REQUEST FOR A SPECIAL PROJECT 2024–2026

MEMBER STATE: The Netherlands

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Project Title: Towards a computationally efficient parameterization for surface shortwave 3D radiative effects in cloud resolving models

To make changes to an existing project please submit an amended version of the original form.)

If this is a continuation of an existing project, please state the computer project account assigned previously.	**N/A**	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2024	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for project year:		**2024**	**2025**	**2026**
High Performance Computing Facility	[SBU]	26.466 M	26.466 M	26.466 M
Accumulated data storage (total archive volume)[2]	[GB]	757.3	1515.7	2272

EWC resources required for project year:		**2024**	**2025**	**2026**
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]			

Continue overleaf.

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[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.

[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.

[3] The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

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Extended abstract

1. Scientific plan

1.1 Background

The complex interaction between aerosols, clouds, and radiation results in a partitioning of the total incoming solar radiation into its direct and diffuse components, which temporally can vary on time scales as small as seconds (e.g. Lohmann et al. 2016, Mol et al. 2023a). For many applications, like e.g., the forecasting of photovoltaic (PV) energy production (Kreuwel et al. 2020) or the photosynthesis and evaporation rates from plant canopies (Vilà-Guerau de Arellano et al. 2023), capturing the high-frequency irradiance variability and direct-diffuse partitioning is crucial.

Numerical weather prediction (NWP) models can not accurately predict the high frequency solar irradiance variability and direct-diffuse partitioning, partially because of their relatively coarse spatial and temporal discretization. Cloud-resolving large-eddy simulations (LES) are a partial solution, as they do manage to capture most of the high frequency total irradiance variability in simulations of realistic weather (van Stratum et al. 2023). However, these LES models – like most NWP models – typically use the two-stream approximation for calculating radiative transfer. With this approximation, complex three-dimensional (3D) radiative effects are not captured, resulting in incorrect diffuse radiation patterns at the surface, and underestimation of peaks in the total solar irradiance (cloud enhancements, e.g. Gristey et al. 2020, Tijhuis et al. 2023).

1.2 Research plan

In the *shedding light on cloud shadows* project (SLOCS, chiel.ghost.io/slocs/) – funded by the Dutch Research Council (NWO) – we aim to understand and accurately simulate the surface solar irradiance variability. To this extent, we have collected unique radiation observations, and developed both explicit and more parameterized methodologies to accurately account for (surface) 3D radiative effects, including:

1. Gridded observations of the solar irradiance at a 10 Hz frequency, collected during several measurement campaigns in the Netherlands, Germany (https://fesstval.de/), Spain (http://www.hymex.org/?page=liaise), and the Amazon basin (https://cloudroots.wur.nl/), under different cloud and plant canopy conditions.
2. A dataset including 10 years of 1 Hz radiation observations from the Baseline Surface Radiation Network (BSRN) station at Cabauw, the Netherlands (Knap, 2022), including cloud and irradiance variability statistics (Mol et al. 2023b)
3. An online GPU based ray-tracer, that can accurately account for the 3D radiative effects in cloud resolving simulations (Veerman et al. 2023).
4. A computationally efficient parameterization that corrects the surface diffuse radiation fields from a two-stream radiation solver for the 3D radiative effects. This parameterization has the potential to greatly improve the surface probability distribution of the diffuse and global irradiance in cloud resolving simulations, with a negligible computational overhead (Tijhuis et al. 2023).

To demonstrate the potential of the new explicit simulation methods in LES, Figure 1. shows time series of the global horizontal irradiance from the BSRN observations (top left), and LES and ERA5 without accounting for 3D radiative effects (top right). The bottom row shows LES with the surface parameterization from Tijhuis et al. (2023, bottom left), and LES with the ray tracer from Veerman et al. (2023, bottom right). Both LES simulations in the bottom row nicely manage to capture the 3D radiative effects, with cloud enhancements exceeding the clear sky radiation.

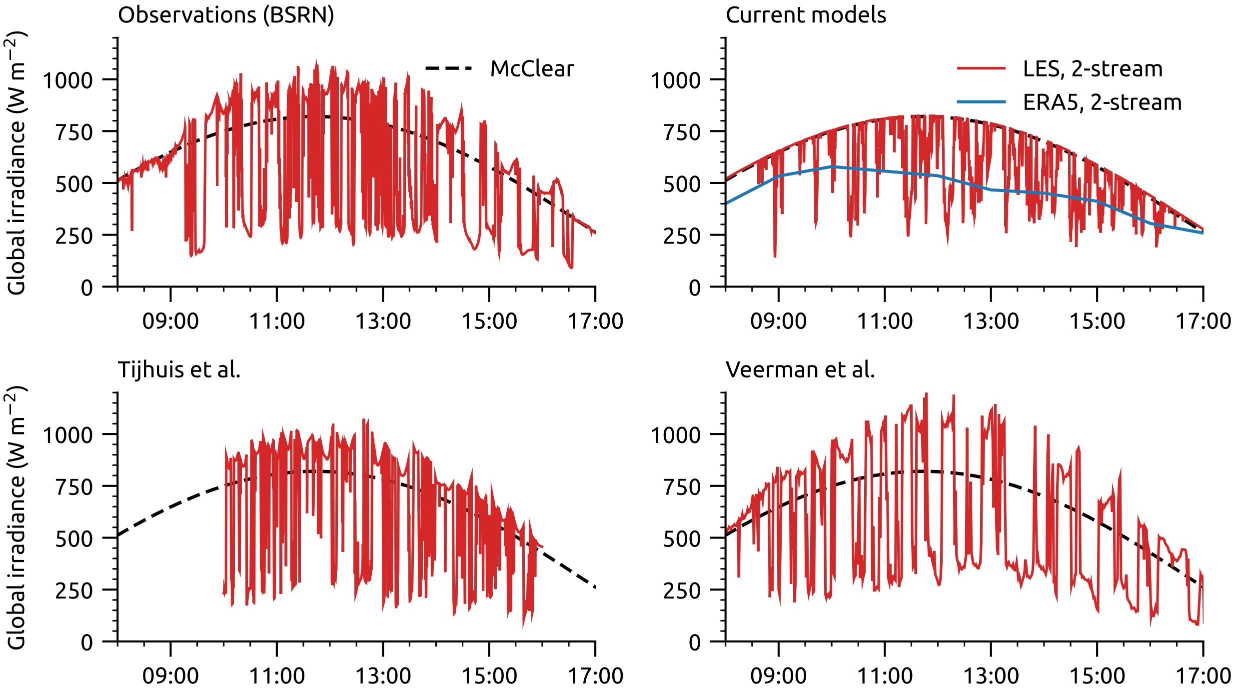

Figure 1. Time series of the global surface solar irradiance on 15 August 2016 over Cabauw, the Netherlands, from the 1 Hz BSRN observations (top left), both LES and ERA5 without accounting for 3D radiative effects (top right), using the surface parameterization from Tijhuis et al. (2023, bottom left), and using the GPU based ray tracer from Veerman et al. (2023, bottom right). The dashes line shows the clear sky global solar irradiance from McClear.

The surface parameterization from Tijhuis et al. (2023) has only been demonstrated as a proof of concept for a selected number of days. Our goal is to further develop and statistically validate this parameterization with the unique set of available observations under different cloud conditions, to create a robust model available to the scientific community for use in cloud-resolving models.

Our plan is to systematically assess the impact of several model choices by simulating a selected set of twelve days – all with different types of broken cloud conditions – over Cabauw, the Netherlands. For the simulations, we will use the open-source MicroHH LES model (van Heerwaarden et al. 2017), coupled to ERA5 using the open-source (LS)^{2}D Python package (van Stratum et al. 2023). In this model setup, we simulate realistic weather, but using doubly periodic lateral boundary conditions (e.g. Neggers et al., 2012). Although such a setup has its limitations, it allows for simulations on relatively small domains at a high resolution, which is required to capture solar radiation variability down to the second scale (van Stratum et al. 2023). These simulations will include:

1. A baseline set, which will be used to (a) validate the simulation setup without accounting for the 3D radiative effects in LES, and (b) provide the surface direct and diffuse solar radiation fields, which will be processed offline to test the parameterization in a diagnostic setup, without interfering with the model physics.
2. Like (1), but with the surface parameterization included online in LES. As a result, the surface 3D radiative effects interact directly with the land-surface model. As shown by Veerman et al. (2023), this interaction is the main cause of differences in cloud properties caused by 3D radiative effects.
3. Like (1), but with a tilted column approach (e.g. Gabriel & Evans 1996, Varnai & Davies 1999), which additionally displaces the location of the cloud shadow.
4. Like (2), but with a tilted column approach.

In addition to these runs, we plan to simulate all twelve days on a larger domain using open lateral boundary conditions, again using MicroHH coupled to ERA5. As shown by Schemann et al. (2020), an LES setup with open boundaries has the potential to improve the representation of clouds in LES. These large domain simulations are however typically a compromise between domain size and resolution. To limit the computational costs, all days will be simulated on a 100 m horizontal resolution, with only four days simulated at a for LES more appropriate horizontal resolution of 50 m.

All simulations will be validated with the Cabauw BSRN direct and diffuse radiation observations. For the large domain simulations, we will additionally use other surface and tower observations available over the Netherlands within the Ruisdael Observatory (https://ruisdael-observatory.nl/), and routine observations from automatic weather stations (AWS). In addition, the simulations with doubly periodic boundary conditions will also be compared with simulations using the GPU based ray tracer. Given the limited GPU resources in the European Weather Cloud, these GPU simulations will be performed at the Snellius supercomputer in the Netherlands.

2. Description simulation system

MicroHH (van Heerwaarden et al. 2017, microhh.org, github.com/microhh/microhh) is an open-source LES model capable of running on either CPUs or NVIDIA GPUs. Over the last years, all model physics needed for the simulation of realistic weather have been implemented. This includes the RTE-RRTMGP radiation code (Pincus et al. 2019) with optionally an online GPU based ray tracer (Veerman et al. 2023) and a coupling to (CAMS) aerosols, a land-surface model based on CHTESSEL (Balsamo et al. 2011), and a single moment ice microphysics scheme (Tomita, 2008).

The entire model is written in C++ and CUDA-C++, and only relies on the NetCDF-C and FFTW libraries as external dependencies. The code uses MPI for parallelization, and MPI-IO for the in- and output of all two and three-dimension fields. The statistics (time series and vertical profiles) are stored in NetCDF format.

The code has demonstrated excellent scaling, both in weak scaling tests up to 32’768 cores at the Juqueen supercomputer in Jülich, and strong scaling tests up to 8’192 cores at the SuperMUC supercomputer in München, as shown in Figure 2.

For the coupling of LES to ERA5, we use the open-source Python package $(LS)^2D$ (van Stratum et al. 2023, pypi.org/project/ls2d, github.com/LS2D/LS2D)

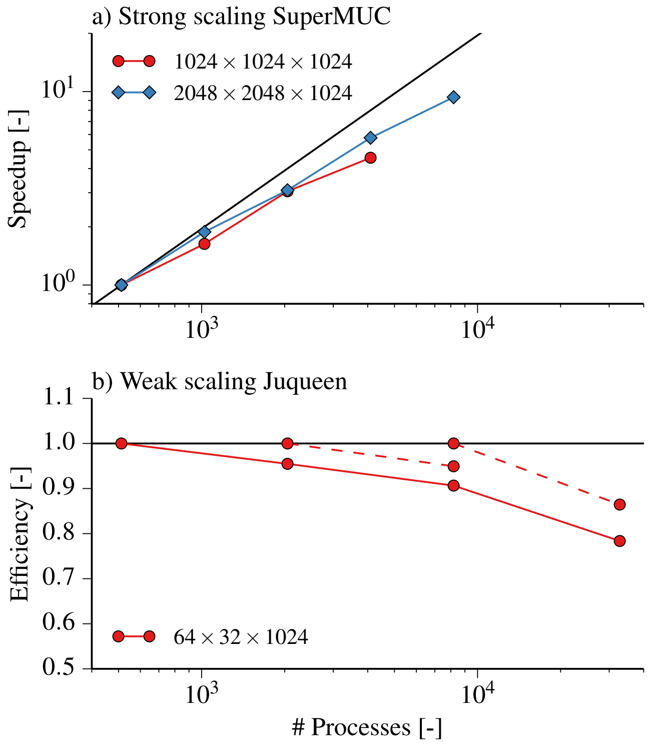

Figure 2. Strong and weak scaling of the dynamic core of MicroHH. For details, see van Heerwaarden et al. (2017)

3. Justification computing resources

As we currently do not have access to the ECMWF supercomputer, the numbers below have been obtained from benchmarks at the Snellius supercomputer in the Netherlands. This system consists of AMD EPYC processors with 128 cores per node (https://servicedesk.surf.nl/wiki/display/WIKI/Snellius+hardware+and+file+systems).

Small domain with doubly periodic boundary conditions.

In the intended model setup (25.6 × 25.6 km^2 domain at 50 m resolution), the simulation of a single day requires ~5000 CPU hours. The simulation of 12 days in four different model configurations thus costs around 5000 × 12 × 4 = ~240’000 CPU hours.

The data that we need to store in the archive consists mainly of 2D surface fields of various quantities. Per simulated day, this requires ~10 GB of storage, resulting in a total archive space of 480 GB.

Large domain with open boundary conditions.

The simulations with open lateral boundary conditions (~300 km^2 domain at 100 m resolution) requires ~90’000 CPU hours per day. For 12 days in total, this thus requires ~1’080’000 CPU hours. The 4 days simulated at 50 m resolution will costs an additional 2’880’000 CPU hours.

Per simulated day at 100 m resolution, ~64 GB of data needs to be archived. At 50 m resolution, the storage is ~256 GB per day. This results in a combined total of 1.792 TB of archive space.

Total computational request.

Combined, we request a total of 4.2 million CPU hours = 4.2 × 18.91 = **79.4 million SBUs**, with **2.272 TB of archive space**.

4. References

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