A new global raster water mask at 250 m resolution

M.L. Carroll*, J.R. Townshend, C.M. DiMiceli, P. Noojipady and R.A. Sohlberg

Department of Geography, University of Maryland, College Park MD, USA

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Accurate depiction of the land and water is critical for the production of land surface parameters from remote sensing data products. Certain parameters, including the land surface temperature, active fires and surface reflectance, can be processed differently when the underlying surface is water as compared with land. Substantial errors in the underlying water mask can then pervade into these products and any products created from them.

Historically many global databases have been created to depict global surface water. These databases still fall short of the current needs of the terrestrial remote sensing community working at 250 m spatial resolution. The most recent attempt to address the problem uses the Shuttle Radar Topography Mission (SRTM) data set to create the SRTM Water Body Data set (SWBD 2005). The SWBD represents a good first step but still requires additional work to expand the spatial coverage to include the whole globe and to address some erroneous discontinuities in major river networks.

To address this issue a new water mask product has been created using the SWBD in combination with MODIS 250 m data to create a complete global map of surface water at 250 m spatial resolution. This effort is automated and intended to produce a dataset for use in processing of raster data (MODIS and future instruments) and for masking out water in final terrestrial raster data products.

This new global dataset is produced from remotely sensed data and provided to the public in digital format, free of charge. The data set can be found on the Global Land Cover Facility (GLCF) website at http://landcover.org. This dataset is expected to be a base set of information to describe the surface of Earth as either land or water which is a fundamental distinction upon which other descriptions can be made.

Keywords: digital earth; land cover; remote sensing; MODIS; water

1. Introduction

Accurate depiction of the land and water is critical for the production of land surface parameters from remote sensing data products. Without such a reliable mask there will be areas of water to which terrestrial algorithms will be applied and conversely areas of land to which water algorithms are applied. Among the important parameters requiring a mask include the cloud mask (Strabala 2004), land surface temperature (Wan et al. 2002), active fires (Justice et al. 2002), and surface reflectance (Vermote et al. 2002). Many global databases have been created to depict global surface water, but these databases still fall short of the needs of the
terrestrial remote sensing community especially for products with a 250 m spatial resolution.

Existing global databases of water boundaries (Table 1) have been developed using one of two basic approaches. In the vector-based approach, shorelines, lake and river boundaries are determined using survey maps. This provides a continuous vector around the water body in question. In the raster-based approach, satellite imagery is used to determine the presence of water primarily through spectral classification. The former approach results in a continuous representation of the land-water boundary but is limited by the quality of the underlying survey data. These data have been collected by many different organisations with varying techniques and quality of observations. The latter approach usually reliably depicts larger water bodies, but is compromised by drainage-line discontinuities where the width of the river is smaller than the sensor’s spatial resolution, or when the water signal is mixed with that of adjacent vegetation. Additionally, spectral classification requires unobscured observation of the ground surface. Areas, such as the tropics, with frequent and dense cloud cover can be difficult to depict.

The following examples illustrate the shortcomings of currently available surface water data sets.

1) In ‘Streams and Water Bodies of the United States’ (2002) produced by the United States Geological Survey (USGS), tributaries of the Ohio River are not included along the northeastern border between Kentucky and Ohio as well as the entire border between West Virginia and Ohio.

2) In the ‘World Vector Shoreline’ (2004) produced by the National Geospatial Intelligence Agency (NGA) and National Oceanic and Atmospheric Administration (NOAA), there was no update for a 10km shift in the location of the mouth of China’s Huang (Yellow) River since 1978 owing to the seaward growth of the delta.

3) The water mask provided in ‘EOS/AM-1 Digital Elevation Model Data Sets’ (1999) produced by NASA Jet Propulsion Laboratory (JPL) is limited by its coarse spatial resolution of 1km, which results in insufficiently defined coastlines.

4) An even more critical issue with the ‘EOS/AM-1 Digital Elevation Model Data Sets’ (1999) is that many rivers are offset from their actual location. Such is the case with the Tapajos and Xingu Rivers in South America, the location of which are in error by as much as 10 km (Figure 1).

5) The recent Boston University (BU) Water Mask (2004), which is now in use as the standard water mask used for products derived from the Moderate Resolution Imaging Spectro-radiometer (MODIS), is limited by its spatial resolution of 1 km (Figure 2). This mask does not reliably depict continuous hydrologic networks, but typically does label drainage systems in the correct locations. In Figure 1 the BU mask is in orange and can be seen behind the new 250 m water mask in blue.

6) The Global Lakes and Wetlands Database (GLWD) (2004) produced by Lehner and Doll, combines existing vector maps for the purpose of representing surface water for climate modelers. This is merely a compilation of existing maps most generated prior to 1996 and not updated for existing
<table>
<thead>
<tr>
<th>Data set</th>
<th>Author</th>
<th>Last update</th>
<th>Resolution</th>
<th>Issues</th>
<th>Type</th>
</tr>
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<tr>
<td>Global Self-Consistent Hierarchical, High Resolution Shoreline Database</td>
<td>National Geophysical Data Center</td>
<td>2004</td>
<td>200 m; 1 km; 5 km; 25 km</td>
<td>No rivers; coasts and inland lakes only.</td>
<td>Vector</td>
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<td>World Vector Shoreline</td>
<td>National Geospatial Agency</td>
<td>2004</td>
<td>100 m</td>
<td>Based on survey data; locational accuracy varies by region.</td>
<td>Vector</td>
</tr>
<tr>
<td>Regionally Accessible Nested Global Shorelines</td>
<td>Rainer Feistel</td>
<td>1999</td>
<td>1 km</td>
<td>Limited spatial resolution.</td>
<td>Vector</td>
</tr>
<tr>
<td>Continental Watersheds and River Networks for Use in Regional and Global Hydrologic and Climate Modeling Studies</td>
<td>University of Texas at Austin</td>
<td>2000</td>
<td>10 km; 55 km; 110 km</td>
<td>Very coarse spatial resolution</td>
<td></td>
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<td>HYDRO1K</td>
<td>U.S. Geological Survey</td>
<td>1996</td>
<td>1 km</td>
<td>Limited spatial resolution.</td>
<td>Raster &amp; Vector</td>
</tr>
<tr>
<td>EDC Land-Sea Mask</td>
<td>Land Processes DAAC</td>
<td>1996</td>
<td>1 km</td>
<td>Limited spatial resolution; locational accuracy varies by region.</td>
<td>Raster</td>
</tr>
<tr>
<td>BU (MODIS) Land-Sea Mask</td>
<td>Boston University</td>
<td>2004</td>
<td>1 km</td>
<td>Limited spatial resolution; significant discontinuities in river networks.</td>
<td>Raster</td>
</tr>
<tr>
<td>SRTM Water Body Detection (SWBD)</td>
<td>NASA-JPL</td>
<td>2005</td>
<td>90 m</td>
<td>Lacks complete global coverage; discontinuities remain in some major rivers.</td>
<td>Vector</td>
</tr>
</tbody>
</table>
conditions; for example Lake Chad and the Aral Sea are shown at historical extents. Additionally, the spatial resolution of the raster data set is only 1 km.

The available vector data sets, including GLWD, and the Digital Chart of the World, share a common set of original input files at a scale of 1:1,000,000. These were mostly derived from the US Defense Mapping Agency Operational Navigation
Charts (ESRI 1992, Lehner and Doll 2004). The latest update to any of the published data is 1992 according to the User’s Guide (Lehner and Doll 2004). The World Vector Shoreline was derived mostly at 1:250,000 and was a reasonable representation of the coastline at the time, but is out of date and does not include interior lakes and rivers. Inaccuracies in the location of rivers and coastlines are shared among the GLWD and others, such as the Digital Chart of the World, because they share a common heritage. This is particularly apparent in South America where the Tapajos River, for example, is shifted by as much as 10 km. In Figure 1 the mask shown in cyan is the original Moderate Resolution Imaging Spectro-radiometer (MODIS) Earth Observing System (EOS) water mask. This mask also shares a common heritage with the vector data sets and exhibits the inaccuracy in location of this river.

The Shuttle Radar Topography Mission (SRTM) collected 30 m interferometric Synthetic Aperture Radar data over the course of 11 days in February 2000. For security reasons data were released to the public at the degraded 90 m resolution except for the US. The purpose of the mission was to create a new, consistent, fine resolution Digital Elevation Model (DEM) with nearly global coverage. The process of converting the raw data to a DEM created, as a byproduct, the identification of

Figure 2. MODIS Vegetation Continuous Fields (VCF) with current 1 km MODIS EOS water mask overlain in blue. The blocky appearance and discontinuous drainage lines are consistent with 1 km raster water masks. (Figure available in colour online.)
water bodies. Water bodies had to be identified so that consistent elevation values could be maintained for non-land areas. The water bodies were given an elevation 1m below the elevation of the surrounding shoreline and rivers were given a consistently decreasing value to create an even flow. The result was a reliable depiction of water bodies for a large portion of the globe. It was then decided to release this depiction as a separate data set called the SRTM Water Body Data set or SWBD (SWBD 2005). Most of the remotely sensed data products depicting water have been derived from spectral data that were then classified. The use of SRTM data to create a water mask represents a different method of using remotely sensed data to create a global consistent mask than any of the products shown in Table 1.

Recently, at MODIS Science team meetings in October 2006 and April 2008, the science community’s needs for a new land water mask were discussed and it was agreed that a mask created at 250 m resolution would meet many of the needs of the current users of MODIS data. Additionally, it would be valuable for future missions such as National Polar-orbiting Operational Environmental Satellite System (NPOESS) and the NPOESS Preparatory Project (NPP) which will produce products at similar spatial resolutions. The global raster dataset will be distributed in digital format through the Global Land Cover Facility website http://landcover.org.

2. Methods
The new 250 m land/water mask was created in three sections using 3 different data sources. The main body of the product from 54° S to 60° N was created using the SWBD and supplemented with MODIS 250 m data as necessary. The area between 60° and 90° N was generated completely from MODIS 250 m data, while the area covering Antarctica between 60° and 90° S was generated using the Mosaic of Antarctica (MOA) product (Haran 2005).

The SWBD was used because of its fine spatial resolution and because of its consistent representation of the land surface. Because the SRTM data were collected over a short time period of only 11 days, it should provide a spatially coherent representation of surface water. Additionally, the cloud penetrating properties of the Radar offers superior performance over optical data alone, particularly in cloudy areas such as the humid tropics. Using this remotely sensed data product has the advantage of a single source of information, unlike the typical vector data sets which are dependent on disparate sets of information to create a single data set.

The SWBD represents a significant improvement in the representation of land and water. Unfortunately, a variety of problems remain with this data set. Foremost is coverage, because it extends only from 54° S to 60° N. In the south this omits Antarctica, and in the north this omits most of Alaska, the northern parts of Canada, Europe, and Asia, as well as Greenland. In addition, the SWBD was created as ArcView shapefiles in Geographic projection and subsetted into 1° squares. This format is acceptable for local or small regional studies, but is cumbersome for doing large area studies. Note that there are over 12 300 individual files necessary to get the full coverage of land surface for the SWBD. If one tries to stitch together a large number of these (enough to make a single MODIS tile, for example), in most cases the software (ARCGIS 9) will crash because of the daunting number of individual shapes. In addition, despite best efforts there are still data gaps in the SWBD (Figure 3). These gaps can occur when there are mid-stream islands and/or where cloud cover
was persistent (personal communication, James Slater of the SWBD team 11 April 2006). An attempt was made by the SWBD team to use the Landsat Geocover data to fill these gaps, but gaps remain where the Geocover data was also too cloudy to make a determination.

A global 250 m data set in 16 day composites for the entire 8 years of Terra data and 6 years of Aqua data, Collection 5, is online at the University of Maryland. This data set (MOD44C) was originally created as the input to the MOD44A (Vegetative Cover Conversion) and MOD44B (Vegetation Continuous Fields VCF) products. For a full description of these products see Carroll et al. (2006). During the compositing process the daily surface reflectance data (Vermote and Kotchenova 2008) was interrogated using a decision tree algorithm to distinguish between water and land. This daily depiction of water was stored in the 16-day composite data as a sum of ‘hits’ labeled as water in the process. These ‘hits’ were then interrogated and used where ever gaps exist in the SWBD.

The MODIS mosaic of Antarctica (MOA), available from the National Snow and Ice Data Center (NSIDC) DAAC, is a mosaic of MODIS 250 m level 1b (L1B) data for the continent of Antarctica (Haran et al. 2005). This was generated using the Radarsat Antarctic Mapping Project Antarctic Mapping Mission 1 (RAMP AMM1) data (Haran et al. 2005) as a reference to overlapping MODIS observations to create a fine resolution (125m) image for the continent of Antarctica. This vector shoreline product is available from the National Snow and Ice Data Center (NSIDC) Distributed Active Archive Center (DAAC).

All data sets used here are available free of charge from various websites and have either been published or used in products that have appeared in peer reviewed publications. (See the Acknowledgements for access information.)

2.1 Area from 54° S to 60° N

Initially, the SWBD was reprojected to MODIS Sinusoidal projection, converted from vector to raster and stitched into MODIS tiles at the native 90 m spatial
resolution. These 90 m resolution tiles were aggregated to 250 m resolution by absolute averaging to yield percent water content per pixel. Gaps in the SWBD derived 250 m map were detected and filled in an automated way using the methodology shown in Table 2. Figure 4 shows an example of a gap being detected and filled using the methodology in Table 2.

Because the SRTM data were collected over a short period in February 2000 the MODIS data used for gap filling was chosen from the years 2000 and 2001 in order to keep temporal consistency with water bodies that experience change over time. The SWBD did not provide coverage between 54° S to 60° S; however there is essentially no land surface in this area. There are a total of six MODIS tiles with land in them in this latitudinal belt and there is only the southern part of the South

Table 2. Description of gap detection and filling algorithm.

1. Use the SWBD converted to raster and subset into MODIS tiles as the base mask
2. Group areas of contiguous water pixels into discrete water bodies
3. Create a reference map using 1 year of 250 m daily water and land ‘hits’
   - From the MOD44C composites for a year, compute the sum of land ‘hits’ and
     the sum of water ‘hits’
   - Those pixels with at least 100 total observations and greater than 75% water
     ‘hits’ are considered water
4. Working within a 10 × 10 pixel kernel
   - Search for discrete water bodies that terminate within the kernel
   - If found use the reference map (created from a year of daily water ‘hits’) to find
     suitable observations to connect the water bodies
   - Constraint: if the total number of water pixels in the kernel before adding from
     the reference exceeds 20 (there are 100 pixels in a 10 × 10 kernel) do not try to
     connect
   - This constraint helps avoid problems of connecting lakes

Figure 4. Shows the progression of the gap detection and filling for the SWBD. 4(a) shows the mouth of the Amazon river in Brazil with a major gap in the SWBD. 4(b) the area in red is water derived from MODIS 250 m data that are being inserted in the gap detected in 4(a). 4(c) shows the finished product with all water in blue leaving a relatively seamless result. (Figure available in colour online.)
Sandwich Islands that are not included in the SWBD in 1 tile (h16v14). These islands were mapped using MODIS 250 m data.

2.2 Area from 60° to 80° N

MOD44C 250 m 16-day composites are also available for areas between 60° and 90° N where the SWBD is not available. These data were used to create a new 250 m resolution land/water mask. The data were classified using regression tree classification (Breiman et al. 1984). MODIS data are provided in standard subsets 10° square called ‘tiles’. These tiles form a grid that is 36 tiles wide (referred to as horizontal and shortened to ‘h’ in tile ID’s) and 18 tiles high (referred to as vertical and shortened to ‘v’ in tile ID’s), see Figure 5. To find a tile ID one needs to cross reference the ‘h’ or horizontal with the ‘v’ or vertical. Numbering in the grid begins with 00 so to find California, United States we see that we cross the horizontal to h08 and go down the vertical to v05 and the tile ID is h08v05. Training data were derived using the aggregated SWBD using a tile in the MODIS v03 tile row (50° to 60° N) and the tree was applied to tiles in rows v01 and v02 geographically nearby. A total of three different trees were used one in North America, one in Europe, and one in northern Asia. Different trees were used in different geographic locations to accommodate locally different ground cover to maximise the efficiency of the tree. The regression trees were applied to multiple time periods and the resulting classifications were averaged to increase the confidence that features were mapped correctly.

The regression tree yields a subpixel estimate of the water component of a pixel. Features were determined to be water bodies if the averaged classification result showed 50% or greater water content. This threshold is consistent with the threshold used to determine water using the averaged SWBD data for regions between 54° S to 60° N.

![Figure 5. The global MODIS Sinusoidal tile grid.](http://landweb.nascom.nasa.gov/developers/sn_tiles/sn_bw_10deg.html)
2.3 Area from 80° to 90° N
Tiles in row v00 (80° to 90° N) were handled separately because most of the water in this area remains frozen even in summer owing to the high latitude and in some cases there are ice shelves that extend from the land to the ocean. In the MODIS tile grid there are only four tiles in this region which contain land. Because of the complex landscape with permanent sea ice and frozen interior water bodies, the method applied to lower latitudes did not work sufficiently well in this region. To solve this problem, an inverse mapping approach was adopted whereby water was determined by first mapping the visible land, and the area outside the projection. The remaining area was initially labeled as water.

Mapping was done by creating a decision tree with 3 classes land, ice and water and applying it to the four 16-day composites that comprise July and August for 5 years from 2003 to 2007. Images from July and August were used to coincide with the timing when snow cover was minimal. The information from 2003 to 2007 was combined to yield a single static map for each of the four tiles. Interior ice sheets were determined by visual interpretation of MOD44C composites and referencing with the classified image. Ice sheets were then mapped into the land water mask as land. The EOS DEM for MODIS contains the old water mask and was found to have substantial locational shifts which made it unsuitable to use in determining elevation. The NSIDC 1 km DEM (DiMarzio et al. 2007) for Greenland was used in the area of the McKinley Sea in the Northeastern corner of Greenland owing to the existence of an ice shelf.

2.4 60° to 90° S
The MOA grounding line vector data set has been reprojected from Polar Stereographic to Sinusoidal, converted from vector to raster and subset into MODIS tiles. The polyline shapefile was converted to a polygon and rasterised such that any data inside the polygon was considered land and anything outside the polygon is considered water. This reformatted product is included in the beta release of the new 250 m water mask as the land water mask for Antarctica. The grounding line is the point at which the ice sheet is still resting on solid rock (Scambos et al. 2007). The cryospheric community has used this reference in their products for a number of years.

2.5 Quality assurance data layer
A QA layer was created that shows which data source provided the water pixel. For example, the area seen in red in Figure 4 has a value that is distinct from the area shown in blue designating that it came from a different source (in this case MODIS). Users can utilise the information in this layer to assist in the determination of the utility of the data.

Quality assurance was done by opening all tiles and performing a visual inspection. Initial success was determined by visual comparison with MODIS 250 m spectral data to determine if the water mask features did in fact overlay with known water features. The new 250 m water mask was found to have good agreement with known water bodies. Spatial fidelity between tiles where different
sources of data were used was tested by stitching together four MODIS tiles along the boundaries. This process was repeated in a moving window from left to right across the MODIS tile grid shown in Figure 5. The tiles in rows v00 – v03 were all tested in this manner and obvious discontinuities were determined to be rare and were resolved by additional discrete mapping of the specific local region using decision tree classification. Validation efforts are discussed in the validation section (Section 4) of this text.

3. Results

The new 250 m water mask is a global raster data set in the sinusoidal projection, subset into tiles matching the MODIS tile grid. There are three discrete values represented:

- 0 Land
- 1 Water
- 253 Fill (outside the projection)

This dataset is intended to replace the old EOS 1 km Land/Water mask originally created in the mid-1990s and updated in 2002. The 2002 update was global except for 80° to 90° N (where no data were available at that time) and was performed by Boston University (Salomon et al. 2004). This update solved numerous errors including many misplaced rivers in South America but was limited by the 1 km spatial resolution and the inability to solve problems in the far north owing to lack of data. Figure 6 shows the difference between the new 250 m water mask and the old EOS Land/Water mask for an area of northern Greenland. The old EOS mask, seen in 6(b), is shifted ~35 km from where the water actually exists, the new 250 m water mask, seen in 6(c), corrects this issue.

Joining the SWBD and the MODIS 250 m data produces a heterogeneous data set. Figure 7(a) shows part of the Scandinavian Peninsula spanning the 60° line of latitude. The spatial continuity across the line is remarkable, and the improvement over the existing 1km data set (Figure 7(b) and 7(c)) is evident. This example shows that while there may be some disparities between the MODIS data and SWBD the differences are quite minor. This result was consistent with results found in other areas across the globe.

Figure 6. (a) Shows a composite of MODIS summer imagery for 2003–2007 for northern Greenland near the McKinsey Sea. (b) Shows the composite image with the current 1 km MODIS EOS land water mask overlain in red. (c) Shows the composite image with the new 250 m water mask overlain in blue. (Figure available in colour online.)
Substantial improvement in spatial detail of the new mask has already been shown in Figure 1 for areas where the SWBD was used. Comparable improvement in spatial detail is seen in the northern latitudes where there is a high density of small lakes. Figure 8 shows this improved representation for central Canada west of Hudson Bay as compared to the 1 km mask. Similar improvements are seen in Scandinavia, and Siberia.

Figure 7. (a) Overview of the Scandinavian peninsula, (b) 250 m resolution view of the old EOS 1 km water mask, (c) the new 250 m water mask using the SWBD below 60 N and MODIS 250 m data above.
Figure 8. Improved representation of lakes in Boreal Canada west of Hudson Bay as compared to the old EOS water mask. The large lake in the north centre is Reindeer Lake on the border between Saskatchewan and Manitoba in Canada.

Figure 9. Comparison of the new 250 m water mask with the old EOS water mask for four MODIS tiles in the Mid-Atlantic region of the United States.
The mapping of Antarctica is done using the vector representation of the grounding lines for the ice sheets. Evaluating this with data from MODIS is difficult owing to the limitations of visible data. The cryospheric scientists in the MODIS Science team requested that the data be represented in this way so we honored that request.

A quantitative comparison of the old 1km water mask and the new 250 m water mask was undertaken for four adjoining MODIS tiles in the Mid-Atlantic region of the United States (tiles h11v04, h11v05, h12v04, h12v05). Figure 9 shows the results of this comparison visually and the numerical results are shown in Table 3. Water bodies in this region include Deep Ocean, coastal bays, inland rivers and inland lakes. A total of 6,369,127 pixels were mapped as inland water in the new 250 m water mask. The ocean pixels were excluded from the statistical analysis. The new water mask identified 1,274,106 pixels as water that were previously mapped as land. This represents >68,000 km$^2$ of new surface water area or 20% more water represented in the new map than was present in the old map. Additionally, nearly 330,000 pixels that were previously mapped as water were re-mapped as land in the new mask. This represents ~5% of the total inland water pixels in the old mask or nearly 18,000 km$^2$.

In areas north of 60° N features smaller than 2 to 3 MODIS pixels can be missed owing to the spatial resolution of the MODIS instrument. This can result in a feature that is represented by the finer resolution SRTM product up to the 60° N line and then under represented by the coarser MODIS resolution. This situation was intensely investigated by the developers and found to be a rare occurrence. Data were used from multiple years of MODIS data to minimise any impact of flooding on the output product. Small islands off the coast of mainland continents may be missed but this occurs rarely and should have little impact on downstream processing of data products, which is the primary purpose of this product.

### 4. Validation

The new land/water mask is intended to replace the 1km MODIS EOS raster data set currently being used in MODIS data production. As such the results from the new mask are primarily being judged against the mask that it is replacing. However additional comparisons with other products have been performed.

<table>
<thead>
<tr>
<th>Data set comparison</th>
<th>Number of Pixels</th>
<th>Area mapped (km$^2$)</th>
<th>Percent of total pixels</th>
</tr>
</thead>
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<tr>
<td>New 250 m land pixels previously mapped as water in the old EOS Water Mask</td>
<td>329,922</td>
<td>17,705</td>
<td>5.18%</td>
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<tr>
<td>New 250 m inland water pixels previously mapped as land in the old EOS Water Mask</td>
<td>1,274,106</td>
<td>68,374</td>
<td>20.00%</td>
</tr>
<tr>
<td>Total number of pixels mapped as inland water</td>
<td>6,369,127</td>
<td></td>
<td></td>
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Validation of the SWBD has already been performed by NASA-JPL. In summary the absolute vertical accuracy was determined to be \( \sim 9 \) m and the absolute geolocation accuracy was determined to be \( \sim 8 \) m (Rodriguez et al. 2006). Validation of the MOA has been performed by the developers of the MOA (Haran et al. 2005). The developers ‘found no discrepancies greater than 125 m for fixed objects in well mapped areas in more than 260 scenes.’ (Haran et al. 2005) For purposes of this project this validation was accepted and not repeated.

Validation for the region between 60\(^\circ\) and 90\(^\circ\) N in North America was done using a 30 m land cover classification. These data are available for Alaska in the United States in the National Land Cover Dataset (NLCD) (Homer et al. 2001). These data were created within the last 5 years using Landsat data from 1990 to 2000 and are being made available to us from the USDA Forest Service. Table 4 shows the results of the analysis of the NLCD data set compared to the new 250 m water mask and also the old EOS 1km mask. The NLCD was aggregated from 30 m to 250 m by exact averaging. A pixel from the NLCD was determined to be water if it contained 50% or greater water. This aggregated map was compared with both the new 250 m mask and the old EOS mask. The old EOS 1 km mask was resampled to 250 m resolution using nearest neighbour resampling. All three datasets were converted from raster to polygon data and the polygons were ‘dissolved’ to join neighbouring polygons. After the dissolve, polygons were selected based on location where ‘new 250 m mask polygons intersect NLCD water polygons’ and similarly where the ‘old EOS mask polygons interest NLCD water polygons’. The results are displayed in Table 4. Commission error was calculated by (# intersecting polygons/total # polygons) and the Omission error was calculated by ((Total NLCD polygons - # intersecting polygons)/Total NLCD polygons).

The results for the new 250 m water mask show that 98% of the polygons intersect with NLCD polygons, leaving only 2% of all 250 m polygons outside of NLCD polygons. However, the new 250 m water mask overestimates the surface area of water by 18% compared with the NLCD. This overestimation is typically at the border of water bodies where the coarser MODIS spatial resolution overlaps the true land/water boundary as compared to the finer resolution data. Hence, a mask created from finer resolution data could provide an even better representation of the water features. Nearly 21% of the NLCD polygons did not have any intersection with new 250 m mask polygons. This number was higher than expected but upon further review the NLCD polygons that did not have intersections were mostly 1-2 pixel polygons. It is likely that these were undetectable using MODIS data owing to their

<table>
<thead>
<tr>
<th>Data set</th>
<th>Total # of polygons</th>
<th># of polygons intersecting NLCD</th>
<th>Commission Error</th>
<th>Omission Error</th>
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<tbody>
<tr>
<td>Total NLCD water polygons</td>
<td>122114</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<tr>
<td>New 250 m water mask polygons</td>
<td>98514</td>
<td>96552</td>
<td>1.99%</td>
<td>20.93%</td>
</tr>
<tr>
<td>Old EOS water mask polygons</td>
<td>4227</td>
<td>3043</td>
<td>28.01%</td>
<td>97.51%</td>
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small size relative to MODIS spatial resolution (250 m) and were picked up by the NLCD owing to its finer native spatial resolution (30 m). Additionally, the NLCD was not intended for the purpose of detecting water. Water is merely a byproduct of identifying different classes of land cover, so there may be errors in the NLCD resulting in false detections of water in that data set. The NLCD was used for this analysis because it was derived independently from the MODIS data set and the accuracy is stated by the developers as ~90% (Homer et al. 2001). The EOS water mask showed that 72% of the polygons matched polygons from the NLCD. The old EOS water mask missed nearly 98% of all polygons shown in the NLCD. The poor performance of the old EOS 1 km mask relative to the NLCD is attributable to the coarse spatial resolution compared to the small size of the lakes in Alaska, the region covered.

5. Remaining issues

There are still some remaining issues that could not be alleviated with the new water mask. These issues include discontinuities in small rivers, which occurred infrequently in rivers that have sections smaller than 250 m in width, and hence were difficult to detect with MODIS. We will investigate in the future whether Landsat and Aster can be used automatically to fill the gaps possibly intelligent interpolation procedures based on the known rules of behaviour of drainage patterns. Persistent floating sea ice was often labeled as land typically occurring in areas north of 75° N latitude. We attempted to clear these by manually digitising the features if they were labeled as ocean in the old EOS 1km water mask, but some may remain. The QA layer maintains the information for how each pixel was derived and does show if a pixel was derived by digitisation. Where the ice shelf extends into the sea from the land, as in Greenland, some Islands north of Siberia and Antarctica, the land boundary is difficult to determine and errors may occur. However, given that the principal purpose of the mask is to ensure that terrestrial and oceanic algorithms are applied to the appropriate pixels this should not be regarded as a major deficiency. Small artifacts may exist in areas where there were recurring cloud or terrain shadows that went undetected or where the sensor viewing geometry was far off nadir. Both of these are minimised through the use of multiple composites from multiple years.

6. Conclusions

The new 250 m water mask is a dramatic improvement over the current 1km raster mask that is used in MODIS data processing and many other purposes. The product will be included in the MODIS Collection 6 reprocessing as the standard water mask used in the creation of many of the MODIS standard products. It will also be incorporated into the MODIS Vegetation Continuous Fields product as well as the MODIS Land Cover product. This product is not intended to be used for hydrologic modeling and caution should be used until the remaining discontinuities in rivers have been resolved.

The land water mask product was released as a beta product to the MODIS Science Team for evaluation purposes in February 2009. The product will also be suitable for use with similar coarse resolution satellite data from other systems. It will
be officially released by June 2009 and will be available in MODIS tile format through the special collections at the Land Processes DAAC and also available in alternate formats through the Global Land Cover Facility (GLCF) (www.landcover.org).

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- SWBD 2005 available from ftp://e0srp01u.ecs.nasa.gov/srtm/version2/SWBD/
- NLCD 2001 http://www.mrlc.gov/nlcd_multizone_map.php
- NSIDC 1km DEM Greenland available from ftp://sidads.colorado.edu/pub/DATA SETS/DEM/nsidc0305_icesat_greenland_dem/
- MOA available from ftp://sidads.colorado.edu/pub/DATASETS/MOA/coastlines/

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Notes on contributors
Mark Carroll is the PI for the NASA grant for developing the new 250 m Land/Water mask. This project combines several remotely sensed data products to generate an up to date mask of the location and extent of global surface water.

He graduated with a Bachelor of Science degree in Natural Resources Management from the University of Maryland, College Park in 1996. Since then he has done field work in reconstructed wetlands, and hydrology; performed and developed wet chemistry techniques for water quality analysis; and for the past nine years has been developing data products using remotely sensed data, primarily MODIS. Currently, he is employed as a full time research analyst at the University of Maryland, College Park and is completing his Master's degree.

John Townshend is carrying out research on global land cover characterisation through the use of remotely sensed data. The objectives are both to provide an improved quantitative depiction of land cover but also to provide reliable data on rates of land cover change.

Regional studies have focused on South America especially in Bolivia and Paraguay where wall-to-wall analyses have been performed using higher resolution Landsat data.

He also is the PI of the Global Land Cover Facility which houses the largest on-line collection of Landsat data in the world along with MODIS products. These are used by many thousands of users from throughout the world.

Charlene DiMiceli is a scientific programmer working on MODIS projects for the Department of Geography at the University of Maryland. She has her B.S. (’80) in Mathematics from Portland State University. Her current interests include the application of data mining techniques to remote sensing data, and detection and analysis of land and surface water change.

Praveen Noojipady is currently a PhD student at the Department of Geography, University of Maryland, College Park. He holds a bachelors degree in Civil Engineering and a masters in Water Resources Engineering. His present interests are global land cover dynamics with special emphasis to changing environment, climate, and energy balance.

Robert Sohlberg has 15 years’ experience working on research related to land cover change, wildfire dynamics, natural disasters, and the design of systems to produce integrated observations utilising satellite and airborne platforms. He has served as PI and co-I on grants from the USDA Forest Service and NASA's AIST, EOS, REASoN, SENH, and Synergy II programs. An associate member of the MODIS science team he also serves as project scientist for development of SensorWeb 3G via funding from NASA's Advanced Information Systems
Technology program. The SensorWeb effort won the 2008 R&D 100 award for most significant technological advances of the year and has conducted demonstrations to monitor floods and wildfires.

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