Riverside Data
LWIR Results

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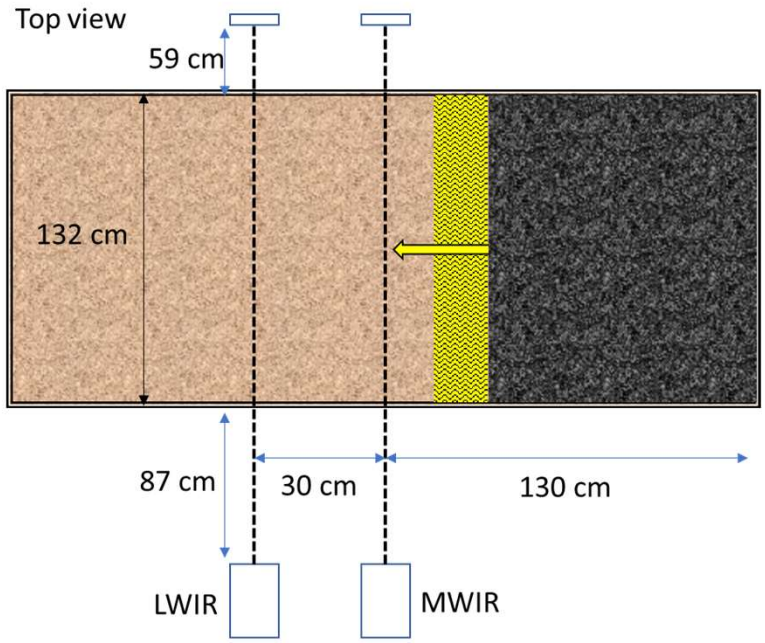
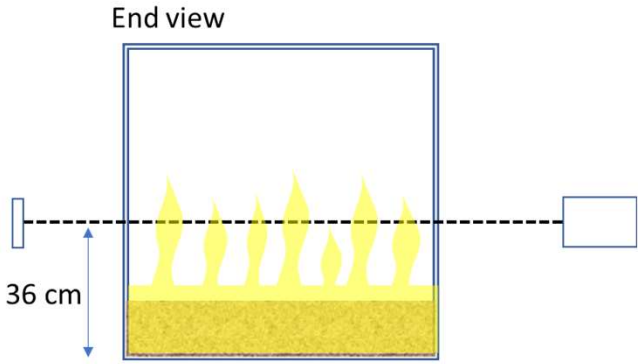
Experimental configuration





Measurement path length inside wind tunnel: 264 cm (double-pass)
Regions outside wind tunnel assumed to remain at ambient conditions

Measured quantities for each ECQCL/detector:

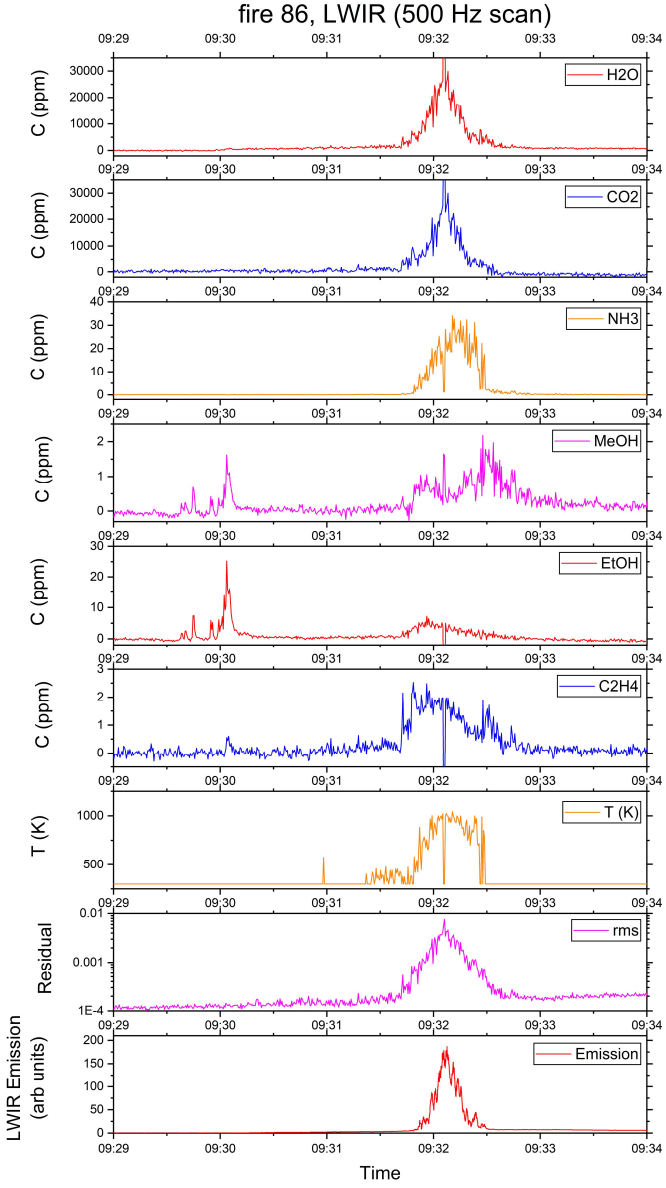
1. ECQCL transmitted intensity vs (wavenumber, time) measured modulated signal *amplitude*
2. Spectrally-integrated emission (MWIR or LWIR) from measured modulated signal *offset*

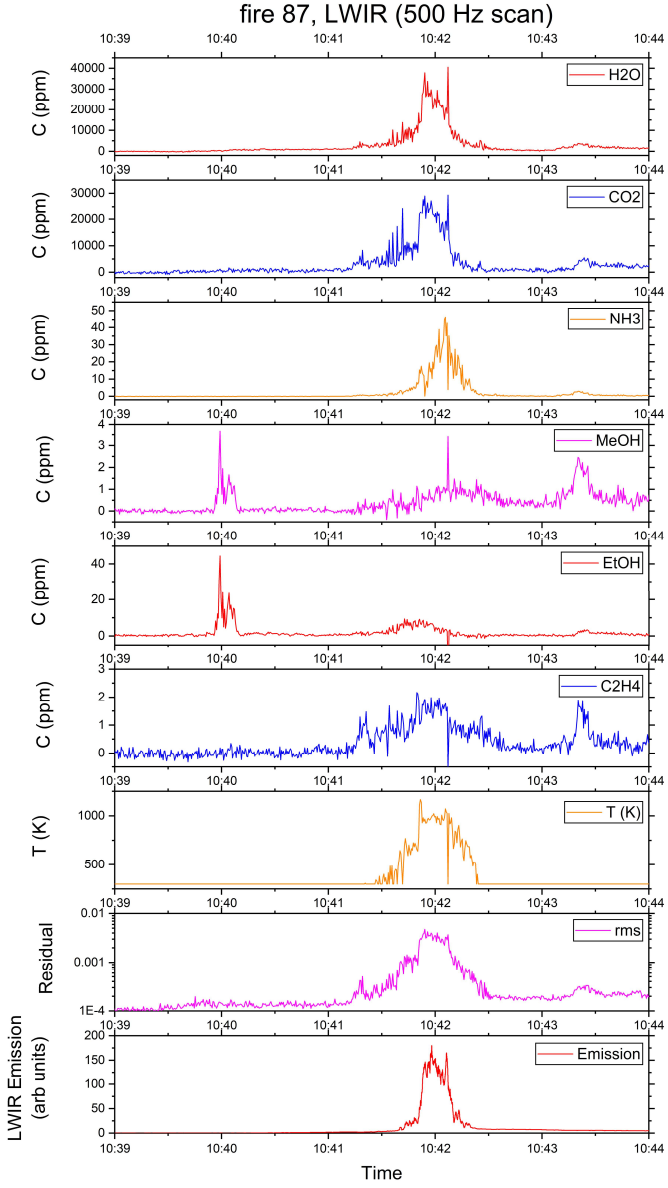
LWIR ECQCL Data

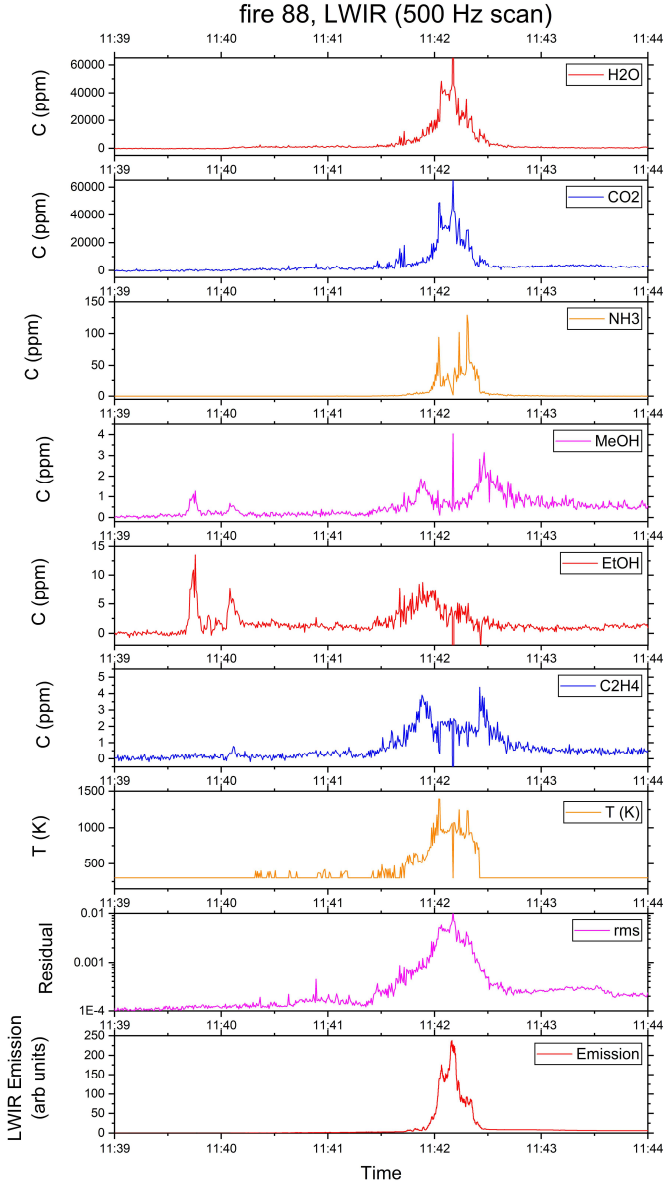
- Have good spectral data runs from 9x burns (3x each type)
  - Two scan rates/ranges used
- Data from other burns was used to optimize scan settings – not useful for full analysis and comparison
- Fixed wavelength data will be used to characterize turbulence

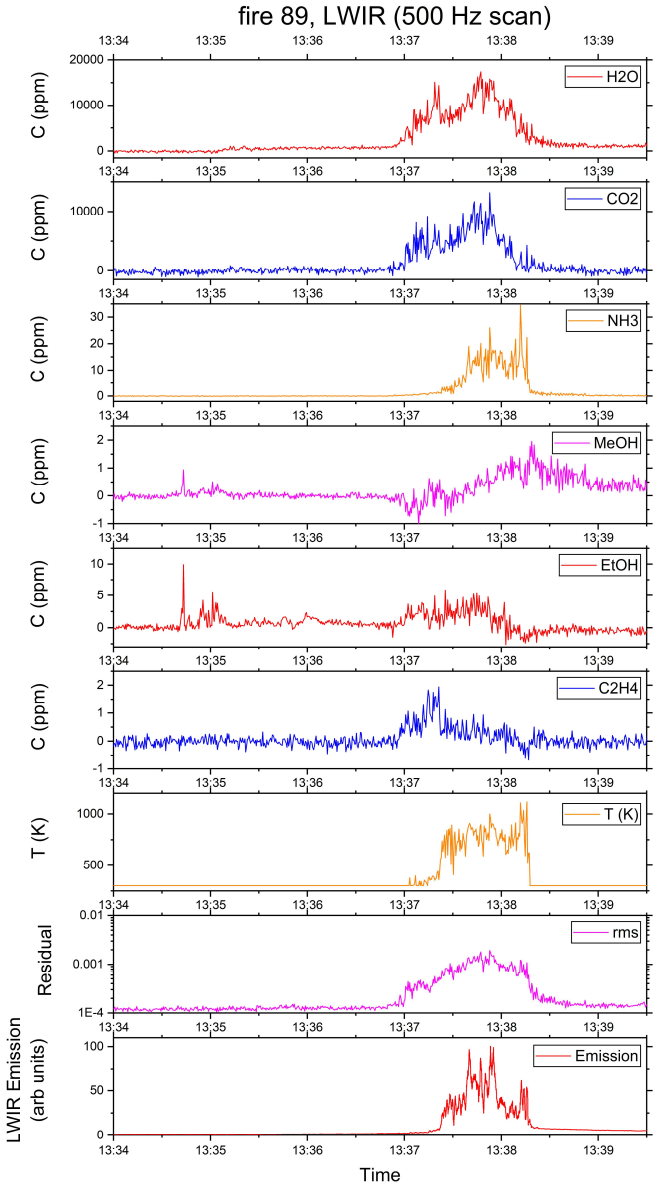
Date	Burn identifier	Ignition	end of bed	Burn notes	f scan (Hz)	total scans	start nu	end nu	delta nu	nu pts
11/1/2018	**fire86**	9:30:00 AM	9:33:02 AM	**sparkle, cold**	500	92550	920	1150	0.1	2300
11/1/2018	**fire87**	10:40:00 AM	10:42:29 AM	**ilex, cold**	500	97800	920	1150	0.1	2300
11/1/2018	**fire88**	11:40:00 AM	11:43:00 AM	**lyonia, cold**	500	99825	920	1150	0.1	2300
11/1/2018	**fire89**	1:35:00 PM	1:38:48 AM	**ilex**	500	107750	920	1150	0.1	2300
11/1/2018	**fire90**	2:45:00 PM	2:49:47 PM	**sparkle**	500	117000	920	1150	0.1	2300
11/1/2018	**fire91**	3:30:00 PM	3:34:33 PM	**lyonia**	500	145175	920	1150	0.1	2300
11/2/2018	**fire92**	9:30:00 AM	9:34:05 AM	**ilex**	100	21055	910	1215	0.05	6100
11/2/2018	**fire93**	10:41:15 AM	10:45:44 AM	**lyonia**	100	23140	910	1215	0.05	6100
11/2/2018	**fire94**	11:28:15 AM	11:32:28 AM	**sparkle**	100	23545	910	1215	0.05	6100
11/2/2018	**fire95**	1:42:45 PM	1:46:17 PM	**sparkle**	fixed wavelength					

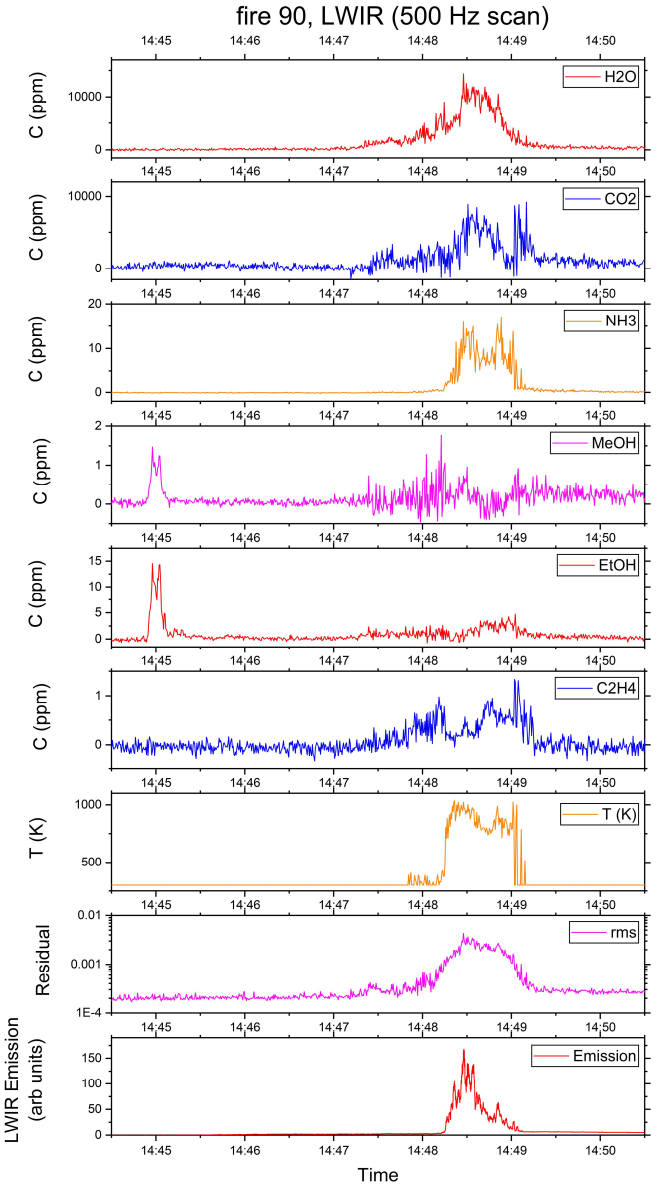
LWIR results – mixing ratios vs time

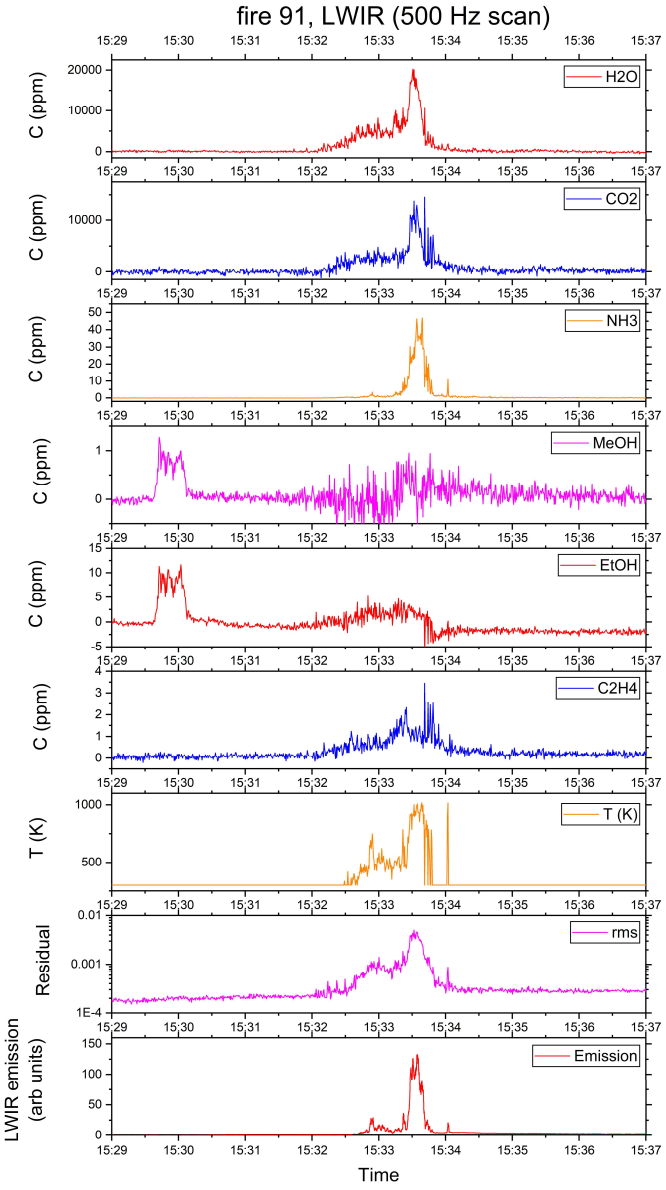

fire 86, LWIR (500 Hz scan)
H2O
CO2
NH3
MeOH
EtOH
C2H4
T (K)
rms
Emission
C (ppm)
T (K)
Residual
LWIR Emission (arb units)
Time

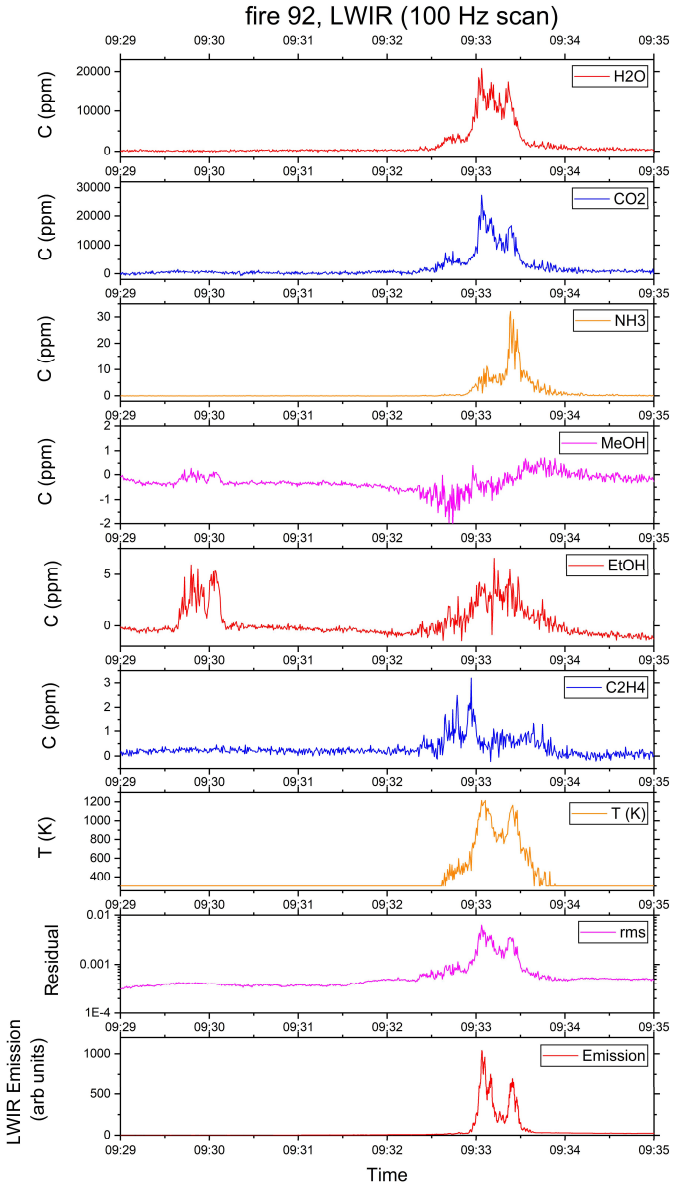

fire 87, LWIR (500 Hz scan)
H2O
CO2
NH3
MeOH
EtOH
C2H4
T (K)
rms
Emission
C (ppm)
T (K)
Residual
LWIR Emission (arb units)
Time

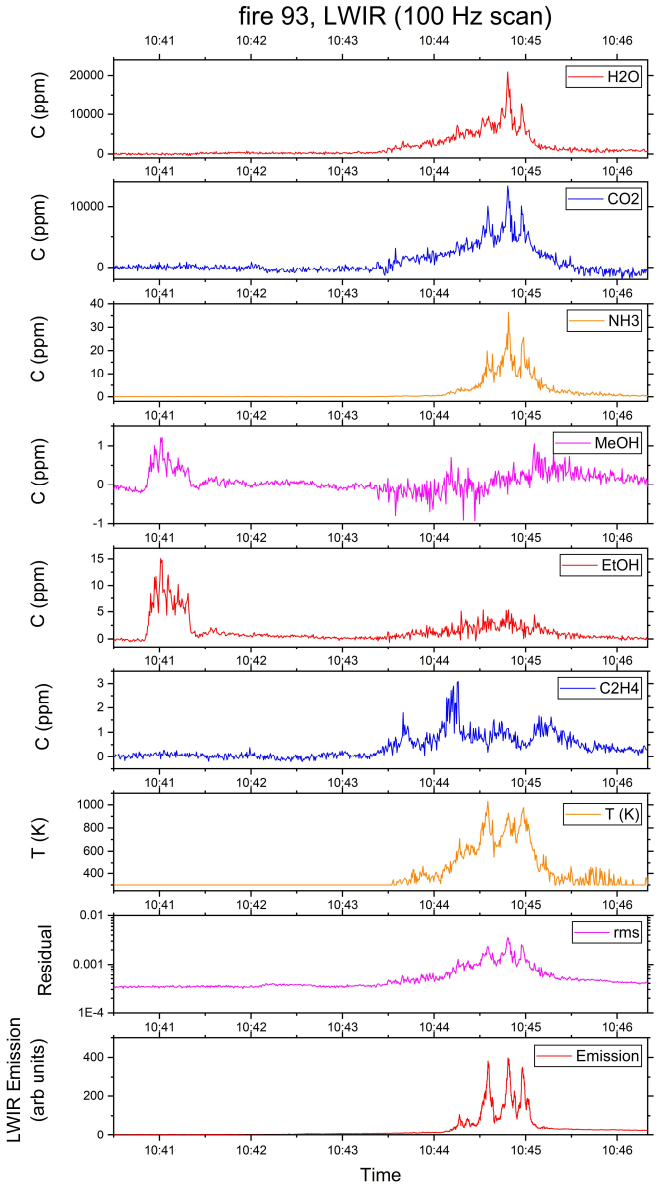

fire 88, LWIR (500 Hz scan)
H2O
CO2
NH3
MeOH
EtOH
C2H4
T (K)
rms
Emission
C (ppm)
T (K)
Residual
LWIR Emission (arb units)
Time

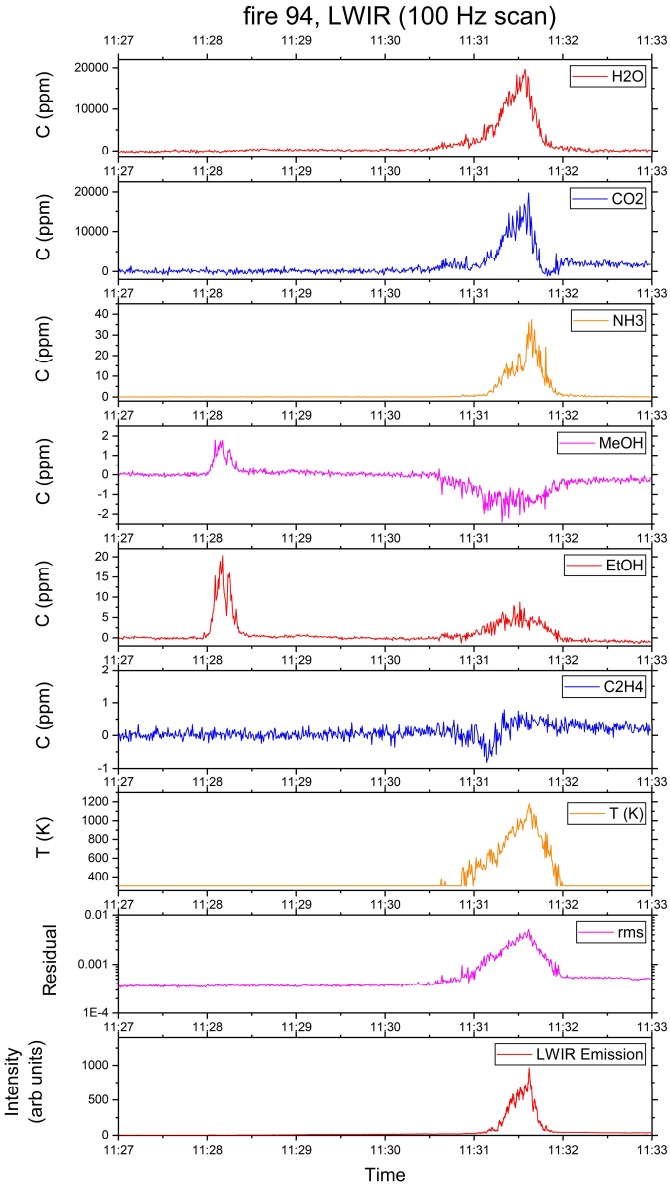

fire 89, LWIR (500 Hz scan)
H2O
CO2
NH3
MeOH
EtOH
C2H4
T (K)
rms
Emission
C (ppm)
T (K)
Residual
LWIR Emission (arb units)
Time

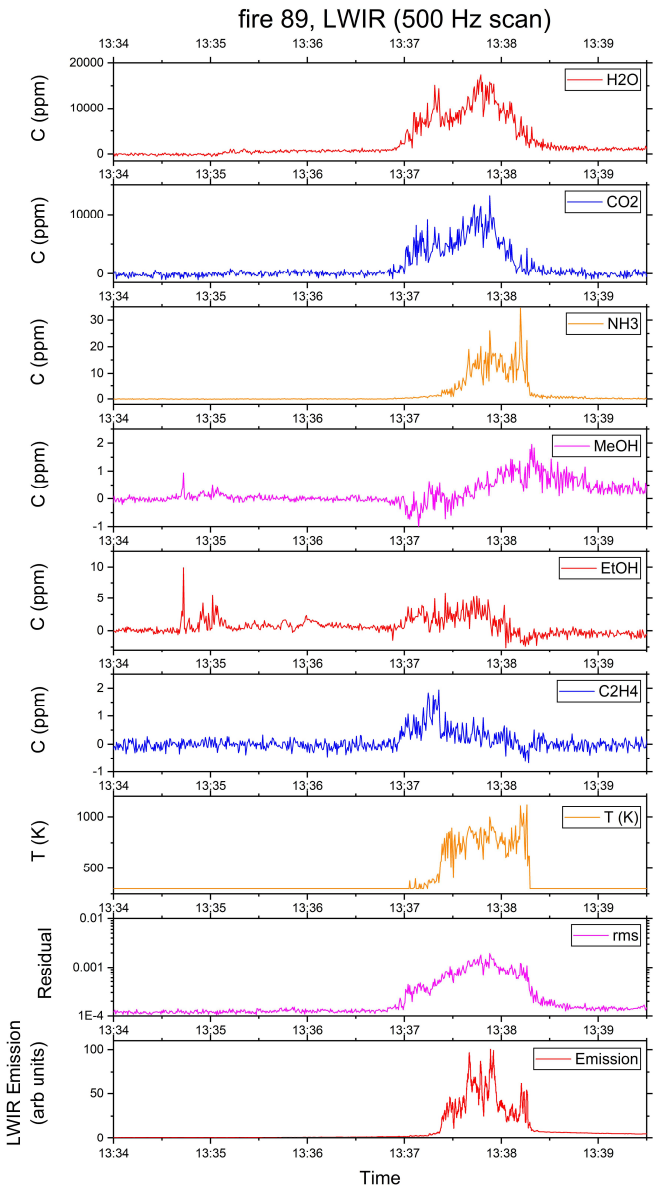

fire 90, LWIR (500 Hz scan)
H2O
CO2
NH3
MeOH
EtOH
C2H4
T (K)
rms
Emission
C (ppm)
T (K)
Residual
LWIR Emission (arb units)
Time


fire 91, LWIR (500 Hz scan)
H2O
CO2
NH3
MeOH
EtOH
C2H4
T (K)
rms
Emission
C (ppm)
T (K)
Residual
LWIR emission (arb units)
Time

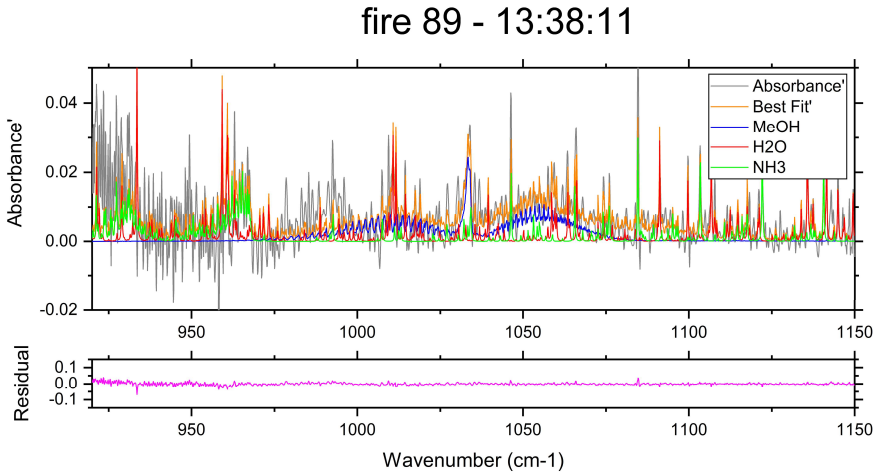

fire 92, LWIR (100 Hz scan)
H2O
CO2
NH3
MeOH
EtOH
C2H4
T (K)
rms
Emission
C (ppm)
Residual
LWIR Emission (arb units)
Time


fire 93, LWIR (100 Hz scan)
H2O
CO2
NH3
MeOH
EtOH
C2H4
T (K)
rms
Emission
C (ppm)
Residual
LWIR Emission (arb units)
Time

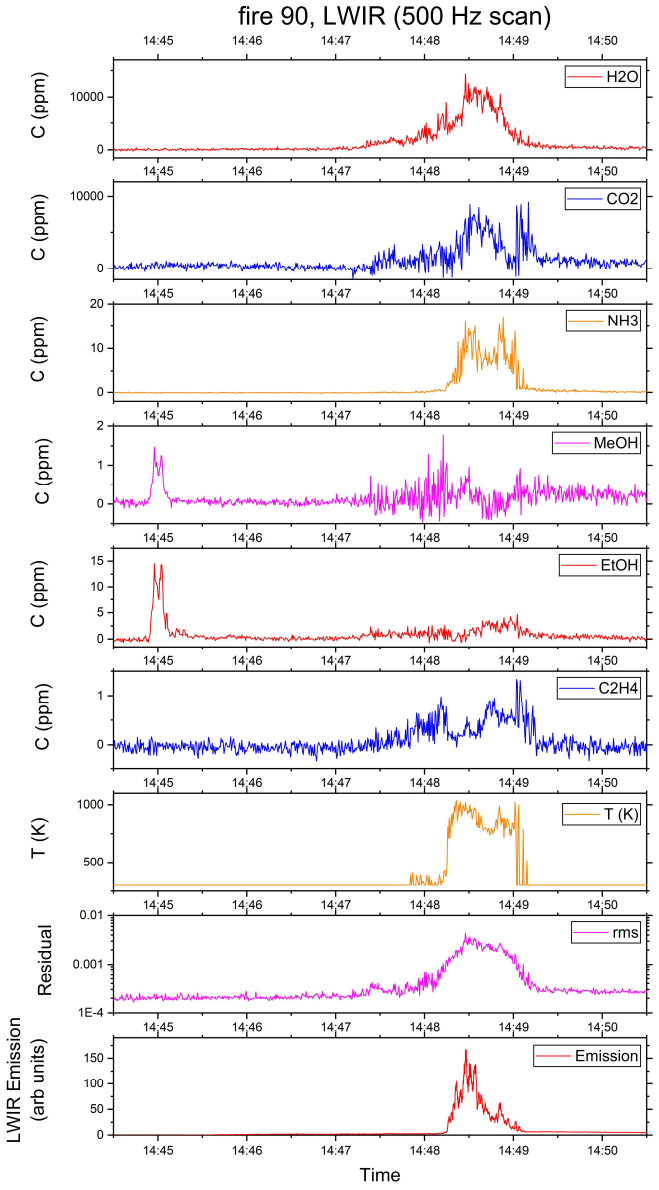

fire 94, LWIR (100 Hz scan)
H2O
CO2
NH3
MeOH
EtOH
C2H4
T (K)
rms
LWIR Emission
C (ppm)
Residual
Intensity (arb units)
Time

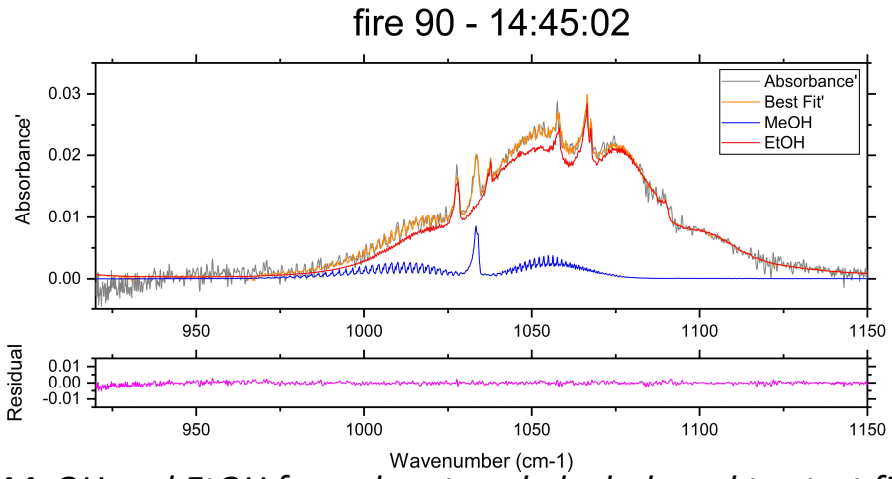


- Temperature and emission intensity are correlated, as expected
- Temperature determined from H2O spectrum reaches ~ 1000K
  - Transmission through flame region
  - Will compare with temperatures from MWIR spectra
- H2O and CO2 concentrations are highest during flame region
  - Concentrations are reasonable (1-2%)
  - Will compare with values from MWIR spectra
- NH3, C2H4 (ethylene) observed
- EtOH and MeOH observed pre-flame from fire starting fluid (denatured alcohol)
- MeOH observed after flame front
- RMS fit residuals increase during flame region due to turbulence and fit errors at high temperatures, but still good

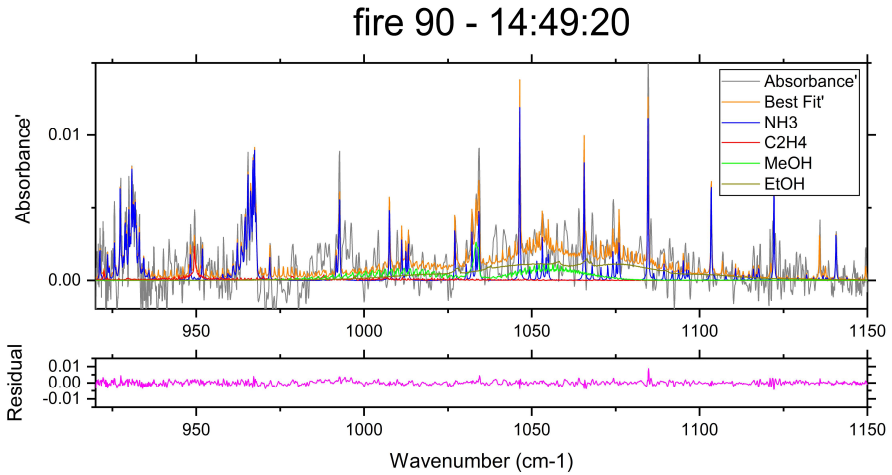


Evidence of MeOH near trailing edge of flame front

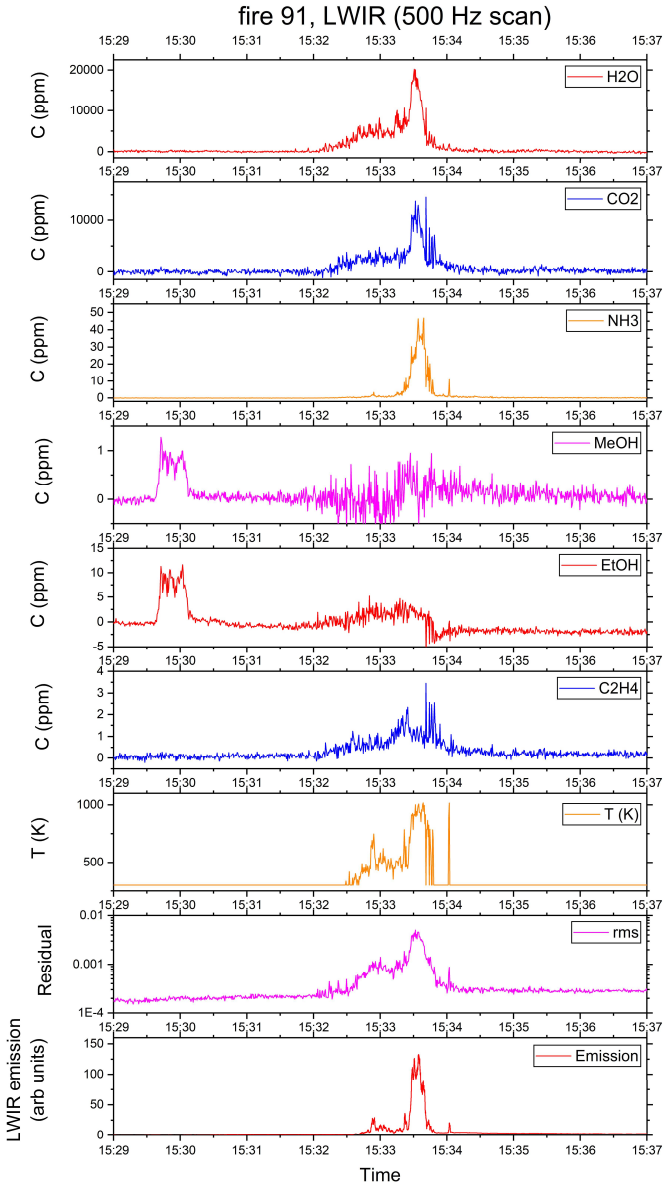


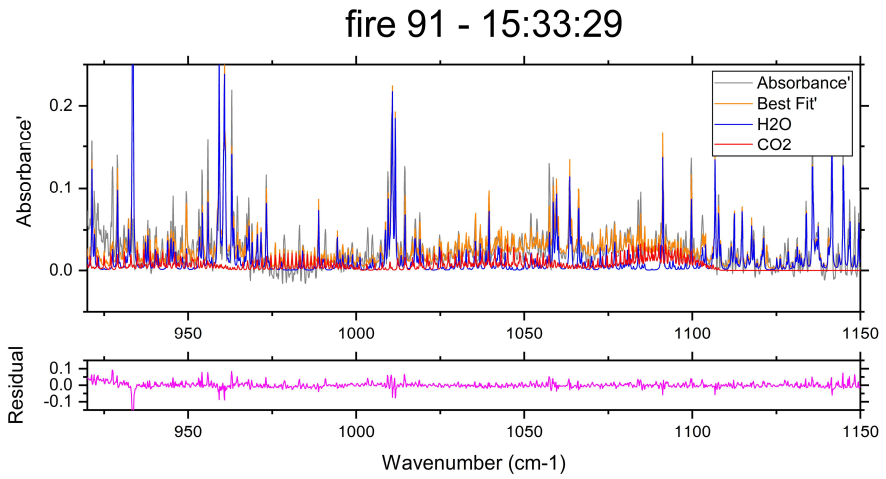


MeOH and EtOH from denatured alcohol used to start fire



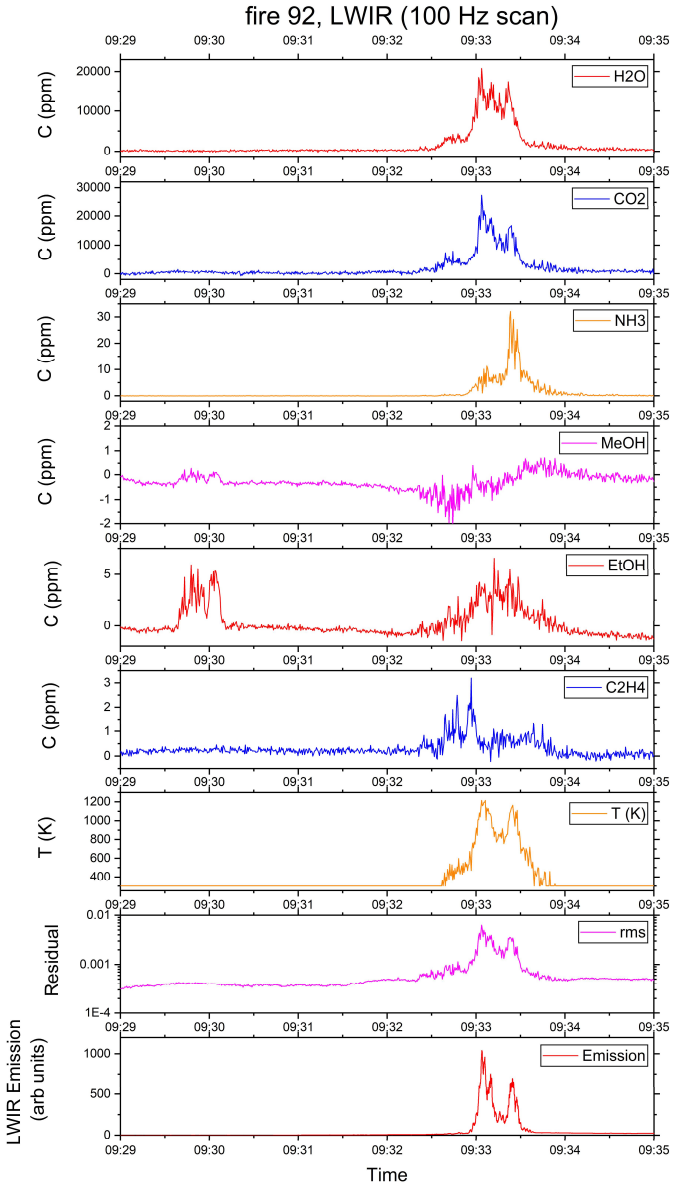
Nearly all species co-existing at tailing edge of flame front

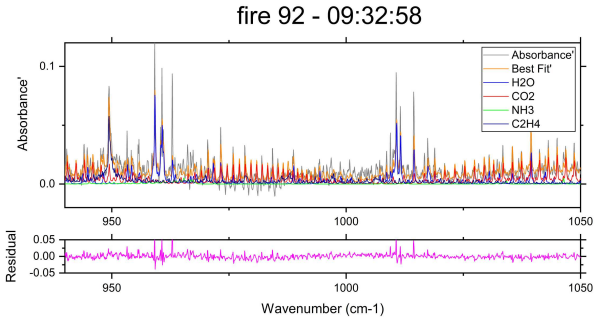


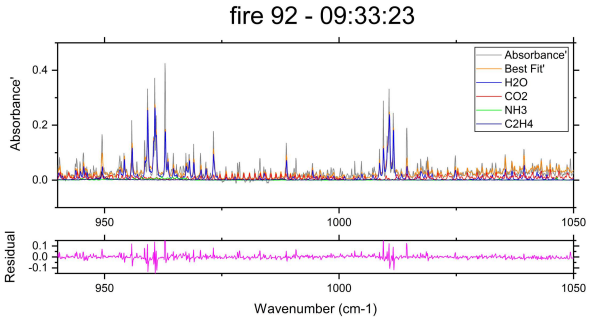


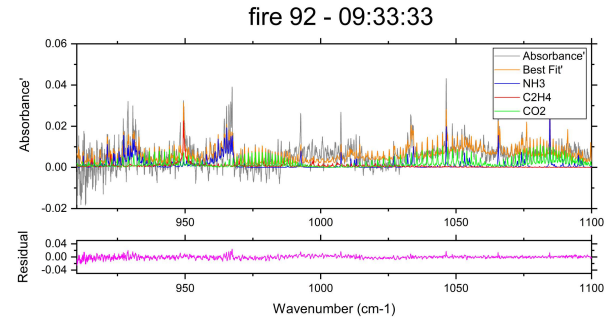
Example of high-temperature H2O and CO2 spectral fit

Note problems with fitting temperature for this run, and effect on fits for other species. Also affects mixing ratio calculations

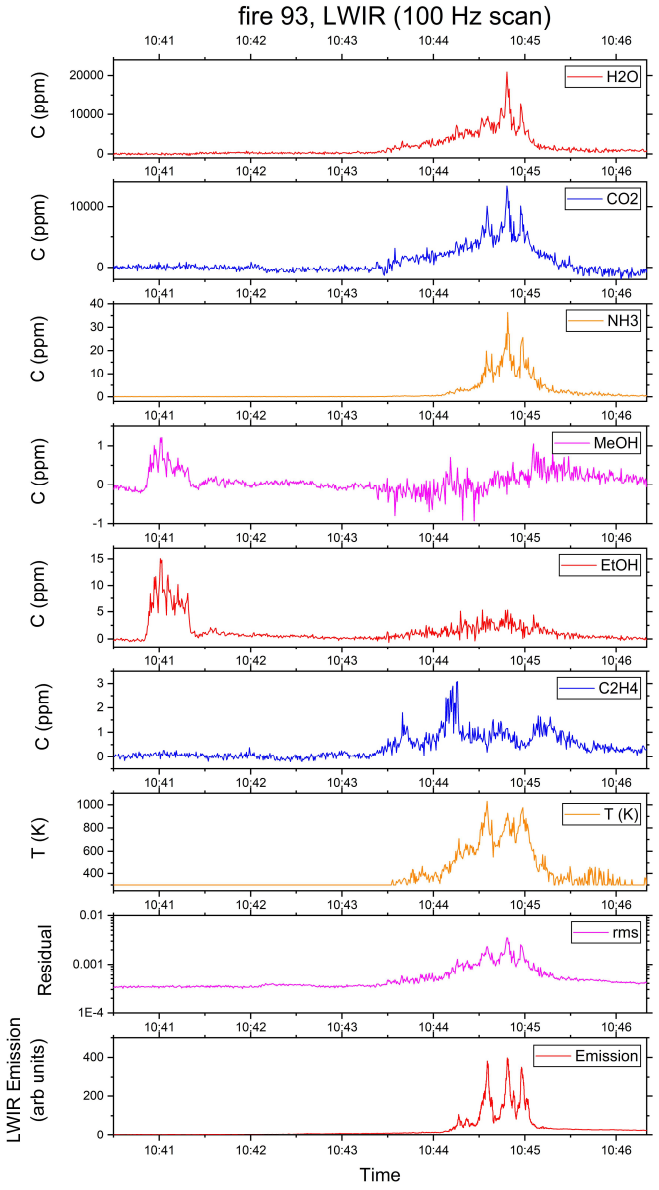




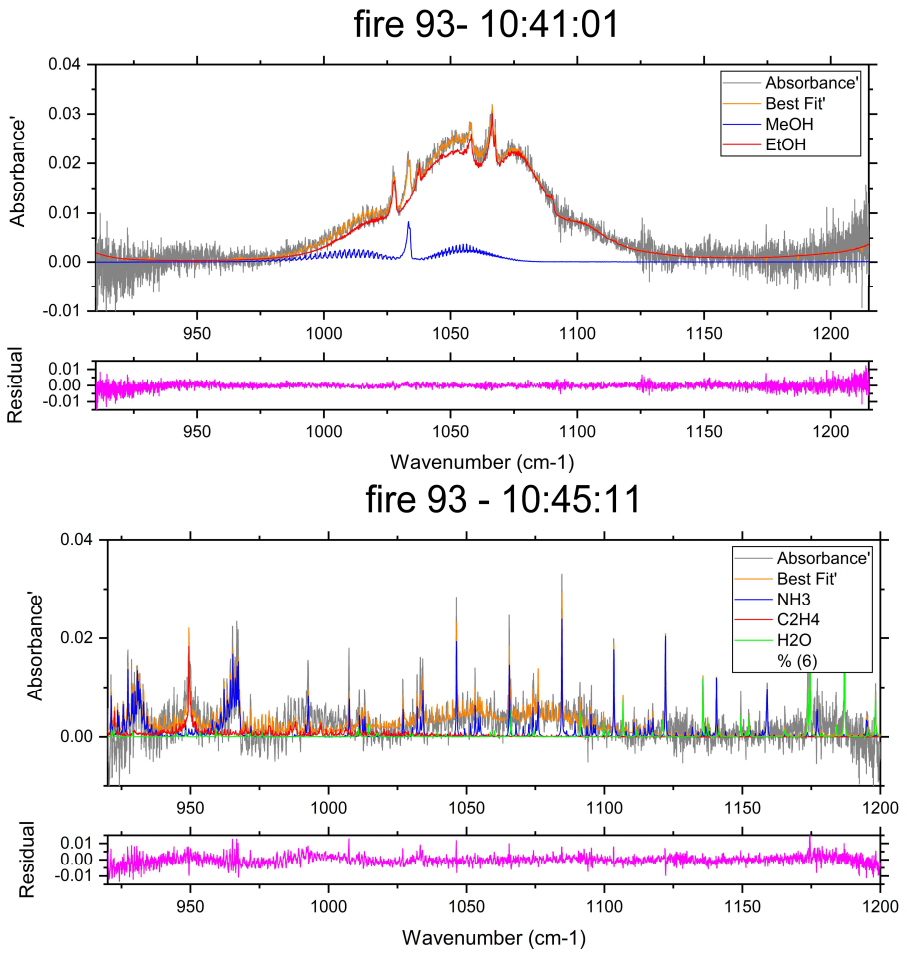




Examples of spectra from 100 Hz scan with broader scan range



Examples of spectra from 100 Hz scan with broader scan range



Data preparation

- Wavenumber axis calibrated for each scan using measured etalon transmission and comparison to measured reference spectrum (F152a)
  - Both scans acquired immediately before or after experimental run of fire data
- Background calculated from average of first 1s of experimental run
- Absorbance spectrum calculated for every subsequent spectrum
- Absorbance averaged to 0.5 s intervals
  - For 500 Hz scan rate, 250 spectra were averaged
  - For 100 Hz scan rate, 50 spectra were averaged
- Resulting absorbance spectra show the *change* in absorbance relative to pre-flame ambient conditions
  - Mixing ratios are therefore relative to ambient values (ie ambient concentrations = 0)

Analysis Notes

- Two stage analysis
  - Step 1 – used subset of spectrum to fit H_2O spectrum only and determine temperature using nonlinear LSF
    - H2O spectrum calculated from HITRAN parameters
    - For 50 Hz scan, used region 1150-1215 cm-1
    - For 250 Hz scan, used region 1090-1150 cm-1
    - Pre-subtracted 7th order polynomial baseline and PCA spectra from background analysis
  - Step 2 – used full spectrum to fit all species using linear weighted LSF
    - H2O, CO2, NH3 spectra calculated from HITRAN at each T from step 1
    - MeOH, EtOH, and C2H4 spectra from NWIR at T=25C
    - Includes PCA spectra from background analysis
    - Includes polynomial baseline fit (7th order)
- Reasoning for two-stage analysis
  - Single-step linear LS fits were very poor during flame region with elevated temperatures
  - Single-step nonlinear fit to full spectrum was attempted, but showed poor convergence and was very slow
  - Isolating section of spectrum with dominant H2O features shows better nonlinear fit convergence and is relatively fast
  - Linear LSF is robust and very fast, and shows better fits using H2O and CO2 calculated at elevated temperature
- Measured quantities from fitting algorithm:
  - Column density for H2O, CO2, NH3
  - Mixing ratio determined from fit to RTP NWIR spectrum of MeOH, EtOH, and C2H4
  - Average temperature of H2O (T)
- Reported mixing ratios are scaled for measured T using ideal gas law relationship and measurement path length (264 cm)
- Other species investigated but could not find clear evidence of distinguishing spectral features in data
  - Acetic acid, formic acid, SO2
  - Would need higher signal/longer pathlength to measure these species

Limitations of measurement and analysis

- Measurement is path-integrated over a turbulent source with high spatial and temporal variations
  - At many times, the ECQCL beam was propagating through the flame region, which includes extreme temperature variations
  - Fit results show path-averaged values of concentrations and temperatures
  - Measured spectra are a weighted sum over multiple temperature regions, and may show a combination of high-temperature and lower-temperature species
  - Inherent high uncertainty for absolute accuracy
- For some species (MeOH, EtOH, and C2H4), used room-temperature absorbance spectra from NWIR
  - Calculations of MeOH and C2H4 using HITRAN yielded poor fitting convergence, especially at high temperatures regions
  - Visual inspection of measured spectra shows good match to NWIR spectra
  - However, should use caution in interpreting absolute mixing ratios due to temperature effects