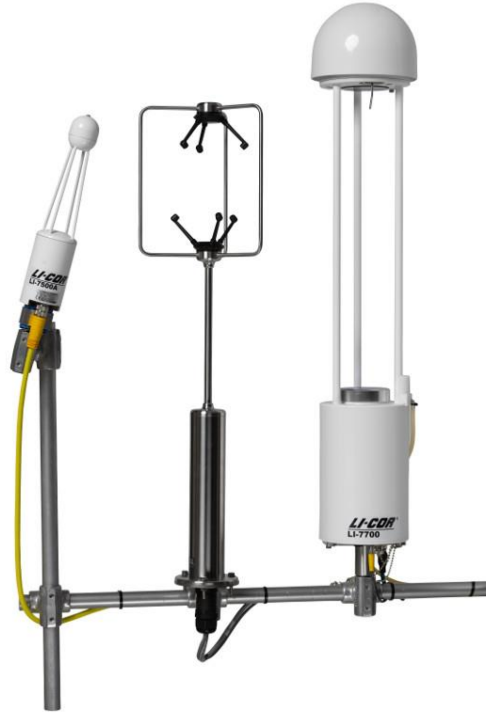

EC **Instrument Theory Overview**

Liukang Xu

Topics

- Basic concepts
  - Accuracy (精度）and precision (RMS， 分辨率)
- Theory of operation for EC instruments
  - Sonic anemometer （超声风速仪）
  - CO_2/H_2O analyzer (CO2/H2O 分析仪， LI-7500A, RS, DS, LI-7200A)

涡度协方差的基本公式

$$F = \overline{\rho_a}\,\overline{w's'}$$

$$\frac{g\ dry\ air}{m^3} \times \frac{m}{s} \times \frac{g\ CO_2}{g\ dry\ air} = \frac{g\ CO_2}{m^2 s}$$

Anemometer

NDIR Analyzer

Laser Analyzer

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对 仪 器 的 要 求

- Accurate & precise
- Fast (at least 10 Hz)
- Aerodynamic design of instruments and structure
- For long-term measurements in remote areas

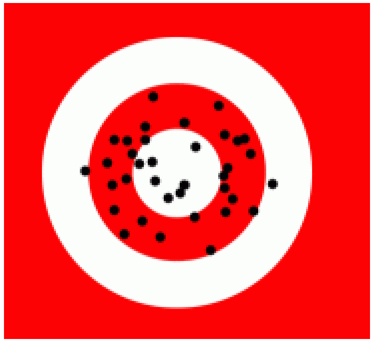
  robust to environmental challenges

  low power consumption

Accuracy （精度）& Precision （分辨率）

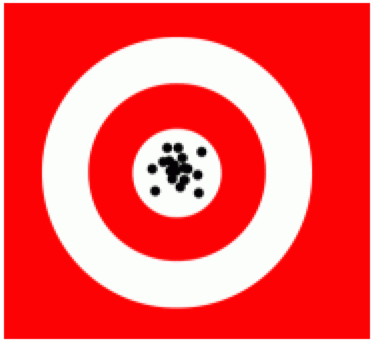
Accurate, No
Precise, No

Accurate, Yes
Precise, No



Accurate, No
Precise, Yes

Accurate, Yes
Precise, Yes



Accuracy， 精度

$$Accuracy = \left|\frac{CO_{2\_measured} - CO_{2\_True}}{CO_{2\_Ture}}\right| \times 100\%$$

RMS: Root Mean Square， 均方根

Time series data, $x_1\ x_2\ x_3\ x_4 \cdots\cdots\cdots, x_n$

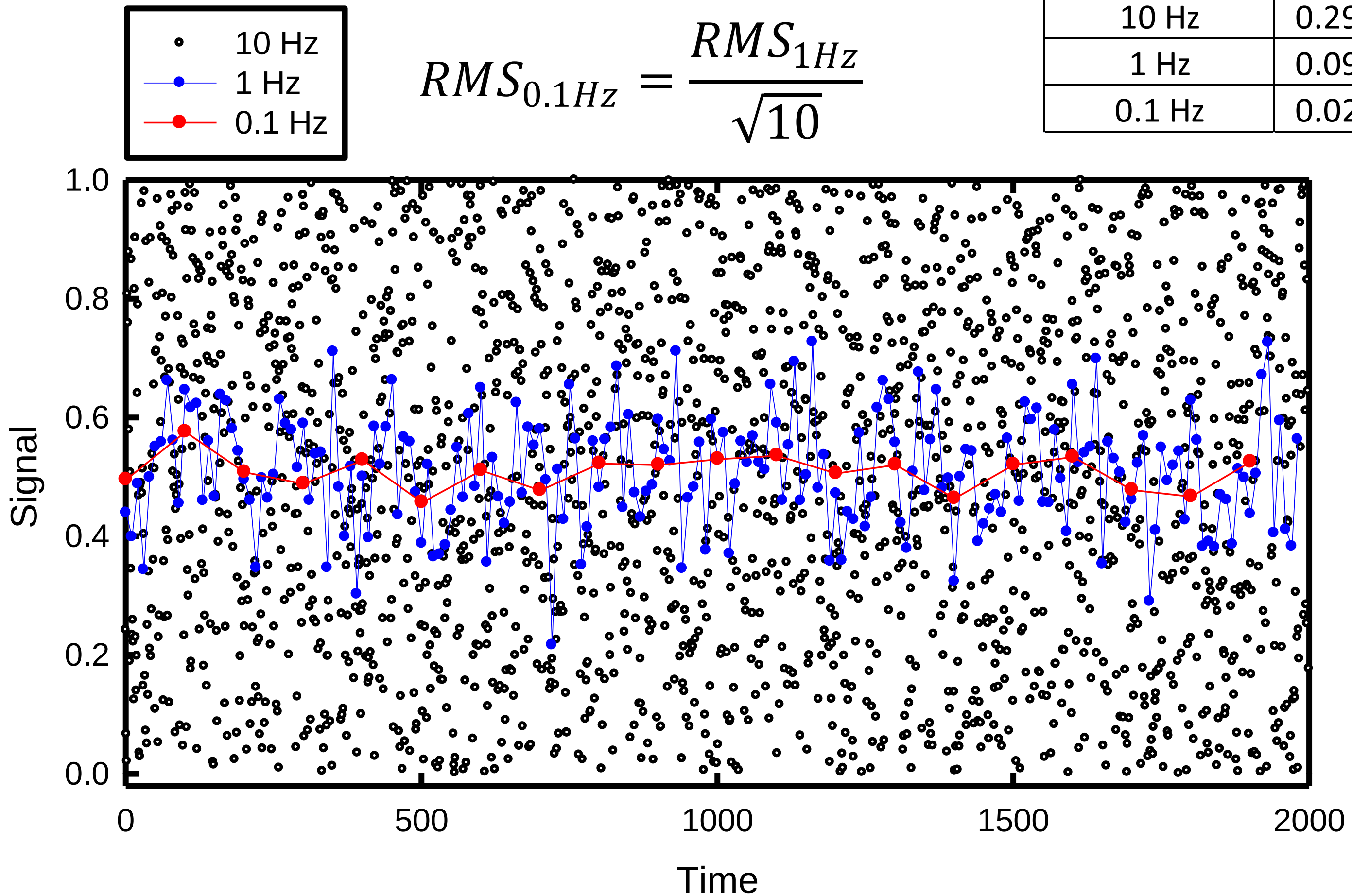
$$RMS = \sqrt{\frac{1}{n}\sum_{i=1}^{i=n}(x_i - \bar{x})^2}$$

Precision (RMS) vs. averaging time

$$RMS_{10Hz} = RMS_{1Hz} \times \sqrt{10}$$

$$RMS_{0.1Hz} = \frac{RMS_{1Hz}}{\sqrt{10}}$$

Sampling rate	RMS
10 Hz	0.293
1 Hz	0.094
0.1 Hz	0.029



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Specification for LI-840A, LI-850

CO_2
Measurement range: 0-20,000 ppm
Accuracy: Better than 1% of reading
RMS noise at 370 ppm with 1-Hz sampling rate: <1 ppm

H_2O
Measurement range: 0-80 (mmol mol^{-1}, ppt)
Accuracy: Better than 1.5% of reading
RMS noise at 10 ppt with 1-Hz sampling rate: <0.01 ppt

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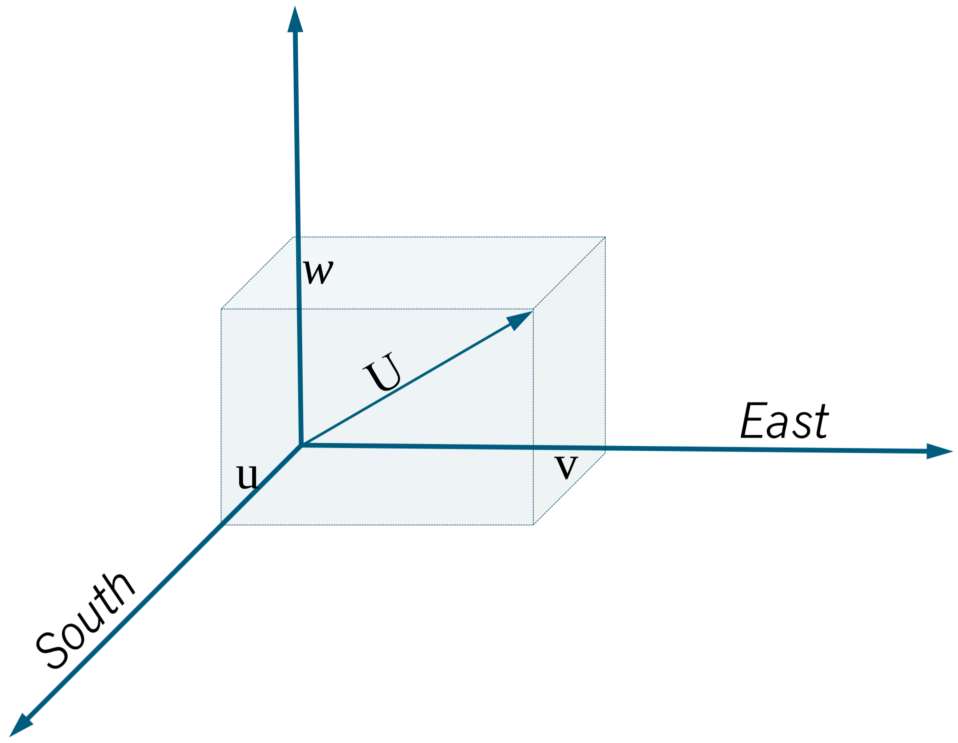
Specification for LI-7500RS

	CO_2	H_2O
Calibration Range	0-3000 ppm	0-60 mmol/mol
Accuracy	Within 1% of reading (nominal)	Within 1% of reading (nominal)
Zero drift (per °C)	±0.1 ppm typical ±0.3 ppm max.	±0.03 mmol/mol typical ±0.05 mmol/mol max.
RMS Noise: 5 Hz @370 ppm CO_2: 10 Hz and 10 mmol m^{-1} H_2O: 20 Hz	0.08 ppm 0.11 ppm 0.16 ppm	0.0034 mmol/mol 0.0047 mmol/mol 0.0067 mmol/mol
Gain drift (% of reading per °C)	±0.02% typical ±0.1% max. @370 ppmv	±0.15% typical ±0.30% max. @20 mmol/mol
Direct sensitivity to H_2O (mol CO_2/mol H_2O)	±2.00E-05 typical ±4.00E-05 max.	- -
Direct sensitivity to CO_2 (mol H_2O/mol CO_2)	- -	±0.02 typical ±0.05 max.

超声风速仪测量原理



超声风速仪

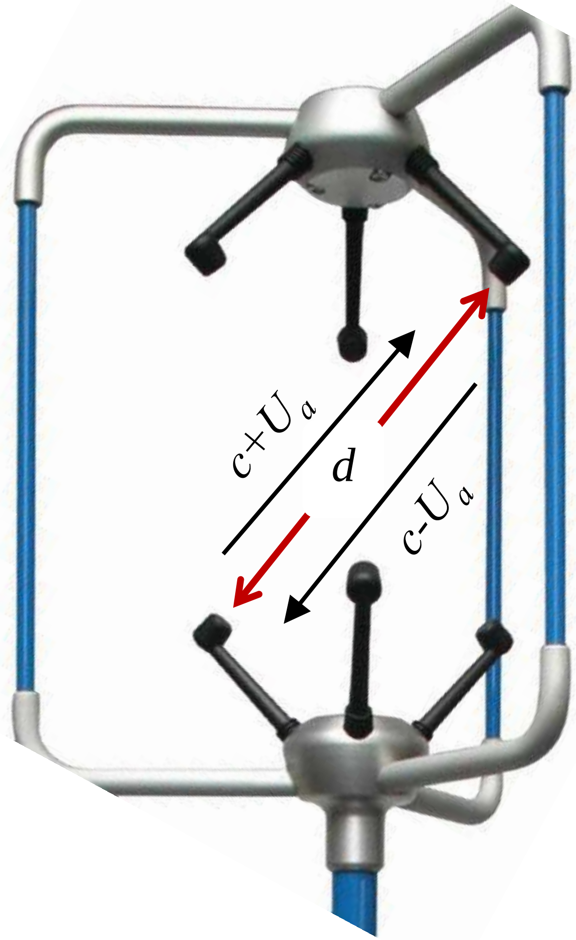
$$t_o = \frac{d}{c + U_a}$$

$$t_b = \frac{d}{c - U_a}$$

$$U_a = \frac{d}{2}[\frac{1}{t_o} - \frac{1}{t_b}]$$

$$\begin{bmatrix} U_x \\ U_y \\ U_z \end{bmatrix} = A \begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix}$$

A is a 3x3 coordinate transformation matrix



超声风速仪

$$c = \frac{d}{2}\left[\frac{1}{t_o} + \frac{1}{t_b}\right]$$

$$c^2 = \gamma_d R_d T_s$$

γ_d: the ratio of specific heat of moist air at constant pressure to that at constant volume.

R_d is the gas constant for dry air

T_s: the sonic temperature

$$T_s = \frac{c^2}{\gamma_d R_d} - 273.15$$

Virtual temperature, 虚温， $T_v(K)$

the temperature that dry air would have if its pressure and density were equal to those of a sample of moisture air.

$$T_v = T(K) \times (1+0.61q)$$

q: Specific humidity: g H_2O per g moist air

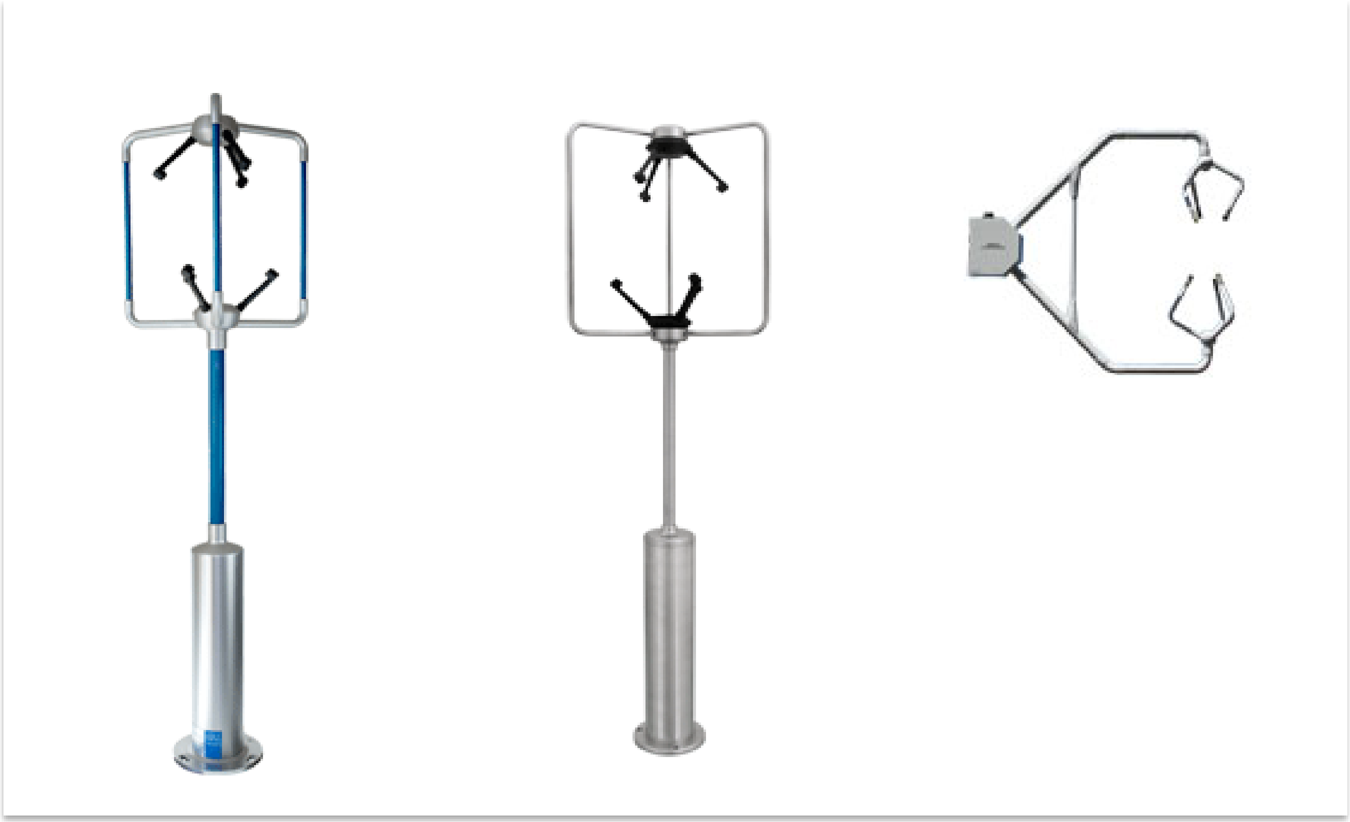
Sonic temperature, 超声温度， $T_s(K)$

$$T_s = T(K) \times (1+0.51q)$$

Air temperature, 空气温度， T

Sonic anemometers

WindMaster	WindMaster Pro	CSAT3



CO_2/H_2O 气体分析仪

$[CO_2] \sim \alpha \sim f(e, L, c)$

Where: **α:** absorbance

e: molar absorbtivity of CO_2

L: optical pathlength

c: density of CO_2

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开路 CO_2/H_2O 分析仪的工作原理

0.1 m pathlength

1 atm pressure

25°C

400 ppm CO_2

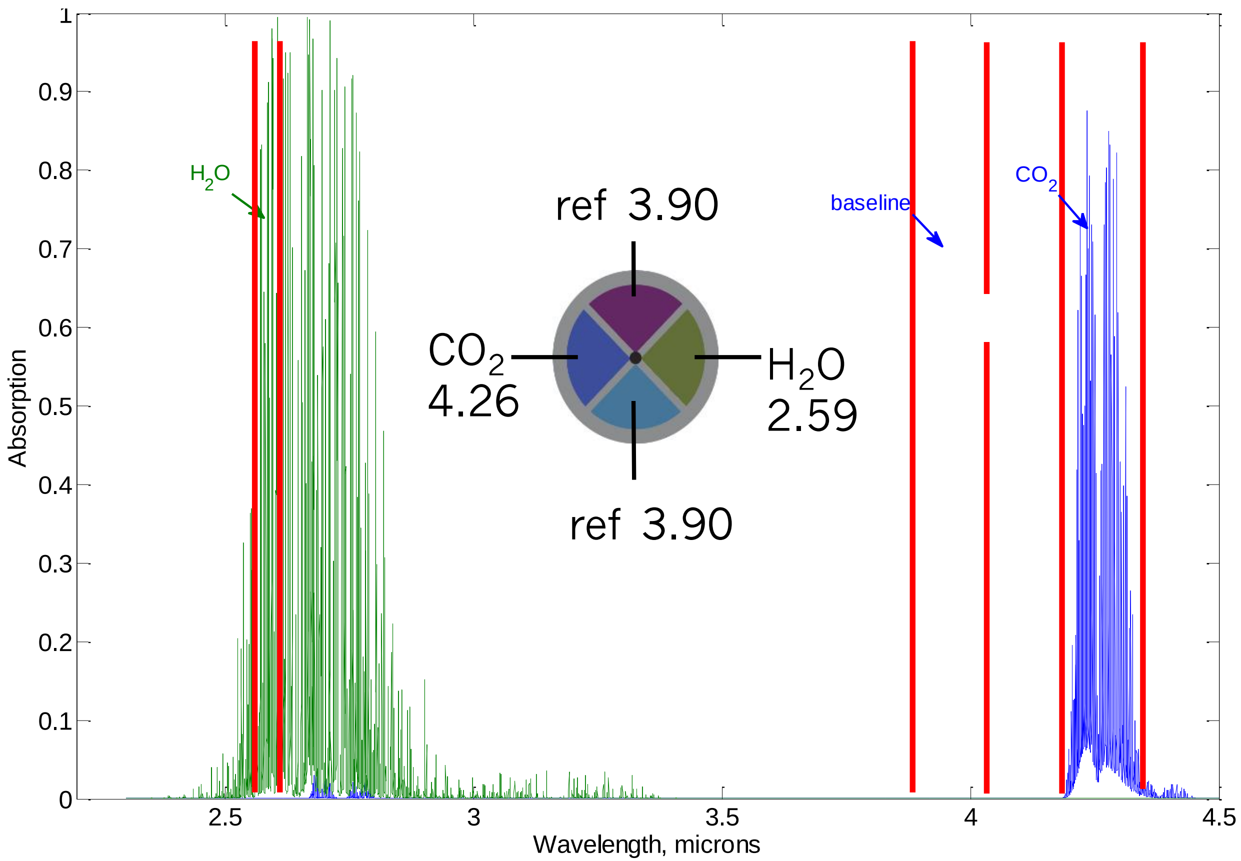
Absorption $\frac{(I_o - I)}{I_o} \approx 0.10$

开路 CO_2/H_2O 分析仪的工作原理

$$Density = f\left(\frac{I_o - I}{I_o}\right)$$

Dirt or dust will block light, how do we deal with this issue?

开路气体分析仪



$$\alpha_i = (1 - \frac{A_i}{A_{io}})$$

A_i is power received in absorbing wavelength for CO_2

A_{io} is power received in non-absorbing wavelength

Advantages of open-path CO_2/H_2O analyzer

Low power consumption (~4-8 W) for the analyzer. The whole flux site can be operated with solar panels. Designed for remote field sites where AC is not available.

Professor Baldocchi's Vaira site in California. Courtesy of Youngryel Ryu at UC Berkeley

Other advantages of open-path configuration

- High Speed: up to 40 Hz
- High Precision: RMS noise of 0.11 ppm CO_2, 0.0047 ppt H_2O at 10 Hz sampling rate
- No pump needed, easy to setup
- Absence of tubing eliminates delays, no tubing attenuation for CO_2 and H_2O
- Excellent stability, suitable for harsh environments
- Easy to do maintenance

Limitations of open-path analyzer

If there is any obstruction to the infrared beam in the optical path, the analyzer will not properly operational. So during rain, snow, fog weather conditions, the data will be invalid.

Therefore, if a study site has high precipitation or frequent foggy weather, a closed-path analyzer is preferred.

The enclosed-path alternative

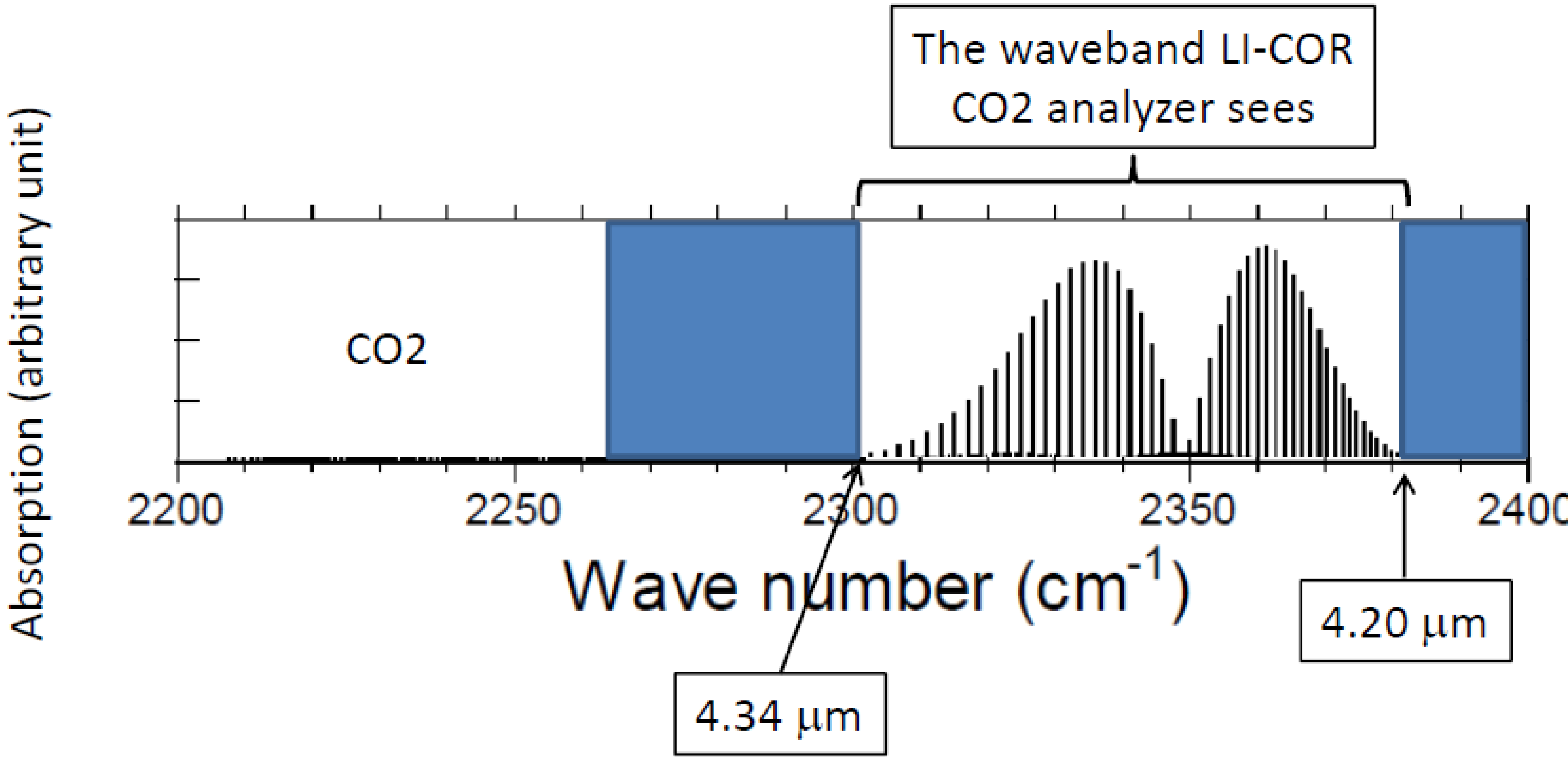
Advantages of LI-7200A

- Weatherized closed path configuration
- Lower power consumption than typical closed path analyzer
- Fewer data loss due to rain, ice, condensation

Disadvantage of LI-7200A

- But need more maintenance

Main difference between NDIR-based analyzers and laser-based analyzer



Summary

Accuracy, precision

Theory of operation

- Sonic anemometer
- CO_2/H_2O gas analyzer (LI-7500A, RS, DS, 7200A,RS)

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Thank you　！