Accurate greenhouse gas remote sensing using open-path dual-comb spectroscopy

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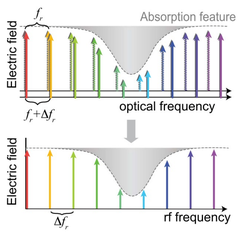
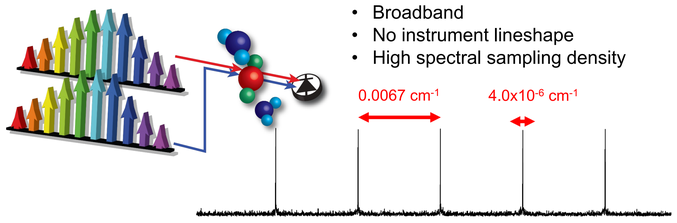
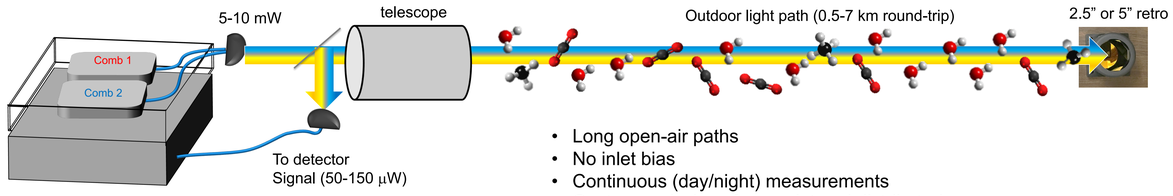
Dual Comb Spectroscopy





- Broadband
- No instrument lineshape
- High spectral sampling density



- Long open-air paths
- No inlet bias
- Continuous (day/night) measurements
- Capture emissions from point and distributed sources

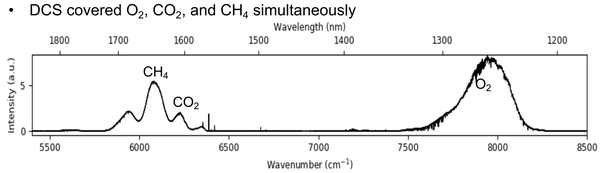
Accuracy considerations

O_2 concentration measurement in Δ-band

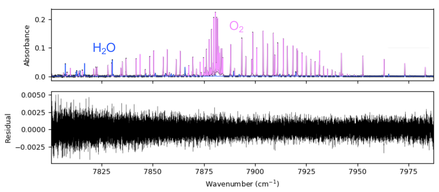
Goal: test absolute concentration retrieval accuracy

Why O_2:
- Expected O_2 concentration well know
- Accurate laboratory line parameters[5]
- Can be used to extract dry mole fraction of CO_2 and CH_4 in future

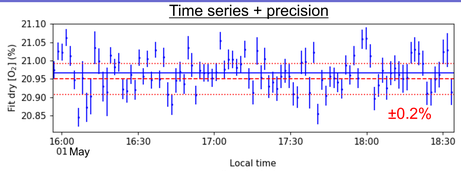
Setup:
- Measurement across 560-m round-trip path
- DCS covered O_2, CO_2, and CH_4 simultaneously



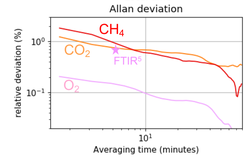
Absorbance spectrum + fit



Time series + precision

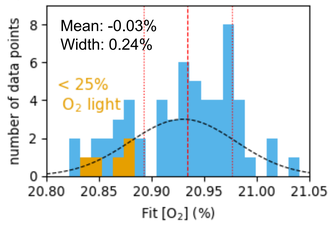


Allan deviation



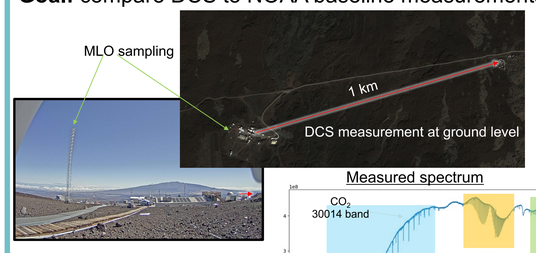
Measure over variety of atmospheric and instrumental parameters

Parameter	min	max
T (K)	277	301
P (hPa)	817	834
H_2O (%)	0.2	1.0
L (m)	281	283.5
dither (mV_{pp})	350	700
low-pass (MHz)	70	100
O_2 power (μW)	10	100
total power (μW)	25	200



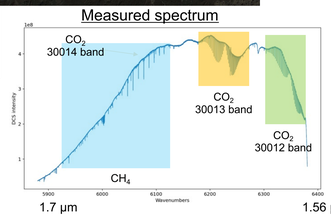
Open path validation of spectral databases

Goal: compare DCS to NOAA baseline measurements at Mauna Loa Observatory (MLO)

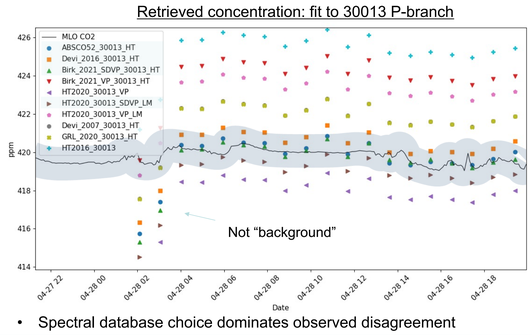


- Temporal differences between measurements likely driven by local atmospheric conditions
- Select “background” time period with stable concentration measurements from both systems

Measured spectrum



Retrieved concentration: fit to 30013 P-branch



- Spectral database choice dominates observed disagreement

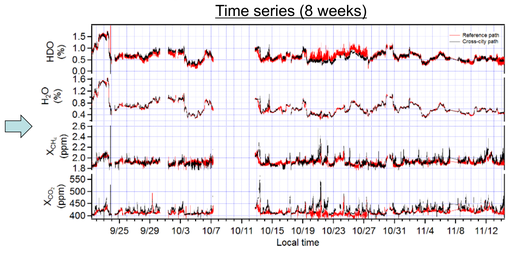
City-scale monitoring

City emissions using open-path DCS

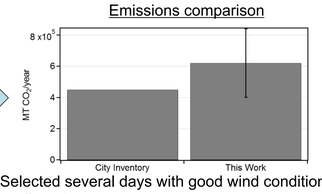
Goal: measure emissions from distributed source (e.g., city)

Beam paths

Time series (8 weeks)



Emissions comparison



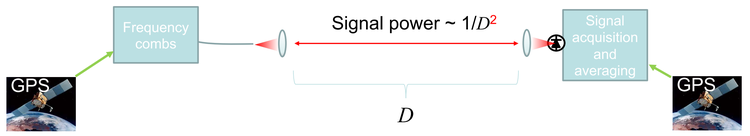
- Selected several days with good wind conditions
- Traffic only
- Gaussian plume model using traffic count data
- Scaled to yearly emissions

Extending the spatial coverage

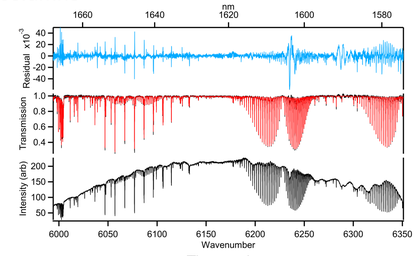
Goal: extend path lengths to cover larger areas, enclose cities, perform vertical columns

”Unfolded” one-way path

Power scaling as $1/D^2$ instead of $1/D^4$ with reflector
Requires synchronization between comb system and data acquisition



Example spectrum

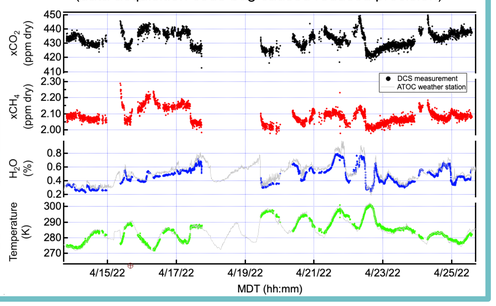


Launch optics

Receive optics

Time series

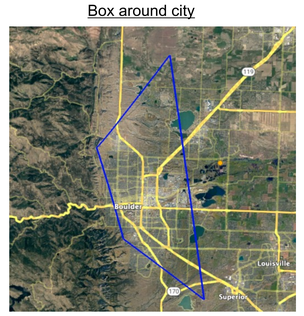
1 ppm CO_2 precision in 2 minutes
(data acquisition code bug caused reduced precision)



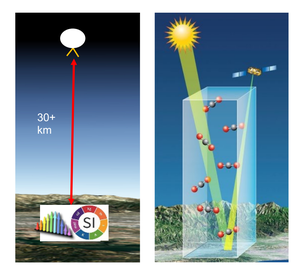
Outlook and Conclusions

- Dual comb spectroscopy provides high spectral resolution with no instrument lineshape, which enables accurate concentration retrievals and validation of spectral databases
  - Measurements of O_2 with 0.24% scatter and 0.03% mean bias
    - Still investigating sources of scatter
  - Open-path validation of spectral databases
    - 2% variation with database choice
    - Newer databases with laboratory intensities + speed dependence + line mixing show smallest deviation for CO_2 30013 P branch
- Long path length >14 km using one-way path
  - Urban measurements – upwind/downwind, box around area
  - Vertical columns – satellite calibration/validation

Box around city



Vertical column



References and Acknowledgements

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Funding: NASA Instrument Incubator Program NIST Greenhouse Gas Initiative NRC Postdoctoral Fellowship