THERMAL INFRARED TEMPERATURES AND VERTICAL HEAT FLUX

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Abstract

There is a lot of modern literature which shows that the vertical heat flux near the surface can be detected by means of modern remote sensing data such as NDVI and thermal infrared temperature (TIR). A contradiction seems to exist in that convective vertical flux of sensible heat over a pine forest is not proportional to TIR temperatures as measured by satellites and low flying aircraft. Measurement of temperature, humidity, vertical velocity and thus vertical heat flux, TIR temperatures and others are done by means of a powered glider over different types of vegetation. For normal arable land at very low altitude correlations between vertical heat flux and TIR temperatures are found, but not over pine forests. An explanation is given about the possible reasons for such a contradiction.

Introduction

The powered glider has proved to be a very important tool to detect the planetary boundary layer (Hacker, 1987; Lindemann 1976 and others). It is easy to handle under reasonable costs. It has been accepted that vertical velocity measurements of the air can be determined by the vertical velocity of the aircraft due to the low wing loading in convective scale. Higher frequent turbulent wind components need the determination of wind fluctuations relative to aircraft, which successfully has been done by means of a Rosemount Five Hole Probe (Williams A.G. and J. Hacker 1992).

The energy budget at the surface can be determined by means of atmospheric and soil characteristics and possibly by the soil surface temperature. This can be measured by means of a TIR Thermal Infrared Thermometer. This equipment can easily be mounted on a powered glider. First results of such measurements will be shown.

The vertical fluxes and the TIR measurements

The vertical fluxes of latent and sensible heat are related to atmospheric and soil characteristics. The energy budget of the surface is generally written as:

$$Rn = H + LE + S \qquad (1)$$

in which Rn is the radiation balance, H the sensible heat flux, LE the latent heat flux, and S the heat flux into soil.

The radiation balance is also determined by soil characteristics such as albedo etc.. The formula 1 can more explicitly be given in the form (Gebhardt, 1991):

Rn **H** **LE**
S

$$Rn = 1/ra\ g\ cp\ (Tc - Ta) + 1/rc\ 1/y\ g\ ca\ (e^*\ (Tc) - e\ (Ta) + k\ dT/dz \text{ at } z = 0$$

Tc - surface temperature of vegetation
Ta - air temperature
ra - aerodynamic drag coefficient of heat
cp - specific heat capacity (constant pressure)
g - density of air
rc - turbulent exchange coefficient of water vapor
y - psychrometric constant
e(T) - water vapor pressure at temperature T
e* - saturated water vapor pressure
k - heat conductivity of soil
dT/dz - gradient of soil temperature at the surface

Tc is the TIR temperature, which is predominantly related to vertical flux of sensible heat and implicitly to heat flux into soil. Even the water vapor and thus the latent heat flux is related to a temperature, which can be detected as TIR temperature.

The fluxes of the formula 1 are fluxes to be existent very close to the surfaces. When thermal convection prevails, which is very common under warm season sunshine con-

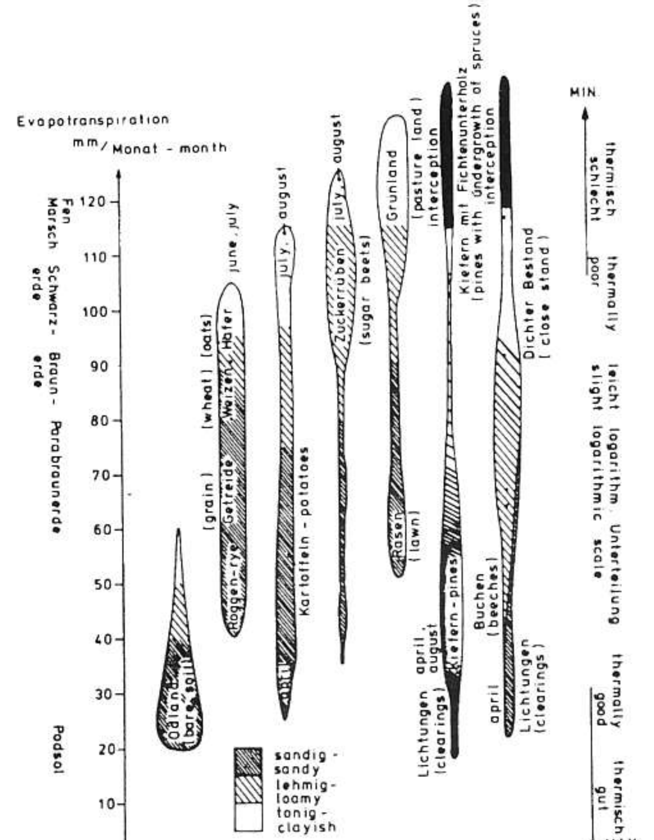

Figure 1. Monthly evapotranspiration of different kinds of vegetation as a function of type of soil. Classification in loamy, clayish and sandy corresponds to the relative land utilization of the single kind of vegetation. Evapotranspiration is approximately inverted proportional to flux of sensible heat. (Construction after: Becker, Blaney-Cridde, Klapp, Kiese, Schott, Tajchmann, Berz, Lutzke)

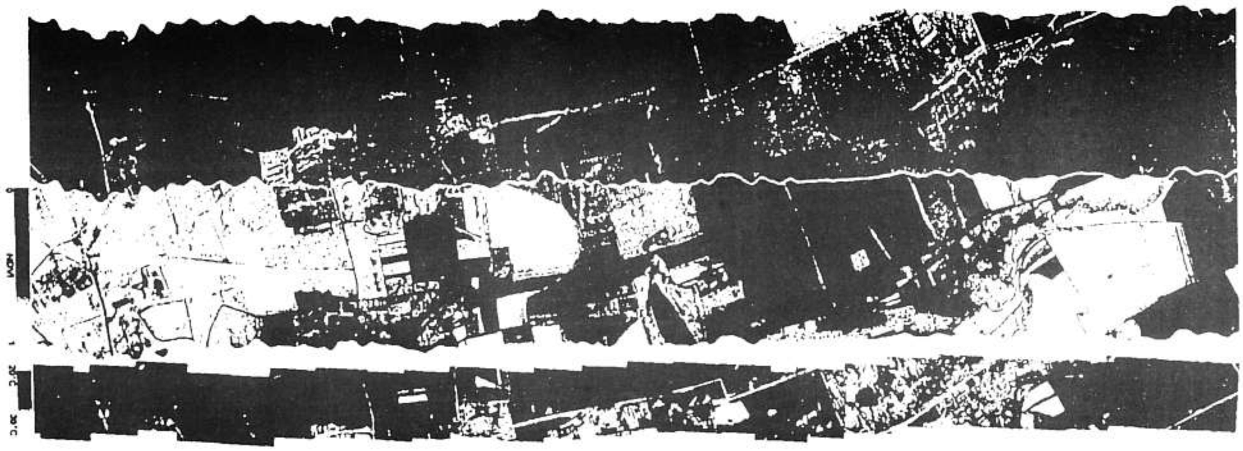

Figure 2. Aircraft measurement of arable land of different vegetation with casi (compact airborne spectrographic imager) for true color and NDVI (normalized differential vegetation index) and with infametrics 760 for Thermal Infrared Temperature near Weimar/Apolda (Germany) at 10th of July, 1992.

ditions, the surface (sensible) fluxes organize the lower atmosphere such that convective cells form. These cells have the appropriate relation between friction and buoyancy to leave the surface layer and to ascend into the whole planetary boundary layer. Once having left the surface layer the buoyant convective cells are more and more influenced by forces in the free atmosphere. such as the horizontal wind as function of altitude. The contact and the correlation to the surface values must decrease more and more with increasing altitude.

By measurement, and by glider pilot's knowledge, there is a lot of information collected; which areas, which kind of vegetation, which period of vegetation cycles are favorable and not so favorable soil characteristics for thermal convection development. These experiences also contain information about the quality of forests for thermal convection. Some of this information has been collected more than a decade ago (Lindemann, 1981). Figure 1 shows comprehensive results of types of vegetation in relation to soil characteristics. The main results refer to evapotranspiration. As the heat flux into soil is at least less than evapotranspiration, which is proportional to latent heat flux (see Formula 1), more evapotranspiration means less sensible heat flux and is thus proportionally opposite to the development of thermals. Sandy soil and vegetation especially pines on sandy ground have minor latent heat flux and thus good thermal development.

The areas of Poland and Brandenburg are well known in that good thermal convection conditions exist, especially over coniferous forests. Quite contradictory, the TIR detection from NOAA satellites show lower temperatures than the arable surroundings even on days during intensive thermal convection. Figure 2 is an aircraft measurement with two remote sensors - a compact airborne spectrographic imager (casi) and a thermal infrared thermometer (Inframetrics 760). At the bottom of the picture forests have a high NDVI and a low TIR temperature. The forest is mixed by deciduous and coniferous trees and thus not yet developed in relation to quality of thermal convection. The thermal convection quality is not known in this special area, but the TIR temperatures are low. If there is a contradiction between heat flux and TIR temperatures, this should be solved.

Blümel (1997) has proved that the daily mean sensible heat flux can be determined from the measurements of the thermodynamic surface temperature and from a one-time-of day air temperature observation but for lower vegetation and not for forests.

First measurements of TIR and first experiences

The measurements were done by a powered glider ASK 16, which is instrumented with PT 100 temperature, a Vaisala Humicap, Rosemount pressure transducers also for vertical velocity, a GPS navigation system, and a Heimann KT 19 TIR thermometer.

The TIR temperature which will be accepted as the surface temperature in this study has a diurnal cyclus similar to the air temperature to be measured 2 m higher. The TIR amplitudes are known to be much larger. The air temperature under conditions free of advection, condensation, etc. is a result of surface temperature by means of molecular contact. It is well known (Lindemann 1981), that different soil produce different fluxes and thus different fluxes in convective scale. As the temperatures are changing diurnally the next problem to solve is, if the different types of soil can be detected by their TIR temperature and if their daylight TIR emissions are similar relatively to each other. It is not expected that the TIR temperatures are the same on each sunshine day in summer season, which is not possible because of the dependence on air temperature and thus of airmass characteristics.

All measurements have been done in the vicinity of Berlin near the small town of Belzig (75 km SW of Berlin), over arable fields (rye, maize, wheat), over the dry grass airfield of Lüsse, over pine forests with clearings, and over the town of Belzig.

Figure 3 shows a flight over a combination of fields of rye, maize, and wheat during two different days. Although the absolute temperatures differ by more than 5 °C, the shape of the temperatures of different crops is quite similar, even the absolute differences in temperatures are quite

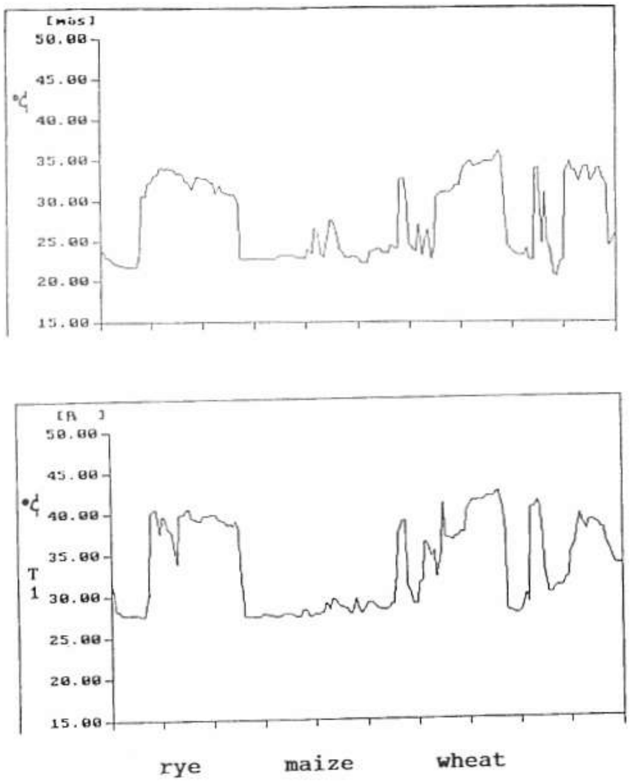

Figure 3. Thermal Infrared Temperature (TIR) measurements (°C) in 200m above ground at a selected flight path (length 4,500m) near airfield Lüsse at two different days above different kind of crop: rye, maize and wheat. Top: June 5, 1996 at 15.40 local time. Bottom: June 7, 1996 10.40 local time.

similar.

The next step is to determine typical temperature differences over different crops and to detect the TIR temperatures over coniferous forest especially. Figure 4 shows the measurements of the 17 of June, 1997. Clearings (in coniferous forest) and the dry grass airstrip are hottest nearly all over the day. The lowest temperatures have been measured over the pine forests. Figure 5 shows similar characteristics but with smaller amplitude for the 29th of June, 1997. So measurements of this kind over coniferous forests validate the other measurements of from satellites and aircraft. They show lower temperatures than over arable land. This will be discussed in a later chapter.

17/6/97 time	10,04	12,42	13,25	16,24	17,59
rye	22,2	30,2	29,4	28,3	29,2
dry grass airfield	30,1	30,7	33,4	34,2	28,1
pine forest	17,8	22,4	22,7	22,6	
different crop	23,9	26,5	26,7	25,9	
clearings	23,1	34,1	34,7	31,2	

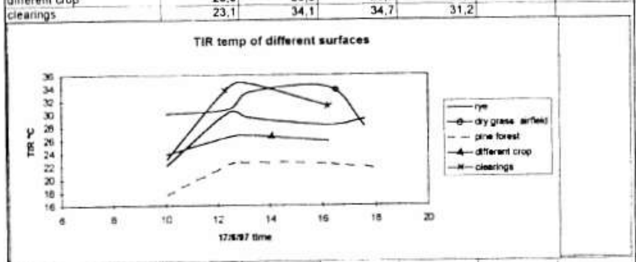

Figure 4..

	9,34	12,01	18,32
rye	27,1	30,4	33,2
dry grass airfield	31,6	33,4	34,1
pine forest	26,8	30,6	31,8
different crop	28,1	31,8	31,1
clearings	31,6	31,8	33,1
town	29,1	32,3	31,5

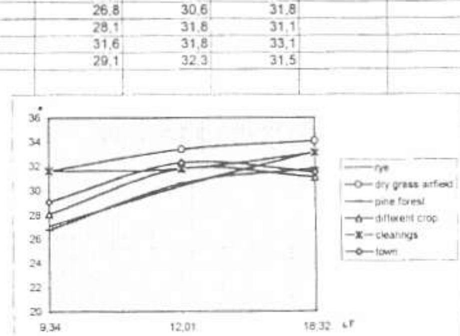

Figure 5. TIR temperatures (°C) of different surfaces at the 29th of June, 1997 at three different times: 9.34, 12.01 and 18.32 local time near Belzig, Brandenburg flight altitude between 200 and 300 m GND.

Correlation of air and TIR temperatures and vertical heat flux

A positive correlation between vertical heat flux and TIR temperature means that TIR and potential air temperature and additionally vertical velocity correlate. A first test is shown in Figure 6. A flight 30m over the airfield is proving, that TIR temperatures and air temperatures are very well correlated with a factor of more than 0.6. The vertical velocity in convective scale is at least not correlated, thus the vertical heat flux in convective scale is not sufficient to be determined. Here turbulent flow measurements are necessary, as the lower boundary layer up to less than 100 m above ground is governed by change of structure to form thermal cells. Smaller turbulent buoyant volumes collect to a larger volume.

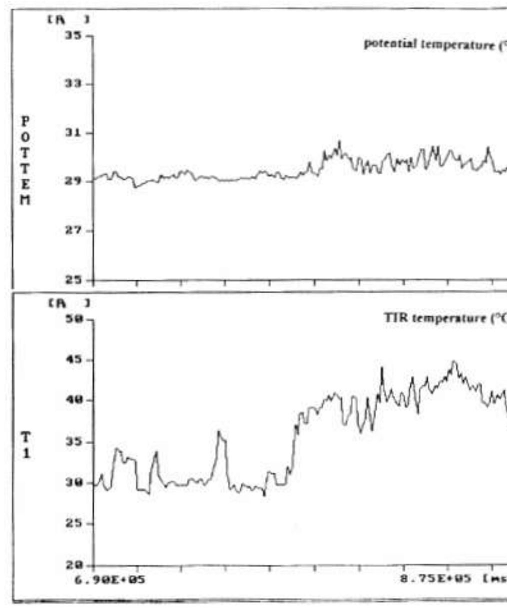

Figure 6.. Low flight of 30 m over grass airfield on 29th of June, 1997 at 12.02 local time.

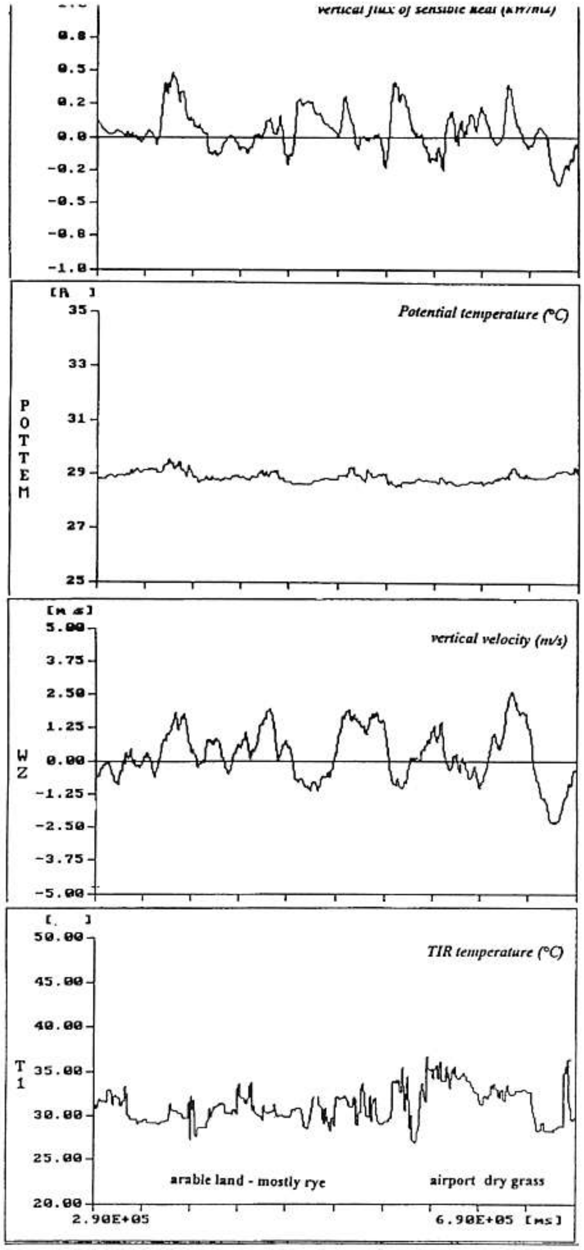

Figure 7. Aircraft measurements of convective parameters for ASK 16 D-KMET near Belzig, Germany on 29th of June, 1997 at 12.02 local time and 160 m GND.

At higher altitudes, when the forming process has at least transitioned into real thermal bubbles, vertical velocity and potential temperature is well correlated to present positive vertical heat flux. In low altitudes (Figure 7 - 160 m GND) a slight positive correlation of 0.1 is detectable. In this case, there was only a very low horizontal wind of less than 6 knots, so that the updrafts refer at least a little bit to the soil below. Figure 8 shows a flight leg over coniferous forest and clearings in between, which at least has no positive correlation. But if a mean updraft and mean sensible heat flux over such a leg is formed, coniferous forests with clearings and additionally the airport itself has better thermals than the normal arable land of rye, wheat and maize. A correlation of the mean heat flux (mean over a leg

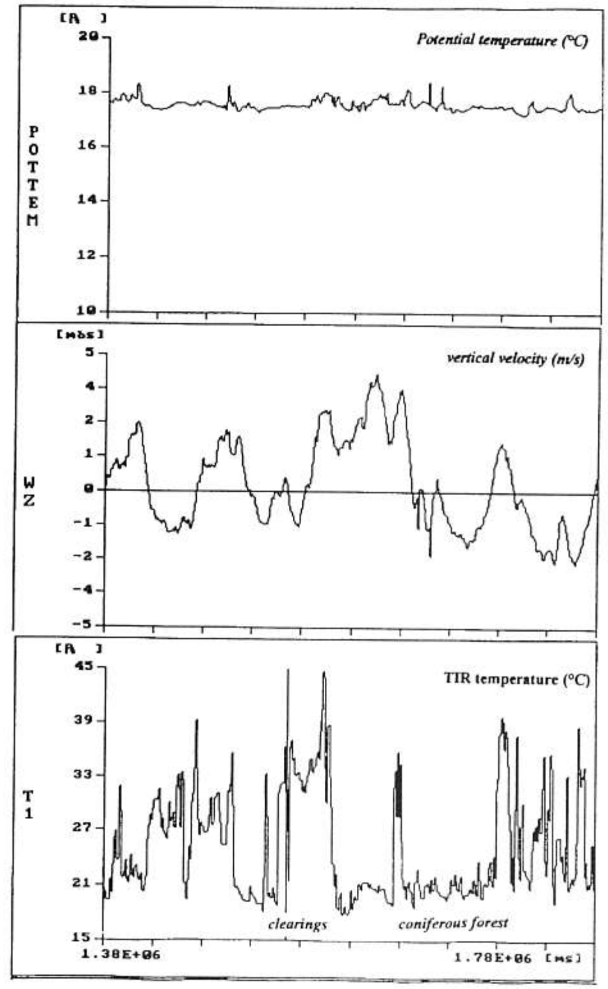

Figure 8. Quasi-horizontal flight legs over different kinds of soil and vegetation for vertical flux of sensible heat near Belzig, Germany on 17th of June, 1997 at 160 m GND.

length of about 5 kms) to the mean vegetation characteristics can be improved, if the vegetation TIR is correlated to a downwind leg parallel to the TIR leg. thus regarding the horizontal transport of bubbles by the wind.

Reasons for the low TIR temperatures over coniferous forests

As satellite and aircraft measurements have shown, the TIR temperatures are really low over coniferous forests. It must be taken into account, which spatial resolution is taken. For the NOAA satellite pictures the resolution is about 1 km, and for the aircraft image (Figure 1) about 5 - 8 m. The Heimann KT 19 aboard the motorglider has a resolution of about 10 m. Atmospheric corrections have not been performed in this stage of measurements. Due to the low altitude they seem not to be necessary.

Figure 9 (Lorenz, 1970) shows some temperature profiles through a spruce standing. The temperature increases from forest ground until the top of the trees, and is at the tops higher than the air temperature, which is a good indicator for buoyant thermal development.

From this stage of knowledge even if the density of standing of the trees within the detected forests is not known exactly, it must be regarded that the TIR sensor

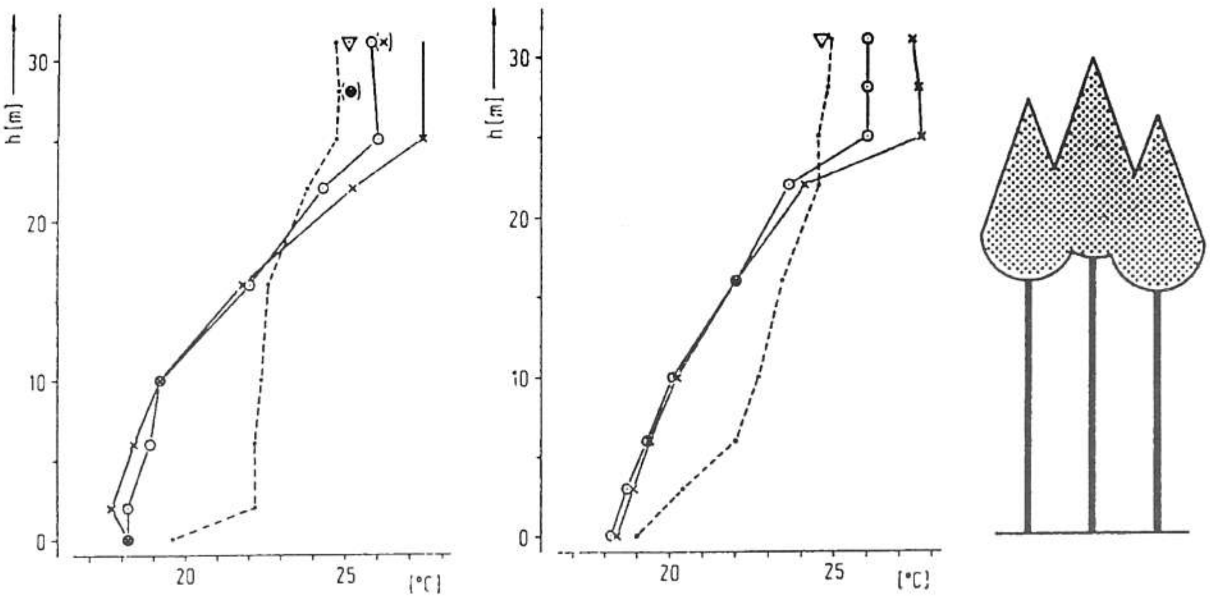

Figure 9. Profiles of surface temperature (TIR) (lines) and air temperature (dashed) in a spruce forest (Ebersberg)on 25th of September, 1967 after Lorenz at 13 local time.

primarily sees the cooler forest floors rather than the hotter forest tops.

Future work

An air temperature measurement within a pine forest stand must be made by a slow flying aircraft and/or a very high resolution TIR camera must be used to distinguish between tress and forest floor. For practical use, TIR pictures from satellite over known coniferous forests should not be used for thermal convection determination.

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