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UNIVERSITÀ DEGLI STUDI FIRENZE
DISPAA
DIPARTIMENTO DI SCIENZE DELLE PRODUZIONI AGROALIMENTARI E DELL'AMBIENTE

UNIVERSITÄT FÜR BODENKULTUR WIEN
BOKU
DEPARTMENT FÜR WASSER-ATMOSPHÄRE-UMWELT

EUROPEAN COMMISSION
Horizon 2020
EUROPEAN UNION FUNDING FOR RESEARCH & INNOVATION

Workshop 2018

SERBIA FOR EXCELL, WORKSHOP, 2018

Potential of photographs digitalization and thermal imaging for plant studies

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Introduction

- Research topics of Working group atmospheric radiation (BOKU)
  - Radiation modelling
  - Ground based remote sensing
  - Energy balance of streams
  - Urban energy balance modelling
  - 3-D radiation modelling and Ray Tracing

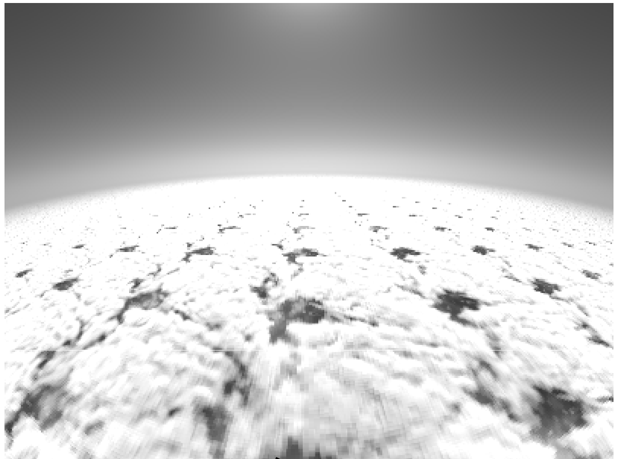
Potential of photographs digitalization and thermal imaging for plant studies

1. Introduction (Physical background, Methods)
2. Drought stress experiment
3. Analysis of webcam images for phenological studies
4. Combination of images with Ray Tracing modelling
5. Conclusion

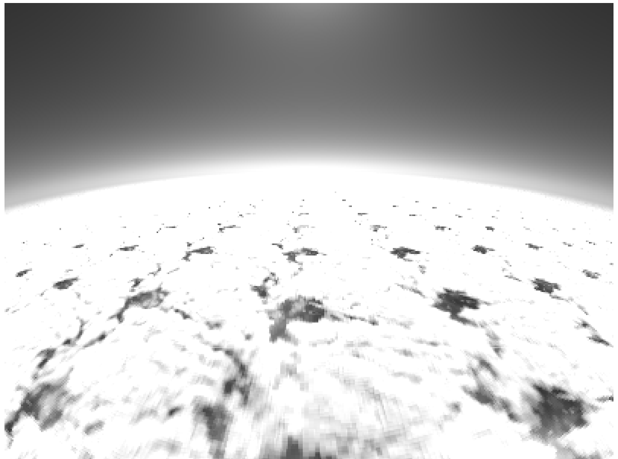
Creation of visible images (RGB red, green, blue principle)

1 Channel single color radiant intensity distribution

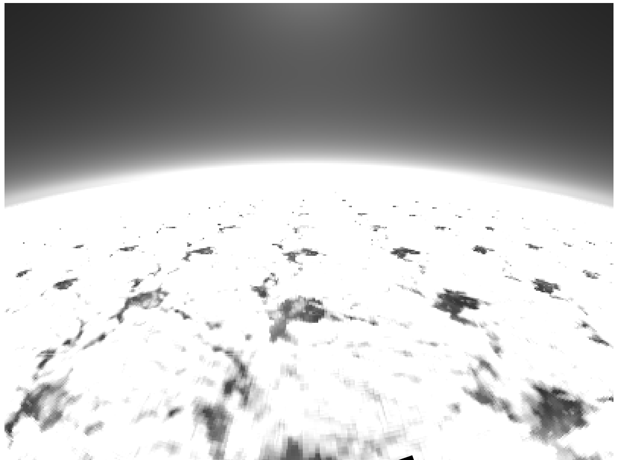
BLUE (0.45 μm)



GREEN (0.55μm)



RED (0.67μm)



Introduction

DIGITALIZATION OF PHOTOGRAPHS

BLUE CHANNEL (0.45 µm)

GREEN CHANNEL (0.55µm)

RED CHANNEL (0.67µm)

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Introduction

DIGITALIZATION OF PHOTOGRAPHS

PHOTOGRAPH BLUE (0.45 µm)

PHOTOGRAPH GREEN (0.55µm)

PHOTOGRAPH RED (0.67µm)

2. Drought stress experiment

Tomato plants (Solanum lycopersicum) with different types of water amount treatments

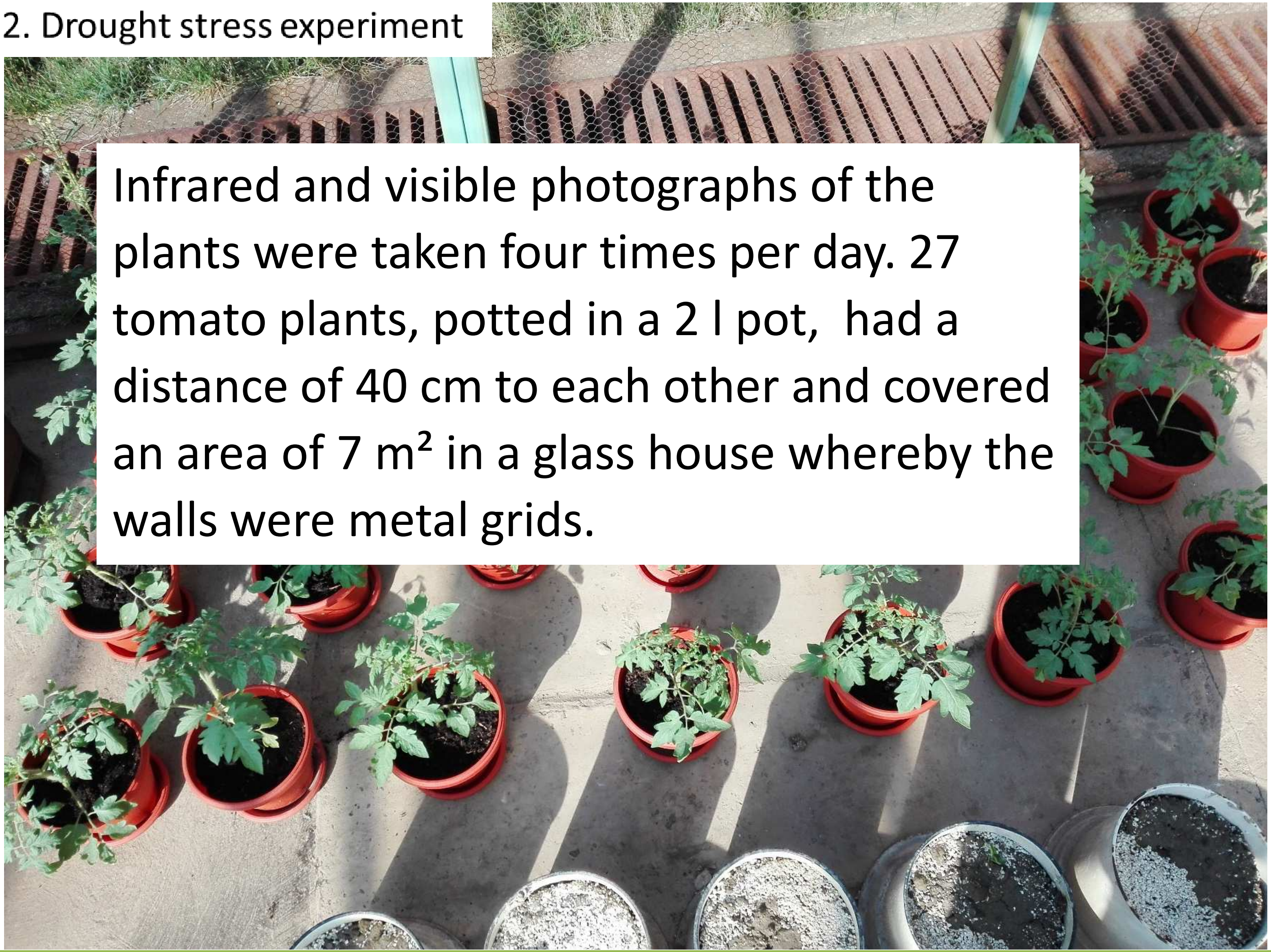
Treatment 1 (L1) well watered (900 ml/d)

Treatment 2 (L2) medium water stress (600 ml/d)

Treatment 3 (L3) strong water stress (300 ml/d).

Additionally extreme treatment level of no watering. Three plants in shade not watered for one day.

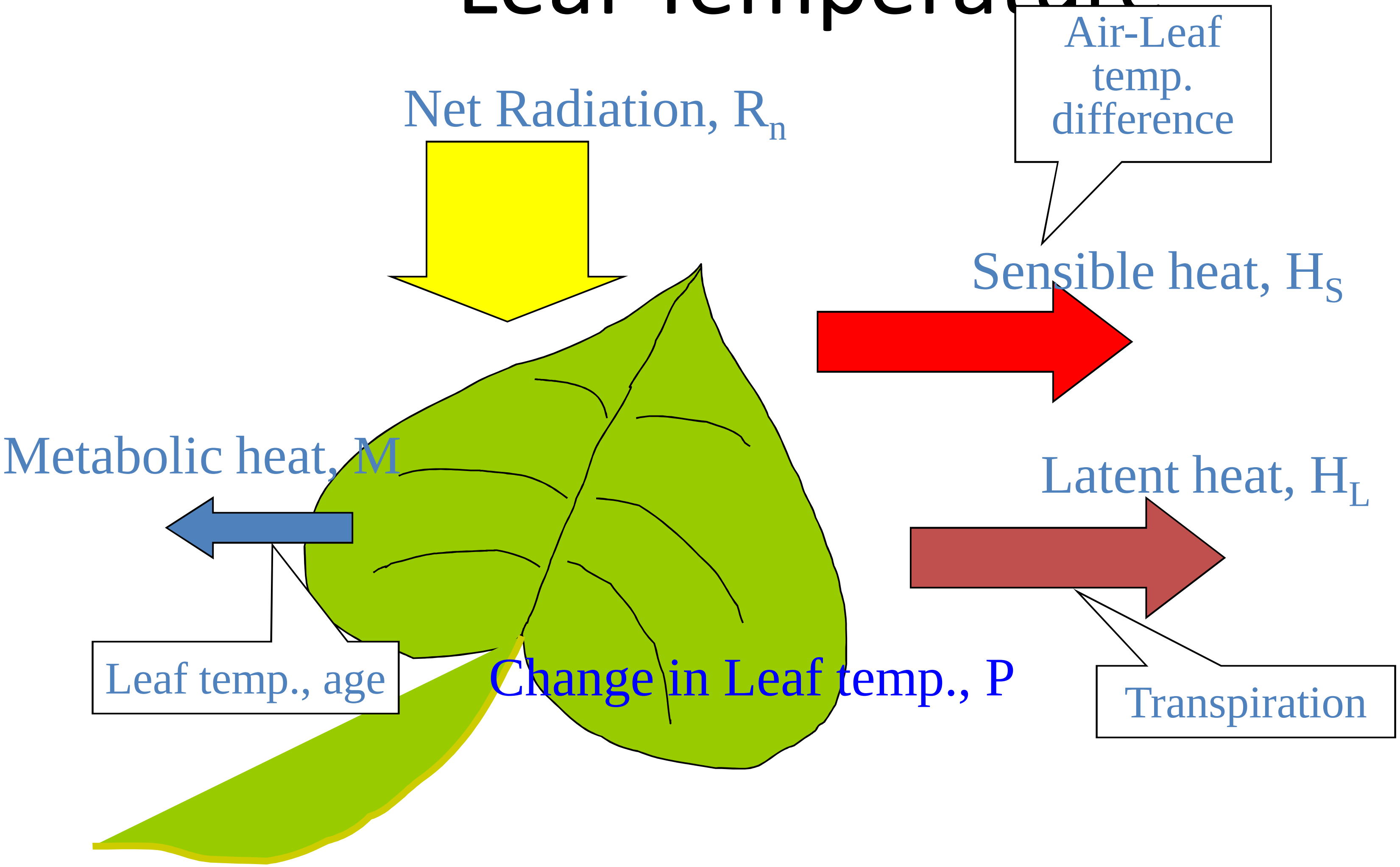
2. Drought stress experiment



Infrared and visible photographs of the plants were taken four times per day. 27 tomato plants, potted in a 2 l pot, had a distance of 40 cm to each other and covered an area of 7 m² in a glass house whereby the walls were metal grids.

A) Introduction: Thermal emission

Leaf Temperature



Balance $R_n + H_S + H_L$ + M + P = 0

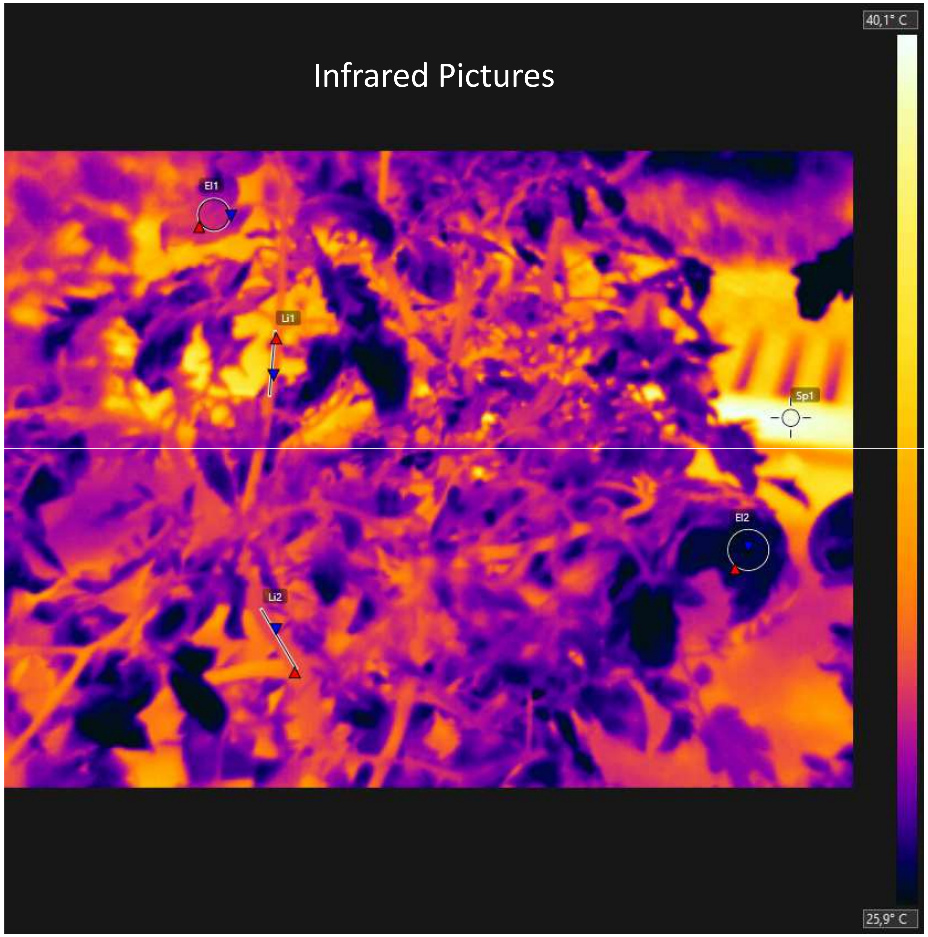
Introduction

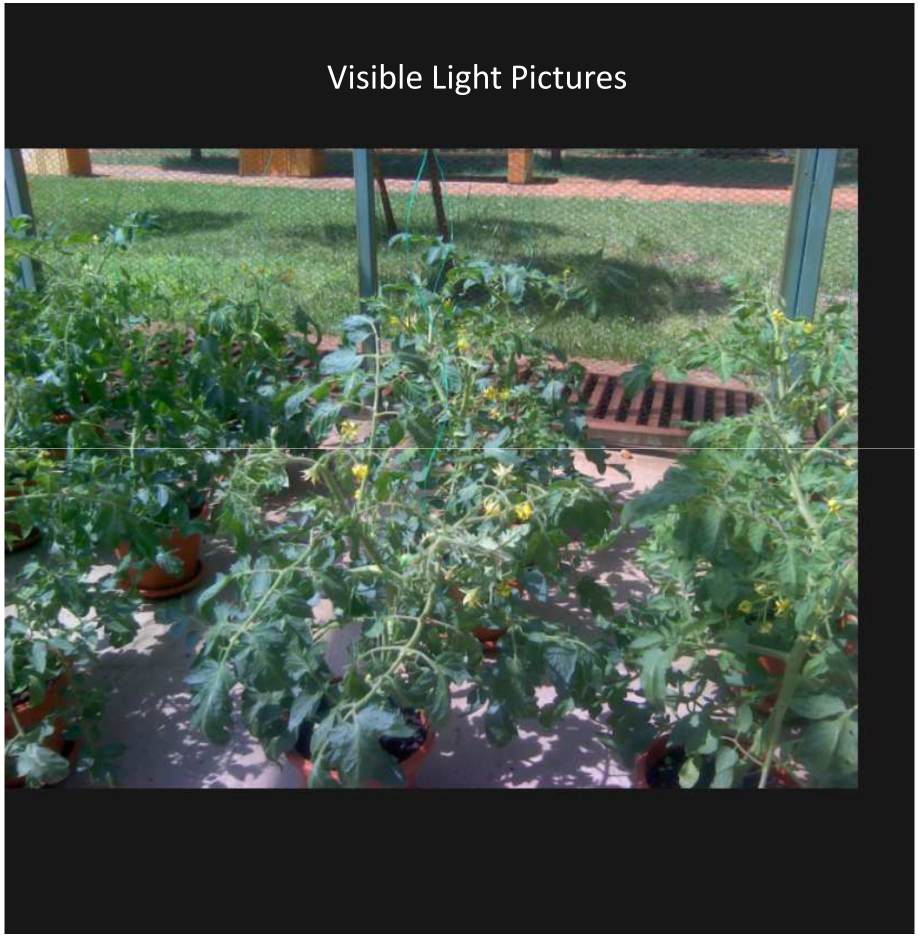
THERMAL INFRARED CAMERA

Measures Longwave emission of object
and calculates the surface temperature following
Stefan Boltzman law and assuming an
Emission coefficient of the object

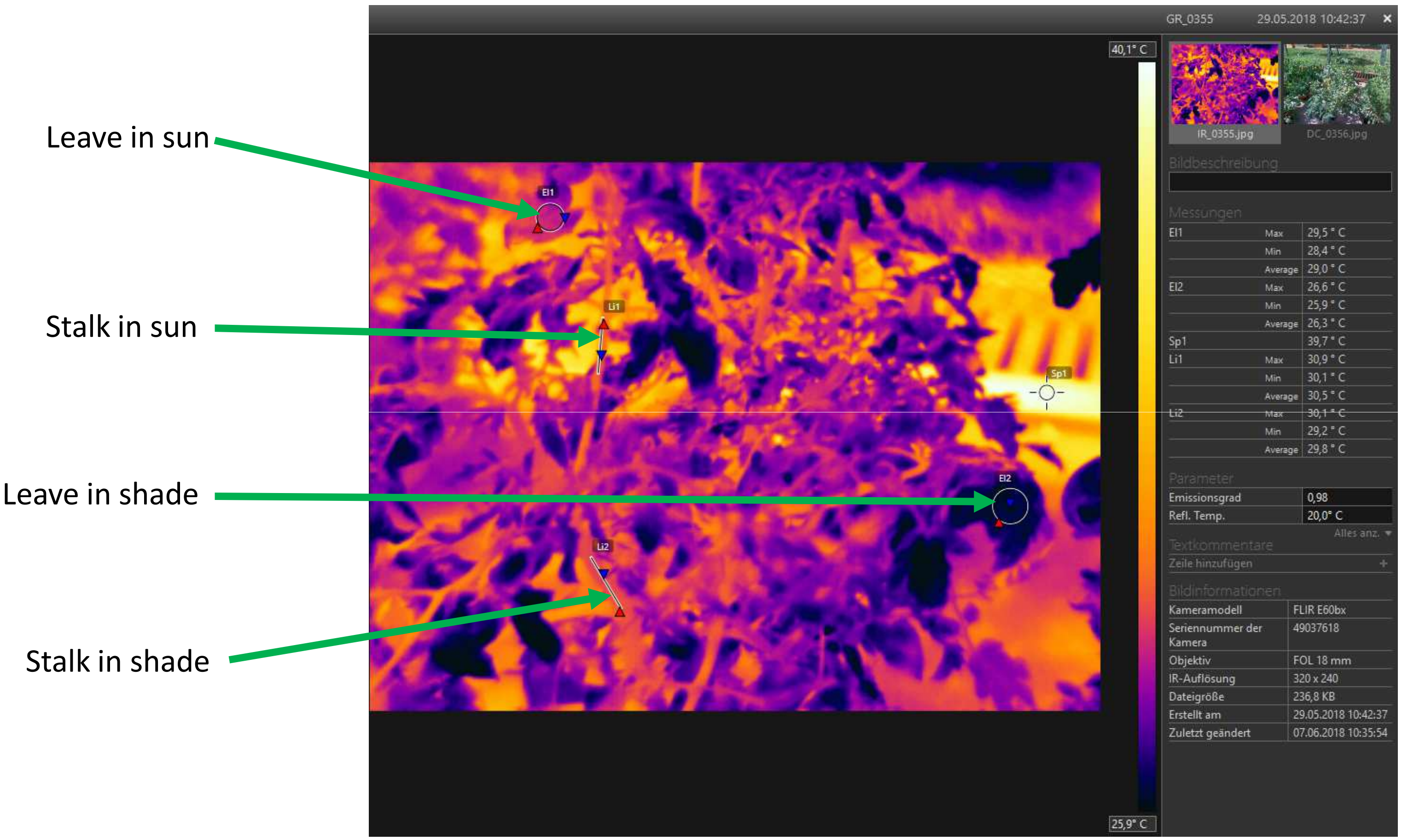
2. Drought stress experiment

MEASUREMENTS





2. Drought stress experiment



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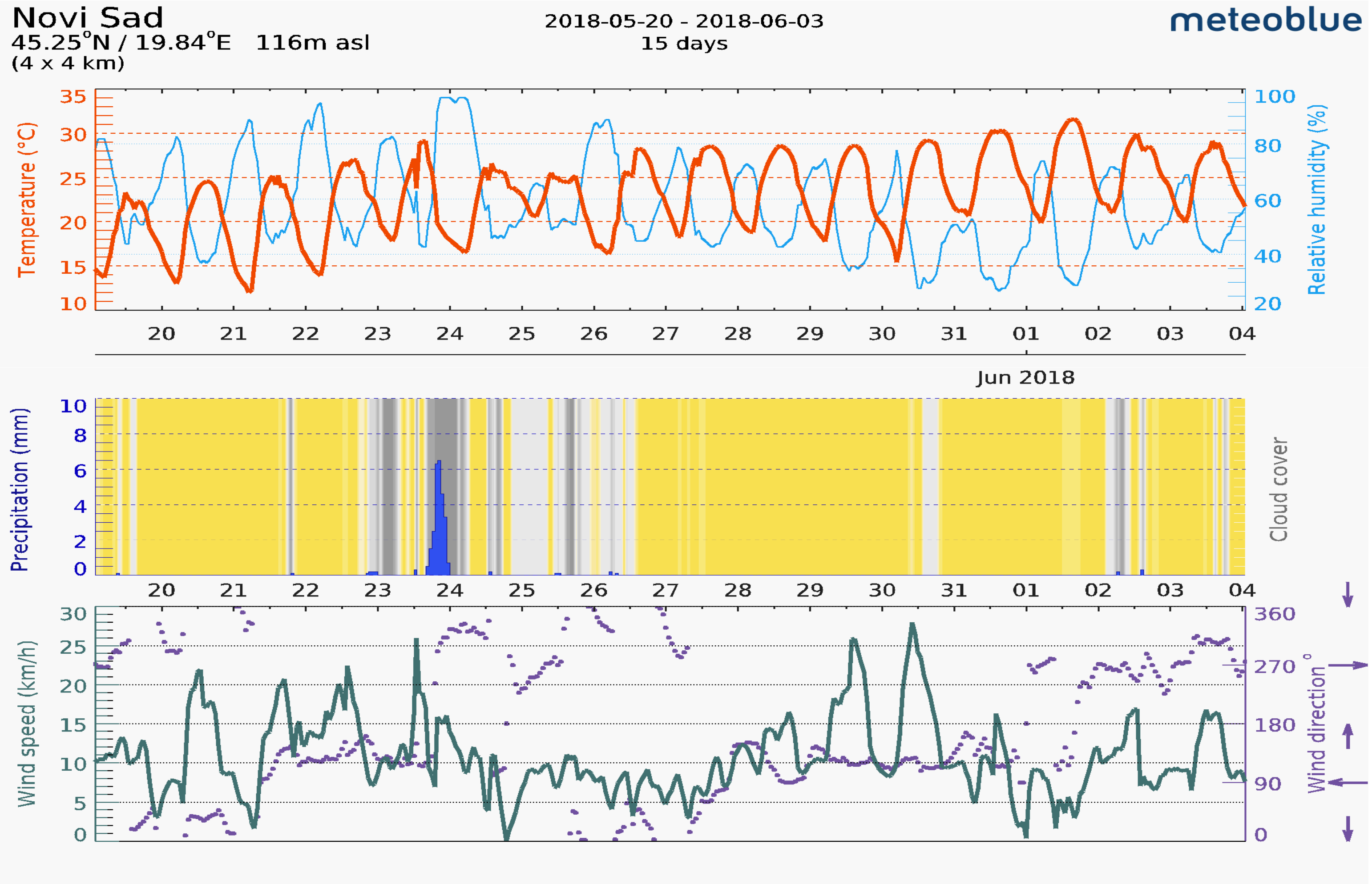
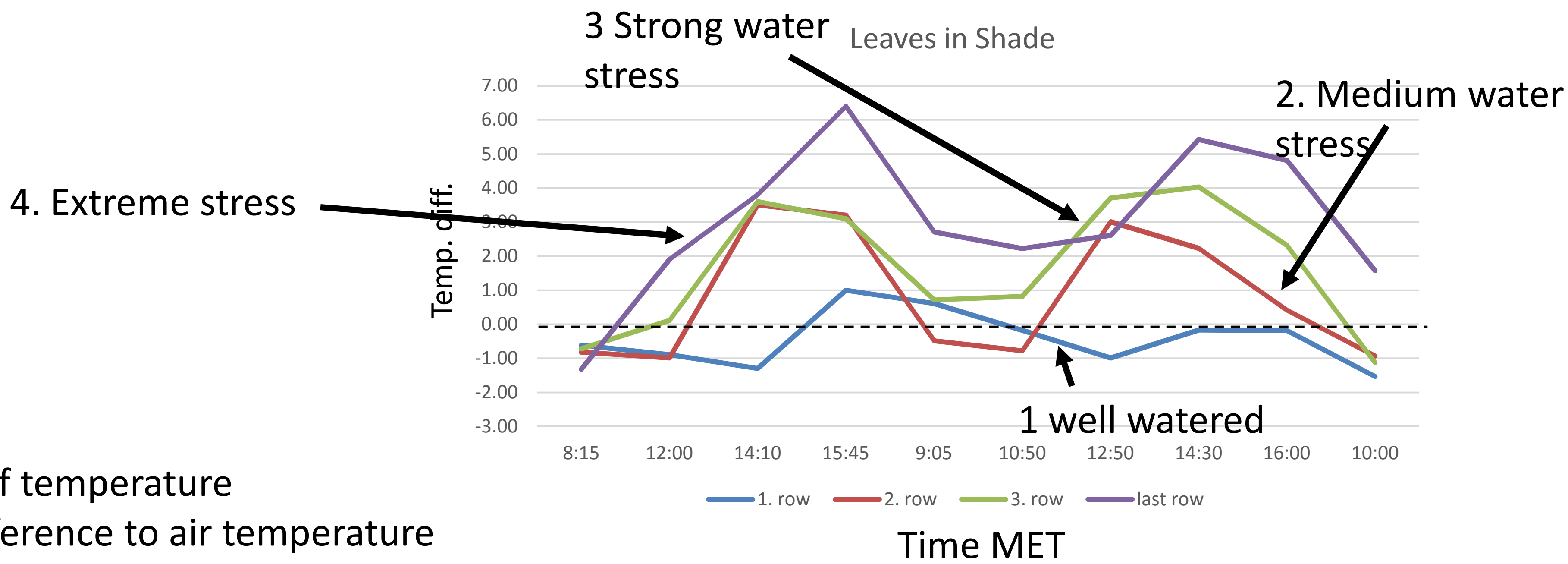
2. Drought stress experiment

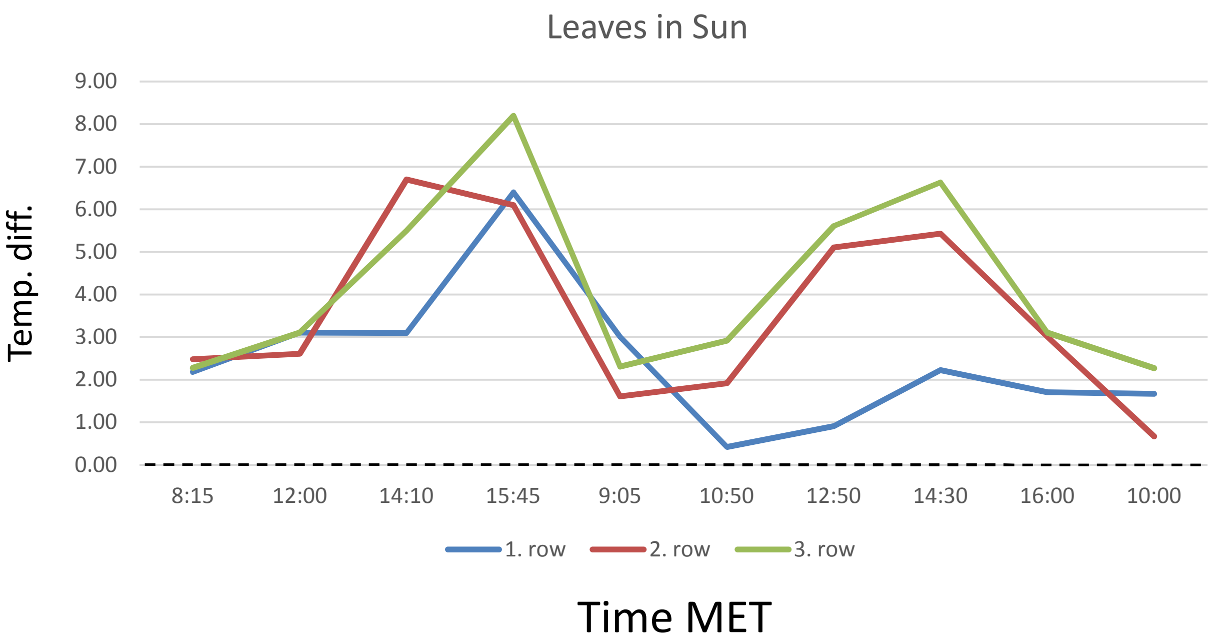
Compare the leaf temperature with air temperature



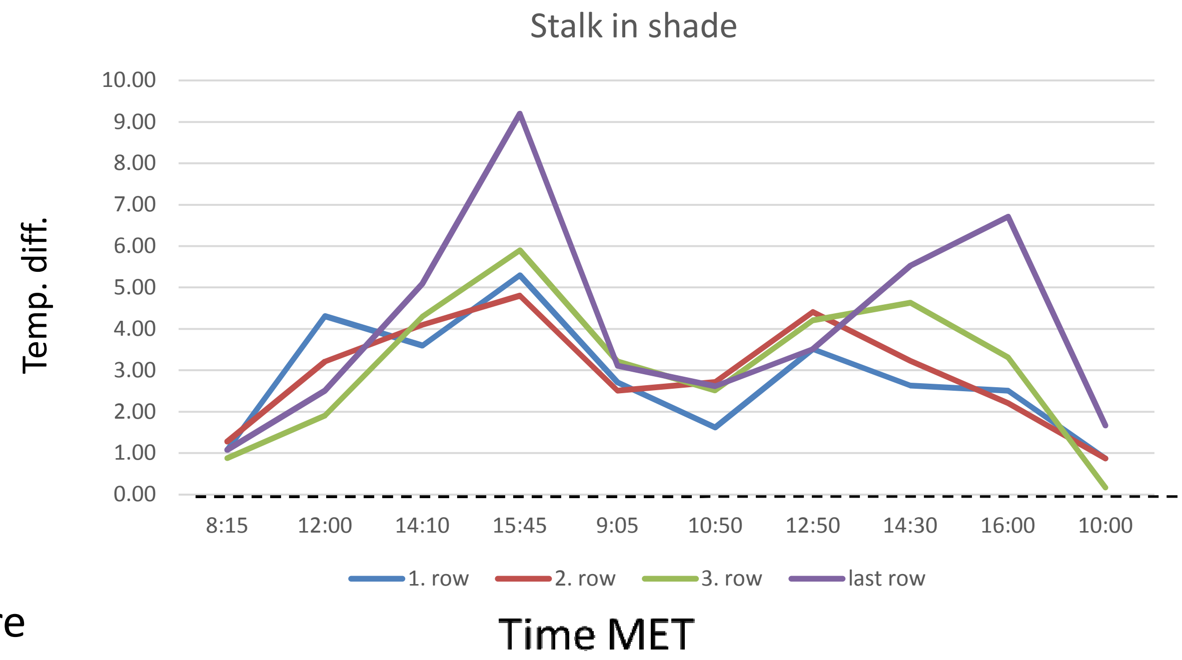
2. Drought stress experiment



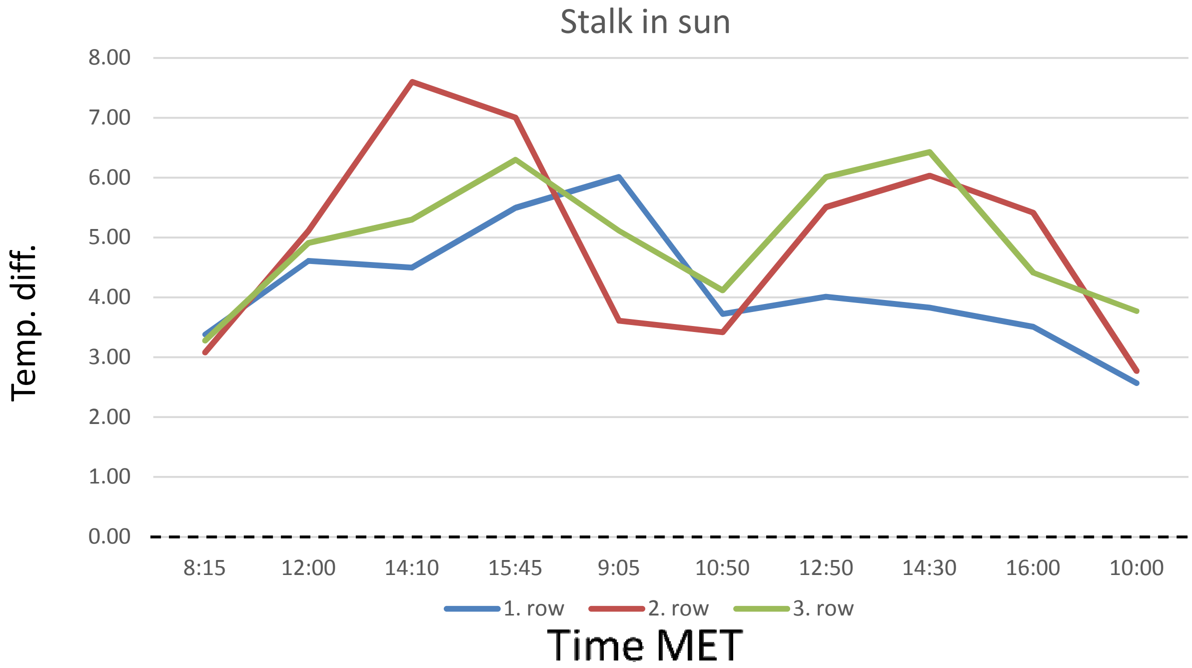
Leaf temperature
Difference to air temperature
leaf T. – air T.



2. Drought stress experiment



Stalk temperature
Difference to air temperature
stalk T. – air T.



2. Drought stress experiment

1 no stress, 2 moderate stress, 3 strong stress, 4 extreme

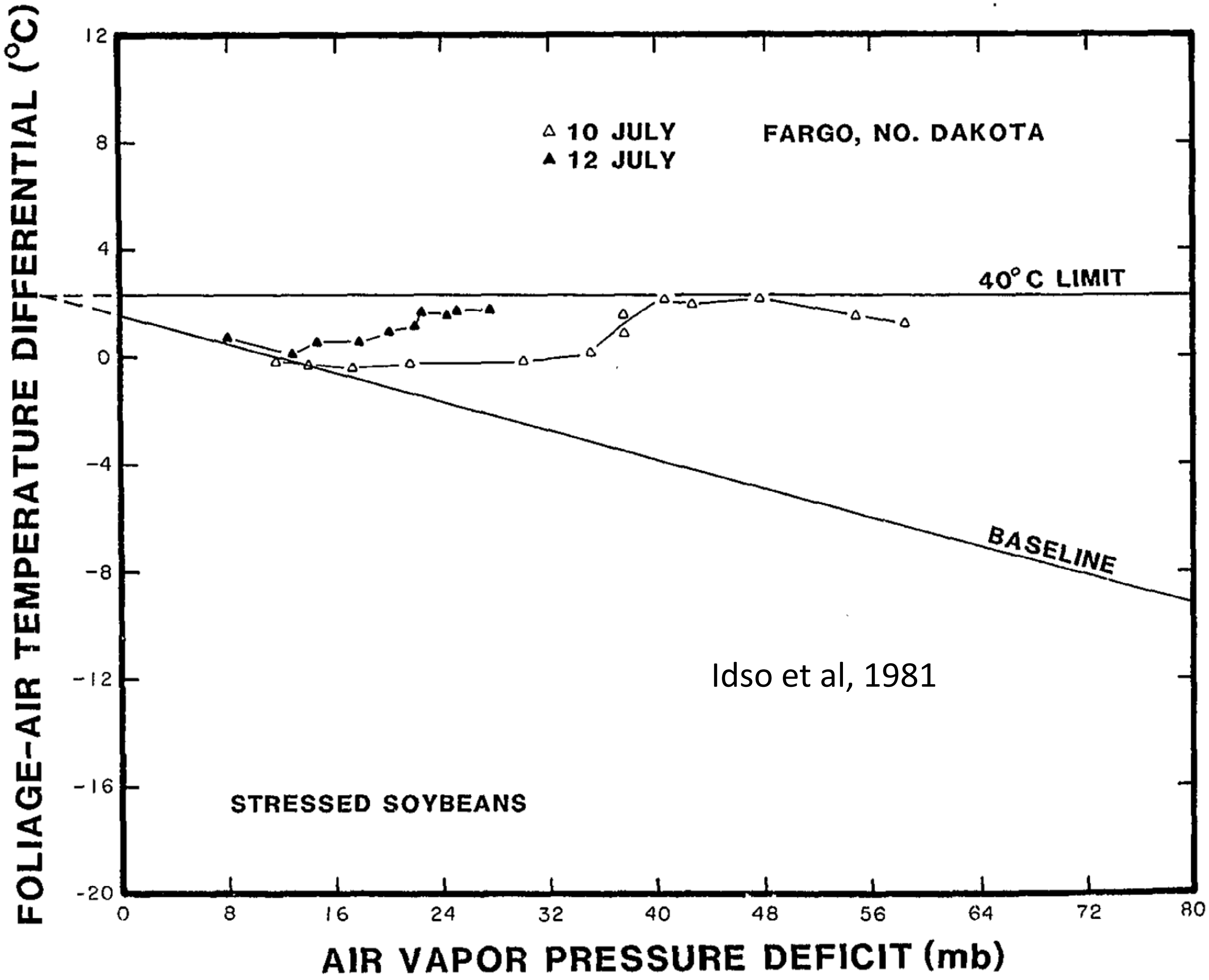
Leaf temp. – air temp

Leaves in shade				
Time [CEST]	1. row	2. row	3. row	last row
08:15	-0.62	-0.82	-0.72	-1.32
12:00	-0.89	-0.99	0.11	1.91
14:10	-1.30	3.50	3.60	3.80
15:45	1.00	3.20	3.10	6.40
09:05	0.61	-0.49	0.71	2.71
10:50	-0.18	-0.78	0.82	2.22
12:50	-0.99	3.01	3.71	2.61
14:30	-0.17	2.23	4.03	5.43
16:00	-0.19	0.41	2.31	4.81
10:00	-1.53	-0.93	-1.13	1.57
	-0.43	0.83	1.65	3.01

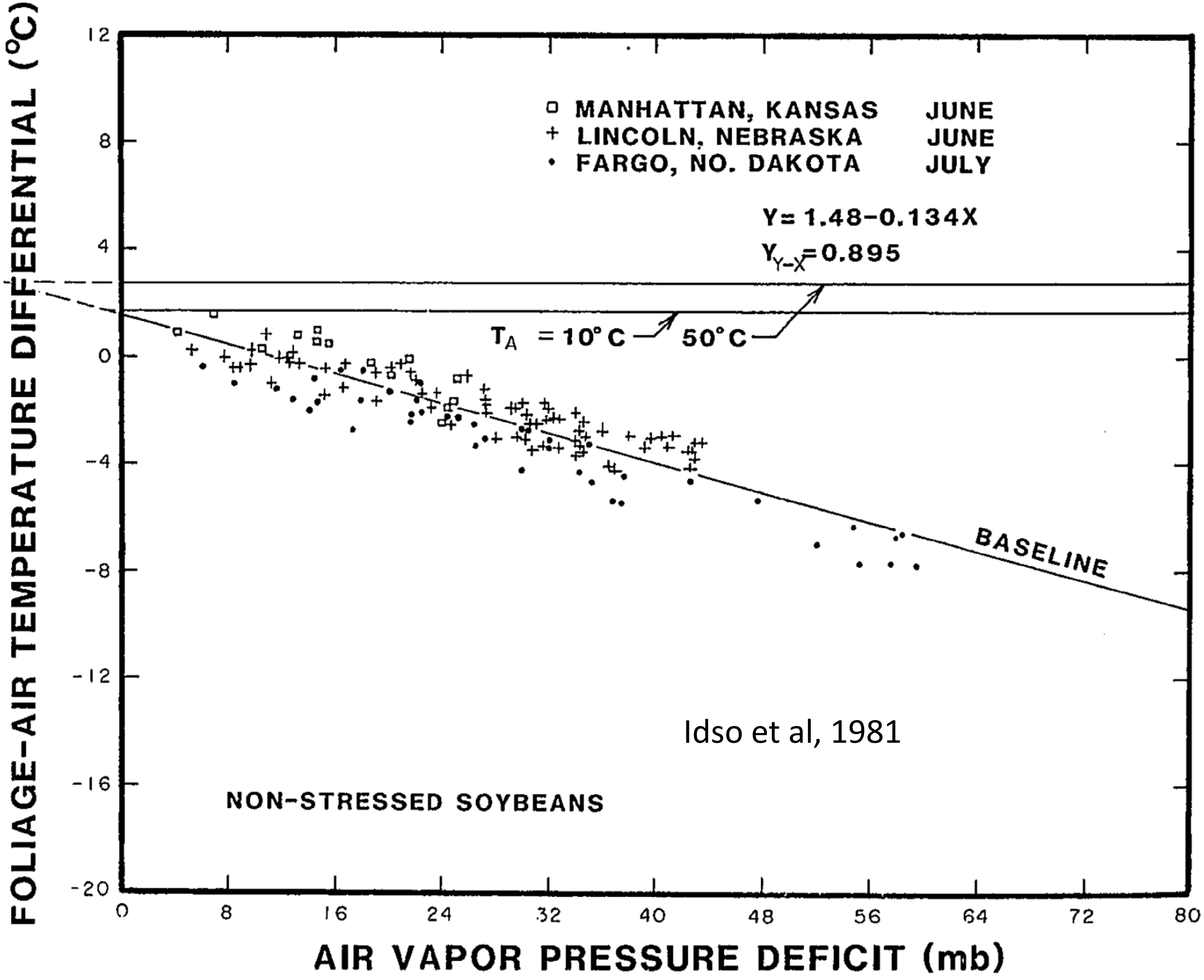
Leaves in sun			
Time [CEST]	1. row	2. row	3. row
08:15	2.18	2.48	2.28
12:00	3.11	2.61	3.11
14:10	3.10	6.70	5.50
15:45	6.40	6.10	8.20
09:05	3.01	1.61	2.31
10:50	0.42	1.92	2.92
12:50	0.91	5.11	5.61
14:30	2.23	5.43	6.63
16:00	1.71	3.01	3.11
10:00	1.67	0.67	2.27
	2.47	3.56	4.19

Stalk in shade				
Time [CEST]	1. row	2. row	3. row	last row
08:15	1.08	1.28	0.88	1.08
12:00	4.31	3.21	1.91	2.51
14:10	3.60	4.10	4.30	5.10
15:45	5.30	4.80	5.90	9.20
09:05	2.71	2.51	3.21	3.11
10:50	1.62	2.72	2.52	2.62
12:50	3.51	4.41	4.21	3.51
14:30	2.63	3.23	4.63	5.53
16:00	2.51	2.21	3.31	6.71
10:00	0.87	0.87	0.17	1.67
	2.81	2.93	3.10	4.10

Stalk in sun			
Time [CEST]	1. row	2. row	3. row
08:15	3.38	3.08	3.28
12:00	4.61	5.11	4.91
14:10	4.50	7.60	5.30
15:45	5.50	7.00	6.30
09:05	6.01	3.61	5.11
10:50	3.72	3.42	4.12
12:50	4.01	5.51	6.01
14:30	3.83	6.03	6.43
16:00	3.51	5.41	4.41
10:00	2.57	2.77	3.77
	4.16	4.95	4.96



Idso et al, 1981



Idso et al, 1981

2. Drought stress experiment

Energy balance equation + Peymann Monteith equation

$$T_o - T_a = \frac{r_a}{\rho_a c_p} \frac{(R_n - G)\gamma(1 + r_s/r_a)}{\Delta + \gamma(1 + r_s/r_a)} - \frac{\mathrm{VPD}}{\Delta + \gamma(1 + r_s/r_a)}$$

T_o = Temperature at the surface level (°C)
T_a = Air temperature (°C)
r_a = aerodynamic resistance (s/m)
r_s = surface resistance (s/m)
R_n = Net radiation (W/m²)
G = Soil heat flux (W/m²)
ρ_a = air density (kg/m³)
c_p = specific heat at constant pressure (J./(kg.°C))
γ = psychrometric constant (Pa/°C)
Δ = slope of the saturated vapour pressure vs. Temperature curve (Pa/°C)
VPD = vapour pressure deficit at the reference level (Pa)

2. Drought stress experiment

Usually lower baseline (fully watered crop)

$$T_o - T_a = a - b\,\mathrm{VPD}$$

Upper baseline (drought stressed crop: stomata closed)

$$T_o - T_a = \frac{r_a}{\rho_a c_p}(R_n - G) = a'$$

T_o = Temperature at the surface level (°C)

T_a = Air temperature (°C)

VPD = vapour pressure deficit at the reference level (Pa)

R_n = Net radiation (W/m^2)

G = Soil heat flux (W/m^2)

ρ_a = air density (kg/m^3)

c_p = specific heat at constant pressure (J./(kg.°C))

CWSI Crop Water Stress Index

Calculation:

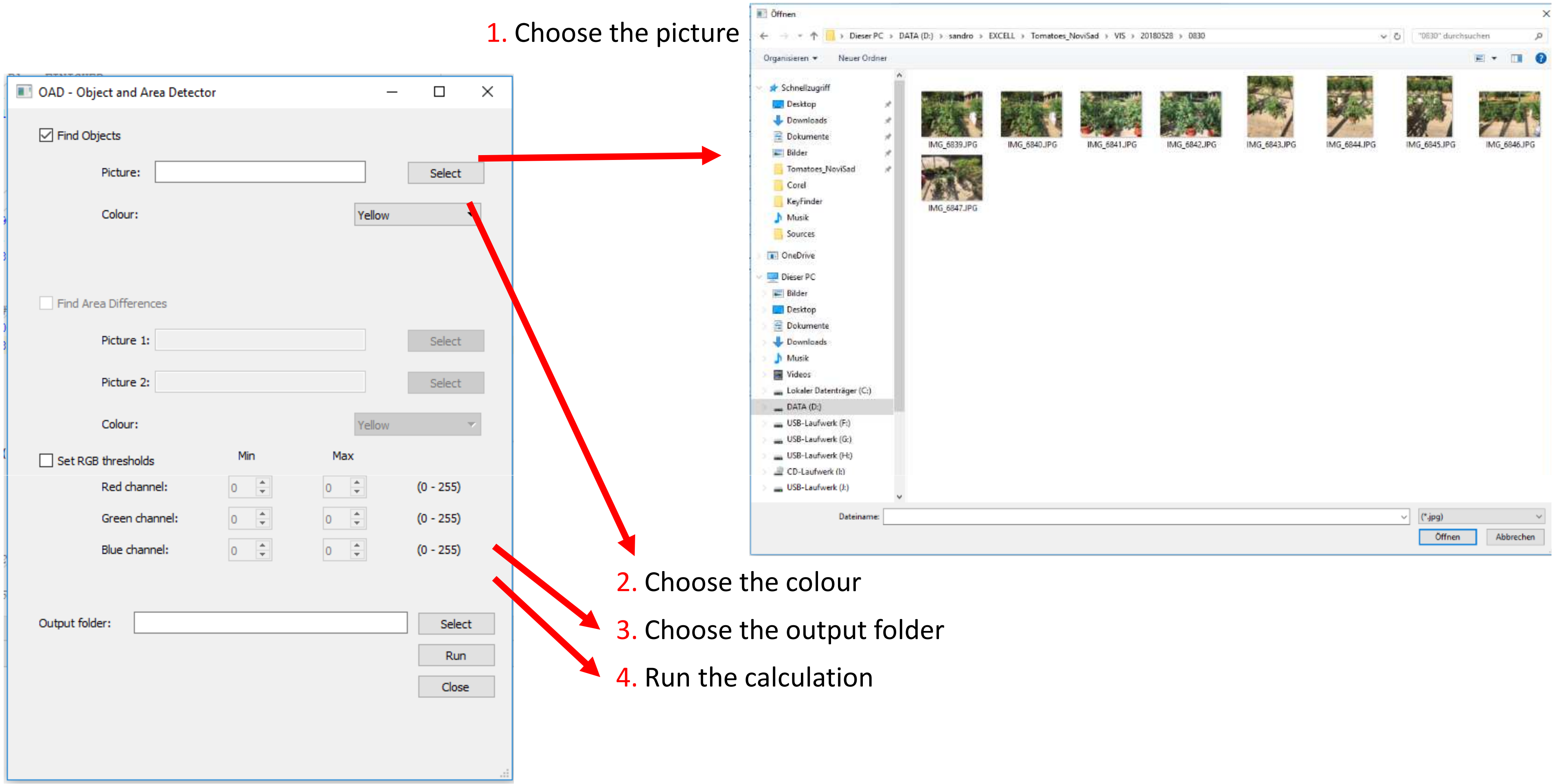
CWSI = [(Ts – Ta) – D2] / (D1 – D2)

- Ts: canopy temperature
- Ta: air temperature
- D1: max difference of plant temp (Ts) and air temp (Ta) (e.g. +3 °C)
- D2 = A + B* AVPD (AVPD: Atmospheric vapour pressure deficit)

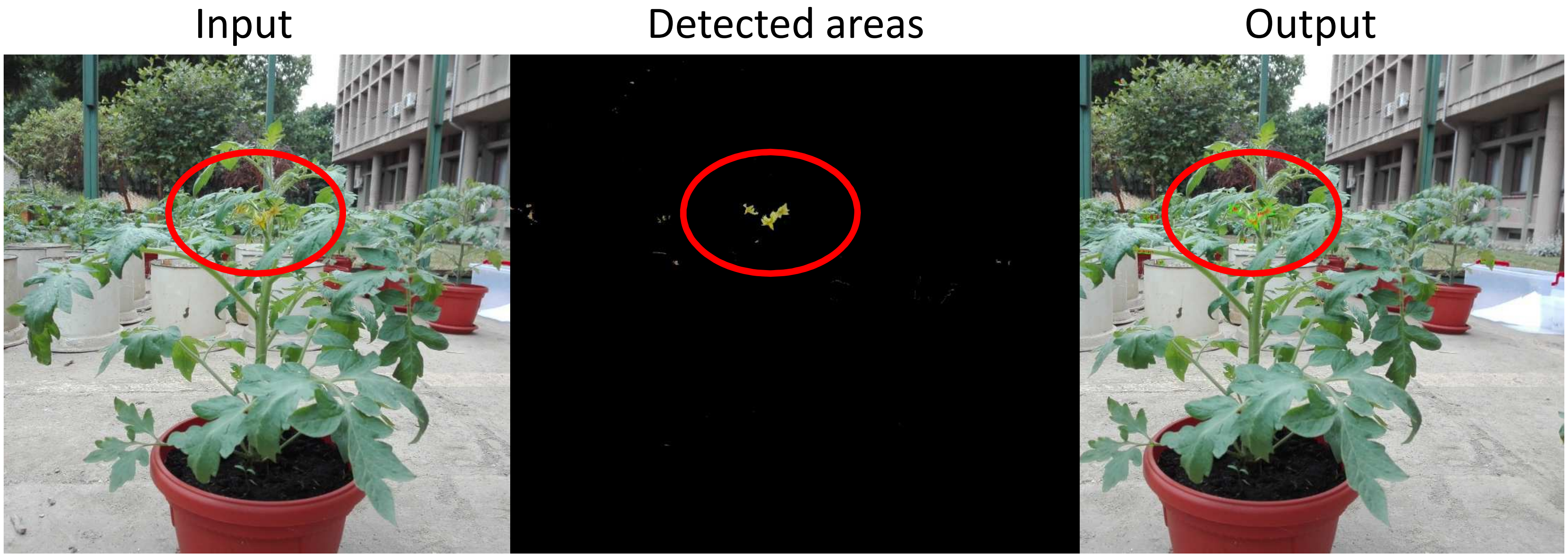
<u>Conditions for measuring canopy temperature</u>:

- ✓ optimal time: at noon – crop is experiencing maximum diurnal stress levels
- ✓ cloudless days: changes of solar radiation intensity cause fluctuation of temp three times higher then soil water changes (*Roth et al. 2004)*
- ✓ density of plants: at vegetative growth still influence of soil temp.!!

2. Drought stress experiment



2. Drought stress experiment



Further calculations to detect plant stress

Last row – 28.5.

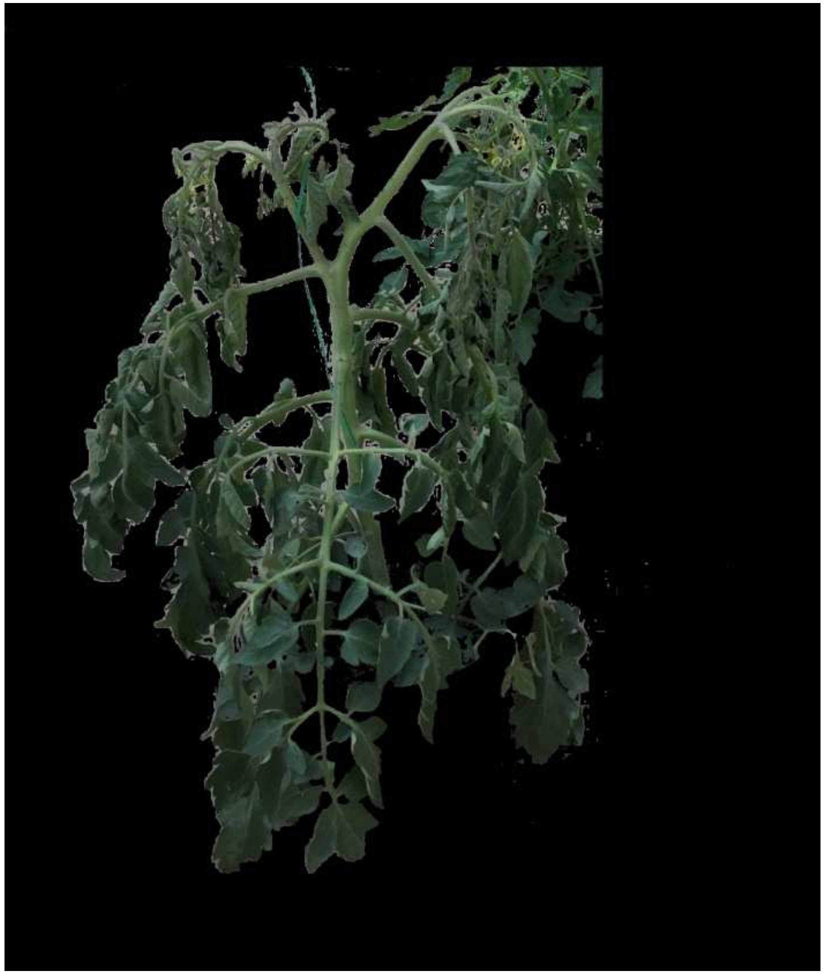
Last row – 29.5.

2. Drought stress experiment

Detect green colour

Last row – 28.5.

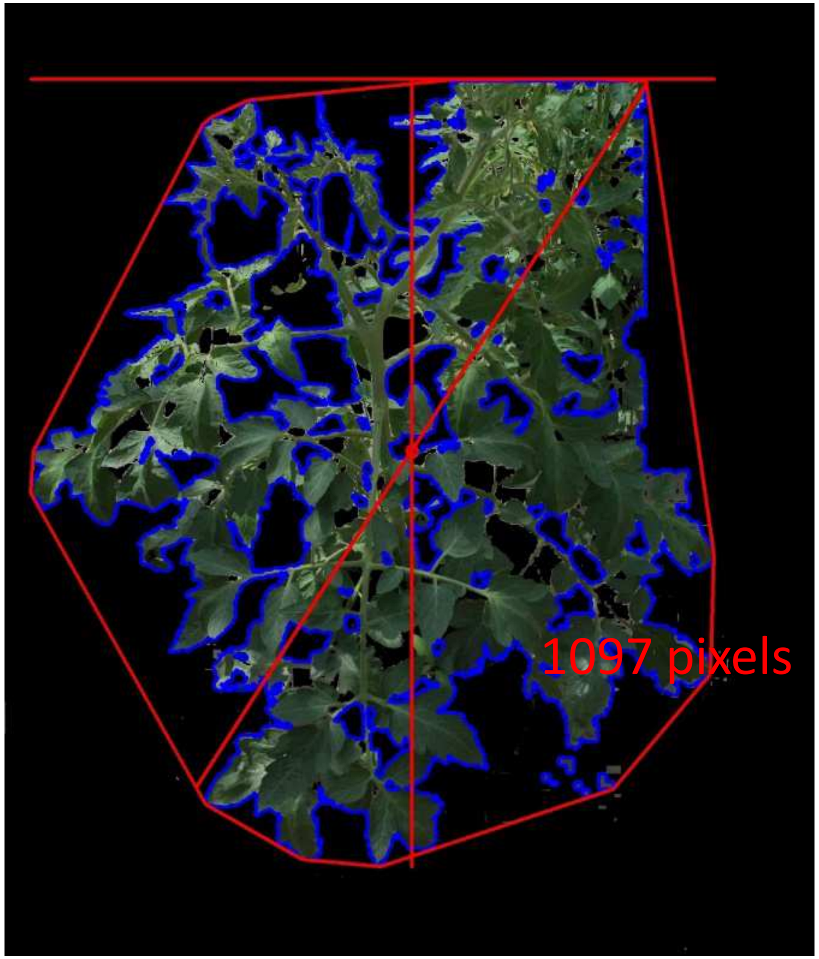
Last row – 29.5.



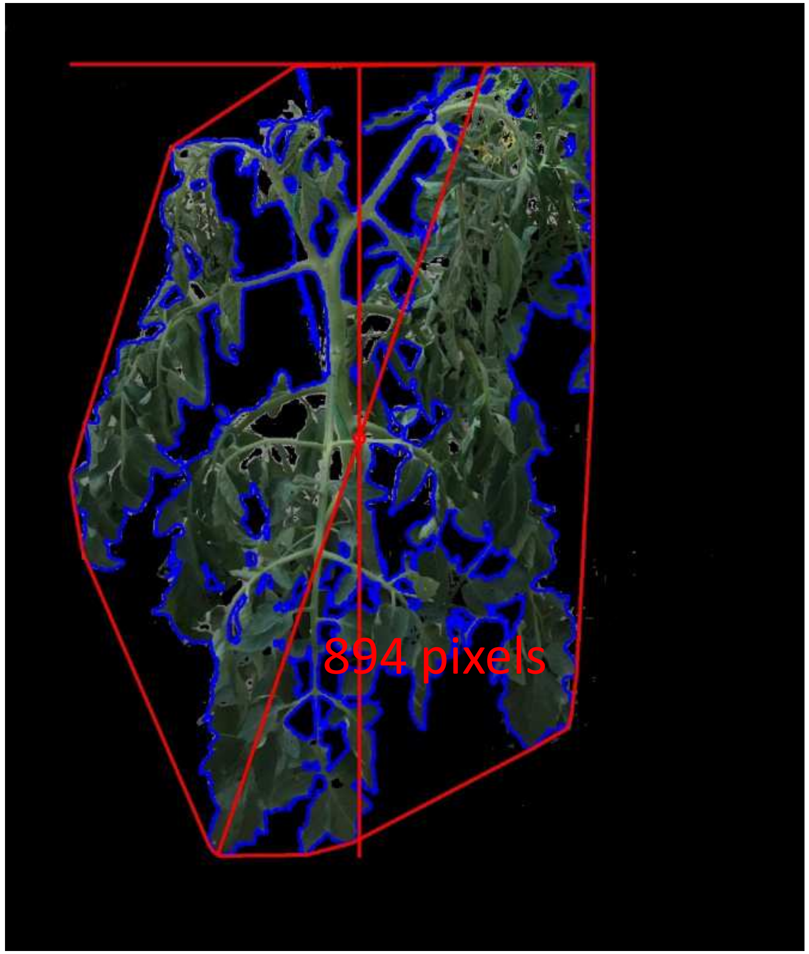
2. Drought stress experiment

Calculate center of plant and the minor axis of the ellipse (red) using plantCV software (Gehan et al., 2017)

Last row – 28.5.



Last row – 29.5.



2. Drought stress experiment

Possible next steps for drought stress experiment:

- Accuracy of thermal IR camera??

- Test the PlantCV software for other plants

3. Analysis of webcam images for phenological studies

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3. Analysis of webcam images for phenological studies

p1


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www.wachauermarille.at
Wachauer Marille - Webcam 06.04.2018 13:01
+0.0°C 0%
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HD Webcams

Slide 30

p1 philipp, 26/06/2018


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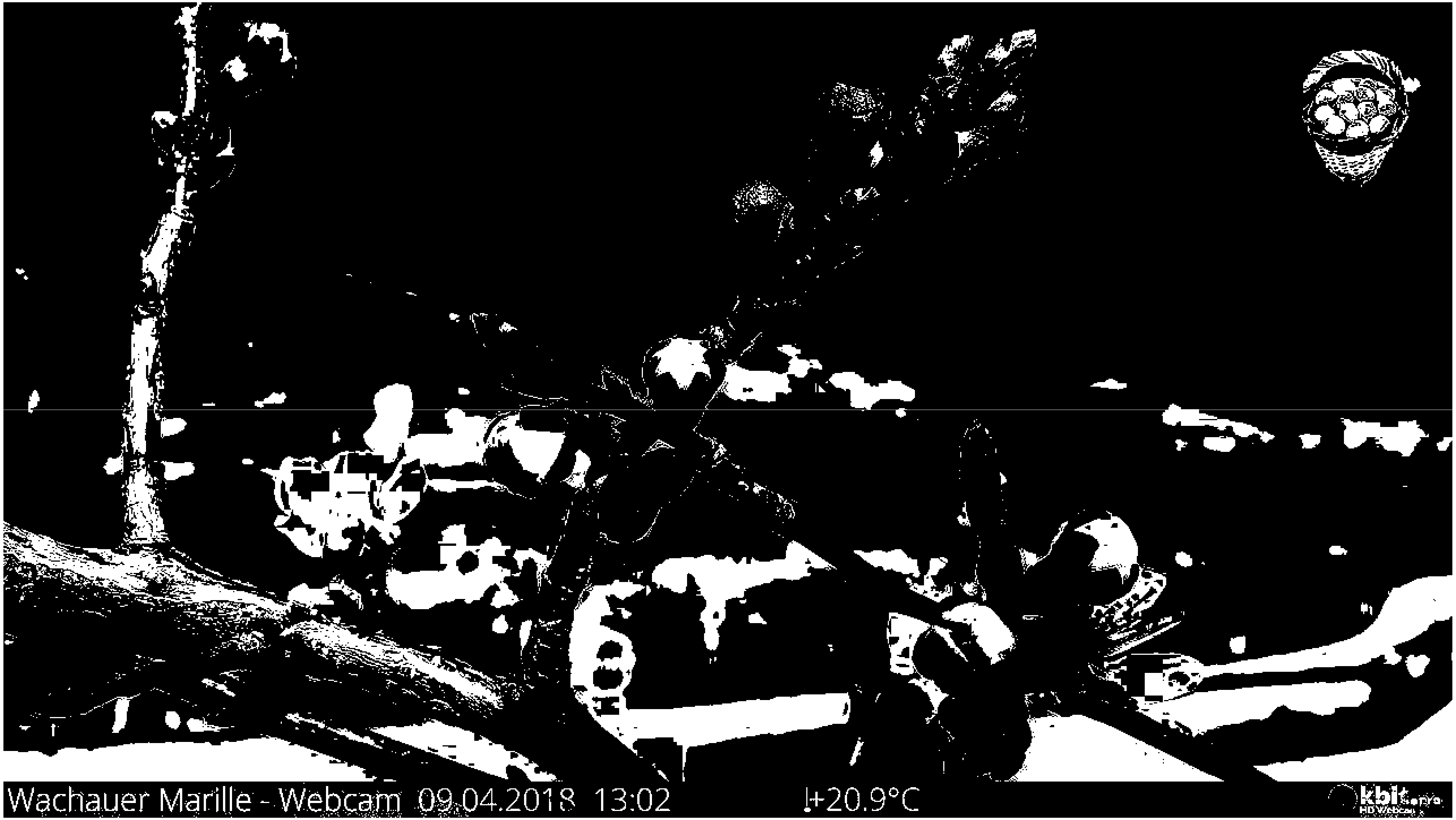
HD Webcams

Threshold = 130

Threshhold = 150

Threshold = 150, remove blue sky

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Threshold = 130


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+26.3°C
kbit.pro
HD Webcams


Wachauer Marille - Webcam 09.04.2018 16:02
+26.3°C

3. Analysis of webcam images for phenological studies

Next steps:

Problems with scene illumination: test different correction algorithms (e.g. Sonnentag et al., 2012)

Pixel(R,G,B) = > Pixel (R*3*255/T, G*3*255/T, B*3*255/T)

Where T = R + G + B
R = pixel in red channel (1 – 255)
G = pixel in green channel (1 – 255)
B = pixel in blue channel (1 – 255)

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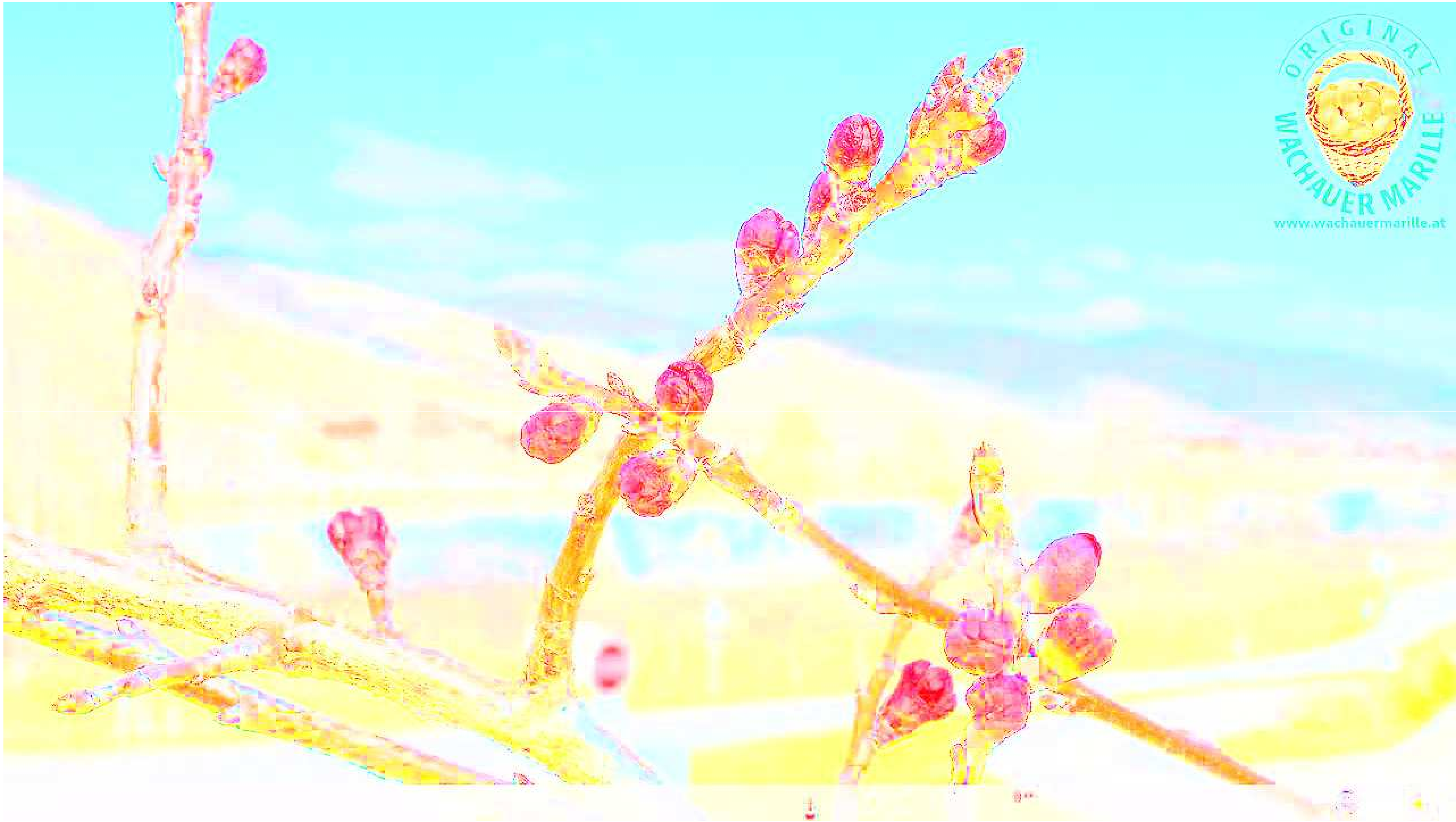

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4. Combination of images with Ray Tracing modelling

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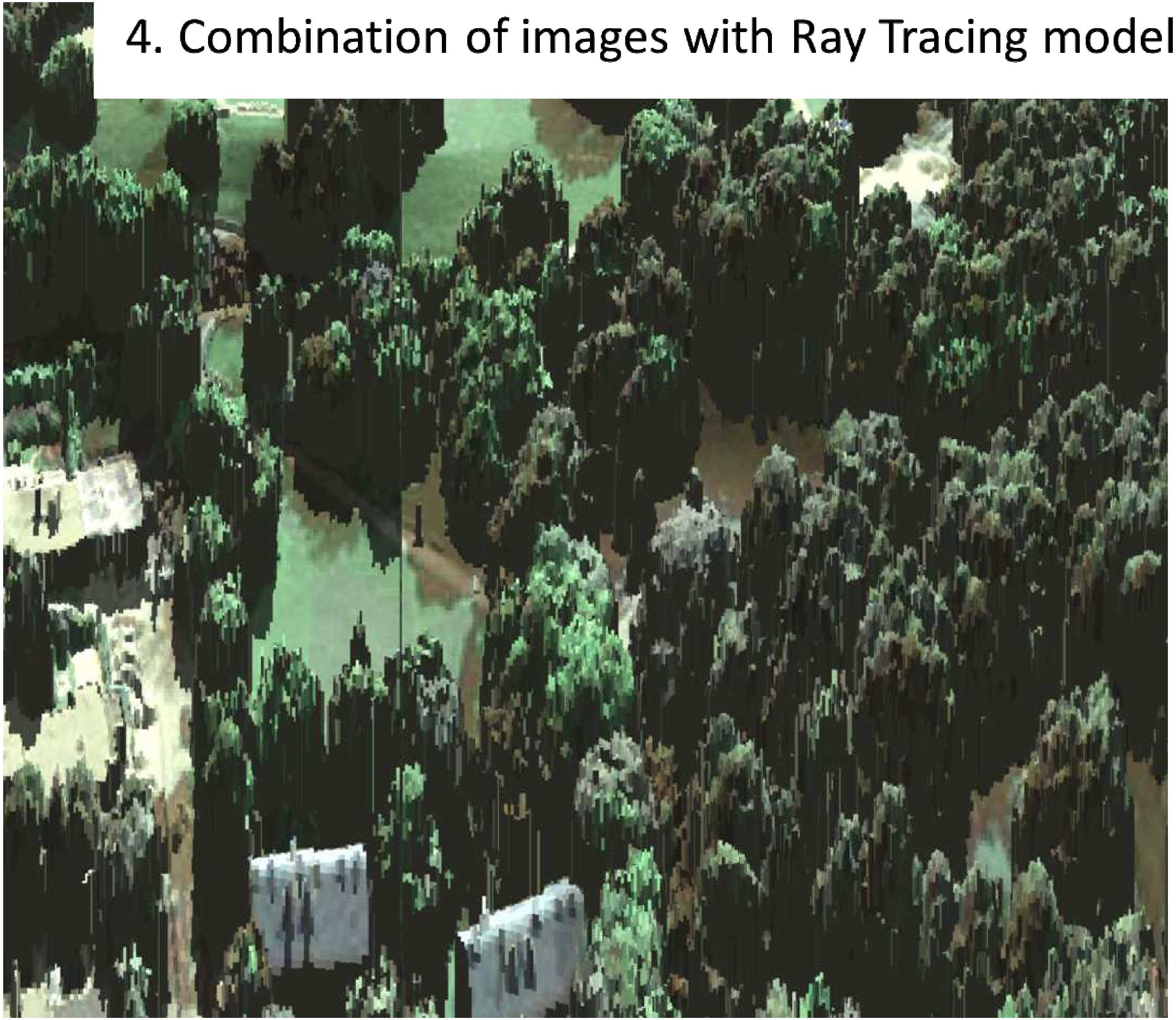


4. Combination of images with Ray Tracing modelling

Calculation of reflected radiance towards observer in the red, green, blue channels:

- 50 cm digital elevation map of Vienna
- Reflectance in red, green and blue at the respective pixels

↓

Radiation model which calculates incident radiation and reflected radiance towards observer => ground reflectance field

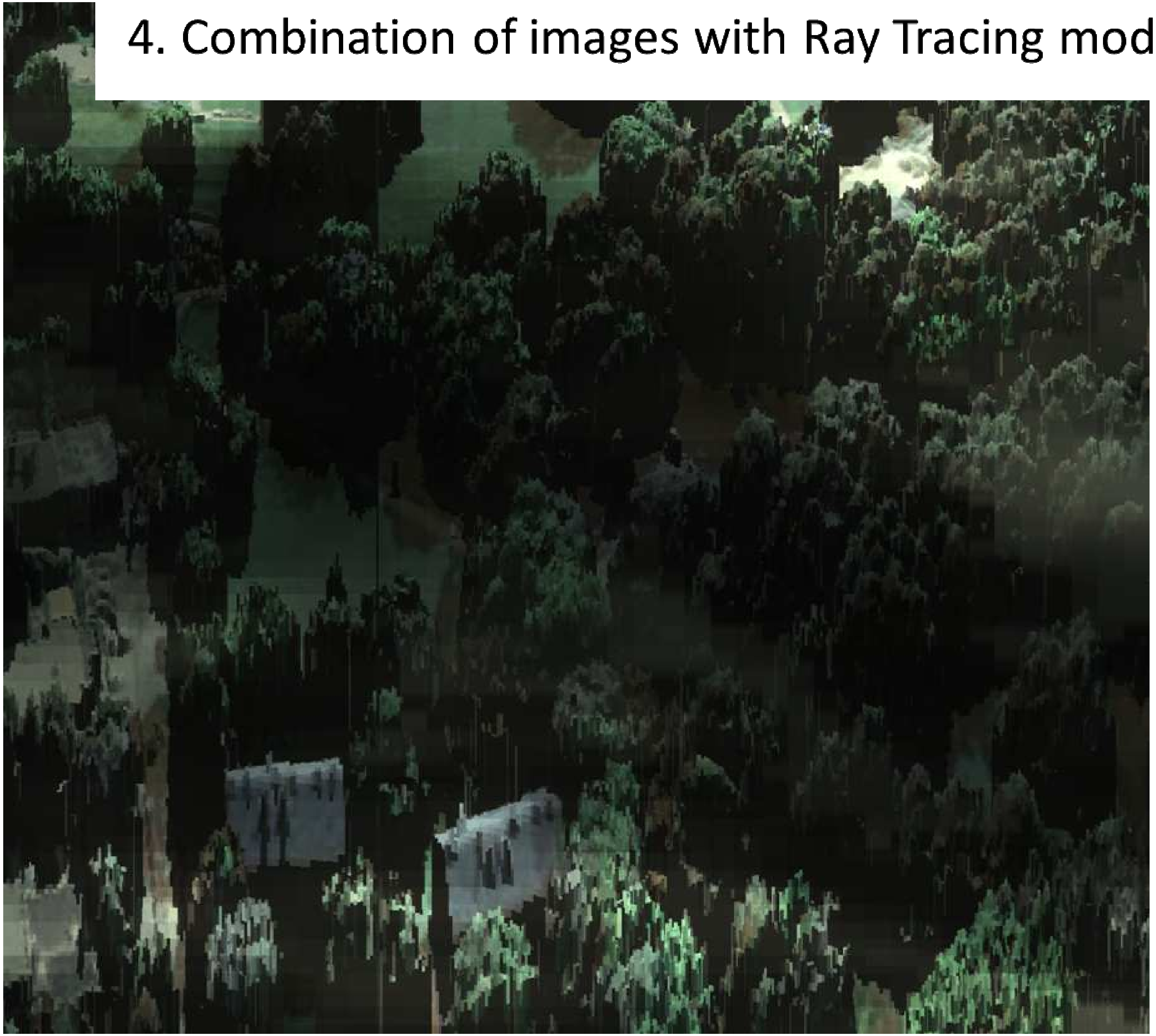
↓

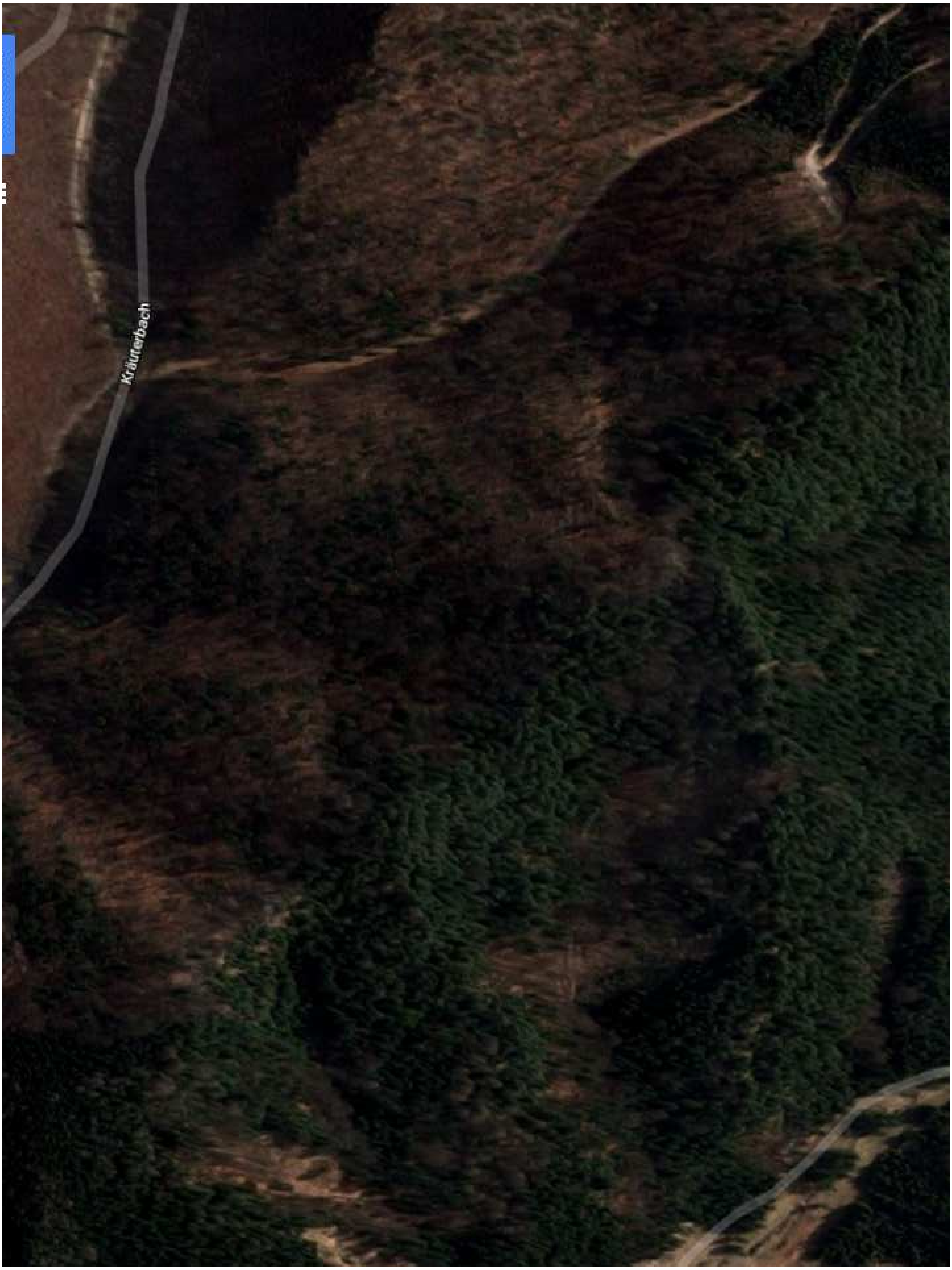
Radiative transfer model (Ray Tracing) which takes atmospheric effects into account

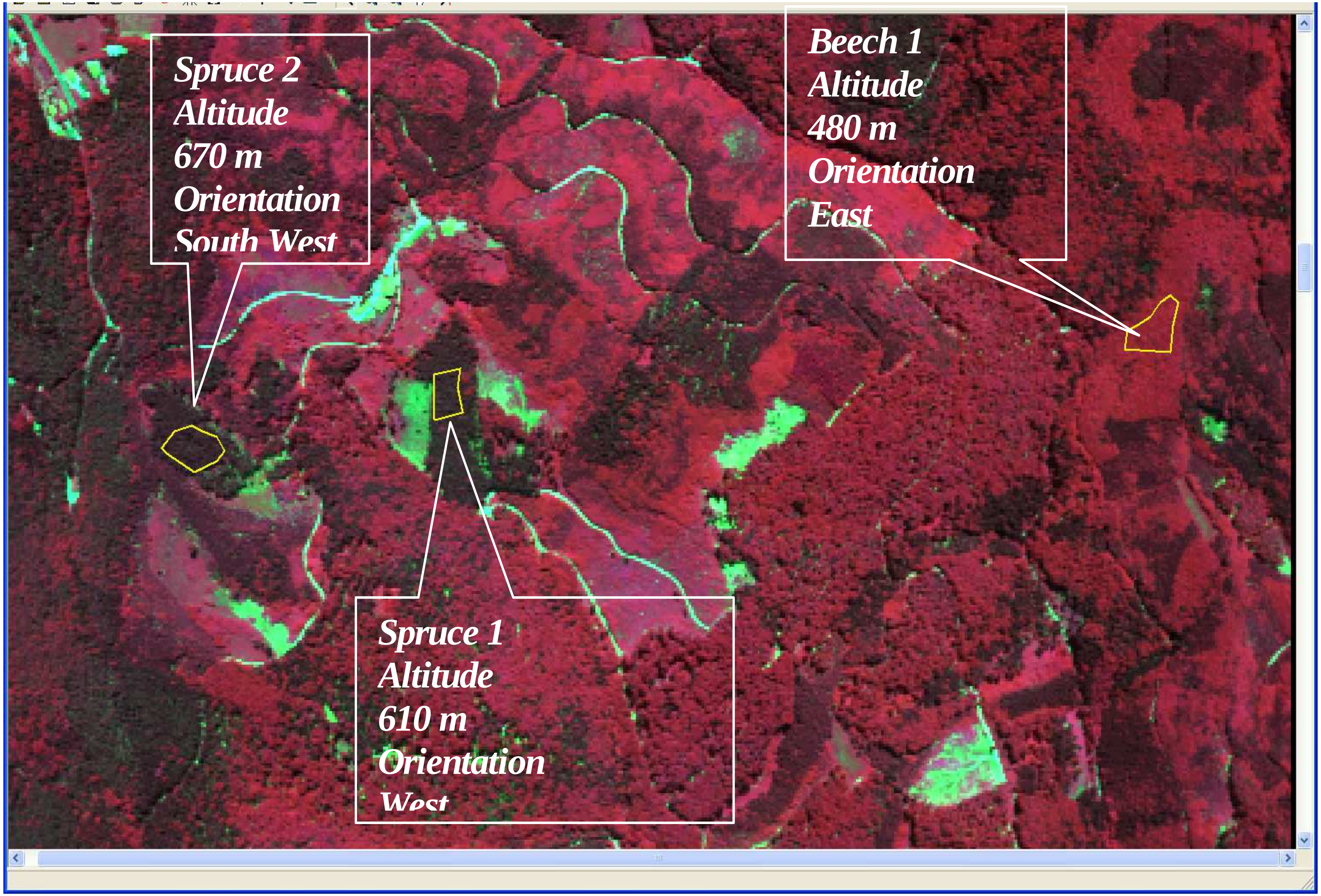
↓

Combine 3 RGB channels to make a visible picture

4. Combination of images with Ray Tracing modelling




Kräuterbach



Hymap: Bildflug vienna4, 21.6.2005, Bandkombination 24/17/8

4. Combination of images with Ray Tracing modelling

Possible next steps:

Use Ray Tracing for retrieval of plant characteristics

Include energy balance model to investigate small scale effects using imaging information

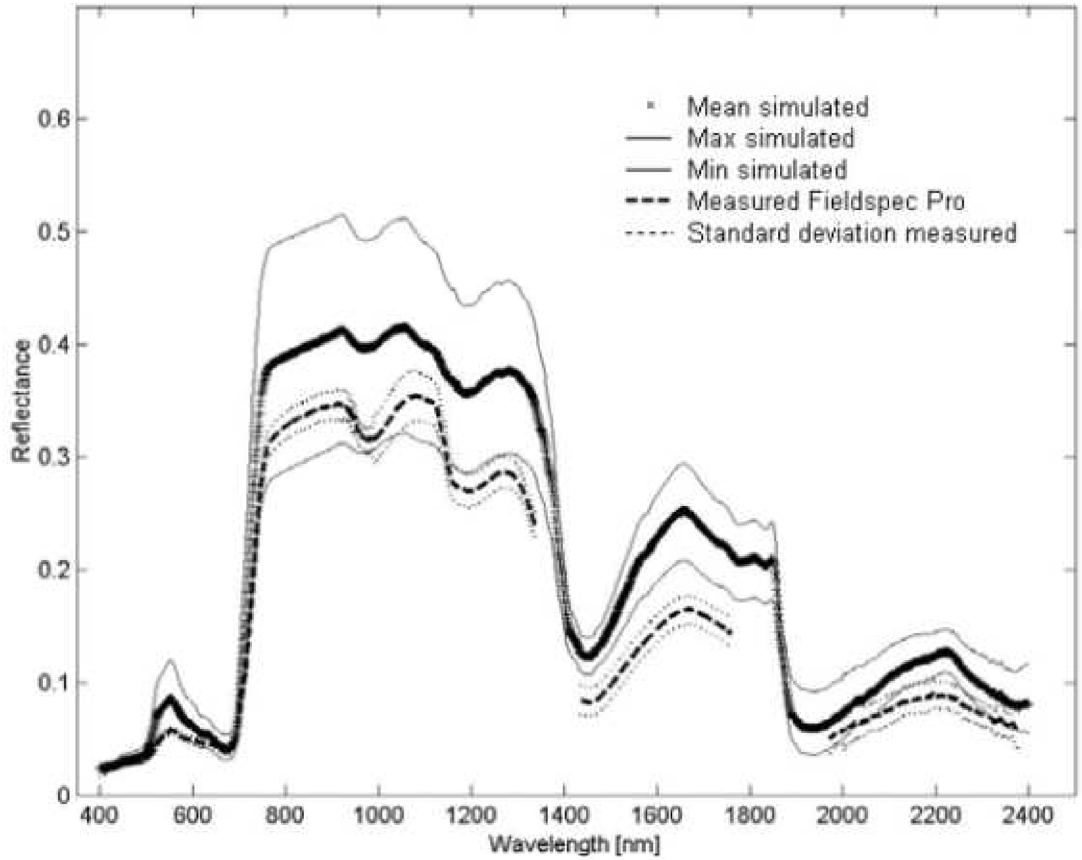
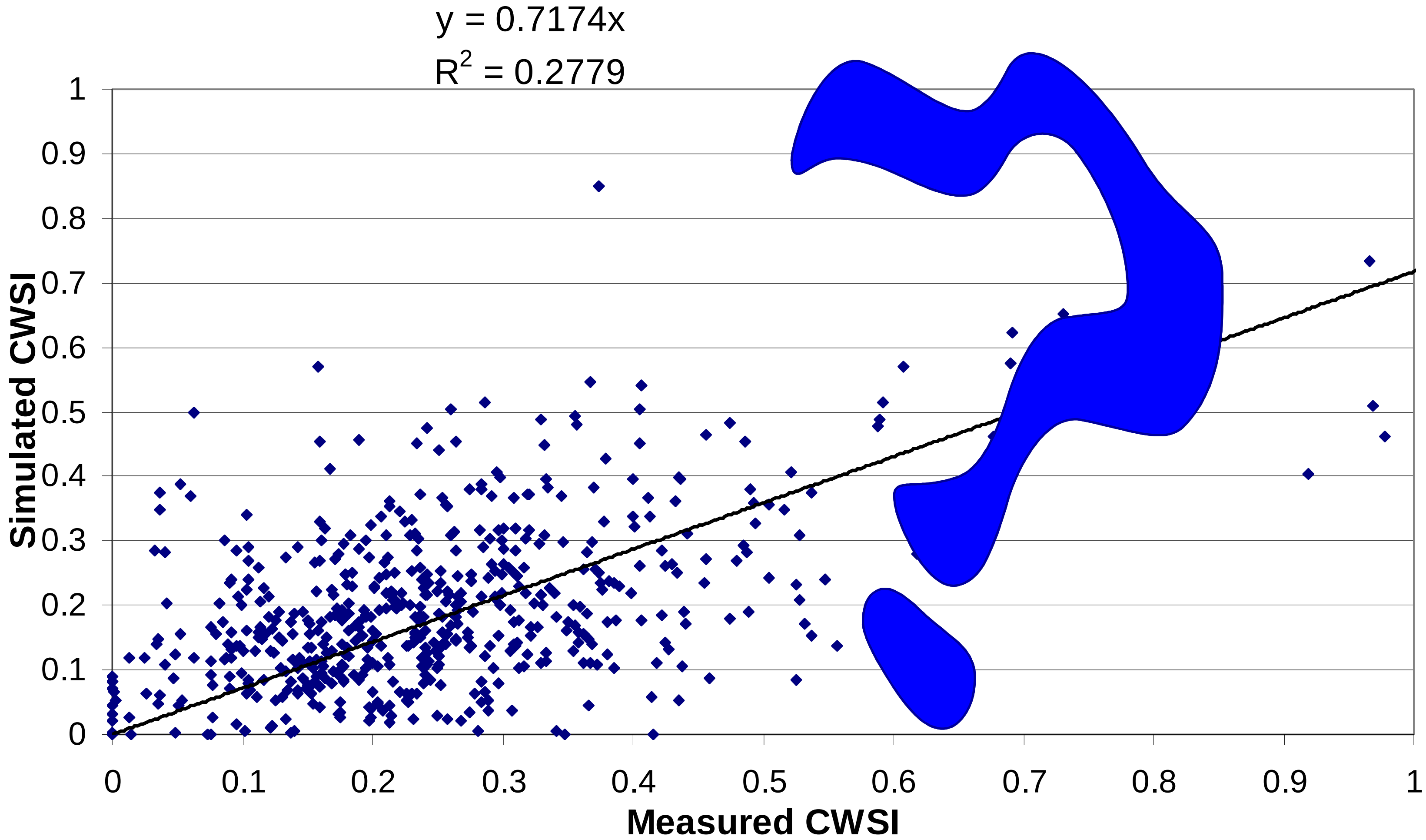
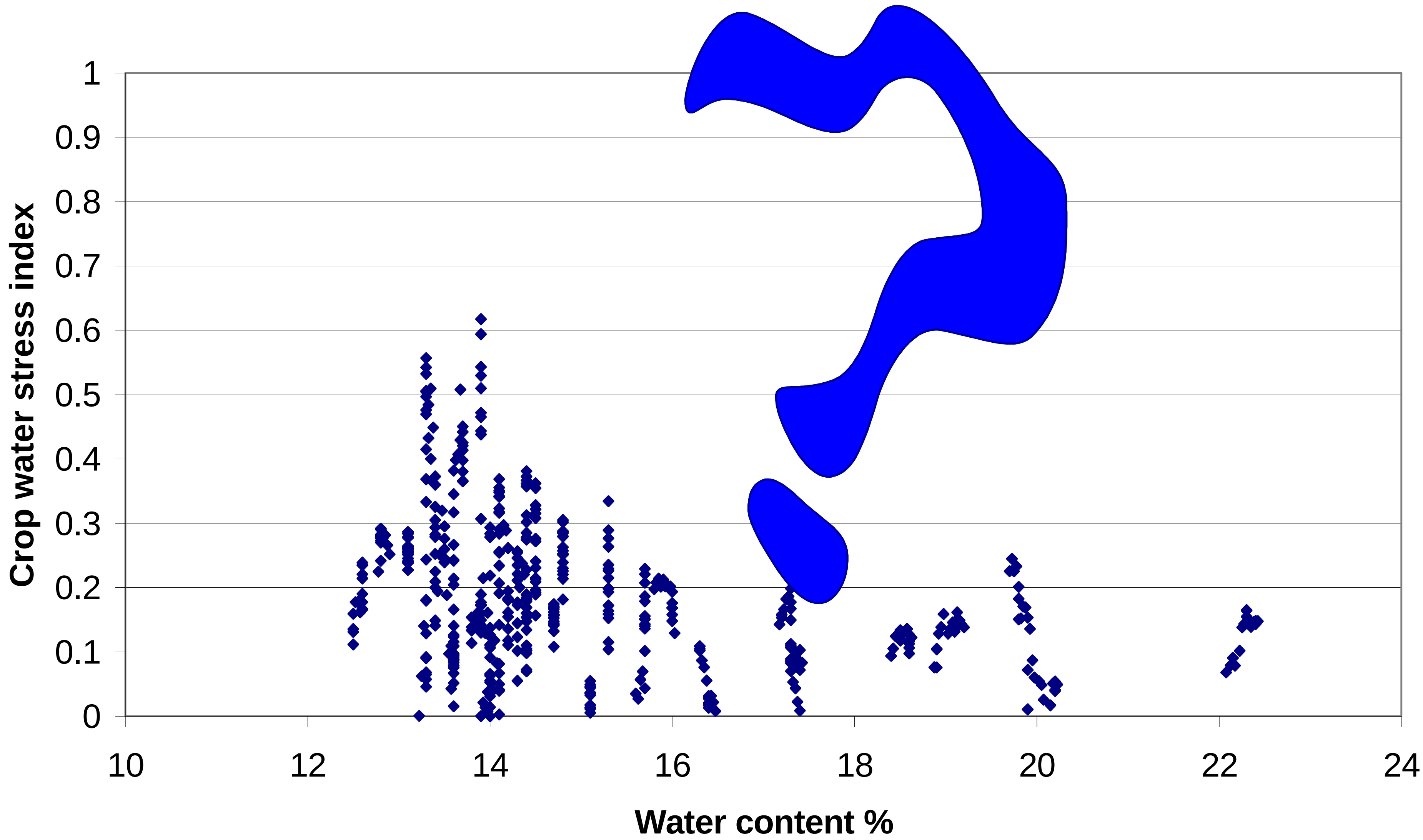


Figure 3: Simulated spectra for rainfed wheat compared to FieldSpec measured for varying canopy variables

D) First preliminary results: comparison CWSI with simulated lower baseline and with measured lower baseline



D) First preliminary results: crop water stress index using energy balance method



A) Introduction: Crop water stress index

This method is however used only during cloudless conditions

A) Introduction: Other method for CWSI calculation

Energy balance method (Alves and Pereira, 2000):

$$T_s - T_w = \frac{\gamma}{\Delta + \gamma} \frac{r_a}{\rho_a c_p} (R_n - G)$$

T_s = Temperature of the leaf (°C)
T_w = Wet bulb temperature (°C)
R_n = Net radiation (W/m²)
G = Soil heat flux (W/m²)
ρ_a = air density (kg/m³)
c_p = specific heat at constant pressure (J./(kg.°C))
γ = psychrometric constant (Pa/°C)
Δ = slope of the saturated vapour pressure vs.Temperature curve (Pa/°C)

Possibility to calculate CWSI for cloudy conditions?

A) Introduction: Conditions for determination CWSI

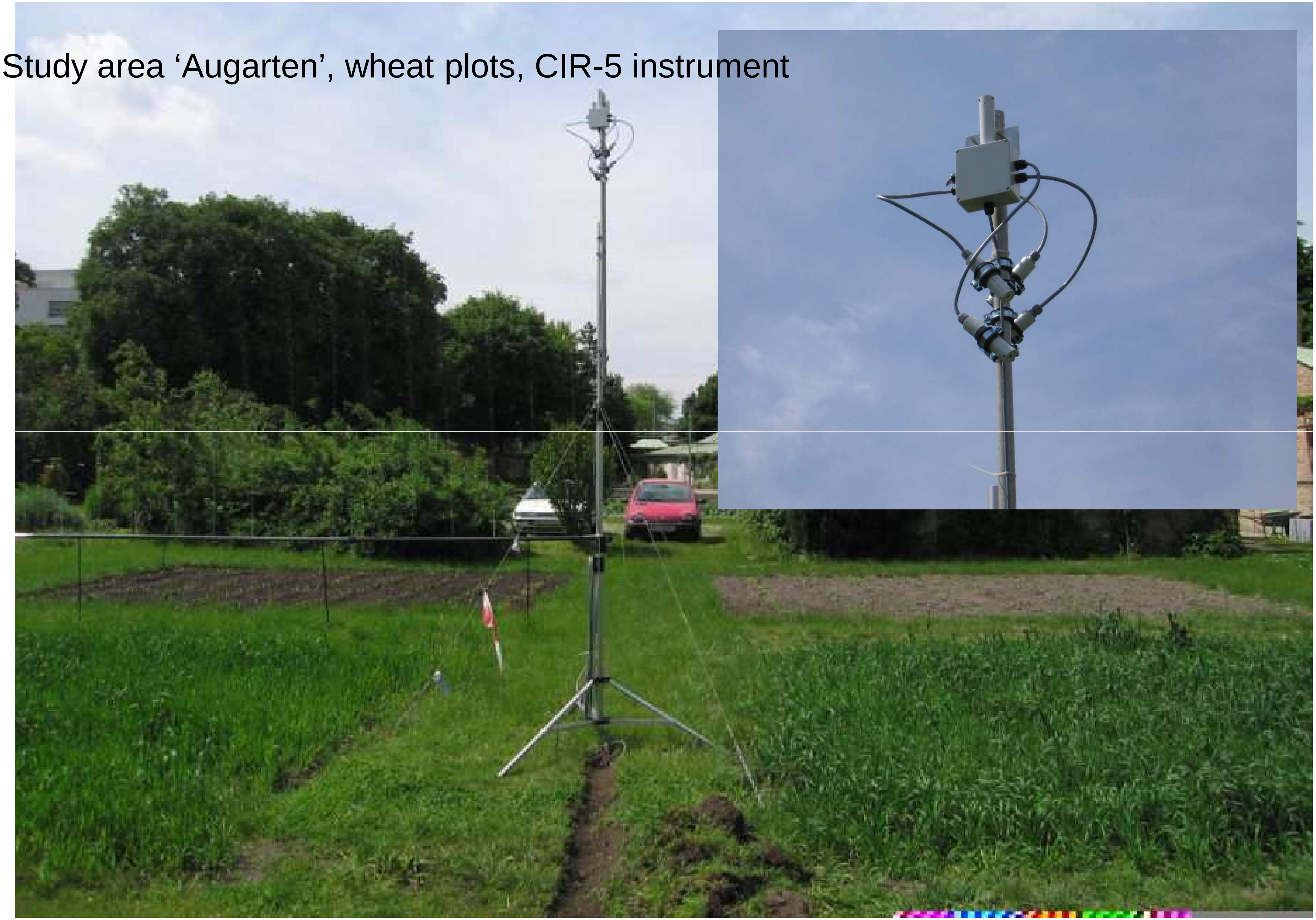
Requirements for conditions of measurements?.

A) Homogeneous canopy over a length of 200 m to avoid fetch effect.

B) Sensors should always look at the sunlit leaves since the energy of the sun strongly influences the leaf temperature

A) Introduction: Study area Augarten

Study area ‘Augarten’, wheat plots, CIR-5 instrument



A) Introduction: Study area Augarten

Problem with site and experiment

A)Fetch effect

Size of plot is 4x6 m. Ideal conditions required 200 m homogeneous field

B) Sensors are oriented towards east and towards west.
Shading effects not ideal for measurements

B) Objectives of the study

- Is it possible to calculate a CWSI for non ideal conditions (cloudy, fetch effect, non ideal orientation of the sensors)?

- **Is it possible to obtain a lower baseline for these conditions?**

- **Correlation with soil water content and plant physiological measurements?**

C) Material and methods: measurements

Measurements

- Thermal measurement with CIR-5, *continuously* during the whole vegetation period of the wheat: 15/05 – 17/07 2006, measuring canopy temperature of two wheat plots (irrigated and rainfed) at the study test-site ‘Augarten’ (Vienna, Austria)

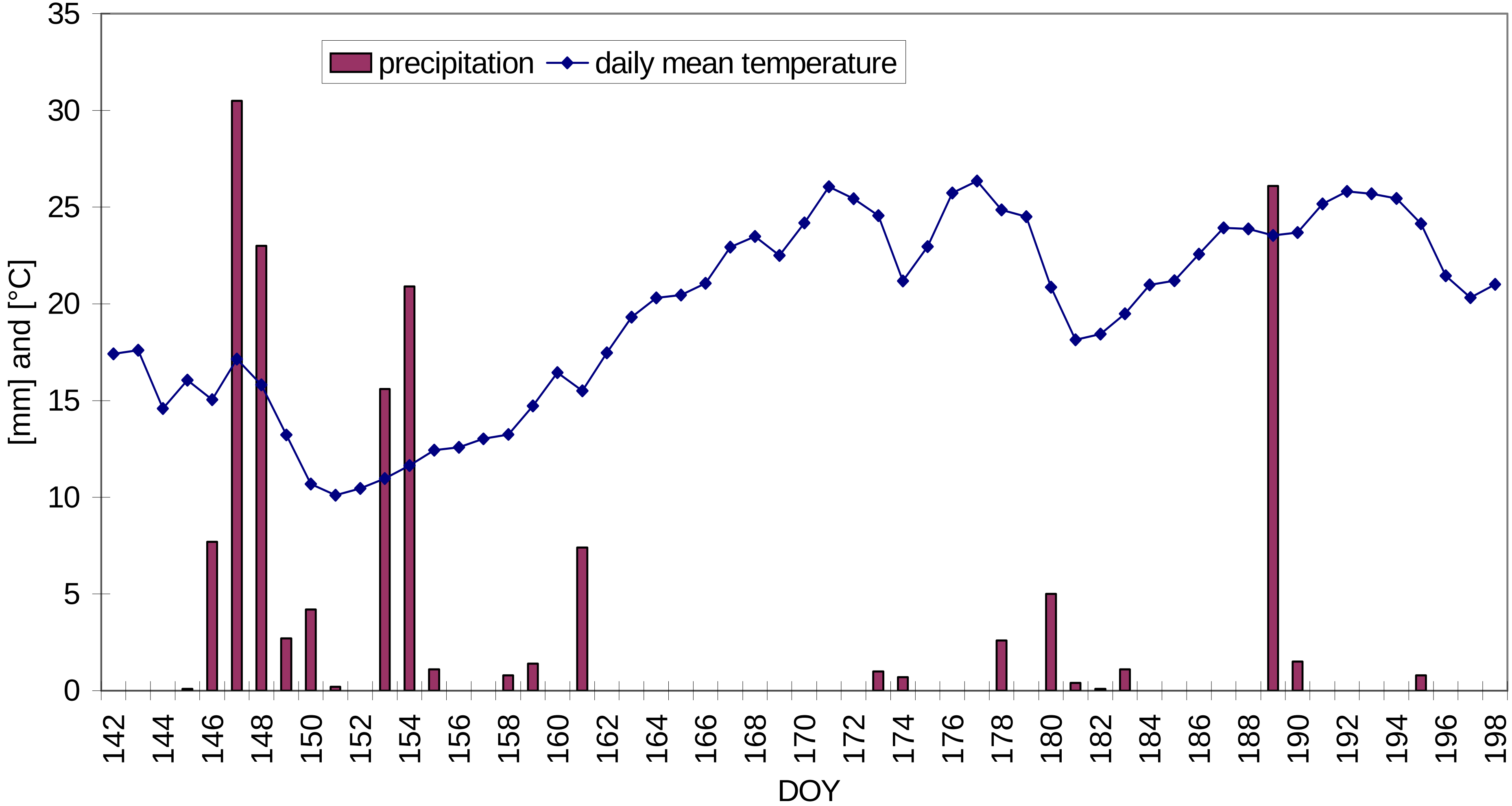
- Meteorological data: air temperature, humidity, radiation (*continuously*)

- Volumetric soil water content measurements, TDR probes in 10, 20 and 40 cm depth (*continuously)*

- Physiological parameter: actual leaf conductance, leaf water potential, leaf osmotic potential, relative water content (*at the three growth stages)*

C) Material and methods: Weather conditions

TEMPERATURE AND PRECIPITATION DURING THE MEASUREMENT PERIOD



C) Material and methods: Physiological measurements

		Ψ_w		Ψ_π		g_L US		g_L LS	
		ir	rf	ir	rf	ir	rf	ir	rf
predawn	vegetative	-1.8	-1.9	-10.1	-11.5***				
	flowering	-2.4	-4.6***	-13.4	-13.4				
	grain filling	-6.8	-11.3***	-13.0	-14.9***				
midday	vegetative	-6.8	-7.8	-11.7	-13.4***	541.4	364.2**	601.1	177.0***
	flowering	-17.2	-20.1*	-18.5	-18.7	632.7	523.2**	568.7	361.1**
	grain filling	-18.3	-19.9	-15.6	-17.1*	721.0	537.4**	609.1	328.5***

Summary of results from physiological measurements.

Abbreviations: ir: irrigated; rf: rainfed;

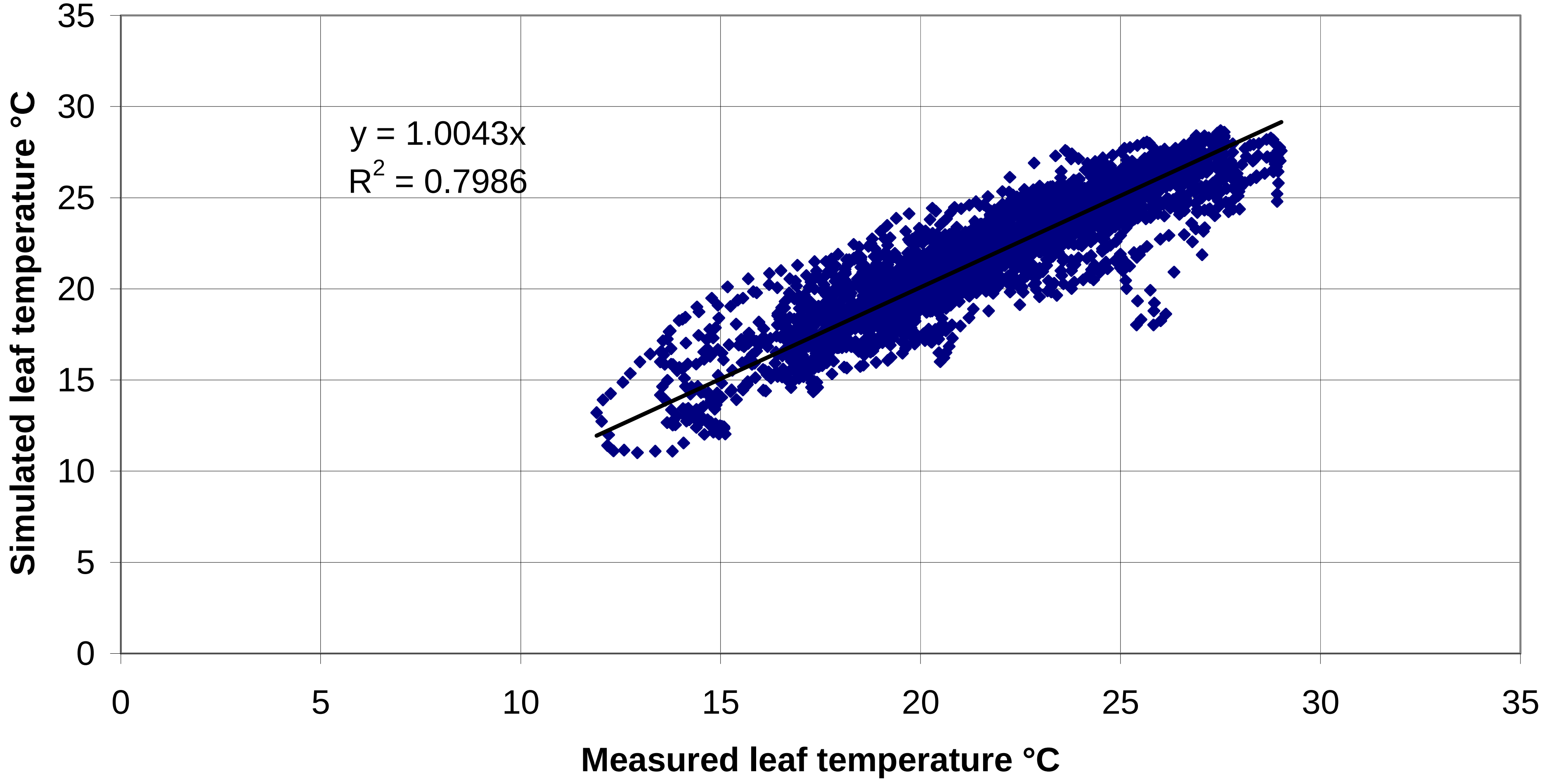
Ψ_w: leaf water potential [bar];

Ψ_π: leaf osmotic potential [bar];

RWC: relative water content [%];

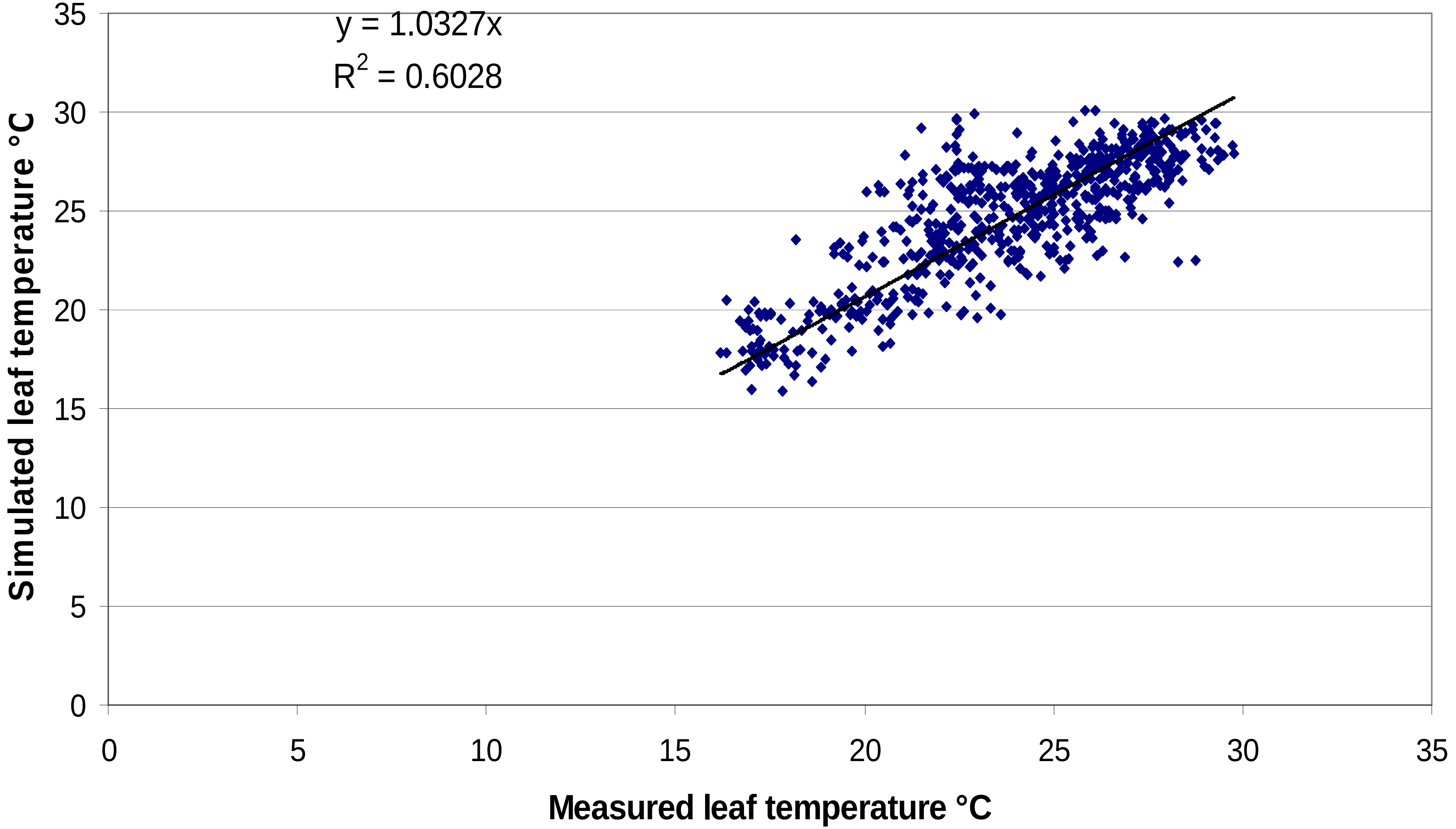
g_L: leaf conductance [$mmol.m^{-2}.s^{-1}$]; US: upper leaf surface; LS: lower leaf surface. Significance levels refer to the differences between rainfed and irrigated plants. ***: $p \leq 0.001$; **: $p \leq 0.01$; *: $p \leq 0.05$; n=5-30.

D) First preliminary results: leaf temp. of irrigated plots using energy balance method

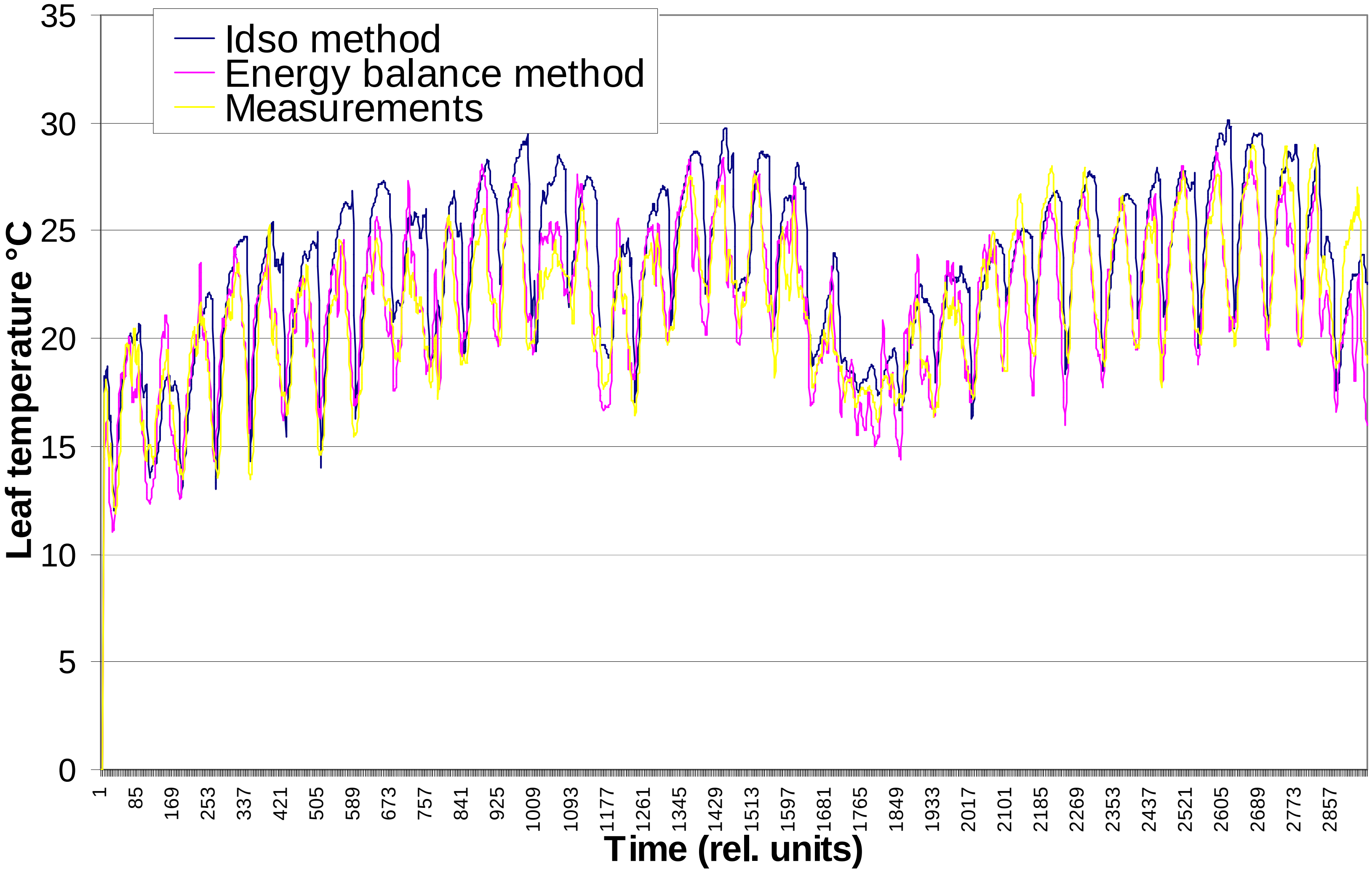


D) First preliminary results: leaf temp. of irrigated plots: classical Idso method (with vapour pressure deficit)

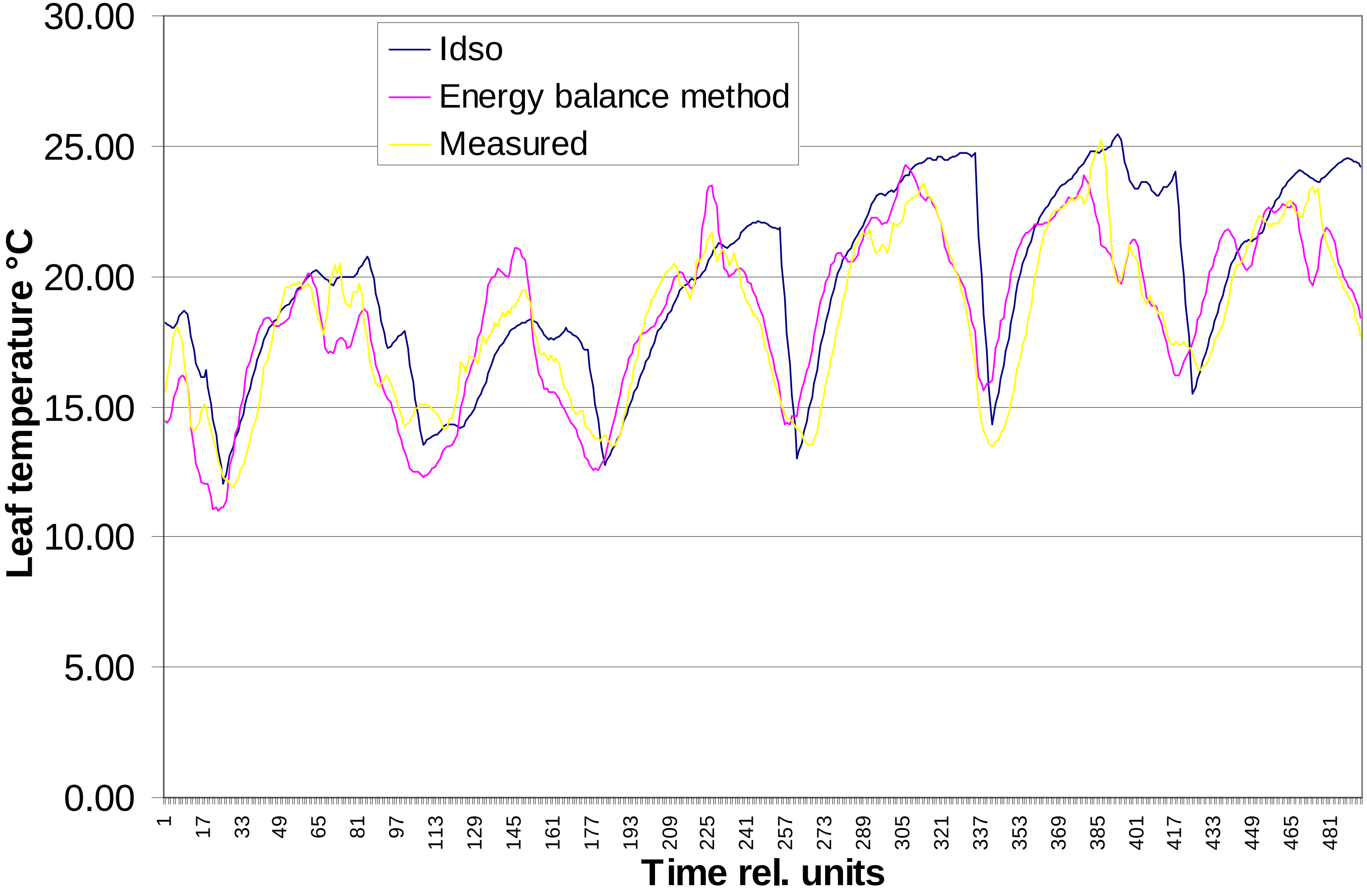
Only from 12h00 to 15h00, all sky conditions



D) First preliminary results: comparison of leaf temp. of watered plots using energy balance method and Idso meth.



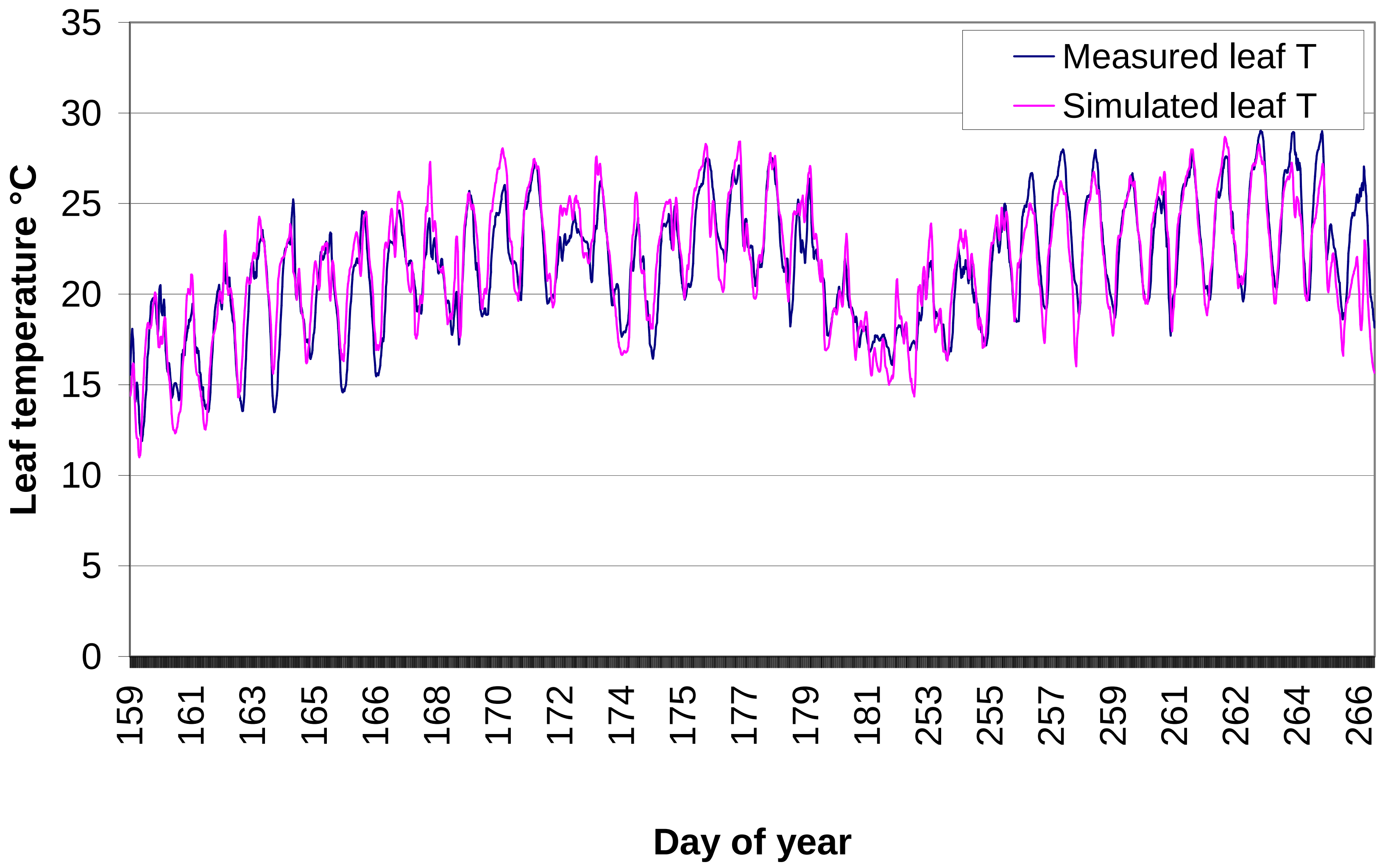
D) First preliminary results: comparison of leaf temp. of watered plots using energy balance method and Idso meth.



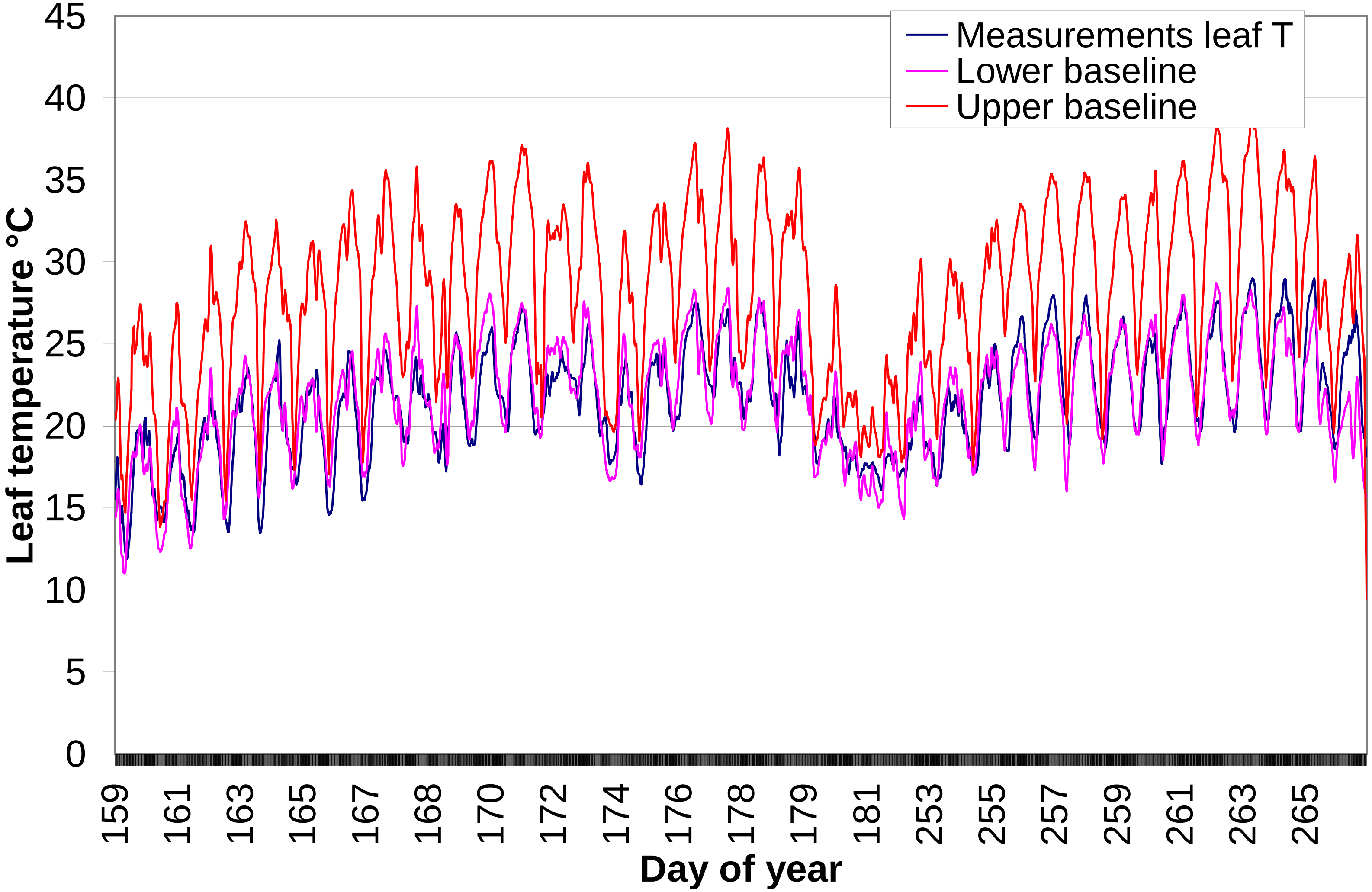
D) Preliminary results: first statements

Energy balance method is more accurate than method by Idso for the determination of lower baseline for all sky conditions

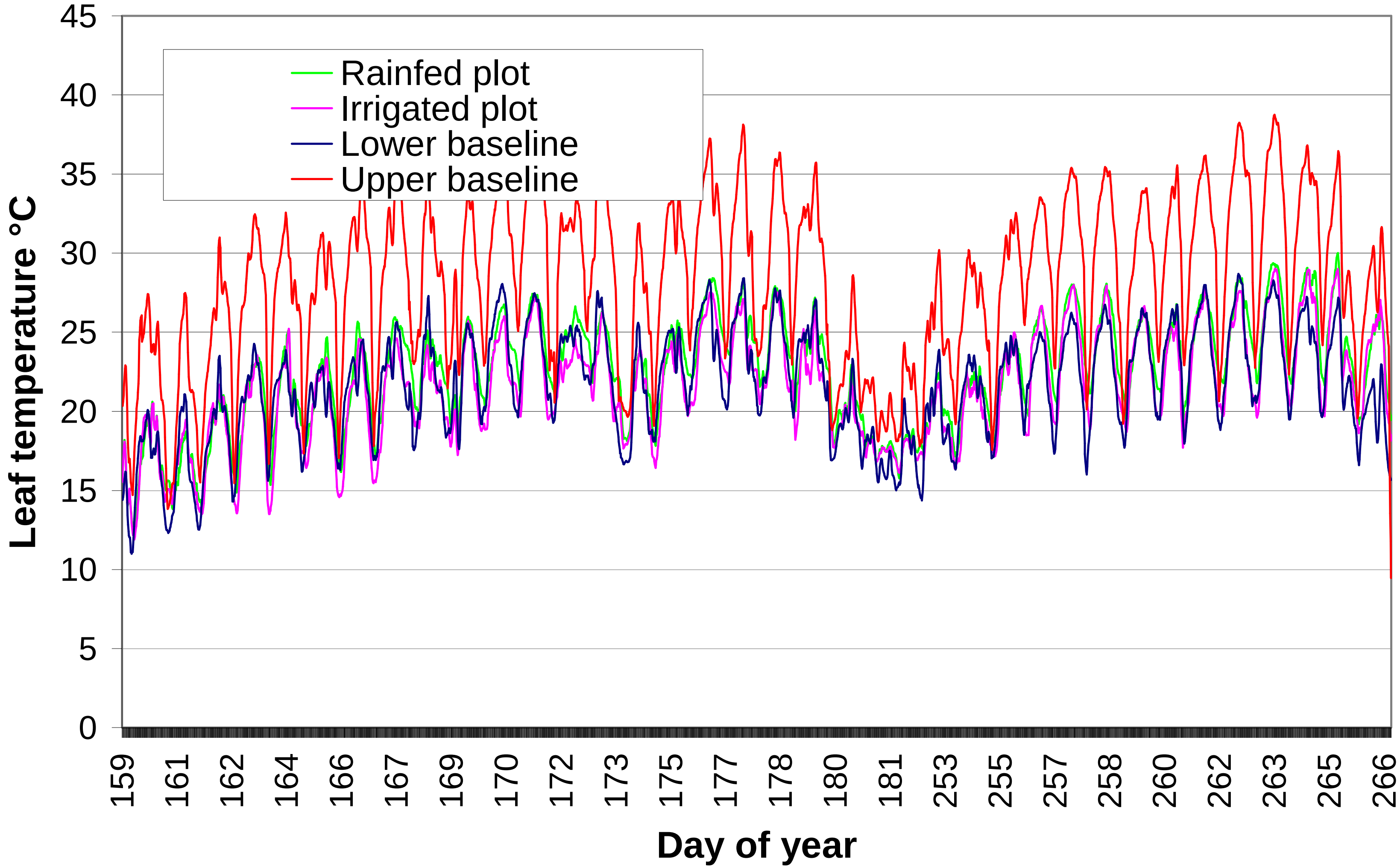
D) First preliminary results: leaf temp. of watered plots using energy balance method



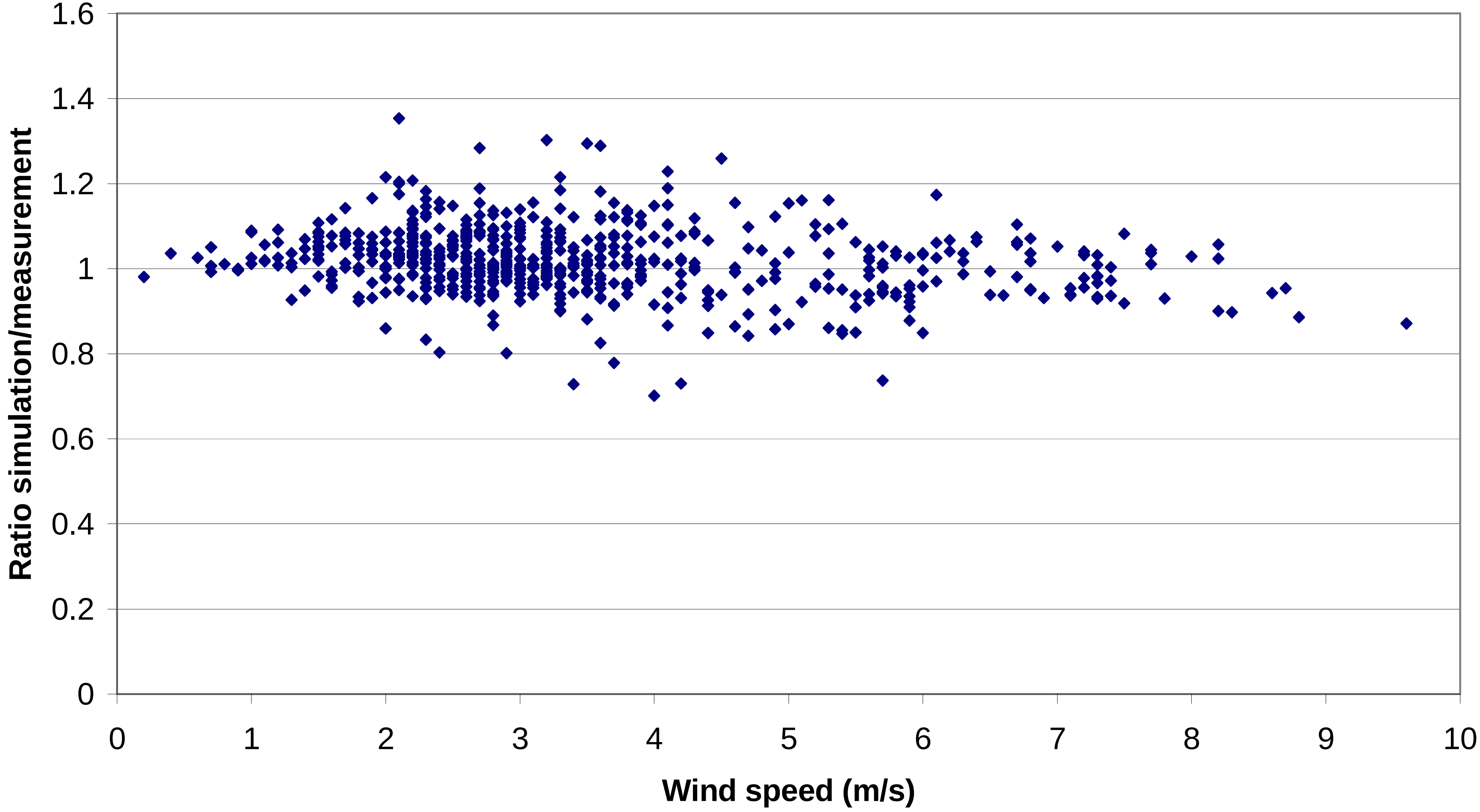
D) First preliminary results: lower and upper baselines



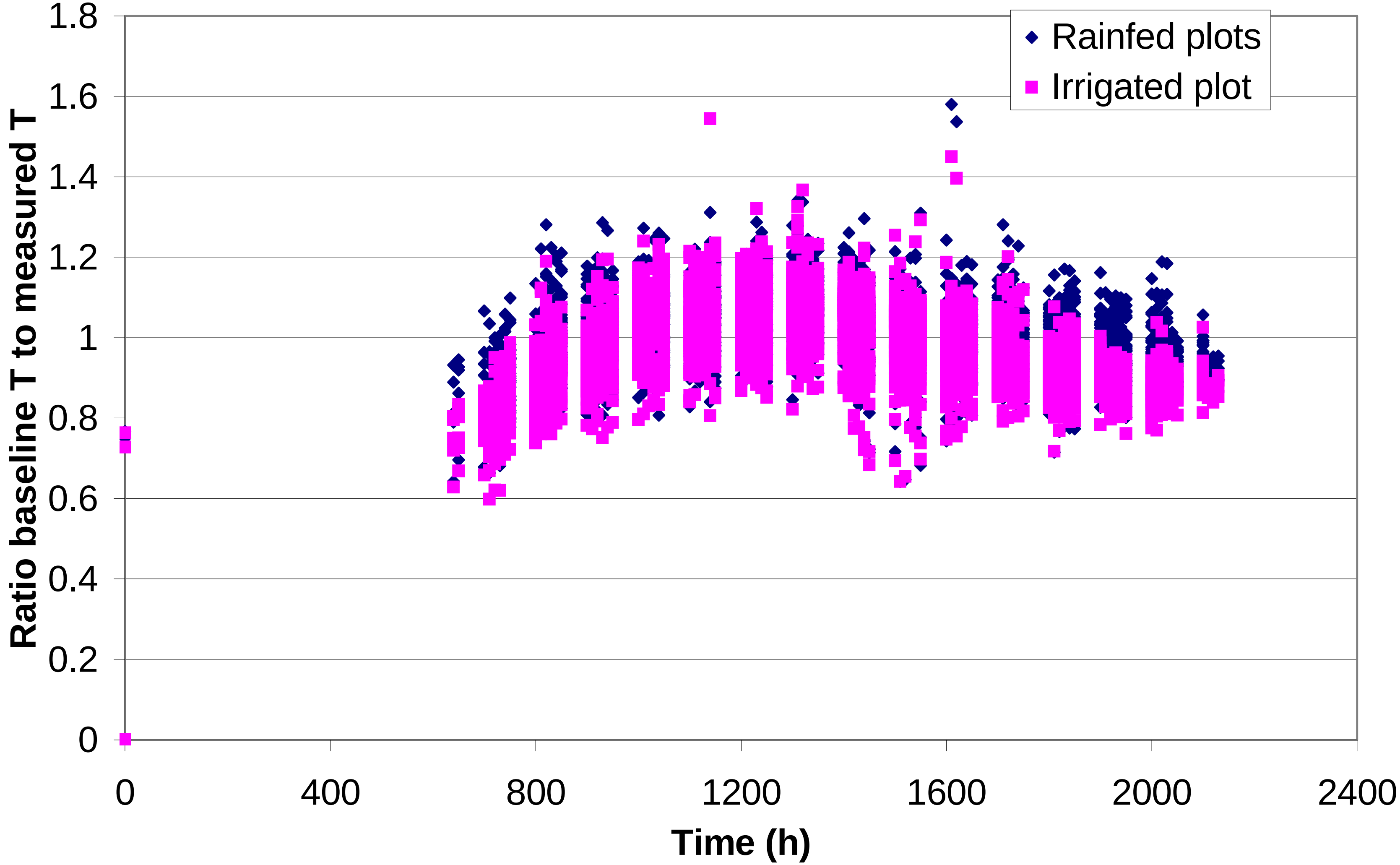
D) First preliminary results: lower and upper baselines



D) First preliminary results: wind effect on determination of leaf temperature



D) First preliminary results: orientation effect on determination of leaf temperature



D) First preliminary results: orientation effect radiation balance vs global irradiance reference