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Assessing exergy of forest ecosystem using airborne and satellite data

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Interactions of the energy flows of forest ecosystem with environment are formed by a suite of forest structure, functions and pathways of self-control. According to recent thermodynamic theory for open systems, concept of exergy of solar radiation has been applied to estimate energy consumptions on evapotranspiration and biomass production in forest ecosystem or to indicate forest decline and human land use impact on ecosystem stability. However, most of the methods for exergy estimation in forest ecosystem is not stable and its physical meaning remains on the surface. This study was aimed to contribute to understanding the exergy of forest ecosystem using combination of remote sensing (RS) and eddy covariance technologies, specifically: 1/to explore exergy of solar radiation depending on structure of solar spectrum (number of spectral bands of RS data), and 2/to explore the relationship between exergy and flux tower eddy covariance measurements.

Two study forest sites were located in Western Beskids in the Czech Republic. The first site was dominated by young Norway spruce, the second site was dominated by mature European beech. Airborne hyperspectral data in VNIR, SWIR and TIR spectral regions were acquired 9 times for study sites during a vegetation periods in 2015-2016. Radiometric, geometric and atmospheric corrections of airborne data were performed. Satellite multispectral Landsat-8 cloud-free 21 scenes were downloaded and atmospherically corrected for the period from April to November 2015-2016. Evapotranspiration and latent heat fluxes were collected from operating flux towers located on study sites according to date and time of remote sensing data acquisition. Exergy was calculated for each satellite and airborne scene using various combinations of spectral bands as: $Ex=\bar{E}out\ (K+\ln \bar{E}out/\bar{E}in)+R$, where Ein is the incoming solar energy, Eout is the reflected solar energy, R = Ein-Eout is absorbed energy, Eout/Ein is albedo and K is the Kullback increment of information.

Thermal bands decreased exergy value by near 60%, which is in agreement with principles of radiation balance. Spectral band 555-569 and region 740-853 (9 spectral bands) from airborne hyperspectral data, and spectral regions 430-450, 530-590 and 640-670 nm from satellite multispectral data were shown the most informative for exergy calculation for two forest ecosystems. Exergy from airborne data overestimated exergy from satellite data by 6-10%. Aggregation of airborne hyperspectral bands into multispectral satellite spectral bands did not affect exergy values significantly ($p<0.05$). The correlation between exergy and evapotranspiration from flux tower was higher using airborne data ($r = 0.81$ and $r = 0.82$) than using satellite data ($r = 0.74$ and $r = 0.76$) for spruce and beech forest sites.