Evaluation of Atmospheric Pressure on the Temperature Measurement Method by Three-Wavelength CO_2 DIAL

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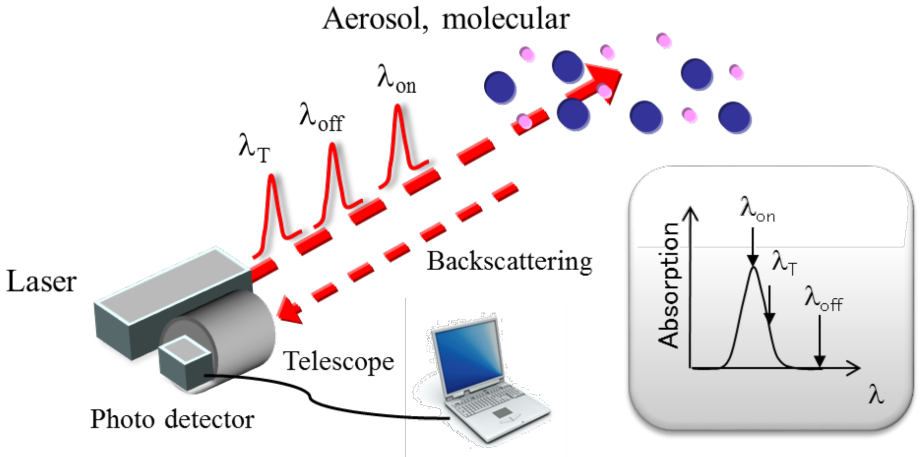
We have developed a new differential absorption lidar (DIAL) system with the three-wavelength to measure temperature profiles in the lower troposphere using a CO_2 absorption spectrum at 1.57 μm.

The CO_2 absorption coefficient depends on wavelength, temperature, pressure, and CO_2 density in the atmosphere. We consist of two DIALs using three wavelengths. Therefore, assuming the atmospheric pressure profile, the temperature that matches CO_2 densities obtained from both DIALs is numerically analyzed.

The discrepancy between the assumed atmospheric pressure and the actual atmospheric pressure is one of the error sources for the atmospheric temperature measurement.

We estimate the atmospheric temperature error caused by the estimated atmospheric pressure over our lidar site.



Characteristics of the three-wavelength CO_2-DIAL system

DIAL equations

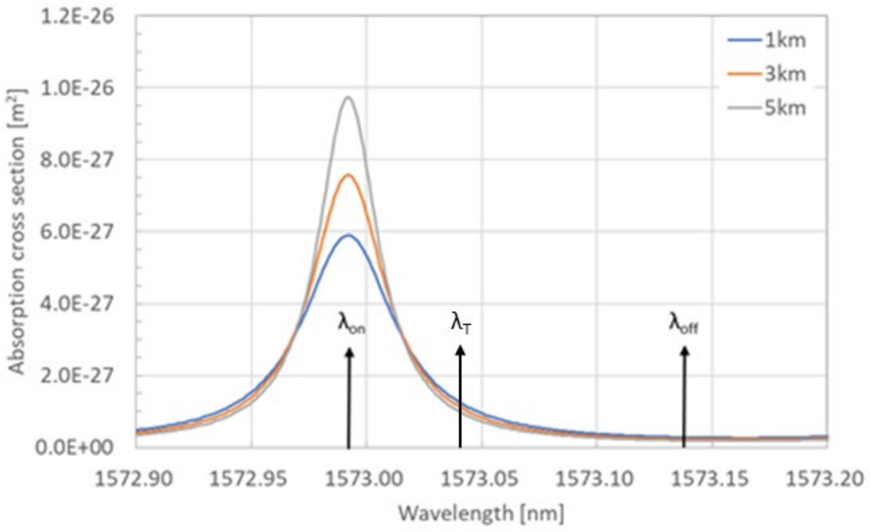
$$\lambda_{on}, \lambda_{off} : \quad N_{CO2}(r) = \frac{1}{2\Delta\sigma_{on}(r)\Delta r} \ln\left[\frac{S(r+\Delta r, \lambda_{off})}{S(r, \lambda_{off})} \frac{S(r, \lambda_{on})}{S(r+\Delta r, \lambda_{on})}\right]$$

$$\lambda_{on}, \lambda_{T} : \quad N_{CO2}(r) = \frac{1}{2\Delta\sigma_{T}(r)\Delta r} \ln\left[\frac{S(r+\Delta r, \lambda_{T})}{S(r, \lambda_{T})} \frac{S(r, \lambda_{on})}{S(r+\Delta r, \lambda_{on})}\right]$$

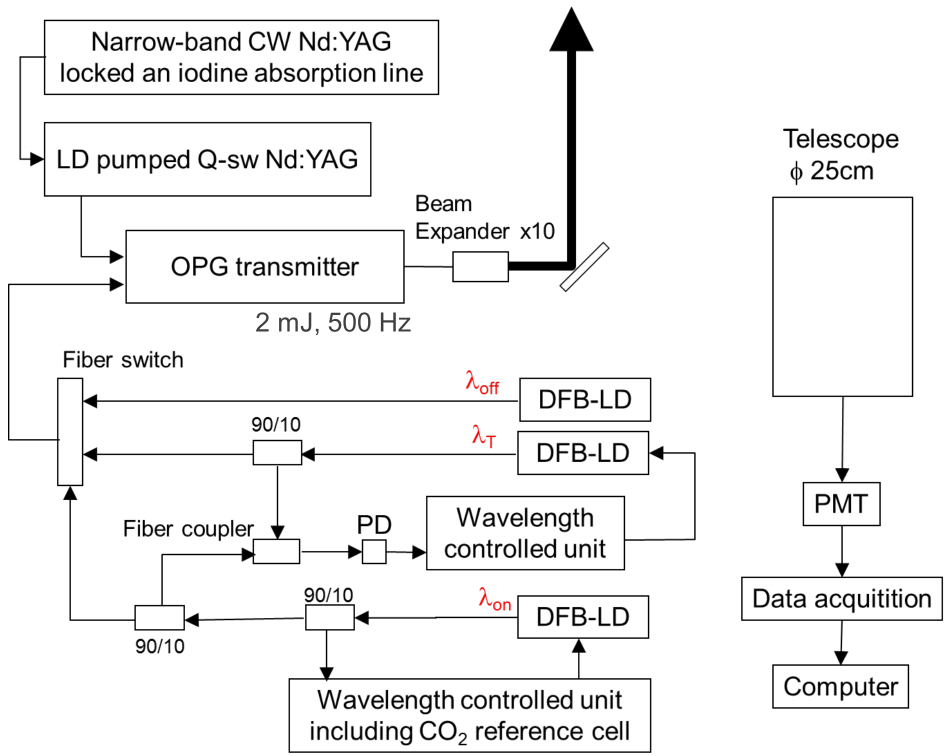
$$\Delta\sigma_{on} = |\sigma_{on} - \sigma_{off}|, \qquad \Delta\sigma_{T} = |\sigma_{on} - \sigma_{T}|$$

$N_{CO2}(r)$: CO_2 density (/m^3), $S(r, \lambda)$: Lidar signal
$\sigma(r)$: CO_2 absorption cross-section

- $\sigma(r)$ depends on wavelength, temperature, pressure.
- Temperature that matches $N_{CO2}(r)$ obtained from both DIALs is numerically analyzed.



Absorption cross-section spectra of CO_2 around 1573 nm at altitudes of 1 km, 3km and 5 km.

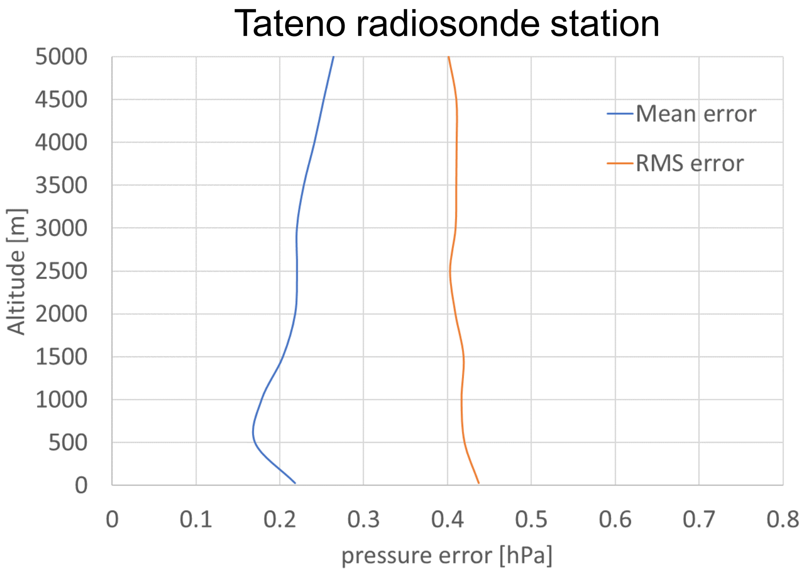


Schematic diagram of the three-wavelength DIAL system used for measuring temperature profiles in the atmosphere. (λ_{on} : 1572.992 nm, λ_T : 1573.040 nm, λ_{off} : 1573.137 nm)

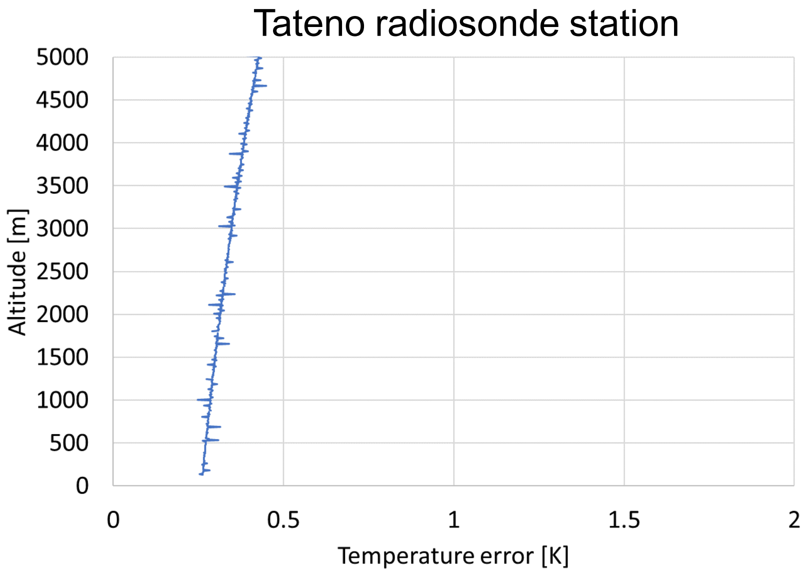
Evaluation of atmospheric pressure profiles

We defined the pressure profile of the radiosonde observation as a true value, and we calculated mean pressure errors and route mean square (RMS) pressure errors of the NCEP GDAS/FNL data using all annual data in 2020.

Radiosonde Tateno station : 36.06N, 140.13E
NCEP GDAS/FNL grid point : 36.00N, 140.25E (12.6 km away)



Mean and RMS pressure errors obtained by comparing radiosonde data over the Tateno station and NCEP GDAS/FNL analysis data during 2020.



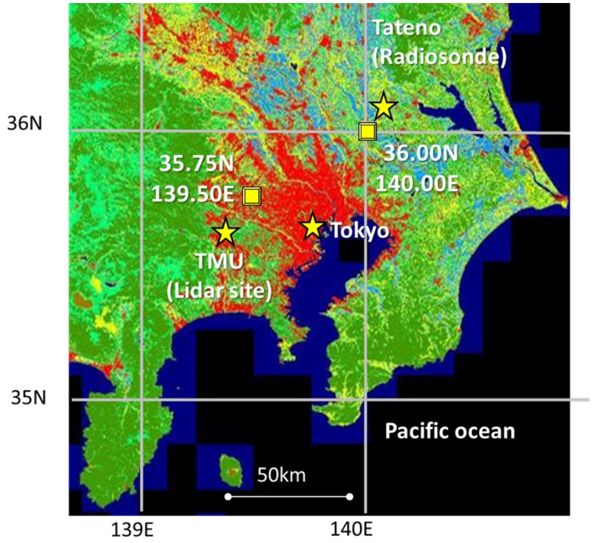
Temperature error due to the total pressure error dp, which is the sum of mean and RMS pressure errors.

How about at our lidar site?

TMU lidar site : 35.66N, 139.37E
Nearby grid point : 35.75N, 139.50E
(15.6 km away)

The distance is almost the same as the distance between Tateno and the nearby grid point.

Therefore, we consider that the difference between the actual pressure profile over the TMU lidar site and NCEP data is similar to the difference between the radiosonde and NCEP data.



Analysis examples of the temperature error

Figures show a temperature error dT, pressure error dp, and CO_2 mixing error dMR calculated using radiosonde data at Tateno and NCEP GDAS/FNL data.

The CO_2 mixing ratio is assumed 400 ppm constant.

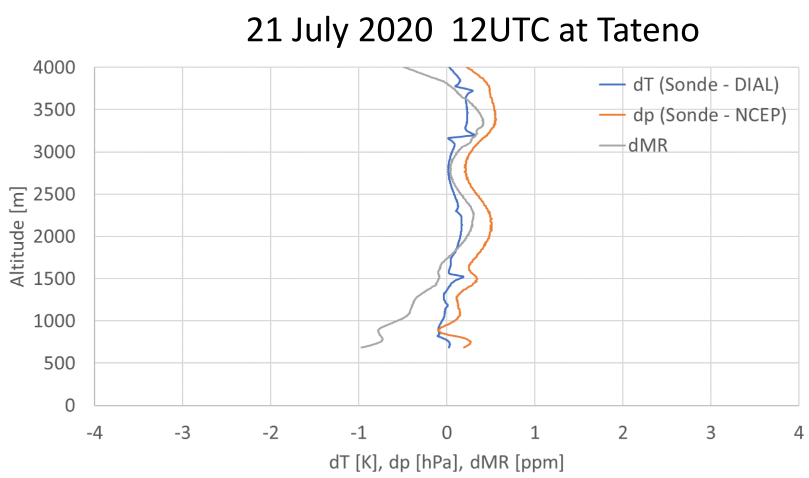
<u>July 21, 2020, 12UTC</u>

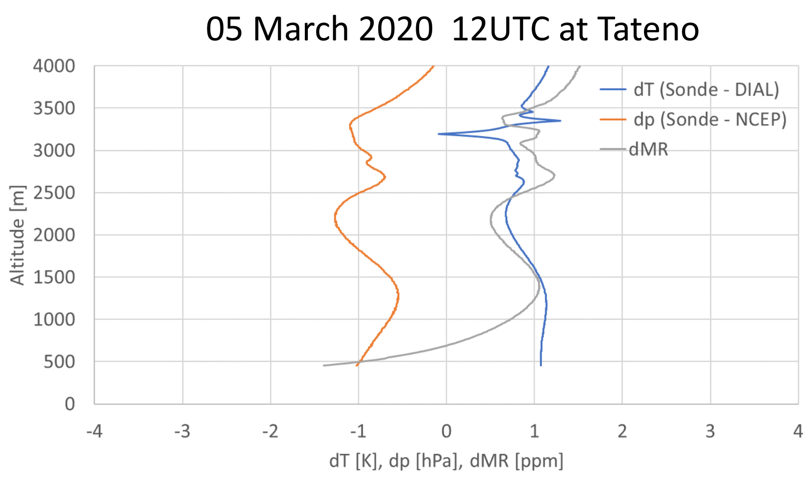
- Temperature errors are close to 0 because pressure errors are close to 0.

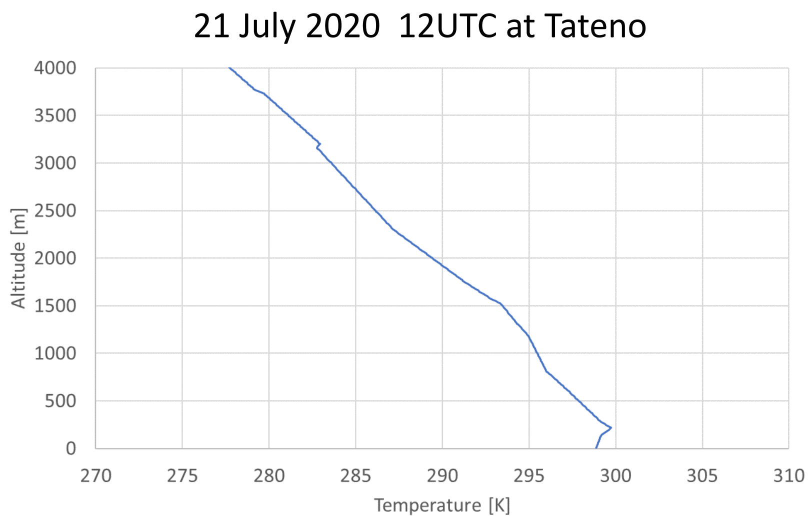
<u>March 5, 2020, 12UTC</u>

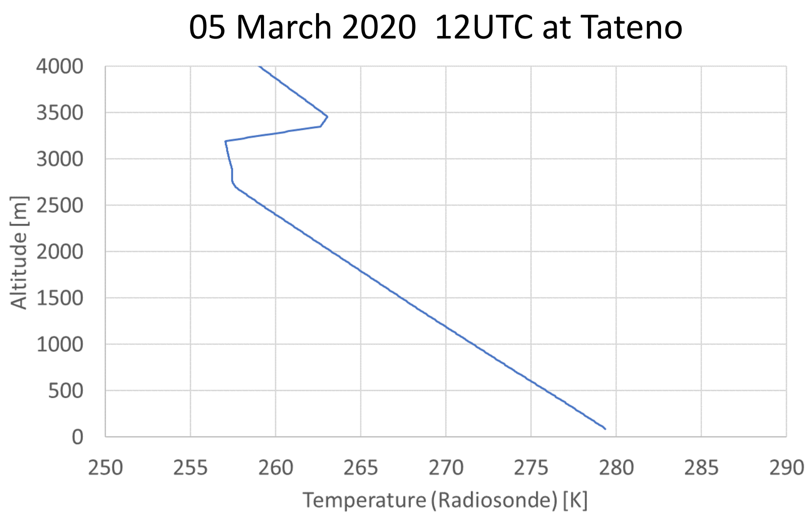
- Since pressure errors are around -1 hPa, the temperature errors are larger than 21 July.
- The temperature in the reverse layer near the altitude of 3 km is in good agreement within an error of 1 K.

Therefore, The accuracy of temperature analysis using NCEP pressure data is sufficient.







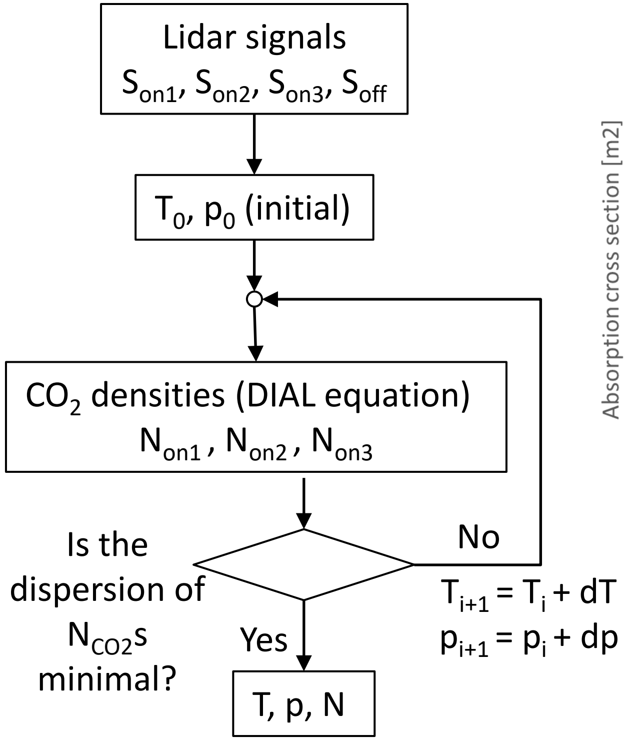


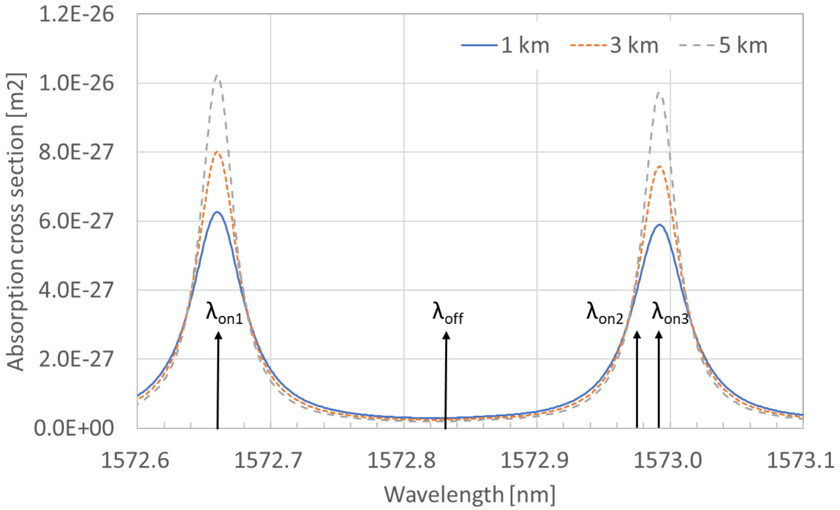
Four-wavelength DIAL for simultaneous temperature and pressure measurements

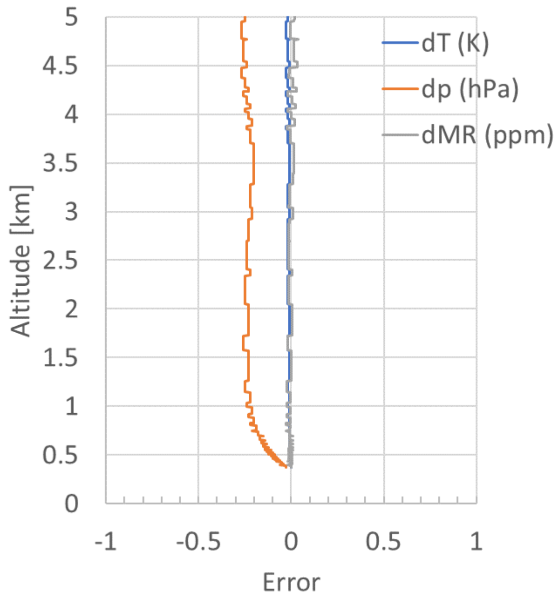
3 on-lines and 1 off-line

λ_{on1} : 1572.660 nm, λ_{on2} : 1572.973 nm, λ_{on3} : 1572.992 nm, λ_{off} : 1572.826 nm

Calculate temperature T, pressure p, and CO_2 density N_{CO2} from each on-line and off-line pair from the DIAL equation.







The temperature error is almost zero. It is shown that the temperature can be measured with higher accuracy than the three-wavelength DIAL method.

The error of the CO_2 mixing ratio is the difference between the average value of each CO_2 mixing ratio obtained by the three DIALs and the assumed 400 ppm.

Conclusion

Three-wavelength DIAL for temperature measurement

- We have developed the temperature measurement DIAL consisting of the three-wavelengths of the peak absorption (λ_{on}), the intermediate absorption (λ_T), and the weak absorption (λ_{off}) wavelengths tuned on a single CO_2 absorption spectrum.
- The temperature is calculated by two DIAL equations obtained from the combination of the pair of λ_{on} and λ_{off}, and the pair of λ_{on} and λ_T. In that case, the pressure data of the NCEP GDAS/FNL analysis data at the closest grid point to the TMU lidar site is used to suppress the error of the pressure broadening of the absorption spectrum profile.
- The temperature error caused by the pressure error of NCEP GDAS/FNL analysis data is 0.4 K or less at an altitude of 5,000 m or less.

Four-wavelength DIAL for temperature measurement

- Four-wavelength DIAL consists of three DIALs using three on-lines and an off-line.
- Temperature and pressure are determined when the standard deviation of the CO_2 density obtained from each DIAL is minimized.
- The advantage of this method is that the temperature error is almost zero. In addition, pressure and CO_2 density can be obtained with higher accuracy than the three-wavelength DIAL technique.