3D PRINTING OF ELEVATION DATA SETS: ASTER & SRTM DEMs, LIDAR DSMs and DTMs

Dave Tewksbury - Geosciences - Hamilton College - Clinton, NY - USA

Abstract

Digitized elevation data for most of the Earth's land surface are readily available for download from sites such as The National Map, CGIAR-Consortium for Spatial Information, USGS Earth Explorer or Open Topography, as well as other sources. Depending on the platform that collected the data, resolutions range from 90 m per pixel to < 1 m per pixel for some LiDAR data

Software packages such as ArcGIS and Global Mapper, along with many others, are able to read these data files and produce pseudo-3D hillshaded images. Using LiDAR point cloud data, these programs can produce 3D views on a monitor. Until recently, printing has been limited to 2D prints. The advent of relatively inexpensive 3D printers with quality resolution has changed the picture.

Elevation data processed in ArcGIS, Global Mapper and Accutrans3D can be printed on an Ultimaker2 3D printer using the printer-supplied Cura software. Print times vary with the size and resolution of the 3D print. Ultimaker2 has four native resolutions: Fast (0.2 mm), Normal (0.1 mm), High (0.06 mm) and Ultra high (0.04 mm). Using Normal (0.1 mm) resolution, most print samples take 6 - 20+ hours to print, depending on the size. The printer has a maximum build volume of 223 x 223 x 205 mm (L, W, H).

Elevation data can be printed either horizontally (real world view) or vertically (within the limits of the build volume). Printing horizontally results in layering that mimics contour lines and can be useful in teaching topo map/contour concepts. This layering can mask fine detail features, however, so the most detailed prints are achieved by printing vertically rather than horizontally at the same resolution.

Scaling and vertical exaggeration are necessary for most data sets. Scaling is easily accomplished within the Cura printer software with a single button ("scale to fit build volume") command. Most projects require a vertical exaggeration of 1.5 - 5 X to produce a useful print. This, too, is easily accommodated in the Cura software. Vertical exaggeration is very much a "season to taste" value. Unfortunately, with print times running many hours to tens of hours, it is impossible to use a "test print" to determine quickly what the ideal vertical exaggeration is for a given data set.

You do not run off a model just before class.

Elevation Data sets

The National Map

http://viewer.nationalmap.gov/viewer/

Elevation data color coded by resolution displays holdings of 1 meter, 1/9 arc-second and 1/3 arc-second elevation data (DEMs). This refers to the cell size in the raster data set and has nothing to do with the actual accuracy of the data. Smaller cell size equals higher resolution and larger files.

Earth circumference @ Equator approximately 40,000 kilometers

40,000 km / 360 degrees = approximately 111 kilometers/degree

111 Kilometers / 60 minutes = 1.85 kilometers/ arc minute

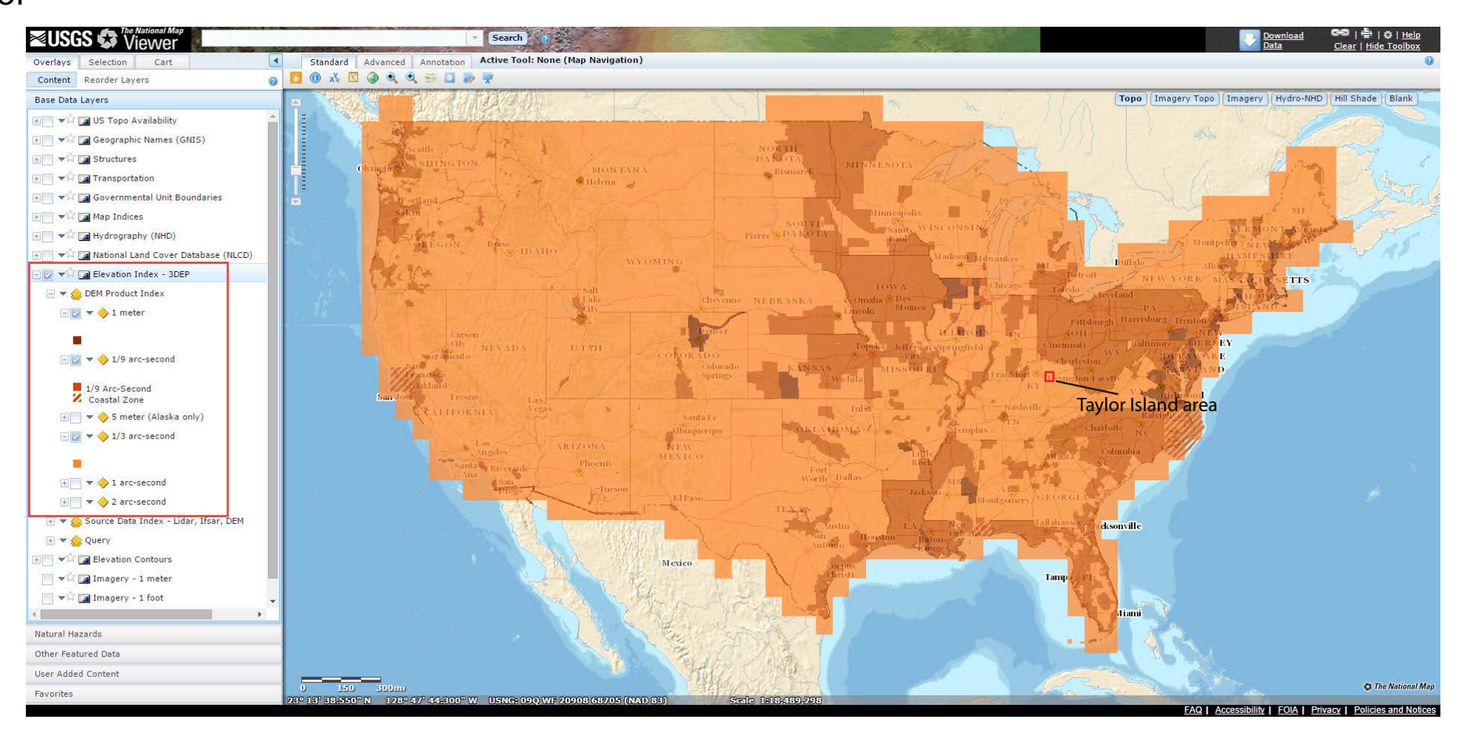
or 1850 meters / arc minute

1850 meters / 60 seconds = 30.8 meters / arc second

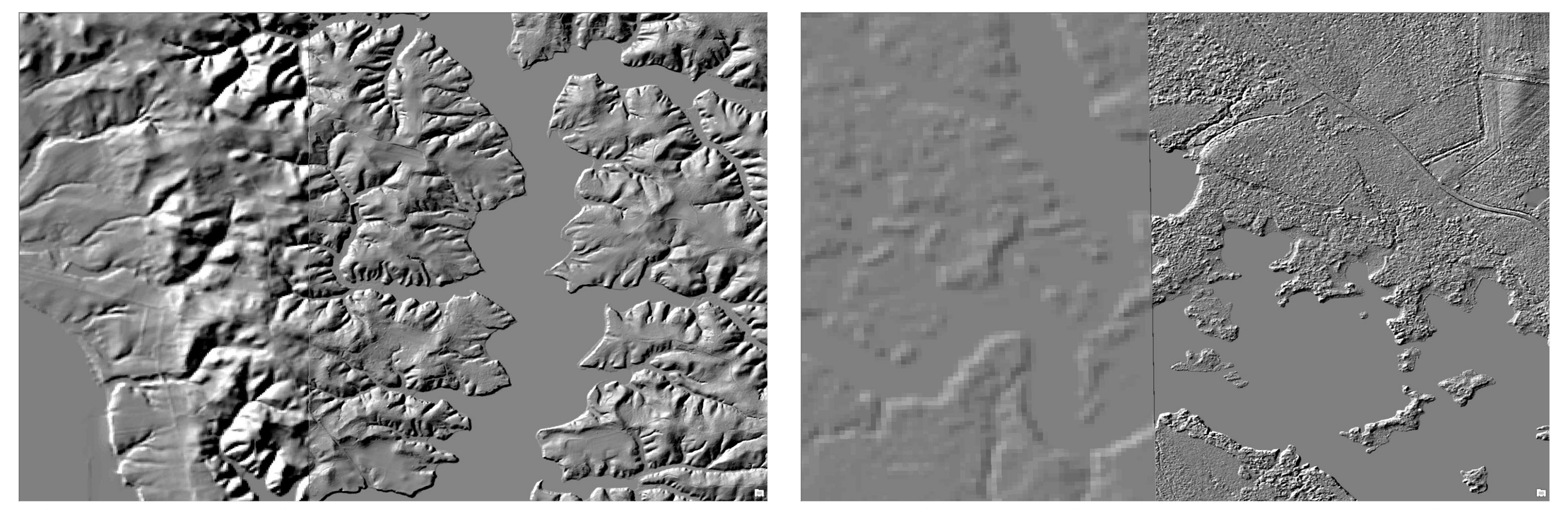
1 arc second = approximately 30 meters

1/3 arc second = approximately 10 meters

1/9 arc second = approximately 3 meters



Hillshades of 1/3 arc second, 1/9 arc second and 1 meter data of portions of the Taylor Island, Maryland quad downloaded from The National Map site shows the effect of the smaller cell size on resolution. Images are zoomed to the raster resolution of the finer data set.



1/3 arc second (10 meter) raster cells | 1/9 arc second (3 meter) raster cells | 1/3 arc second (10 meter) raster cells | 1 meter raster cells

The CGIAR Consortium for Spatial Information (CGIAR-CSI)

http://srtm.csi.cgiar.org/

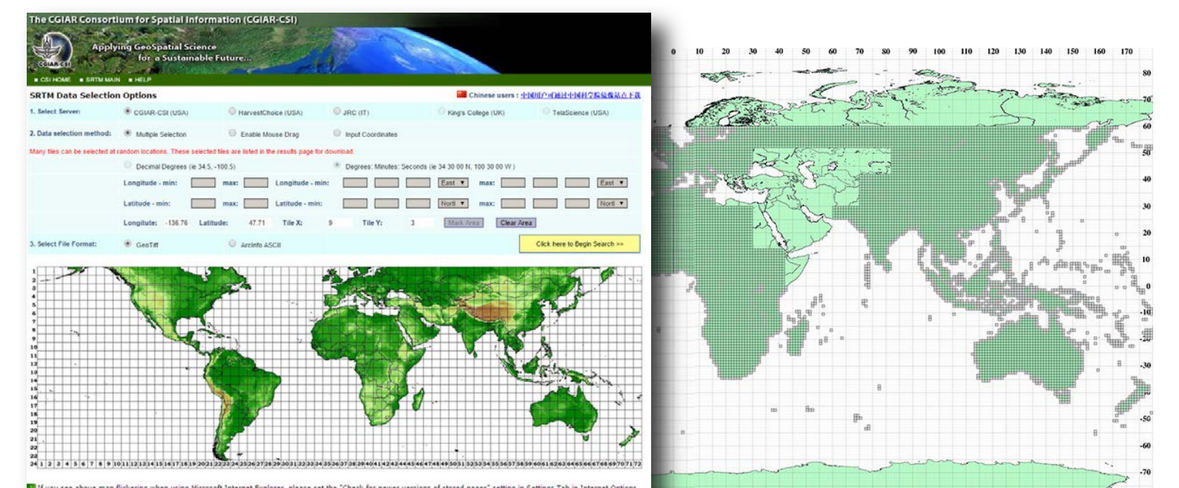
CGIAR was the site to go to for global Shuttle Radar Topography Mission (SRTM) data. SRTM data on this site is 90 meters/pixel.

Until September of last year this was the best resolution SRTM data available on a global scale.

On September 23, 2014 the United States began releasing global 1 arc-second (30 meter/pixel) SRTM data. This is the resolution the SRTM data was originally collected at. Previously 1 arc-second SRTM data was only available for the United States

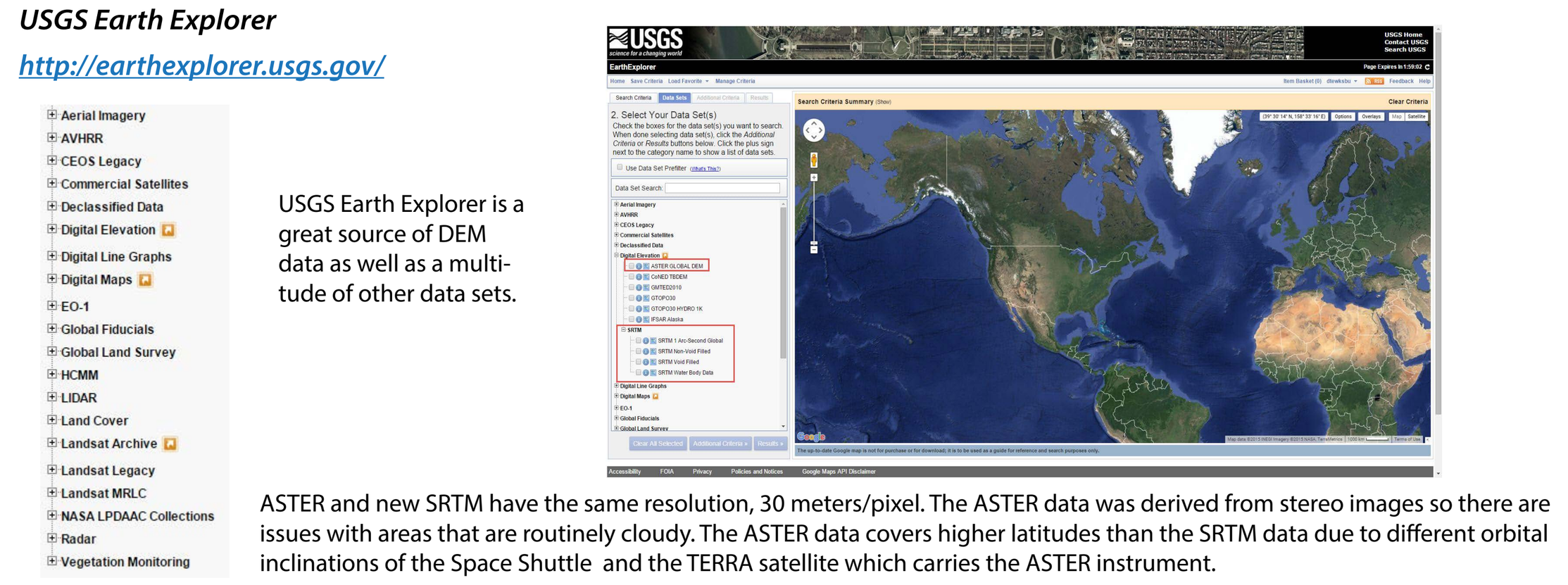
Now Earth Explorer has global 1 arc-second SRTM data 30 meters per pixel

http://www2.jpl.nasa.gov/srtm/images/SRTM_Jan2015.gif



USGS Earth Explorer

http://earthexplorer.usgs.gov/



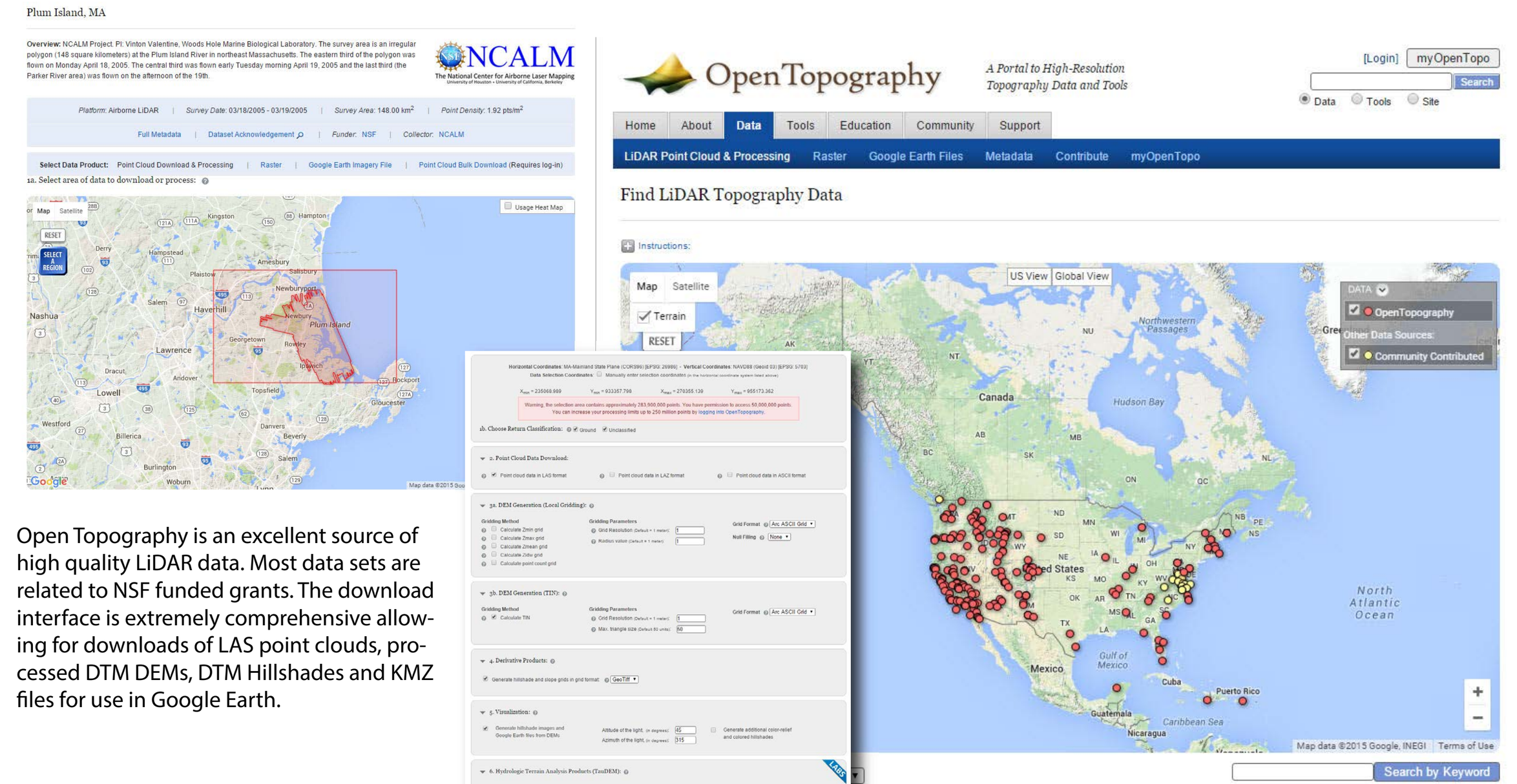
USGS Earth Explorer is a great source of DEM data as well as a multitude of other data sets.

ASTER and new SRTM have the same resolution, 30 meters/pixel. The ASTER data was derived from stereo images so there are issues with areas that are routinely cloudy. The ASTER data covers higher latitudes than the SRTM data due to different orbital inclinations of the Space Shuttle and the TERRA satellite which carries the ASTER instrument.

In the SRTM data group there are two listings for SRTM data. There is the 1 arc-second global and the SRTM void filled, which is the older 90 meter/pixel global data.

Open Topography

http://www.opentopography.org/



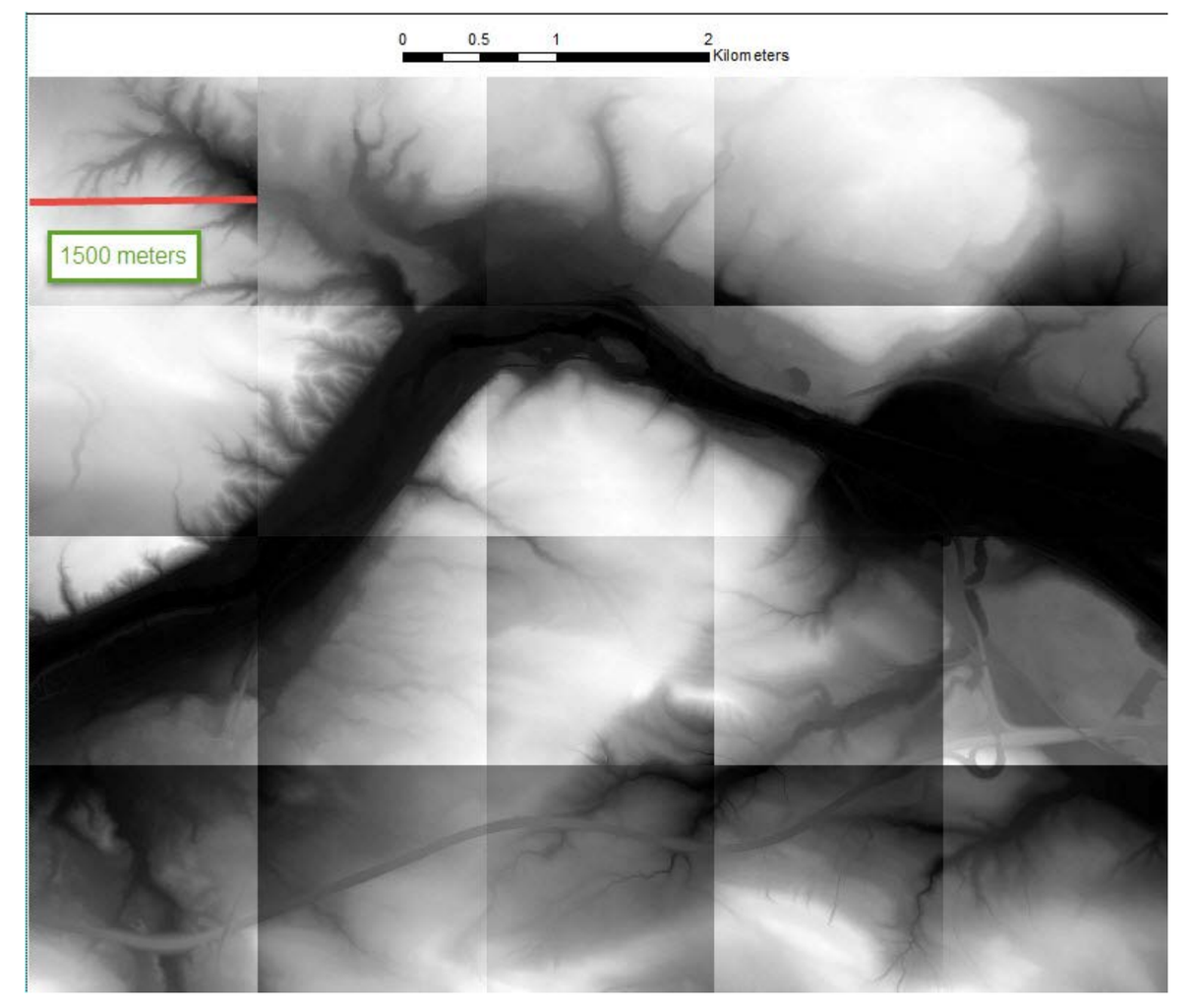
Open Topography is an excellent source of high quality LiDAR data. Most data sets are related to NSF funded grants. The download interface is extremely comprehensive allowing for downloads of LAS point clouds, processed DTM DEMs, DTM Hillshades and KMZ files for use in Google Earth.

Processing elevation data in ArcGIS 10.3 and Global Mapper 17

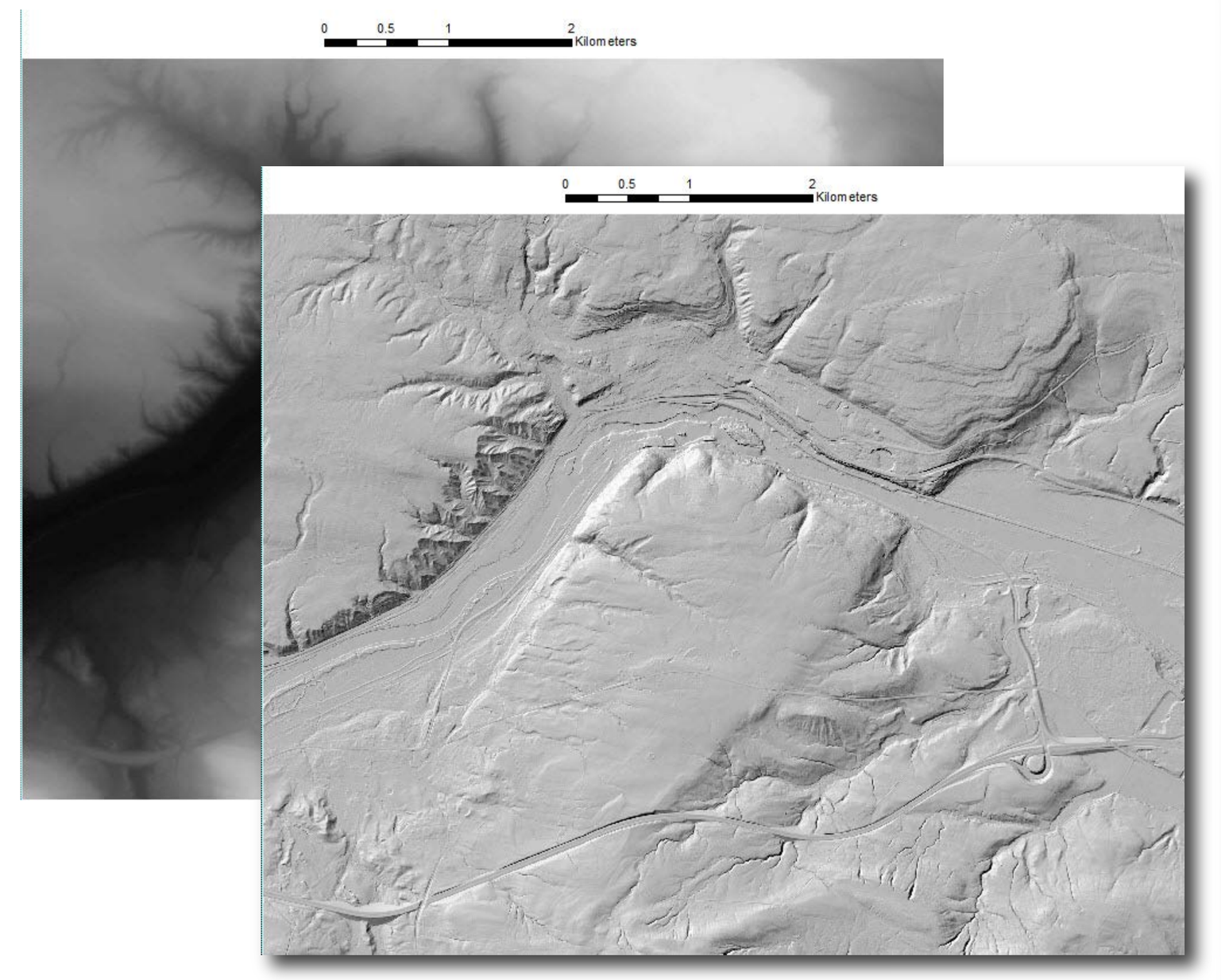
Either ArcGIS or Global Mapper can be used to process elevation data for import into AccuTrans3D software. Screen shots in following workflows are based on ArcGIS 10.3 and Global Mapper 17.

Processing elevation data in ArcGIS 10.3

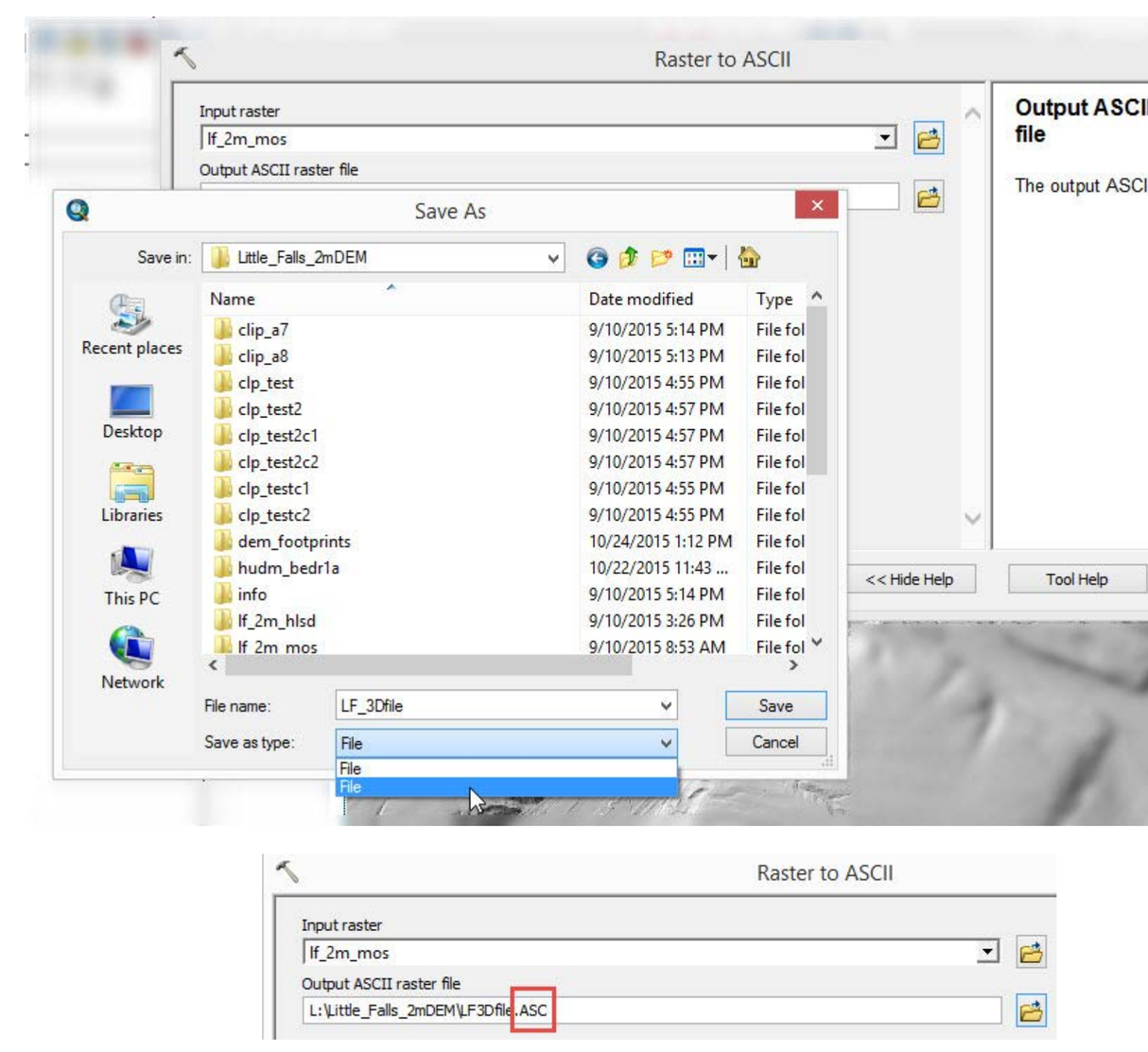
Twenty DTM tiles downloaded from the NYS GIS Clearinghouse (https://gis.ny.gov/) loaded into new ArcMap document. Each tile is 1500 meters square with a resolution of 2 meters/pixel.



Tiles are mosaicked and hillshaded to visually evaluate. Hillshading is not necessary in preparing a file for 3D printing.

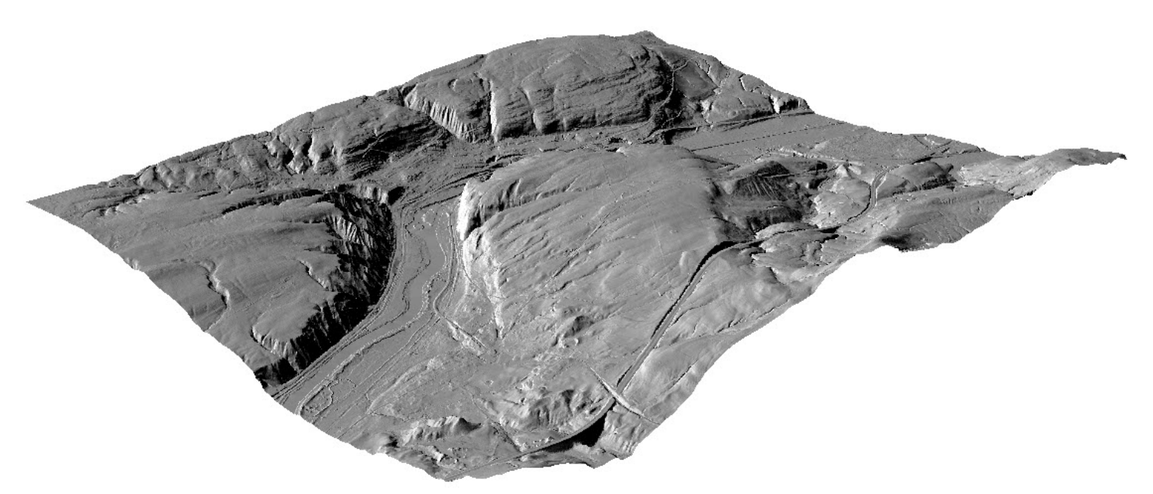


Mosaicked DTM is exported as an ArcInfo ASCII Grid file for use in AccuTrans3D. Use Raster to ASCII tool (**ArcToolbox > Conversion Tools > From Raster > Raster to ASCII**)
When using this tool it is critical in the Save As box to set the "Save as type" pull-down to the second "File". The output file must show .ASC as the file type. If the file is .TXT the wrong "file" in the pull-down was used.



This .ASC file is opened in AccuTrans3D in the next step.

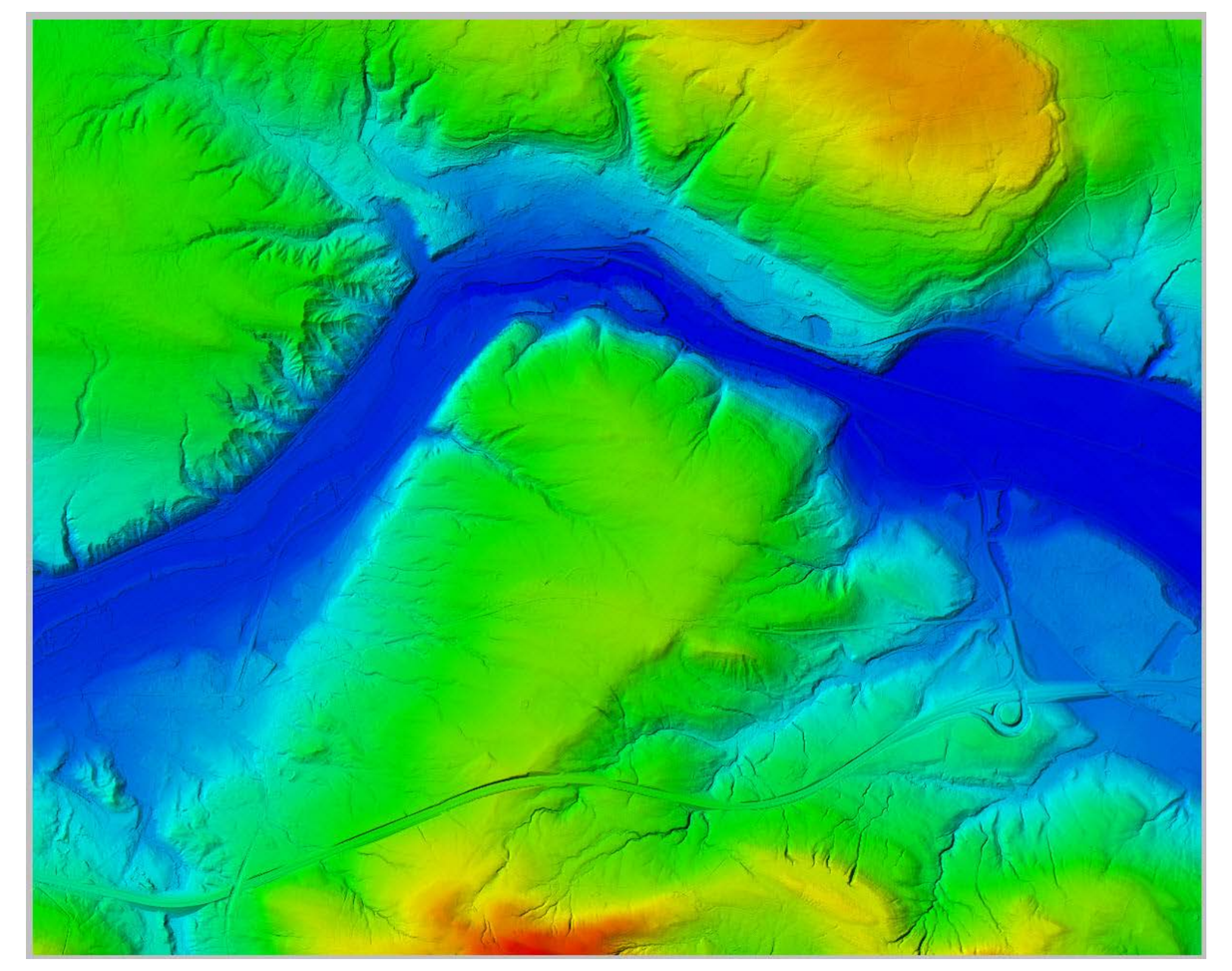
Using ArcScene, 3D view of DTM hillshade mapped to the DTM file. Same vertical exaggeration as used for printed 3D model (3X).



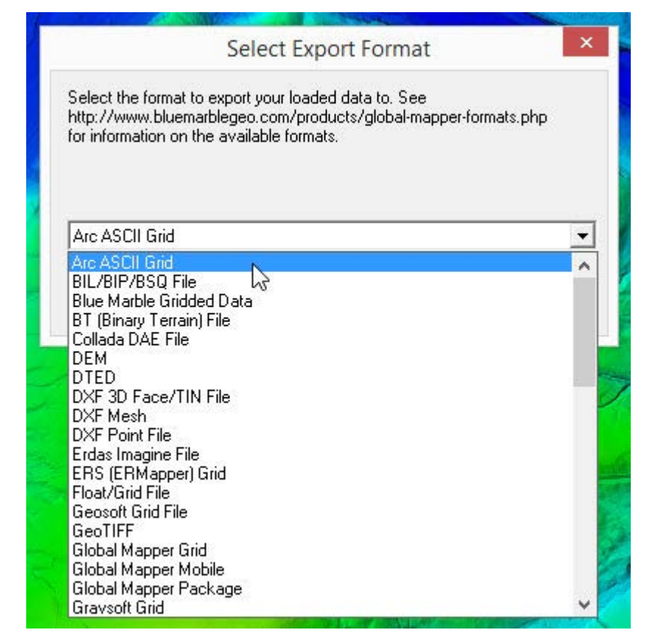
ArcGIS does a poor job exporting rasters as KML/KMZ files. Version 10.3 (**ArcTools > Conversion Tools > To KML > Layer to KML**) produces a reasonable KML/KMZ for viewing in Google Earth of single channel raster data. Images and topo quads exported as KML/KMZ still come into Google Earth highly pixelated. Global Mapper is the program to use for consistent quality KML/KMZ files from all types of data sets.

Processing elevation data in Global Mapper 17

Twenty DTM tiles downloaded from the NYS GIS Clearinghouse (https://gis.ny.gov/) opened in Global Mapper by shift clicking on the list of tiles. Global Mapper automatically mosaicks the tiles, applies a hillshade and a color ramp shader. Each tile is 1500 meters square with a resolution of 2 meters/pixel.

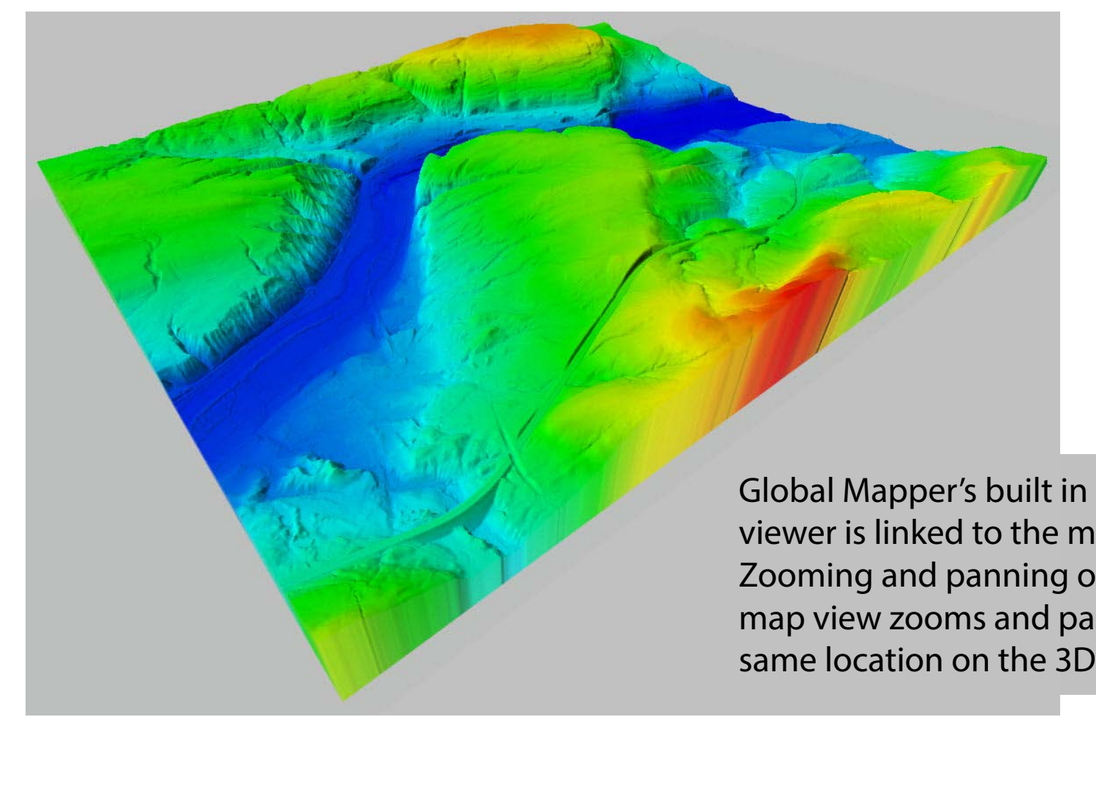


Export the data using **File > Export > Export Elevation Grid** and select **Arc ASCII Grid** from the pull-down.

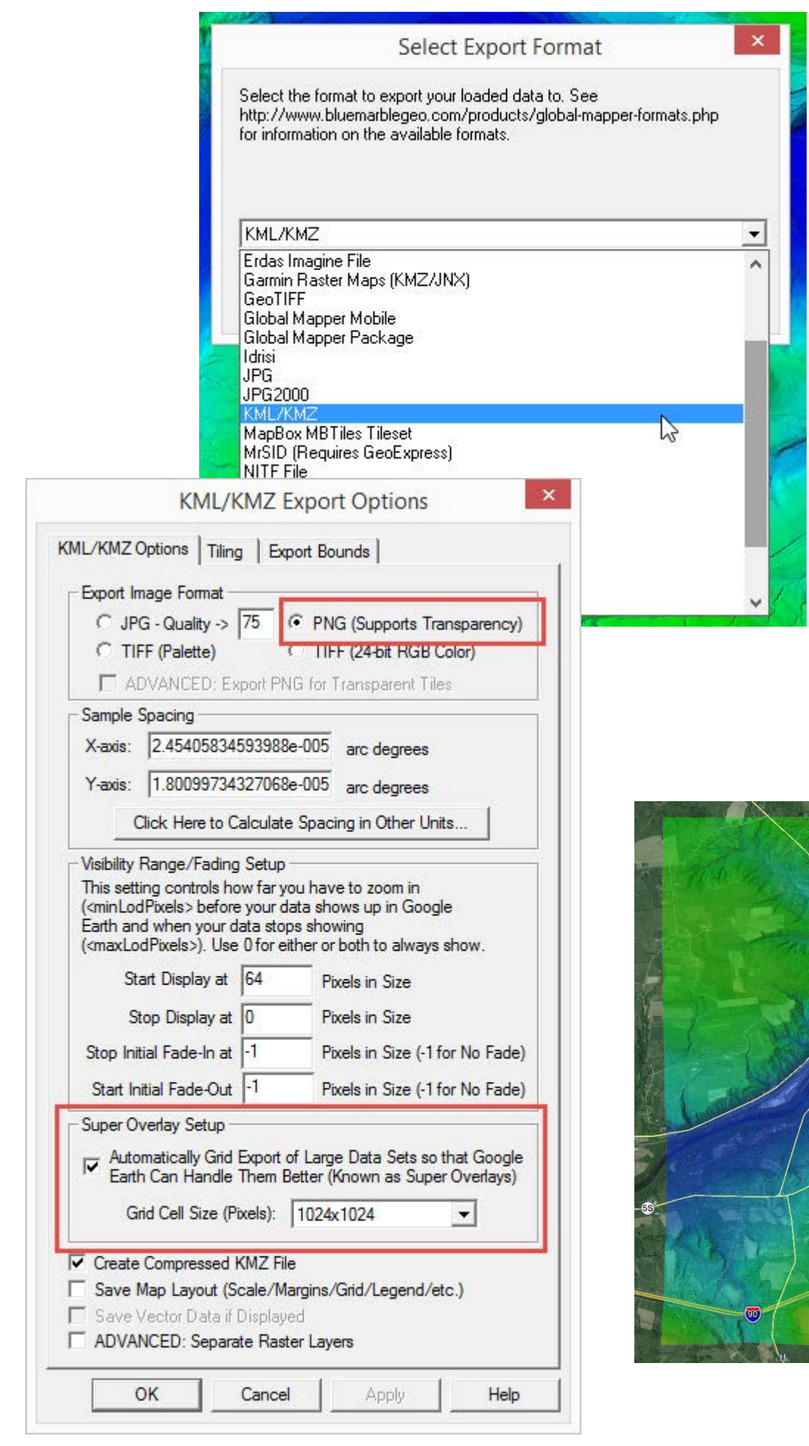


In the Save As window that opens, navigate to where the file is to be saved, name the file and click OK.

This .ASC file is opened in AccuTrans3D in the next step.



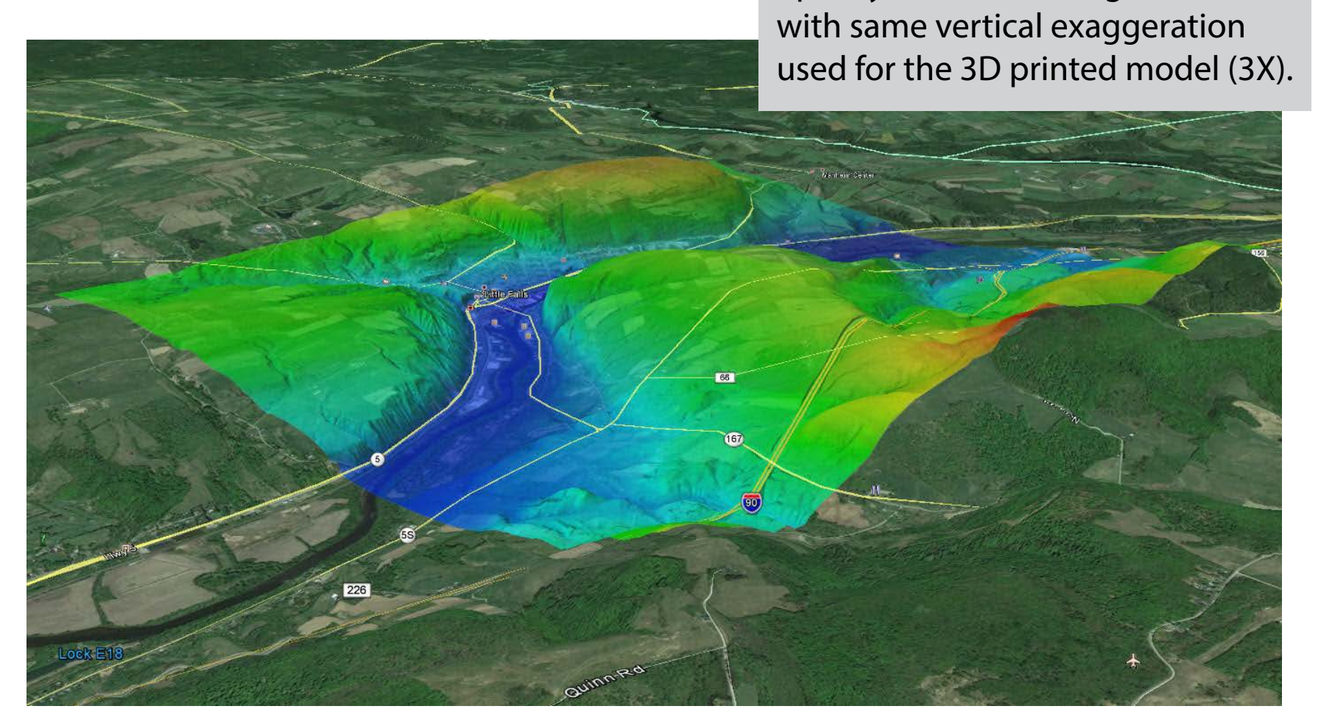
Global Mapper's built in 3D viewer is linked to the map view. Zooming and panning on the map view zooms and pans to the same location on the 3D view.



Global Mapper is like a Swiss Army knife for handling different file formats. GM does an excellent job exporting rasters as KML/KMZ files, something that ArcGIS does not do well in most cases.

Select PNG to enable transparency in the KML/KMZ when viewed in Google Earth. Also be sure that the Super Overlay box is checked. This is the key to producing quality raster KML/KMZ files.

Exported KML/KMZ with lowered opacity viewed in Google Earth with same vertical exaggeration used for the 3D printed model (3X).

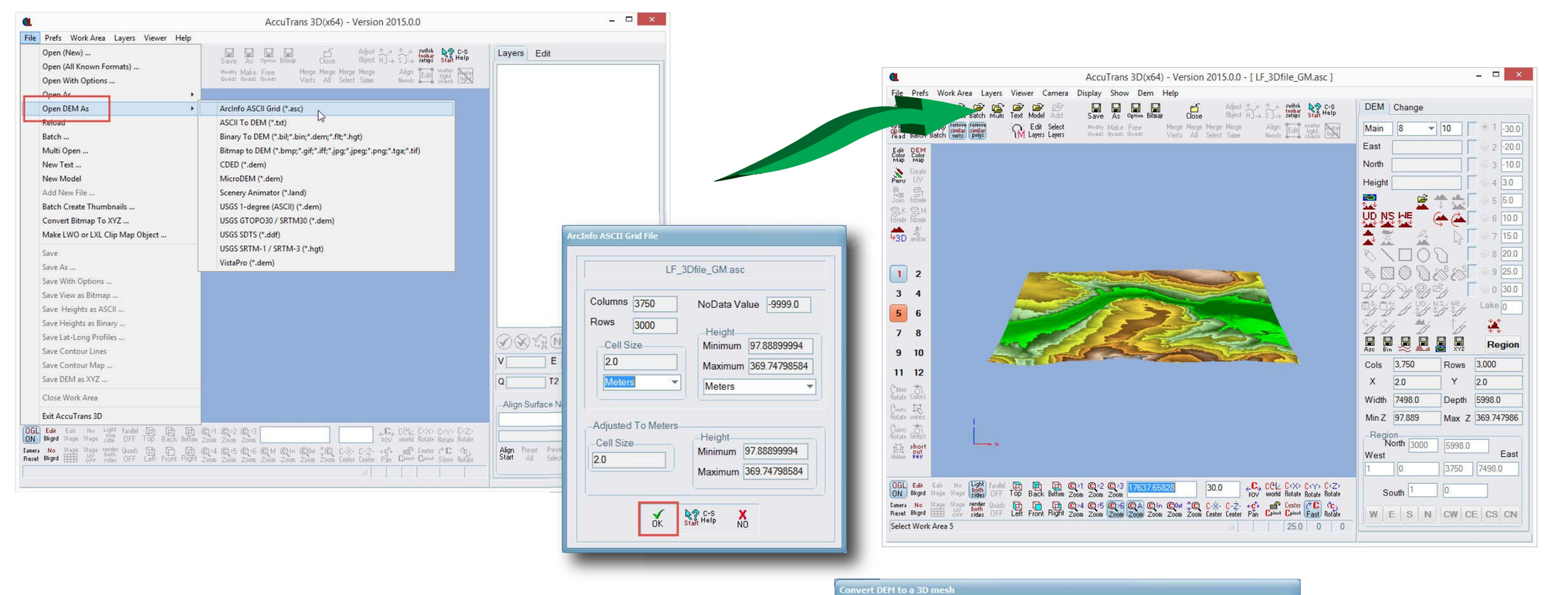


Processing ASC files in AccuTrans 3D (modified from workflow of Gregor Lútolf)

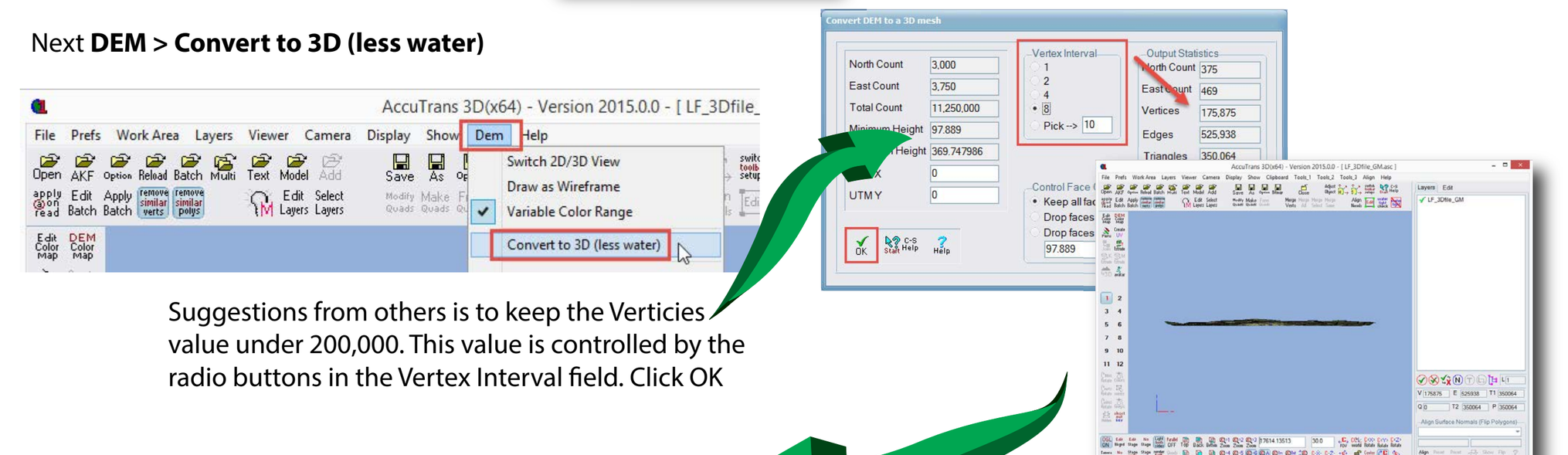
AccuTrans 3D (http://www.micromouse.ca/) is a $20 Canadian program used to generate STeroLithography files (STL) from the elevation ASC files exported from ArcGIS or Global Mapper. STL is a file format native to 3D Systems CAD software, describing the surface of a 3D object without color or texture attributes. (https://en.wikipedia.org/wiki/STL_(file_format)

STL is a file format supported by the Ultimaker 2 3D printer software.

In AccuTrans 3D open the ASC file (**File > Open DEM as > ArcInfo ASCII Grid (asc)**) and click OK in ArcInfo ASCII Grid dialog box to display the DEM in the main window.

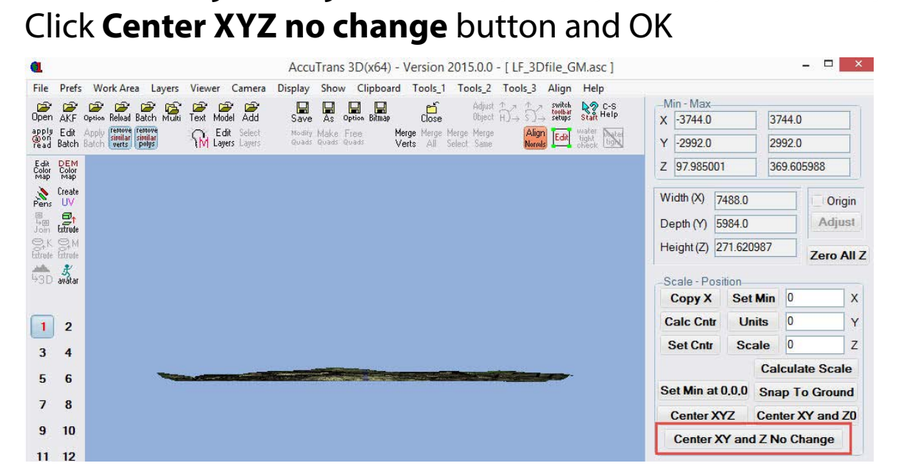


Next **DEM > Convert to 3D (less water)**



Suggestions from others is to keep the Verticies value under 200,000. This value is controlled by the radio buttons in the Vertex Interval field. Click OK

Tools 1 > Adjust Object (mirror, scale, rotate , translate)
Click **Center XYZ no change** button and OK



According to Wayne Hogue, developer of AccuTrans 3D, models in AccuTrans 3D are unitless until units are assigned and the model is scaled. It is possible to skip these steps and exturde the base, but without units it is impossible to know what the base thickness will be until the model is in the 3D printer software.

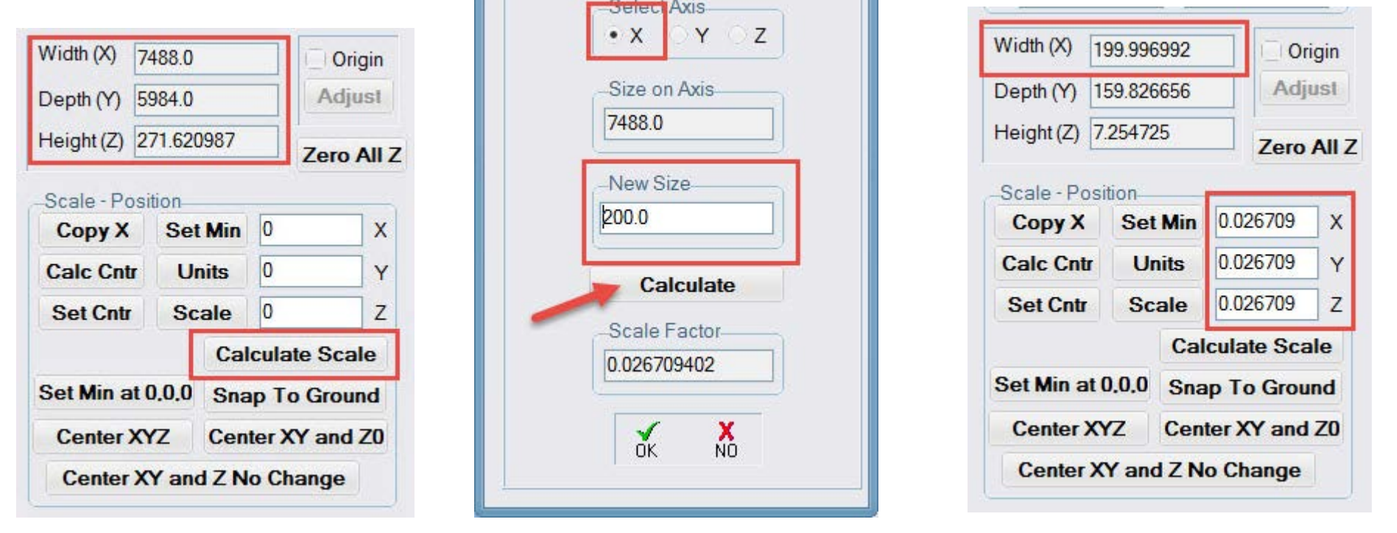
The goal is to scale the model's long dimension to approximate the build dimensions of the 3D printer. For the Ultimaker 2, 200 mm is a good number to aim for to produce a model close to the maximum build size.

Tools 1 > Adjust Object (mirror, scale, rotate , translate) AGAIN

In the Scale-Position window on the right side of the screen click the Calculate Scale button.

In dialog box enter 200 in the New Size field and click **Calculate** to generate Scale Factor, click OK

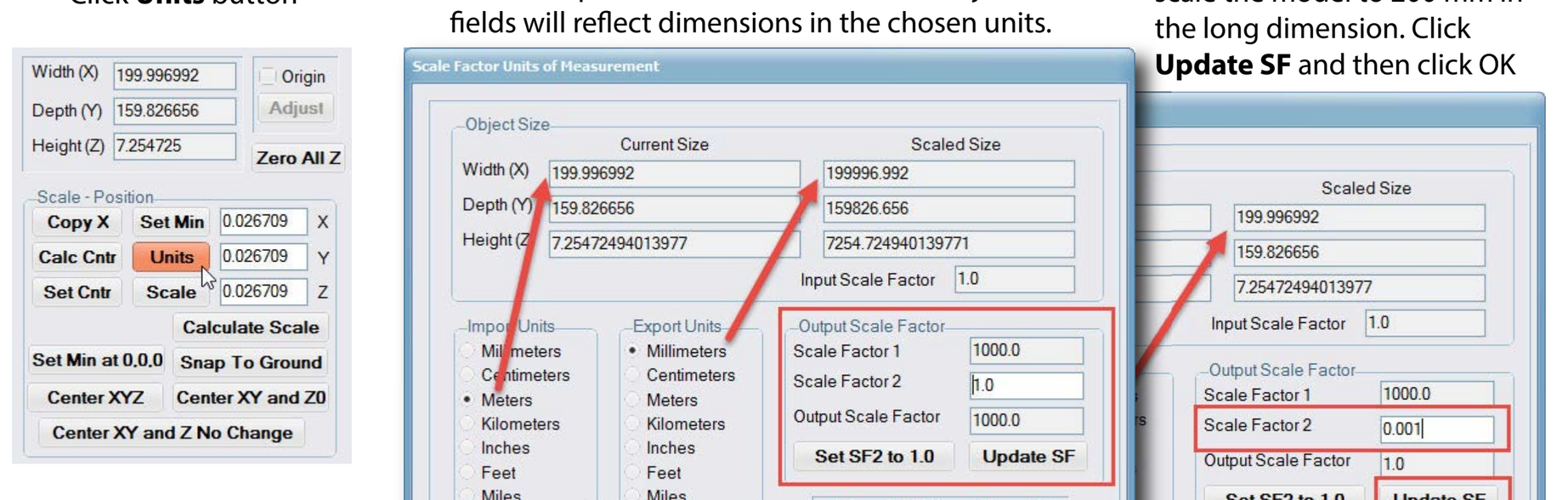
Scale factor is entered in XYZ fields and new width, depth and height are shown. These are still unitless numbers.



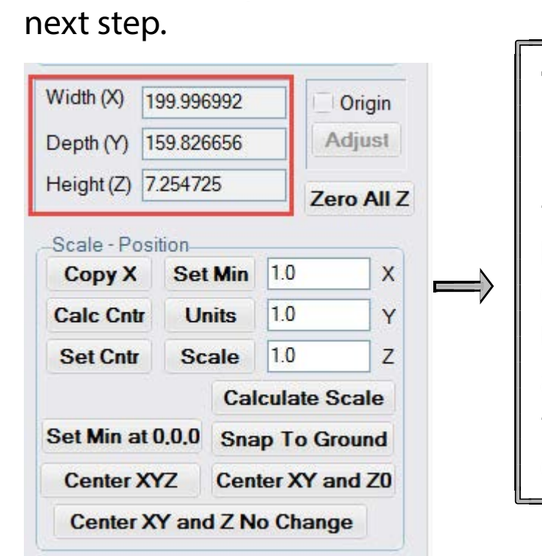
Click **Units** button

Scale factor units dialog box opens. Set input units to meters, export units to millimeters and object size fields will reflect dimensions in the chosen units.

In the scale factor 2 window enter an appropiate factor to scale the model to 200 mm in the long dimension. Click **Update SF** and then click OK

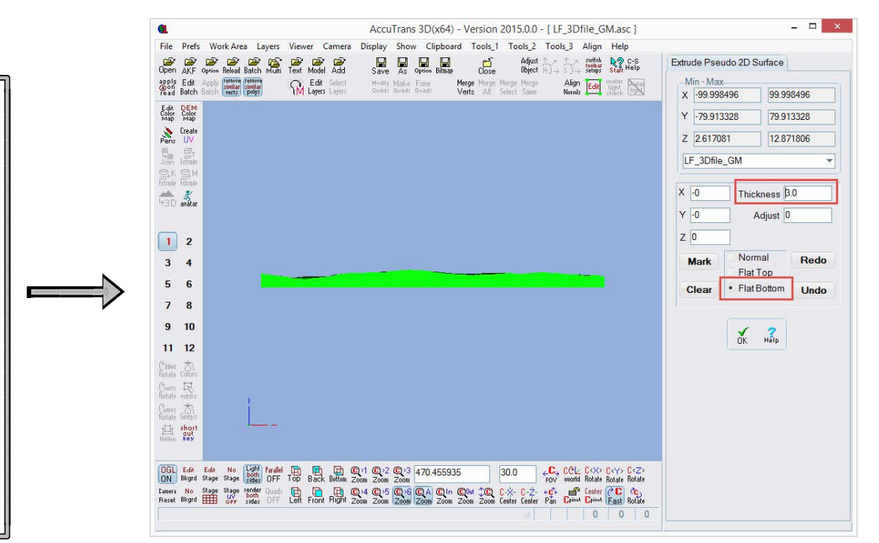


Scale is reflected in the main window and these units are now mm. Note the Height value as it is important in the next step.

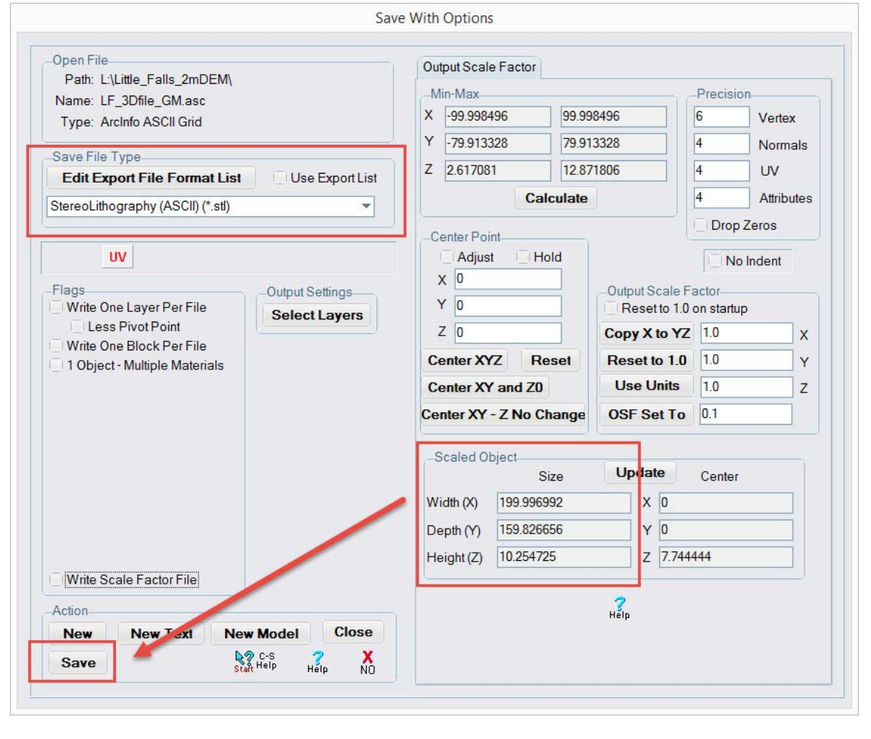


Tools 1 > Extrude Pseudo 2D Surface

In the Thickness window enter a value for the base thickness and check the Flat Bottom radio button. Thickness is in mm. Click Extrude button to display extrusion. Use Undo button and thickness value to adjust as needed. Thickness will be added to Z value noted in prevous step. Vertical exaggeration will increase this value.



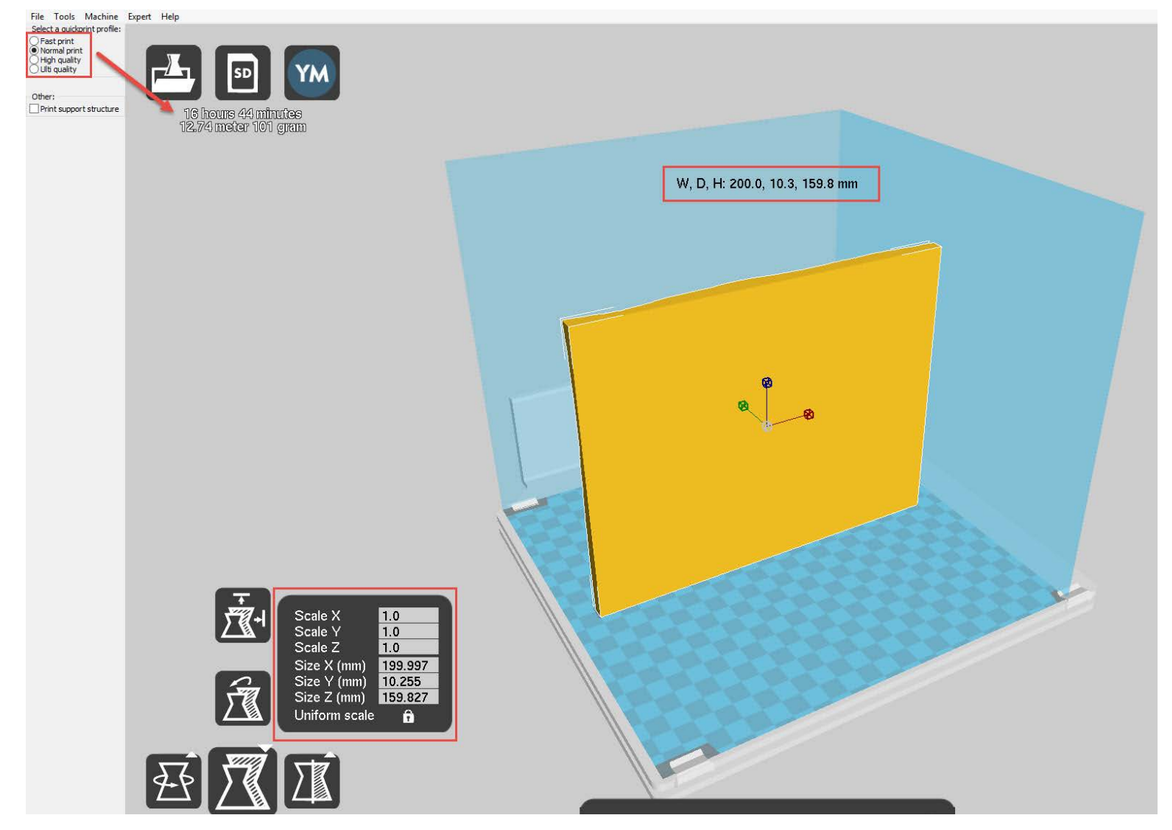
File > Save with Options
Set Save File Type to **StereoLithography (ASCII) (stl)**
Check the Scaled Object dimensions are correct and click Save. Regular Save As dialog box opens, browse to appropriate location to save file. Default file name is same as input file with .stl ending.



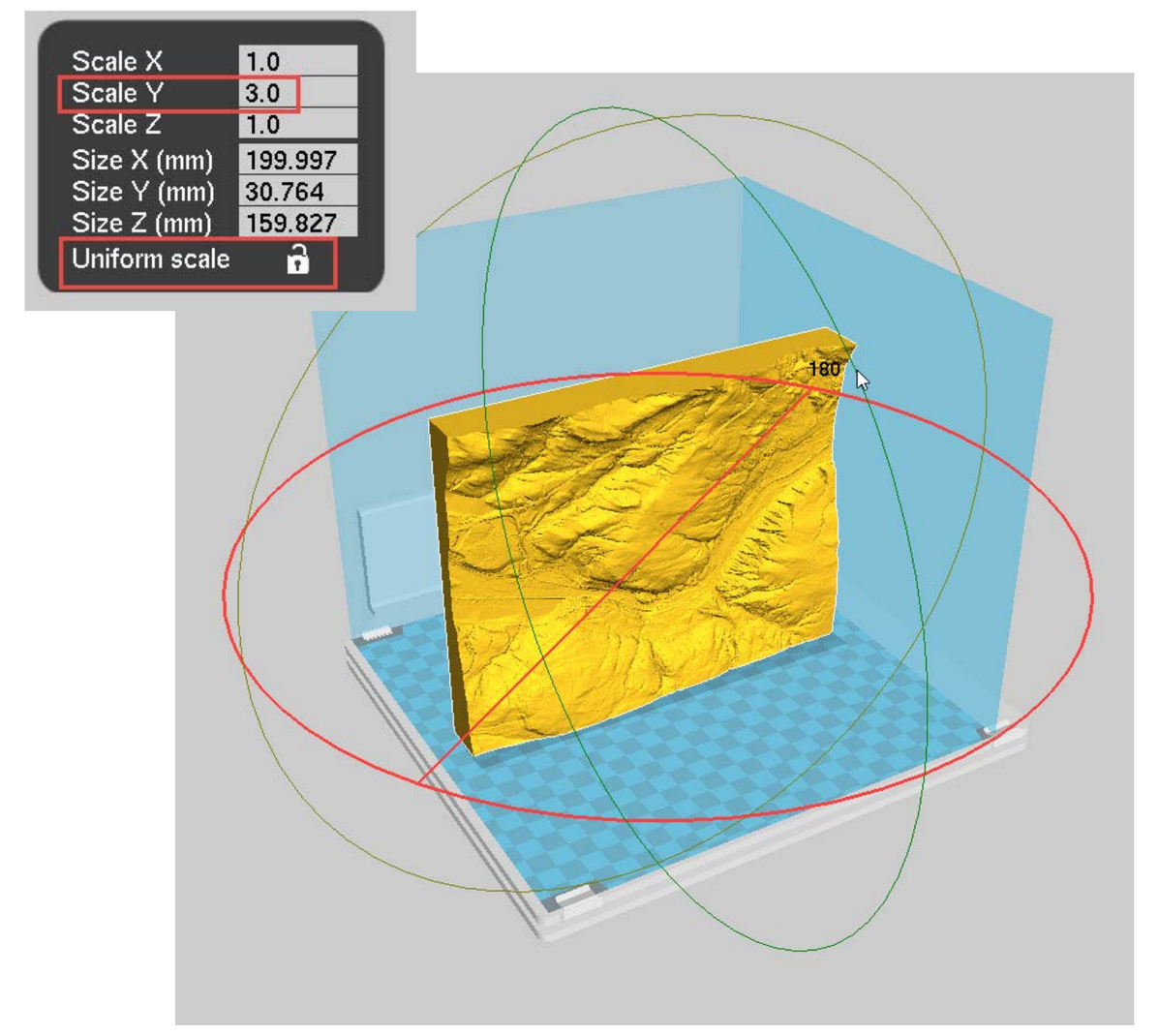
On to the 3D printer software to print the model.

Open STL file in Utimaker CURA software

File > Load model
Model opens in printer build volume image. Dimensions are dispalyed and tools to rotate, scale and mirror are available. Build quality , build time and material useage are also displayed.

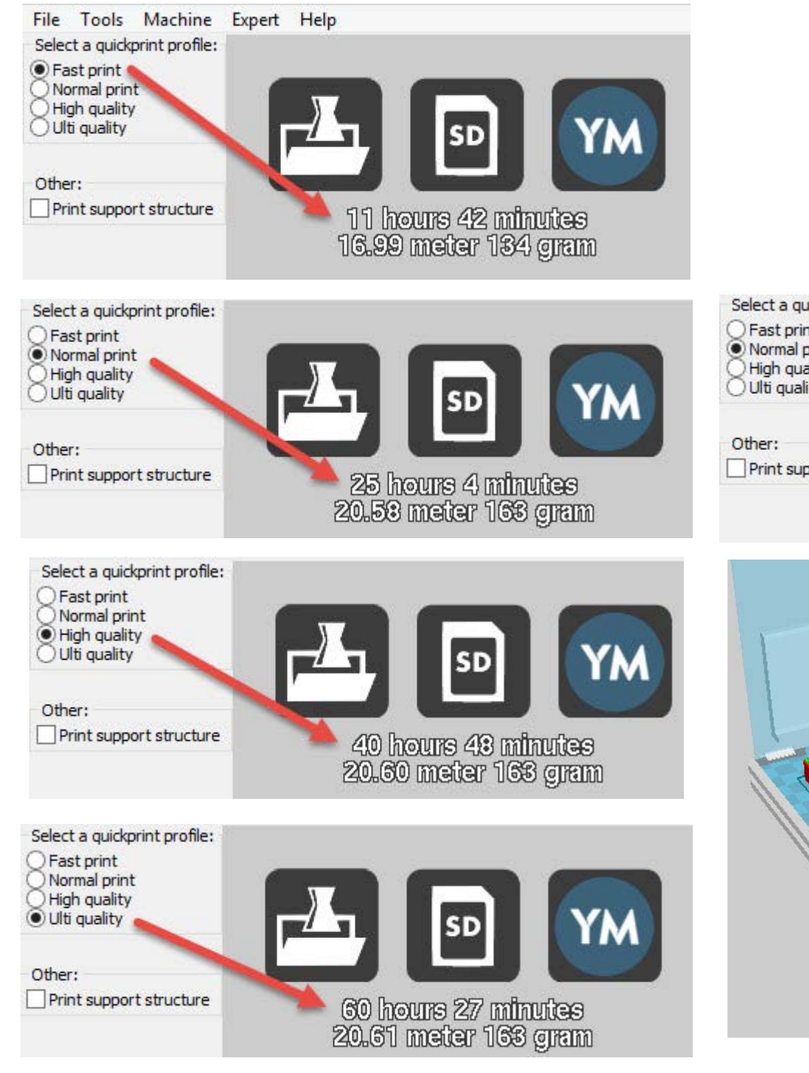


Using Scale tool 3X vertical exaggeration is added, because model is vertical, exaggeration is applied to Y axis. Unlock Uniform Scale before applying exaggeration. Rotate tool used to rotate model 180 degrees to show DTM surface rather than flat base.

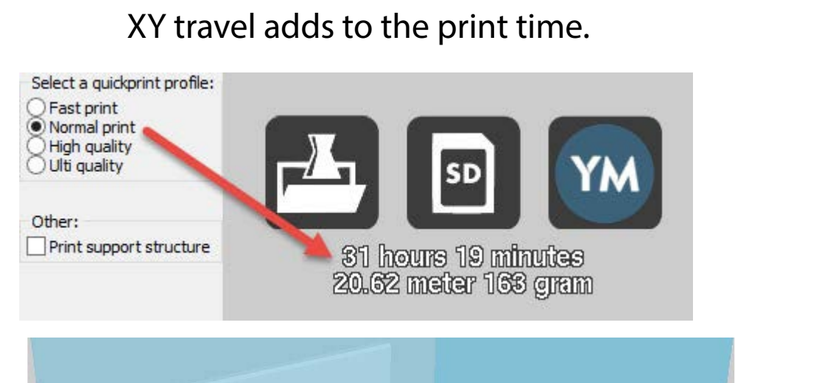


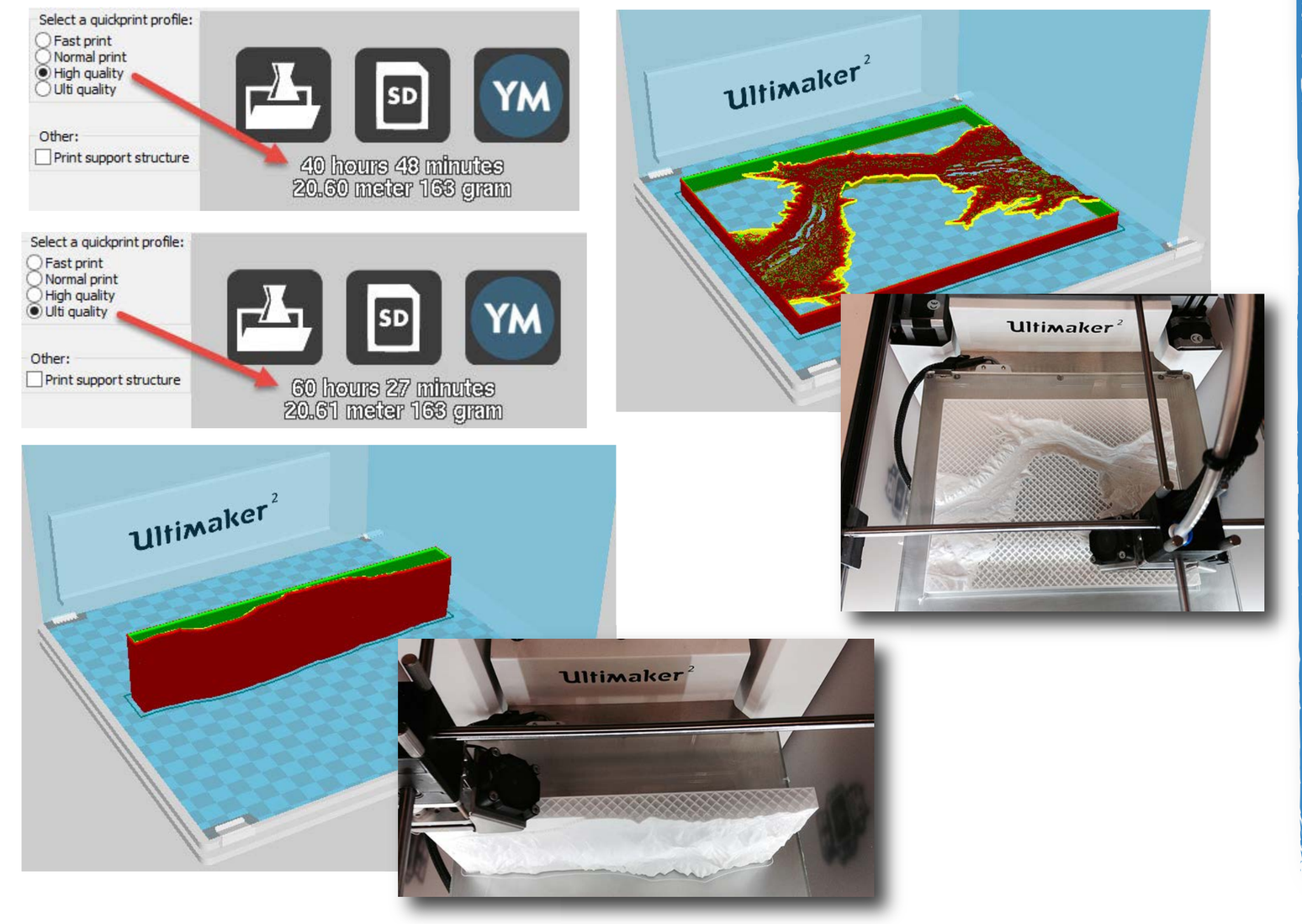
For a given model, build quality governs the print time. Model orientation also plays a smaller role. All models displayed are printed in Normal mode.

Print times for this model in vertical orientation for all four print modes.



Normal print time for this model in horizontal orientation. Greater XY travel adds to the print time.



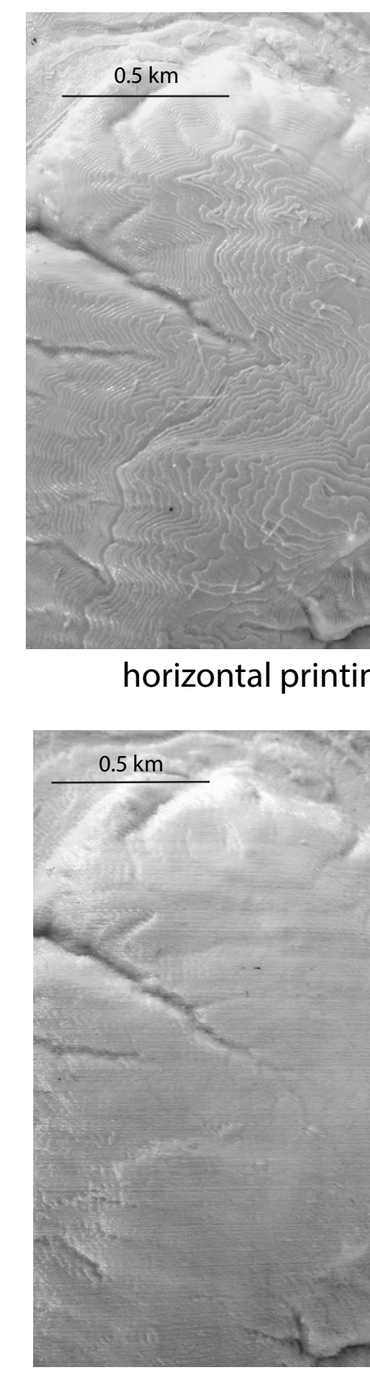


red frame shows approximate area of details at right

3D print of Little Falls LiDAR DTM data (printed in vertical orientation). Real world area approximately 7.5 km by 6 km. Model X dimension 200 mm.

When printing the print head moves in an XY direction and as each layer is completed, the build plate moves down incrementally so the next layer can be constructed.

This model was printed both vertically and horizontally to show the "contouring effect" with horizontal printing. Both models printed to exactly the same scale and exactly the same print quality. Unless "contour effect" is desired, vertical printing produces a smoother, more detailed model. Models also print slightly faster due to the reduced XY travel distance the print head has to move when printing each layer.



horizontal printing

vertical printing

About the Ultimaker 2 https://ultimaker.com/en/products/ultimaker-2

Printer costs $2500 -$2700, is about the size of a networked laser printer and weighs less than 12 lbs. It is a stand-alone item. Print file is saved to an SD card which the printer reads. Computer is not tied up while the printer is printing.

https://ultimaker.com/en/products/materials

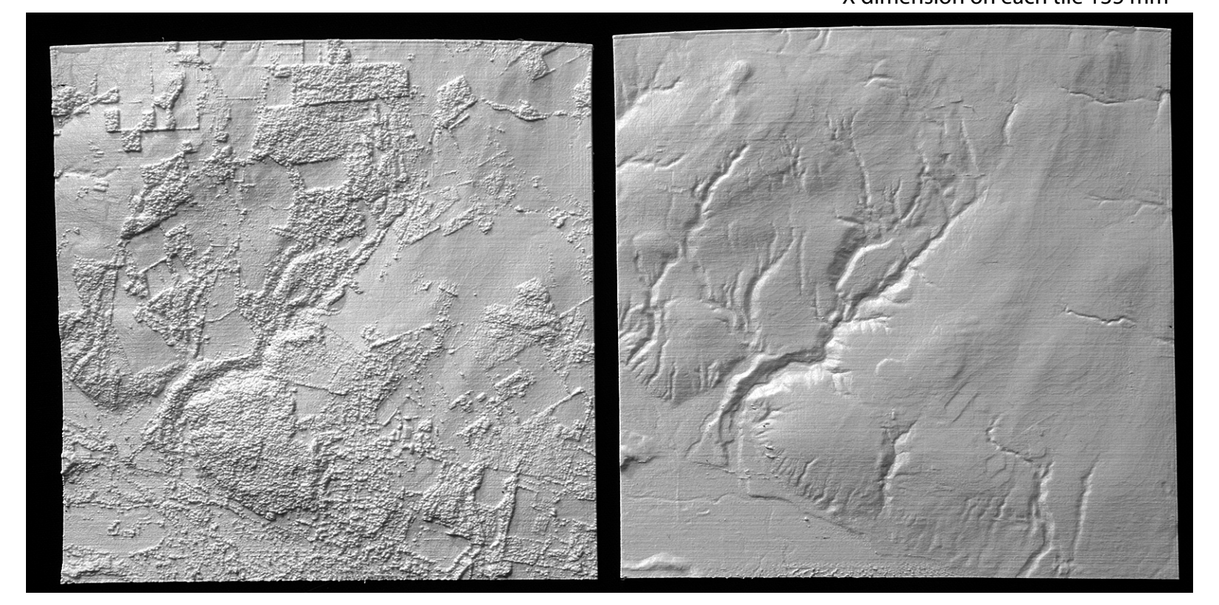
Printer uses fuseable filament to print. ABS, CPE and PLA material is available in a number of colors. Filament is sold in 750 gram rolls. All sample models are printed with white CPE (750 gram roll about 90 meters) which costs about $.66 per meter. Little Falls model used about 20 meters per print.

Sample Projects

Hamilton College area 3D prints

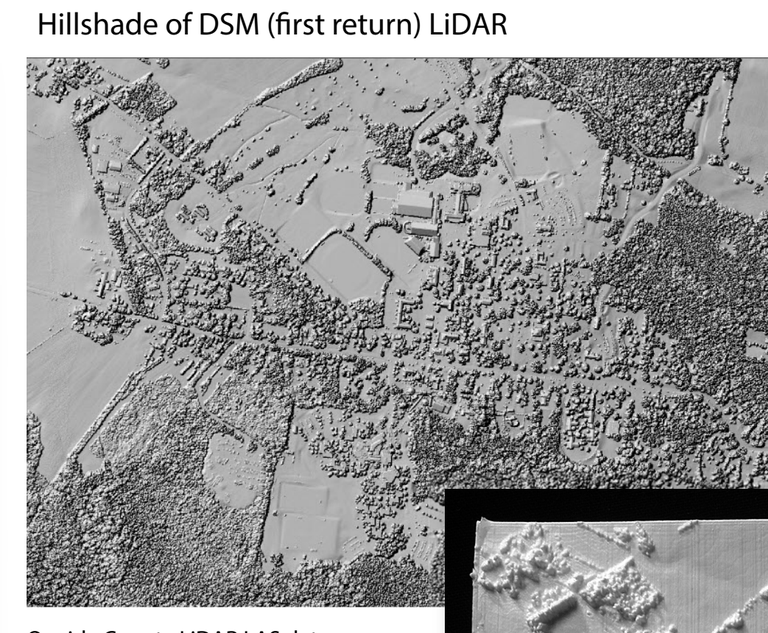
DSM (first return data) from Oneida County LiDAR LAS data (left)
DTM (bare earth) from Oneida County LiDAR LAS data (right)

X dimension on each tile 135 mm



Hamilton College campus detail

Hillshade of DSM (first return) LiDAR



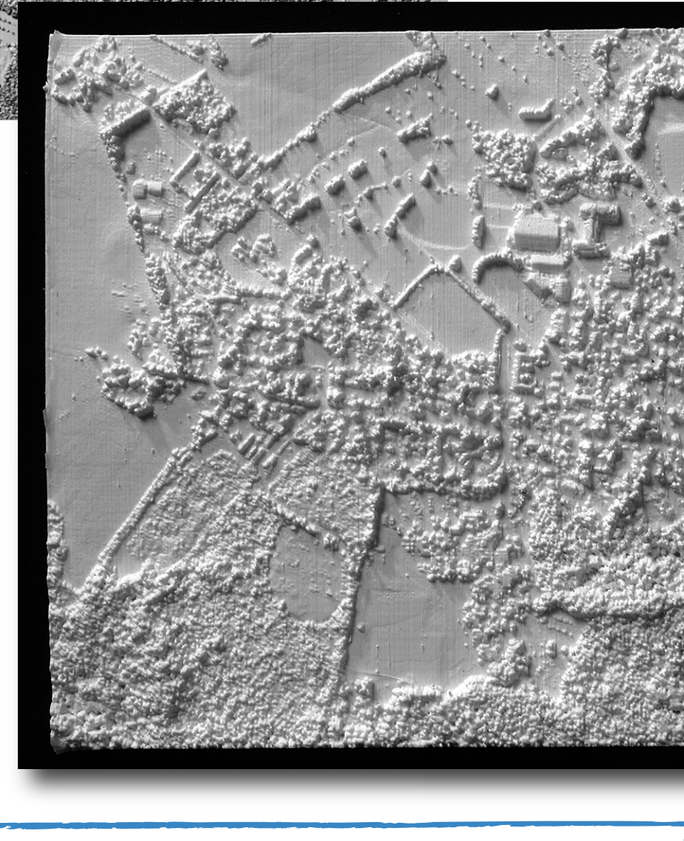
Oneida County LiDAR LAS data

ArcMap hillshade of first return data above.

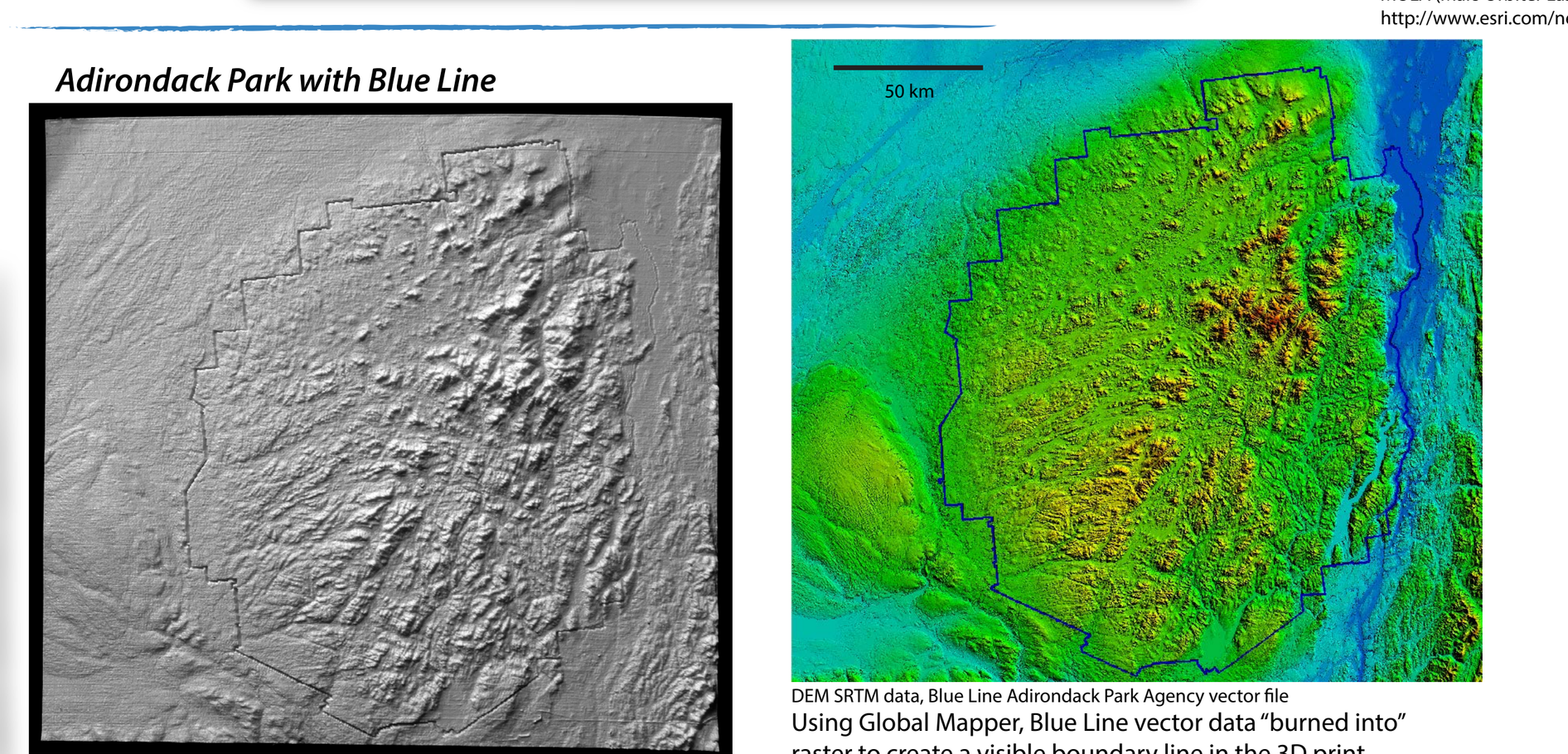
3D print of first return LiDAR data (DSM), right.

2 meter/pixel resolution

X dimension 200 mm



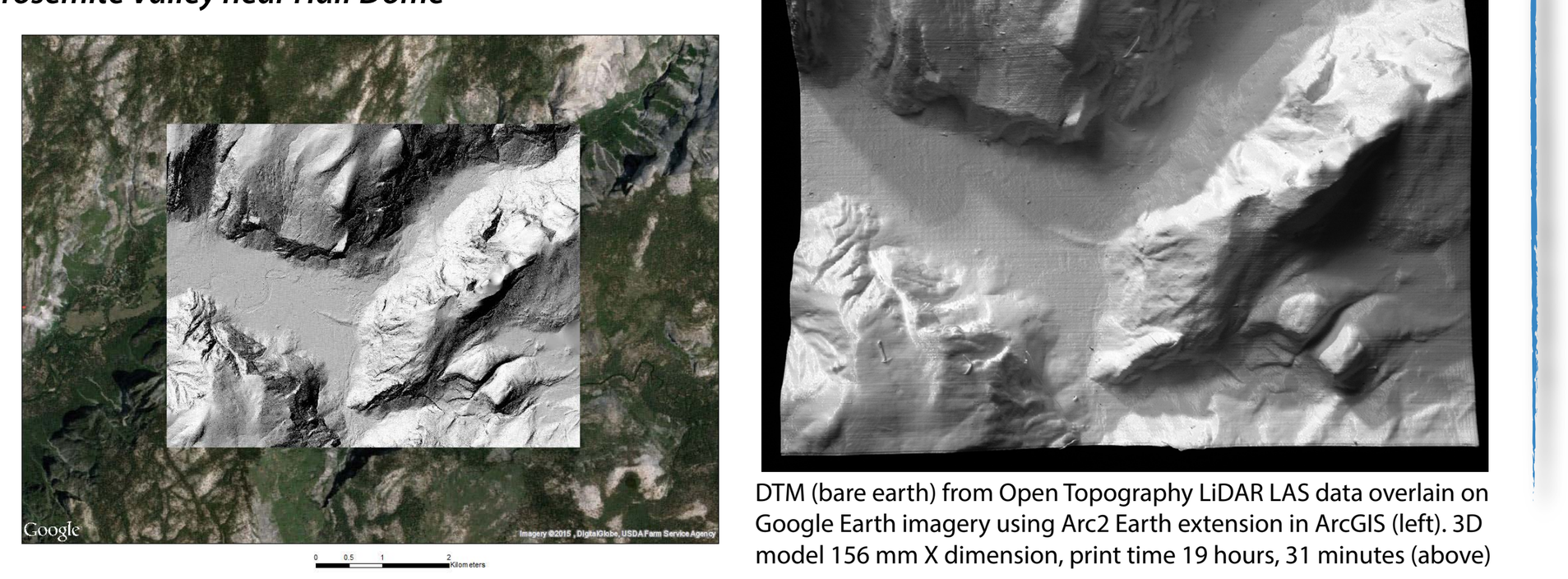
Adirondack Park with Blue Line



3D print X dimension 210 mm and print time of 30 hours and 37 minutes.

DEM SRTM data, Blue Line Adirondack Park Agency vector file
Using Global Mapper, Blue Line vector data "burned into" raster to create a visible boundary line in the 3D print.

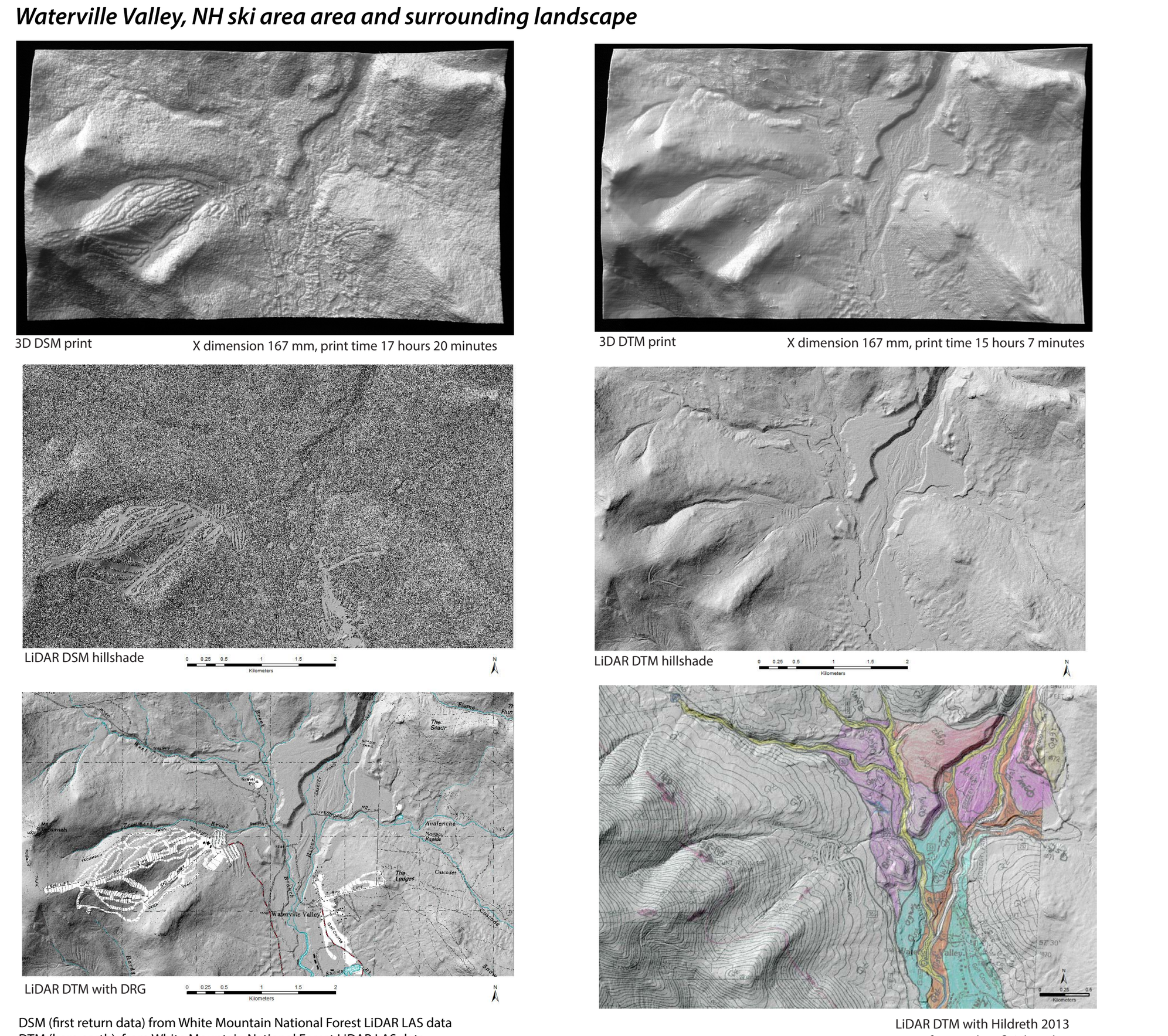
Yosemite Valley near Half Dome



DTM (bare earth) from Open Topography LiDAR LAS data overlain on Google Earth imagery using Arc2 Earth extension in ArcGIS (left). 3D model 156 mm X dimension, print time 19 hours, 31 minutes (above)

Sample Projects continued

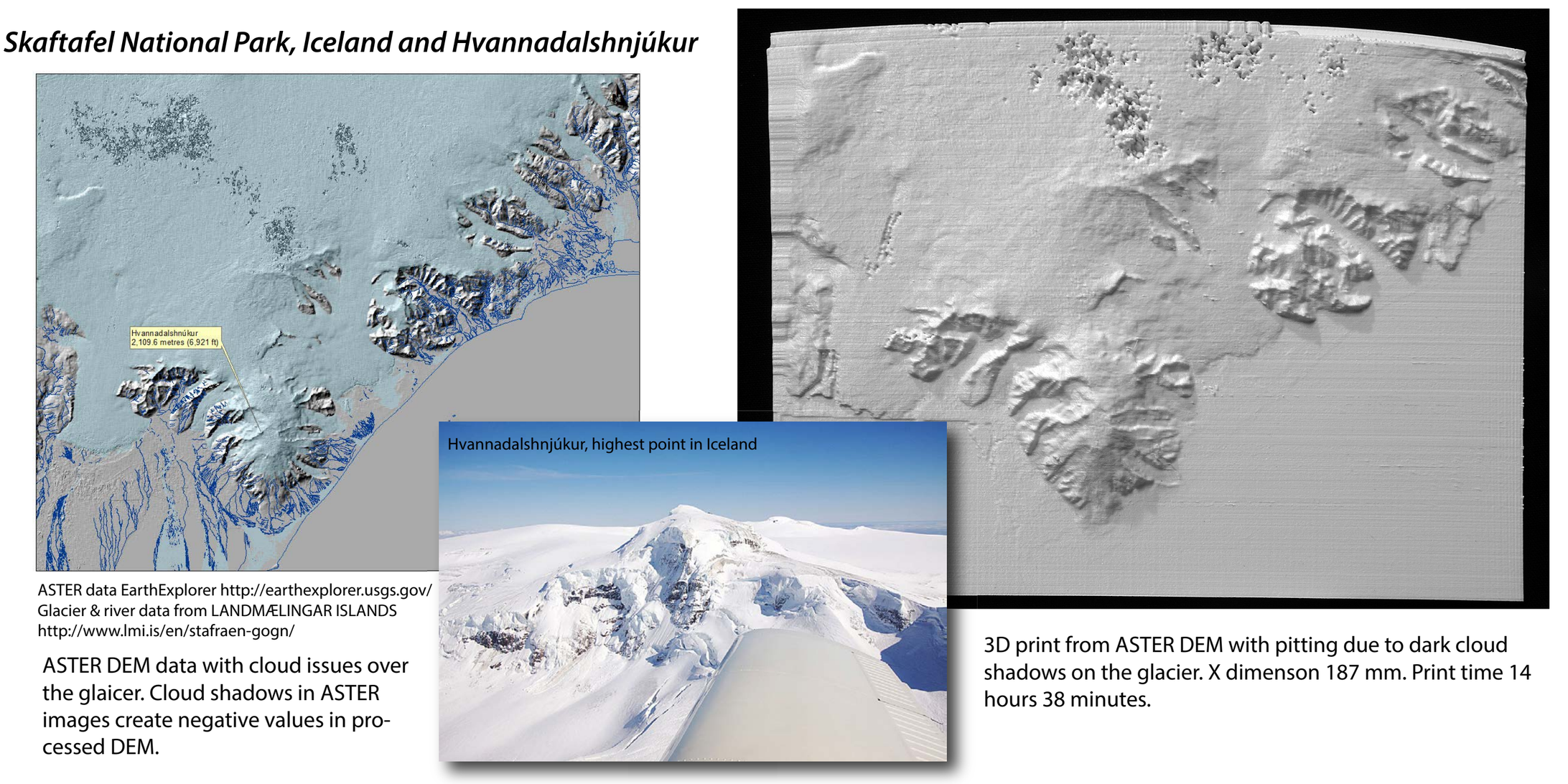
Waterville Valley, NH ski area area and surrounding landscape



DSM (first return data) from White Mountain National Forest LiDAR LAS data
DTM (bare earth) from White Mountain National Forest LiDAR LAS data
Waterville Valley & Mt. Tripyramid DRGs (http://www.granit.unh.edu/data/search)
Waterville Valley surficial geology map by Carol Hildreth, 2013, cortesy of Rick Chorman, NH state geologist

LiDAR DTM with Hildreth 2013 georeferenced surficial geology map

Skaftafel National Park, Iceland and Hvannadalshnjúkur



ASTER data EarthExplorer http://earthexplorer.usgs.gov/
Glacier & river data from LANDMÆLINGAR ISLANDS
http://www.lmi.is/en/stafraen-gogn/

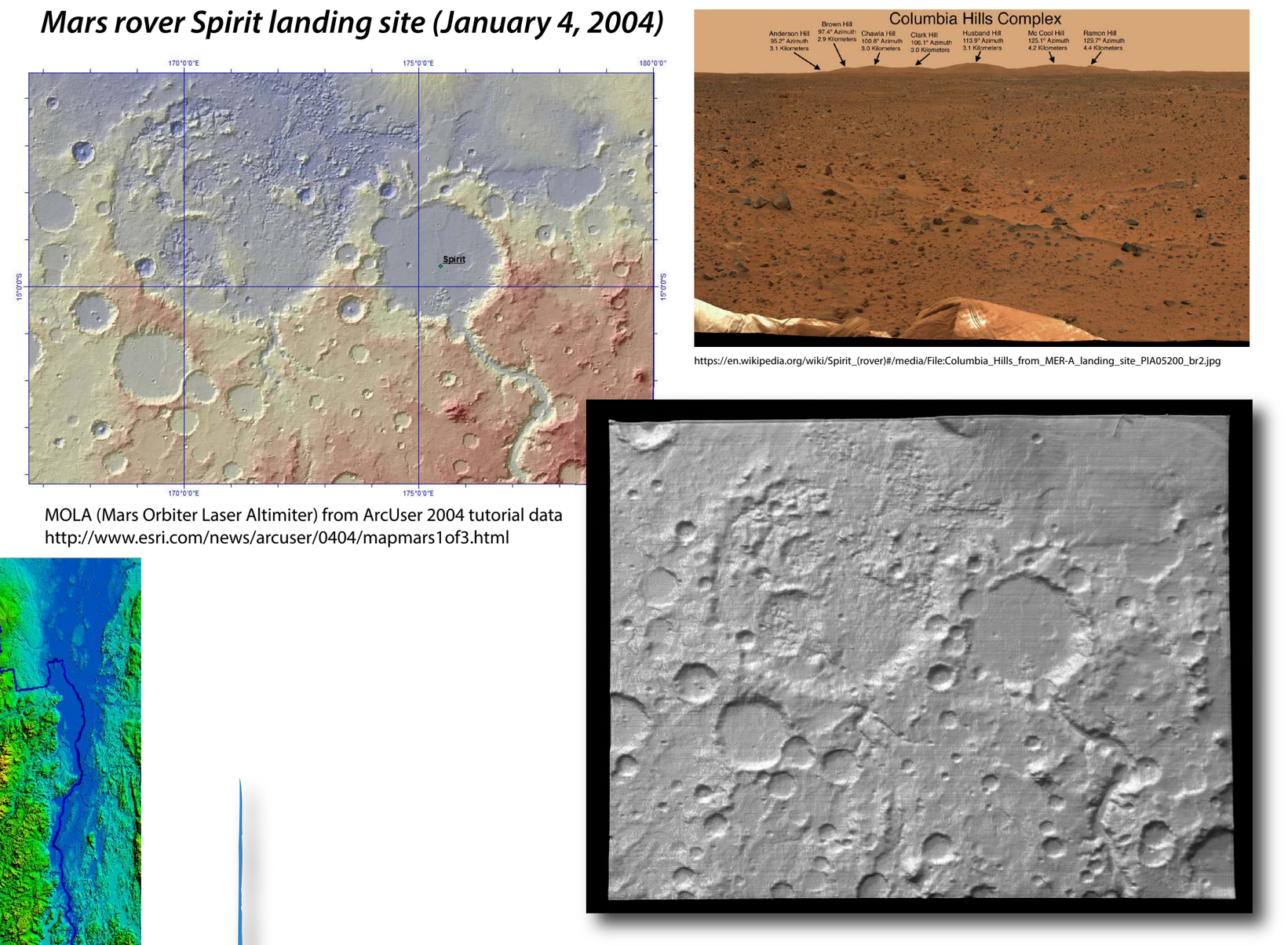
ASTER DEM data with cloud issues over the glaicer. Cloud shadows in ASTER images create negative values in processed DEM.

Hvannadalshnjúkur, highest point in Iceland

https://en.wikipedia.org/wiki/Hvannadalshn%C3%BAkur#/media/File:Hvannadalshnukur_August_2011.jpg

3D print from ASTER DEM with pitting due to dark cloud shadows on the glacier. X dimenson 187 mm. Print time 14 hours 38 minutes.

Mars rover Spirit landing site (January 4, 2004)

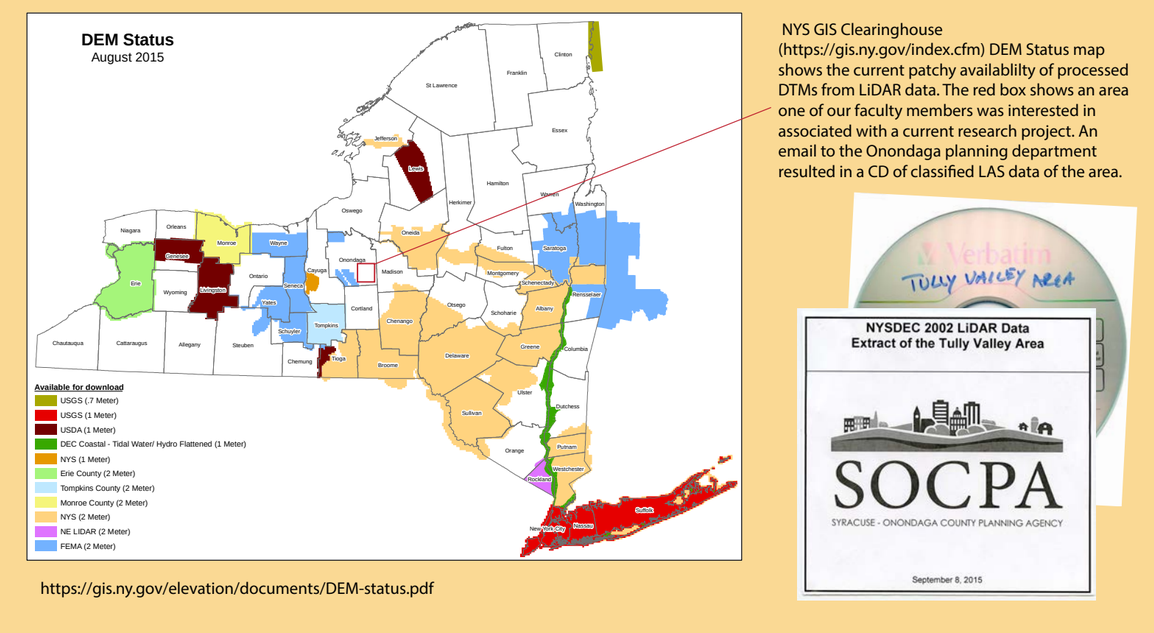


MOLA (Mars Orbiter Laser Altimiter) from ArcUser 2004 tutorial data
http://www.esri.com/news/arcuser/0404/mapmars1of3.html

https://en.wikipedia.org/wiki/Spirit_(rover)#/media/File:Columbia_Hills_from_MER-A_landing_site_PIA05200_br2.jpg

3D print from MOLA data. X dimension 165 mm, print time 16 hours and 58 minutes.

It pays to ask about data



NYS GIS Clearinghouse (https://gis.ny.gov/index.cfm) DEM Status map shows the current patchy availability of processed DTMs from LiDAR data. The red box shows an area one of our faculty members was interested in associated with a current research project. An email to the Onondaga planning department resulted in a CD of classified LAS data of the area.

https://gis.ny.gov/elevation/documents/DEM-status.pdf

References and Acknowlegements

Gregor Lútolf: http://sdu.ictp.it/3D/resources/maps_to_3D.pdf
Shapespeare: http://www.the3dprintedfuture.com/shapespeare/?p=1
http://www.the3dprintedfuture.com/shapespeare/?p=31
http://www.the3dprintedfuture.com/shapespeare/?p=41

Fredrick Chorman, NH State geologist for making WMNF LiDAR data availble

Wayne Hogue @ Micromouse (AccuTrans3D software) for assistance with scaling and units

Jeff Howe @ Blue Marble Geographics (Global Mapper software) for assistance with Global Mapper STL files

Josie Wilford @ Blue Marble Geographics (Global Mapper software) for assistance with technique for "burnng" Blue Line into Adirondack DTM & Global Mapper STL files