

SolarPILOT™ and SolTrace  
Open Source Software

Mike Wagner, Ph.D.  
SAM Webinar Series  
July 18, 2018

# Abstract

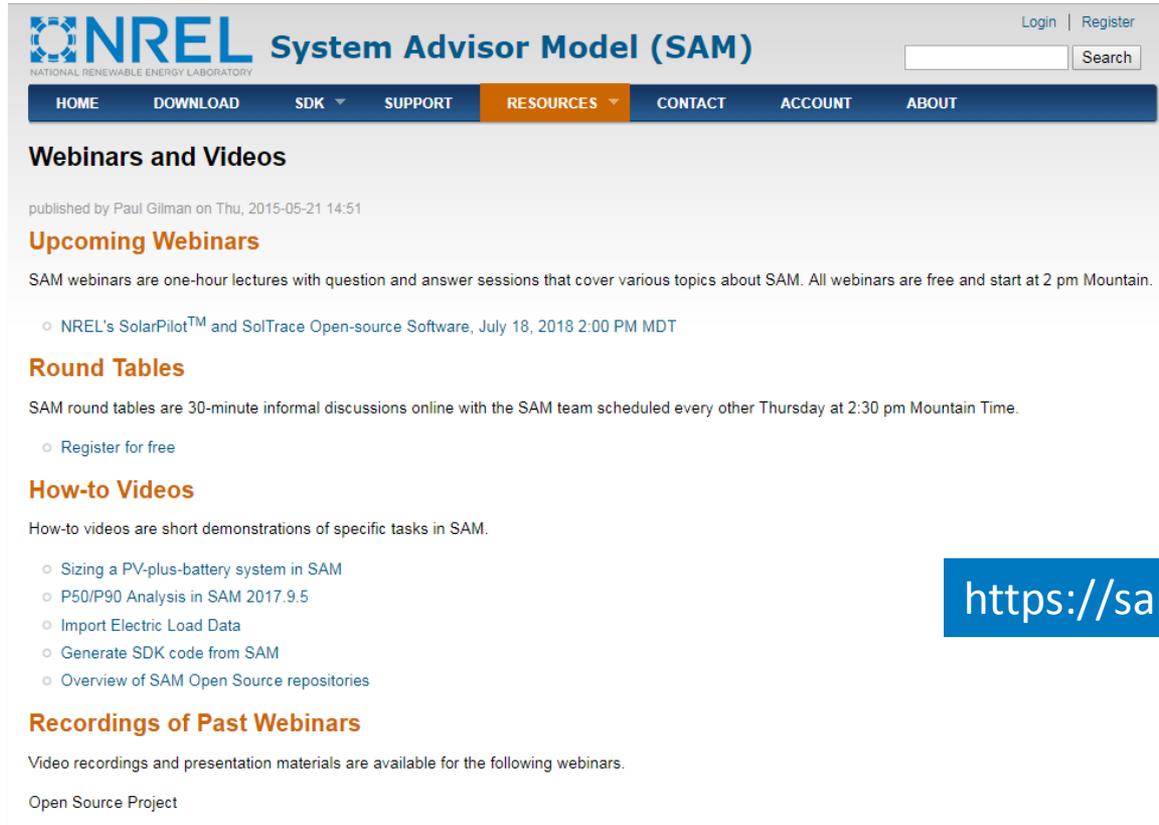
NREL is excited to announce that its SolarPILOT™ and SolTrace software packages have both recently been made open source software! Join Dr. Mike Wagner for a webinar in which he will present recent updates to both software packages, the workflow for building and/or contributing to the open source projects, and an introduction to software usage. SolarPILOT™ is NREL's tool for the design, characterization, and optimization of concentrating solar power tower solar field geometry. It is capable of modeling optical performance either with an analytical algorithm, or with Monte-Carlo ray tracing using SolTrace's embedded 'coretrace' engine. SolarPILOT is included in SAM's power tower models in limited form. While SolarPILOT is used by SAM's power tower models, the stand-alone user interface offers substantially more functionality; features include scripting, optimization, flux intensity plotting, complex land boundaries, multiple heliostat or designs, and others. SolTrace is a general ray tracing tool for concentrating optics, and has been in use by NREL, industry, and researchers for nearly 20 years.

The webinar will consist of three parts. In the first half hour, Mike will cover updates to SolarPILOT, including review of the optimization tool and field plotting tool. The second half hour will include a review of SolTrace and demonstrate its use in modeling a power tower system. In the remaining time, Mike will cover the open source projects and allow time for questions and answers.

# Outline

- Introduction and overview
- SolarPILOT
  - Overview and recent development
  - Optimizing power tower systems [example]
  - Scripting [example]
- SolTrace
  - Overview and recent development
  - Modeling power tower optical performance
- Open source project overview
- Retrieving and compiling the code
- Contributing
- Q&A

# Registration links and webinar recordings



The screenshot shows the NREL System Advisor Model (SAM) website. At the top left is the NREL logo with the text 'NATIONAL RENEWABLE ENERGY LABORATORY'. To its right is the title 'System Advisor Model (SAM)'. Further right are links for 'Login' and 'Register', and a search box with a 'Search' button. Below this is a navigation menu with items: HOME, DOWNLOAD, SDK, SUPPORT, RESOURCES (highlighted in orange), CONTACT, ACCOUNT, and ABOUT. The main content area is titled 'Webinars and Videos' and includes a publication date: 'published by Paul Gilman on Thu, 2015-05-21 14:51'. It features three sections: 'Upcoming Webinars' with a link to 'NREL's SolarPilot™ and SolTrace Open-source Software, July 18, 2018 2:00 PM MDT'; 'Round Tables' with a link to 'Register for free'; and 'How-to Videos' with a list of links: 'Sizing a PV-plus-battery system in SAM', 'P50/P90 Analysis in SAM 2017.9.5', 'Import Electric Load Data', 'Generate SDK code from SAM', and 'Overview of SAM Open Source repositories'. The final section is 'Recordings of Past Webinars' with the text 'Video recordings and presentation materials are available for the following webinars.' and a link for 'Open Source Project'.

<https://sam.nrel.gov/webinars>

# Presenter Bio

## Mike Wagner

- Mechanical Engineer and Principal Investigator, 2009-current
- Author of SolarPILOT and several CSP models in SAM
- Other research includes system design, operations, and maintenance optimization; Next-gen CSP technology, gas phase HTF system development
- Author of 40+ conference and journal publications
- Education: BS/MS University of Wisconsin, PhD Colorado School of Mines

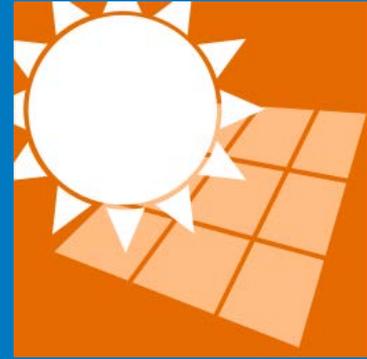
<https://www.nrel.gov/research/michael-wagner.html>



## *Acknowledgement:* **Tim Wendelin**

- Lead author of SolTrace
- Sr. Engineer at SolarDynamics (2017-current)
- NREL (retired, 1984-2017)





# SolarPILOT

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Overview and recent development

# Solar Power tower Integrated Layout and Optimization Tool



- Definition and characterization of power tower CSP solar fields
- Research and design tool for power tower optical subsystem
- User interface tied into detailed simulation code
- Developed at NREL with DOE funding
- Integrated into SAM as the power tower optical characterization engine

Wagner, M.J., and Tim Wendelin. "SolarPILOT : A Power Tower Solar Field Layout and Characterization Tool." *Solar Energy* 171, no. September 2018 (2018): 185–96.

The screenshot displays the SolarPILOT software interface for configuring a receiver. The main window is titled "SolarPILOT | base\_system\_large-helio.spt" and includes a menu bar (File, Tools, Help) and a project tree on the left. The project tree shows a hierarchy: Climate, Markets, Costs, Plant, Layout Setup, Heliostats, Template 1, Receivers (with "Receiver 1" selected), Simulations, Field Layout, Performance Simulation, Parametrics, Results, Layout Results, Receiver Flux Profile, and System Summary.

The main configuration area is divided into several panels:

- Receiver geometry:** Receiver type is set to "Flat plate". Receiver height is 8 m. Options for "Optimize receiver height", "Restrict receiver height range", and "Represent receiver as polygon" are present. Height range values are 30 m (Maximum) and 5 m (Minimum). Number of receiver panels is 12. Receiver panel azimuthal orientation is 0 [deg]. Receiver orientation azimuth is 0 [deg]. Receiver orientation elevation is -40 [deg]. A note states: "For non-planar receivers, the receiver will be oriented such that the primary parent with the specified azimuth angle will be tilted at the specified elevation angle. Other panels will be oriented along the arc of specified radius lying within the rotated receiver midline plane."
- Receiver position:** Receiver positioning offset - X axis is 0 [m], - Y axis is 0 [m], and - Z axis is 0 [m]. Options for "Limit receiver panel span angle" and "Receiver optical height" (150.0 [m]) are present. Span angle values are -180 [deg] (Min.) and 180 [deg] (Max.).
- Optical properties:** Allowable peak flux is 800 [kW/m<sup>2</sup>]. Receiver thermal absorptance is 1.0.
- Thermal losses:** Design point receiver thermal loss is 30 [kW/m<sup>2</sup>].
- Load-based thermal loss adjustment:** 0th order coefficient is 1 [kW/m<sup>2</sup>], 1st order coefficient is 0, 2nd order coefficient is 0, and 3rd order coefficient is 0.
- Receiver width:** Receiver width is 8 [m]. Options for "Optimize aperture width" and "Restrict aperture width range" are present. Width range values are 30 [m] (Maximum) and 5 [m] (Minimum).
- Aperture geometry shape:** Set to "Rectangular". Receiver cavity curvature radius is 7.75 [m]. Cavity curvature centroid offset is 0 [m]. Receiver aspect ratio (H/W) is 1.00. Receiver absorber area is 64.0 [m<sup>2</sup>].

At the bottom right, there is a small inset image showing a solar tower receiver field with the SolarPILOT logo and the NREL logo overlaid.

# What is SolarPILOT?



## What it is...

A tool for

- creating heliostat field layouts and characterizing optical performance
- screening potential development sites
- optimizing solar field design parameters
- investigating heliostat performance in detail
- optical calculations using both ray trace and analytical routines
- use by researchers, developers, and universities

## What it is *not*...

A tool for

- annual solar field production analysis
- power block or thermal energy storage simulation
- detailed cost analysis
- financial modeling
- ignoring due diligence
- always getting the right answer

# Capabilities



- Create solar field layouts, or import heliostat positions manually
- Simulate optical performance of the solar field or of individual heliostats
- Simulate different receiver geometries, multiple receivers
- Characterize receiver flux profiles at different solar positions and irradiance levels
- Impose heliostat aiming algorithms for flux profile control
- Optimize a wide range of parameters for lowest cost of energy
- Plot field performance and flux intensity
- Script layout and simulation actions using LK
- **Simulate with analytical & ray-trace methods**
  - **Direct integration with NREL's SolTrace**

# Standalone versus SAM-integrated tool



- SolarPILOT comes in two forms
  - Standalone tool that provides substantial functionality
  - SAM power tower characterization engine with limited functionality

**Design point definition**

Helioselect criteria: TOU-weighted power

Optimization simulations: Representative profiles

6 Number of days to simulate 2 Simulation hour frequency

Day No.	Month	Day	Peak DNE W/m <sup>2</sup>	Total DNE kWh/m <sup>2</sup>	No. hours
19	January	19	663.0	2.7	7
80	March	21	792.9	3.8	8
141	May	21	852.1	4.3	8
202	July	21	799.0	4.5	9
263	September	21	836.0	4.1	8

**Design values**

Solar field design power: 670 [MWh]

Design-point DNE value: 950 [W/m<sup>2</sup>]

Sun location at design point: Summer solstice

**Field configuration**

Tower optical height: 135 [m]

Layout method: Radial Stagger

Radial spacing method: No blocking-dense

Acimuthal spacing factor: 2

Acimuthal spacing reset limit: 1.33

Packing transition limit factor: 1

Offset slip plane for blocking:

Allowable blocking in slip plane: 0.5

**Advanced layout options**

Enable optical layout zone method

Min. optical layout zone size - radial: 0.1 [tower-h]

Max. optical layout zone size - radial: 1 [tower-h]

**Field Boundaries**

Minimum solar field extent angle: 180 [deg]

Maximum solar field extent angle: 180 [deg]

Minimum heliostat distance: 146.3 [m]

Maximum heliostat distance: 3832.5 [m]

Bounds scale with tower height

Maximum field radius: 9.5

Minimum field radius: 0.75

Use field land bounds

	Units	Value	Mean	Minimum	Maximum	\$/k. dev
Total plant cost	\$	20,158,366.78				
Simulated heliostat area	m <sup>2</sup>	120040				
Simulated heliostat count	-	866				
Power incident on field	MW	118700				
Power absorbed by the receiver	kW	606.43				
Power absorbed by HTR	MW	368.20				
Clearance efficiency	%	100.00	100.00	100.00	100.00	0.0000
Shading efficiency	%	97.88	97.88	66.34	100.00	1.2031
Concave efficiency	%	71.74	72.99	29.29	100.00	22.8966
Reflective efficiency	%	90.25	90.25	90.25	90.25	0.0000
Blocking efficiency	%	90.84	91.12	84.14	100.00	3.0056
Attenuation efficiency	%	91.10	91.12	84.14	96.82	3.2021
Image intercept efficiency	%	95.67	95.65	72.67	100.00	1.6876
Absorption efficiency	%	94.80				
Solar field optical efficiency	%	54.20	15.98	85.48	38.4381	
Optical efficiency incl. receiver	%	51.83	18.79	88.33	35.4211	
Incident flux	W/m <sup>2</sup>	598.39	43.93	931.64	252.2924	

**molten salt tower**

**Location and Resource**

**System Design**

**Tower and Receiver**

**Power Cycle**

**Thermal Storage**

**System Control**

**System Costs**

**Lifetime**

**Financial Parameters**

**Time of Delivery Factors**

**Incentives**

**Depreciation**

**Simulate** | **Parameters** | **Stochastic** | **Macros**

**Helioselect Field**

Import...	X Position	Y Position
Export...	-398.332	-1174.68
Copy	999.831	-865.019
	-1569.55	211.71
Paste	-1298.36	1188.62
	1258.78	1231.51
Helioselect:	848.955	1606.33
	-835.792	647.982
8790	425.324	-1365.17
	767.124	1648.68
	1558.22	364.153
	-715.218	-1062.02
	-1493.27	-158.471
	1339.000	-1131.873

Generate heliostat layout

Optimize solar field geometry

Always layout automatically  Always optimize

Solar field geometry optimization calculates the number of heliostats above, and tower height, receiver height and diameter on Tower and Receiver page.

**Optimization Settings**

Initial optimization step size: 0.06

Maximum optimization iterations: 200

Optimization convergence tolerance: 0.001

**Helioselect Properties**

Helioselect width: 12.2 m

Helioselect height: 12.2 m

Ratio of reflective area to profile: 0.97

Single helioselect area: 144.375 m<sup>2</sup>

Image error (loop, single-axis): 1.53 mrad

Reflected image conical error: 4.32749 mrad

Number of heliostat facets - X: 2

Number of heliostat facets - Y: 8

Helioselect Incusion method: Ideal

**Helioselect Operation**

Helioselect stow/deploy angle: 8 deg

Wind slow speed: 15 m/s

Helioselect startup energy: 0.025 kWh/hr

Helioselect tracking power: 0.055 kWh/m<sup>2</sup>

Design-point DNI: 950 W/m<sup>2</sup>

**Atmospheric Attenuation**

Polynomial coefficient 0: 0.006789

Polynomial coefficient 1: 0.1046 1/km

Polynomial coefficient 2: -0.017 1/km<sup>2</sup>

# Field layout process



To generate a new layout, SolarPILOT:

1. **Collects** inputs and settings from the input pages.
2. **Pre-processes** the weather data or solar irradiance model to generate a set of simulation points for design evaluation.
3. **Generates a list of all possible heliostat positions** that satisfy the land boundary and layout rules that you choose on the Layout Setup page.
4. **Simulates the performance of the field** - including each possible heliostat in the layout from step (3) - over the set of simulation points generated in step (2).
5. **Sorts all possible heliostats by the performance metric** that you specify in the Heliostat selection criteria field on the Layout Setup page.
6. **Calculates the power delivered** by each heliostat at the **reference condition** by running a single simulation using the reference values specified on the Layout Setup page.
7. **Deletes heliostats in order of worst-performing to best-performing** while the power delivered at the reference condition is still satisfied.

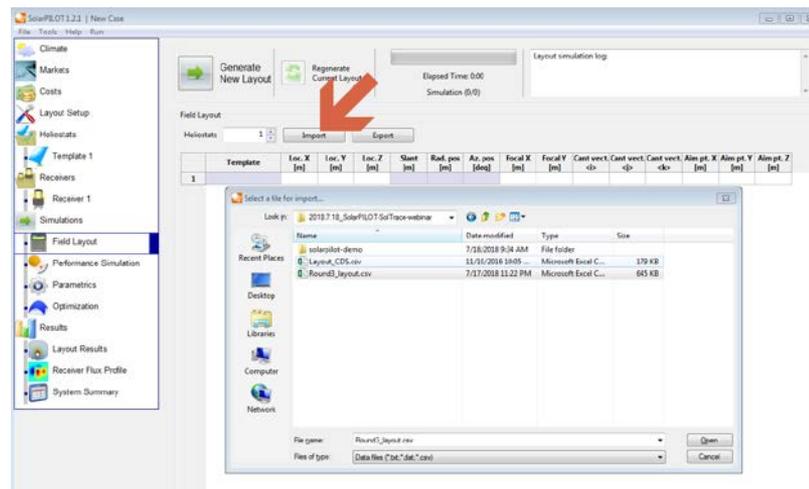
# User-specified heliostat positions



Column	Description	Units
1	Template #	-
2	Heliostat is enabled	-
3	Heliostat at position	-
4	Location (x)	m
5	Location (y)	m
6	Location (z)	m
7	Focal length (x)	m
8	Focal length (y)	m
9	Cant vector (i)	-
10	Cant vector (j)	-
11	Cant vector (k)	-
12	Aim pt (x)	m
13	Aim pt (y)	m
14	Aim pt (z)	m

To import a layout:

- Specify the receiver, tower, and heliostat properties
- On the Field Layout page, click “Import”
- The selected file must be formatted according to the guidelines in the help menu!



# Performance calculations



- Ray Tracing (numerical)
  - Can model any surface-based geometry
  - Characterize flux intensity, directionality, and multiple surface interactions
  - Computationally intensive
- Analytical with Gaussian approximation
  - Rapidly compute flux characteristics and system efficiency
  - Ideal for use in layout and optimization calculations
  - Does not provide directionality detail
  - Not as accurate as ray tracing
- Two approaches are complementary

The screenshot shows the SolarPILOT 1.2.1 software interface. The main window is titled "Simulate performance" and displays various simulation parameters. The "Sun position" section shows "Simulation time spec. method" set to "Hour/Day", "Direct Normal Irradiation" at 950 [W/m<sup>2</sup>], "Month of the year" at 3, "Day of the month" at 20, and "Hour of the day" at 12 [hr]. The "Calculated solar azimuth angle" is 182.4 [deg] and the "Calculated solar elevation angle" is 55.1 [deg]. The "Simulation parameters" section includes "Heliostat aim point method" set to "Image size priority", "Min. image offset from receiver edge - Y" at 2, "Min. image offset from receiver edge - X" at 2, "Aim point distribution sampling" set to "Triangular", and "Flux simulation model" set to "Hermite (analytical)". The "Flux grid resolution" is set to 25 for both horizontal and vertical directions. The "Clouds" section has a checkbox for "Simulate cloud transient" which is unchecked.

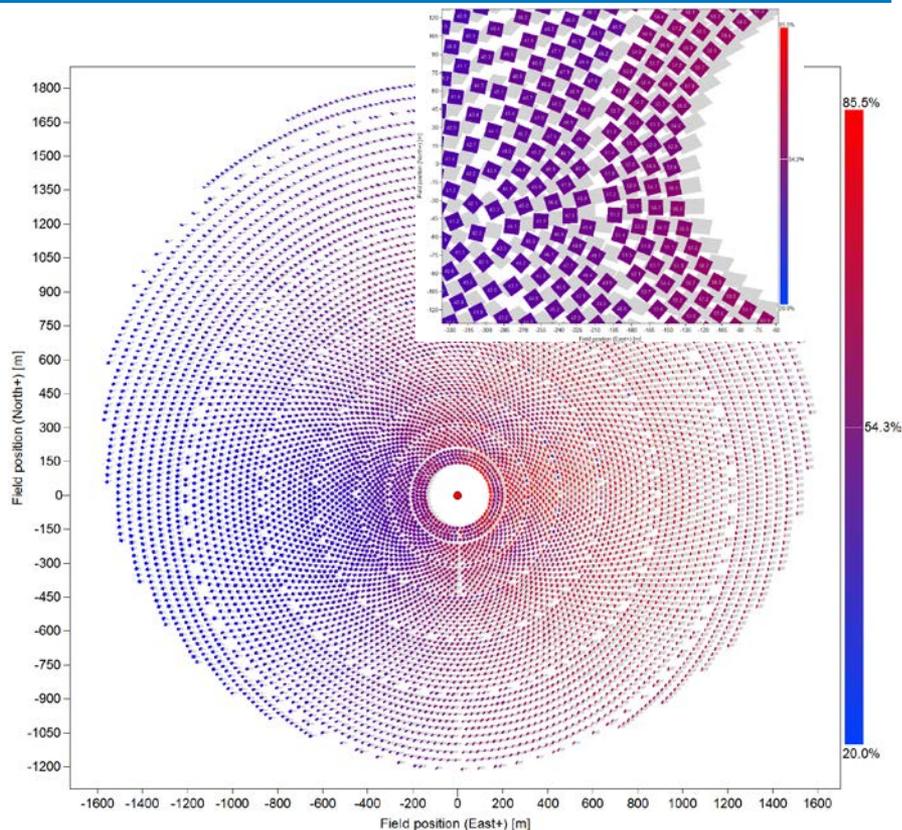
On the right side, there is a table titled "Sort heliostats by:" with a dropdown menu set to "Slant range". The table lists 29 heliostats with columns for Geometry, Location, Radial pos., Azim. pos., and Aim point. The data is as follows:

#	Geometry	Location	Radial pos.	Azim. pos.	Aim point
1	Template 1	-58.3, 121.2, 0.0	134.5 [m]	-25.7 [deg]	-4.3, 7.7, 181.9
2	Template 1	-126.2, 46.6, 0.0	134.5 [m]	-69.7 [deg]	-8.4, 2.7, 181.9
3	Template 1	126.2, 46.6, 0.0	134.5 [m]	69.7 [deg]	8.4, 2.7, 181.9
4	Template 1	66.3, -117.0, 0.0	134.5 [m]	150.5 [deg]	5.2, -7.1, 174.1
5	Template 1	123.1, -54.2, 0.0	134.5 [m]	113.8 [deg]	8.0, -3.8, 176.7
6	Template 1	-131.1, 30.1, 0.0	134.5 [m]	-77.1 [deg]	-8.4, 2.7, 187.1
7	Template 1	-129.0, -38.0, 0.0	134.5 [m]	-106.4 [deg]	-8.7, -1.7, 181.1
8	Template 1	-50.8, -124.5, 0.0	134.5 [m]	-157.8 [deg]	-3.2, -8.2, 184.5
9	Template 1	50.8, -124.5, 0.0	134.5 [m]	157.8 [deg]	3.2, -8.2, 175.0
10	Template 1	131.1, 30.1, 0.0	134.5 [m]	77.1 [deg]	8.4, 2.7, 176.7
11	Template 1	58.3, 121.2, 0.0	134.5 [m]	25.7 [deg]	4.3, 7.7, 176.7
12	Template 1	-123.1, -54.2, 0.0	134.5 [m]	-113.8 [deg]	-8.0, -3.8, 174.1
13	Template 1	119.2, 62.3, 0.0	134.5 [m]	62.4 [deg]	7.5, 4.7, 181.9
14	Template 1	-119.2, 62.3, 0.0	134.5 [m]	-62.4 [deg]	-7.5, 4.7, 187.1
15	Template 1	-80.7, -107.6, 0.0	134.5 [m]	-143.1 [deg]	-5.2, -7.1, 184.5
16	Template 1	-87.1, 102.5, 0.0	134.5 [m]	40.4 [deg]	-6.0, 6.4, 171.6
17	Template 1	87.1, 102.5, 0.0	134.5 [m]	40.4 [deg]	6.0, 6.4, 176.7
18	Template 1	-73.3, 112.8, 0.0	134.5 [m]	-33.0 [deg]	-4.3, 7.7, 171.6
19	Template 1	-93.8, -96.4, 0.0	134.5 [m]	-135.8 [deg]	-6.8, -5.6, 172.4
20	Template 1	-99.5, 90.5, 0.0	134.5 [m]	47.7 [deg]	-6.0, 6.4, 176.7
21	Template 1	-110.2, 77.1, 0.0	134.5 [m]	-55.0 [deg]	-7.5, 4.7, 177.6
22	Template 1	110.2, 77.1, 0.0	134.5 [m]	55.0 [deg]	7.5, 4.7, 187.1
23	Template 1	129.0, -38.0, 0.0	134.5 [m]	106.4 [deg]	8.7, -1.7, 177.6
24	Template 1	-66.3, -117.0, 0.0	134.5 [m]	-150.5 [deg]	-5.2, -7.1, 179.3
25	Template 1	90.5, 90.5, 0.0	134.5 [m]	47.7 [deg]	6.0, 6.4, 171.6
26	Template 1	-115.2, -69.5, 0.0	134.5 [m]	-121.1 [deg]	-8.0, -3.8, 181.9
27	Template 1	73.3, 112.8, 0.0	134.5 [m]	33.0 [deg]	4.3, 7.7, 187.1
28	Template 1	-105.3, -83.6, 0.0	134.5 [m]	-128.4 [deg]	-6.8, -5.6, 186.2
29	Template 1	34.5, -130.0, 0.0	134.5 [m]	165.1 [deg]	3.2, -8.2, 184.5

# Field performance plot



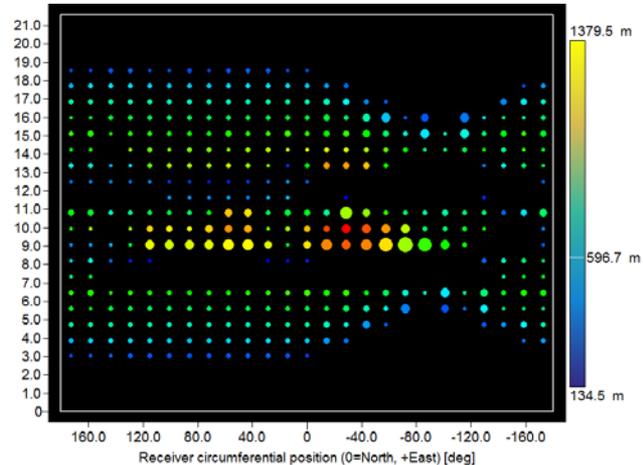
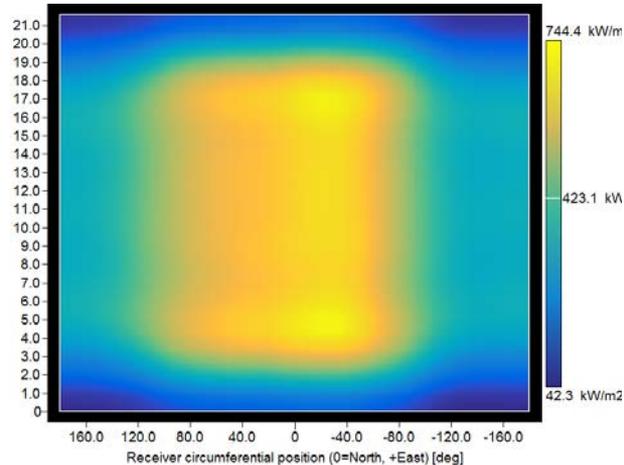
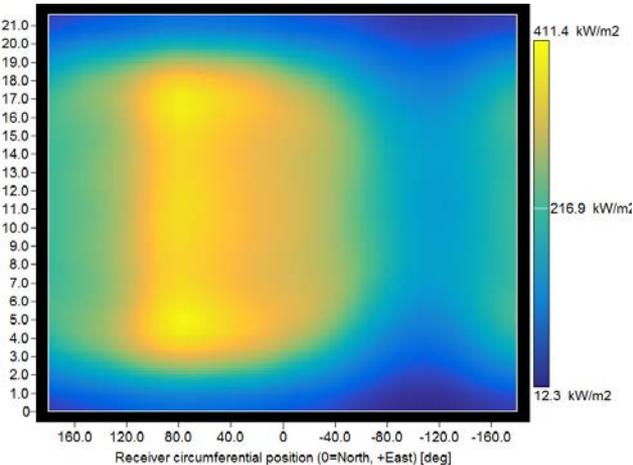
- Displays heliostat positions, land constraints, and efficiency values for each heliostat.
- Interactive selection of heliostats and removal from layout (new)
- Data can be exported into tabular format

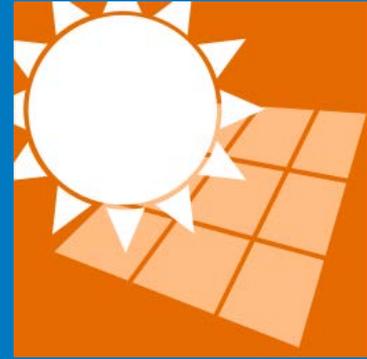


# Flux and aim plots



- SolarPILOT generates flux intensity plots on the receiver surfaces
- The field can be simulated at any sun position or DNI value
- Plots can be scaled and adjusted for resolution
- The heliostat aim point plot illustrates the aiming strategy for the selected flux plot





# SolarPILOT

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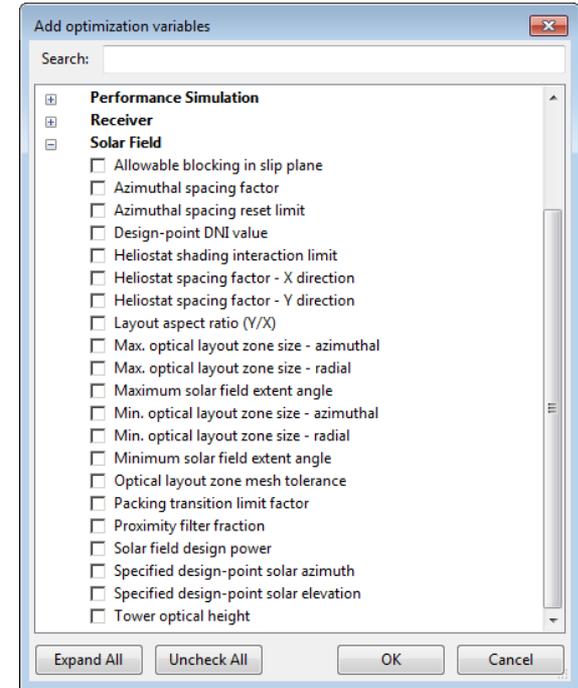
Optimizing power tower systems

# Optimization overview



- Power tower design is complex, with many trade-offs!
- Many input parameter values can be optimized
- SolarPILOT uses the [COBYLA](#) algorithm (part of the NLOpt library) to optimize the selected variables
  - Represents the objective function as a multi-dimensional linear surface within a local trust region
  - Incorporates nonlinear constraint (allowable peak flux)
  - SolarPILOT calculates the actual peak flux for a given design and compares it with this value
  - The objective function seeks to minimize pseudo LCOE

$$obj = \frac{cost_{tot}}{E_{expect}} \cdot \left( 1 + \left( 1 - \frac{\dot{Q}_{sf}}{\dot{Q}_{sf,des}} \right) \cdot R_{penalty} \right)$$



# Case study



- Consider a new plant near Phoenix, AZ
- An agricultural enterprise is selling cultivated land near transmission and with [good DNI resource](#)
- A developer would like to build a tower facility at the location, but needs to evaluate the property for power production potential, tower height, and tower location

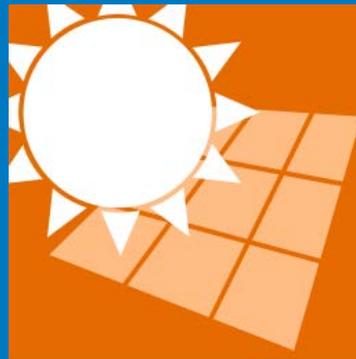
**SolarPILOT can help!**

# Case study steps: Live Demo



1. Identify the location, and download the weather file
2. Open SolarPILOT and specify parameters
  - Thermal power rating = 450 MWt
  - Climate file
  - Best guess tower height and position
  - Land constraint type
3. Create land geometry (Google Earth, e.g.)
4. Import land geometry and tower position
5. Run layout
6. Set up optimization table
7. Optimize
8. Apply (if satisfied)

Optimization variable settings	Initial	Lower bound	Upper bound	Initial step
Tower height [m]	150	None	None	10
Tower offset – x [m]	-200	-300	500	50
Tower offset –y [m]	400	-50	600	50



# SolarPILOT

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Scripting

# Scripting



- SolarPILOT includes approximately 375 settings, input variables, and parameters that can be manipulated by the user
- A primary goal of the scripting interface is to provide a mechanism for assignment and retrieval of input and output parameters
- A wide range of tasks are achievable through scripting

```
/*
Script to test modifying heliostat soiling
*/

//create an arbitrary function to affect soiling in an area near a road
function soil( loc )
{
    x = loc[0];
    y = loc[1];

    if( y > 0 || x < y)
        return 1.;

    return 1. - 0.5*rand()*exp(-abs(x-y)/500);
} //.. end of function

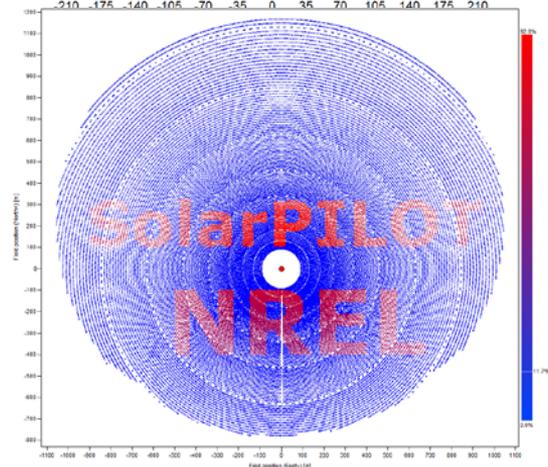
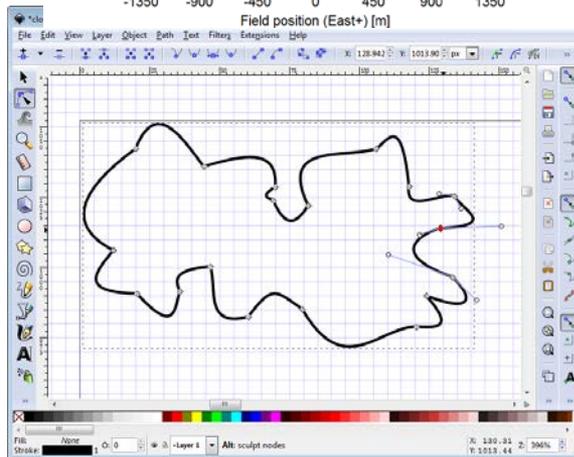
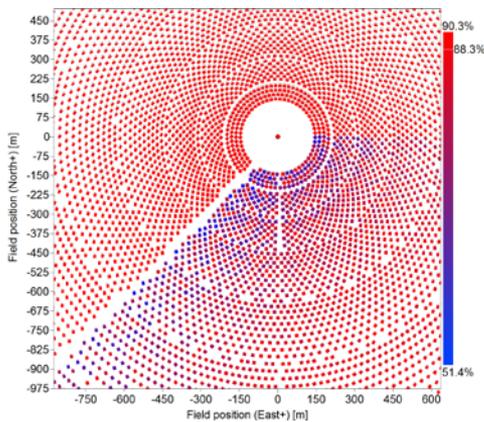
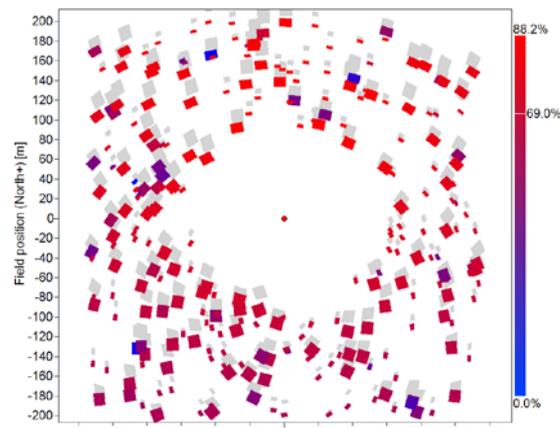
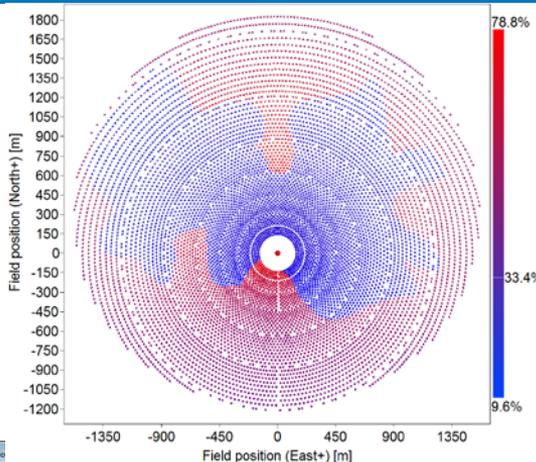
//add the access road and assign variables
radmax = 2000; rw=40;
add_land_area([[0,0],[-radmax,-radmax],[-radmax,-radmax-rw],[0,-rw]], 'exclusion', false);
run_layout(); //Generate a new heliostat field layout
hels = get_layout(); //get information about all heliostats in the layout
//modify the soiling factor based on location
refs = []; hids = [];
for(i=0; i<#hels; i++)
{
    refl = 0.95 * soil( [hels[i][1],hels[i][2]] ); //call the soiling function
    hids[i] = hels[i][0];
    refs[i] = refl;
}

modify_heliostats(hids, {'soiling'=refs}); //update heliostat soiling
run_performance(); //run a performance simulation
update_interface(); //update the solarpilot GUI with the results
```

# Scripting examples



- Local soiling
- Cloud shapes
- Random templates
- Enabling/disabling





# SolTrace

---

Overview and recent development

# Overview



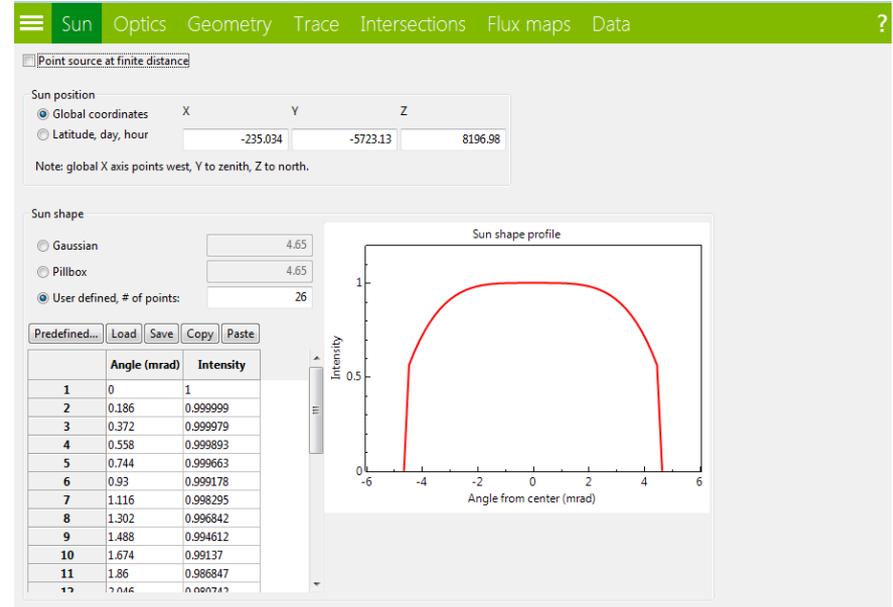
- A specified number of rays are traced from the sun through the system
- Each traces through the defined system while encountering various optical interactions
- Rays replicate real photon interactions and can therefore provide accurate results for complex systems that cannot be modeled otherwise
- Accuracy increases with the number of rays traced, and larger ray numbers means more processing time
- Organization:
  - The optical system is organized into “stages”
  - A stage is comprised of “elements” consisting of a surface, an optical interaction type, an aperture shape, and, if appropriate, a set of optical properties
  - Two characteristics completely define the “sun” as the light source: the angular intensity distribution of light across the sun’s disk, referred to as the sun shape, and the sun’s position.

Wendelin, Tim. “SolTrace: A New Optical Modeling Tool for Concentrating Solar Optics.”  
*NREL/TP-5500-59163*. Golden, CO, 2013.

# Recent work



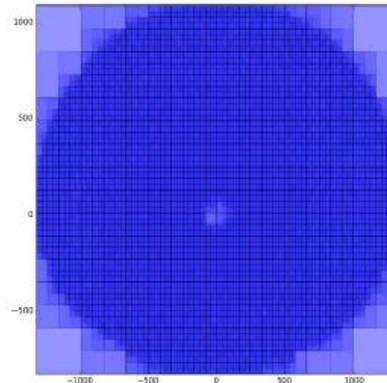
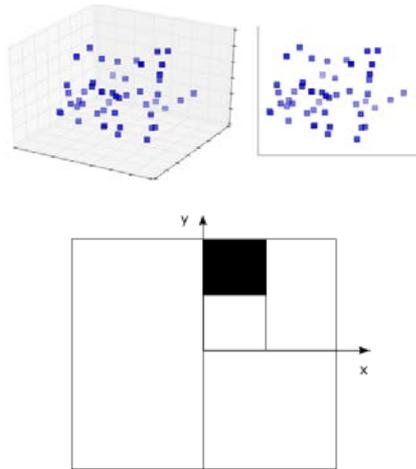
- User interface
  - The interface has been ported from Qt to wxWidgets and C++
  - The new GUI is consistent with SAM, SDKtool, and other CSP tools
  - The interface features enhanced ray plotting and is more responsive
- Speed improvement
  - NREL modified SolTrace to improve run times for power tower systems



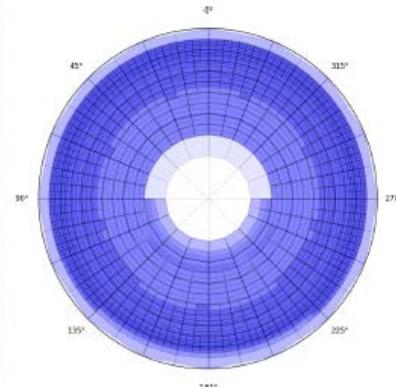
# Speed improvement for point focus



- SolTrace provides general ray-tracing functionality that is slow for systems with very large numbers of elements (e.g., power tower heliostat fields)
- Computational expense is reduced by creating localized groups of elements, a small subset of which are retrieved for intersection testing based on the position of the random sun ray
- Elements are grouped by their projection onto the plane normal to the sun vector using a binary search tree



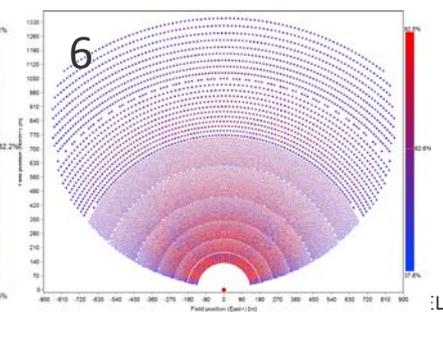
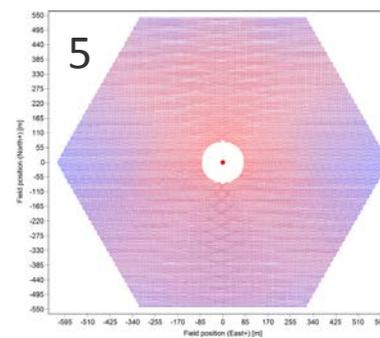
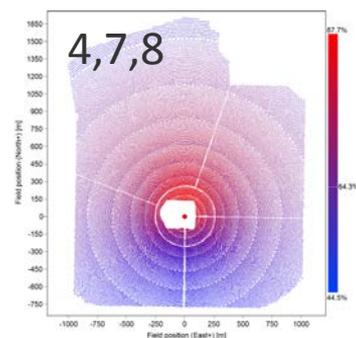
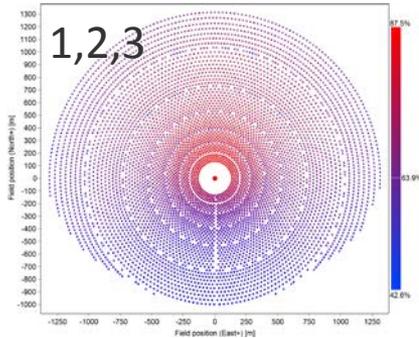
(a) Sun-projection mesh in cartesian coordinates.



(b) Receiver-projection mesh in polar coordinates.

# Speed improvement results

Case	# Elements	Description	Base [s]	New Time [s]	Improve. Factor
1	100,512	Default SolarPILOT case, 500 MWt	11,672	6.7	1742x
2	100,512	Same as Case 1, afternoon sun position, $\theta = 23^\circ$ , $\alpha=253^\circ$	8,325	6.4	1300x
3	6,282	Default SolarPilot case with single-facet heliostats	927	2.5	370x
4	95,174	Ivanpah-like solar field	6,531	9.6	680x
5	34,188	eSolar-like hexagonal field	5,447	6.1	893x
6	79,812	North field, mixed heliostats (small near tower, large outer ring)	6,683	6.2	1078x
7	60,127	Ivanpah Unit 2 solar field with random vertical heliostat displacement	4,042	3.7	1092x
8	60,127	Ivanpah Unit 2 solar field with high optical slope error ( $\sim 10$ mrad)	3,830	3.7	1035x





# SolTrace

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Modeling power tower optical performance

# Creating SolTrace input from SolarPILOT



- Create a heliostat field layout with SolarPILOT
- Run a performance simulation with the analytical model to set aimpoints
- Select “Keep existing” for heliostat aim point method
- Select “SolTrace” for flux simulation model
- Export SolTrace .stinput file
- Open in SolTrace

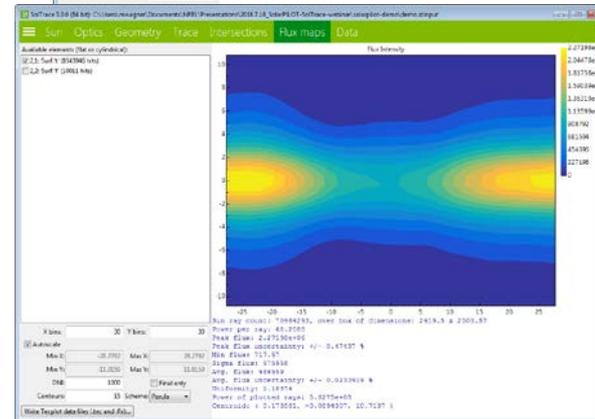
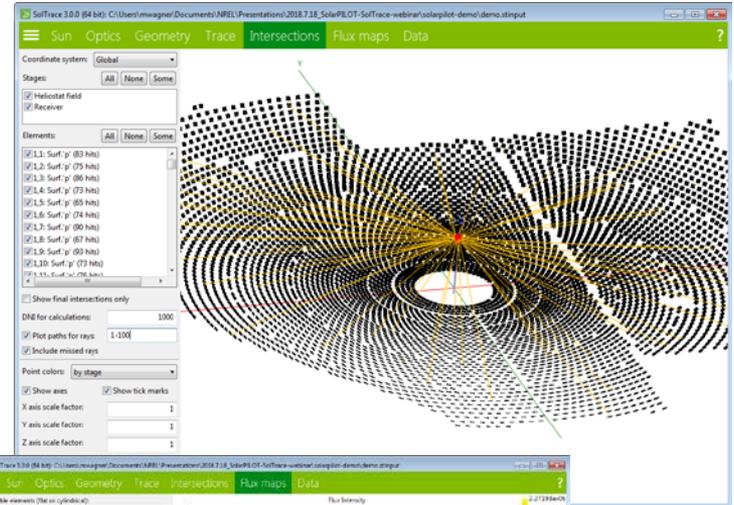
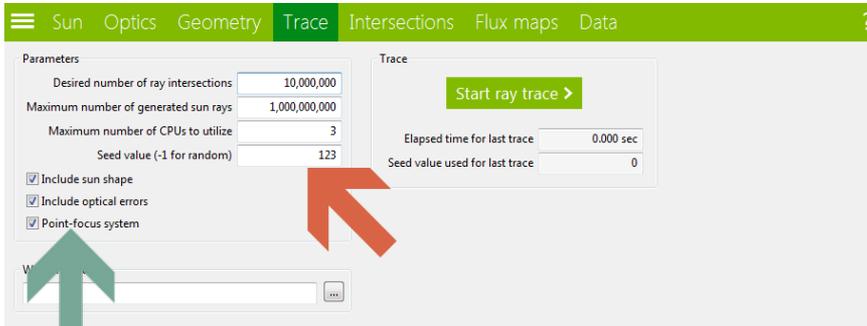
The screenshot shows the 'Simulate performance' window in SolarPILOT. The 'Simulation parameters' section is highlighted, showing the 'Flux simulation model' set to 'SolTrace'. A red arrow points to this dropdown menu. Another red arrow points to the 'Export SolTrace .stinput file' button at the bottom. The 'Sun position' section shows a simulation time of 'Hour/Day' with a Direct Normal Irradiation of 950 W/m2. The 'Simulation parameters' section includes options for 'Heliostat aim point method' (Keep existing) and 'Flux simulation model' (SolTrace). Below this, there are fields for 'Flux grid resolution - Horizontal' (25) and 'Flux grid resolution - Vertical' (25). A warning message states: 'Specify the maximum number of flux nodes in the horizontal and vertical directions. This will apply to each receiver flux surface.' and 'The simulation will run until either the minimum ray intersection count or the maximum generated rays is met.' The 'Desired number of ray intersections' is set to 1000000 and the 'Maximum number of generated rays' is set to 100000000. The 'Seed value' is set to -1. The 'Optical errors' section has 'Include sun shape' and 'Include optical errors' checked. A 'Save all raytrace data' button is also visible. The 'Export SolTrace .stinput file' button is highlighted with a red arrow.

#	Geometry	Location	Radial pos.	Azim. pos.	Aim
1	Template 1	-93.8, -96.4, 0.0	134.5 [m]	-135.8 [deg]	-6.2
2	Template 1	-105.3, -83.6, 0.0	134.5 [m]	-128.4 [deg]	-6.9
3	Template 1	105.3, -83.6, 0.0	134.5 [m]	128.4 [deg]	6.9
4	Template 1	87.1, 102.5, 0.0	134.5 [m]	40.4 [deg]	5.7
5	Template 1	-87.1, 102.5, 0.0	134.5 [m]	-40.4 [deg]	-5.7
6	Template 1	-123.1, -54.2, 0.0	134.5 [m]	-113.8 [deg]	-8.1
7	Template 1	123.1, -54.2, 0.0	134.5 [m]	113.8 [deg]	8.1
8	Template 1	115.2, -69.5, 0.0	134.5 [m]	121.1 [deg]	7.6
9	Template 1	-115.2, -69.5, 0.0	134.5 [m]	-121.1 [deg]	-7.6
10	Template 1	-42.3, 127.7, 0.0	134.5 [m]	-18.3 [deg]	-2.8
11	Template 1	42.3, 127.7, 0.0	134.5 [m]	18.3 [deg]	2.8
12	Template 1	-66.3, -117.0, 0.0	134.5 [m]	-150.5 [deg]	-4.4
13	Template 1	66.3, -117.0, 0.0	134.5 [m]	150.5 [deg]	4.4
14	Template 1	17.6, -133.3, 0.0	134.5 [m]	172.5 [deg]	1.2
15	Template 1	-17.6, -133.3, 0.0	134.5 [m]	-172.5 [deg]	-1.2
16	Template 1	-126.2, 46.6, 0.0	134.5 [m]	-69.7 [deg]	-8.3
17	Template 1	126.2, 46.6, 0.0	134.5 [m]	69.7 [deg]	8.3
18	Template 1	-110.2, 77.1, 0.0	134.5 [m]	-55.0 [deg]	-7.2
19	Template 1	110.2, 77.1, 0.0	134.5 [m]	55.0 [deg]	7.2
20	Template 1	-108.3, 106.3, 0.0	151.8 [m]	-45.6 [deg]	-6.3
21	Template 1	108.3, 106.3, 0.0	151.8 [m]	45.6 [deg]	6.3
22	Template 1	-0.0, 151.8, 0.0	151.8 [m]	-0.0 [deg]	0.0
23	Template 1	129.5, 79.1, 0.0	151.8 [m]	58.6 [deg]	7.5
24	Template 1	-129.5, 79.1, 0.0	151.8 [m]	-58.6 [deg]	-7.5
25	Template 1	-11.4, -151.3, 0.0	151.8 [m]	-175.7 [deg]	-0.7
26	Template 1	11.4, -151.3, 0.0	151.8 [m]	175.7 [deg]	0.7
27	Template 1	81.6, 127.9, 0.0	151.8 [m]	32.5 [deg]	4.7
28	Template 1	-81.6, 127.9, 0.0	151.8 [m]	-32.5 [deg]	-4.7
29	Template 1	104.2, -110.4, 0.0	151.8 [m]	136.7 [deg]	6.1
30	Template 1	-104.2, -110.4, 0.0	151.8 [m]	-136.7 [deg]	-6.1
31	Template 1	126.3, -84.1, 0.0	151.8 [m]	123.6 [deg]	7.3
32	Template 1	-126.3, -84.1, 0.0	151.8 [m]	-123.6 [deg]	-7.3
33	Template 1	150.4, -20.1, 0.0	151.8 [m]	97.6 [deg]	8.7
34	Template 1	-150.4, -20.1, 0.0	151.8 [m]	-97.6 [deg]	-8.7

# Tracing and interpreting results



- Trace options should be customized for the analysis you are doing
- Make sure you run sufficient rays to achieve problem convergence
- Set the number of CPU's as desired
- For point focus systems, select the point focus factor option. This enables the speed improvement method.



# Open source projects

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Overview



# Motivation



- We are excited to continue working on SolarPILOT and SolTrace and fostering a new community of contributors.
- **Transparency**
  - Look at the underlying code that you are interested in
- **Flexibility**
  - Change the way a model works for research purposes
  - Change heliostat geometries to be specific to a developer
- **Collaboration**
  - Add new heliostat or receiver models
  - Add new layout techniques or error distributions
- We'd love to learn how you use NREL's open-source code! It helps us tailor our efforts and get funding to develop the tools.



- NREL will continue to maintain and release official desktop versions of SolarPILOT and SolTrace.
  - Releases built from the open-source repositories
  - User contributions can be considered for inclusion in official versions

A screenshot of a web browser displaying the NREL website. The URL is https://www.nrel.gov/csp/solarpilot.html. The page features the NREL logo and a search bar. Below the navigation menu, there is a breadcrumb trail: Concentrating Solar Power &gt; Solar Power tower Integrated Layout and Optimization Tool. A sidebar on the left lists SolarPACES, SolarPILOT (highlighted), and SolTrace. The main content area has the heading "Solar Power tower Integrated Layout and Optimization Tool" and a paragraph describing the tool's purpose and development by NREL. A second paragraph details the tool's components and its use of the DELSOL3 engine.

A screenshot of a web browser displaying the NREL website. The URL is https://www.nrel.gov/csp/soltrace.html. The page features the NREL logo and a search bar. Below the navigation menu, there is a breadcrumb trail: Concentrating Solar Power &gt; SolTrace. A sidebar on the left lists SolarPACES, SolarPILOT, and SolTrace (highlighted). The main content area has the heading "SolTrace" and a paragraph describing the software tool's development at NREL for modeling CSP systems and analyzing their optical performance. It also mentions the availability of source code and the NREL's openness to contributions.



- Licensed under a mixed MIT-type license and GPLv3 license.
- Commercial businesses can use SolarPILOT, SolTrace, SSC and SAM under the MIT-type restrictions
  - You can use these in software you develop for your business.
- Research entities, including national labs, institutions of higher learning, and non-profits are restricted under a GPLv3-type license.
  - You can use the code in your research, but must make your changes publicly available.



- Why the mixed license?
  - Want to encourage companies to use SolarPILOT and SolTrace as a foundation for growing their business in a fairly unrestricted way.
  - Want to encourage research institutions to share back any new innovations or make them publicly available so that the community as a whole benefits.
- Please see full licenses here:
  - <https://github.com/NREL/SolarPILOT/blob/develop/LICENSE.md>
  - <https://github.com/NREL/SolTrace/blob/develop/LICENSE.md>

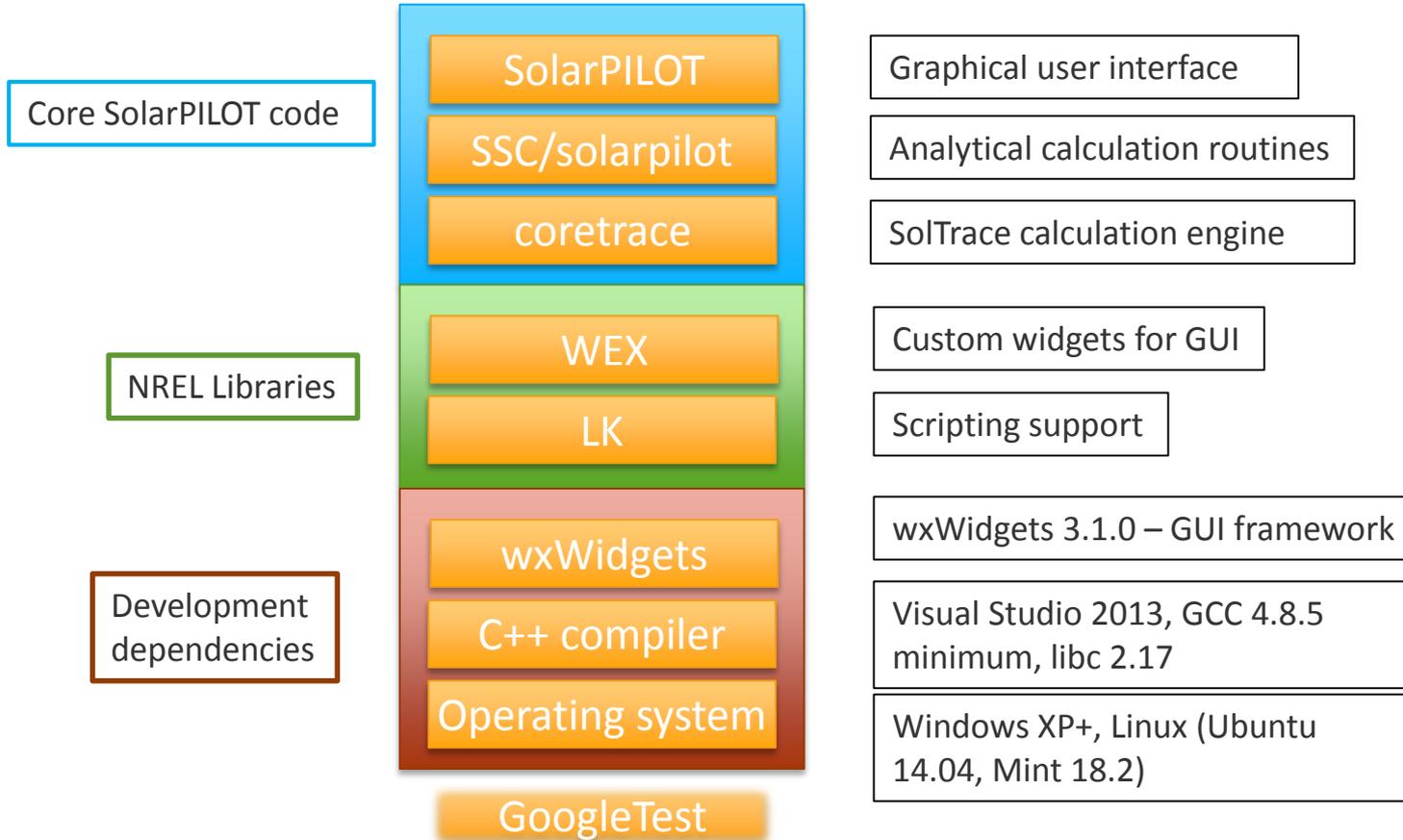
# Open source projects

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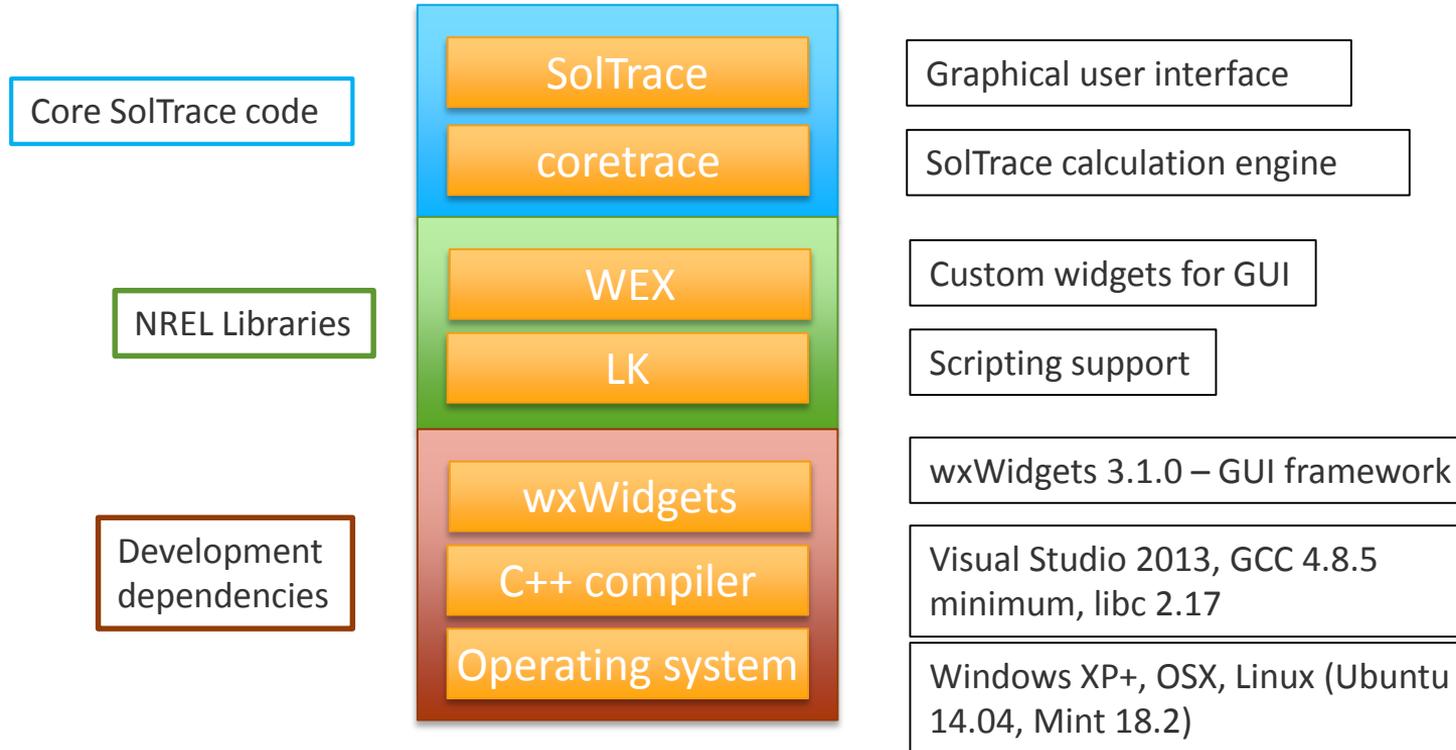
Retrieving and compiling code



# SolarPILOT code architecture



# SolTrace code architecture



# Git repository locations



Repository	URL
wxWidgets	<a href="https://www.wxwidgets.org/downloads">https://www.wxwidgets.org/downloads</a>
WEX	<a href="https://github.com/NREL/wex">https://github.com/NREL/wex</a>
LK	<a href="https://github.com/NREL/lk">https://github.com/NREL/lk</a>
SSC	<a href="https://github.com/NREL/ssc">https://github.com/NREL/ssc</a>
SolTrace	<a href="https://github.com/NREL/SolTrace">https://github.com/NREL/SolTrace</a>
SolarPILOT	<a href="https://github.com/NREL/SolarPILOT">https://github.com/NREL/SolarPILOT</a>

If you are new to Git and GitHub, please checkout: <https://guides.github.com/>

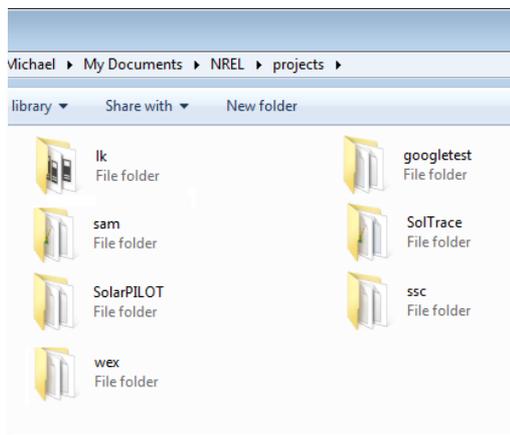
# Build instructions



For detailed build instructions see the [SolarPILOT](#) or [SolTrace](#) wikis

## General quick steps:

- Set up your development tools:
  - Windows: Visual Studio 2017 Community
  - Linux: g++ compiler
- Download the wxWidgets 3.1.1 source code
- Build wxWidgets and set environment variables
- For each dependency, fork and clone the repository into a local project folder, build the project, and then (Windows only) create environment variables
- Build the projects in order
  - SolarPILOT: wxWidgets, LK, WEX, SolTrace/coretrace, SolarPILOT
  - SolTrace: wxWidgets, LK, WEX, SolTrace/app
- This process can take some time, depending on computer speed



# Open source projects

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Contributing





## First Steps

- Read contribution instructions:
  - <https://github.com/NREL/solarpilot/blob/develop/CONTRIBUTING.md>
  - <https://github.com/NREL/soltrace/blob/develop/CONTRIBUTING.md>
- Send an email to [solarpilot.support@nrel.gov](mailto:solarpilot.support@nrel.gov) or [soltrace.support@nrel.gov](mailto:soltrace.support@nrel.gov) agreeing to the contribution policy

## Second Steps

- Scope your change and estimate how much time it will take. If the contributions are small (i.e, bug fixes), simply submit changes via pull request.
- If contributions are large, you will need to submit a description of the change for review. If the contribution fits within the project goals, we will work with you to create a plan to get the change incorporated.

# Knowing where to contribute



*SolarPILOT consists of [several code repositories](#), so you will need to determine where to make your contribution*

- If you are making a change to the SolarPILOT's underlying performance algorithms, only the [SSC](#) repository is affected
- If you are adding a new feature that changes both calculations and the user interface, then both the SolarPILOT repository and the SSC repository are affected
- If you are adding scripting functionality, the SolarPILOT repository is affected. If modifying script language tools, the LK repository is affected.
- If you need help figuring out where your contribution should go, please let us know

# Technical contribution process

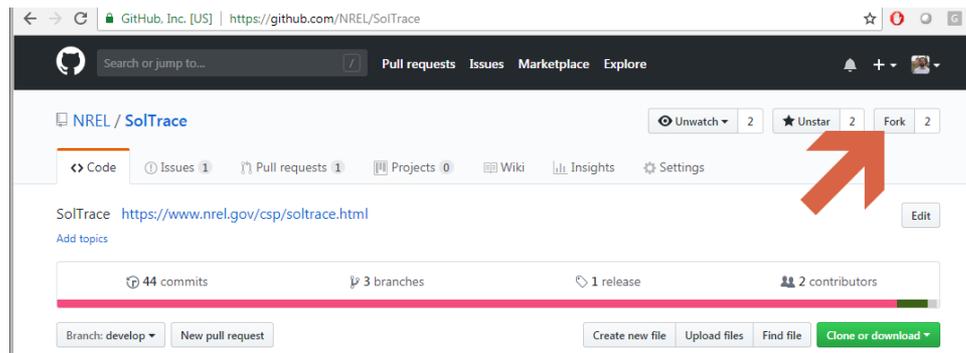


1. Install your favorite Git client application



Git Bash

2. Create a fork of the repo (or all) to which you are contributing



3. Clone your fork(s) and build according to instructions

```
$ git clone https://github.com/NREL/1k...
$ git clone https://github.com/NREL/wex...
$ git clone https://github.com/NREL/soltrace...
$ git clone https://github.com/NREL/ssc...
$ git clone https://github.com/NREL/solarpilot...
```

4. Create a branch on the fork off of develop (new feature) or a tagged release (bug fix)

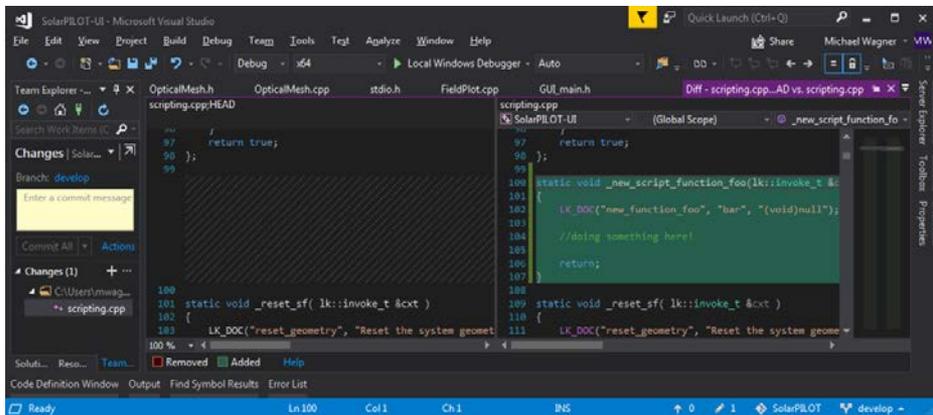
```
$ git checkout v1.
v1.1.0 v1.2.0 v1.2.1
```

```
$ git checkout -b my-patch-branch...
```

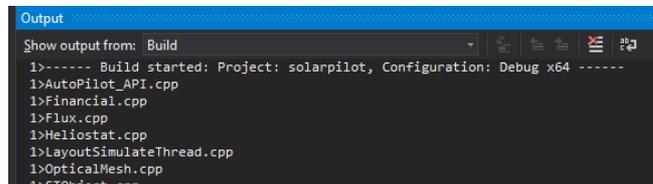
# Technical contribution process



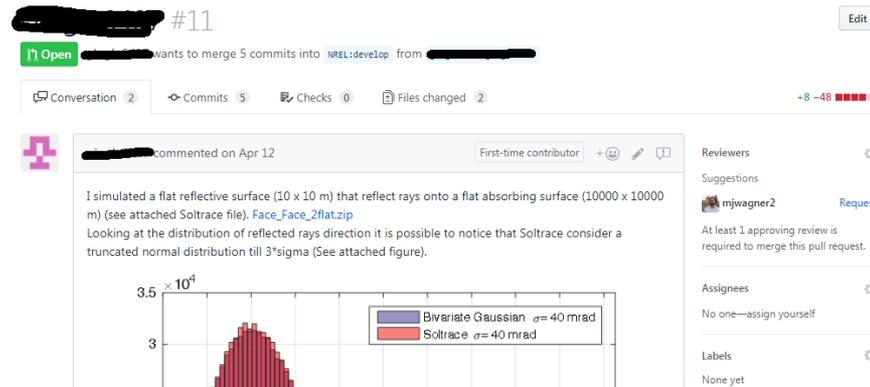
## 5. Make your code modifications



## 6. Build and test affected projects



## 8. Start a pull request on GitHub. We will review, comment, and merge in official version



## 7. Commit and push changes to your branch

```
$ git commit -a -m "adding bug fix for heliostat aiming vector"
```

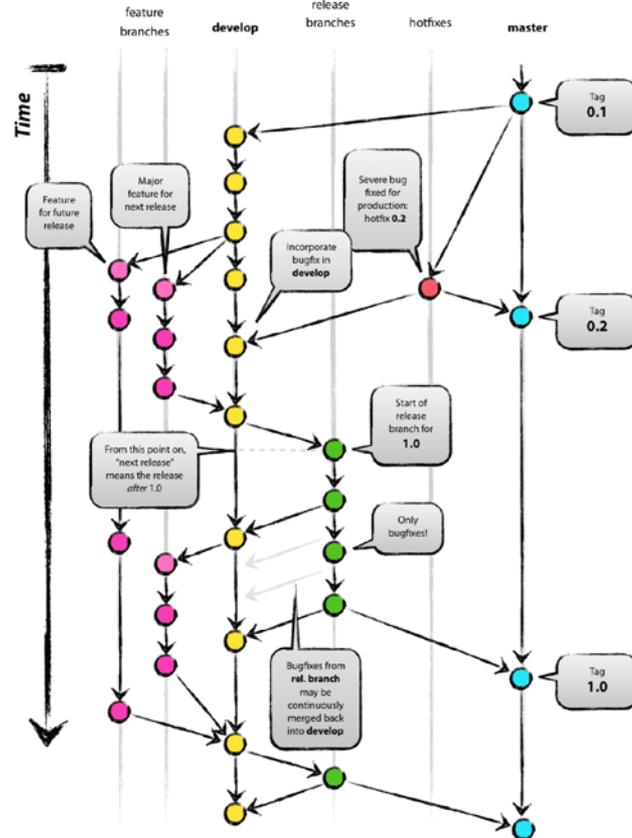
```
$ git push myremote my-patch-branch
```

# More on branches



Branch	Access	Description	Branch from	Merge from	Merge to
master	admin	Current stable version	---	patch, release	---
develop	SolarPILOT-RW	Bleeding edge development version	---	feature, patch, release	---
patch	Contributors	Hotfixes for current major.minor release	Master @tag	---	master, develop, patch
release	SolarPILOT-RW	Next release version	develop	patch	master, develop
feature-<name>	Contributors	All new development	develop, feature-<other>	develop, feature-<other>	develop, feature-<other>

<https://github.com/NREL/SolarPILOT/blob/master/CONTRIBUTING.md>



<https://nvie.com/posts/a-successful-git-branching-model/>

# Creating GitHub issues



Search or jump to...

Pull requests Issues Marketplace Explore

NREL / SolarPILOT

Unwatch 4 Unstar 3 Fork 1

Code Issues 0 Pull requests 0 Wiki Insights Settings

## Visualization of land boundaries #19

Closed opened this issue on Apr 13 · 2 comments

commented on Apr 13

See images below. The first image correctly shows the default land boundaries (-180° to +180°) with the correct radial limits.  
For the second image, the land boundaries have been changed to (-175°, +180°). However, the plot shows them as if they were (-180°, -175°).

Final position (steps) [m]

Assignees: No one—assign yourself

Labels: bug

Projects: None yet

Milestone: No milestone

Notifications: Unsubscribe

2 participants

If you discover a bug in the code, want to add a new feature, or have a question, use **GitHub issues** to tell us

# Thank you

---

[www.nrel.gov](http://www.nrel.gov)

**NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.**

