DoD 3.0 Beta Tutorial
DEM of Difference Uncertainty Analysis Software

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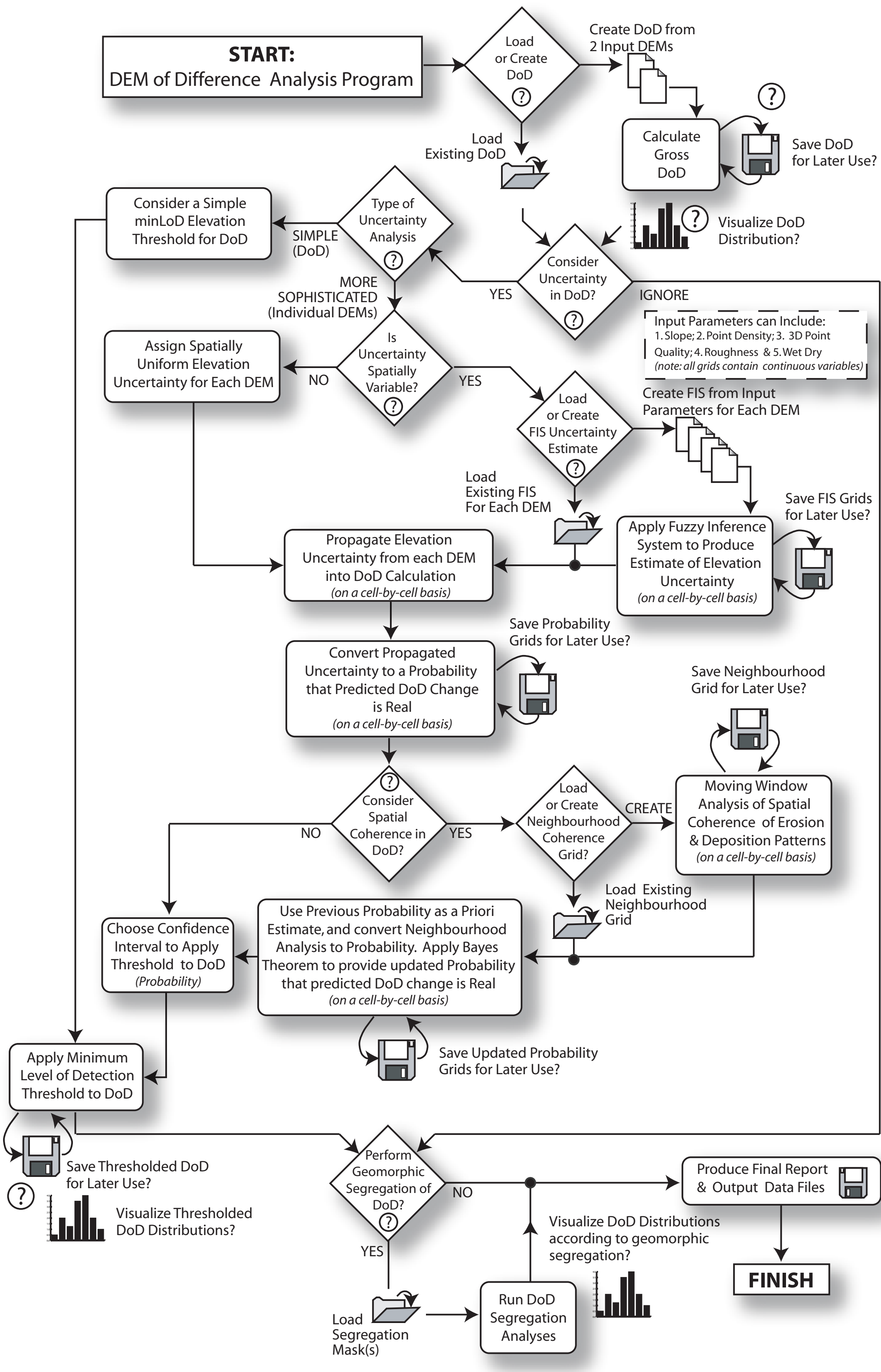
Introduction

This tutorial is intended to help you through the different pathways you can take through the DoD3 software wizard. The tutorial will use the example data from Sulphur Creek provided with the zip file. The first part covers basics of navigating through the software. The later half covers more advanced topics for when you start preparing your own data for use in the software or modifying the source code yourself. The screen shots in this tutorial were taken from a Mac OS, and the appearance will be slightly different in Windows. The tutorial is not comprehensive, but should hopefully give you enough direction to navigate through the program. If you experience crashes during the program, check the Matlab Scripts and Functions section and confirm that you have met the minimum requirements specified in the ReadMe file. You may need to make minor tweaks to the code to get it to work for your circumstances.

Tutorial Topics:

Different Pathways

As described in Chapter 4 of Wheaton (2008), there are six different pathways through the DoD software analysis. The flowchart on the next page shows the primary navigation options through the wizard dialogs in DoD3. The six pathways represent the different routes you might take as a user based on the decision points (diamonds). If you are trying to repeat the type of analyses reported in the Wheaton *et al.* (2009) ESPL paper, you want a Pathway 4 analysis.


START:
DEM of Difference Analysis Program
Load or Create DoD
Create DoD from 2 Input DEMs
Calculate Gross DoD
Save DoD for Later Use?
Load Existing DoD
Visualize DoD Distribution?
Consider Uncertainty in DoD?
IGNORE
YES
Type of Uncertainty Analysis
SIMPLE (DoD)
Consider a Simple minLoD Elevation Threshold for DoD
MORE SOPHISTICATED (Individual DEMs)
Input Parameters can Include:
1. Slope; 2. Point Density; 3. 3D Point Quality; 4. Roughness & 5. Wet Dry
(note: all grids contain continuous variables)
Is Uncertainty Spatially Variable?
NO
YES
Assign Spatially Uniform Elevation Uncertainty for Each DEM
Load or Create FIS Uncertainty Estimate
Create FIS from Input Parameters for Each DEM
Load Existing FIS For Each DEM
Save FIS Grids for Later Use?
Apply Fuzzy Inference System to Produce Estimate of Elevation Uncertainty
(on a cell-by-cell basis)
Propagate Elevation Uncertainty from each DEM into DoD Calculation
(on a cell-by-cell basis)
Save Probability Grids for Later Use?
Convert Propagated Uncertainty to a Probability that Predicted DoD Change is Real
(on a cell-by-cell basis)
Save Neighbourhood Grid for Later Use?
Consider Spatial Coherence in DoD?
NO
YES
Load or Create Neighbourhood Coherence Grid?
CREATE
Moving Window Analysis of Spatial Coherence of Erosion & Deposition Patterns
(on a cell-by-cell basis)
Load Existing Neighbourhood Grid
Use Previous Probability as a Priori Estimate, and convert Neighbourhood Analysis to Probability. Apply Bayes Theorem to provide updated Probability that predicted DoD change is Real
(on a cell-by-cell basis)
Choose Confidence Interval to Apply Threshold to DoD
(Probability)
Save Updated Probability Grids for Later Use?
Apply Minimum Level of Detection Threshold to DoD
Save Thresholded DoD for Later Use?
Visualize Thresholded DoD Distributions?
Perform Geomorphic Segregation of DoD?
NO
YES
Produce Final Report & Output Data Files
Visualize DoD Distributions according to geomorphic segregation?
FINISH
Load Segregation Mask(s)
Run DoD Segregation Analyses

The same flowchart is shown in each of the Pathway sections to show what each pathway represents. The pathways represent different choices about the type of uncertainty analysis you wish to undertake. The options range from no uncertainty analysis (Pathway 1: a.k.a. gross DoD) to a spatially variable, probabilistic uncertainty analysis combining fuzzy inference systems and a spatial coherence filter (Pathway 4). The table below highlights the primary differences between each of the pathways (refer to the ESPL Wheaton *et al.* (2009) paper or Wheaton (2008) thesis for fuller explanation).

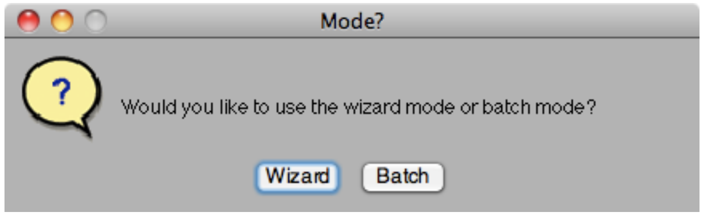
	Pathway					
Sub-Method:	1	2	3	4	5	6
Gross DoD Analysis?	Y	Y	Y	Y	Y	Y
Simple $_{min}$LoD Elevation Threshold for DoD?	N	Y	N	N	N	N
Spatially Uniform: separate $\delta(z)$ for each DEM?	N	N	N	N	Y	Y
Spatially Variable: FIS defined $\delta(z)$ for each DEM?	N	N	Y	Y	N	N
Bayesian Updating Based on Spatial Contiguity Index?	N	N	N	Y	Y	N
Probabilistic $_{min}$LoD Confidence Interval Threshold for DoD?	N	N	Y	Y	Y	Y

All wizard-based DoD analyses using DoD3 start in the same way and proceed through the same sequence of steps. It is not until you reach the point at which you decide how to consider uncertainty in the DoD (second diamond in flowchart) that you have a different sequence of wizard dialogs. This first part of the tutorial walks you up to that point and based on your decisions from there you can navigate to the different pathways to see what the dialogs look like.

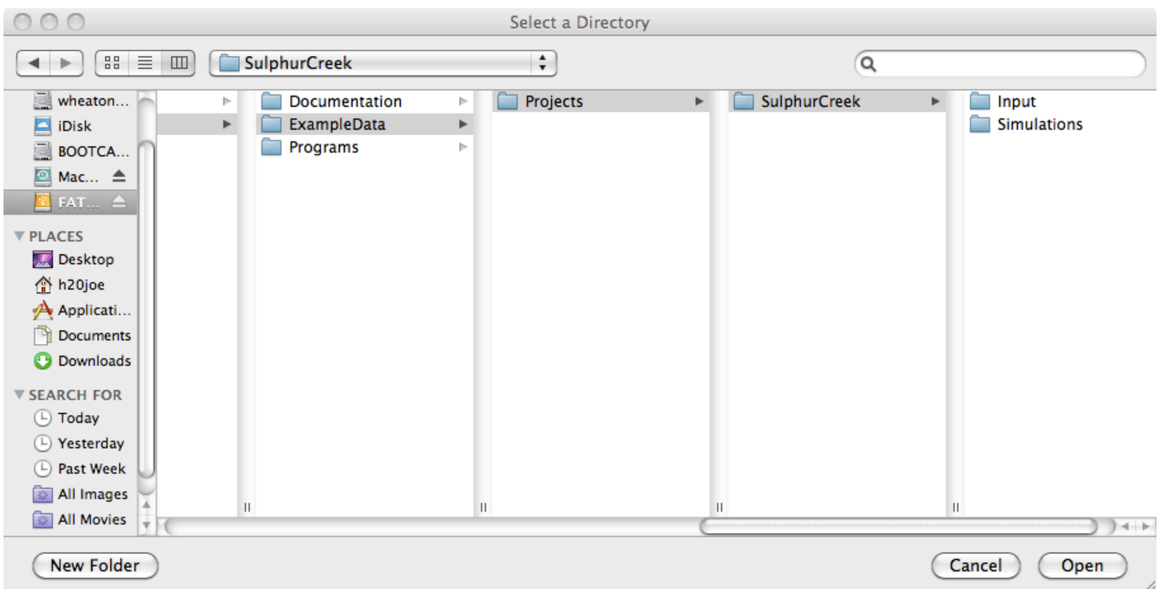
To Start

Open Matlab and change your current directory to that which you unzipped the program files in (note, your project files and analyses can be anywhere on your machine). Run DoD3, by typing 'DoD3' at the command prompt and pressing enter. For this tutorial we will use data found in the 'Example Data' folder, but you can easily substitute it with your own once you've prepared your input data in the proper format (see read me file).

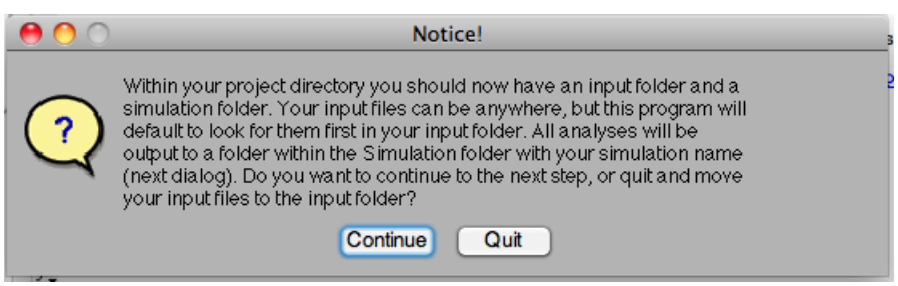
The first wizard dialog will ask you if you wish to run in a wizard mode or a batch mode. Normally, you will run the program in a wizard mode.



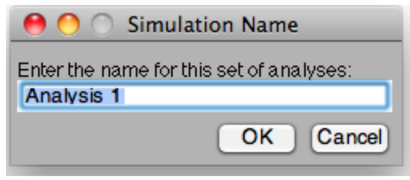
You will be asked to select a project directory. For this example, navigate from the root directory through 'ExampleData' -> 'Projects' and select 'SulphurCreek' as your directory. It is common for one project to run many different types of analyses or have analyses for different time frames. When doing these analyses, it is not necessary (and can be confusing) to duplicate the input files required to run the analyses. All input files should be put 'Input' folder or its subfolders. When you are asked to load inputs at later steps, the default will be to look here first (although they can be placed anywhere you can navigate to). Then all analyses that are preformed are placed in the 'Simulations' folder.



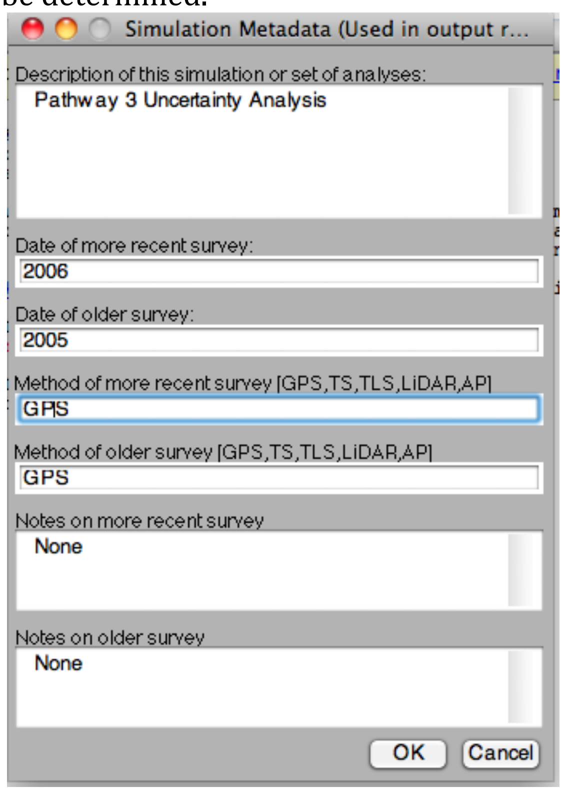
Upon selecting the project folder, a warning dialog will appear notifying you that an 'Input' folder and Simulations' folder have been created in your project directory if they did not already exist. Note that every time you run DoD_3, the analysis you run is referred to as a simulation and stored in the 'Simulations' folder.



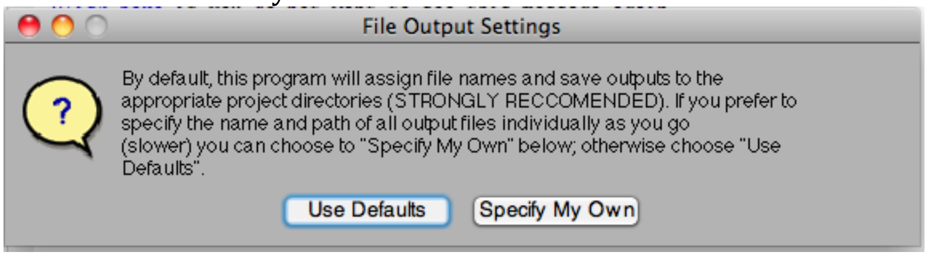
You will then be asked to specify a name for your analyses. You can call these anything you wish and a folder of that name will be created in the 'Simulations' folder. One convention is to name your analyses with a pathway prefix (e.g. PW3 for pathway 3) a descriptive middle (e.g. of the date of the two DEMs being compared) and a confidence interval suffix (e.g. _95CI for a 95% confidence interval). For example a pathway 3 analysis of DEMs surveyed in 2005 and 2006 and thersholded at a 95% confidence interval might be referred to as PW3_2006-2005_95CI. If you specify a name that already exists you will be asked if you wish to overwrite those analyses.



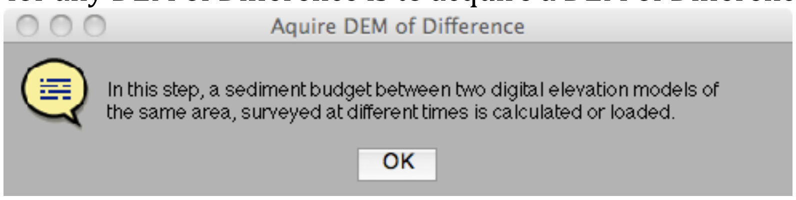
Next you will be asked to enter metadata for the analyses. This information simply gets saved in the output report at the end of the analyses so if you are trying to decipher previous analyses you have enough information to do so. The date fields are important as they determine how all figures will be labeled and how some of the output filenames will be determined.



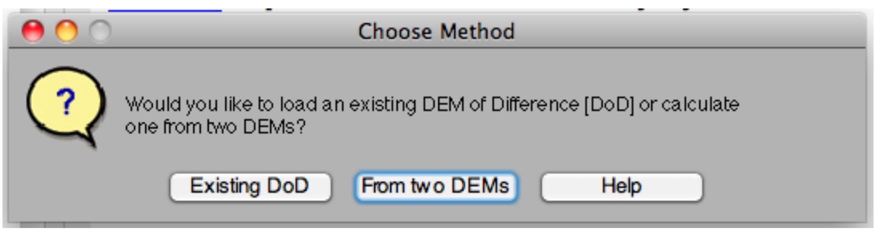
After specifying metadata for the analysis, you will be asked whether you want to specify your own filenames for every output from that simulation, or whether you wish to use the defaults. It is much faster to use the defaults, otherwise, you will be asked to specify the name and path of every output from the analysis. By using the defaults, they are consistently stored in your simulation folder and cross comparison of different analyses is easier.



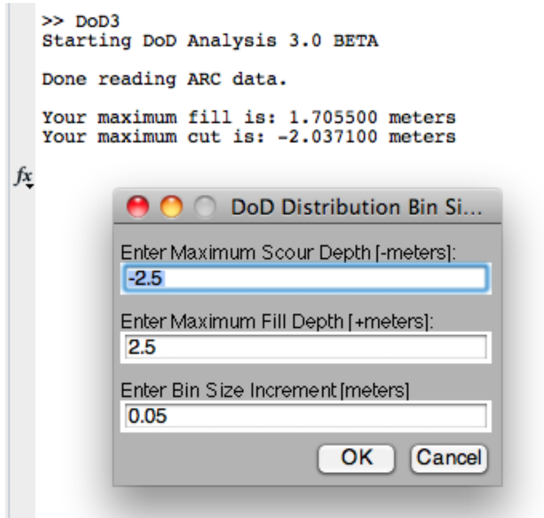
The first step for any DEM of Difference is to acquire a DEM of Difference.



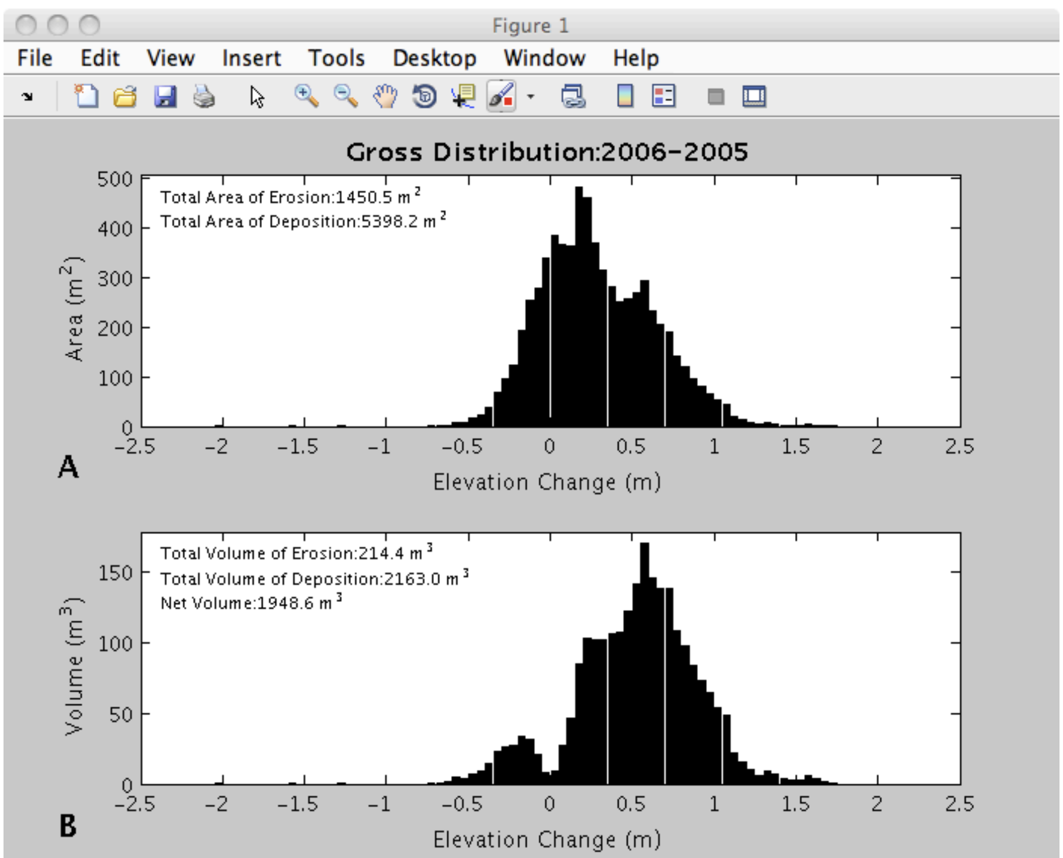
To calculate a DEM of difference between two DEMs, select that option and follow the prompts to load the newer and then older DEM. If you already have calculated the DEM of difference (only needs to be calculated once), you can simply load this using the 'Existing DoD' button. For this example, choose the 'Existing DoD' and then load the '2006 Feb – 2005Dec_DoD.asc' raster found in the Input folder.



After you load your two DEMs or a DEM of Difference (DoD), the maximum fill depth and cut depth in meters are reported in the Matlab command window. This is done so that you have a basis for selecting appropriate limits for your histogram. The default is +/- 2.5 meters, which works well for many fluvial settings. However, if you want your histogram to span your entire range of elevation change values, you should double check what gets reported in the command window. The other critical parameter here is the bin size increment, which is set at a default of 5 cm. Too fine of an increment can produce discontinuous looking distributions, whereas too coarse of an increment can produce a very blocky histogram.



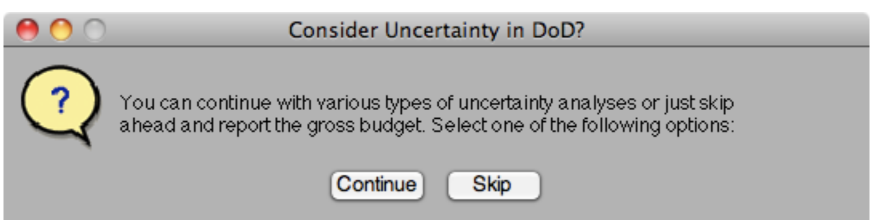
After you specify the bin sizes and limits, the program will calculate histograms of the DoD and you will see the results of this plotted as a figure. You can save or modify this figure at this stage or later, but a tif and jpg of the figure will be saved in the simulation folder under the name of DoD_Dist_Gross_AV (for gross unthresholded DEM of difference distribution showing areal and volumetric).



It is worth taking a moment to explain what these elevation change distributions (ECDs) are showing as the ECDs are one of the primary outputs used to summarize the various forms of DoD analyses. The top plot (A) is an areal ECD and shows the distribution of elevation change in terms of surface area experiencing each magnitude of elevation change. The shape of this distribution is the same as what you'd see if you looked at a histogram of raster values for the DoD, but instead of the vertical axis being a cell count, it has been multiplied by the cell area (raster resolution) to show the proportion of the surface experiencing what types of change. It is very common for a majority or high percentage of the surface to be centered around zero representing a combination of no change, minimal change and/or noise. The total area of erosion (i.e. the integral of the area under curve to the left of 0), and the total area of deposition (i.e. the integral of the area under curve to the right of 0) are reported in the upper left corner.

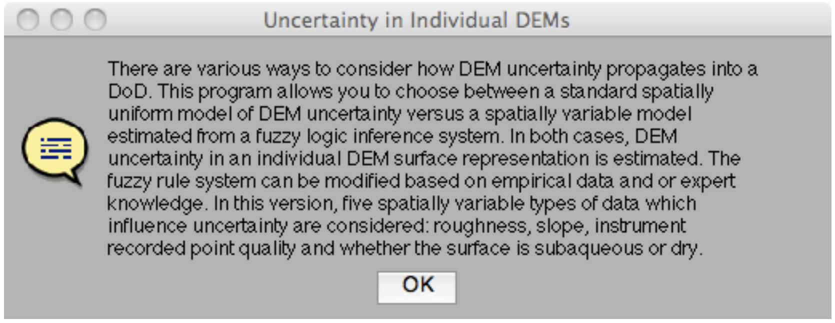
The bottom plot (B) is a volumetric ECD and shows the distribution of elevation change in terms of a volume of mass moved (either by net erosion or net deposition). The vertical axis values have been determined by multiplying the area in each bin by the central value of elevation change in that bin. The result is that the shape of the distribution can be quite different, because low magnitude changes are modulated and large magnitude changes are amplified. The volumetric distributions are more helpful in terms of geomorphic sediment budgeting, because they represent the net amount of work done (presumably by geomorphic change) as a change in storage (volume in this case). The total volume of erosion and deposition are reported in the upper right hand corners as well as the difference of the two, which gives an indication whether the whole area within the ECD is net-aggradational or net depositional, or in net balance.

From this point your responses to the next dialogs determine your pathway, so navigate ahead to the next appropriate subsection. Next you will be asked whether you want to consider Uncertainty in the DoD. If you choose 'Skip', this is a Pathway 1 analysis. For Pathways 2 through 6, choose 'Continue'.

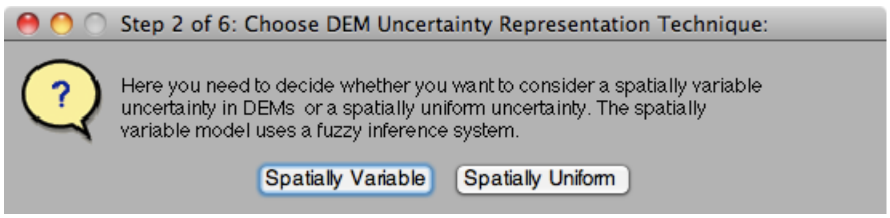


The first choice is whether to do a simple (elevation threshold based) uncertainty analysis or a more sophisticated probabilistic uncertainty analysis. If you choose a 'Simple', this is the equivalent of Pathway 2 Analysis. If you choose 'More Sophisticated', this will allow a Pathway 3, 4, 5 or 6 analysis.

Immediately you are given a warning dialog explaining the upcoming options:



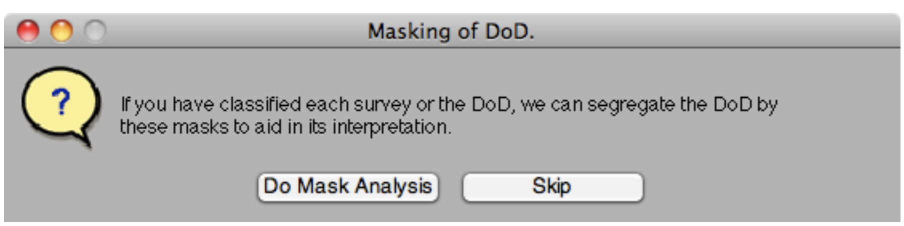
Just click OK to continue past this. Next you will be asked whether you want to consider

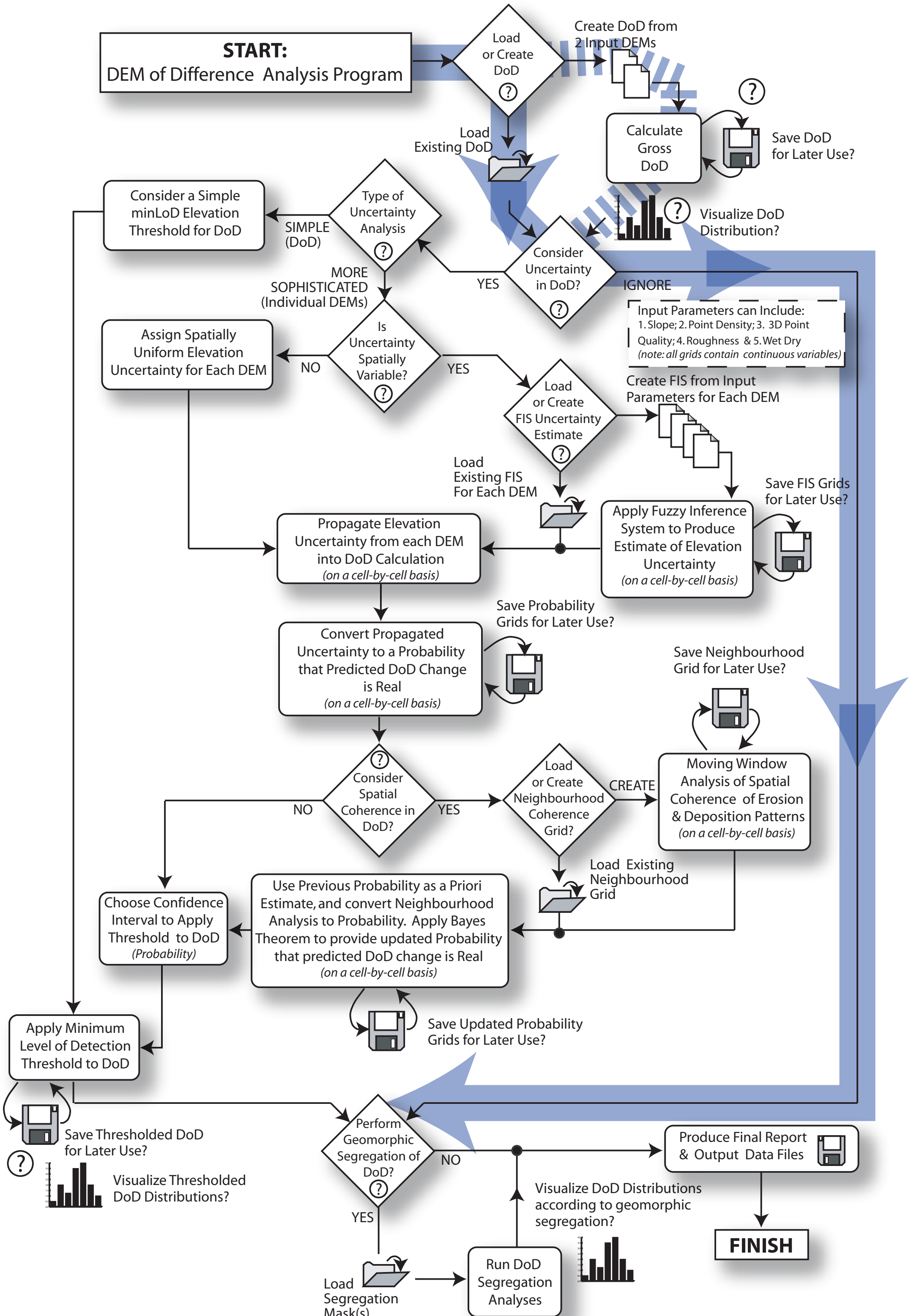


If you choose 'Spatially Variable', you can do a Pathway 3 or 4 analysis, whereas if you choose 'Spatially Uniform' you will be able to do a Pathway 5 or 6 analysis.

Pathway 1

As indicated in the flowchart on the next page, a Pathway 1 analysis includes no uncertainty analysis and is just a gross DoD calculation. This is a useful end-member for comparison with various types of uncertainty analysis and it the first step of every other pathway in DoD3. After doing a Pathway 1 analysis, you are then asked if you would like to a DoD Budget segregation (see Budget Segregation):





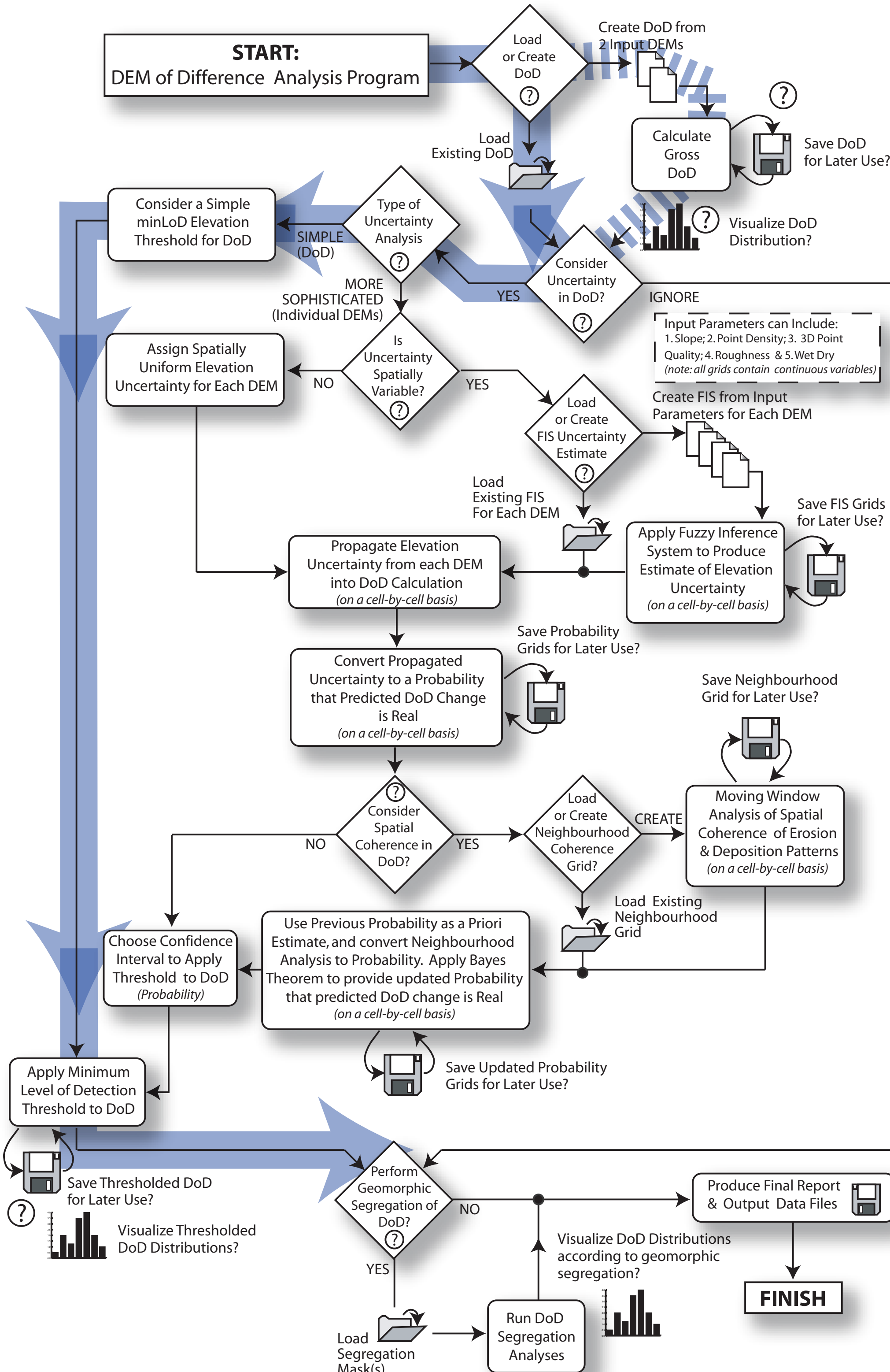
Pathway 1 Analysis in DoD3

Pathway 2

A pathway 2 analysis is the simplest form of uncertainty analysis allowed in this program. This is a simple application of a spatially uniform minimum level of detection (in meters). You are simply asked to specify the value of your minimum level of detection in a dialog. For more information on how these values are reasonably arrived at, see Wheaton (2008, chapter 4).

The next step is to Threshold your DoD based on this value (see DoD Thresholding).

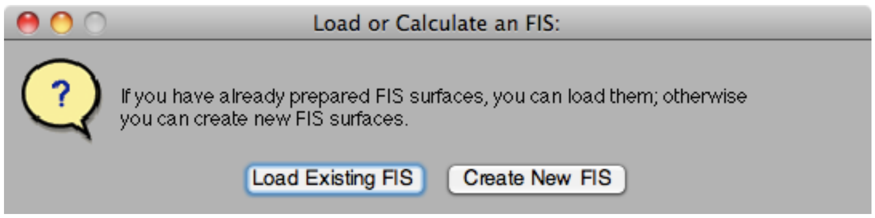
The flowchart on the next page illustrates the pathway.



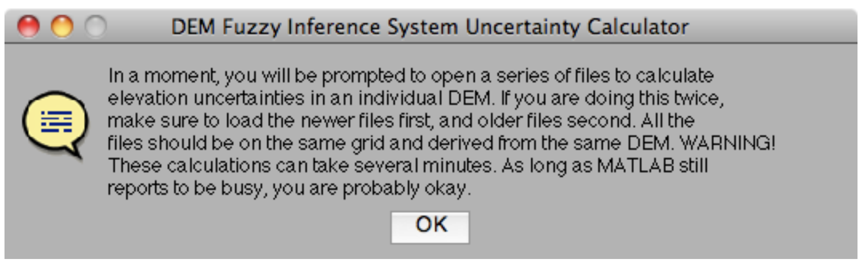
Pathway 2 Analysis in DoD3

Pathway 3

In a pathway 3 analysis, you are using a fuzzy inference system (FIS) to estimate the surface representation uncertainty of your DEMs on a cell by cell basis in each DEM (see flow chart at end of this section). Thus, this is a spatially variable analysis. A separate FIS estimate of elevation uncertainty is needed for both the newer DEM and the older DEM. As indicated below, you are given the option to either load a grid previously calculated (saves time) or to Create a New FIS. In this example, we will 'Create a New FIS' using our Sulphur Creek datasets.



A notification dialog appears explaining the process and warning you to be patient as the calculation can be slow:



The way a new FIS estimate of uncertainty is calculated depends on what input data you have available. This version[1] of the program has built into it rules systems calibrated for GPS and total station surveys with various combinations of five potential inputs. The two mandatory inputs are slope and point density (see readme file), whereas roughness (in meters), 3D GPS point quality (in meters) and water depth (in meters) are all optional. For many topographic surveys, these defaults will likely work well, but you may wish to calibrate, modify or extend the FIS using the fuzzy logic toolbox (see here for more information).

The way the program knows which FIS is to use, is based on what inputs you tell it you have and load a grid for. We start with slope analysis:

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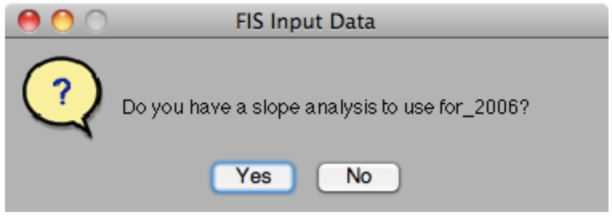
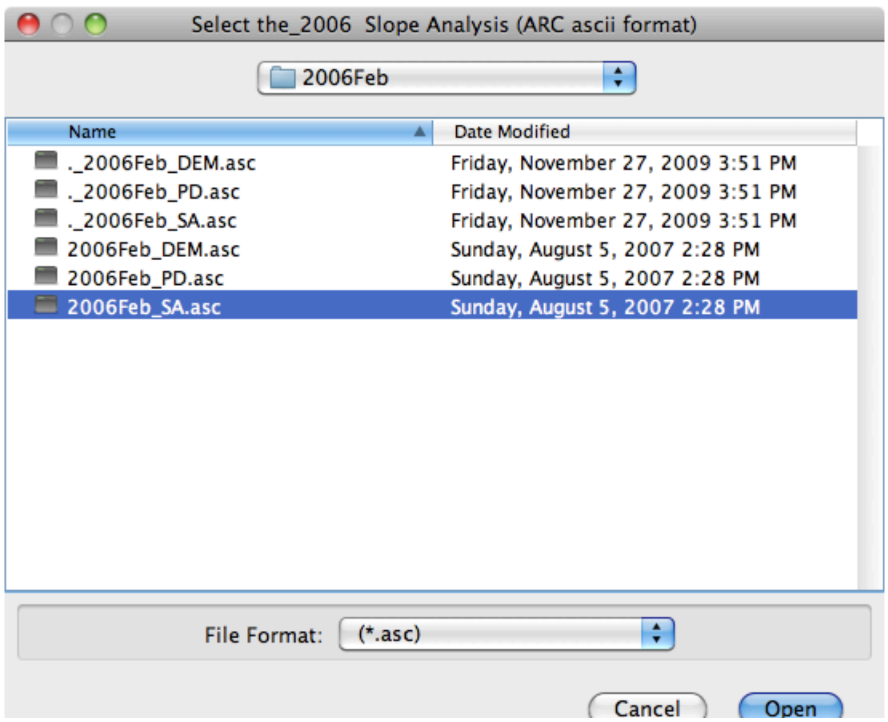
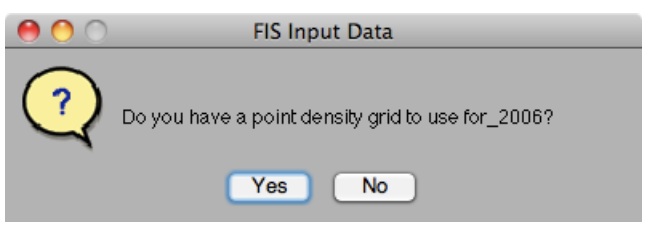
[1] Later versions of DoD3 (currently under development) will include the option to use FIS systems for airborne LiDaR (green and Near-IR), aerial photogrammetry, and ground-based LiDaR in addition to total station and GPS surveys. See readme for more information.



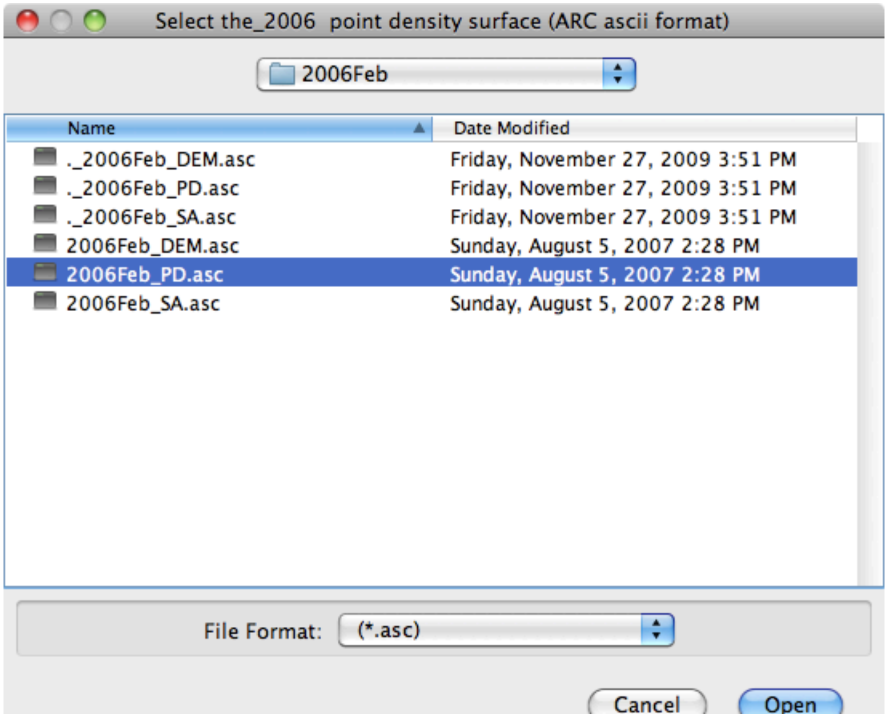
Answer yes to this question and you will be asked to load the '2006 Slope Analysis' grid in our example (the more recent survey). You can find this in the '2006Feb' folder within the Input folder and named '2006Feb_SA.asc':



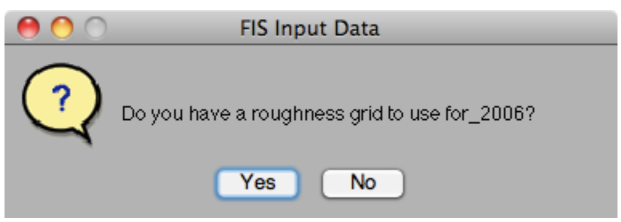
After this has loaded, you are asked if you want to load a point density grid from 2006 (for this example).



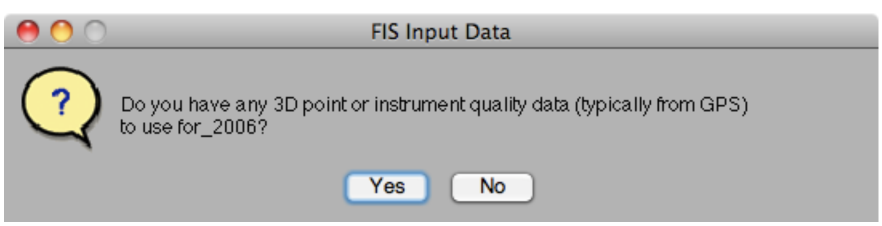
Again, answer yes and you will be asked to load the '2006 Point Density Surface' grid (calculated in points per square meter). You can find this in the '2006Feb' folder within the Input folder and named '2006Feb_PD.asc':



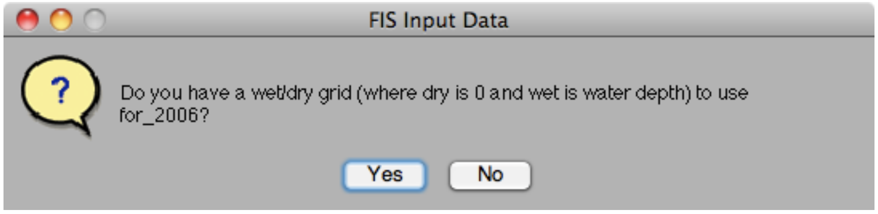
The next question is whether you want to load a rougness grid. For our example, I have not provided you with a rougness grid so answer 'No'.



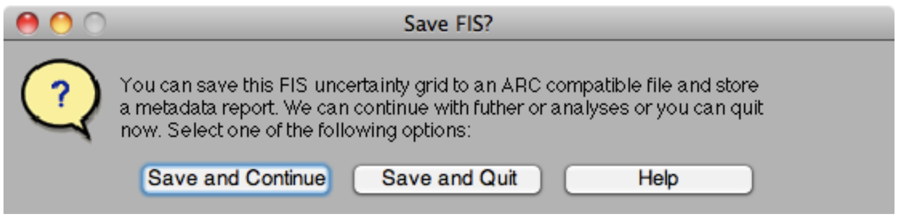
The next question is whether you want to load a 3D point or instrument quality grid (in meters). For our example, I have not provided you with a 3D point quality grid so answer 'No'.



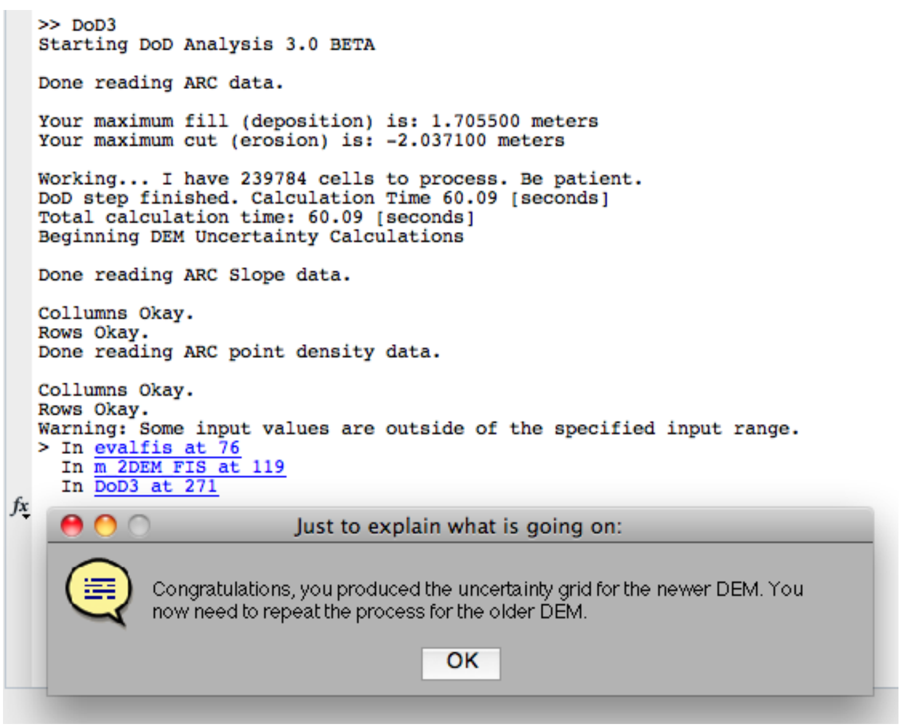
The final question is whether you want to load a wet/dry grid (or water depth). For our example, I have not provided you with a wet/dry grid so answer 'No'.



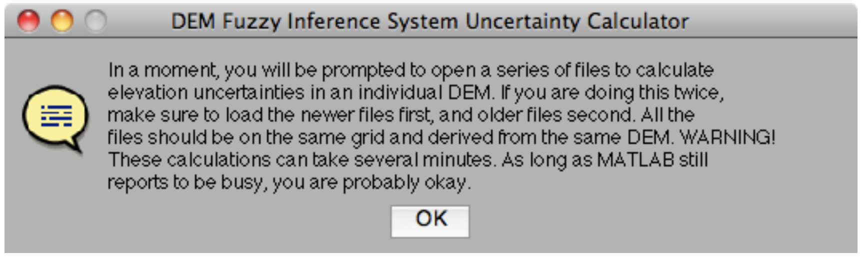
If all you wanted to do is calculate these FIS grids, you can save the FIS grids and quit out of the program at this stage. If you wish to proceed with your Pathway 3 or Pathway 4 analysis, click 'Save and Continue' (do not click 'Help'… there is none).



After answering this last question, you will notice that Matlab is busy and it may take some time for it to complete the calculation of the FIS grid. Do not be alarmed if a warning message appears at the command prompt notifying you some of the input values are outside the specified input range of the FIS (such cells will be ignored). When the process is complete a message dialog informs you that you are done with the analysis for the newer DEM and need to repeat the steps for the older DEM:

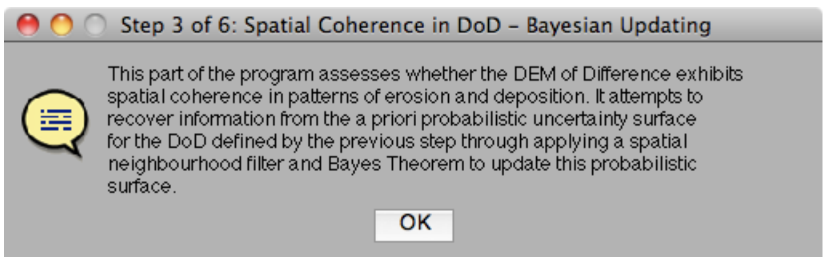


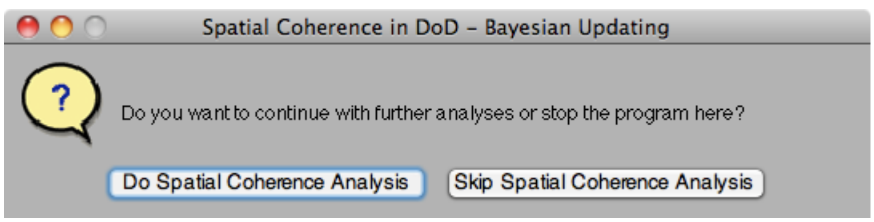
Click 'OK' to proceed.



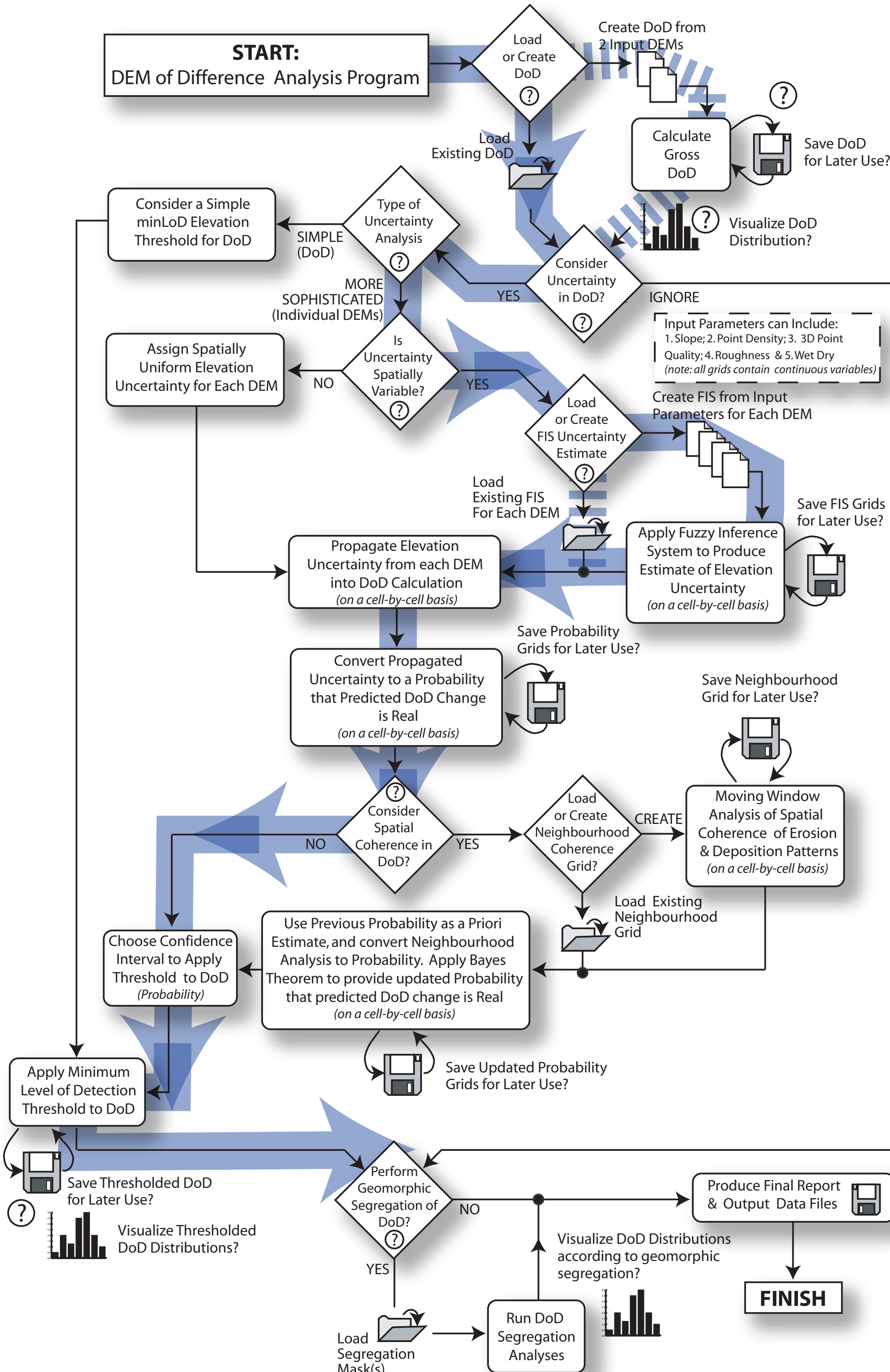
Next, the same sequence of dialogs above will repeat and prompt you to load or create a FIS.

After the FIS grid for the older (second) DEM has been loaded or calculated, you are done with the core part of the Pathway 3 analysis. You are then advanced to a message dialog that explains that the next step is a Spatial Coherence Analysis. This would represent a Pathway 4 analysis.





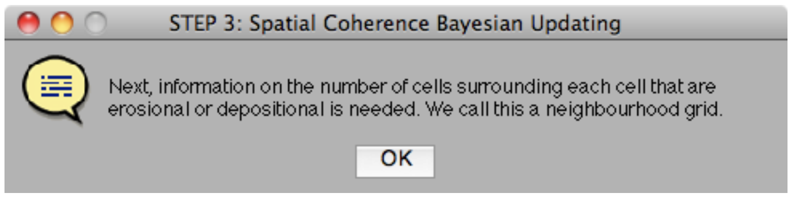
If you've chosen to 'Skip Spatial Coherence Analysis' (i.e. sticking with just a Pathway 3 Analysis), you will next be asked if you want to view and/or save a probability grid (based on the two FIS grids) that the change is real. The next step is to Threshold your DoD based on these probabilities (see DoD Thresholding).



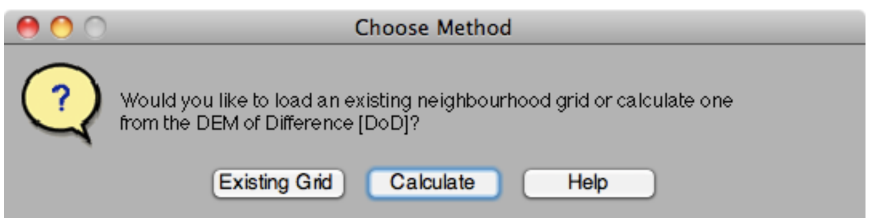
Pathway 3 Analysis in DoD3

Pathway 4

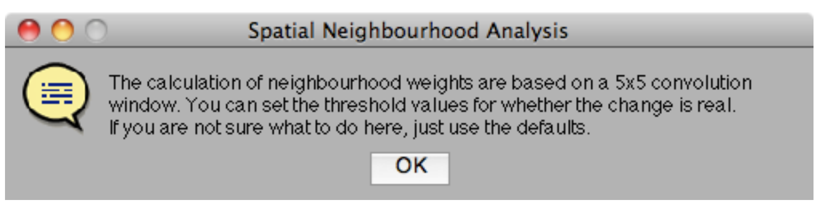
In a pathway 4 analysis, you essentially update the probability that DoD changes are real from a Pathway 3 Analysis (using the spatially variable fuzzy inference system) with an analysis of the spatial coherence of elevation changes (see flow chart at end of this section). Bayes theorem is invoked to update the a priori probabilities from the FIS with new information about the spatial coherence of change. Refer to Pathway 3 above, for the first steps of the Pathway 4 analysis. Once you've chosen to 'Do Spatial Coherence Analysis', you should see the following dialog:



Click OK and you asked whether or not you need to calculate or load the spatial coherence counts (or neighborhood grids) for erosion and deposition. These grids simply represent the count in a 5x5 window of the number erosional cells and depositional cells respectively surrounding a cell. As within previous steps, you have the option to load an existing calculation[2] to save time, or to calculate these grids from scratch based on the DoD you have loaded:



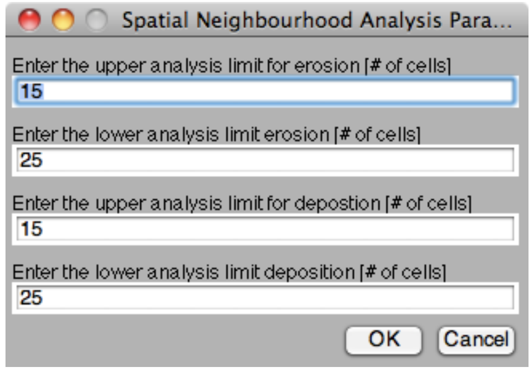
For our example, lets choose to 'Calculate' the grids. First you are given a simple message box explaining what to do next.



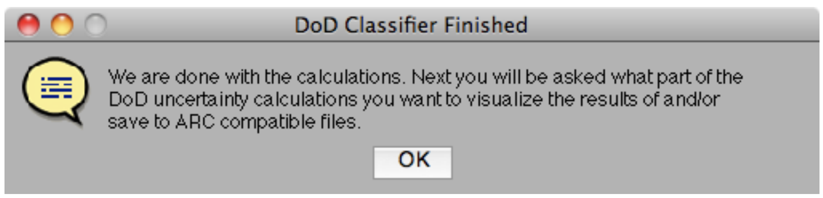
As indicated, the defaults are typically a safe bet, but the next dialog is allowing you to change the parameters of the simple linear transform function that converts the cell counts to a probability. A sensitivity analysis of these values is reported in

[2] Once the neighborhood grids are calculated for a DoD, they do not need to be recalculated. Simply copy them to your input directory. You will find neighborhood grids in the 'ExampleData' -> 'Projects' -> 'SulphurCreek' -> 'Input' -> 'Nbr' folder.

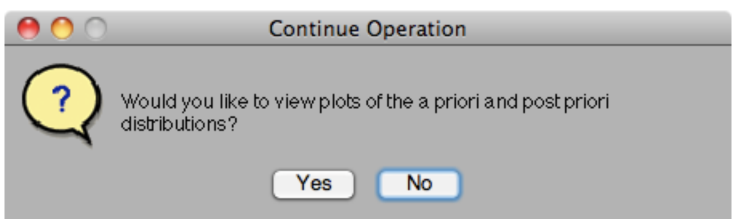
Chapter 4 of Wheaton (2008), but your upper limit should not exceed 25. For this example, just use the default values.



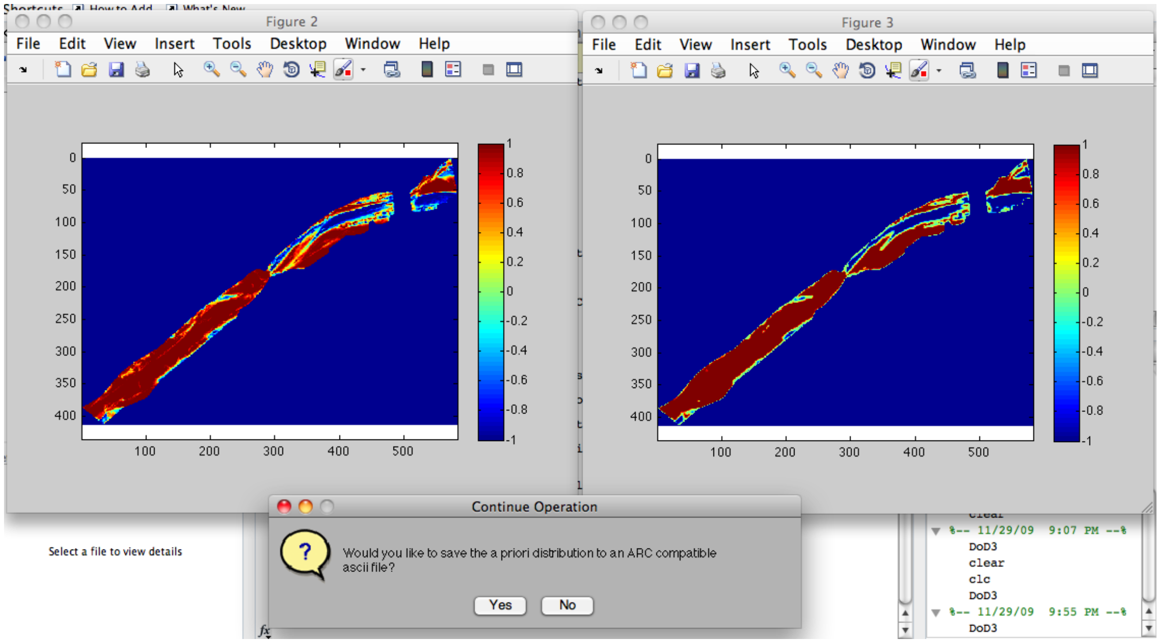
When the calculations are finished, you are given the following message dialog (same dialog appears whether you have loaded or calculated neighborhood grids).



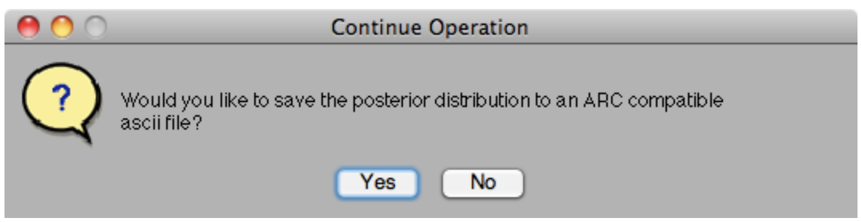
Next you are given the option to view (with a Matlab figure) the probability surfaces created with these analyses. The a Priori is the result of the FIS system, and the Posterior is the result of the Pathway 4 analysis. I typically click 'No' here.



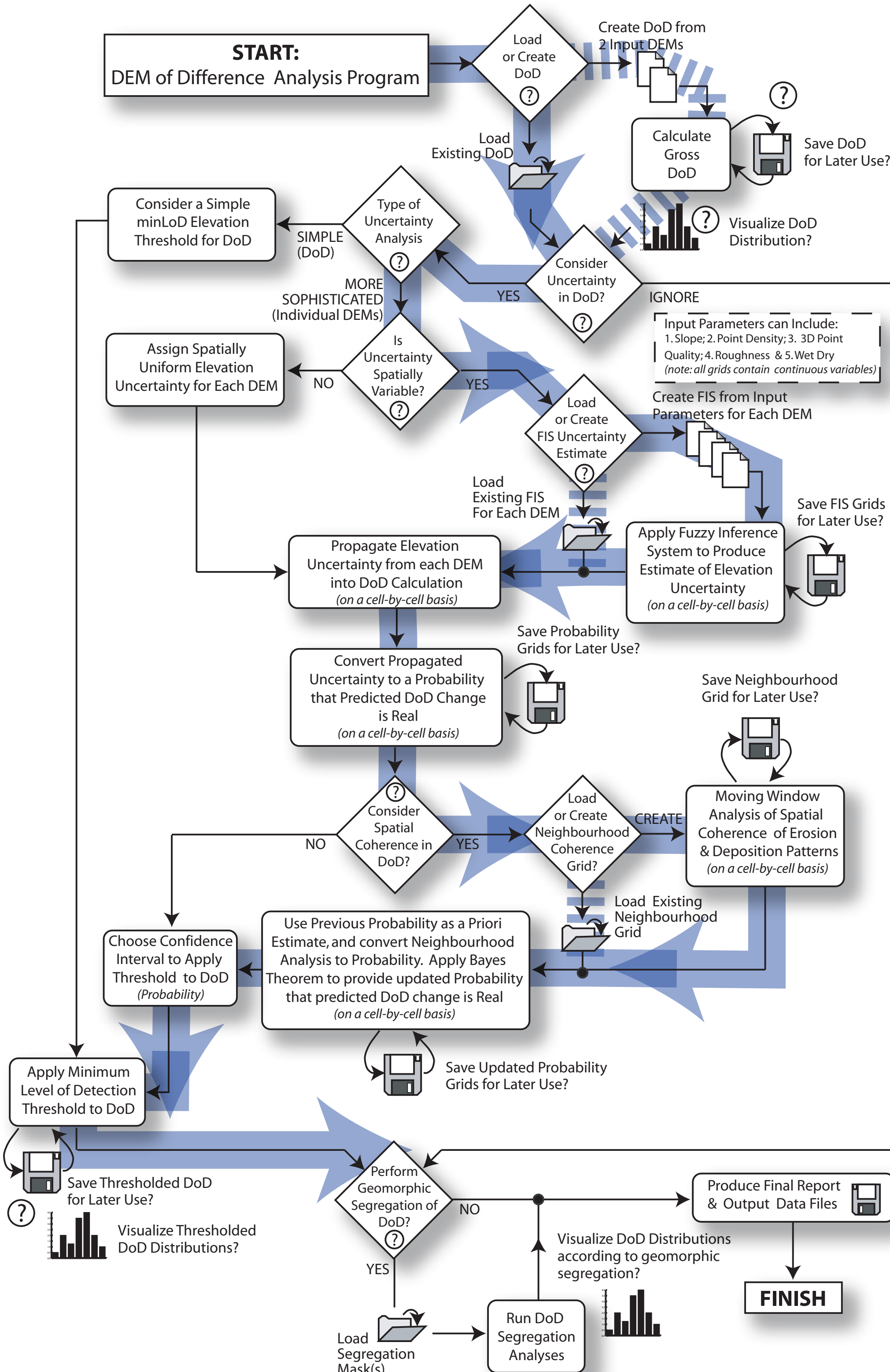
If you do instead click 'Yes', you will see two figures produced. I would not suggest modifying these figures or zooming in on them until after the program has completed running. At that point you can then modify and save them. The values produced are probabilities. Positive values are probabilities of deposition being real, whereas negative probabilities are probabilities of erosion being real.



You then have the option to save both the a priori and posterior probability grids to an Ascii raster file. If you choose yes (recommended), these grids will be saved to your 'OutputRasters' folder for the simulation (see [Project File Management]) and you can visualize them later.



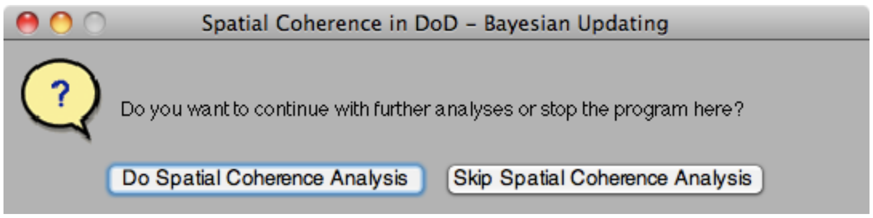
The next step is to Threshold your DoD based on these probabilities (see [DoD Thresholding]).



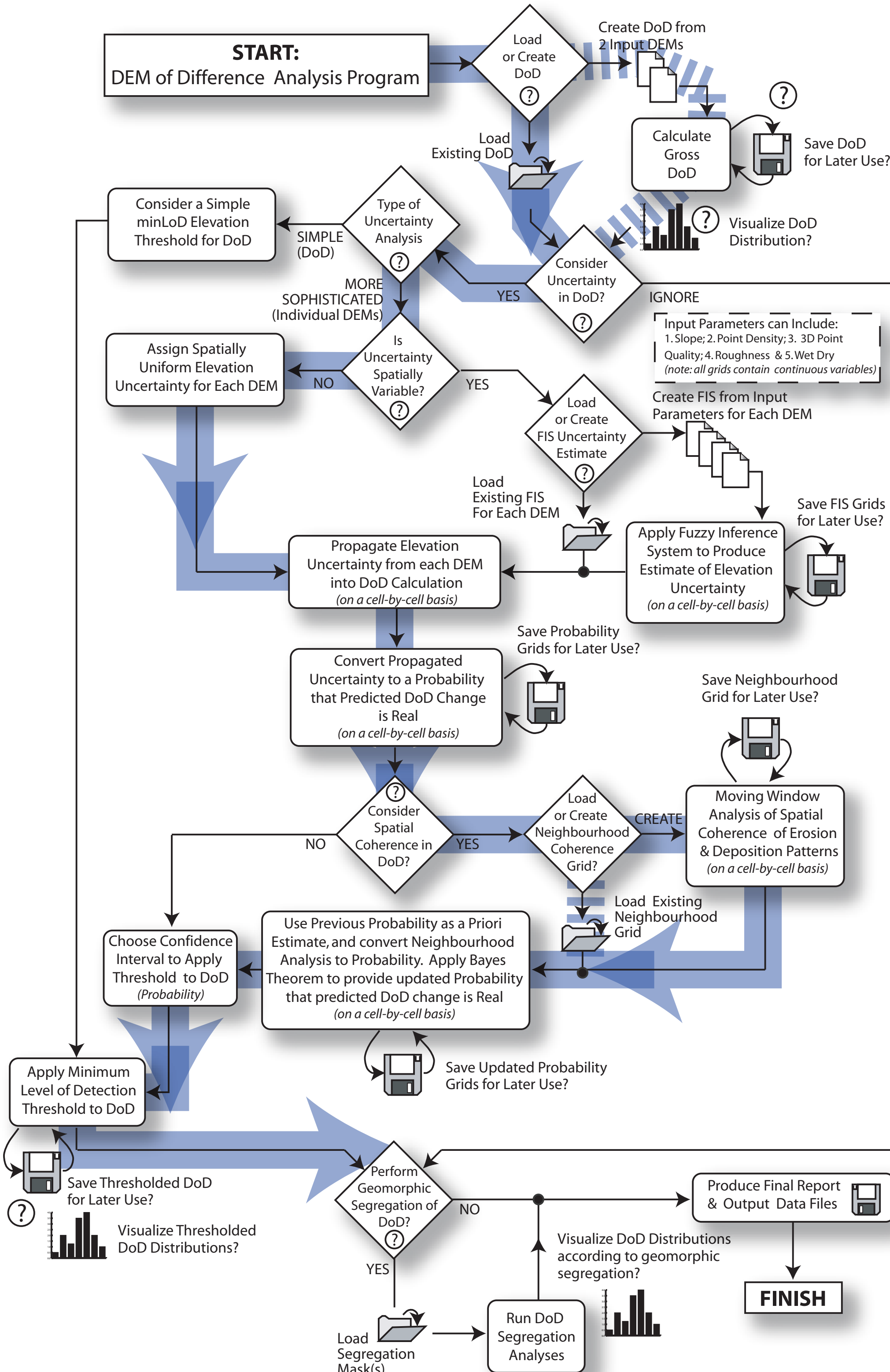
START:
DEM of Difference Analysis Program
Load or Create DoD
Create DoD from 2 Input DEMs
Calculate Gross DoD
Save DoD for Later Use?
Load Existing DoD
Visualize DoD Distribution?
Consider Uncertainty in DoD?
IGNORE
YES
Type of Uncertainty Analysis
SIMPLE (DoD)
Consider a Simple minLoD Elevation Threshold for DoD
MORE SOPHISTICATED (Individual DEMs)
Is Uncertainty Spatially Variable?
NO
Assign Spatially Uniform Elevation Uncertainty for Each DEM
YES
Input Parameters can Include:
1. Slope; 2. Point Density; 3. 3D Point Quality; 4. Roughness & 5. Wet Dry
(note: all grids contain continuous variables)
Load or Create FIS Uncertainty Estimate
Create FIS from Input Parameters for Each DEM
Load Existing FIS For Each DEM
Save FIS Grids for Later Use?
Apply Fuzzy Inference System to Produce Estimate of Elevation Uncertainty
(on a cell-by-cell basis)
Propagate Elevation Uncertainty from each DEM into DoD Calculation
(on a cell-by-cell basis)
Save Probability Grids for Later Use?
Convert Propagated Uncertainty to a Probability that Predicted DoD Change is Real
(on a cell-by-cell basis)
Save Neighbourhood Grid for Later Use?
Consider Spatial Coherence in DoD?
NO
YES
Load or Create Neighbourhood Coherence Grid?
CREATE
Moving Window Analysis of Spatial Coherence of Erosion & Deposition Patterns
(on a cell-by-cell basis)
Load Existing Neighbourhood Grid
Use Previous Probability as a Priori Estimate, and convert Neighbourhood Analysis to Probability. Apply Bayes Theorem to provide updated Probability that predicted DoD change is Real
(on a cell-by-cell basis)
Choose Confidence Interval to Apply Threshold to DoD
(Probability)
Save Updated Probability Grids for Later Use?
Apply Minimum Level of Detection Threshold to DoD
Save Thresholded DoD for Later Use?
Visualize Thresholded DoD Distributions?
Perform Geomorphic Segregation of DoD?
NO
Produce Final Report & Output Data Files
FINISH
YES
Visualize DoD Distributions according to geomorphic segregation?
Load Segregation Mask(s)
Run DoD Segregation Analyses

Pathway 5

Pathway 5 is a useful variant of the uncertainty analysis, which uses the spatial coherence filter described in Pathway 4, but does not rely on a spatially variable input estimate of uncertainty in each individual DEM (i.e. a FIS from Pathway 3). It instead allows you to update a probability estimate of the DoD change being real from a Pathway 6 analysis using the spatial coherence analysis. The Pathway 5 analysis is depicted on the flowchart on the next page. To initiate a Pathway 5 analysis, simply run a Pathway 6 analysis and when prompted with the following dialog, choose 'Do Spatial Cohrence Analysis'.



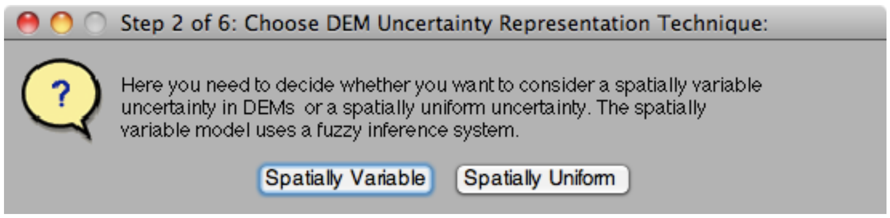
Then follow the steps in Pathway 4 Analysis.


START:
DEM of Difference Analysis Program
Load or Create DoD
Create DoD from 2 Input DEMs
Calculate Gross DoD
Save DoD for Later Use?
Load Existing DoD
Visualize DoD Distribution?
Consider Uncertainty in DoD?
IGNORE
YES
Type of Uncertainty Analysis
SIMPLE (DoD)
Consider a Simple minLoD Elevation Threshold for DoD
MORE SOPHISTICATED (Individual DEMs)
Is Uncertainty Spatially Variable?
NO
Assign Spatially Uniform Elevation Uncertainty for Each DEM
YES
Input Parameters can Include:
1. Slope; 2. Point Density; 3. 3D Point Quality; 4. Roughness & 5. Wet Dry
(note: all grids contain continuous variables)
Load or Create FIS Uncertainty Estimate
Create FIS from Input Parameters for Each DEM
Load Existing FIS For Each DEM
Save FIS Grids for Later Use?
Apply Fuzzy Inference System to Produce Estimate of Elevation Uncertainty
(on a cell-by-cell basis)
Propagate Elevation Uncertainty from each DEM into DoD Calculation
(on a cell-by-cell basis)
Save Probability Grids for Later Use?
Convert Propagated Uncertainty to a Probability that Predicted DoD Change is Real
(on a cell-by-cell basis)
Save Neighbourhood Grid for Later Use?
Consider Spatial Coherence in DoD?
NO
YES
Load or Create Neighbourhood Coherence Grid?
CREATE
Moving Window Analysis of Spatial Coherence of Erosion & Deposition Patterns
(on a cell-by-cell basis)
Load Existing Neighbourhood Grid
Choose Confidence Interval to Apply Threshold to DoD
(Probability)
Use Previous Probability as a Priori Estimate, and convert Neighbourhood Analysis to Probability. Apply Bayes Theorem to provide updated Probability that predicted DoD change is Real
(on a cell-by-cell basis)
Save Updated Probability Grids for Later Use?
Apply Minimum Level of Detection Threshold to DoD
Save Thresholded DoD for Later Use?
Visualize Thresholded DoD Distributions?
Perform Geomorphic Segregation of DoD?
NO
YES
Produce Final Report & Output Data Files
FINISH
Visualize DoD Distributions according to geomorphic segregation?
Load Segregation Mask(s)
Run DoD Segregation Analyses

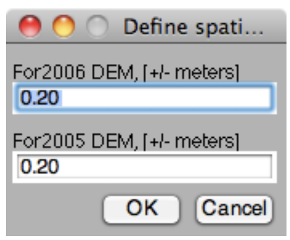
Pathway 6

Pathway 6 is a slightly more sophisticated form of uncertainty analysis then a Pathway 2 analysis in that it allows the uncertainty (in meters) of two input DEMs to be specified interpedently. The uncertainty is assumed to be spatially uniform for the whole DEM, but this does allow differences between surveys to be accounted for (e.g. one surveyed with LiDaR and one surveyed with GPS).

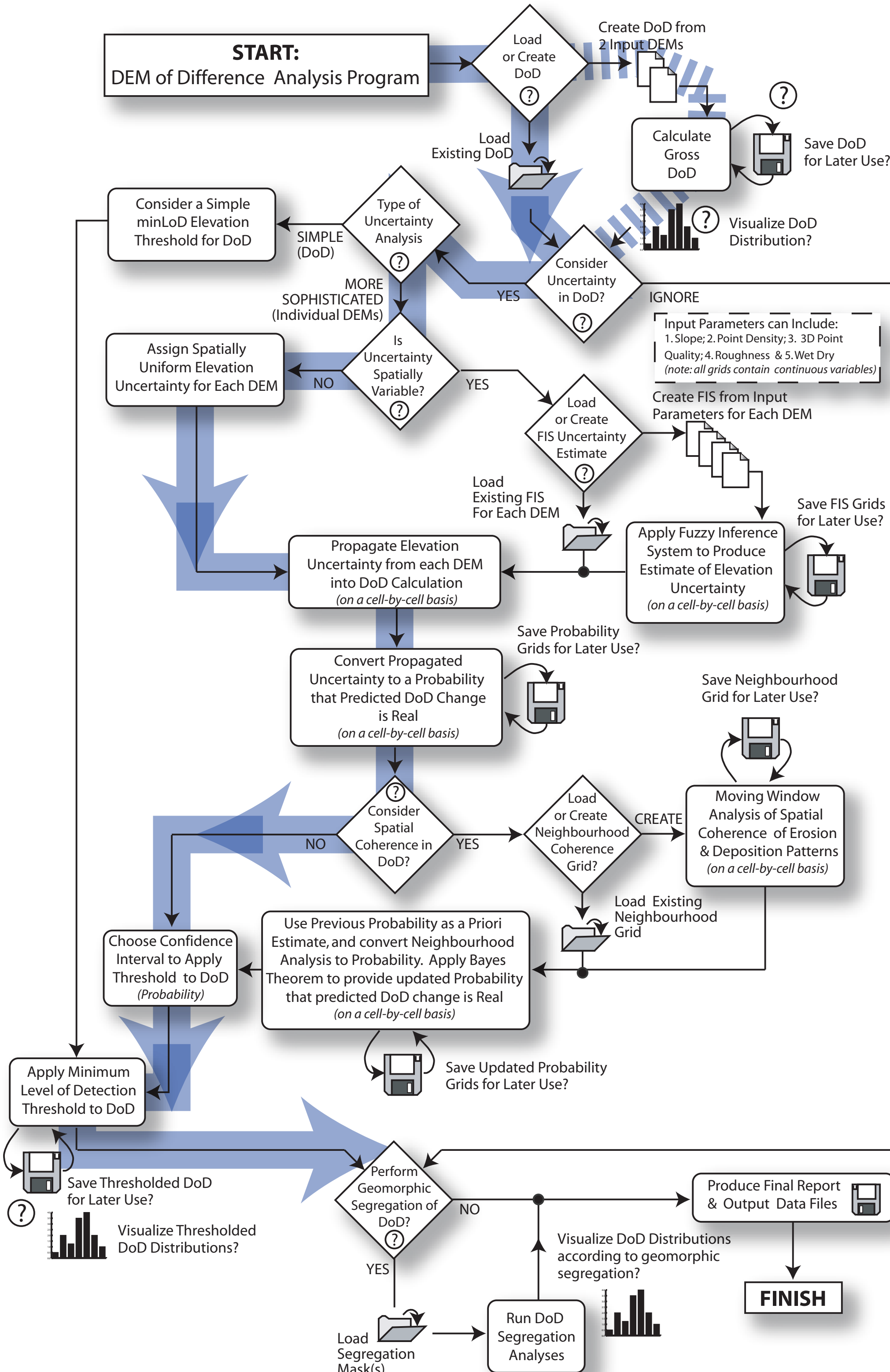
To initiate a Pathway 6 analysis, when prompted with the following dialog, choose 'Spatially Uniform'.



You will then be prompted to enter in the values of uncertainty for each DEM (in this case both have been specified at 20 cm).



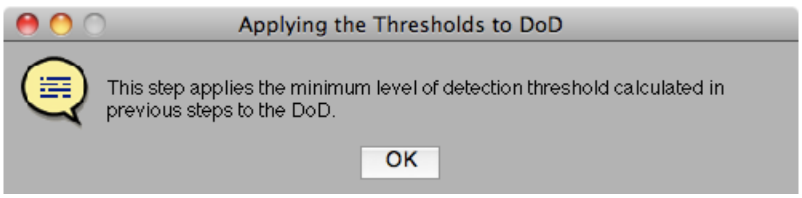
You are then presented with the choice whether to perform the Spatial Coherence Analysis (see Pathway 4) and make this a Pathway 5 analysis, or to skip it and leave it as a Pathway 6 analysis. The flowchart on the next page highlights these differences.



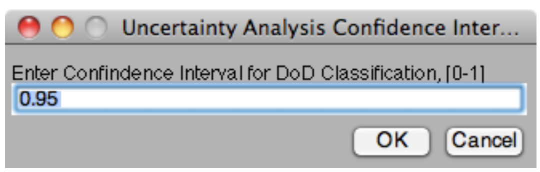
START:
DEM of Difference Analysis Program
Load or Create DoD
Create DoD from 2 Input DEMs
Calculate Gross DoD
Save DoD for Later Use?
Load Existing DoD
Visualize DoD Distribution?
Consider Uncertainty in DoD?
YES
IGNORE
Type of Uncertainty Analysis
SIMPLE (DoD)
Consider a Simple minLoD Elevation Threshold for DoD
MORE SOPHISTICATED (Individual DEMs)
Is Uncertainty Spatially Variable?
NO
Assign Spatially Uniform Elevation Uncertainty for Each DEM
YES
Input Parameters can Include:
1. Slope; 2. Point Density; 3. 3D Point Quality; 4. Roughness & 5. Wet Dry
(note: all grids contain continuous variables)
Load or Create FIS Uncertainty Estimate
Create FIS from Input Parameters for Each DEM
Load Existing FIS For Each DEM
Save FIS Grids for Later Use?
Apply Fuzzy Inference System to Produce Estimate of Elevation Uncertainty
(on a cell-by-cell basis)
Propagate Elevation Uncertainty from each DEM into DoD Calculation
(on a cell-by-cell basis)
Save Probability Grids for Later Use?
Convert Propagated Uncertainty to a Probability that Predicted DoD Change is Real
(on a cell-by-cell basis)
Save Neighbourhood Grid for Later Use?
Consider Spatial Coherence in DoD?
NO
YES
Load or Create Neighbourhood Coherence Grid?
CREATE
Moving Window Analysis of Spatial Coherence of Erosion & Deposition Patterns
(on a cell-by-cell basis)
Load Existing Neighbourhood Grid
Choose Confidence Interval to Apply Threshold to DoD
(Probability)
Use Previous Probability as a Priori Estimate, and convert Neighbourhood Analysis to Probability. Apply Bayes Theorem to provide updated Probability that predicted DoD change is Real
(on a cell-by-cell basis)
Save Updated Probability Grids for Later Use?
Apply Minimum Level of Detection Threshold to DoD
Save Thresholded DoD for Later Use?
Visualize Thresholded DoD Distributions?
Perform Geomorphic Segregation of DoD?
NO
YES
Produce Final Report & Output Data Files
Visualize DoD Distributions according to geomorphic segregation?
FINISH
Load Segregation Mask(s)
Run DoD Segregation Analyses

DoD Thresholding

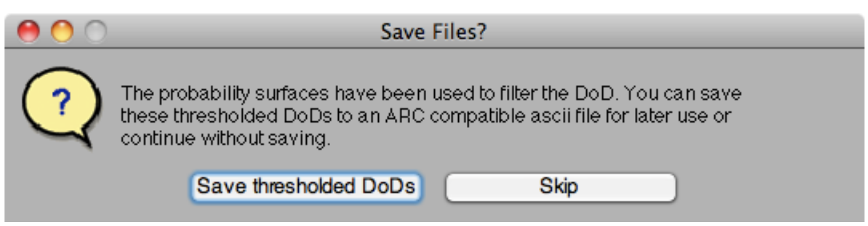
Once you have your best estimate of the uncertainty in a DoD, you can use that information to threshold the DoD. This process is described in both Wheaton *et al.* (2009) and Wheaton (2008, Chapter 4) in detail. Briefly, either an elevation change minimum level of detection is defined (i.e. Pathway 2 or Pathway 6) or a probabilistic minimum level of detection is defined (i.e a confidence interval from Pathway 3, 4 or 5). Then the cells in the original DoD with values beneath these thresholds are changed from their original values to no-data cells (i.e. they are threshold out or removed on the basis that they can not be distinguished from noise). When you reach this step of the program you will see an informational dialog as follows:



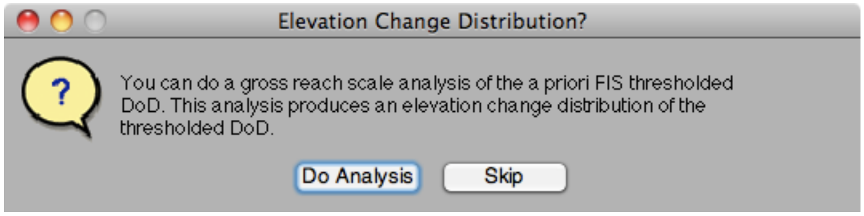
If you used Pathway 2 or 6, the thresholding may be automatic, but if you used pathways 3, 4 or 5, you will see a dialog asking you for a value between 0 and 1 (i.e. the decimal probability) you wish to threshold at. Obviously, a higher value is a more conservative estimate, and a lower value is more liberal.



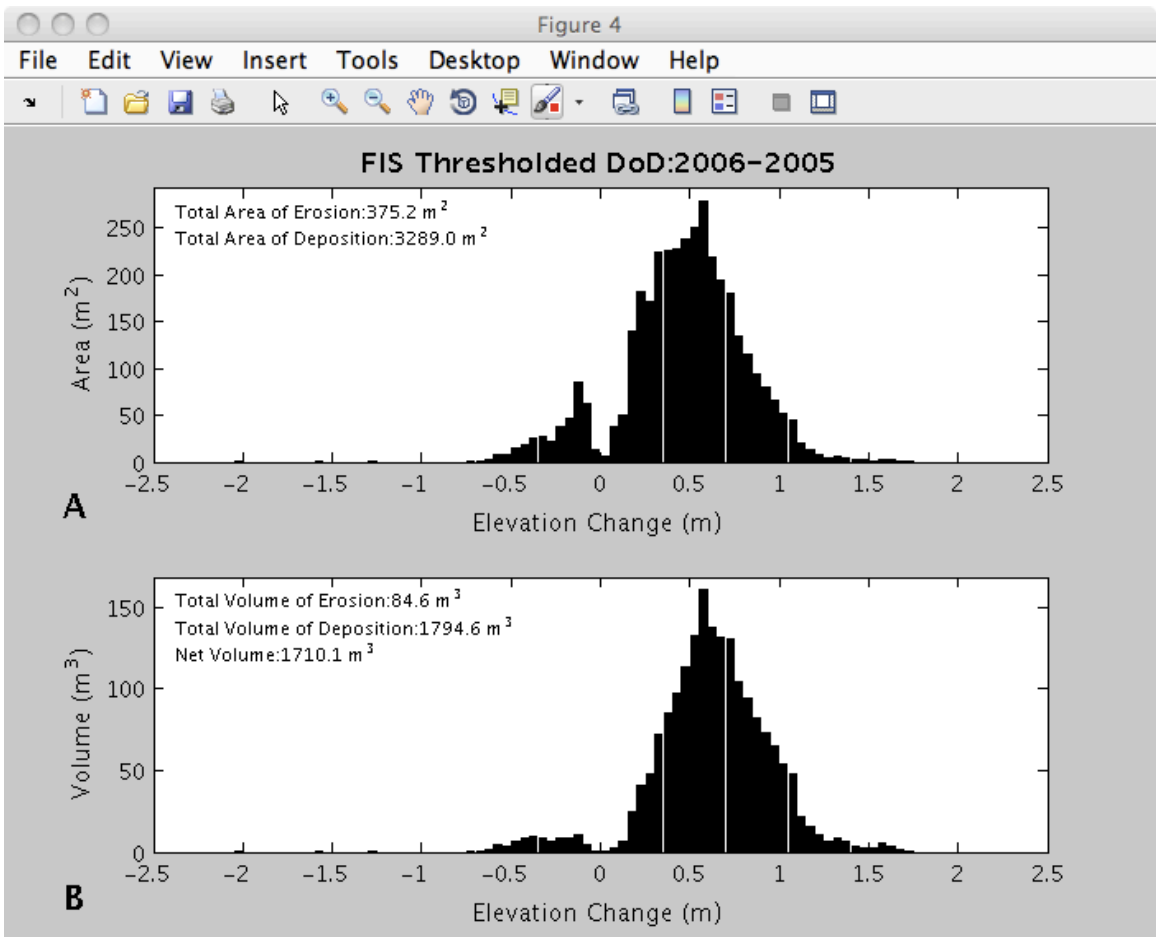
After the thresholding is complete, you are asked if you would like to save an Ascii raster of your thresholded DoD (recommended). If you choose to, this grid will be stored in your 'OutputRasters' folder.



A useful way of comparing the influence of DoD analysis is to compare the elevation change distribution (ECD) of the original DoD with that of the thresholded DoD. The next step asks you whether you wish to do this analysis (recommended).

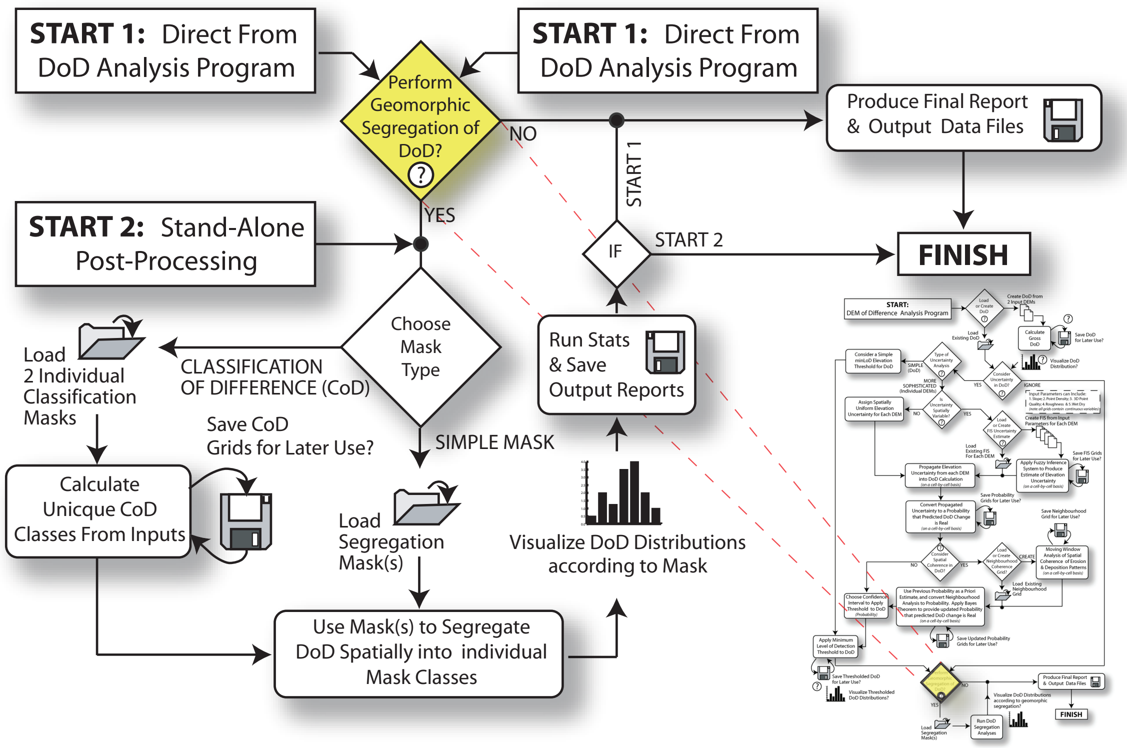


If you choose to 'Do Analysis', a figure will be produced similar to below. A *.jpg and *.tif of the same figure are saved in your simulation folder. If you did a Pathway 4 or 5 analysis, using the spatial coherence filter, you will also be prompted to do this twice (once for the a priori ECD and once for the posterior ECD). At the end of the analysis, you can modify and/or save these figure(s).



Budget Segregation

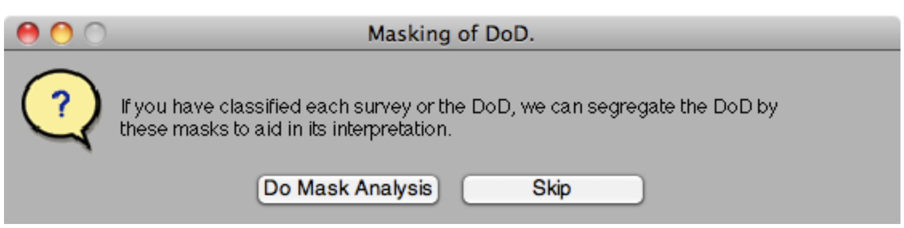
Budget segregation is described extensively in Chapter 5 of Wheaton (2009). In a nutshell, once you have your best estimate of DoD changes (i.e. a thresholded DoD from Pathway 2, 3, 4, 5 or 6 analysis), you then use spatial masks (i.e. polygons) to quantify how much change has taken place in discrete spatial locations. To run, the polygons need to be converted to rasters with a unique integer corresponding to each category (see [Project File Management]() and the ExampleData for examples). The budget segregation is one of the last steps to the DoD3 program (optional), or it can be run as a stand alone application (using A_Geomorph.m) as shown below.



DoD Uncertainty Software

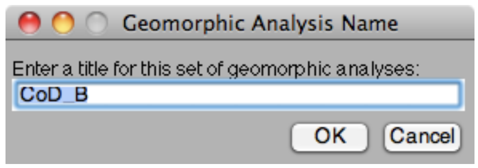
There are two types of mask analyses possible. The simple mask uses a single input mask to segregate the polygon. The Classification of Difference (CoD) mask asks for two classification masks (typically one of the older DEM and one of the newer DEM) and then calculates unique categories of change (to use as masks) from the difference between the two classifications. Below we will walk through a simple example using data from Sulphur Creek. Note that CoD examples can also be found in the 'Example Data' -> 'Projects' -> 'SulphurCreek' -> 'Input' -> 'Geomorph' -> 'GoD' folder.

Assuming we are entering the Mask Analysis from the DoD3 program, you are then asked if you would like to a DoD Budget segregation:

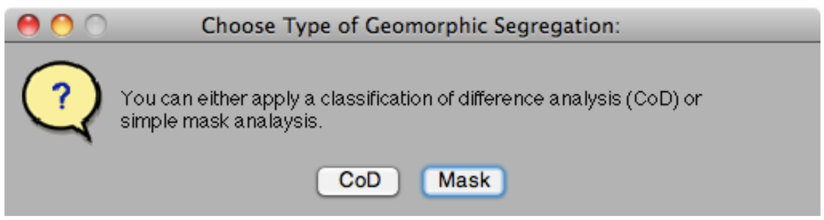


If you choose to 'Skip' the masking or budget segregation step, the Final Report (see here) is then produced and you are asked if you would like to view the final thresholded DoD. Choose 'Do Mask Analysis' for our example.

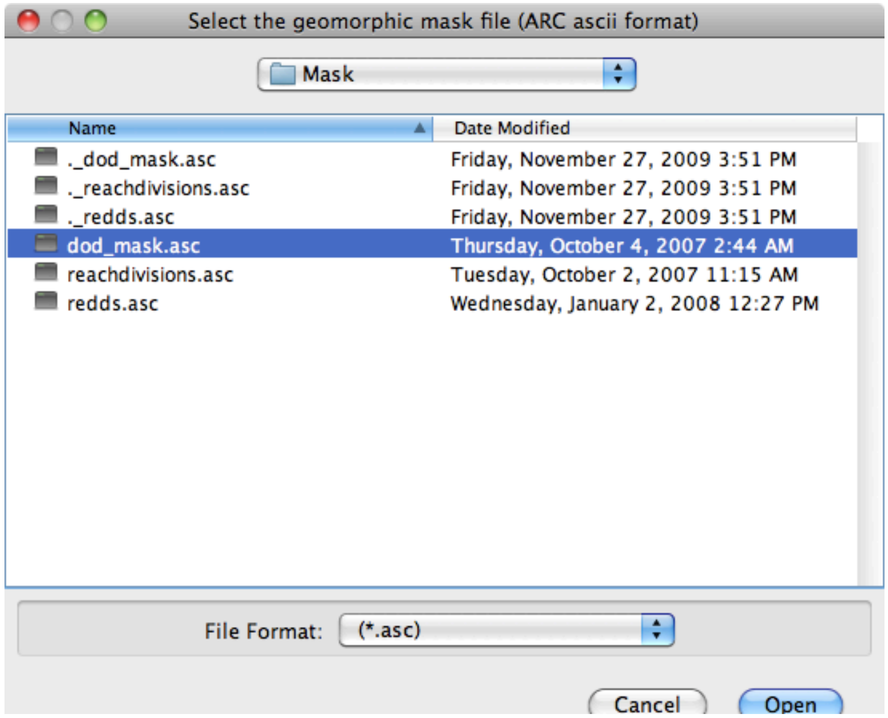
As it is possible and typical to segregate the same DoD budget in a variety of ways, you can repeat this geomorphic analysis (using the 'A_Geomorph.m' program'). Accordingly, here you are prompted to enter a name for your masking analysis. This will create a folder (of the same name) in a 'Geomorph' subdirectory of your simulation.



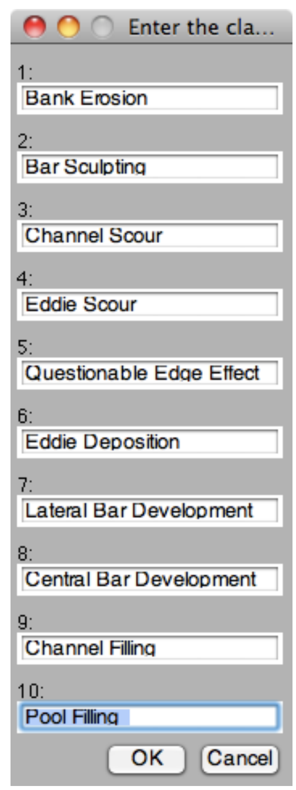
You are then prompted to specify what type of segregation you are going to do. In our example we will do a simple mask, so use 'Mask':



You are then prompted to load the input mask you wish to use. We will load a file called 'dod_mask.asc', which can be found in 'Example Data' -> 'Projects' -> 'SulphurCreek' -> 'Input' -> 'Geomorph' -> 'Mask'. This mask is reported in Chapter 6 of Wheaton (2008) and a figure can be found below showing the mask. It represents a gemorphic interpretation of the change from a combination of DoD interpretation, field evidence and repeat aerial photography.

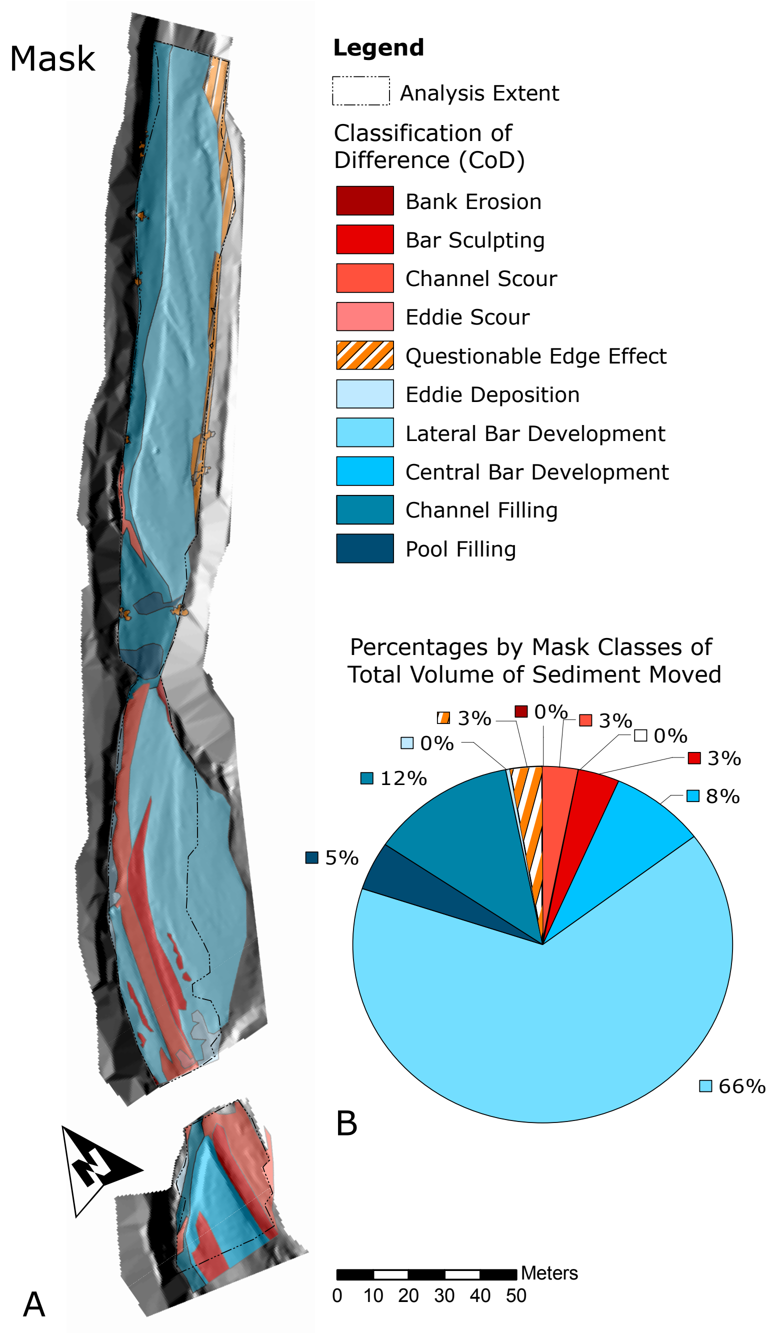


After the file is loaded, the program looks to see how many unique integers it can find in the raster (see code for limitations or to extend). The integers represent the unique mask categories of the classification. Based on what it finds, it produces a dialog box with the classification category number and a text box for you to enter in the correct descriptions of the categories (used for output figures and report). For our example, change values to those shown at right. Notice that 1 through 4 are erosional categories, 5 is a questionable category (another filter for questionable areas of the DoD) and 5-10 are depositional categories.

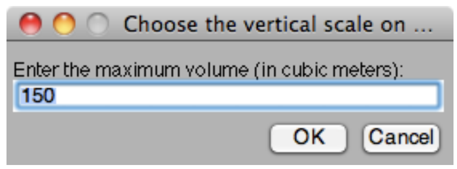


The portion labeled as 'A' of the figure at right shows the classification mask we are loading in this example.

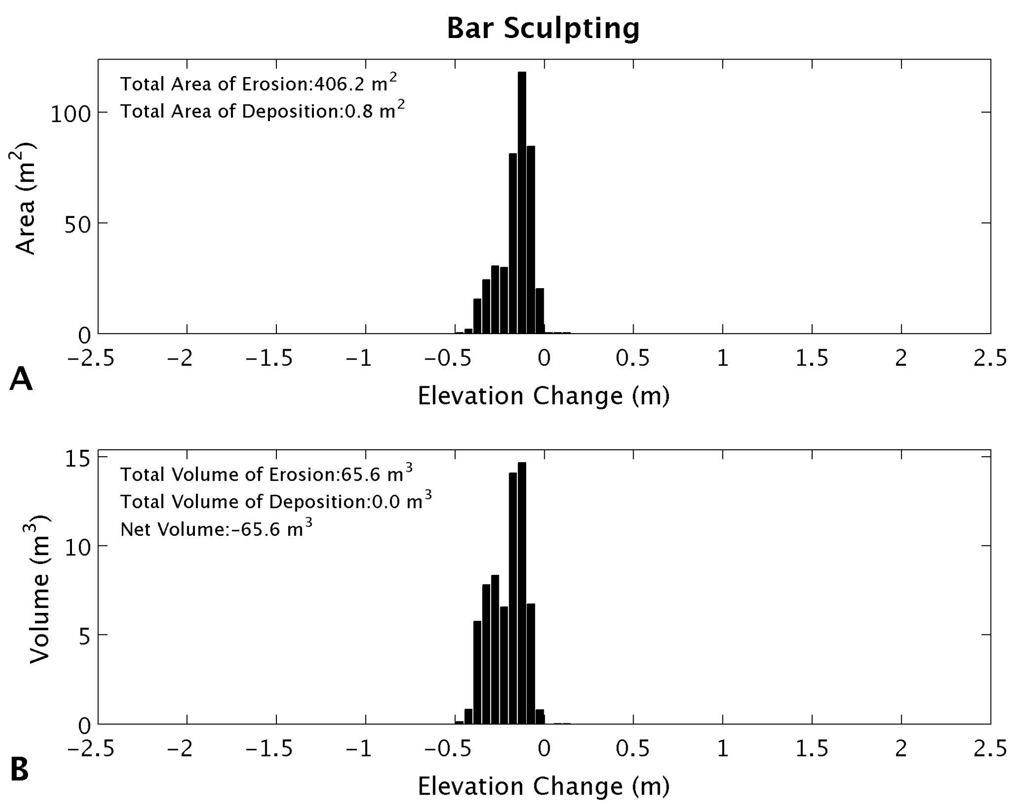
The portion labeled as B is a pie chart showing one summary of the masking analysis. Here the total volume of change has been divided by the volume of change in each category to determine what category was responsible for producing the most change (i.e. geomorphic work). In this example, lateral bar development dominates. These and other analyses can be summarized from a *.csv file in the output folder that has the '_Summary.csv' suffix.



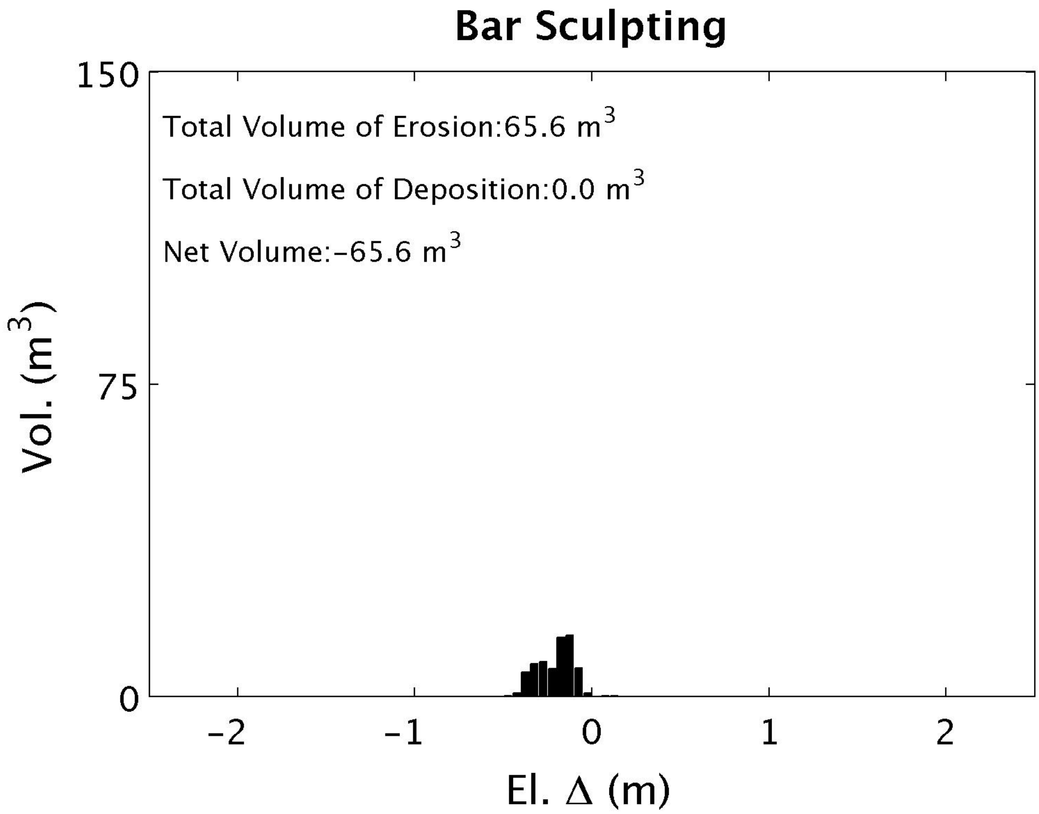
What happens is that elevation change distributions are calculated for each category. Two figures for each are produced, 1) a combined plot showing the areal and volumetric ECD; and 2) a plot showing just the volumetric ECD with a common maximum volume for the ECD to allow easier inter-comparison (you'll see the benefits of this in the figures below). Thus, the next dialog prompts you to enter in this maximum fill volume for the second ECD. A good rule of thumb is to use 50% of the maximum volume on the vertical axis of the unthresholded DoD ECD. It may take some trial and error to arrive an appropriate value. In our example, just use the default 150 cubic meter value:



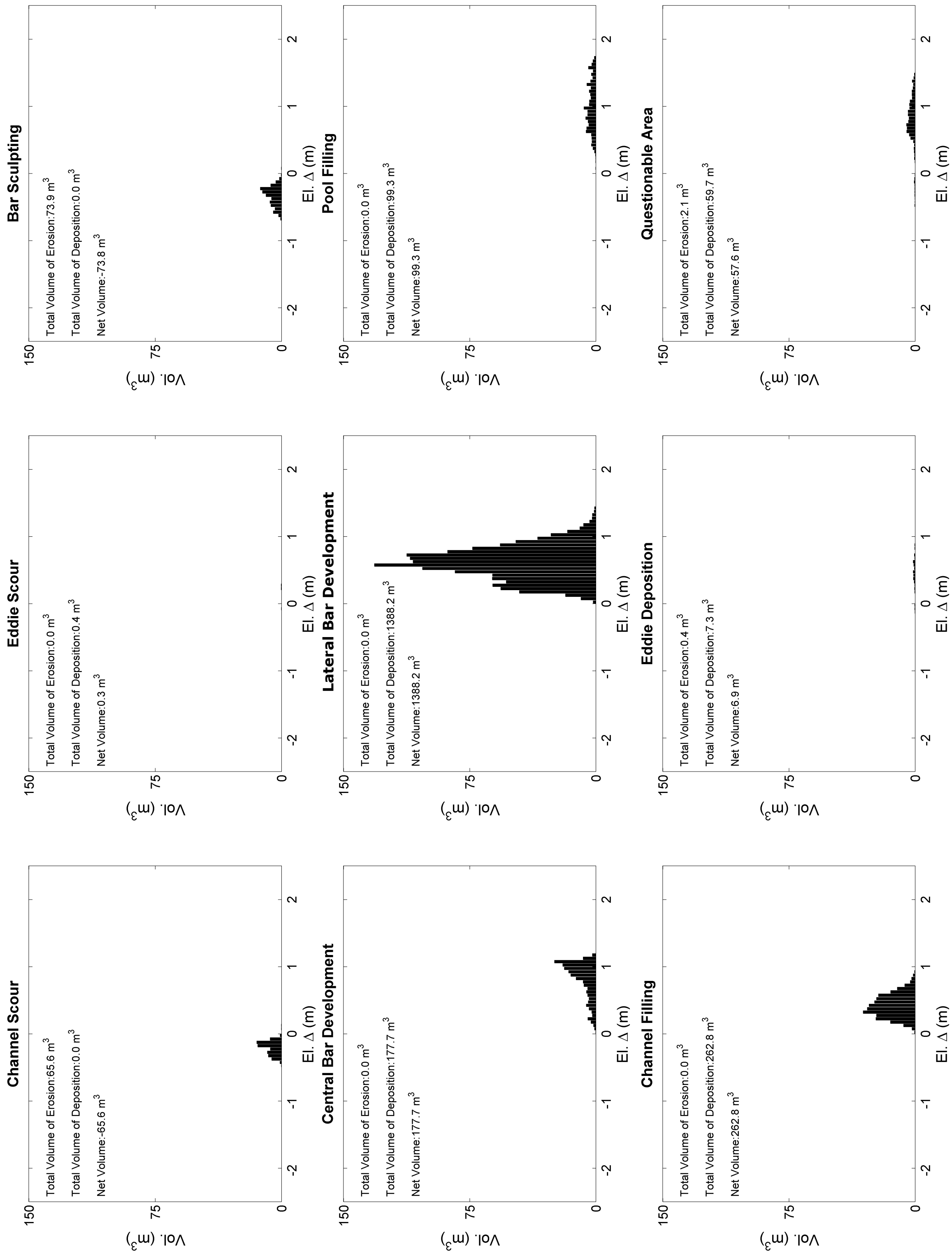
You will then see the program cycle through its production of all the ECD plots (be patient). It saves *.jpgs and *.tiffs of each as well as a *.csv file of each. The combined areal and volumetric figures look something like below:



Notice that the vertical axis is scaled to whatever the peak values of the ECD are and the text label at the top of the figure comes from that which was entered in the earlier dialog for the categories. The second figure that gets produced has its vertical axis set to the value, which was specified (150 in this example). And just shows the volumetric ECD. Notice that the distribution looks much smaller when plotted like this.



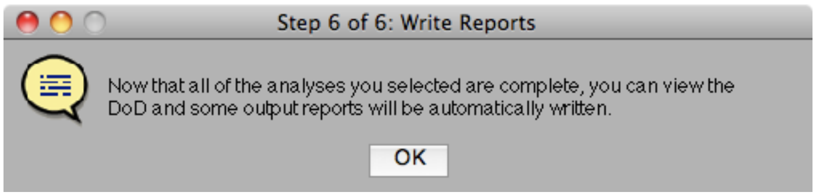
The utility of this becomes apparent in the figure shown on the next page. The figure shows an intercomparison of 9 of the 10 categories of change defined by the masks. It allows for an easy identification of the dominant categories of change as well as highlighting distinctive signatures of change.


Channel Scour
Total Volume of Erosion:65.6 m3
Total Volume of Deposition:0.0 m3
Net Volume:-65.6 m3
Eddie Scour
Total Volume of Erosion:0.0 m3
Total Volume of Deposition:0.4 m3
Net Volume:0.3 m3
Bar Sculpting
Total Volume of Erosion:73.9 m3
Total Volume of Deposition:0.0 m3
Net Volume:-73.8 m3
Central Bar Development
Total Volume of Erosion:0.0 m3
Total Volume of Deposition:177.7 m3
Net Volume:177.7 m3
Lateral Bar Development
Total Volume of Erosion:0.0 m3
Total Volume of Deposition:1388.2 m3
Net Volume:1388.2 m3
Pool Filling
Total Volume of Erosion:0.0 m3
Total Volume of Deposition:99.3 m3
Net Volume:99.3 m3
Channel Filling
Total Volume of Erosion:0.0 m3
Total Volume of Deposition:262.8 m3
Net Volume:262.8 m3
Eddie Deposition
Total Volume of Erosion:0.4 m3
Total Volume of Deposition:7.3 m3
Net Volume:6.9 m3
Questionable Area
Total Volume of Erosion:2.1 m3
Total Volume of Deposition:59.7 m3
Net Volume:57.6 m3
Vol. (m3)
El. Δ (m)

d

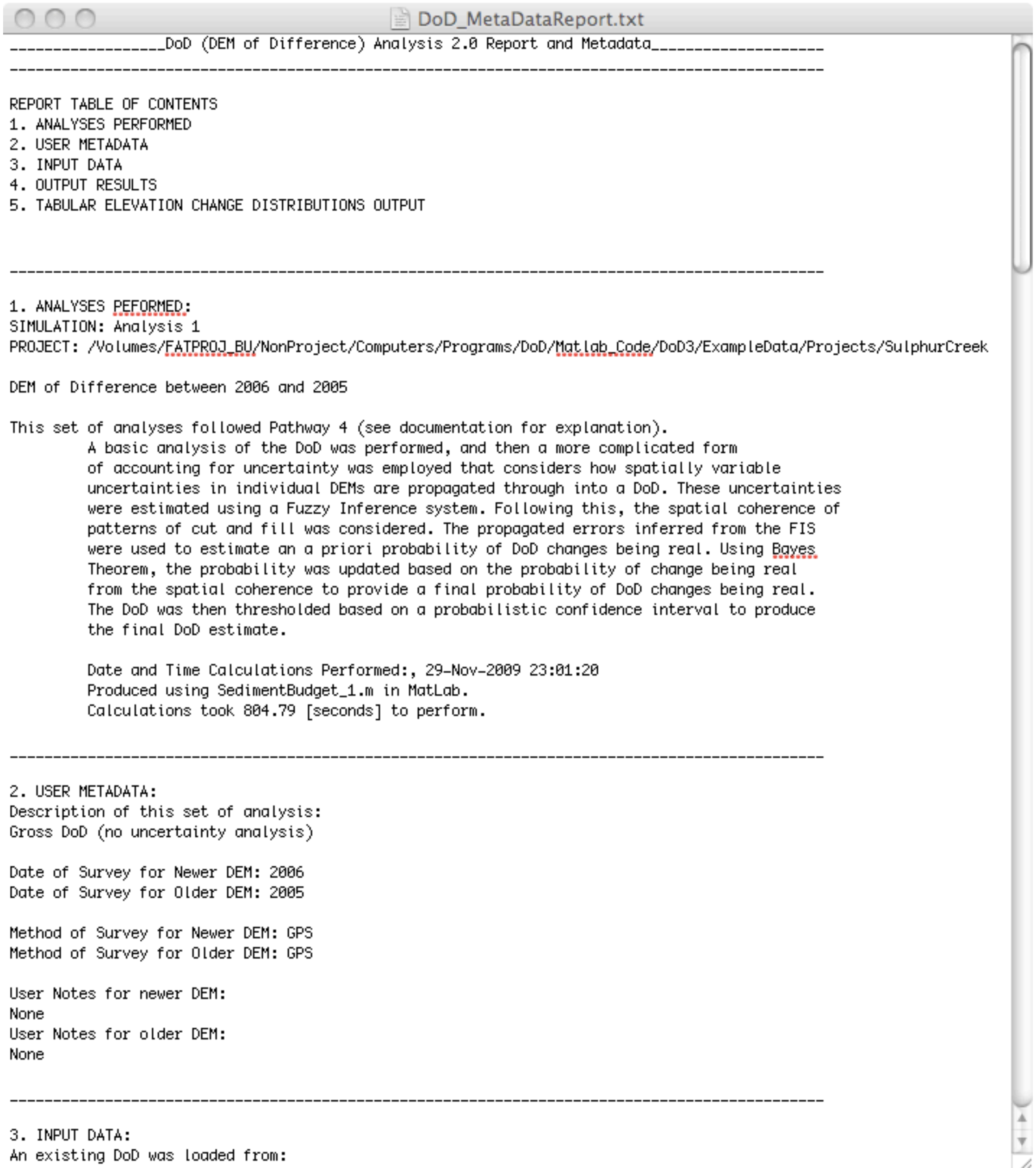
Final Report

At the end of any successful DoD3 analysis, the program attempts to produce several outputs to assist you in later interpretation or reanalysis of the results. When you see the dialog below, you know you've successfully reached this point.



Depending on what Pathway you chose, different outputs are reported. All will have a DoD_MetaDataReport.txt and a file with the '_ElevDist.csv' suffix as well as a 'BatchParamters.csv file. The '_ElevDist.csv' file contains a comma separate file showing all the outputs of the various ECDs of the DoD produced. This enables you to load the data into any other program for subsequent analysis of the ECD or to make your own custom figures. The 'BatchParametrs.csv' file contains all the parameters necessary to rerun the exact same analysis (see Batch Processing section for more information).

On the next page an example of a portion of the 'DoD_MetaDataReport.txt' is shown. The report is intended to provide a summary of the analyses conducted to aid you in later interpretation of simulation results.



DoD_MetaDataReport.txt

```
_________________DoD (DEM of Difference) Analysis 2.0 Report and Metadata___________________
--------------------------------------------------------------------------------------------

REPORT TABLE OF CONTENTS
1. ANALYSES PERFORMED
2. USER METADATA
3. INPUT DATA
4. OUTPUT RESULTS
5. TABULAR ELEVATION CHANGE DISTRIBUTIONS OUTPUT



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1. ANALYSES PEFORMED:
SIMULATION: Analysis 1
PROJECT: /Volumes/FATPROJ_BU/NonProject/Computers/Programs/DoD/Matlab_Code/DoD3/ExampleData/Projects/SulphurCreek

DEM of Difference between 2006 and 2005

This set of analyses followed Pathway 4 (see documentation for explanation).
         A basic analysis of the DoD was performed, and then a more complicated form
         of accounting for uncertainty was employed that considers how spatially variable
         uncertainties in individual DEMs are propagated through into a DoD. These uncertainties
         were estimated using a Fuzzy Inference system. Following this, the spatial coherence of
         patterns of cut and fill was considered. The propagated errors inferred from the FIS
         were used to estimate an a priori probability of DoD changes being real. Using Bayes
         Theorem, the probability was updated based on the probability of change being real
         from the spatial coherence to provide a final probability of DoD changes being real.
         The DoD was then thresholded based on a probabilistic confidence interval to produce
         the final DoD estimate.

         Date and Time Calculations Performed:, 29-Nov-2009 23:01:20
         Produced using SedimentBudget_1.m in MatLab.
         Calculations took 804.79 [seconds] to perform.

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2. USER METADATA:
Description of this set of analysis:
Gross DoD (no uncertainty analysis)

Date of Survey for Newer DEM: 2006
Date of Survey for Older DEM: 2005

Method of Survey for Newer DEM: GPS
Method of Survey for Older DEM: GPS

User Notes for newer DEM:
None
User Notes for older DEM:
None

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3. INPUT DATA:
An existing DoD was loaded from:
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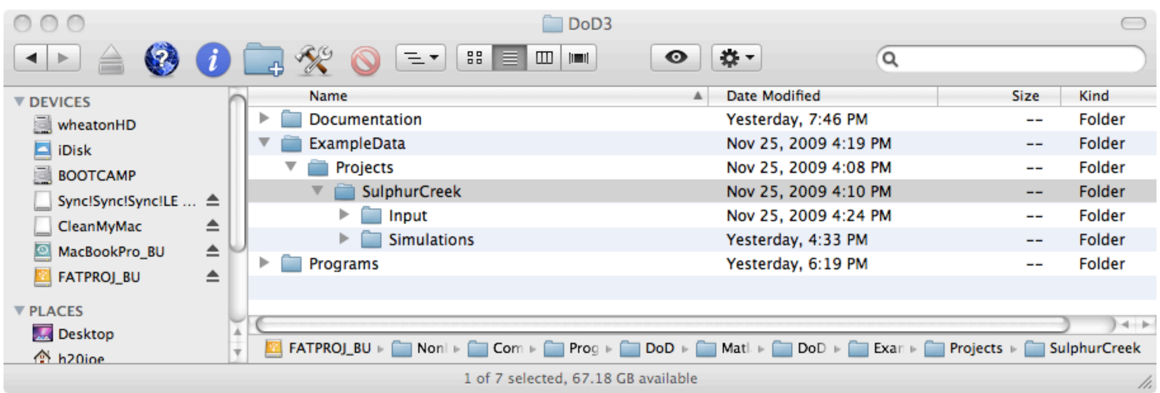
Batch Processing

It is not uncommon to want to perform a sensitivity analysis of the uncertainty analysis to varying parameters. Every simulation produced with the DoD3 program produces an output file called 'BatchParamters.csv'. This file has a header row with the parameter names and a second row with the parameter values for that simulation. You can rerun any simulation by simply starting DoD3, running it in batch mode and reading this file.

Alternatively, you can run numerous simulations in a batch processing mode by editing this file to have multiple rows. You can call your batch simulation file anything you wish while saving it as a *.csv file. I recommend saving this in your Input directory. An example is provided (see Project File Management). Each row will have a different suite of parameter values (for example, minimally it will have different simulation names). The batch program then goes through and runs each simulation in order. The best way to see how to properly format the batch file is to run a regular wizard mode simulation of the type of pathway you whish to run. Then copy the row from that BatchParameters.csv file to the *.csv file you are producing for batch processing and edit them from there.

Project File Management

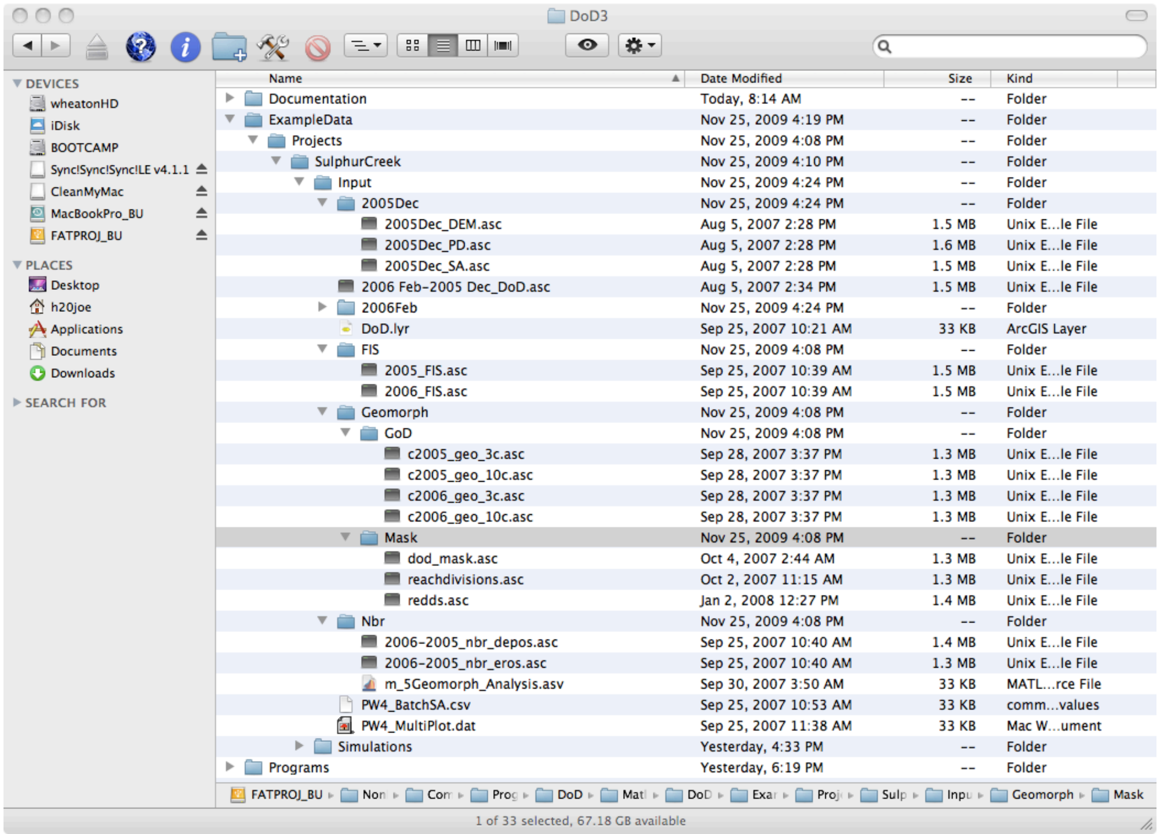
As mentioned above, you can specify your project folder to sit any where on your machine or network that Matlab can see. A sample project folder has been provided for you in the ExampleData folder in the zip file. Note that in this case the project folder is 'SulphurCreek' and not 'Projects'. You could choose to put multiple projects in the the 'Projects' folder.



Within every project folder that DoD3 runs on, there will always be an 'Input' folder and a 'Simulations' folder. In the data provided to you, only the 'Input' folder exists initially, but after one DoD3 analysis, the 'Simulations' folder will appear.

The Input Folder

For many projects, you will run a wide range of analyses off a relatively small set of input data. Instead of duplicating this input data and copying into each simulation folder, that input data can be housed in one place. The 'Input' folder is required for this. Where ever you are asked in DoD3 to load data, it defaults to point the open file dialog to this 'Input' folder. You can organize your input data in anyway you wish (i.e. with any naming convention and with or without subdirectories). As an example, we will describe how the input data are organized for the SulphurCreek example below:



At the root level in this input folder we have only three files:

- *2006 Feb-2005 Dec_DoD.asc* : An ascii raster DoD between February 2006 and December 2005
- *PW4_BatchSA.csv* : This is an example of a batch processing input file (for running DoD3 in batch mode) for a pathway 4 sensitivity analysis (NOTE: this would need to be updated to work on your machine, because the file paths will be incorrect)
- *PW4_Multiplot.dat* : This is an example of a multi-plot input file for use with the A_MultDistPlot tool (note: this would need to have the path and simulation folder names updated to work)

Within the subfolders, we have a variety of folders:

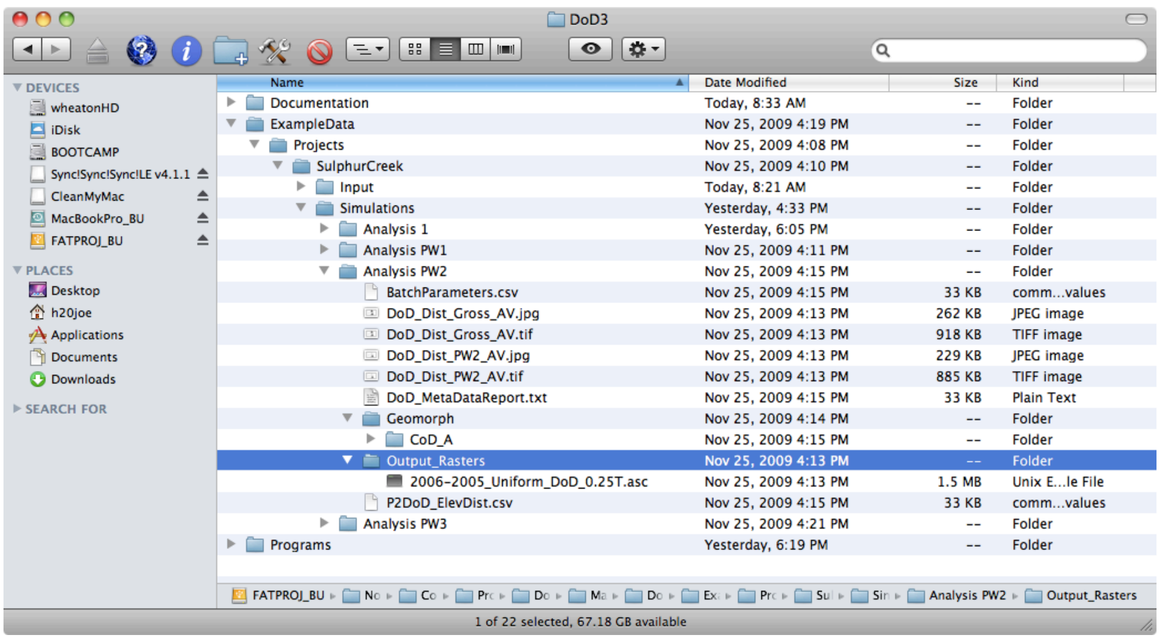
- *2005Dec* – This folder contains the DEM raster and the point density and slope analysis input rasters for the FIS from 2005
- *2006Feb* – Same types of rasters as above but for 2006
- *FIS* – This folder contains the raster output of a FIS analysis using the 2-rule point density and slope analysis data (these can be called up from DoD3 once they are run once, instead of re-running them each time… much quicker)
- *Geomorph*

- *GoD* – Contains a geomorphic classification of difference input rasters (for 3 and 10 category classifications)
- *Mask* – Contains three types of DoD Masks (a geomorphic interpretation, a sub-reach mask, and a Chinook redd mask)

- *Nbr* – The spatial coherence grids for erosion and deposition for the 2006-2005 DoD (these too can be called up from DoD3 once they are run once, instead of re-running them each time… much quicker)

The Simulation Folder

Depending on the type of analysis you run and the answers to the wizard questions, you will have different contents in your simulation folders. Each simulation (or analysis) you run will have it own subfolder in the Simulation folder. Below we show the contents of a simulation called 'Analysis PW2':



Within the that folder we see some common files and subfolders:

- *BatchParameters.csv*: This CSV file gets created every time you run a simulation and is a complete record of all the parameters used to run that simulation. It can be used in batch mode to repeat an analysis, or by copying the rows (e.g. in excel) and modifying the correct parameters it can be used to batch process numerous simulations.
- *DoD_Dist_Gross_AV* (jpg & tif) – These are just image files of the gross elevation change distributions (ECDs) with no uncertainty accounting
- *DoD_Dist_PW2_AV* – These are image files of gross ECDs with a pathway 2 analysis
- *DoD_MetaDataReport.txt* – This is the text file output report, which summarizes all of the analyses
- *Geomorph* folder – This where all masking analyses get outputted. Note that in this case there is a CoD_A folder (Classification of Difference A). You can

and often do run multiple masks over the same DoD analysis and these would each get stored in here as different subdirectories.

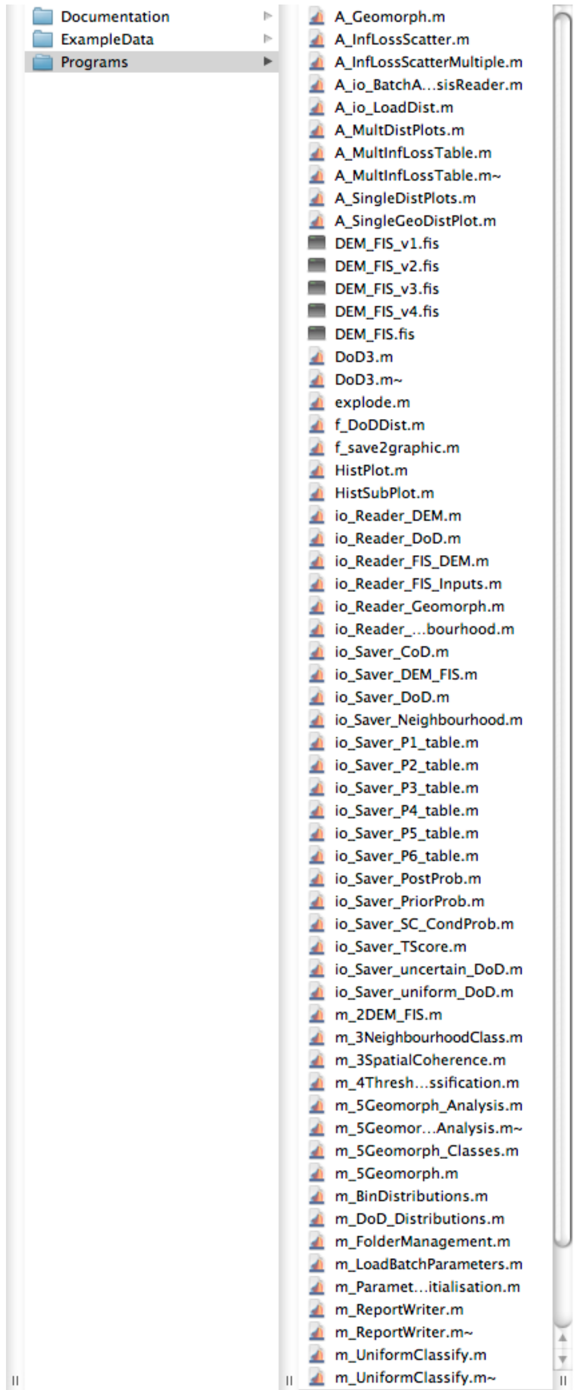
- *Output Rasters* folder – This is where any output rasters created during your analysis get stored. These include your thresholded DoD rasters, FIS output rasters, spatial coherence output rasters, DoD probability maps, etc. Although you can view these rasters in Matlab, typically, these rasters are best visualized in another stand-alone GIS application.
- *P2DoDElevDist.csv* file – This CSV file gets outputted from every analysis and contains the raw data to produce the histograms of all the elevation change distributions associated with that simulation. This can be used to make your own figures in any program (e.g. Excel, or using some of the analysis tools here in Matlab)

Matlab Scripts & Functions – Program Folder

Within the 'Programs' folder, you will find a mix *.m Matlab script and function files and *.fis fuzzy inference files.

The naming convention for the *.m files is as follows:

- DoD3.m is the main program file to access the wizard program or batch processing version.
- All *.m files with the 'A_' prefix are analysis programs, some of which are called from DoD3 and some of which can be run as stand-alone files on outputs from DoD3
- The handful of *.m files with the 'f_' prefix are functions
- All *.m files with the 'io_' prefix are scripts for reading in data from files and writing output data to files (primarily ASCII raster grids).
- Any *.m file with a 'm_' prefix is one of the primary method scripts called in DoD3



The *.fis files are created using the fuzzy logic toolbox. If you wish to change the existing membership functions or rules (but keep the same inputs), you can do this manually in the *.fis files or with the help the fuzzy logic toolbox's GUI. If you wish to extend the fuzzy inference system, you will need to create a new *.fis using the fuzzy logic toolbox and then update the calls to this *.fis within the m_2DEM_FIS.m file (line 47 updates the call to the *.fis file). You will also need to update the io_Reader_FIS_Inputs.m file to add additional inputs.

Some notes about the Code

You will notice that pretty much everything loaded or calculated gets stored in memory. This was done partly to make code development easier and have flexibility in pathway. It is however very inefficient. When you're working with smaller rasters (i.e. less then 100 MB) with a machine with more than 2GB RAM, this tends not to be a problem. However, with larger rasters you may exceed your memory limits. You can insert lines in your code to clear some of the unnecessary grids from Matlab's memory.[3]

Another inefficient feature of the code is the use of ascii text rasters. These are much slower to read in and write out then binary raster formats. However, ascii raster formats are readable buy a wide variety of other programs and are nice for troubleshooting because you can read them with any text editor (e.g. notepad).

As Matlab is a non-complied language, it is very slow at running loops. Where possible, the code has been vectorized to speed it up. However, there are certain grid operations we could not get to work as easily or flexibly and have left these in loops. This is again an inefficient feature of the code.

The above shortcomings are all part of the reasons the program is being parsed over into a compiled C++ library, which will drive a platform independent web application and an ArcGIS plugin (toolbar). However, for many users who might only make slight modifications to the sourecode, this Matlab version should be relatively straightforward to follow and or modify.

[3] The C++ library version under development will be much more memory efficient and quicker

Matlab Version Notes:

This program was originally developed in Matlab 6 running in Windows XP Pro, and this release was tested and in Matlab 7.8.0.347 (R2009a) on Mac OSX 10.6.2. There have been minor syntax differences between older and newer releases. If running an older version, you may need to edit the code. If you are attempting to run this without the Fuzzy Logic Toolbox installed, the code will crash in Pathways 3 & 4.

References:

Wheaton JM. 2008. *Uncertainty in Morphological Sediment Budgeting of Rivers*. Unpublished PhD, University of Southampton, Southampton, 412 pp. Available at: http://www.joewheaton.org.uk/Research/Projects/PhDThesis.asp.

Wheaton JM, Brasington J, Darby SE and Sear D. 2009. Accounting for uncertainty in DEMs from repeat topographic surveys: Improved sediment budgets *Earth Surface Processes and Landforms.* **34**. DOI: 10.1002/esp.1886.