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Trajectory Analysis of CO_2 Concentration Increase Events in the Nocturnal Atmospheric Boundary Layer Observed by the Differential Absorption Lidar

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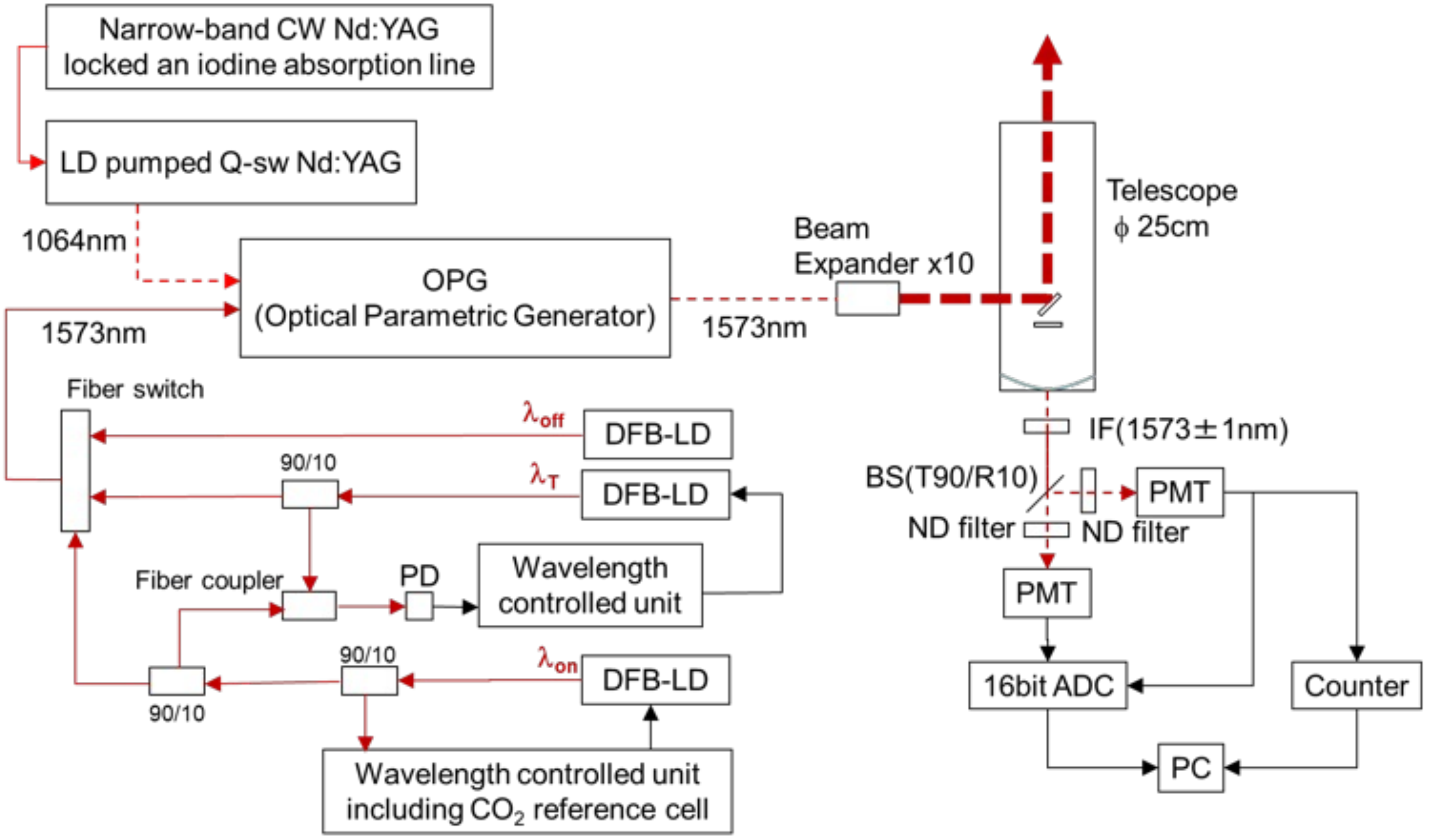
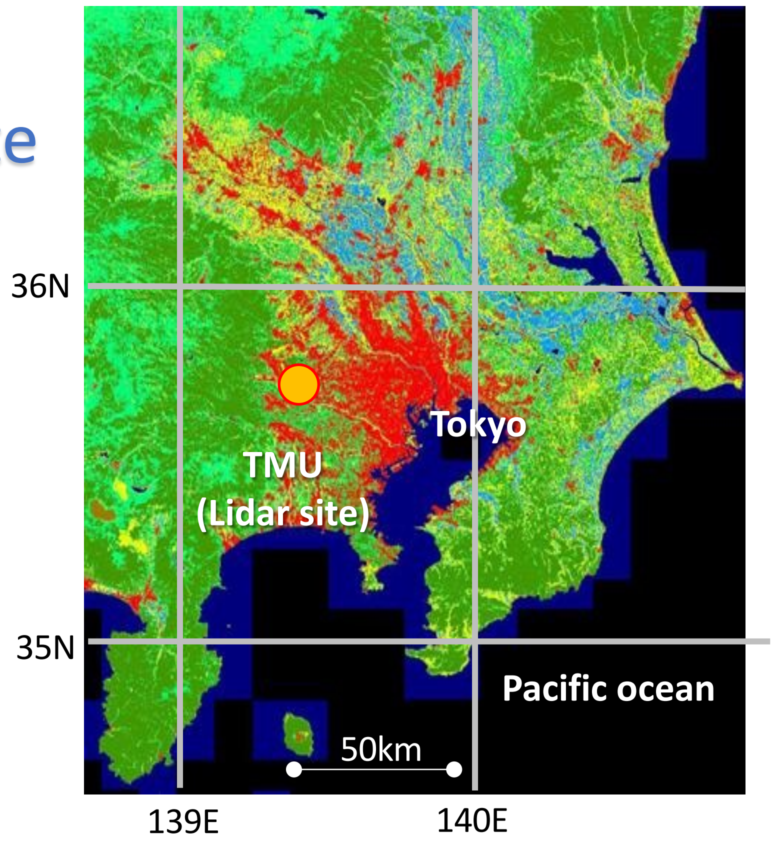
Introduction

- Inverse techniques using atmospheric transport models are developed to estimate CO_2 sources and sinks based on the observed data.
- The accurate vertical CO_2 profiles in the troposphere are highly desirable in the inverse techniques to improve quantification.
- Lidar instruments are thought to be one of the best methods for observing the vertical distribution of greenhouse gasses.
- We have performed vertical profile measurement of the CO_2 mixing ratio at Tokyo Metropolitan University (TMU) using a differential absorption lidar (DIAL) with a wavelength of 1.6 μm.
- Trajectory analysis was performed using a 3D atmospheric transport model to obtain information on the sources of increased CO_2 at night.

Three Wavelength CO_2 DIAL System and TMU Lidar Site

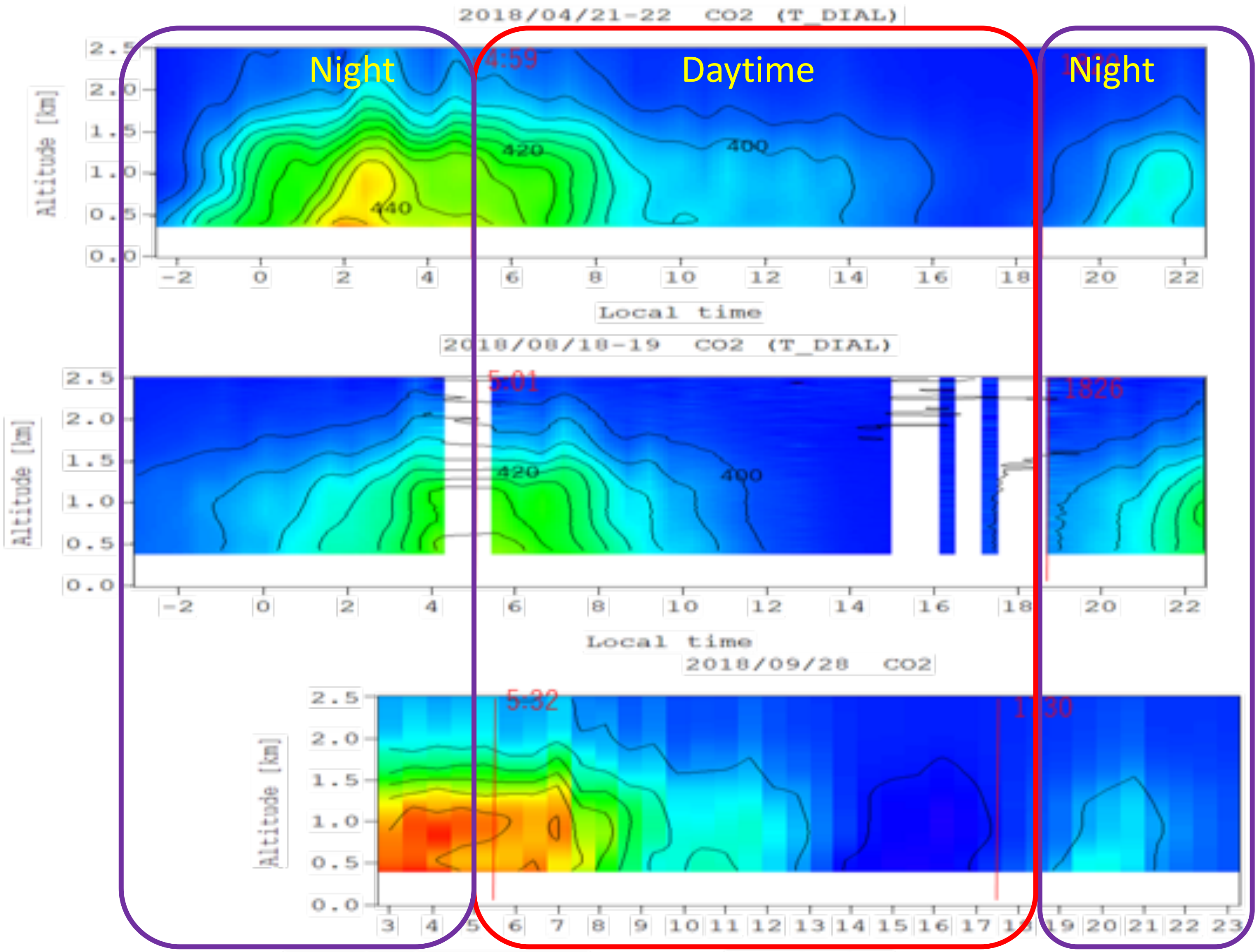




System parameters for the three-wavelength DIAL

Wavelengths	1572.992 nm (λ_{on}) 1573.137 nm (λ_{off}) 1573.040 nm (λ_T)
Pulse energy	6 mJ
Repetition rates	400 Hz (Total) 200 Hz (λ_{on}), 100 Hz (λ_{off} and λ_T)
Vertical resolution	300 m
Time resolution	30 min
Telescope diameter	250 mm
Quantum efficiency	8 %
Interference filter	1.0 nm (FWHM)

Typical Diurnal Variation of CO_2 Profiles on Clear Days



Daytime

- CO_2 concentration decreases 2-3 hours after sunrise
- The sink for CO_2 reduction is plants (photosynthesis)

Night

- CO_2 concentration may increase sharply after midnight
- Increase in mixing ratio is 20 to 50ppm
- The peak time of concentration increase is not constant
- No seasonal dependence
- Cannot be explained by human activity or forest breathing

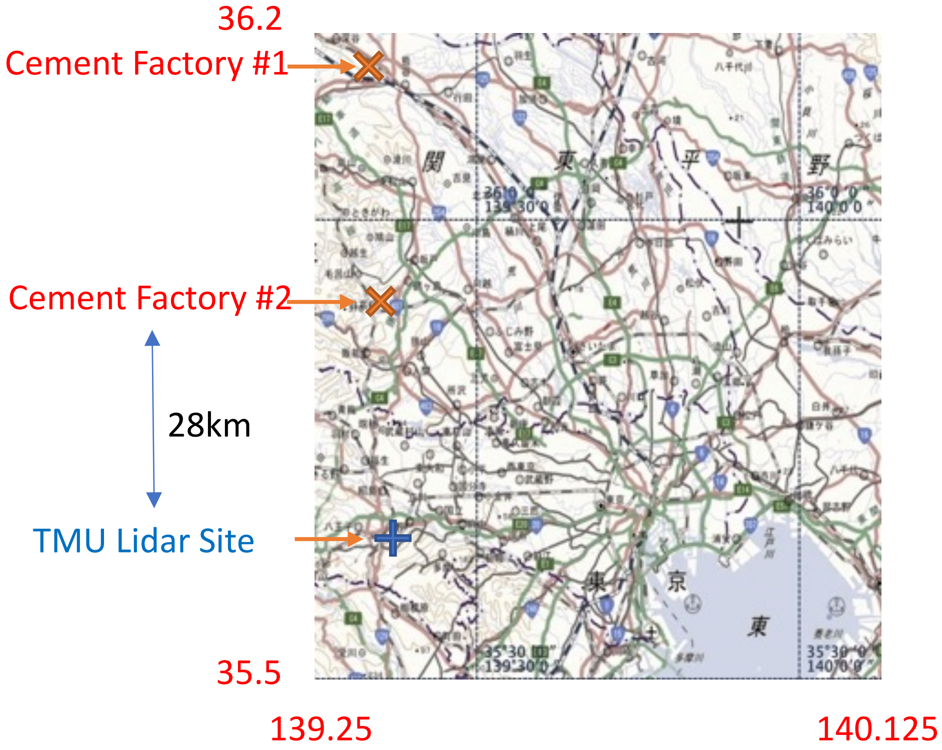
Back Trajectory Analysis

Meso-Scale Model (Original)

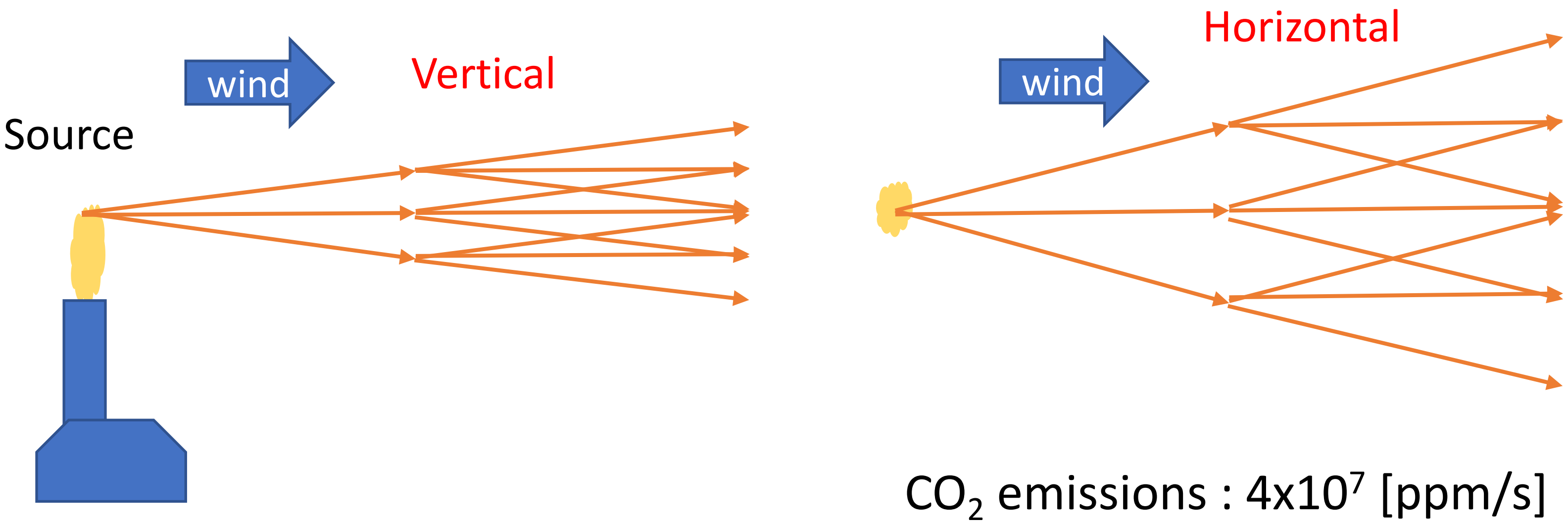
- Map Area： 78km × 78km
- Horizontal Mesh：~11km
- Vertical Resolution：200~500m
- Time Interval：3 Hour

Interpolation

- Horizontal Mesh：1km
- Vertical Resolution：105m
- Time Interval：20 min



Local Three-dimensional Dispersion Analysis



CO_2 emissions : 4×10^7 [ppm/s]
(estimated from public data)

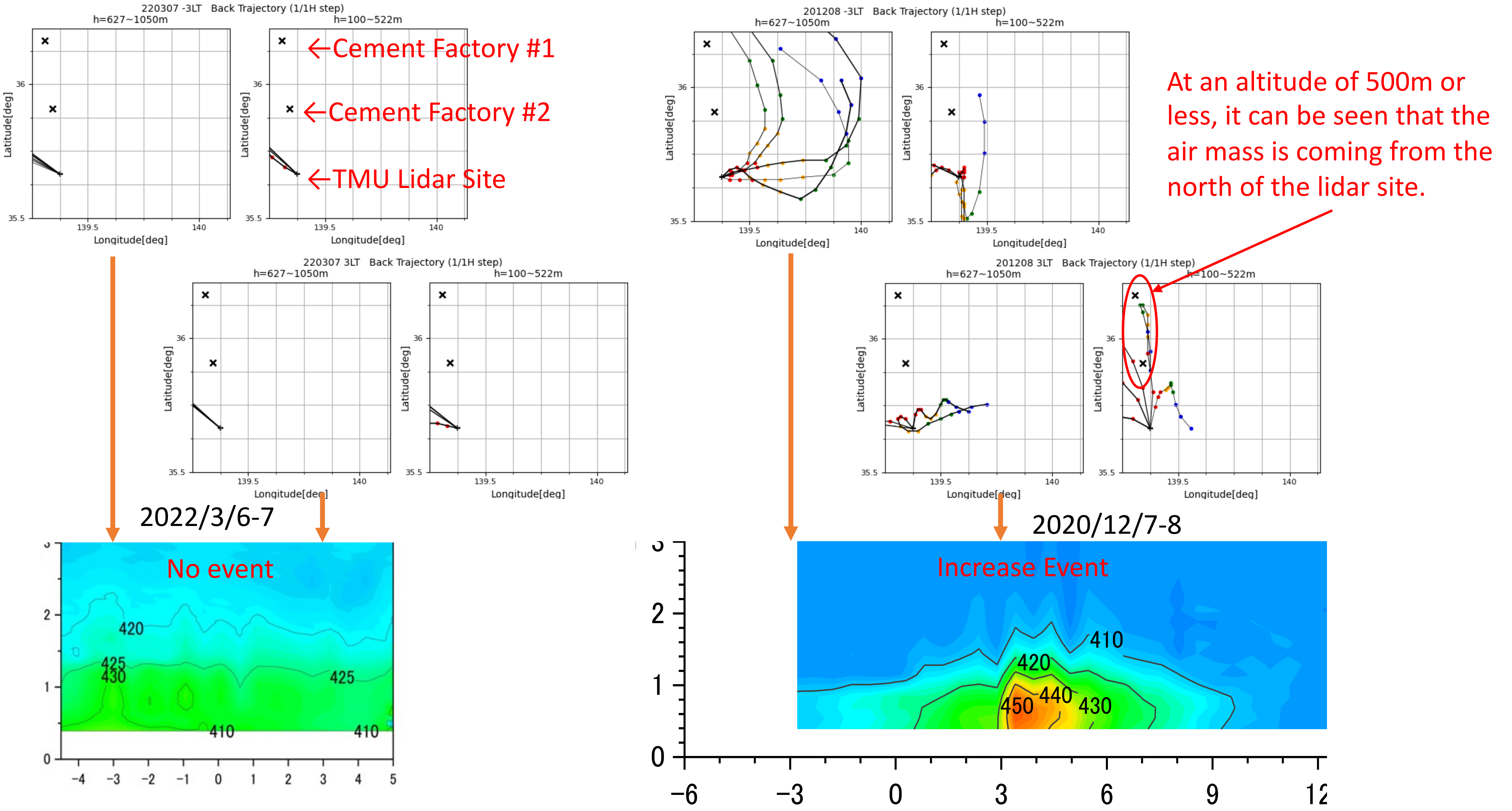
Gaussian plume model

$$C(x,y,z) = \frac{Q}{2\pi U \sigma_y \sigma_z} e^{\left(-\frac{y^2}{2\sigma_y^2}\right)} e^{\left(-\frac{z^2}{2\sigma_z^2}\right)}$$

C : mean concentration of diffusing substance at (x, y, z)
- x : downwind distance
- y : crosswind distance
- z : vertical distance above ground

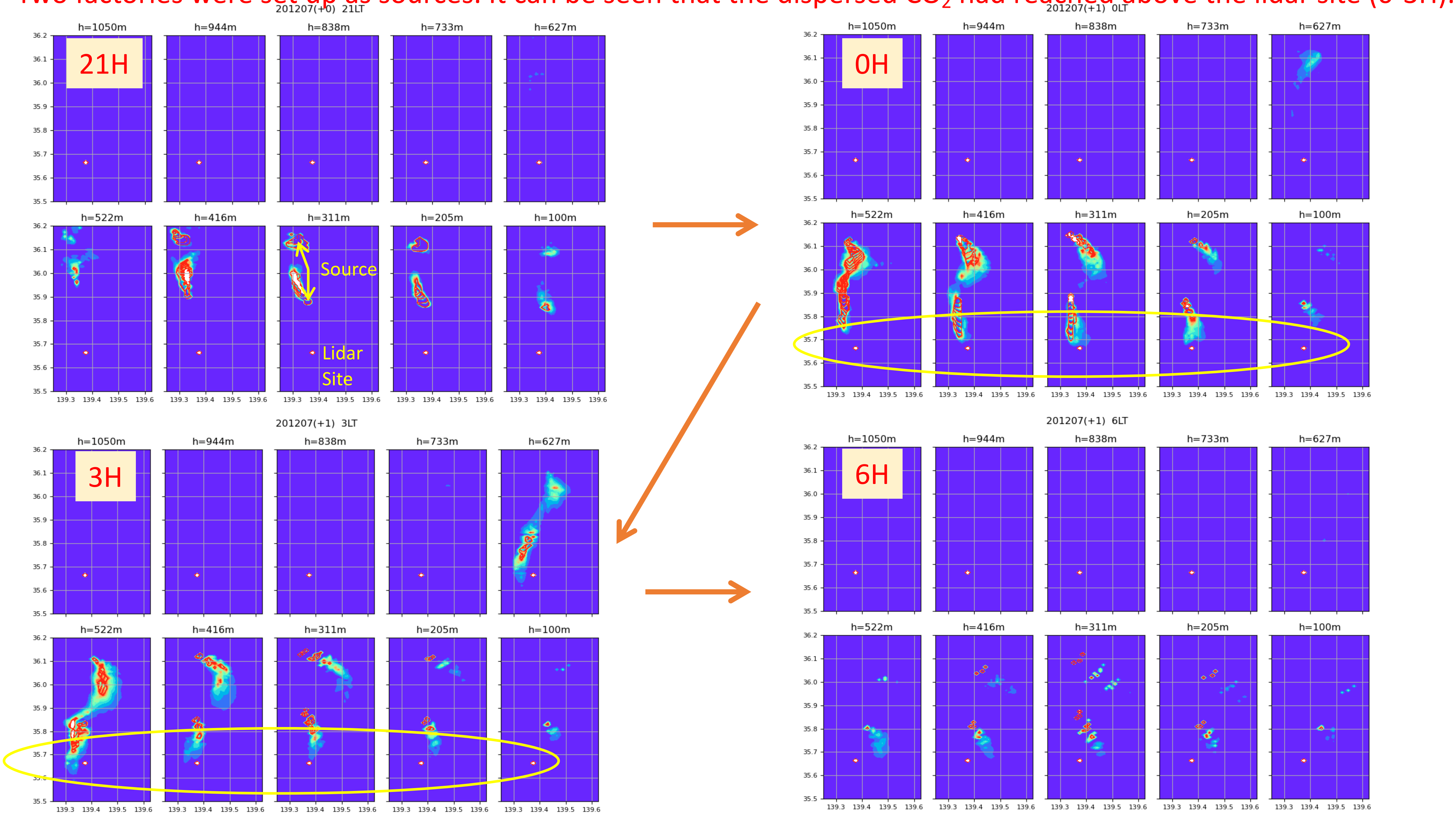
Q : mean concentration of diffusing substance from source
σy , σz : lateral and vertical dispersion coefficient function
u : mean wind velocity in downwind direction

Backward Trajectory Analysis at 10 Altitudes, Start of Run at 21H and 3H

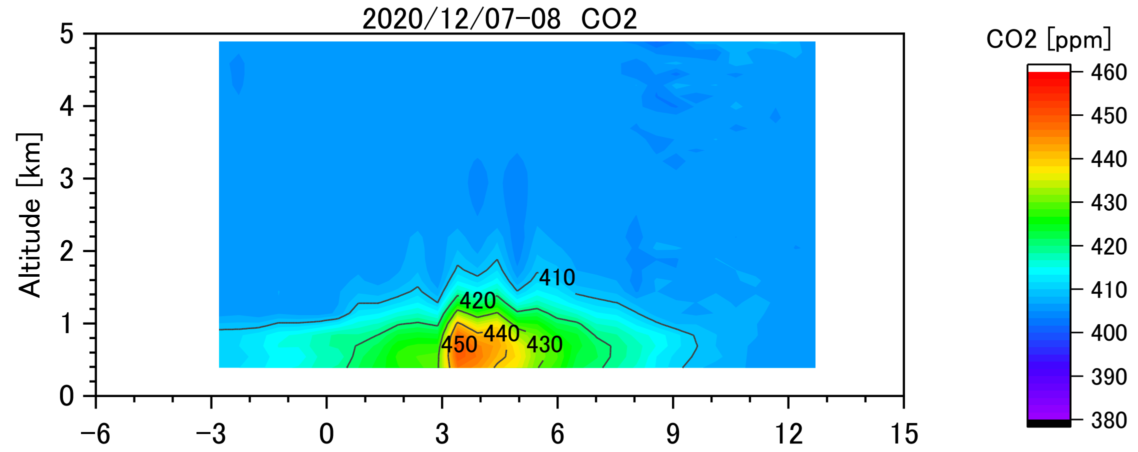


Local Three-dimensional Dispersion Analysis (2020/12/7-8)

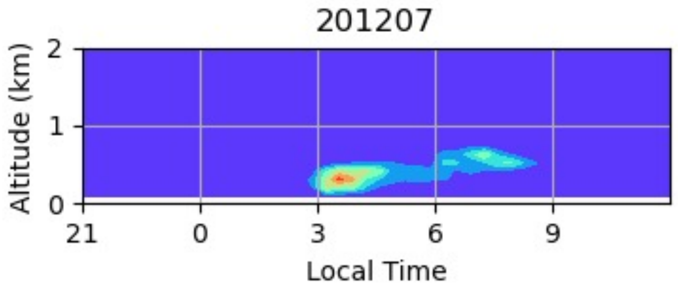
Two factories were set up as sources. It can be seen that the dispersed CO_2 had reached above the lidar site (0-3H).



(a)



(b)



(a) Time-height cross-section of CO_2 mixing ratio at the TMU lidar site.

(b) Time-height cross-section of the increase in the CO_2 mixing ratio at the TMU lidar site calculated by local three-dimensional dispersion analysis at 12 altitudes.

Compared with observation results and three-dimensional dispersion analysis, the increase in the CO_2 mixing ratio is in good agreement in both time and altitude.

Conclusion

- Local three-dimensional dispersion analysis was used to reproduce the rapid increase in CO_2 mixing ratio in the lower layer at night.
- The source of this CO_2 is estimated to be a factory to the north of the observation site, and it is thought that high concentrations of CO_2 were transported to the lidar site due to local wind convergence during the night.
- It has been shown that CO_2 -DIAL is useful for identifying the source of CO_2 and monitoring the amount of CO_2 emissions.