Compact FTIR Spectrometer for total column measurement in urban environments

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Outline

- Introduction
- How does FTS work and its “strange features”
- Measurement on the roof of Boston University
- Future plan
Measuring Greenhouse Gas Emission in Urban Areas

Surface measurement

Vertical column measurement

Ground-based

Satellite-based

High – resolution room-sized spectrometer

Low – cost transportable spectrometer

Hour (MST)

FTS

CO₂

H₂O

NH₃

CO

CH₄

CO₂

H₂O

NH₃

CO

CH₄
**BRUKER IFS125HR**

**Scanner Compartment**
1. Scanner
2. Scanner data cable
3. 2nd light barrier
4. Scanner motor

**Detector Compartment**
5. Beam splitter (λ-dependent)
6. Detector 1 (InGaAs)
7. Detector 2 (Si-diode)

**Source Compartment**
1. NIR source (Tungsten lamp)
2. MIR source (Globar)
3. Temperature switch
4. Source-selection mirror
5. movable mirror (source <-> Solartracker)
6. Solartracker inlet
7. 1st Aperture

**Interferometer Compartment**
8. Beam splitter (CaF₂)
9. Retroreflecting Mirror
10. adjustable prism
11. Laser detector
12. Laser detector
13. status LEDs
14. 1st light barrier
15. Scanner with Retroreflecting Mirror
16. 2nd Aperture
### Comparison TCCON and our instrument

<table>
<thead>
<tr>
<th></th>
<th>TCCON</th>
<th>Our spectrometer</th>
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</thead>
<tbody>
<tr>
<td>Spectral resolution</td>
<td>0.02 cm⁻¹</td>
<td>0.1 cm⁻¹</td>
</tr>
<tr>
<td>Size</td>
<td>Room</td>
<td>1m x 1m (same size as TCCON Sun tracker)</td>
</tr>
<tr>
<td>Cost spectrometer</td>
<td>300000 dollars</td>
<td>40000 dollars</td>
</tr>
<tr>
<td>Cost suntracker</td>
<td>55000 dollars</td>
<td>3000 dollars or less</td>
</tr>
<tr>
<td>Precision</td>
<td>ca. 0.1 ppm (1σ)</td>
<td>under investigation</td>
</tr>
<tr>
<td></td>
<td>5 min integrating time</td>
<td></td>
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</tbody>
</table>

Tradeoff between spectral resolution and size/cost Possible to achieve the same precision?
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Setting the Gold Standard in FT-IR

Thermo Scientific Nicolet 6700 & 8700 Spectrometers

Approximately: 1m x 1m

www.thermo.com/ftir
FTS using diffuser for gathering sun light
Why Use Diffuser?

Conventional TCCON instrument:

Our FTS:

- Critical optical alignment
- Mirrors not rugged
- Observe only part of the sun (sunfield of view: 0.5°)

Weather proof, easy alignment
Whole sun observing -> insensitive to sun variability (acceptance angle > sun field of view)

Light is divergent
1. Central burst -> low resolution information
   Side-lobes  ->  high resolution information

2. Interferogram is infinitely long

3. Interferogram is symmetric at x – axis  ->  spectrum is real
Problems we are confronted with

- Asymmetry of the spectrum and line-broadening

- Negative Absorption
Measured spectrum (CO$_2$ region)

Spectrum broadened and asymmetric
Influence of divergent light?

1) Lower spectral resolution

\textit{Off-axis beam and on-axis ray interfering cause ‘self - apodization’ in interferogram}

2) Ring pattern image at detector

\textit{Different part of detector see different Phase of interference pattern}

\textbf{Fundamental mode (On-axis Ray)}

\textbf{Side mode (off-axis ray)}
Improved spectrometer design for high spectral resolution

Iris selects the “wanted” information – collimated light
Comparison our FTS with/without iris

New design improves spectral resolution, looks promising
Comparison TCCON (jena) and our Suntracker

Bruker Solar Tracker A547
(Quadrant diode for sun tracking + 2 mirrors)
Active tracking

Our sun tracker
(star tracker + aluminum foil)
Programmable – inverse sun clock
Problems we are confronted with

- Asymmetry of the spectrum and broadening

- Negative Absorption
“Discovery”: negative absorption
Phase spectrum

\[ \text{Phase spectrum} = \arctan\left( \frac{\text{Imaginary (spectrum)}}{\text{real (spectrum)}} \right)\]

--- ideal phase spectrum
--- real phase spectrum

Interferogram asymmetric
Negative to positive: phase correction

Intensity vs. Wavenumber (1/cm)

- Inappropriate phase correction
- Corrected phase correction

Water absorption

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4000 5000 6000 7000 8000 9000 10000
-1 0 1 2 3
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First deployment: on the roof of Boston University: 42.2N, 71.5W
Simple Suntracker: approx. half of sidereal rate in altitude/azimuth directions
Promising spectrum quality: as narrow as TCCON (izana), symmetric lineshape
Comparison TCCON and Harvard FTS (CH$_4$ absorption)

Promising spectrum quality: as narrow as TCCON (izana), symmetric lineshape
Comparison TCCON and Harvard FTS (CO$_2$ absorption)

Promising spectrum quality: as narrow as TCCON (izana), symmetric lineshape
Simple retrieval*

*based on satellite retrieval program developed by k. Chance

Normalization with oxygen @ 1.3 µm: Optical pathlength uncertainty and scattering effect are eliminated
Fitting result $\text{O}_2$ (noon time): 22.76%

Comparison between fit and measurement

Good fit agreement despite of imperfect modelling of instrument function
Fitting result CO\textsubscript{2} (noon time): 413.7 ppm
Dry-mole fraction (rationed with oxygen): 380.8 ppm

Comparison between fit and measurement

Good fit agreement despite of imperfect modelling of instrument function
Conclusion

- Compact spectrometer
  - *Internal iris selecting collimated light*
  - *Simple diffuser + inverse sun clock*

- Promising spectral quality

- Straightforward retrieval scheme provides good fit result
Future

Instrument calibration at Caltech

Measurement Verification at Mt. Wilson

On Top of Prudential building

Where else to measure?
WRF – VPRM Simulation in Boston
John, Bruce
Frank Hase
Barry McManus
David Sayres