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Incorporation of Solstice Ray-tracing into Numerical Modelling of CSP Systems

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This paper presents an overview of the application of Solstice in modelling concentrating solar power (CSP) systems by researchers in the Solar Thermal Group at the Australian National University. Solstice (SOLar Simulation Tool In ConcEntrating optics) is a free open-source ray-tracing software jointly developed by PROMES-CNRS[1] and Méso-Star[2] (Caliot et. al., 2015). It is a command-line tool with simple input and output file formats that facilitate automated or manual operation. Solstice applies the energy-partitioning method to achieve a faster convergence rate than collision-based algorithms. It is efficient in large field simulations by sampling rays at the first intersection on the primary reflector surface. In addition, it uses the Embree library from Intel and is fully parallelisable on shared-memory architecture, such that is capable of computing the annual performance of a ~50 MW_{th} solar field in two minutes. Solstice takes input files for the solar facility including geometric elements such as stereolithography (STL) geometry files, and spectral data (solar radiative intensity, refractive index, extinction coefficient and reflectivity), and computes the flux maps on solar receivers (with the associated statistical standard deviation). Results can be visualised using ParaView[3].

Validation

Solstice is fast and reliable. The performance of Solstice has been validated by a side-by-side comparison in three rounds of tests with five other widely used optical modelling tools in CSP (Wang et. al., 2019). Figure 1 shows that good agreement is observed, except for a deviation in predicting blockage losses in the morning sun positions, which remains the topic of future work.

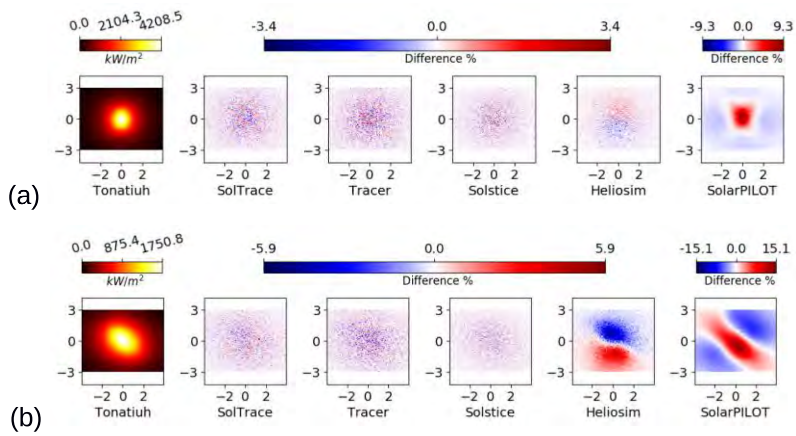


Figure 1. A comparison of Solstice with five other optical modelling tools on simulations of a central tower CSP system at (a) solar noon and (b) morning sun positions. The difference in percentage is the difference of flux value over the maximum flux value of the reference case. Flux map axis labels are in metres.

1 Solstice PROMES: https://www.labex-solstice.fr/solstice-software/
2 Solstice meso-star: https://www.meso-star.com/projects/solstice.html
3 Paraview: https://www.paraview.org/

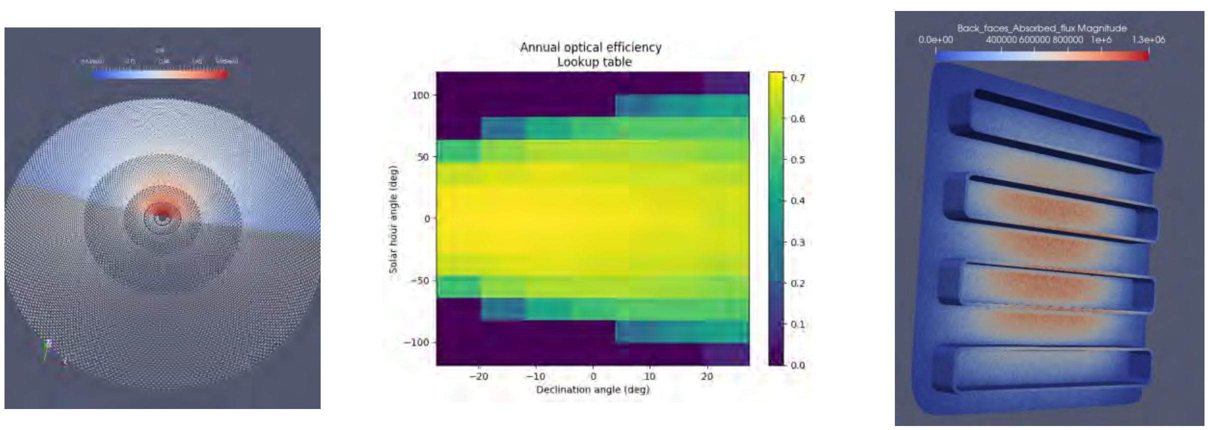
Field

A heliostat field layout method has been implemented as a wrapper around Solstice for field performance analysis and design[4]. For a specified design power of the field, a large radial staggered field is first generated, and then sent to Solstice for optical performance simulation. The performance of each heliostat is obtained. Based on the resulting performance ranking of each heliostat, the oversized field is then trimmed until it satisfies the specified design power. Figure 2(a) shows an example.

The annual performance of a field can also be assessed quickly. By simply assigning two values, namely the total number of days in the year (*m*) and a total number of sun positions in each day (*n*), the sky is discretised into $m \times n$ mesh elements. All the sun positions in the discretised sky will be calculated and input into Solstice for the optical simulations. Results are collected and converted into a format suitable for system-level study, e.g. techno-economic analysis (TEA), as shown in Figure 2(b).

Receiver

Optical simulations of complex-shaped cavity receivers from an STL mesh model, as shown in Figure 2(c), can be done quickly using Solstice. The capability of dealing with detailed receiver models opens the path to integration of sophisticated receiver internal working fluid hydrodynamic and thermal-mechanical models.



(a) a selection of heliostats from an oversized surrounding field based on the visibility of a receiver and the ranking of cosine factors

(b) the optical annual performance lookup table

(c) the flux distribution on a multi-cavity bladed receiver obtained by Solstice and visualised by ParaView

Figure 2. Application examples

Reference

Caliot, C., Benoit, H., Guillot, E., Sans, J., Ferriere, A., Flamant, G., Coustet, C., Piaud, B. , 2015. Validation of a Monte Carlo Integral Formulation Applied to Solar Facility Simulations and Use of Sensitivities. Journal of Solar Energy Engineering, Vol. 137.

Wang, Y., Potter, D., Asselineau, C.-A., Corsi, C., Wagner, M., Caliot, C., Piaud, B., Blanco, M., Kim, J.-S., Pye, J., 2019. Verification of Optical Modeling on Sunshape and Surface Slope Error. Submitted to Solar Energy (July 2019), preprint available online.

[4] Solstice Python wrappers: https://github.com/anustg/solstice-scripts