St. Petersburg Scientific Research Center for Ecological Safety RAS

Mapping of Taiga Ecosystems Evapotranspiration by Using Results of EOS and Flux Tower observations

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PEEX collaboration meeting St. Petersburg, Helsinki 2020

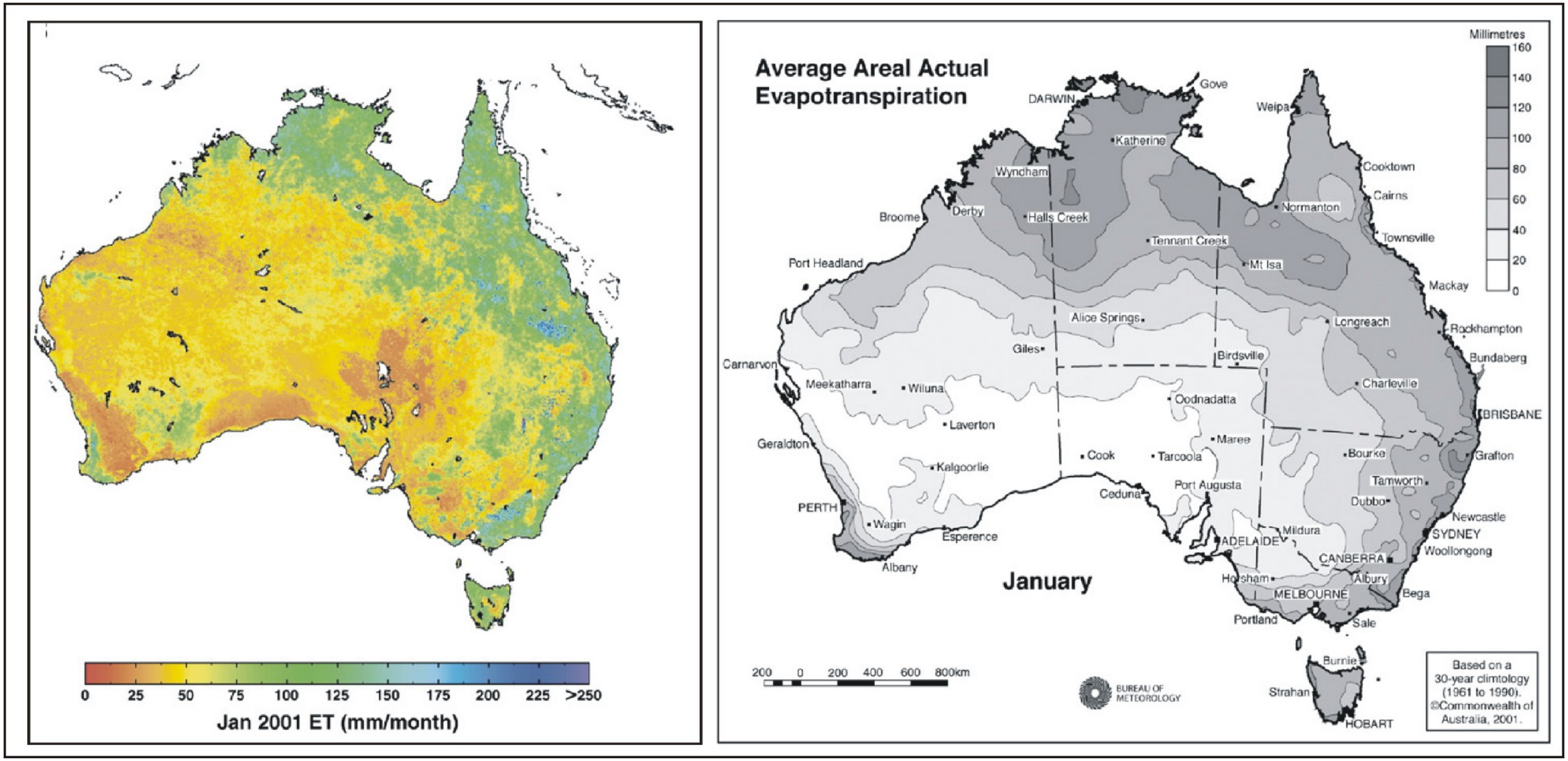
State of Art

Helen A. Cleugh, Ray Leuning, Qiaozhen Mu, Steven W. Running. Regional evaporation estimates from flux tower and MODIS satellite data. Remote Sensing of Environment 106 (2007) 285–304.

Maps of the Monthly Evapotranspiration of Australia

On the base of satellite IR-thermal survey & flux tower

On the base of 30-year climatology (1961 to 1990)



Australian Method

Helen A. Cleugh, Ray Leuning, Qiaozhen Mu, Steven W. Running. Regional evaporation estimates from flux tower and MODIS satellite data. Remote Sensing of Environment 106 (2007) 285–304.

Major Relations

$$H = \rho c_p \frac{T_s - T_a}{R_a}, \quad (1)$$

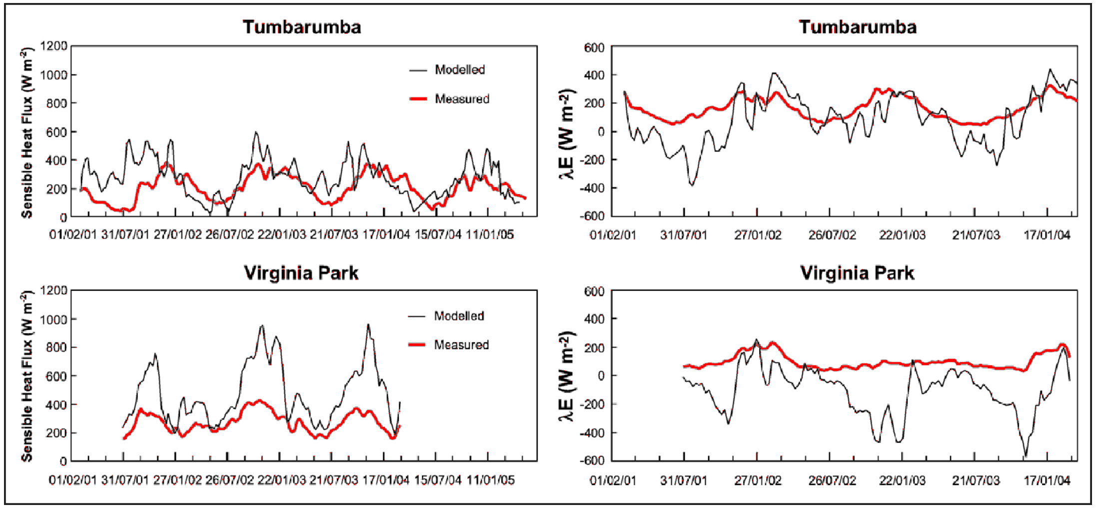
$$\lambda E = \frac{\rho c_p}{\gamma} \frac{e_s - e_a}{R_a + R_s}, \quad (2)$$

$$A = R_n - G - \Delta S = H + \lambda E, \quad (3)$$

where H, λE and A are the fluxes of sensible heat, latent heat and available energy, R_n is net radiation, G is soil heat flux; ΔS is the heat storage flux; T_s, T_a are the aerodynamic surface and air temperatures; e_s, e_a are the water vapour pressure at the evaporating surface and in the air; R_a is the aerodynamic resistance, R_s is the surface resistance to evaporation, λ is the latent heat of evaporation, ρ is air density, and c_p is the specific heat capacity of air. The psychometric constant γ is given by $\gamma = (M_a/M_v)(c_p P_a/\lambda)$, where M_a and M_v are the molecular masses of dry air and water vapour and P_a is atmospheric pressure.

Time series of measured and simulated: heat (H) and evaporation (λE) fluxes

Data are smoothed 8-day averages from 2001 to 2005 and are for the period 10:00–11:00 AM only



Main idea: - to use flux towers to measure aerodynamic resistance and for the **moment of satellite flight** to extend the results to the total investigating territory with help of Terra/Aqua(MODIS) satellite IR-thermal data.

Shortcomings of the Australian method

1. The method is attractive, but the significant portion of Russia and Finland situated in the another geographical zone - Taiga Biome.

2. The traditional theory of boundary layer heat transfer is correct for arid and semi-arid regions and incorrect for the forested territories, because vegetation, as an alive object, regulates it's own temperature by an evaporation.

3. It is not possible to map precisely a daily averaged evaporation, because the evaporation regime of forest is different during day and night.
More over, each windflaw distorts results.

4. The heat flux into the soil G must be determined empirically – the source of errors.

Conclusions:

1) The traditional equations, based on the theory of boundary layer heat transfer of land surface has to be modified for the Taiga Biome.

2) It is better to apply **the thermal inertia approach**, because:
   - it provides possibility to measure the daily averaged evaporation;
   - this approach more conservative to windflaws;
   - "soil" heat flux can be retrieved as solution via the thermal inertia.

Project

Target: the method of daily averaged evaporation rate mapping by using EOS and flux tower data, applied for forest ecosystems

Subject of investigation: a surface energy budget of the Taiga Biome ecosystems

Objectives:

- To develop new equations of energy exchange, suitable for a forest cover.
- To simulate elements of the surface energy budget of forest ecosystems by using new equations and flux tower data.
- To verify the forest cover temperatures, retrieved from satellite data by outgoing IR-thermal irradiance, measured by the flux tower.
- To map daily averaged evaporation of territory of Leningrad Oblast' and Finland on the base of flux towers and EOS data.

Surface Energy Budget

Major relations

$$S * (1\text{-}A) = H + LE + G + R \qquad (1)$$

where:

S – shortwave solar radiation;
A – surface albedo;
H – sensible heat flux;
LE – latent heat flux;

G – heat flux in the soil;
R – far IR radiation budget;

$$H = k * \rho * c * \Delta T/\Delta h \quad (2)$$

$$LE = D * \rho * L * \Delta e/p_a \Delta h \quad (3)$$

where:

$\Delta T = T_{surf} - T_{air}$, - temperature difference between the surface and air on the height Δh;
k – heat exchange (turbulent) coefficient ;
ρ, c – air density and heat capacity;

$\Delta e = e_{surf} - e_{air}$; vapor partial pressure difference between the surface and air on the height Δh;
D – mass exchange (turbulent diffusion) coefficient;
p_a – air pressure
L – specific latent heat;
ρ – air density;

Modified Equations

$$H = k * \rho * c * \Delta T/\Delta h \qquad (4)$$

$$LE = D*\rho*L*\Delta e/p_a\Delta h$$

k - heat exchange coefficient;
$\Delta T = T_{surf} - T_{air}$, - temperature difference between the surface and air on the height Δh;
ρ and c – air density and heat capacity;

D - mass exchange coefficient;
$\Delta e = e(T_{surf})$ - e_{air} - vapor partial pressure difference between the surface and air on the height Δh; p_a – air pressure; L – specific latent heat;

$$\mathbf{k = \gamma * (S + W)} \qquad (6)$$

γ – heat exchange factor (model parameter)

$$\mathbf{D = \chi * (S + W)} \qquad (7)$$

χ – model parameter

Normalized: **W** – wind speed; **S** – shortwave solar radiation.

$$G_\tau(P) = S_\tau * (1\text{-}A) + H_\tau(\gamma) + LE_\tau(\chi) + R_\tau \qquad (8)$$

P – thermal inertia; τ – time.

Solution of this system of equations regarding P, χ, γ, G was done by using method of impulse response function (*Jaeger J.C. Pulsed surface heating of a semi-infinite solid. Quat. of Applied Mathematics. Vol. XI, 1953, pp. 132-137.)*

Data

<u>Object of investigation:</u> Taiga Biome ecosystems of Leningrad Oblast’ of Russia and Finland

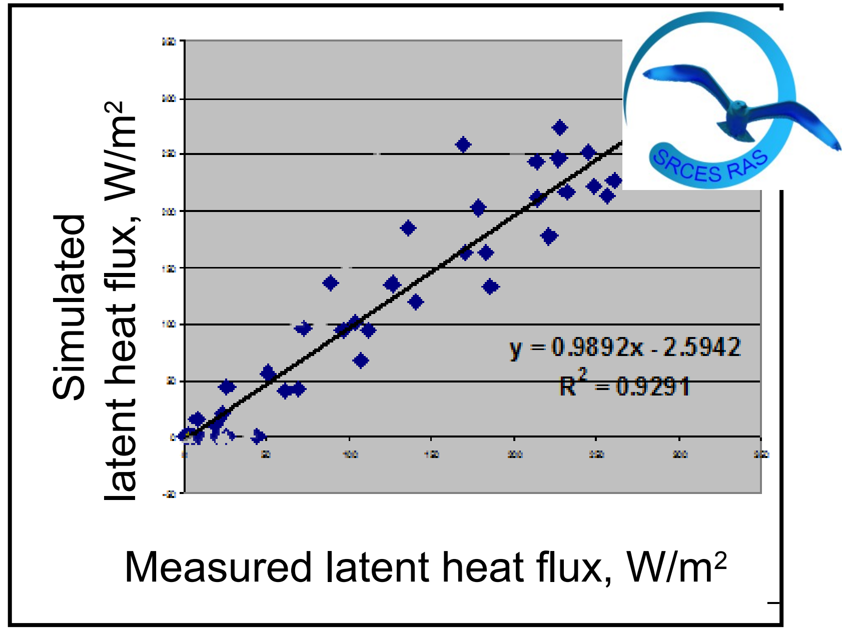
Investigating territory

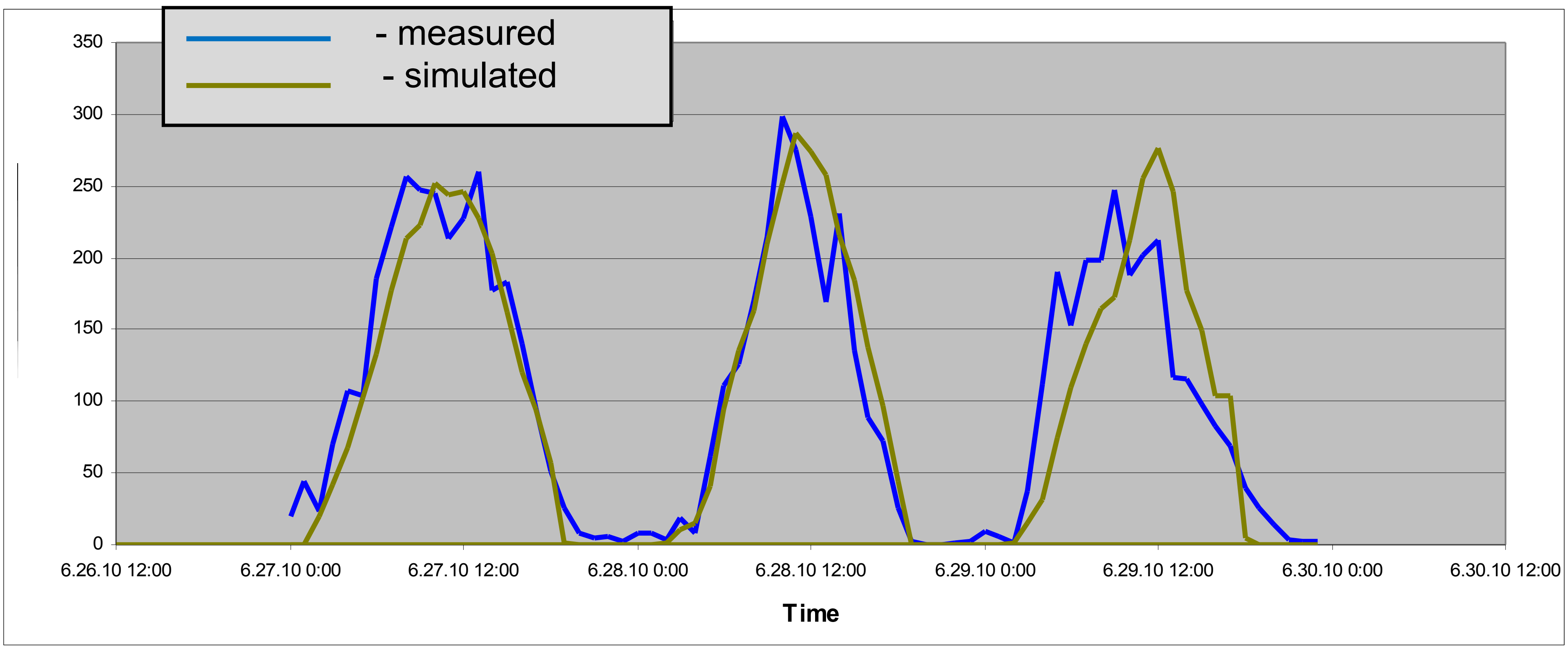
<u>Flux towers:</u>

1 – Siikaneva
2 – Hyytiala
3 – Kumpula
4 - Torni

Forest
Latent Heat Flux:

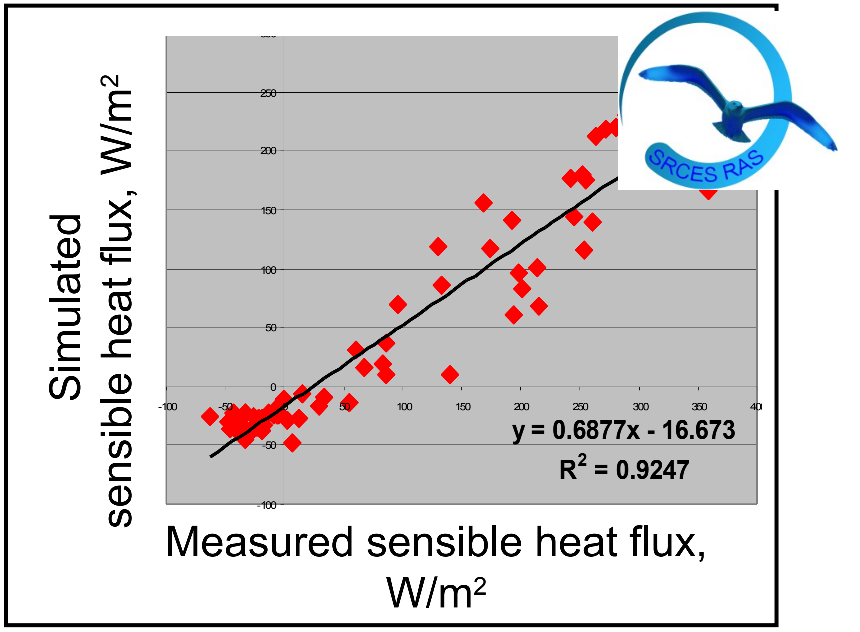
- measured at Hyytiala flux tower;
- simulated by used satellite & meteorological data.

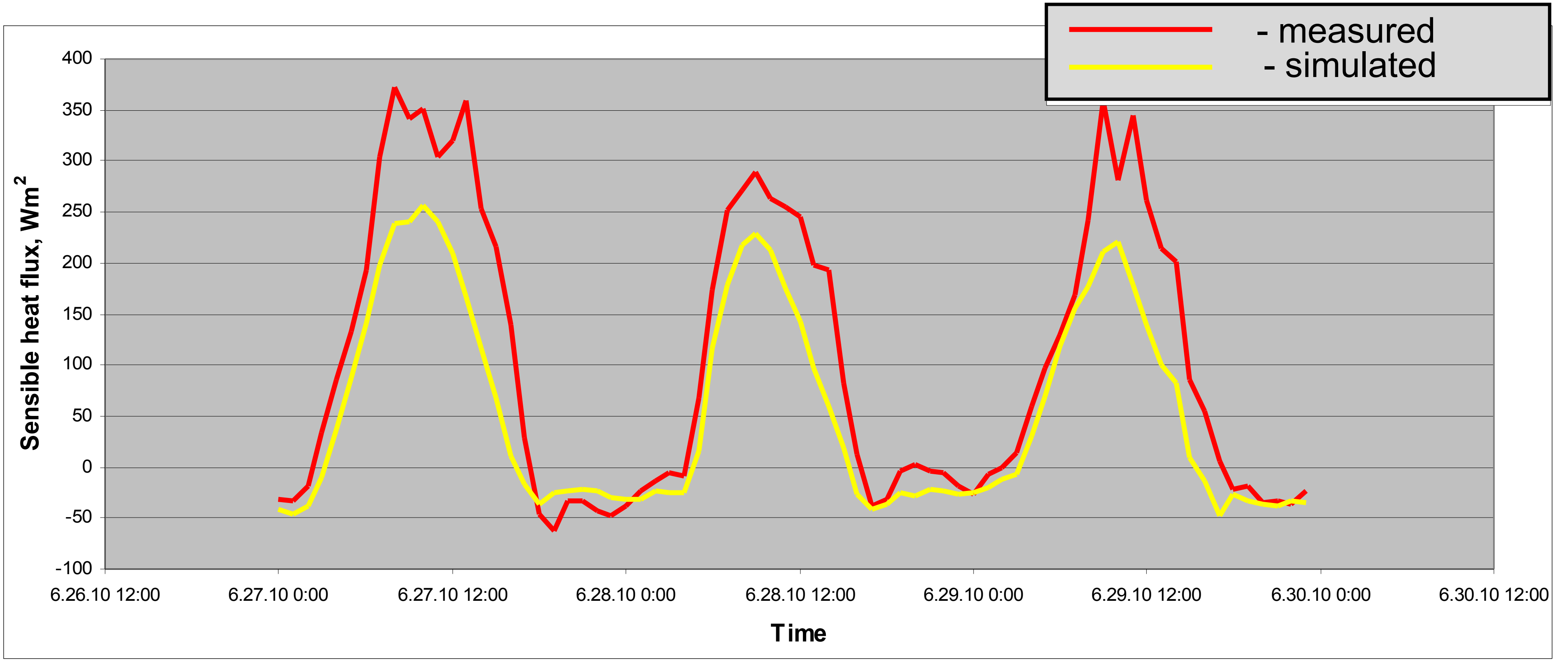




Forest
Sensible Heat Flux:

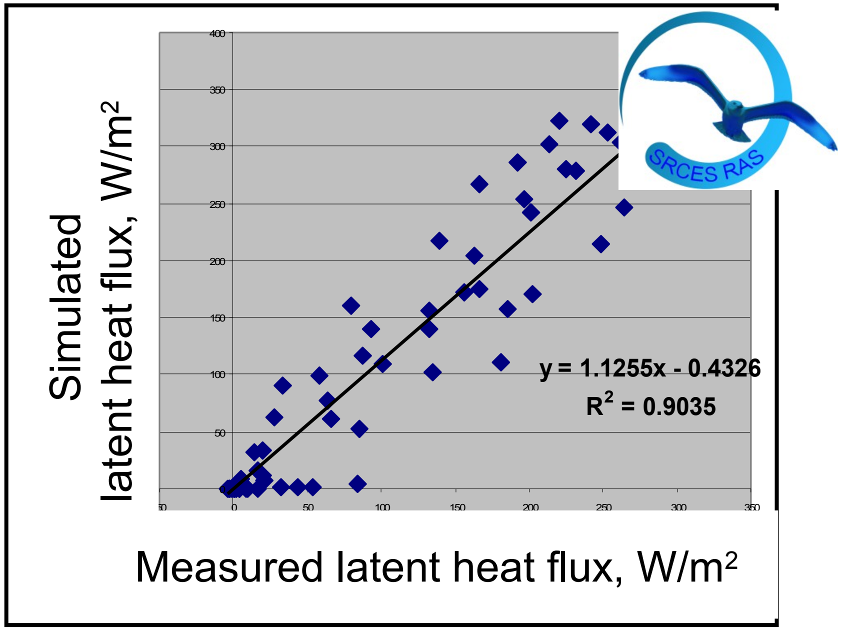
- measured at Hyytiala flux tower;
- simulated by used satellite & meteorological data.

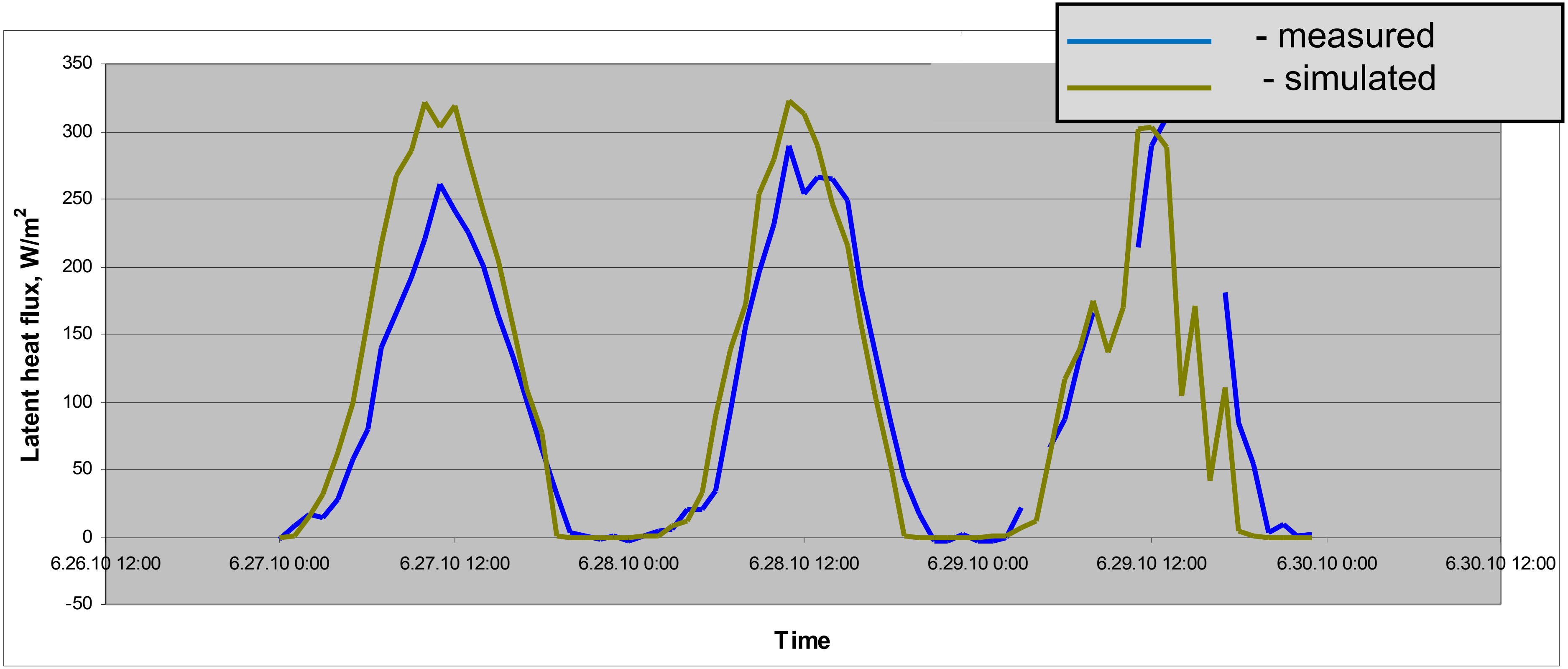




Marshland
Latent Heat Flux

- measured at Siikaneva flux tower;
- simulated by used satellite & meteorological data.





Marshland
Sensible Heat Flux

- measured at Siikaneva flux tower;
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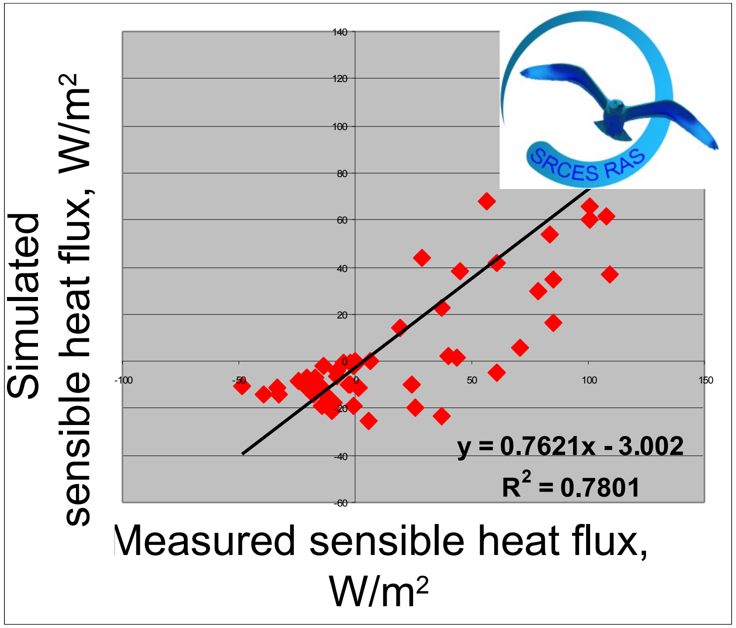
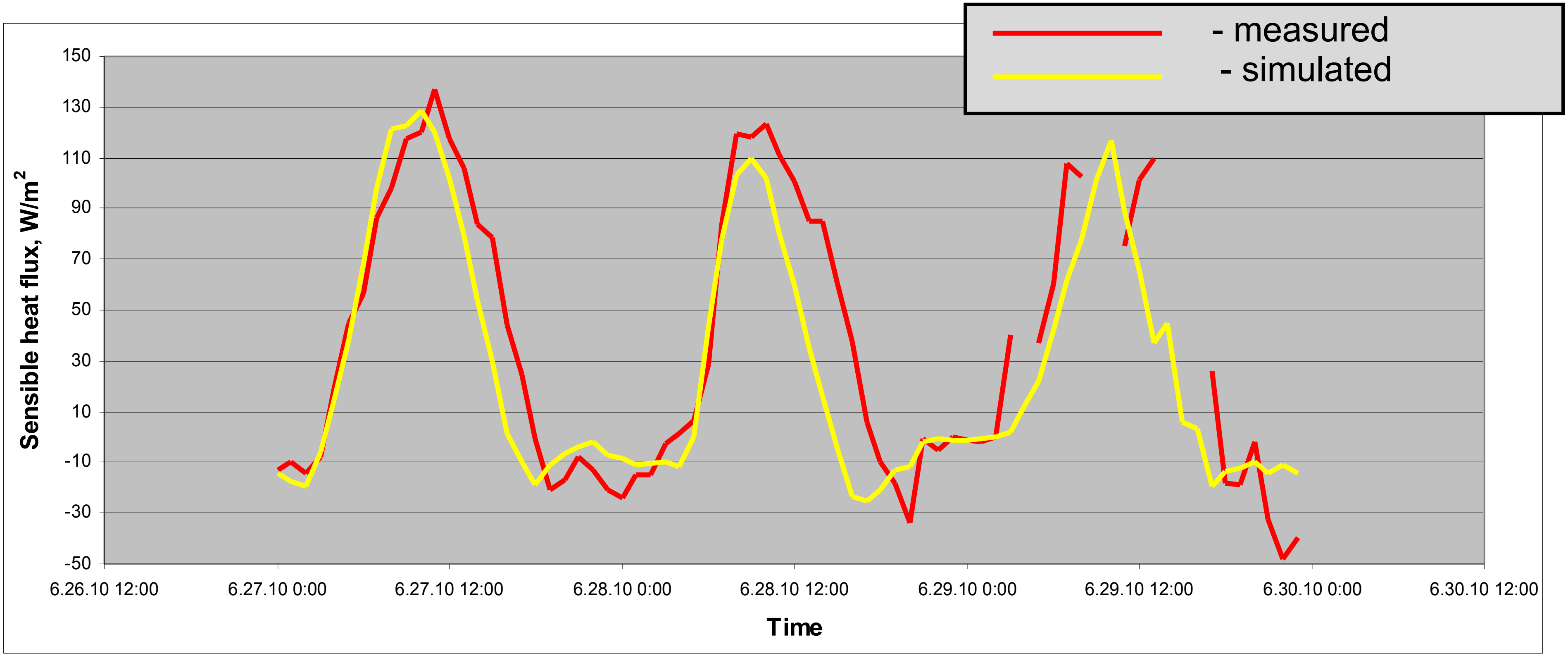




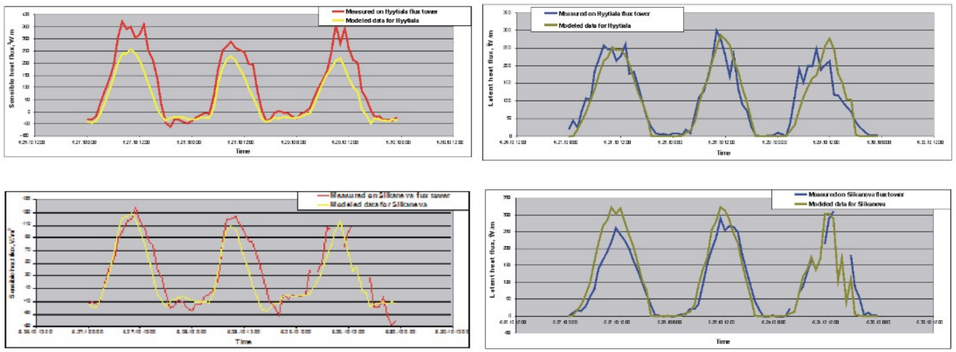
Errors of Fluxes Simulation

Our results

Sensible Heat Flux | Latent Heat Flux

Taiga Forest

Marshland



Our Errors

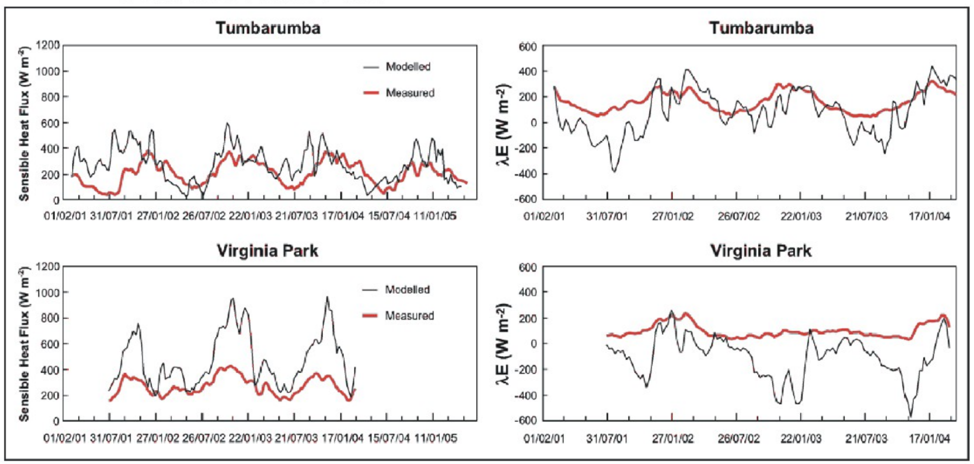
Flux Tower	Latent Heat Flux, W/m²		Sensible Heat Flux, W/m²	
	Accuracy	RMSE	Accuracy	RMSE
Hyytiala forest	3.7	26.6	-49.25	51.28
Siikaneva marshland	10.8	45.5	6.94	32.09

Australian results

Sensible Heat Flux | Latent Heat Flux

Eucalyptus forest

Tropical savanna



Australian Errors

Flux Tower	Latent Heat Flux, W/m²		Sensible Heat Flux, W/m²	
	Accuracy	RMSE	Accuracy	RMSE
Tubarumba	36.2	46.5	-86.7	200.1
Virginia Park	105	112	-204	268.3

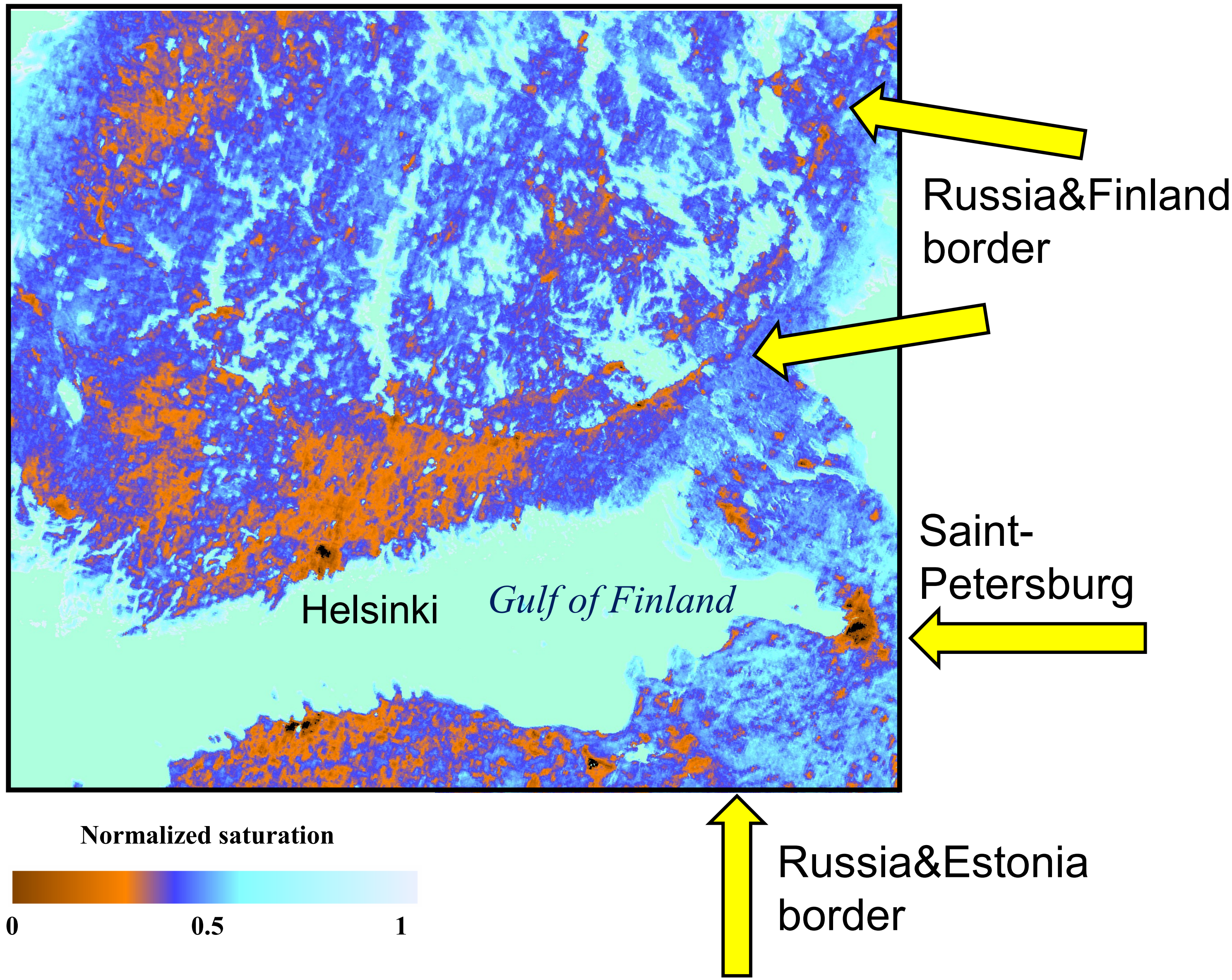
Restrictions & Achievements

Equations (6) and (7) may be applied for satellite data acquainted in conditions of few days stable clear sky weather, only.

The suggested equations for mass & heat exchange coefficients can be applied for the forest, as well as for the marshland.

Map of Water Saturation

27-29, June 2010



Conclusions

- The new heuristic formulas, based on flux time series analyses, provide possibility to simulate surface temperature of Taiga Biome ecosystems more precisely than the traditional equations in desert conditions of Australia.

- The same heuristic mass exchange coefficient can applied for the forest and marshlands.

- A water saturation map reflects differences of evapotranspiration between ecosystem types such as forest, marsh, agricultural and urban areas.

- Forests, located near the border of Finland and Russia, as well as Russia and Estonia are characterized by the different level of evapotranspiration. This phenomenon may be caused by different forest management systems in these countries.