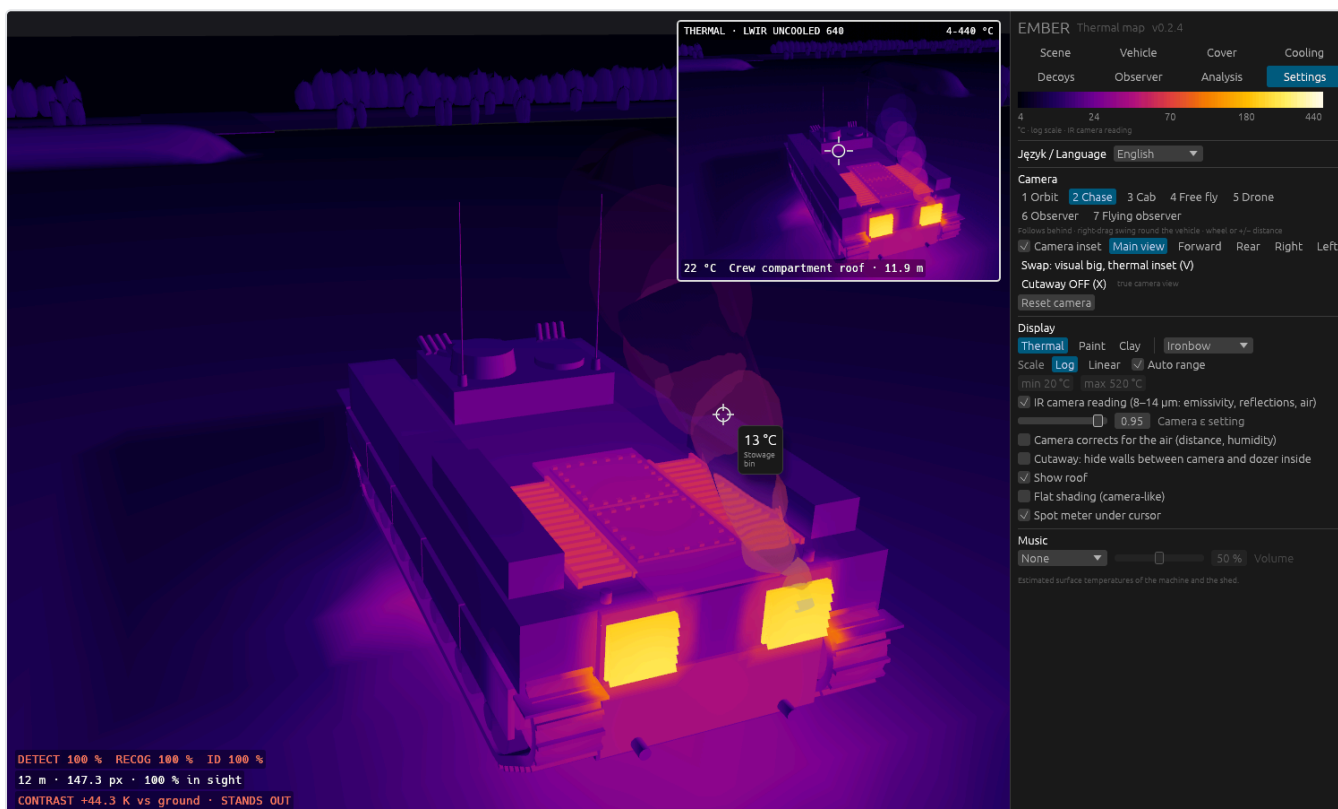


EMBER

Thermal map of heavy vehicles

User Guide

Version 0.2.4 · October 2026



EMBER is an interactive 3D thermal map of a heavy tracked vehicle. It shows how the vehicle looks through a thermal camera in different terrain, weather and times of day, and lets you test how well it can be hidden: coverings, insulation, fans and cooling, water, low-emissivity paint, decoys, and the position of the observer. Every surface in the scene has its own heat physics, and the meters tell you how likely an observer is to detect, recognise or identify the vehicle.

This guide covers version 0.2.4, where the side panel is organised into eight tabs. It is ordered the same way as the program: one chapter per tab, plus getting started, the command line, output files and model limitations.

Contents

1	Getting started	3
	Installing and running · The window · The eight tabs · Keyboard and mouse · A typical session	
2	Scene tab	5
	Scene (terrain) · Live weather · Weather & site · Weather over time	
3	Vehicle tab	8
	Vehicle type · Operating point · Driving · Route and autopilot · Record and replay · Track and exhaust heat · Heat sources	
4	Cover tab	10
	Position · Covering · Mounting · Stand-off layers and insulation · What it covers · Hull paint	
5	Cooling tab	13
	Fans under the covering · Cooling the air · Where the air leaves · Air under the vehicle · Water spray · Power for fans, pumps and sprays	
6	Decoys tab	15
	Other heat sources · Vehicle decoy · Track marks	
7	Observer tab	16
	Thermal camera · Ground post or drone · Flying observer · Missions	
8	Analysis tab	18
	Hottest surface and spot meter · Detection meter · Detection map (all directions) · Timeline graph · Heat trace (cool-down timer) · Masking presets and before / after · Test report and PDF · Screenshot	
9	Settings tab	20
	Język / Language · Camera · Display · Music	
10	Command line	22
11	Files EMBER reads and writes	24
12	Model limitations and known issues	25

1 Getting started

1.1 Installing and running

- EMBER is a single Windows 10/11 program (`EMBER-0.2.4.exe`) delivered in `EMBER-0.2.4-windows.zip` .
Unpack the zip anywhere and run the exe; nothing is installed. It needs a graphics card with DirectX 12 or Vulkan.
- The exe is not code-signed, so Windows SmartScreen may warn on first start. Click **More info** → **Run anyway**.
- The version number is shown in the window title ("EMBER 0.2.4") and at the top of the side panel.
- The source code is in `EMBER-0.2.4-src.zip` (Rust, Bevy 0.20, egui).
- The program runs at about 15 ms of CPU per frame in a busy scene. Heavy calculations (the all-directions detection sweep, the timeline graph) are spread over many frames so the image does not stutter.

1.2 The window

The window has two parts:

- **The 3D view** on the left. It shows the vehicle and scene in the selected display mode (thermal, paint or clay). Overlaid on it are:
- the **camera inset** in the top-right corner: a second thermal view with the camera profile, temperature range, and a crosshair readout (temperature, part name, distance);
- the **detection readout** in the bottom-left corner: detect / recognise / identify probabilities, distance, pixels on the vehicle, share in sight, and the contrast against the background with a rating;
- the **spot meter** tooltip next to the cursor (temperature and name of the surface under it);
- the **timeline bar** along the bottom when it is switched on (key T).
- **The side panel** on the right, with the title, version, the eight tabs and the colour scale.

1.3 The eight tabs

The tabs sit in two rows of four under the title. Hovering a tab lists what it contains, and each tab scrolls on its own.

Tab	What it is for
Scene	Terrain, time of day, season, weather and warm-up
Vehicle	Vehicle type, engine, driving and route, track and exhaust heat, heat sources
Cover	Position behind cover, coverings, stand-off layers and insulation, mounting, low-ε paint
Cooling	Fans, air cooling, water spray, air under the vehicle, power and run time
Decoys	Other heat sources, the vehicle decoy, and track marks
Observer	Thermal camera, ground post or drone, flying observer, missions
Analysis	Meters, detection map, timeline graph, cool-down timer, presets and before/after, report
Settings	Language, camera controls, display and music

The **colour scale** (palette with its temperature marks) is always visible under the tabs, whichever tab is open. The panel can be opened on a given tab from the command line with `--tab` (section 10).

1.4 Keyboard and mouse

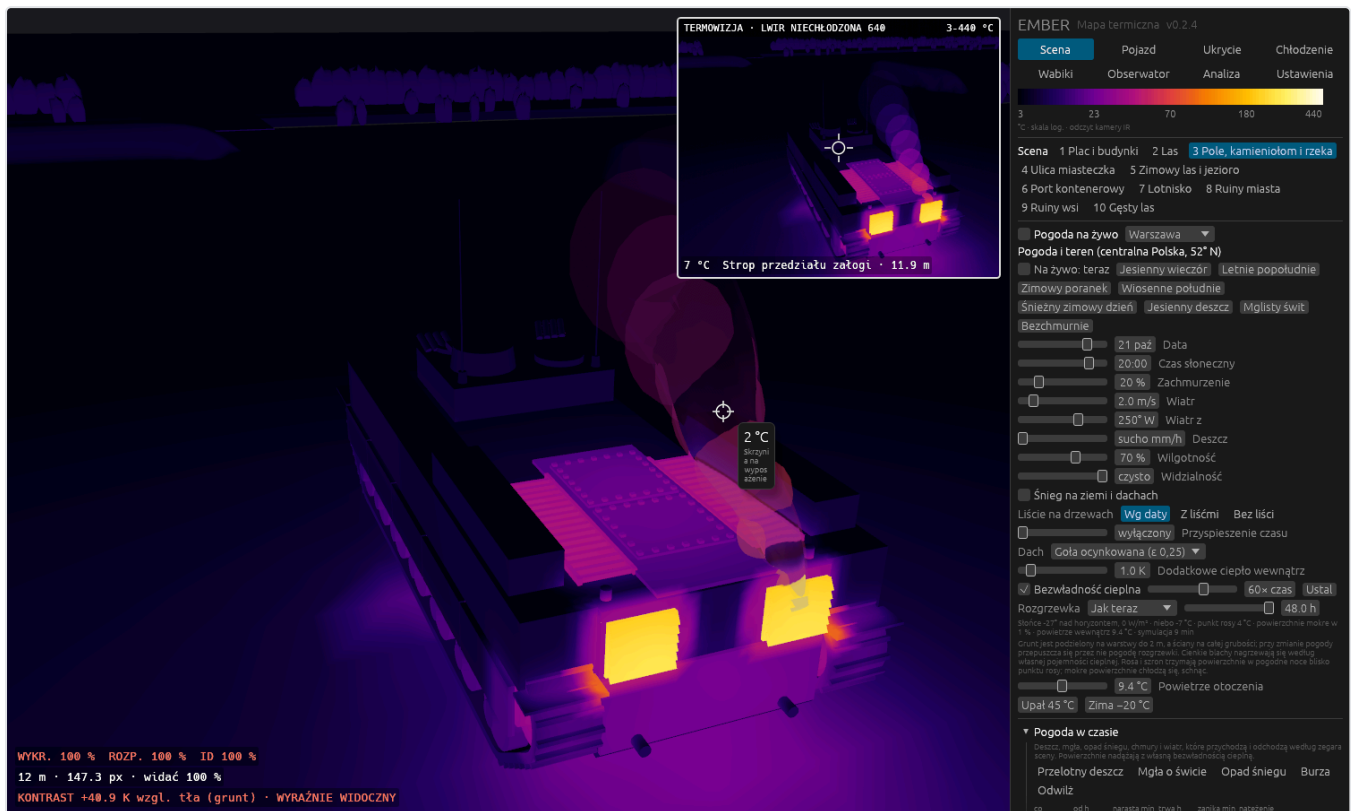
Input	Action
W / S	Drive forward / reverse
A / D	Steer left / right (the vehicle can turn on the spot)
Space	Brake
1 – 7	Camera: Orbit, Chase, Cab, Free fly, Drone, Observer, Flying observer
C	Cycle camera modes
Right mouse button + move	Turn the camera round the vehicle (vehicle stays centred); in Cab and Free fly, look around
Middle mouse button + move	Pan
Mouse wheel or + / –	Zoom (distance, height or lens, depending on the camera mode)
V	Swap the main view and the inset (thermal / visual)
X	Cutaway: hide walls and roof between the camera and the vehicle
I	Thermal imager full screen
T	Show / hide the timeline bar
P	Run / pause the scene clock
F5 / F6	Record a drive / play it back
Left click (route drawing on)	Add a route point; Backspace removes the last one, Enter finishes

Holding the right button over the side panel does not turn the camera.

1.5 A typical session

1. **Scene:** pick the terrain, date, time and weather, and let the warm-up settle the ground and walls.
2. **Vehicle:** set the engine state and load, or drive and park the vehicle where you want it.
3. **Cover** and **Cooling:** choose a covering, layers, fans, power and paint.
4. **Observer:** choose the thermal camera and who is watching from where.
5. **Analysis:** read the contrast and detection meters, sweep all directions, run the clock, compare presets and export a PDF report.

2 Scene tab



Scene tab (interface shown in Polish)

The Scene tab sets where and when the test takes place: terrain, sun, sky, weather and how much the surroundings have warmed up.

2.1 Scene (terrain)

Ten scenes are selectable at the top of the tab. Beyond each detailed area, plain terrain runs out to 700 m so the drone and distant observers have a horizon.

#	Scene	Size	What is in it
1	Yard & buildings	180 × 150 m	Drive-through machine shed, brick workshop, roofless building with a 6 m breach, damaged house, open pole barn, containers, collapsed shed, barriers, gravel heap
2	Forest	220 × 220 m	About 350 branching trees, undergrowth, logs, boulders, two forest tracks and a clearing
3	Field, quarry & river	200 × 200 m	Earth berms, a 1.7 m trench, hedgerows, an arched hangar, a buried garage, a barn with fermenting hay, a granite quarry, a river with a ford
4	Town street	200 × 120 m	2–5 storey heated buildings, a ruin, parked cars (some with warm bonnets), lit street lamps
5	Winter forest & lake	220 × 220 m	Frozen lake, heated log hut, ice fishers, deer; brings a snowy January day
6	Container port	260 × 145 m	Container stacks, running reefers, gantry cranes, a ship, warehouses
7	Airfield	520 × 320 m	500 m runway, hangars, tower, airliners (two with warm engines), fuel bowser
8	City ruins	200 × 160 m	Shelled panel blocks and tenements, smouldering embers, a burning room, craters, wrecks, hedgehogs, a heated flat
9	Village ruins	240 × 200 m	Houses in every condition, smouldering remains, barns, a church and churchyard, orchards
10	Dense forest	124 × 124 m	Trees every 4–6 m, thick undergrowth, a winding track, a clearing with a fire

Open fire and embers saturate the colour scale, as they would in a real camera.

2.2 Live weather

- **Live weather** fetches current conditions from Open-Meteo for one of 12 cities or custom coordinates, every 15 minutes. **Fetch now** updates immediately.
- **Live: now** follows the PC clock instead: today's date, the current solar time, and the typical air temperature for the time of year (central Poland, 52° N), updated every 5 minutes.

2.3 Weather & site

- **Presets:** Autumn evening, Summer afternoon, Winter morning, Spring noon, Snowy winter day, Autumn rain, Foggy dawn, Clear weather.
- **Date** and **Solar time** (the sun is highest at 12:00 solar time).
- **Cloud cover**, **Wind** speed and **Wind from** (direction). Wind bends the exhaust plume and carries its heat downwind.
- **Rain** (mm/h). Wet surfaces are pulled towards the wet-bulb temperature, so sun and vehicle heat show much less; rain also absorbs infrared on the way.
- **Humidity**. Water vapour absorbs long-wave infrared, so warm humid air shortens thermal range.
- **Visibility** (fog and haze). A thermal camera sees several times further through haze than the eye, but thick fog stops it too.
- **Snow on the ground and roofs**. Lying snow has ϵ 0.98, cannot rise above 0 °C and insulates the ground.

- **Leaves on trees:** *By date* (budding late April to mid-May, falling October to mid-November), *With leaves* or *Without leaves*.
- **Time-lapse:** runs the clock up to 2 h per second, with surfaces warming and cooling with their real thermal lag.
- **Roof** finish of the buildings (for example bare galvanised, ϵ 0.25) and **Extra indoor heat**.
- **Thermal lag** (on by default, 60× time) makes surfaces follow the weather with their real inertia; **Settle** jumps the walls to steady state.
- **Warm-up:** 24–48 h of past weather (*As now* or *Recorded* from live weather) is passed through the ground and walls before the scene is shown, so they hold the right heat.
- **Ambient air** temperature slider, with the quick buttons **Hot day 45 °C** and **Winter –20 °C**.

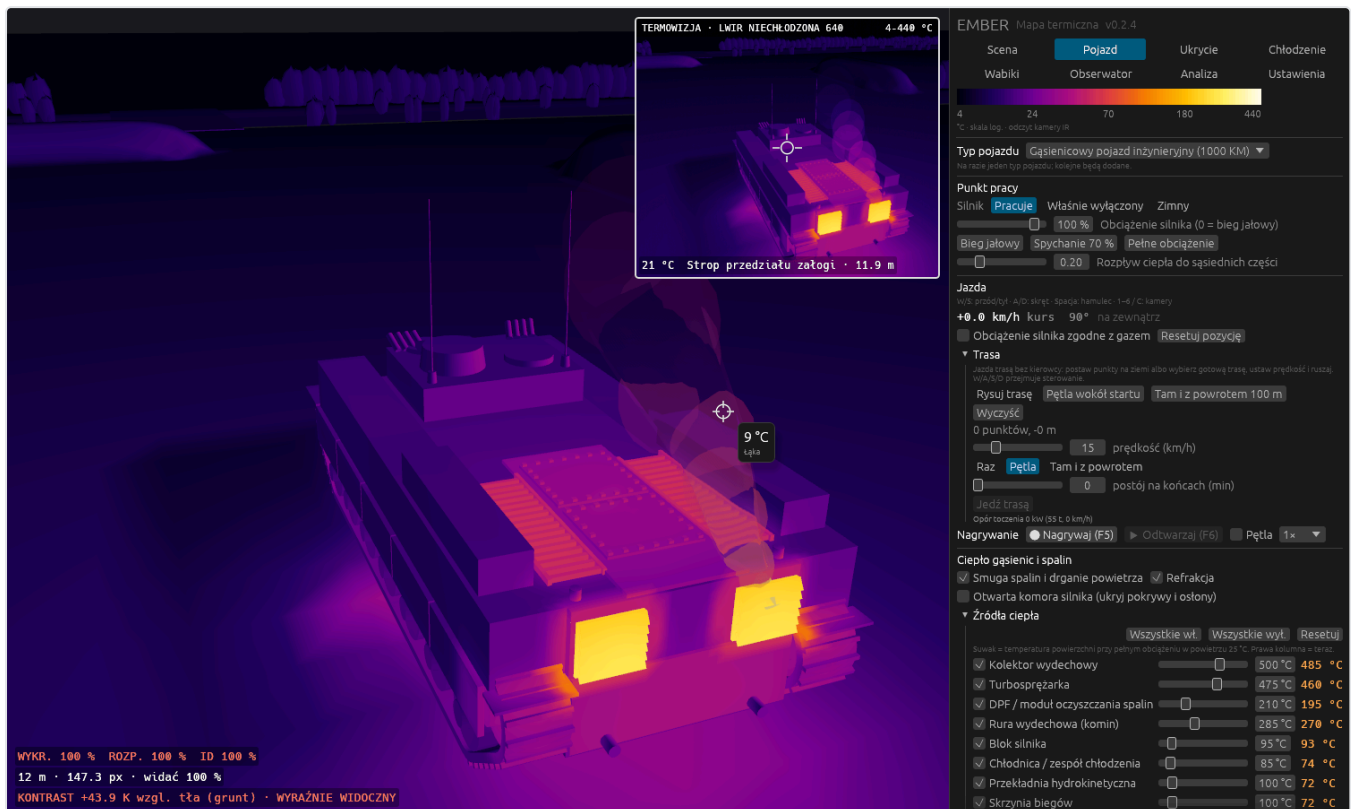
The physics behind the scene includes a Brutsaert clear-sky model, direct and diffuse sun, natural and forced convection, eight-layer ground and walls, dew, frost and drying, shadows from roofs and canopies, transpiring leaves, heated buildings, the vehicle's shadow and warm patch beneath it, and the vehicle's radiation and exhaust onto its surroundings.

2.4 Weather over time

Changing a slider jumps the weather at once. A **weather scenario** instead changes conditions over scene time, and every surface responds with real inertia, so you can watch contrast rise and fall.

- Each event has a type, a start (hours from scenario start), ramp-up minutes, duration in hours, fade minutes and strength. Types: **Rain** (mm/h), **Fog** (km visibility, down to 0.05 km), **Snowfall** (cm/h), **Cloud**, **Wind** (m/s) and **Air temperature** (change in K). Up to 12 events; **+ event** adds one.
- **Ready-made scenarios:** *Passing shower* (45 min of 6 mm/h rain, wind, 3 K cooler), *Fog at dawn* (builds to 200 m visibility over an hour, lasts 3 h), *Snowfall* (3 h at 2 cm/h, 2 K cooler), *Storm* (40 min at 25 mm/h, 14 m/s wind, 6 K cooler), *Thaw* (7 K warmer, drizzle, then fog).
- **Start weather** begins at the current hour (if the clock is stopped it starts at 60×); **Stop weather** restores the settings from before. A progress bar shows current rain, visibility, snowfall, cloud, wind and snow depth on the ground and on the vehicle.
- Snow only settles with the air below about +1 °C (the panel warns otherwise). Settling snow builds up on cool upper surfaces of the hull and covering and melts over hot spots, so the vehicle "disappears" except for its warm patches.
- Rain streaks and snowflakes are drawn in the main view. Snowflakes attenuate infrared more than rain of the same intensity; fog hurts MWIR more than LWIR.

3 Vehicle tab



Vehicle tab (interface shown in Polish)

The Vehicle tab sets what the vehicle is doing: engine state, driving, routes, and the heat of its tracks, exhaust and individual sources.

3.1 Vehicle type

At the top of the tab. For now there is one type: the **1000 hp tracked engineering vehicle** (about 45 t, 735 kW V12 diesel at the rear, about 60 km/h on road, turns on the spot). The type sets the shape, where the engine and exhaust are, and the heat sources; the list is ready for more types.

The vehicle is modelled in detail: seven road wheels per side, idlers at the front and drive sprockets at the rear, tracks with grousers, a 60 mm armoured hull with thinner side skirts, fenders and stowage boxes, a rear deck with radiator grilles and bolted hatches, and slanted exhaust louvers in the rear plate. Inside the engine compartment are the manifolds, two turbochargers, the gearbox and torque converter, and radiators under the grilles. Every part heats and cools at a rate set by its plate thickness: thin skirts and boxes follow the weather within minutes, the 60 mm hull lags by hours.

3.2 Operating point

- **Engine:** *Running* (at the load below; a cold engine warms up over about half an hour), *Just stopped* (with a *Switched off ago* slider, 0–180 min) or *Cold* (stood overnight, every part at air temperature). After switch-off the fan and pump stop, so the engine bay air keeps rising for about 15 minutes before everything cools over 1–3 h.
- **Engine load** 0–110 % (0 = low idle), with the buttons *Low idle*, *Dozing 70 %* and *Full load*. Coolant is held at about 90 °C by the thermostat, even in frost.
- **Heat spread to neighbours:** how much heat flows from hot parts into adjacent ones.

3.3 Driving

- The panel shows speed, heading and whether the vehicle is outside, inside a shed or blocked. Walls block the vehicle; gates do not. The engine must be running to drive.
- **Engine load follows throttle:** load comes from how hard you drive instead of the slider.
- **Reset position** returns the vehicle to its start point.

3.4 Route and autopilot

The vehicle can drive a route on its own while the thermal model reacts to driving.

- **Draw route:** each left click on the ground adds a point (up to 40). Backspace removes the last one; **Finish drawing (Enter)** ends it. The right mouse button still turns the camera.
- **Ready routes:** *Loop round the start* (8 points on a circle of about 35 m, moved off buildings and walls) and *There and back 100 m*. **Clear** removes the route.
- The route is drawn in the main view as a line with posts (yellow while drawing, blue afterwards, next point red); it does not appear in the thermal camera.
- **Speed** 2–60 km/h; mode **Once**, **Loop** or **There and back**; **stop at the ends** 0–30 min with the engine idling or off.
- **Drive route / Stop route.** The autopilot turns on the spot for sharp angles and slows before points. If stuck for more than 3 s it skips to the next point and counts it. W/A/S/D takes over; *Drive route* resumes from the nearest point.
- The route runs in real time whatever the clock speed, so with a sped-up day the vehicle drives normally while heating and cooling run faster.
- **Rolling resistance** (about $0.04 \cdot m \cdot g \cdot v$; 55 t at 30 km/h $\approx$ 180 kW) heats the running gear: tracks 45 %, road wheels and idlers 30 %, final drives 25 %. The panel shows this split, distance, laps and skipped points.

3.5 Record and replay

Record (F5) captures position, heading, speed, engine and load ten times a second, for up to 10 minutes (route drives included). **Play (F6)** replays it, with **Loop**, rate 0.5–4× and a scrub slider. A recording made in another scene cannot be replayed.

3.6 Track and exhaust heat

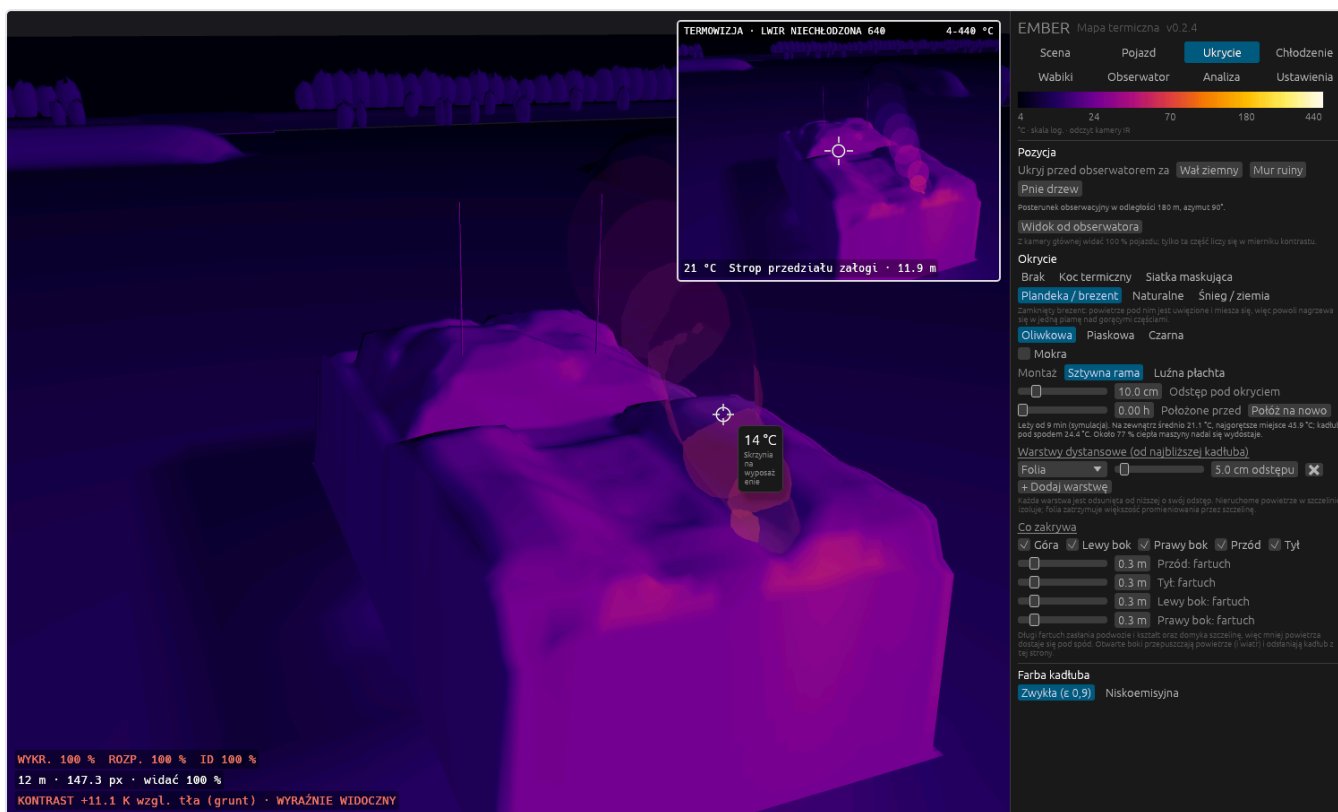
- **Exhaust plume & heat shimmer**, bent by the wind.
- **Refraction:** the image really bends through the hot air over the exhaust. Turn it off on slow graphics cards.
- **Open engine bay** hides the hood and guards to show the engine inside.
- The exhaust louvres blow hot gas down at the ground behind the vehicle: a warm patch 2–4 m behind when parked, a streak when driving, shifted by the wind.

3.7 Heat sources

Each source can be switched on or off and has a slider for its surface temperature at full load in 25 °C air; the right-hand column shows its temperature now. **All on**, **All off** and **Reset** act on the whole list, and **Heat spread per source** sets how far each one's heat spreads.

Defaults: exhaust manifold 500 °C, turbocharger 475 °C, exhaust pipe 285 °C, DPF 210 °C, torque converter and gearbox 100 °C, engine block 95 °C, radiator 85 °C, final drives 77 °C, hydraulic tank 75 °C, actuators 60 °C, rollers 45 °C, fuel tank 40 °C. Each part has realistic gradients (turbine hotter than compressor, manifold hottest near the turbo, and so on).

4 Cover tab



Cover tab (interface shown in Polish)

The Cover tab hides the vehicle: where it stands, what covers it and how, the layers under the covering, and the hull paint.

4.1 Position

- **Hide from the observer behind:** *Berm*, *Ruin wall* or *Tree trunks*. EMBER searches within 70 m for a spot where that obstacle blocks at least 30 % of the vehicle from the observer post and drives there. Berms are in the Field scene (and rubble heaps in the ruins), ruin walls in the City and Village ruins and the Yard, and trunks close enough in the forests.
- **View from observer** puts the main camera at the observer post. Only the part of the vehicle the main camera can see counts in the contrast meter.

4.2 Covering

Covering	Behaviour	Settings
None	Bare vehicle	
Thermal blanket	Foil, low emissivity, mirrors the cold sky	Outer emissivity, insulation
Camo net	Multispectral net on poles; air flows freely under it so it stays near air temperature, but the hull shows through gaps	Coverage %, low-emissivity patches (ϵ about 0.45)
Tarp / canvas	Closed: trapped air mixes and slowly warms into one blob over the hot parts	Colour: Olive, Sand, Black
Natural	Cut branches (wilt and dry within a day or two), Straw (light, insulating), Sod/turf (heavy, moist, dries first over hot spots)	Thickness, coverage, <i>Cut ago</i>
Snow / earth	Burying. Snow cannot rise above 0 °C so it thins over hot spots; soil dries and turns warmer over them	Depth

Wet: absorbent coverings (canvas, fabric net, natural materials) can be soaked when laid, with water in l/m². Evaporation keeps them near the wet-bulb temperature until they dry; the panel shows when. Below freezing the water turns to ice and stops cooling.

4.3 Mounting

- **Rigid frame:** a steady air gap all round (**Gap under the covering** slider), nowhere touching the hull.
- **Loose sheet:** thrown over the vehicle. Where it touches (roof edges, grilles, hatches, exhaust louvres), heat conducts straight through and shows as hot spots in the hull's shape. **Touching the hull** sets the contact share. The panel warns when the sheet touches the louvres or grilles, and in strong wind that a loose sheet may slide off or expose an edge.
- **Laid ago** (hours) and **Lay fresh:** the covering is laid at air temperature and run forward by the hours set. The panel shows the outside temperature, the hottest spot, how much of the vehicle's heat still gets through, and how far snow has melted or soil has dried.

4.4 Stand-off layers and insulation

Up to four layers under the covering, innermost first, each standing off the one below by its gap (2–50 cm). Still air in the gaps insulates, and foil faces stop most radiation across a gap. + **Add layer** adds one; the cross removes it.

Material	Conductivity λ (W/m·K)	Thickness	Notes
Foil, Net, Canvas, Metal sheet, Rubber mat		fixed	Basic layers
Foam		20 mm	Kept for compatibility
Mineral wool	0.035–0.040	20–200 mm	Soaks up water and insulates much worse when wet
PIR/PUR foam board	0.022–0.028	10–120 mm	Rigid boards, often foil-faced
Aerogel mat	0.015–0.020	5–20 mm	Thin and flexible; best per mm

PIR/PUR and aerogel can be **foil-faced** on the outside (low emissivity). The panel shows the total R-value. Thick insulation also stores heat, so it warms slowly and keeps giving heat off after the covering is removed.

4.5 What it covers

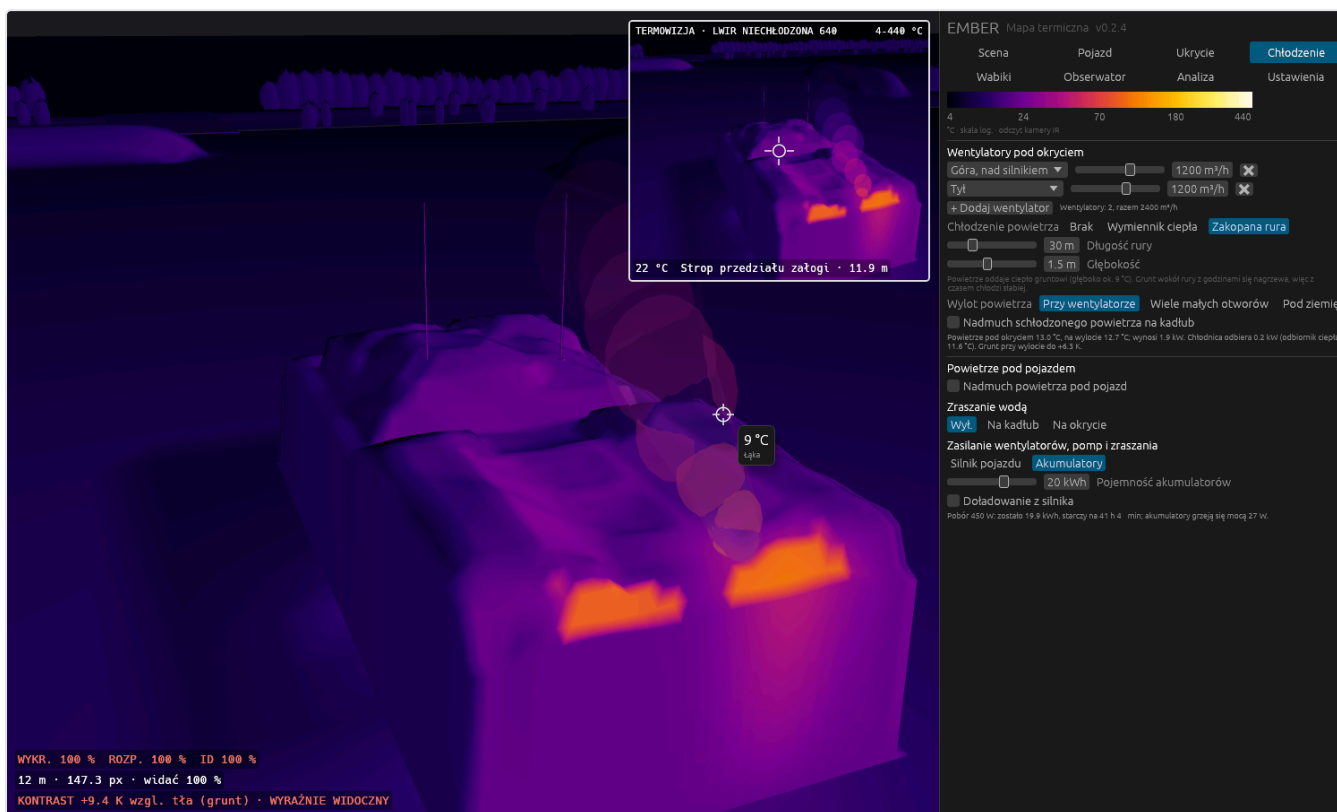
Separate ticks for **Top**, **Left side**, **Right side**, **Front** and **Back**, each side with its own skirt length (0–2 m). A long skirt hides the running gear and cuts the air flowing underneath.

- With only **Top** ticked, the covering becomes a roof: **Top overhang over open sides** (0 cm – 2 m) runs it flat past the outline, like a roof on poles. Air flows freely underneath, so less heat builds up, but the hull sides and wheels are visible from the side.
- An open side counts as bare hull in the contrast meter. A drone overhead sees mostly the top, a ground observer sees a side.
- More open sides mean more ventilation: a cooler covering but warmer air escaping at the edges.
- **Wind** carries heat out through open sides and edges depending on its direction, leaving a warm streak downwind; it cools the covering from outside and makes nets and loose sheets ripple.

4.6 Hull paint

- **Standard (ϵ 0.9)** or **Low-emissivity** with an ϵ slider 0.10–0.95. Low ϵ glows less with the hull's own heat but mirrors more of its surroundings: the cold clear sky on top (it can read colder than the background), walls and trees on the sides.
- **Zones:** Engine deck; Roof and top front; Sides; Front; Rear; Running gear (off by default, since paint wears off there quickly). The zone is worked out per surface point, so one plate can be low- ϵ on top and standard on its side. The engine bay interior and glass never change.
- The panel shows what share of the visible surface is painted. The meters, camera and report use emissivity per point.

5 Cooling tab



Cooling tab (interface shown in Polish)

The Cooling tab removes heat from under the covering and from the vehicle. Fans, air cooling and blowing onto the hull need a covering (chosen in the Cover tab); air under the vehicle, water spray and power work without one.

5.1 Fans under the covering

- Up to **8 fans**, each with a **position** (Top, over the engine; Front; Back; Left side; Right side) and a **flow** (200–3000 m³/h). **+ Add fan** puts new fans over the engine and next to the exhaust first, where the warm air is. The panel shows the fan count and total flow.
- The fans push warm air out from under the covering. It spills out round the edges and spreads, rather than leaving as a jet: a warm streak at the edges, warm air rising and blown downwind, and warmed ground at the outlet.
- A fan near a heat source moves hotter air and works better. Fans appear as small housings under the covering, with slightly warm motors.
- More air exchange lowers the temperature under the covering and of the covering itself, but sends the heat outside. The panel shows the air under the covering, the outlet temperature and the heat carried out (kW).

5.2 Cooling the air

- **None.**
- **Heat exchanger:** *Effectiveness* 30–80 % and *Cooling water*. Lowers the outlet temperature.
- **Buried pipe:** *Pipe length* and *Depth*. The air gives its heat to the soil (about 9 °C deep down). The soil round the pipe warms over the hours, so the pipe cools less as time goes on, and a faint warm strip can appear above it.

The panel shows the outlet temperature before and after cooling, the heat taken by the cooler and the outlet's contrast against the ground.

5.3 Where the air leaves

- **At the fan:** one outlet per fan.
- **Many small openings:** a perforated hose round the vehicle (set the number of openings). The same heat spread over a large area raises each point only slightly, so it blends into the background.
- **Underground:** into a trench or the soil.

Blow cooled air onto the hull sends part of the cooled air back under the covering onto the hull, where it scrubs heat off the plates. It needs a cooler; without one it blows outside air.

5.4 Air under the vehicle

Blow air under the vehicle: a fan blows outside air under the hull so the ground beneath does not warm up. This shrinks the warm footprint left after the vehicle moves off (visible in the cool-down timer) and the warm patch showing under the skirts.

5.5 Water spray

- **Off, On the hull or On the covering,** with water flow (l/h), water temperature and a **Water store** (l) with time until empty.
- Water cools by warming up and by evaporating; how well depends on humidity, temperature and wind. After the spray stops, the water film dries as it would after rain.
- Wet ground round the vehicle cools too and can look colder than the background, which is also a contrast. Below freezing the water turns to ice and stops cooling.

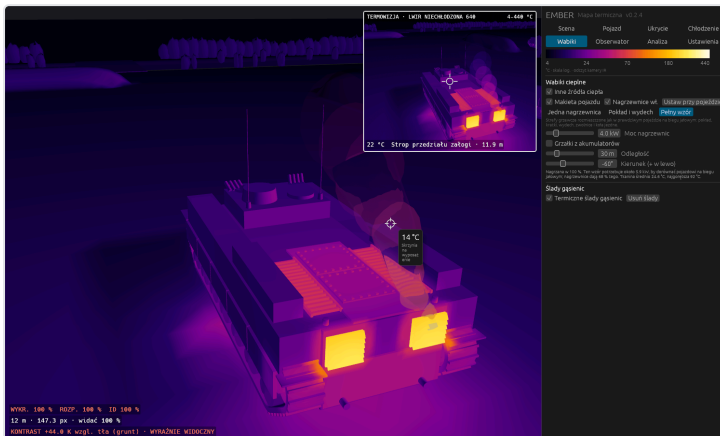
5.6 Power for fans, pumps and sprays

There is no separate generator; choose one of two sources:

- **Vehicle engine:** the engine has to run (at least idling; if it was stopped or cold, it is switched to idle). The draw is added to the engine load, so exhaust, manifold, radiator and engine bay run hotter: more heat to hide. Set **Fuel in the tank**; the panel shows consumption and run time.
- **Batteries:** the engine can stay off and cool down normally. Set **Battery capacity** (5–60 kWh). The panel shows the draw, energy left and how many hours it will last. When the batteries are flat everything stops, and with the clock running you can watch the covering warm up again. Batteries and inverter lose a few percent as heat under the covering.
- **Recharge from the engine:** every set number of minutes the engine runs for a set time to charge the batteries (the vehicle warms up meanwhile).

The same batteries can also power the vehicle decoy's heaters (Decoys tab); the combined draw and run time are shown in both places.

6 Decoys tab



Decoys tab (interface shown in Polish)

The Decoys tab controls other warm things in the scene that can draw an observer's eye, and the marks the vehicle leaves behind.

6.1 Other heat sources

Other heat sources shows or hides the people, deer, a running generator and a campfire placed in every scene: the kind of warm clutter a thermal camera picks up besides the vehicle.

6.2 Vehicle decoy

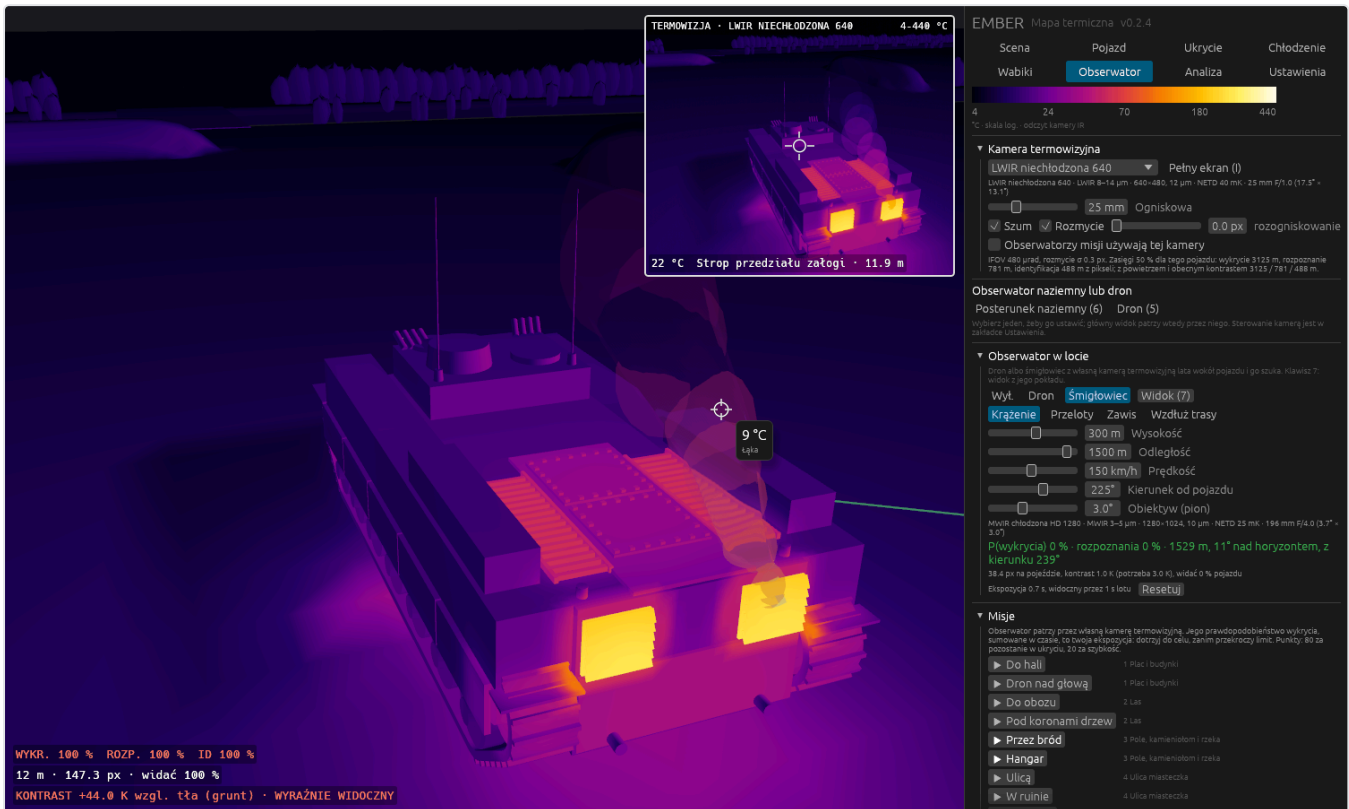
A fabric replica of the vehicle with heaters inside, set up near it to draw the observer's attention.

- **Vehicle decoy** shows the replica; **Heaters on** switches its heating; **Place near vehicle** puts it next to the vehicle again.
- **Fidelity** (heating pattern):
 - *One heater*: warms the whole replica evenly, a uniform blob with warm running gear and no hot spots, which gives it away up close.
 - *Deck and exhaust*: heater mats under the engine deck and the heater's exhaust at the louvres; hull and running gear stay at ambient.
 - *Full pattern*: heating zones laid out like the real vehicle at idle: deck, grilles, exhaust, final drives and road wheels.
- **Heater power (kW)**, **Distance** and **Bearing** (+ to the left).
- The panel shows how warm the replica is, how much power the chosen pattern needs to match the real vehicle at idle and what share the heaters provide, plus the fabric's mean and hottest temperatures.
- **Heaters off the batteries** draws power from the battery pack in the Cooling tab (set its capacity there, or here if the covering runs off the engine). The panel shows the combined draw, hours left and state of charge. When the batteries run out the heaters stop and the replica cools to fabric temperature in about 10 minutes. Without batteries the decoy has unlimited power.

6.3 Track marks

- **Thermal track marks**: warm (or cool) bands the tracks leave on the ground, drawn per pixel on a 12.5 cm map covering 128 m round the vehicle, with the grouser pattern. Friction heat grows with load, speed and turning; churned soil or snow shows too. They fade over 10–30 minutes depending on the surface. Turning the tick off hides them at once.
- **Clear marks** wipes the existing marks.

7 Observer tab



Observer tab (interface shown in Polish)

The Observer tab sets which thermal camera is used and who is looking for the vehicle, from where.

7.1 Thermal camera

Profile	Band	Array	Pixel	NETD	Lens (horizontal FOV)
LWIR uncooled 320	8–14 μm	320 × 240	17 μm	60 mK	19 mm (16°)
LWIR uncooled 640 (default)	8–14 μm	640 × 480	12 μm	40 mK	25 mm (17°)
LWIR uncooled HD 1280	8–14 μm	1280 × 1024	12 μm	50 mK	35 mm (25°)
MWIR cooled 640	3–5 μm	640 × 512	15 μm	20 mK	100 mm (5.5°)
MWIR cooled HD 1280	3–5 μm	1280 × 1024	10 μm	25 mK	120 mm (6.1°)
Custom	LWIR / MWIR	320 × 240 – 1280 × 1024	8–25 μm	15–150 mK	9–300 mm, F/1–F/4

- **Focal length** can be changed for any profile; the field of view follows.
- **MWIR vs LWIR:** in MWIR radiance rises much more steeply with temperature, so hot spots glow strongly while small differences near ambient are weaker (the low NETD of cooled arrays makes up for this). MWIR passes better through warm humid air, LWIR better through fog, smoke and drizzle. In daylight MWIR picks up sun glints off walls and metal, which adds clutter, so the detection meter asks for more contrast. Sky reflections differ by band.
- **Noise:** each pixel jitters by the NETD every frame, and uncooled arrays add faint column stripes; it shows more when the colour range is narrow. **Blur:** the optics' diffraction spot ($2.44 \cdot \lambda \cdot F\#$, larger in LWIR) plus a **defocus** slider 0–3 px.
- **Full screen (I):** the camera's own picture, at its resolution with noise and blur, fills the 3D view. The main 3D view itself stays clean for analysis.

- **Mission observers use this camera:** off by default, so missions keep their own cameras and scores stay comparable.
- The panel shows the IFOV (μ rad), blur, and the 50 % **detection / recognition / identification ranges** for this vehicle, from geometry alone and with the current air and contrast.

The camera applies to the inset, the detection meter, the flying observer and (if ticked) missions.

7.2 Ground post or drone

- **Ground post (6):** a tripod far away with a telephoto lens (30–1500 m, lens 0.5–45°). Set **Distance**, **Bearing** and **Lens field of view**. **Patrol** walks a 120 m beat across the line of sight, keeping the lens on the vehicle. The tripod can be moved to the vehicle's current spot.
- **Drone (5):** hovers 10–600 m above the vehicle, or patrols a circle round the area (set radius and patrol speed) with its camera looking ahead and down.

Picking either switches the main view to look through it. Camera controls are in the Settings tab.

7.3 Flying observer

A drone or helicopter with its own thermal camera flies round the vehicle and looks for it.

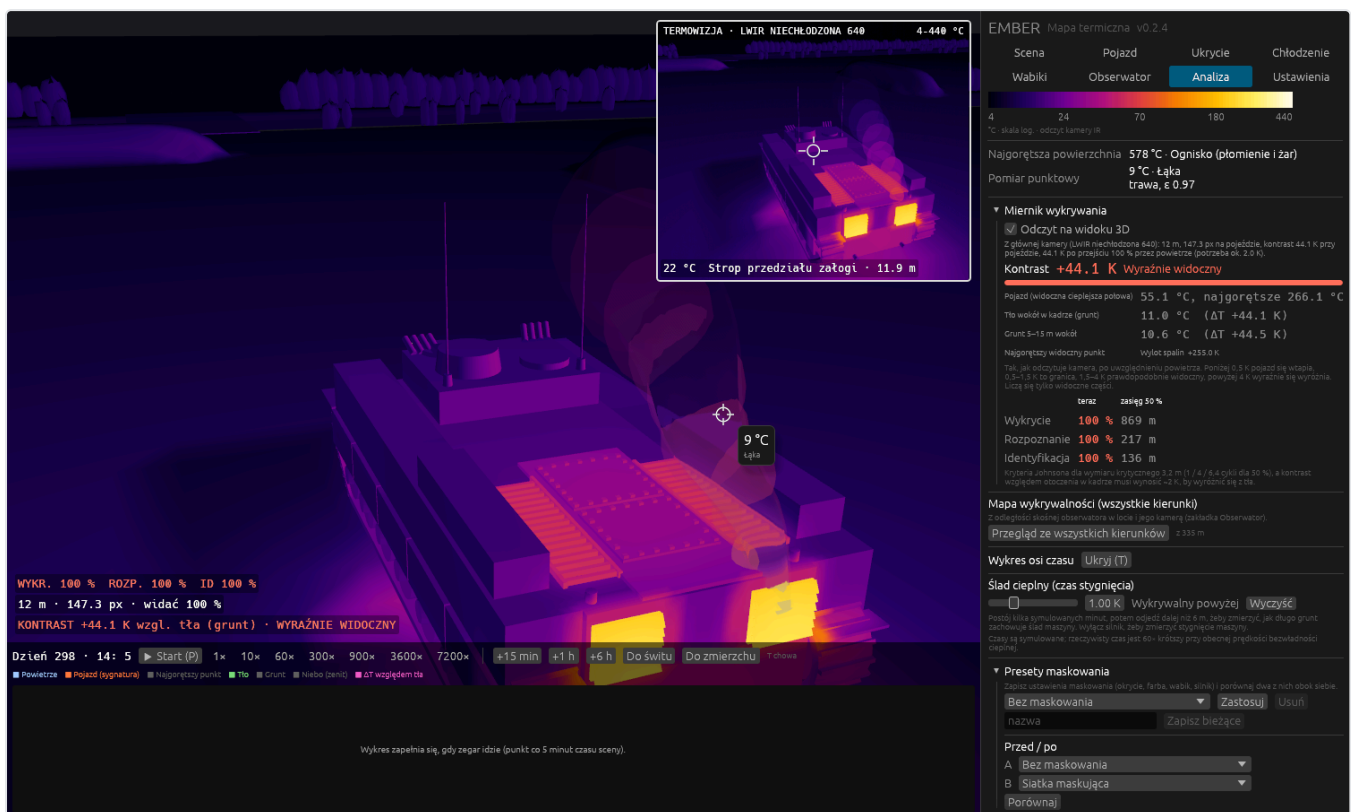
- **Off, Drone** (default 150 m height, 300 m away, LWIR 640 with a 40° lens, 50 km/h) or **Helicopter** (default 300 m, 1500 m away, MWIR HD 1280 turret with zoom 0.5–60°, default 3°, 150 km/h). The helicopter has warm engines and exhaust of its own.
- **Flight:** *Orbit* (radius = distance), *Passes* (straight runs with the closest point at the set distance), *Hover* (at a bearing and distance, with slight drift), *Along the route* (flies the route from the Vehicle tab in a loop).
- **Height** 20–3000 m, **Distance** 0–8000 m, **Speed** 10–300 km/h, **Bearing from the vehicle**, **Lens (vertical)**.
- **View (7)** puts the main camera in its turret; with **I** you see exactly its noisy image.
- It is drawn in 3D with a crosshair in the threat colour and a line to the vehicle. Live readouts: detect and recognise probability, distance, bearing and elevation, pixels on the vehicle, contrast and threshold, share in sight, **exposure** (probability summed over time) and time with detection above 50 %. **Reset** clears the exposure.

7.4 Missions

Eleven short tasks across the scenes: *Into the shed*, *Drone overhead*, *To the camp*, *Under the canopy*, *Across the ford*, *Hangar*, *Down the street*, *In the ruin*, *Across the ice*, *Among the containers*, *Into the hangar*.

- The observer is a post with a 640×480 camera and a 9° lens, or a drone with 640×512 and 40°. Its detection probability summed over time is your **exposure**: reach the goal (green ring) before it exceeds the budget. The red ball marks the observer.
- Score: 80 points for staying hidden and 20 for speed, ★ to ★★★, with the best score for the session. **Restart**, **End** and **Observer's view** (main camera at the observer, with its lens).

8 Analysis tab



Analysis tab, with the timeline bar shown (interface shown in Polish)

The Analysis tab measures how visible the vehicle is and records the results.

8.1 Hottest surface and spot meter

The top of the tab shows the **hottest surface** in the scene (temperature and name) and the **spot meter** reading for the surface under the cursor (temperature, name, material and ε).

8.2 Detection meter

- **Contrast:** the visible warmer half of the vehicle against the background around it in the frame and against the ground 5–15 m round it, in °C as the camera reads it after the air. Rating: *Blends in* (< 0.5 K), *Borderline* (0.5–1.5 K), *Probably visible* (1.5–4 K), *Clearly visible* (> 4 K). Only parts the camera can see count.
- **Hottest point in sight**, for example "exhaust outlet +255 K" or "fan outlet, front, +3.2 K", so you know what to fix first.
- **Detect / Recognise / Identify:** probability now and the 50 % range, from the Johnson criteria for a 3.2 m critical dimension (1, 4 and 6.4 cycles), the camera's pixels and field of view, contrast weakened by the air, and lines of sight to points on the vehicle (berms, hedges, buildings and trees lower the score). The threshold depends on NETD and band.
- **Readout over the 3D view** shows these numbers in the bottom-left corner.

8.3 Detection map (all directions)

Sweep all directions computes detection from **24 bearings** (every 15°) and **5 elevations** (5°, 15°, 30°, 50°, 75°), 120 points, at the flying observer's slant range and with its camera, using real lines of sight and the contrast from that side. It works without an observer flying.

The result is a **sky map**: a circle with north up, bearing round the edge, straight overhead in the middle; green is unseen, red is certain. The **worst direction** (white ring), **best direction** (blue ring) and the share of the sky

that sees the vehicle above 50 % are listed below. The sweep takes a few seconds and shows its progress.

8.4 Timeline graph

Show / Hide (T) toggles the bar along the bottom of the 3D view.

- **Run / Pause (P)** and speeds 1×, 10×, 60×, 300×, 900×, 3600× and 7200×. Jumps: **+15 min**, **+1 h**, **+6 h**, **To dawn**, **To dusk** (computed from date and latitude); after a jump the ground and walls are recomputed over the last day and a half.
- The graph covers the last 24 h of scene time, one point every 5 minutes: **Air**, **Vehicle (signature)**, **Hottest point**, **Backdrop**, **Ground**, **Sky (zenith)**, **ΔT vs backdrop**, and with fans **Under the cover** and **Fan outlet**. Click a series name to hide or show it. Weather bands along the top: rain blue, fog grey, snow white, strong wind green.

8.5 Heat trace (cool-down timer)

After a stop and moving more than 6 m away, the panel measures the patch of ground left behind: how much warmer or cooler it is and when it will drop below **Detectable above** (default 1 K), with a forecast graph. After switching the engine off, the same is shown for the vehicle, naming the slowest-cooling surface. Times are given in scene time and real time. *Thermal lag* (Scene tab) must be on. **Clear** resets it.

8.6 Masking presets and before / after

- A **preset** stores the full masking set-up: covering and all its options (sides, mounting, layers, fans, cooling, outlet, power, water, laid ago), paint and zones, decoy and engine state. Type a name and **Save current**; **Apply** or **Delete** from the list. Presets are saved to `EMBER-presets.json` next to the program.
- Built-in presets: *No masking*, *Camo net*, *Thermal blanket*, *engine off 1 h*, *Tarp + mineral wool 100 mm*, *Full (tarp, PIR 60 mm, 2 fans, buried pipe, batteries)*, *Low-e paint on the top*.
- **Before / after**: pick **A** and **B** and press **Compare**. EMBER applies A, lets the scene settle, captures the view with its readouts, does the same for B, then puts everything back. The window shows both images side by side with a table: detect / recognise / identify, rating, ΔT vs backdrop and ground, vehicle signature, hottest point, share in sight, distance, air under the cover and power left. Results are saved to `reports/compare-<date>/`. It works in any camera, including the flying observer's view.

8.7 Test report and PDF

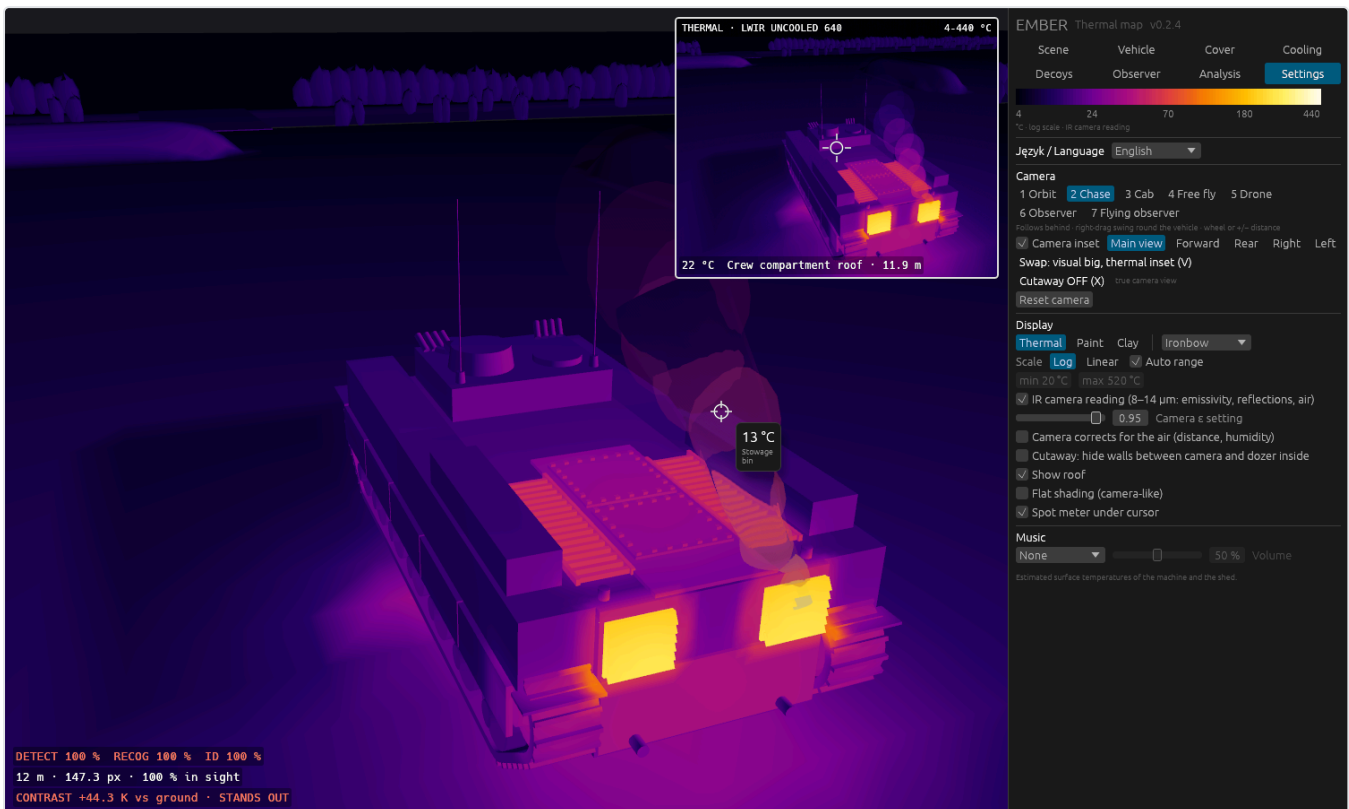
Export writes `reports/report-<date>-<time>/` next to the program, containing `screenshot.png`, `detection.png`, `detection.csv`, `timeline.csv`, `report.md` and **EMBER-report.pdf**. **Open folder** opens it; **Clear log** resets the detection log (the last hour is kept).

The A4 PDF is in the interface language and contains: title page with all settings and the detectability table; the thermal picture with readouts; the camera and its DRI ranges; detection over time, the sky map and the flying observer's exposure; the timeline chart; and the last before / after comparison. Charts are vector graphics.

8.8 Screenshot

Screenshot saves a PNG of the view in the working folder.

9 Settings tab



Settings tab (English interface)

The Settings tab holds the language, camera controls, display options and music.

9.1 Język / Language

Switches the whole interface between **English** and **Polish**: labels, tooltips, readouts, scene and part names, missions and reports. The choice is saved in `EMBER-lang.txt` next to the program; `--lang en|pl` sets it from the command line.

9.2 Camera

Mode	Key	Behaviour	Wheel or + / -
Orbit	1	Turns round the vehicle, kept in the middle; middle-drag pans	Distance 1.5–250 m
Chase (default)	2	Follows behind; right-drag swings round the vehicle	Distance 3–150 m
Cab	3	Operator's seat; right-drag looks around	Field of view 5–75°
Free fly	4	Arrows move, R/F up/down, Shift faster; drag or Q/E, PgUp/PgDn to look	Fly forward/back; Shift+wheel sets speed
Drone	5	Hovers above; right-drag circles	Height 10–600 m
Observer	6	Fixed tripod far away, telephoto	Lens 0.5–45°
Flying observer	7	Rides with the flying observer, looking at the vehicle	

- **Camera inset:** on or off, showing **Main view** or a roof camera facing **Forward**, **Rear**, **Right** or **Left**.

- **Swap (V):** thermal big with visual inset, or visual big with thermal inset. The visual view is Paint or Clay (Clay if Display is set to Thermal).
- **Cutaway (X):** on hides walls and roof between the camera and the vehicle inside a building; off shows exactly what a camera at that spot would see.
- **Follow** and **Reset camera**.

9.3 Display

- **Thermal, Paint or Clay** view, and the palette: Ironbow, Inferno, Rainbow, White hot, Black hot.
- **Scale:** Log or Linear, **Auto range** or manual min / max.
- **IR camera reading** (on by default): the camera computes each pixel from Planck's law with angle-dependent emissivity, sky and surroundings reflections, and the air's transmission and own glow. Off shows true surface temperatures.
- **Camera ϵ setting:** the emissivity the camera assumes, as on a real camera.
- **Camera corrects for the air:** like entering distance, humidity and air temperature on a real camera, so distant targets no longer read towards air temperature.
- **Cutaway, Show roof, Flat shading** (camera-like) and **Spot meter under cursor**.

9.4 Music

None (default) or one of five built-in synthetic loops (Dark drone, Tense pulse, Calm industrial, Warm pad, Diesel groove), with a volume slider.

10 Command line

Options can be added after the exe name, for example in a Windows shortcut: `EMBER-0.2.4.exe --scene field --hour 22 --tab analysis`. Anything not given on the command line starts at its default and can still be changed in the panel.

Panel and interface

```
--tab scene|vehicle|cover|cooling|decoys|observer|analysis|settings (or 1-8)
--lang pl|en --music 1-5 --screenshot
```

Scene, time and weather

```
--scene yard|forest|field|urban|winter|port|airfield|city|village|woods
--day 1-365 --hour 0-24 --ambient °C --cloud --wind --rain mm/h
--visibility km --snow --leaves on|off --roof painted --timelapse
--live-weather
--warmup same|clear|overcast|rain|clouding|recorded --warmup-hours 24-48
--weather-script shower|fog|snow|storm|thaw [--script-at 2]
--timeline --speed 600
```

Vehicle and driving

```
--engine cold|stopped:<minutes> --load 0-1.1 --pos x,z --yaw degrees
--engine-bay --no-refraction
--route loop|line|x1,z1;x2,z2;... --route-speed 20 --route-mode once|loop|back
--route-stop 2 --route-stop-engine idle|off
```

Cover, cooling and paint

```
--cover net|blanket|tarp|branches|straw|sod|snow|earth
--cover-gap --cover-age --cover-depth --overhang --hide berm|wall|trunks
--cover-sides top,left,right,front,back --roof-overhang 0.5
--mount frame|loose [--contact 30]
--layers wool:100,pir:40,aerogel:10 --faced
--fans 3 --fan-flow 1200 [--fan-pos rear,rear,top]
--cooling none|exchanger:60|pipe:20,1.5 --outlet single|spread:40|ground
--blow-hull --blow-under
--power engine|battery:20 [--fuel 80] [--recharge 4,0.5]
--spray 40 --wet-cover 1.5
--hull-paint 0.4 [--paint-zones deck,roof,sides,front,rear,running]
```

Decoys

```
--no-decoys --decoy --decoy-power --decoy-bearing --decoy-dist --decoy-battery
```

Camera, observer and display

```
--cam orbit|chase|cab|free|drone|observer|flyer --view --dist m --patrol
--swap --cutaway --true-temp --paint --clay --flat --ir
--imager lwir320|lwir640|lwir1280|mwir640|mwir1280 [--netd 50] [--blur 1.5]
        [--no-noise] [--imager-view]
--flyer drone|heli --fly orbit|pass|hover|route --fly-alt 300 --fly-dist 1500
--fly-speed 40 --fly-bearing 90
--sweep          (sweep all directions after start-up)
--mission 1-11
```

Presets and reports

```
--preset "name"      --compare "A","B"      --report      --pdf
```

11 Files EMBER reads and writes

All files are kept next to the program (the working folder).

File or folder	Contents
EMBER-lang.txt	The chosen interface language
EMBER-presets.json	Your masking presets; copy it to move presets to another computer
reports/report-<date>-<time>/	Test report: screenshot.png , detection.png , detection.csv , timeline.csv , report.md , EMBER-report.pdf
reports/compare-<date>/	Before / after: A.png , B.png , A-B.png , compare.md
*.png in the working folder	Screenshots

detection.csv holds the detection samples together with the temperature under the covering, the outlet temperature and the run time left (fuel or batteries). report.md lists all settings: scene and weather, vehicle and engine, camera, covering and its sides, mounting, layers, fans, cooling, water, power, paint, route, observer, weather scenario and preset.

12 Model limitations and known issues

Model limitations

- All temperatures and probabilities are engineering estimates for visualisation, not measured data.
- The route autopilot does not plan detours: it drives straight from point to point, so obstacles have to be avoided with route points.
- Noise and blur appear only in the camera inset and imager full screen; the main 3D view stays clean.
- The before / after comparison captures A and then B at the same place and time; it does not run two simulations at once.
- The helicopter and drone do not block the view of the vehicle and cast no shadows.
- The flying observer sees the scene in the band of the selected thermal camera; its own camera changes the resolution, lens, NETD and blur.
- Time jumps on the timeline recompute the ground and walls over the last day and a half (like *Settle*), not step by step.

Known issues in 0.2.4

- The autopilot still skips route points on terrain with obstacles.