Measurement of CO_2 from Space using the ACDL Lidar onboard DQ-1

Lu Zhang[1], Xingying Zhang[1], Xifeng Cao[1], Jiqiao Liu[2], Weibiao Chen[2],Minqiang Zhou[3]

1.National Satellite Meteorological Center (National Center for Space Weather) , China Meteorological Administration (CMA)
2.Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences
3.Institute of Atmospheric Physics, Chinese Academy of Sciences

中国科学院上海光学精密机械研究所
Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences

中国科学院大气物理研究所
Institute of Atmospheric Physics,Chinese Academy of Sciences

Contents

Introduction of ACDL onboard DQ-1

Great Events of DQ-1

2015-01
Approved in advance(DQ-1)

2017-08
Project was approved

2019-03
First Airborne CO2 -IPDA LIDAR in Shan Haiguan

2019-10

The First Workshop of Application of Spaceborne Lidar in Atmospheric Detection

2021-07

Second Airborne CO2 -IPDA LIDAR in Dunhuang

2022-04

Introduction of ACDL onboard DQ-1

Specification of ACDL on DQ-1

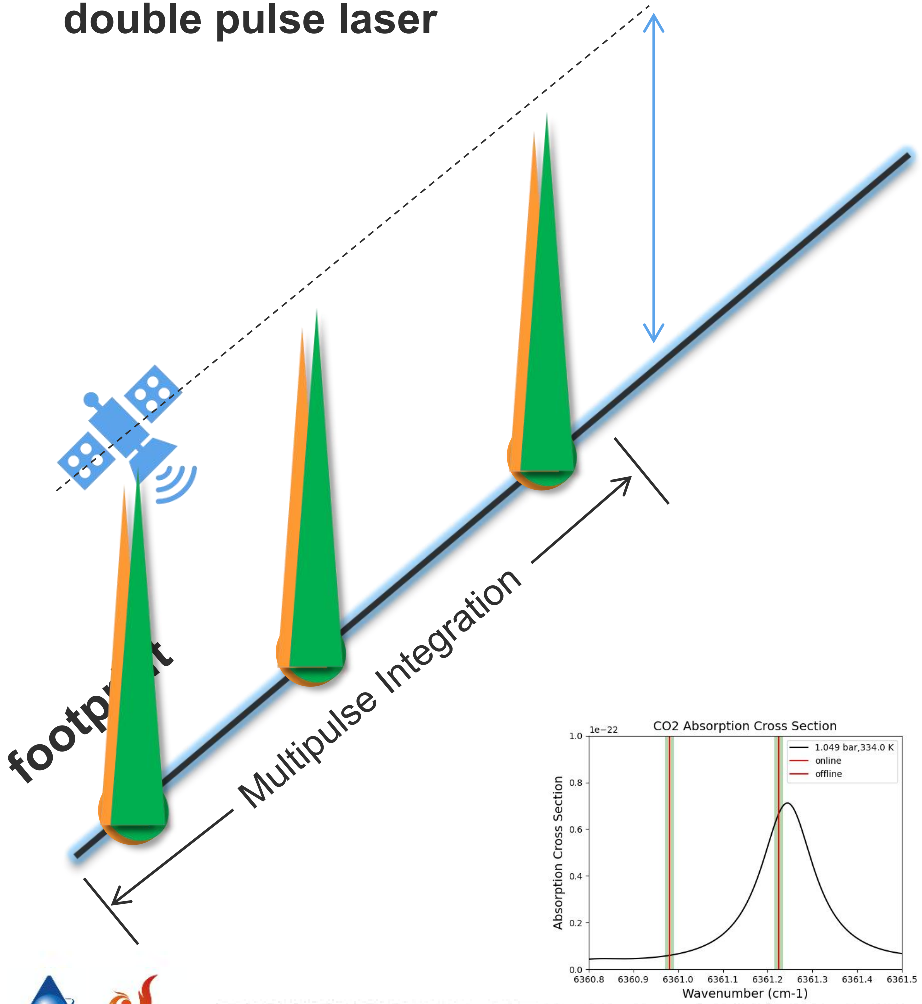
Specification	ACDL/DQ-1
Altitude (km)	705km
Inclination	98.2^{o}
Crossing time	13:30
Repetition frequency	20 Hz
Wavelength1	150mJ@532nm
Wavelength2	110mJ@1064nm
Online wavelength	75mJ@1572.024 nm
Offline wavelength	75mJ@1572.085nm
Pulse width (on/off)	15ns
Field of view	100 µrad

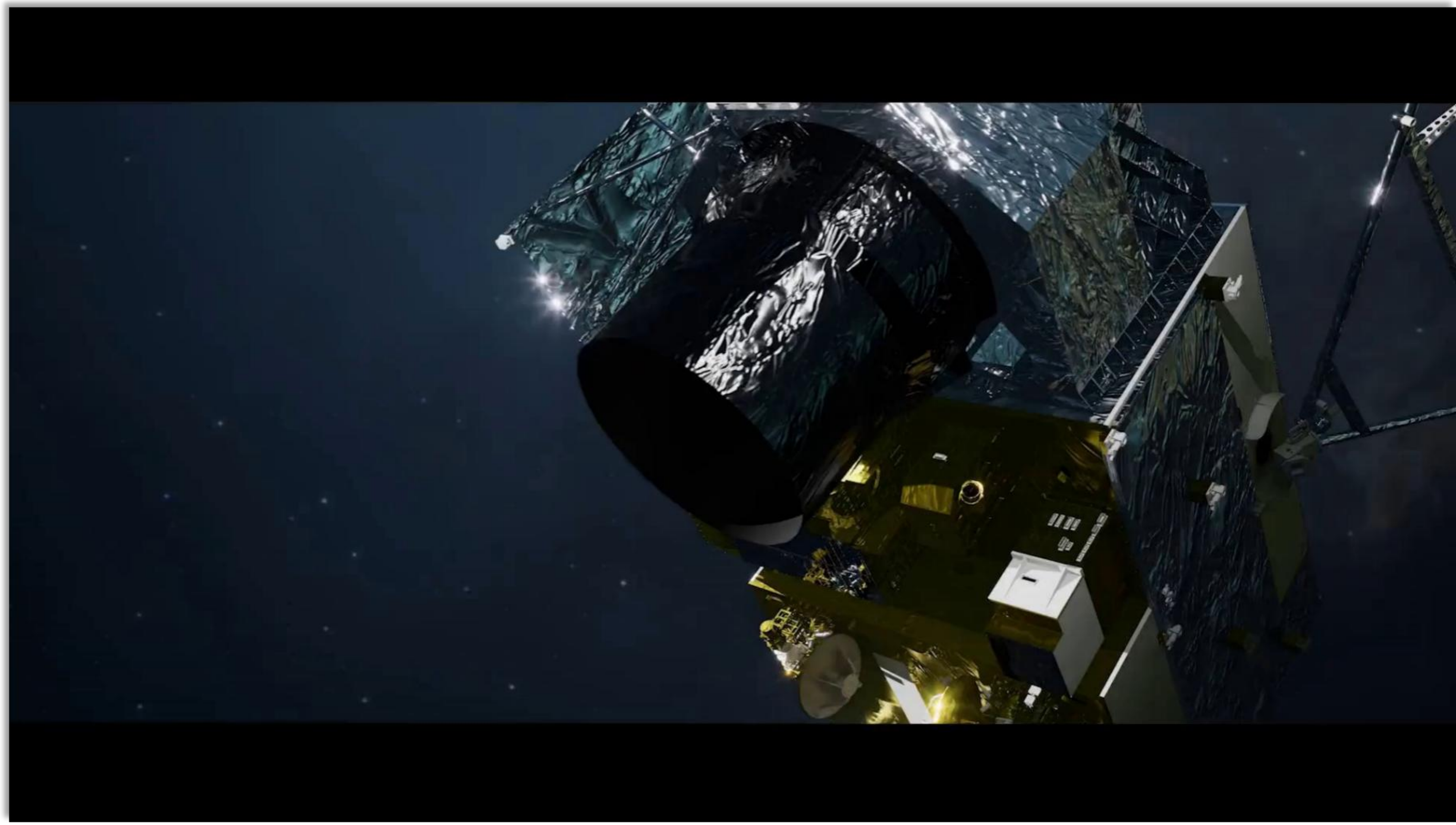
Other instruments on DQ-1

- POSP, WSI and DPC for aerosol and cloud
- EMI for O3，SO2 and NO2

Detection Mechanism display

double pulse laser





Inverse algorithm and result

Inverse algorithm

- **The lidar equation for on-line and off-line**

$$P(\lambda_{on}, R_A) = \frac{Q_{on}}{\pi}\frac{E_{on}}{t_{on}}\frac{A}{(R_A - R_G)^2}\eta_r\varphi_r \cdot exp[\tau(\lambda_{on}, R_A)]$$

$$P(\lambda_{off,}R_A) = \frac{Q_{off}}{\pi}\frac{E_{off}}{t_{off}}\frac{A}{(R_A - R_G)^2}\eta_r\varphi_r \cdot exp[\tau(\lambda_{off}, R_A)]$$

- **The Differential Absorption Optical Depth (DAOD) of CO2**

$$DOAD == \int_{P_G}^{P_A} \rho_{CO2}(p,T) \cdot WF(p,T)dp = \frac{1}{2} ln\left[\frac{P(\lambda_{off,}R_A) \cdot P_0(\lambda_{on})}{P(\lambda_{on,}R_A) \cdot P_0(\lambda_{off})}\right]$$

- **Under the assumption of $\rho_{CO2}(p,T)$ remaining constant with respect to range, the $\rho_{CO2}(p,T)$ can be extracted from integral formula,**

$$DOAD \approx \rho_{CO2} \cdot \int_{P_G}^{P_A} WF(p,T)dp$$

$$WF(p,T) = \frac{\sigma(\lambda_{on},p,T) - \sigma(\lambda_{off},p,T)}{[1+\rho_{H2O}(p,T)] \cdot g \cdot M_{dry}} N_A$$

- **The weighted-average column dry-air volume mixing ratio of CO2: XCO2**

$$\mathrm{XCO2} = \frac{1}{2}\frac{ln\left[\frac{P(\lambda_{on,}R_A) \cdot P_0(\lambda_{off})}{P(\lambda_{off,}R_A) \cdot P_0(\lambda_{on})}\right]}{\int_{P_G}^{P_A} WF(p,T)dp}$$

Inverse algorithm and result

The flow chart of retrieval CO2 by ACDL

- **Six stages**

Pulse signal screening

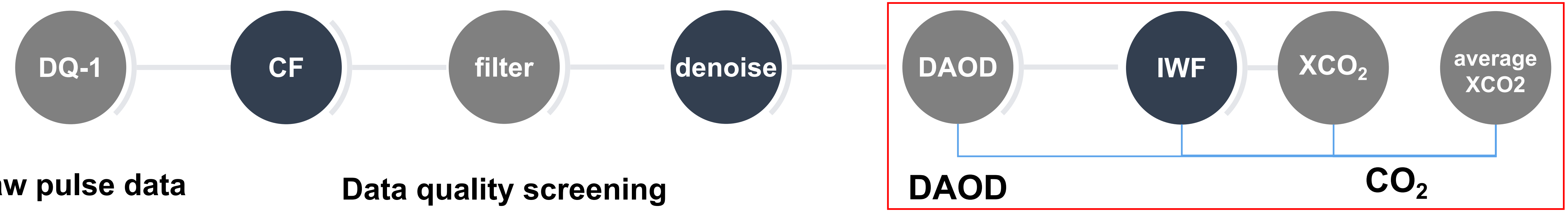
Pulse signal in the echo signal is extracted and identified

Background noise elimination

The background noise of different data segments is different, and the corresponding segment of background noise should be reduced respectively.

Integral of the weight function

The integral of weight function is calculated by pressure profile, temperature profile, water vapor profile, absorption cross section and elevation information



Raw pulse data

Reading and Display

Data quality screening

Check the signal to remove lost and weak signals

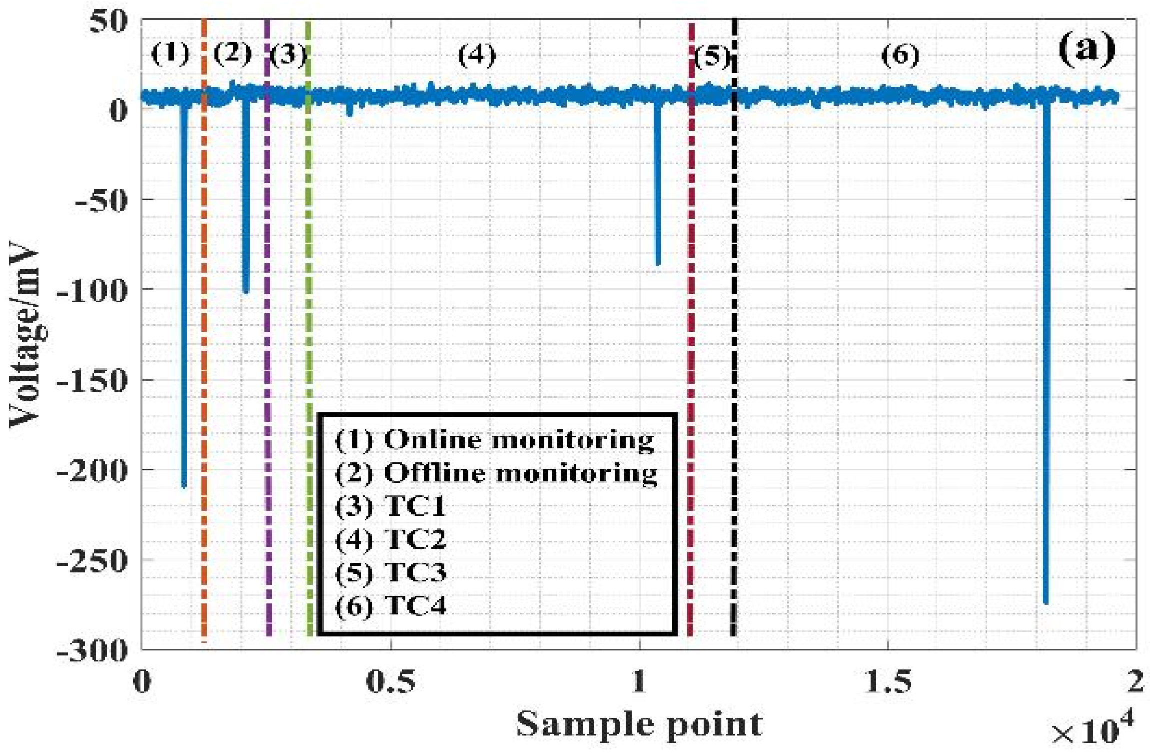
The DOAD is calculated by online and offline monitoring and echo signals

The CO2-weighted column concentration is obtained by the ratio of DOAD and IWF

Inverse algorithm and result

SNR of ACDL

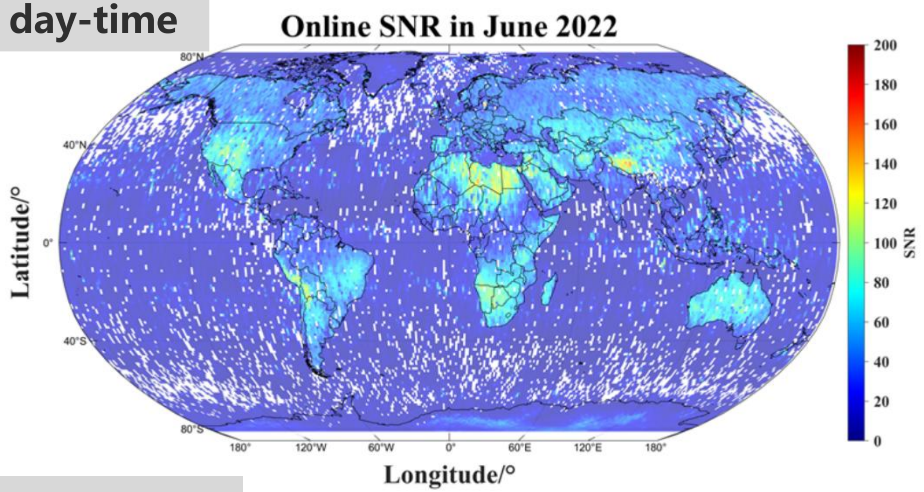
- pluse



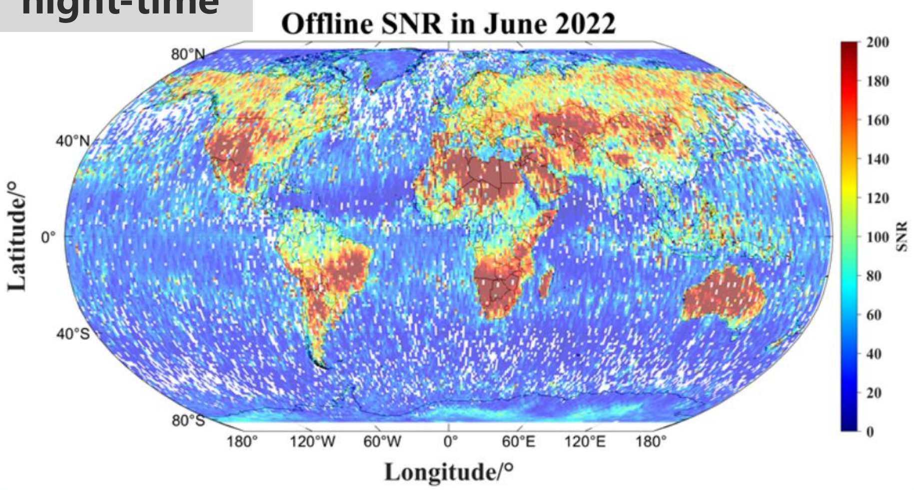
- Distribution of SNR

$$SNR = \frac{P_v}{\sigma_{noise}},$$

day-time



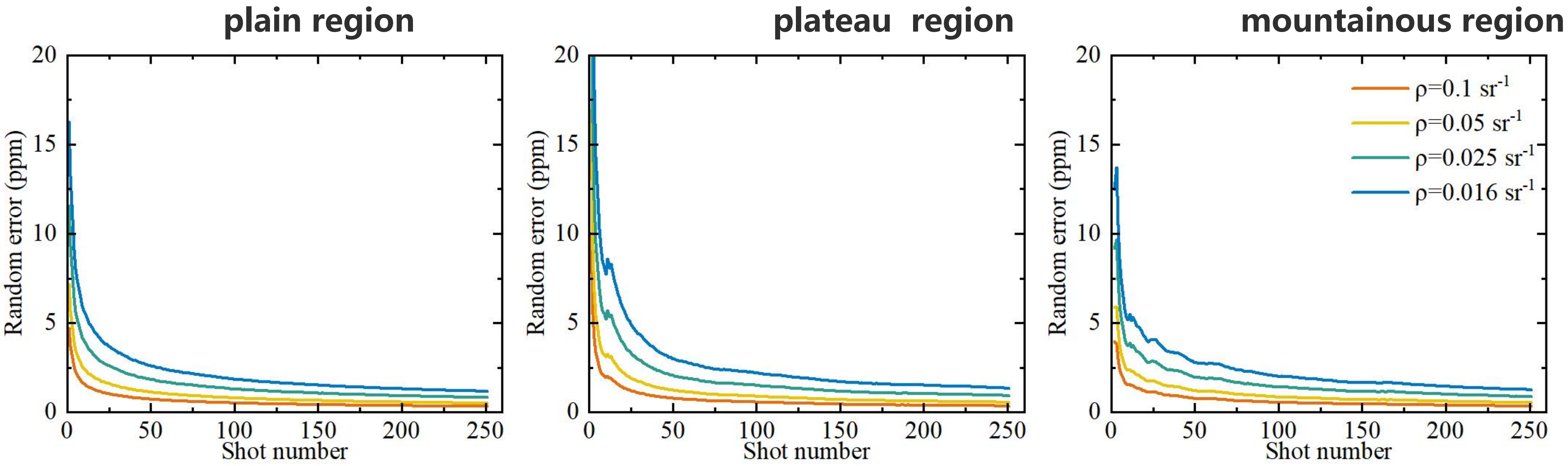
night-time



Fan Can et.al, Preliminary analysis of global column-averaged CO concentration data from the spaceborne Aerosol and Carbon dioxide Detection Lidar onboard AEMS To be published in Optics Express

Inverse algorithm and result

The random error decreases with the number of pulses for average



- Different terrain and surface reflectance
- With demand for 1ppm : land ---150 shots,sea about 250 shots

Xifeng Cao, Xingying Zhang, Lu Zhang, Minqiang Zhou , Yuhan Jiang, Jiqiao Liu, Tiantao Cheng, Chuncan Fan, Cheng Chen, and Lin Chen. Averaging Scheme for the Aerosol and Carbon Detection LiDAR Onboard DaQi-1 Satellite [J], IEEE Transactions on Geoscience and Remote Sensing, 2024, 62. doi: 10.1109/TGRS.2024.3380639.

Inverse algorithm and result

Multiple-pulse for average method

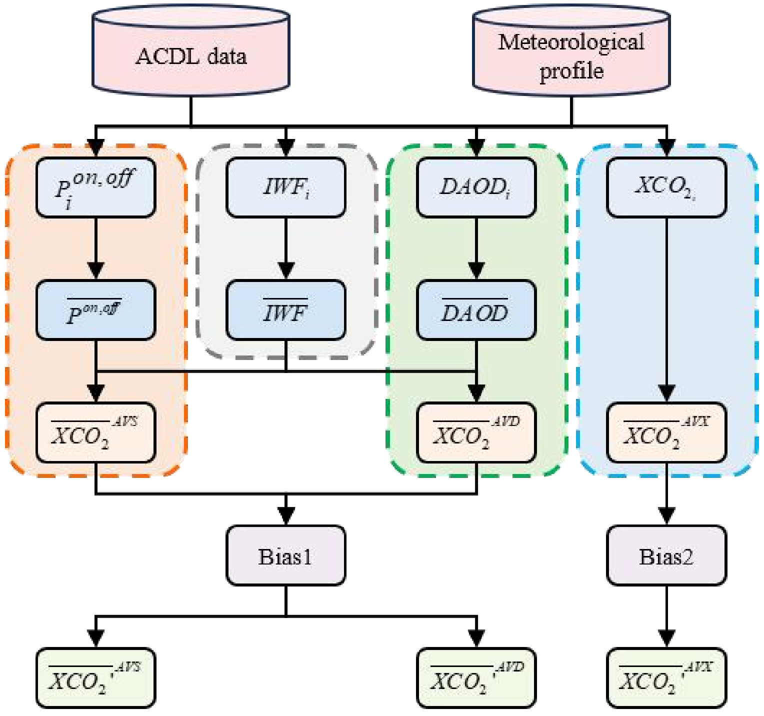
- **There are three types of pulse averaging: Averaging of CO2 Columns(AVX), Averaging of Differential Absorption Optical Depth(AVD),Averaging of Signals(AVS)**

$$XCO_2 = \frac{DAOD}{IWF} = \frac{1}{IWF}\ln\frac{P(\lambda_{on})}{P(\lambda_{off})} \quad (1)$$

$$\overline{XCO_2}^{AVX} = < \frac{DAOD}{IWF} > \quad (2)$$

$$\overline{XCO_2}^{AVD} = \frac{< DAOD >}{< IWF >} \quad (3)$$

$$\overline{XCO_2}^{AVS} = \frac{-\frac{1}{2}\ln\frac{< P(\lambda_{on}, r) >< P_0(\lambda_{off}) >}{< P(\lambda_{off}, r) >< P_0(\lambda_{on}) >}}{< IWF >} \quad (4)$$

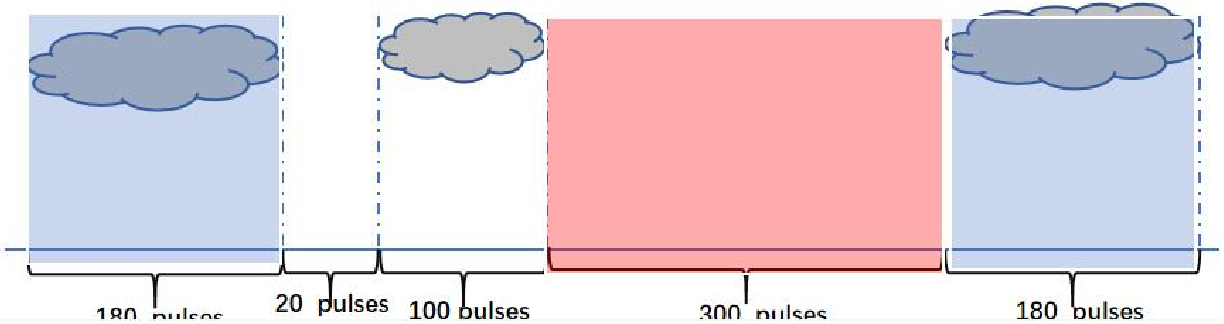


three types of pulse averaging

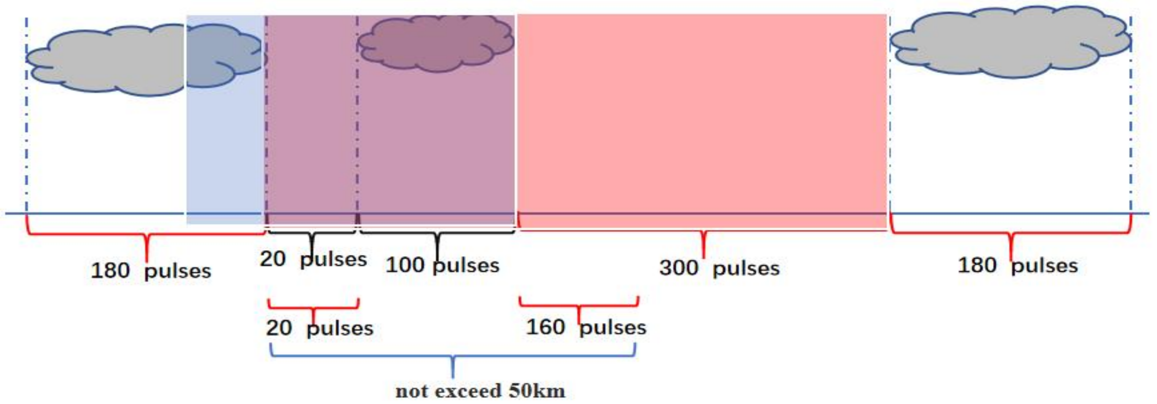
Inverse algorithm and result

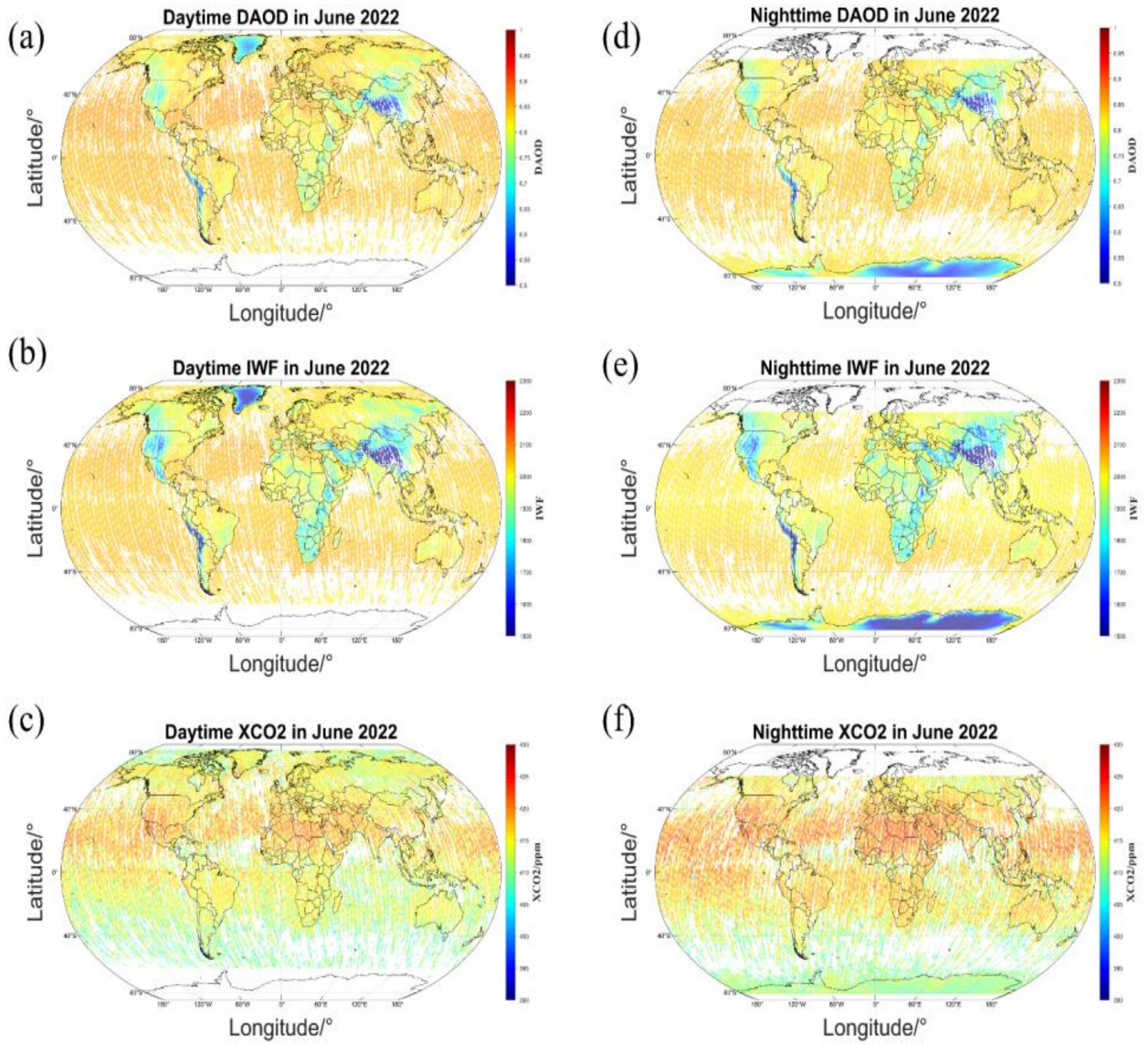
Multiple-pulse average strategies and results

- Clear sky first



- Data quantity first





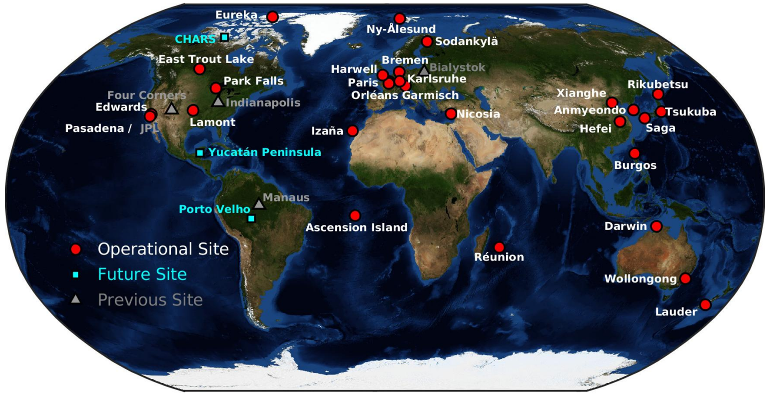
Retrievals from ACDL measurements from 1th June 2022 to 30th June 2022

Validation

validation

TCCON for validating the XCO2 by ACDL

- **Threshold of matching**: less than 1° and 1h
- **The difference between TCCON and ACDL**



TCCON:

$$XCO_2' = \frac{\int_0^{\infty} \rho_{CO2}(r) n_{dryair}(r) dr}{\int_0^{\infty} n_{dryair}(r) dr}$$

ACDL:

$$XCO_2 = \frac{\int_0^{\infty} (\sigma_{on} - \sigma_{off}) \rho_{CO2}(r) n_{dryair}(r) dr}{\int_0^{\infty} (\sigma_{on} - \sigma_{off}) n_{dryair}(r) dr}$$

$\rho_{CO2}(r)$: dry air volume mixing ratio of CO2 at altitude r

$n_{dryair}(r)$:is the total molecular number density of dry air at altitude r.

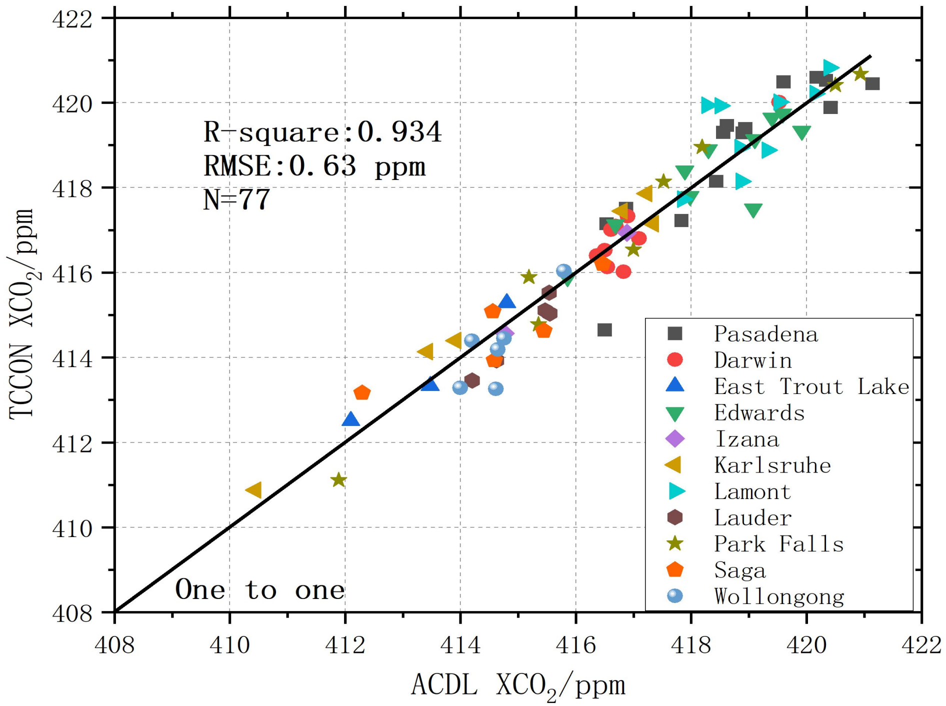
σ_{on}: absorption cross section of the on-line

σ_{off}:absorption cross section of the off-line

Validation

Validation

- 1. Correlation analysis: The correlation analysis between the ACDL and the synchronous observation of TCCON station was carried out to evaluate the reliability of XCO2 from ACDL.



This method may not suitable for valibation.

Validation

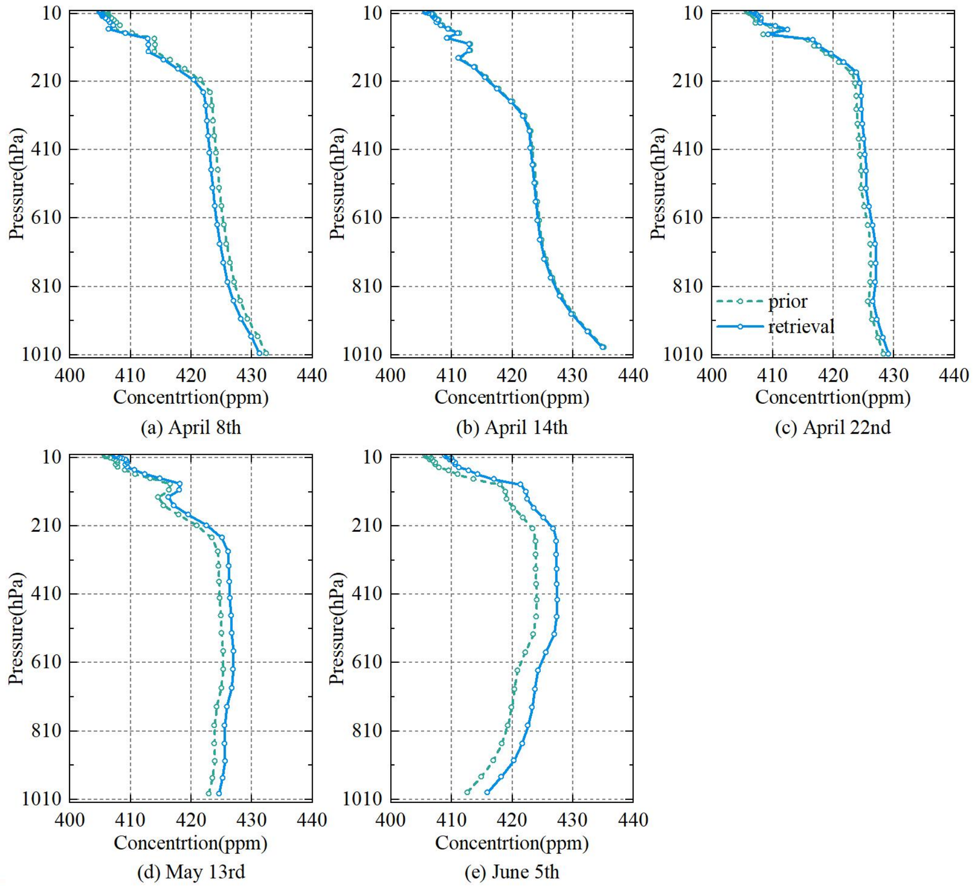
Validation

- 2. The prior profile is used in the active inversion algorithm to achieve the unity of the active and passive detection results

$$\int_{P_G}^{P_A} K \cdot \rho'_{CO2}(p,T) \cdot WF(p,T)dp = \frac{1}{2} ln \left[\frac{P(\lambda_{off},R_A) \cdot P_0(\lambda_{on})}{P(\lambda_{on},R_A) \cdot P_0(\lambda_{off})}\right]$$

- $K \cdot \rho'_{CO2}(p,T) = \rho_{CO2}(p,T)$

Time	method1	method2	TCCON	Diff 1	Diff 2
2023/4/8	422.66	422.34	422.86	-0.20	-0.52
2023/4/15	422.21	422.20	422.56	-0.35	-0.36
2023/4/22	424.74	424.19	424.18	-0.56	0.01
2023/5/13	424.52	423.78	423.11	1.41	0.67
2023/6/5	424.81	423.72	423.39	1.42	0.33



(a) April 8th (b) April 14th (c) April 22nd (d) May 13rd (e) June 5th

Plan

- **Validation**
- Recalculate all data , comparing with TCCON open data by two method.
- 1 or 2 time aircore, get CO_2 profile.
- Comparing DQ-1 and OCO-2.
- **Production**
- L2 pruduct above cloud, no cloud,subcloud.
- Complete ATBD, preparing for data opening policy release

Email: zhanglu_nsmc@cma.gov.cn


THANKS
NSMC
NCSW