



AOMSUC-15 FYSUC-2025

FIFTEENTH ASIA-OCEANIA METEOROLOGICAL SATELLITE USERS' CONFERENCE
THE JOINT 2025 FENGYUN SATELLITE USER CONFERENCE

Advances in Lidar Development and Applications to Satellite Calibration

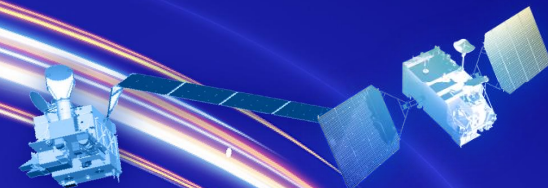
Xiao Zhisheng

Qingdao Leice Transient Technology Co., Ltd



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**LEICE LIDAR
PRODUCTS**

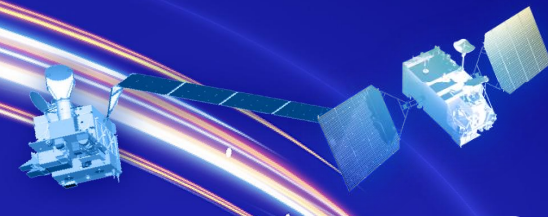
03.

CASE ANALYSIS



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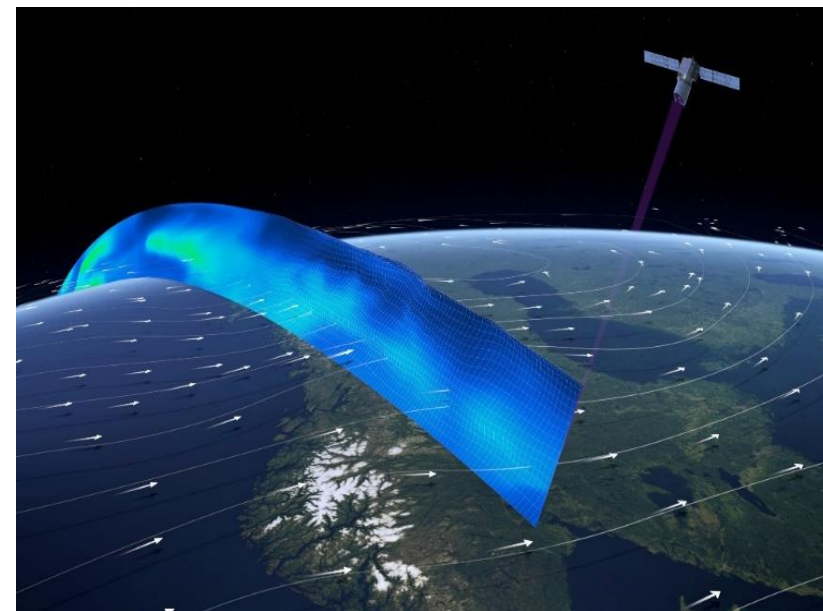
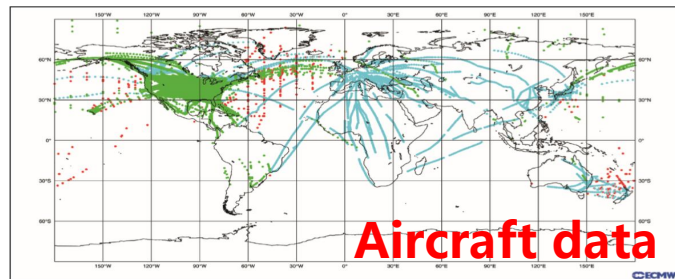
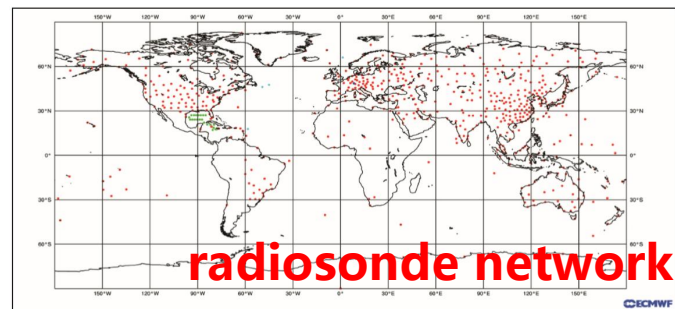
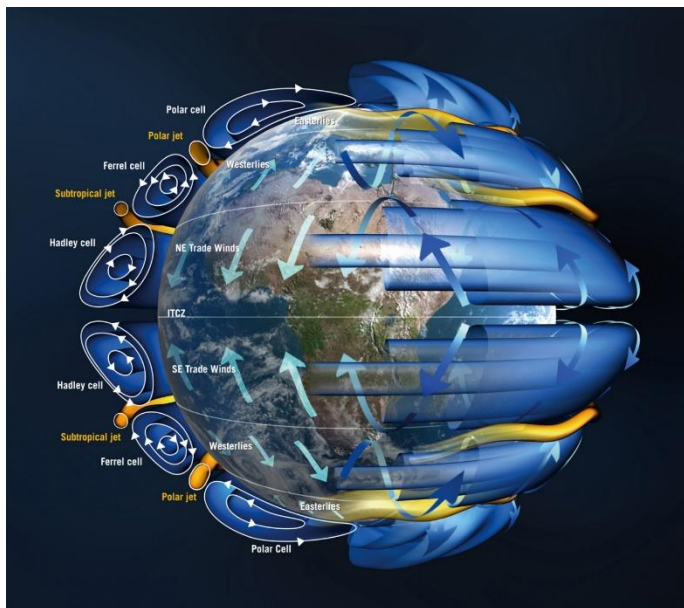
THE IMPORTANCE OF CALIBRATING SATELLITES

Large-scale variations in winds have a decisive influence on weather patterns and the long-term evolution of Earth's climate.

The Global Observing System has **limitations** in terms of data coverage, the continuity of detection height and data accuracy.

Aeolus: First spaceborne lidar for wind measurement

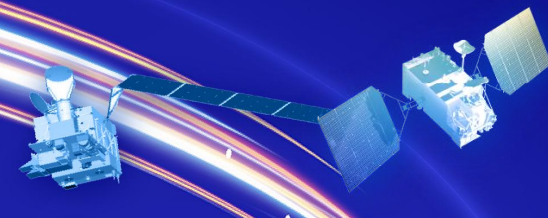
Improving Numerical Weather Prediction (NWP)
Advancing Dynamics & Climate Process Understanding





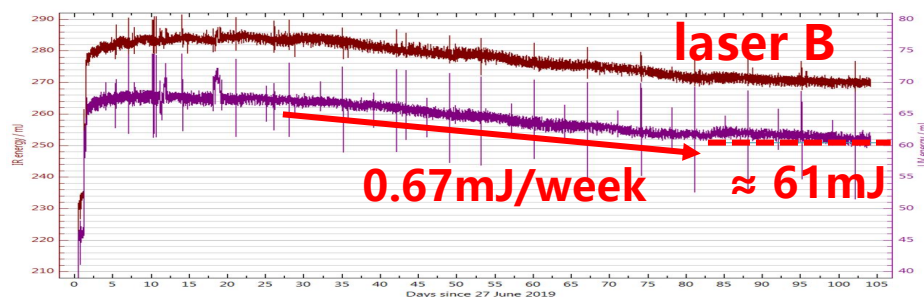
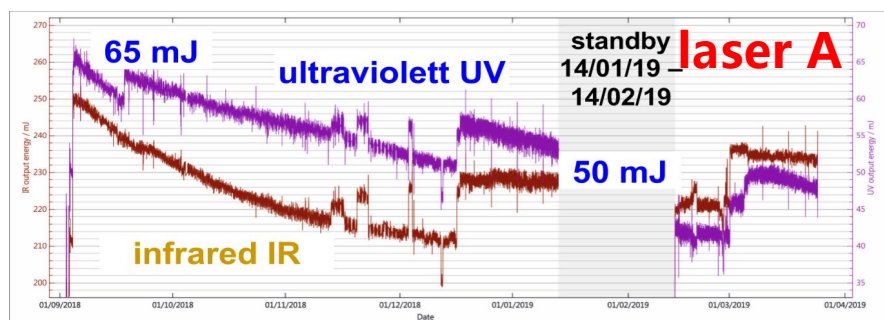
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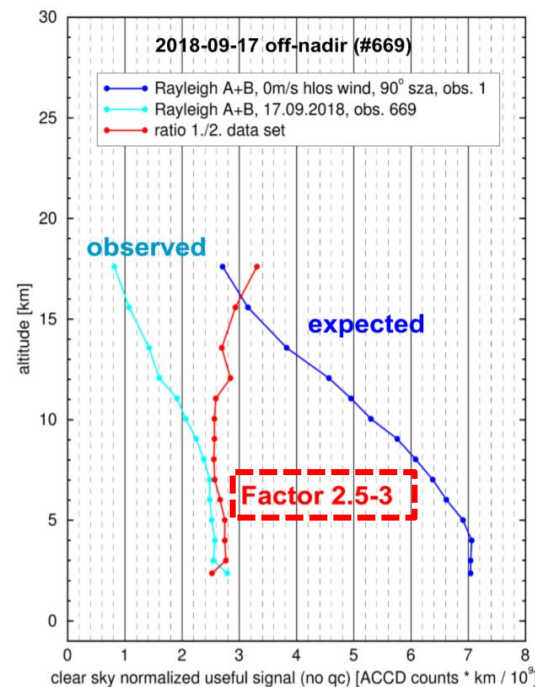


THE IMPORTANCE OF CALIBRATING SATELLITES

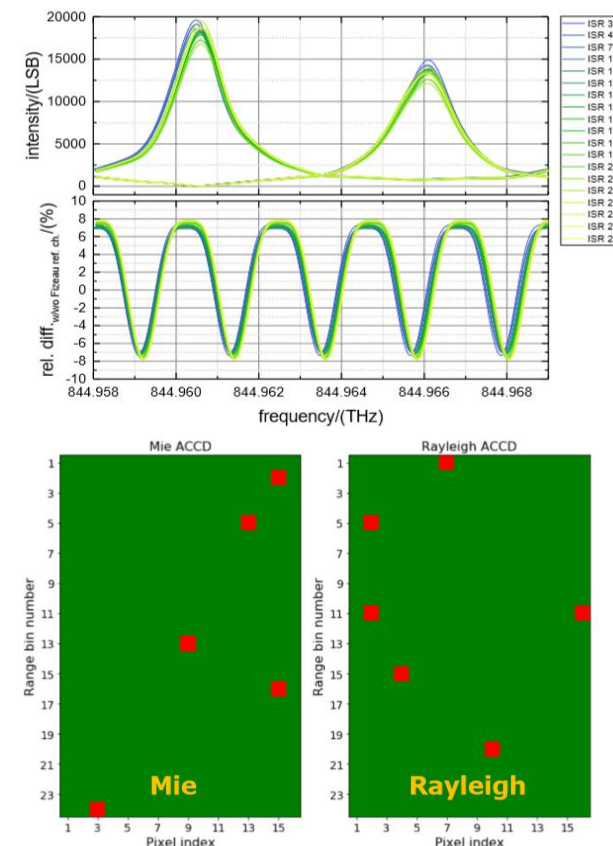
Issues encountered in Aeolus



Both the original laser (Laser A) and the switched laser (Laser B) exhibited **lower-than-expected single-pulse energy** and showed sustained degradation for most of the time.



The intensity of the received return signal was lower than expected.

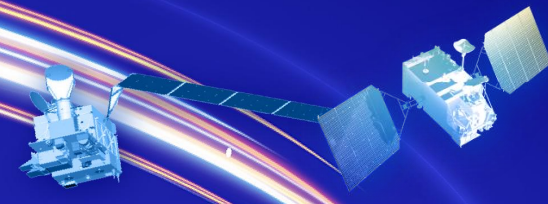


Sporadic detector frequency jitter and ACCD hot pixels



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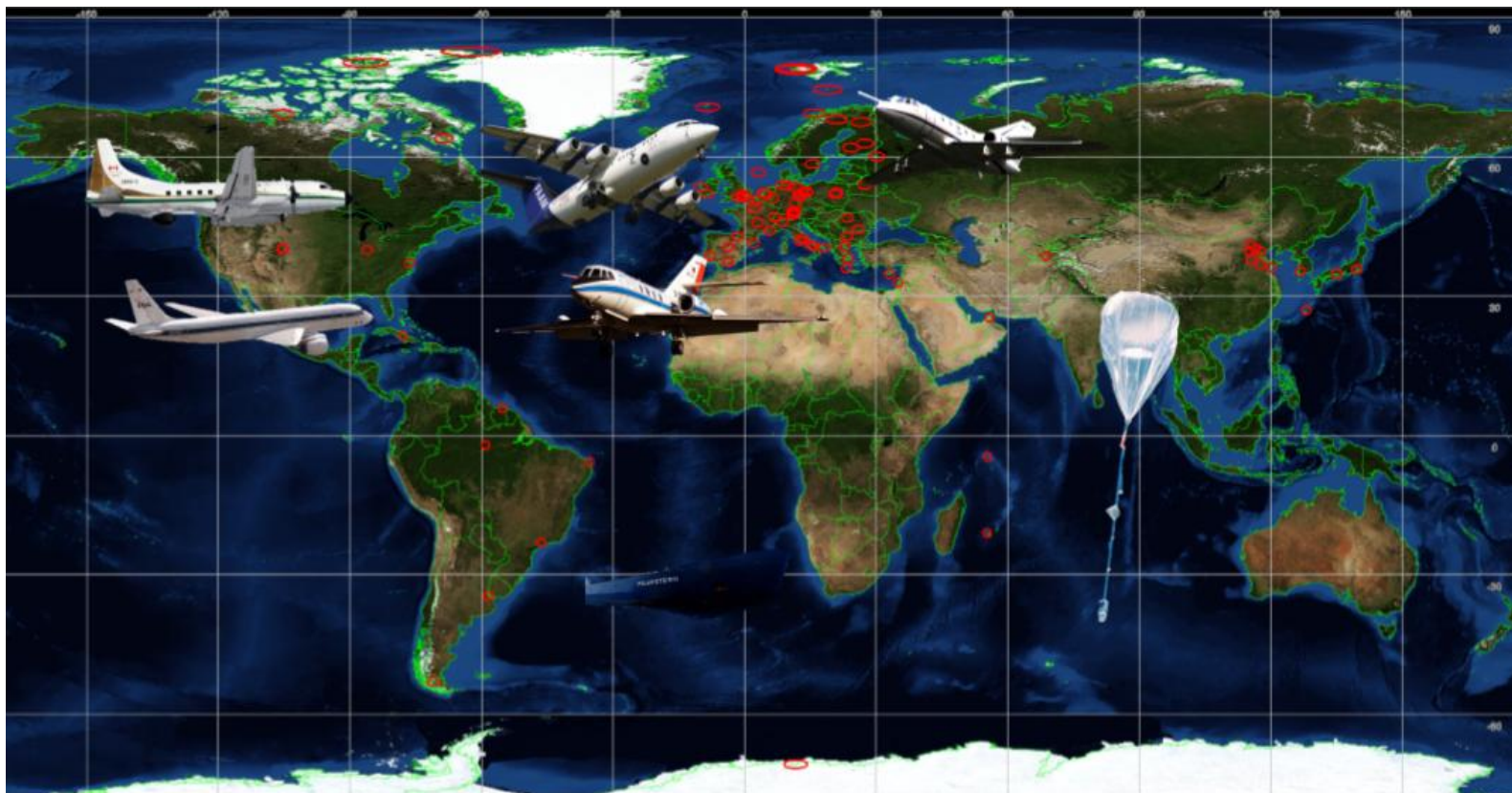
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THE IMPORTANCE OF CALIBRATING SATELLITES:

Satellite product QA should be based on multi-platform, multi-instrument observations.

Comparative analysis of these data supports targeted improvements in sensor performance, retrievals, and QC.



✓ In map

Selection of ground based co-located measurements of winds and/or aerosol/cloud products(e.g., wind lidar; aerosol lidar/ceilometer)

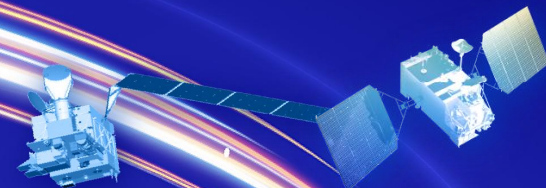
✓ Selection of additional themes:

- Airborne validation
- Radiosondes
- Super-pressure Balloons
- Satellite-based
- Model-based
- Statistical
- NWP impact studies



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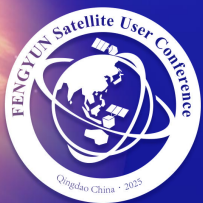
BACKGROUND

02.

**LEICE LIDAR
PRODUCTS**

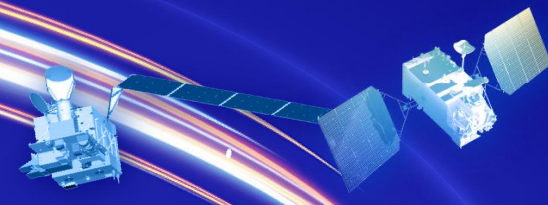
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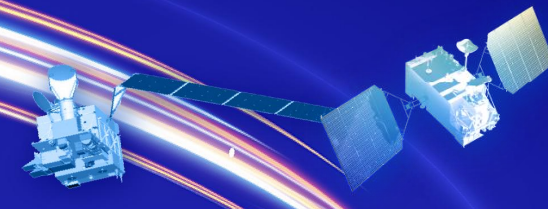
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LEICE Lidar Products

10⁺ types of standardized products, 5⁺ types of new products under development





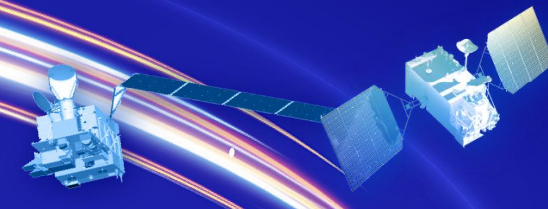
LEICE Lidar Products



WindMast Vertical Profile Lidar

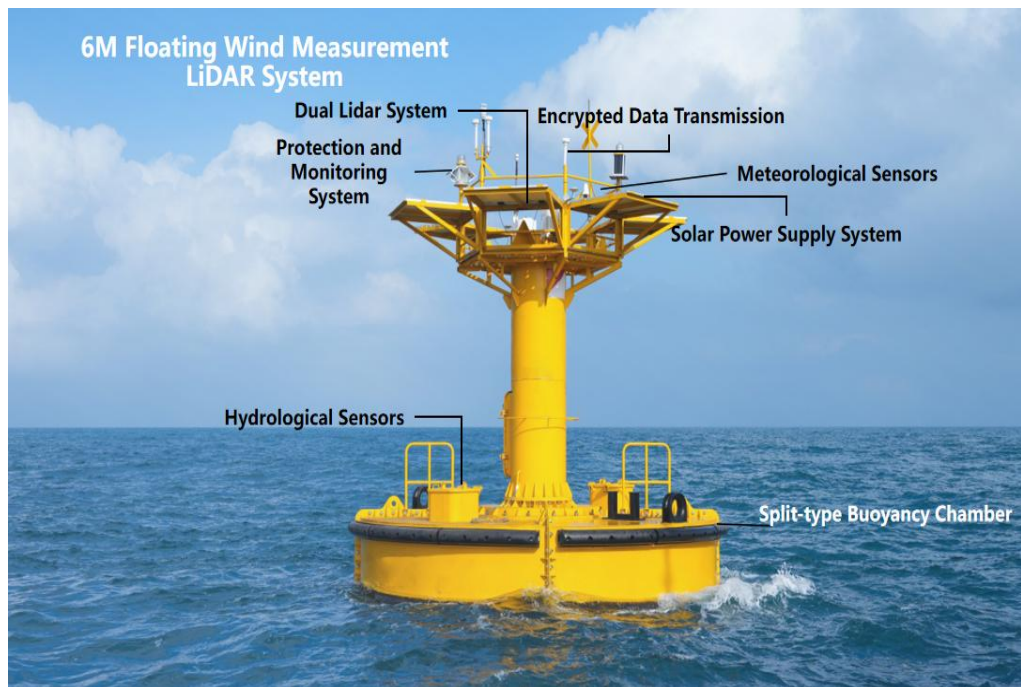
- **Built-in Real-time Attitude Correction** : Supports fixed-site and dynamic environments: vehicle-mounted, and shipborne applications.
- **Flexible Deployment**: Lightweight and easy to operate (total weight < 35 kg), compatible with wind-solar hybrid and fuel cell power systems—ideal for diverse deployment scenarios.
- **Robust Performance**: Designed for continuous and stable operation in challenging inland, coastal, and high-altitude environments.

Item	Parameter
Detection range	30m-3000m
Spatial resolution	15m/30m/60m/150m(Configurable)
Laser wavelength	1550nm, Invisible and eye-safe
Pulse width	100ns~400ns
Temporal resolution	1s ~ 10min (Configurable)
Radial velocity range	-50m/s~+50m/s
Wind speed measurement range	0 ~ 75m/s
Wind speed accuracy	≤0.1m/s
Wind direction measurement range	0 ~ 360°
Wind direction accuracy	≤3°
Scan mode	DBS/VAD

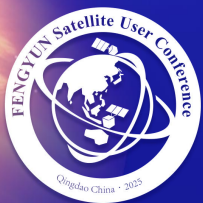


LEICE Lidar Products

Floating Buoy Lidar

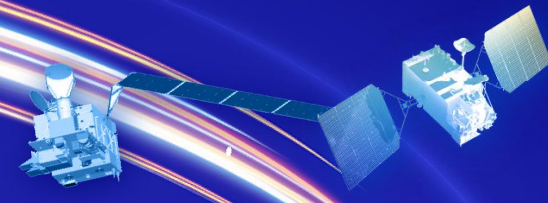


Parameter Item	Specification
Detection altitude range	10m–350m (expandable to 500m)
Altitude resolution	Configurable for any 24 heights within 10–350m range via software; maximum resolution of 1m
Laser wavelength	1550nm, invisible and eye-safe
Data refresh time	1s/1min/2min/5min/10min (software configurable)
Wind speed measurement range	0–75m/s
Wind speed accuracy	≤0.1m/s
Wind direction accuracy	<3° (when average wind speed >2m/s)
Scanning method	Multi-beam scanning/VAD
Weight	<30kg
Dimensions (L×W×H)	580×385×585mm
Average power consumption	<80W



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LEICE Lidar Products

Wind3D Scanning wind lidar



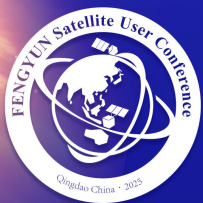
Medium Range 6km
(Maximum range up to 8km)
Wind3D 6000



Long Range 12km
(Maximum range up to 15km)
Wind3D 10K

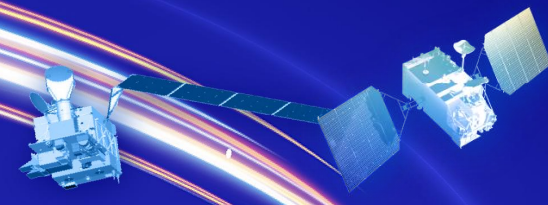
- **Optical pulse coherent Doppler** technology for simultaneous wind and aerosol measurements.
- **Unattended operation**, remote data access and device monitoring.
- **Flexible scan modes**, multi-angle measurement capability.

Items	Parameter
Detection range	45m ~ 6000m / 60m ~ 15000m
Spatial resolution	15m/30m/60m/150m (Configurable)
Laser wavelength	1550nm, Invisible and eye-safe
Pulse width	100ns~400ns
Pulse energy	≥150 / 300μJ
Temporal resolution	1s ~ 10min (Configurable)
Radial velocity range	-50m/s~+50m/s
Wind speed measurement range	0 ~ 75m/s
Wind speed accuracy	≤0.1m/s
Wind direction measurement range	0 ~ 360°
Wind direction accuracy	≤3°
Scan mode	fixed point/DBS/VAD/PPI/RHI/CAPPIScripting
Servo scanning range	Horizontal:0 ~ 360°, Vertical scanning:-90 ~ +270°
Servo accuracy	0.1°
Scanning Speed	55°/s (max)



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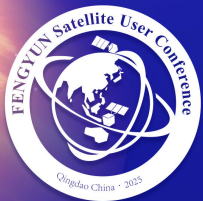
LEICE Lidar Products



Wind3D 30K Scanning wind lidar

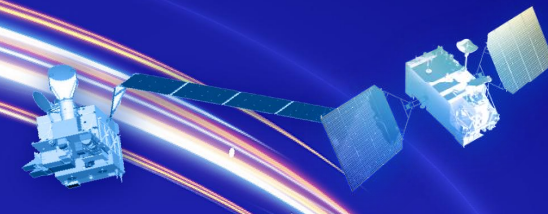
- Low Blind Zone: **30m** low blind zone detection
- Ultra-Long Detection :**Detection capability over 30km**
- Flexible Observation Modes: Supports coordinated measurement with multiple scanning modes
- High Robustness: Sustained and stable operation under harsh environments such as high temperature, high humidity, and extreme cold

Parameter Item	Specification
Radial Detection Range	30m ~ 30,000m
Radial Distance Resolution	User-configurable: 15m / 30m / 60m / 150m
Laser Wavelength	1550nm, invisible and eye-safe
Pulse Energy	$\geq 150\mu\text{J}$
Data Refresh Rate	1Hz ~ 10Hz (software-configurable)
Radial Velocity Range	-50m/s ~ +50m/s
Horizontal Wind Speed Measurement Range	0-75m/s
Wind Direction Range	0° ~ 360°
Horizontal Wind Speed Measurement Error	$\leq 0.1\text{m/s}$
Horizontal Wind Direction Measurement Error	$< 3^\circ$
Scanning Mode	Fixed-point / DBS / VAD / PPI / RHI / CAPPI (script-programmable)
Servo Scanning Range	Azimuth: 0° ~ 360°, Elevation: -40° ~ +190°
Pointing Accuracy	$\geq 0.03^\circ$
Scanning Speed	Up to 90°/s (maximum)



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LEICE Lidar Products Raman Temperature and Humidity Lidar (WATCL 15K)



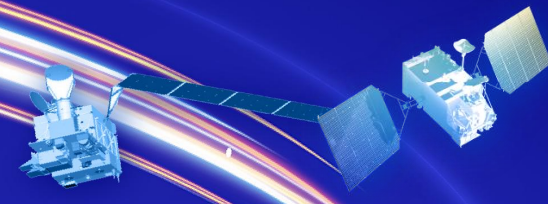
- **Wide application range**
- **High accuracy:** The temperature detection accuracy of this radar can reach less than 1K, and the water vapor mixing ratio detection accuracy can reach less than 5%, which is 0.01g/kg, so it can better monitor the atmosphere.
- **Self-calibration design:**It can automatically correct the depolarization ratio on a regular basis, and provide remote network control and monitoring to realize data uploading and sharing.

Item	Parameter
Detection range	0.2-15km (clear sky)
Spatial resolution	7.5m (user configurable)
Temporal resolution	1s (user configurable)
Laser source	Nd: YAG (355nm/ 532nm)
Detector	Photomultiplier tube PMT
Telescope	Cassegrain
Data output	water vapor mixing ratio, temperature, humidity, aerosol extinction coefficient, backscattering coefficient, lidar ratio, linear particle depolarization ratio, color ratio, wavelength index, cloud height.
Detection sensitivity	temperature is better than 1K, water vapor is better than 0.01g/kg



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LEICE Lidar Products

Tropospheric Direct Detection Doppler Lidar



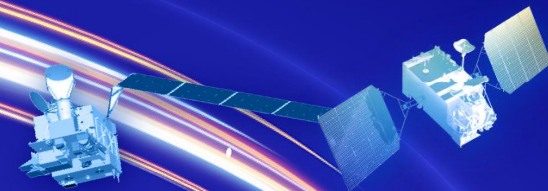
The WindMast Trop 15K Tropospheric Doppler Lidar combines **optical incoherent absorption** with **optical coherent Doppler frequency shift detection**, enabling precise three-dimensional wind field monitoring across the troposphere from **30 m to 15,000 m**. Featuring **boundary layer-troposphere continuous monitoring** and **mobile observation** capabilities.

System parameters		Index
Detection altitude		30m ~ 15000m
High resolution		10m ($\leq 300\text{m}$) ; 30m/60m ($> 300\text{m}$)
Temporal resolution		30s/1min/5min/10min (configurable)
Wind speed and direction measurement range	1. Wind speed	0~100m/s
	2. Wind direction	0° ~ 360°
Wind speed and direction measurement accuracy	1. Wind speed	30m ~ 3000m: $\leq 0.5\text{m/s}$; 3000m ~ 6000m: $\leq 1\text{m/s}$; 6000m ~ 12000m: $\leq 1.5\text{m/s}$
	2. Wind direction	$\leq 10^\circ$
Power supply	1.. Mains power supply	AC 220V ($1\pm 10\%$) , 50Hz ($1\pm 5\%$)
	2. Power consumption	$\leq 4500\text{W}$
Transportability indicators	Dimensions (L× W×H): $\leq 2000\text{mm}\times 2000\text{mm}\times 2200\text{mm}$; Weight: $\leq 1800\text{kg}$	

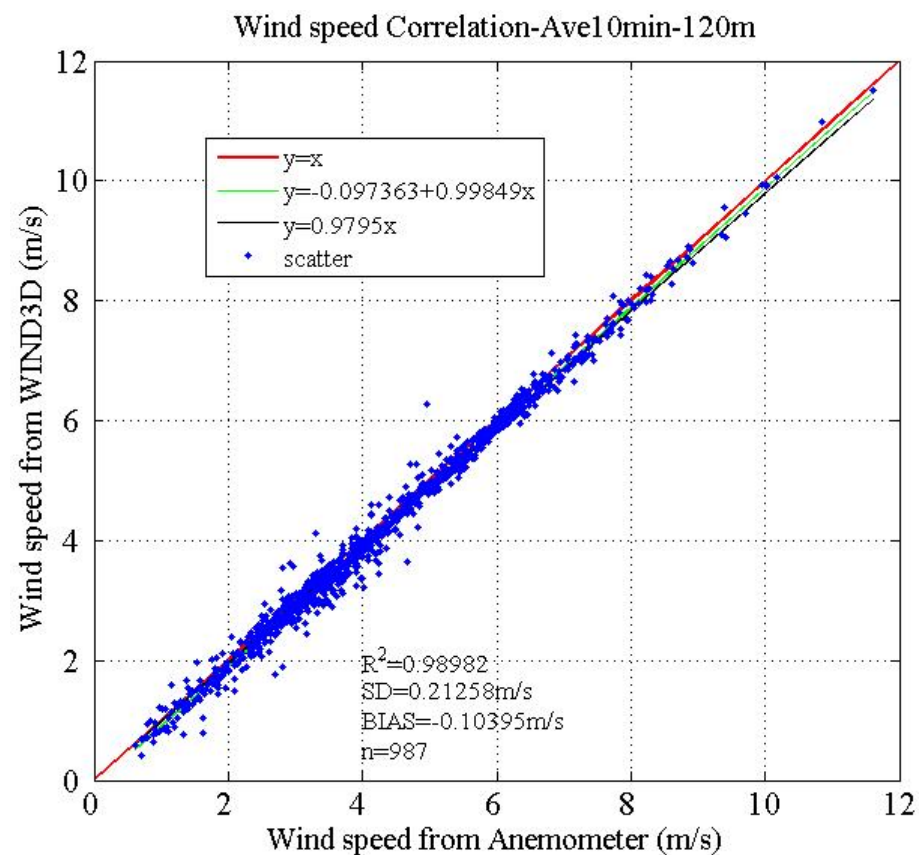


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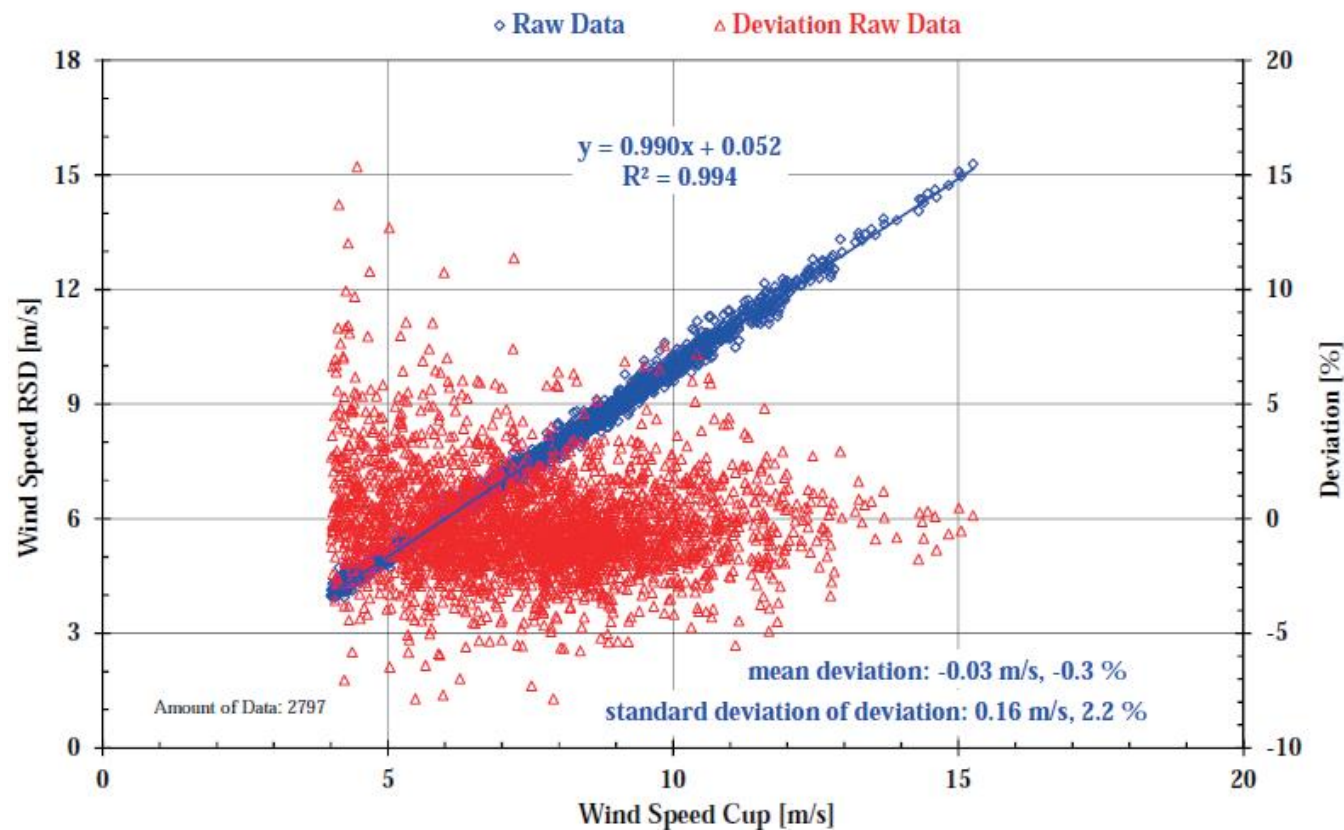
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LEICE Lidar Products : Validation of LEICE Lidar Measurement Data



Intercomparison between Wind3D6000 and wind mast

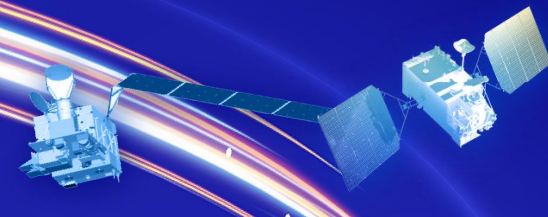


Intercomparison between WindMast PBL and wind mast

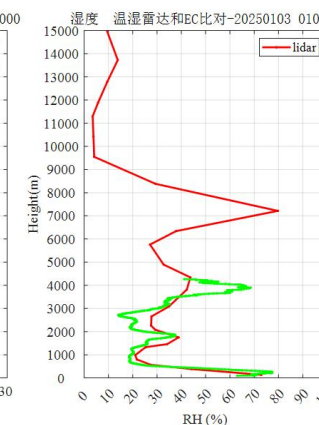
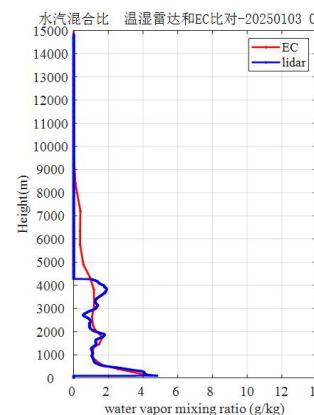
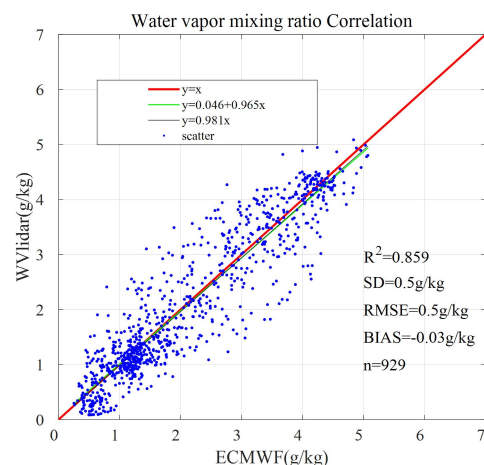
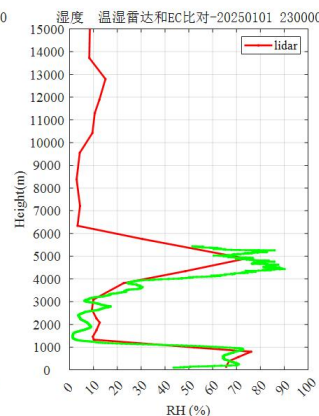
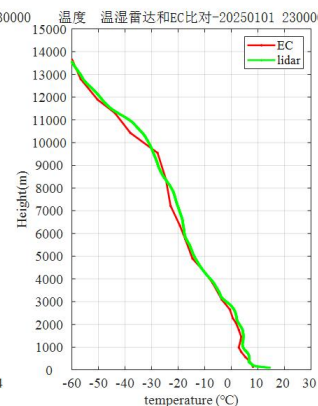
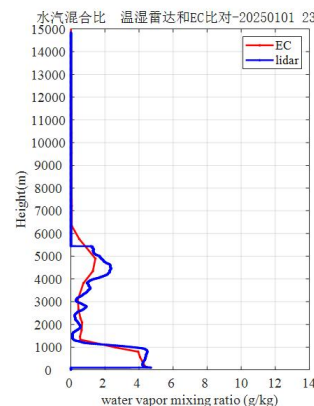
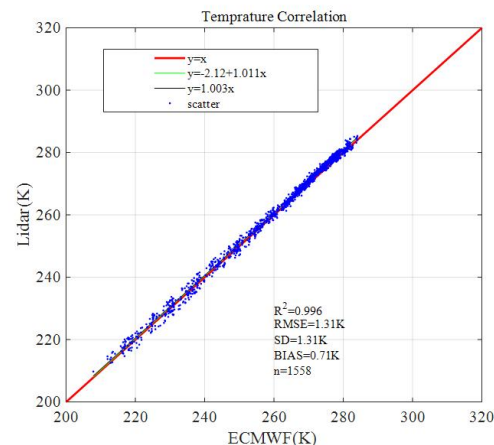


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LEICE Lidar Products : Validation of LEICE Lidar Measurement Data

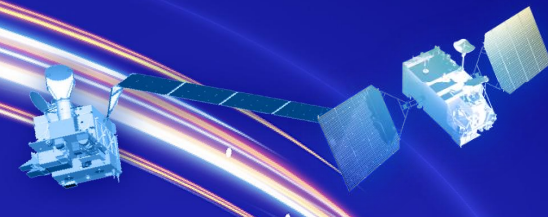


Intercomparison between Raman Temperature and Humidity Lidar and ERA5

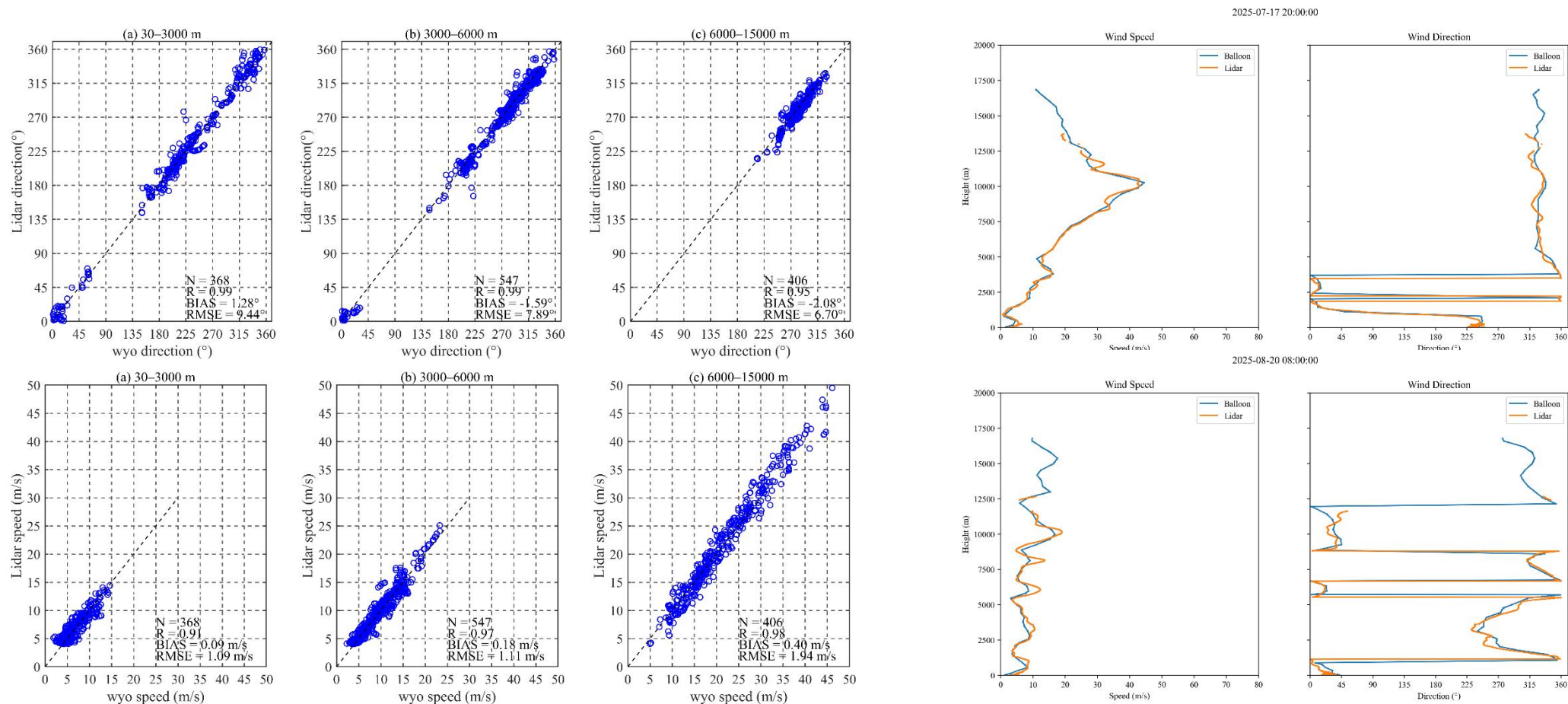


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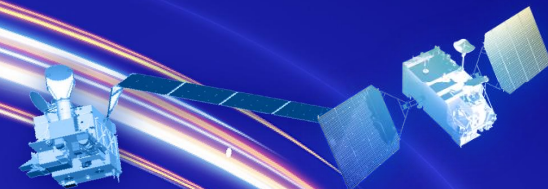
LEICE Lidar Products : Validation of LEICE Lidar Measurement Data





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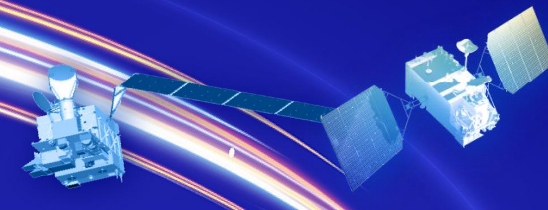
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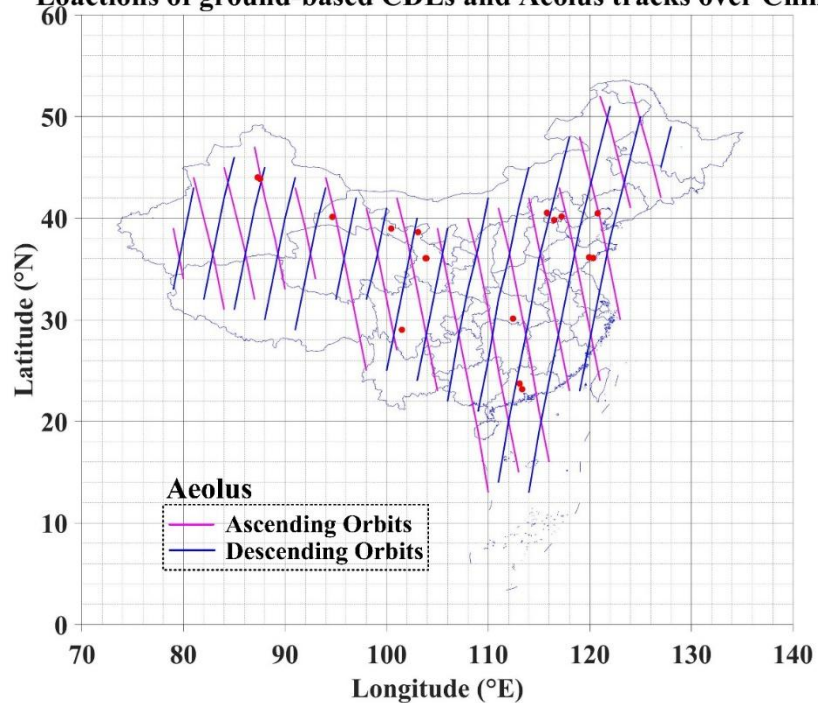


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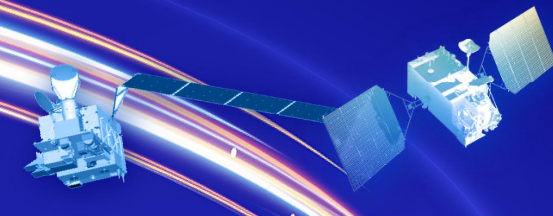


Locations of ground-based CDLs and Aeolus tracks over China

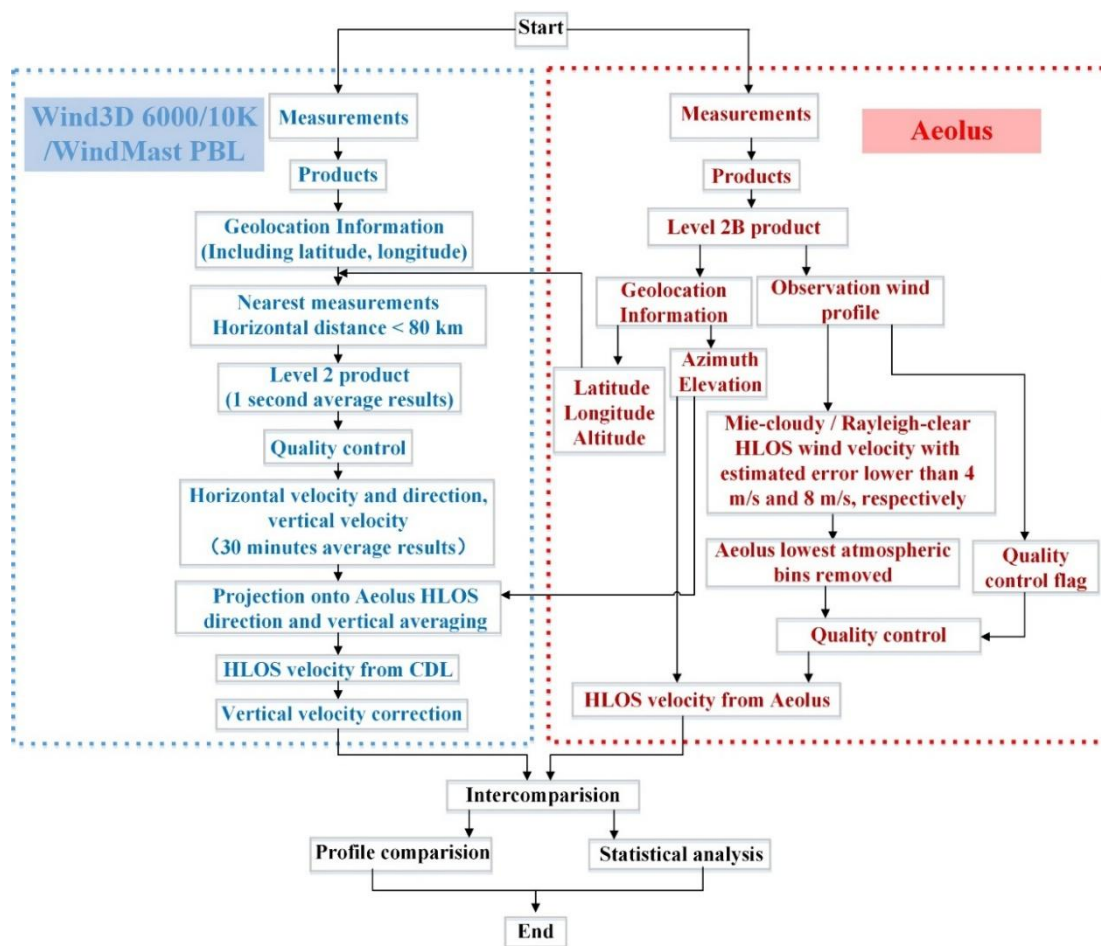


Since January 2020, LEICE ground-based coherent wind-lidar sites participating in the VAL-OUC campaign. The pink and blue lines indicate Aeolus ascending and descending orbits, respectively. Red dots mark the locations of the ground-based lidars.

Validation campaign	Instruments	Location	Latitude/Longitude	Observation period
VAL-OUC	WindMast PBL	Dunhuang	40.12° N, 94.66° E	2020.01.07-2020.12.29
	WindMast PBL	Lanzhou	36.05° N, 103.91° E	2020.01.07-2020.12.29
	WindMast PBL	Zhangye	38.97° N, 100.45° E	2020.01.05-2020.12.27
	Wind3D 6000	Jingzhou	30.11° N, 112.44° E	2020.06.24-2020.07.22
	Wind3D 6000	Pinggu, Beijing	40.15° N, 117.22° E	2020.04.21-2020.06.02
	Wind3D 6000	Changji	44.01° N, 87.30° E	2019.12.24-2020.03.01 2020.12.04-2020.12.23
	Wind3D 6000	Jiulong, Sichuan	29.01° N, 101.50° E	2020.10.24-2020.11.29
	Wind3D 6000	Jiaozhou, Shandong	36.14° N, 119.93° E	2020.12.17-2020.12.31
	Wind3D 6000	Qingyuan, Guangdong	23.71° N, 113.09° E	2020.05.12-2020.08.27
	Wind3D 6000	Xidazhuangke, Beijing	40.52° N, 115.78° E	2020.01.07-2020.05.31
	Wind3D 6000	Yizhuang, Beijing	39.81° N, 116.48° E	2020.04.07-2020.08.25
	Wind3D 6000	Huludao	40.47° N, 120.78° E	2020.11.01-2020.12.28
	Wind3D 6000	Wuwei	38.62° N, 103.09° E	2020.04.11-2020.12.26
	Wind3D 6000	Lanzhou	36.05° N, 103.83° E	2020.01.04-2020.12.26
	Wind3D 6000	Southern University of Science and Technology	23.16° N, 113.34° E	2020.10.13-2020.12.29
	Wind3D 6000	Urumqi	43.85° N, 87.55° E	2020.10.14-2020.12.24
	Wind3D 6000	Qingdao	36.07° N, 120.34° E	2020.11.02-2020.12.28



Ground-Based Validation of Spaceborne Wind Lidar : Strategy (Case: Aeolus)



Data Selection Criteria:

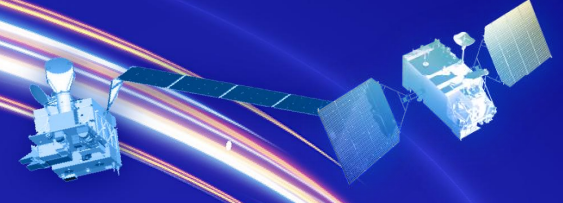
CDL (Coherent Doppler Wind Lidar):

- $\text{SNR} > -10 \text{ dB}$

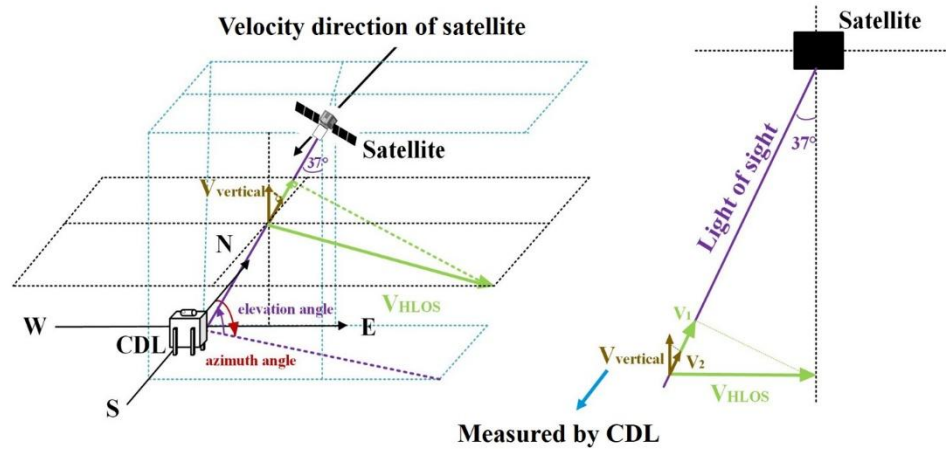
Aeolus:

- “Validity flag” is true
- Level-2B Rayleigh-clear error $< 8 \text{ m/s}$
- Level-2B Mie-cloudy error $< 4 \text{ m/s}$

- Due to contamination from strong surface backscatter, the Aeolus observations in the lowest near-surface range bins are unusable.
- The horizontal distance between the ground-based CDL and the Aeolus ground footprint is $\leq 80 \text{ km}$.
- In principle, the CDL and Aeolus can be considered strictly co-temporal.
- Because the CDL has finer range resolution, its observations were averaged onto the Aeolus range-bin grid for strict one-to-one matching.



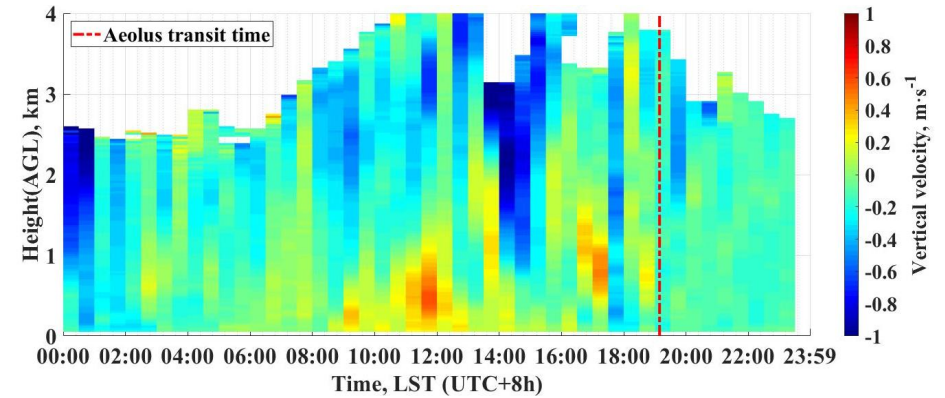
Ground-Based Validation of Spaceborne Wind Lidar: Principle of Vertical-Velocity Correction



Schematic of how vertical velocity affects Aeolus HLOS wind retrievals

As illustrated, when the vertical velocity V_{vertical} is in the same sense as the Aeolus HLOS direction, the relationship between the CDL and Aeolus HLOS winds is:

$$\text{HLOS}_{\text{CDL}} = \text{HLOS}_{\text{Aeolus}} - V_{\text{vertical}} \cot 37^\circ$$



Vertical velocity observed by the ground-based coherent Doppler wind lidar in Zhangye on 10 May 2020

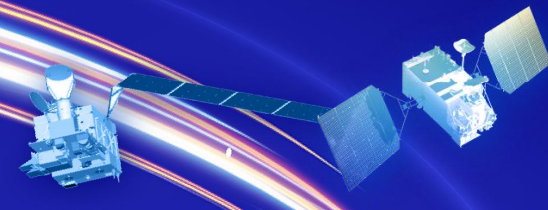
Conversely, when V_{vertical} is opposite in sense to the Aeolus HLOS direction, the relationship becomes:

$$\text{HLOS}_{\text{CDL}} = \text{HLOS}_{\text{Aeolus}} + V_{\text{vertical}} \cot 37^\circ$$



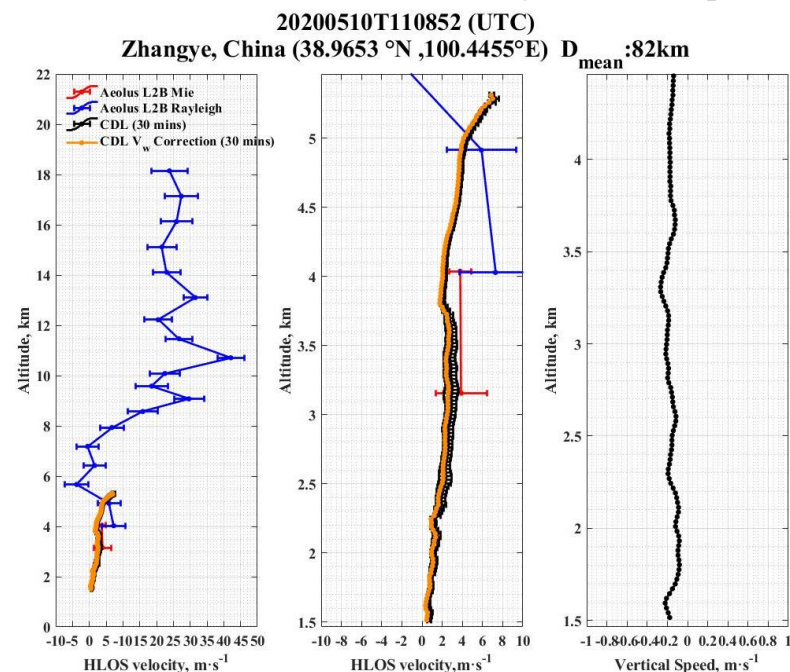
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Ground-Based Validation of Spaceborne Wind Lidar

Results and Discussion: Case-by-Case Comparison



10 May 2020, Zhangye — Co-temporal comparison of horizontal line-of-sight (HLOS) wind profiles from Aeolus and Wind3D 6000.

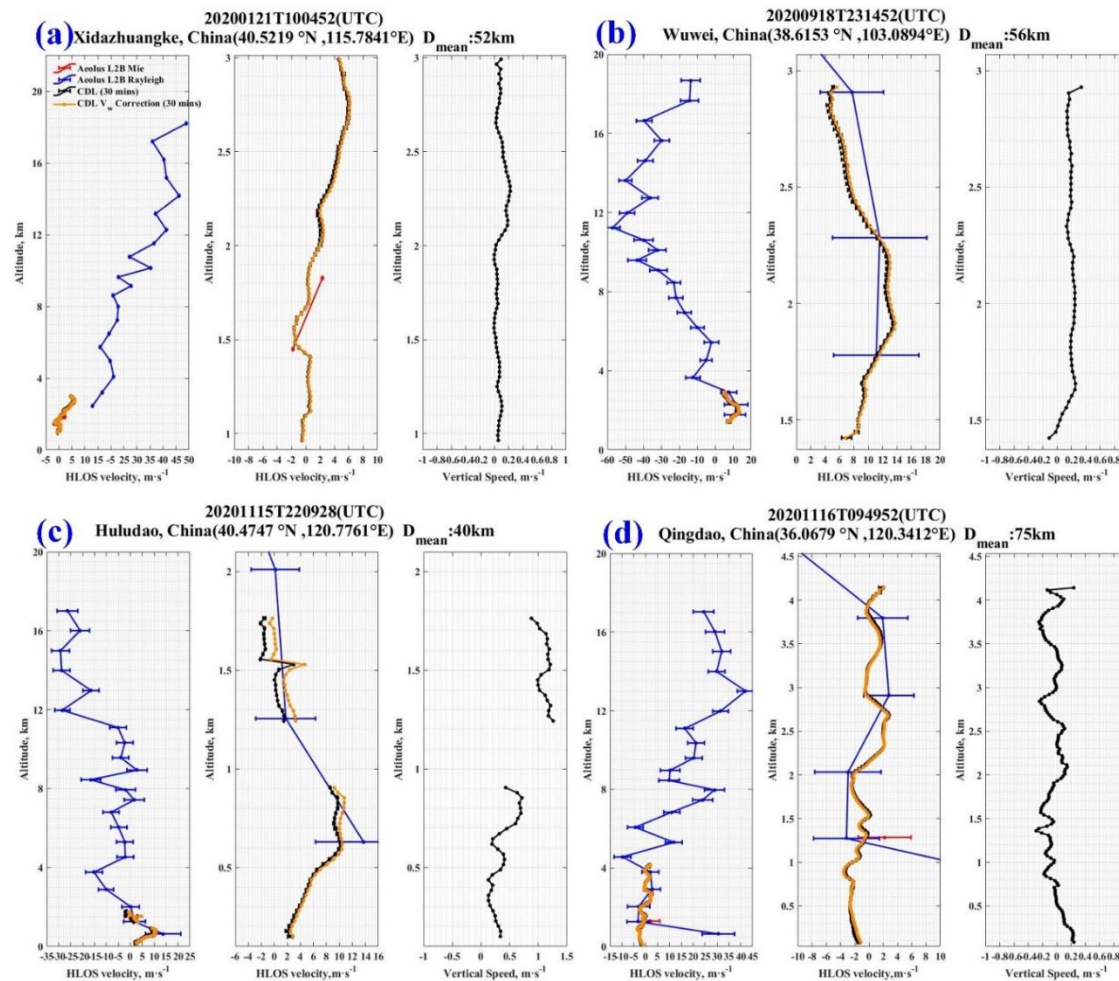
Left panel: overall comparison

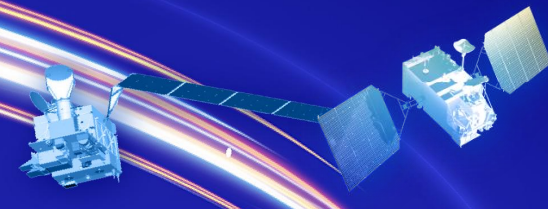
Red: Aeolus L2B Mie-cloudy HLOS wind profile

Blue: Aeolus L2B Rayleigh-clear HLOS wind profile

Black: HLOS wind profile retrieved by the coherent Doppler wind lidar

Yellow: HLOS wind profile from the coherent lidar after vertical-velocity correction

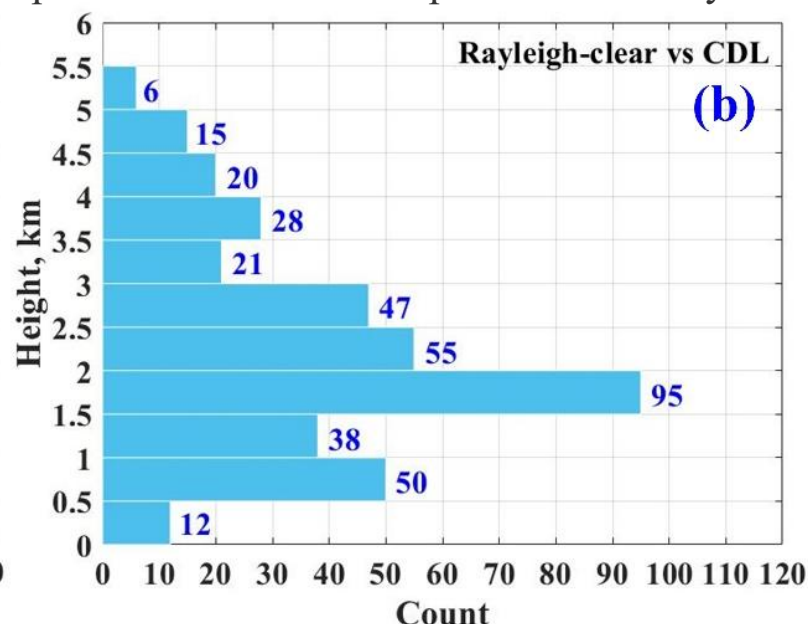
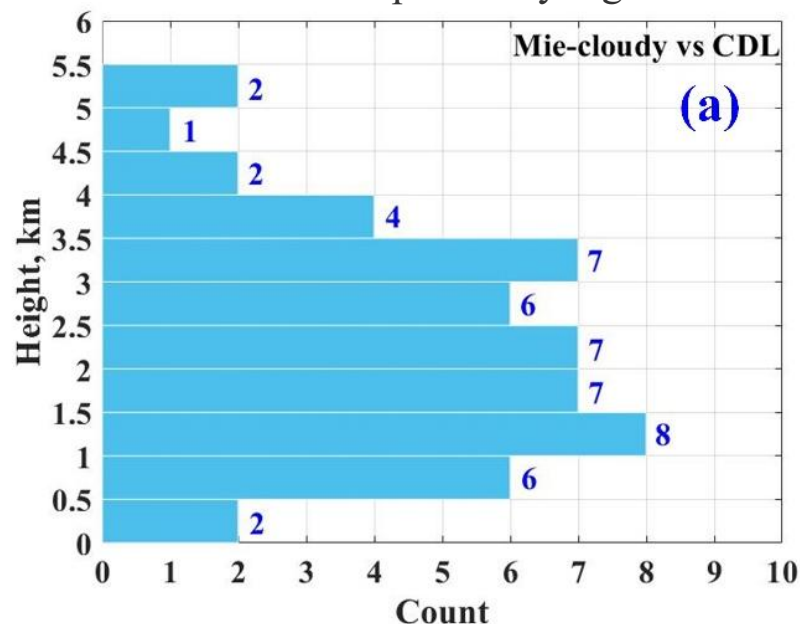




Ground-Based Validation of Spaceborne Wind Lidar: Statistical Comparison

We performed a statistical analysis of all co-located observations from Aeolus and the ground-based coherent Doppler wind lidars deployed under VAL-OUC.

- The VAL-OUC intercomparison covered the entire year of 2020.
- Observations were conducted at 17 sites.
- In total, we obtained 387 co-temporal Rayleigh-clear comparisons and 52 co-temporal Mie-cloudy comparisons.

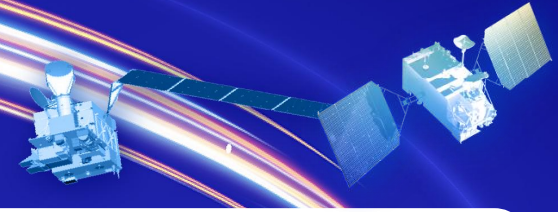


Vertical distribution of comparison data: Aeolus L2B Rayleigh-clear & Mie-cloudy HLOS vs. ground-based CDL radial winds

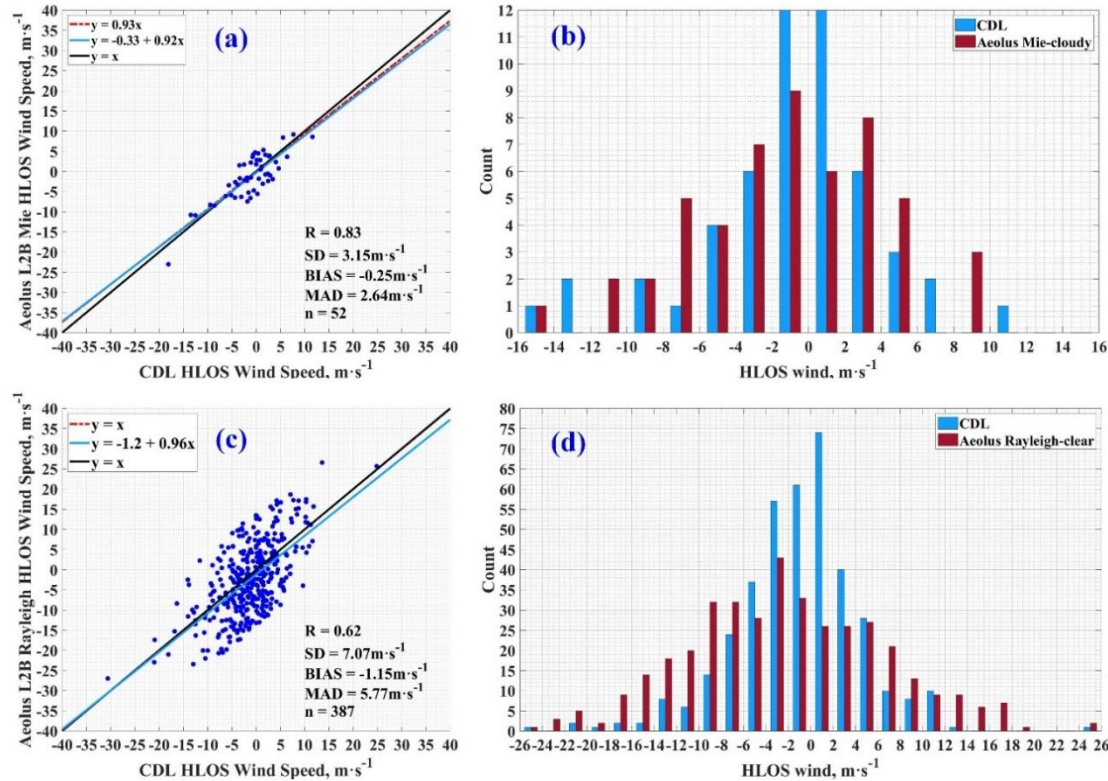


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Ground-Based Validation of Spaceborne Wind Lidar: Statistical Comparison



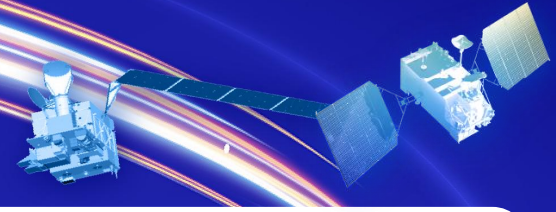
Comparison Results between the CDL and Aeolus

Channel	Mie-cloudy	Rayleigh-clear
Number of comparison pairs	52	387
Correlation coefficient	0.83	0.62
Standard deviation (m/s)	3.15	7.07
Mean absolute error (m/s)	2.64	5.77
Bias (m/s)	-0.25	-1.15
Slope (through-origin fit)	0.93	1.00
Intercept (fit with intercept)	-0.33	-1.20

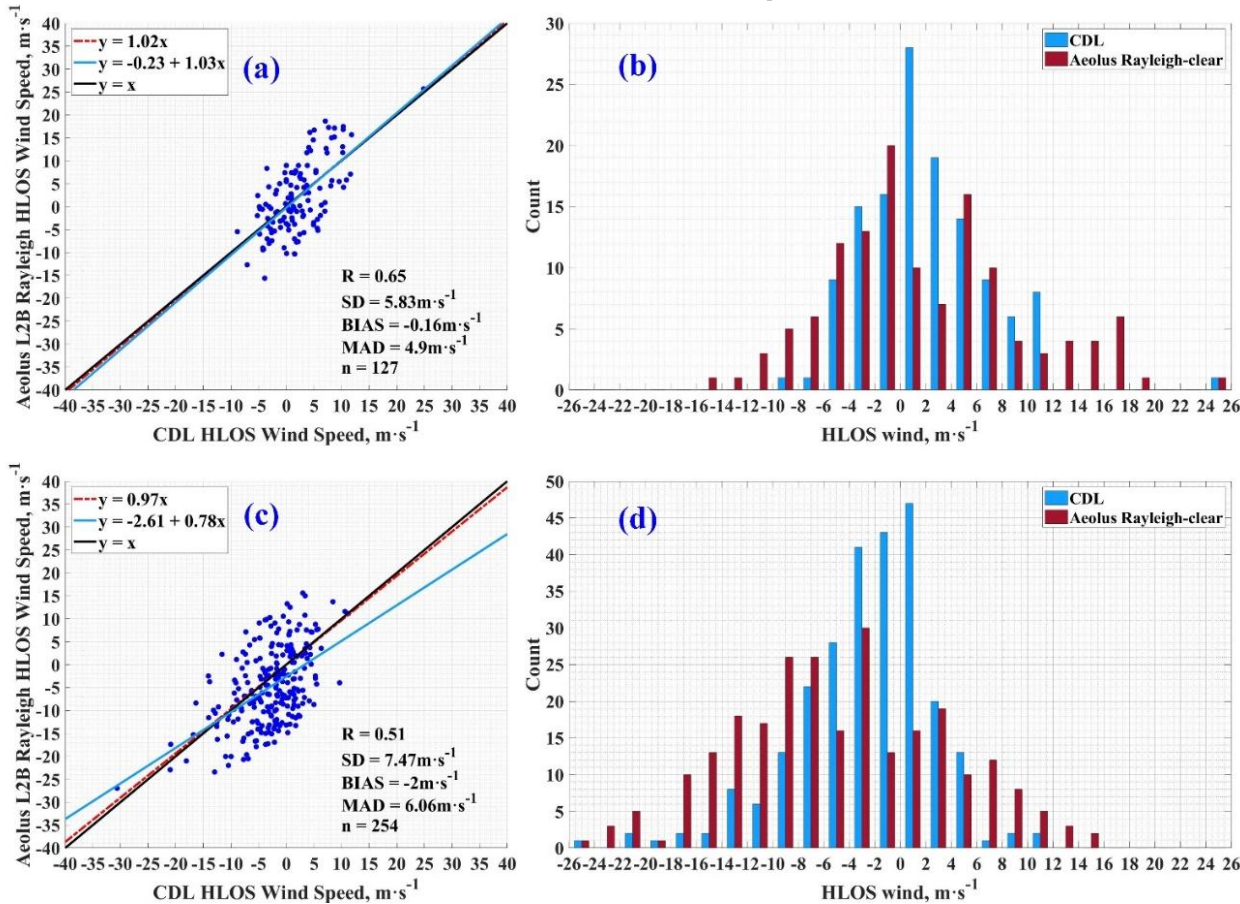
During the comparison processing, if the absolute difference between the Aeolus and CDL measurements exceeded one standard deviation (1σ), both data points were discarded and excluded from the statistics. Consequently,

- 15 (22.39%) Mie-cloudy
 - 94 (19.54%) Rayleigh-clear
- comparison pairs were removed.

- Comparison between Aeolus L2B HLOS winds (Rayleigh-clear / Mie-cloudy) and the CDL.
- In panels (a) and (c), the red dashed line denotes the through-origin (zero-intercept) fit, the blue line denotes the linear fit with intercept, and the black line is the reference line $y = x$.
- Panels (b) and (d) show histograms of HLOS wind-speed counts: blue bars for CDL HLOS counts and red bars for Aeolus HLOS counts.



Ground-Based Validation of Spaceborne Wind Lidar: Statistical Comparison



Comparison Results: CDL vs. Aeolus

ascending/descending orbits	ascending-orbit	descending-orbit
Number of comparison pairs	127	254
Correlation coefficient	0.65	0.51
Standard deviation (m/s)	5.83	7.47
Mean absolute error (m/s)	4.90	6.06
Bias (m/s)	-0.16	-2.00
Slope (through-origin fit)	1.02	0.97
Intercept (fit with intercept)	-0.23	-2.61

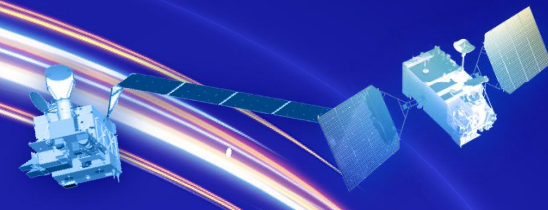
The ascending-orbit data show slightly better performance than the descending-orbit data in terms of relative error, mean absolute error (MAE), and bias.

Intercomparison of Aeolus Rayleigh-clear HLOS winds with ground-based coherent Doppler wind lidar, stratified by ascending/descending orbits

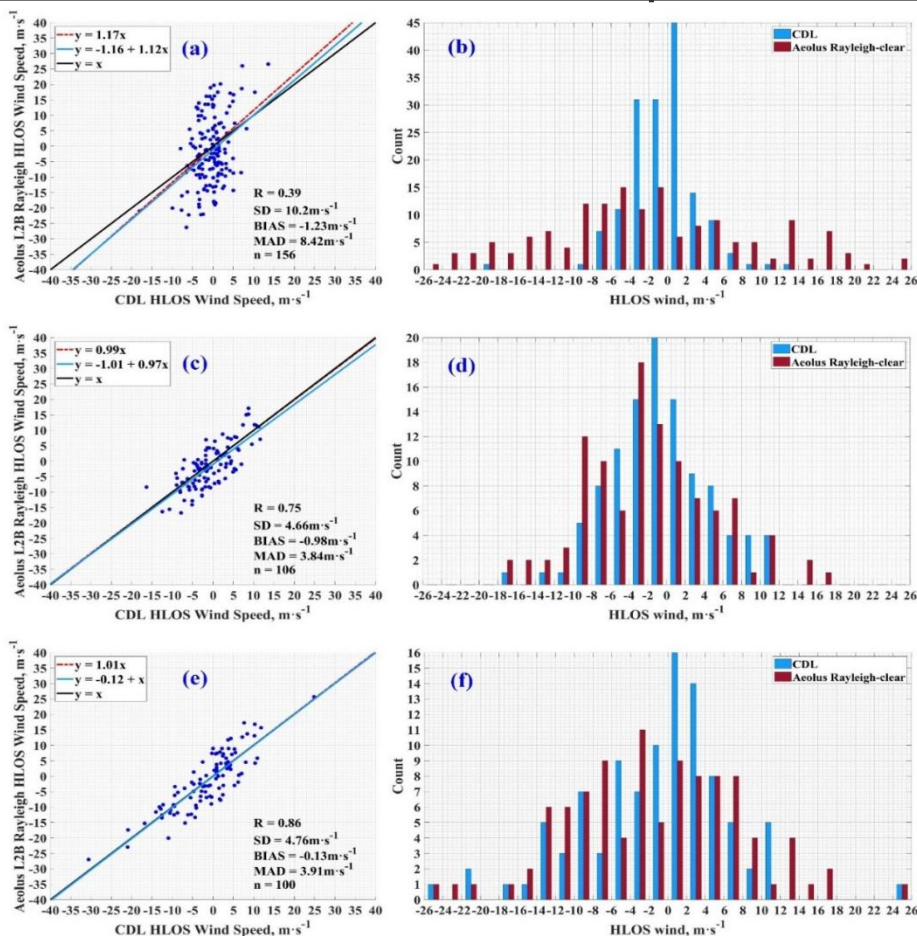


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Ground-Based Validation of Spaceborne Wind Lidar: Statistical Comparison



Intercomparison of Aeolus L2B HLOS wind speeds with coherent Doppler wind lidar across processing baselines

Comparison Results: CDL vs. Aeolus

Processing baseline	07 and 08	09 and 10	11
Number of comparison pairs	156	106	100
Correlation coefficient	0.39	0.75	0.86
Standard deviation (m/s)	10.20	4.66	4.76
Mean absolute error (m/s)	8.42	3.84	3.91
Bias (m/s)	-1.23	-0.98	-0.13
Slope (through-origin fit)	1.17	0.99	1.01
Intercept (fit with intercept)	-1.16	-1.01	-0.12

Baseline 07 & 08: January–April 2020

Baseline 09 & 10: May–September 2020

Baseline 11: October 2020 onward

Thanks to the [M1 mirror temperature-bias correction](#), a redesigned

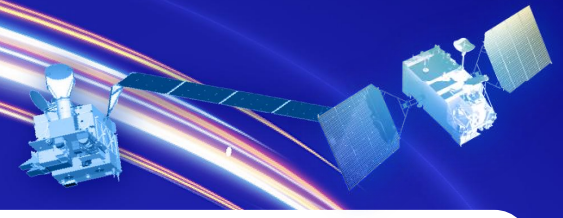
[SNR threshold](#), and [the work of the global cal/val team](#), Baselines 09/10/11

show [marked improvements](#) in correlation, standard error, and bias compared with Baselines 07/08.



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Summary

- ◆ After rigorous quality control and screening, **387 Rayleigh-clear** and **52 Mie-cloudy** co-located comparison pairs were obtained.
- ◆ Based on these co-located observations, **Aeolus Level-2B HLOS winds** (Rayleigh-clear and Mie-cloudy) were validated against CDL measurements.

For **Mie-cloudy** data (52 profiles), the **correlation coefficient**, **standard deviation**, **mean absolute deviation**, and **bias** were **0.83**, **3.15 m s^{-1}** , **2.64 m s^{-1}** , and **-0.25 m s^{-1}** , respectively. The **through-origin slope** was **0.93**, while the **fitted slope and intercept** were **0.92** and **-0.33 m s^{-1}** , respectively.

For **Rayleigh-clear** data (387 profiles), the corresponding values were **0.62**, **7.07 m s^{-1}** , **5.77 m s^{-1}** , and **-1.15 m s^{-1}** , with a through-origin slope of **1.00** and a fitted slope and intercept of **0.96** and **-1.20 m s^{-1}** .

Comparisons between **ascending and descending orbits** showed that ascending-track observations generally agreed slightly better with CDL winds.

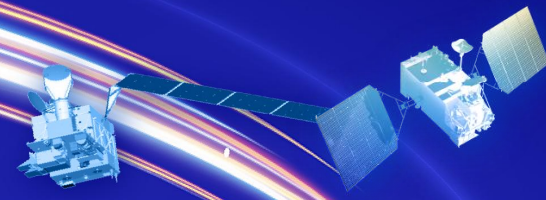
Furthermore, cross-validation of **Baselines 07/08, 09/10, and 11** indicated that the **consistency within the planetary boundary layer** was relatively poor for Baselines 07/08, whereas Baselines 09/10/11 exhibited **marked improvements**—benefiting from the **M1-mirror temperature-bias correction**, a **redesigned SNR threshold**, and **the efforts of the global calibration/validation team**.

- ◆ Remaining discrepancies may arise from **Mie-signal contamination in the Rayleigh channel**, the **horizontal separation** between the CDL site and Aeolus footprint, or **small-scale atmospheric dynamics** not resolved by the satellite.



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Summary

Leice Transient: Pioneer of LiDAR Remote Sensing



Vision

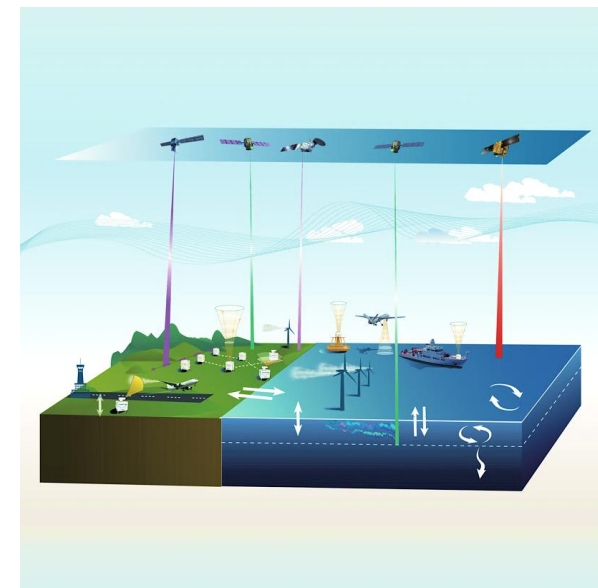
Laser Remote Sensing to empower **green, safe, and high-quality development.**

Mission

To be the Leader of "**Ground-Ocean-Air-Space**" Remote Sensing LiDAR Technology.

Built on **30+ years of laser remote sensing expertise** from Ocean University of China, Leice Transient is transforming cutting-edge scientific research into industrial-leading LiDAR solutions to power the future of earth remote sensing.

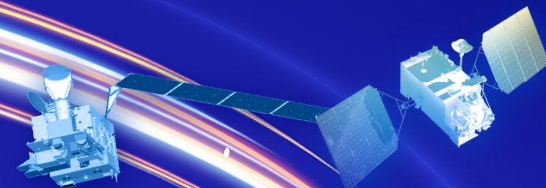
Our **200+** specialists in physics, engineering, data science and meteorology deliver world-class expertise in **LiDAR products, AI modeling, algorithm development, and complex data processing** — earning us a leading market share domestically and the trust from clients worldwide.





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THANKS

