Continuous estimation of gross primary productivity and evapotranspiration from an Unmanned Aerial System

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Introduction

Satellite-based optical imagery cannot provide information on the land surface during cloudy periods. This issue is especially relevant for high latitudes where overcast days are common. Current remote sensing-based models of gross primary productivity (GPP) or evapotranspiration (ET) are biased towards clear sky conditions, lacking important information on biophysical processes under cloudy conditions (Wang et al., 2018).

Unmanned Aerial Systems (UAS) can collect optical and thermal signals at unprecedented very high spatial resolution (< 1 meter) under sunny and cloudy weather conditions. This provides a great opportunity to continuously monitor vegetation carbon assimilation and water consumption under both sunny and cloudy conditions.

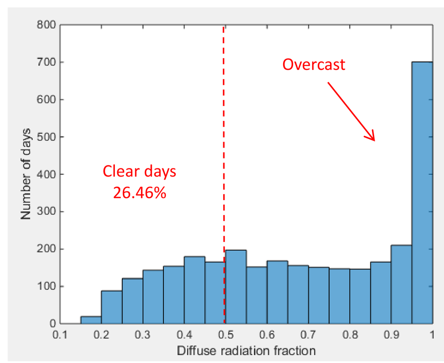


Figure 1. Observed daily diffuse fraction in the Soroe eddy covariance flux site of Denmark from 2004 to 2012. This indicates the fraction of cloudy days.

Objective

1. Use UAS multispectral and thermal imagery to estimate soil water content (SWC), GPP and ET.
2. Provide an framework to continuously estimate GPP and ET from UAS observations.

UAS

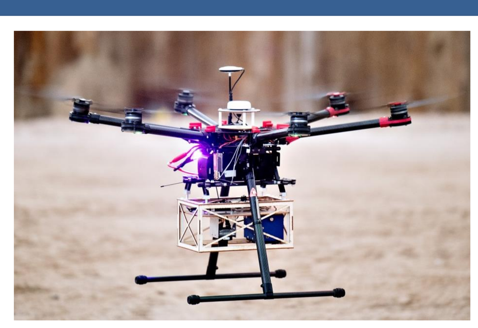


Figure 2. UAS platform DJI S900

Figure 3. UAS payload (a RGB camera to retrieve DEM; a thermal infrared camera to estimate temperature; a multispectral camera MCA to obtain optical vegetation indices)

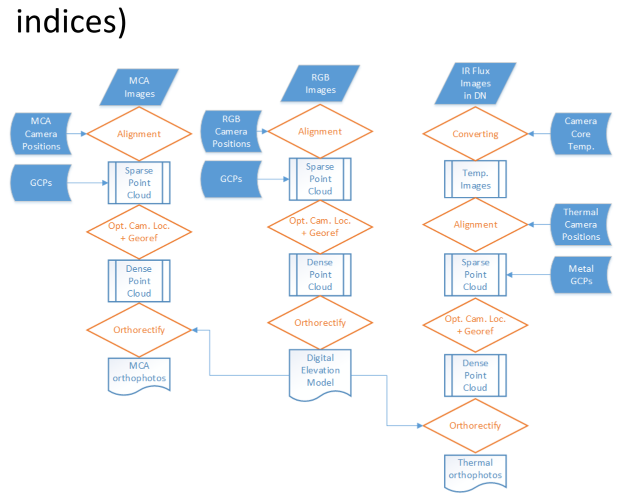


Figure 4. Workflow for UAS image processing

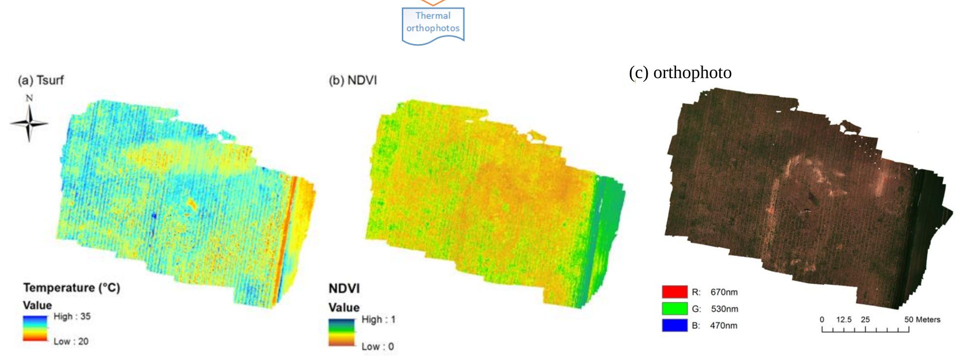


Figure 5. UAS surface temperature (a), normalized different vegetation index (NDVI, b) and true color orthophoto (c) on 25th May 2016

Methods and data

Methods:

The workflow of this study is shown in Figure 6. The major parts are outlined as below.

- Snapshot estimation
  - ✓ SWC: Temperature-vegetation dryness index (TVDI)
    - Compare with Time Domain Reflectometry (TDR) SWC
  - ✓ GPP and ET: A joint light use efficiency GPP and Priestley–Taylor Jet Propulsion Laboratory ET model (Wang et al., 2018)
    - Validate with eddy covariance observations
- Continuous estimation
  - ✓ Statistical based interpolation (Vegetation index NDVI)
  - ✓ Model based interpolation: Soil-Vegetation Energy, water and CO_2 traNsfer model (SVEN, Figure 7)
  - ✓ Data assimilation (Ensemble Kalman filter, surface temperature Ts)

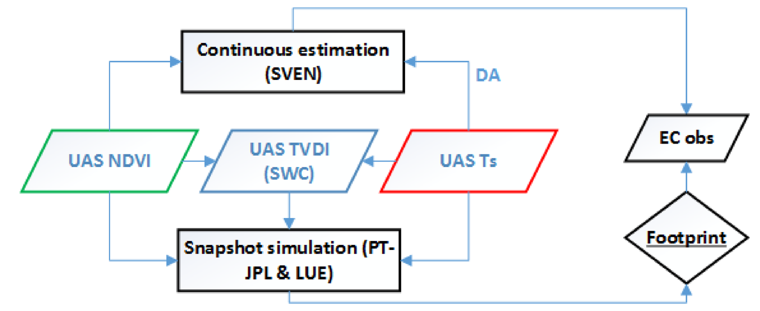


Figure 6. The work flow of this study

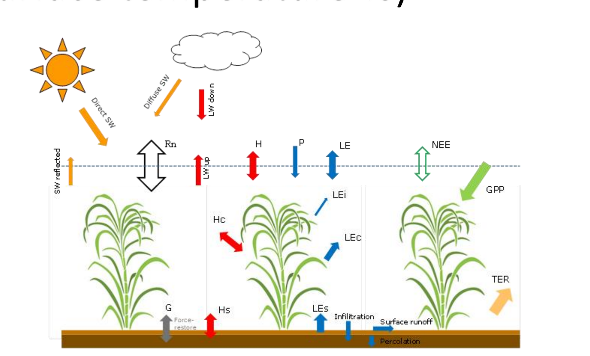


Figure 7. The major processes simulated in SVEN

Flight campaigns and data:

- Forest flux sites: Risoe willow bioenergy plantation (11 ha)

Table 1. The information of flight campaigns

Date	Time	weather condition
11-04-2016	9:33-10:15	cloudy
02-05-2016	14:20-14:57	cloudy
12-05-2016	10:14-11:05	sunny
25-05-2016	10:01-10:33	sunny
15-08-2016	14:00-14:30	cloudy
07-10-2016	11:31-12:05	sunny
19-05-2017	11:52-15:39	sunny
26-05-2017	11:13-14:46	sunny
18-06-2017	12:27-13:01	cloudy

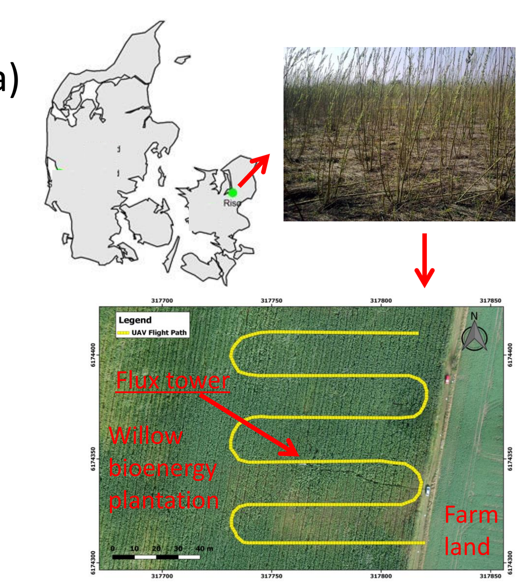


Figure 8. The study sites (Risoe)

- Data: UAS multispectral and thermal imagery, metrological forcing, eddy covariance observations, field measurements (SWC)

Results

- **Snapshot estimation**

SWC

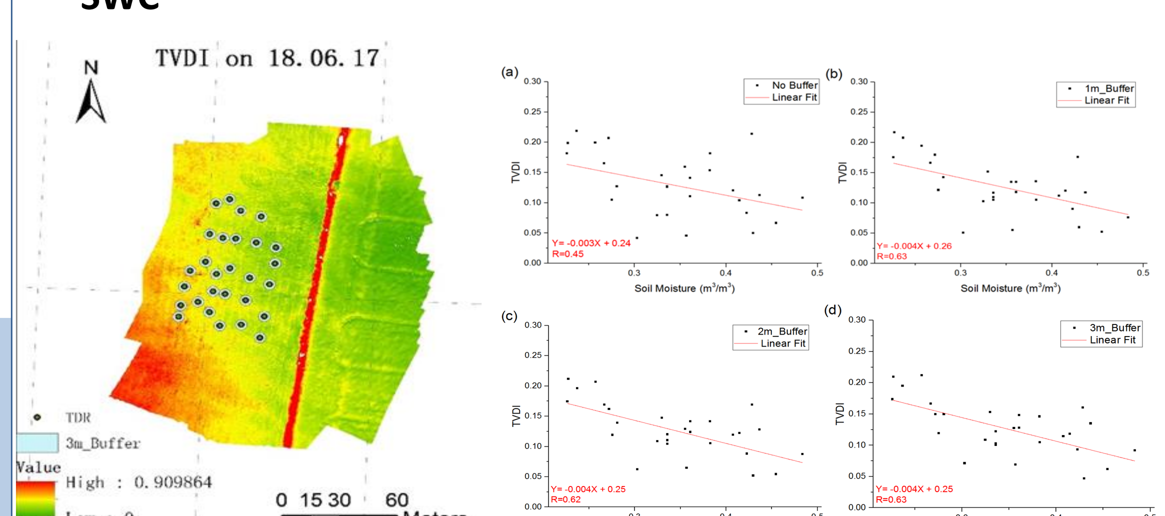


Figure 9. The comparison between TVDI and TDR SWC on 18th June 2017 with different radiuses of buffer zones. (a) no buffer. (b) 1m radius buffer. (c) 2 m radius buffer. (d) 3 m radius buffer. The correlation coefficient could reach to 0.63.

Reference: Wang, S., Ibrom, A., Bauer-Gottwein, P., & Garcia, M. (2018). Incorporating diffuse radiation into a light use efficiency and evapotranspiration model: An 11-year study in a high latitude deciduous forest. *Agricultural and Forest Meteorology*, *248*, 479-493.

Results

GPP and ET

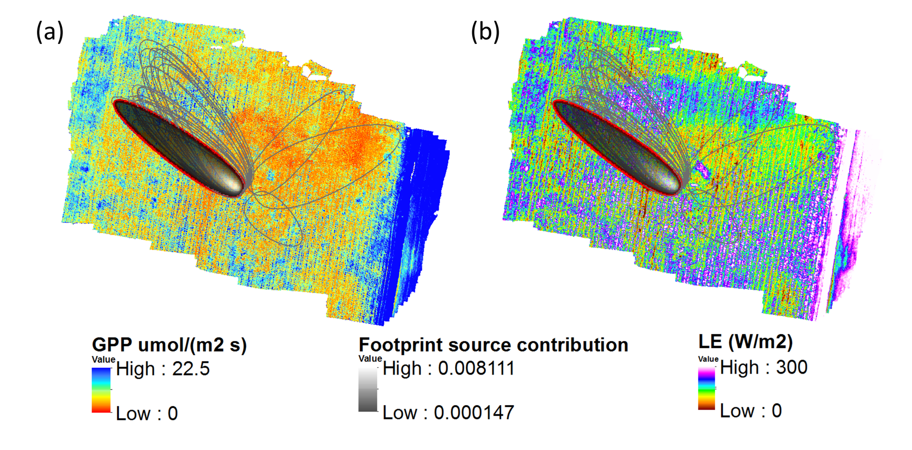


Figure 10. The spatial maps of simulated GPP (a) and LE (b) at 10:00-10:30 A.M. on May 25th 2016. The circles represent 75% footprint source for different half hours during the day time.

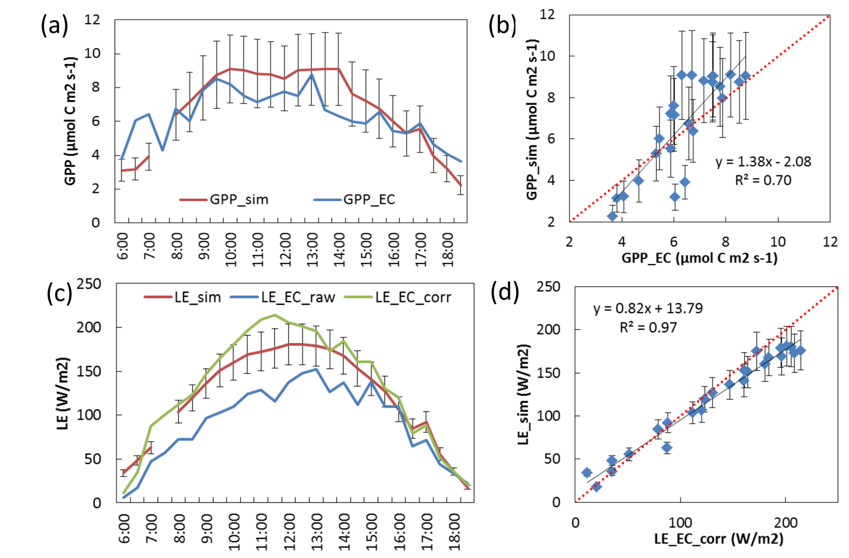


Figure 11. The simulated GPP (a, b) and LE (c, d) on May 25th 2016. LE_EC_corr is corrected with energy balance closure errors. Error bars stand for standard deviation.

- **Continuous estimation of GPP and ET**

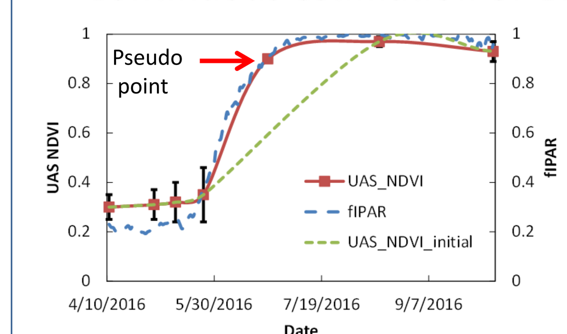


Figure 12. The comparison between interpolated UAS NDVI (with / without one pseudo observation) and observed intercepted PAR (from PAR sensors above and below canopy). UAS NDVI is the average NDVI value of UAS observations for the willow plantation. The spline method was used for interpolation. The error bar stands for the standard deviation. Here we added one pseudo point in order to represent the true phenology change well.

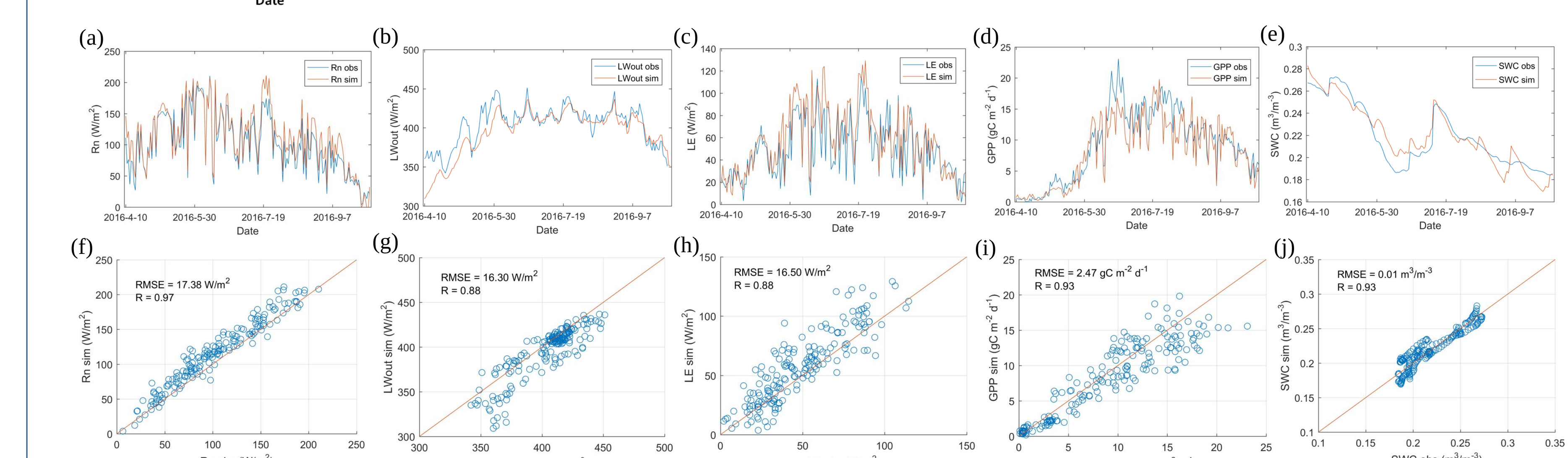
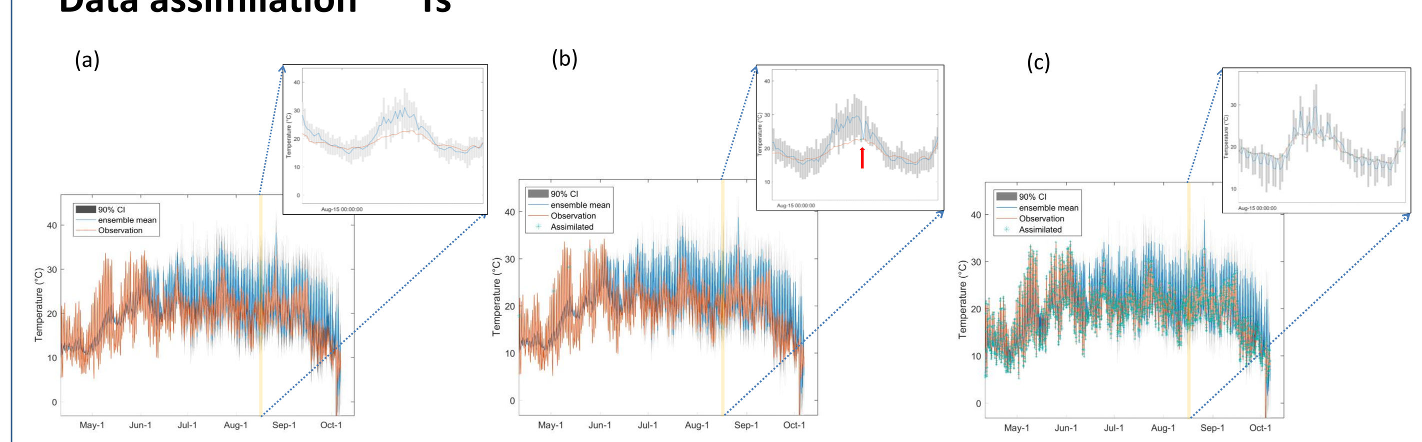


Figure 13. The performance of SVEN to continuously simulate Rn, LWout, LE, GPP and SWC with interpolated UAS NDVI as inputs. The simulated daily Rn, LE, GPP and SWC (15 cm depth) were compared with daily observations. For Rn, LE, GPP and SWC, the performance is good. But for LWout, the simulation performance is not very good.

Data assimilation Ts



Scheme	R	RMSE
Open loop	0.89	3.16
DA UAS data	0.89	3.14
DA synthetic data	0.92	1.86

Figure 14. The comparison between open loop run (a), data assimilation with UAS Ts observations (b), and data assimilation with synthetic data (six UAS flights per day). The performance of simulation with different schemes was shown in the left table. This result indicate high frequency UAS observations are needed for improving surface temperature simulation.

Conclusion and future work

This study provides a framework on continuous estimation of GPP and ET from UAS optical and thermal imagery to fill gaps between data acquisitions. Results indicate UAS observations could accurately simulate water and CO_2 flux exchange between the land surface and atmosphere. Future work will focus on assimilating spatial UAS thermal imagery into SVEN.

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