H2020

First demonstration measurements

FLAIR - FLying ultrA-broadband single-shot InfraRed Sensor
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Abstract:
This report documents the first field tests that were performed in Beromünster, Switzerland, in June 2020.

Document History

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Executive Summary

This report documents the first field test of the FLAIR instrument. We performed the first field campaign at the airfield in Beromünster (Switzerland). The instrument was mounted on a hot air zeppelin and operated during a test flight. Methane was released in a controlled way from a gas cylinder for simulating a significant methane source. The zeppelin flew several times through the plume of the artificial methane source. Thus, the capabilities of the FLAIR instrument for detecting elevated methane concentration were demonstrated. This first field campaign showed that the FLAIR instrument can successfully be operated on an airborne platform. The field tests provided valuable experience and information for the second planned field campaign.

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Acronym	Meaning
MPC	Multipass Cell
CRDS	Cavity Ring-Down Spectroscopy
NUC	Non-Uniformity Correction

Table 1 - List of acronyms

Formula	Chemical compound
CH_4	Methane
H_2O	Water Vapor
N_2	Dinitrogen

Table 2 - List of chemical compounds

1 Introduction

The main objective of work package 6 is the evaluation of the performance of the FLAIR instrument and the proof that the developed instrument can be autonomously operated on a flying platform for measuring elevated methane concentrations. In this deliverable we demonstrate the capabilities of the FLAIR system when deployed and flying on a hot air zeppelin and measuring methane released from an artificial source. The field test was performed at the airfield in Beromünster (Switzerland) and next to the atmospheric research station, where methane is measured routinely at different heights of the Beromünster tall tower (up to 212 m).

1.1 Document description/ purpose

This document constitutes the FLAIR delivery D6.2, which is crucial for evaluation the performance of the FLAIR instrument under flying conditions.

2 Flight tests in Beromünster

2.1 Site description

A field test campaign was performed in the morning of June 24, 2020 in Beromünster, Switzerland. The campaign took place at the Beromünster airfield, which is in close proximity to the Beromüster tall tower, where reference measurements are available on different height levels up to 212m above ground.
At the air field, a 5-meter mast was installed. A 3D sonic anemometer was mounted on the top of the mast, measuring wind speed and wind direction for the duration of the campaign. The average wind speed during the campaign was around 0.75 m/s, mostly from the south / south-west (Figure 1). The outlet of an artificial CH_4 source (compressed gas cylinder of natural gas, flow of 100 liters per minute) was placed close to the top of the 5-meter mast.

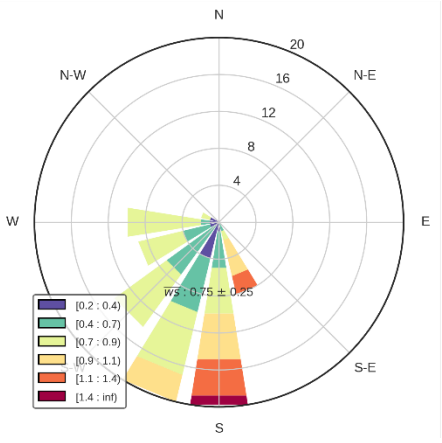

Figure 1. Wind rose during the campaign showing the wind speed and the direction.

The FLAIR instrument was installed on a hot air zeppelin (Figure 2a). It was planned to fly the hot air zeppelin over the airfield and through the plume of the artificial methane source and finally to the Beromünster tall tower (Figure 2b). In order to ensure a successful detection of methane released from the artificial source, the path of the zeppelin was to approach the source from the north. The zeppelin took off around 5 AM and was flying at low altitude over the airfield. After a couple of

successful fly-overs over the gas source, the zeppelin flew to and around the Beromünster tall tower before flying back and landing at the airfield.

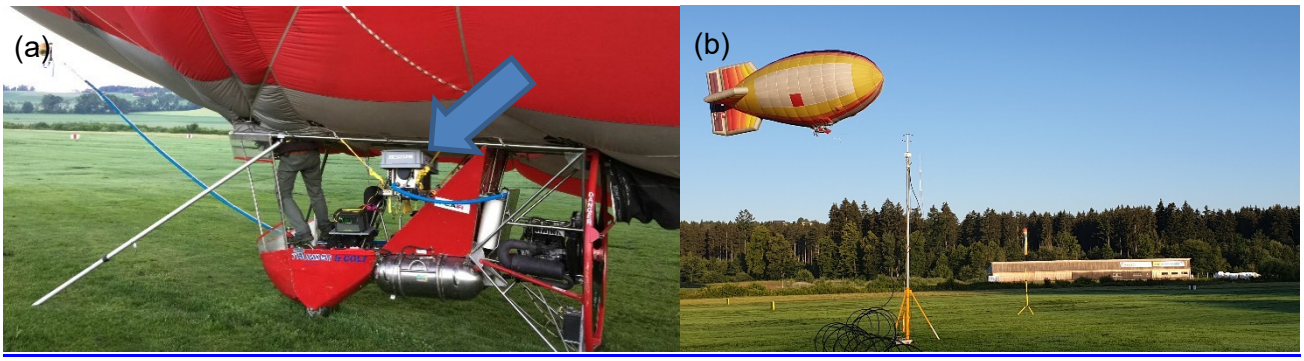

Figure 2. (a) Picture of FLAIR sensor (blue arrow) installed on the hot air zeppelin and (b) the hot air zeppelin carrying FLAIR instrument. The wind mast and the tubing of the artificial methane source are visible in (b). In addition, the Beromünster tall tower can be seen in the center of (b). The Beromünster tall tower is located in western direction from the airfield in a distance of about 2 km.

The retrieved concentrations by the FLAIR instrument are depicted in Figure 3. Note that we have applied the previously found correction multiplication factor of 1.66 (see deliverable 6.2) to the CH_4 concentrations. Figure 3(b) shows a zoom to the low CH_4 concentrations (atmospheric) part of the curve, and Figure 3(c) shows a zoom to the elevated CH_4 concentrations in the artificial plume. The retrieved atmospheric concentration of CH_4 is very close to the expected atmospheric concentration with an average value of 1.9 ppm and a standard deviation of 0.65 ppm. In fact, there is no clear systematic offset as found during the tests in the temperature controlled environment of the NABEL site in Dübendorf. This may be due to the non-uniformity correction (NUC) of the camera, which depends on environmental parameters, in particular the camera temperature.
The response time of the instrument is determined by the refresh rate of the MPC. At the chosen gas flow rate, a response time of about 3 seconds can be expected. The rise and fall time of the retrieved CH_4 concentration when flying through the plume of the artificial methane source indicates a good agreement with the expected response time.

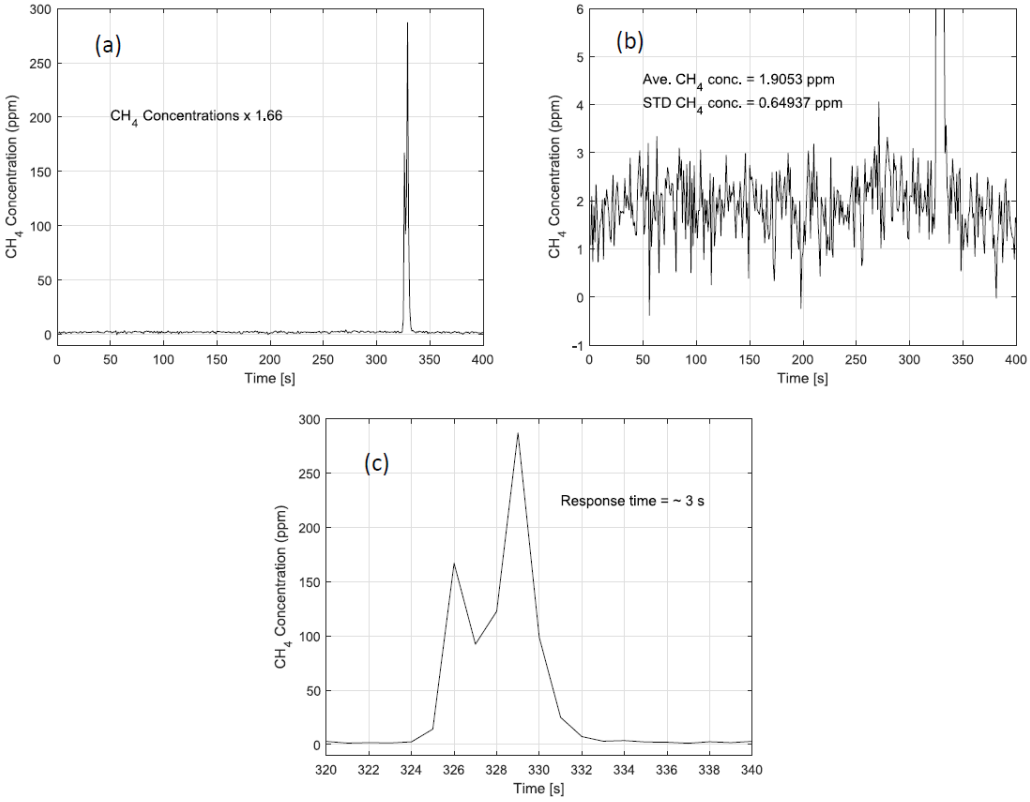

Figure 3. (a) the retrieved CH_4 concentrations, (b) zoom to the low CH_4 concentrations (atmospheric) part of the curve, and (c) zoom to elevated CH_4 concentrations in the artificial plume

Figure 4(a) shows the retrieved H_2O concentrations with no correction factors applied. The retrieved H_2O concentrations show an average value of 0.86% and a standard deviation of 0.071%. At high levels of CH_4, there is a cross-talk visible in the retrieved H_2O concentrations caused by the fitting algorithm. Figure 4(b) demonstrates a zoom to this cross-talk part.

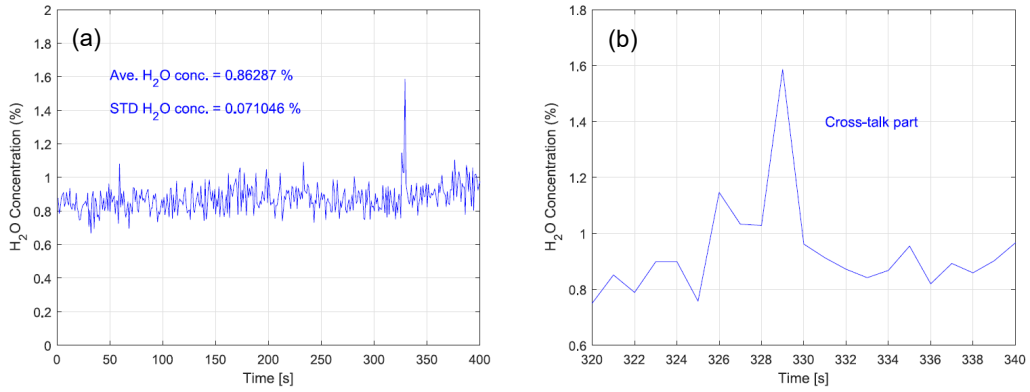

Figure 4.(a) The retrieved H_2O concentrations and (b) A zoom to the cross-talk region

At the relatively low prevailing wind speeds, it was difficult to identify the plume of the artificial methane source and to detect the existence of the methane source with the airborne FLAIR sensor system. In order to understand why elevated methane concentrations were not detected in all fly-overs, the CH_4 measurements were combined with the corresponding GPS data (Figure 5). Figure 5a shows the trajectory and altitudes of the zeppelin during the campaign, and Figure 5b is the trajectory with the terrain. The detection of methane emitted by the artificial source was successful when the Zeppelin

was at ~663 m (12 m above ground), and the wind was blowing from the south at ~0.8 m/s. In contrast, the artificial plume was not detected for the flight at ~675 m (24 m above ground) with barely any wind (Figure 5f).

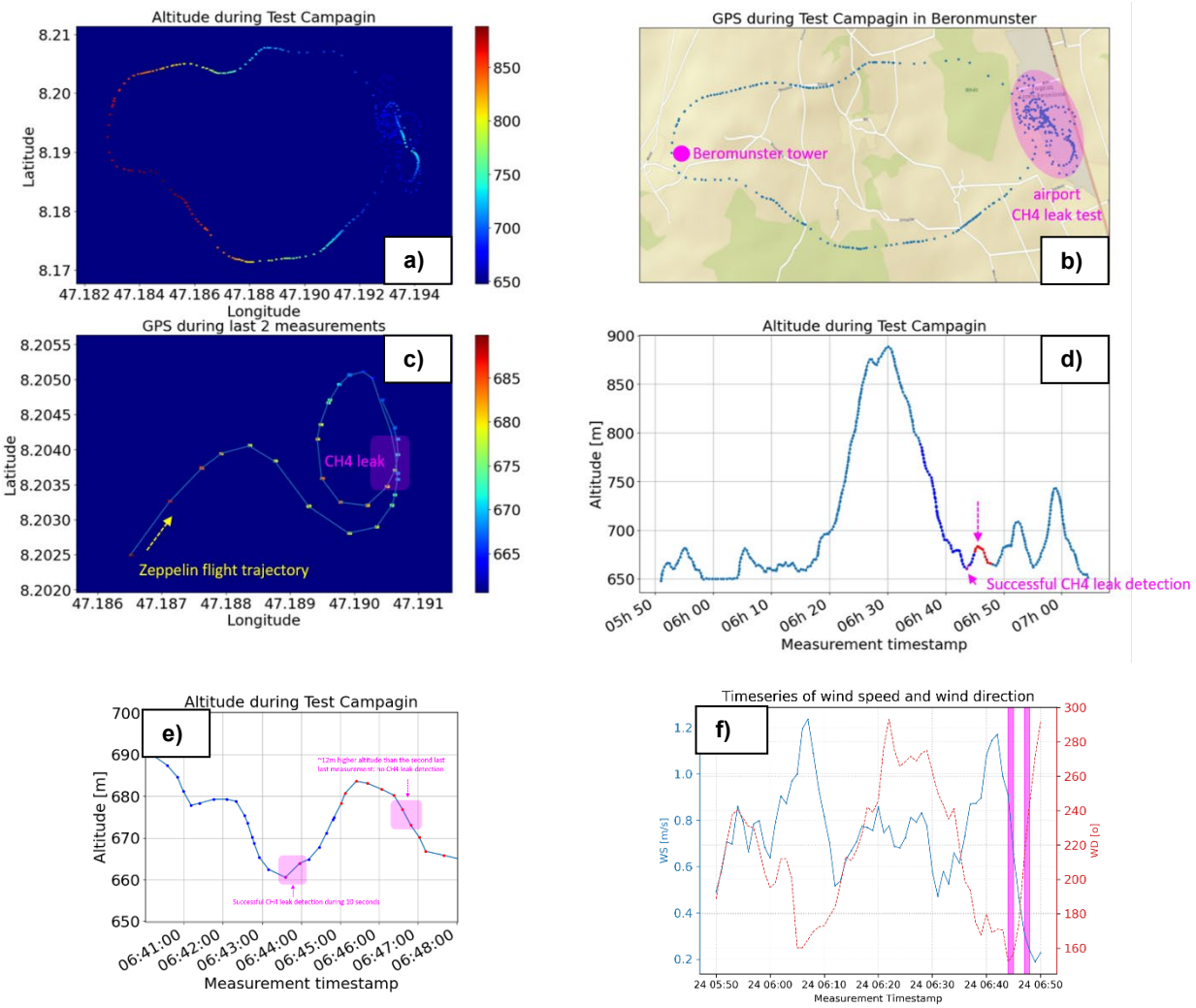

Figure 5. (a) Trajectory and altitudes of the zeppelin route,(b) trajectory with regard to the tower and methane source, (c) trajectory and altitudes of the last 2 measurements, (d) altitude vs time, (e) zoom into the successful leak detection, and (f) time series of wind speed and direction

This field test campaign was documented and the pictures and videos are available on the project surfdrive (https://surfdrive.surf.nl/files/index.php/s/qrYHPUQdxtHK1zb). More details on the data processing are presented in the following section.

2.2 Details of the data processing

Figure 6 demonstrates the measured FLAIR sensor spectra dataset, which contains 400 spectra measured in ~400 s.

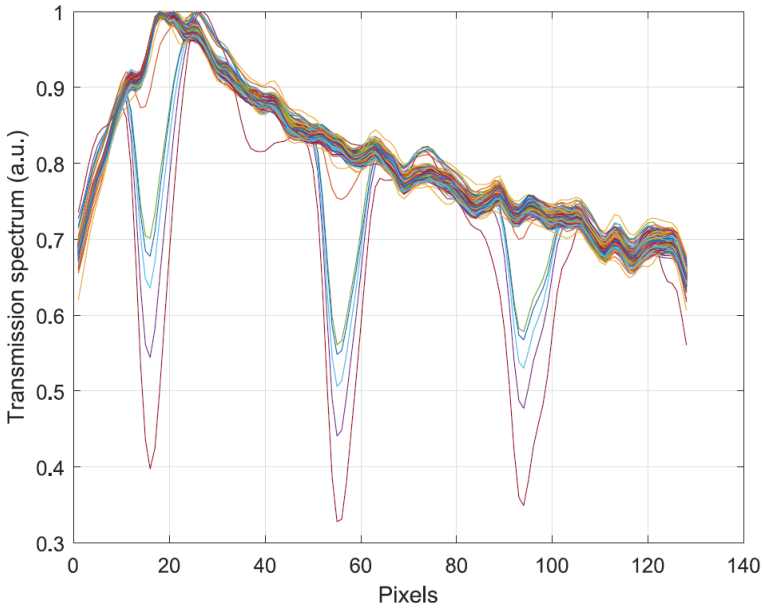

Figure 6. The measured FLAIR sensor spectra dataset containing 400 spectra recorded in ~6.5 minutes

Only a small number of spectra demonstrate elevated levels of CH_4 concentration. The premeasured background spectrum (measured in CSEM) is shown in Figure 7.

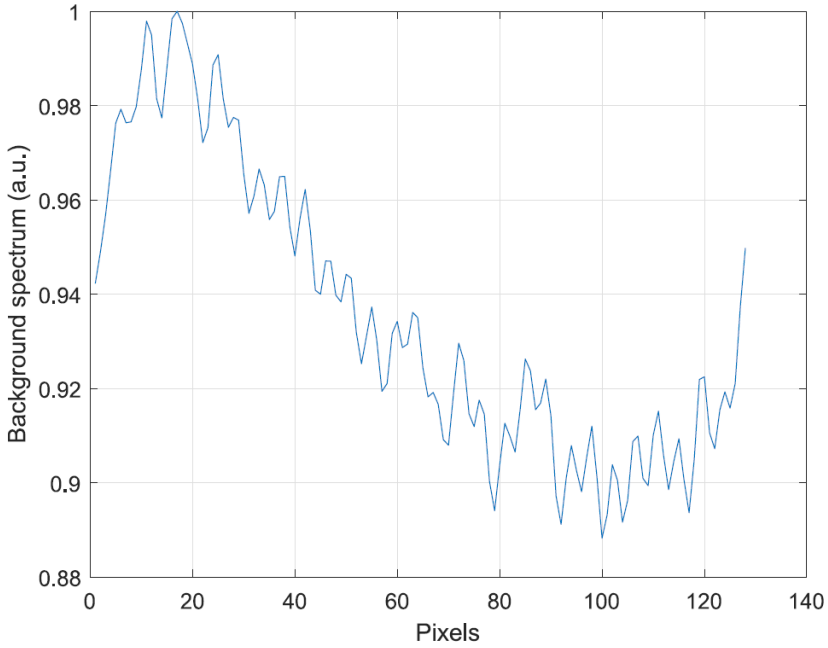

Figure 7. The premeasured background spectrum measured in CSEM using a N_2 filled MPC and averaging time of 2 minutes

Figure 8 demonstrates the normalized spectra, retrieved by dividing the measured spectra (shown in Figure 6) by the background spectrum (shown in Figure 7). Figure 9 demonstrates the corresponding absorption spectra (absorbance) by applying a natural logarithm to the normalized spectra.

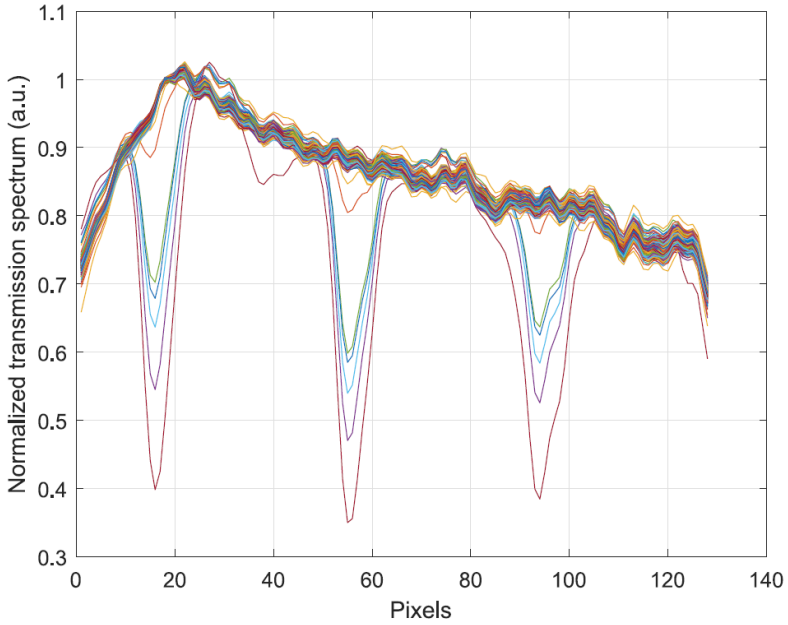

Figure 8. Normalized spectra retrieved from dividing the measured spectra by the background spectrum

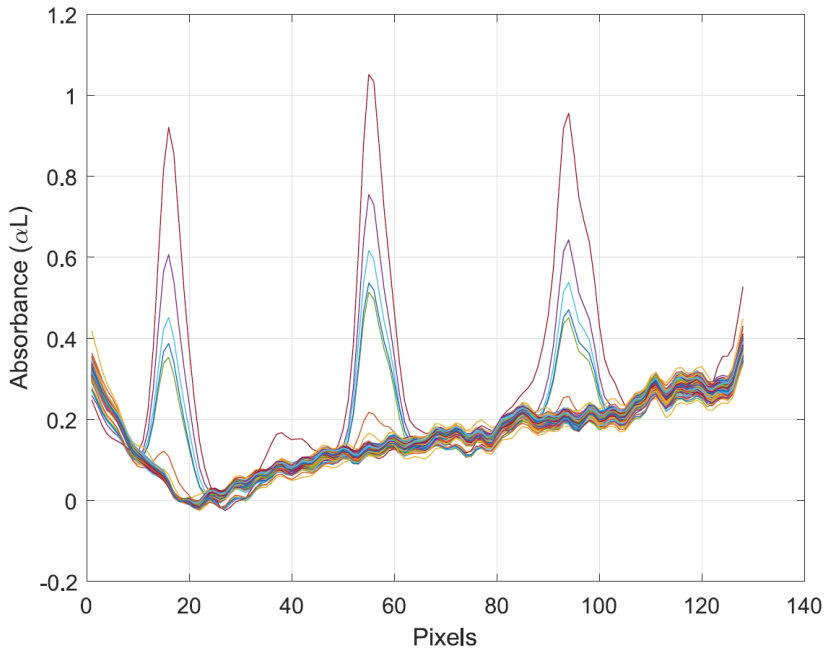

Figure 9. Normalized spectra retrieved from dividing the measured spectra by the background spectrum

The measured spectra are on top of a large baseline, which cannot be removed by normalization. By using a ninth order polynomial in the fitting routine, we can remove the remaining baseline. In addition, since the pre-calibration of the spectrum was missed probably due to the rotation of the grating, we performed a new calibration for mapping the pixels to wavenumbers using a linear equation, using one of the spectra that demonstrates high CH_4 absorption. The new equation is:

Wavenumber = 0.263 * Pixel number + 2943.8

Figure 10 demonstrates the fit to a few measured spectra that do not show elevated levels of CH_4 concentration. The measurement (after removing the remaining baseline) is in black, The CH_4 fitted spectrum is in green, the H_2O fitted spectrum is in blue, the total absorbance fit is in red, the residual of the fit is in magenta and the removed baseline is in cyan. Same as before, the water absorption features are higher than the camera noise level especially at ~2975 cm^{-1}, but the methane absorption features are buried in the camera noise.

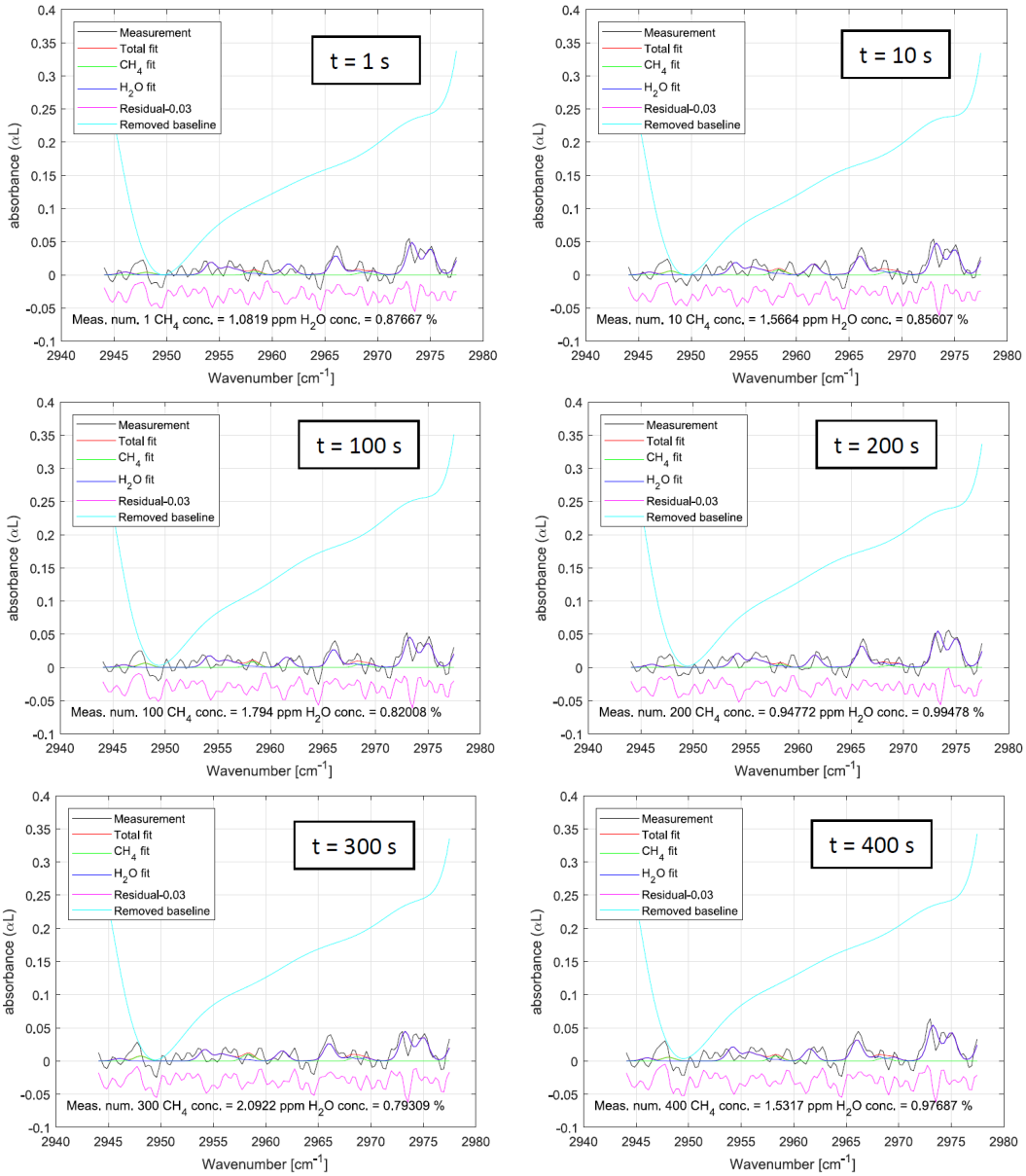

Figure 10. Fit to a few measured spectra that do not show elevated levels of CH_4 concentration. The measurement (after removing the remaining baseline) is in black, The CH_4 fitted spectrum is in green, the H_2O fitted spectrum is in blue, the total absorbance fit is in red, the residual of the fit is in magenta and the removed baseline is in cyan spectrum

Eight particular spectra, measured from t = 325 to t = 332, show elevated concentrations of CH_4. Figure 11 demonstrates the fit to these spectra. The color-coding of the curves are the same as the previous figure.

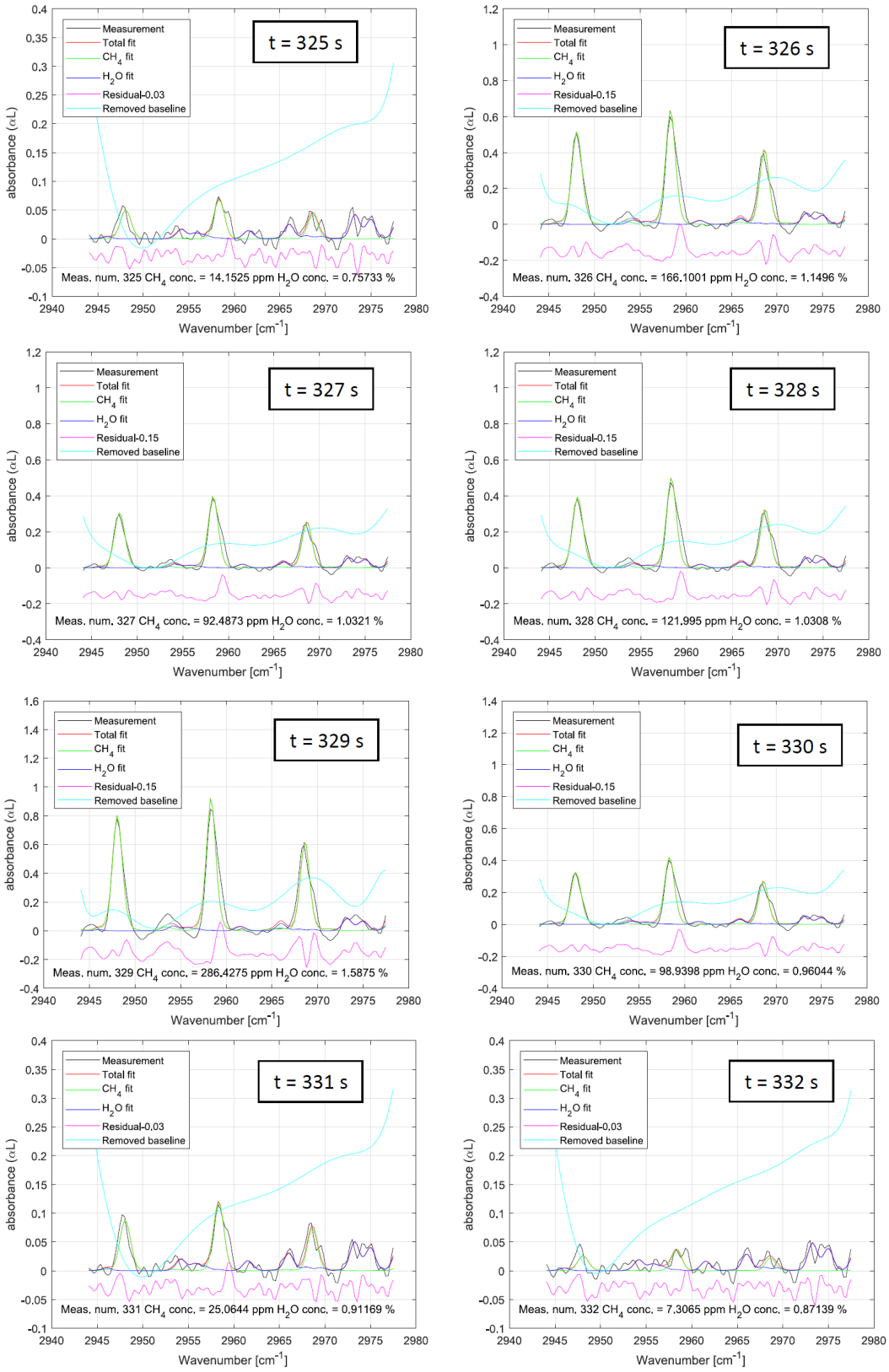

Figure 11. The fit to the eight measured spectra that show elevated levels of CH_4 concentration. The color coding is the same as the previous figure

The residuals of the fits demonstrate some structures, especially for higher CH_4 concentrations, that most probably are due to the simplified linear mapping of the pixel numbers to wavenumber domain.

A better mapping by using a higher order polynomial can probably reduce these structures to lower than the noise level; however, the retrieved CH_4 concentrations from the fit would not change drastically since the current absorption features in the measurement and the fit generally demonstrate a good matching on the y scale (absorption strength). Note that for spectra demonstrating higher CH_4 absorption, the baseline is different compared to other spectra. This may be due to hydrocarbons, other than CH_4, that are found in the natural gas sample (mainly ethane and propane). Although we cannot identify these other hydrocarbons due to the limited optical bandwidth of the FLAIR spectrometer, the results demonstrate that a baseline fitting routine can effectively remove a broadband interfering absorption feature and we can retrieve CH_4 concentrations in the presence of other hydrocarbons.