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Eddy Covariance measurements of stable isotopes (δD and δ^{18}O) in water vapor

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Motivation

Stable isotopes are a promising tool to enhance our understanding of ecosystem gas exchange: Studying δ^{18}O and δD in water vapor can e.g. help to understand the seasonal dynamics of evapotranspiration and the usage of different water resources by plants. With recent developments in laser spectroscopy, direct Eddy Covariance (EC) measurements to investigate fluxes of stable isotopologues became feasible.

Objectives

- Present technical aspects of our setup to perform Eddy Covariance measurements for stable isotopologues in water vapor using a high-frequency and high-flow optimized Los Gatos Water Vapor Isotope Analyzer (WVIA) such as calibration strategy and tubing
- Show the capability of the high-flow and high-frequency optimized WVIA to perform 2 Hz measurements of H_2O_v in a continuous setup: Evaluate instrument precision and discuss the resulting spectra and cospectra.

Conclusions

- The high-flow and high-frequency optimized water vapor isotope analyzer (WVIA) showed suitable characteristics (Allan deviation and spectral energy distribution) to perform Eddy covariance measurements of stable isotopes in H_2O_v
- An intensive 3-step calibration strategy is necessary to compensate for the analyzers concentration dependency and drift.

Setup

- **Measured quantities:**
  - 2 Hz-measurements of c_{H2O} (water concentration) and its isotopic composition δD and δ^{18}O
  -20 Hz-measurements of 3D-wind velocity
- **Instruments:** High-flow optimized Water Vapor Isotope Analyzer (WVIA, *Los Gatos Research Inc.*, USA), 3D Anemometer (R3, *Gill Instruments*, UK)
- **Main Tube:** Polyethylene tube with stainless steel coating, heated to 4°C above ambient temperature; 60 m long; 6.5 mm inner diameter
  Flow app. 14 slpm ; Reynolds number >3000

Figure 1: Field site: Eddy Covariance tower in a managed beech forest in Germany

Calibration

- **Water vapor concentration (c_{H2O}) - calibration**
  Repeated manual measurements using a Dew Point Generator
- **c_{H2O}-dependency of δ values (hourly measurements in the field)**
  Using a Water Vapor Isotope Standard Source (WVISS, Los Gatos)
- **Absolute δ - scale calibration (repeated manual measurements)**
  Using 5 water standards at different δ-values

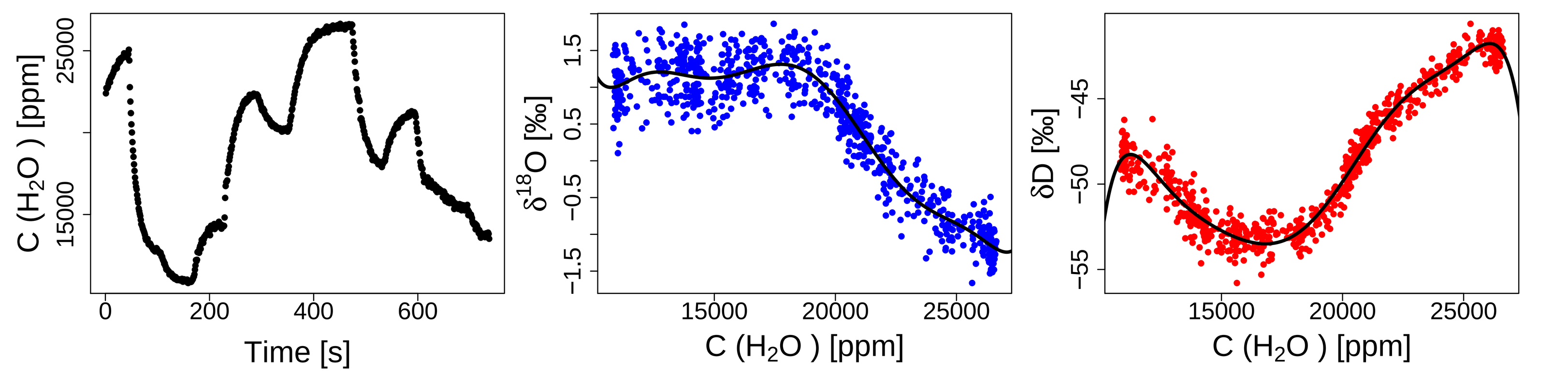

Figure 2: Hourly measurement of concentration-dependency of δ-values; left: water vapor concentration c_{H2O} vs. time t; middle and right: δ-values plotted vs. c_{H2O}

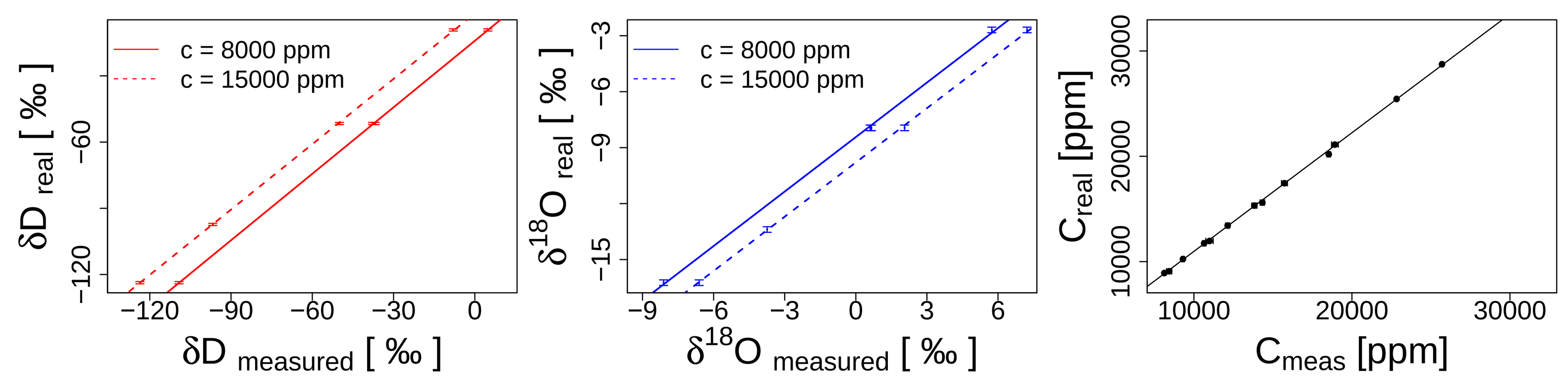

Figure 3: Absolute water concentration (c_{H2O})-scale calibration and the absolute δ-scale calibration

Allan deviation (precision)

- The instrument's precision depends on water concentration c_{H2O} (c.f. Fig. 4)
- Allan deviation σ_A at τ_{meas}=0.5 s (min. meas. time) is below 1 ‰ for both δ-values
- Allan deviation σ_A at $\tau_{cal}\approx10^3$ s (time between calibrations) is below 1 ‰ for both δ-values

	$c_{H2O} \approx 6\,000$		$c_{H2O} \approx 20\,000$	
	δD [‰]	δ^{18}O [‰]	δ^{13}C [‰]	δ^{18}O [‰]
σ_A (0.5 s)	1.40	0.45	0.70	0.30
σ_A (1 s)	1.00	0.34	0.50	0.20
σ_A (10 s)	0.40	0.13	0.21	0.07
σ_A (100 s)	0.12	0.05	0.10	0.07

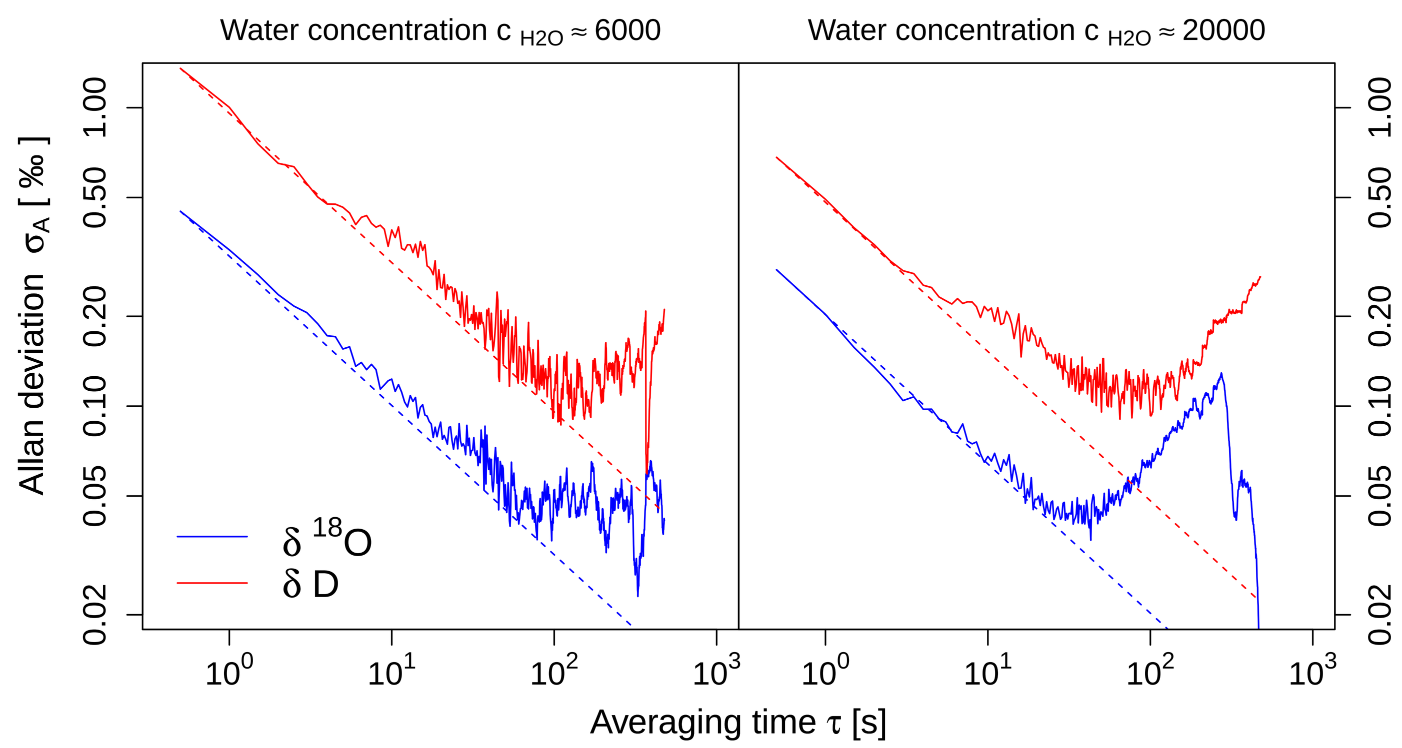

Figure 4: Allan Deviation σ_A as a function of averaging times τ for different concentrations C, based on nighttime measurements in the field

Spectral energy (tube attenuation)

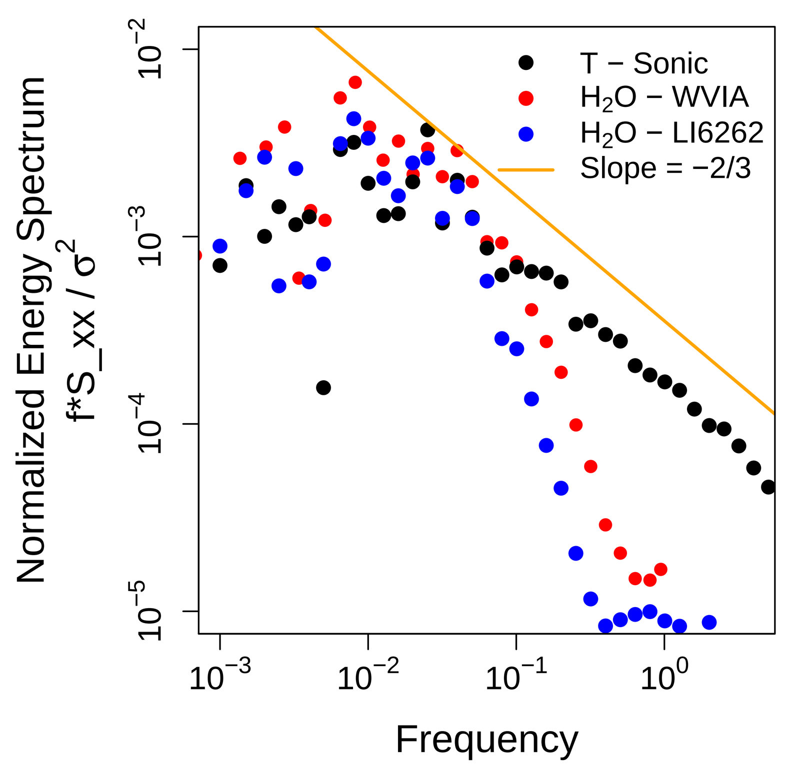

Figure 5: Double logarithmic plot of the spectral energy S_{xx} scaled with natural frequency f and normalized with variance σ^2 for an example day at midday

- High frequency (HF)-dampening of WVIA-measurements is comparable with the HF dampening of a permanently installed LI6262 with comparable tubing.
- At high frequencies, the spectral energy for H_2O rises again (possibly related to aliasing).
- The individual spectral energies for each water isotopologues (not shown) is similar to the shown spectral energy H_2O_v - WVIA (shown in Fig. 5).

Cospectra

- The cospectrum between vertical wind velocity w and the concentration of a transported quantity (e.g. c_{H2O}) reflects the flux on different timescales.
- The measured cospectrum for water vapor shows similar behavior for the different water analyzers (WVIA and LI6262)
- Despite possible Aliasing (c.f. energy spectrum, Fig. 5), the cospectrum of wind velocity w and water concentration c_{H2O} measured with the WVIA (c.f. Fig 6) does not show a rise of flux contributions at higher frequencies.

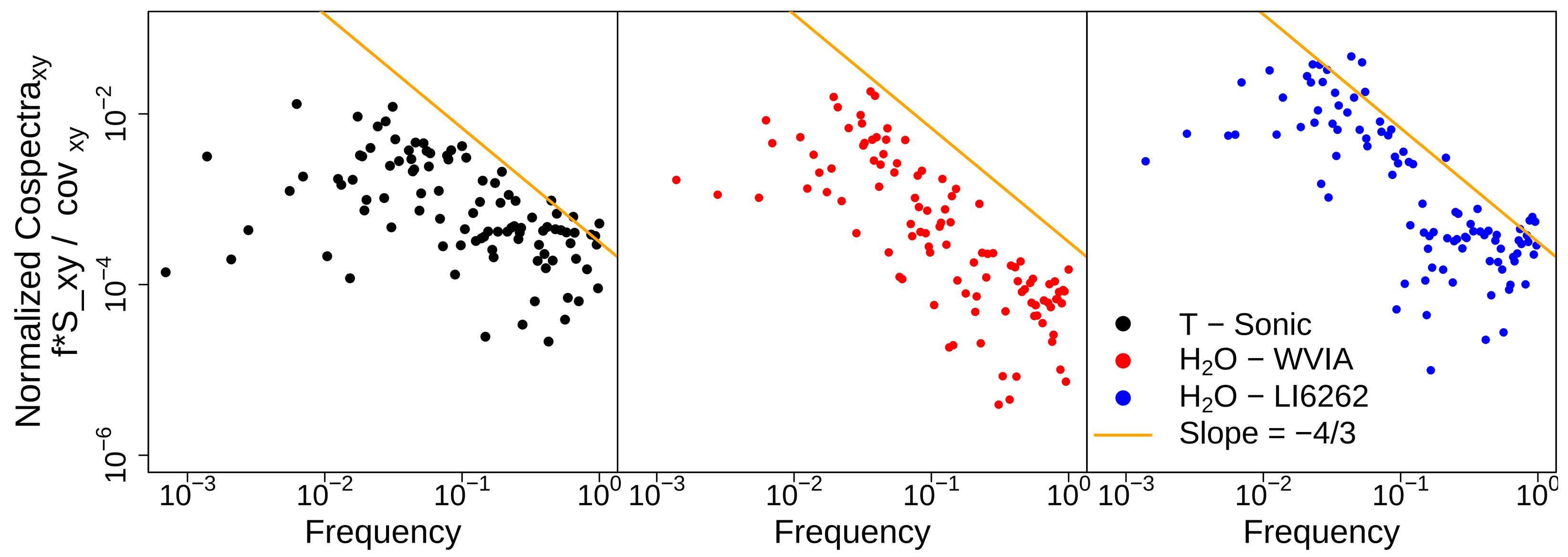

Figure 6: Double logarithmic plot of cospectra S_{xy} between vertical wind-velocity $x = w$ and different measured quantities y (sonic temperature T or water concentration $C(H_2O_v)$ - scaled with nat. frequency f and normalized with the resp. covariance cov(x,y) for an example day at midday, the individual cospectra between wind velocity w and each water isotopologues (not shown) show the same behavior as the cospectrum between w and c_{H2O} - WVIA

Outlook / next steps:

- Calculation of H_2O_v fluxes for each isotopologue over the measurement period (a full growing season) based on the 2 Hz setup presented here.
- Comparison of measured isotopologue fluxes to leaf water enrichment (measured intensively with IRMS in spring/summer 2016)

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