Water and plants regulate temperature and local climate – a case studies from Třeboň Biosphere Reserve and Mau Forest in Kenya

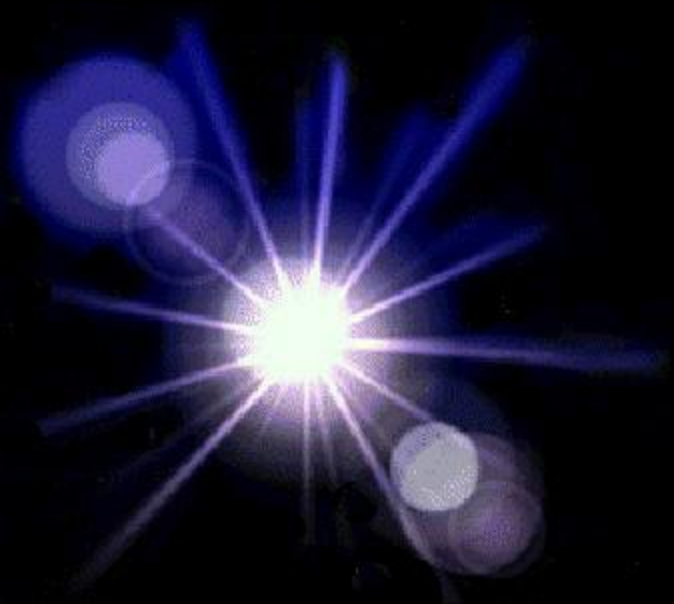
Jan Pokorný, Petra Hesslerová

ENKI, o.p.s. Třeboň
Czech University of Life Sciences in Prague
Czech Republic

28 years ago we hosted 2nd Intecol Wetlands Conference c. 130 participants
(24 from USA)

Content

- Solar energy from Sun to Earth´s surface
- Distribution of solar energy in ecosystems and on a dry surface (ground measurements, RMS)
- High surface temperature of dry surfaces is not recorded by standard method
- Deforestation results in temperature increase and water shortage (Mau Forest)
- Role of water and plants in climate must not be reduced to albedo and sink/source of CO_2.
- Water and plants damp climate extremes directly



Solar energy increases temperature
of Earth to 290 K (18 centigrades)

180 000 TW comes from Sun to Earth

12 TW

energy in economy of
the World (fossil fuels etc.)

Solar constant

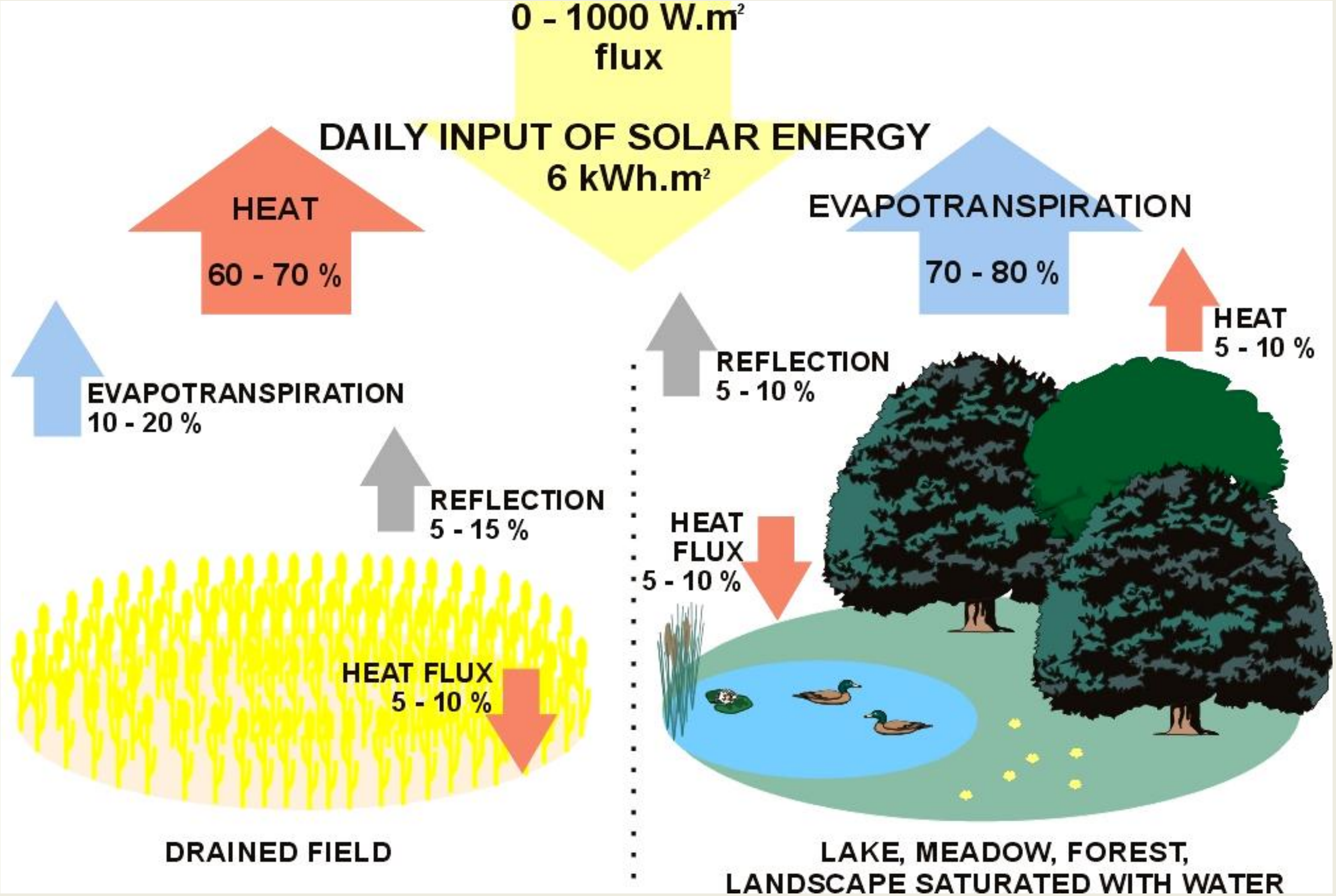
Solar energy warms the Earth to an average temperature of around 17 C or 290 K. For a mean distance between the Sun and the Earth, the intensity of solar radiation incident upon a surface perpendicular to the Sun's rays measured above the atmosphere is approximately

1367 W m^{-2}.

This quantity is called the solar constant

During a year flux of solar energy fluctuates **from 1412 W m^{-2}** in early January **to 1321 W m^{-2}** in early July due to eliptic trajectory of Earth around Sun.

EVAPOTRANSPIRATION COOLS

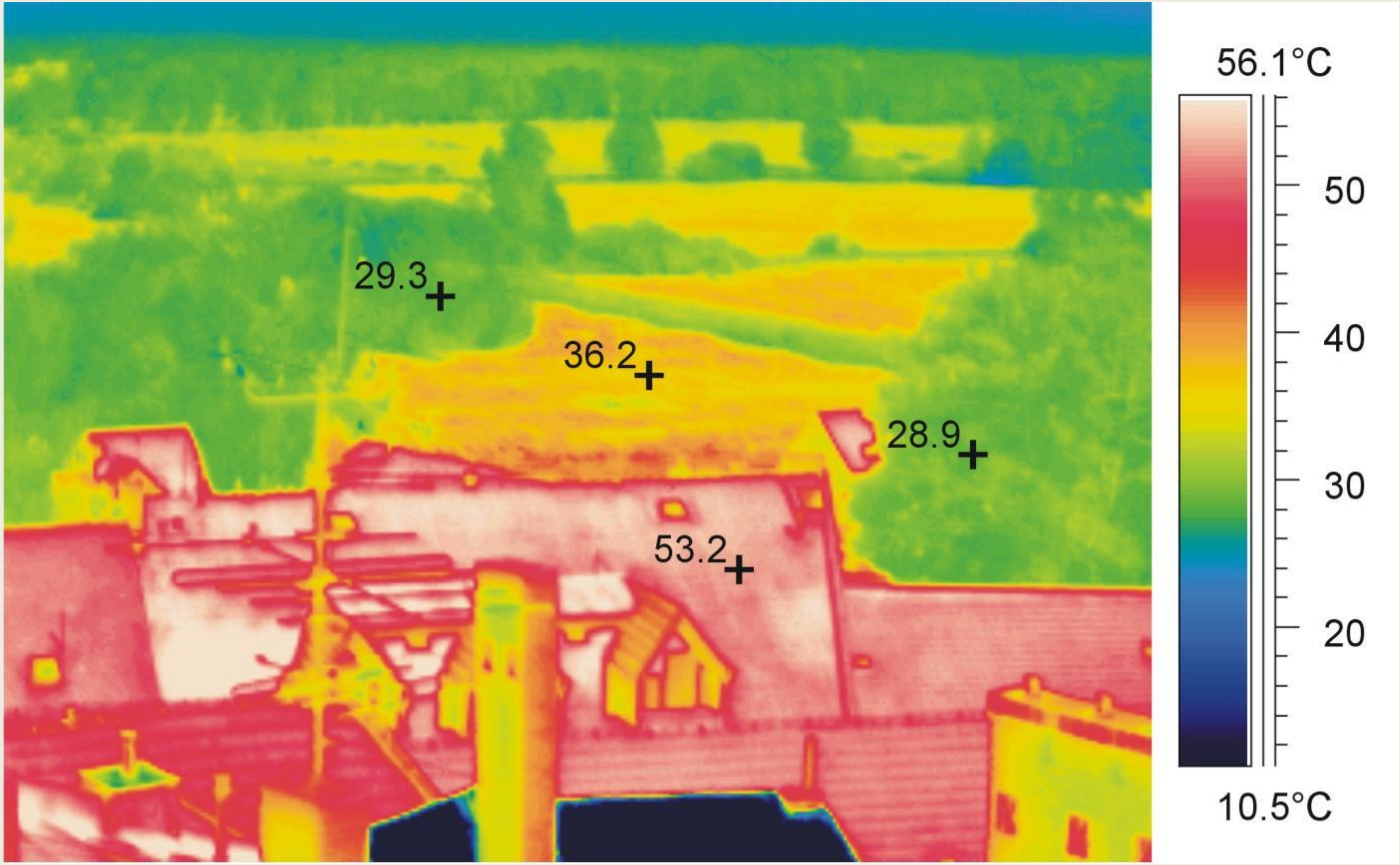


Higher temperature

Lower temperature

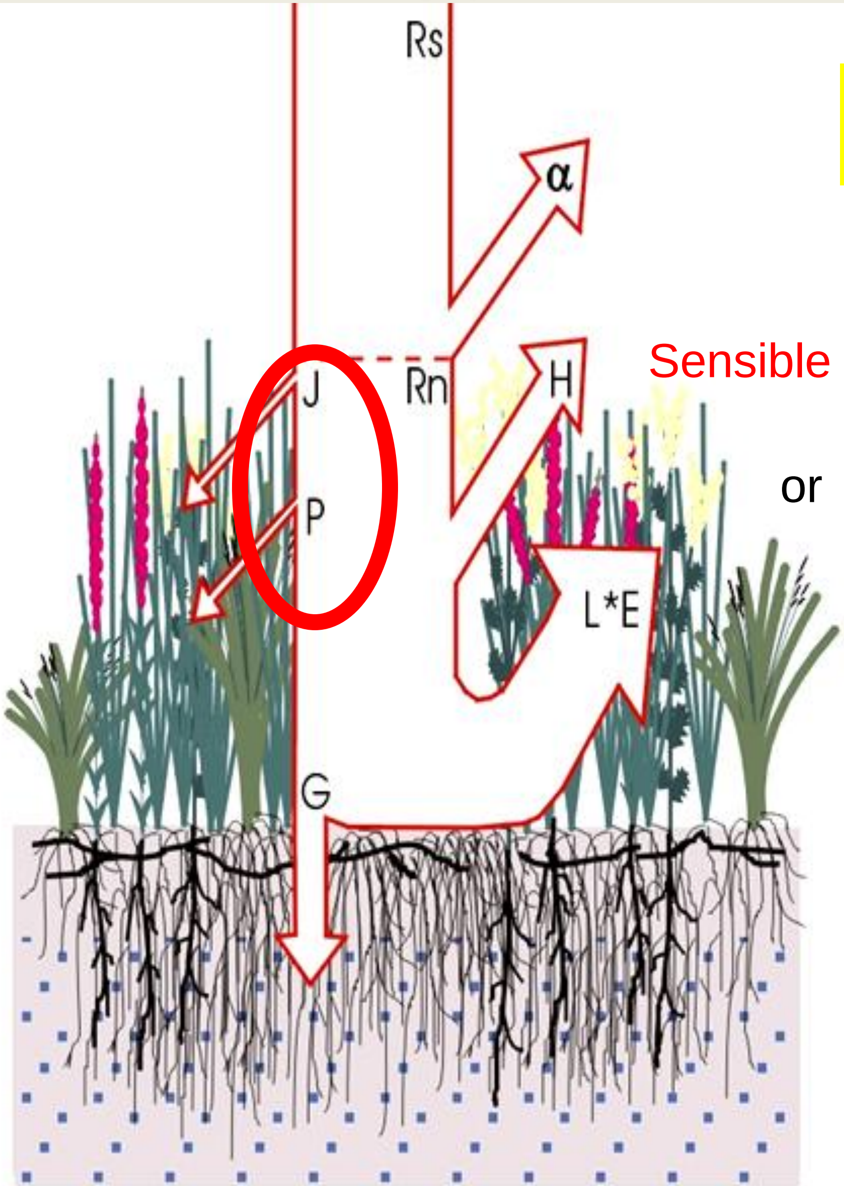
View from Třeboň townhall to wet meadows

IR picture made by termovision camera –high temperature of roofs, low temperature of wetlands (Wet Meadows).



Energy fluxes in ecosystem

$$R_n = J + P + G + H + L*E$$



Sensible heat

or

Latent heat of ET

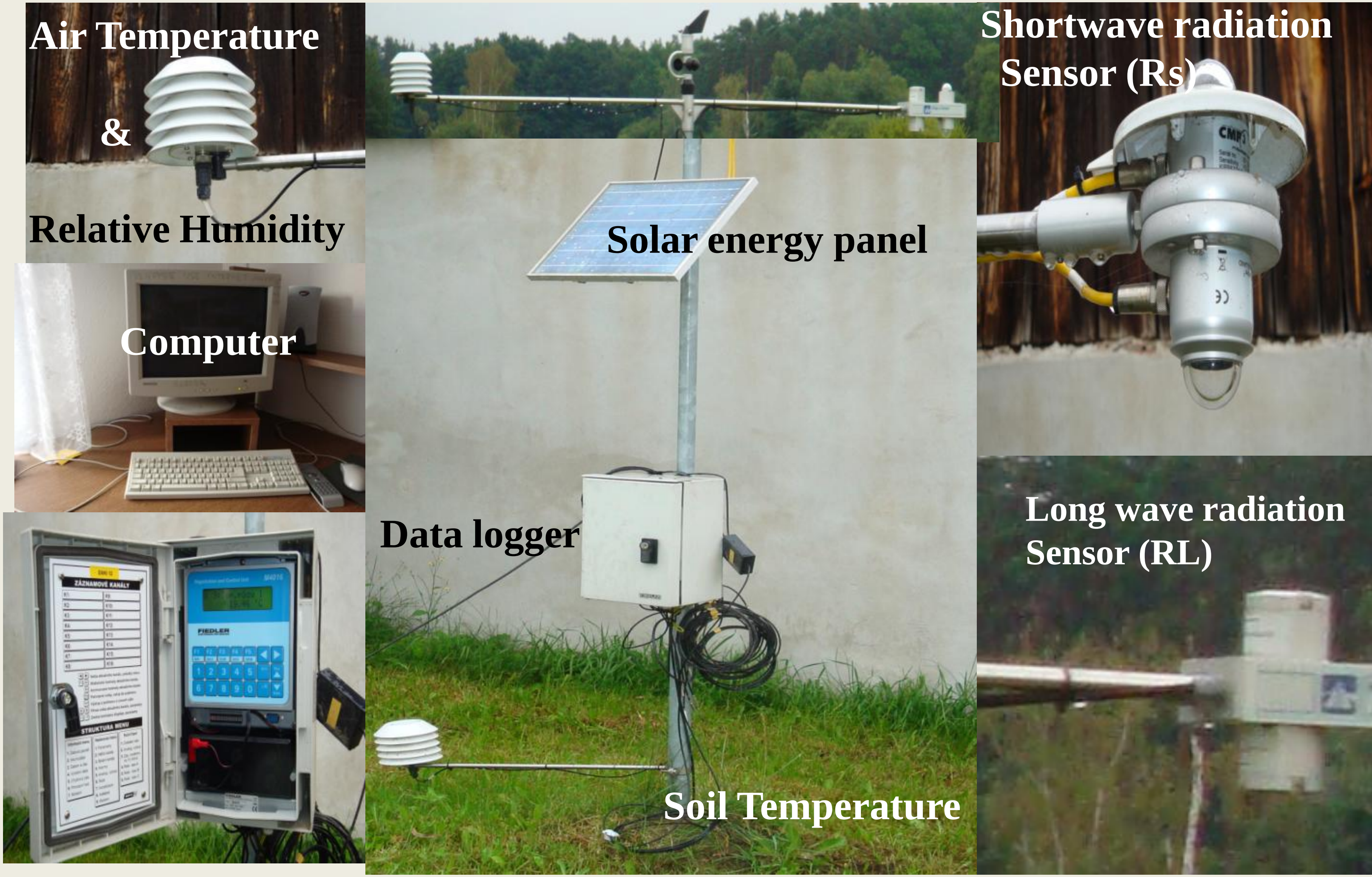
- Rs - global radiation
- Rn - net radiation
- α - albedo (reflection)
- H - sensible heat flux
- L*E - latent heat * evapotranspiration
- G - ground heat flux
- J - accumulation of heat in biomass
- P - photosynthesis

Ground measurements of energy fluxes

Meteorological station – Wet meadows

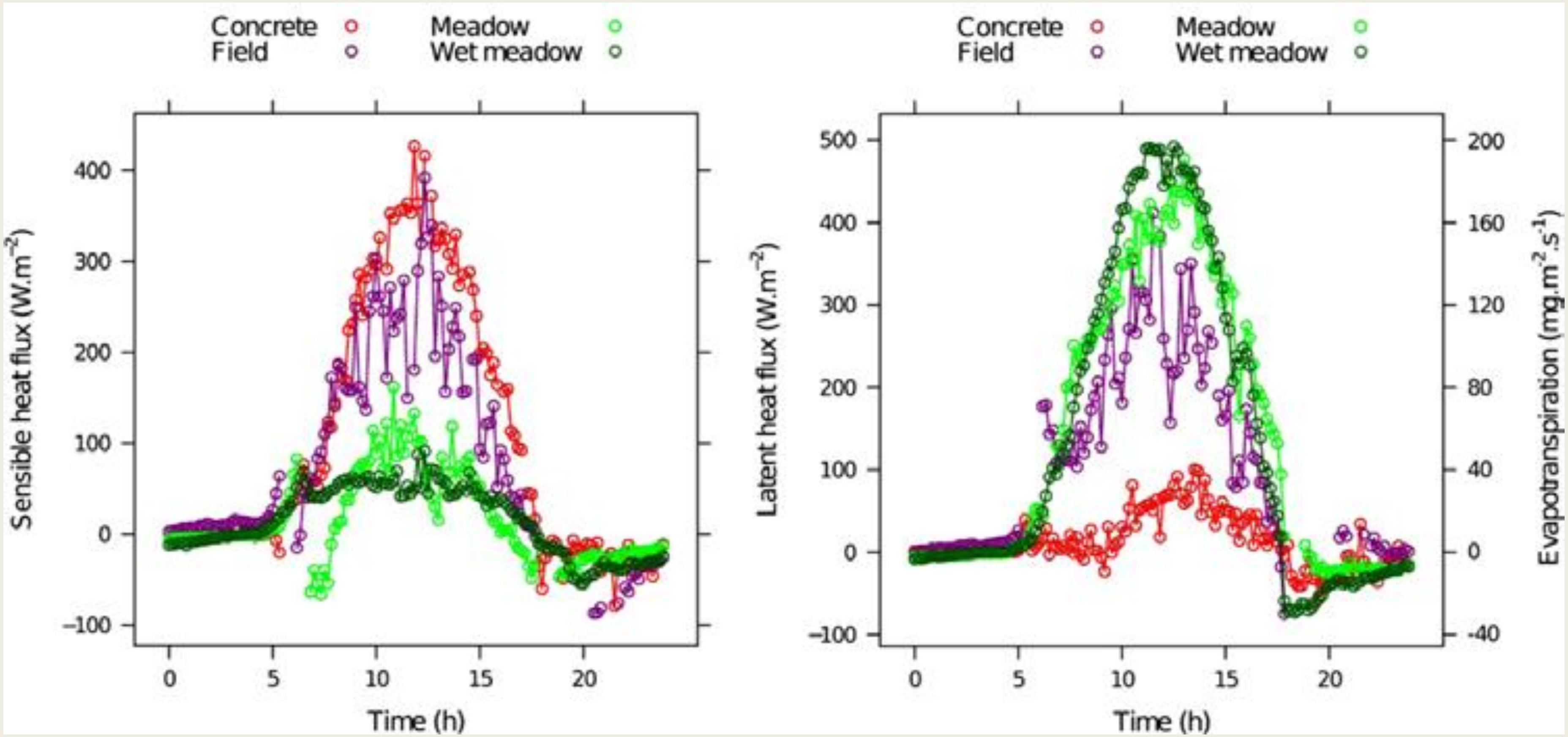
Meteorological station at the concrete surface

Materials and Methods



Comparison: wetland x dry surface

Sensible and latent heat fluxes and rate of evapotranspiration on a sunny day



Evapotranspiration reaches 500Wm2

Pokorný, J., Brom. J., Čermák, J., Hesslerová, P., Huryna, H., Nadyezhdina, N., Rejšková, A. (2010): How water and vegetation control solar energy fluxes and landscape heat. *International Journal of Water.* Vol. 5, No. 4, pp. 311-336

Remote sensing –
thermal scanning of radiation surface temperature

1. **near-ground** (up to 1 000 m) - an **airship** equipped with GPS was developed and successfully tested

2. **broad-scale** monitoring (300 - 5000 m) by **aircraft** with photogrammetric equipment. Both aerial devices are equipped with FLIR thermographic cameras operating within a spectral range of 7.5 – 15 µm.

3. **Large-scale (**several hundreds kms**) satellite images** (commonly in 7 – 14 µm)

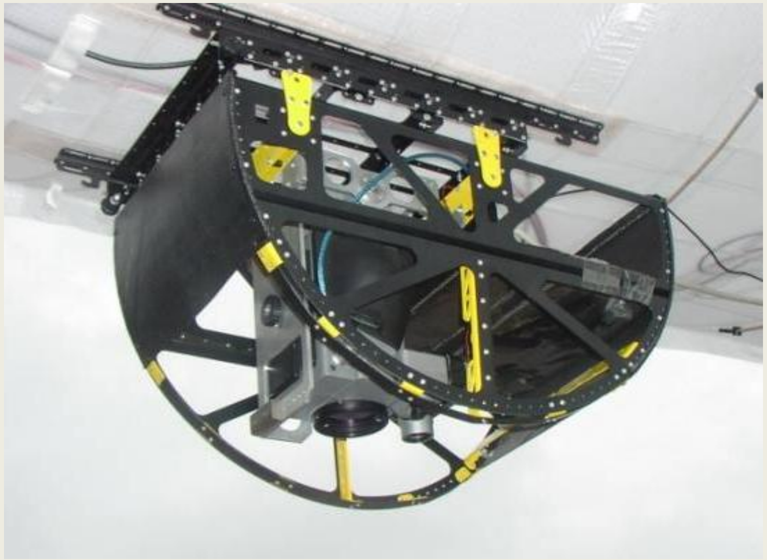
Jirka, V., Pokorný, J., Kobrzek, F., et al. (2011) Soustava prostředků pro zjišťování energetických toků v přízemní vrstvě atmosféry. Česká republika. Užitný vzor, 22671 U1. 2011-09-12. (The system for detecting energy flows in the ground layer of the atmosphere. The Czech Republic. Utility model, 22671 U1. 2011-09-12.)

Airship

A helium-filled airship (**8 m long)** - equipped with an **inertial measurement unit** for direct measurements of the heeling angle and acceleration in all directions in relation to a coordinate system of the gondola, an accurate **altimeter**, short-wave **radio stations** with a range of at least 10 km and a **GPS** navigation device.

•Its operating **speed** is 5 m/s; **height** up to 1000 m and the maximum **duration** of the flight is 30 minutes.

•A gravity suspension located on the gondola is balanced to keep at a right angle to the Earth's surface. Attached are cammeras operated with a common trigger. The frequency of photography is derived from the forward speed of the airship.



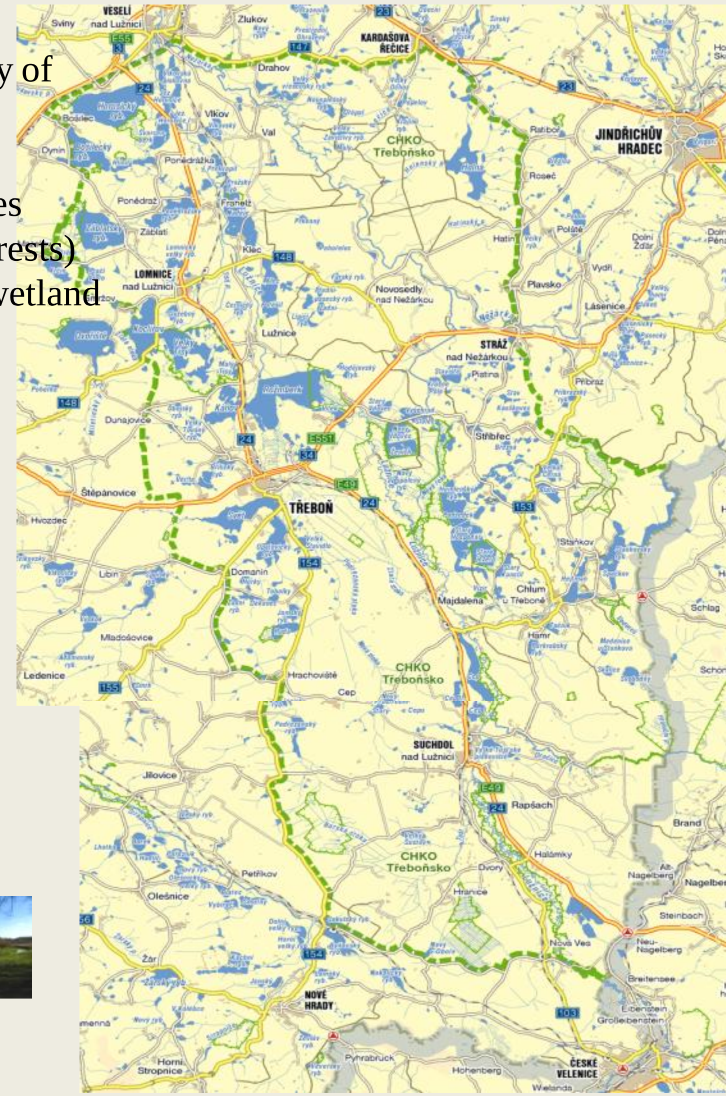
Třeboňsko Landscape Protected Area

Třeboňsko (700 km^2) - shallow basin in altitudes between 410 – 550 a.s.l.

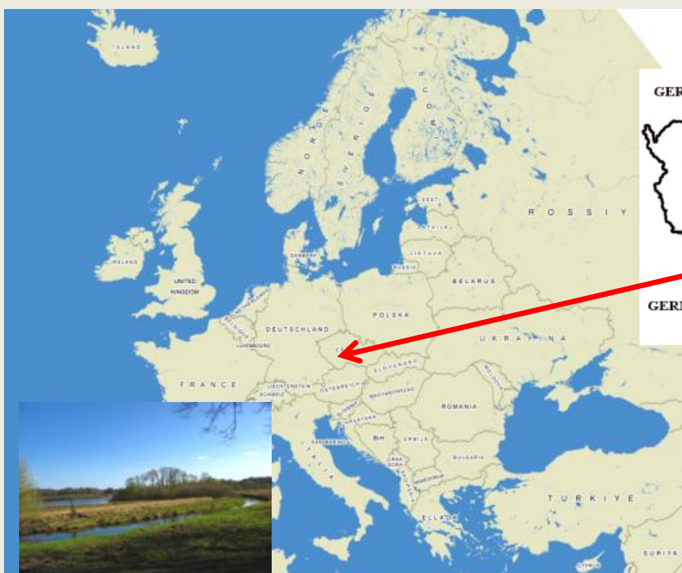
-**marshy area** -12th century gradually **changed by humans** - construction of a sophisticated network of canals, watercourses and fish ponds

- natural ecosystems remained preserved - extraordinary diversity of habitats.

-The **fish ponds** (approx. 500) are the dominant landscape features
- 50 % **forests** (coniferous, deciduous, remnants of floodplain forests)
-transitional bogs, warm steppe sites, wet meadows, fish ponds, wetland ecosystems



-UNESCO's **Man and Biosphere** program in 1977
- **Ramsar convention -** peat bogs, fish ponds, wetland habitats



www.mapy.cz

www.mapy.cz

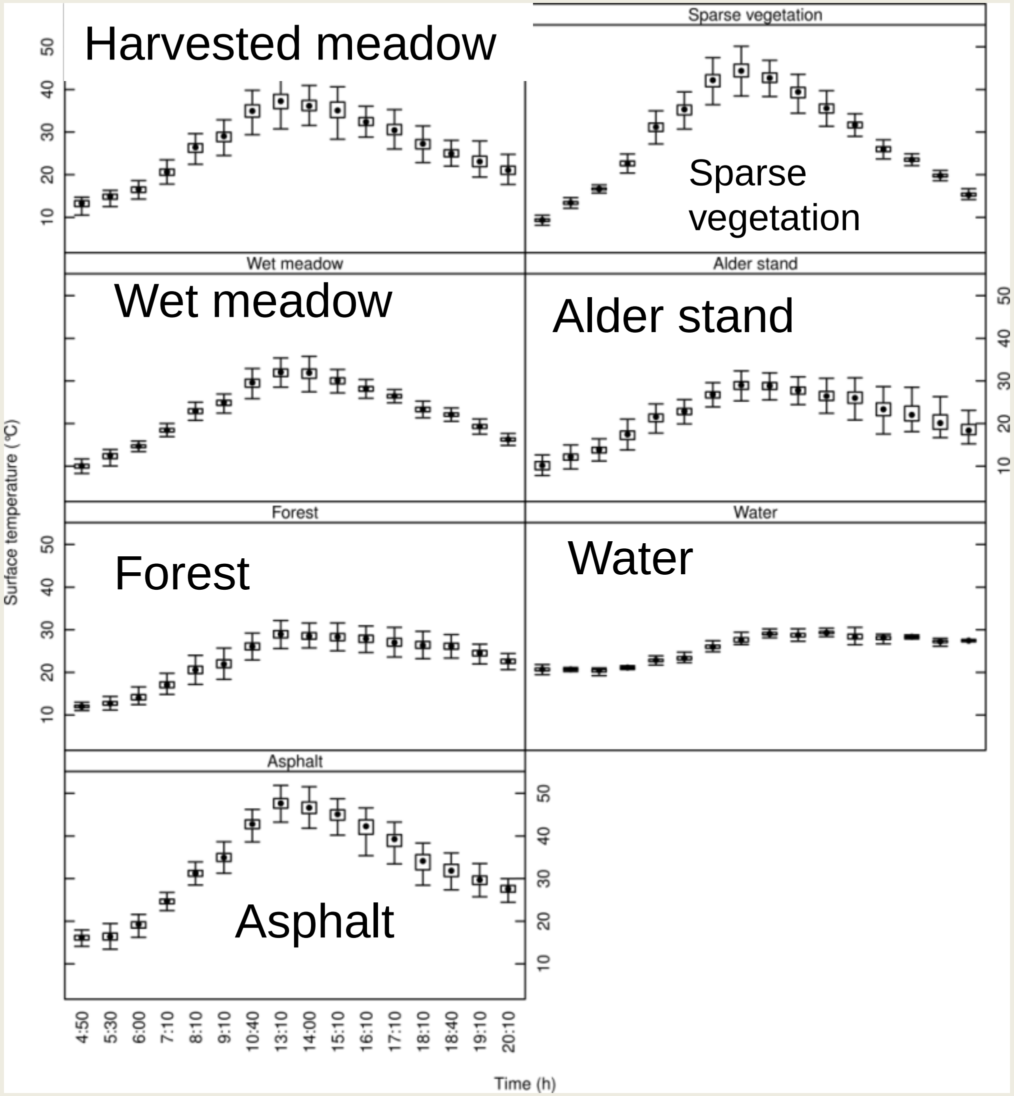
Daily dynamics of radiation surface temperature of different land cover types in a temperate cultural landscape

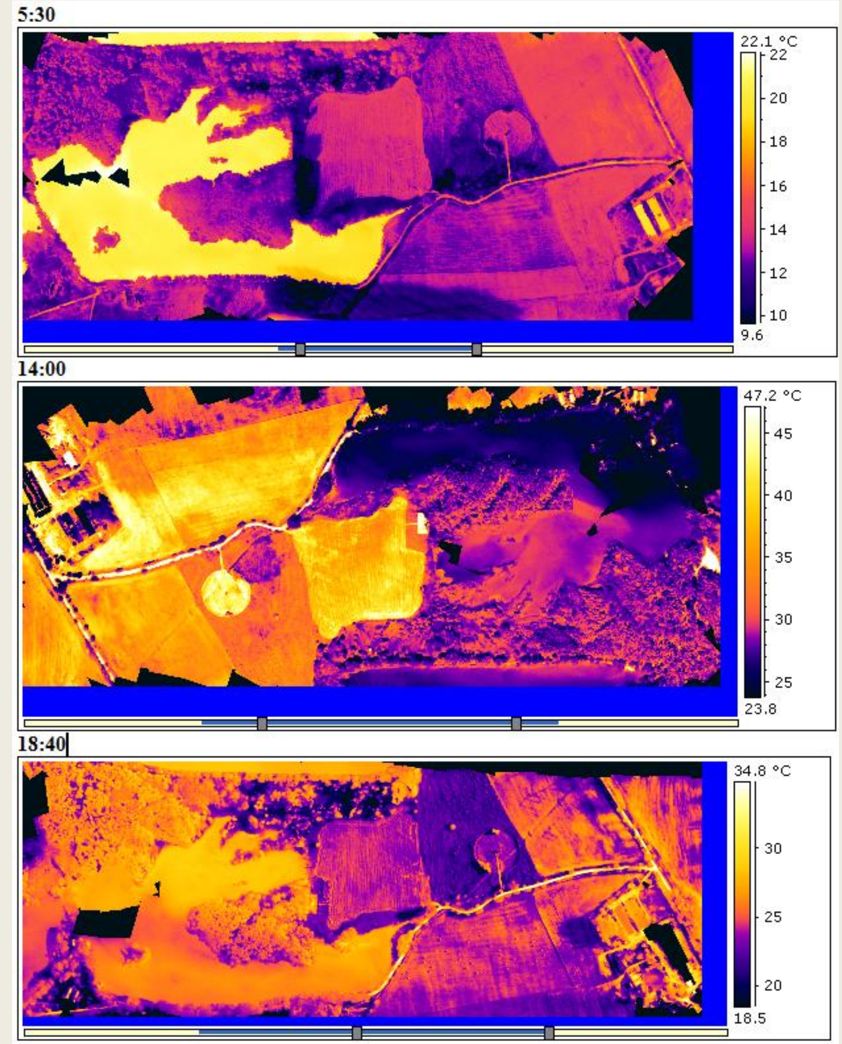
- to record the differences in **spatial and temporal dynamics of *surface temperature T_s* during a hot summer day** in a diverse cultural landscape

- What is the **relation between the *surface temperature T_s*** daily dynamics **and the *air temperature T_a*,** i.e. one of the main climate indicators?

surface temperature T_s = radiation temperature; emitted energy, **manifestation of the object s state**; measured by the systems detecting radiation reflected or emitted in the thermal part of the electromagnetic spectrum (commonly in 7 – 14 µm); reflects the surface characteristics ; interacts with biosphere

air temperature T_a = kinetic temperature; is an internal manifestation of the average translational energy of the molecules constituting a body; measured in a screen (2 meters above the ground) by a standardized method, the **purpose of which is to minimize the effect of surface characteristics** on the measured T_a





Daily courses of *surface temperature*

Daily courses of T_s of the studied localities. Each point is calculated from 1000 randomly selected pixel values. Points describe the median of the data, boxes are lower and upper quartiles and whiskers show 1.5 times of inter-quartile range of the data or maximum and minimum values if extremes did not occur. Extreme values are not shown in the graph.

Table Mean surface temperature (T_s) characteristics measured by the thermal camera from 4:50 to 20:10 in sixteen scanning times. T_{smin} temperature minimum, T_{smax} temperature maximum, D_s temperature difference, T_{savrg} mean temperature, SD_{sd} surface temperature variability throughout the day

Locality	T_{smin}	T_{smax}	D_s	T_{savrg}	SD_{sd}
HM	9.3	44.2	34.8	28.0	10.98
WM	10.0	31.9	21.9	22.6	6.78
AS	10.1	28.9	18.8	21.7	5.95
F	12.0	29.0	17.0	22.8	5.77
SV	13.2	37.2	24.0	26.4	7.70
W	20.4	29.3	8.9	25.6	3.41
A	16.1	47.6	31.4	33.0	10.19

HM – harvested meadow, **WM** – wet meadow, **AS** – alder stand, **F** – forest, **SV** – sparse vegetation, **W** – water, **A** - asphalt

Table Differences between Ts and Ta at 2m above ground. *Negative values – Ts is lower than Ta, positive (red) values – Ts is higher than Ta*

	Air temperature	Difference of mean surface temperature (T_s) of the localities (remote sensing) [C]						
Time	**Mean T_a at 2m [C]**	**Harvested meadow**	**Wet meadow**	**Alder stand**	**Forest**	**Sparse vegetation**	**Water**	**Asphalt**
4:50	10.5	-1.15	-0.55	-0.37	1.52	2.70	9.92	5.62
5:30	11.8	1.61	0.47	0.42	0.93	3.16	8.90	4.63
6:00	15.2	1.41	-0.61	-1.43	-0.99	1.23	5.12	3.82
7:10	18.5	4.08	-0.11	-1.29	-1.43	2.07	2.45	6.07
8:10	22.0	9.00	0.86	-0.81	-1.46	4.20	0.82	9.16
9:10	25.0	10.17	-0.14	-2.19	-2.90	3.89	-1.59	9.89
10:40	28.0	13.94	1.37	-1.36	-1.92	6.80	-2.04	14.52
13:10	30.1	14.07	1.79	-1.23	-1.13	7.13	-2.44	17.53
14:00	30.0	12.57	1.69	-1.27	-1.39	6.23	-0.86	16.63
15:10	30.7	8.51	-0.67	-3.03	-2.35	4.55	-1.96	14.19
16:10	31.0	4.58	-2.87	-4.58	-3.10	1.57	-1.62	10.95
17:10	31.1	0.51	-4.72	-5.16	-4.06	-0.50	-2.78	7.66
18:10	30.1	-4.05	-6.76	-6.72	-3.71	-2.95	-1.94	3.68
18:40	28.6	-5.08	-6.52	-6.23	-2.54	-3.57	-0.30	3.24
19:10	26.7	-6.92	-7.49	-6.29	-2.34	-3.60	0.45	2.94
20:10	20.6	-5.19	-4.33	-1.90	1.95	0.49	6.87	7.05

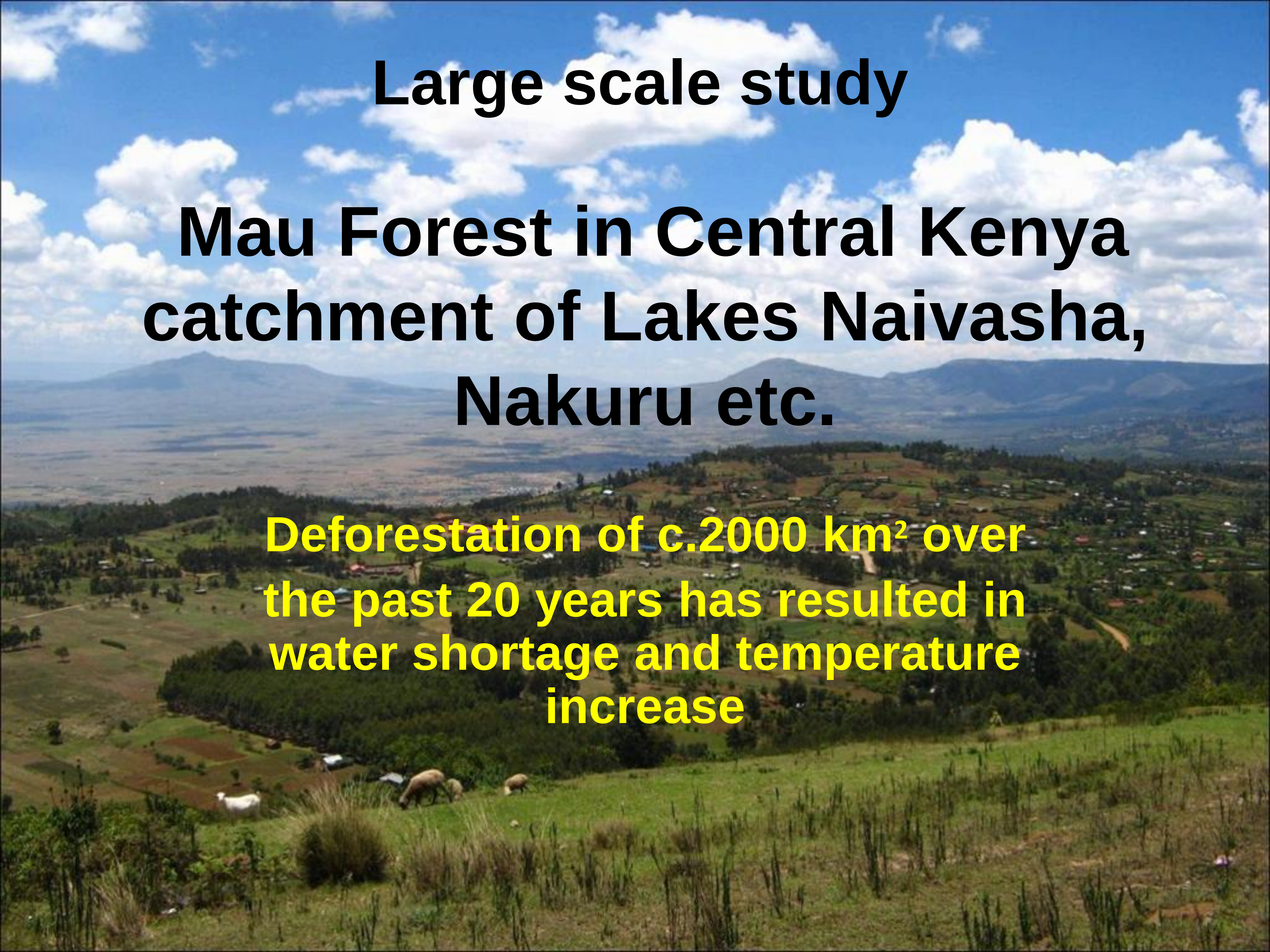
Effect of drainage on surface temperature is not reflected by standard method (air T at 2m)

- Maximum surface temperature of forest (**29.0 °C**), **water (29.3 °C)** **wet meadow (31.9 °C)** differ evidently from **asphalt (47.6 °C)** and **harvested meadow (44.2 °C).**

- Maximum surface temperature of dry surfaces (asphalt, harvested meadow) are **significantly higher (up to 17 °C) than** their **air temperature measured at 2m height in a screen.**

- Vegetation and water mitigate surface temperature fluctuations. Drainage, and removal of permanent vegetation cause surface temperature to rise. This isn't directly reflected by standard measurements of air temperature, which is evaluated in climatology.

Hesslerová, P., Pokorný, J., Brom, J., Rejšková – Procházková, A. *Daily dynamics of radiation surface temperature of different land cover types in a temperate cultural landscape.* Submitted.

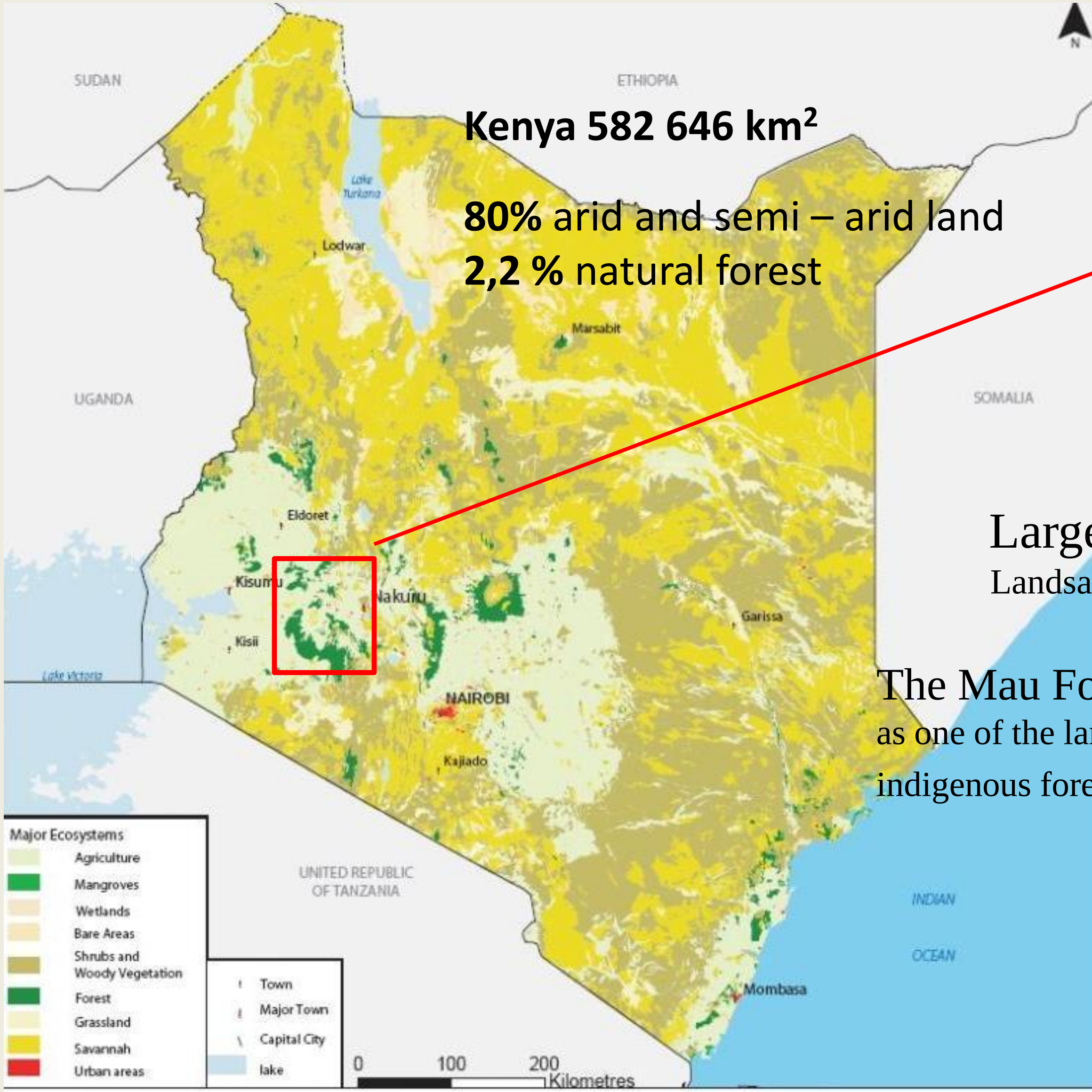


Large scale study

Mau Forest in Central Kenya catchment of Lakes Naivasha, Nakuru etc.

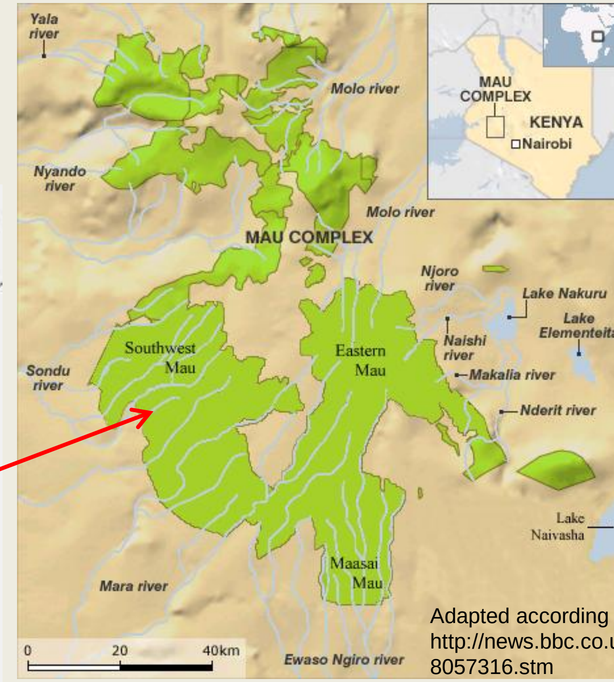
Deforestation of c.2000 km^2 over the past 20 years has resulted in water shortage and temperature increase

Mau Forest - Kenya



Kenya 582 646 km^2

80% arid and semi – arid land
2,2 % natural forest



Adapted according to: http://news.bbc.co.uk/2/hi/8057316.stm

Large scale thermal data – satellites

Landsat TM6 – spatial resolution 120m / 60 m

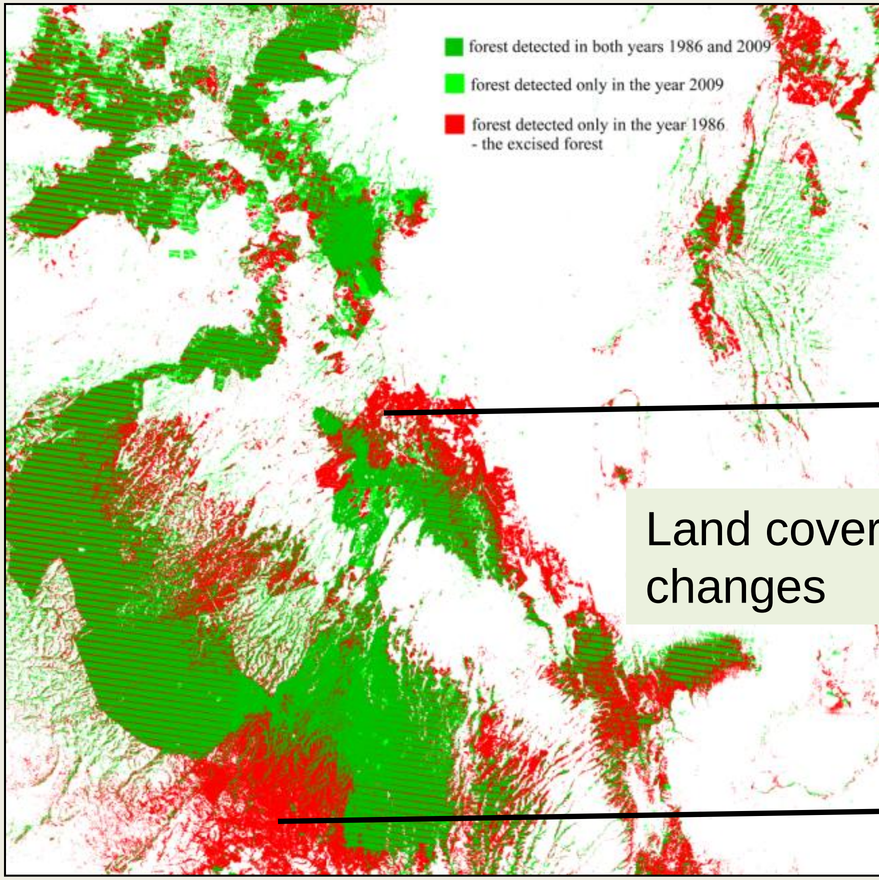
The Mau Forest Complex (4000 km^2) is referred as one of the largest remaining continuous blocks of indigenous forest in East Africa = WATER TOWER

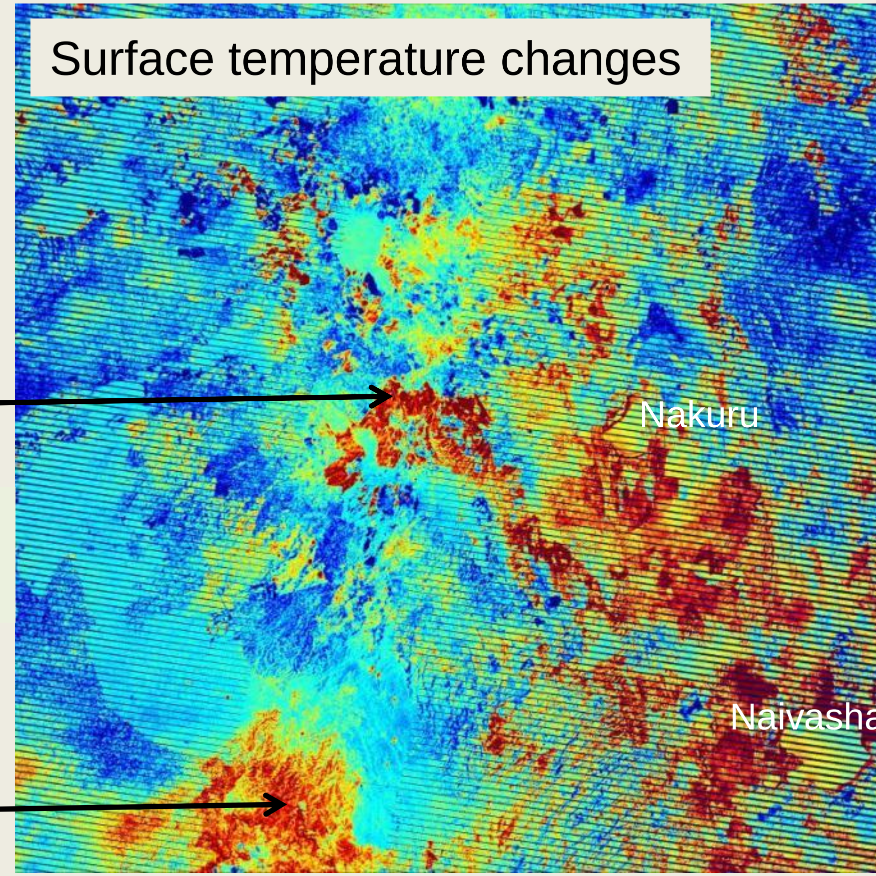
Since 1980 s **large scale deforestation**

Natural consequences – water shortage, temperature fluctuations
Social consequences – eviction, riots

Kenya Atlas of the Changing Environment; FAO 2003; Chapter 4: Environmental Hotspots; Available from: http://na.unep.net/atlas/kenya/downloads/chapters/Kenya_Screen_Chapter4a.pdf

Total area changes (1986-2009) of dense and humid forests within Mau forest region – based on Landsat satellite images assessment

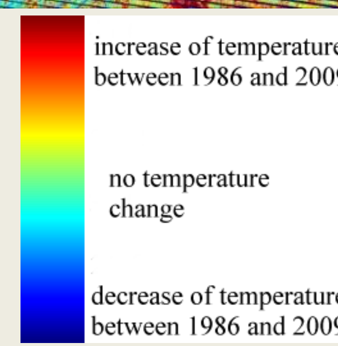


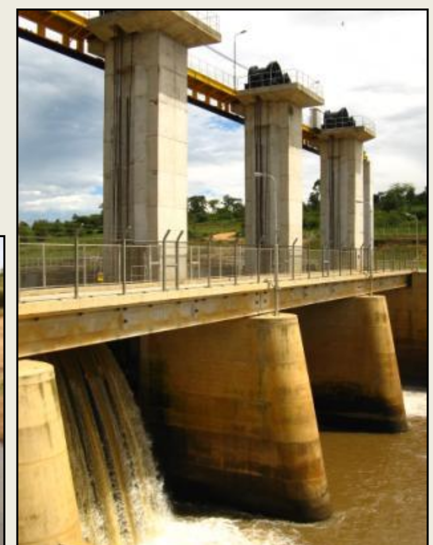


1986: 520 000 ha
2009: 340 000 ha

Clear cuts:
180 000 ha

The changes of temperature between the years 1986 and 2009, gained as image difference of the standardized temperature. It is evident; the extreme rise of temperature is bounded with the areas of deforestation. Its consequences are also evident in the Rift Valley region, between the great Lakes Nakuru and Naivasha. Some areas having been converted into fast-growing plantation forest show the opposite trend.

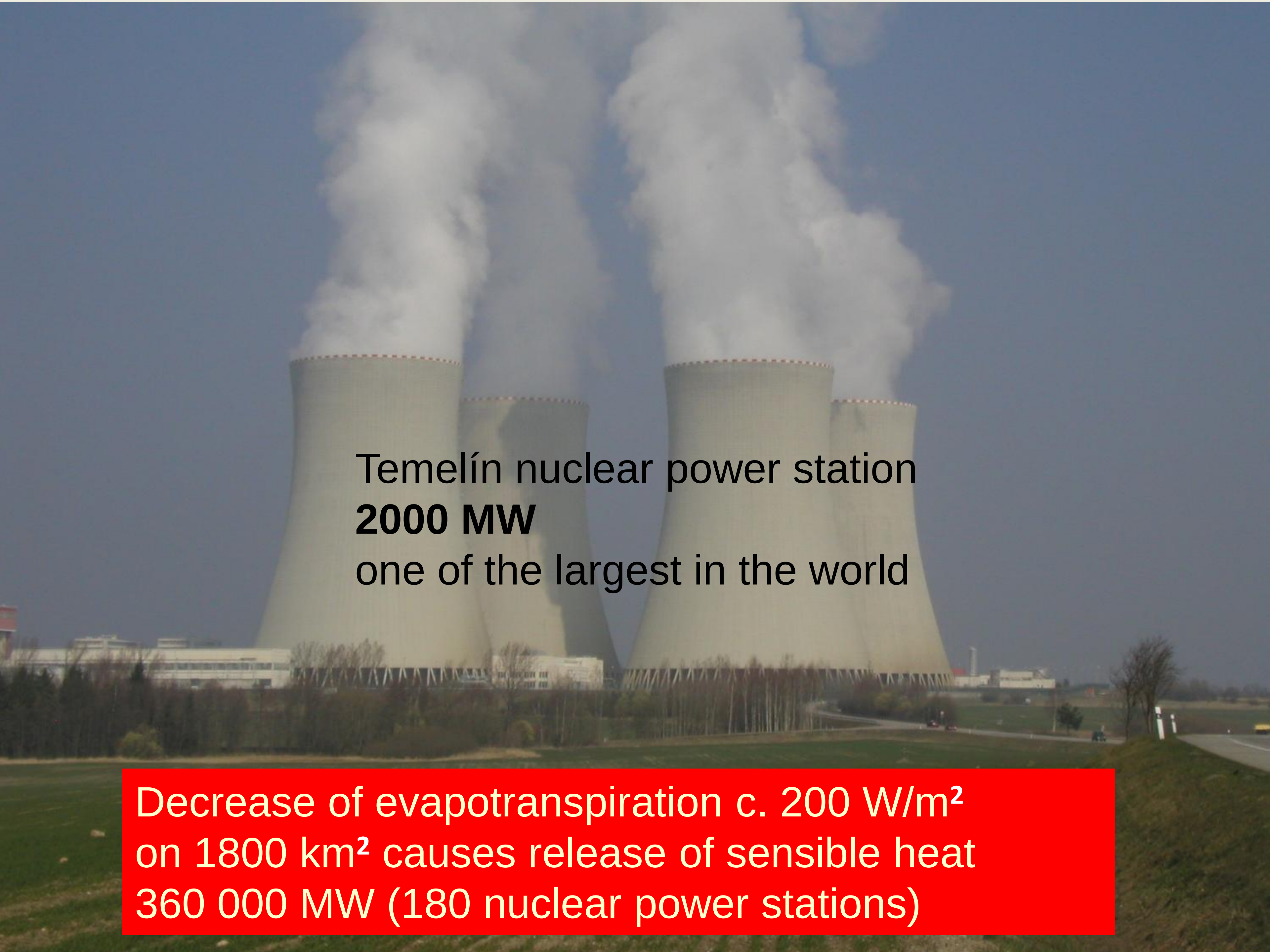




… few numbers

- Consider: air at temperature 25 °C can contain up c. 22 grams/ m^3; at 40 ° C has a doubled capacity (50 g / m^3)
- Deforestation and the consequent **rise of temperature (40 °C)** lead to a transport of warm and relatively dry air into the upper atmosphere (glacier melting on mountains)
- 0,7 kWh (2 500kJ) is needed to evaporate 1 liter of water
- Decrease in evapotranspiration of about 2 mm/ km^2/day = decrease in evaporation of 2 000 000 litres and release of 1.4 million kWh sensible heat.
- The Mau Forest complex has lost 1800 km^2 during last two decades - 2,6 billion kWh sensible heat released from this area a day
- CHANGES OF LAND COVER acclerate transport of huge amount of hot air nd water into atmosphere

Hesslerová, P., Pokorný, J. (2010): Forest clearing, water loss, and land surface heating - the cost of development in Kenya. *International Journal of Water.* Vol. 5, No. 4, pp. 401-418



Temelín nuclear power station
2000 MW
one of the largest in the world

Decrease of evapotranspiration c. 200 W/m^2
on 1800 km^2 causes release of sensible heat
360 000 MW (180 nuclear power stations)

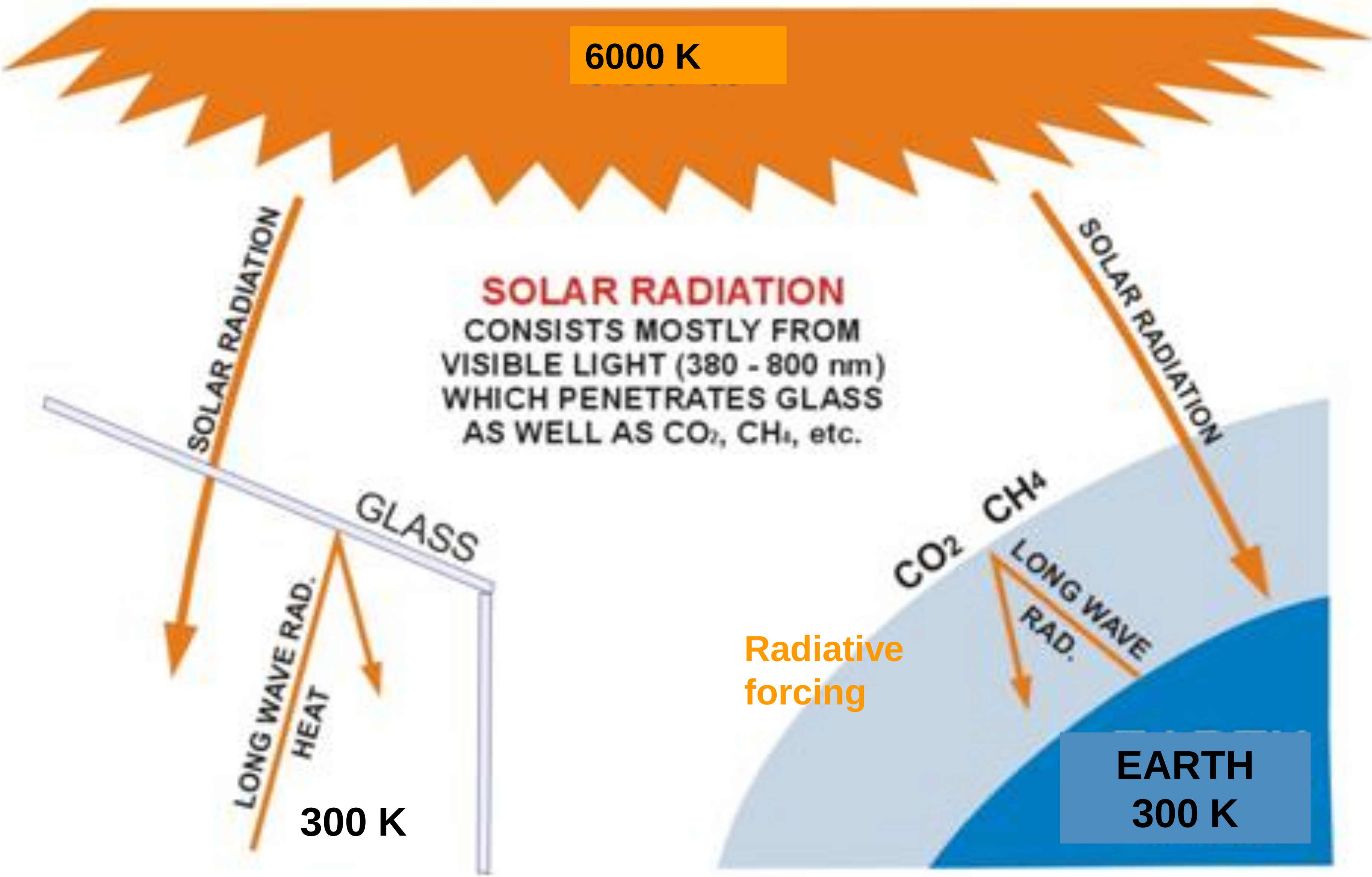
Energy fluxes linked with life processes – feedback to supply of solar energy

- Primary production (**photosynthesis**): **W/m²**
- **Evapotranspiration**: **hunderds W/m²**
- **Decomposition** of organic matter in soil: **tens W/m²**
- **Ground heat flux** up to **100W/m²**
- **Heating of plant** stands: several to **tens W/m²**
- **Radiative forcing 1 – 3W/m² from year 1770**
- **Life processes can easily compensate for radiative forcing**
- **1412 W m^{-2}** in early January **to 1321 W m^{-2}**

Energy fluxes in ecosystems (life processes) are uncomparably higher than radiative forcing caused by increased CO_2

- in climate change science changes in vegetation cover are considered mainly in relation to changes of surface reflection **(albedo**) and as a **sink/source of CO_2**

Green House Effect



Fluxes of solar energy in ecosystems

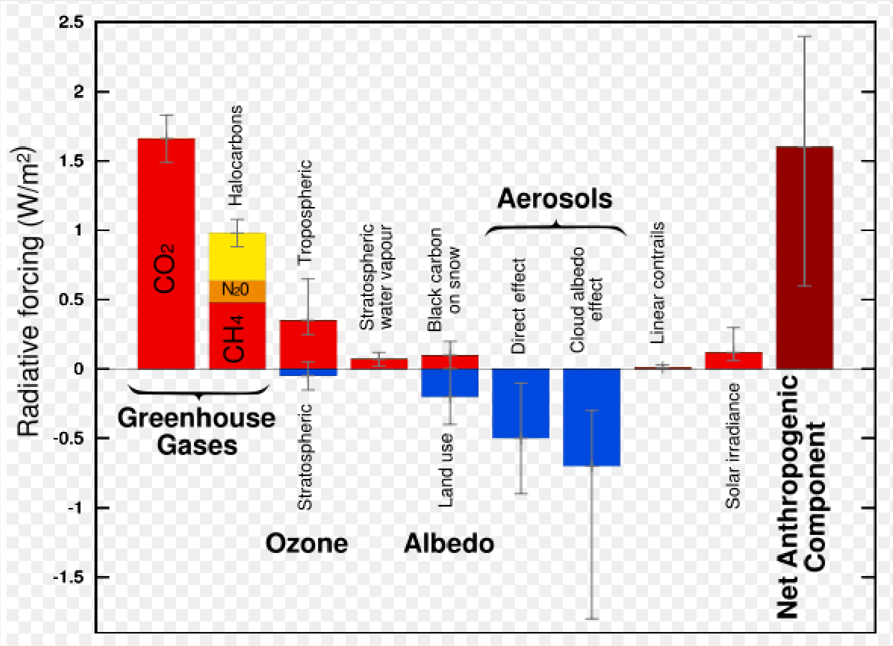
Evapotranspiration: **hunderds W. m^{-2}**

Decomposition of organic matter in soil: **tens W. m^{-2}**

Heating of plant stands: **several to ten W. m^{-2}**

Heat flux to soil: **up to 100W.m^{-2}**

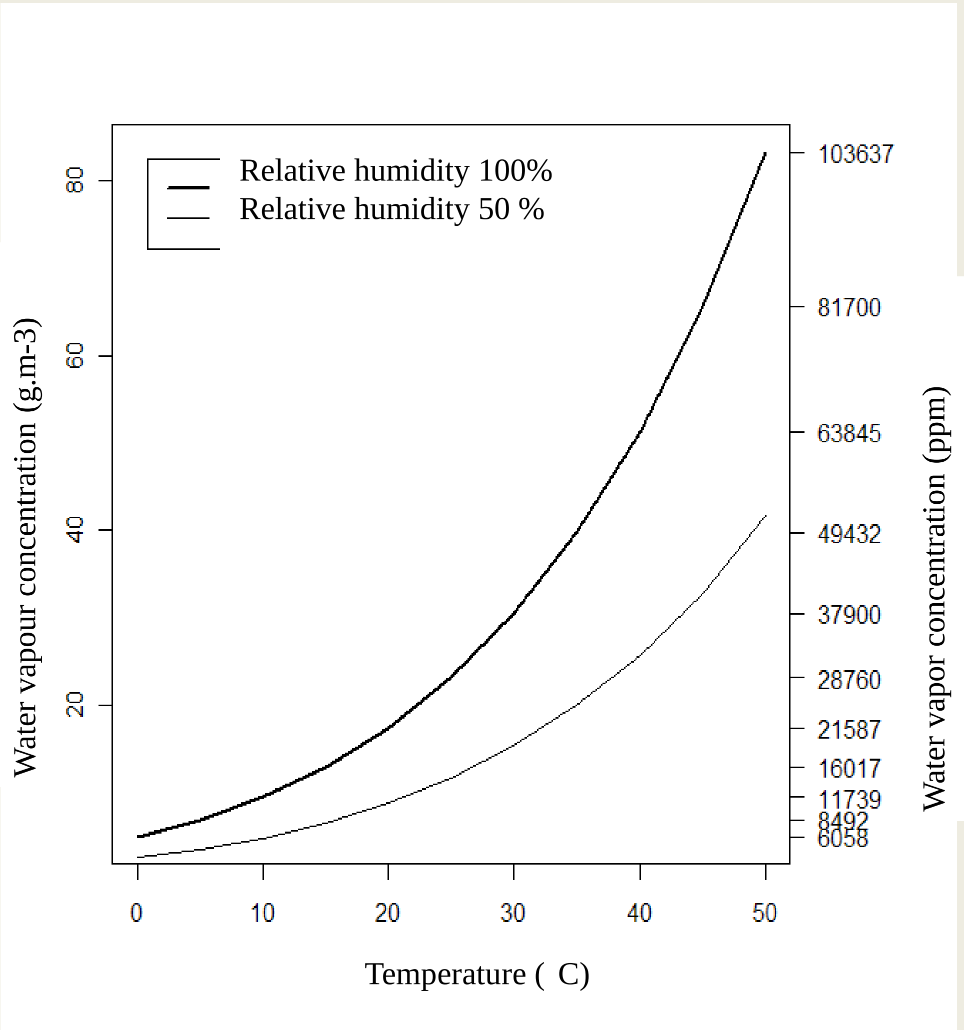
Primary production (photosynthesis): several **W. m^{-2}**



Historical Global Annual Mean Radiative Forcing, 1750 to 2000; ©IPCC 2007

Radiative forcing caused by increase of CO_2 and other greenhouse gases from 1750 **1 – 3 W.m^{-2}**

Concentration of water vapour in atmosphere is substantialy higher than concentration of carbon dioxide, methane etc. Changes of phases of water (liquid, gaseous, solid) are linked with energy binding/release. Turnover of water vapour is fast.



concentration of CO_2 380 ppm

methane 1.5 ppm

water vapour several thousands up to hundred thousands ppm

Water vapour and CO_2 in air

the amount of water vapour found in plant stands and in the atmosphere is many times higher and **it changes dramatically** across time and space. For example, air saturated with water **at 21°C** contains:

18 gm–3 of water vapour, i.e., **22,400 ppm.**

Air saturated with water **at 40°C** contains:

50 gm–3 of water vapour, i.e., **62,200 ppm**.

Carbon dioxide increased from 280 to 390 ppm (1750 till present)

Methane rised from 0.6 to 1.5 ppm

Life processes directly affect distribution of solar energy on Earth

- **Indirect effect of vegetation**: production or sequestration of green house gases

- **Direct effect:**

  damping of heat potentials by evapotranspiration

  (humans create potentials by drainage – overheating)

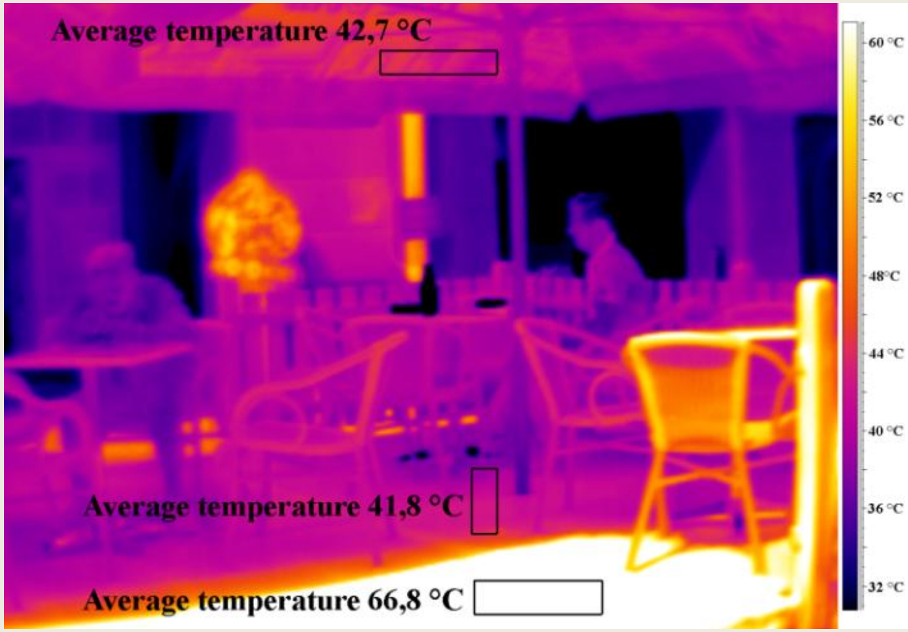
  Biosphere dissipate solar energy in terms of non-equilibrium thermodynamic. There is no simple radiation balance of Earth –Universe driven by albedo and dry greenhouse gases.

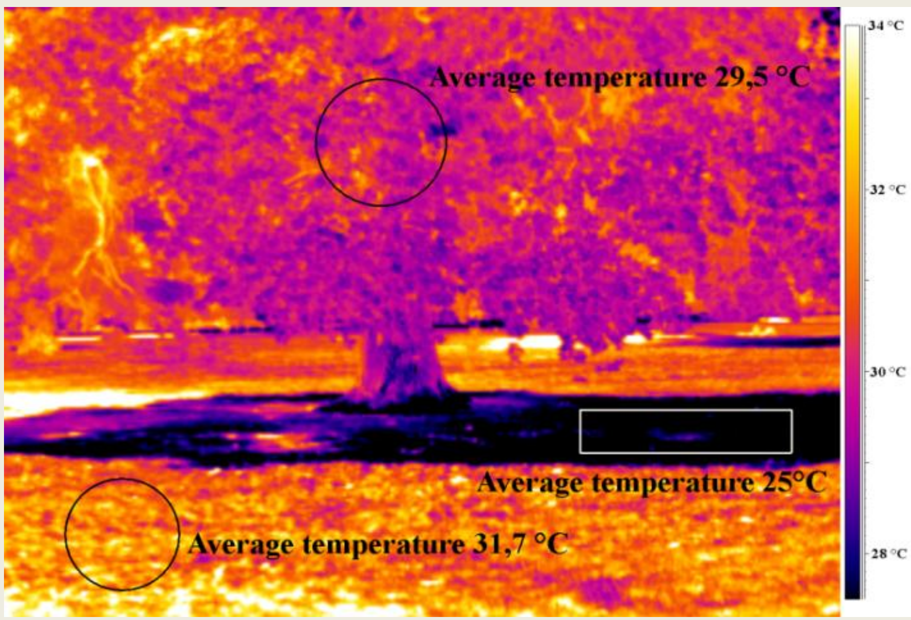
Life abhors gradients

E.D. Schneider, D. Sagan, 2005 Into the Cool, Energy Flow, Thermodynamics and Life.

Difference between the shade of parasol(umbrella) and a tree?

- *Let´s go back to square of Třeboň town*
- A tree cools by transpiration of water
- 100litres of transpired water a day = 70kWh cooling effect on square and 70 kWh warming effect in cool places where water vapour condensates
- Compare with an manufactured air-con! Is it able to mimic a tree? For what price? = ecosystem services

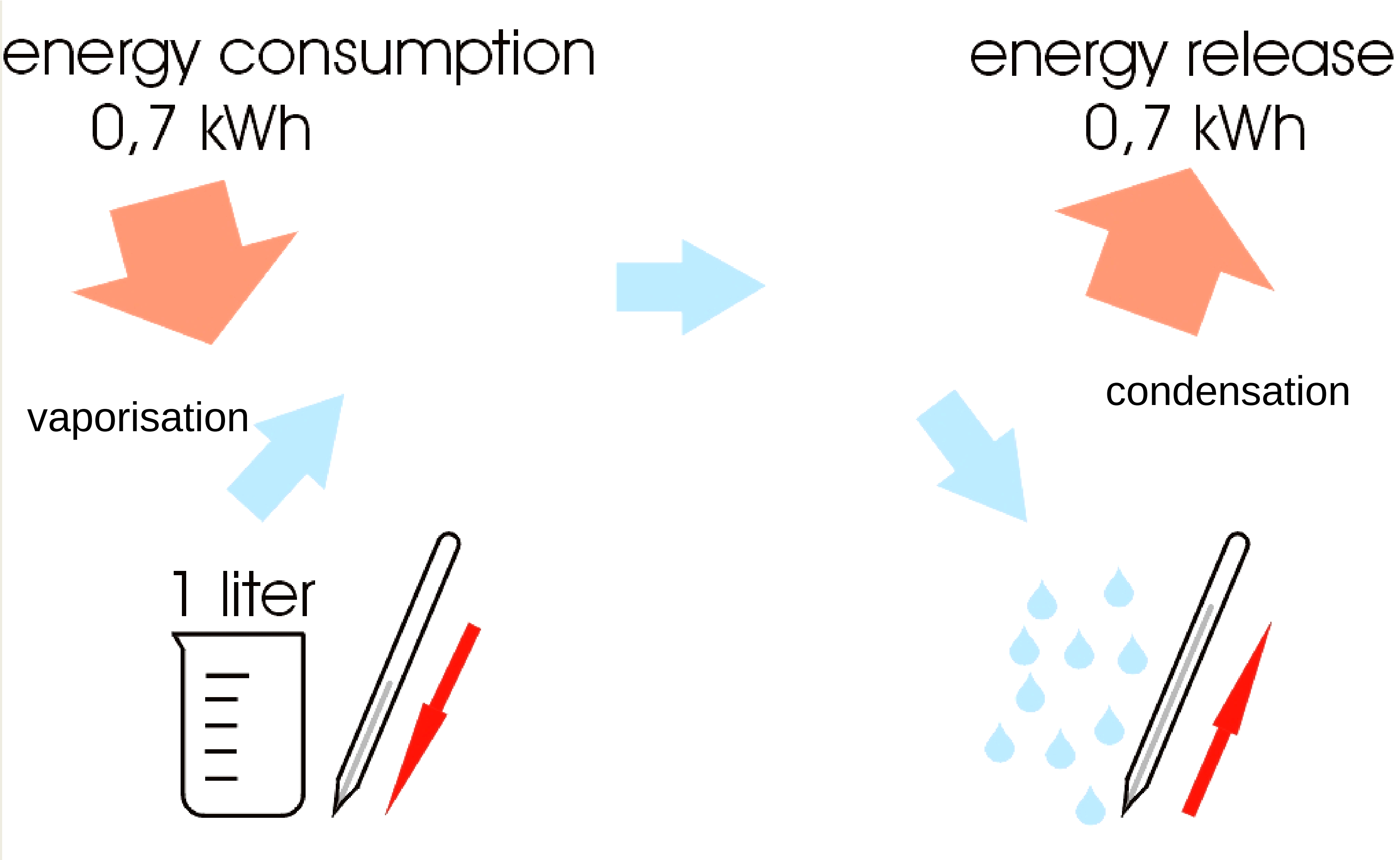




Eiseltová, M., Pokorný, J., Hesslerová, P., Ripl, W. (2012): Evapotranspiration – A Driving Force in Landscape Sustainablility. *In*. Irmak A. (ed.) *Evapotranspiration - Remote Sensing and Modeling.* InTech, pp. 305 – 328.
Available from: http://www.intechopen.com/articles/show/title/evapotranspiration-a-driving-force-in-landscape-sustainability

Makarieva, A.M., Gorshkov, V.G. (2007) Biotic pump of atmospheric moisture as driver of the hydrological cycle on land. Hydrol Earth Syst Sci 11(2), 1013–1033.

LATENT HEAT of water vaporization – princip of perfect airconditioning: cooling (vaporisation) and warming (condensation)



Do you really think that science provides a true and honest explanation of the causes of climate change?

- IPCC focuses on correlations between mean Earth temperature and concentration of GHG (carbon dioxide, methane etc.).
- Mitigation of climate change through reduction of GHG (carbon dioxide, methane) is recommended. Incentives are aimed at „low carbon society“.
- **Why restoration of water cycle through vegetation cover is not supported?**

Desertification

- Earth losses annualy 200 000 km^2 of productive land due to lack of water
- Desertification: 60 000 km^2/year
- **According to FAO: 30 - 40 % of continents surface suffer from water defficiency.**

(6.45 x 107 km^2).

Stop desertification and bring back water and vegetation:

- Air-conditioning via short water cycle
- More water,more biomass, more food
- Biodiversity increase
- Carbon sequestration
- Recycling of nurients and water
- Employment
- **Any negative effect??**

Kravčík, M., Pokorný, J., Kohutiar, J. et al: 2009, Water for Recovery of Climate
www.waterparadigm.org
Eiseltová, M., Pokorný, J., Hesslerová, P., Ripl, W. 2011 Evapotranspiration – A Driving Force in Landscape Sustainability In: Ayse Irmak (ed.)Evapotranspiration – Remote Sensing and Modeling, InTechopen, pp 305 – 328, Rijeka, Croatia

NOTHING NEW

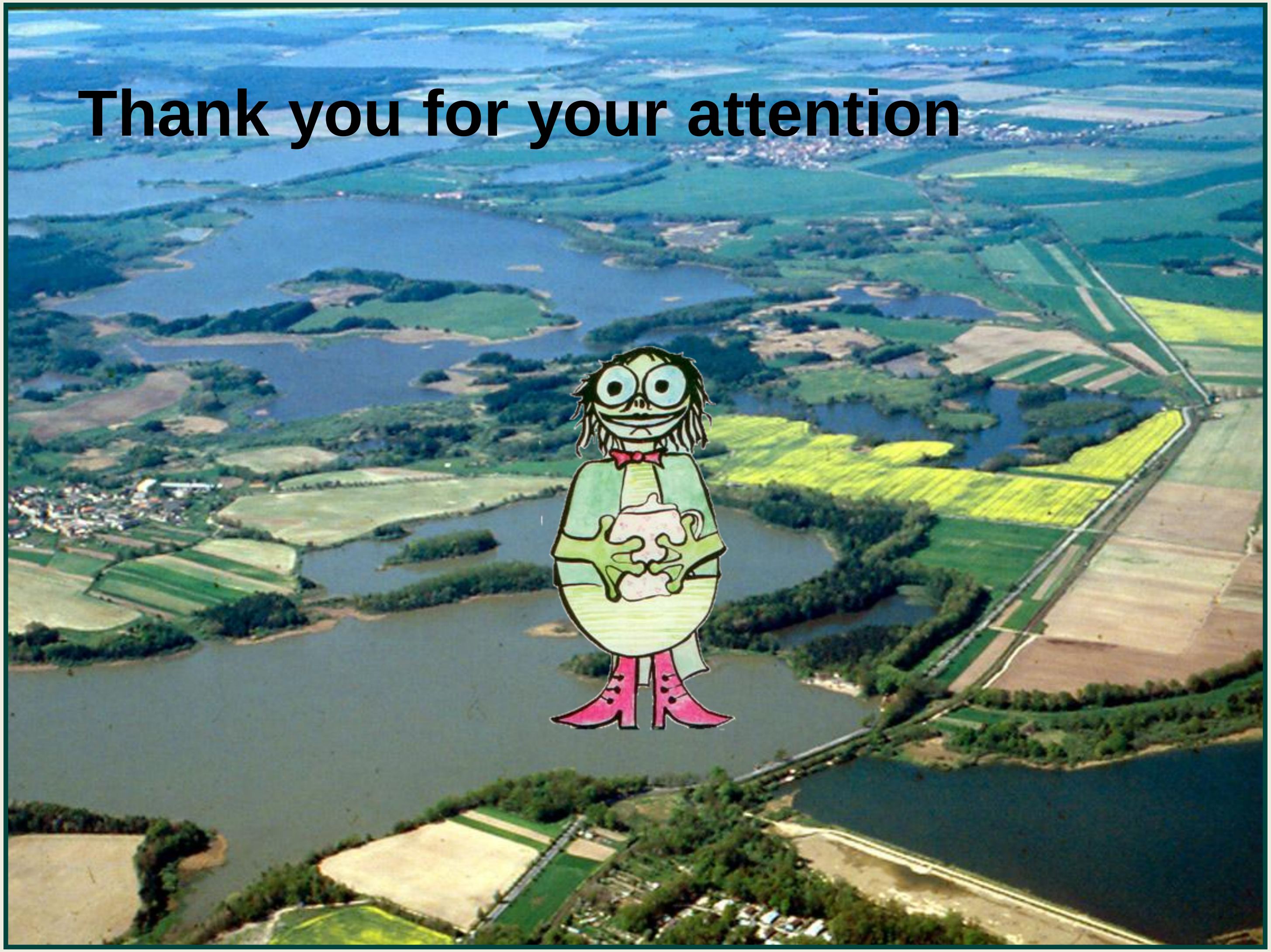
Bohemian King, Roman Emperor

CHARLES IV.

„…We order to all towns to build up ponds so that Our Kingdom, Bohemia, has a lot of fishes and moisture…Water in swamps and bogs accumulated should evaporate under the condition of sun and warm breeze and so will affect healthy on plants as a vapour.“

Maiestas Carolina (1351 – 1353)

South Bohema, Třeboň region, Czech Republc



Fishponds – artificial lakes were constructed in 16th century