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

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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 elliptic trajectory of Earth around Sun.
EVAPOTRANSPIRATION COOLS

DAILY INPUT OF SOLAR ENERGY
6 kWh.m²

0 - 1000 W.m² flux

HEAT
60 - 70 %

EVAPOTRANSPIRATION
70 - 80 %

EVAPOTRANSPIRATION
10 - 20 %

REFLECTION
5 - 10 %

REFLECTION
5 - 15 %

HEAT FLUX
5 - 10 %

DRAINED FIELD
Higher temperature

HEAT FLUX
5 - 10 %

LAKE, MEADOW, FOREST,
LANDSCAPE SATURATED WITH WATER
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

Latent heat of ET

Rs - global radiation
Rn - net radiation
\( \alpha \) - 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

- Air Temperature
- Relative Humidity
- Computer
- Shortwave radiation Sensor (Rs)
- Long wave radiation Sensor (RL)
- Solar energy panel
- Data logger
- Soil Temperature
Comparison: wetland x dry surface

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

Evapotranspiration reaches 500Wm2

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)

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 cameras operated with a common trigger. The frequency of photography is derived from the forward speed of the airship.
Třeboňsko Landscape Protected Area

Třeboňsko (700 km²) - 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
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. $T_{s\text{min}}$ temperature minimum, $T_{s\text{max}}$ temperature maximum, $D_s$ temperature difference, $T_{s\text{avrg}}$ mean temperature, $SD_{sd}$ surface temperature variability throughout the day.

<table>
<thead>
<tr>
<th>Locality</th>
<th>$T_{s\text{min}}$</th>
<th>$T_{s\text{max}}$</th>
<th>$D_s$</th>
<th>$T_{s\text{avrg}}$</th>
<th>$SD_{sd}$</th>
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<td>HM</td>
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<td>44.2</td>
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<td>17.0</td>
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<tr>
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<td>25.6</td>
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<td>47.6</td>
<td>31.4</td>
<td>33.0</td>
<td>10.19</td>
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</table>

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

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean $T_a$ at 2m [°C]</th>
<th>Harvested meadow</th>
<th>Wet meadow</th>
<th>Alder stand</th>
<th>Forest</th>
<th>Sparse vegetation</th>
<th>Water</th>
<th>Asphalt</th>
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<td>9.92</td>
<td>5.62</td>
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<td>1.61</td>
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<td>0.42</td>
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<td>3.16</td>
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<td>1.23</td>
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<td>3.82</td>
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</tr>
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</table>

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.

Large scale study

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

Deforestation of c.2000 km² over the past 20 years has resulted in water shortage and temperature increase.
Mau Forest - Kenya

Kenya 582,646 km²
80% arid and semi-arid land
2.2% natural forest

Large scale thermal data – satellites
Landsat TM6 – spatial resolution 120m / 60m

The Mau Forest Complex (4000 km²) is referred to as one of the largest remaining continuous blocks of indigenous forest in East Africa = WATER TOWER

Since 1980s large scale deforestation

Natural consequences – water shortage, temperature fluctuations
Social consequences – eviction, riots
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/m³; at 40 °C has a doubled capacity (50 g/m³)
- **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/km²/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 km² during last two decades - 2,6 billion kWh sensible heat released from this area a day
- **CHANGES OF LAND COVER** accelerate transport of huge amount of hot air and water into atmosphere

Temelín nuclear power station

2000 MW
one of the largest in the world

Decrease of evapotranspiration c. 200 W/m² on 1800 km² 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**): \( W/m^2 \)
- **Evapotranspiration**: hundreds \( W/m^2 \)
- **Decomposition** of organic matter in soil: tens \( W/m^2 \)
- **Ground heat flux** up to 100\( W/m^2 \)
- **Heating of plant stands**: several to tens \( W/m^2 \)
- **Radiative forcing** 1 – 3\( W/m^2 \) 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

Solar radiation consists mostly from visible light (380 - 800 nm) which penetrates glass as well as CO$_2$, CH$_4$, etc.

Radiative forcing

EARTH 300 K
Fluxes of solar energy in ecosystems

Evapotranspiration: hundreds 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\(^{-2}\)

Radiative forcing caused by increase of CO\(_2\) and other greenhouse gases from 1750 1 – 3 W.m\(^{-2}\)

Historical Global Annual Mean Radiative Forcing, 1750 to 2000; ©IPCC 2007
Concentration of water vapour in atmosphere is substantially 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**

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
• 100 litres of transpired water a day = 70 kWh 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

LATENT HEAT of water vaporization – principle of perfect air conditioning: cooling (vaporisation) and warming (condensation)

energy consumption 0.7 kWh

vaporisation

energy release 0.7 kWh

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 annually 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 deficiency. (6.45 x 10$^7$ 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 nutrients and water
- Employment
- Any negative effect??


www.waterparadigm.org

…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)
Fishponds – artificial lakes were constructed in 16th century

Thank you for your attention