18.5 55
04:10 7 Oct. 2003 Snow Site B (recent precip.) 64° 33.32′ S, 116° 34.90 E	60.3		Terra, 00:25 Terra, 02:05	70.8 63.0	51.3 25.1	65.9 110.9	0.243(2) 0.258(3)	15 ± 5 34 ± 12	18.5 55
03:10 20 Oct. 2003 Snow Site A (wet snow) 65° 16.26′ S, 109° 27.78′ E	56.3	170 ± 50	Terra, 01:35 Aqua, 07:10	62.2 61.7	18.4 14.9	66.1 112.3	0.282(4) 0.307(3)	151 ± 30 144 ± 25	160 172
03:20 20 Oct. 2003 Snow Site B (wet snow) 65° 16.26′ S, 109° 27.78′ E	56.3		Terra, 01:35 Aqua, 07:10	62.2 61.7	18.4 14.9	66.1 112.3	0.282(4) 0.307(3)	151 ± 30 144 ± 25	160 172

[1]Normalized Difference Radiance Ratio (NDRR).

[2]All in situ snow spectra-to-grain-size conversions run with 60 degree solar zenith angle.

[3]Acquisition start time for five-minute scene (UTC).

[4]Mean of five near-site pixel values.

Error Sources

Wolfe et al. (2002) estimated the accuracy of the Level-1A geolocation data to be 50 m, considerably better than the Level-1B ground-equivalent nadir pixel size of 250 m.

The accuracy and precision of this geolocation was tested using known surface sites, such as South Pole Station, Vostok Station, Siple Dome camp and traverse trail, Megadunes Camp runway, and Dome Concordia camp, and areas of well-mapped coastline such as Ross Island and the northern Antarctic Peninsula. Investigators did not find discrepancies greater than 125 m in the projected location of a fixed object among the 260 scenes or relative to well-mapped coastline positions. Furthermore, identical features in areas where separate images overlap on the grid align to within one grid cell. As such, in areas where the position of mapped coast differs from the MOA image, the investigators believe that the MOA is more accurate relative to, for example, the CIA coastline database or the Antarctic Digital Database.

Discrepancies did not exceed 125 m in the projected location of a fixed object among the 260 scenes or relative to well-mapped coastline positions. Further, overlapped areas of separate images showed identical feature locations on the grid to within one grid cell.

The mean image weight and image count 750 m data products are provided as a means for users to assess image quality in various parts of the MOA. In general, the MOA quality is higher in areas of both high count and high weight.

Three sources of error are described below: geolocation error, surface obscurations, and snow grain size error.

The component MODIS scenes and the final MOA mosaic are geolocated to within an estimated 50 m, considerably less than the satellite image pixel size or the final grid spacing. This estimate was checked by comparisons with coastlines, field camps, mountain peaks, and other mosaics and maps. Coastline and grounding line files are estimated to be accurate, tracking the best estimate of these features, to within 250 m, or two grid cells. The coastline grounding-line interpretation may not be accurate in all areas.

The mosaic composite is almost perfectly cloud-cleared. Some areas of thin clouds, cirrus cloud shadows, and fog or low-lying small clouds are present in the northeastern Ronne Ice Shelf region, which was persistently cloudy throughout the 2003-2004 austral summer. Other known sites where clouds remain are the grounding line near Bailey Ice Stream (79.67° S, 33.1° W), the ice tongue of Jutulstraumen Glacier (70° S, 0° E), and the Mobiloil Inlet and adjacent Solberg Inlet (68.4° S, 66.5° W). In numerous areas, small patchy clouds and shadows, less than approximately 1 km in size, resulted from using the 750 m resolution images for cloud evaluation and masking. In addition, the investigators identified several areas with features that appear to be blowing snow on the scale of hundreds of square kilometers, particularly in East Antarctica over the upper slopes of the ice sheet. Blowing snow appears as low-contrast mottlings of the surface, often arranged in approximately linear bands oriented near the mean katabatic wind direction, as mapped by Parish and Bromwich (1991). Also, widespread, low-contrast artifacts from hoar frost patches can be seen in regions where fog or emerging vapor from the snowpack have formed frost crystals on the surface. In general, the artifacts appear as sharp-edged patches, often with a sawtooth or flame-like outline, that cross-cut undulations or other topography on the ice surface. Images from late spring or early summer were selected where possible to reduce the number of hoar patches, and then averaged over a sufficiently long period of time (frost patches change on a scale of days) to reduce the intensity of these features in the composite image.

Optical snow grain size error is approximately +/- 50 micrometers, estimated by compariing in situ spectra of varying snow grain sizes with near-simultaneous MODIS images that were processed in the same manner as the MOA grain size composite scenes. However, snow grain size varies greatly over the period of image acquisition for the MOA. As such, large ranges of snow grain sizes were averaged together in some areas, for example, in melting areas or warm but sub-freezing areas that experienced numerous snowfalls followed by snow diagenesis.

Sensor or Instrument Description

The MODIS instruments collect 12-bit radiometric data in 36 spectral bands, ranging from 0.4 µm to 14.4 µm in wavelength. Bands 1 and 2 are imaged at a nominal resolution of 250 m at nadir, bands 3-7 at 500 m, and bands 8-36 at 1000 m.

The Terra satellite, launched 18 December 1999, crosses the equator from north to south (descending node) at 10:30 a.m. local time; Aqua, launched 4 May 2002, crosses from south to north (ascending node) at 1:30 p.m. local time. Both satellites occupy sun-synchronous, near-polar, circular orbits at an altitude of 705 km. The MODIS instruments' ±55 degree scanning pattern produces a 2330 km cross-track by 10 km along-track swath with nearly complete global coverage every one to two days.

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Related Data Collections

- MODIS Mosaic of Antarctica 2008-2009 (MOA2009) Image Map

- Images of Antarctic Ice Shelves
- MODIS Data at NSIDC
- RAMP AMM-1 SAR Image Mosaic of Antarctica, Version 2
- Antarctic 1 km Digital Elevation Model (DEM) from Combined ERS-1 Radar and ICESat Laser Satellite Altimetry

Related Web Sites

- SCAR Antarctic Digital Database Version 6.0
- MODIS Characterization Support Team
- MS2GT Software at NSIDC
- NOAA/ESRL Global Monitoring Division

6. Document Information

Acronyms and Abbreviations

The following acronyms and abbreviations are used in this document:

Acronym	Description
AMM	Antarctic Mapping Mission
ARISE	Antarctic Remote Ice Sensing Experiment
ASCII	American Standard Code for Information Interchange
AVHRR	Advanced Very High Resolution Radiometer
BRDF	Bi-directional reflectance distribution function
DISORT	Discrete Ordinate Radiative Transfer
DN	Digital number
EOS	Earth Observing System
EWA	Elliptical weighted average
FTP	File Transfer Protocol
GB	Gigabyte
IDL	Interactive Data Language
MB	Megabyte
MOA	Mosaic of Antarctica
MODIS	Moderate Resolution Imaging Spectroradiometer
MS2GT	MODIS Swath-to-Grid Toolbox
NASA	National Aeronautics and Space Administration
NDRR	Normalized Difference Radiance Ratio
NIR	Near infrared
NSIDC	National Snow and Ice Data Center
RAMP	RADARSAT Antarctic Mapping Project
SAR	Synthetic Aperture Radar
SBDART	Santa Barbara DISORT Atmospheric Radiative Transfer
SCAR	Scientific Committee on Antarctic Research
TOA	Top of atmosphere
URL	Uniform Resource Locator
UTC	Coordinated Universal Time
VIS	Visible

Document Creation Date

February 2006

Document Revision Date

November 2013

ASK US