

SSC Reference Manual

Aron Dobos & Paul Gilman

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Abstract

The SSC (SAM Simulation Core) software library implements the underlying renewable energy system modeling calculation engine utilized by the popular desktop System Advisor Model (SAM) tool. SSC provides a simple and programmer-friendly application programming interface (API) that allows developers to directly integrate SAM calculations into other tools. The API includes mechanisms to set input variable values, run simulations, and retrieve calculated outputs. The library is provided to users as pre-compiled binary dynamic libraries for Windows, Mac OSX, and Linux, with the bare minimum system library dependencies. While the native API language is ISO-standard C, language bindings for MATLAB, and Python are included. The API and model implementations are thread-safe and reentrant, allowing the software to be efficiently utilized in a parallel computing environment.

This document describes the software architecture of SSC, introduces the SSC Development Environment tool, explains how to set up simulations from code, query the library for variable information, and provides examples and “case studies” in various programming languages to ease the adoption of SSC into other systems.

Note. The reader is assumed to have familiarity with the C programming language, as well as some level of proficiency using the System Advisor Model (SAM) tool.

Contents

1	Overview	4
1.1	Framework Description	4
1.2	Modeling an Energy System	4
2	A Basic Example: PVWatts	5
2.1	Write the program skeleton	6
2.2	Create the data container	6
2.3	Assign values to the module input variables	7
2.4	Run the module	7
2.5	Retrieve results from the data container and display them	8
2.6	Cleaning up	8
2.7	Compile and run the C program	8
2.8	Some additional comments	9
3	Data Variables	9
3.1	Variable Names	9
3.2	Variable Types	9
3.3	Data Types	10
3.4	Variable Documentation	11
3.5	Required Variables, Constraints, and Default Values	12
3.6	Manipulating Data Containers	13
3.7	Assigning and Retrieving Values	14
3.7.1	Numbers	14
3.7.2	Arrays	14
3.7.3	Matrices	15
3.7.4	Strings	16
3.7.5	Tables	16
4	Simulation Modules	17
4.1	Simple Method 1: Return True or False	17
4.2	Simple Method 2: Return First Error Message	19
4.3	Explicit Module Instantiation	19
4.4	Running with Progress Updates, Warnings, and Errors	20
4.5	Retrieving Messages	23
4.6	Querying SSC for Available Modules	24
5	Version Information	24
6	SSCdev	25
6.1	Using SSCdev	25
6.2	SSCdev Menus	26
6.3	Module Browser	27
6.3.1	Run a Simulation from the Module Browser	28
6.4	Data Container	28
6.4.1	Data Files	29

6.4.2	Time Series Graphs and Statistical Tables	29
6.5	Script Editor	30
6.6	SSCdev Example 1: Run a Simulation Module without Scripting	31
6.7	SSCdev Example 2: Use a Script to Build a Model	32
7	Language Interfaces	35
7.1	Python	35
7.2	MATLAB	36
7.3	C# and .NET	38
7.4	Java	39
8	C API Reference	40
9	Legal	41

1 Overview

The SAM simulation core (SSC) software development kit (SDK) provides tools for creating models of renewable energy systems using the SSC library. The System Advisor Model (SAM) desktop application is a user-friendly front-end for the SSC library that uses SSC modules to perform all system performance and financial calculations. This manual assumes that the reader is familiar with SAM's suite of performance and financial models, input and output variables, and other capabilities. The SDK consists of the application programming interface (API), library, programming language wrappers, integrated development environment, code samples, and this manual.

1.1 Framework Description

The SSC framework provides a generic mechanism for running modules, setting values of module inputs, and reading values of module outputs. The mechanisms are generic because they do not depend on the module. For example, the same mechanism provides access to the PVWatts (`pvwattsv1`) and Utility IPP (`ippppa`) modules.

Using an SSC module is analogous to calling a function in a programming language: you pass parameter values to the function, run the function, and then read values returned by the function. In SSC, you store input variables in a data container, run the module, and retrieve outputs from the same data container:

1. Create a data container of type `ssc_data_t` for model input variables.
2. Call a simulation module such as `pvwattsv1` or `ippppa`, both of type `ssc_module_t` to process variables in the data container. If the module runs successfully, it populates the data container with output variables. If it fails, it generates error messages.
3. Retrieve results from the data container.

1.2 Modeling an Energy System

The SSC simulation modules process weather data files, simulate the performance of energy systems and their components, and calculate financial cash flows and metrics.

Creating a model of a renewable energy system in SSC involves running a set of modules to represent the physical system and a financing structure. For example, a model of a residential photovoltaic system might require four modules:

- `pvwattsv1`: Defines the system's design parameters and calculates the hourly output over a single year.
- `annualoutput`: Calculates the system's annual output over the system's multi-year life.
- `utilityrate`: Calculates the value of energy generated by the system for each hour of the first year, and as an annual total for subsequent years.
- `cashloan`: Calculates financial metrics including the cost of energy, net present value, based on installation and operating costs, incentives, taxes, and loan parameters.

The following pseudocode shows what a program that calculates the net present value of a residential photovoltaic system would look like. It calls the modules in the order shown above, with some outputs of each module serving as inputs for the next. Because the modules do not all use the same names or units for variables representing the same quantities, some code is required to translate values. For example, the `pvwattsv1` module's output variable `ac` which is the hourly energy in Wh produced by the system, while the `annualoutput` module's input variable `energy_net_hourly` is in kWh.

1. Create data container
2. Assign values to `pvwattsv1` input variables
3. Run `pvwattsv1`
4. Retrieve system hourly output from data container
5. Convert hourly output values from Wh to kWh
6. Assign values to annual output input variables
7. Run `annualoutput`
8. Retrieve yearly output values from data container
9. Assign values to `utilityrate` input variables
10. Run `utilityrate`
11. Retrieve energy values from data container
12. Assign values to `cashloan` input variables
13. Run `cashloan`
14. Retrieve net present value from data container
15. Display net present value

2 A Basic Example: PVWatts

In this section, we write a short command-line C program to calculate the total annual energy production of a 1 kW PV system at a particular location. The program performs the following tasks:

1. Create Data Container
2. Assign values to the `pvwattsv1` input variables
3. Run `pvwattsv1`
4. Retrieve system hourly output values from the data container
5. Add up the hourly values and convert them to kWh
6. Display the total annual output

The complete source code for this program is included with the SSC SDK in the file `example1_pvwatts.c`.

This example is written in C, SSC's native language. The language interfaces included with the SDK and describe in §7 allow you to use SSC in programs written in other languages.

You can also use the scripting language included with SSCdev to run SSC modules and build models based on SSC as described in §6

2.1 Write the program skeleton

To start, we'll write the program skeleton. It includes the standard input-output and `sscapi.h` header files. The SSC API header file must be included in any program that uses SSC functions.

The main function gives the weather file as a command line argument. It must be in one of the formats that `pvwattsv1` can read, TMY2, TMY3, EPW, or SMW.

```
#include <stdio.h>
#include "sscapi.h"

int main(int argc, char *argv[])
{
    if ( argc < 2 )
    {
        printf("usage: pvwatts.exe <weather-file>\n");
        return -1;
    }

    // run PVWatts simulation for the specified weather file

    return 0;
}
```

2.2 Create the data container

Next we replace the comment in the program skeleton with code that creates the SSC data container that will store all input and output variables.

The `ssc_data_create()` function returns a value of type `ssc_data_t`, which we assign to the variable `data`.

If the function call fails due to the system having run out of memory, the function returns `NULL`. By checking the function's return value, we can be sure that it succeeded in creating the data container.

```
ssc_data_t data = ssc_data_create();
if ( data == NULL )
{
```

```

        printf("error: out of memory.\n");
        return -1;
    }

```

2.3 Assign values to the module input variables

The `pvwattsv1` module requires six input variables. You can use the approach described in §3.4 to list information about a module's input and output variables. You can also use the SSCdev module browser described in §6 to explore the variables.

The `pvwattsv1` input variables are numbers, except for the weather file name which is a string. SSC also supports array, matrix, and table data types.

```

ssc_data_set_string( data, "file_name", argv[1] ); // set the weather file name
ssc_data_set_number( data, "system_size", 1.0f ); // system size of 1 kW DC
ssc_data_set_number( data, "derate", 0.77f );      // system derate
ssc_data_set_number( data, "track_mode", 0 );      // fixed tilt system
ssc_data_set_number( data, "tilt", 20 );           // 20 degree tilt
ssc_data_set_number( data, "azimuth", 180 );       // south facing (180 degrees)

```

2.4 Run the module

To run the `pvwattsv1` module, we first create an instance of the module by passing its name as a string to the `ssc_module_create()` function, and then run the module.

The `ssc_module_create()` function may return NULL if it does not recognize the name or if the system is out of memory.

```

ssc_module_t module = ssc_module_create( "pvwattsv1" );
if ( NULL == module )
{
    printf("error: could not create 'pvwattsv1' module.\n");
    ssc_data_free( data );
    return -1;
}

```

The `ssc_module_exec` runs the module we created with the data container stored in `data` and returns a value of 1 if the simulation succeeds. If any of the module's required input variables use the wrong data type or a value that does not meet constraints, or if the simulation fails for some other reason, it returns a value of 0.

```

if ( ssc_module_exec( module, data ) == 0 )
{
    printf("error during simulation.\n");
    ssc_module_free( module );
    ssc_data_free( data );
    return -1;
}

```

The `ssc_module_exec()` function is one way to run a module. For more details about the function and others that run modules with different options for handling errors, see §4.4.

2.5 Retrieve results from the data container and display them

If the simulation succeeds, we can retrieve the model outputs that we want from the data container. For this example, the only output we need is the hourly AC energy produced by the system, which we will use to calculate the system's total annual AC energy in kWh. For the `pvwatts_v1` module, the system's hourly energy is stored in the `ac` variable in Wh.

```
double ac_total = 0;
int len = 0;
ssc_number_t *ac = ssc_data_get_array( data, "ac", &len );
if ( ac != NULL )
{
    int i;
    for ( i=0; i<len; i++ )
        ac_total += ac[i];
    printf("ac: %lg kWh\n", ac_total*0.001 );
}
else
{
    printf("variable 'ac' not found.\n");
}
```

2.6 Cleaning up

Now that we're done with the simulation, we should free the memory associated with the module and data container. The `ssc_module_free()` function releases the module, and `ssc_data_free()` frees memory associated with the data container.

```
ssc_module_free( module );
ssc_data_free( data );
```

2.7 Compile and run the C program

This description explains how to compile and run the C program in Windows using the MinGW development environment, assuming we saved the code to the file `example1_pvwatts.c`. This example was tested with MinGW gcc version 4.6.2.

To compile and run the program, the following files must be in the same folder:

- The `.c` file containing the program code
- The `sscapi.h` header file
- The dynamic library file, for example `ssc32.dll`

- The `daggett.tm2` weather file

To compile the program, type the following command at the Windows command prompt:

```
c:\> gcc example1_pvwatts.c ssc32.dll -o pvwatts.exe
```

To run the program, specify a weather file on the command line. Here, we use the TMY2 file for Daggett, California:

```
c:\> pvwatts.exe daggett.tm2
ac: 1668.23 kWh
```

Note: You may need to rename the `ssc32.dll` file to `ssc.dll` for the program to compile and run successfully.

2.8 Some additional comments

The `ssc_data_t` and `ssc_module_t` data types are opaque references to internally defined data structures. The only proper way to interact with variables of these types is using the defined SSC function calls. As listed in the `sscapi.h` header file, both are typedef'd as `void*`.

3 Data Variables

Simulation model inputs and outputs are stored in a data container of type `ssc_data_t`, which is simply a collection of named variables. Internally, the data structure is an unordered map (hash table), permitting very fast lookup of variables by name. Every input and output variable in SSC is designated a *name*, a *variable type*, and a *data type*, along with other meta data (labels, units, etc).

3.1 Variable Names

The variable name is how SSC identifies data, and your program must use the predefined names to refer to the variables. A variable names may contain letters, numbers, and underscores. SSC does not distinguish between uppercase and lowercase letters, so `Beam_Irradiance` is the same variable as `beam_irradiance`.

3.2 Variable Types

The *variable type* identifies each variable as an input, output, or in-out variable. In the SSC API, these values are defined by the following constants listed below.

```
#define SSC_INPUT 1
#define SSC_OUTPUT 2
#define SSC_INOUT 3
```

Input variables must be defined before calling a module. Output variables are calculated by the module, which adds them to the data container after running. In-out variables must be defined before running the module, which changes its value after running.

From the perspective of the data container, inputs and outputs are equivalent. The data container is just a pile of data, and provides no information about whether its variables are input, output, or in-out variables. Only the simulation modules specify the variable type.

3.3 Data Types

Every variable in SSC is assigned a particular data type. Each simulation module specifies the data type of each variable it requires as input and output.

SSC can work with numbers, text strings, one-dimensional arrays, two-dimensional matrices, and tables. The data type constants are listed below.

```
#define SSC_INVALID 0
#define SSC_STRING 1
#define SSC_NUMBER 2
#define SSC_ARRAY 3
#define SSC_MATRIX 4
#define SSC_TABLE 5
```

All numbers are stored using the `ssc_number_t` data type. By default, this is a typedef of the 32-bit floating point C data type (`float`). The purpose of using `float` instead of the 64-bit `double` is to save memory. While a simulation module may perform all of its calculations internally using 64-bit precision floating point, the inputs and results are transferred into and out of SSC using the smaller data type.

Arrays (1-D) and matrices (2-D) store numbers only. There is no provision for arrays or matrices of text strings, or arrays of tables. Arrays and matrices are optimized for efficient storage and transfer of large amounts of numerical data. For example, a photovoltaic system simulation at 1 second timesteps for a whole year would produce 525,600 data points, and potentially several such data vectors might be reported by a single simulation model. This fact underscores the reasoning behind our decision to use the 32-bit floating point data type: just 20 vectors of 525,600 values each would require 42 megabytes of computer memory.

SSC stores all numbers as floating point. A module may limit a numeric variable to an integer, boolean (0 or 1), or positive value using a constraint flag as described in §3.5. The constraints are checked automatically before the module runs.

Text strings (`SSC_STRING`) are stored as 8-bit characters. SSC does not support multi-byte or wide-character string representations, and all variable names and labels use only the 7-bit ASCII Latin alphabet. Consequently, text is stored as null (`'\0'`) terminated `char*` C strings. The weather file name is a common input variable that uses the `SSC_STRING` data type.

The table (`SSC_TABLE`) data type is the only hierarchical data type in SSC. It allows a simulation module to receive or return outputs in a structured format with named fields. A table is a named variable that is itself a data container, which can store any number of named variables of any

SSC data type. Currently, most SSC modules do not make heavy use of tables, but they are fully implemented and supported for future modules that may require them.

3.4 Variable Documentation

Each module defines all of the input variables it requires and output variables it produces. The SSC functions described below return information about the variables defined by a module. Each variable specifies the information shown in Table 1.

Field	Description
Variable type	SSC_INPUT, SSC_OUTPUT, SSC_INOUT
Data type	SSC_NUMBER, SSC_STRING, SSC_ARRAY, SSC_MATRIX, SSC_TABLE
Name	Variable name (case insensitive)
Label	A description of the variable's purpose
Units	The units of the numerical value(s)
Meta	Additional information. Could specify encoding of values, see below.
Group	General category of variable, e.g. "Weather", "System Input"
Required	Specifies whether the variable must be assigned a value. See §3.5
Constraints	Constraints on the values or number of values. See §3.5
UI Hints	Suggestions on how to display this variable. Currently unused.

Table 1: Variable information provided by SSC

The `ssc_module_var_info()` function queries a module and returns a `ssc_info_t` reference. The `while` loop below calls `ssc_module_var_info()` until all of the module's variables have been displayed. This example assumes that the variable `module` was successfully created as described in §4.3 or in the example in §2.4. You can use a similar approach to list available modules with their descriptions as described in §4.6.

```
int i=0;
ssc_info_t p_inf = NULL;
while ( p_inf = ssc_module_var_info( module, i++ ) )
{
    // var_type: SSC_INPUT, SSC_OUTPUT, SSC_INOUT
    int var_type = ssc_info_var_type( p_inf );

    // data_type: SSC_STRING, SSC_NUMBER, SSC_ARRAY, SSC_MATRIX, SSC_TABLE
    int data_type = ssc_info_data_type( p_inf );

    const char *name = ssc_info_name( p_inf );
    const char *label = ssc_info_label( p_inf );
    const char *units = ssc_info_units( p_inf );
    const char *meta = ssc_info_meta( p_inf );
    const char *group = ssc_info_group( p_inf );
    const char *required = ssc_info_required( p_inf );
    const char *constraints = ssc_info_constraints( p_inf );
}
```

```

// here, you can print all of this data to text file
// or present it in another way to the user

printf( "%s %s (%s) %s\n", name, label, units, meta );
}

```

Another option for exploring a module’s variables is SSCdev. It displays the variables in an interactive GUI spreadsheet-style interface described in §6.3.

3.5 Required Variables, Constraints, and Default Values

The *Required* and *Constraints* fields of a variable’s documentation indicate whether the variable is required or optional, and whether it has a default value. Table 2 shows the *Required* flags and their meanings, and Table 3 shows the *Constraints* flags.

Flag	Description
*	Variable requires a user-specified value. If a required variable is not assigned a value before running the module, the simulation fails.
?	Optional variable. SSC ignores the variable unless a value is specified.
?=<value>	Default value, where <value> may be a number, a text string, or comma-separated array, depending on the data type of the variable.

Table 2: *Require* field tags

For some modules with a large numbers of input variables, SSC assigns default values to minimize the number of values that must be specified. SSC uses the default value unless a different value is specified. For example, the `pvwattsv1` module uses the default value of 45 degrees for `rotlim` unless the value is changed, indicating a default maximum tracker rotation angle of 45 degrees for single-axis trackers. Some other input variables may have a specialized purpose, and the default value is the recommended one for most applications. For example, the `pvwattsv1` input variable `enable_user_poa` variable enables an option to replace the weather file with data representing the array’s plane-of-array irradiance to allow for running the model with measured radiation data, or data from another model. The default value of zero is for the standard mode that uses a weather file as input.

SSC performs some data input validation before running a simulation using the *constraints* field. The field lists flags that SSC uses to limit the range of a numeric input variable, or define the required length of an input array. A selection of the flags used by SSC is listed in Table 3. These flags are defined internally by the modules, and are not user-editable. An empty *constraints* field does not necessarily indicate that the module does not check the variable’s value before running. The module writer may have inadvertently omitted a constraint flag, and may use code within the module to check the values when the module runs.

Constraints can be combined to further restrict the value of a number. For example, in `pvwattsv1`, the `track_mode` variable’s constraints field is “MIN=0,MAX=3,INTEGER”. This specification limits

Flag	Description
MIN=<value>	Specifies the minimum permissible value for a number
MAX=<value>	Specifies the maximum permissible value for a number
BOOLEAN	Requires the number to be equal to 0 (false) or 1 (true)
INTEGER	Requires the number to be an integer value
POSITIVE	Requires the number to have a positive, non-zero value
LOCAL_FILE	Requires the text string to be a local file on disk that is readable and exists

Table 3: Some constraints recognized by SSC

the possible values of the variable to 0, 1, 2, or 3, which are the numeric values associated with a fixed, 1-axis, 2-axis, or azimuth-axis tracking PV system.

3.6 Manipulating Data Containers

As we saw in the PVWatts example in §2, a data container is created and freed using the `ssc_data_create()` and `ssc_data_free()` functions. Here, some additional functions for working with data containers are explored.

The `ssc_data_unassign()` function removes a variable from the container, releasing any memory associated with it. To erase all of the variables in a container and leave it empty (essentially resetting it), use the `ssc_data_clear()` function. For example:

```
ssc_data_unassign( data, "tilt" ); // remove the 'tilt' variable
```

```
ssc_data_clear( data ); // reset the container by erasing all the variables
```

To find out the names of all variables in a container, use the functions `ssc_data_first()` and `ssc_data_next()`. These functions return either the name of a variable, or NULL if there are no more variables in the container.

The `ssc_data_query()` function returns the data type of the specified variable, which is useful for subsequently retrieving its value. The example below prints out the text of all the string variables in a data container:

```
const char *name = ssc_data_first( data );
while( name != 0 )
{
    // do something, like query the data type
    int type = ssc_data_query( data, name );

    if ( type == SSC_STRING )
    {
        const char *text = ssc_data_get_string( data, name );
        printf("string variable %s: %s\n", name, text );
    }

    name = ssc_data_next( data );
}
```

```
}
```

3.7 Assigning and Retrieving Values

This section discusses the particulars of assigning and retrieving variable values. Note that assigning a variable that already exists in the container causes the old value to be erased.

3.7.1 Numbers

Numbers are transferred and stored using the `ssc_number_t` data type. To assign a value:

```
ssc_data_set_number( data, "track_mode", 2 ); // integer value
ssc_data_set_number( data, "tilt", 30.5f ); // floating point value
```

```
ssc_number_t azimuth = 182.3f;
ssc_data_set_number( data, "azimuth", azimuth ); // from a variable
```

To retrieve a numeric value, it first must be declared because the retrieval function returns true or false. False is returned if the specified variable does not exist in the data container.

```
ssc_number_t value;
if( ssc_data_get_number( data, "tilt", &value ) )
    printf( "tilt = %f\n", value );
else
    printf( "not found\n" );
```

3.7.2 Arrays

Arrays are passed to SSC using standard C arrays (pointers), along with the length of the array. Examples:

```
ssc_number_t monthdays[12] = { 31,28,31,30,31,30,31,31,30,31,30,31 };
ssc_data_set_array( data, "nday", monthdays, 12 );
```

```
// dynamically allocate an array of size len
ssc_number_t *xx = (ssc_number_t*) malloc( sizeof(ssc_number_t)*len );
for( i=0; i<len; i++ ) xx[i] = i*i;
```

```
ssc_data_set_array( data, "isquared", xx, len );
```

```
free( xx ); // SSC does not take ownership, so free any arrays here.
```

Note: When assigning an array, SSC makes an internal copy, and does not take ownership of the array passed in. Thus it is up to the user to deallocate any memory created in the client code as appropriate.

Array data is retrieved from SSC using the `ssc_data_get_array()` function. The length of the retrieved array is returned in the length reference parameter. If the requested variable is not assigned, or is not an `SSC_ARRAY`, NULL is returned. Example:

```
int len = 0;
const ssc_number_t *array = ssc_data_get_array( data, "xx", &len );

if( array != NULL && len > 0 )
{
    printf("len: %d, first item=%f\n", len, array[0] );
}
```

Note: The `ssc_data_get_array()` returns a reference to internally managed memory: do not deallocate or otherwise change the array returned by it. This is done to improve efficiency when working with large data vectors.

3.7.3 Matrices

Matrices are two dimensional arrays of numbers. In SSC, matrices are stored as one contiguous array, in row-major order. Like arrays, they consist of `ssc_number_t` data and are passed to SSC using standard C arrays, along with the number of rows and columns.

Row-major ordering means that the two dimensional array is flattened into a single dimensional vector. In a 4x3 matrix, the flattened vector will have 12 values in which indices [0..3] represent the first row, [4..7] the second row, and [8..11] the third row. Example:

```
ssc_number_t mat[12] = { 4,4,5,1,
                        6,7,2,5,
                        1,6,2,3 };
```

```
ssc_data_set_matrix( data, "mat1", mat, 4, 3 );
```

Note: SSC creates an internal copy of the matrix passed to `ssc_data_set_matrix()`. If the matrix was allocated dynamically, it is up to the user written client code to deallocate it properly: SSC does not take ownership.

Matrices are returned in the same format. If the requested variable does not exist or is not a matrix, NULL is returned. Example:

```
int nrows, ncols;
ssc_number_t *mat = ssc_data_get_matrix( data, "mat1", &nrows, &ncols );

if( mat != NULL && nrows == 4 && ncols == 3 )
{
    int r, c, index = 0;
    for( r=0; r<nrows; r++ )
        for( c=0; c<ncols; c++ )
            printf( "mat[%d,%d]=%f\n", r, c, mat[index++] );
}
```

Note: The `ssc_data_get_matrix()` returns a reference to internally managed memory: do not deallocate or otherwise change the array returned by it.

3.7.4 Strings

SSC supports null-terminated ASCII text strings as a data type. Setting a string value is straightforward. SSC creates an internal copy of the string data. Examples:

```
ssc_data_set_string( data, "weather_file", "c:/Data/Weather/TX Abilene.tm2" );
```

```
const char *location = "Hawaii";  
ssc_data_set_string( data, "location", location );
```

Retrieving strings is similarly straightforward:

```
const char *location = ssc_data_get_string( data, "location" );  
if( location != NULL )  
    printf("location = %s\n", location );
```

Note: Do not free or modify the pointer returned by `ssc_data_get_string()`. A reference to an internally managed character byte array is returned.

3.7.5 Tables

Tables provide a way to communicate data to SSC in a hierarchical structure format. This data type is not used by any of the current SSC modules. (SSCdev (§6) fully supports tables.) Before a table can be assigned, it must be created and filled with variables. A table is simply a normal data container. Example:

```
ssc_data_t table = ssc_data_create(); // create an empty table  
ssc_data_set_string( table, "first", "peter" );  
ssc_data_set_string( table, "last", "jones" );  
ssc_data_set_number( table, "age", 24 );  
  
ssc_data_set_table( data, "person", table ); // assign the table  
  
ssc_data_free( table ); // free the table after it is assigned
```

Since a table is just an `ssc_data_t` object, it can store any SSC data type, including another table. This structure allows for nested tables, as potentially needed by a future complicated simulation module.

Note: SSC creates an internal copy of the table and all of its variables. As such, the table should be deallocated after it is assigned, per the example above.

Retrieving a table is straightforward:

```
ssc_data_t table = ssc_data_get_table( data, "person" );  
if( table != NULL )
```



```

{
    printf( "person.first = %s\n", ssc_data_get_string( table, "first" ) );
    printf( "person.last = %s\n", ssc_data_get_string( table, "last" ) );
}
// do not free the 'table' variable: it is internal to SSC

```

Note: The `ssc_data_get_table()` function returns an internal reference to a data container. Do not deallocate or otherwise modify the returned reference.

Note that the `ssc_data_first()` and `ssc_data_next()` functions described in §3.6 can be used to determine all of the fields of a table.

4 Simulation Modules

The SSC framework exposes several simulation modules that calculate outputs given inputs. Each module can run independently of all the others, provided that all the input variables that are required are provided by the user. The System Advisor Model (SAM) tool often runs several SSC modules in succession to simulate the whole system performance and economic evaluation. In between successive calls to different SSC modules, SAM may change the names or scale the output variables of one module to set it up with appropriate inputs for the next one.

Table 4 shows the SSC simulation modules at the time of this writing. You can generate a list of current modules with descriptions using the method described in §4.6. Most of the SSC modules are available in the SAM user interface as a performance or financial model option, or as an option for modeling a component of the system.

SSC provides for ways to invoke a simulation module. Each method involves a different level of interaction during the execution of the model, differences in how errors and warnings are retrieved, and the appropriateness for use in a multithreaded environment.

4.1 Simple Method 1: Return True or False

The simplest way to call a module is to use the `ssc_module_exec_simple()` function. This method prints any warnings or errors to the console, and simply returns true or false. The PVWatts example from earlier could be written as:

```

ssc_data_t data = ssc_data_create();
ssc_data_set_string( data, "file_name", "TX Abilene.tm2" );
ssc_data_set_number( data, "system_size", 4 );
ssc_data_set_number( data, "derate", 0.77f );
ssc_data_set_number( data, "track_mode", 0 );
ssc_data_set_number( data, "tilt", 20 );
ssc_data_set_number( data, "azimuth", 180 );

if( ssc_module_exec_simple( "pvwattsv1", data ) )
{

```

Module	Description
6parsolve	Calculates a set of parameters from manufacturer module specifications for the CEC module model
annualoutput	Calculates Year 1 hourly and monthly, and Years 2 and later total annual system output for use in cash flow calculations
cashloan	Residential and commercial financial model
equpartflip	Partnership flip financial models
geothermal	Geothermal power model
geothermalui	Calculates interim design values for the geothermal power model
ippppa	Commercial PPA and Independent Power Producer (IPP) financial models
irradproc	General purpose irradiance processor for calculating POA
levpartflip	Leveraged partnership flip financial model
pv6parmod	CEC module model
pvsandiainv	Sandia inverter model
pvsamv1	Flat-plate PV model
pvwattsfunc	Runs a the PVWatts model for a single timestep instead of as an 8760 hourly model
pvwattsv1	PVWatts model
saleleaseback	Sale lease back financial model
singleowner	Single owner financial model
swh	Solar water heating model
test_irr	Internal rate of return calculator from utility financing models for testing
test_pvshade	PV self-shading model for testing
timeseq	Converts start time, end time, and time step into arrays of time stamps (seconds, minutes, hours, days, months)
utilityrate	Calculates the value of energy using complex utility rate structures
wfreader	Reads format weather data files in the following formats: TMY2, TMY3, EPW, SMW)
windpower	Wind power model

Table 4: List of SSC simulation modules

```

    int i, len;
    ssc_number_t ac_sum = 0;
    ssc_number_t *ac = ssc_data_get_array( data, "ac", &len );
    for( i=0;i<len;i++ ) ac_sum += ac[i];
    printf( "success, ac: %f Wh\n", ac_sum );
}
else
    printf( "an error occurred\n" );

ssc_data_free( data );

```

Note that there is no need to explicitly create an `ssc_module_t` object using `ssc_module_create()`; the function will return false if the module name specified could not be found or could not be created.

The `ssc_module_exec_simple()` function is thread-safe, provided that the module called is itself thread-safe. It is intended that all SSC modules are implemented in a thread-safe manner. The primary downside to using this simple invocation method is that the host program receives no progress updates, and the error messages and warnings cannot be programmatically retrieved after the module has finished running.

4.2 Simple Method 2: Return First Error Message

The second module invocation method is very similar to the first, except that the first error message is returned to the caller. Because this function uses a global variable to store the first error messages during the course of module execution, this invocation method should not be used in a multithreaded host environment. This is explicitly indicated by the `_nothread` suffix on the function name. Example:

```

// ... set up a data container with inputs ...

const char *error = ssc_module_exec_simple_nothread( "pvwattsv1", data );
if( error == NULL )
    printf("success!\n");
else
    printf( "module failed with error: %s\n", error );

```

In this case, a NULL return value indicates that no error occurred. As with the simplest method 1, there is no way to retrieve additional errors or warnings after the module has finished running. Progress updates are also not provided to the calling environment.

4.3 Explicit Module Instantiation

A third way to run a computation module is to explicitly create a module object, execute it with a data container, and then release it. This is the method we used for the PVWatts example in §2.4.

The SSC function `ssc_module_create()` function is used to create a new instance of a computation module. The function returns an opaque reference of type `ssc_module_t` to the module object, or returns `NULL` if the module could not be created. The single parameter required is the name of the module requested. If a module is created successfully, it must eventually be released when it is no longer needed via the `ssc_module_free()` function. Example:

```
// ... set up a data container with inputs ...
ssc_module_t module = ssc_module_create( "cashloan" );
if ( NULL == module )
    printf("could not create 'cashloan' module!\n");
else
{
    // ... query the module for variable info or run it ...

    // free the module when it is no longer needed
    ssc_module_free( module );
}
```

The advantage of explicitly creating a module is that all errors, warnings, and log messages generated during the course of the module's execution will be saved and can be later retrieved using the `ssc_module_log()` function, which is described subsequently in detail in §4.5. Alternatively, if the goal is simply to obtain information about the input and output variables associated with a module as in §3.4, the module must be explicitly instantiated also.

The next section describes a mechanism for running compute modules and providing real-time progress updates, reporting messages as they occur, and canceling a module's execution before it has finished.

4.4 Running with Progress Updates, Warnings, and Errors

The last (most complex) way to run a module is to provide a special function that can handles error and warning messages as they are generated, as well as provide progress updates to the controlling host software. To accomplish this, the client code must provide a *handler* (aka *callback*) function to SSC. The handler function must have the signature below.

```
ssc_bool_t (*handler)( ssc_module_t module,
    ssc_handler_t handle,
    int action,
    float f0,
    float f1,
    const char *s0,
    const char *s1,
    void *user_data );
```

Note: This module invocation method is only supported in the native C language API for SSC. The other programming language interfaces provided with SSC (MATLAB, Python, C#, Java) do not support callback functions via the foreign-function-interface (FFI) wrappers. However, log messages (notices, warnings, errors) can still be retrieved after a simulation is completed using the `ssc_module_log()` function (see §4.5), although real-time progress updates cannot be issued.

Supposing that such a function named `my_ssc_handler_function()` has been defined, used the `ssc_module_exec_with_handler()` function to run the module. You may pass an a generic data pointer to the function also, so that within the context of the handler the messages or progress updates can be routed accordingly.

```
void *my_data = <some user data to send to the callback, or NULL>;

if ( ssc_module_exec_with_handler( module, data, my_ssc_handler_function, my_data ) )
    printf("success!\n");
else
    printf("fail!\n");
```

The code below represents the default handler built into SSC. Note that the handler function must return a boolean (0/1) value to indicate to SSC whether to continue simulating or not. This provides the option to abort the simulation if a user has clicked a cancel button in the meantime, or similar. The various parameters are used to convey SSC status information to the handler, and have different meanings (and data) depending on the `action_type` parameter.

```
static ssc_bool_t default_internal_handler( ssc_module_t p_mod, ssc_handler_t p_handler,
    int action_type, float f0, float f1,
    const char *s0, const char *s1,
    void *user_data )
{
    if (action_type == SSC_LOG)
    {
        // print log messages to console
        std::cout << "Log ";
        switch( (int)f0 ) // determines type
        {
            case SSC_NOTICE:
                std::cout << "Notice: " << s0 << " time " << f1 << std::endl;
                break;
            case SSC_WARNING:
                std::cout << "Warning: " << s0 << " time " << f1 << std::endl;
                break;
            case SSC_ERROR:
                std::cout << "Error: " << s0 << " time " << f1 << std::endl;
                break;
            default:
                std::cout << "Unknown: " << f0 << " time " << f1 << std::endl;
                break;
        }
    }
}
```

```

    }
    return 1;
}
else if (action_type == SSC_UPDATE)
{
    // print status update to console
    std::cout << "Progress " << f0 << "%:" << s1 << " time " << f1 << std::endl;
    return 1; // return 0 to abort simulation as needed.
}
else
    return 0;
}

```

As noted in previous sections, the default handler simply prints warnings, errors, and simulation progress updates to the standard output stream on the console. To implement a custom handler, it is recommended to copy the structure of the handler above, but to replace the output to the console with specialized handling for the messages and progress. For example, in a graphical user interface program, the `user_data` pointer could be used to pass in a pointer to a dialog class containing a progress bar and a text box. The messages could be sent to the text box, and the progress bar updated appropriately. The custom SSC handler function implemented in the graphical SSCdev tool (based on the excellent wxWidgets GUI library) is reproduced below, showing how messages and progress can be reported to the user.

```

static ssc_bool_t my_handler( ssc_module_t p_mod, ssc_handler_t p_handler, int action,
    float f0, float f1, const char *s0, const char *s1, void *user_data )
{
    wxProgressDialog *dlg = (wxProgressDialog*) user_data;
    if (action == SSC_LOG)
    {
        wxString msg;

        switch( (int)f0 )
        {
            case SSC_NOTICE: msg << "Notice: " << s0 << " time " << f1; break;
            case SSC_WARNING: msg << "Warning: " << s0 << " time " << f1; break;
            case SSC_ERROR: msg << "Error: " << s0 << " time " << f1; break;
            default: msg << "Unknown: " << f0 << " time " << f1; break;
        }

        // post the SSC message on the application-wide log window
        app_frame->Log(msg);

        return 1;
    }
    else if (action == SSC_UPDATE)
    {
        // update progress dialog with percentage complete
    }
}

```

```

        dlg->Update( (int) f0, s0 );
        wxGetApp().Yield(true);

        return 1; // return 0 to abort simulation as needed.
    }
    else
        return 0; // invalid action
}

```

The return value of the handler function is checked by compute modules to determine whether the calculations should proceed. In the example above, no facility is provided for canceling a simulation as the handler function always returns 1 (true). However, a dialog box with a cancel button could set a flag in the user data structure when pressed. If the cancel flag is set to true, the handler function could return 0 (false) to abort the simulation. It is left as an exercise to the user to implement such functionality in their host program.

4.5 Retrieving Messages

During simulation, a module may generate any number of (hopefully) informative messages about warnings or errors encountered. The custom handler approach allows these messages to be reported to the user as the simulation progresses, but they are also stored in the module for retrieval later. The `ssc_module_log()` function allows the client code to retrieve all the messages, regardless of which execute function was used to run the module. Example:

```

const char *text;
int type;
float time;
int index = 0;
while( (text = ssc_module_log( module, index++, &type, &time )) )
{
    switch( type ) // determines type
    {
        case SSC_NOTICE:
            std::cout << "Notice: " << text << " time " << time << std::endl;
            break;
        case SSC_WARNING:
            std::cout << "Warning: " << text << " time " << time << std::endl;
            break;
        case SSC_ERROR:
            std::cout << "Error: " << text << " time " << time << std::endl;
            break;
        default:
            std::cout << "Unknown: " << text << " time " << time << std::endl;
            break;
    }
}

```

In essence, the `ssc_module_log()` is called repeatedly with an increasing index number until the function returns `NULL`, indicating that there are no more messages. Along with the text of the message, information about the type (notice, warning, error) and the time that it was issued by the module are reported.

Note: Do not free the C string returned by `ssc_module_log()`. It is a reference to internally managed memory.

4.6 Querying SSC for Available Modules

SSC provides a programming interface by which the library can be queried about all of the modules contained within it. The example below prints all of the available modules to the console along with their version numbers and descriptions:

```
ssc_entry_t entry;
int index = 0;
while( entry = ssc_module_entry( index++ ) )
{
    const char *module_name = ssc_entry_name( entry );
    const char *description = ssc_entry_desc( entry );
    int version = ssc_entry_version( entry );

    printf( "Module %s, version %d: %s\n", module_name, version, description );
}
```

5 Version Information

Functions are included in SSC to return version information and details about the particular build. For example:

```
int version = ssc_version();
const char *build = ssc_build_info();

printf( "ssc version %d: %s\n", version, build );
```

On Windows, this code may print:

```
ssc version 22: Windows 32 bit Visual C++ Nov 13 2012 18:44:14
```

On Linux, a newer version of SSC may report something like:

```
ssc version 24: Unix 64 bit GNU/C++ Dec 5 2012 11:42:51
```


Operating System	Directory Name	SSCdev Version	Library
Windows 32-bit	win32	sscdev32.exe	ssc32.dll
Windows 64-bit	win32	sscdev64.exe	ssc64.dll
OS X 64-bit	osx64	sscdev.app	ssc64.dylib
Linux 64-bit	linux64	sscdev64.bin	ssc64.so

Table 5: SSCdev and Library Versions

6 SSCdev

SSCdev is the developer interface for SSC. It allows you to explore variables in the SSC modules, run individual modules, and write scripts to build and test your models. When you run modules in SSCdev, it displays all of the variables in the data container with their values.

Use SSCdev for the following tasks:

- Learn how modules you plan to use in your model work before before you start programming.
- Troubleshoot problems with your implementation of SSC modules.
- Build and test models in the LK script using the SSCdev script editor.

6.1 Using SSCdev

Using SSCdev involves running the executable, and loading the appropriate SSC library:

1. Run the executable file shown in Table 5 for your operating system. For example, the 32-bit Windows executable `sscdev32.exe` is in the `win32` directory of the SDK package.
2. On the **File** menu, click **Choose SSC library**. Be sure to choose the correct library for your version of SSCdev. For example, for 32-bit Windows, choose the `ssc32.dll` library.

A list of modules should appear in the module browser, and the library path and name should appear in the status bar at the bottom of the SSCdev window. If the module browser is empty, try choosing the SSC library again.

3. Click a module's name to see its variables. For example, click `pvwattsv1` to see a list of the PVWatts module's 46 variables.

Note: To see the SSCdev version information, on the **Help** menu, click **About**.

SSCdev displays a list of available modules, and lists each module's input and output variables, but does not provide enough information to completely understand the modules. You should be prepared to use the SAM user interface and documentation together with SSCdev to help you understand how the modules and variables work.

For example, the `annualoutput` module includes a variable named `energy_availability` that uses the data type `SSC_ARRAY`. Why is the data type not `SSC_NUMBER` instead? To find out, we can examine the `annualoutput` input variables in SAM's user interface, which displays them on the Performance Adjustment input page. The `energy_availability` variable appears with the label

“Percent of annual output,” and SAM provides two options for entering the variable’s value: As a single value or as an annual schedule. The array data type is necessary to store the annual values. The **annualoutput** module assumes that if there is a single non-zero value at the top of the array, that value represents a single adjustment factor that applies to all years. Otherwise it applies values from the array to each year.

For some variables, even the SAM user interface may not be helpful. When you need help with an SSC module or variable, ask a question as a comment on the SAM website’s SDK page. For example, you might wonder what the **annualoutput** module’s **system_use_lifetime_output** variable does. That variable is not on any of SAM’s input pages, and the information in SSCdev does not explain its function. The variable determines whether the module generates a single set of 8,760 hourly values for the **hourly_e_net_delivered** variable, or whether it generates a set of 8,760 values for each year in the analysis period. All of SAM’s performance models use a value of zero except for the geothermal model, which is a special case and requires lifecycle output data to accurately represent changes in resource over time as it is depleted and replenished. For most cases, you should set its value to zero.

6.2 SSCdev Menus

File

Start simulation Runs the active module in the module browser.

Load/unload SSC library Loads or unloads the current SSC library for troubleshooting. If a module does not run, you can try unloading and reloading the library.

Choose SSC library Displays a file dialog where you can choose and load the SSC library. Be sure to choose the correct library for your version of SSCdev.

Load data file Open a data file. (.bdat).

Save data file Save the variables in the data container to a data file. (.bdat).

Recent files Display a list of recent data (.bdat) and script (.lk) files.

Exit Quit SSCdev.

Script

The Script menu commands duplicate the buttons in the Script Editor. They are implemented as menu items to make the shortcut keys available.

Open Open a script file (.lk).

Save Save the current script.

Find Find text in the current script.

Find next Find the next instance of a text string in the current string.

Run script Run the current script.

Help

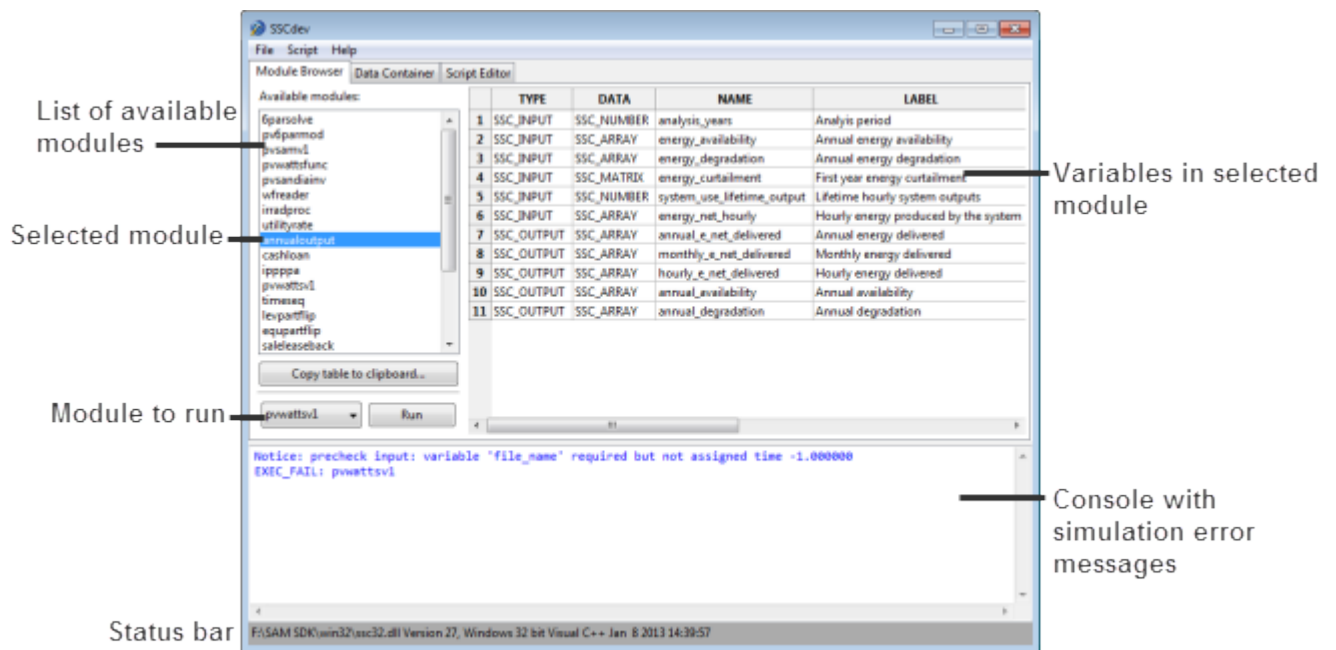


Figure 1: Module browser

The **About** command displays information about the current version of SSCdev.

6.3 Module Browser

The module browser displays the modules available in the current SSC library. When you choose a module from the list, it also shows a list of the module's variables. It can:

- Display a list of available SSC modules.
- Display module variables.
- Copy a tab-delimited list of a module's variables to your computer's clipboard.
- Run a single module using variable values defined in the data container.

Note: If the module browser is empty, check the status bar at the bottom of the SSCdev window to see whether the correct SSCdev library is loaded. See §?? for instructions to load a library.

You can use the module browser as a reference while you are developing your model to help ensure that you assign values to all of the required input variables, and use the correct data types and units.

You can also use the module browser with the data container to manually set values of input variables and run modules individually. This might be useful for learning how a module works, or

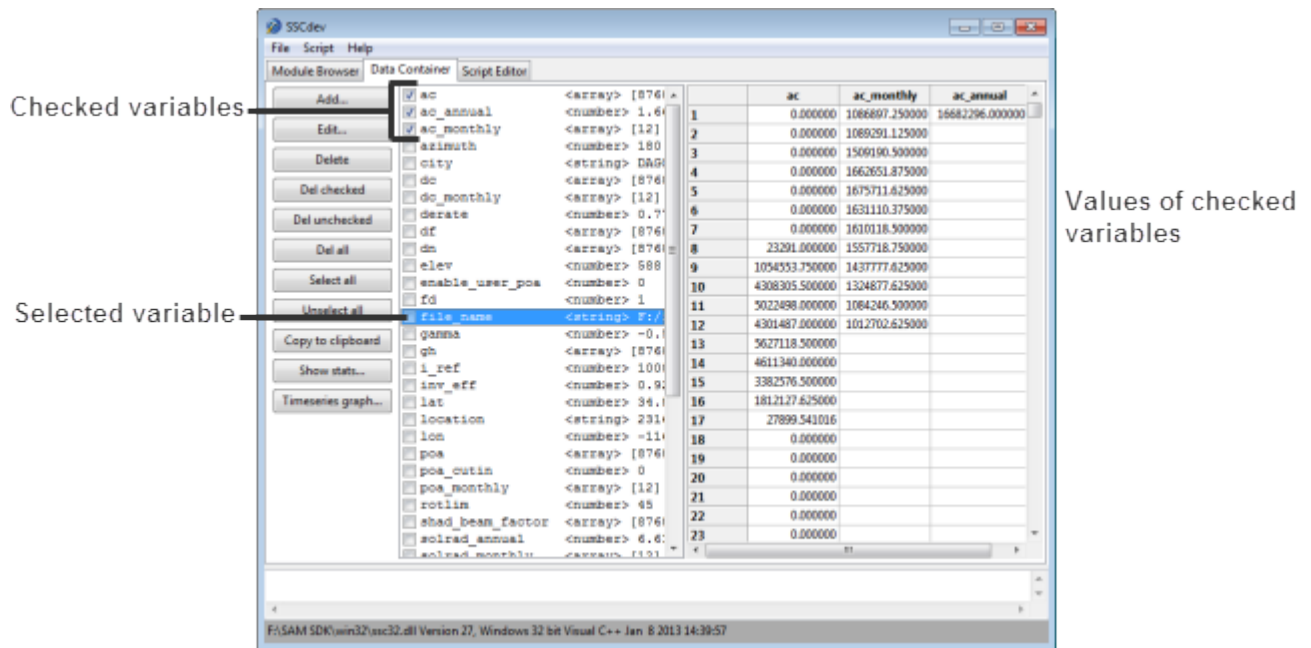


Figure 2: Data container

for troubleshooting your model's implementation of a module.

6.3.1 Run a Simulation from the Module Browser

To run a simulation from the module browser, choose a module from the list and click **Run**. SSCdev displays information about the simulation in the notification pane.

6.4 Data Container

The data container displays a list of variables for the current set of simulations. When you run a module from the data browser, you must add input variables to the data container by hand using the **Add** and **Edit** buttons. When you run modules from the script editor, the data container is automatically populated with variables from the script. You can use the data container commands for the following tasks:

- Add, edit, and remove variables from the data container.
- Copy a tab-delimited list of variable names and values to your computer's clipboard.
- Show graphs of time series data.

The data container commands act either on the selected variable indicated with a blue highlight, or on variables with a check mark:

Add Add a variable to the data container. If you add a module's input variable to the data container, be sure to use the variable's exact name and data type as it appears in the module browser.

Edit Change the selected variable's name, data type, or value.

Delete Remove the selected variable from the data container.

Del checked Remove all variables with check marks from the data container.

Del unchecked Remove all variables without check marks from the data container.

Del all Delete all variables from the data container.

Select all Check all variables in the data container. This command may take several seconds to complete.

Unselect all Clear check marks from all variables in the data container.

Copy to clipboard Copy the data container table as a tab-delimited list of selected variable names and their values to the clipboard.

Show stats Display a table of statistics for the selected variable, which must be of type `SSC_ARRAY` with 8,760 values.

Timeseries graph Display time series and statistical graphs of variables with check marks, which must be of type `SSC_ARRAY` with 8,760 values.

Note: If you manually add variables to the data container before running a script that does not use the variables, they will be deleted from the data container.

6.4.1 Data Files

You can save and open the contents of the data container in a data file (`.bdat`) using the **Save data file** and **Load data file** commands on the File menu. The data files use a binary format, and store all of the variables in the data container.

6.4.2 Time Series Graphs and Statistical Tables

When the data container includes hourly arrays with 8,760 values, you can display the hourly data and statistical summaries:

Select an hourly array and click **Show stats** to display a statistical summary of the array data in a table. You can export data from the monthly table by selecting it using your computer's copy-to-clipboard keyboard shortcut (Ctrl-C) in windows.

Check one or more hourly arrays and click **Timeseries graph** time series data and statistical summaries in graphs. You can export graph images and tables of graph data by right-clicking graphs and selecting commands in the shortcut menu.

See §?? for an example.

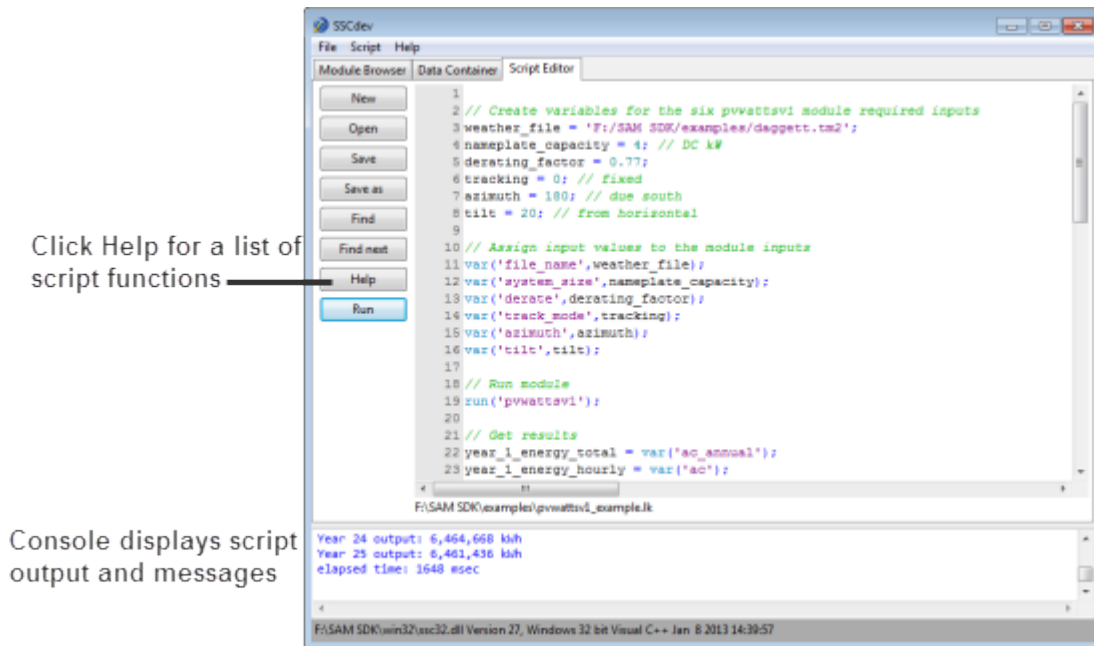


Figure 3: Script editor

6.5 Script Editor

The script editor allows you to write, edit, and run scripts in the LK scripting language to build and test models using the SSC modules.

For a list of script functions, click **Help**.

The script editor commands are:

New Clear the current script from the script editor.

Open (Ctrl-O) Open a script file (.lk).

Save (Ctrl-S) Save the current script file (.lk).

Save as Save the current script to a different file (.lk).

Find (Ctrl-F) Find text in the current script.

Find next (F3) Find the next instance of text in the current script.

Help Display a list of script functions.

Run (F5) Run the current script.

6.6 SSCdev Example 1: Run a Simulation Module without Scripting

The following example shows how to use the module browser to explore and run the `pvwattsv1` module. You can use the same steps to explore other simulation modules.

Note: As described in §??, the module browser can only run a single simulation module at a time. To combine modules to build a model, you can write a script as described in §??.

As we saw in §1.2, the `pvwattsv1` simulation module reads data from a weather file and inputs from the data container that define the system's size, array orientation and type of tracking, and derating factor, and calculates values for the 1 by 8760 array storing the system's hourly electricity output over a single year.

To explore the `pvwattsv1` simulation module in the module browser:

1. Start SSCdev and be sure the correct SSC library is loaded as described in §??
2. On the **Module Browser** tab, click the `pvwattsv1` name to see a list of the module's variables. The inputs are of type `SSC_INPUT`. Of the inputs, only a subset indicated by (*) are required and have no default value, as described in §3.5. At a minimum, you must assign values to these variables to run the module.
3. In the drop-down list under the list of available modules, choose the `pvwatts1` module and click **Run** (or press **F6**).

A message about the `file_name` variable appears in the SSCdev notification panel. That is because `file_name` is a required variable, but it does not yet have a value.

4. In the variable viewer, click **Add**, and type "file_name" for the variable name, assign it the `SSC_STRING` data type, and click **file** to assign it the value of one of the TMY2 files included in the SDK Examples folder (for example, *daggett.tm2*).
5. Next, add the remaining 5 required variables shown in the module browser, using the data type and units shown in the table. For example, `system_size` should be `SSC_NUMBER` with a value in kilowatts. Be sure to use variable names and data types that exactly match those in the module browser.

When you are finished, you should see a table similar to Table 6. This is the model's data container, which so far contains the required input for the `pvwattsv1` simulation module.

6. Press **F6**, or on the module browser, click **Run** to run the module.

The data container should now show a table with all of the `pvwattsv1` module variables. You can edit and view the variable values:

- Use the check boxes to add or remove variables from the table. Double-click the variable's name to edit it (or select the variable and click **Edit**).
- Display graphs of any array with 8,760 values. For example, to view the cell temperature and AC output variables, clear all of the check boxes, check the `tcell` and `ac` variables, and click **Time series graph**.
- Display a table of statistical values for any variable with 8,760 values. For example, select

file_name	system_size	derate	track_mode	azimuth	tilt
.../daggett.tm2	4	0.77	0	180	20

Table 6: The 6 required input variables for the pvwattsv1 module with their values

the **poa** variable to show the plane-of-array irradiance minimum, maximum, total, mean, and monthly values, and click **Show stats**.

Note: To display the statistical summary of an hourly variable, select it by clicking its name in the list rather than checking it.

6.7 SSCdev Example 2: Use a Script to Build a Model

This example first runs the **pvwattsv1** simulation module as we did in Example 1, and then combines it with the **annualoutput** module to create a simple model that estimates a PV system’s annual output over a multi-year period.

The first part of the script performs three tasks:

1. Assign values to the required input variables for **pvwattsv1**.
2. Run the module.
3. Display the total annual output.

The next part of the script uses the system’s AC output calculated by the **pvwattsv1** module to estimate the system’s total annual output over multiple years:

1. Assign values to the required input variables for **annualoutput**.
2. Run the module.
3. Display the year-by-year output.

The **pvwattsv1** module’s required input variables are shown in Table 6. The module browser shows each variable’s data type, units, and any constraints.

```
// Create variables for the six pvwattsv1 module required inputs
weather_file = 'F:/SAM SDK/examples/daggett.tm2';
nameplate_capacity = 4; // DC kW
derating_factor = 0.77;
tracking = 0; // fixed
azimuth = 180; // due south
tilt = 20; // from horizontal

// Assign input values to the module inputs
var('file_name',weather_file);
var('system_size',nameplate_capacity);
var('derate',derating_factor);
var('track_mode',tracking);
```



```

var('azimuth',azimuth);
var('tilt',tilt);

// Run module
run('pvwattsv1');

// Get results
year_1_energy_total = var('ac_annual');
year_1_energy_hourly = var('ac');

sum_of_hourly = sum(year_1_energy_hourly);

// Display results
outln("Year 1 output: " + sprintf('%',',to_int(year_1_energy_total)) + " kWh");
outln(" as sum of hourly output: " + sprintf('%',',to_int(sum_of_hourly)) + " Wh");
outln();

```

The next part of the script uses the `annualoutput` module to calculate the system's output over a multi-year period. It has the six required inputs shown in Table 7.

Name	Data Type	Units
analysis_years	SSC_NUMBER	years
energy_availability	SSC_ARRAY	%
energy_degradation	SSC_ARRAY	%
energy_curtailment	SSC_MATRIX	none
system_use_lifetime_output	SSC_NUMBER	none
energy_net_hourly	SSC_ARRAY	kW

Table 7: The six required input variables for the `annualoutput` module

The module browser does not provide information about the size of the `energy_availability` and `energy_degradation` arrays, or the `energy_curtailment` matrix. We can refer to the SAM user interface to explore those variables further. SAM displays them on the Performance Adjustment page as shown in Table 8.

Variable	Name in SAM	Size
energy_availability	Percent of annual output	1x1 to 1x50
energy_degradation	Year-to-year decline in output	1x1 to 1x50
energy_curtailment	Hourly Factors	24x12

Table 8: Information from the SAM user interface about the inputs to `annualoutput`

The SAM user interface allows the **Percent of annual output** (`energy_availability`) and **Year-to-year decline in output** (`energy_degradation`) variables to be specified either as a single value or as an "annual schedule." The input table for the annual schedule has a maximum size of 50 rows, indicating the maximum size of the arrays. If the array has a single value, `annualoutput` applies that value to each year in the analysis period. This behavior is described in SAM's Help system.

The 24 columns and 12 rows of the input table for the **Hourly Factors** variable shows the dimensions of the (energy_curtailment) matrix.

```
// Create variables for the annualoutput module required inputs
// system_output already defined above
analysis_period = 25;
availability = [98];
degradation = [0.05];
curtailment = [ [1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1],
                 [1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1],
                 [1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1],
                 [1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1],
                 [1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1],
                 [1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1],
                 [1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1],
                 [1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1],
                 [1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1],
                 [1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1],
                 [1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1],
                 [1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1],
                 [1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1] ];

hourly_mode = 0;

// Assign input values to the module inputs
var('analysis_years', analysis_period);
var('energy_availability', availability);
var('energy_degradation', degradation);
var('energy_curtailment', curtailment);
var('system_use_lifetime_output', hourly_mode);
var('energy_net_hourly', year_1_energy_hourly);

// Run module
run('annualoutput');

yearly_energy = var('annual_e_net_delivered');

for ( i = 1; i <= analysis_period; i++)
{
    outln("Year " + i + " output: " + sprintf('%',to_int(yearly_energy[i])) + ( " kWh"));
}
```

7 Language Interfaces

The SSC software development kit (SDK) includes interfaces for using SSC directly from programming languages other than its native C language interface. This section describes each language interface's system and software requirements, as well any limitations in functionality compared with the native C interface.

7.1 Python

Python is a popular object-oriented scripting language that is either interpreted directly from source code or compiled into an intermediate bytecode. Most installations of the Python interpreter include the *Ctypes* package, which provides a *foreign function interface (FFI)* capability for directly utilizing dynamic libraries.

The Python language interface has been tested on Windows using the popular ActivePython distribution, as well as on Linux and OSX using the pre-installed Python packages.

The Python API is defined in the `sscapi.py` source file included in the SDK. The file includes example code if it is invoked as the main source program.

Note: In the PySSC class constructor, a *Ctypes* object is created by referencing the `ssc.dll` dynamic library. It is up to the user to modify the file name and/or path of this library to be appropriate for the operating system and platform.

The structure of SSC API calls in Python is slightly different from the C interface, since an instance of the PySSC class must be created first. Example:

```
ssc = PySSC()
dat = ssc.data_create()

ssc.data_set_string(dat, 'file_name', 'daggett.tm2')
ssc.data_set_number(dat, 'system_size', 4)
ssc.data_set_number(dat, 'derate', 0.77)
ssc.data_set_number(dat, 'track_mode', 0)
ssc.data_set_number(dat, 'azimuth', 180)
ssc.data_set_number(dat, 'tilt_eq_lat', 1)

# run PV system simulation
mod = ssc.module_create("pvwattsv1")

if ssc.module_exec(mod, dat) == 0:
    print 'PVWatts V1 simulation error'
    idx = 1
    msg = ssc.module_log(mod, 0)
    while (msg != None):
        print '\t: ' + msg
        msg = ssc.module_log(mod, idx)
```

```

        idx = idx + 1
    else:
        ann = 0
        ac = ssc.data_get_array(dat, "ac")
        for i in range(len(ac)):
            ac[i] = ac[i]/1000
            ann += ac[i]
        print 'PVWatts V1 Simulation ok, e_net (annual kW)=', ann
        ssc.data_set_array(dat, "e_with_system", ac) # copy over ac

    ssc.module_free(mod)

    ssc.data_free( dat )

```

Notice that the structure of creating and freeing data containers and modules is identical to the C language API, except that the functions are members of the PySSC class. For more information, peruse the `sscap_i.py` source file for additional examples and usage cases.

7.2 MATLAB

MATLAB is a numerical computing language that is widely used for data processing, algorithm development, and plotting. It is a proprietary product that is available on OSX, Linux, and Windows.

The SSC MATLAB interface has been tested with MATLAB 7.5 (2007b) 32-bit on Windows. The built-in MATLAB *foreign function interface (FFI)* library routines that are used to interface to SSC require a C compiler to be installed on the computer alongside MATLAB to automatically preprocess the SSC header file. Some versions of MATLAB include a C compiler such as LCC installed by default, while other versions and/or platforms may require one to be installed separately. See <http://www.mathworks.com/support/compilers/R2012b/win64.html> for more information.

The SSC API is provided in the `ssccall.m` M-file. The interface provides a single MATLAB function called `ssccall(...)` that accepts different parameter arguments to invoke the various SSC library calls. The example below shows how to setup and run the *pvwattsv1* module from MATLAB.

```

ssccall('load');

% create a data container to store all the variables
data = ssccall('data_create');

% setup the system parameters
ssccall('data_set_string', data, 'file_name', 'abilene.tm2');
ssccall('data_set_number', data, 'system_size', 4);
ssccall('data_set_number', data, 'derate', 0.77);
ssccall('data_set_number', data, 'track_mode', 0);

```

```

ssccall('data_set_number', data, 'tilt', 30);
ssccall('data_set_number', data, 'azimuth', 180);

% create the PVWatts module
module = ssccall('module_create', 'pvwattsv1');

% run the module
ok = ssccall('module_exec', module, data);
if ok,
    % if successful, retrieve the hourly AC generation data and print
    % annual kWh on the screen
    ac = ssccall('data_get_array', data, 'ac');
    disp(sprintf('pvwatts: %.2f kWh',sum(ac)/1000.0));
else
    % if it failed, print all the errors
    disp('pvwattsv1 errors:');
    ii=0;
    while 1,
        err = ssccall('module_log', module, ii);
        if strcmp(err,''),
            break;
        end
        disp( err );
        ii=ii+1;
    end
end

% free the PVWatts module that we created
ssccall('module_free', module);

% release the data container and all of its variables
ssccall('data_free', data);

% unload the library
ssccall('unload');

```

The MATLAB language interface automatically attempts to detect the platform and load the correct SSC dynamic library. You must ensure that the `sscapi.h` C language header file can be located by MATLAB, as well as the library appropriate for your system.

For additional information, consult the MATLAB code examples supplied with the SSC SDK, as well as the content of the `ssccall.m` file itself.

7.3 C# and .NET

The C# language interface provides direct access to the SSC library from the Microsoft .NET software environment. C# is an object-oriented garbage-collected language that is compiled typically to an intermediate bytecode that is executed in a managed environment by the bytecode interpreter engine. Objects and memory are directly managed by the interpreter, relieving programmers of the burdens of detailed memory management. However, since SSC is implemented at its core in a native compiled machine code library, care must be taken by the typical C# programmer to ensure that the interface to the unmanaged SSC library is properly utilized.

The C# SSC language interface is provided as a single source file called `SSC.cs`. This file contains direct invocation mappings to the unmanaged C library API, as well as an easy-to-use wrapper around the low-level function calls. This API has been tested using Visual Studio 2012 .NET on Win32 and x64. .NET implementations on other platforms such as Mono have not been tested.

To call the SSC library from C#, include the `SSC.cs` file in your .NET project in Visual Studio. For each opaque data pointer type in the SSC native C API, there is a similarly named C# class within the SSC namespace. See the example below on how to create a data container and module to run PVWatts. Additional examples of the other SSC API functions using the C# wrapper classes is available in the included test program in the SDK.

```
private void btnPVWatts_Click(object sender, EventArgs e)
{
    txtData.Clear();

    SSC.Data data = new SSC.Data();

    data.SetString("file_name", "abilene.tm2");
    data.SetNumber("system_size", 4.0f);
    data.SetNumber("derate", 0.77f);
    data.SetNumber("track_mode", 0);
    data.SetNumber("tilt", 20);
    data.SetNumber("azimuth", 180);

    SSC.Module mod = new SSC.Module("pvwattsv1");

    if (mod.Exec(data))
    {
        float tot = data.GetNumber("ac_annual");
        float[] ac = data.GetArray("ac_monthly");
        for (int i = 0; i < ac.Count(); i++)
            txtData.AppendText "[" + i + "]: " + ac[i] + " kWh\n");
        txtData.AppendText("AC total: " + tot + "\n");
        txtData.AppendText("PVWatts test OK\n");
    }
    else
    {
        int idx = 0;
```

```

String msg;
int type;
float time;
while (mod.Log(idx, out msg, out type, out time))
{
    String stype = "NOTICE";
    if (type == SSC.API.WARNING) stype = "WARNING";
    else if (type == SSC.API.ERROR) stype = "ERROR";

    txtData.AppendText("[ " + stype + " at time:" + time + " ]: " + msg + "\n");
    idx++;
}

txtData.AppendText("PVWatts example failed\n");
}
}

```

Note: The SSC C# class library is designed to properly handle allocation and freeing of underlying native SSC data types. However, due to the nature of the .NET runtime environment's garbage collector, it may appear that SSC objects are not freed right away. While it is possible to invoke the garbage collector manually, it is generally not recommended to do so by the Visual Studio documentation.

For more information, consult the `SSC.cs` source file, as well as the example Visual Studio project provided with the SDK.

7.4 Java

The Java interface to SSC utilizes the low-level Java Native Interface (JNI) specification to directly access the SSC library. The JNI wrapper consists of a C source file `jssc.c` that wraps the SSC native C language API into JNI methods that can be compiled and loaded by the Java Virtual Machine (JVM) at runtime. The source code for the JNI wrapper is included in the SDK, as well as a more programmer-friendly high-level Java SSC class that invokes the JNI layer.

The JNI interface marshals opaque C pointers as the 64-bit `jlong` data type, ensuring compatibility in both 32 and 64 bit implementations.

Compiling the JNI interface layer requires a C compiler and the Java SDK (for the JNI header files). The example included with the SSC SDK was tested using the freely downloadable MinGW gcc compiler on 32-bit Windows (<https://www.mingw.org>), and the Java JDK 1.7. Refer to the `README.txt` in the `[sdk]/languages/java/` folder for specific information on compiling the JNI interface layers for your particular SDK runtime environment.

Once the JNI wrapper library has been compiled for your particular JDK version, the PVWatts example can be invoked from within Java as below:

```

public class SSC_Java_Example {

    public static void main(String[] args)
    {
        System.loadLibrary("sscapiJNI32");

        SSC sscobj = new SSC("pvwattsv1");

        sscobj.Set_String("file_name", "abilene.tm2" );
        sscobj.Set_Number("system_size", 4.0f );
        sscobj.Set_Number("derate", 0.77f );
        sscobj.Set_Number("track_mode", 0 );
        sscobj.Set_Number("tilt", 20 );
        sscobj.Set_Number("azimuth", 180 );

        if ( sscobj.Exec() )
        {
            float[] ac = sscobj.Get_Array( "ac" );
            float sum = 0;
            for( int i=0;ac.length;i++)
            {
                sum += ac[i];
            }
            System.out.println("ac total: " + sum);
            System.out.println("PVWatts example passed");
        }
        else
        {
            System.out.println("PVWatts example failed");
        }
    }
}

```

For more information on utilizing the Java language layer, consult Java code examples provided in the SDK.

8 C API Reference

9 Legal

The System Advisor Model (“Model”) is provided by the National Renewable Energy Laboratory (“NREL”), which is operated by the Alliance for Sustainable Energy, LLC (“Alliance”) for the U.S. Department Of Energy (“DOE”) and may be used for any purpose whatsoever.

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