Thermals

influenced by ground and vegetation

What influence does soil moisture have on the formation of thermals?

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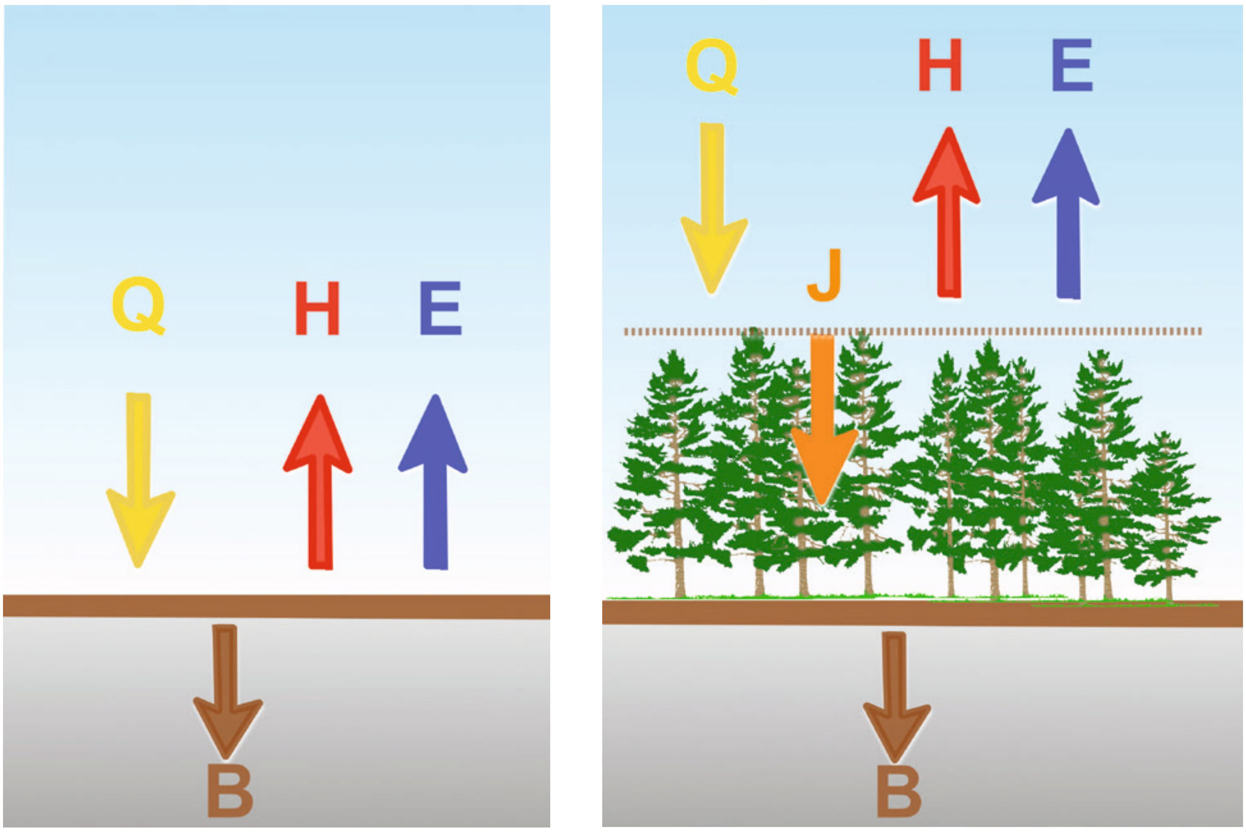
The theory lessons for the glider licence already deal with the radiation and energy balance of the atmosphere. There we learned that a significant part of the sun's radiant energy is converted into heat by absorption at the earth's surface. How much solar energy arrives at the Earth's surface depends on the reflection and absorption in the atmosphere.
If one wants to determine the conversion of the radiation energy at the earth's surface into other forms of energy, the reflection of the radiation as well as the angle of incidence of the radiation must be taken into account. It depends on the time of day and the season how steep or flat the radiation is. Finally, the radiation balance Q (the available radiation energy per square metre) describes the energy available for conversion into other forms of energy.
Where the ground is heated by radiation, the earth's surface transfers some of the heat by conduction to deeper soil layers (ground heat flux B) and some to the air directly above (flux of sensible heat H). This heating of the air is already replaced at low altitudes by the turbulent flow of sensible heat (further called H). H decreases with altitude, whereby the heating of the higher air layers takes place because a part of the heat transferred by H remains in each altitude layer. Convection, i.e. „thermics", with its up and downdrafts, is responsible for heat transport.
At ground level, the flow of latent energy E also occurs in connection with evaporation. This transport of water vapour is also turbulent and is carried by the updrafts and downdrafts. However, it only changes the temperature of the air if the water vapour liquefies – especially in clouds (***picture 1***).

The energy conversion processes at the earth's surface are described by the energy balance equation in the form Q - B - E - H = 0 or Q = B + E + H, i. e. the energy flows radiation balance (Q directed towards the earth's surface during the day) and the ground heat flow B, the flow of sensible heat H and the flow of latent heat E (all directed away



Picture 1 Terms of the energy balance at the earth's surface: on radiation days, the energy flows (radiation balance Q, directed towards the earth's surface) as well as the soil heat flux B, the flux of sensible heat H and the flux of latent heat E (all directed away from the earth's surface) cancel each other out at the earth's surface (left). In the case of vegetation (right), the energy turnover in the plant stand must also be taken into account

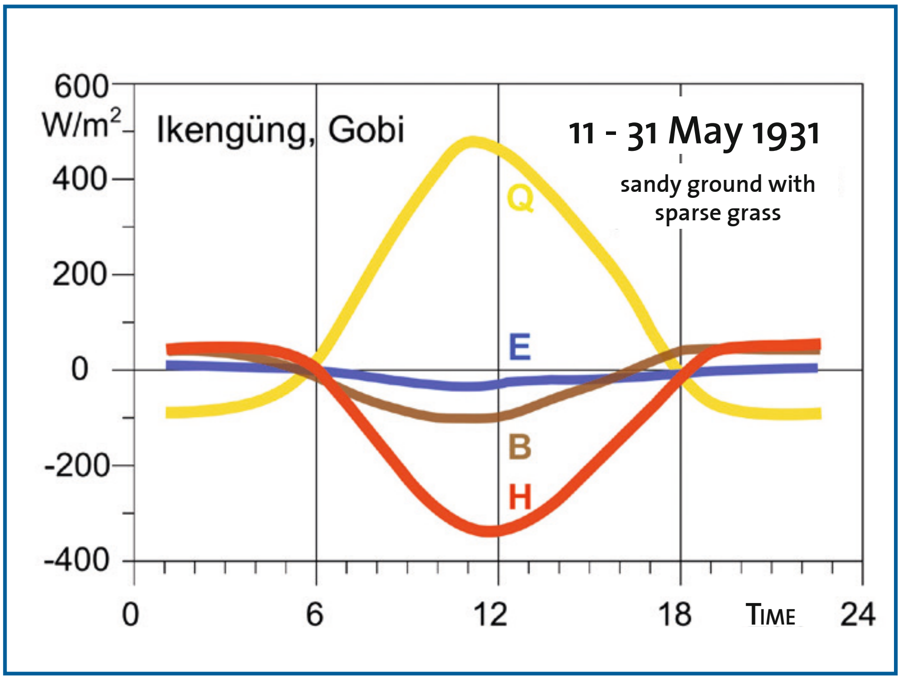
from the earth's surface during the day) cancel each other out. Q indicates how much energy is available to be converted into B, E and H. The energy is divided into three parts. Their distribution may vary at any time and at any place.

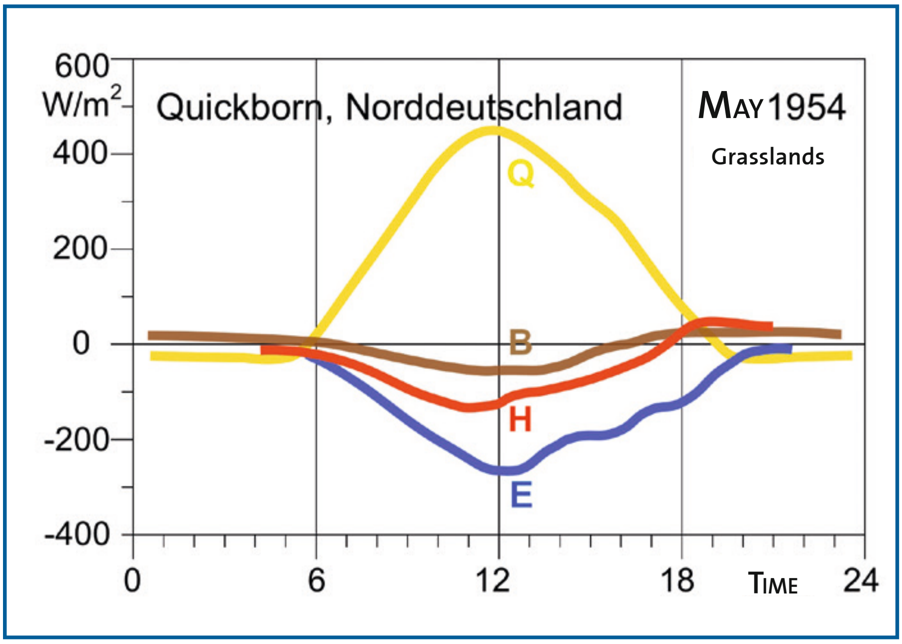
In the case of vegetation, the energy conversion in the plant stock (J) must also be taken into account. Now the upper edge of the vegetation is the surface of the earth. The energy transformation in the plant stock is also directed away from the reference plane during the day.

It is important for thermal development that the earth's surface – and thus the air near the surface – heats up particularly strongly. This causes the air close to the ground to experience lift and set up updrafts. Thus for the greatest possible flow of sensible heat we need the highest possible irradiance. The ground surface should be illuminated locally as steeply and directly as possible (few clouds) and be dark (low radiation reflection). A small latent heat flux (dry surface) with little evaporation is a huge advantage for large H. A low soil heat flux B (dry soil) also favours large H.

Picture 2 shows the daily course of the energy balance components on a radiation day over desert soil and over a moist meadow. In terms of magnitude, the components are distributed at midday as shown in ***Table 1***.

Over vegetation-free soils (desert), the flux of sensible heat H dominates over that of latent heat E. Over vegetation with sufficient soil moisture, the flux of latent heat dominates over that of sensible heat.





Picture 2 Diurnal variation of the components of the energy balance on radiation days: above desert soil with very small E (latent heat flux) and large H (sensible heat flux) during the day, below humid meadow with larger E (latent heat flux) than H (sensible heat flux)

Table 1 Typical energy balance values of dry and wet soil (same source as picture. 2)

	dry surface	damp meadow
Radiation balance (Q)	500 W/m²	500 W/m²
Soil heat flow (B)	100 W/m²	50 W/m²
Latent heat flow (E)	0 W/m² (sehr klein)	350 W/m²
Current sensible heat (H)	400 W/m²	100 W/m²

Material	Conditions	Density (kg/m³) * 10³	Heat capacity (J/m³K)*10⁶	Thermal conductivity W/mK
Air	20°C, silent	0,0012	0,0012	0.025
Water	20°C, silent	1,0	4,18	0,57
sandy soil (40% pore volume)	fresh	1,6	1,28	0,30
	saturated	2,0	2,96	2,20
Clay (40% pore volume)	dry	1,6	1,42	0,25
	saturated	2,0	3,10	1,58
Peat (80% pore volume)	dry	0,3	0,58	0,06
	saturated	1,1	4,02	0,50
Stone	massive	2,7	2,02	2,90

Table 2 Heat capacity and thermal conductivity of various soil as well as water and air (same source as picture 2)

Two factors in particular determine soil heat flux: heat capacity and thermal conductivity. The heat capacity describes the energy that must be supplied to a body of mass m in order to increase its temperature by 1K. The thermal conductivity is the measurement of the substance‘s ability to conduct heat.

If we look at the corresponding values in ***Table 2***, we can see that different grain size determines water content. The finer the soil (high clay content and correspondingly low sand content), the finer the pores and the better the water adheres to the walls. And this is important: the higher the water content, the greater the soil heat flow. And the finer-grained the soil, the longer it retains water, and the greater it‘s evaporation potential!

As a rule, of course, the soil in our cultivated landscapes are not „bare“, but covered with plants, which tend to reduce the soil‘s surface temperature and whose surface then represents the earth‘s surface. But here, too, soil moisture plays an important role: the flow of latent heat is determined by the vegetation and the soil water content. On one hand, plant transpiration is essentially determined by the water supply in the uppermost soil layers, and on the other hand, higher soil moisture leads to an increasing thermal conductivity and heat capacity, i.e. the soil heat flux.

Thus, detailed model calculations for seven weather situations of the COPS project (Convective and Orographically induced Precipitation Study, summer 2007) showed 0.3 to 1.7 degrees lower temperatures at 2 m height with wetter soil (+25 %) compared to the reference run and a 25 to 50 % reduced turbulent heat flux. With drier soil, the air temperature increased by 1.3 to 2.7 degrees

Vegetation	Transpiration power
evergreen conifers	1400-1700 µmol $H_2O/(m^2s)$
grasslands	3000-4500 µmol $H_2O/(m^2s)$

Table 3 Transpiration capacities of different vegetation

and the turbulent heat flux by more than 50 % on average.

The model results can be considered typical, since the model was supported by many measurement data and was based on real summer weather situations. The additional evaporation with vegetation thus modifies the distribution of the energy supplied to the earth's surface to the flow of sensible and latent heat via the soil moisture. ***Table 3*** shows the transpiration performance of evergreen conifers and meadows: Meadows are at the upper end of the transpiration rates, deciduous trees in the middle range and conifers at the lower end. The flow of latent heat behaves accordingly – with the same water supply.

If we look at our cultivated area, the vegetation is generally well adapted to the water supply of the soil: on rather well-moistened soil or soil with a high water storage capacity, plants with a high water consumption and high evapotranspiration can also be found! Accordingly, the rule on evapotranspiration still applies: the higher the soil moisture, the lower the heating of the air near the ground!

Let us summarise the considerations on the radiation and energy balance: The warming of the air close to the ground is greater,

- the more radiation energy reaches a surface and remains there (summer half-year, little cloud screening, steep incidence of radiation, low reflection)
- the lower the evapotranspiration (the transpiration of the plants and evaporation of the soil).

A side effect is that a higher soil moisture leads to a lower dew point depression and thus to a lower rise of the cumulus cloud base because of the continued evaporation and the lower temperature rise during the day.

40 years ago, we developed our thermal map for northern Germany on the basis of these considerations on soil moisture (www.imk-tro.kit.edu/5291.php).

The regionally prevailing soils also cause typical differences in soil water contents, especially from one to two days after rainfall. Vegetation or crops are adapted to different soil and do not change the general picture. Sandy soil promote strong warming of surface, and loamy soil, of course, including waters and river floodplains, allow only weaker warming.

The type of soil thus causes a higher or lower warming of the air near the ground and thus, in turn, sooner or later onset of thermals and rising cumulus cloud base.

However, these considerations are not only useful for large-scale observations of the thermal quality of regions, but also for detailed considerations of locations with better chance to generate thermals. On days when the wind is weak, we need sufficiently large areas that can heat up more than their surroundings.

On the plain, these usually drier surfaces are characterised by a higher brightness, which, however, also means a reduced radiation balance (greater reflection, more radiation is reflected). The same applies to vegetation stands: plants „in full sap“ with pronounced evapotranspiration tend to appear darker green, dried out grain or bushes more beige. A dried-out plant stand reduces evapotranspiration and soil heat flux, which often results in a lower radiation balance. The result is, for example, high temperatures in ripe grain stands.

This is somewhat more difficult in forests, which covers a third of Germany. Here, the stand (the treetops or the bushes) forms the „earth‘s surface“. As a rule, we find forests in our cultivated landscape where farming is not profitable. This may be due to the orography (steep slopes, terrain edges), but also to the water supply (alluvial plains in river lowlands or on boggy ground on the one hand, pine forests on sandy ground on the other).

Whereas high evapotranspiration results in lower temperatures above wetlands, the situation is different for dry ground at tree-top height. Comparative measurements at the city of Freiburg above a lawn and in/above a pine forest with comparable subsoil showed that on the one hand the midday evaporation/flow of latent heat as well as the stock and soil heat flow did not show large differences, but on the other hand the flow of sensible heat did.

The peak value of the sensible heat flux over the pine forest was almost twice as large as that over the lawn. Accordingly, the midday temperatures at the upper edge of the tree canopy were higher than those above the lawn. The main factor for the greater warming was the higher value of radiation balance (15 %) resulting from the lower reflection of the pine forest surface (0.11 compared to 0.22. i.e. factor 2).

The reduced evapotranspiration of the pine forest compared to a grassland area was also observed in measurements in northern Germany. The ratio of sensible to latent heat flow, also called the „Bowen ratio“, was 0.2, i.e. the flow of sensible heat was 5 times greater than that of latent heat. In a meadow, the ratio is more like 1.0, which is attributed to the pines‘ reduced transpiration capacity.

Under the influence of the wind, forests (and rivers alike) can also form break-off edges for heated air packets. Forests can therefore be sources of thermals themselves, but under the influence of wind they can also be the edges of the forest!

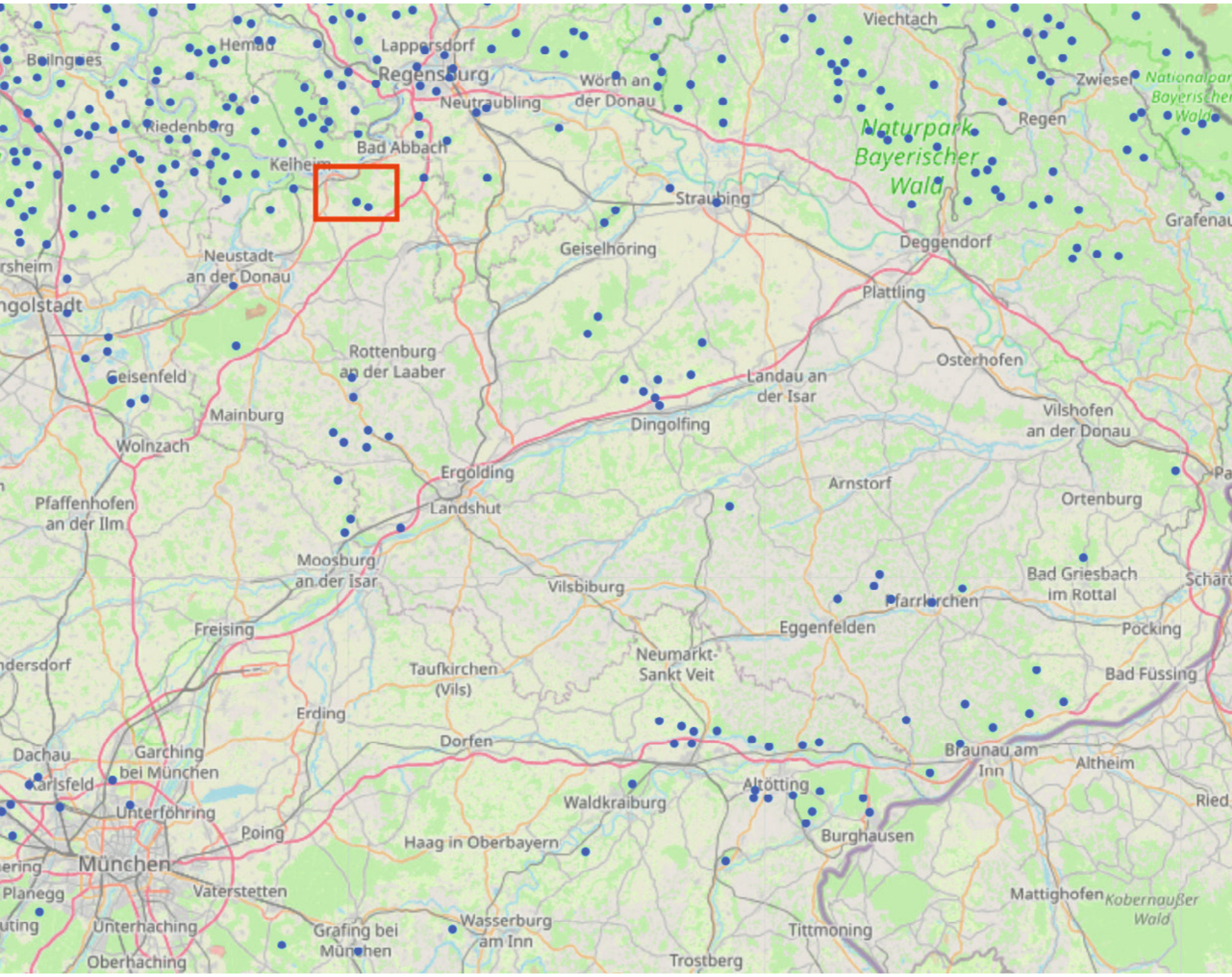
A summary of the considerations for windless days can be: In the lowlands, look for thermals over dried areas (away from floodplains and wetlands) with no or with dried vegetation or pine forests; in weak winds look for trigger points like edges in the terrain, e. g. hills, forest edges or rivers on the downwind side. In hilly country, search along breakaway edges of sunny slopes or above forested sunny slopes.

Orographic structures are influencing the heating of the air near the ground in two directions: First, direct solar radiation increases on sun-exposed surfaces and second, the soil water content is reduced by runoff. In addition, the heated air can „creep up“ the slope and thus inevitably encounters a departure edge!

To verify these derivations, one can refer to own experience in gliding or use the „Thermal Information Map“ (www.thermalmap.info/thermalmap.php) by Tim and Richard Stuhler. The map generated here from OGN and IGC data from thousands of cross-country glider flights shows locations with frequent altitude gains due to thermal circling. The potential trigger point on the ground was determined on the basis of wind offset, inclination and altitude, and an algorithm was used to localise, bundle and weight areas of accumulation.

I picked out Lower Bavaria and the surrounding area, a region I feel at home when flying (***picture 3***).

The lower Bavarian hilly landscape is relatively homogeneous with a heavy, loamy soil (loess) on a substructure of marine and freshwater deposits, into which broader river valleys (glacial valleys) are embedded. Due to the fertility of the soil, large areas of the landscape are used for agriculture and



Picture 3 Hotspots according to the Thermal Information Map for the Lower Bavarian hill country based on OpenStreetMap

only 1/5 of the surface is covered with forests. After precipitation, the water tends to run off above ground. This region can only be classified as „thermally weak".

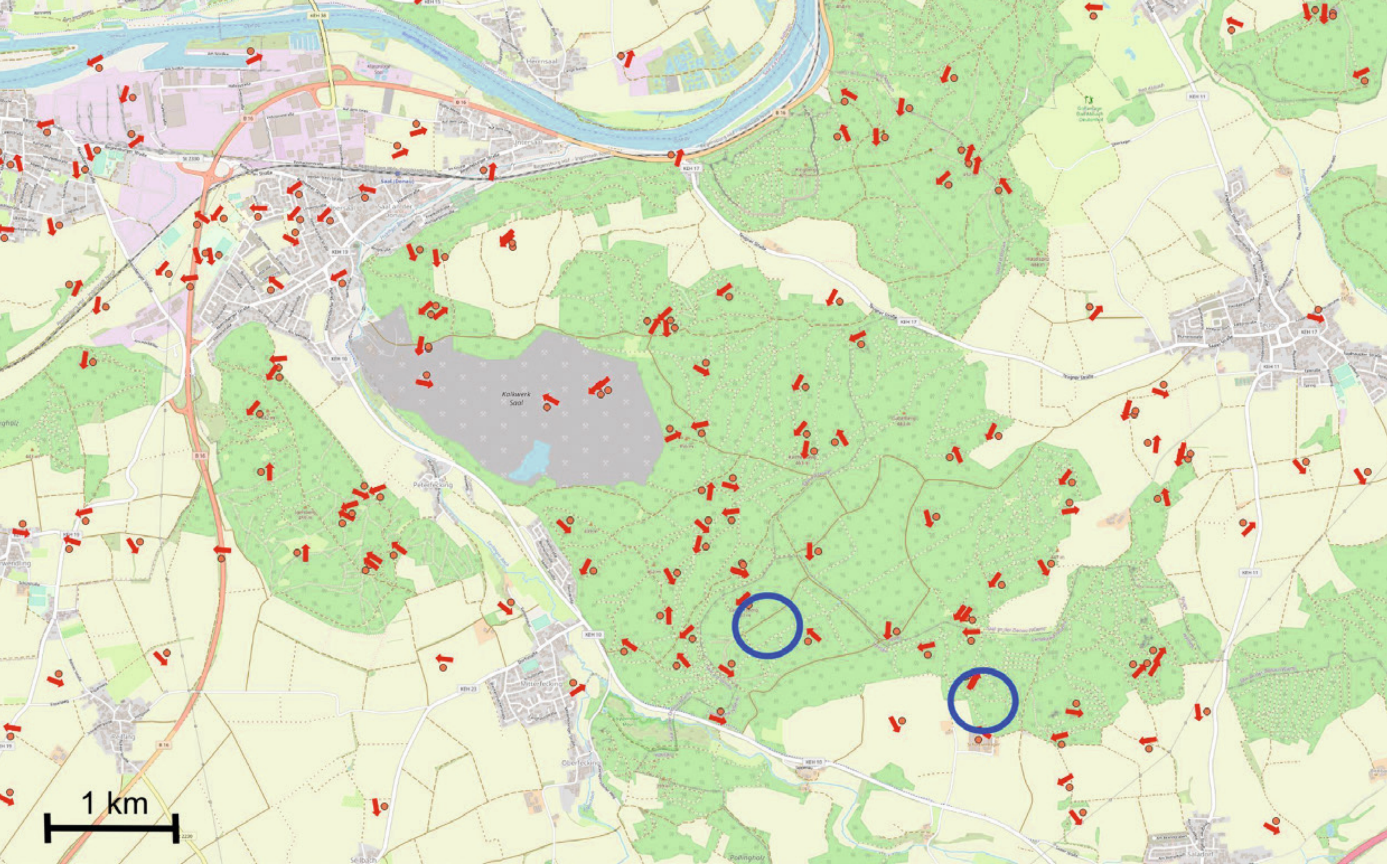
The Franconian Alb, a hilly plateau with deeply incised river valleys such as that of the Altmühl, borders to the north. The subsoil consists mainly of karstic limestone and dolomite with a thin layer of weathered clay and limestone fragments. Due to the limestone subsoil, precipitation drains underground through its crevices and fissures, which leads to a lack of water on the Alb. Accordingly, agricultural use is limited here and the proportion of forest is greater. This region is is „thermally rather good".

Even the first glance at the map (***picture 3***) shows two things:

- There are many more hotspots above the Alb than over the Lower Bavarian hills.
- With very few exceptions, the hotspots are located over the rather extensive forest areas.

The lack of hotspots over the lower Bavarian hills is probably mainly due to the fact that the region is thermally weak, and thus tends to be avoided by gliders.

A detailed examination of the hotspots over the lower Bavarian hills shows that they are either located on the northern flanks of the valleys



Picture 4 Calculated release points of better updrafts on low wind days near Saal an der Donau (Thermal Information Map)

above forests (wooded sunny hillside partly on the northern edge of the Inn and Isar valleys), above wide forest areas or in the valley area on terrain steps. Above the Alb, the hotspots are found above the more extensive forest areas. And not only on the wind-facing sides of the forest (break-away edge)!

As an example, I have chosen a forest area east-southeast of Kehlheim (***picture 4 and red marking in picture 3***). Tim Stuhler was kind enough to generate a section of the data showing the presumed trigger points of updrafts in light winds (less than 20 km/h), with at least 1.5 m/s climb, sufficient vertical extent and not too high thermal entry. On one hand, this reduces the number of upwinds shown, but on the other hand it makes a detailed view of individual upwind sources possible: the total amount of all recorded upwinds shows a close proximity of sources!

Actually, this is not very surprising in flat and hilly terrain: here only a part of the updraft sources is stationary, then flow dynamic effects, the place of origin, the lifetime and the interaction with the environment influence the structure, shape and position of an updraft (*see our part 4 of the article series „The thermal updraft – its structure and flow behaviour“*).

I think that every glider pilot knows one or two „house whiskers“ in his airfield environment, which are not always found in exactly the same place. That‘s why the Stuhlers‘ approach of bundling the calculated upwind sources is absolutely fine!

Another aspect that must be considered for a stronger updraft with sufficient vertical extent in stationary thermal sources is that the source has a sufficiently large catchment area of heated air in the ground-level over-adiabatic layer: this usually has to be a few square kilometres. Therefore, smaller quarries usually do not work as a reliable thermal source.

Back to picture 4: What is interesting about this area is that here – in addition to the forest area on a hilltop – there is also a quarry (on the western flank of the forest) and a somewhat larger village (Saal an der Donau). Two core points are marked on the hotspot map (marked with a blue circle in ***picture 4***). These are located on south-facing forest flanks. Here, the individual calculated trigger points do not show a clear wind direction (shown with a red arrow).

The majority of the individual trigger points above the forest area are located near individual hilltops. Actually not quite unexpected: the vegetation above the flanks with a relatively low reflection heats up the most, and the over-adiabatic layer breaks up near a ridge. Some trigger points at the edge of the forest area also indicate detachment at the forest edge. Here the thesis is wonderfully confirmed: Always follow the forests!

Although it has an extension of two kilometres in an east-west direction, the quarry does not necessarily stand out as a preferred thermal source! As expected, however, the release points are also assigned to the south-facing flanks of the quarry.

The district of Obersaal is also assigned some upwind sources – also comprehensible. However, it is difficult to explain the causes of the individual thermal sources above the fields; in the end, many local and temporary effects play a role in causing the updrafts here.

Convection is a certain form of turbulence – and turbulence is characterised by a disorderly flow in the atmosphere, which is characterised by vortex formation and decay. However, theoretical knowledge of „convection“ as well as experience gained on gliding flights may help to increase the probability of finding a single thermal updraft! ♦

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