

Accurate Greenhouse Gas Remote Sensing using Open-path Dual-comb Spectroscopy

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Rapidly expanding range of greenhouse gas monitoring satellites

Can <u>open-path dual-comb spectroscopy</u> help improve precision and accuracy?

2

Open-path dual-comb spectroscopy





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CO₂ spectral database evaluation (DCS comparison to Mauna Loa WMO record)



2 Horizontal/vertical ground truth (Measure CO₂ at swathe scales)



Sector-resolved CH₄ fluxes (Inventory optimization at regional scales)

Spectral database evaluation







Residual structure feeds back to model adjustments





Lab measurements



- Easier control over thermodynamic parameters
- Concentration can be independently verified
- Gas samples tailored to measurement

Open-path measurements



- Measures the actual atmosphere (CIA effects, etc.)
- Eliminates adsorption on cell interior
- Doesn't require a retrieval algorithm (assuming a homogenous horizontal path)

1 DCS measurements at Mauna Loa





If (when) the two measurements don't match, why?

- Path inhomogeneity (local sources/sinks)
- Spectral database errors

1 DCS comparison to WMO record





Similar trend and constant offset from MLO suggests local sources are not important contributors

Most models don't consistently reach necessary precision and accuracy (0.1%)

Model 1: Birk et al, JQSRT, 2021 Model 2: Devi et al, JQSRT, 2016 Model 3: HITRAN 2020 + Devi et al, 2007 Model 4: HITRAN 2020





Example: OCO-3 SAM data over Boulder CO

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Example: OCO-3 SAM data over Boulder CO



Longest DCS measurement to date Works under high turbulence conditions

2 Ground-truth CO_2 data at swathe scales



Can provide validation/constraints on highest pressure level of *a priori* CO_2 (CH₄, H₂O) profiles

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But economic sector optimization remains difficult without <u>sector-apportioned</u> CH₄ data

Maasakkers, *et al. Environ. Sci. Technol.* **50**, 13123–13133 (2016). Cusworth et al., *Commun Earth Environ* **2**, 242 (2021).



Future work and directions for open-path DCS

AEROMMA campaign (July 2023) Open-path NIR and MIR DCS over NYC



Vertical path measurements to balloon/plane



7.5 5.0 4.0 Latitude 3.0 2.5 ppbv 2.0 1.75 35° 1.5 1.25 1.0 20° N 0.5 160° W 138° W 116°W 72° W 50° W Longitude

Surface NH₃ | 06 Jul 2014

Other trace gas species targeted by satellites Ammonia, ethane \rightarrow CrIS HCHO \rightarrow TEMPO

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Shephard, M. W. et al. Atmos Chem Phys 20, 2277-2302 (2020).