

Active and Passive Collaborative Remote Sensing XCO₂ Based on DQ-1/DQ-2

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Abstract

After two years of operation in orbit with DQ-1, the performance of its LiDAR system has been evaluated. The LiDAR measurements were compared with TCCON. Due to limitations in the active and passive observation mechanisms, we analyze the differences between these measurements to explore their ability to quantify CO₂ sources and sinks. This approach represents a very promising observation method for the forthcoming DQ-2 satellite, which will be equipped with both active and passive instruments.

Introduction

The Aerosol and Carbon Detection LiDAR (ACDL) onboard DQ-1 is the world's first spaceborne Integral Path Differential Absorption (IPDA) LiDAR instrument, which can be used to measure carbon dioxide and aerosols in the atmosphere. ACDL emits two laser pulses of adjacent wavelengths with a CO₂ absorption peak of 1 572.024 nm (on-line) and a CO₂ non-absorption peak of 1 572.085 nm (off-line). The column-averaged dry-air mixing ratio of CO₂ can be derived from ratio of the two echo signals. Furthermore, the positions of these two laser pulses are strictly screened to reduce the influence of aerosol, water vapor and other factors on CO₂ retrieval.

Basic concepts

The Differences and Connections between Active and Passive remote sensing:

XCO₂ definition :
$$XCO_2' = \frac{\int_0^\infty \rho_{CO_2}(r) n_{dryair}(r) dr}{\int_0^\infty n_{dryair}(r) dr}$$

The XCO₂ of DQ-1 :
$$XCO_2 = \frac{\int_{P_A}^{P_G} \rho_{CO_2}(p, T) \cdot WF(p, T) dp}{\int_{P_A}^{P_G} WF(p, T) dp}$$

The XCO₂ of OCO-2:
$$XCO_2 = \frac{\int_{P_A}^{P_G} \rho_{CO_2}(p, T) \cdot c(p, T) dp}{\int_{P_A}^{P_G} c(p, T) dp}$$

where,

$$c(p, T) = \frac{1}{[1 + \rho_{H_2O}(p, T)] g M_{dry}} \quad WF(p, T) = \frac{[\sigma(\lambda_{on}, p, T) - \sigma(\lambda_{off}, p, T) N_A]}{[1 + \rho_{H_2O}(p, T)] g M_{dry}}$$

ρ_{CO_2} is the profile of CO₂, n_{dryair} is The number of molecules in dry air, $\sigma(\lambda_{on}, p, T)$, $\sigma(\lambda_{off}, p, T)$ is the CO₂ absorption cross-section of online and offline, ρ_{H_2O} is the ratio of water vapor mixture, g is the gravity, N_A is Avogadro's constant. M_{dry} is the molar mass of dry air, P_A is the pressure of top layer of the atmosphere. P_G is the pressure of ground.

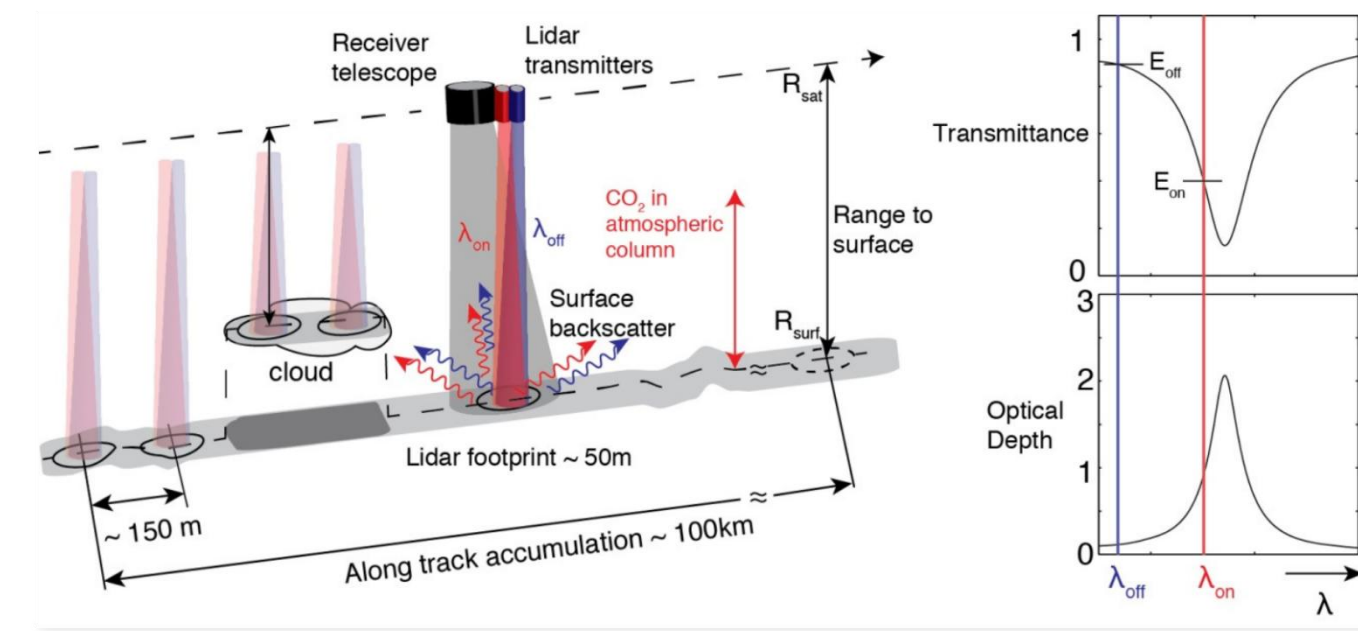


Fig1. Principle of IPDA Measurement

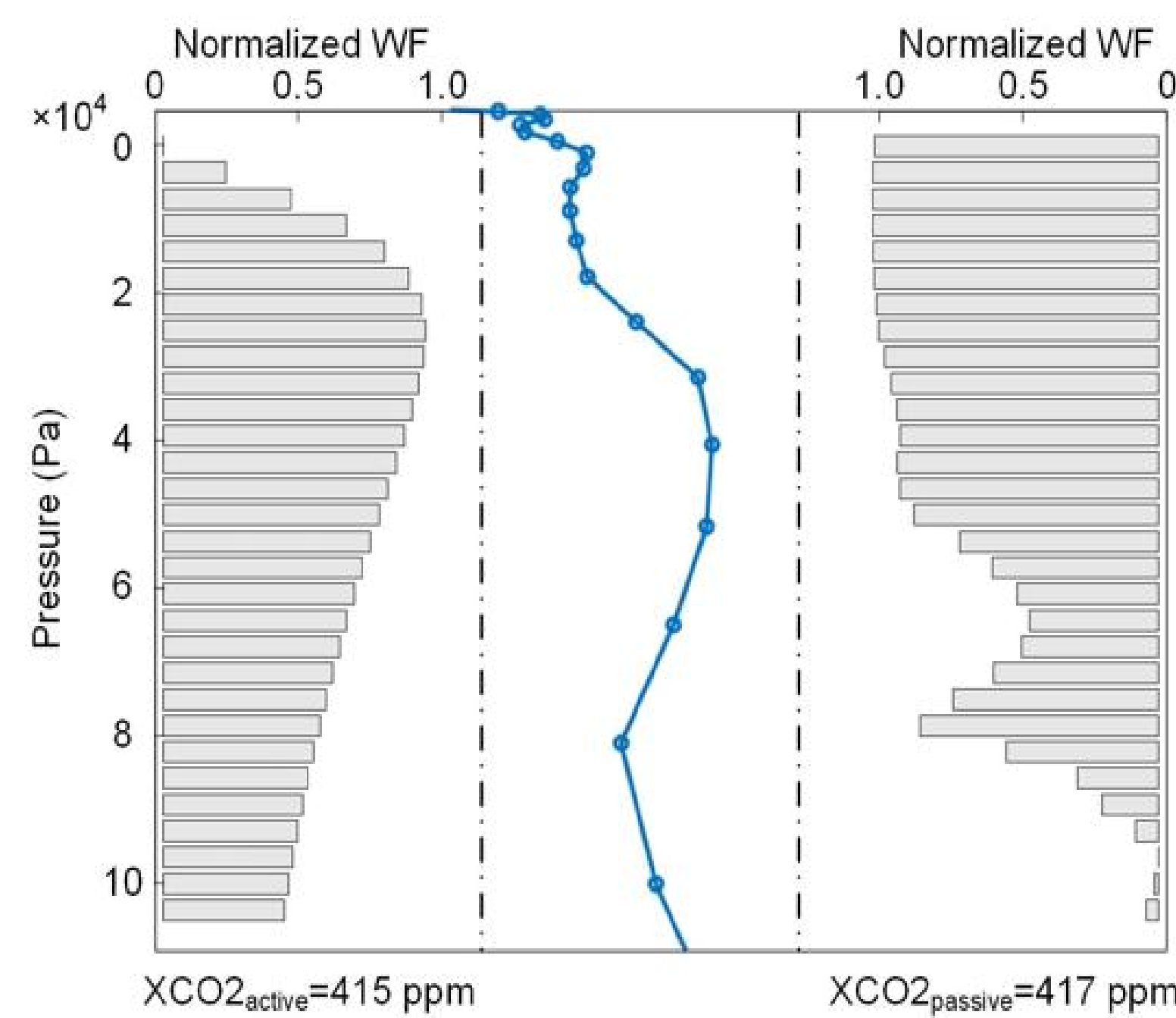


Fig 2. Active and passive measurements with different weights function (CO₂ profiles are the same, but weights function are different)

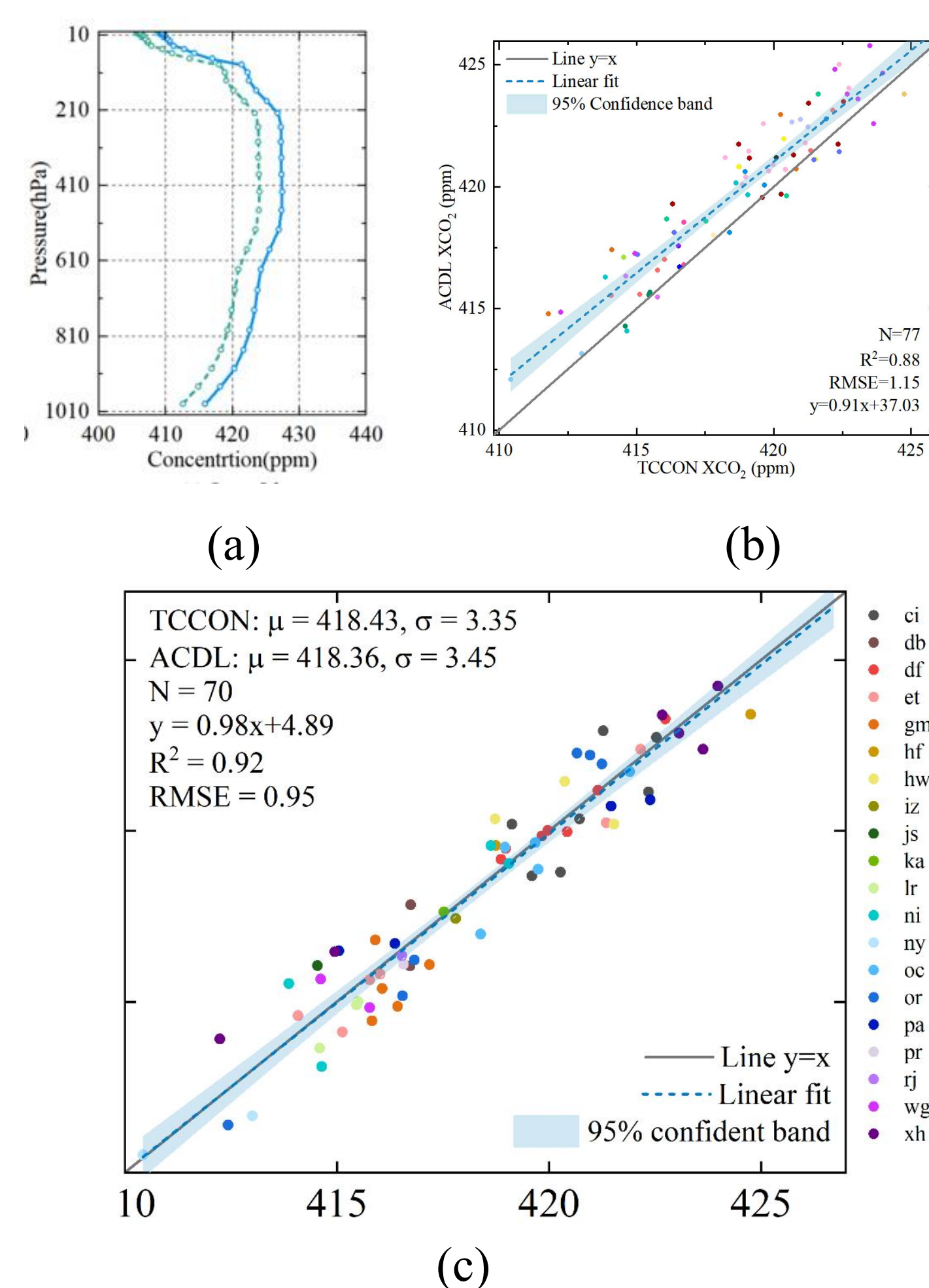


Fig 3. CO₂ prior profile scaling schematic diagram (a is the profile before and after scaling, b is the result of direct comparison with TCCON, c is the result after using this method and compared with TCCON)

Results and Discussions

After using the scaling method for verification, the RMSE between DQ-1 and the TCCON is 0.95 ppm, and the R² is 0.92. Moreover, due to the different mechanisms of active and passive measurement of XCO₂, we discovered that the sensitivity of the two to near-ground CO₂ is different. Perhaps there are new findings.



2025/07 Qing Dao

Connection between active and passive

Connections of weight function:

$$WF(p, T) = c(p, T) \cdot [\sigma(\lambda_{on}, p, T) - \sigma(\lambda_{off}, p, T) N_A]$$

The measurement's sensitivity relies on the differential absorption cross-section, which is the difference between the values at the on-line and off-line wavelengths.

The Valibration of DQ-1 XCO₂ by TCCON

Connection between Active and Passive:

If we get a prior profile of CO₂: $\rho'_{CO_2}(p, T)$, using α to scaling the *prior profile* :

$$\alpha \cdot \rho'_{CO_2}(p, T) = \rho_{CO_2}(p, T)$$

The integral of scaled profile can provide the same XCO₂ as the passive method.

α can get from the Lidar measurement as :

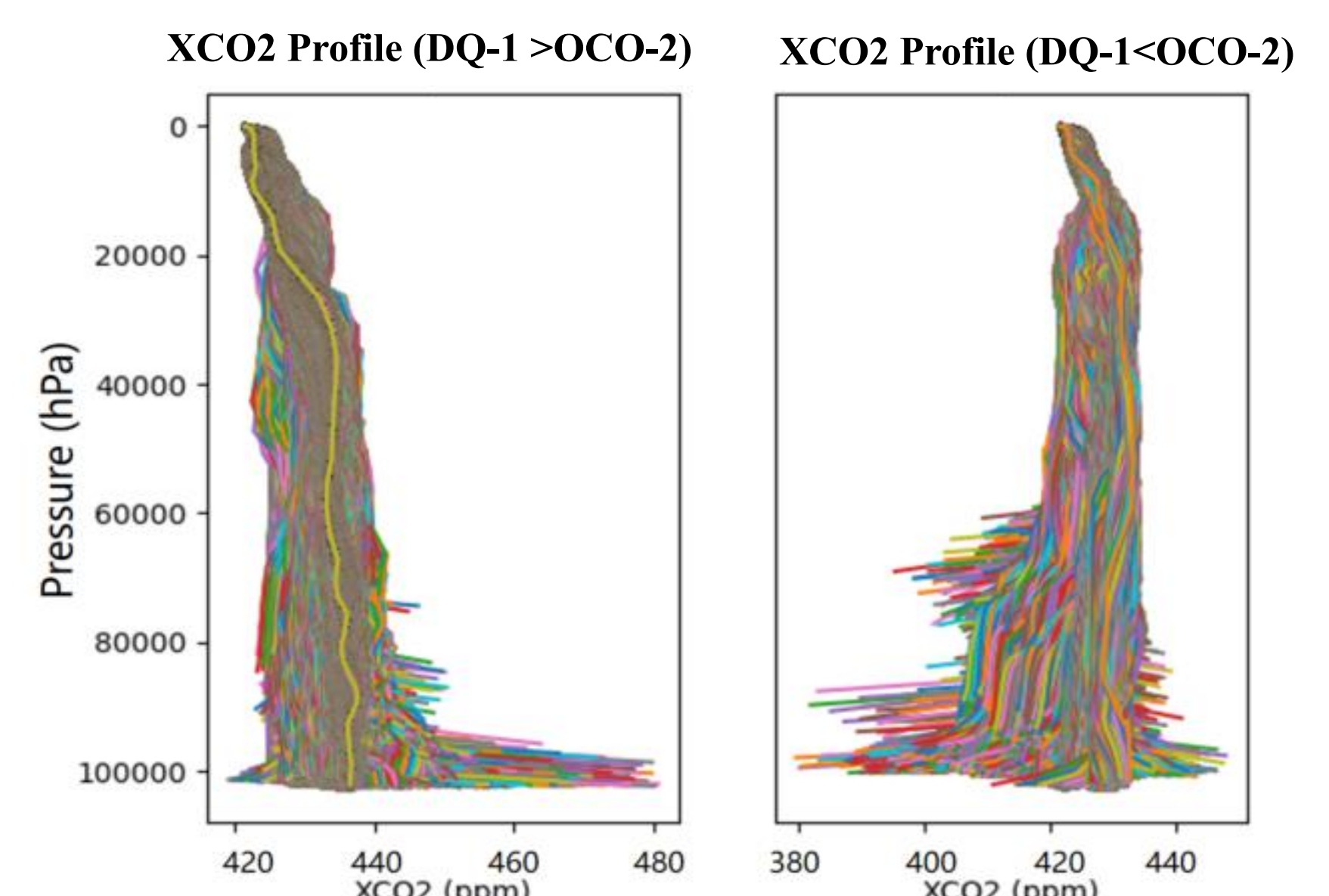
$$\frac{\int_{P_G}^A \alpha \rho'_{CO_2}(p, T) \cdot WF(p, T) dp}{\int_{P_G}^A WF(p, T) dp} = \frac{1}{2} \ln \left[\frac{P(\lambda_{on}, R_A) \cdot P_0(\lambda_{off})}{P(\lambda_{off}, R_A) \cdot P_0(\lambda_{on})} \right]$$

The profile scaling algorithm reduces the systematic bias observed in direct comparisons between DQ-1 and TCCON measurements, thereby improving the agreement between the two datasets.

Active and Passive Collaborative

Simulations of Active and Passive measurement of CO₂.

The difference between DQ-1 and OCO-2 provides insight into the vertical CO₂ profile. A lower XCO₂ from DQ-1 compared to OCO-2 suggests an lower CO₂ near the surface; conversely, a higher value from DQ-1 indicates that surface concentrations are relatively larger.



Major References

- [1]Cao X, Zhang X, Zhang L, et al. Averaging Scheme for the Aerosol and Carbon Detection LiDAR Onboard DaQi-1 Satellite [J]. IEEE Transactions on Geoscience and Remote Sensing, 2024, 62
- [2]L. Zhang et al., Does the Satellite Sensing Column-Averaged Dry-Air Mole Fraction CO₂ (XCO₂) Require Oxygen Concentration From O₂-A Band for Normalizing?[J] IEEE Transactions on Geoscience and Remote Sensing, 2025,6
- [3]ACDL/DQ-1 Calibration Algorithms – Part 2: 1572 nm for Column Concentration of Carbon Dioxide, AMT, in preparation

