

Coupled Retrieval of the Three Phases of Water from Spaceborne Hyperspectral Measurements

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Introduction

Imaging spectroscopy makes it possible to identify and quantify water in different states due to the presence of sufficient narrow bands in the near-infrared (NIR). The use of spaceborne measurements enables new possibilities in mapping local and global trends of water vapor, liquid water and ice. On the one hand, it is essential for evaluating plant physiological status and health. On the other, it supports the prediction of snow melt rates and the availability of fresh water. We developed a coupled three phases of water retrieval for spaceborne hyperspectral measurements such as DESIS, PRISMA or the upcoming EnMAP, CHIME and SBG missions. Our method is based on a maximum likelihood estimation and integrated in an atmospheric correction procedure by linking the MODTRAN radiative transfer code to a surface reflectance model based on the Beer-Lambert law. We evaluate the performance of the algorithm through a sensitivity analysis on simulated EnMAP spectra and use CHRIS-PROBA data as a proxy for future satellite missions to compare the retrieval results with ground-based measurements. Confirmatory of previous studies, we additionally show results from airborne AVIRIS-C data.

Methods

Approach

Discriminative absorption lines of water vapor, liquid water and ice

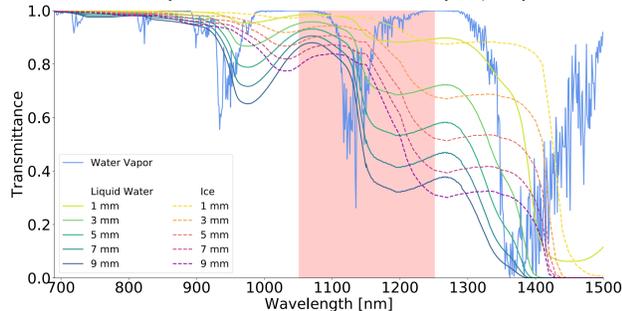


Fig. 1: Overlapping transmittance spectra of water vapor, liquid water and ice. Water vapor: 5 mm precipitable water. Liquid water and ice: five different path lengths from 1 to 9 mm. The absorption window used for spectral fitting is displayed in light red.

1. Modeling of TOA radiance using radiative transfer simulations:

$$L_{TOA} = L_0 + \frac{1}{\pi} * \frac{\rho_{s,\lambda}(E_{dir}\mu_{sun} + E_{dif})T_{\uparrow}}{1 - S\rho_{s,\lambda}} \quad (1)$$

with surface reflectance model based on Beer-Lambert-law:

$$\rho_{s,\lambda} = (a + b\lambda)e^{-d_w\alpha_{w,\lambda} - d_i\alpha_{i,\lambda}} \quad (2)$$

2. Inversion of forward model (Eq. 1) using maximum likelihood estimation:

- Matching simulated and measured spectra within spectral fitting window evaluated by pre-defined cost function
- Calculation of correlation errors and retrieval uncertainties

Conclusion

Our coupled retrieval infers CWV and CWC from simulated EnMAP TOA radiances showing very high R^2 of 0.99 and 0.96, respectively. Moreover, CWC retrieved from CHRIS-PROBA data features an R^2 of 0.80 compared with ground-based measurements. Despite the high correlation, CWC is systematically overestimated. This is caused by multiple scattering within the canopy, which largely depends on canopy structural parameters such as LAI and height. Since the Beer-Lambert law actually has to be applied to non-scattering media, our surface reflectance model needs to be improved by additional terms, e.g., based on the directional area scattering factor (DASF) or spectral invariants, as part of future research. Nevertheless, our method leads to improvements in atmospheric correction procedures by producing smoother and more plausible CWV maps since biases due to background reflectance are reduced. It also delivers a promising basis for future EnMAP-based snow parameter retrievals.

Acknowledgments

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Data

Simulated EnMAP TOA radiances

- PROSPECT + Hyperspectral Simulation of Canopy Reflectance system (HySimCaR) + EnMAP end-to-end Simulation tool (Eetes)
- CHRIS-PROBA (CP) measurements, Barrax, Spain, 07/14/2003 (ESA SPARC'03 campaign)
- AVIRIS-C data, Sierra Nevada, CA, 02/24/2015

Results

Sensitivity analysis on simulated EnMAP radiances

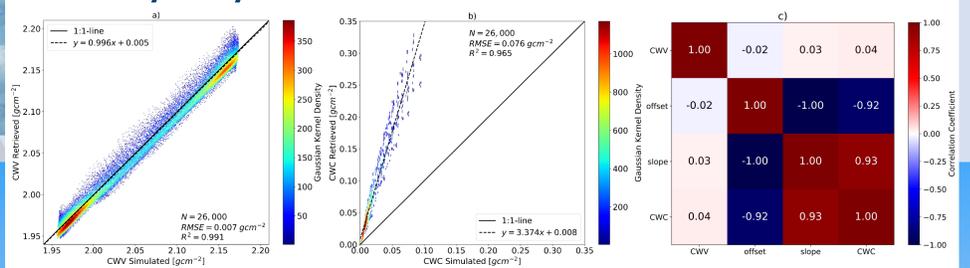


Fig. 2: a) and b) Comparison of derived water vapor (CWV) and canopy water content (CWC), respectively, with the simulation input. c) State vector correlation error matrix.

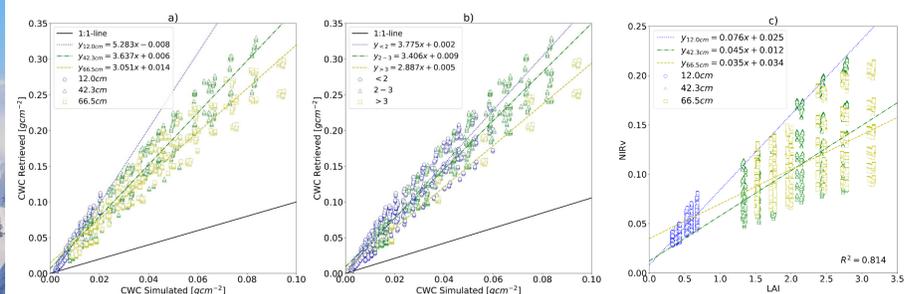


Fig. 3: Comparison of retrieved with simulated CWC as a function of a) mean canopy height, and b) LAI. c) Comparison of NIRv with LAI for different mean canopy heights.

Results from CP data

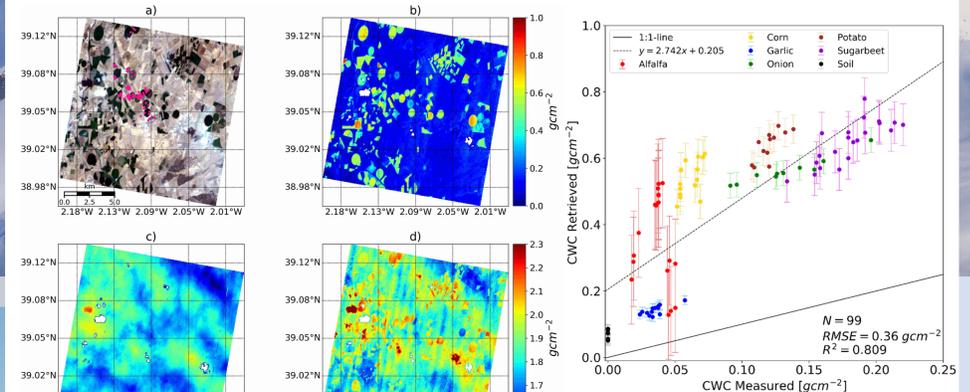


Fig. 4: a) True-color image with pink colored points representing locations of field measurements (RGB: 653/563/481 nm). b) CWC map derived from the coupled retrieval. c) CWV map derived from the coupled retrieval. d) CWV map derived from a band ratio retrieval. e) CWV and f) CWC uncertainties for the coupled retrieval. White colored pixels indicate masked clouds.

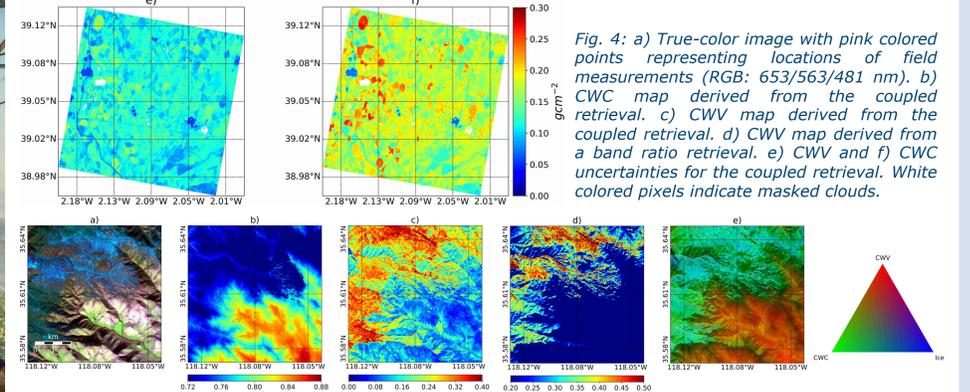


Fig. 5: Comparison of retrieved CWC with field measurements of CWC for different crop types.



Fig. 6: Results from AVIRIS-C data. a) False-color image (RGB: 1602/870/560 nm). b) CWV map. c) Liquid water map. d) Ice map. e) Combined three phases map (RGB: CWV/Liquid/Ice).