



Spatio-temporal distribution of ammonia over Korea using CrIS satellite: Validation with *in-situ* measurements and bias correction

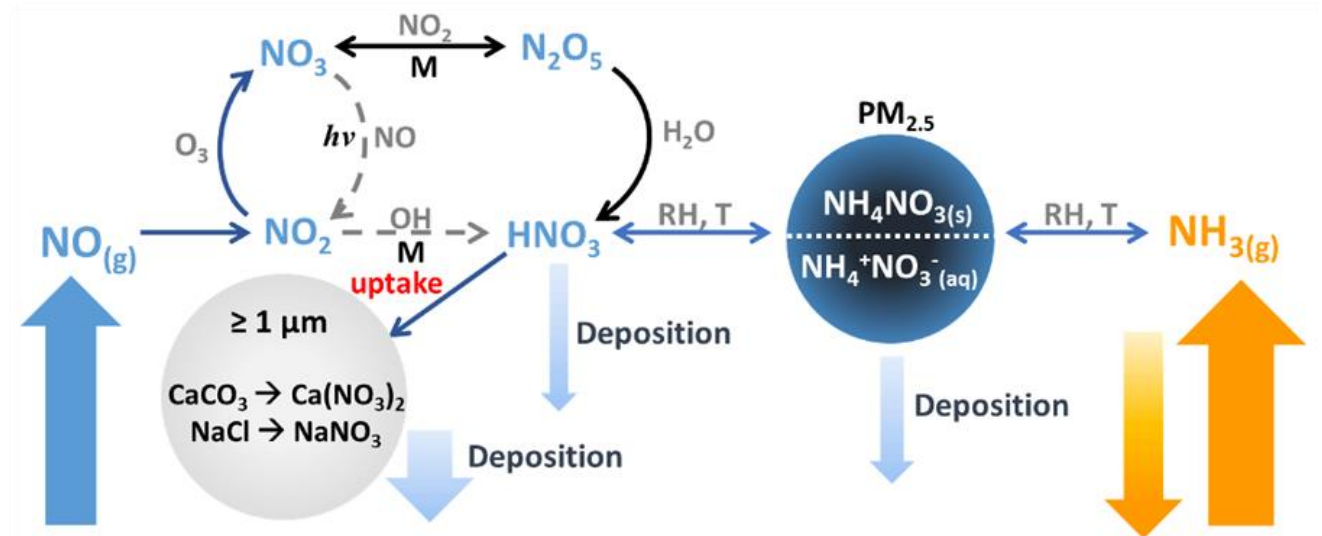
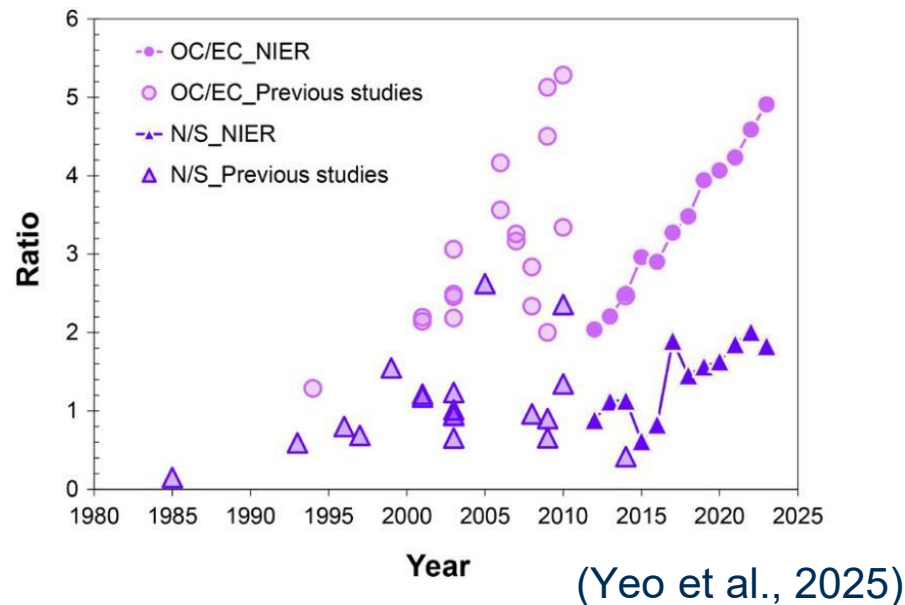
Yongjoo Choi

Hankuk University of Foreign Studies, Korea
EANET Seminar 2025, 2025-12-22

Research background (1)



- Mitigation policies for $PM_{2.5}$ (e.g, NO_x reduction) have been implemented to address high wintertime nitrate episodes, but atmospheric nitrate concentrations have not declined to the same extent as other pollutants.
- Because nitrate aerosol forms through multiple pathways, making it difficult to diagnose without a comprehensive understanding of tropospheric chemistry.
- Among these, NH_3 has a short atmospheric lifetime and large domestic emissions, suggesting that variations in domestic NH_3 emissions may strongly influence nitrate levels.



Research purposes



- Because observation data for NH_3 are limited, we aim to compile NH_3 measurements by emission source and region to fill our gap of knowledge

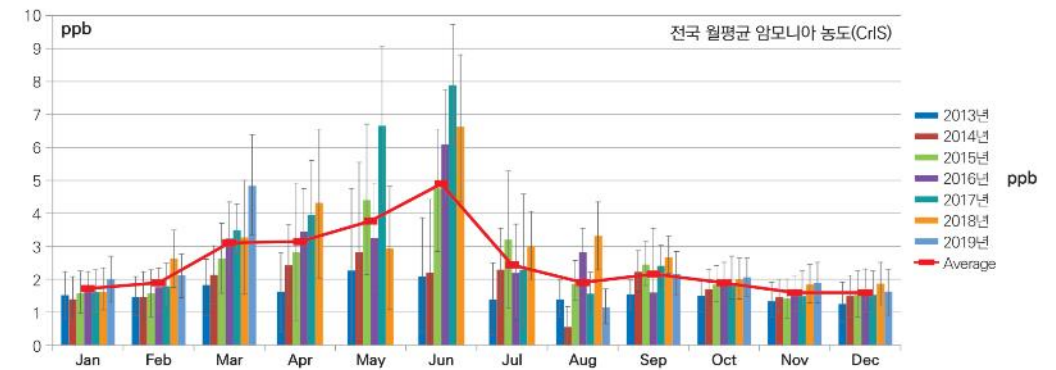
- passive sampler

- satellite measurements

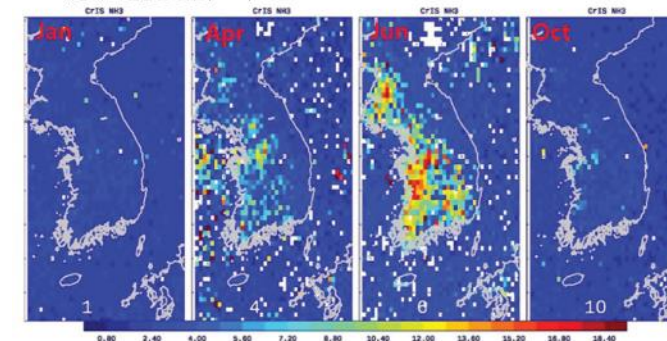
(1) Analysis of ammonia emission characteristics and regional spatial distribution using passive sampling

(2) Assessment of the feasibility of satellite-based ammonia monitoring through validation against in situ measurements

(3) Estimation of spatial distribution of NH_3 at surface level using machine learning.



CrIS 위성자료 월평균 변환(2017)



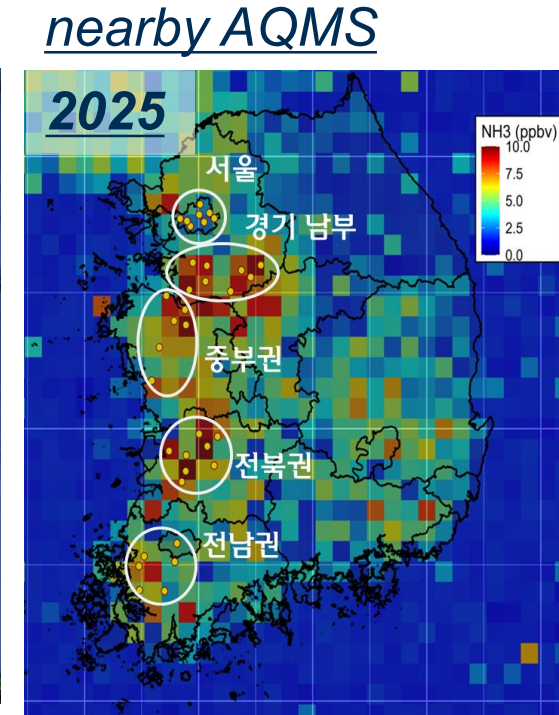
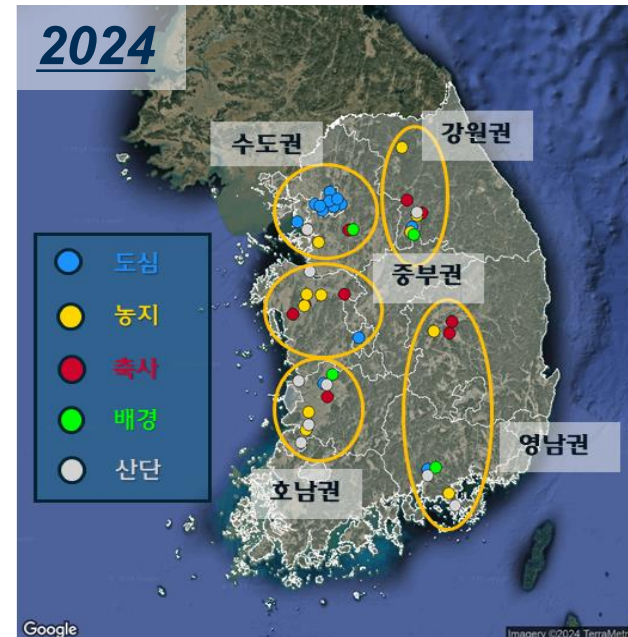
[Shim et al, 2023]

in-situ measurements sites

■ NH₃ Passive sampler

- periods

- 1st: 2022.06– 2023.02 (45 sites, 35 weeks)
- 2nd: 2023.06 – 12 (43 sites, 20 weeks)
- 3rd: 2024. 05 – 10 (48 sites, 15 weeks)
- 4th: 2025. 05 – 10 (45 sites, 15 weeks)



Example of installation of passive sampler



Urban 1



Urban 2



Farmland 1



Industry 1



Livestock 1

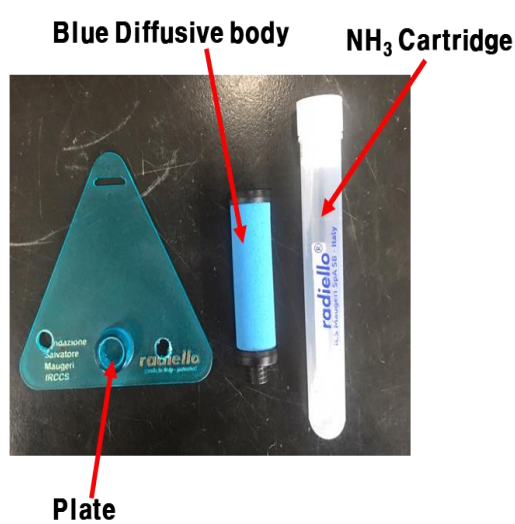


Farmland 2

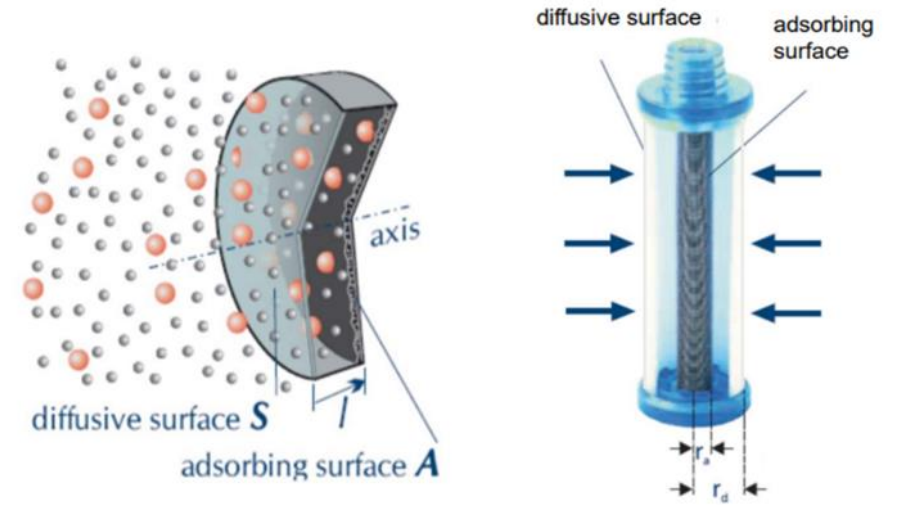


Passive sampler?

Passive sampler sets



Principal of passive sampler



- The sampler is composed of:
 - Blue diffusive body (RAD1201) + Triangular support plate (RAD121) + Vertical adapter (RAD122) + Chemical absorption cartridge (RAD168)
- NH₃ is captured by adsorption in the form of NH₄⁺
 - NH₄⁺ in PM_{2.5} does not penetrate through the blue diffusive body
 - For a 24-hour exposure, the detection limit is 1 μg m⁻³.
 - The 2σ uncertainty corresponds to 6.5% of the total allowable exposure range.

NH₃ analysis



- NH₄⁺ analyzed using cation ion chromatography (IC)
 - Instrument: Thermo Scientific Dionex ICS-1100
 - cation column: Dionex IonPac™ CS12A
 - eluent: For 1 L, mix 1.3 mL methanesulfonic acid (MSA)
 - flow rate: Set from 0.5 mL min⁻¹ → fixed at 1.0 mL min⁻¹
 - detector current: 59 mA
 - calibrated with six levels of NH₄⁺ standard solution



NH₃ analysis



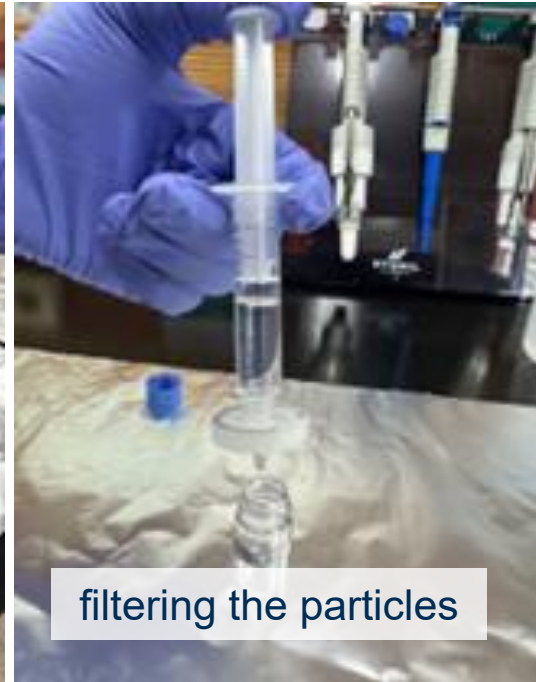
Adding DI 8 ml



Sonication during 60 mins



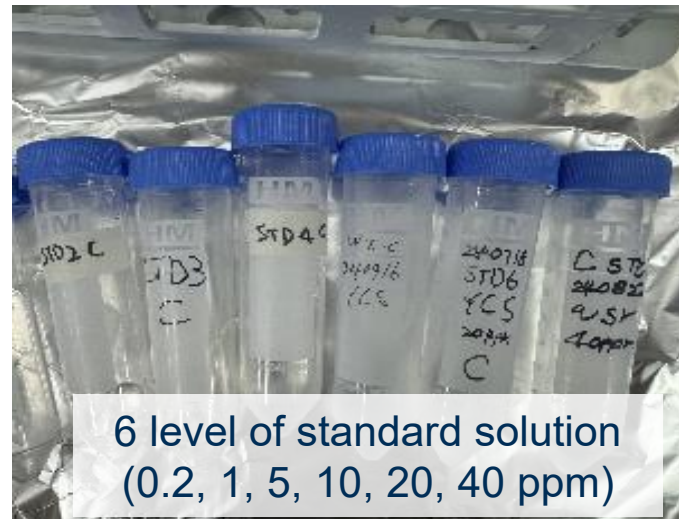
Vortexing 2 mins



filtering the particles



Storage in vial



6 level of standard solution (0.2, 1, 5, 10, 20, 40 ppm)



IC analysis

NH₃ analysis



- Equation of conversion from NH₄⁺ to NH₃

- Temp. and pres.: AWS data from a nearby station (near the measurement site)

$$D_{NH_3}(T,P) = D_{0,1} \times \left(\frac{P_0}{P}\right) \times \left(\frac{T}{T_0}\right)^{1.81}$$

$$Q_{NH_3} = D_{NH_3}(T,P) \times \frac{A}{\Delta X}$$

$$C_{NH_3} = \frac{10^6 \times m_{NH_3}}{t \times Q_{NH_3}}$$

D_{NH₃} = Diffusivity of NH₃ in atmosphere (cm² sec⁻¹),

D_{0,1} = 0.1978 (273K), 1 atm (cm² sec⁻¹)

P = Ambient Pressure (atm), **P₀** = 1 atm,

T = Local Temperature (K), **T₀** = 273K (0°C),

Q_{NH₃} = Diffusional flow rate through passive sampler (cm³ sec⁻¹)

A/ΔX = 14.2 cm (Day et al., 2012)

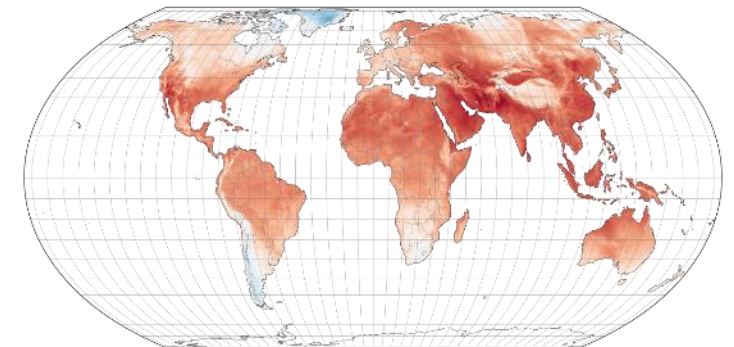
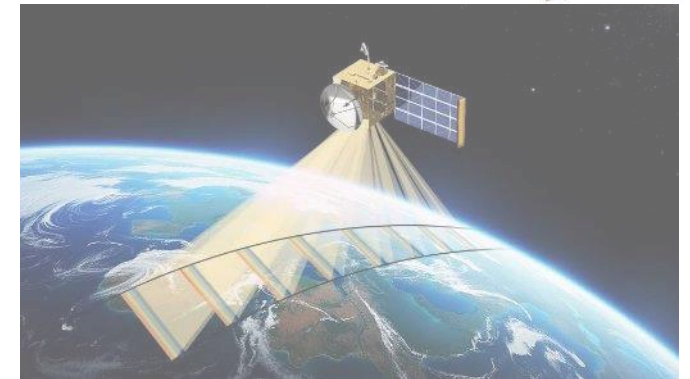
m_{NH₃} = NH₃ mass measured by IC (μg)

t = Sampling time (sec),

C_{NH₃} = NH₃ Concentration in air (μg m⁻³)

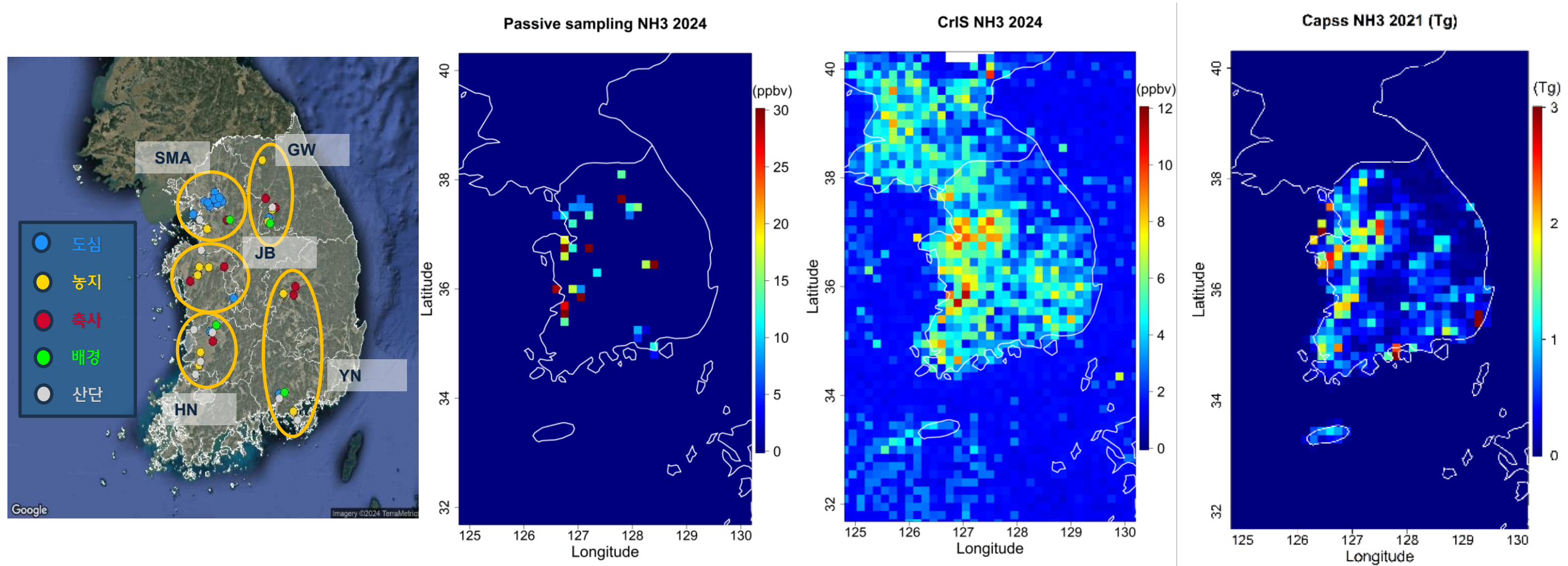
Ancillary data

- CrIS (Cross-track Infrared Sounder; NOAA-20)
 - Twice-daily observations (13:30 PM, 01:30 AM)
 - Swath: 2,200 km width ($0.15^\circ \times 0.15^\circ$ grid size)
 - Total NH_3 vertical column (molec cm^{-2}) and land fraction
 - $\text{Quality_Flag} \geq 5$ and $\text{Cloud_Flag} = 0$
- MODIS (Moderate Resolution Imaging Spectroradiometer)
 - Landcover data(2022~2024); QC = 0, 2
 - Spatial resolution : 500 m x 500 m
 - IGBP type(w/ 17 categories)
- ERA5 (ECMWF Reanalysis v5)
 - Spatial resolution : $0.25^\circ \times 0.25^\circ$ (hourly data)
 - Temp, RH, WD, WS, PBLH, Precipitation



Spatial distribution of NH₃ in 2024

- Both passive sampling and satellite observations can similarly detect hot spot regions in CAPSS 2021.



Estimation for NH₃ conc. at surface level (1)

- Input data : NH₃(*in-situ*, CrIS), Temp, RH, PBLH, WD, WS, season
land-fraction, land cover; 1~17(ratio), precipitation

- MLR (Multiple Linear Regression)

$$\text{NH}_{3 \text{ in situ}} = C_1 + C_2 \cdot \text{NH}_{3 \text{ satellite}} + C_3 \cdot \text{Temp} + C_4 \cdot \text{RH} + C_5 \cdot \text{PBLH} + C_6 \cdot \text{WD} + C_7 \cdot \text{WS} \\ + C_8 \cdot \text{season} + C_9 \cdot \text{land fraction} + C_{10} \cdot \text{landcover} + C_{11} \cdot \text{precip}$$

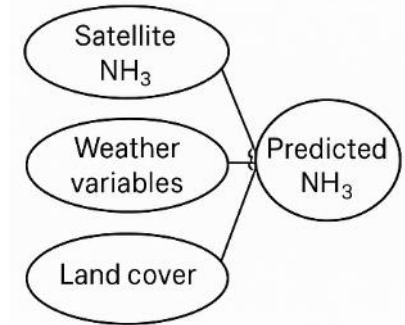
- RF (Random Forest)

- Decision tree–based ensemble learning algorithm
- Individual tree predictions are combined using averaging (regression) or majority (classification)
- Model validation using 10-fold cross-validation (CV)

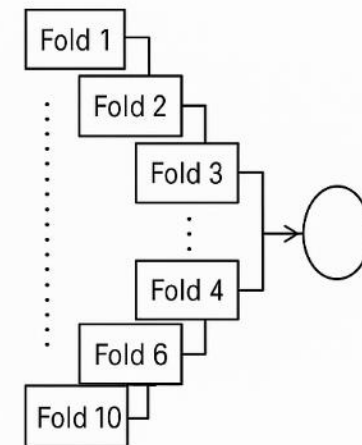
- ANN (Artificial Neural Network)

- trained using MLP(Multi-Layer Perceptron)
- 10-fold CV for validation and to minimize overfitting

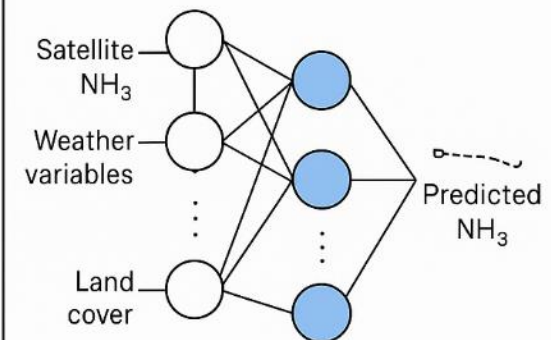
Multiple Linear Regression (MLR)



Random Forest (RF)

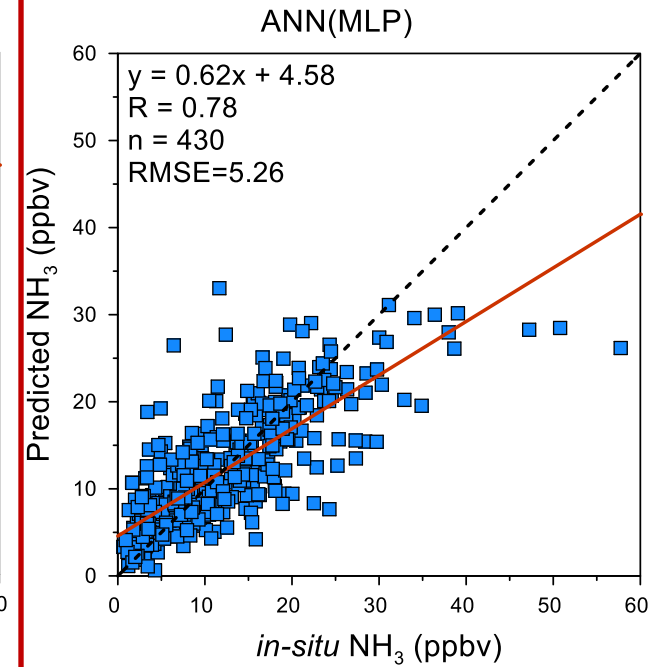
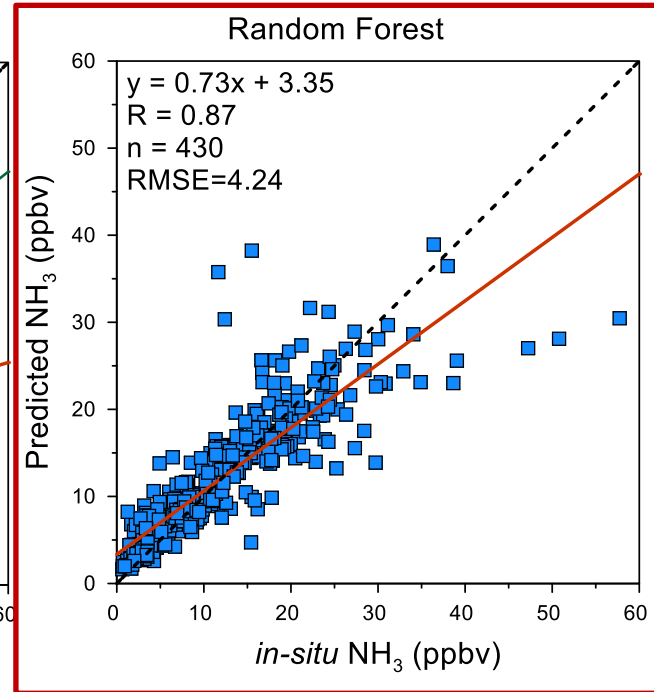
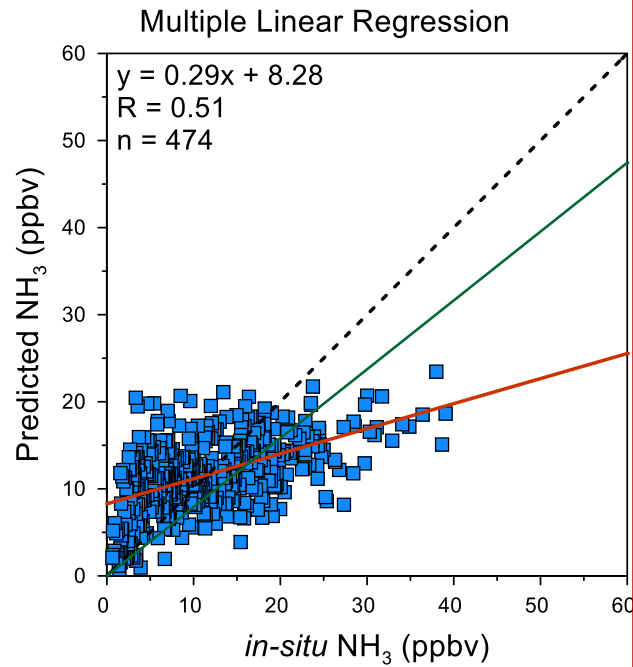
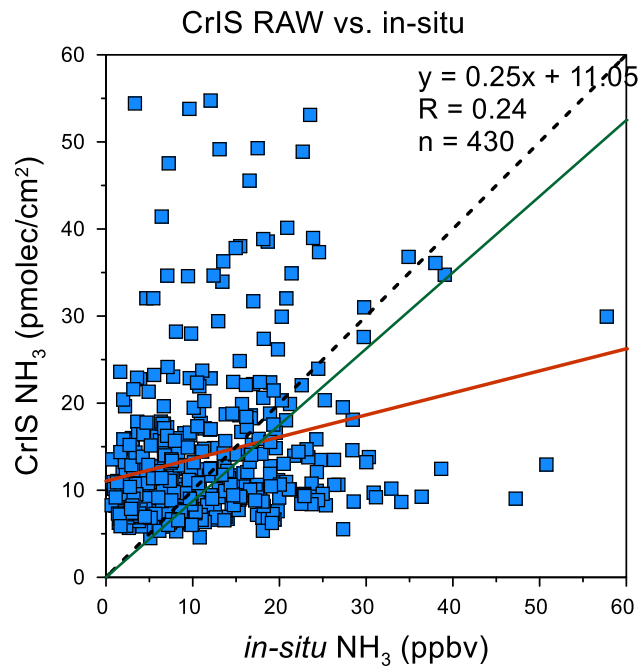


Artificial Neural Network (ANN)



Estimation for NH₃ conc. at surface level (2)

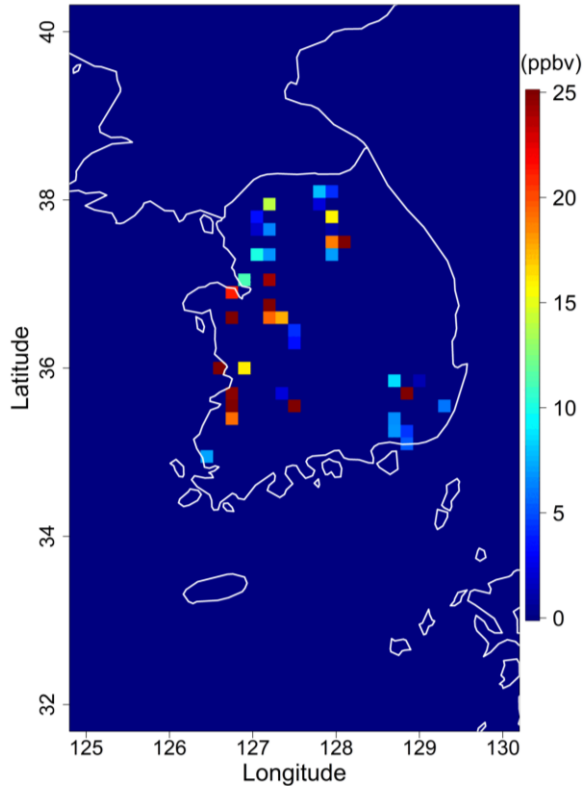
- RF(R=0.87) shows best performance than ANN(R=0.78) and MLR(R=0.51) along with RMSE



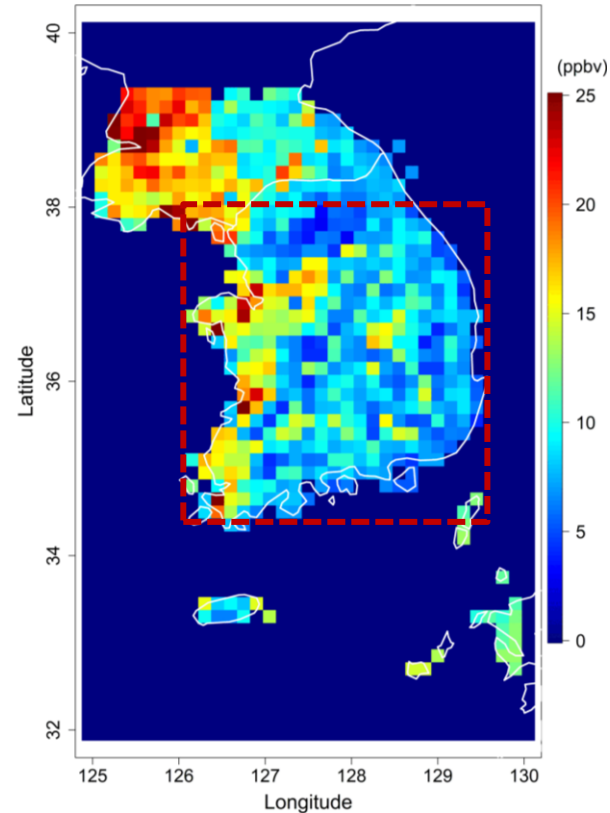
Estimation for NH₃ conc. at surface level (3)

- Monthly variation of NH₃ from *in situ* vs. RF prediction

Passive sampling NH₃ 2022-2024 01

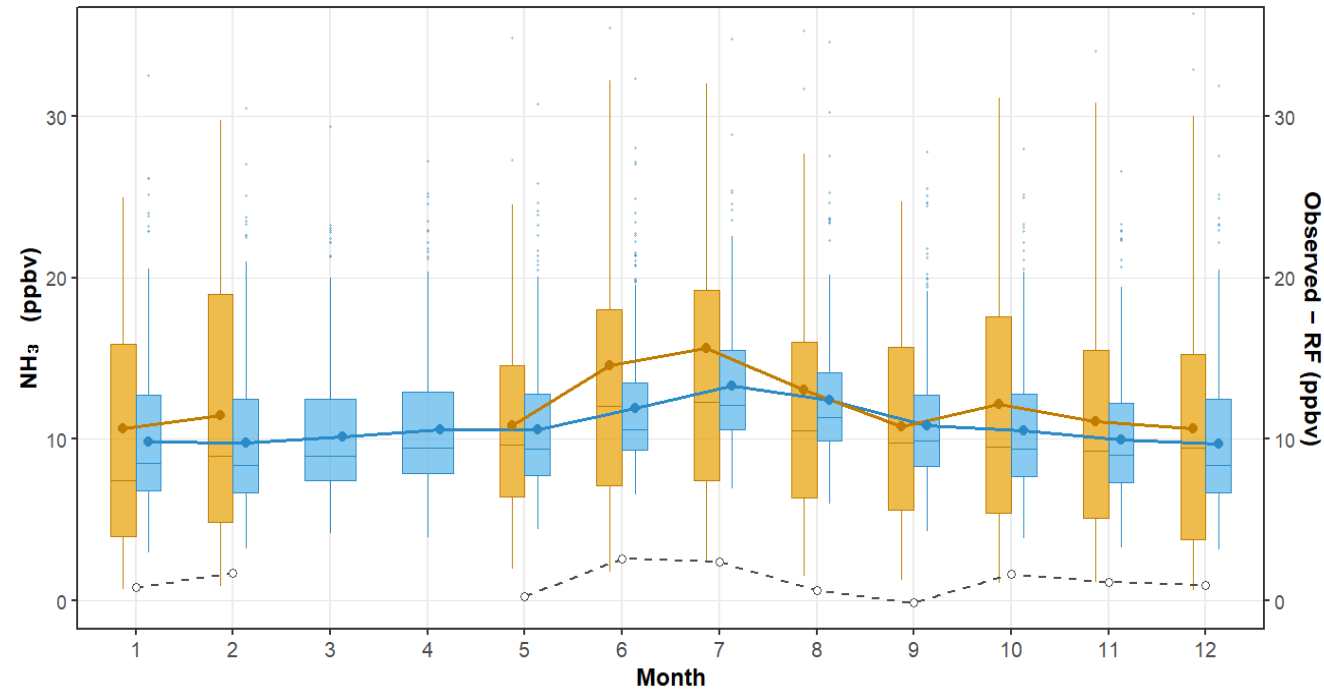


RF NH₃ (ppbv) Month 01



Domain: 34.20–38.20°N, 126.00–129.45°E

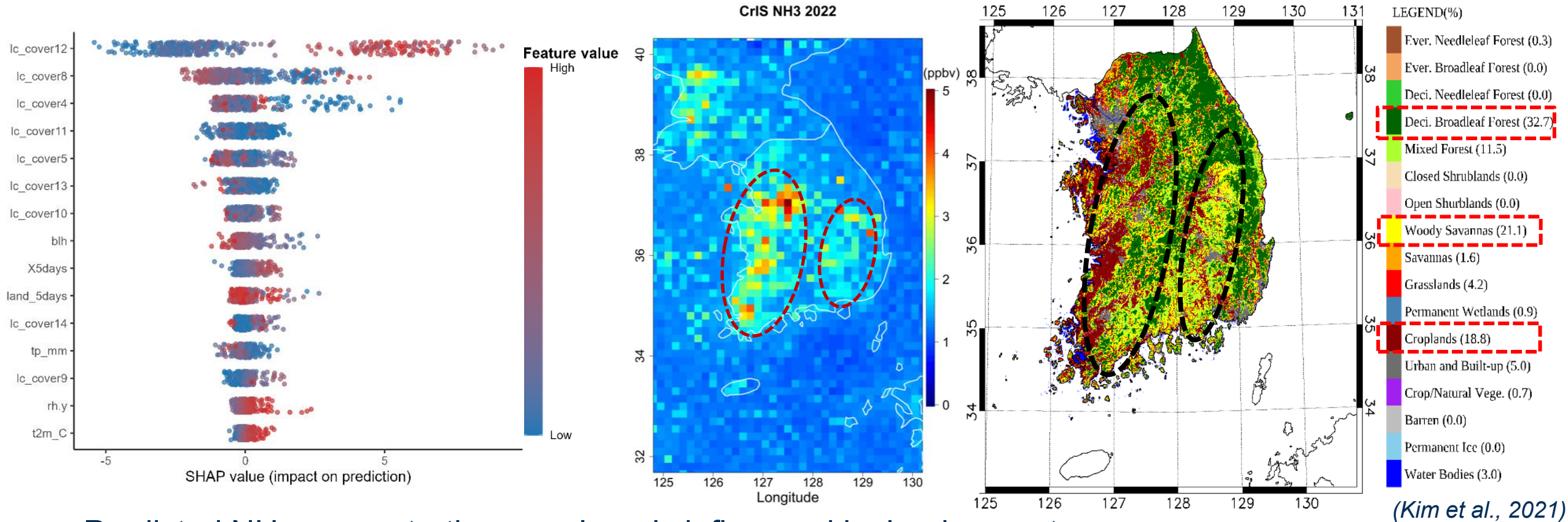
Observed RF



- Similar variation in monthly variation from both *in-situ* and satellites with low bias

Estimation for NH₃ conc. at surface level (4)

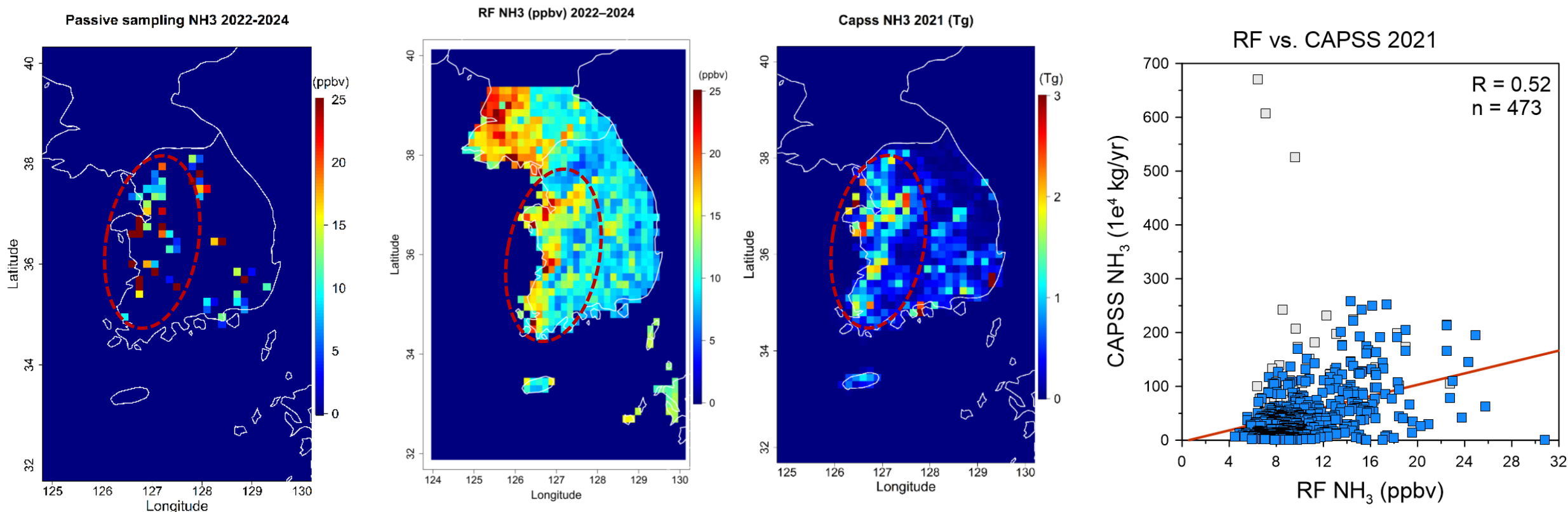
■ Contribution of variables for RF



- Predicted NH₃ concentrations are largely influenced by land-cover type
 - Key land-cover classes: landcover12 (croplands), landcover8 (woody savannas), landcover4 (deciduous broadleaf forests)
- Among non-land-cover variables, PBL height is identified as the most influential factor

Estimation for NH₃ conc. at surface level (5)

- Predicted NH₃ from RF with CAPSS in 2021



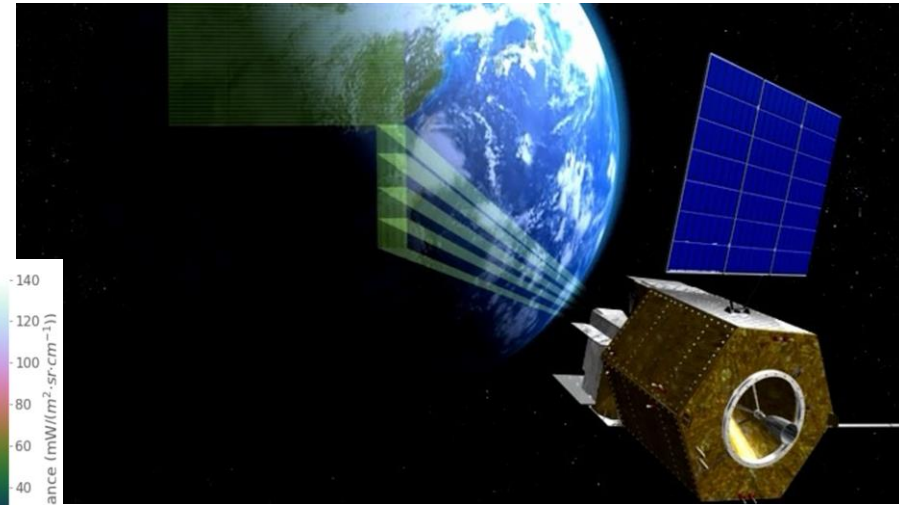
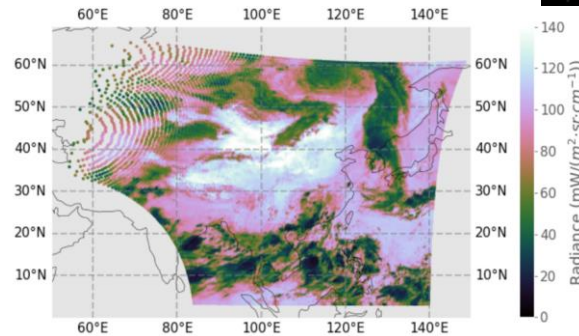
- *in-situ* and CAPSS show similar spatial patterns of high NH₃ concentrations/emission regions
 - notably the Seoul Metropolitan Area and the southwestern region
- Comparison between annual mean NH₃ and CAPSS emissions (mobile + area sources) shows a meaningful correlation (R = 0.52)

Other satellites will be tested!



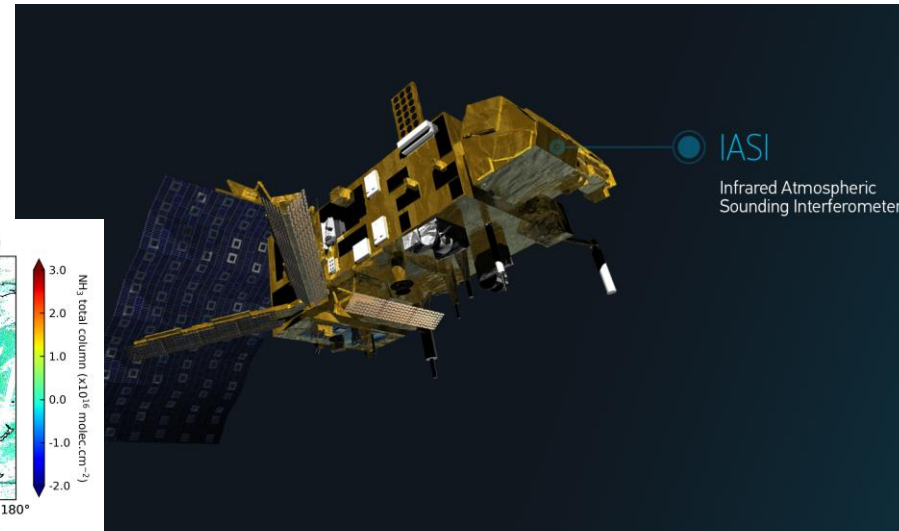
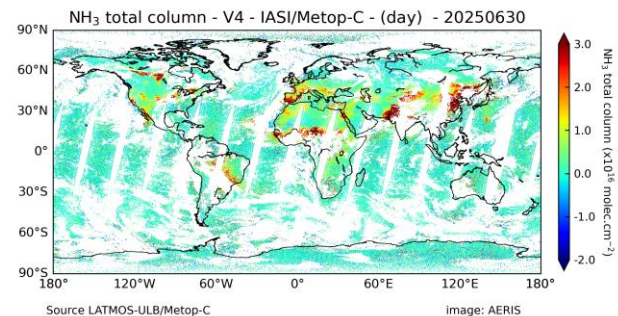
■ GIIRS(Geostationary Interferometric Infrared Sounder)

- FengYun-4A (2016) and FengYun-4B (2021)
- A geostationary (35,787 km)
- Spatial resolution: ~12 km at nadir
- Temporal resolution: 2 hours
- total vertical column density (molec cm⁻²)



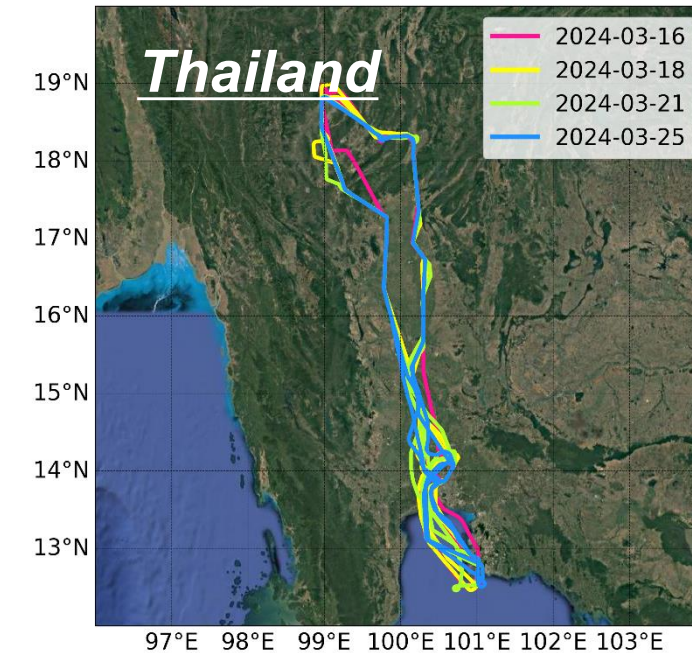
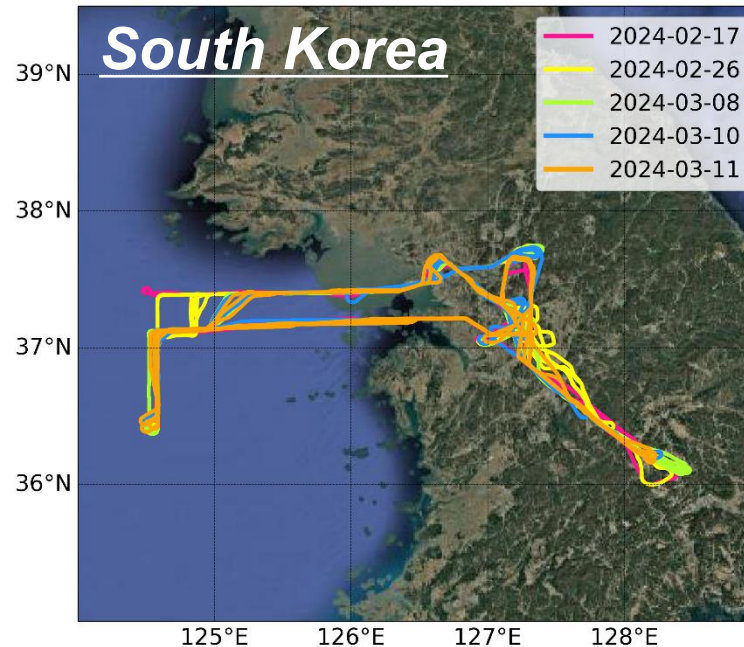
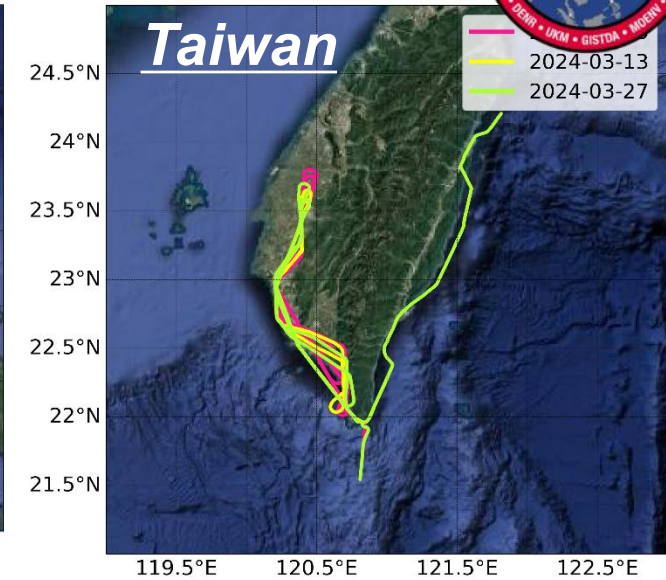
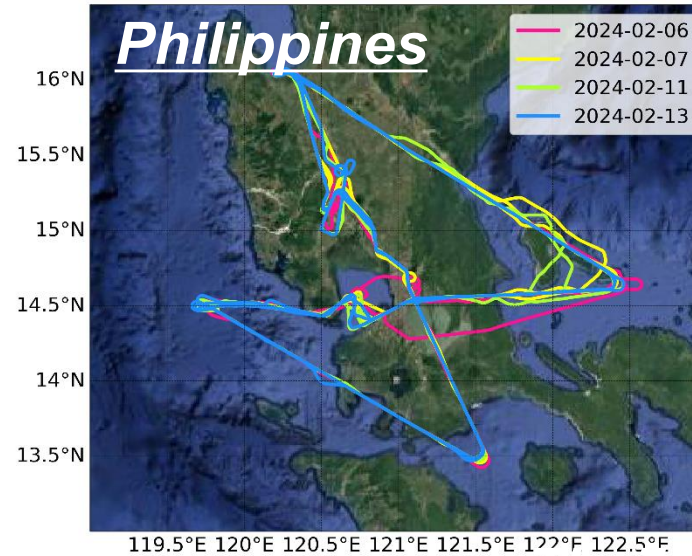
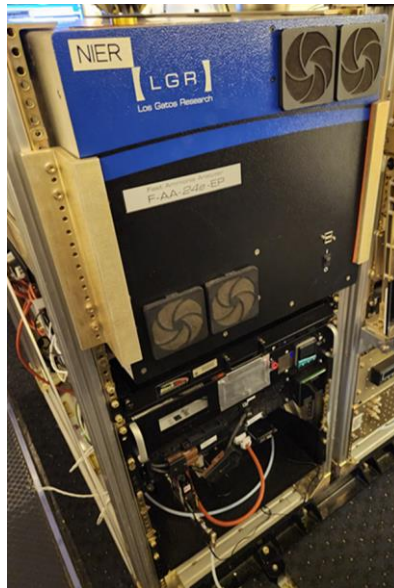
■ IASI (Infrared Atmospheric Sounding Interferometer)

- MetOp-A (2006), MetOp-B (2012), and MetOp-C (2018)
- Polar-orbiting twice-daily overpasses (09:30 and 21:30)
- Swath: 2,100 km
- Spatial resolution: ~12 km at nadir
- total vertical column density(molec cm⁻²)



Validation of the CrIS NH₃ vertical profile

- OA-ICOS (Off-Axis Integrated Cavity Output Spectroscopy)
 - Detection limit: 0.19 ppbv (1second, 1 σ)
 - Uncertainty: 10%
 - Due to limitations in pumping efficiency, response time increased to 7 seconds
 - Time resolution: 1Hz



Take home messages

- To evaluate the spatial distribution of NH_3 over Korea, in situ measurements should be integrated with satellite observations (e.g., CrIS).
 - **in-situ**: a single site located near a hot spot source (2022–2024) or within the urban air-quality monitoring network (2025)
 - **Satellite**: mean concentrations derived at $\sim 15 \text{ km} \times 15 \text{ km}$ resolution
- **Quantitative** assessment can be biased due to strong local influences near emission sources.
- Qualitative** assessment suggest that satellites can potentially detect high-emission regions.
- After applying statistical methods to the satellite data, the resulting monthly variation patterns appear reasonable.
- In future work, satellite data will be used to identify missing emission sources and/or to derive monthly activity factors.



대기오염측정소



@AQMS

Thank you