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## **A continuous hyperspatial monitoring system of evapotranspiration and gross primary productivity from Unmanned Aerial Systems**

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Unmanned Aerial Systems (UAS) can collect optical and thermal hyperspatial (<1m) imagery with low cost and flexible revisit times regardless of cloudy conditions. The reflectance and radiometric temperature signatures of the land surface, closely linked with the vegetation structure and functioning, are already part of models to predict Evapotranspiration (ET) and Gross Primary Productivity (GPP) from satellites. However, there remain challenges for an operational monitoring using UAS compared to satellites: the payload capacity of most commercial UAS is less than 2 kg, but miniaturized sensors have low signal to noise ratios and small field of view requires mosaicking hundreds of images and accurate orthorectification. In addition, wind gusts and lower platform stability require appropriate geometric and radiometric corrections. Finally, modeling fluxes on days without images is still an issue for both satellite and UAS applications. This study focuses on designing an operational UAS-based monitoring system including payload design, sensor calibration, based on routine collection of optical and thermal images in a Danish willow field to perform a joint monitoring of ET and GPP dynamics over continuous time at daily time steps.

The payload (<2 kg) consists of a multispectral camera (Tetra Mini-MCA6), a thermal infrared camera (FLIR Tau 2), a digital camera (Sony RX-100) used to retrieve accurate digital elevation models (DEMs) for multispectral and thermal image orthorectification, and a standard GNSS single frequency receiver (UBlox) or a real time kinematic double frequency system (Novatel Inc. flexpack6+OEM628). Geometric calibration of the digital and multispectral cameras was conducted to recover intrinsic camera parameters. After geometric calibration, accurate DEMs with vertical errors about 10cm could be retrieved. Radiometric calibration for the multispectral camera was conducted with an integrating sphere (Labsphere CSTM-USS-2000C) and the laboratory calibration showed that the camera measured radiance had a bias within  $\pm 4.8\%$ . The thermal camera was calibrated using a black body at varying target and ambient temperatures and resulted in laboratory accuracy with RMSE of 0.95 K. A joint model of ET and GPP was applied using two parsimonious, physiologically based models, a modified version of the Priestley–Taylor Jet Propulsion Laboratory model (Fisher et al., 2008; Garcia et al., 2013) and a Light Use Efficiency approach (Potter et al., 1993). Both models estimate ET and GPP under optimum potential conditions down-regulated by the same biophysical constraints dependent on remote sensing and atmospheric data to reflect multiple stresses. Vegetation indices were calculated from the multispectral data to assess vegetation conditions, while thermal infrared imagery was used to compute a thermal inertia index to infer soil moisture constraints. To interpolate radiometric temperature between flights, a prognostic Surface Energy Balance model (Margulis et al., 2001) based on the force-restore method was applied in a data assimilation scheme to obtain continuous ET and GPP fluxes.

With this operational system, regular flight campaigns with a hexacopter (DJI S900) have been conducted in a Danish willow flux site (Risø) over the 2016 growing season. The observed energy, water and carbon fluxes from the Risø eddy covariance flux tower were used to validate the model simulation. This UAS monitoring system is suitable for agricultural management and land-atmosphere interaction studies.