Riverside Data MWIR Results

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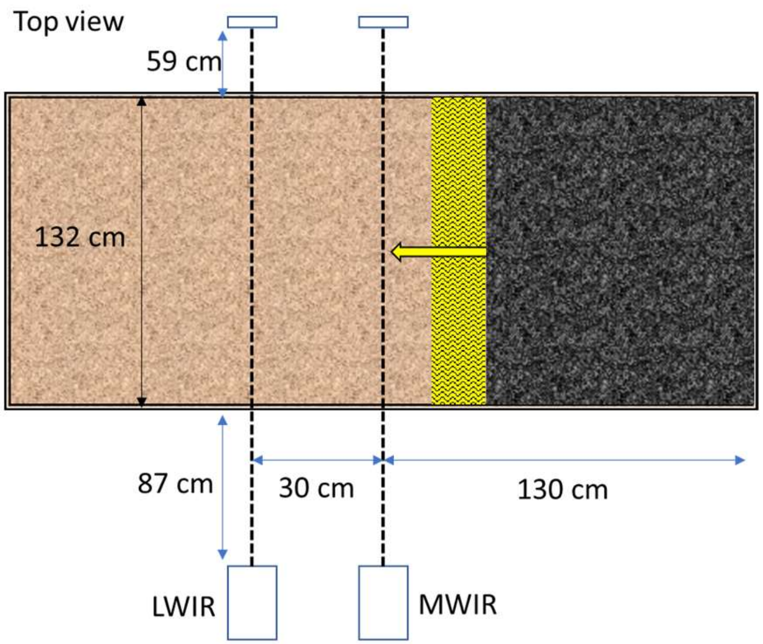
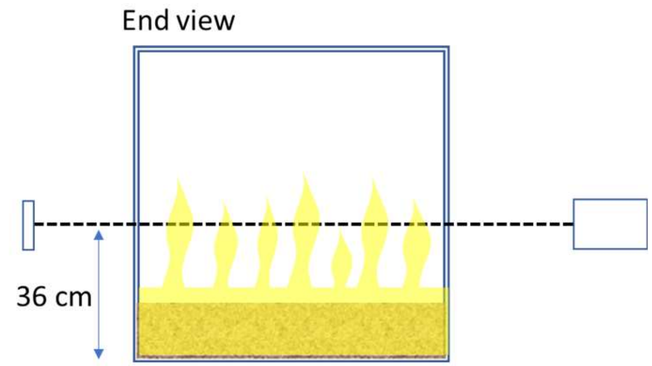
Experimental configuration





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:

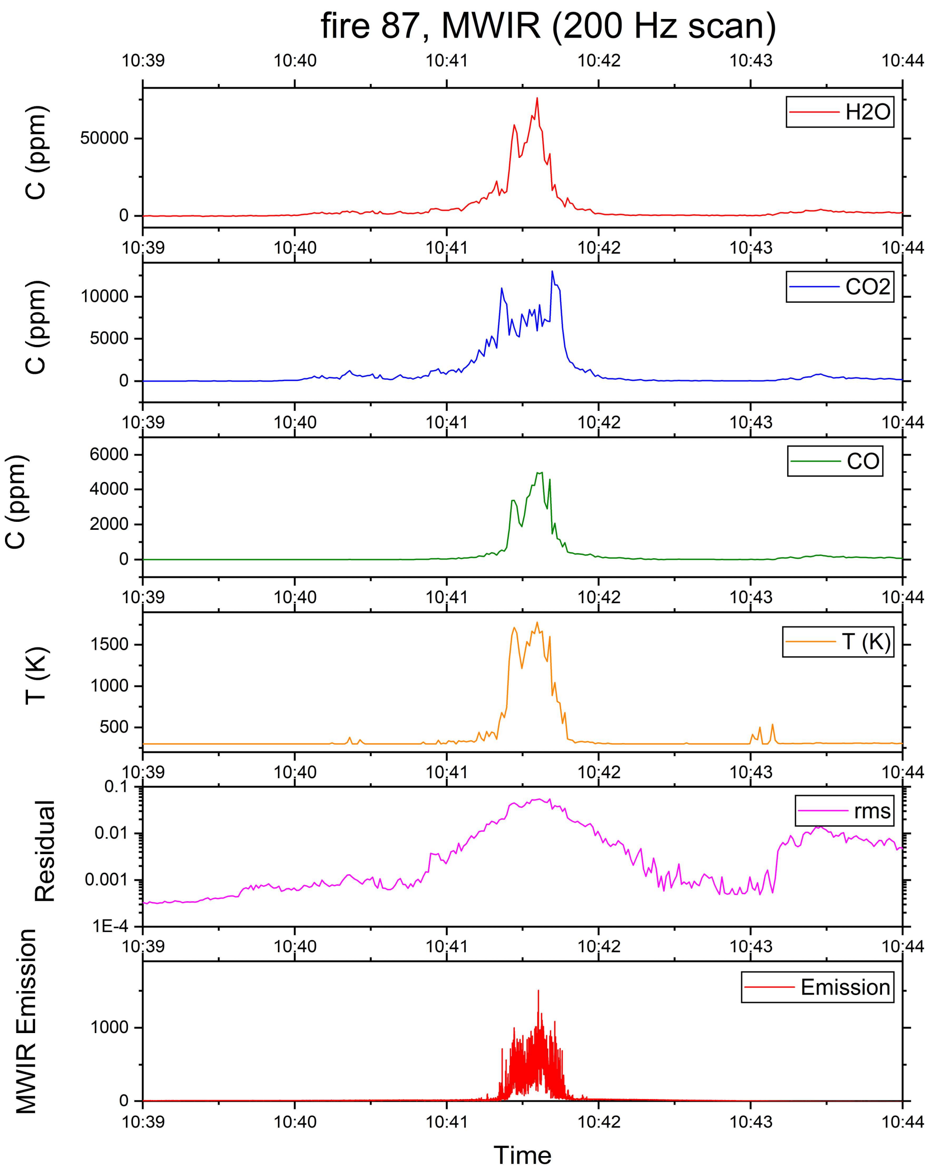
1. ECQCL transmitted intensity vs (wavenumber, time) measured modulated signal *amplitude*
2. Spectrally-integrated emission (MWIR or LWIR) from measured modulated signal *offset*

MWIR ECQCL Data

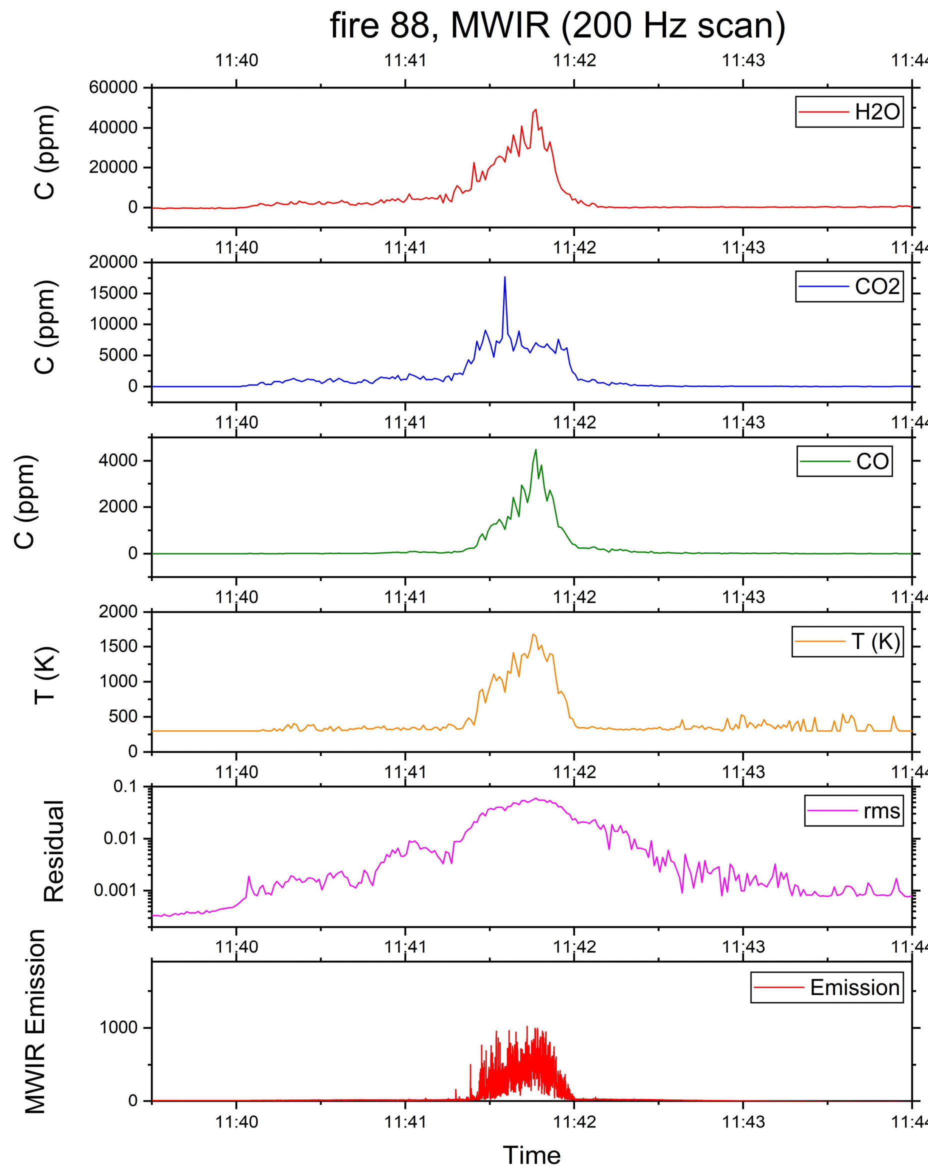
- Have good spectral data runs from 9x burns (3x each type)
  - Two scan rates/ranges used
- Data from other burns was used to optimize scan settings – not useful for full analysis and comparison
- Fixed wavelength data will be used to characterize turbulence

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	**fire87**	10:40:00 AM	10:42:29 AM	**ilex, cold**	200	39110	2089	2262	0.05	3460
11/1/2018	**fire88**	11:40:00 AM	11:43:00 AM	**lyonia, cold**	200	40960	2089	2262	0.05	3460
11/1/2018	**fire89**	1:35:00 PM	1:38:48 AM	**ilex**	200	43750	2089	2262	0.05	3460
11/1/2018	**fire90**	2:45:00 PM	2:49:47 PM	**sparkle**	200	49540	2089	2262	0.05	3460
11/1/2018	**fire91**	3:30:00 PM	3:34:33 PM	**lyonia**	200	57620	2089	2262	0.05	3460
11/2/2018	**fire92**	9:30:00 AM	9:34:05 AM	**ilex**	100	21815	2062	2292	0.05	4600
11/2/2018	**fire93**	10:41:15 AM	10:45:44 AM	**lyonia**	100	26735	2062	2292	0.05	4600
11/2/2018	**fire94**	11:28:15 AM	11:32:28 AM	**sparkle**	100	30355	2062	2290	0.05	4560
11/2/2018	**fire95**	1:42:45 PM	1:46:17 PM	**sparkle**	fixed wavelength					

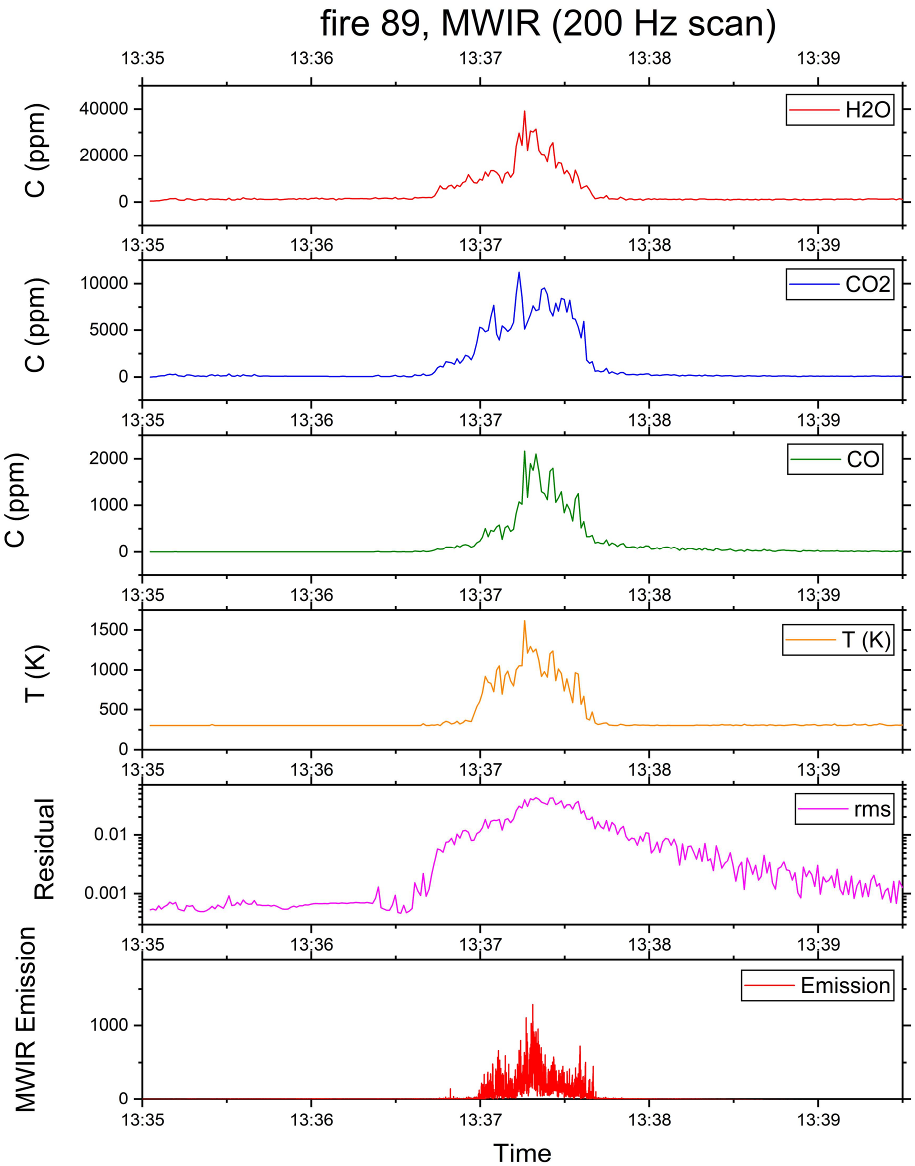
MWIR results – mixing ratios vs time

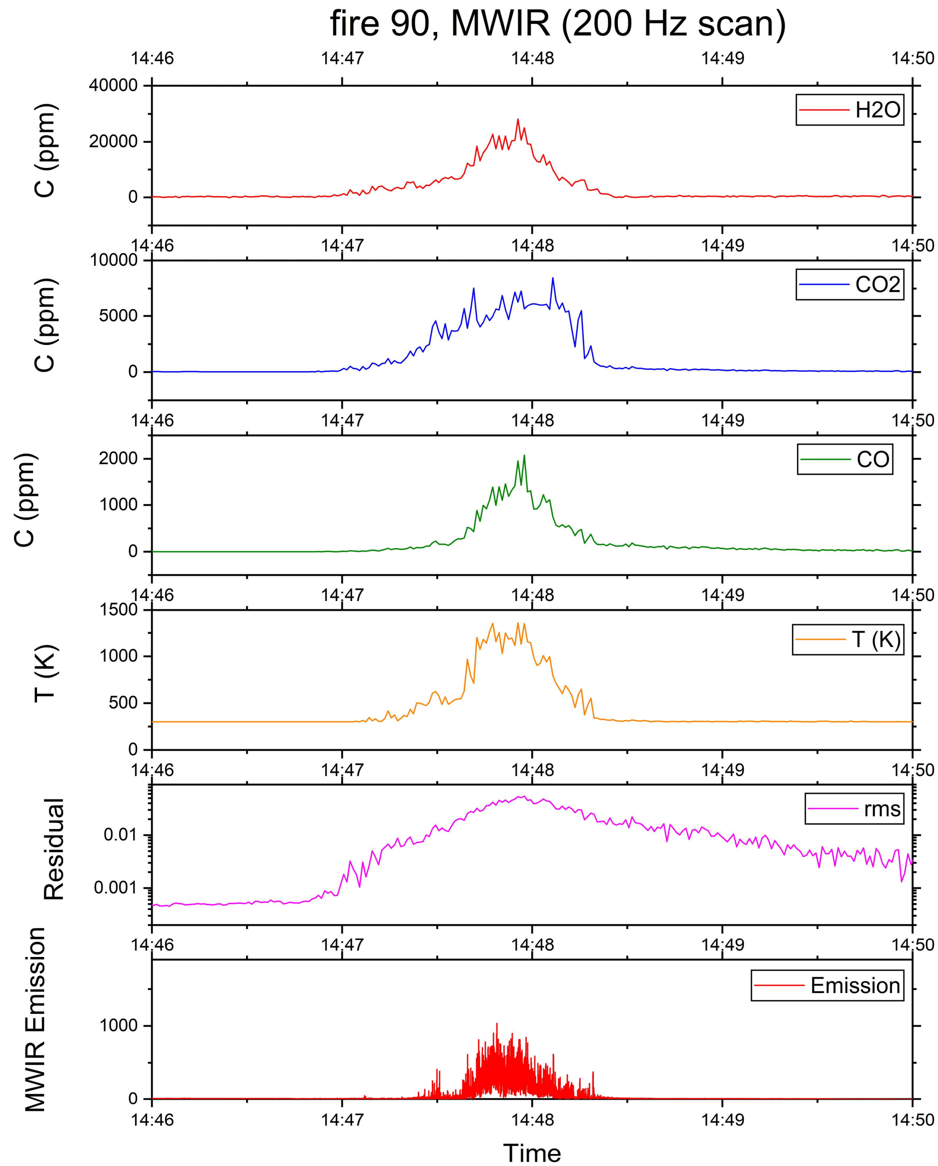


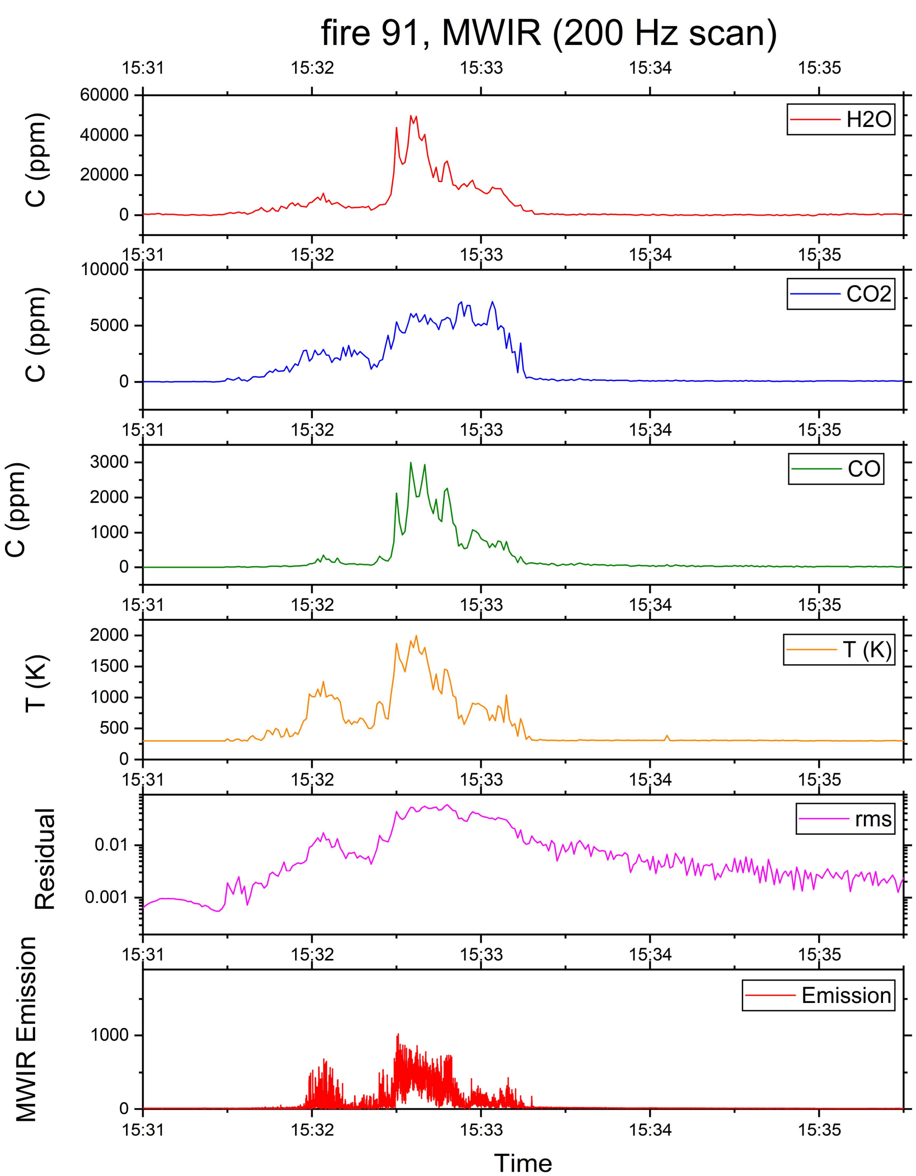
fire 87, MWIR (200 Hz scan)
C (ppm)
H2O
CO2
CO
T (K)
rms
Residual
Emission
MWIR Emission
10:39
10:40
10:41
10:42
10:43
10:44
Time

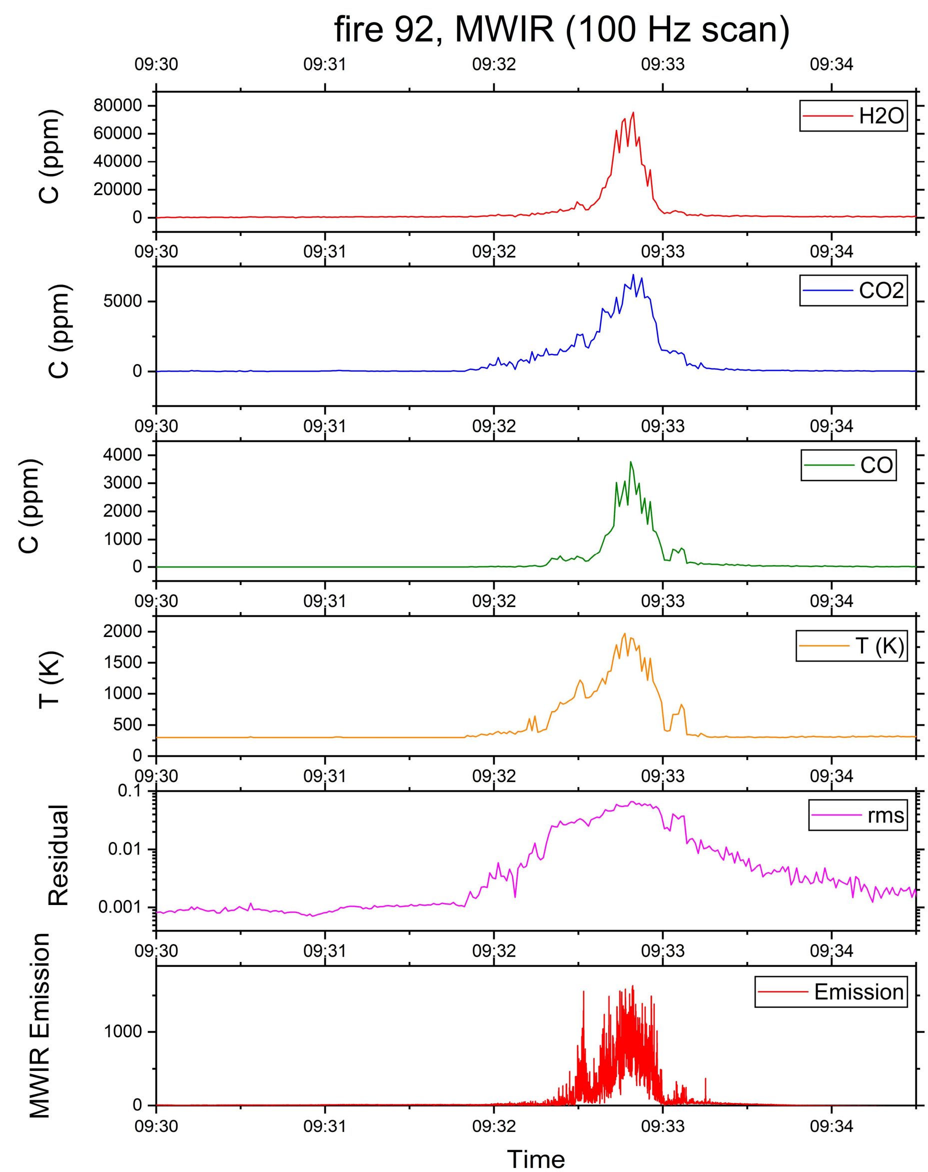


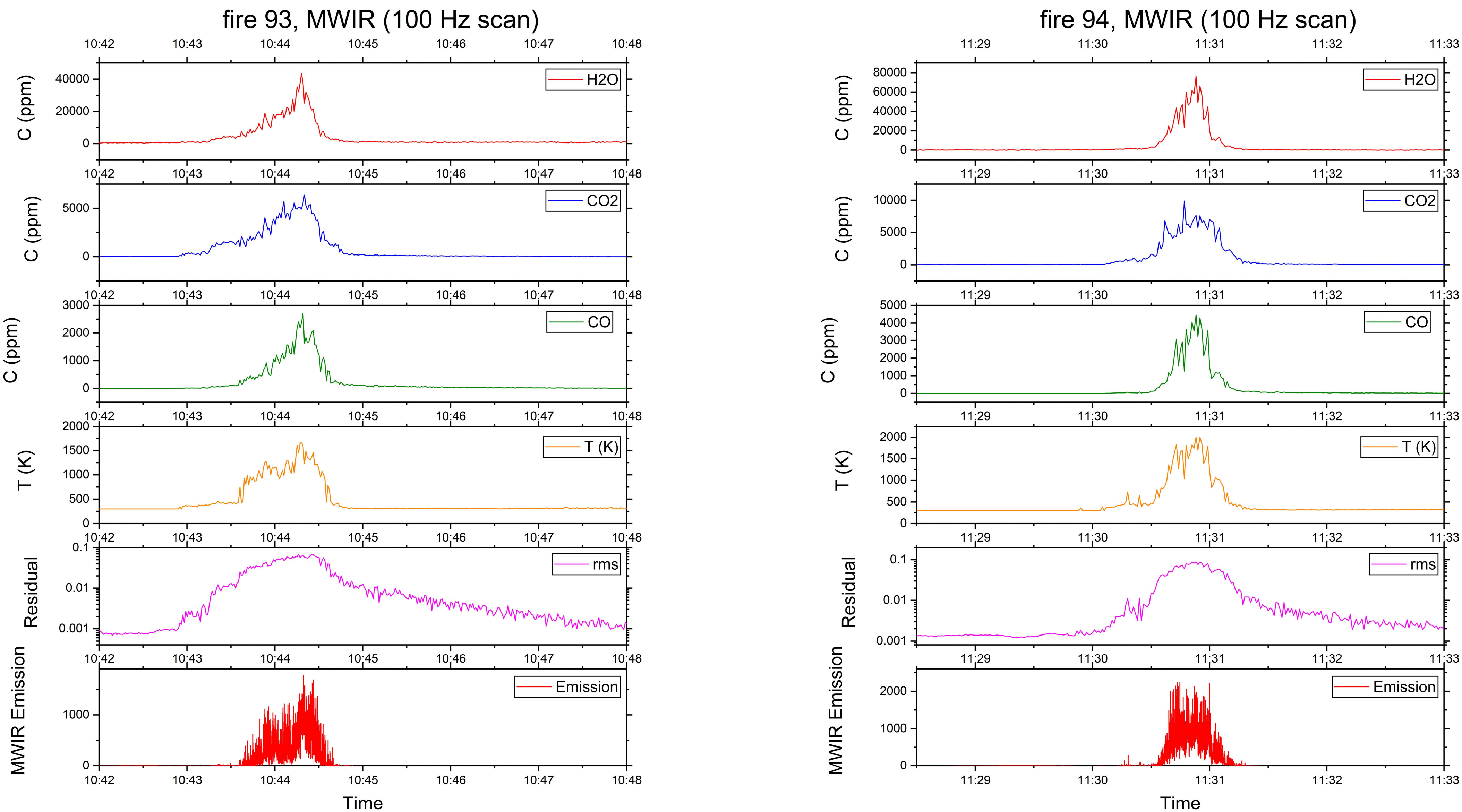
fire 88, MWIR (200 Hz scan)
C (ppm)
H2O
CO2
CO
T (K)
rms
Residual
Emission
MWIR Emission
11:40
11:41
11:42
11:43
11:44
Time


fire 89, MWIR (200 Hz scan)
H2O
CO2
CO
T (K)
rms
Emission
C (ppm)
T (K)
Residual
MWIR Emission
Time
13:35
13:36
13:37
13:38
13:39

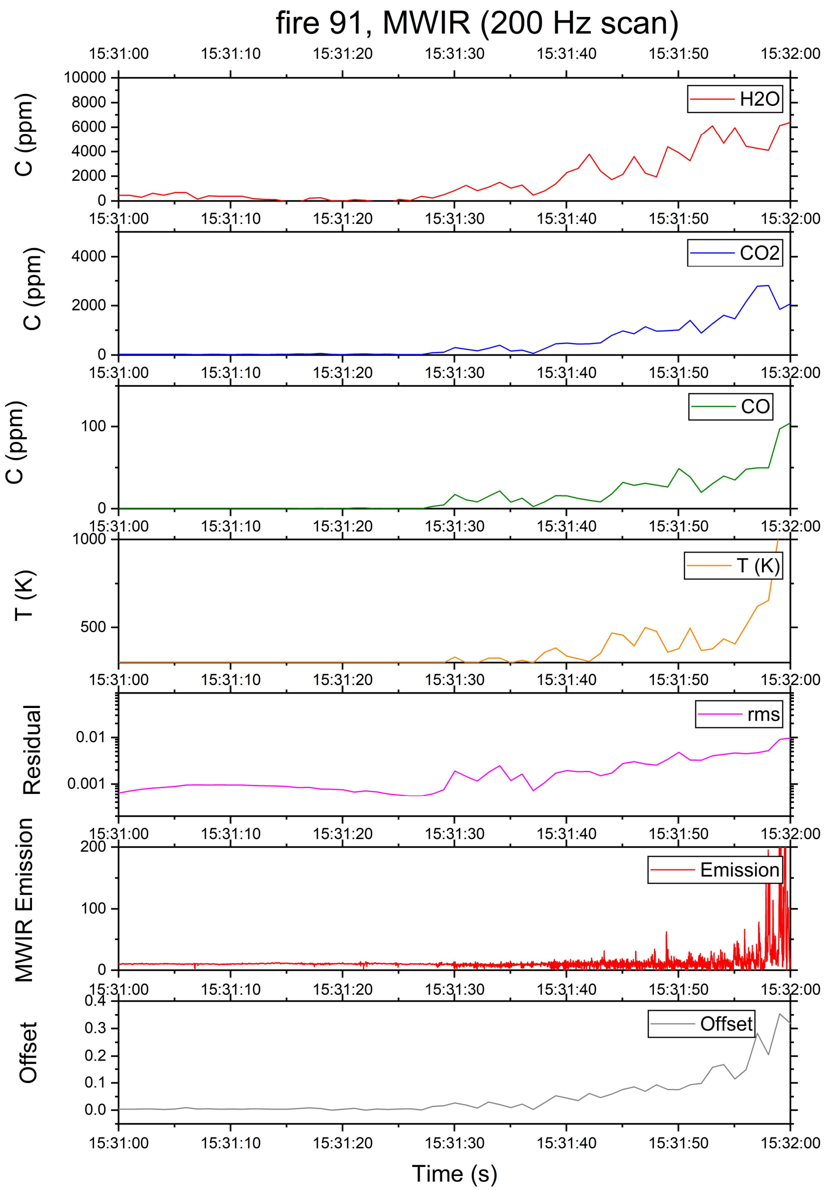

fire 90, MWIR (200 Hz scan)
H2O
CO2
CO
T (K)
rms
Emission
C (ppm)
T (K)
Residual
MWIR Emission
Time
14:46
14:47
14:48
14:49
14:50

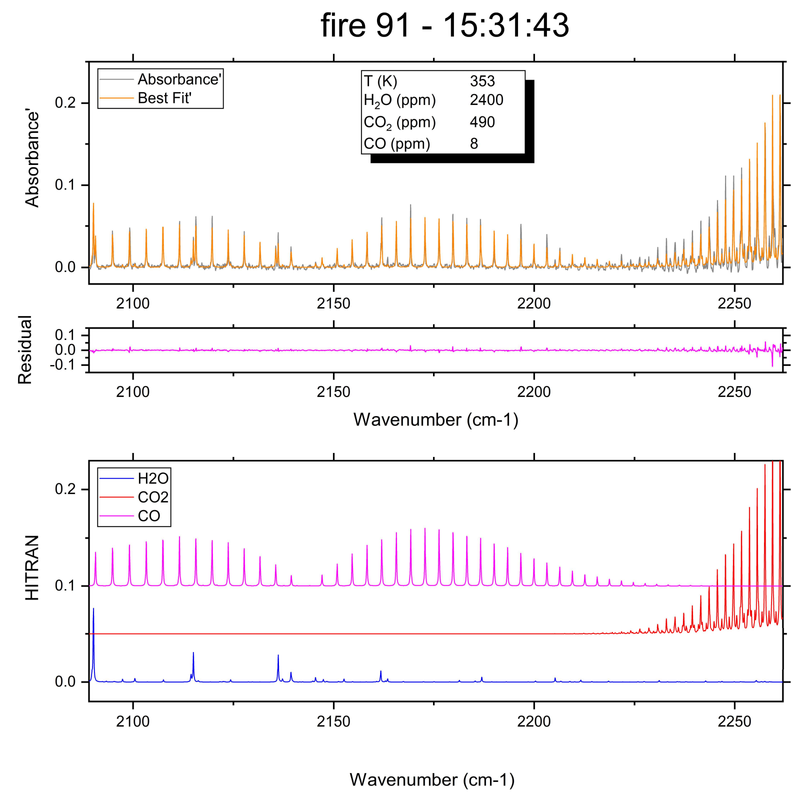

fire 91, MWIR (200 Hz scan)
H2O
CO2
CO
T (K)
rms
Emission
C (ppm)
T (K)
Residual
MWIR Emission
15:31
15:32
15:33
15:34
15:35
Time


fire 92, MWIR (100 Hz scan)
H2O
CO2
CO
T (K)
rms
Emission
C (ppm)
T (K)
Residual
MWIR Emission
09:30
09:31
09:32
09:33
09:34
Time

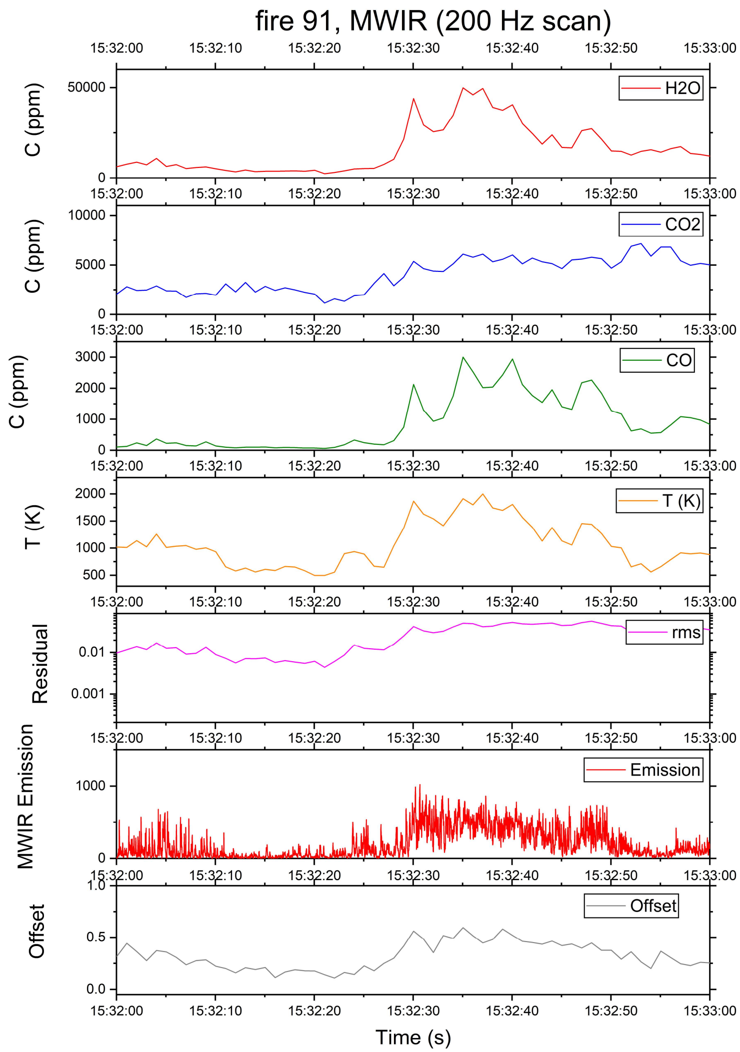


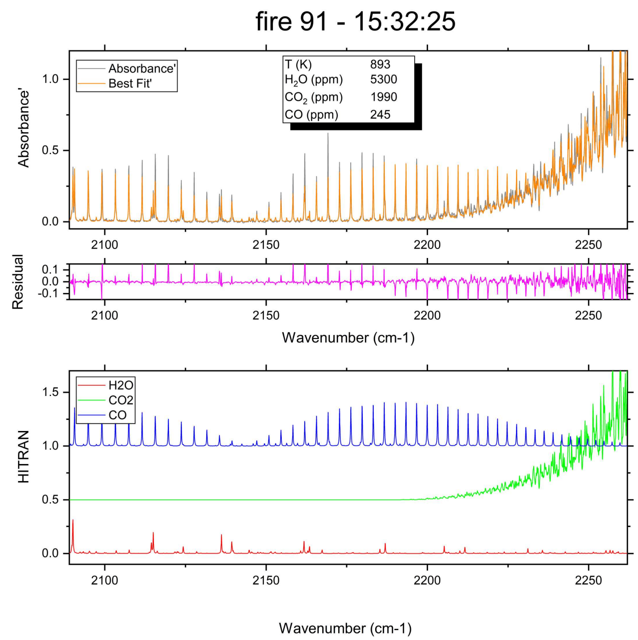
fire 93, MWIR (100 Hz scan)
fire 94, MWIR (100 Hz scan)
H2O
CO2
CO
T (K)
rms
Emission
C (ppm)
T (K)
Residual
MWIR Emission
Time
10:42
10:43
10:44
10:45
10:46
10:47
10:48
11:29
11:30
11:31
11:32
11:33

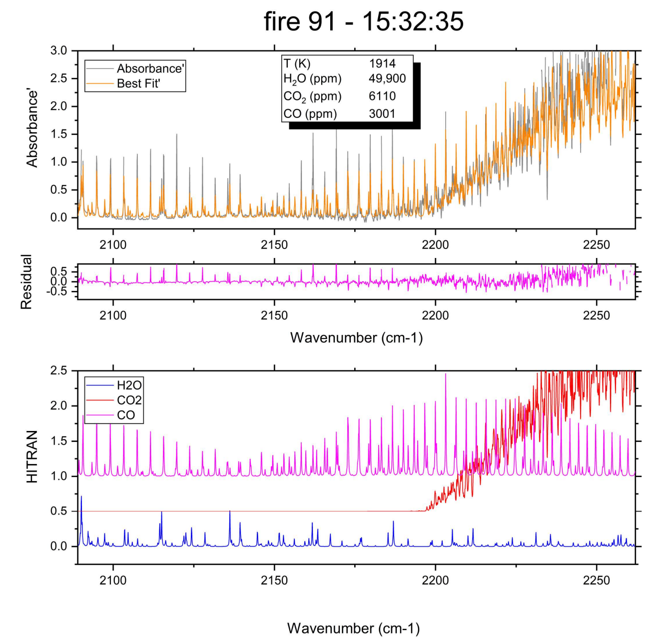




- Spectral features of H2O, CO, CO2 identified and measured with high SNR
- Gases detected before arrival of flame front
- Gas composition before arrival of flame front shows low CO relative to CO2 (flaming regime)
    - MCE = 0.98



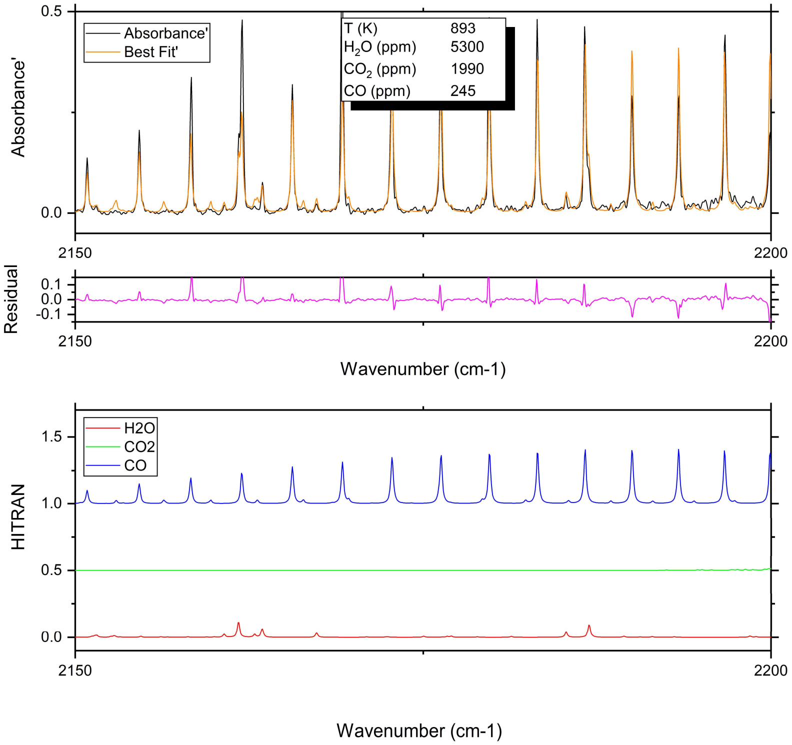




- Flame region shows high temperatures 800-1900 K
  - Change in band profiles of CO and CO2
  - Appearance of hot CO2 lines
  - High optical density and near continuum of hot CO2 lines not ideal for temperature determination
  - Suspect fit temperature is higher than actual temperature
- H2O, CO2, CO concentrations highest during flame region
- RMS fit residuals increase during flame region due to turbulence and model errors at high temperatures

fire 91 - 15:32:25

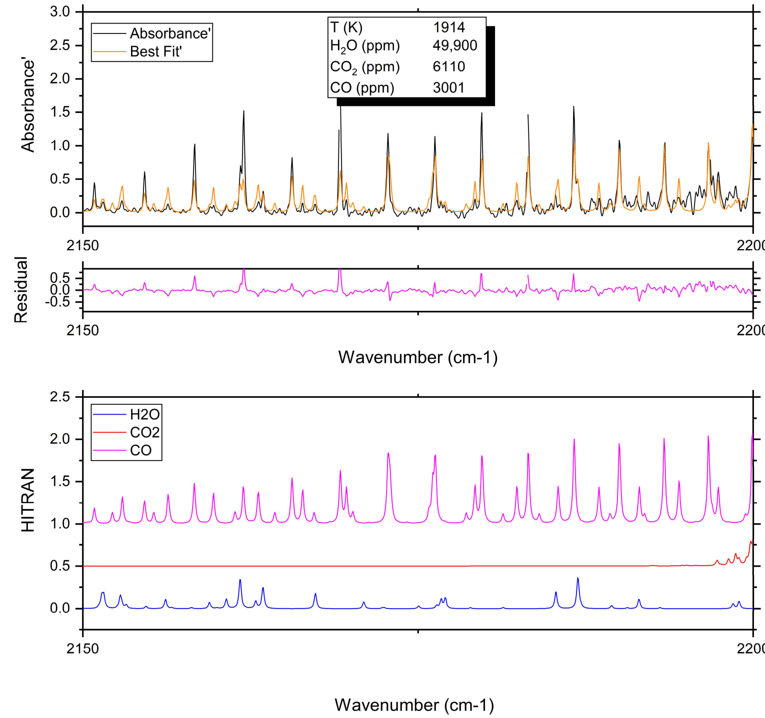
Some evidence of CO hot band lines, but still not definitive



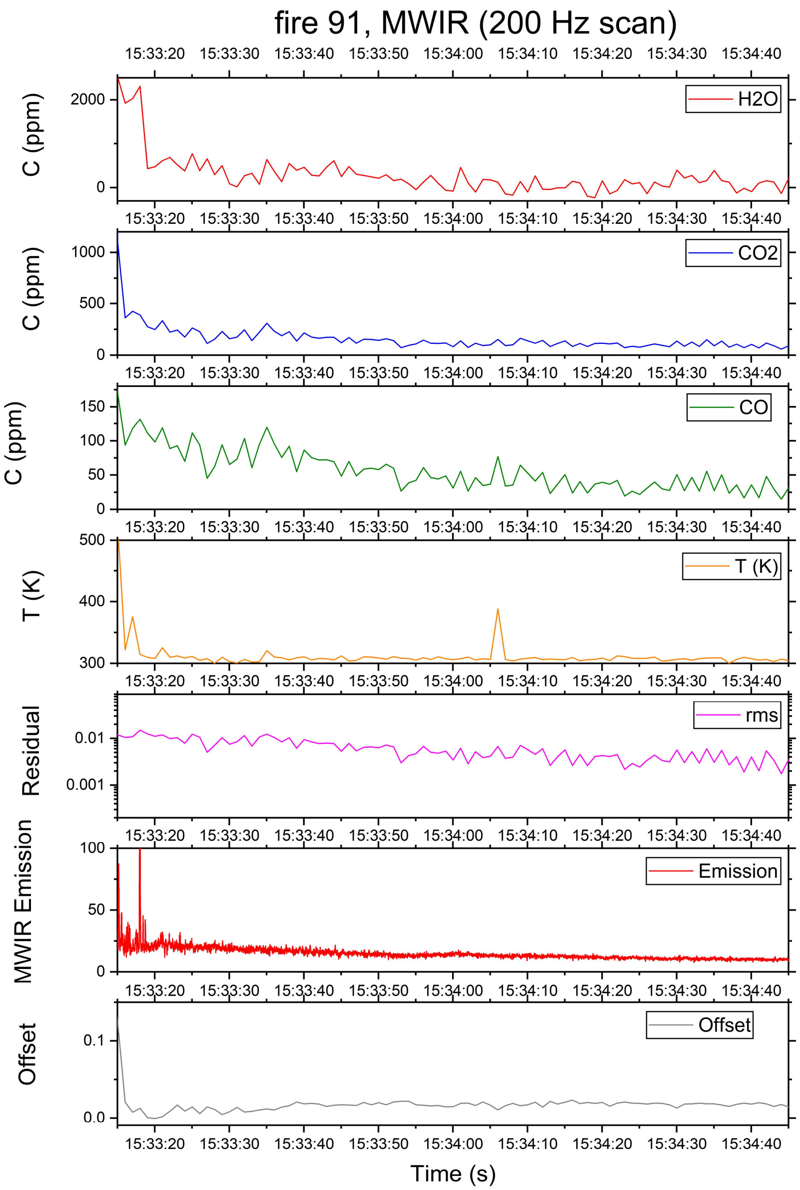
fire 91 - 15:32:35

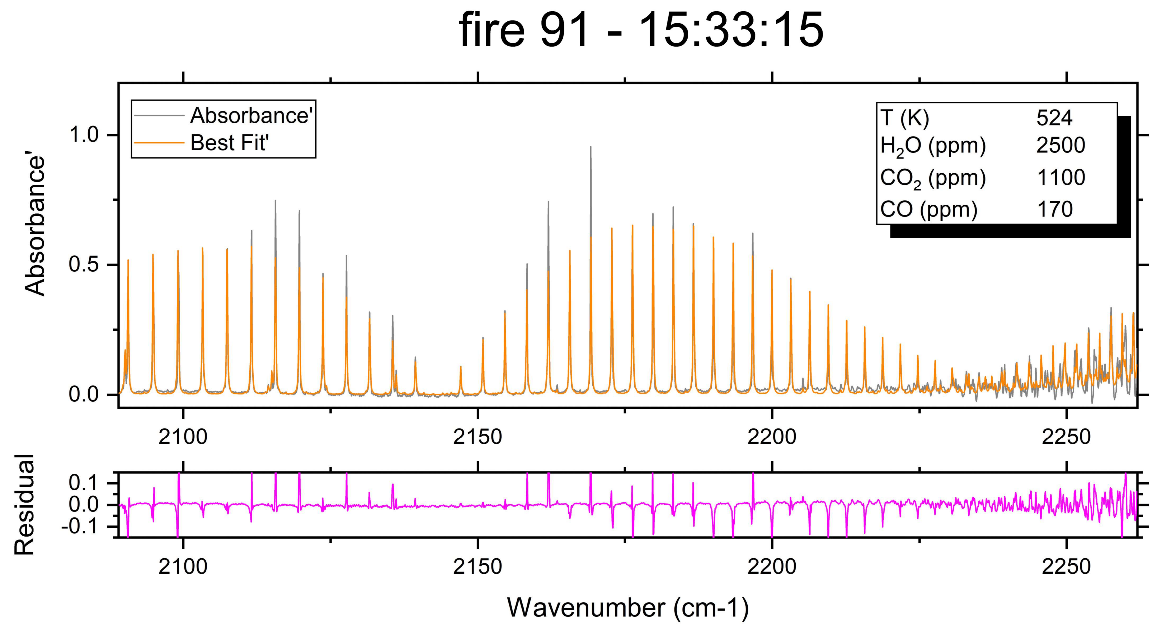
appears to overestimate temperature (by looking at CO hot band lines)

Fit may be dominated by CO_2 at this time

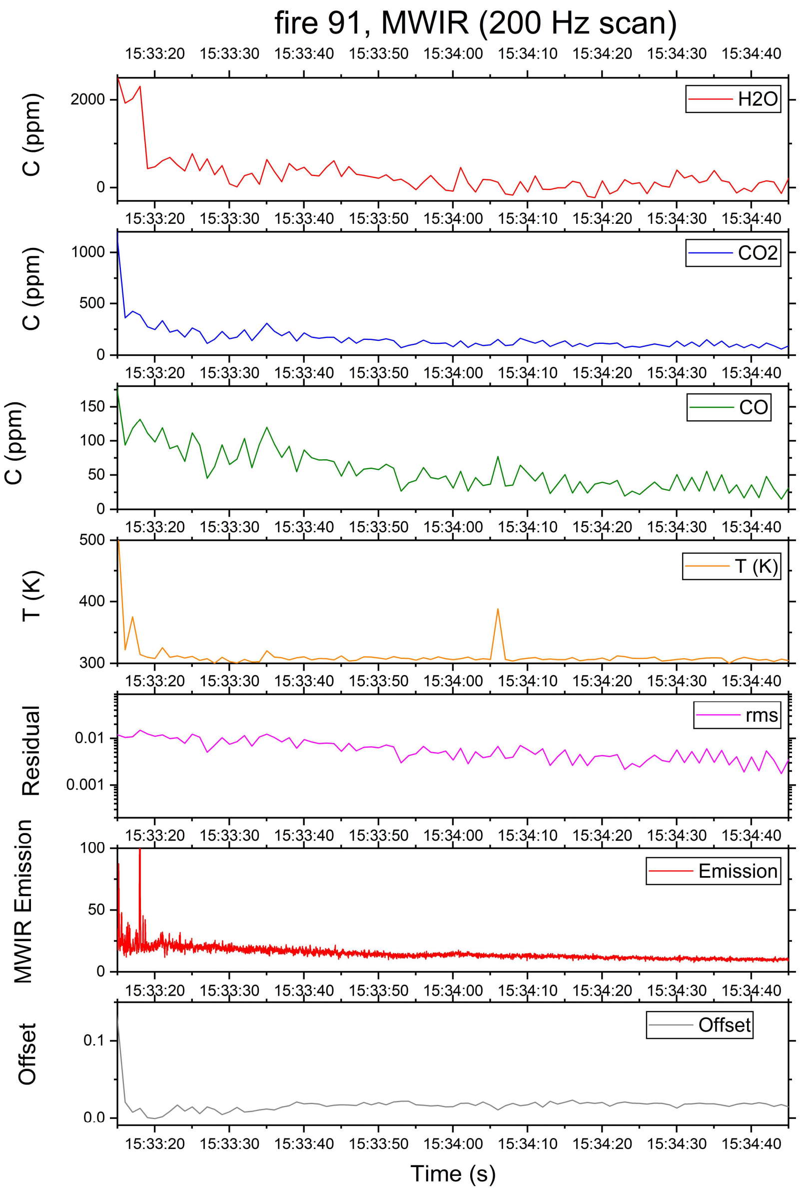


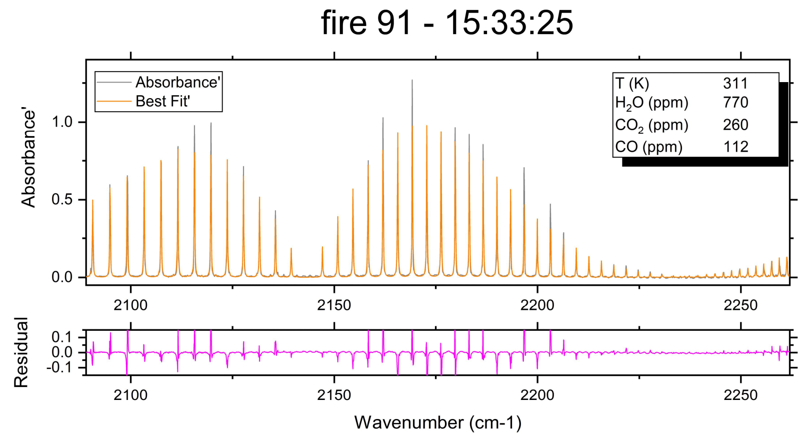
- Fit appears to overestimate temperature, based on over-estimating strength of CO hot band lines
- Fit is dominated by CO2 hot lines at these temperatures
- Should treat temperatures and mixing ratios determined at these times with caution

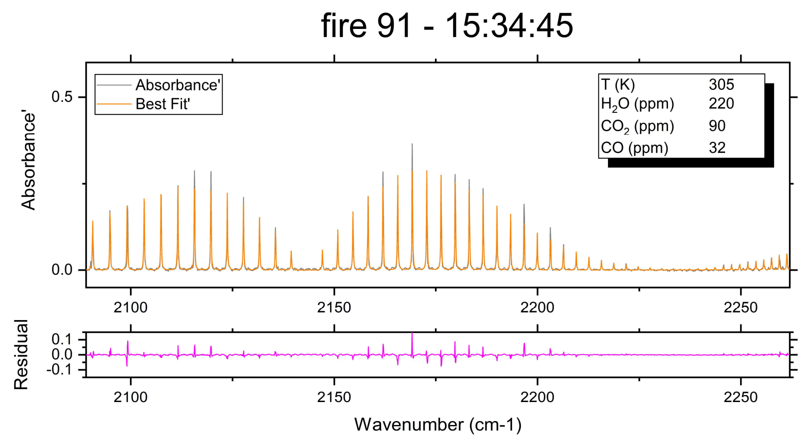




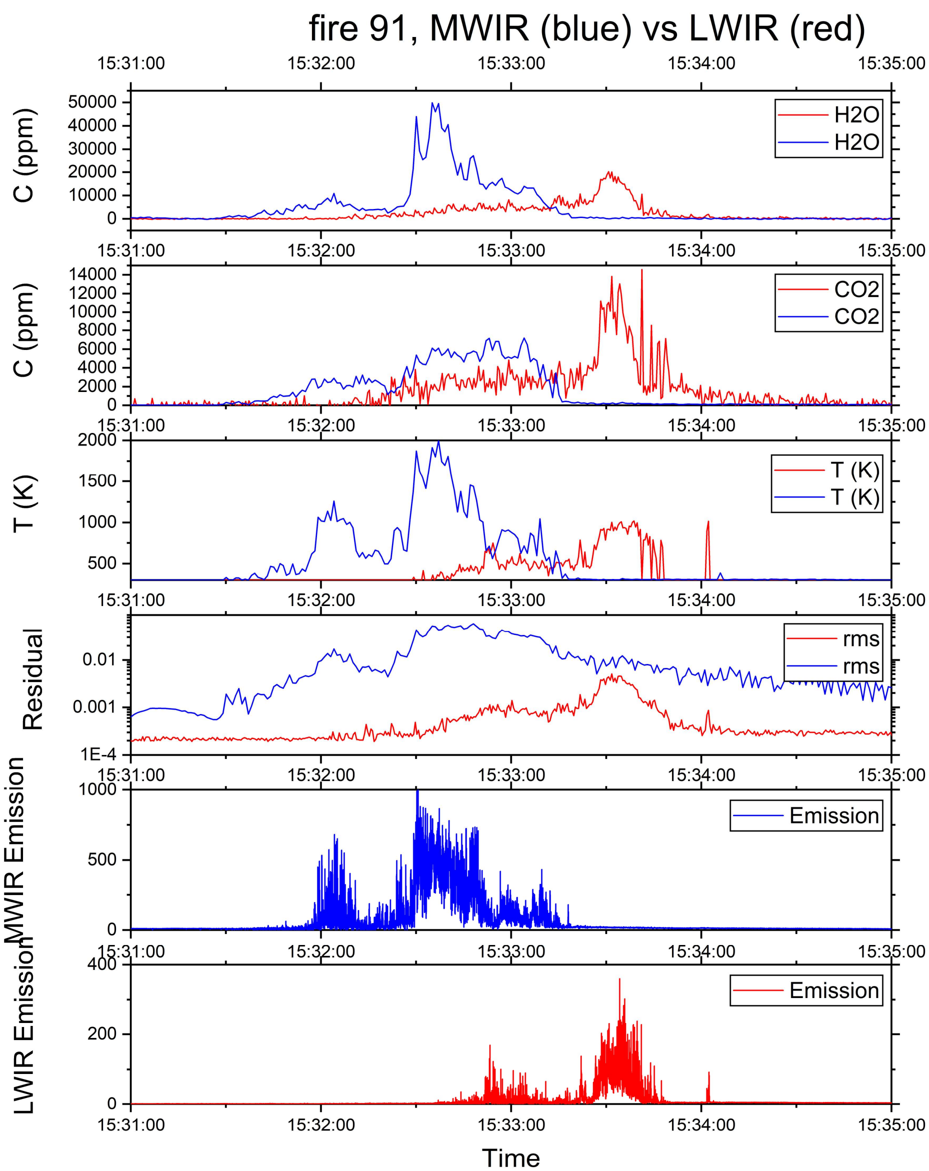
- Tailing edge of flame front shows better spectral fits due to reduction in CO2
- MCE = 0.87 indicates increase in smoldering relative to flaming







- H2O, CO2, CO detected for > 1 min after passing of flame front
- MCE ~ 0.7 indicates strong smoldering regime



- MWIR beam located closer to start of burn, and shows arrival of flame front before LWIR beam
  - Estimate speed of flame front to be ~ 30 cm/min.
- H2O and CO2 have lower noise for MWIR due to stronger absorption cross-sections (especially at lower temperatures).
- MWIR and LWIR emission show similar qualitative behavior with two peaks
  - Smaller first peak could be arrival of soot or hot gases before arrival of flame front
  - Larger second peak corresponds to arrival of flame front
  - Emission temporal behavior correlated with temperatures determined from spectral fits
- Peak temperatures from MWIR are higher than from LWIR
  - Could indicate fitting/model errors in either channel
  - Aside from fitting/model errors, temperatures will already have high absolute uncertainty due to path averaged measurement and temporal averaging
  - Best to treat temperatures as relative measure during flame front propagation, not as absolute temperature measurement
  - Temperature differences will also affect mixing ratio calculations at highest temperatures
- Overall, highest confidence in temperatures and mixing ratios at temperatures <~500K, with uncertainty increasing for higher temperatures

Data preparation notes

- Wavenumber axis calibrated for each scan using measured etalon transmission and comparison to measured combustion gases spectrum (CO + CO2)
    - Etalon 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 1 s intervals
    - For 200 Hz scan rate, 200 spectra were averaged
    - For 100 Hz scan rate, 100 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 – Fit CO, CO2, H2O spectrum and determine temperature using nonlinear LSF
    - Spectrum calculated from HITRAN parameters
    - No baseline fitting to avoid problems with CO2 band at high temperatures
  - Step 2 –Fit all species using linear weighted LSF
    - CO, CO2, H2O spectra calculated from HITRAN at each T from step 1
    - Includes polynomial baseline fit (5^{th} order)
- Measured quantities from fitting algorithm:
  - Column density for H2O, CO2, CO
  - Average temperature (T)
    - Determined by CO +CO2 band profiles
    - Dominated by appearance of CO2 hot lines at elevated temperatures
    - Near continuum of overlapping CO2 lines and high optical density is not ideal, and will increase errors in temperature
- Reported mixing ratios are scaled for measured T using ideal gas law relationship and measurement path length (264 cm)

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
  - Should use caution in interpreting absolute mixing ratios due to temperature effects