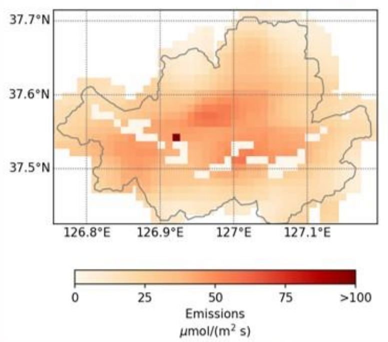
METHOD

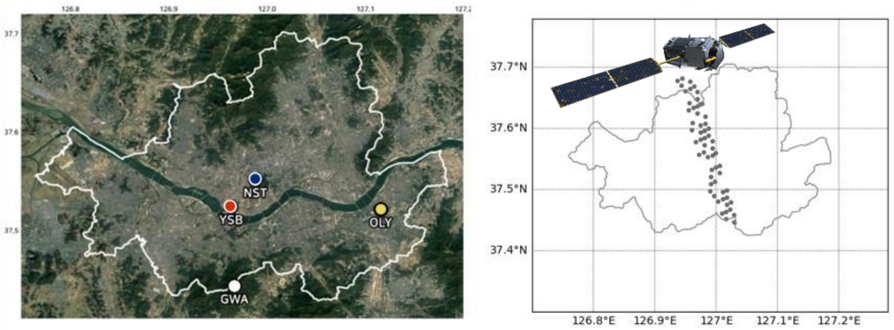
Sojung Sim*, Sujong Jeong
(Seoul National University)

1. Bayesian inverse modeling framework in Seoul

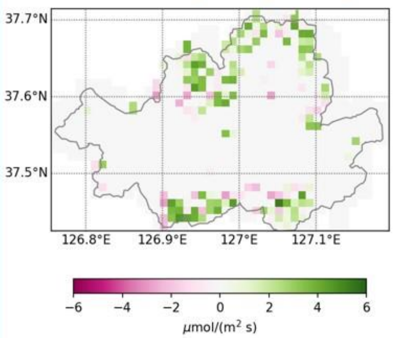
Carbon emission (ODIAC)



Observation (ground & OCO-2 satellite)

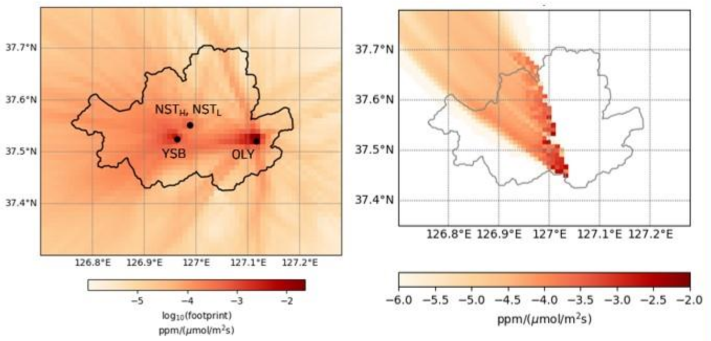


Carbon uptake (CASS)

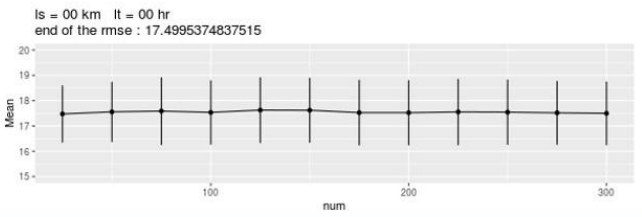


$$\hat{s} = s_p + (HQ)^T (HQH^T + R)^{-1} (z - Hs_p)$$

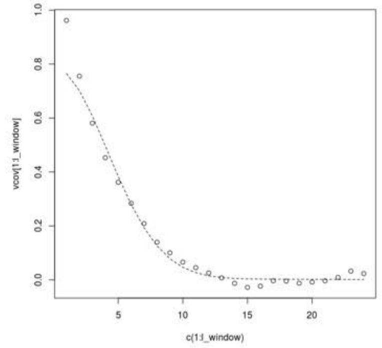
Footprint (WRF-STILT & WRF-XSTILT)



Prior emission error covariance



Observation error covariance



Calculate optimized emissions through the minimization of cost function

$$L_s = \frac{1}{2}(\mathbf{z} - \mathbf{Hs})^T \mathbf{R}^{-1}(\mathbf{z} - \mathbf{Hs}) + \frac{1}{2}(\mathbf{s} - \mathbf{s}_p)^T \mathbf{Q}^{-1}(\mathbf{s} - \mathbf{s}_p)$$

$$\hat{\mathbf{s}} = \mathbf{s}_p + (\mathbf{HQ})^T (\mathbf{HQH}^T + \mathbf{R})^{-1} (\mathbf{z} - \mathbf{Hs}_p)$$

s: posterior best estimate of emissions
s_p: prior emission
H: Jacobian matrix of footprint
Q: Prior emission error covariance
R: Observation error covariance
z: Observed enhancement

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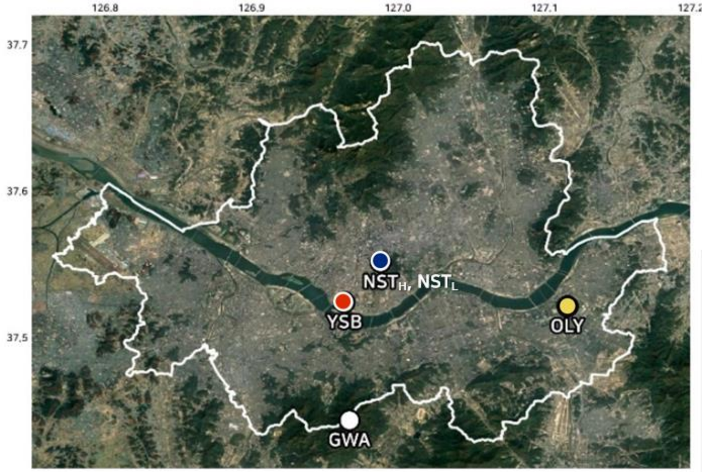
2. Data

① Observation

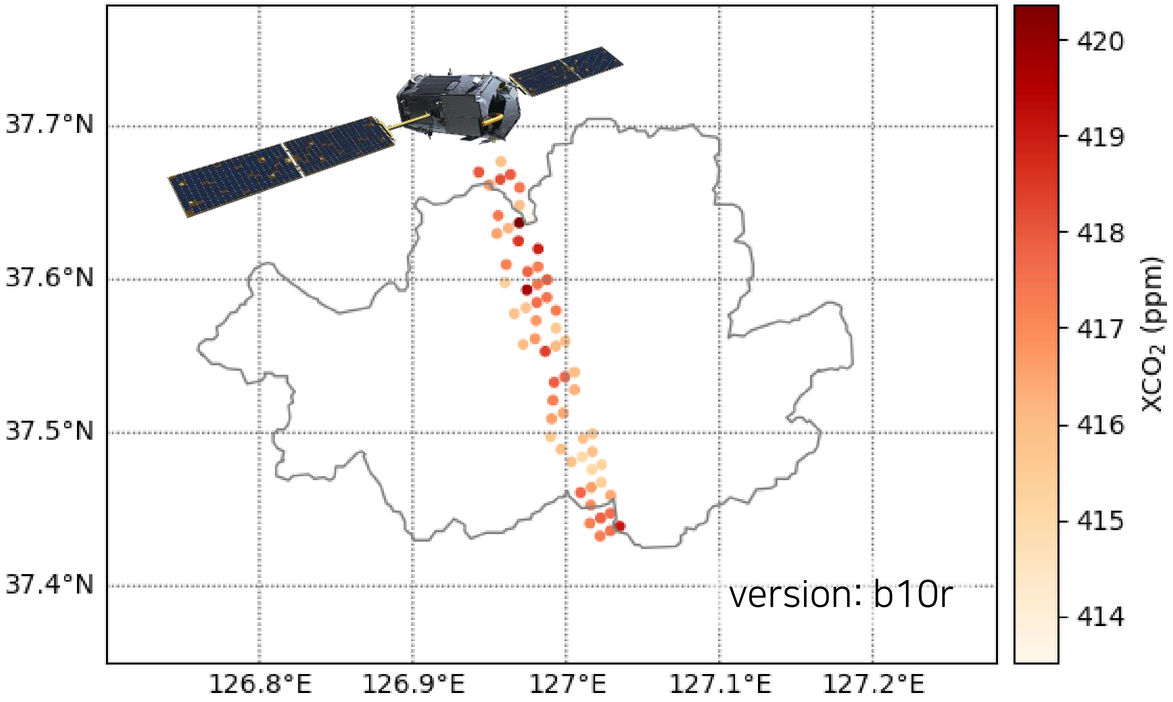
Using CO_2 concentration data from 4 observation sites and OCO-2 satellites when passing through Seoul

<Ground>

Site code	Full name	Height (m)
YSB	Yongsan Building	113
NST_H	Namsan Seoul Tower-High	420
NST_L	Namsan Seoul Tower-Low	265
OLY	Olympic Park	27
GWA (background)	Gwanak Mountain	629



<Satellite>



2020/4/5 13:00 - 57 soundings

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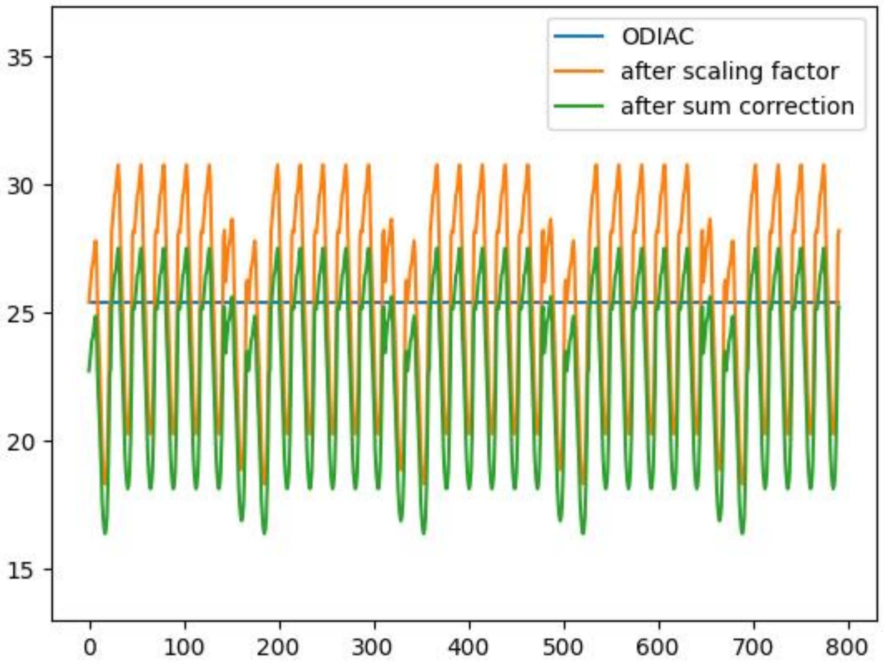
2. Data

② Carbon emission (ODIAC)

Open-source Data Inventory for Anthropogenic CO_2

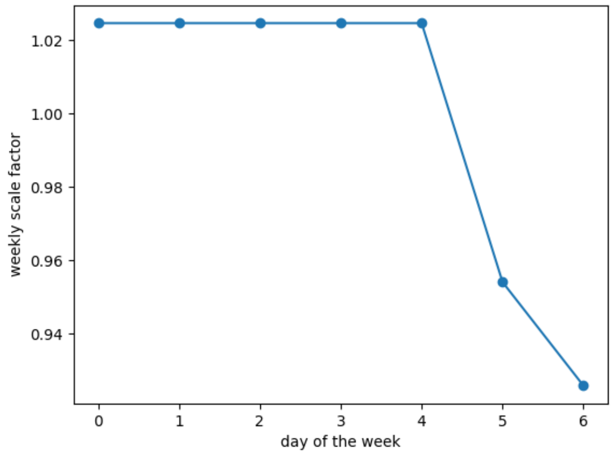
Calculation of CO_2 emissions from fossil fuels by 1km and 1 month

<Time series of ODIAC>

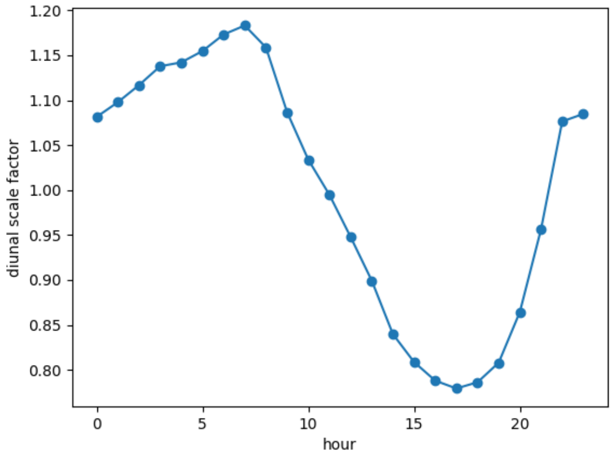


Modification to time

<weekly scale factor in Seoul>



<diurnal scale factor in Seoul>



- Monthly data to hourly by applying temporal scale factor

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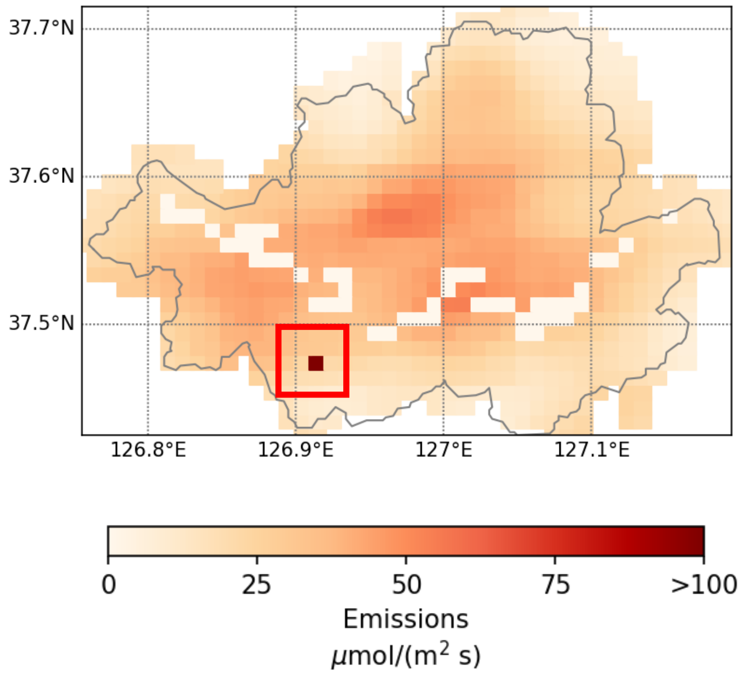
2. Data

② Carbon emission (ODIAC)

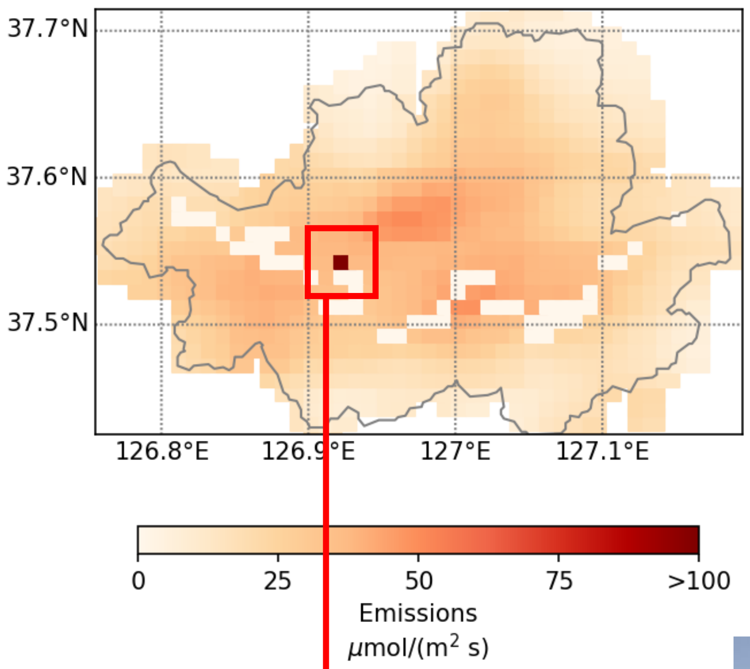
Open-source Data Inventory for Anthropogenic CO_2

Modification of space

<Spatial distribution of ODIAC(before)>



<Spatial distribution of ODIAC(after)>



Korea Central Power Corporation Seoul

- Correcting incorrect plant location

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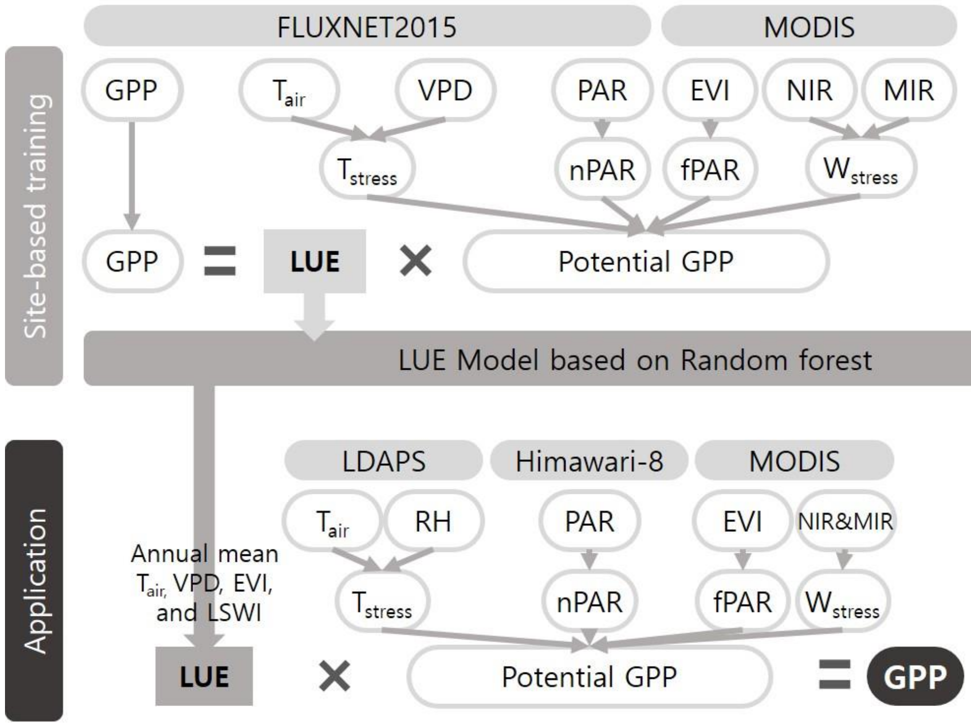
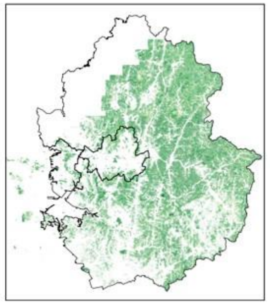
2. Data

③ Carbon uptake (CASS)

CArbon Simulator from Space

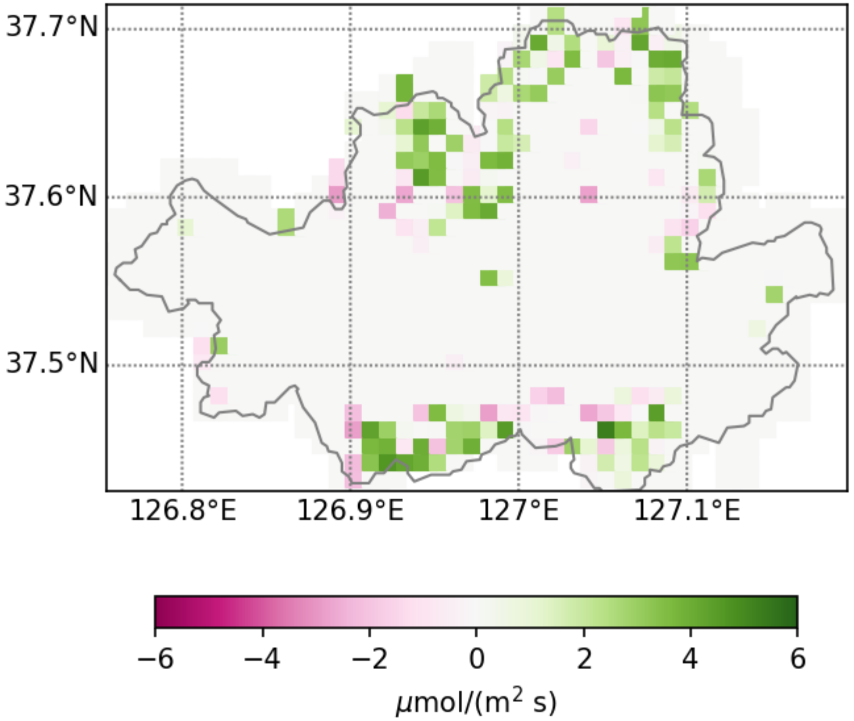
CO_2 uptake by various vegetation resources like urban forests and park by 250m, 1 hour





(해상도: 250m, 1시간)

<Spatial distribution of CASS>



METHOD

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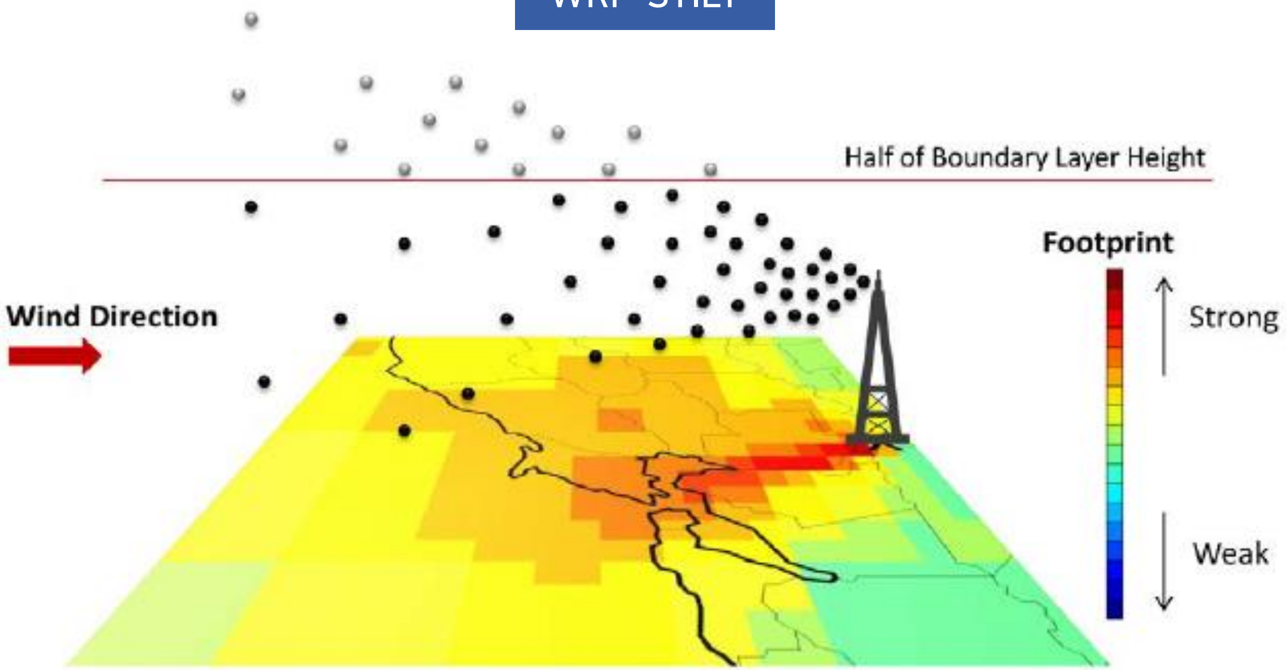
2. Data

④ Footprint

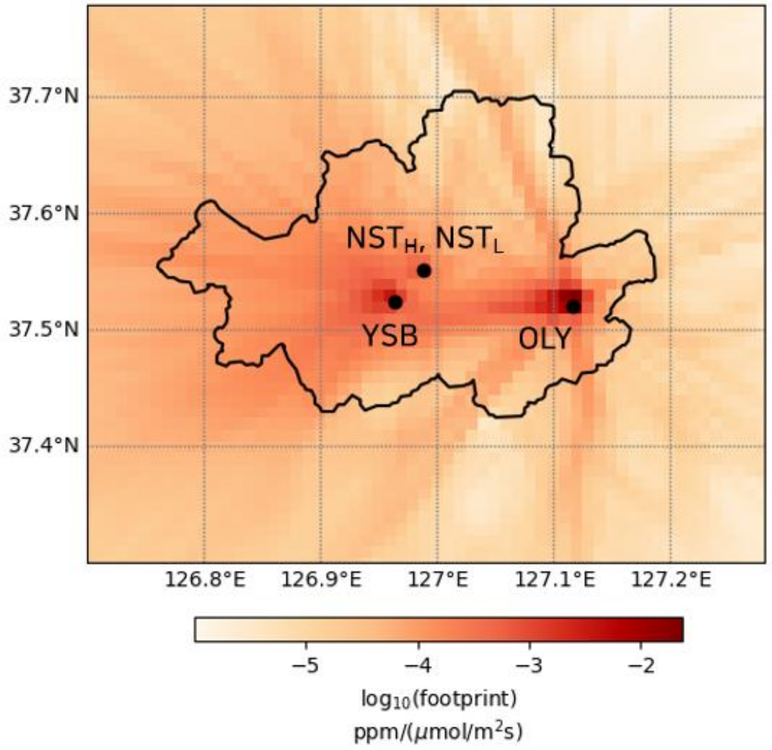
- Sensitivities of observation point to the upwind emission source area (influence), 1 hour & 1 km
- 1000 particles, 24h backward

WRF-STILT



[Fischer et al., 2016]

<Spatial distribution of footprint for ground observations>



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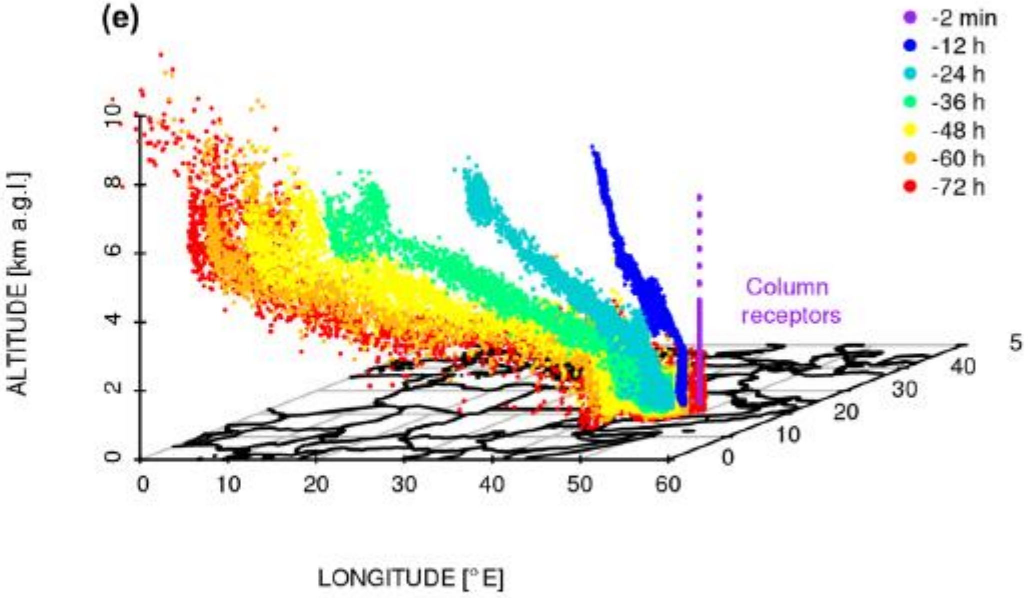
2. Data

④ Footprint

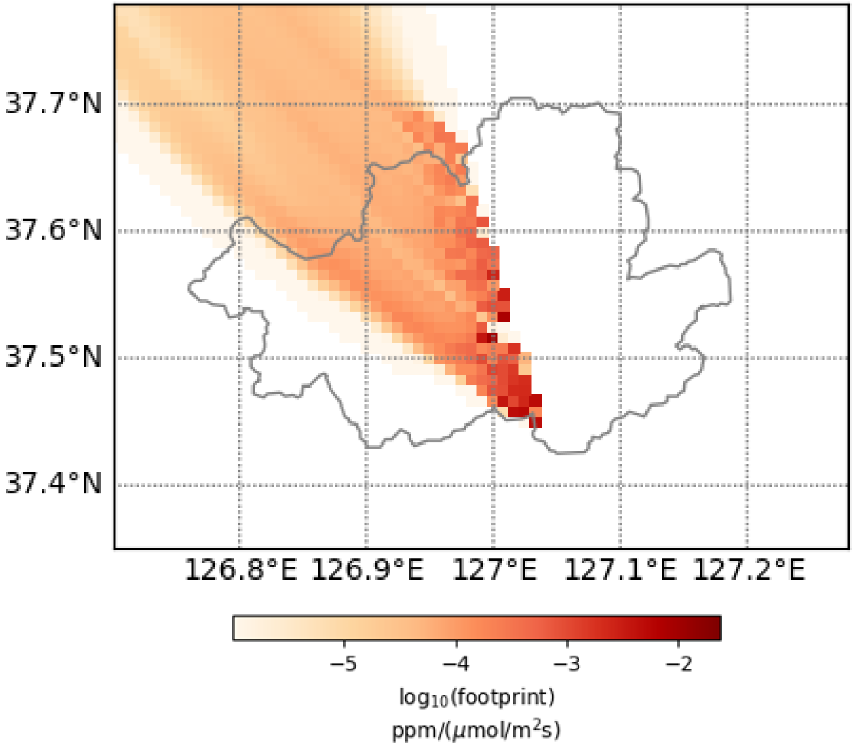
- Sensitivities of observation point to the upwind emission source area (influence), 1 hour & 1 km
- 1000 particles for each column level, 24h backward for satellite

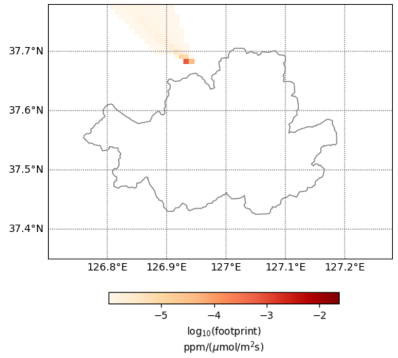
WRF-XSTILT



[Wu et al., 2018]

<Spatial distribution of footprint for satellite observations>





METHOD

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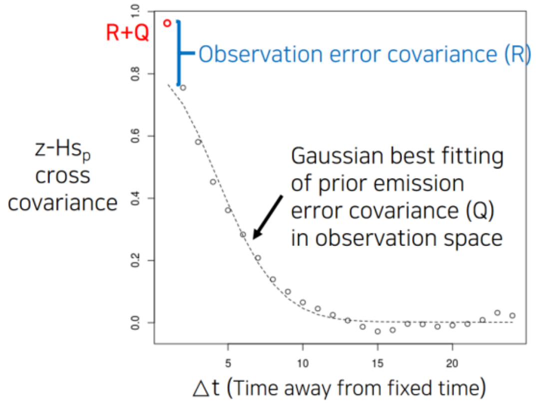
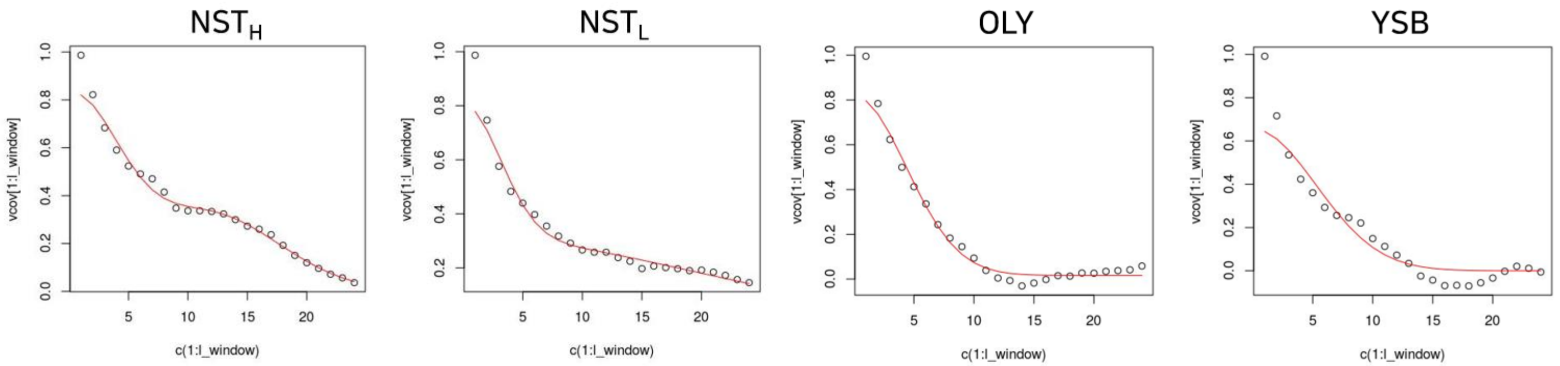
2. Data

⑤ Observation error covariance (R)

- Using the Gaussian best fitting method by Hollingsworth & Lonnberg (1986)
- For satellite data, we used uncertainties provided by OCO-2





⑥ Prior emission error covariance (Q)

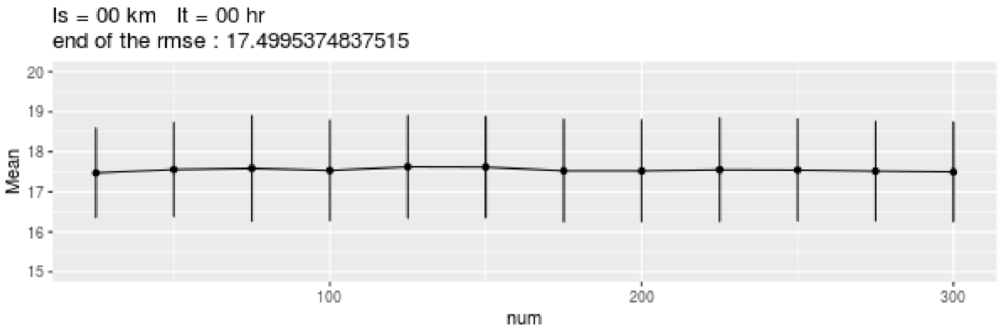
- Q inflation to match Gaussian best fitting

$$\mathbf{Q} = \mathbf{I}_\sigma (\mathbf{D} \otimes \mathbf{E}) \mathbf{I}_\sigma$$

1) σ: Difference between ODIAC and ISAAC (Seoul Target Inventory)

2) D: Temporal covariance $\mathbf{D} = \left[\exp\left(-\frac{\mathbf{X}_\tau}{l_\tau} \right) \right]$

3) E: Spatial covariance $\mathbf{E} = \left[\exp\left(-\frac{\mathbf{X}_s}{l_s} \right) \right]$



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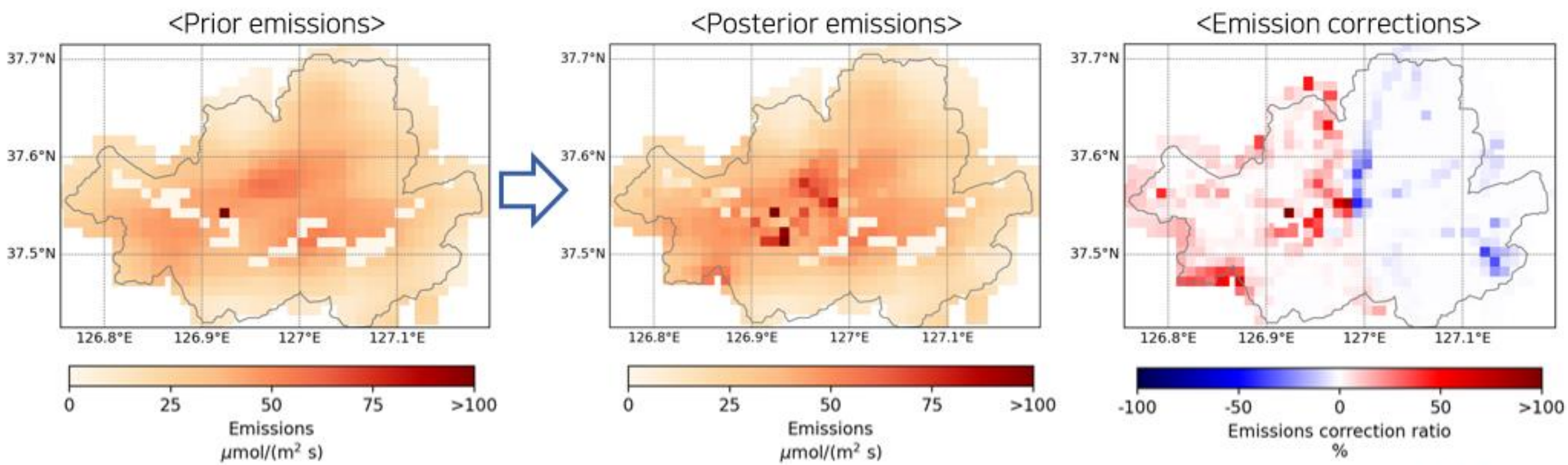
1. Spatial distribution of carbon emissions in Seoul



	Prior	Posterior	
Mean value:	26.376 μmol/(m^2 s)	28.872 μmol/(m^2 s)	Correction ratio: 9.5 %
Uncertainty:	4.04 μmol/(m^2 s)	3.59 μmol/(m^2 s)	Uncertainty reduction: 11.2%

- The average value of prior and posterior carbon emissions in April 2020 were 26.376 μmol/(m^2 s) and 28.872 μmol/(m^2 s), respectively.
- As a result of verifying urban carbon emissions over Seoul through the Bayesian inverse model, it was found that posterior carbon emissions increased by 9.5%.
- In other words, it means that the prior carbon emissions were underestimated, and this trend was evident in the western part of Seoul.
- The uncertainty of carbon emissions was compared to verify the performance of the Inverse model, and it was reduced by 11.2% through the Inverse model.

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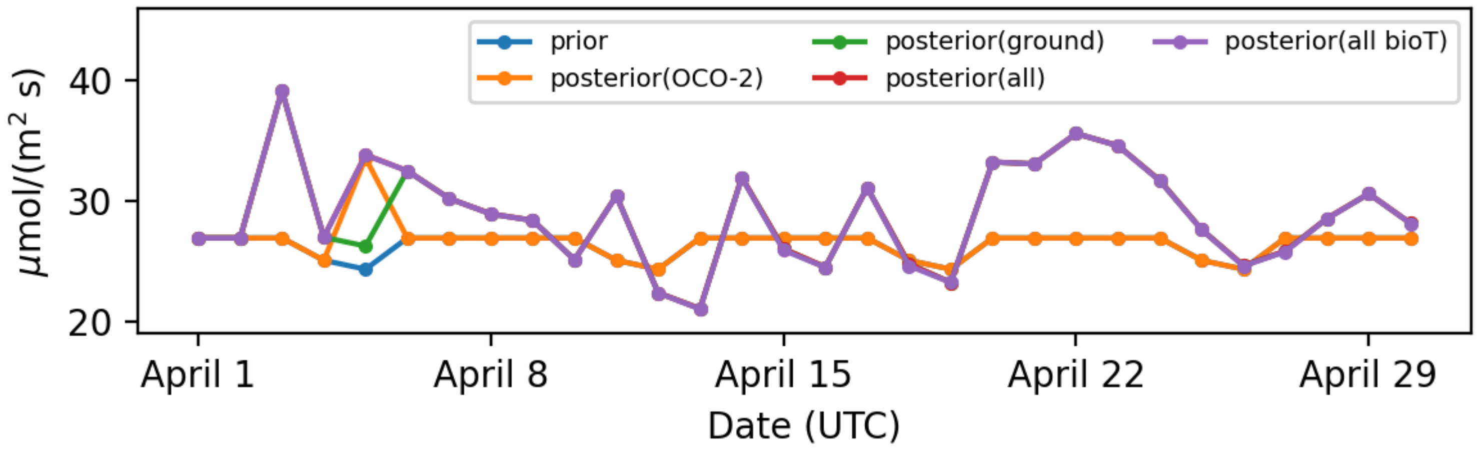
2. Time series of carbon emissions in Seoul

<Time series of carbon emission (daily mean)>



<Comparison of emission correction ratio and uncertainty reduction according to input data>

	OCO-2	ground	all	all, bio T
Correction ratio	1.13%	8.62%	9.55%	9.46%
Uncertainty reduction	0.06%	11.19%	11.20%	11.20%

- If only OCO-2 was included as observation, it would be significantly corrected on April 5 when the satellite past.
- In the case of 4/5 it can be seen that it was largely corrected by satellite observation rather than ground observation.
  → The OCO-2 data can only be corrected on a specific day, but the degree of correction on that day is very large.
- When both ground and satellite observations(all observation data) were used, the correction was greatest, and the uncertainty was also significantly lowered.
- There was no significant change in the case of additional considering the vegetation effect, but the ratio of increase in emission correction was slightly lowered.