2018

Orhan Eroglu, Dylan R. Boyd, Mehmet Kurum

Infor**M**ation **PR**oc**ES**sing and **S**ensing (IMPRESS) Lab

http://impress.ece.msstate.edu/

SCoBi Simulator User's Manual

v1.0

Table of Contents

1. Introduction

1.1. General

SCoBi, the **S**ignals of Opportunity **Co**herent **Bi**static scattering model and simulator, is a framework that is designed to use the Information Processing and Sensing (IMPRESS) Lab's fully coherent scattering model within a user-friendly simulation interface to enable comprehensive analysis of bistatic SoOp configurations for land applications. The current SCoBi release (v1.0.0) boasts the following capabilities:

- Fully polarimetric analysis with any combination of linear and/or circular polarizations
- Antenna property realizations including antenna orientation, pattern, and cross-polarization coupling
- Interferometric effect implementation caused by complex voltage and beamforming
- Geometry effects induced by altitude, orientation, and spreading loss over vegetation depth and soil moisture profile

SCoBi generates power and complex field outputs for the direct signals between the transmitter and the receiver, and the coherent reflection coefficient and reflectivity outputs regarding the specular point between the antennas. The SCoBi model is capable of handling the diffuse vegetation scattering mechanisms through Monte Carlo simulations via distorted Born approximation, but this feature is not included in the current version of the SCoBi simulator framework. A comprehensive description of the theory behind the model can be found in [1].

1.2. System Requirements

SCoBi supports the following platforms and environments:

- OS: Windows 10 64-bit
- Environment: MATLAB R2015a (the oldest version that is tested with SCoBi) or above

1.3. Downloading and Installation

SCoBi software can be accessed from the following ***github*** repository:

https://github.com/impresslab/SCoBi

It can also be downloaded from the following URL:

http://impress.ece.msstate.edu/impress-lab/software/scobi/source-code/

There is no installation requirement for the current version. In other words, it can be directly run from within the source code when it is downloaded.

1.4. About This Document

The SCoBi User's Manual has been prepared to document the architectural design of the SCoBi simulator framework, to help the potential developers understand the implementation details, and to expedite further extensions to the system.

This document has its own version number convention regardless of that of the SCoBi simulator software. The two-digit version number of this document represents the major updates (to the document) in the first digit and minor changes in the second digit. On the other hand, the three-digit version number of the SCoBi software represents the major updates to the framework in the first digit, minor changes in the second digit, and bug-fixes in the third digit.

1.5. Help SCoBi Improve

Please send us an email via the following address to make requests or to report any bugs through using the software:

impress@ece.msstate.edu

1.6. How to Cite This Study?

The SCoBi software is open-source under GNU General Public License (GPL) and freely available with its documentation, design, and tutorial videos. However, the developers of the SCoBi model and the simulator would appreciate those who cite the corresponding studies below in the case they are used:

SCoBi Model:

M. Kurum, M. Deshpande, A. T. Joseph, P. E. O'Neill, R. Lang, and O. Eroglu, "SCoBi-Veg: A generalized bistatic scattering model of reflectometry from vegetation for Signals of Opportunity applications," *IEEE Trans. Geosci. Remote Sensing, Press*.

SCoBi Simulator:

O. Eroglu, Dylan R. Boyd, and M. Kurum, "SCoBi: A free, open-source, SoOp coherent bistatic scattering simulator framework," *IEEE Geosci. and Remote Sensing Magazine, Review*.

2. SCoBi Simulator Basics

2.1. Initial Run

The SCoBi simulator comes with an initial set of default inputs for a number of distinct SoOp analyses. The included simulation scenarios for this release encompass the analysis of bare-soil, root-zone soil moisture profiles, agricultural canopies, and forested terrain. SCoBi will generate values for the received direct signal's power density and electric field and will also generate reflectivity values for the received coherently scattered field. To run these default sample scenarios or user-customized simulation scenarios, the user can run the simulator application from:

./source/lib/runSCoBi.m

A graphical user interface (GUI) window welcomes the user and provides selection buttons to load one of the available default SoOp analysis types. This interface is titled the ***Analysis Selection Window*** and is described in **section 2.2**. When one analysis type is chosen (i.e. clicked), the ***Simulation Input Window*** is opened with a set of default inputs. The ***Simulation Input Window*** is described in **section 2.3**. To make an easy first run, the ***runSCoBi*** button can be clicked with no change in to the default inputs. The simulator will run with the default inputs set and will generate outputs in the output directories that will be described in **section 3.3 Simulation Results.**

2.2. Analysis Selection Window

This window welcomes the user as a main GUI window when SCoBi is run. It is designed to provide an easy way of selecting the SoOp analysis of interest and to prepare the ***Simulation Input Window*** with default or last-used inputs of that analysis. It also allows the user to easily learn the SCoBi system and differences between analyses by providing default inputs for each analysis.

It currently houses the following analysis options that are ready to run:

- Agriculture
- Forest
- Soil
- Root-zone

Future options that this window will allow for are also shown within this window:

- Snow
- Topography
- Permafrost
- Wetlands

Additionally, the documentation of SCoBi (User's Manual, Developer's Manual, Quick Start Guide, and software design file that is created with unified modeling language (UML) models by using the Sparx Systems' Enterprise Architect tool) can be accessed from the pop-up window produced by the ***Documents*** button within the ***Analysis Selection Window***. General information about then current version of SCoBi and reference documentation can be viewed from the window generated by the ***About*** button.

The ***Analysis Selection Window*** is displayed in ***Figure 1***.

Figure 1: Analysis Selection Window

2.3. Simulation Input Window

SCoBi provides a ***Simulation Input Window*** after selecting an analysis type from the ***Analysis Selection Window.*** It should be noted that the user's selection of an analysis type in the ***Analysis Selection Window*** merely loads the ***Simulation Input Window*** with default inputs and does not generate a different interface for the selected analysis type. In fact, any combination of the available analysis types can be configured from the ***Simulation Input Window*** if the inputs are correctly selected. It should be noted, however, that loading or selecting certain analysis types may lead to enabling/disabling of inputs that are required or unnecessary within this window. The analysis type can be changed at any time from this window as described in **section 2.3.1** ***Analysis Selection Buttons***. A sample snapshot of the ***Simulation Input Window*** can be seen in **Figure 2**.

The ***Simulation Input Window*** has the following pushbuttons and panels which will be described in detail in the next subsections:

- Analysis Selection Buttons

- Simulation Settings
- Transmitter Inputs
- Receiver Inputs
- Ground Inputs
- Input Files
- Action Buttons

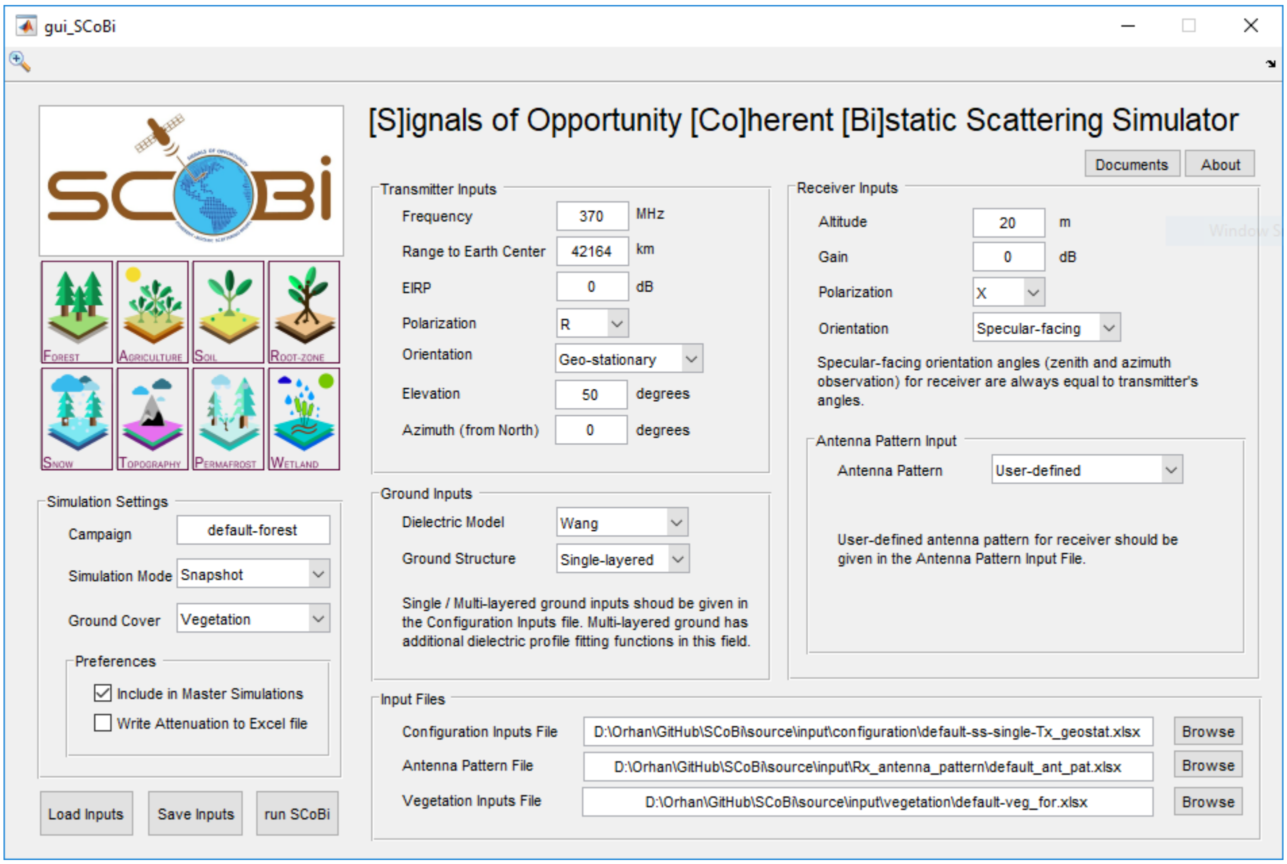

Figure 2: Simulation Input Window. Opened with default input values for the Forest simulation module.

2.3.1. Analysis Selection Buttons

These buttons are mainly located in the ***Analysis Selection Window*** in order to choose the analysis of interest and load the ***Simulation Input Window*** with the corresponding input set. However, the ***Simulation Input Window*** also has the same buttons for the sake of allowing user to switch to another analysis at any time. When one of the buttons is clicked, the ***Simulation Input Window*** is updated to reflect the input of the selected analysis. These buttons are shown in **Figure 3**.

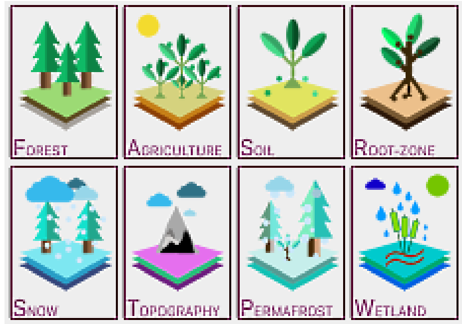

Figure 3: Analysis Selection Buttons. Presently, only Forest, Agriculture, Soil, and Root are functioning.

If a custom-user simulation has been previously run, the selection from the analysis selection ***Analysis Selection Window*** or ***Analysis Selection Buttons*** will load the most recent simulation settings that the user has created.

2.3.2. Simulation Settings

The ***Simulation Settings*** panel includes the main setting parameters of a simulation that determine the output directory name, simulation mode, ground cover, and preferences. This panel is displayed in **Figure 4**. These options are described in the subsections below.

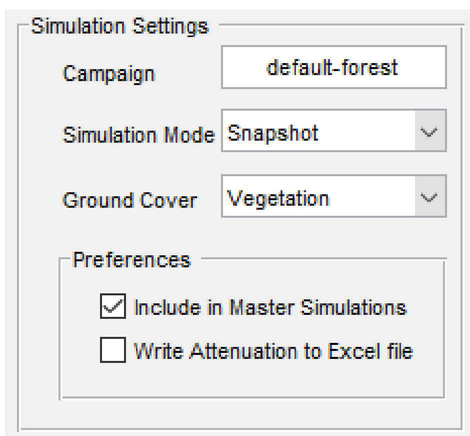

Figure 4: Simulation Settings Panel

2.3.2.1. Campaign

Campaign is an editable text input that is used to name the simulation output directory. The campaign variable is merged with the time-stamp of the time a simulation is run. The user can freely decide on a campaign name; however, it is highly recommended to choose a self-explanatory name such as:

“Corn-Maturity-MS-39762” for a corn field that is at its maturity growth-stage and located in Mississippi at the zip code 39762.

2.3.2.2. Simulation Mode

SCoBi simulator currently supports two different simulation modes: ***Snapshot*** or ***Time-series***. The simulation mode determines the structure of the ***Configuration Inputs File*** which is described in detail in section ***3.1 Inputs***.

2.3.2.2.1. Snapshot Simulation

Snapshot simulation is the appropriate mode for generating large amount of SoOp simulated data for comprehensive analysis. The simulator runs simulations for all the snapshots (i.e. combinations) of the following configuration inputs and scene parameters such as: Transmitter incidence and azimuth angles (if Transmitter is not ***Geo-stationary***), surface roughness (via root mean square height), and volumetric soil moisture (VSM).

Please refer to section ***3.1*** Inputs to see how ***Snapshot*** mode affects the ***Configuration Inputs File*** in detail.

2.3.2.2.2. Time-series Simulation

Time-series simulation mode is the perfect option to analyze realistic scenarios. This mode requires the user provides a ***Configuration Inputs File*** in a suitable form for time-series which has its requirements described in section ***3.1 Inputs*** in detail.

2.3.2.3. Ground Cover

Ground cover can be determined to be ***Bare-soil*** or ***Vegetation*** cover. The ***Ground Cover*** value determines if the ***Vegetation Inputs File*** is needed or not. The effect of ***Bare-soil*** and ***Vegetation*** is described in detail both below and in section ***3.1 Inputs***.

2.3.2.3.1. Bare-soil

When ***Bare-soil*** is selected, there is no need for vegetation inputs, the ***Vegetation Inputs File*** GUI elements are disabled, and SCoBi does not operate its functions for canopy computations (such as propagation) and only generates the outputs for bare soil.

2.3.2.3.2. Vegetation

Vegetation cover option requires a ***Vegetation Inputs File*** of the correct form, which is described in section ***3.1 Inputs***. This file can be given via the ***Vegetation Inputs File - Browse*** button in the ***Input Files*** panel. This selection makes SCoBi perform the vegetation-related functions and generate both vegetation and bare soil results.

2.3.2.4. Preferences

There are currently two preferences in the SCoBi:

2.3.2.4.1. Include in Master Simulations

This preference is for running a simulation whether as a temporary trial or a recorded one that is logged in the ***Master Simulations File*** (Will be described in **section 3.3.3** ***Master Simulations*** **File**).

2.3.2.4.2. Write Attenuation to Excel File

This preference is for recording the attenuation output of a simulation with vegetation cover into an MS Excel file for further analysis.

2.3.3. Transmitter Inputs

This panel includes editable text fields and pop-up menus for transmitter-related inputs, as shown in **Figure 5**.

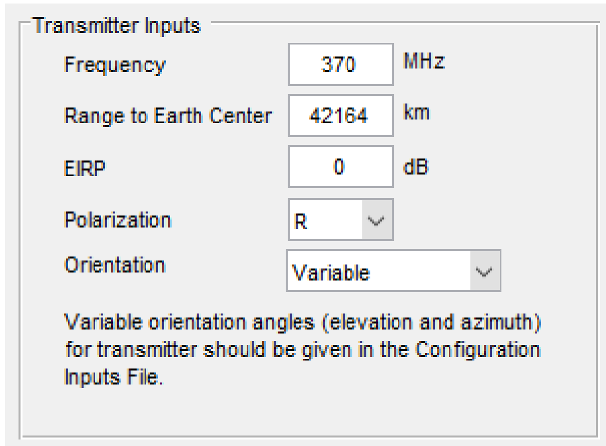

Figure 5: Transmitter Inputs Panel

2.3.3.1. Frequency

This editable text field is dedicated to the transmitter antenna's operating frequency. It should be filled with numerical values in MHz units.

2.3.3.2. Range to Earth Center

The transmitter's range to Earth center should be given (in kilometers).

2.3.3.3. EIRP

EIRP of the transmitter should be given in decibels and it makes an offset impact on the results.

2.3.3.4. Polarization

Polarization of the transmitter can be chosen to be:

- R: Right hand circular polarization (RHCP)
- L: Left hand circular polarization (LHCP)
- X: Linear X-polarization (direction of vertical polarization)
- Y: Linear Y-polarization (accounts for horizontal polarization since Y-axis is always considered parallel to the ground plane)

2.3.3.5. Orientation

The SCoBi simulator currently supports two different transmitter orientations: ***Geo-stationary*** or ***Variable***. The orientation of the transmitter determines the structure of the Configuration Inputs File, which is described in detail both below and in section ***3.1 Inputs***.

2.3.3.5.1. Geo-stationary

Geo-stationary transmitter orientation requires a transmitter to have fixed elevation and azimuth angles even if the simulation spans a temporal range. Therefore, when the transmitter orientation is chosen to be ***Geo-stationary***, the fixed ***Elevation (El0)*** and ***Azimuth (Ph0)*** angles should be given in degrees in the ***Simulation Input Window***. In addition, there should be no ***El0*** and ***Ph0*** columns in the ***Configuration Inputs File***.

2.3.3.5.2. Variable

Variable transmitter orientation enables a transmitter to have changing elevation and azimuth angles in a simulation. Therefore, when the transmitter orientation is chosen to be ***Variable***, the ***Elevation (EL0)*** and ***Azimuth (PH0)*** angle values should be given in degrees in the ***Tx_el (deg)*** and ***Tx ph (deg)*** columns in the ***Configuration Inputs File***. For details of this input file, please refer to section ***3.1 Inputs***.

2.3.4. Receiver Inputs

This panel includes editable text fields and pop-up menus for receiver-related inputs, as shown in **Figure 6**.

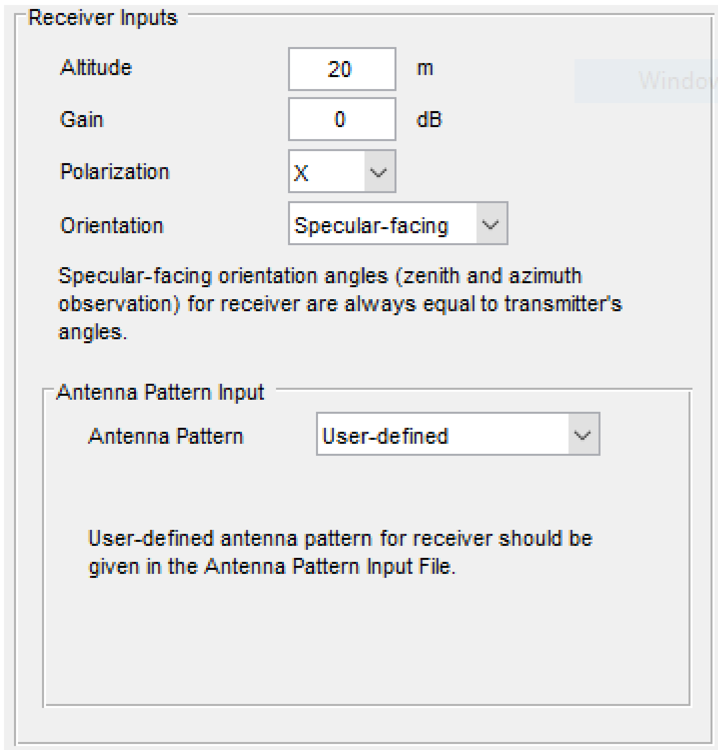

Figure 6: Receiver Inputs Panel

2.3.4.1. Altitude

Receiver altitude should be given in meters in numerical values. The altitude makes only difference on the received power calculations.

2.3.4.2. Gain

Antenna gain of the receiver should be given in decibels and it makes an offset impact on the results.

2.3.4.3. Polarization

Polarization of the receiver can be chosen to be:

- R: Right hand circular polarization (RHCP)
- L: Left hand circular polarization (LHCP)
- X: Linear X-polarization (Stands for vertical polarization)
- Y: Linear Y-polarization (Accounts for horizontal polarization since Y-axis is always considered parallel to the ground plane)

2.3.4.4. Orientation

SCoBi simulator currently supports two different receiver orientations: ***Fixed*** or ***Specular-facing***. ***Fixed*** orientation means that receiver observes a fixed point with constant looking and azimuth angles, which setup is common, for example, in tower applications. ***Specular-facing*** means that the receiver gets the same orientation angles for changing transmitter orientations, which is hard to obtain in real-world experiments, but might allow to create more simulated data.

2.3.4.4.1. Fixed

The fixed ***Zenith Observation (Theta)*** and ***Azimuth (Phi)*** angles should be given in degrees in the ***Simulation Input Window***.

2.3.4.4.2. Specular-facing

When the receiver is ***Specular-facing***, there is no need to provide the zenith observation angles; instead, the SCoBi simulator always equates the receiver's orientation angles to the transmitter's, even if the configuration changes.

2.3.4.5. Antenna Pattern

SCoBi simulator currently supports two different receiver antenna pattern generation methods: ***Generalized-Gaussian*** or ***User-defined***. A third option ***Cosine to the power n*** is also listed in the pop-up menu for reference to developers. Antenna pattern selection affects if ***Antenna Pattern File*** is needed or not, which effect is described in detail bot below and in section ***3.1 Inputs***.

2.3.4.5.1. Generalized-Gaussian

A simple generalized Gaussian antenna pattern can be created quickly by giving the significant parameter values via the ***Simulation Input Window***. When this option is selected under the ***Antenna Pattern*** pop-up menu, SCoBi shows the following parameters for user input:

- ***Beamwidth***: Half-power beamwidth of the antenna pattern should be given in degrees in numerical values.
- ***Side-lobe level***: The levels of the first side-lobes should be given in decibels in numerical values.
- ***Cross-pol level***: The level of the cross-polarization of the antenna pattern should be given in decibels in numerical values.
- ***Pattern Resolution***: The minimum sensitivity of the antenna pattern should be given in degrees in numerical values.

2.3.4.5.2. User-defined

This option requires an ***Antenna Pattern File*** of the correct form, which is described in section ***3.1 Inputs***. This file can be given via the ***Antenna Pattern File - Browse*** button in the ***Input Files*** panel.

2.3.5. Ground Inputs

This panel includes pop-up menus and checkboxes for ground-related inputs (**Figure 7)**.

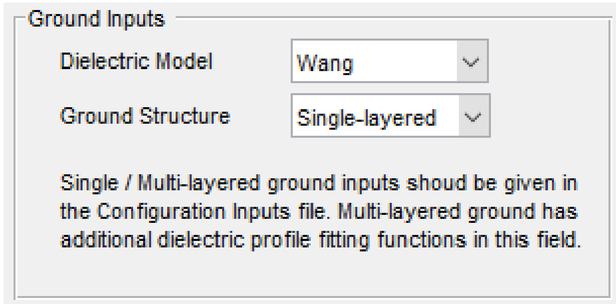

Figure 7: Ground Inputs Panel

2.3.5.1. Dielectric Model

SCoBi currently supports three dielectric models: ***Dobson***, ***Mironov***, and ***Wang***. Surface dielectric through the simulations is calculated by the selected dielectric model.

2.3.5.2. Ground Structure

SCoBi supports analyses for both ***Single-layered*** and ***Multi-layered*** ground structures. The ground structure selection affects the ***Configuration Inputs File***, which is described in detail in section ***3.1 Inputs***.

2.3.5.2.1. Single-layered

When ***Single-layered*** ground structure is selected, the rest of the ground inputs should be given in the ***Configuration Inputs File,*** details of which are described in section ***3.1 Inputs***.

2.3.5.2.2. Multi-layered

When ***Multi-layered*** ground structure is selected, checkboxes are shown for four different fitting functions for dielectric profiles through the multiple ground layers:

- 2nd-order
- 3rd-order
- Discrete slab
- Logistic regression

This option is dedicated to root-zone analysis. Any subset of these fitting functions may be selected for ***Multi-layered*** ground analysis. The rest of the ***Multi-layered*** ground inputs should be given in the ***Configuration Inputs File,*** details of which are described in section ***3.1 Inputs***.

2.3.6. Input Files

This panel houses the browsing buttons and text fields that enable loading and presentation of the MS Excel input files, if required depending on the other inputs on the ***Simulation Input Window***. The Excel input files that can be loaded and shown within his panel are as follows, as shown in Figure 8:

- Configuration Inputs File: Default files that are provided with the SCoBi distribution are located under ***./source/input/configuration/*** directory.
- Antenna Pattern File: Default files that are provided with the SCoBi distribution are located under ***./source/input/Rx_antenna_pattern/*** directory.
- Vegetation Inputs File: Default files that are provided with the SCoBi distribution are located under ***./source/input/vegetation/*** directory.

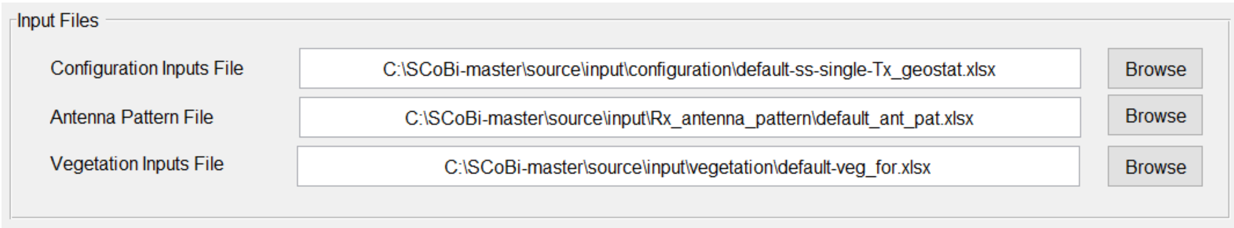

Figure 7: Ground Inputs Panel

2.3.7. Action Buttons

Action buttons are located in the ***Simulation Input Window*** for the aim of overall management, as shown in **Figure 9**.

2.3.7.1. Load Inputs

A simulation input can be loaded any time into the ***Simulation Input Window***.

2.3.7.2. Save Inputs

The current state of the ***Simulation Input Window*** can be saved as a simulation input (.mat) file.

2.3.7.3. RunSCoBi

RunSCoBi button is for running the simulation with the current state of the ***Simulation Input Window***. If no change is made on the recently loaded or saved simulation inputs, SCoBi immediately begins to run after this button is clicked. Otherwise, the software prompts the user to save the current state of the ***Simulation Input Window*** as a different simulation inputs file.

2.3.7.4. Exit

The window close button of the ***Simulation Input Window*** can be used to terminate SCoBi. When the button is clicked, SCoBi prompts user to confirm the termination.

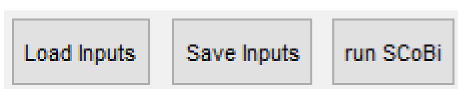

Figure 9: Action buttons

3. Analysis with SCoBi

3.1. Inputs

There are two main types of the inputs for a SCoBi simulation: ***Simulation Inputs*** and ***Excel Input Files***.

3.1.1. Simulation Inputs

Simulation inputs are initially provided as default simulation input files, and their values can be altered by modifying the defaults and saving new input files. Simulation inputs are accessed through GUI (***Simulation Input Window***), saved as "***.mat***" files. Simulation input files map all information (from single parameter values to full paths for Excel input files) to variables within the SCoBi simulator in order to perform the user's simulation of interest. The user deals with simulation inputs only via GUI. Initially provided, default simulation input files can be found within the ***./source/input/system*** directory. It is suggested that the newly generated simulation input files stored in the same location as well; however, it is not required.

When SCoBi is run, the ***Simulation Input Window*** is loaded with the recently saved simulation input file. Otherwise, it is loaded with the default simulation input file for the selected analysis type. If no default input file is present (since input files can be removed by the user), the window is opened empty.

Whenever there is a change to the recently loaded or saved simulation input file and ***RunSCoBi*** button is clicked, SCoBi prompts the user to save the current state of the ***Simulation Input Window*** as a new simulation input file.

3.1.2. Excel Input Files

SCoBi simulations may require from one to three separate MS Excel input files depending on the chosen settings and parameter values within the simulation inputs. It is highly encouraged that users view the example Excel input files in the following directories before creating their own:

- ***./source/input/configuration,***
- ***./source/input/Rx_antenna_pattern,*** and
- ***./source/input/vegetation***

3.1.2.1. Configuration Inputs File

A ***Configuration Inputs File*** is required in every simulation and consists of two sheets: ***Dynamic*** and ***Ground***. While the order of the sheets is required for the operation of SCoBi, the name of these sheets can be arbitrary. The first sheet in the ***Configuration Inputs File*** should correspond to the ***Dynamic*** sheet and the second sheet should correspond to the ***Ground*** sheet. Additionally, it is suggested that these two sheets be named ***Dynamic*** and ***Ground*** as depicted in ***Figure 10***.

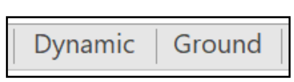

Figure 10: Example Vegetation Inputs File Sheet Titles

The ***Dynamic*** sheet defines parameters that may be given changing values within a simulation. Variable parameters include timestamps, azimuth and elevation angles of the transmitter, root-mean-square height (RMSH) roughness of the soil surface, and volumetric soil moisture.

The ***Ground*** sheet consists of static parameters that define the ground structure such as soil texture, soil bulk density, layer depths where soil moisture probes are located, and layering effects.

The content (being the name and value of variables within the ***Dynamic*** and ***Ground*** sheets) found in the ***Configuration Inputs File*** should be prepared according to the joint requirements of the simulation mode and analysis type. In other words, ***Configuration Inputs File*** should be created in a way that it satisfies all the directives listed for the following parameters. Example input files will be given after the requirements for all the parameters are described.

While the order of the parameter columns in both ***Dynamic*** and ***Ground*** spreadsheets of the ***Configuration Inputs File*** is required for the operation of SCoBi, the name of the parameters can be arbitrary. However, it is suggested that the parameter columns be named as in the examples in section **3.1.2.1.4 Example Configuration Inputs File** for the sake of familiarity.

3.1.2.1.1. Simulation Mode Effect: Snapshot vs. Time-series

Simulation mode selection places requirements on writing the ***Dynamic*** sheet of the ***Configuration Inputs File,*** but not on the ***Ground*** spreadsheet. The requirements for creating a ***Configuration Inputs File*** that satisfies SCoBi's different simulation modes are described as follows:

3.1.2.1.1.1. Snapshot

Snapshot simulations are just for analyzing the combinations of changing configurational and environmental parameters such as transmitter orientation, surface roughness, and soil moisture. There is no need for timestamp information in a ***Snapshot*** mode; therefore, there should not be a ***DoY*** (Day-of-Year) column in the ***Dynamic*** sheet of the ***Configuration Inputs File***. The following parameter columns may be included with totally different number of rows (samples) than each other in the ***Dynamic*** spreadsheet:

Tx_el(deg)	Transmitter elevation (EL0, complements the incidence angle to 90 degrees, i.e. 90 - θ) angle in degrees. This is the angle formed between the ground surface and the vector located along between specular point along the ground surface and the transmitter.
Tx_ph(deg)	Transmitter azimuth (PH0, ϕ) angle in degrees. This is the heading or compass direction described clockwise from magnetic North.
RMSH(cm):	Surface roughness – root mean square height in centimeters
VSM(cm3/cm3):	Volumetric soil moisture in cm^3/cm^3

3.1.2.1.1.2. Time-series

Time-series simulations are for analyzing a temporally changing configuration and environment. In other words, in a Time-series simulation, there should be configurational and environmental parameter values as well as timestamps, which have exactly the same length or some of them are constant. Thus, following parameters may be given in separate columns in ***Dynamic*** spreadsheet as same-length sequences or only one value (to represent being constant) for a period in time:

DoY	Day of Year. A notation to write the month, day, hour, minute, second, etc. of a given timestamp with days being the given unit. Day one is generally midnight of January 1st of a given year.
El_th(deg	Transmitter elevation (El, 90 - θ) angle in degrees. This is the angle formed between the ground surface and the vector located along between specular point along the ground surface and the transmitter.
Tx_ph(deg)	Transmitter azimuth (phi, ϕ) angle in degrees. This is the heading or compass direction described clockwise from magnetic North.
RMSH(cm):	Surface roughness – root mean square height in centimeters
VSM(cm3/cm3):	Volumetric soil moisture in cm^3/cm^3

3.1.2.1.2. Transmitter Orientation

Transmitter orientation selection affects the ***Dynamic*** sheet of the ***Configuration Inputs File***. When transmitter orientation is ***Geo-stationary***, there should be neither ***Elevation Angle (EL0)*** nor ***Azimuth Angle (PH0)*** columns in the ***Dynamic*** sheet.

3.1.2.1.3. Ground Structure: Single-layered vs. Multi-layered

Ground structure selection may make effects on both the ***Dynamic*** and ***Ground*** sheets of the ***Configuration Inputs File***. The effects of the ground structures are described as follows:

3.1.2.1.3.1. Single-layered

Single-layered ground structure simulations only require the ***Volumetric Soil Moisture*** and ground texture information for the ground surface. Therefore, there should be only one ***VSM(cm3/cm3)*** column in the ***Dynamic*** sheet. The following parameter columns should be included with only one row for numeric values in addition to the column names row in the ***Ground*** sheet:

sand_ratio	Sand ratio of the ground surface within [0,1]
clay_ratio	Clay ratio of the ground surface within [0,1]
rho_b(g/cm3)	Bulk density of the soil in g/cm^3

3.1.2.1.3.2. Multi-layered

Multi-layered ground structure simulations require the ***VSM(cm3/cm3)*** and ground texture information for multiple layers of the ground. Number of ***VSM(cm3/cm3)*** columns in the ***Dynamic*** sheet should exactly match the number of ground layers to be analyzed. Each ***VSM(cm3/cm3)*** corresponds to ***VSM*** measurements in a different ground layer. The following parameter columns should be included with the equal number of rows for numeric values as in the number of ground layers in addition to the column names row in the ***Ground*** sheet:

layer_depth	Layer depths of each ground layer should be given in meters. Thus, this column should include its name in the first row, then enough number of layer depths as much as the number of ground layers.
sand_ratio	The percentage of sand within the ground layer with a range of [0,1]. This column should include its name in the first row, then enough number of sand ratios as much as the number of ground layers.

clay_ratio	The percentage of clay within the ground layer with a range of [0,1]. This column should include its name in the first row, then enough number of clay ratios as much as the number of ground layers.
rho_b(g/cm3)	Bulk densities of the ground layers in g/cm^3. This column should include its name in the first row, then enough number of bulk densities as much as the number of ground layers.
delZ(m)	Layer discretization in meters. Only one value is enough to make discretization through all the ground layers.
zA(m)	Air layer thickness in meters.
zB(m)	The bottom-most layer thickness in meters. This should generally be defined to be greater than or equal to the penetration depth of the SoOp transmitter's frequency and beneath the deepest point of interest within the soil moisture profile. The total layer depth will then become the largest value in the column for ***layer_depth*** **plus the value of zB**.

3.1.2.1.4. Example Configuration Inputs File

Table 1 demonstrates the ***Dynamic*** spreadsheet of the ***Configuration Inputs File*** when

- ***Simulation Mode*** is ***Snapshot,***
- ***Transmitter Orientation*** is ***Variable***, and
- ***Ground Structure*** is ***Single-layered***.

All values of the parameters within each column will be combined with the values of the parameters within the other columns since **Table 1** defines a ***Snapshot*** simulation. This means that **Table 1** will result in 210 (7x2x3x5) different simulations. The transmitter's elevation angle (***Tx_el(deg)***) will be varied from 10° to 70° in 10° increments. The transmitter's azimuth (***Tx_ph(deg)***) will be varied at 0° and 15°. The root-mean-square height roughness (***RMSH(cm)***) will be varied from 0.5, 1, and 1.5 cm. **Table 1** is an example of a ***Single-layered*** ground structure so that soil moisture has one column on varying values for the ground surface in which it will be varied from 0.05 to 0.25 cm^3/cm^3.

The definitions for variables seen in the ***Dynamic*** spreadsheet of **Table 1** will require defined ***Ground*** spreadsheet parameters similar to the definitions seen in **Table 7**.

*Table 1: Example **Dynamic** spreadsheet of the **Configuration Inputs File** when Simulation Mode is **Snapshot**, Transmitter Orientation is **Variable**, and Ground Structure is **Single-layered**.*

Tx_el(deg)	Tx_ ph(deg)	RMSH(cm)	VSM(cm3/cm3)
10	0	0.5	0.05
20	15	1	0.10
30		1.5	0.15
40			0.20
50			0.25
60			
70			

Table 2 demonstrates the ***Dynamic*** spreadsheet of the ***Configuration Inputs File*** when

- ***Simulation Mode*** is ***Snapshot,***
- ***Transmitter Orientation*** is ***Variable***, and
- ***Ground Structure*** is ***Multi-layered***.

All values of the parameters within each column will be combined with the values of the parameters within the other columns since ***Table 2*** defines a ***Snapshot*** simulation. This means that ***Table 2*** will result in 10,752 (7x2x3x4x4x4x4) different simulations. The transmitter's elevation angle (***Tx_el(deg)***) will be varied from 10° to 70° in 10° units. The transmitter's azimuth (***Tx_ph(deg)***) will be varied at 0° and 15°. The root-mean-square height roughness (***RMSH(cm)***) will be varied from 0.5, 1, and 1.5 cm. ***Table 2*** is an example of a ***Multi-layered*** ground structure so that soil moisture has also a multi-layered profile in which the soil moisture at 5, 10, 20, and 40 centimeters is defined. It is worth noting here that the number and depth of the soil moisture measurements can be different than what is exemplified here. The values between these defined points are interpolated using different function fits as defined in section ***2.3.5.2.2 Multi-layered***.

The definitions for variables seen in the ***Dynamic*** spreadsheet of ***Table 2*** will require defined ***Ground*** spreadsheet parameters similar to the definitions seen in ***Table 8***.

*Table 2: Example **Dynamic** spreadsheet of the **Configuration Inputs File** when Simulation Mode is **Snapshot**, Transmitter Orientation is **Variable**, and Ground Structure is **Multi-layered**.*

Tx_el (deg)	Tx_ ph0 (deg)	RMSH (cm)	VSM_5 (cm3/cm3)	VSM_10 (cm3/cm3)	VSM_20 (cm3/cm3)	VSM_40 (cm3/cm3)
10	0	0.5	0.374	0.364	0.374	0.436
20	15	1	0.374	0.361	0.372	0.440
30		1.5	0.375	0.355	0.375	0.440
40			0.371	0.332	0.388	0.440
50						
60						
70						

Table 3 demonstrates the ***Dynamic*** spreadsheet of the ***Configuration Inputs File*** when

- ***Simulation Mode*** is ***Snapshot,***
- ***Transmitter Orientation*** is ***Geo-stationary***, and
- ***Ground Structure*** is ***Single-layered***.

Whenever ***Transmitter Orientation*** is ***Geo-stationary***, the transmitter orientation columns (***Tx_el(deg)*** *and* ***Tx_ph(deg)***) are discarded from the ***Dynamic*** spreadsheet regardless of the other parameter selections (***Simulation Mode*** and ***Ground Structure***) since the fixed orientation angle values are given via ***Simulation Input Window***. Processing of the input in **Table 3** is then similar to that in **Table 1** (combinations of all the columns).

*Table 3: Example **Dynamic** spreadsheet of the **Configuration Inputs File** when Simulation Mode is **Snapshot**, Transmitter Orientation is **Geo-stationary**, and Ground Structure is **Single-layered**.*

RMSH (cm)	VSM(cm3/cm3)
0.5	0.05
1	0.10
1.5	0.15
	0.20

Table 4 demonstrates the ***Dynamic*** spreadsheet of the ***Configuration Inputs File*** when

- ***Simulation Mode*** is ***Snapshot,***
- ***Transmitter Orientation*** is ***Geo-stationary***, and
- ***Ground Structure*** is ***Multi-layered***.

Whenever ***Transmitter Orientation*** is ***Geo-stationary***, the transmitter orientation columns (***Tx_el(deg)*** *and* ***Tx_ph(deg)***) are discarded from the ***Dynamic*** spreadsheet regardless of the other parameter selections (***Simulation Mode*** and ***Ground Structure***) since the fixed orientation angle values are given via ***Simulation Input Window***. Processing of the input in **Table 4** is then similar to that in **Table 2** (combinations of all the columns).

*Table 4: Example **Dynamic** spreadsheet of the **Configuration Inputs File** when Simulation Mode is **Snapshot**, Transmitter Orientation is **Geo-stationary**, and Ground Structure is **Multi-layered**.*

RMSH (cm)	VSM_5 (cm3/cm3)	VSM_10 (cm3/cm3)	VSM_20 (cm3/cm3)	VSM_40 (cm3/cm3)
0.5	0.374	0.364	0.374	0.436
1	0.374	0.361	0.372	0.440
1.5	0.375	0.355	0.375	0.440
	0.371	0.332	0.388	0.440

Table 5 demonstrates the ***Dynamic*** spreadsheet of the ***Configuration Inputs File*** when

- ***Simulation Mode*** is ***Time-series,***
- ***Transmitter Orientation*** is ***Variable***, and
- ***Ground Structure*** is ***Single-layered***.

Each row in this ***Dynamic*** spreadsheet corresponds to a ***Time-series*** data; the number of simulations will be equal to the number of rows beneath the ***DOY*** heading (7 for the example seen in **Table 5**). The value of 123.75, for example, corresponds to the 123rd day of the year, May 3, at a time 75% through the day, 6:00PM. The transmitter's elevation angle (***Tx_el(deg)***) and the effective soil moisture of the ground surface (***VSM(cm3/cm3)***) changes as a function of time defined by the ***DOY*** column while the transmitter's azimuth angle (***Tx_ph(deg)***) and the root-mean-square-height of the soil (***RMSH(cm)***) remains fixed throughout the displayed time period. Since **Table 5** displays a ***Dynamic*** sheet for a ***Single-layered*** soil moisture profile, a corresponding ***Ground*** spreadsheet will be required similar to one seen in **Table 7**.

*Table 5 Example **Dynamic** spreadsheet of the **Configuration Inputs File** when Simulation Mode is **Time-series**, Transmitter Orientation is **Variable**, and Ground Structure is **Single-layered**.*

DOY	Tx_el(deg)	Tx_ph(deg)	RMSH(cm)	VSM(cm3/cm3)
123.72917	40.7	200	0.5	0.37388012
123.73958	40			0.37388012
123.75	40.1			0.37492744
123.76042	40.4			0.371428366
123.77083	39.6			0.369494043
123.78125	39.6			0.369494043
123.79167	39.8			0.369494043

Table 6 demonstrates the ***Dynamic*** spreadsheet of the ***Configuration Inputs File*** when

- ***Simulation Mode*** is ***Time-series,***
- ***Transmitter Orientation*** is ***Variable***, and
- ***Ground Structure*** is ***Multi-layered***.

Each row in this ***Dynamic*** spreadsheet corresponds to a ***Time-series*** data, similar to **Table 5**; but now for a ***Multi-layered*** soil moisture profile. Hence, a corresponding ***Ground*** spreadsheet will be required similar to one seen in **Table 8**. Note also that **Table 6** includes transmitter azimuth angles and surface roughness that vary with time, in contrast to **Table 5**.

*Table 6 Example **Dynamic** spreadsheet of the **Configuration Inputs File** when Simulation Mode is **Time-series**, Transmitter Orientation is **Variable**, and Ground Structure is **Multi-layered**.*

DOY	Tx_el (deg)	Tx_ph (deg)	RMSH (cm)	VSM-5 (cm3/cm3)	VSM-10 (cm3/cm3)	VSM-15 (cm3/cm3)	VSM-25 (cm3/cm3)
123.72917	40.7	200	0.5	0.373	0.398	0.413	0.415
123.73958	40	210	0.52	0.375	0.398	0.409	0.416
123.75	40.1	220	0.48	0.329	0.390	0.412	0.418
123.76042	40.4	230	0.55	0.356	0.385	0.415	0.420
123.77083	39.6	240	0.51	0.399	0.400	0.426	0.430
123.78125	39.6	250	0.49	0. 413	0.422	0.447	0.455
123.79167	39.8	260	0.54	0.429	0.456	0.470	0.475

Table 7 demonstrates the ***Ground*** spreadsheet of the ***Configuration Inputs File*** when

- ***Ground Structure*** is ***Single-layered***

*Table 7 Example **Ground** spreadsheet of the **Configuration Inputs File** when Ground Structure is **Single-layered**.*

sand_ratio	clay_ratio	rho_b (g/cm3)
0.8	0.07	1.25

Note that in **Table** 7, we find that our ***sand_ratio*** value is 80% of the total effective soil layer, and our ***clay ratio*** is 7% of the total effective soil layer. Our soil bulk density (***rho_b***) is 1.25 g/cm^3 for the effective single layer soil profile.

Table 8 demonstrates the ***Ground*** spreadsheet of the ***Configuration Inputs File*** when

- ***Ground Structure*** is ***Multi-layered.***

*Table 8: Example **Ground** spreadsheet of the **Configuration Inputs File** when Ground Structure is **Multi-layered**.*

layer_depth (m)	sand_ratio	clay_ratio	rho_b (g/cm3)	delZ (m)	zA (m)	zB (m)
0.05	0.1	0.31	1.4	0.001	0.1	0.3
0.1	0.1	0.31	1.4			
0.2	0.1	0.31	1.4			
0.4	0.1	0.34	1.5			

Note that in ***Table 8,*** we have placed variable soil moisture points at 5 cm, 10 cm, 20 cm, and 40 cm under the **layer_depth** column. The **sand_ratio**, **clay_ratio**, and **rho_b** parameters must be defined at each of these depths. The air layer (**zA**) has been defined to be 10 cm, and the bottom-most layer (**zB**) is defined as 30 cm. Given our bottom soil moisture point location is 40 cm, our total profile will be 10cm + 40cm + 30cm = 80 cm with our bottom soil layer being a point 70 cm beneath the surface of the soil. The layer discretization is 1 mm (**delZ**). Because we have defined 4 different ***layer_depths*** within this ***Ground*** sheet, we will require 4 columns that define the soil moisture content at these depths (***VSM5_cm3cm3***, ***VSM10_cm3cm3***, ***VSM20_cm3cm3***, and ***VSM40_cm3cm3***) in the corresponding ***Dynamic*** sheet for the variables seen in ***Table 8***'s ***Ground*** sheet. An example of this can be seen in ***Table 2***.

3.1.2.2. Antenna Pattern File

Antenna Pattern File is required only if the receiver antenna pattern is selected to be ***User-defined***. It consists of four sheets within an Excel spreadsheet: ***gnXX, gnXY, gnYX,*** and ***gnYY***, which holds the normalized voltage values for co- and cross-polarizations for X and Y ports. An example antenna pattern file can be found in ***./source/input/Rx_antenna_pattern***.

Antenna pattern should be provided such that in each sheet of the Excel file, columns represent the theta-angle look-up and rows represent the phi-angle look-up. Theta (θ) angles have a 180° scan, while phi (ϕ) angles have a 360° scan.

Note that the antenna pattern files do not have headers within the Excel spreadsheet. Each sheet consists of numbers only.

3.1.2.3. Vegetation Inputs File

Vegetation Inputs File is required only if the ground cover is selected to be ***Vegetation***. It consists of two spreadsheets: ***Layers*** and ***Kinds***. While the order of the sheets is required for the operation of SCoBi, the name of these sheets can be arbitrary. The first sheet in the ***Vegetation Inputs File*** should correspond to the ***Layers*** sheet and the second sheet should correspond to the ***Kinds*** sheet. Additionally, it is suggested that these two sheets be named ***Layers*** and ***Kinds*** as depicted in ***Figure 11***.

Figure 11: Vegetation Inputs File spreadsheets

An example Vegetation Inputs File for each of analysis types ***Forest*** and ***Agriculture*** is included in:

./source/input/vegetation.

3.1.2.3.1. Layers

The ***Layers*** sheet should provide detailed information about the vegetation layer thicknesses and the content of each individual layer. Vegetation layer can be divided into a number of sub-layers by defining separate layer thicknesses for the purpose of locating specific ***Kinds*** (***Leaf***, ***Branch***, ***Trunk***, or ***Needle***) into different layers. Thicknesses of the vegetation cover should be given (in integer or double numbers in meters) in the second column of the ***Layers*** spreadsheet in a way that ascending rows should represent an ascending height from top to bottom. The first column of the ***Layers*** spreadsheet is reserved to the names of individual layers. This column should be included in any ***Vegetation Inputs File***; however; the name of each row in this column can be arbitrary. The example ***Vegetation Inputs Files*** use meaningful layer names to increase familiarity with the vegetation layer structure. For each separate vegetation layer. The first row is reserved for the descriptions of columns. Again, this row should be included in any ***Vegetation Inputs File***; however; the name of each row in this column can be arbitrary. In other words, the actual layer data should begin from the second row and the second column.

For each vegetation layer row, columns after the thickness column should have the information about content of each vegetation layer. This information is related to the ***Kinds*** spreadsheet, and each vegetation layer can include from one to several ***Kinds*** (Please refer to section ***3.1.2.3.2 Kinds*** for naming conventions***)***. The content of each layer should be given such that exactly one ***Particle ID*** (the same as given in the ***Kinds*** spreadsheet) exists in a column as shown in **Table 9**. For instance in **Table 9**, Layer 2 has L1 (first kind of the type Leaf), B2 (second kind of the type Branch), B3 (third kind of the type Branch), and B4 (fourth kind of the type Branch); however, Layer 4 only includes T1 (first kind of the type Trunk) that is intuitive to put ***Trunk*** fixed to the ground. In addition, the spreadsheet represents such a vegetation cover that can be analyzed as four distinct layers, each including different ***Trunk***, ***Branch***, and ***Leaf Kinds***.

Table 9: Example Layers spreadsheet for Vegetation Inputs File

	Thickness (m)	Included Kinds			
Layer 1 (Top)	2	L1	B4		
Layer 2	4	L1	B2	B3	B4
Layer 3	3	B1	B2		
Layer 4 (Bottom)	4	T1			

3.1.2.3.2. Kinds

The ***Kinds*** sheet should provide detailed information about the scatterer types and kinds declared in the ***Layers*** sheet. The four scatterer ***Types*** used in SCoBi are ***Leaf***, ***Branch***, ***Trunk***, or ***Needle***. A ***Leaf*** should be considered as an elliptical disk, while the types ***Branch***, ***Trunk***, and ***Needle*** are considered as cylinders. Several ***Kinds*** of a ***Type*** can be defined in this spreadsheet (e.g. L1, L2, etc.).

The whole sheet should define the different Kinds of scatterers that are exist in the vegetation layers. First column of the spread sheet is reserved for row descriptions. This column should be included in any Vegetation Inputs File, but the names of the rows in this column can be arbitrary. However, the example input files have meaningful row names for ease. Each column after the first column should represent one of the ***Kinds***. As seen in ***Table 9***, the ***Kinds*** can be reused throughout the different layers. There are nine rows for each column that define the following information:

Particle ID — It can be also assumed the Kind name. A character array, where the first character must be one of the following letters ‘L’, ‘B’, ‘T’’ or ‘N’ to stand for the ***Types*** (***Leaf, Branch, Trunk,*** or ***Needle)***, and next characters should be integer to represent a specific ***Kind*** of the selected ***Type*** (e.g. “L1”, “L2”, “T1”, “B3”, etc.). This ID is used in the ***Layers*** sheet to link the vegetation layers to the scatterer ***Kinds***.

Density — The number of scattering particles within one cubic meter.

Dimension1 — Either the radius of the start of a cylinder (***Branch***, ***Trunk***, or ***Needle***) or major axis of an elliptical disk (***Leaf***) in meters.

Dimension2	Either should be the radius of the end of a cylinder (***Branch***, ***Trunk***, or ***Needle***) or minor axis of an elliptical disk (***Leaf***) in meters.
Dimension3	Either the length of a cylinder (***Branch***, ***Trunk***, or ***Needle***) or thickness of an elliptical disk (***Leaf***) in meters.
epsr_real	The real part of the dielectric constant of a scatterer. This is sometimes referred to as the relative permittivity of a scattering particle.
epsr_im	The imaginary part of the dielectric constant of a scatterer. This is sometimes referred to as the
Begin Angle	The minimum interval value of the scatterer orientation that is assumed to be uniformly distributed between two angular boundaries.
End Angle	The maximum interval value of the scatterer orientation that is assumed to be uniformly distributed between two angular boundaries.

An example ***Kinds*** spreadsheet is displayed in ***Table 10***.

Table 10: Example Kinds spreadheet for Vegetation Inputs File

L1	B1	B2	B3	B4	T1
0	1	1	0	0	1
11.12	0.016	0.188	0.734	1.933	0.005
1.02E-01	4.30E-02	1.58E-02	9.80E-03	4.50E-03	8.73E-02
1.02E-01	4.30E-02	1.58E-02	9.80E-03	4.50E-03	8.73E-02
1.20E-04	1.87E+00	1.54E+00	6.36E-01	4.81E-01	6.17E+00
35.2	12	12	12	12	15.6
5.3	2.93	2.93	2.93	2.93	3.8
5	20	10	5	5	0
85	50	60	85	85	0.1

3.2. Simulation Preparation Flow

The preparation process of different SCoBi simulations may differ based on the analysis type and configurations selected by the user, although the general flow is the same. In this section, the flow of the overall simulation preparation will be described, and changes within steps due to different parameter selections will be emphasized by using example scenarios.

1. The first and most significant step of creating a SCoBi simulation is to determine the SoOp analysis type, the bistatic configuration (transmitter and receiver characteristics, and the geometry), ***Simulation Mode***, ***Vegetation Cover***, and the ***Ground Structure***.
2. The second major step is either the preparation of the required Excel input files (***Configuration***, ***Vegetation***, and ***Antenna Pattern*** input files, if needed), or use of the existing default files for the simulation of interest. Details of the requirements for the contents of the Excel input files when using the default ones or preparing new ones are mentioned in **section 3.1.2 Excel Input Files**, and it is highly recommended to read that section carefully.
3. The final main step is to give individual simulation parameters through the ***Simulation Input Window***, to select the Excel input files through this window, and to run SCoBi.

Two different examples regarding these three major steps will be provided in this section:

3.2.1. Global Navigation Satellite System Reflectometry (GNSS-R) Vegetation Analysis

The major three steps of a GNSS-R simulation can be described as follows:

1. In a GNSS-R simulation, the transmitter can be one of the typical GNSS satellites. In this example, an ***Agriculture*** SoOp analysis over a ***Vegetation Cover*** of an agricultural field will be considered. The transmitter will be a GNSS satellite operating at L1A-band with a ***Variable*** orientation (for the purpose of analyzing the changing transmitter angles). The receiver will be a ground-based GNSS receiver, which has a ***Generalized-Gaussian*** antenna pattern. Further details about the transmitter and the receiver parameters will be given below. This simulation will be a ***Snapshot*** simulation, where the combinations of simulation parameters are used for generating individual simulation snapshots to generate large amount of simulated data. ***Ground Structure*** will be ***Single-layered*** since the surface dielectric calculations are considered enough for such a vegetation analysis scenario.
2. For such a simulation, below Excel input files (either the default or the newly generated files) must satisfy the simulation specifications in the first major step as follows:
   a. ***Configuration Inputs File***: It should satisfy:
      - ***Simulation Mode***: ***Snapshot***,
      - ***Transmitter Orientation***: ***Variable***, and
      - ***Ground Structure***: ***Single-layered***

      which corresponds to a file similar to what is shown in **Table 1** and **Table 7** for ***Dynamic*** and ***Ground*** spreadsheets, respectively.

   b. ***Vegetation Inputs File***: It should represent the agricultural field of interest, in a similar way to what is shown in **Table 9** and **Table 10** for ***Layers*** and ***Kinds*** spreadsheets, respectively.

c. ***Antenna Pattern File***: This simulation does not involve this file since the receiver antenna pattern is a ***Generalized-Gaussian.***

3. The type of analysis should be chosen ***Agriculture*** in the ***Analysis Selection Window***.

   It should be noted again that the selection of the analysis type does not prevent the user to study another analysis in the ***Simulation Input Window***, but it helps determine the simulation parameters within this window easier. For example, ***Multi-layered*** ground could be defined within the ***Configuration Inputs File*** even if the analysis type was selected to be ***Soil*** (Single-layered).

   In addition, it can be concluded that the analysis type should be picked regarding the main interest of the simulation; then, the other effects can be still performed. For instance, if a ***Multi-layered*** ground analysis was the main concern of this simulation, but an agricultural terrain would be studied over that surface, analysis type should have been chosen as ***Root-zone***, and agricultural field should be defined with the help of vegetation parameters (***Vegetation-cover*** and ***Vegetation Inputs File***).

   Simulation Inputs Window: All the simulation parameters are determined via this window, as described in detail in **section 2.3 Simulation Input Window**.

   a. ***Campaign***: It should be given as a unique name that reflects the content of this simulation. It may ***be*** the geo-location, if any, of the simulated field, or any meaningful character array. For example., it can be assumed “GNSSR-Corn_Reproductive-MS-39762” for this example, which shows this simulation is a GNSS-R analysis over a corn field that is at reproductive stage and located in MS 39762.
   b. ***Simulation Mode***: It is ***Snapshot*** for this simulation; details for ***Simulation Mode*** are described in **section 2.3.2.2 Simulation Mode**. Note again that this selection affects the content of the ***Configuration Inputs File***. Please refer to **section 3.1.2.1.1 Simulation Mode Effect: Snapshot vs. Time-series** for details of such effects.
   c. ***Ground-cover***: It is ***Vegetation*** for this simulation.
   d. ***Preferences***: Preferences of this simulation should be determined as well. If this simulation is of a temporary purpose, then it should not be included in the ***Master*** simulations. Attenuation can be written to Excel file when it is a ***Vegetation-cover*** simulation and the attenuation details are of interest.
   e. ***Transmitter Frequency***: Because this is a GNSS-R scenario, the frequency should be one of the GNSS frequencies (e.g. L1A – 1575.42 MHz)
   f. ***Transmitter Range to Earth Center***: This range is also based on the transmitter selection. The transmitter’s range to Earth center should be given properly for the GNSS satellite selected. For example, it can be 26578 km in this simulation.
   g. ***Transmitter EIRP***: If it is known for the selected transmitter, then it can be given. If it is not known, then an ***EIRP*** value of user’s choice can be given since it has only an offset effect on the simulated results. For example, it can be 0 dB in this simulation.
   h. ***Transmitter Polarization***: Similar to the above parameters, polarization of the transmitter should be chosen properly. For example, it can be a RHCP in this simulation.

i. ***Transmitter Orientation***: It is ***Variable*** in this example. Note again that this is an important parameter that also affects the content of the ***Configuration Inputs File***. Please refer to **section 3.1.2.1.2 Transmitter Orientation** for details of such effects.
j. ***Ground Dielectric Model***: Any one of the available models can be selected. For instance, ***Dobson*** can be chosen in this scenario.
k. ***Ground Structure***: It is ***Single-layered*** in this example. Note again that this is an important parameter that also affects the content of the ***Configuration Inputs File***. Please refer to **section 3.1.2.1.3 Ground Structure: Single-layered vs. Multi-layered** for details of such effects.
l. ***Receiver Altitude***: It is 20 m in this simulation.
m. ***Receiver Gain***: Similar to ***EIRP***, if it is known for the selected receiver, then it can be given. If it is not known, a ***Gain*** value of user's choice can be given since it has only an offset effect on the simulated results. For example, it can be 0 dB in this simulation.
n. ***Receiver Polarization***: Polarization of the receiver should be chosen properly. For example, it can be a RHCP in this simulation.
o. ***Receiver Orientation:*** It can be chosen Specular-facing in this example to get rid of antenna pattern effects and polarization mismatch.
p. ***Receiver Antenna Pattern Input:*** It can be selected ***Generalized-Gaussian*** with the following parameters:
    i. ***Beamwidth:*** 30 degrees
    ii. ***Side-lobe level***: 30 dB
    iii. ***Cross-polarization level***: 25 dB
    iv. ***Pattern resolution***: 1 degree
q. ***Input Files:*** The Excel input files should be fed accordingly via the Browse buttons.
r. ***Run SCoBi:*** The simulation can be run with the above parameters.

3.2.2. P-band Vegetation Analysis

The major three steps of a P-band vegetation analysis simulation can be described as follows:

1. In this example, ***Forest*** SoOp analysis over a ***Vegetation Cover*** of a forest field will be considered. The transmitter will be a satellite operating at P-band with a ***Variable*** orientation (for the purpose of analyzing the changing transmitter angles). The receiver will be a ground-based antenna with a ***User-defined*** pattern. Further details about the transmitter and the receiver parameters will be given below. This simulation will be a ***Snapshot*** simulation, where the combinations of simulation parameters are used for generating individual simulation snapshots to generate large amount of simulated data. ***Ground Structure*** will be ***Single-layered*** since the surface dielectric calculations are considered enough for such a vegetation analysis scenario.
2. For such a simulation, below Excel input files (either the default or the newly generated files) must satisfy the simulation specifications in the first major step as follows:
    a. ***Configuration Inputs File***: It should satisfy:
        - ***Simulation Mode***: ***Snapshot***,
        - ***Transmitter Orientation***: ***Variable***, and
        - ***Ground Structure***: ***Single-layered***

which corresponds to a file similar to what is shown in **Table 1** and **Table 7** for ***Dynamic*** and ***Ground*** spreadsheets, respectively.

b. ***Vegetation Inputs File***: It should represent the forest field of interest, in a similar way to what is shown in **Table 9** and **Table 10** for ***Layers*** and ***Kinds*** spreadsheets, respectively.

c. Antenna Pattern File: The user defined antenna pattern can be given as described in **sections 2.3.4.5.2 User-defined** and **3.1.2.2 Antenna Pattern File*.***

3. The type of analysis should be chosen ***Forest*** in the ***Analysis Selection Window***.

Simulation Inputs Window: All the simulation parameters are determined via this window, as described in detail in **section 2.3 Simulation Input Window**.

a. ***Campaign***: For example, it can be assumed "Forest-P_band-MS-39762" for this example, which shows this simulation is a Forest analysis at P-band and located in MS 39762.

b. ***Simulation Mode***: It is ***Snapshot*** for this simulation; details for ***Simulation Mode*** are described in **section 2.3.2.2 Simulation Mode**. Note again that this selection affects the content of the ***Configuration Inputs File***. Please refer to **section 3.1.2.1.1 Simulation Mode Effect: Snapshot vs. Time-series** for details of such effects.

c. ***Ground-cover***: It is ***Vegetation*** for this simulation.

d. ***Preferences***: Preferences of this simulation should be determined as well. If this simulation is of a temporary purpose, then it should not be included in the ***Master*** simulations. Attenuation can be written to Excel file when it is a ***Vegetation-cover*** simulation and the attenuation details are of interest.

e. ***Transmitter Frequency***: Because this is a P-band scenario, the frequency should be a P-band frequency (e.g. 370 MHz)

f. ***Transmitter Range to Earth Center***: For example, it can be 42164 km in this simulation.

g. ***Transmitter EIRP***: If it is known for the selected transmitter, then it can be given. If it is not known, then an ***EIRP*** value of user's choice can be given since it has only an offset effect on the simulated results. For example, it can be 0 dB in this simulation.

h. ***Transmitter Polarization***: Similar to the above parameters, polarization of the transmitter should be chosen properly. For example, it can be a RHCP in this simulation.

i. ***Transmitter Orientation***: It is ***Variable*** in this example. Note again that this is an important parameter that also affects the content of the ***Configuration Inputs File***. Please refer to **section 3.1.2.1.2 Transmitter Orientation** for details of such effects.

j. ***Ground Dielectric Model***: Any one of the available models can be selected. For instance, ***Mironov*** can be chosen in this scenario.

k. ***Ground Structure***: It is ***Single-layered*** in this example. Note again that this is an important parameter that also affects the content of the ***Configuration Inputs File***. Please refer to **section 3.1.2.1.3 Ground Structure: Single-layered vs. Multi-layered** for details of such effects.

l. ***Receiver Altitude***: It is 50 m in this simulation.

m. ***Receiver Gain***: Similar to ***EIRP***, if it is known for the selected receiver, then it can be given. If it is not known, a ***Gain*** value of user's choice can be given since it has only an offset effect on the simulated results. For example, it can be 0 dB in this simulation.
n. ***Receiver Polarization***: Polarization of the receiver should be chosen properly. For example, it can be an X-pol in this simulation.
o. ***Receiver Orientation:*** It can be chosen Specular-facing in this example to get rid of antenna pattern effects and polarization mismatch.
p. ***Receiver Antenna Pattern Input:*** It should be selected ***User-defined*** antenna pattern.
q. ***Input Files:*** The Excel input files should be fed accordingly via the Browse buttons.
r. ***Run SCoBi:*** The simulation can be run with the above parameters.

3.2.3. P-band Root-zone Analysis

The major three steps of a ***Root-zone*** simulation at P-band can be described as follows:

1. In such a simulation, a ***Root-zone*** SoOp analysis over a ***Bare-soil*** will be considered. The transmitter will be a ***Geo-stationary*** (orientation) communication satellite that operates at P-band (e.g. 370 MHz). The receiver will be a ground-based receiver, which has a ***Generalized-Gaussian*** antenna pattern. Further details about the transmitter and the receiver parameters will be given below. This ***Simulation Mode*** will be ***Time-series***, where a temporal analysis is performed. ***Ground Structure*** will be ***Multi-layered*** since the dielectric calculations through the multiple layers of the soil are of major interest in this example.
2. For such a simulation, below Excel input files (either the default or the newly generated files) must satisfy the simulation specifications in the first major step as follows:
   a. ***Configuration Inputs File***: It should satisfy:
      - ***Simulation Mode***: ***Time-series***,
      - ***Transmitter Orientation***: ***Geo-stationary***, and
      - ***Ground Structure***: ***Multi-layered***

      which corresponds to a file similar to what is shown in **Table 6** and **Table 8** for ***Dynamic*** and ***Ground*** spreadsheets, respectively, except that **Table 6** should be modified for a ***Geo-stationary*** transmitter as in **Table 4**.

   b. ***Vegetation Inputs File***: This simulation does not involve this file since the ***Vegetation Cover*** is a ***Bare-soil***.
   c. ***Antenna Pattern File***: This simulation does not involve this file since the receiver antenna pattern is a ***Generalized-Gaussian.***
3. The type of analysis should be chosen ***Root-zone*** in the ***Analysis Selection Window***.

   Simulation Inputs Window: All the simulation parameters are determined via this window, as described in detail in **section 2.3 Simulation Input Window**.

   a. ***Campaign***: It can be given, for instance, "Root_zone-P_band-MS-39762" for this example, which shows this simulation is a ***Root-zone*** analysis through P-band and located in MS 39762.
   b. ***Simulation Mode***: It is ***Time-series*** for this simulation; details for ***Simulation Mode*** are described in **section 2.3.2.2 Simulation Mode**. Note again that this

selection affects the content of the ***Configuration Inputs File***. Please refer to **section 3.1.2.1.1 Simulation Mode Effect: Snapshot vs. Time-series** for details of such effects.

c. ***Ground-cover***: It is ***Bare-soil*** for this simulation.
d. ***Preferences***: Preferences of this simulation should be determined as well. If this simulation is of a temporary purpose, then it should not be included in the ***Master*** simulations.
e. ***Transmitter Frequency***: It can be 370 MHz for this example.
f. ***Transmitter Range to Earth Center***: For example, it can be 42164 km in this simulation.
g. ***Transmitter EIRP***: If it is known for the selected transmitter, then it can be given. If it is not known, then an ***EIRP*** value of user's choice can be given since it has only an offset effect on the simulated results. For example, it can be 0 dB in this simulation.
h. ***Transmitter Polarization***: Similar to the above parameters, polarization of the transmitter should be chosen properly. For example, it can be a RHCP in this simulation.
i. ***Transmitter Orientation***: It is ***Geo-stationary*** in this example (Elevation angle: 40 degrees, Azimuth angle: 0 degree). Note again that this is an important parameter that also affects the content of the ***Configuration Inputs File***. Please refer to **section 3.1.2.1.2 Transmitter Orientation** for details of such effects.
j. ***Ground Dielectric Model***: Any one of the available models can be selected. For instance, ***Dobson*** can be chosen in this scenario.
k. ***Ground Structure***: It is ***Multi-layered*** in this example. Note again that this is an important parameter that also affects the content of the ***Configuration Inputs File***. Please refer to **section 3.1.2.1.3 Ground Structure: Single-layered vs. Multi-layered** for details of such effects.
l. ***Receiver Altitude***: It is 20 m in this simulation.
m. ***Receiver Gain***: Similar to ***EIRP***, if it is known for the selected receiver, then it can be given. If it is not known, a ***Gain*** value of user's choice can be given since it has only an offset effect on the simulated results. For example, it can be 0 dB in this simulation.
n. ***Receiver Polarization***: Polarization of the receiver should be chosen properly. For example, it can be an X-pol in this simulation.
o. ***Receiver Orientation:*** It can be chosen **Fixed** (Zenith observation angle: 40 degrees, Azimuth observation angle: 0 degree) in this.
s. ***Receiver Antenna Pattern Input:*** It can be selected ***Generalized-Gaussian*** with the following parameters:
    i. ***Beamwidth:*** 30 degrees
    ii. ***Side-lobe level***: 30 dB
    iii. ***Cross-polarization level***: 25 dB
    iv. ***Pattern resolution***: 1 degree
p. ***Input Files:*** The Excel input files should be fed accordingly via the Browse buttons.
q. ***Run SCoBi:*** The simulation can be run with the above parameters.

3.3. Simulation Results

Simulation results are generated under the following directory:

\source\sims

Sims folder may contain the following two folders:

- **temp**: If the preference under ***Simulation Settings*** is not chosen to be ***Include in Master Simulations***, then output is generated under this folder. It can be seen like a temporary simulation folder which holds the simulations that do not have significant analysis purposes.
- **master**: If the preference under ***Simulation Settings*** is chosen to be ***Include in Master Simulations***, then output is generated under this folder. In addition, brief information about every simulation if this type is added to the ***Master Simulations File*** (***master_sims.xlsx***) file.

3.3.1. Simulation Name

Simulation names are generated uniquely under **\temp** or **\master** folder by using the ***Campaign*** parameter and the timestamp that the simulation is run.

Example

The record of the simulation that are included in master simulations is logged with the simulation name into ***Master Simulations File***, which will be described in the next section.

The actual output of each simulation is generated under its unique simulation name folder, where the following folders are common:

- ***figure***: This folder may include the common plots that are generic for any type of simulations if plots are generated by the user. In other words, the SCoBi has general-purpose plotting functions (e.g. reflectivity as a function of transmitter elevation angle), but it does not plot them automatically. Figures are stored under this folder when plotted by the user.
- ***input***: This folder stores the copies of the simulation input and MS Excel input files used in the current simulation in the folder **\used_files**. The purpose of this folder is to avoid possible information loss if the actual input files of a simulation are removed or corrupted after it is run. The **\input** folder also keeps the ***input_report.txt*** file that is shown immediately when a simulation is run and stored here for user's reference. It also keeps the ***inputParamsStruct.mat*** file that is for SCoBi simulation controls and not for the user.
- ***metadata***: This folder may include some meta-data of a simulation when it is needed, currently only propagation calculations.
- ***products***: This folder is the exact product folder of a simulation. It stores the direct field and power, and specular reflection coefficient and reflectivity results of a simulation. This folder is described in detail in section ***3.3.2 Products***.

3.3.2. Products

The ***/products*** folder involves the following structure for direct and specular outputs:

- Direct
  - "field" folder
  - "power" folder

    - Real and imaginary parts of "**Kd**" constant (described in detail in [1])
- Specular
    - "reflection coefficient" folder
    - "reflectivity" folder
    - Real and imaginary parts of "***Kc***" constant (described in detail in [1])

If the simulation is a ***Time-series*** simulation, ***DoYs.dat*** file that keeps the Day-of-Year timestamps for each observation is also saved under the **\products** folder.

If the simulation has a ***Multi-layered*** ground structure, then the ***\reflection coefficient*** and **\reflectivity** folders of the Specular term has the following subfolders for different dielectric profiles supported:

- 2nd-order
- 3rd-order
- Discrete slab
- Logistic regression

The above subfolders may keep (If they were selected for the current simulation) separate Specular term results for the corresponding dielectric profile.

All output files begin with a description of the entailed product size. The first line indicates how many dimensions (***n***) the product contains. The next ***n*** lines then detail how many elements lie along this dimension. For example, if a product file starts with

```
2.0000
2.0000
1323.0000
```

Then we can see that there are two dimensions: one dimension with 2 elements and another dimension with 1,323. Another way to state this is that this file contains a 2-dimensional table of elements with two rows and 1,323 columns.

The next lines, defined by the number of dimensions, would then describe the elements of the corresponding output product.

3.3.2.1. Direct Field Products

The products of the direct field seen by the receiver are recorded in eight files by the SCoBi simulator in **\<simulation_name>\products\direct\field**. The file description and naming conventions is described in ***Table 11.***

Table 11: The naming convention and definition of the direct field products

Filename	Description
Dir01_i	The imaginary portion of the electric field for transmitter polarization state 1 assuming an ideal antenna.
Dir01_r	The real portion of the electric field for transmitter polarization state 1 assuming an ideal antenna.
Dir1_i	The imaginary portion of the electric field for transmitter polarization state 1 using the simulated antenna (as given in the inputs).
Dir1_r	The real portion of the electric field for transmitter polarization state 1 using the simulated antenna (as given in the inputs).
Dir02_i	The imaginary portion of the electric field for transmitter polarization state 2 considering an ideal antenna.
Dir02_r	The real portion of the electric field for transmitter polarization state 2 assuming an ideal antenna.
Dir2_i	The imaginary portion of the electric field for transmitter polarization state 2 using the simulated antenna (as given in the inputs).
Dir2_r	The real portion of the electric field for transmitter polarization state 2 using the simulated antenna (as given in the inputs).

The contents of each file contain a $2 \times m$ matrix where m is the number of simulations performed. Each of the 2 elements correspond to the field contribution seen by ports 1 and 2.

3.3.2.2. Direct Power Products

The power of the direct signal received by the receiver is simulated by SCoBi and stored in **\<simulation_name>\products\direct\power**. The file description and naming conventions are described in **Table 12**.

Table 12: The naming convention and definition of the direct power products

Filename	Description
Dir01	The received power by a simulated <u>ideal</u> antenna for transmitter polarization state 1
Dir1	The received power by the simulated antenna (as given in the inputs) for transmitter polarization state 1
Dir02	The received power by a simulated <u>ideal</u> antenna for transmitter polarization state 2
Dir2	The received power by the simulated antenna (as given in the inputs)for transmitter polarization state 2

The contents of each file contain a $4 \times m$ matrix where m is the number of simulations performed. Each of the 4 elements correspond to the co-polarized and cross-polarized power terms seen by the ports 1 and 2..

3.3.2.3. Reflection Coefficient Products

The reflection coefficients seen by the receiver is recorded by SCoBi in **\<simulation_name>\products\specular\reflection_coefficient**. Depending on the simulation type, subsequent files describing the fit function for a given multilayer soil moisture profile may be contained in this folder. The file description and naming convention for the reflection coefficient values is described in **Table 13.**

Table 13: The naming convention and definition of the reflection coefficient products

	Description
Bare01_i	The imaginary portion of the reflection coefficient seen over a bare soil scattering surface assuming an ideal antenna for the transmitter polarization state 1.
Bare01_r	The real portion of the reflection coefficient seen by a bare soil scattering surface assuming an ideal antenna for the transmitter polarization state 1.
Bare1_i	The imaginary portion of the reflection coefficient seen over a bare soil scattering surface for the simulated antenna (as given in the inputs) for the transmitter polarization state 1.
Bare1_r	The real portion of the reflection coefficient seen over a bare soil scattering surface for the simulated antenna (as given in the inputs) for the transmitter polarization state 1.
Bare02_i	The imaginary portion of the reflection coefficient seen over a bare soil scattering surface assuming an ideal antenna for the transmitter polarization state 2.
Bare02_r	The real portion of the reflection coefficient seen over a bare soil scattering surface assuming an ideal antenna for the transmitter polarization state 2.
Bare2_i	The imaginary portion of the reflection coefficient seen over a bare soil scattering surface for the simulated antenna (as given in the inputs) for the transmitter polarization state 2.
Bare2_r	The real portion of the reflection coefficient seen over a bare soil scattering surface for the simulated antenna (as given in the inputs) for the transmitter polarization state 1.
Veg01_i	The imaginary portion of the reflection coefficient seen over a (bare soil + vegetation layer) scattering surface assuming an ideal antenna for the transmitter polarization state 1.
Veg01_r	The real portion of the reflection coefficient seen over a (bare soil + vegetation layer) scattering surface assuming an ideal antenna for the transmitter polarization state 1.
Veg1_i	The imaginary portion of the reflection coefficient seen over a (bare soil + vegetation layer) scattering surface for the simulated antenna (as given in the inputs) for the transmitter polarization state 1.
Veg1_r	The real portion of the reflection coefficient seen over a (bare soil + vegetation layer) scattering surface for the simulated antenna (as given in the inputs) for the transmitter polarization state 1.
Veg02_i	The imaginary portion of the reflection coefficient seen over a (bare soil + vegetation layer) scattering surface assuming an ideal antenna for the transmitter polarization state 2.
Veg02_r	The real portion of the reflection coefficient seen over a (bare soil + vegetation layer) scattering surface assuming an ideal antenna for the transmitter polarization state 2.
Veg2_i	The imaginary portion of the reflection coefficient seen over a (bare soil + vegetation layer) scattering surface for the simulated antenna (as given in the inputs) for the transmitter polarization state 2.
Veg2_r	The real portion of the reflection coefficient seen over a (bare soil + vegetation layer) scattering surface for the simulated antenna (as given in the inputs) for the transmitter polarization state 1.

The contents of each file contain a $2 \times m$ matrix where m is the number of simulations performed. Each of the 2 elements correspond to the reflection coefficient seen by the ports 1 and 2.

3.3.2.4. Reflectivity Products

The reflectivity of the SoOp's specular contribution seen by the receiver is recorded by SCoBi in **\<simulation_name>\products\specular\reflectivity**. Depending on the simulation type, subsequent files describing the fit function for a given multilayer soil moisture profile may be contained in this folder. The file description and naming convention for the reflection coefficient values is described in **Table 14**.

Table 14: The naming convention and definition of the reflectivity products

	Description
Bare01	The specular signal reflectivity seen by an ideal receiver antenna over a bare soil surface using for the transmitter polarization state 1
Bare1	The specular signal reflectivity seen by the simulated receiver antenna (as given in inputs) over a bare soil surface for the transmitter polarization state 1
Bare02	The specular signal reflectivity seen by an ideal receiver antenna over a bare soil surface for the transmitter polarization state 1
Bare2	The specular signal reflectivity seen by the simulated receiver antenna (as given in inputs) over a bare soil surface for the transmitter polarization state 1
Veg01	The specular signal reflectivity seen an ideal receiver antenna over a (bare soil + vegetation layer) surface for the transmitter polarization state 1
Veg1	The specular signal reflectivity seen by the simulated receiver antenna (as given in inputs) over a (bare soil + vegetation layer) surface for the transmitter polarization state 1
Veg02	The specular signal reflectivity seen an ideal receiver antenna over a (bare soil + vegetation layer) surface for the transmitter polarization state 1
Veg2	The specular signal reflectivity seen by the simulated receiver antenna (as given in inputs) over a (bare soil + vegetation layer) surface for the transmitter polarization state 1

The contents of each file contain a $4 \times m$ matrix where m is the number of simulations performed. Each of the 4 elements correspond to the co-polarized and cross-polarized power values seen by ports 1 and 2.

3.3.3. Master Simulations File

Master Simulations File is for the purpose of logging the simulations that have importance. Simulations that are logged into the ***Master Simulations File*** can be identified easily by checking their row in this file in the future. The file shows the significant parameters of the simulation besides its unique name.

On the other hand, **\temp** simulations are for temporary cases. They generate the same output with the master simulations; however, they are not included in the ***Master Simulations File.***

4. Visualization and Plotting Tools

SCoBi currently contains example plotting functions for user output located at **./source/lib/scobi/plot**. Future updates to SCoBi are expected to include graphical user interfaces for using thee plotting functions and visualizing output products.

The current version of the SCoBi software provides two simple plotting functions to help the user examine the simulation outputs. They are not aimed at providing advanced analysis capabilities for the simulation results in this version. However, the user may modify these functions or create new ones from scratch on own initiative. In addition, advanced plotting functions (such as Time- series Multi-layer dielectric profiles) will be available by the near-future versions.

- **plotReflectivityVsEL.m**: This function plots the reflectivity as a function of changing transmitter elevation angles. It is only applicable (as is) to the default ***Agriculture*** inputs, which is provided with the current version. In other words, it can be directly applied (without requiring any modification) to simulation outputs that are performed by using the default ***Agriculture*** inputs. Modifying this function to apply for other scenarios is upon the developer's initiative. When this function is run, it prompts the user to choose the simulation folder. The user should select one of the folders with the simulation names (<***campaign_name***> + <***time_stamp***>) under either ***\temp*** or ***\master*** folders, then click OK. It generates the plot in **Figure 12** and saves it with the following details:

  Filename: ***Reflectivity_vs_EL-PH_15-VSM_0dot15-RMSH_1.tif***

  Folder: **.**<***simulation_name***>***\figure\specular\reflectivity\vs_EL***

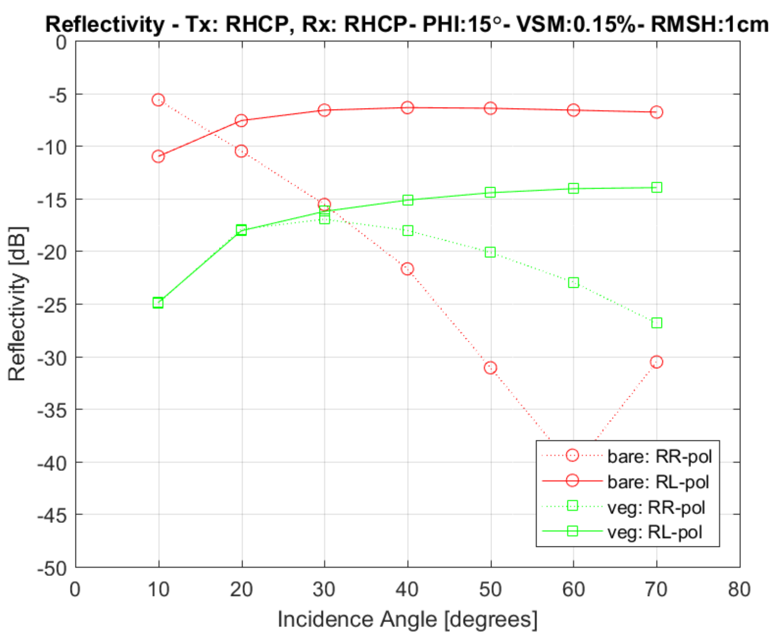

Figure 12: Reflectivity as a function of Elevation Angle (For default ***Agriculture*** *inputs)*

- **plotReflectivityVsVSM.m:** This function plots the reflectivity as a function of changing volumetric soil moisture values. It is only applicable (as is) to the default ***Forest*** inputs, which is provided with the current version. In other words, it can be directly applied (without requiring any modification) to simulation outputs that are performed by using the default ***Forest*** inputs. Modifying this function to apply for other scenarios is upon the developer's initiative. When this function is run, it prompts the user to choose the simulation folder. The user should select one of the folders with the simulation names (<***campaign_name***> + <***time_stamp>***) under either ***\temp*** or ***\master*** folders, then click OK. It generates the plot in **Figure 13** and saves it with the following details:

  Filename: ***Reflectivity_vs_VSM-EL_50-PHI_0-RMSH_1dot5.tif***

  Folder: **.**<***simulation_name***>***\figure\specular\reflectivity\vs_VSM***

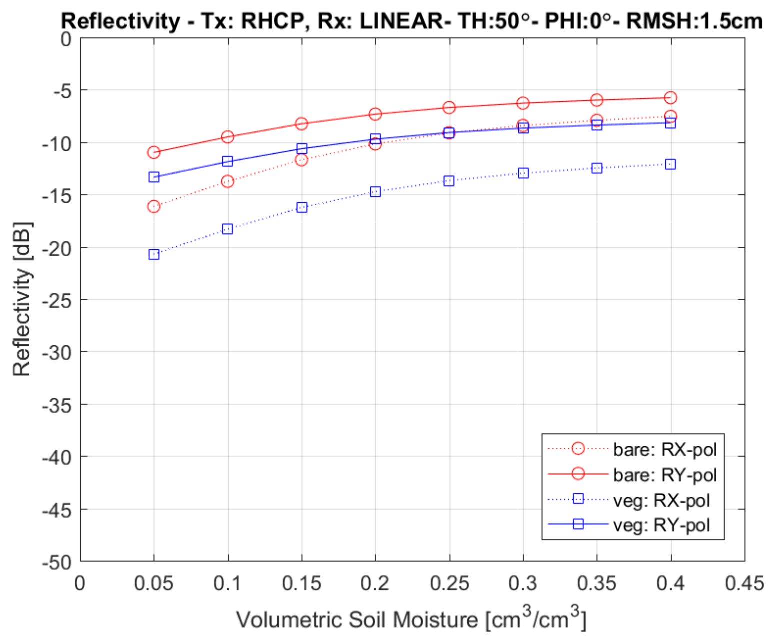

*Figure 13: Reflectivity as a function of Volumetric Soil Moisture (For default **Forest** inputs)*

References

[1] M. Kurum, M. Deshpande, A. T. Joseph, P. E. O'Neill, R. Lang, and O. Eroglu, "SCoBi-Veg: A generalized bistatic scattering model of reflectometry from vegetation for Signals of Opportunity applications," *IEEE Trans. Geosci. Remote Sensing, Press*, 2018.