



Shadow Flicker Module Guide

User manual, inputs, solar geometry, receptor calculations, raster outputs and technical interpretation

Technical guide to the Shadow Flicker module

This document explains how the plugin currently works, including its outputs, assumptions and limitations. It separates the calculation scenarios and explains the raster workflow so that every cell can be interpreted correctly.

Use

Complete workflow in QGIS

Physics

Solar position and angular method

GIS

Receptors, DEM and GeoTIFF

Traceability

Fields, equations and checks

Contents

The guide follows the real module workflow: input preparation, time configuration, geometric calculation, output generation and review of limitations.

Section	Pages	What it provides
A. Use and inputs	3-15	Basic workflow, QGIS layers, turbine geometry, receptors, coordinates, time zone, scenarios and parameters.
B. Physics and calculation	16-27	DEM, solar position, target angles, numerical example, tolerance, sampling, sensitivity and metrics.
C. Execution and GIS results	28-41	Validation, receptor layer, summary, matrices, raster workflow, filters and files.
D. Validation and scope	42-46	Performance, troubleshooting, interpretation, limitations and current implementation details.
E. Technical appendices	47-54	Variable dictionary, equations, NOAA chain, validation and scope text.

Recommended reading

For a first run, pages 3-15 are sufficient. For technical justification, also review pages 16-27 and appendices 47-54. Before delivery or publication, review the validation and scope section on pages 42-46.

1. What the module actually calculates

Per receptor

- Astronomical hours/year
- Availability-adjusted hours
- Minutes/year
- Affected days
- Maximum minutes/day
- Worst day

Time distribution

- Monthly breakdown
- 12 months × 24 hours matrix
- Calendar of affected timestamps
- Dominant turbine
- Individual contribution

Spatial outputs

- QGIS point layer
- Severity symbology
- Annual GeoTIFF
- Month/hour filtered GeoTIFF
- Auxiliary NPZ file

What the result represents

The engine counts time intervals in which the solar position falls inside the angular tolerance of the rotor as viewed from the receptor. It is geometric shadow-flicker potential, not a measurement of visual intensity.

It is not a flicker-intensity model

The module does not calculate blade-pass frequency, RPM, blade count, luminous contrast, irradiance, cloud cover or visual perception.

Scope

Preliminary screening and layout comparison. It does not replace a permitting assessment performed with the method, data and criteria required by the competent authority.

2. Inputs: minimum, recommended and advanced

Level	Inputs	Use	Caution
Minimum	Turbines + receptors + HH + D + latitude/longitude + year + time zone.	Functional test and initial receptor screening.	Flat terrain; astronomical hours without shielding.
Recommended	Minimum + DEM/DSM + verified IANA zone + 5-minute step.	Traceable GIS screening and comparison of layout options.	DEM changes elevations but does not test full line of sight.
Advanced	Recommended + 1-minute step + raster + time filters + separate availability scenarios.	Detailed maps, monthly analysis and sensitivity review.	Raster and matrices remain astronomical; validate in stages.

Not required

WRG, electrical power curve, Ct, AEP, wind direction or production time series are not needed. The module reuses turbine coordinates, but its physics is independent of the energy calculation.

3. QGIS project and the Refresh button

What the module reads from the project

- Project name and CRS.
- Point layers compatible with VelantisWind layouts.
- Point layers that can be used as receptors.
- Available DEM/DSM rasters.
- Hub-height and rotor-diameter metadata when available.

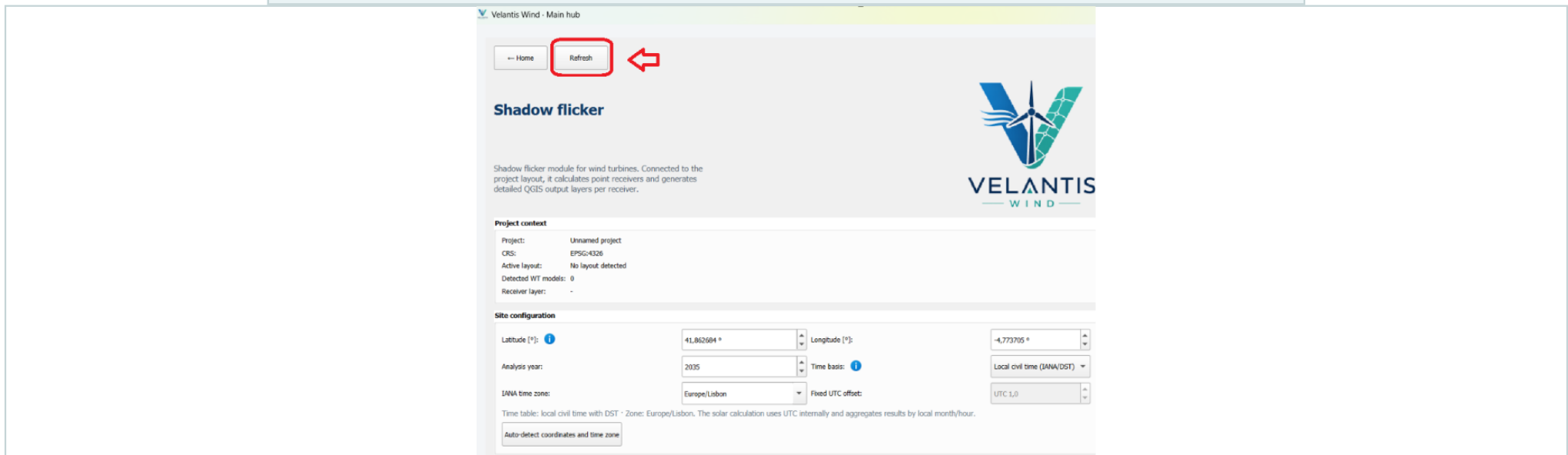
When to press Refresh

- After importing a CSV.
- After creating or editing receptors.
- After loading a DEM.
- When a layer does not appear in a selector.
- After changing project or QGIS profile.

Refresh does not recalculate

It only reloads the layer lists and project context. It does not delete results, restart QGIS or modify saved parameters.

Load layers → open Shadow Flicker → Refresh → select inputs → Check → Calculate



Velantis Wind - Main hub

← Home Refresh ↩

Shadow flicker

Shadow flicker module for wind turbines. Connected to the project layout, it calculates point receivers and generates detailed QGIS output layers per receiver.

Project context

Project:	Unnamed project
CRS:	EPSG:4326
Active layout:	No layout detected
Detected WT models:	0
Receiver layer:	-

Site configuration

Latitude [°]:	41.862694 °	Longitude [°]:	-4.773795 °
Analysis year:	2035	Time basis:	Local civil time (IANA/DST)
IANA time zone:	Europe/Lisbon	Fixed UTC offset:	UTC 1,0

Time table: local civil time with DST · Zone: Europe/Lisbon. The solar calculation uses UTC internally and aggregates results by local monthly/hour.

Auto-detect coordinates and time zone

4. Turbine input: point layer

Required geometry

- Point geometry.
- One feature per wind turbine.
- Coordinates in metric units.
- No null geometries.

Data	Source	Physical use
X, Y	Layer geometry	Distance, target azimuth and raster mask.
HH	Module table	Hub elevation above ground.
D	Module table	Angular rotor radius.
DEM _t	Optional raster	Absolute tower-base elevation.

How each turbine is identified

The engine builds an internal name from the layer name and feature ID. That identifier appears in contribution tables and in the dominant-turbine field.

One layer per run

The current interface selects one turbine layer and applies the geometry shown in the table to every feature. For mixed HH or D, use homogeneous layers and document the combination workflow.

5. Layout import and CRS

Minimum CSV

```
x, y
356123.40, 4640123.80
356850.00, 4640740.20
357420.50, 4641310.75
```

Mandatory checks

- X and Y must use the project CRS.
- Do not treat latitude/longitude as metres.
- The receptor layer must use the same system and units.
- Visually check distances and the site extent.

Coordinate	Accepted examples
X	x, utm x, easting, east, lon, longitude
Y	y, utm y, northing, north, lat, latitude

CRS warning

Column names such as lon/lat may be accepted by an importer, but the shadow calculation expects metric coordinates in the layer/project CRS. Reproject before running the module.

6. Receptors: recommended layer format

Robust format

- Point vector layer.
- One point per dwelling, building, settlement, farm or sensitive location.
- Same metric CRS as turbines.
- Useful fields: id, name, type or category.

Element	Current behaviour
Point	Calculated directly at the point coordinates.
MultiPoint	Use single-point features whenever possible.
Polygon	A point representation is recommended for auditable receptor calculations.
Observer height	Global interface value for the point calculation.

Recommended practice

Create explicit receptor points at the locations to be assessed. Keep a stable identifier so that CSV exports and revised layouts can be compared receptor by receptor.

Do not confuse receptor size and observer height

Observer height affects the vertical target angle. The small receptor size used in the angular tolerance is an internal geometric approximation.

7. Latitude, longitude and automatic detection

What latitude and longitude control

The site coordinates define the apparent solar path, equation-of-time correction and local solar elevation. They must represent the wind-farm site, not the numerical values of the projected CRS.

Automatic detection

- Computes the centroid of the selected turbine layer.
- Transforms it to geographic coordinates.
- Fills latitude and longitude.
- Attempts to suggest a compatible IANA time zone.

Check	Expected
Latitude	Positive north, negative south.
Longitude	Positive east, negative west.
Site point	Inside or close to the turbine layout.
Decimal format	Decimal degrees, not degrees-minutes-seconds.

After automatic detection

Check the values manually, especially near time-zone borders or when the project CRS is missing or incorrectly assigned.

8. Time zone: IANA/DST versus fixed UTC offset

Mode	How it works	Advantage	Risk
Local civil time (IANA/DST)	Builds the yearly timeline with the selected IANA zone and applies the UTC offset valid at every instant.	Represents daylight-saving changes and local civil time.	A wrong zone shifts the hourly matrix.
Fixed UTC offset	Uses the same offset for the whole year.	Simple and reproducible for controlled comparisons.	Does not apply DST; displayed time can differ from civil time.

IANA example

Europe/Madrid → CET/CEST depending on date.

Fixed example

UTC +1.0 during the whole year.

Recommended choice

Use IANA/DST when interpretation depends on local civil time. Use a fixed offset for controlled comparisons that must keep the same displacement all year.

DST handling

In IANA mode, the engine avoids nonexistent or duplicated local hours around seasonal changes and aggregates results by local civil date/hour.

9. Analysis year and temporal grid

Analysis year

The interface accepts 2020-2050. The selected year defines the calendar, leap-year status, dates and monthly distribution.

Step	Recommended use	Effect
1 min	Fine-resolution validation / sensitivity	Highest resolution; highest cost.
5 min	Standard calculation	Good balance.
10-15 min	Quick test	May round event starts and ends.
30-60 min	Diagnostics only	Too coarse for conclusions.

Conversion

Annual minutes = Npositive timestamps × Δt ; annual hours = minutes / 60.

Temporal sensitivity

A smaller step does not change the geometry, but it resolves short alignment windows better. Compare 5 minutes with 1 minute at the highest-impact receptors.

10. General calculation parameters

Control	UI range	Initial value	What it changes
Observer height	0-50 m	2.0 m	Absolute receptor elevation in the point calculation.
Time step	1-60 min	5 min	Temporal resolution of receptor calculations.
Minimum solar elevation	0-30°	3°	Excludes very low sun.
Maximum solar elevation	30-90°	90°	Optional upper filter.
Availability	0-1	0.97	Multiplies annual astronomical hours.
Maximum distance	100-20000 m	2000 m	Filters pairs and defines raster extent/mask.
Raster resolution	25-500 m	100 m	Cell size.
Raster time step	1-30 min	5 min	Independent raster time grid.

Suggested initial configuration

2 m · 5 min · 3°-90° · availability 1.00 for the astronomical scenario · 2000 m · raster disabled. Apply 0.97 or another documented factor as a separate operational scenario.

Recommended calculation scenarios

Working with separate scenarios prevents astronomical potential from being mixed with operational adjustments and helps detect errors before launching a computationally intensive raster calculation.

Scenario	Suggested configuration	Purpose	Primary output
A. Functional test	No DEM · 10 min · availability 1.00 · no raster	Check layers, CRS, site coordinates, time zone and geometry.	hours_year and worst day; plausibility only.
B. Astronomical base	Optional DEM · verified IANA zone · 5 min · availability 1.00	Traceable geometric result for layout comparison.	hours_year, calendar, matrix and contributions.
C. Operational adjustment	Same as B · documented availability	Apply the module annual linear correction.	hours_real; calendar and raster unchanged.
D. Raster map	100 m / 10 min for test; then 50-25 m and 5-1 min	Identify spatial pattern and high-potential zones.	Astronomical GeoTIFF and 12×24 NPZ.

Comparability

Do not compare two layouts if year, time zone, time step, DEM, HH, D or maximum distance also change. Keep a scenario sheet and change one variable at a time.

Availability

The factor only changes receptor hours_real. It does not adjust the monthly matrix, timestamp calendar or raster.

11. Solar-elevation filters and maximum distance

Minimum solar elevation

The filter removes timestamps with solar elevation below the threshold. A value of 3° reduces extremely grazing alignments.

valid = sun above horizon $\wedge \alpha \geq \alpha_{\min} \wedge \alpha \leq \alpha_{\max}$

Maximum distance

The horizontal turbine-receptor distance is calculated. If it exceeds the limit, that turbine contributes 0 h to the receptor.

$$d_h = \sqrt{(x_t - x_r)^2 + (y_t - y_r)^2} \leq d_{\max}$$

Do not confuse the distance limit with a physical shadow length

Maximum distance is a user-defined screening criterion. It is not calculated from irradiance, apparent blade size or contrast.

12. Astronomical hours and availability-adjusted hours

Astronomical scenario

Counts every geometrically aligned timestamp without applying cloud-cover, sunshine-probability or operational corrections.

$$\mathbf{Hastro} = \mathbf{Nunion} \times \Delta t / 60$$

Availability adjustment

The module applies one linear factor to the annual total.

$$\mathbf{Hreal} = \mathbf{Hastro} \times \mathbf{A}$$

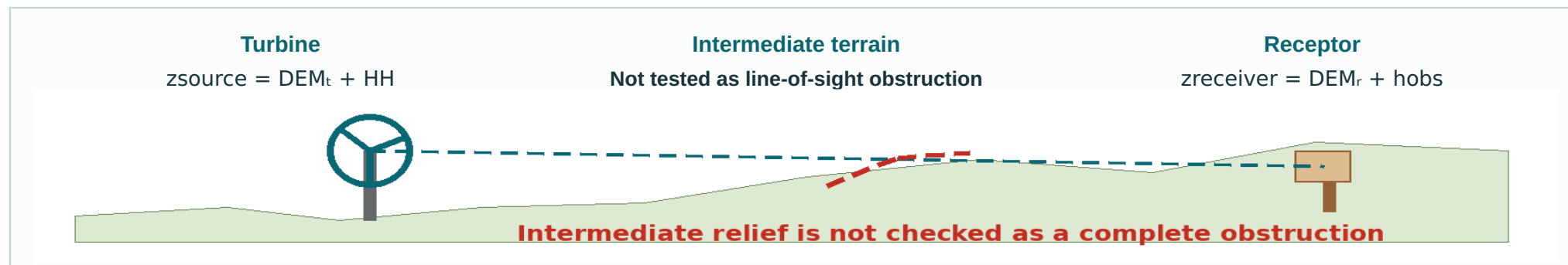
What availability does not represent

It does not include cloud cover, sunshine probability, actual rotor orientation, sector shutdown, hourly curtailment or correlation between operation and solar conditions.

Time matrices remain astronomical

The calendar, monthly breakdown and 12×24 matrix remain astronomical. Only annual hours_real is multiplied by availability.

13. DEM/DSM: implemented behaviour



Correct description

DEM/DSM-aware shadow geometry. The raster is used to adjust the absolute elevations of turbines, receptors and raster cells.

Description to avoid

“Full 3D model with topographic obstruction.” The module does not traverse the intermediate terrain profile to determine whether a ridge blocks the shadow ray.

14. Absolute elevations, reprojection and NoData

Source

$$z_t = \text{DEM}(x_t, y_t) + HH$$

Receptor

$$z_r = \text{DEM}(x_r, y_r) + h_{\text{obs}}$$

Vertical difference

$$\Delta z = z_t - z_r$$

Band

Band 1 is sampled.

Fallback risk

An elevation of 0 m can mean real sea-level terrain or a sampling failure. Verify coverage, band, NoData and CRS before trusting the result.

15. Solar-geometry calculation chain



Implementation

The module uses simplified NOAA-style equations vectorised over the complete year. Solar position is calculated once per scenario and reused for every turbine and receptor.

Not included

No explicit atmospheric-refraction correction is applied and the solar disc is not modelled with a variable radius. A fixed semi-diameter is used in the angular tolerance.

16. Main solar-position equations

Declination

$$\delta = \arcsin[\sin(\lambda_{\text{ecl}})\sin(\varepsilon)]$$

True solar time

$$TST = t_{\text{local}} + E + 4\lambda_{\text{site}} - 60 UTC_{\text{offset}}$$

Equation-of-time correction plus site longitude.

Hour angle

$$H = TST/4 - 180^\circ$$

Signed hour angle in degrees.

Solar elevation

$$\alpha = \arcsin(\sin \phi \sin \delta + \cos \phi \cos \delta \cos H)$$

Angle above the horizon.

Zenith

$$\zeta = \arccos(\sin \phi \sin \delta + \cos \phi \cos \delta \cos H)$$

Complementary angle to solar elevation.

Azimuth

$$\theta_{\text{sun}} = f_{\text{NOAA}}(H, \zeta) \in [-180^\circ, 180^\circ]$$

NOAA branch selected by the sign of H.

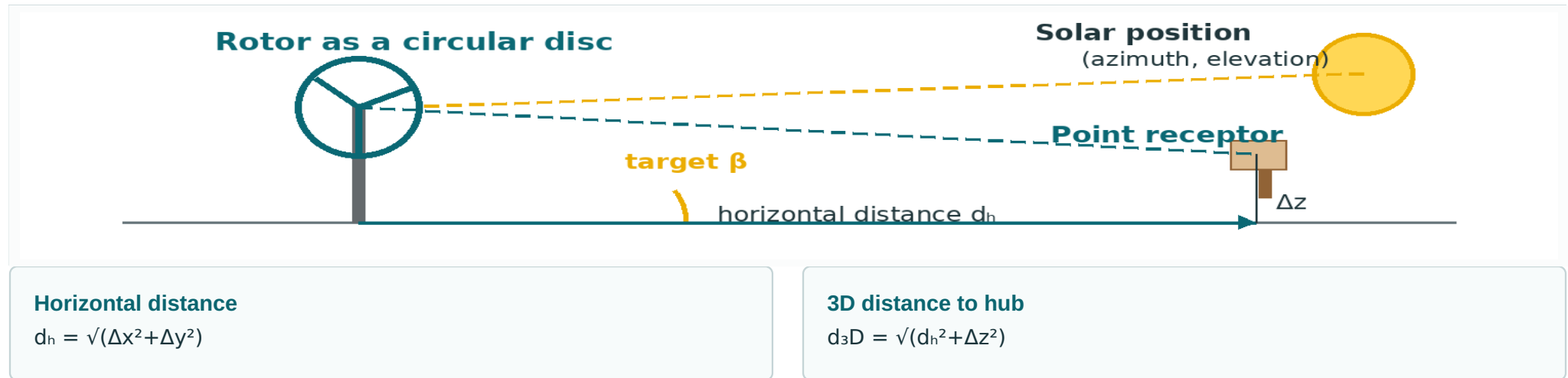
Convention

Azimuth: 0° = North, 90° = East, $\pm 180^\circ$ = South and -90° = West. Elevation: 0° = horizon, 90° = zenith.

Interpretation

The equations are written explicitly so the solar-position chain can be reviewed and audited directly.

17. Turbine-receptor geometry



Horizontal distance

$$d_h = \sqrt{\Delta x^2 + \Delta y^2}$$

Plan-view distance between receptor and turbine.

3D distance to hub

$$d_{3D} = \sqrt{d_h^2 + \Delta z^2}$$

Distance from receptor to turbine hub.

18. Target azimuth, elevation and angular tolerance

Target azimuth

$$\theta_{\text{obj}} = 90^\circ - \text{atan2}(y_t - y_r, x_t - x_r) \rightarrow [-180^\circ, 180^\circ]$$

Target elevation

$$\beta_{\text{obj}} = \text{atan2}(z_t - z_r, d_h)$$

Angular tolerance

$$\gamma = \text{atan2}(D/2 + S_r/2, d_{3D}) + \rho_{\text{sun}}$$

Symbol	Value / meaning
D	Configured rotor diameter.
S_r	2.0 m in the current calculation; representative receptor/window size.
ρ_{sun}	0.2725°; fixed solar angular semi-diameter.
γ	Acceptance radius in the azimuth-elevation plane.

Worst-case rotor disc

The rotor is treated as a complete circular disc. Its plane is not oriented according to wind direction, yaw or tilt.

Numerical example: one turbine-receptor alignment

Illustrative flat-terrain example showing how the variables combine. It is not a real project site.

Input	Value
Turbine	x=0 m, y=0 m
Receptor	x=1000 m, y=0 m
HH	120 m
Observer height	2 m
Rotor diameter D	170 m
Receptor size	2 m

Horizontal distance	$d_h = 1000.00 \text{ m}$
Vertical difference	$\Delta z = 120 - 2 = 118.00 \text{ m}$
3D distance	$d_{3D} = 1006.94 \text{ m}$
Target elevation	$\beta_{\text{obj}} = \text{atan2}(118, 1000) = 6.73^\circ$
Tolerance	$\gamma = \text{atan2}(86, 1006.94) + 0.2725^\circ = 5.15^\circ$

Test solar position	$\Delta\text{azimuth}$	$\Delta\text{elevation}$	Angular error	Result
Az=-92.0° · Elev=8.0°	-2.00°	+1.27°	$2.37^\circ < 5.15^\circ$	Timestamp counted
Az=-100.0° · Elev=8.0°	-10.00°	+1.27°	$10.08^\circ > 5.15^\circ$	Not counted

Physical reading

The receptor is 1 km east of the turbine, so the Sun must be approximately west of the turbine. A larger rotor creates a wider angular window, which narrows as distance increases.

Solved example: step-by-step interpretation

This page complements the numerical example without replacing it. It explains how each intermediate quantity leads to the final counted / not counted decision.

1. Geometry and inputs

Turbine: $x=0$ m, $y=0$ m.
 Receptor: $x=1000$ m, $y=0$ m.
 HH=120 m, hobs=2 m, $D=170$ m, $S_r=2$ m.

The receptor is 1 km east of the turbine.

2. Derived geometry

$d_h=1000.00$ m, $\Delta z=118.00$ m and $d_{3D}=1006.94$ m.
 $\beta_{obj}=6.73^\circ$ defines the target elevation.
 $\gamma=5.15^\circ$ is the angular acceptance radius.

3. Key equations

$$\beta_{obj} = \text{atan2}(\Delta z, d_h)$$

$$\gamma = \text{atan2}(D/2 + S_r/2, d_{3D}) + \rho_{\text{sun}}$$

Sun position	$\Delta\text{azimuth}$	$\Delta\text{elevation}$	Combined error	Compare with γ	Outcome
Az=-92°, Elev=8°	-2.00°	+1.27°	2.37°	$2.37^\circ < 5.15^\circ$	COUNTED
Az=-100°, Elev=8°	-10.00°	+1.27°	10.08°	$10.08^\circ > 5.15^\circ$	REJECTED

4. Decision rule

$$e^2 = \Delta\theta^2 + \Delta\alpha^2 \quad \text{and count when } e \leq \gamma$$

Why Test 1 is counted

Its combined error (2.37°) is smaller than γ (5.15°), so the timestep contributes Δt minutes.

Why Test 2 is rejected

Its combined error (10.08°) is larger than γ (5.15°), so the timestep contributes zero minutes.

19. Shadow criterion and temporal sampling

Wrapped azimuth difference

$$\Delta\theta = \text{wrap}(\theta_{\text{sun}} - \theta_{\text{obj}}) \in [-180^\circ, 180^\circ]$$

Shortest signed azimuth difference.

Vertical difference

$$\Delta\alpha = \alpha_{\text{sun}} - \beta_{\text{obj}}$$

Difference in the elevation plane.

Implemented shadow test

$$e^2 = \Delta\theta^2 + \Delta\alpha^2 \leq \gamma^2$$

Quadratic screening criterion implemented by the engine.

Pre-filters

- Sun above the horizon.
- Solar elevation inside the selected range.
- Horizontal distance inside the maximum.

After the test

- Timestamp date and hour are stored.
- Each positive timestamp contributes Δt minutes.
- Results are aggregated by day, month and hour.

Angular approximation

The test uses a quadratic distance in the azimuth-elevation plane. It is a screening approximation, not an exact spherical angular distance.

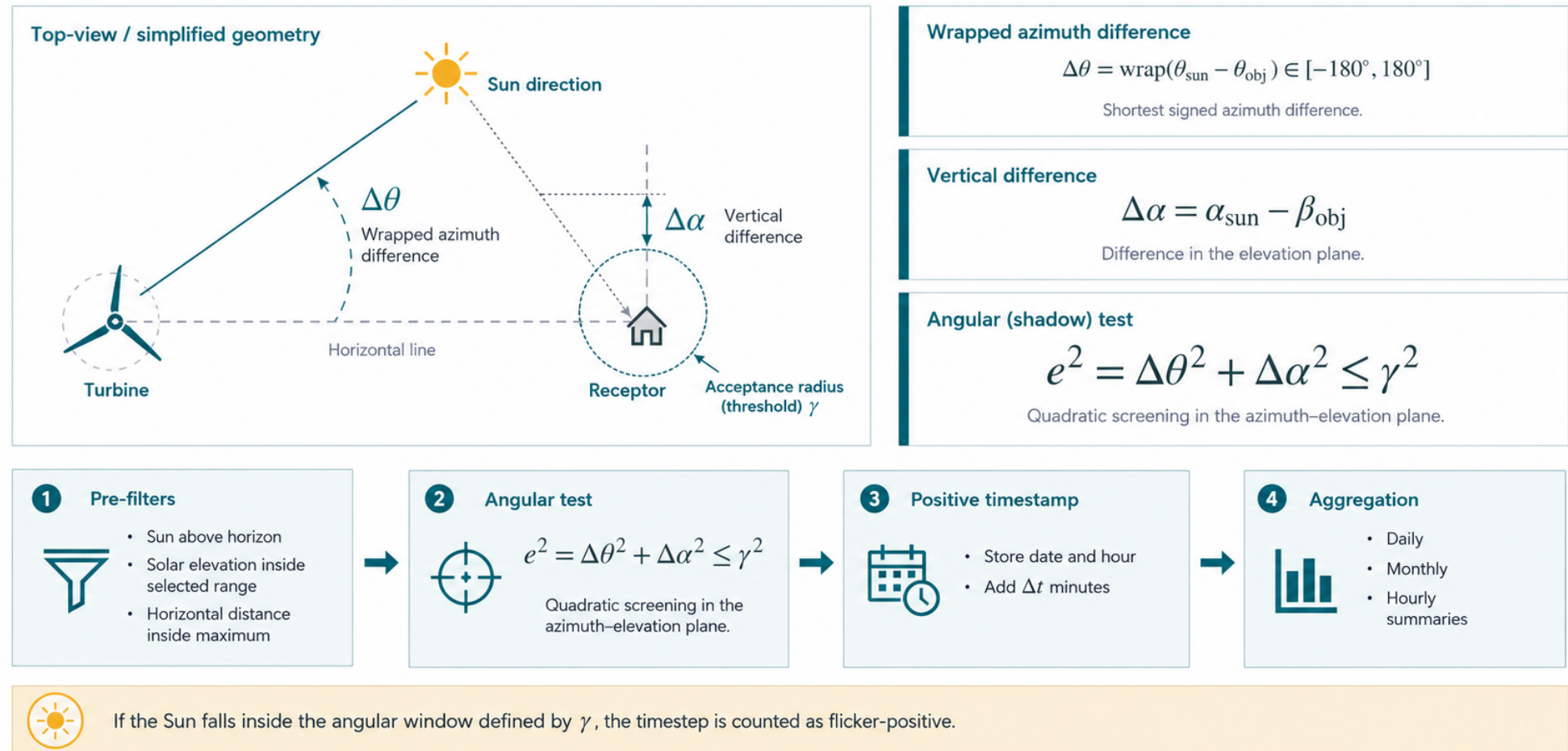
Temporal meaning

The output counts discrete positive timestamps. A finer time step lowers discretisation error.

19A. Visual complement to shadow screening

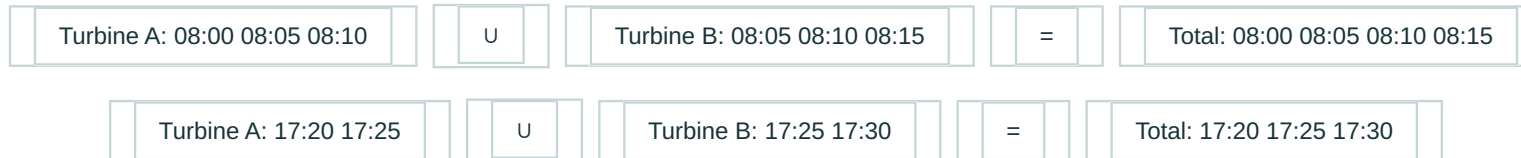
This visual page complements Section 19. It helps interpret the geometric meaning of $\Delta\theta$, $\Delta\alpha$ and γ , and shows how a positive timestep is generated and then aggregated into daily, monthly and hourly summaries.

19. Shadow criterion and temporal sampling



Screening approximation, not an exact spherical angular distance.

20. Multiple turbines: contribution and double counting



Receptor total

Individual calendars are merged as sets. If two turbines affect the same timestamp, the annual receptor total counts it once.

Individual contributions

Each turbine retains its individual hours. Therefore, the sum of turbine contributions may exceed the receptor total when events overlap.

Dominant turbine

The turbine with the largest individual contribution; it is not necessarily the only turbine responsible for the highest-impact periods.

21. Annual and daily metrics

Metric	Calculation	Interpretation
minutes_per_year	$\Sigma \text{ unique timestamps} \times \Delta t$	Astronomical minutes at the receptor.
hours_year	$\text{minutes_per_year} / 60$	Astronomical hours.
hours_real	$\text{hours_year} \times \text{availability}$	Annual linear adjustment.
days_affected	Number of dates with ≥ 1 timestamp	Days with geometric potential.
max_min_day	$\text{max timestamps/day} \times \Delta t$	Worst sampled daily duration.
max_shadow_date	date with highest timestamp count	Worst day of the year.

Discretisation

Metrics are multiples of the time step. With $\Delta t=5$ min, a real 7-minute event can appear as 5 or 10 minutes depending on temporal-grid alignment.

22. Monthly distribution and 12×24 matrix

Monthly breakdown

$$H_m = N_{\text{timestamps}, m} \frac{\Delta t}{60}$$

Hour × month matrix

$$M_{m,h} = \sum_{t \in (m,h)} \Delta t$$

The “All receptors” tab sums matrices. It does not represent a unique site-wide event calendar; it represents accumulated receptor-hours.

Practical reading

Use the monthly breakdown to identify seasonality and the 12×24 matrix to identify the local civil hours with the highest concentration of geometric shadow-flicker potential.

Sensitivity and convergence of the result

Parameter	When increased	When reduced	Recommended check
Time step Δt	Lower cost; more quantisation	Higher resolution; higher cost	5 min base and 1 min at the highest-impact receptors
Maximum distance	More pairs and larger raster	May exclude distant turbines	Compare base limit with +25%
Rotor diameter	Increases γ and potential hours	Narrows angular window	Use exact model D
Hub height	Changes β_{obj} and seasonal pattern	Changes vertical target	Use exact HH and review DEM
Minimum solar elevation	Excludes more low-sun events	Includes more grazing events	Compare 3° with project criterion
Availability	Only increases hours_real	Only reduces hours_real	Keep 1.00 for Hastro

Δt	Non-leap-year timestamps	Relative cost
10 min	52,560	0.5× vs 5 min
5 min	105,120	1×
1 min	525,600	5× vs 5 min

Convergence protocol

- Run 10 min to detect errors.
- Use 5 min as the base scenario.
- Repeat at 1 min for the highest-impact receptors.
- Compare hours/year and max minutes/day.
- Document the difference and adopted step.

Acceptance criterion

The guide does not impose a universal tolerance. The project team must define what 5-versus-1-minute difference is acceptable for the intended use.

23. Complete calculation workflow

1

Read the turbine layer and the configured HH/D values.

2

Resolve DEM and create CRS-aware samplers.

3

Convert turbines and receptors to internal dictionaries.

4

Build the vectorised annual solar cache.

5

Process receptors sequentially.

6

Create the point result layer.

7

Launch raster task in the background if enabled.

8

Show the summary and provide 12×24 CSV export.

Execution policy

Receptors are processed sequentially for QGIS/Windows stability. Raster generation runs as a background QgsTask and uses up to eight internal threads where possible.

24. Check configuration

Check	Blocks run?	What to review
Turbine layer selected, vector, point and non-empty	Yes	Selection and geometry.
Receptor layer selected, vector and non-empty	Yes	Preferably point features.
DEM exists, is raster and valid	Yes	Refresh selector.
Latitude/longitude within range	Yes	Signs and decimal values.
Step, distance and resolution >0	Yes	Numeric parameters.
Minimum elevation < maximum	Yes	Solar filters.
Availability between 0 and 1	Yes	Use fraction, not percentage.
Turbine CRS = receptor CRS	No, diagnostic only	Correct manually.

Mandatory use

Run the configuration check after changing layers, DEM, geometry, time zone or raster settings. A passed check does not replace visual inspection and unit verification.

25. Point result layer

Field	Type	Content
receiver	text	Receptor name.
hours_year	decimal	Astronomical hours/year.
hours_real	decimal	Availability-adjusted hours.
minutes	integer	Astronomical minutes/year.
days_affected	integer	Days with at least one positive timestamp.
max_min_day	integer	Maximum minutes in one day.
exceeds_30h	text	Yes/No internal flag.
exceeds_30m	text	Yes/No internal flag.
category	text	Very low, low, medium, high or critical.
severity	integer	0-4.
h_Jan...h_Dec	decimal	Monthly astronomical hours.

Geometry

The result layer is created in the receptor CRS and uses the original coordinates of each receptor point.

26. Screening categories and symbology

Layer class	hours_year range	Severity	Approximate colour
Very low	< 5 h/year	0	Light green
Low	5 to <10 h/year	1	Green/yellow
Medium	10 to <20 h/year	2	Yellow
High	20 to <30 h/year	3	Orange
Critical	≥30 h/year	4	Red

QGIS layer

category and severity depend on hours_year. exceeds_30m is stored separately.

Summary/tables

The displayed status can become critical when max_min_day > 30 even if hours_year is below 30.

Not a universal legal classification

The classes help order and visualise results inside the plugin. Reinterpret them according to the method and regulation applicable to the project.

Threshold detail

The layer sets exceeds_30h from 30 h inclusive, while summary cards may count receptors with >30 h. Review cases exactly equal to 30.0 h manually.

27. Calculation summary

Cards

- Number of turbines
- Number of receptors
- Maximum annual hours
- Average annual hours
- >30 h
- >30 min/day
- Time zone

Critical receptor

- Name
- Annual hours
- Affected days
- Worst day
- Dominant turbine

Configuration

- Latitude/longitude
- Year
- HH and D
- Time step
- Availability
- Distance
- Solar elevation

Monthly average

The summary monthly table shows average per receptor and total receptor-hours. It must not be interpreted as unique site-wide impact hours.

28. Receptor tables and CSV export

Hour × Month tab

- 24 rows and 12 months.
- Receptor selector or sum of all.
- Values in hours.
- Colour-scaled temporal heat map.

Per Receptor tab

- Astronomical and adjusted hours.
- Affected days and daily maximum.
- Worst date.
- Number of contributing turbines.
- Dominant turbine and hours.
- Screening status.

12×24 CSV

Includes calculation configuration, turbine geometry, receptor tables and final summary. It is the most useful output for temporal audit outside QGIS.

29. Interpreting turbine contributions

Indicator	Meaning	Does not mean
Contributing turbines	Number of turbines with individual contribution >0.	Number of turbines acting simultaneously.
Dominant turbine	Largest individual-hour contribution.	All events originate from that turbine.
Dominant hours	Hours from that turbine before subtracting overlap.	Can be added directly to other turbine totals.

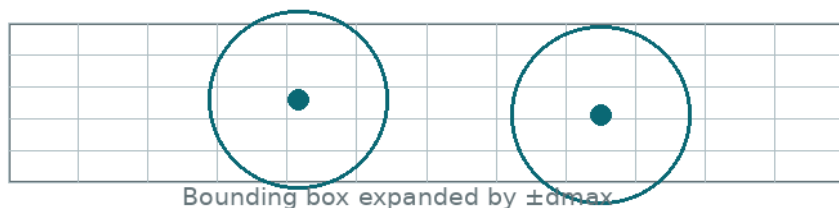
Recommended use

Sort receptors by hours_year, identify the worst day and then review the dominant turbine to guide layout changes or control strategies.

30. Shadow-flicker raster

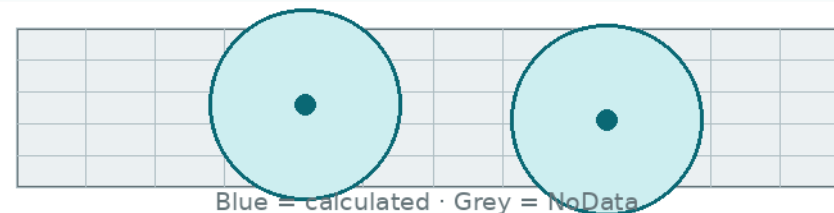
1. Build extent and grid

Bounding box expanded by $\pm d_{max}$ around turbines.



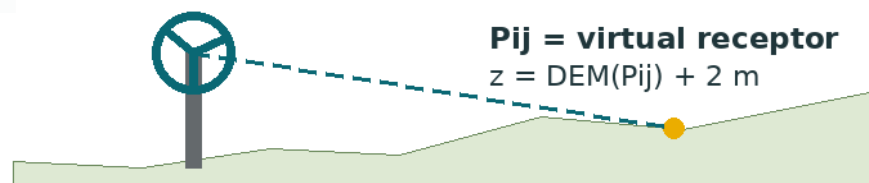
2. Apply distance mask

Blue = calculated · Grey = NoData. A cell is valid if it lies inside at least one



3. Calculate each valid position

P_{ij} becomes a virtual receptor with $z = \text{DEM}(P_{ij}) + 2$ m. All solar timestamps and



4. Save results

Annual GeoTIFF = astronomical hours. NPZ = 12×24 month-hour minutes.



How to read the workflow

The raster does not draw an instantaneous blade shadow. It creates a grid of observation positions, runs the annual angular test at each valid position and stores accumulated hours.

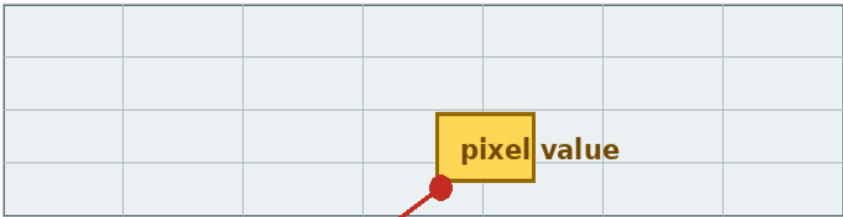
Outputs

GeoTIFF stores annual astronomical hours. NPZ stores minutes by month and hour for every grid position and is used to regenerate filtered TIFs without repeating solar geometry.

What exactly does a raster cell represent?

The cell is displayed as an area

The cell is displayed as an area...



Pij = grid coordinate used by the engine

Meaning of the stored value

-  NoData (-9999): outside the mask
-  0 h: calculated, no alignment
-  >0 h: astronomical hours at Pij

Raster observer elevation

$z_{Pij} = DEM(Pij) + 2.0 \text{ m}$

Item	Current behaviour
Calculation point	Pij = (xi, yj) from the grid.
Observer elevation	zij = DEM(Pij)+2.0 m.
Turbine combination	Union by timestamp.
Written value	Hastro in hours/year.
NPZ	Minutes in 12 months × 24 hours.

Spatial precision

The grid is built from x_range/y_range positions and the value is associated with a GeoTIFF pixel. No explicit half-cell shift is applied, so do not assume the geometry was evaluated exactly at the visual pixel centre.

31. Raster extent, mask and resolution

Rectangular extent $\text{bbox}(\text{turbines}) \text{ expanded } \pm d_{\text{max}}$

Valid mask $M(P_{ij}) = \text{OR}_t[d_h(P_{ij}, T_t) \leq d_{\text{max}}]$

Resolution	Advantage	Cost
100-500 m	Testing and overview.	Few cells; limited detail.
50 m	Spatial compromise.	Intermediate cost.
25 m	Maximum detail allowed by UI.	Many cells and a large NPZ.

NoData versus zero

Outside the union of d_{max} radii, -9999 is written as NoData. Inside the mask, 0 h means the position was calculated but had no alignment during the year.

The circular boundary is not an isochrone

Circular edges around turbines only represent the distance mask. The hour pattern inside should be directional and driven by the solar path.

32. Raster physics and current behaviour

Aspect	Current behaviour
Solar geometry	Same equation family as receptors, with an independent raster step.
Turbines	Evaluated simultaneously; union by timestamp.
DEM	Cell elevation + absolute hub elevation.
Observer height	Fixed at 2.0 m inside the raster task.
Spatial position	x_range/y_range node associated with pixel; no explicit half-cell offset.
Availability	Not multiplied in the annual GeoTIFF.
Receptor size	2 m, equivalent to +1 m in the angular radius.
Threads	Up to 8 threads; NumPy vectorises timestamps × turbines.

Difference from point receptors

Changing observer height in the interface affects point calculations, but the raster uses a fixed 2 m. This must be stated whenever point and raster results are compared.

Consistency between point calculation and raster

Aspect	Point receptors	Annual raster
Coordinate	Exact point geometry	Grid position associated with pixel; not guaranteed to be centre.
Observer height	Interface control	Fixed 2.0 m.
Time step	Receptor step, 1-60 min	Independent raster step, 1-30 min.
Availability	$\text{hours_real} = \text{hours_year} \times A$	Not applied; astronomical TIF.
DEM/DSM	Receptor and turbine elevations	Cell and turbine elevations.
Turbine union	Yes, by timestamp	Yes, by timestamp.
Time output	Calendar + 12×24 per receptor	12×24 NPZ per cell.

Consistency test

- Use availability 1.00.
- Match both time steps.
- Use the same DEM and solar filters.
- Create a receptor exactly at a grid x/y position.
- Compare hours_year with the TIF value.

Expected differences

- Offset between receptor and associated grid position.
- Temporal quantisation.
- Different height if point receptor is not at 2 m.
- Slightly different DEM sampling.
- Float32 rounding in TIF.

Diagnostic

A large systematic difference after matching these conditions should be investigated before using the raster for layout decisions.

33. Raster filtered by month and hour

Selection	Operation on the 12×24 matrix
All months / all hours	Sum all months and hours.
Specific month / all hours	Sum the 24 hours of that month.
All months / specific hour	Sum that hour across all 12 months.
Specific month + hour	Use one month-hour cell.

Conversion

Filtered raster [h] = stored minutes / 60.

No solar recalculation

The Regenerate filtered TIF command reads the NPZ from the last generated raster. Files remain on disk after closing QGIS or changing scenario, but the button only remembers the last path from the current session.

34. Files and output persistence

Output	Format	Location / action
Receptor results	Temporary/memory QGIS layer	Added to project; export for a durable copy.
Annual raster	GeoTIFF	~/shadow_raster folder.
Raster time data	Compressed NPZ	Next to TIF, suffix _data.npz.
Filtered raster	GeoTIFF	Next to base raster.
Receptor matrix	CSV	User-selected path.

Good practice

Use one folder per scenario and include year, time steps, time zone, distance, HH, D, DEM and resolution in its name. Availability does not change the raster but must be documented for point results.

Filter persistence

The NPZ remains on disk, but the regeneration button remembers only the last path created in the current module session.

35. Performance and scalability

Receptor cost $O(N_{\text{receptors}} \times N_{\text{turbines}} \times N_{\text{valid timestamps}})$

Raster cost $O(N_{\text{valid cells}} \times N_{\text{turbines}} \times N_{\text{valid timestamps}})$

Control lever	Reduces time	Impact
Larger time step	Yes, almost linearly	Lower temporal resolution.
Coarser raster	Yes, approximately quadratically with cell size	Lower spatial detail.
Shorter distance	Yes	May exclude impacts.
Receptor-only first	Yes	No map generated.
DEM disabled	Yes during preparation	Loses elevation differences.

NPZ memory

The raster matrix occupies approximately $\text{cells} \times 12 \times 24 \times 4$ bytes before compression. A very fine raster can require several GB during calculation.

36. Common issues and troubleshooting

Symptom	Likely cause	Action
Unreasonably high hours	CRS in degrees or mismatched layer CRS.	Reproject to one metric CRS.
0 h at every receptor	Incorrect site coordinates, time zone, distance, HH/D or solar elevation.	Review configuration; test availability 1.
DEM appears to have no effect	Flat terrain, NoData or 0 m fallback.	Compare sampled elevations and coverage.
Layer does not appear	Loaded after opening the module.	Press Refresh.
Raster is too slow	Resolution/time step too fine.	Test with 100 m and 10 min.
Points and raster disagree	Different step, height or grid position.	Match step; place receptor at grid coordinate.
Circles around turbines	Distance mask interpreted as physical result.	Separate NoData/calculated area from hour pattern.
Shifted time	Wrong IANA zone or fixed offset.	Check local civil time and DST.

37. How to validate and interpret a result

1

Check the wind-farm and receptor locations on the map.

2

Verify a common metric CRS and nearest-receptor distance.

3

Confirm the time zone using an independent source.

4

Run availability 1.00 for the astronomical scenario.

5

Compare 5 minutes with 1 minute at highest-impact receptors.

6

Compare flat terrain with DEM.

7

Review the worst day, month-hour pattern and dominant turbine.

8

Distinguish NoData, 0 h and positive raster values.

9

Document every parameter with the export.

Spatial plausibility

At mid-latitudes, impacts normally concentrate east/west depending on time and season; they should not form a uniform circle around the turbine. A uniform radial pattern can indicate a geometry or CRS problem.

38. Main scope and limitations

Implemented

- Annual solar position.
- Turbine-receptor angular geometry.
- Worst-case rotor disc.
- DEM in absolute elevations.
- IANA/DST and fixed offset.
- Temporal union of turbines.
- Point and raster outputs.

Not implemented

- Intermediate-terrain obstruction.
- Buildings/vegetation as explicit obstacles.
- Wind-dependent rotor orientation.
- RPM, blade count and flicker intensity.
- Cloud cover/sunshine hours.
- Timestamp-level availability or sector shutdown.
- Reflections or diffuse light.
- Spatial averaging within a raster pixel.

Recommended public wording

“Preliminary GIS assessment of shadow-flicker potential using solar geometry, point receptors, DEM/DSM elevation adjustment and raster maps. Results require project-specific validation for regulatory use.”

39. Current implementation details

Topic	Current state	Documentation implication
Turbine/receptor CRS	Difference is reported in diagnostics but may not block.	Require a common CRS.
Multiple models	One selected layer and one HH/D row per run.	Do not claim automatic model mixing.
Raster observer	Fixed 2.0 m.	Do not assume it follows receptor control.
Raster position	Grid node associated with pixel, no explicit half-cell offset.	Do not claim exact pixel-centre evaluation.
Raster availability	Not applied.	TIF represents astronomical hours.
DEM NoData	Fallback 0 m.	Audit coverage and samples.
30 h category	Boundary handling can differ between views.	Review exact-threshold cases.
Contributions	Individual values include overlap.	Do not sum them to obtain receptor total.

Why this page exists

Traceability requires describing what the current code does, not only the intended functionality. Review these points whenever the module is updated.

Appendix A. Variable dictionary

Variable	Unit	Definition
φ, λ	°	Site latitude and longitude.
δ	° or rad	Solar declination.
E	min	Equation of time.
H	°	Solar hour angle.
θ_{sun}	°	Solar azimuth.
α_{sun}	°	Solar elevation.
θ_{obj}	°	Target azimuth to the hub as seen from the receptor; the implemented vector is receptor → turbine.
β_{obj}	°	Angular elevation of the hub relative to the receptor.
γ	°	Rotor + receptor + Sun angular tolerance.
HH	m	Hub height above ground.
D	m	Rotor diameter.
hobs	m	Observer height.
d_h	m	Horizontal distance.
d_3D	m	Distance to hub.
A	-	Availability, 0-1.
Δt	min	Time step.

Appendix B. Condensed engine equations

Elevations

$$z_t = DEM_t + HH \quad z_r = DEM_r + h_{obs}$$

Solar

$$\alpha = \arcsin(\sin \phi \sin \delta + \cos \phi \cos \delta \cos H)$$

Distances

$$d_h = \sqrt{\Delta x^2 + \Delta y^2} \quad d_{3D} = \sqrt{d_h^2 + \Delta z^2}$$

Error

$$e^2 = \text{wrap}(\theta_{sun} - \theta_{obj})^2 + (\alpha_{sun} - \beta_{obj})^2$$

Target

$$\theta_{obj} = 90^\circ - \text{atan2}(\Delta y, \Delta x) \quad \beta_{obj} = \text{atan2}(\Delta z, d_h)$$

Shadow

$$e^2 \leq \gamma^2 \quad \text{with solar and distance filters}$$

Tolerance

$$\gamma = \text{atan2}\left(\frac{D}{2} + \frac{S_r}{2}, d_{3D}\right) + \rho_{sun} \quad \rho_{sun} = 0.2725^\circ$$

Hours

$$H_{astro} = N_{unique} \frac{\Delta t}{60} \quad H_{real} = H_{astro} A$$

Mathematical note

These equations summarise the implemented workflow and provide a compact technical reference for the current engine.

Appendix C. Test protocol and scope text

Smoke tests

- Small case without DEM.
- Same case with DEM.
- IANA versus fixed offset.
- 5 min versus 1 min.
- Receptor-only run.
- Raster 100 m / 10 min.
- Raster cancellation.
- CSV export and filtered TIF.

Consistency tests

- Turbine north/south/east/west of receptor.
- Receptor outside dmax.
- Leap year.
- DST transition.
- DEM with NoData.
- Different CRS to confirm warning.
- Availability 1 and 0.5.
- Case exactly at 30 h.

Recommended scope statement

VelantisWind calculates geometric shadow-flicker potential using NOAA-style solar positions, angular rotor geometry and point receptors. DEM/DSM changes absolute elevations but does not model complete terrain obstruction. Outputs are for screening and must be validated before a regulatory decision.

Continues with the expanded technical appendices

Appendix D. Expanded NOAA solar-position chain

Mathematical sequence used

1. $JD = ((Y - 1900)365.2422) + (doy + 1) + 2415018.5 + t_{local}/1440 - UTC/24$
2. $JC = (JD - 2451545)/36525$
3. $L = (280.460 + 36000.769 JC) \bmod 360$
4. $M_g = 357.52911 + JC(35999.05029 - 0.0001537 JC)$
5. $e = 0.016708634 - JC(0.000042037 + 0.0000001267 JC)$
6. $\lambda = [L + (1.915 - 0.005 JC) \sin M + 0.02 \sin(2M)] \bmod 360$
7. $\epsilon = 23.452 - 0.013 JC$
8. $\delta = \arcsin(\sin \lambda \sin \epsilon)$

True solar time and final angles

9. $E_t = 4 \text{ rad2deg}[Y \sin 2L - 2e \sin M_g + 4eY \sin M_g \cos 2L - 0.5Y^2 \sin 4L - 1.25e^2 \sin 2M_g]$
10. $TST = (t_{local} + E_t + 4 \lambda_{site} - 60 \text{ UTC}) \bmod 1440$
11. $H = TST/4 - 180 \text{ deg}$
12. $\alpha_{sun} = \arcsin(\sin \phi \sin \delta + \cos \phi \cos \delta \cos H)$
13. $\theta_{sun} = f_{NOAA}(H, \zeta)$ in $[-180 \text{ deg}, 180 \text{ deg}]$

What this means for the guide

The previous guide page already showed δ , H , α_{sun} and θ_{sun} . This page adds the intermediate variables that do appear in the module code: JD , JC , L , M_g , e , λ , ϵ and the equation of time. This makes the calculation traceable from civil date all the way to final solar azimuth/elevation.

Actual time convention used by the module

In fixed UTC mode, local time is corrected by a constant offset throughout the year. In IANA/DST mode, the module first constructs the local civil-time grid and then evaluates solar position using the UTC offset applicable to each instant, including daylight saving time. Monthly and hourly tables are always aggregated in local civil time.

Fidelity note

The formulation is NOAA-style and is intended for robust screening. It is not presented as an observational-precision astronomical ephemeris or as a substitute for an external regulatory specification.

Appendix E. Geometric derivation and correction of conventions

Geometry implemented by the engine

$$\Delta x = x_t - x_r \quad \Delta y = y_t - y_r \quad \Delta z = z_t - z_r$$

$$d_h = \sqrt{(\Delta x^2 + \Delta y^2)} \quad d_3D = \sqrt{(d_h^2 + \Delta z^2)}$$

$$\theta_{obj} = 90^\circ - \text{atan2}(\Delta y, \Delta x) \quad \beta_{obj} = \text{atan2}(\Delta z, d_h)$$

Angular tolerance γ

$$\gamma = \text{atan2}(D/2 + S_r/2, d_3D) + \rho_{sun}$$

$D/2$ is rotor radius; $S_r/2$ is the receptor or zone half-size; $\rho_{sun} = 0.2725^\circ$.

Evaluated shadow criterion

$$e^2 = \text{wrap}(\theta_{sun} - \theta_{obj})^2 + (\alpha_{sun} - \beta_{obj})^2 \leq \gamma^2$$

Potential shadow/flicker requires the Sun above the horizon, valid elevation filters and receptor-to-turbine distance not exceeding d_{max} .

Correct physical reading

This formulation is a worst-case angular approximation. The rotor is treated as a disc that is always “available” to generate flicker whenever angular alignment is favourable. The model does not include wind-dependent rotor-plane orientation, detailed blade-passage dynamics, or full intermediate obstruction by terrain or buildings.

Therefore the output should be read as geometric shadow-flicker potential, not as an exact photometric reproduction of the phenomenon.

Appendix F. Complete calculation algorithm

Condensed pseudocode

- 1) Read year, time zone, Δt , latitude/longitude and turbine/receptor geometry.
- 2) Build every timestamp of the year.
- 3) Calculate θ_{sun} , α_{sun} and sun-above-horizon for each timestamp.
- 4) Prepare receptor absolute elevation (DEM + observer height).
- 5) For each turbine, prepare $z_t = \text{DEM} + \text{HH}$, distances, θ_{obj} , β_{obj} and γ .
- 6) Apply filters: Sun up, min/max elevation and distance $\leq d_{\text{max}}$.
- 7) Mark timestamp positive when $e^2 \leq \gamma^2$.
- 8) Merge turbine contributions by temporal OR so an overlapping timestamp is counted once.
- 9) Calculate astronomical hours, adjusted hours, affected days, worst day, monthly distribution, 12x24 matrix and dominant turbine.
- 10) If raster is enabled, repeat the logic for virtual grid receptors.

Operational chain

Year/ Δt → civil timestamps → NOAA-style solar geometry → solar filters → receptor-turbine geometry → angular comparison → temporal turbine union → metrics → GIS / CSV / raster outputs.

Integrated

- Full yearly calendar.
- DST in IANA mode.
- DEM in turbine/receptor/pixel elevations.
- Multiple turbines with no annual double counting.

Not yet integrated

- Real blade-pass frequency.
- Per-turbine operational status per timestamp.
- Wind-dependent rotor-plane orientation.
- Complete 3D obstruction along the path.

How Hreal is calculated

The engine does not rebuild an operational chronology. It first obtains H_{astro} from the astronomical grid, then applies $H_{\text{real}} = H_{\text{astro}} \cdot A$. This is useful for screening but is not equivalent to a chronological operational simulation.

Appendix G. Time discretisation, precision and convergence

How time is counted

The calculation is discrete. If a timestamp satisfies the shadow condition, the whole interval is counted. At $\Delta t=10$ min each positive sample adds 10 minutes; at 5 min it adds 5; at 1 min it adds 1.

The engine does not solve the exact entry/exit instant inside the interval.

Practical implication

Two otherwise identical calculations at different temporal resolutions can differ by more than simple rounding. A finer Δt generally reduces integration error and stabilises the worst day, 12×24 matrix and filtered raster.

Recommended convergence protocol

1. Run a 10-minute reference to confirm inputs. 2. Repeat at 5 minutes and compare H_{astro} , H_{real} , worst day and dominant receptor. 3. Repeat at 1 minute for sensitive or near-threshold cases. 4. Accept the working step when the extra 5-to-1-minute change is small relative to the project decision criterion.

Time step	Relative cost	Recommended use	Technical note
10 min	1×	Smoke test / coarse raster	Fast, but more dependent on temporal grid.
5 min	~2×	Recommended base case	Good robustness/time balance.
1 min	~10×	Fine-resolution validation / near-threshold cases	Reduces discretisation error and stabilises the worst day.

Appendix H. Recommended numerical validation

Case	What is tested	Expected result	If it fails, review
V1	Receptor much farther than dmax	0 h even if solar angles align	Distance filter and CRS units.
V2	Turbine N/S/E/W of receptor	θ_{obj} consistent with geometry	atan2 sign and azimuth convention.
V3	Same low-sun case at minimum elevation 0° and 5°	Fewer hours with higher threshold	Solar-elevation filter.
V4	Availability A=1.0 versus A=0.5	Hreal exactly halves	Hastro must remain constant.
V5	Same receptor with $\Delta t=10, 5$ and 1 min	Progressive convergence of hours and worst day	Excessive step dependence or time-grid bug.
V6	Point receptor and equivalent raster pixel	Similar order of magnitude, not necessarily identical	Raster fixed 2 m height, resolution and raster step.

Minimum validation package

Store with the project: plugin version or build identifier, CRS, module parameters, configuration screenshot, highest-impact receptor, applied availability, selected time step, 10/5/1-minute comparison and an explicit note that the model is DEM-aware screening without complete intermediate obstruction.