

# Gocad Plugin for Bayesian Updating

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*One of the objectives of the CCG is to provide industry with various geostatistical algorithms. A few of the larger software vendors including Paradigm, who releases a software package called Gocad, have made it possible to add custom tools or plugins into their software. For users who have become familiar with such software packages, this makes transferring ideas from research to industry more successful. Most research that is compiled into computer programs at the CCG is done so as command-line programs that use text-based parameter files. Although most of these programs are flexible and portable, they are not very user friendly. When the demand for certain programs is high enough, it is worthwhile to take the time and energy to compile them into a user friendly software package. In this work, an algorithm that is fairly popular among industry called Bayesian updating was compiled as a Gocad plugin.*

## 1. Introduction

Many types of geological and geophysical information are used in the petroleum industry to assess the performance of a reservoir. Several technologies have been developed at the Centre for Computational Geostatistics to merge several of these data types and sources together to more accurately appraise the uncertainty in reservoir models. Incorporating these technologies into workflows within software packages such as Gocad is an effective way to transfer technology to industry. The current version of Gocad includes geostatistical tools for reservoir modeling; however, they are limited to two variables through co-located approaches. Incorporating CCG technology into Gocad as a series of plugins provides the tools for building reservoir property models when several variables and secondary data are available.

This work implements a multivariate technique called Bayesian updating (BU) and all required processing tools that are not already available in Gocad. Some background material is provided including: the BU workflow; the Gocad environment and what is already available for BU; and requirements for developing plugins in Gocad. All the necessary tools implemented in Gocad for the BU workflow are then described individually. These tools are put together into a workflow within Gocad that is described last.

## 2. Background

In Bayesian updating, there are two sets of variables: primary variables that are usually available only at well locations and need to be predicted throughout a modeling domain, and secondary variables that are exhaustive or available everywhere in the modeling domain. Primary variables may include lithology, porosity, permeability, and water saturation. Secondary variables may include several seismic attributes or geometric quantities such as the proximity to a fault. The secondary variables are used as additional information to make better predictions of the primary variables. When the secondary variables have a non-zero and non-spurious correlation with the primary variables, the predictions are better because the error variance is reduced.

To incorporate the secondary information into estimating a primary variable, the secondary variables are merged into a likelihood distribution. When all variables are Gaussian, the likelihood distribution is also Gaussian and is defined by a mean and variance. Computing these is identical to kriging in Equation 1, where  $\mathbf{P}$  is the correlation matrix between the secondary,  $\boldsymbol{\rho}_k$  is the vector of correlations between the  $k^{th}$  primary variable and the secondary, and  $\mathbf{v}_k$  are the solution weights. Defining  $\mathbf{s}(\mathbf{u})$  as the vector of secondary values at a location  $\mathbf{u}$ , the likelihood mean,  $L_k(\mathbf{u})$ , is defined by Equation 2 and the likelihood variance,  $L_k^2(\mathbf{u})$ , by Equation 3, where  $N$  is the number of secondary variables and  $M$  is the number of primary variables.

$$\mathbf{P}\mathbf{v}_k = \boldsymbol{\rho}_k, k = 1, \dots, M \quad 1$$

$$L_k(\mathbf{u}) = \sum_{j=1}^N v_{kj} s_j(\mathbf{u}), k = 1, \dots, M \quad 2$$

$$L_k^2(\mathbf{u}) = 1 - \sum_{j=1}^N v_{kj} \rho_{jk}, k = 1, \dots, M \quad 3$$

Estimating the primary variables using kriging with no additional information provides prior distributions of uncertainty. In Gaussian space, these distributions are defined by a prior mean (the kriging estimate) and prior variance (the estimation variance) denoted  $\mu_k(\mathbf{u})$  and  $\sigma_k^2(\mathbf{u})$  respectively. To compute the updated mean and updated variance from the likelihood and prior, Equations 4 and 5 are used, where  $U_k(\mathbf{u})$  is the updated mean and  $U_k^2(\mathbf{u})$  the updated variance.

$$U_k(\mathbf{u}) = \frac{L_k \sigma_k^2 + \mu_k L_k^2}{(1 - L_k^2)(\sigma_k^2 - 1) + 1}, k = 1, \dots, M \quad 4$$

$$U_k^2(\mathbf{u}) = \frac{L_k^2 \sigma_k^2}{(1 - L_k^2)(\sigma_k^2 - 1) + 1}, k = 1, \dots, M \quad 5$$

Once updated distributions of uncertainty are available, they may be used in further geostatistical analysis. For example, unconditional realizations can be generated and conditioned using the updated distributions. If several primary variables are involved, the realizations can also be correlated using the correlation matrix between the primary variables. Bayesian updating and correlating functionality have been incorporated into Gocad as plugins.

Several components of BU are implied in the previous background material. Organized into a workflow that assumes well data and a geological modeling grid are available, they include:

1. Upscale the well data to the geological grid.
2. Perform declustering if required.
3. Normal score transform all primary and secondary variables.
4. Model variograms of all primary variables.
5. Use kriging to model the prior distributions of uncertainty.
6. Compute the correlation matrix of all variables.
7. Build the likelihood distributions for each primary variable.
8. Compute the updated distributions.
9. Post processing.

Several of these steps are available in Gocad. The tool for upscaling well logs to a grid (an SGrid in Gocad) is found in the Commands->Well->Property menu and is named "Upscale at Grid Resolution" (Figure 1). A few different averaging methods are possible. The selected log is upscaled to both the grid cells and to a blocked log object. Declustering is available, but it requires loading the "Reservoir Data Analysis" (RDA) module when starting Gocad. RDA is applied to properties as a workflow. Cell declustering can be executed as one of the steps. When executed using upscaled wells on the grid, a new property is added to the grid containing the declustering weights. The RDA module also includes steps for trend modeling and histogram smoothing.

A tool to perform the normal score transform is not available in Gocad; however, the underlying function used in other processes such as Gaussian simulation is present. Part of developing the BU plugin was to make this function accessible to users. Variogram modeling can be done using the "Variogram Analyzer" that is accessed with the "Show Spatial Data Analysis" button. For computing the prior distributions of uncertainty, various types of kriging are available in the Commands->SGrid->Geostatistics menu (Figure 2). Kriging mean and variance properties are added to the selected grid object when executed. Note that a theoretically correct implementation of BU requires the use of simple kriging. One of the inputs for kriging is a Gs file. Variogram models created from step 4 are found in the task pane under Resourced->Data Analysis and they may be saved to a Gs file.

The remaining BU steps (6, 7 and 8) are not available in Gocad and were part of the BU plugin development. Plugins are additions to Gocad that extend the existing tools or implement new functionalities. There are several requirements: the Gocad development kit (and workflow development kit to create workflows for plugins); a C++ compiler, Visual Studio 2005 is currently recommended; QT 4, which is useful for creating custom user interfaces; and editors for XML Schema (XSD) and XML Process Definition Language (XPDL) files. QT is not necessary if custom user interfaces or workflows will not be created. XSD and XPDL are only necessary for workflows. A basic plugin can be automatically created using a utility that comes with the Gocad development kit (PluginSkeleton.exe).

### 3. Individual Plugins

Several tools were developed to implement BU in Gocad and perform some post processing using the updated distributions of uncertainty. These tools are implemented as CLI (command line interpreter) commands. User interfaces are automatically generated by the CLI code. Developers can add tools to Gocad quickly without having to be concerned with user interface design and code. Plugins developed as CLI commands for BU include:

1. Normal score transform: the underlying normal score transformation function that is already used by higher level tools such as sequential Gaussian simulation was exposed to users. The normal score transform function from GSLIB (Deutsch and Journel, 1998) was also added.
2. Correlation matrix: a tool to compute the correlation matrix between several reservoir grid properties was created. This tool is supplemented by a correlation matrix viewing tool allowing users to check the results.
3. Likelihood: a tool to compute the likelihood for each primary variable involved in the BU study.
4. Update: This tool merges prior distributions of uncertainty obtained from kriging and the likelihood to acquire the updated distributions.
5. Correlate: This is a post processing tool that uses the updated distributions of uncertainty and the correlation matrix to condition and correlate a set of unconditional realizations for the primary variables.
6. Back transform: the underlying back transformation function already available in Gocad was exposed to users. The function used in GSLIB was also added.

All the plugins are found under the Commands->CCGLAB->General menu. The set of commands is stored under CCGLAB so that future CCG related plugin development may be added to this group. The normal score transform tool (Figure 3) takes grid properties as input. The properties can be those from upscaling logs (primary variables) or exhaustive gridded properties (secondary variables). Weights from declustering that are calculated from the RDA workflow can be used. A region may be input; however, this parameter is currently not implemented and the process is applied everywhere. An advanced tab allows users to input trimming limits and choose to use the normal score transform that is part of Gocad, or to use the CCG version. Both yield similar results; however, the approach used to execute the Gocad version does not appear to break ties, and this requires further investigation.

Executing the Correlation Matrix command opens a user interface for creating a correlation matrix object that is stored as a Gocad resource under Data Analysis (Figure 4). Once created, right clicking on the object brings up an additional menu that allows users to compute, view, rename, or delete the correlation matrix. The compute command (Figure 5) works on grid properties. Multiple primary and secondary properties can be selected so the full correlation matrix required in a particular Bayesian updating workflow is constructed. Although an input for region is available, this functionality is not implemented. Under the advanced tab, users can select to use the maximum pairs that computes the correlation between two variables using the maximum number of defined pairs for those variables. Because different variables may result in different numbers of pairs, there is no guarantee that the resulting correlation matrix will be positive definite. In this case, the matrix must undergo some correction that can be done with the correlation matrix tool. Once computed, the view command allows users to look at the resulting Pearson's, Spearman's, and corrected correlation coefficients as well as the number of pairs used.

The likelihood command (Figure 6) computes a likelihood mean and likelihood variance for each primary property based on the secondary properties. Inputs for the primary and secondary are not necessarily required since they are known by the correlation matrix; however, this offers additional flexibility. Users may determine after generating a correlation matrix that certain variables are redundant or result in erroneous correlation coefficients. Rather than rebuilding the correlation matrix without them, they can be ignored in the primary and secondary property selection. When executed, a likelihood mean and variance grid property is generated for each selected primary property. For mean properties, the input prefix is appended with "mean\_" and for variance properties with "var\_", so the prefixes would be LH\_mean\_ and LH\_var\_ using the inputs shown in Figure 6. Prefixes are attached to the primary property names.

Updating (Figure 7) requires the likelihood mean and variance property as well as a prior mean and variance property. Priors are computed using kriging, which is already part of Gocad. Although this tool only allows one primary variable to be updated at a time, the workflow is setup to compute all updated mean and variance properties for all primary variables involved simultaneously.

The correlate tool (Figure 8) is one approach for post processing the updated distributions. A set of unconditional Gaussian realizations are required, and methods such as sequential Gaussian simulation to do this are already built into Gocad. A different set of realizations should be created for each primary property and with a different initial random number seed. Mean and variance properties from Bayesian updating are used to condition the realizations and the correlation matrix is used to correlate them. Only the first unconditional realization for each primary variable is input to the process. If other realizations exist in the same sequence, they are iterated over automatically.

Backtransformation (Figure 9) is used to transform Gaussian properties to the unit space of the original variables. For example, realizations that have been correlated and conditioned are transformed back to porosity or permeability. As with the normal score tool, either the Gocad version or CCG version can be used. The reference property input is required in the current implementation because a transformation table is not stored within Gocad. Whichever property was originally used to compute the normal scores must be used here so that the transformation table can be rebuilt.

#### **4. Bayesian Updating Workflow**

A workflow so that users can work through the process from selecting a grid to computing updated mean and variance properties was also generated. The workflow assumes several of the necessary steps have already been executed including: upscaling wells to a grid; kriging to generate the prior mean and variance properties; and generating any unconditional realizations if the correlate command is to be used. Steps that are covered include: grid selection; primary and secondary property selection; normal score transformation; correlation matrix computation; prior property selection; and likelihood and updated distribution calculation.

Starting the workflow is done in the Workflows tab by creating a new Bayesian Updating Workflow (Figure 10). Once created, the first task (Figure 11) is selecting a grid and specifying if wells have been upscaled. The purpose of the upscaling question was to have the workflow branch off to a sub-flow for upscaling properties if not already done so; however, this functionality is not implemented. Users must leave the workflow and upscale well properties to the selected grid instead. In the property selection step (Figure 12), all primary and secondary properties involved are selected. If they have not been normal score transformed, users can choose a prefix and run the normal score transform, which is applied to all selected primary and secondary properties.

Computing the correlation matrix is the next step (Figure 13). This only involves selecting a name for the correlation matrix object that is added to the Data Analysis tree. Correlation coefficients between all selected primary and secondary properties from the previous step are computed when the run button is pressed. If an existing correlation matrix that was built using the same properties already exists, it may be selected instead. Results can be checked by clicking the view button that opens the view correlation matrix interface.

Prior distributions are linked into the workflow in the Priors step (Figure 14). Users select prior mean and variance properties for each of the primary variables. An addition could be made to the workflow at this point. If prior mean and variance properties are not available, a sub-flow would be started that walks users through the kriging process for each primary variable, requesting input parameters such as the variogram for each property. The last step only requires users to input a prefix for resulting likelihood mean and variance properties and updated mean and variance properties (Figure 15). Clicking run generates all the associated mean and variance properties. Updated means and variances could then be used to condition and correlate a set of unconditional realizations.

#### **5. Conclusions and Future Work**

Developing plugins within the Gocad environment was a straightforward process. After getting setup with the required software, roughly 2 to 3 weeks of training and practice will enable most users to generate basic plugins with ease; however, this depends on a person's experience with programming and software development. Several aspects of Gocad plugin development were involved in the BU plugins including: generating CLI commands; creating user defined objects; creating an archive to save those objects; developing a workflow; and creating custom user interfaces with QT.

The BU plugins were created to work with SGrid objects in Gocad. This requires wells or other types of input data to be upscaled to the grid. Secondary variables must be imported to the grid as well, or resampled to the correct resolution depending on how they are stored. This may appear as a limitation; however, it forces users to process the data so that it is consistent regarding spatial position and scale.

Getting the BU plugins to a releasable state requires some additional work. All plugins were initially created without a concern about regions. Properties in Gocad can be assigned to different regions for many objects, for example a lithology region in an SGrid. Most of the BU tools need to be updated to handle a specified region. The current version applies the BU process to the whole SGrid. For the normal score transform and back transform tools, a transform table user object should be created and stored. There is also a variety of error checking routines that need to be added to prevent failed runs and crashing. Currently, the workflow assumes all information is available including upscaled wells and prior mean and variance properties. Sub-flows can be added if this is not the case.

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Figures

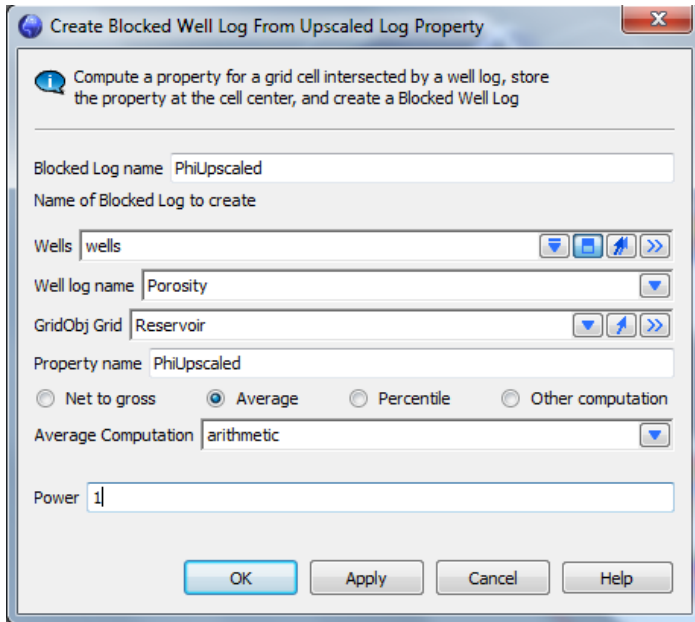


Figure 1: Upscale well logs to grid resolution tool.

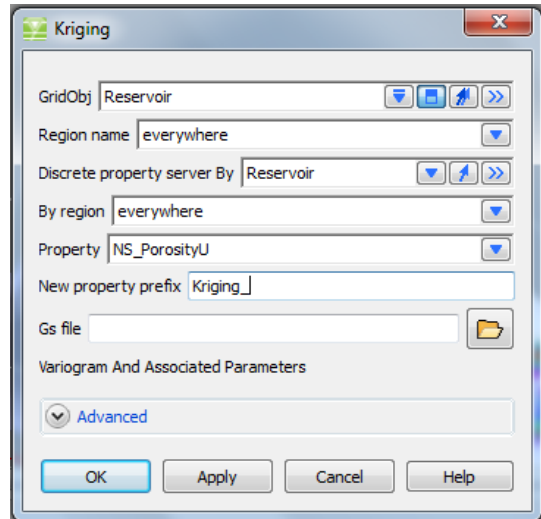


Figure 2: Kriging tool.

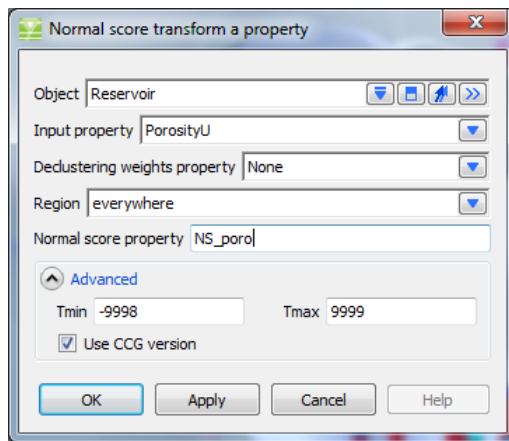


Figure 3: Normal Score command interface.

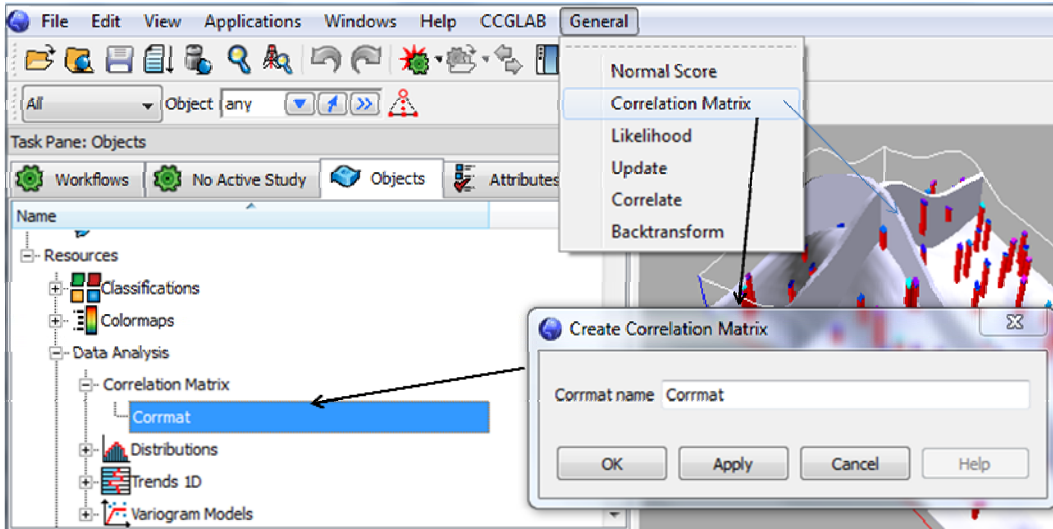


Figure 4: Create correlation matrix interface and location in Resources tree.

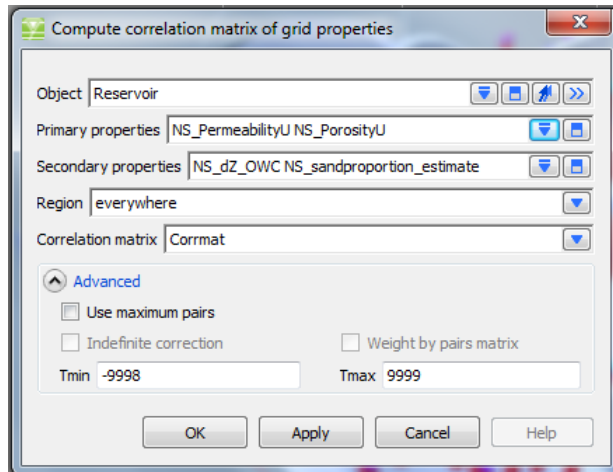


Figure 5: Correlation matrix command interface.

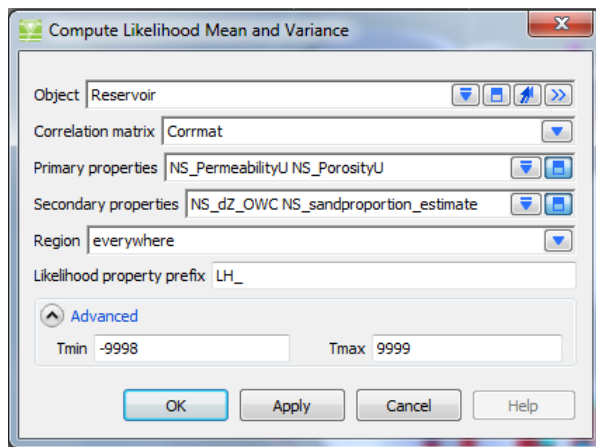


Figure 6: Likelihood command interface.

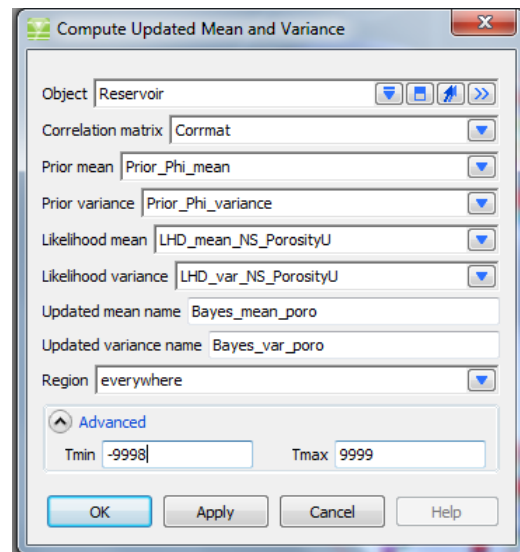


Figure 7: Update command interface.

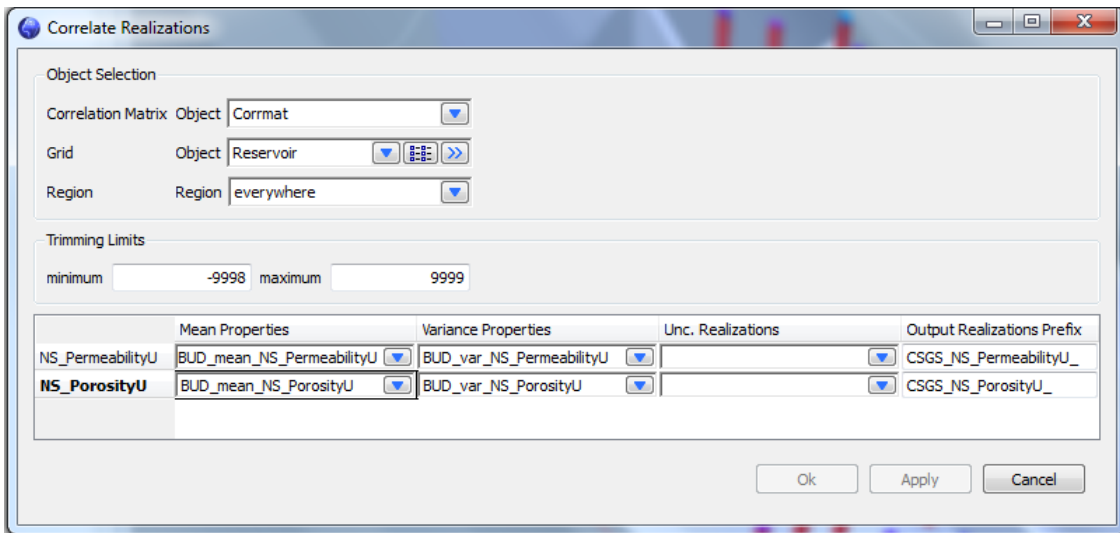


Figure 8: Correlate command interface.

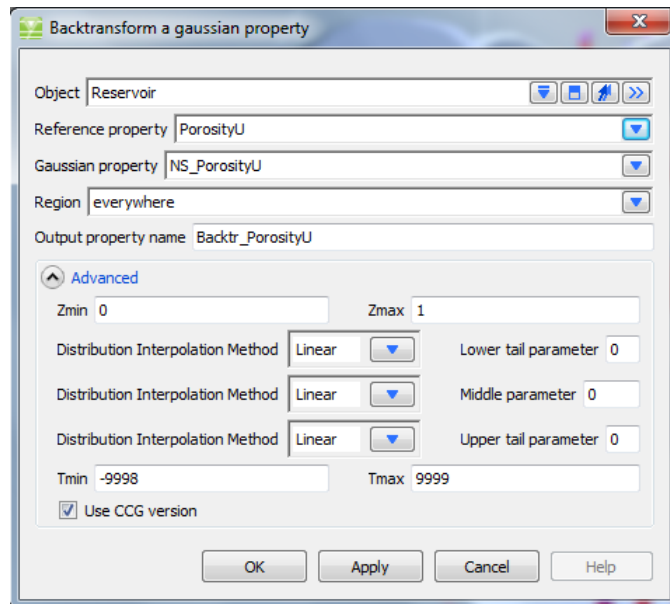


Figure 9: Backtransform command interface.

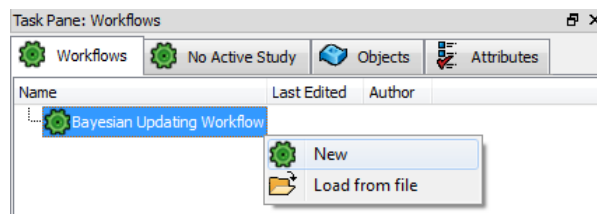


Figure 10: Starting a new Bayesian updating workflow.



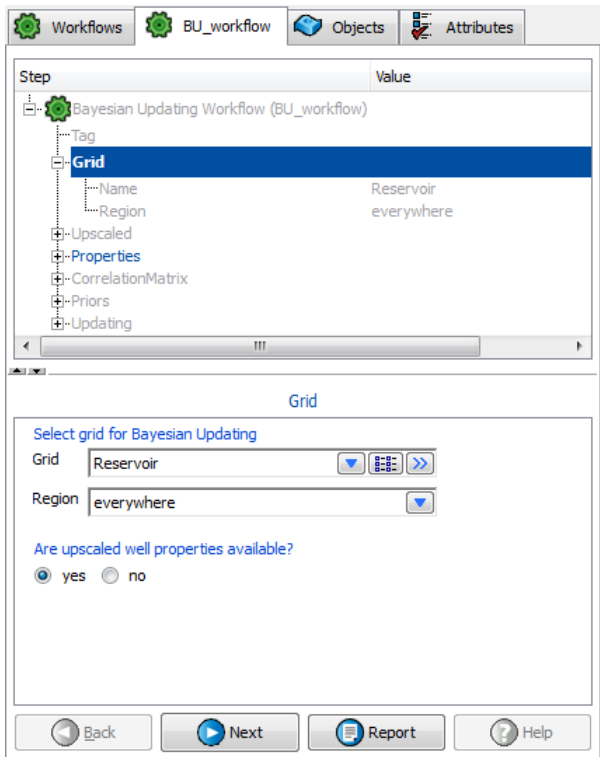


Figure 11: Grid selection task.

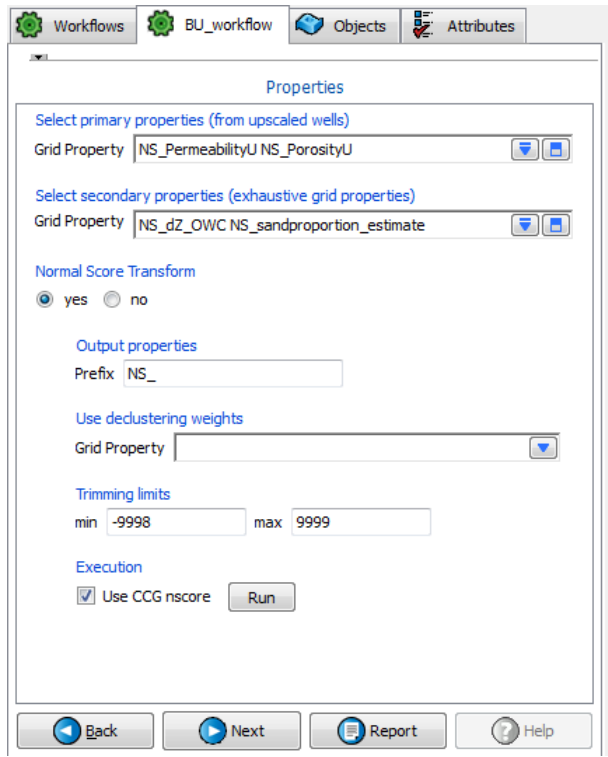


Figure 12: Property selection and normal score step.

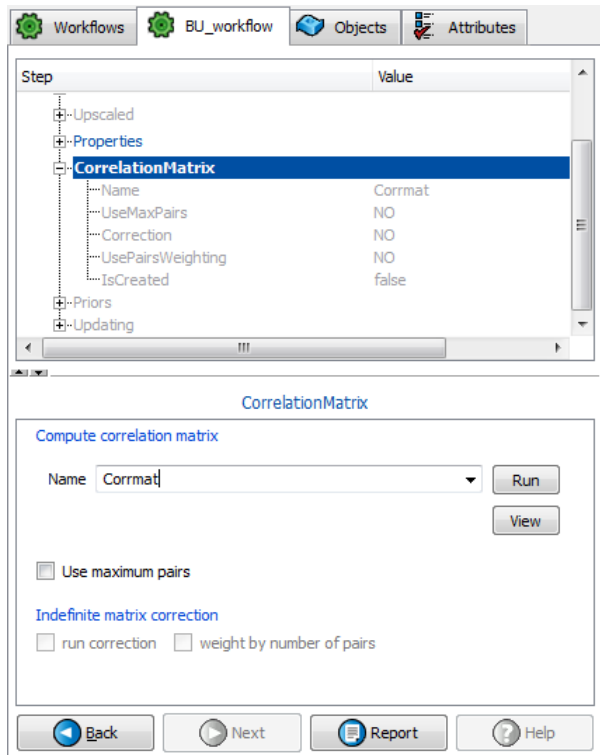


Figure 13: Correlation matrix step.

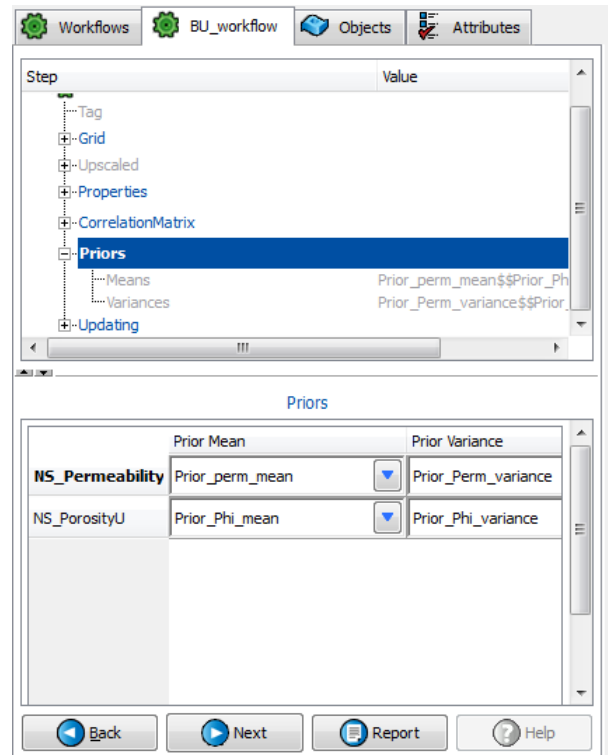


Figure 14: Prior selection step.

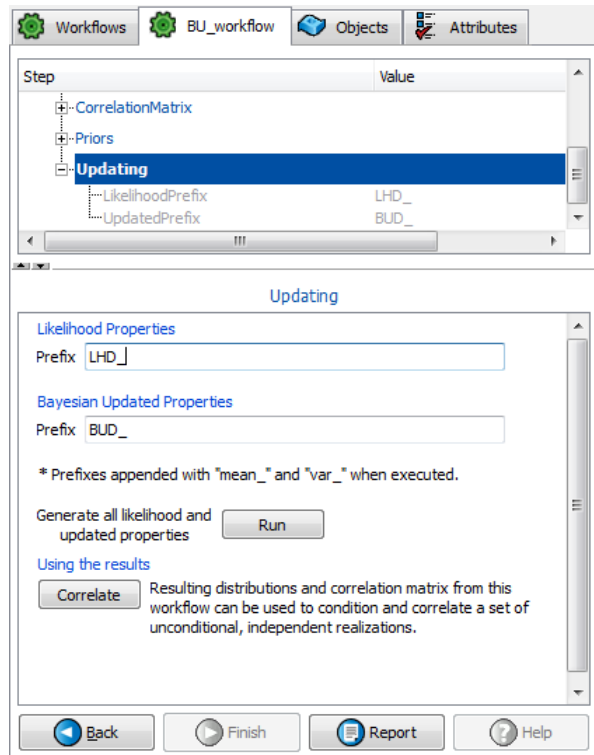


Figure 15: Likelihood and updating step.