Assessment of uncertainties in CO_2 column retrieved from ACDL onboard DQ-1

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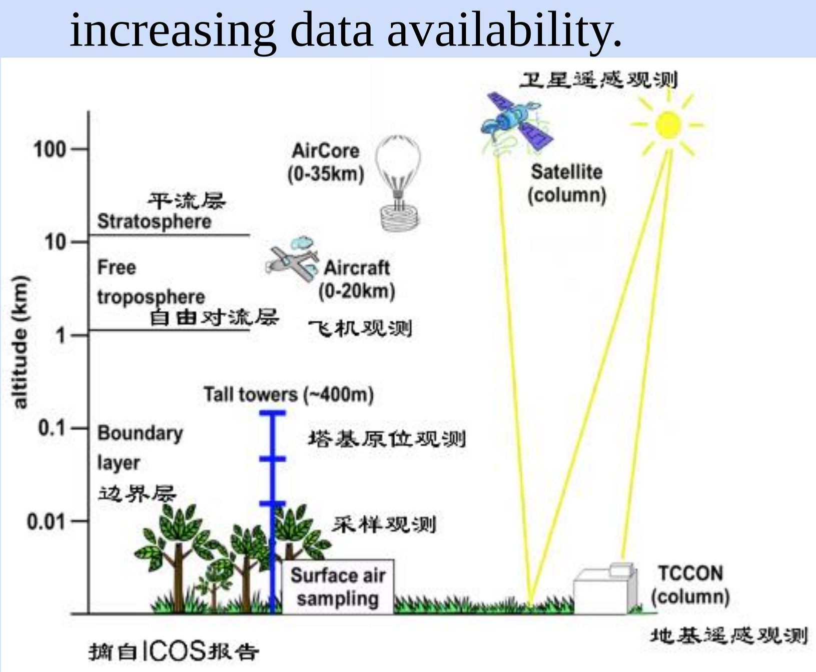
Abstract

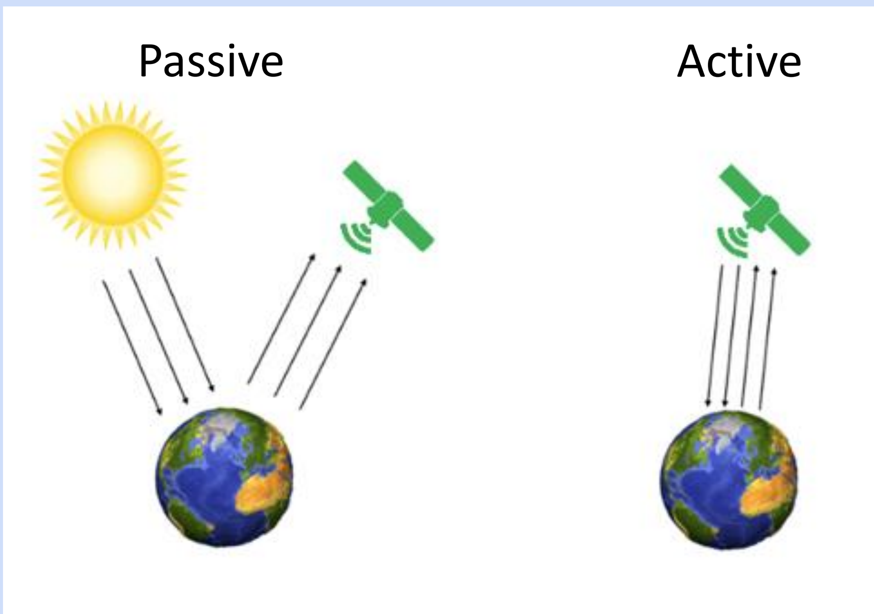
Atmospheric carbon dioxide (CO_2) is the primary anthropogenic driver of climate change, accounting for more than half of the total effective radiative forcing (ERF). The Aerosol and Carbon Detection Lidar (ACDL) instrument, as the first space-borne integrated path differential absorption (IPDA) light detection and ranging (Lidar), was successfully launched in April 2022 onboard the DaQi-1 (DQ-1) satellite. ACDL enables observations to be taken at all latitudes and all times of year owing to their illumination, which allows a new perspective to quantify the global spatial distribution of atmospheric CO_2. In this paper, the performance of the IPDA lidar was evaluated to meet the global weighted column-averaged dry air mixing ratio of carbon dioxide (XCO_2) measurement requirements of less than 1 ppm. The random errors resulting from the noise associated with the detection of the lidar signals were assessed. The simulations of ACDL lidar were conducted. Results showed that the random error was distributed in the range of 0-1.5 parts per million (ppm) with 50 km averaging over land surfaces and 100 km averaging over oceans. In addition, the systematic errors arising from the uncertainty of atmospheric factors, the HITRAN database, instrument parameters, and other factors were also analyzed. The systematic errors were about 0.42 ppm, which meet the requirements of 1 ppm. This study can help to improve the understanding of the measurement uncertainties and provide a reference for CO_2 retrievals and validation.

Introduction

- Atmospheric carbon dioxide (CO_2) is recognized as the most important component of the greenhouse gases, the concentration of which has increased rapidly since the pre-industrial era due to anthropogenic emissions of greenhouse gases (GHG). However, CO_2 sources and sinks remain poorly understood, especially in dynamic regions with large carbon stocks and strong vulnerability to climate change
- Active space sensors enable observations to be taken at all latitudes and all times of year owing to their own illumination compared to passive remote sensing. Additionally, the small footprints allow measurements through gaps in clouds, increasing data availability.



Ground-based measurements



Space-borne measurements

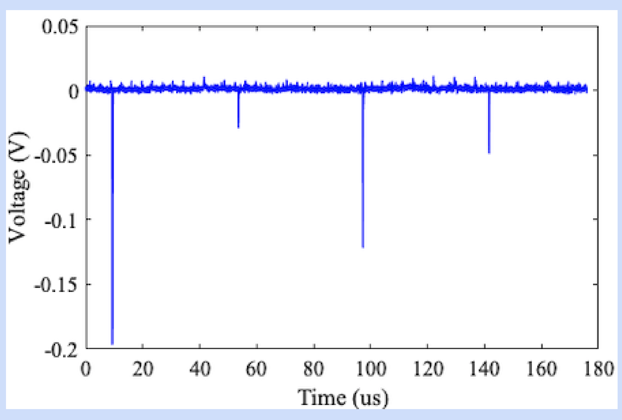
Materials

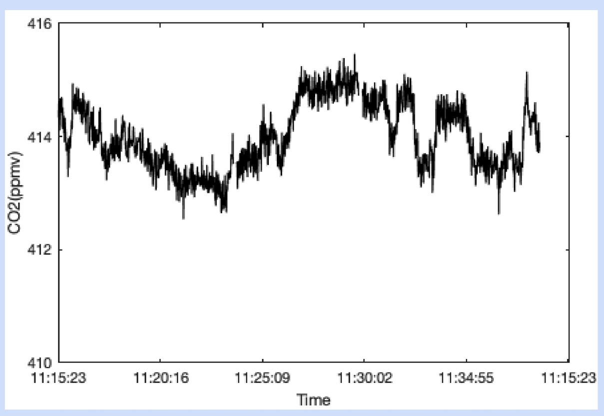
ACDL data

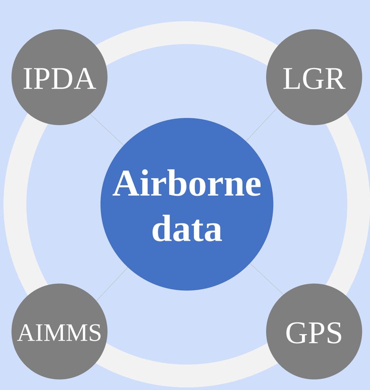
- Spaceborne IPDA lidar observations

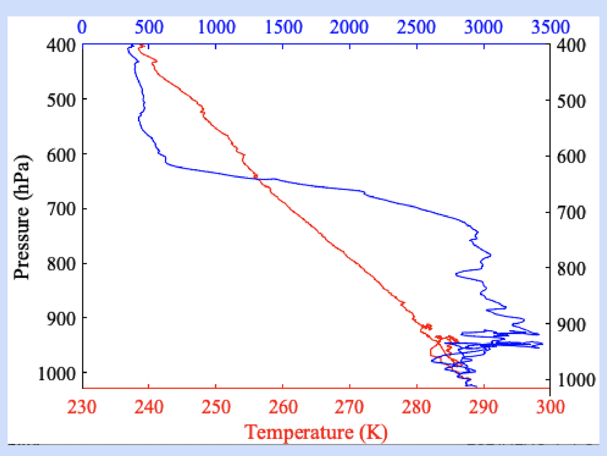
Auxiliary dataset

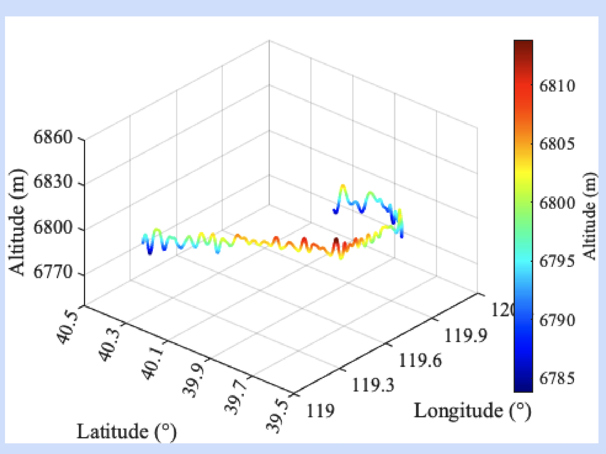
- Profiles of CO_2, temperature, pressure and humidity
- Attitude, position and velocity of the platform





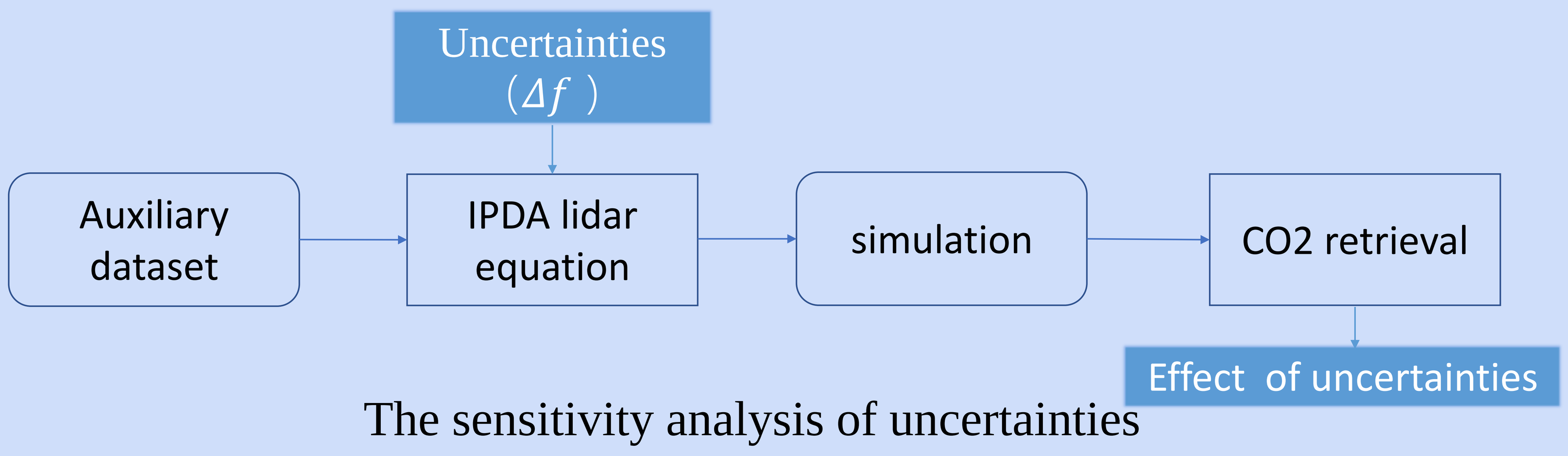




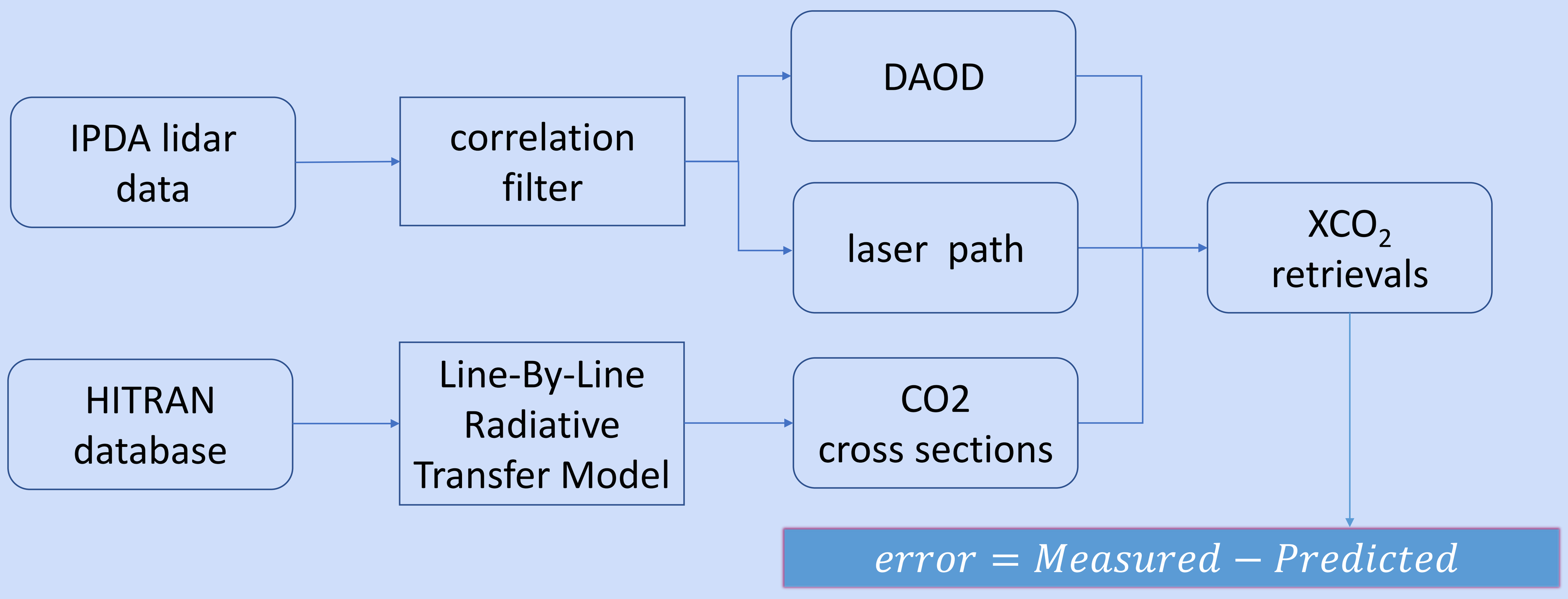


Methods

- The random and systematic errors in ACDL measurements were evaluated based on simulations. The differences between the XCO_2 retrievals with and without interference were used to assess the impact of the uncertainties on CO_2 measurements.

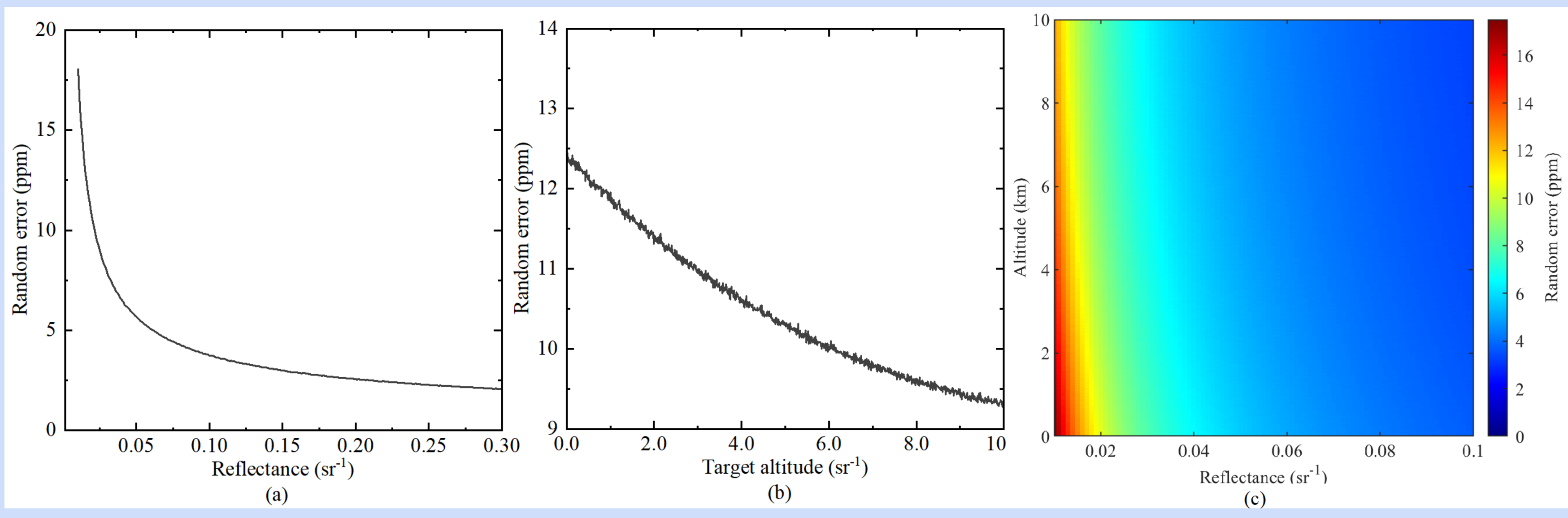


The sensitivity analysis of uncertainties



The retrieval process of IPDA lidar

Results



The impact of surface reflectance and altitude on random errors of a single shot

	Error source	RSE	Absolute error (ppm)	Uncertainty for CO_2
Atmosphere	Surface pressure	0.033%	0.11 ppm	0.5 hPa
	Temperature	0.046%	0.15 ppm	0.5 K
	H_2O mixing ratio	0.015%	0.05 ppm	5%
Line parameters	Line strength	0.021%	0.07 ppm	2%
	Line transition	0.039%	0.13 ppm	0.001 cm^{-1}
	Air-broadened half width	0.012%	0.04 ppm	2%
	Self-broadened half width	0.000%	2.44×10^{-5} ppm	2%
	Temperature scaling exponent of air	0.001%	0.004 ppm	2%
	Temperature scaling exponent of air	0.000%	1.26×10^{-5} ppm	5%
	Pressure shift of air	0.009%	0.03 ppm	0.001 cm^{-1}
	Pressure shift of self	0.000%	1.38×10^{-5} ppm	0.001 cm^{-1}
Transmitter /Receiver	Pulse energy	0.072%	0.24 ppm	5×10^{-4}
	Bandwidth	0.046%	0.15 ppm	40 MHz
	Frequency drift	0.030%	0.10 ppm	0.3 MHz
	Spectral purity	0.033%	0.11 ppm	99.95%
	Path length	0.021%	0.07 ppm	3 m
Other factors	Pointing misalignment	0.030%	0.10 ppm	0.06 mrad
	Temporal interpulse separation	0.015%	0.05 ppm	$\Delta Q/Q<10^{-4}$
Total		0.127%	0.42 ppm	Geometrically added

The impact of uncertainties on CO_2 measurements

Conclusion

- The random errors is negatively correlated to the surface reflectance and the altitude of echo signals.
- The systematic errors were about 0.42 ppm, which is meet the requirements of 1 ppm.

References: 1. Amediek, A.; Fix, A.; Ehret, G.; Caron, J.; Durand, Y. Airborne lidar reflectance measurements at 1.57 µm in support of the A-SCOPE mission for atmospheric CO_2. *Atmos. Meas. Tech.* 2009, *2*, 755–772. https://doi.org/10.5194/amt-2-755-2009.

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