HYDRA: a drone-based hyperspectral radiometer system for aquatic remote sensing applications

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Objective

The “Hyperspectral Drone-based system for above-water Radiometric Acquisitions” (HYDRA) is here proposed for spatially-distributed above-water radiometric measurements specifically supporting the validation of satellite data products from the aquatic environment.

Measurement method

The general above-water method derives the water-leaving radiance L_w as (IOCCG, 2019)

$$L_w(\theta,\phi) = L_T(\theta,\phi) - \rho\, L_i(\theta',\phi),$$

where ϕ is the relative azimuth angle between sensor and sun, θ is the angle from nadir, $\theta' = 180^o - \theta$, and ρ is the sea-surface reflectance factor (ρ-factor), theoretically determined (Mobley et al., 1999).

Measurements are performed for $\phi = 90^o$ and $\theta = 40^o$.

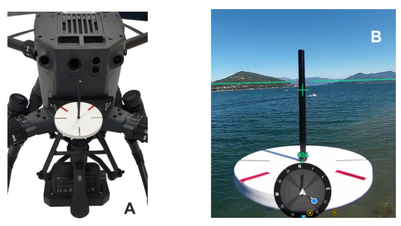
The remote sensing reflectance R_{rs} is further computed correcting for bidirectional effects due to the off-zenith illumination conditions and the non-nadir view of the L_T radiometer (D’ Alimonte et al., 2025).

HYDRA setup

HYDRA, realized at the JRC Marine Optical Laboratory, comprises a drone platform to quantify the radiance from the sea L_T, and a complementary ground-station to measure the sky radiance L_i and the downward irradiance E_s.

First generation ARC and ACC RAMSES radiometers, requiring computer control during field measurements, are operated on the ground-based station. Conversely, a second generation RAMSES G2 ARC radiometer is operated on the drone for L_T acquisitions.

HYDRA: (a) Matrice 350 RTK; (b) L_T radiometer; (c) sun-alignment jig; (d) inflatable buoys.



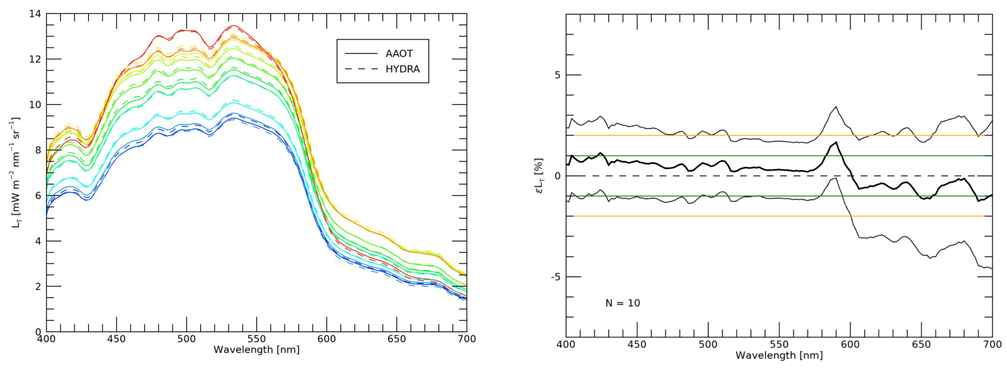
(A) sun-alignment jig installed in front of the fixed camera of the drone. (B) alignment jig as seen through the drone camera with the spike shadow indicating approximately ϕ = 45° with respect to the sun azimuth

HYDRA basic components deployed at a lake site

(A) L_T radiometer in the original steel case and that refitted in the new one (the encircled unit). (B) L_T radiometer deployed underneath the drone (the encircled component).

HYDRA results validation

Measurements to evaluate HYDRA performance took place in the northern Adriatic Sea at the Acqua Alta Oceanographic Tower (AAOT, 45.31N, 12.51E) during almost ideal conditions: sun clear from clouds, and sea state, cloud cover and wind speed lower than 2, 2 oktas and 4 m s^{-1}, respectively.
During these tests, HYDRA L_T measurements were complemented by independent and concurrent L_T measurements performed at the AAOT using RAMSES hyperspectral radiometers.
Matchups of HYDRA and AAOT L_T showed mean spectral differences generally ranging between 0 and +1% in the 400-580 nm interval, and within ±1% in the 580-700 nm interval. The same differences affected the R_{RS} spectra since the same L_i and E_s values were applied to determine HYDRA and AAOT radiometric products.



Left panel: HYDRA and AAOT L_T matchups. Right panel: Average spectral percent differences ε_{LT} (thick black line) determined for the N=10 HYDRA and AAOT L_T matchup values. The thin black lines indicate ±1 standard deviation.

Conclusions

The combination of drone technologies and above-water radiometry offers an efficient and cost-effective mean to collect reference *in situ* data for the validation of aquatic satellite data products.

In addition, HYDRA allows for:

i. performing L_T measurements with the more ideal relative angle ϕ =135° instead of ϕ = 90° required by common deployment platforms;

ii. accurately addressing the impact of adjacency effects in satellite data products from coastal and inland waters;

iii. investigating the perturbing effects in L_T by superstructures supporting above-water radiometric measurements;

iv. characterizing sub-pixel variability within satellite footprints;

Notably, HYDRA largely benefits of the application of consolidated above-water methods and of extensively characterized radiometers, which fully support the application of uncertainty analysis adhering to metrology principles.

Additionally, HYDRA measurements can profit from community efforts on data processing.

Finally, the operation of all L_T, L_i and E_s radiometers on the drone is an ideal future solution for any operational application.

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