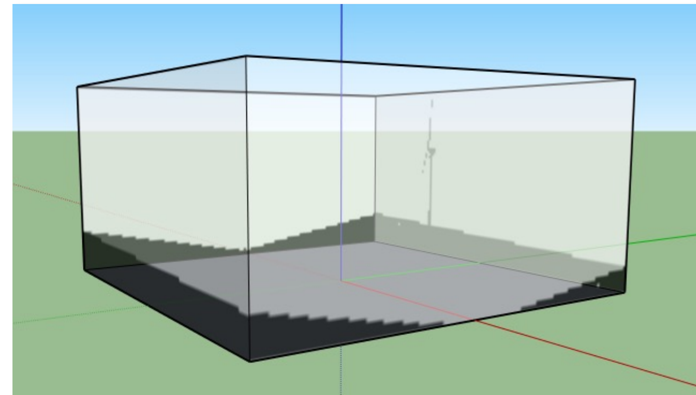
WHEN TRUST MATTERS



A Model for Efficient Shading Evaluation in Large-Scale PV Plants Based in Hemicube Geometry

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PV, DNV & SolarFarmer

- Independent engineers; assurance & risk
- Foundation, with Norwegian HQ
- 5% R&D re-investment
- Strategy goals: Decarbonisation & Digitalisation
- 250 PV Engineers & Scientists

- Software for bankable pre-construction yield estimates
- Industrial & utility scale projects
- 3D: complex terrain & shading
- Easy to use
- Enables scalability

Shading methods

Shading sources: Row-to-row, near scene obstacles (boundary structures, trees, buildings etc.) and terrain

2 approaches

- Geometric shading / View factors
  - Great for row to row shading on arrays laid on (tilted) planes; fast and accurate!
  - But not so easy for complex terrain or for arbitrary near shading obstacles
- Ray tracing
  - For beam shading, plot a line from each point on module to every solar position and loop over all the obstacles to evaluate whether or not that beam path is obscured
  - Great for accuracy but an intensive computation / computational efficiencies likely to be complex
  - … and, for diffuse, need to accumulate shading through weighted collections of paths over all of the sky

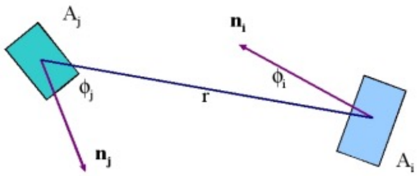
Is there an accurate *enough* method for complex terrain and arbitrary shading obstacles that's faster, or simpler?

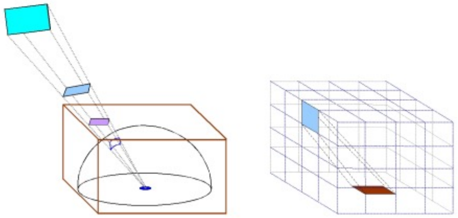
Hemicube finite element approach

- Established method in computer graphics for solving radiosity; rendering scenes with diffusely reflected light
  https://en.wikipedia.org/wiki/Radiosity_(computer_graphics)

- 3D surface polygons amalgamated into patches, then compute the light emitted and collected across all combinations of patch pairs. An efficient solution entails regularised patches and view factor computations
  https://www.doc.ic.ac.uk/~dfg/graphics/graphics2010/GraphicsHandout07.pdf

- SolarFarmer re-purposes just the first step; the so-called hemicube step…





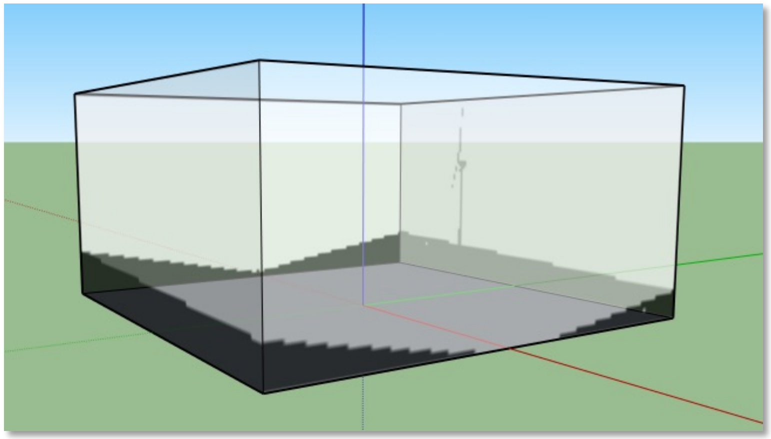
(a) The Hemisphere and Hemicube

(b) Delta form factors

Hemicubes for beam shading

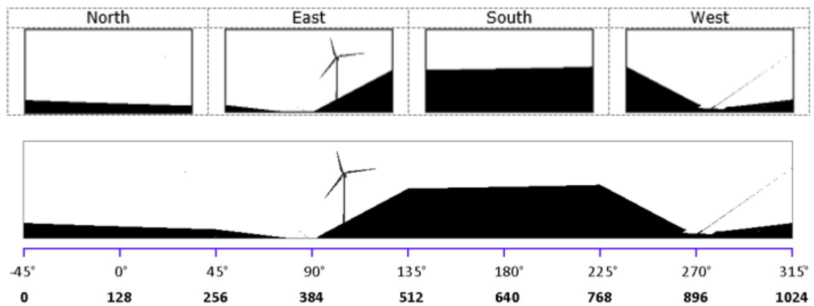
Pre-compute step

- A virtual unit hemicube placed over each point on the module
- Grid each of the 5 faces, M * N pixels
- Evaluate beam shading for each pixel considering all shading obstacles; black = shaded
- Amenable to optimised graphics CPU/GPU instructions
- Store all these hemicube surfaces, for a fixed array they won't change



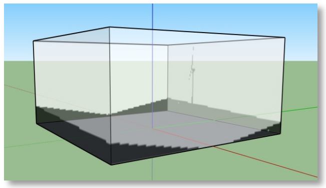
Run-time

- For each solar position, just lookup the appropriate pixel in each hemicube; easy because the hemicube is regular
- Fast. Especially useful when you want to consider a lot of solar angles / small time steps

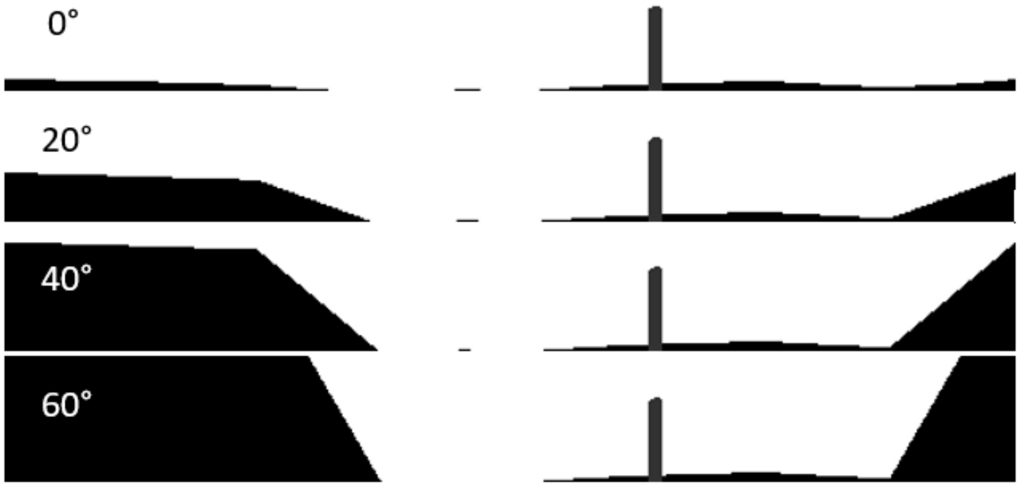


Hemicube silhouetting with multiple tilt angles

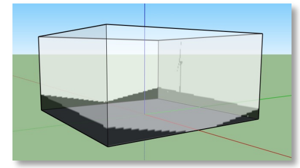
- To re-enforce how the hemicube works…



- … visualise how the shading from the row in front spreads up the hemicube side as the tilt angle increases



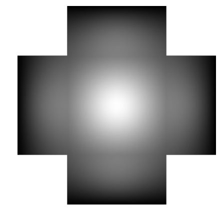
- All shading obstacles handled in a single method; row-to-row, near obstacles & terrain



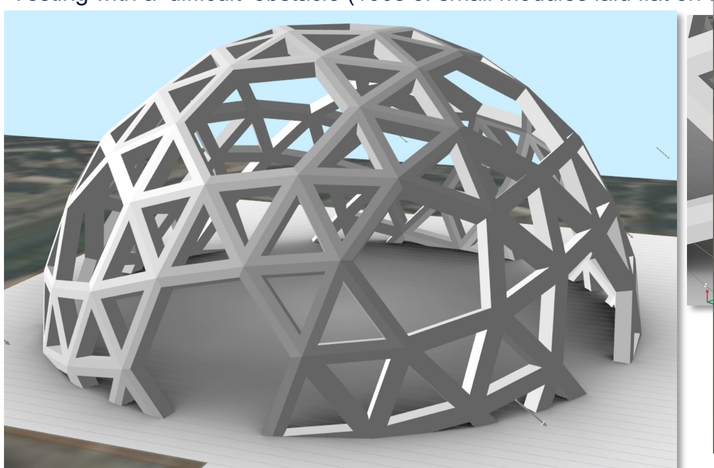
Diffuse irradiance

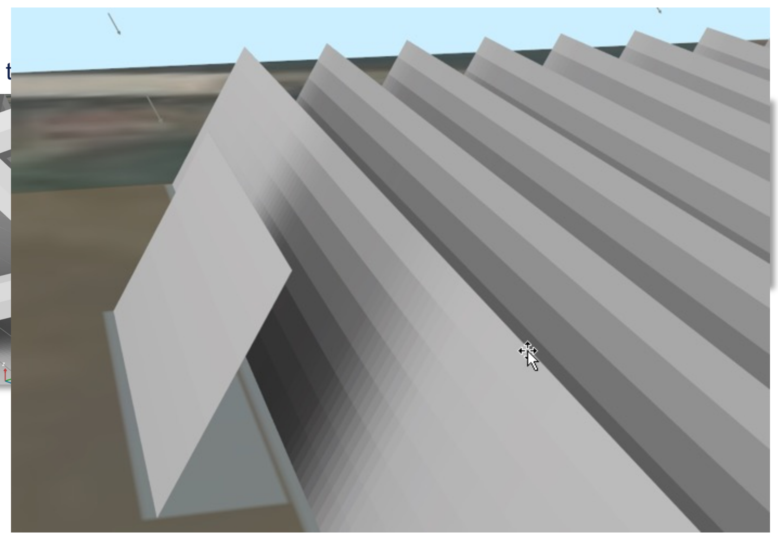
- Hemicube method for beam shading also gets us the diffuse irradiance, almost for free
  - Sky diffuse shading factor ≈ proportion of unshaded pixels
  - Just needs a (pre-computed) pixel weighting map to compensate for hemicube perspective (i.e. it's not a hemisphere) and module relative incidence angle

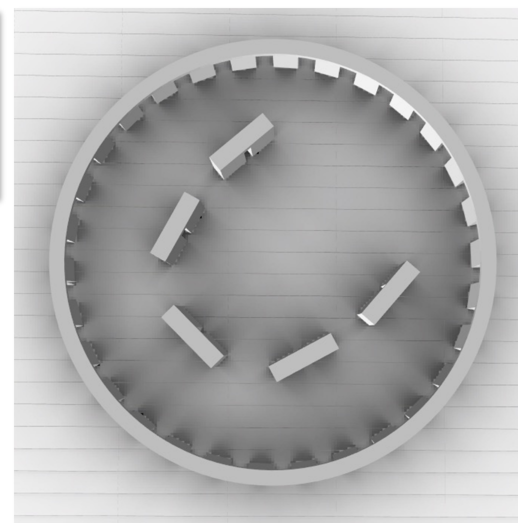
Diffuse shade weighting map, 4 hemicube sides around top



Testing with a 'difficult' obstacle (100s of small modules laid flat on t





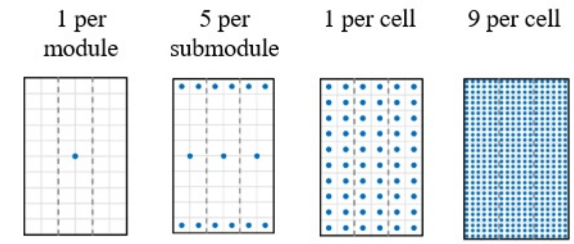


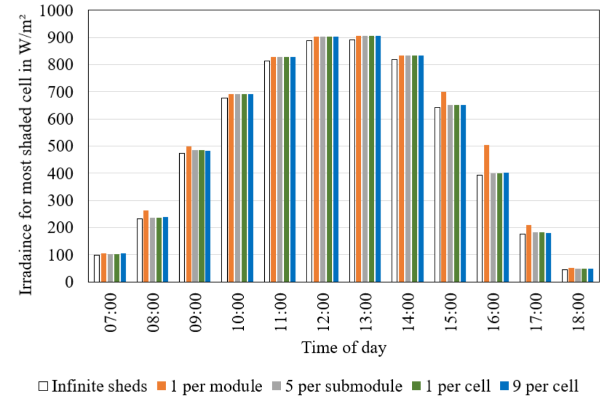
How many hemicubes?

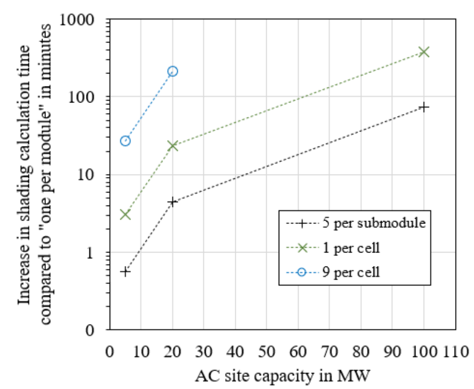
- Investigate yield sensitivity to a range of hemicube placement scenarios; 1 per module through 9 per cell
- For a fixed tilt layout on simple terrain, so we can easily compare (the back row) with infinite sheds
- All methods similar at times of day without shade
- 1 per module assumption under estimates (row-to-row) shading towards each end of the day – underestimates shade
- 5/submodule, 1/cell, 9/cell: < 0.01% yield difference
- Compute time relative to the 1/module case for 5, 20 & 100MW sites; compute time ≈proportional to N hemicubes

  e.g. *4 increase from 5 per submodule to 1 per cell

SolarFarmer defaults to 5 hemicubes per submodule







Current status

- Core method proven & validated across multiple sites
  - 8 published, others confidential
  - Mixture of simple research sites and complex terrain commercial. Working on more validation for complex sites and near shading obstacles; striving for *continuous validation*
  - 11 SolarFarmer methodology & usage publications to date, 2 more this year…

- Run times on a modern PC typically a few minutes for 10MW, an hour or so for 100MW
  - Scales somewhere between O(N) and $O(N^2)$
  - Hemicube pre-compute means small time step / multi-year calculations scale favourably
  - … or run the geometric / view factor methods in seconds (without variable terrain)

- API implemented on Azure Kubernetes cluster
  - Parallelised across many nodes; what took hours now takes minutes
  - Private Preview … while we keep working on the cluster scaling and queuing

Future Work

- More validation … continuously
  - Collaborations?
  - Comparisons with other 3D methods?

- More compute optimisations… explore more accuracy / compute time trade-offs

- Bifacial
  - 3D front side but currently using view factors for the backside - needs hemicubes on the ground and on the backside

- Multi-angle hemicube interpolation for trackers

See more at …

DNV’s Solar Energy Assessment Validation using SolarFarmer

Madison Ghiz, here, today @ 10:55!

DNV solar experts share the latest Solar Energy Validation Methodology, Webinar, 18th May 1pm ET
https://www.dnv.com/power-renewables/events

Uncertainty Considerations in Bifacial Photovoltaic Systems with High Albedo Seasonality, Javier Lorente Lopez, PVSC

Light and Shade – A Hemicube Approach for Efficient Shading Calculations in Utility-Scale PV Plants, Anja Neubert EU-PVSEC

DNV

Thank you

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9. "Validation of the SolarFarmer Software with Operational Data" by A. Neubert, M.A. Mikofski, M. Hamer and P. Rainey, in *37th European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC)*, 2020, pp. 1621 - 1625. DOI: 10.4229/EUPVSEC20202020-5CV.4.10

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