Supplement for: Investigating Regional Halocarbon Emissions: The Seoul Tracer Release Experiment

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S1. MFC Calibration

The mass flow controllers (MFCs, Voegtlin, 60/250 L min^{-1}) we used for this project are factory-calibrated for ambient air; For their use with the pure tracers, a recalibration was necessary, which was conducted in the Empa laboratory. The MFC (0–60 L) used for the HFC-161 tracer was recalibrated earlier, yielding a calibration conversion factor of 0.43 (Rust et al. (2024)). We recalibrated the MFC as part of the present study using a volumeter (DC-2 flow calibrator, DryCal, BIOS, calibrated by the Swiss Federal Institute of Metrology (METAS)). Based on these experiments, we found a calibration conversion factor of 0.49 $\pm$ 0.06, which is in range with the earlier measurements (Rust et al. (2024)).

The same procedure gave a preliminary calibration factor of 0.20 for HFO-1336mzz(E) using the DC-2 flow calibrator (set flows between 5 – 45 L min^{-1}). To calibrate the larger HFO-1336mzz(E) flows used during the releases, a diaphragm gas meter (GZ, model: RF1 c G4 E, Intron) was used, and the volume difference after 1 minute (5 minutes for the smaller flows) was measured. Each flow was determined 3 times, and the average was used for the determination of the calibration factor. MFC flows from 5 – 250 L min^{-1} were calibrated using the GM. Both the results of the DC-2 and the GM are displayed in Figure S1. The final calibration factor used for the HFO tracer was 0.22 $\pm$ 0.01. For each release, the difference between the calculated and weighed tracer was also included as an error.

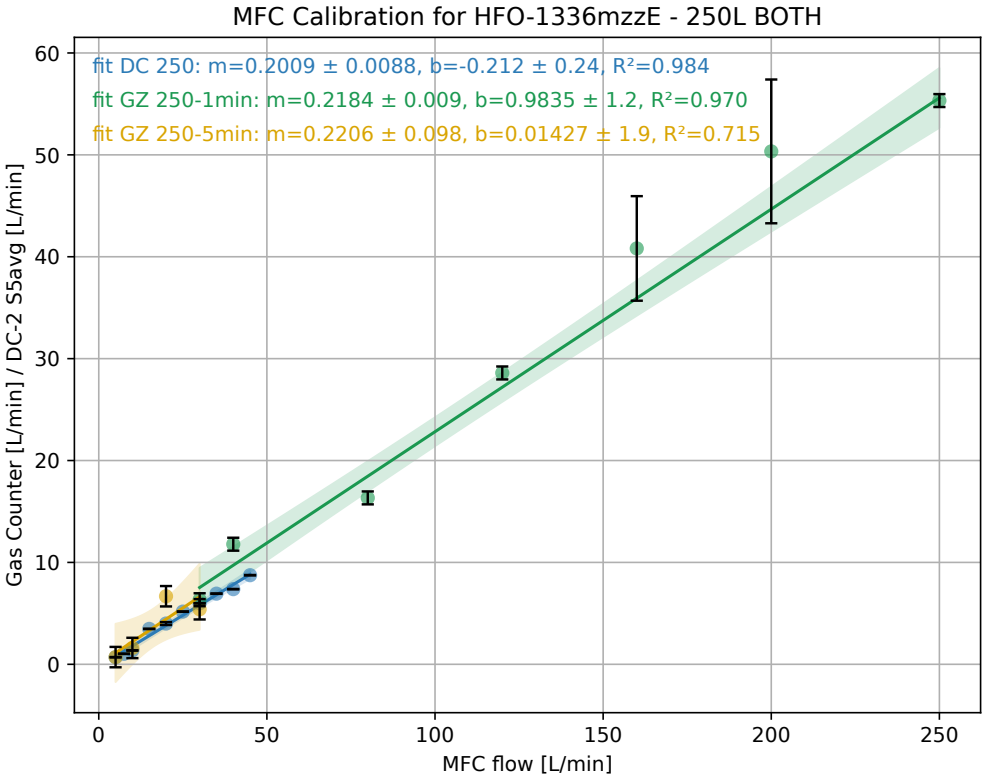


Figure S1. MFC flow vs actual flow for HFO-1336mzz(E) in L min^{-1} using a volumeter (DC-2) and a gas meter. MFC flows from 5 to 250 L min^{-1} were calibrated.

S2. Empa-2016 Primary Calibration Scale for HFO-1336mzz(E)

Because no commercial reference material is available at the ppt (parts-per-trillion, 10^{-12}) mole fraction level for HFO-1336mzz(E), we produced our own primary calibration standard EP-003 at ppt level using volumetric dilution methods. The method follows roughly that outlined in Vollmer et al. (2015). A suite of other new compounds was included in this standard, which, however, have not been published so far.

In a first step (already conducted in 2016), a high-concentration standard was produced (termed 'HCP-008') with nominal mole fractions of 2.4 ppm (parts-per-million, 10^{-6}). For this, an aliquot of each pure compound was transferred into a 34 L internally electropolished stainless steel (ss) tank (Essex Cryogenics, Missouri), which we here term ESX-11-99. This is an "old style" (thin wall, Nupro valve, 600 psi maximum pressure) tank. The volume of ESX-11-99 needed to be determined accurately, and this was done in two ways: Firstly, a method was used that involved filling the tank with synthetic air using a mass-flow controller (MFC) while recording the pressure in the tank. Given the calibration of the MFC, this was done in the pressure range from 0–1 bar. MFC readings were corrected to room temperature, and repeated final pressure readings after filling the tank ensured little variation due to potential warming during the filling. The second method was weight-based, by filling the tank with de-ionised and partially de-gassed water. After thermal equilibration of the water to room temperature, the net weight was converted to a volume using the density of pure water. The first method (34.3 L) was more trustworthy and was applied for the subsequent dilution calculations. The water-based method suffered from potential biases because our high-accuracy, high-weight balance was temporarily unavailable.

ESX-11-99 was then evacuated and dried before filling. Subsequently, de-ionised water was injected into this tank to $\sim$22 mbar, followed by an addition of synthetic air to 100 mbar, both to moisten/condition the surfaces before injecting aliquots of pure compounds.

Some of the pure compounds needed distillation, including HFO-1336mzz(E). For this, the original container was placed into a dewar filled with ethanol and cooled to ~ -100 °C (using liquid-N_2). The headspace was pumped away briefly through the filling setup (consisting of a Valco-VICI 6-port 2-pos valve). The container was then warmed to room temperature before repeating the cooling/pumping twice. Ultimately, the container was warmed to room temperature and the vapour was released into a 5 ml sample loop where the pressure of the compound was measured and cross-checked with published data. For HFO-1336mzz(E), we found a vapour pressure of 1.548 bar (pressure gauge Leo, Keller, Switzerland) at 19.6 °C, which is slightly lower compared with a published value of 1.635 hPa at 20.4 °C (Chemours, 2026). A fraction of the HFO-1336mzz(E) vapour was then pumped off, leaving 0.482 bar in the sample loop. This pressure was found stable over minutes, demonstrating that no condensation had previously occurred in the sample loop. Ultimately, the pure compound was flushed into ESX-11-99. A similar procedure was conducted with other pure compounds, including a set of bootstrap gases for which a primary calibration scale was available. After all compounds were added to ESX-11-99, it was filled with synthetic air (shown to be free of the compounds of interest) to 30 bar and thermally equilibrated with the laboratory air temperature before a final pressure reading was performed. This defined the filling of HCP-008 with the compounds at ppm level. In 2025, an aliquot of HCP-008 was diluted into a 3.8 L cylinder (Swagelok) by a repeated (3 times) pressure-based procedure, during which an aliquot of 1 bar

was pressurised with HFO-1336mzz(E)-free synthetic air to $\sim$120 bar, resulting in an overall dilution factor of 0.5253×10^{-6}, resulting in 1.29 ppt. This dilution, termed EP-003, defines the Empa-2025 primary calibration scale for HFO-1336mzz(E).

EP-003 was measured on the laboratory Medusa-GCMS (empa-medusa) against standards of known bootstrap gas concentrations. The agreement between calculated and measured bootstrap gases was poor, ranging from an underestimated concentration for HCFC-142b of 16% to an overestimated concentration for HFO-1336mzz(Z) of 28% (while, e.g. SF_6 was underestimated by 5% and HCFC-141b agreed within 1% between calculated and measured concentrations.

The poor agreement with some of the bootstrap gases led us to include HFO-1336mzz(E) in a later attempt in 2025, where another primary standard was produced (LC-2025B), including some new compounds not relevant to the present study. Bootstrap gases agreed very well with known calibration scales, and for HFO-1336mzz(E), an agreement between LC-2025B and EP-003 within 3% was found, leading us to some confidence in the assignment for EP-003 and its use as a primary calibration standard.

The quantifiable uncertainties in this standard preparation procedure, as outlined above, are small. However, the poor agreement with some of the bootstrap gases suggests that there are additional significant uncertainties we are not fully accounting for. Based on this information, we estimate an overall absolute uncertainty on the calibration scale for HFO-1336mzz(E) at 15%.

S3. Compounds and tracer properties

Table S1. Overview of measured halogenated target compounds and tracers, ozone-depletion potentials (ODP), global warming potentials (GWP) over a 100-year time frame, previous hydrofluorocarbon (HFC) emission estimates for South Korea, and whether compounds are regulated in South Korea.

Compound	Chemical formula	ODP[a]	GWP 100-yr[a]	Emission estimates for 2024[b] [$\mathrm{kt\,yr^{-1}}$]	Regulation
HFC-161	CH_3CH_2F	0	5	–	None
HFO-1336mzz(E)	(E)-$CF_3CH{=}CHCF_3$	0	7	–	None
HFC-125	CF_3CHF_2	0	3820	1.84± 0.19	Kigali Amendment[c]
HFC-134a	CF_3CH_2F	0	1330	2.85± 0.36	Kigali Amendment[c]
HFC-143a	CF_3CH_3	0	5900	0.38± 0.05	Kigali Amendment[c]
HFC-152a	CF_2HCH_3	0	153	1.51± 0.17	Kigali Amendment[c]
HFC-32	CCH_2F_2	0	749	1.59± 0.18	Kigali Amendment[c]

[a]Annex of the WMO 2022 Ozone Assessment (Burkholder and Hodnebrog (2022)).

[b]Revealing the significant acceleration of hydrofluorocarbon (HFC) emissions in eastern Asia through long-term atmospheric observations (Choi et al. (2024)),

[c] Non-Article 5 countries started reduction in 2019

Table S2. Primary calibration scale (PCS), PCS accuracy per compound and tracer. The propagation uncertainty and measurement precision are instrument-specific, due to different whole air working and transfer standards and measurement setups. For the *in-situ* measurements at Gosan (GSN), the whole air standard repeatability was used. For the flask samples from Anmyeondo (AMY) and Mokpo National University (MNU) analysed with the Empa laboratory instrument, the standard deviation from the triplicate analysis was used as the measure of precision. The propagation uncertainties are estimates of uncertainty along the calibration chain (secondary standards at SIO, tertiary transfer standards, quaternary working standards). For these, we assume similar measurement precisions as given for the individual instruments, and we approximate these uncertainties assuming 2 intercomparison steps.

Compound	PCS	PCS Accuracy [%]	Propagation Uncertainty [%]		Measurement Precision [%]	
			GSN-Med	Empa-Med	GSN-Med	Empa-Med
HFC-161	Empa-2013	10	4.2	4.9	2.9	5.3
HFO-1336mzz(E)	Empa-2016	15	1.4	3.1	1.0	2.4
HFC-125	SIO-14	3.0	0.20	0.32	0.30	0.42
HFC-134a	SIO-05	1.5	0.35	0.40	0.30	0.35
HFC-143a	SIO-07	3.0	0.36	0.42	0.49	0.56
HFC-152a	SIO-05	3.0	0.61	0.54	0.71	0.46
HFC-32	SIO-07	3.0	0.63	0.78	0.83	0.46

S4. FLEXPART Forecast

S4.1. Release November 18, 2024

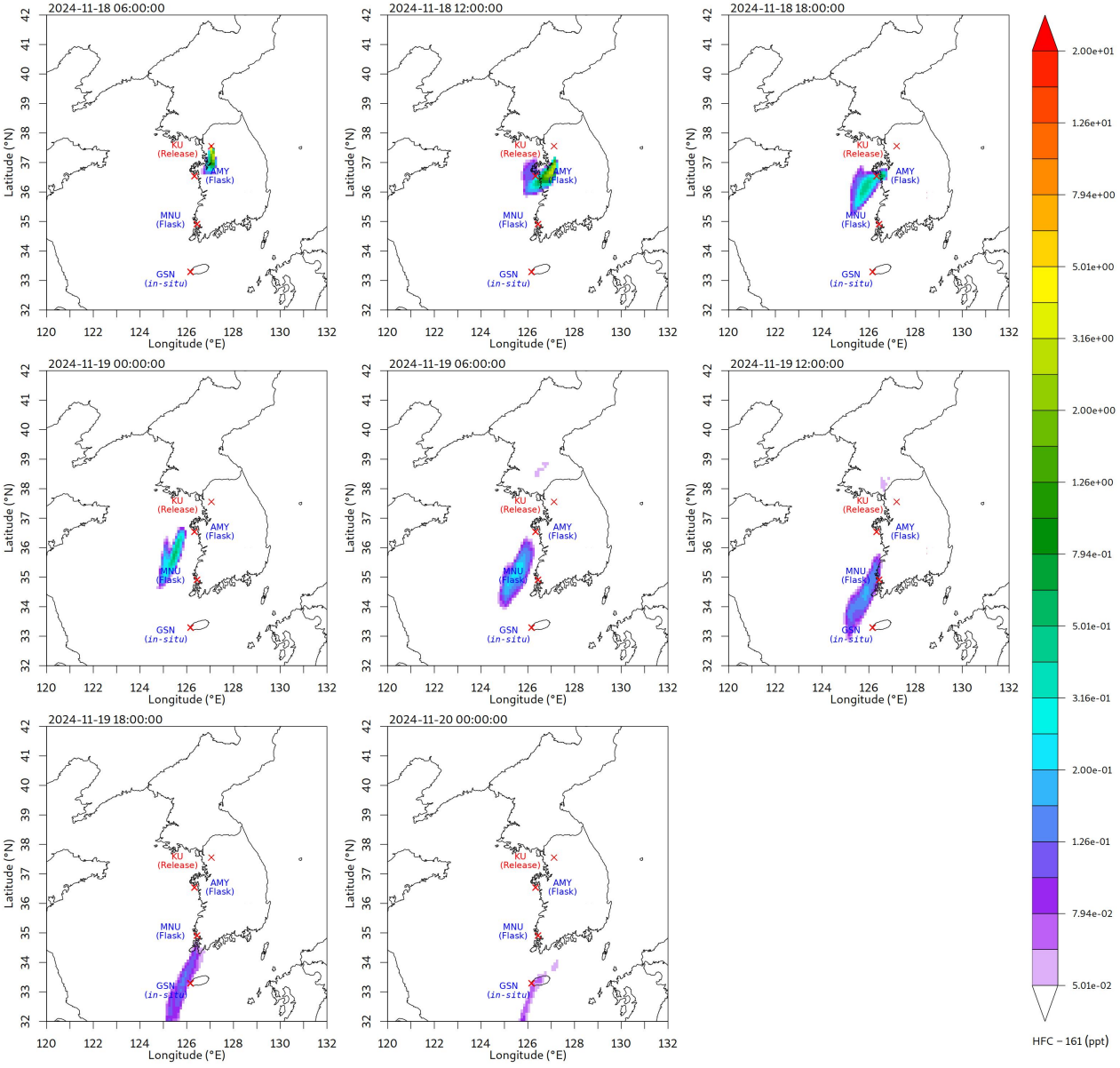


Figure S2. Forecast that was used for the release starting on November 18, 2024, at 08:00 UTC, where the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) were in the trajectory of the tracer plume. The forecast for HFC-161 was used for both tracers.

S4.2. Release November 22, 2024

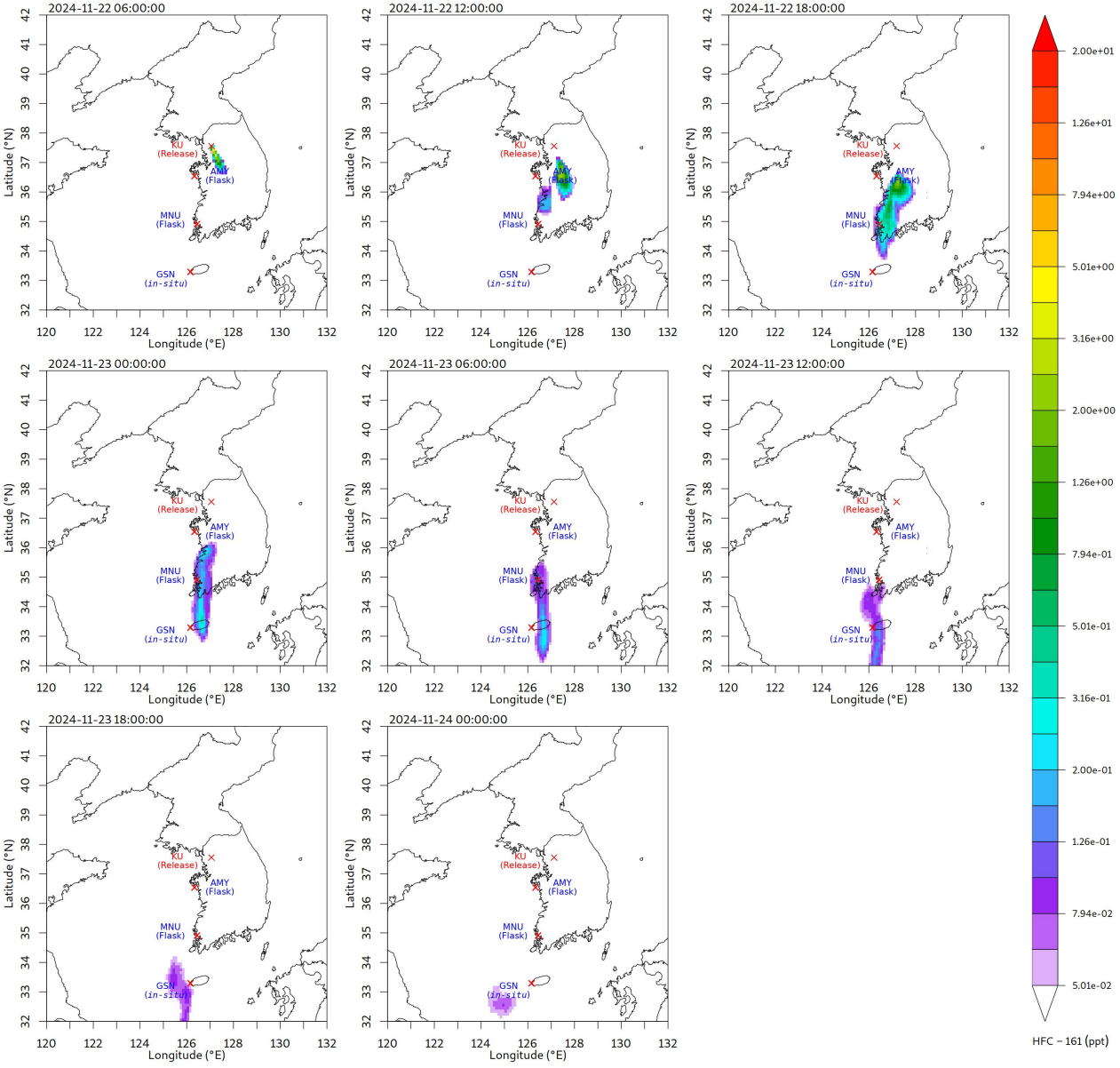


Figure S3. Forecast that was used for the release starting on November 22, 2024, at 06:00 UTC, where the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) were in the trajectory of the tracer plume. The forecast for HFC-161 was used for both tracers.

S4.3. Release April 22, 2025

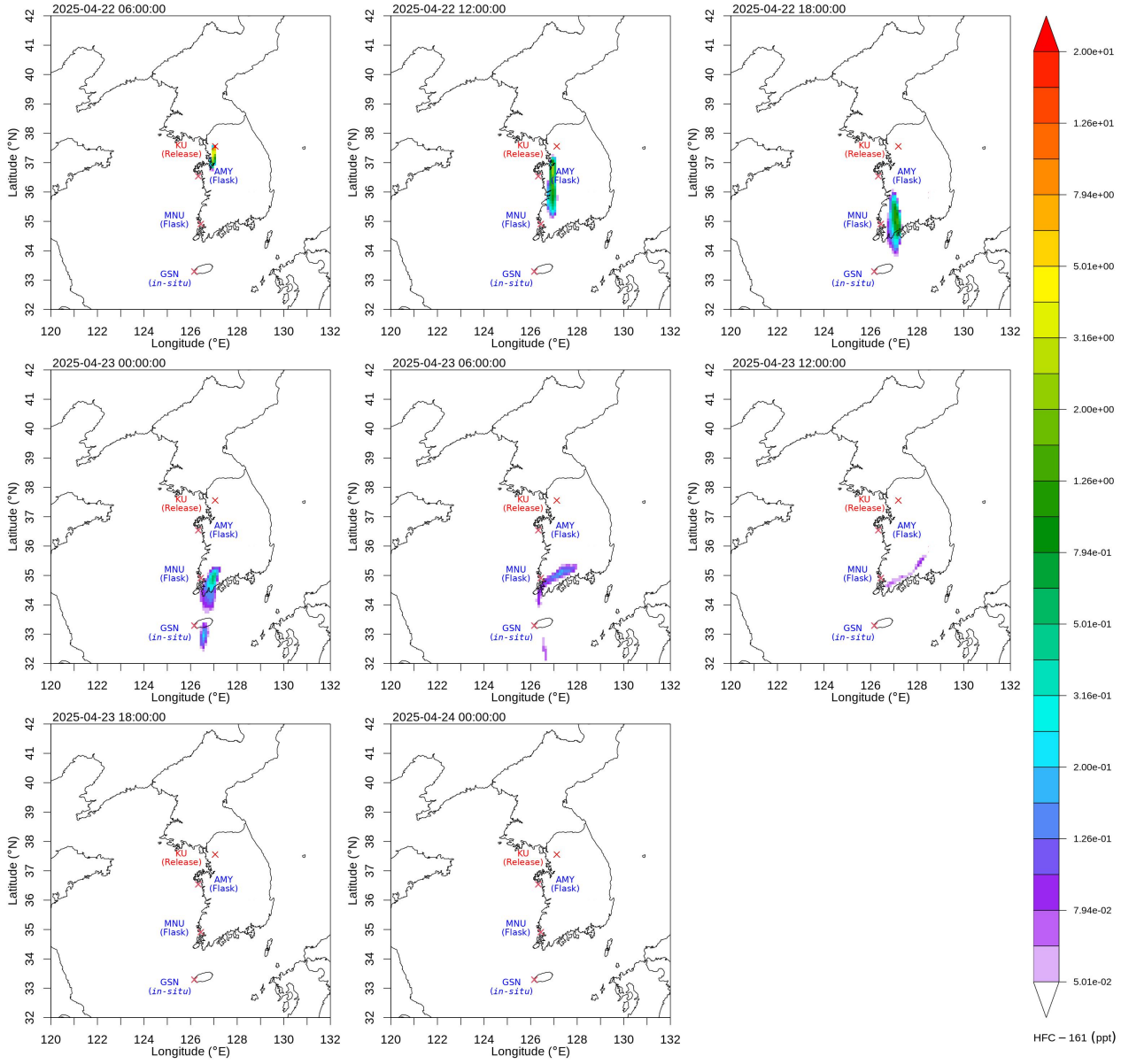


Figure S4. Forecast that was used for the release starting on April 22, 2025, at 06:30 UTC, where the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) were in the trajectory of the tracer plume. The forecast for HFC-161 was used for both tracers.

S4.4. Release May 23, 2025

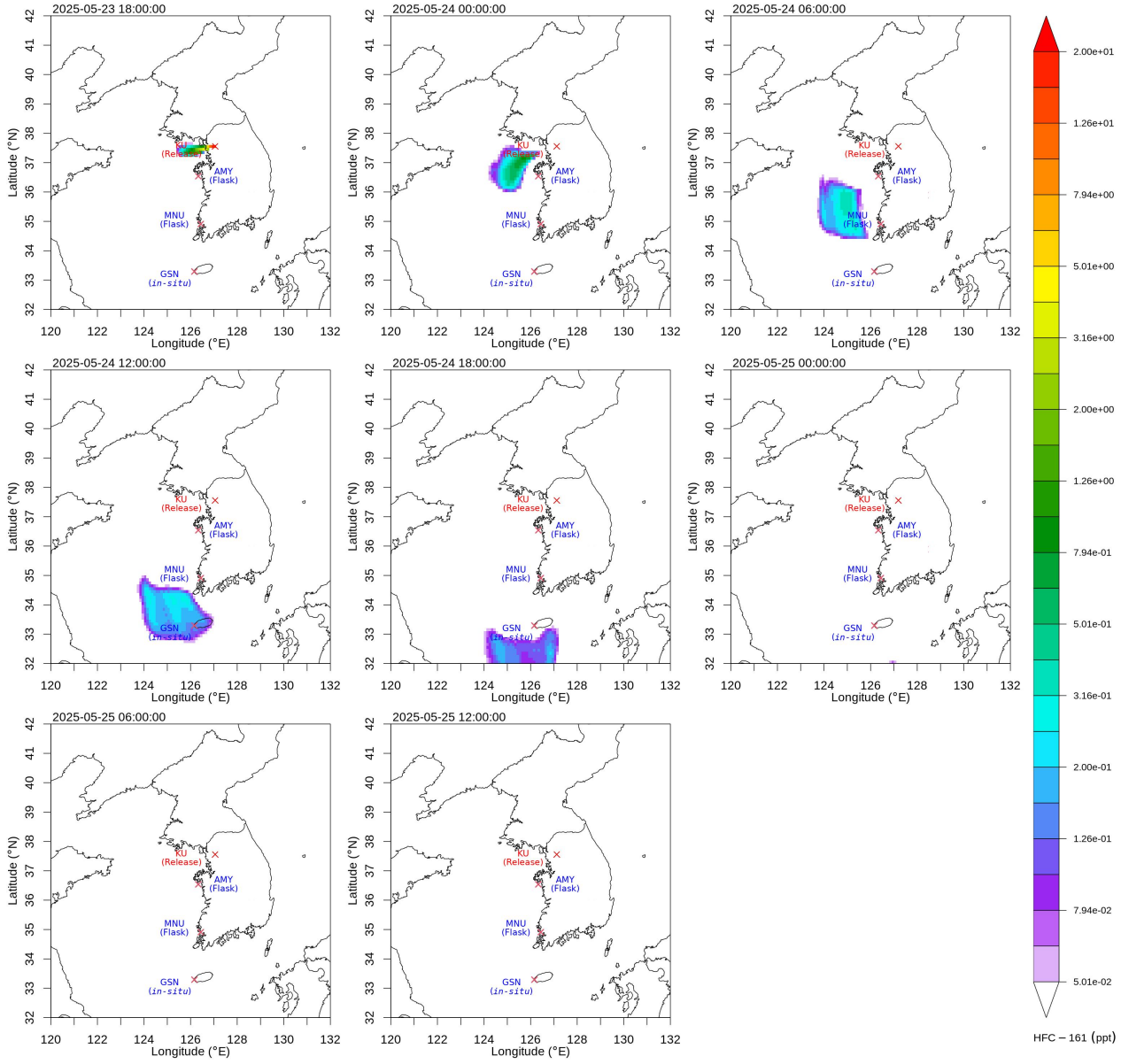


Figure S5. Forecast that was used for the release starting on May 23, 2025, at 18:00 UTC, where the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) were in the trajectory of the tracer plume. The forecast for HFC-161 was used for both tracers.

S5. FLEXPART Simulation after the release

S5.1. HFC-161 Release November 18, 2024

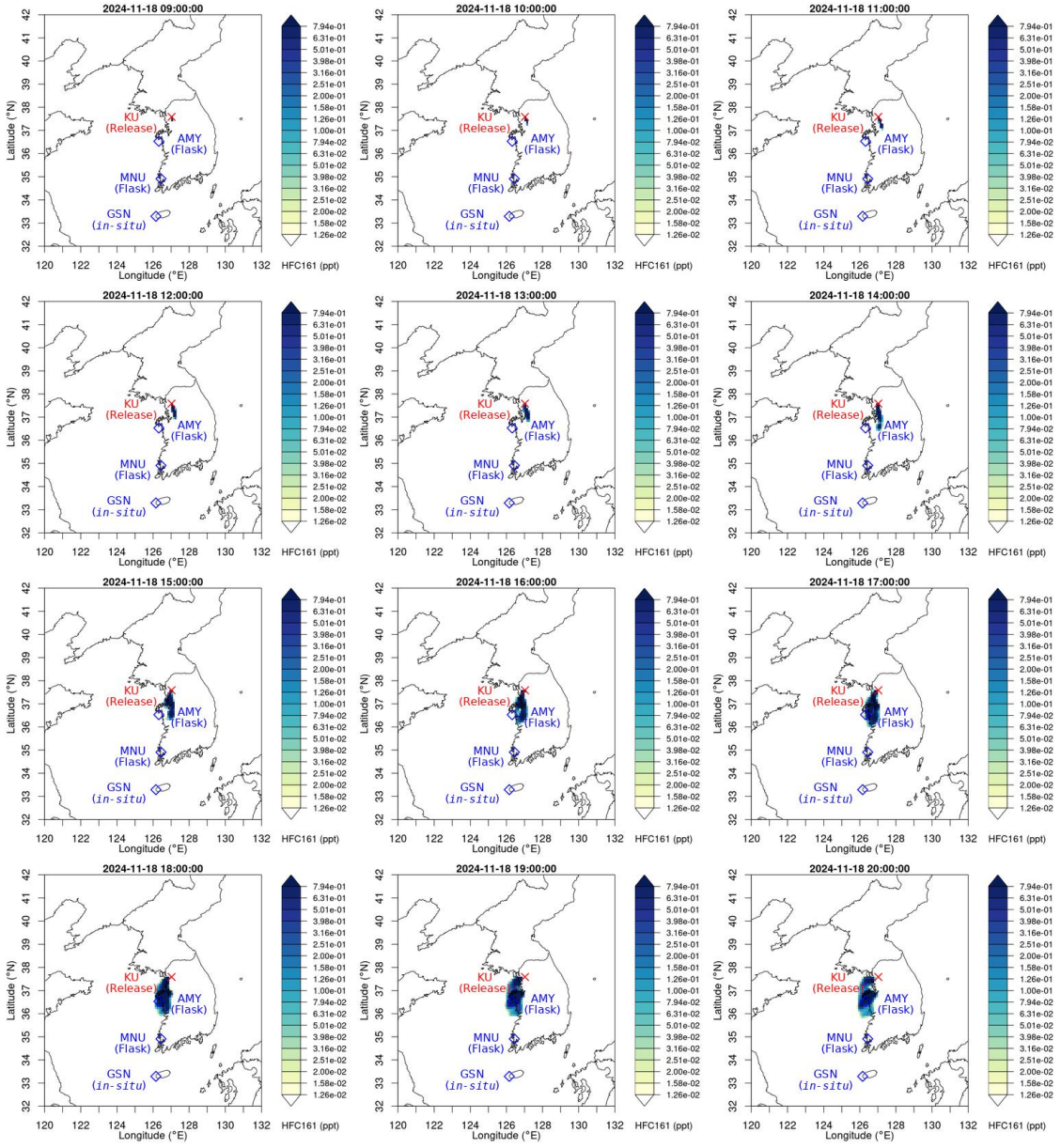


Figure S6. FLEXPART simulation for the HFC-161 dispersion on November 18, 2024, from 09:00 to 20:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

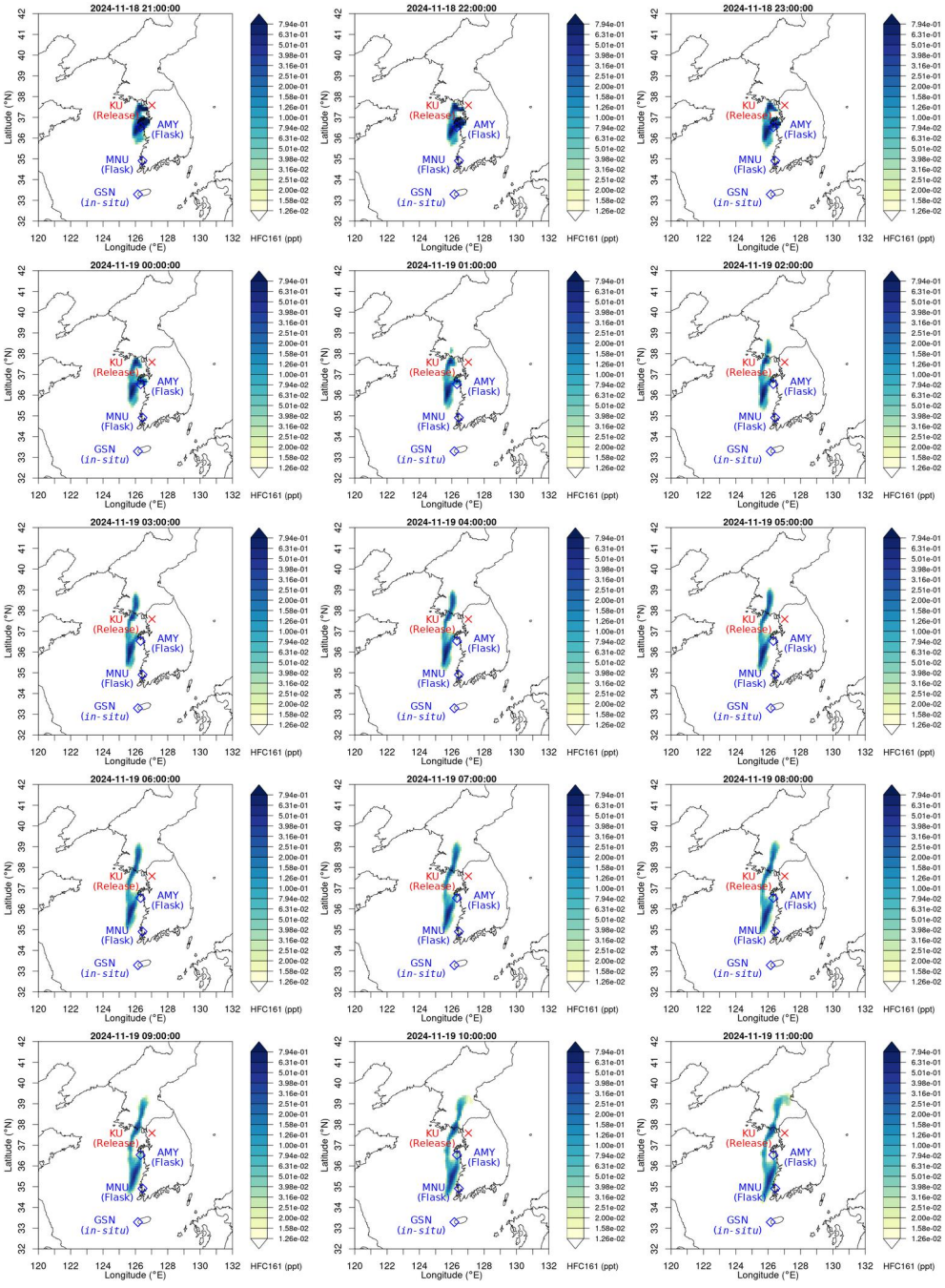


Figure S7. FLEXPART simulation for the HFC-161 dispersion on November 18, 2024, from 21:00 UTC to November 19, 2024, 11:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

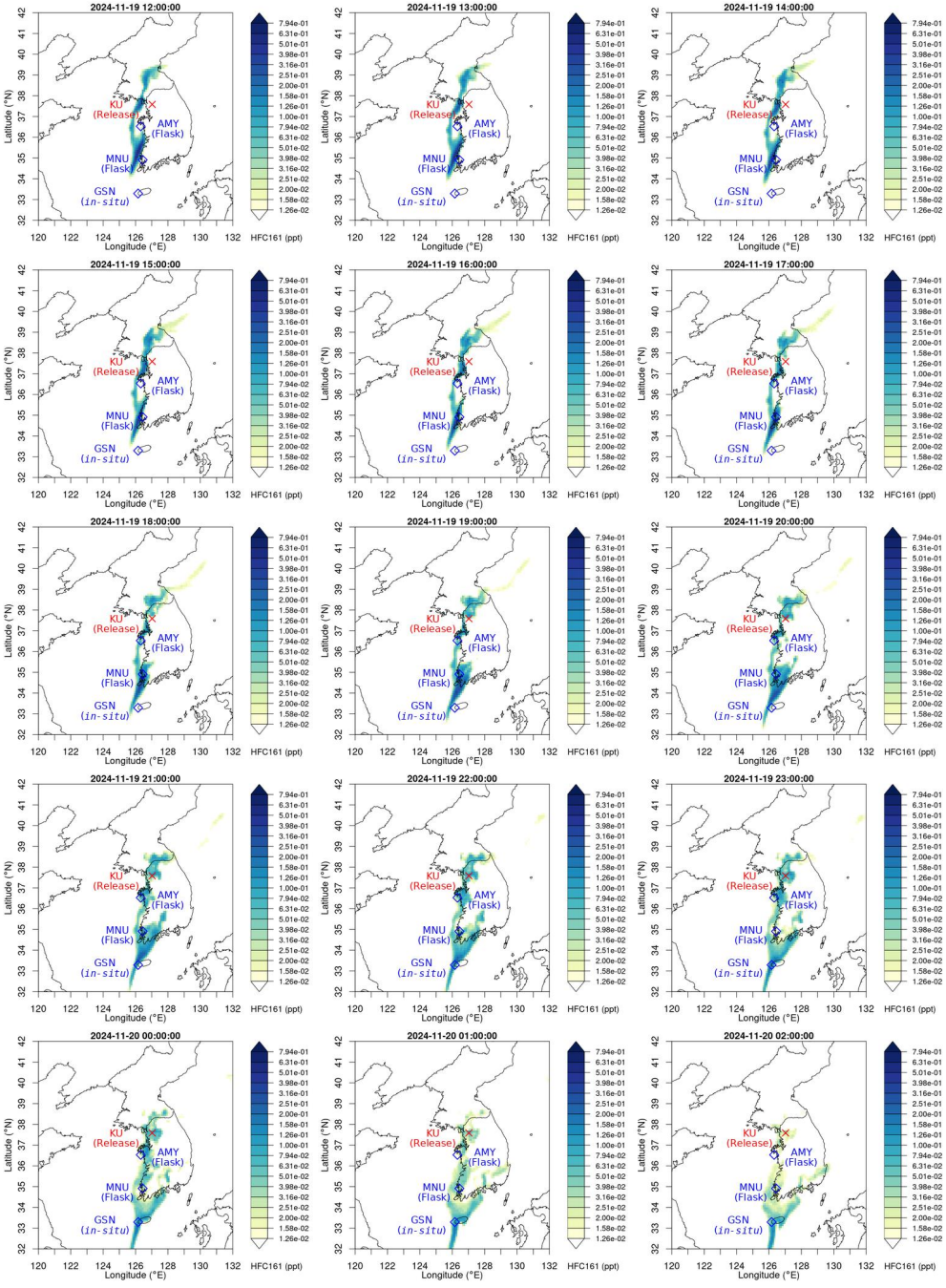


Figure S8. FLEXPART simulation for the HFC-161 dispersion on November 19, 2024, from 12:00 UTC to November 20, 2024, 02:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

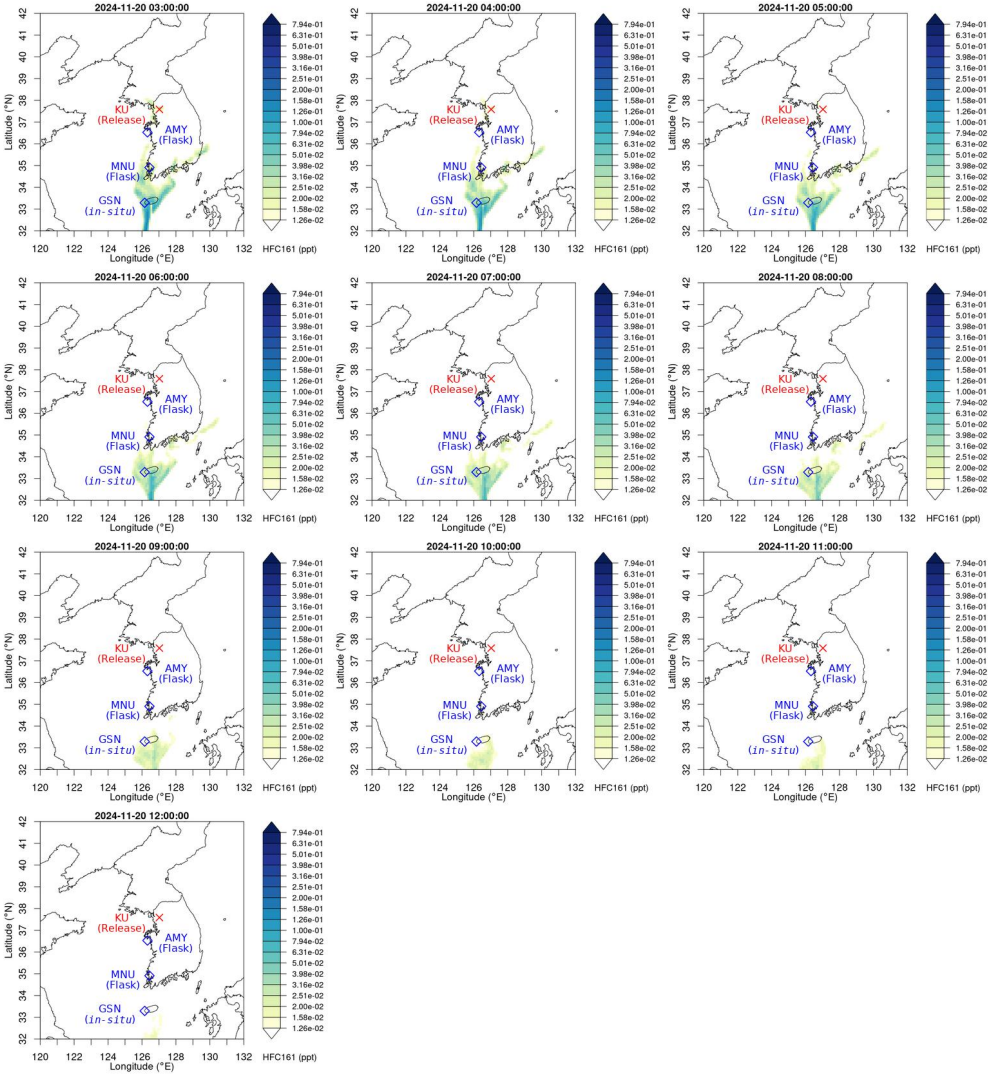


Figure S9. FLEXPART simulation for the HFC-161 dispersion on November 20, 2024, from 03:00 to 12:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

S5.2. HFO-1336mzz(E) Release November 18, 2024

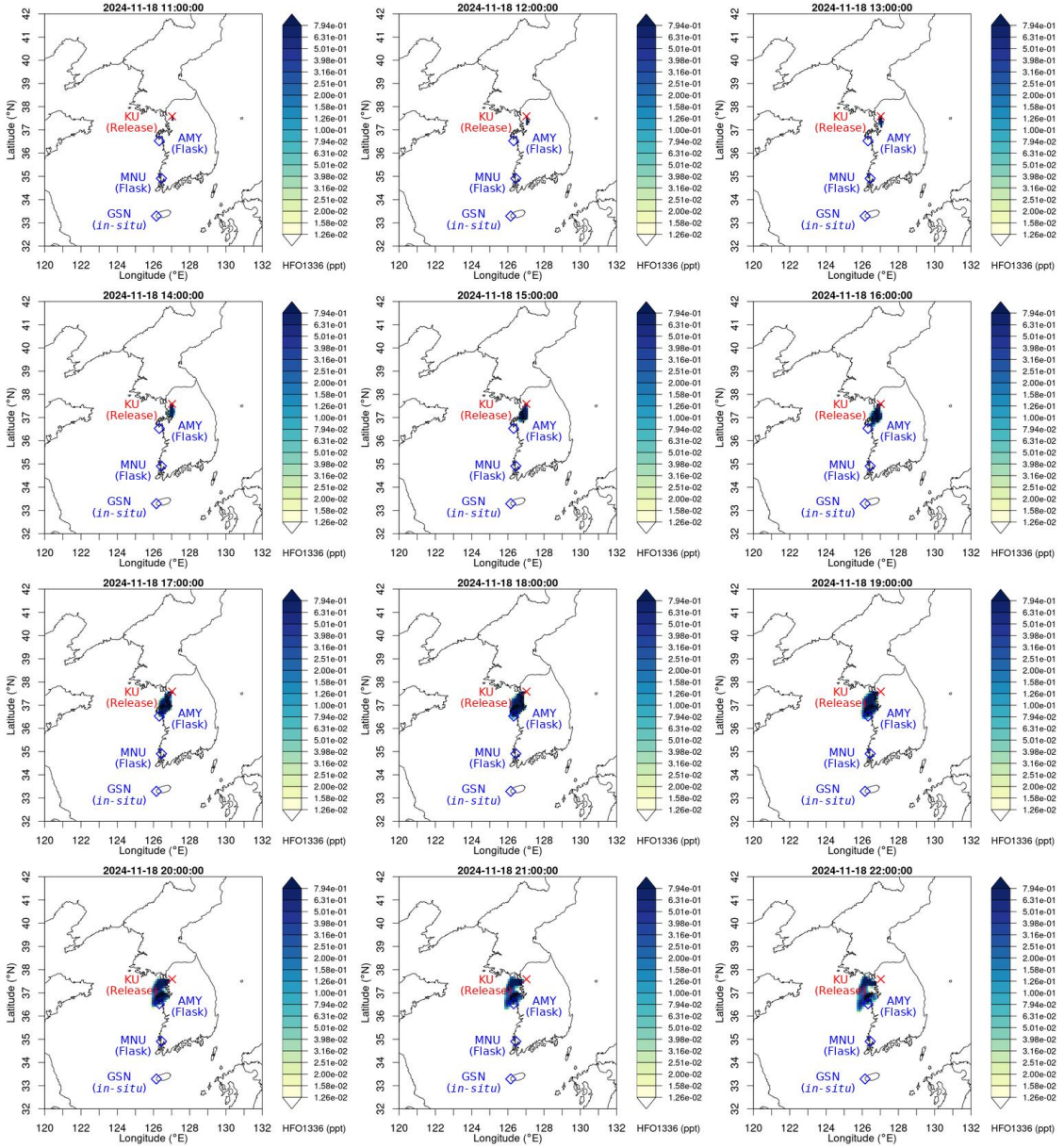


Figure S10. FLEXPART simulation for the HFO-1336mzz(E) dispersion on November 18, 2024, from 11:00 UTC to 22:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

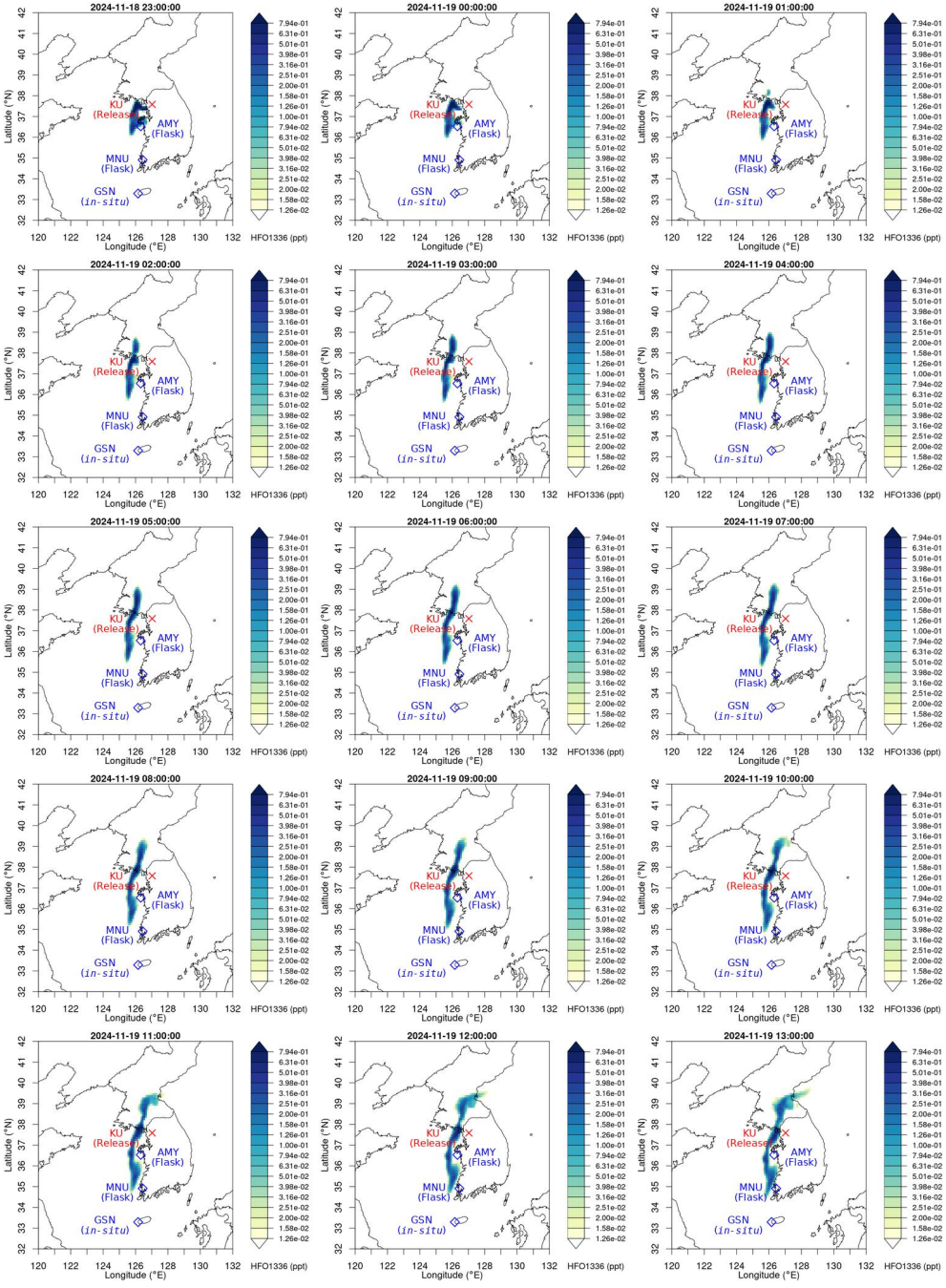


Figure S11. FLEXPART simulation for the HFO-1336mzz(E) dispersion on November 18, 2024, from 23:00 UTC to November 19, 2024, 13:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

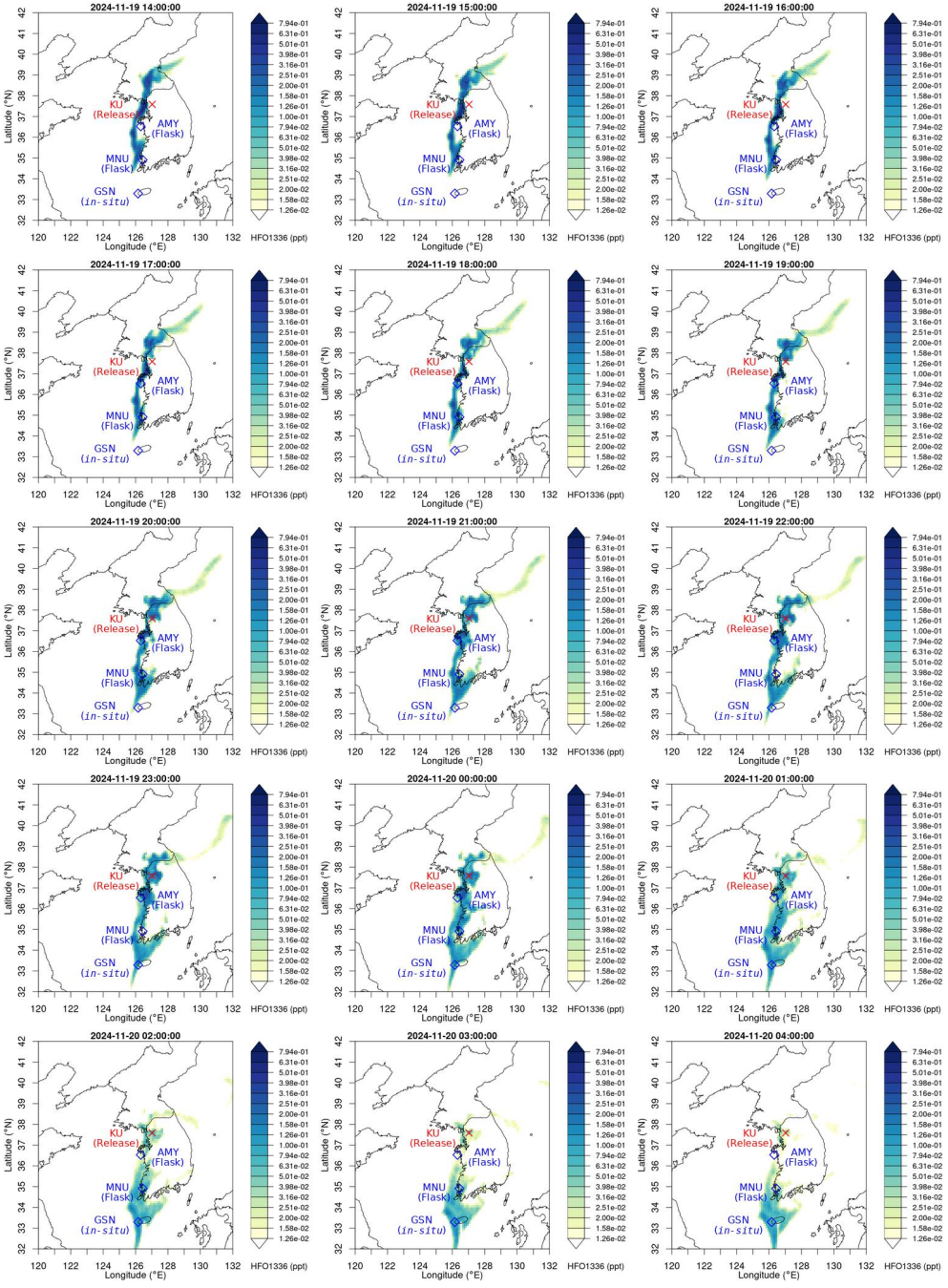


Figure S12. FLEXPART simulation for the HFO-1336mzz(E) dispersion on November 19, 2024, from 13:00 UTC to November 20, 2024, 04:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

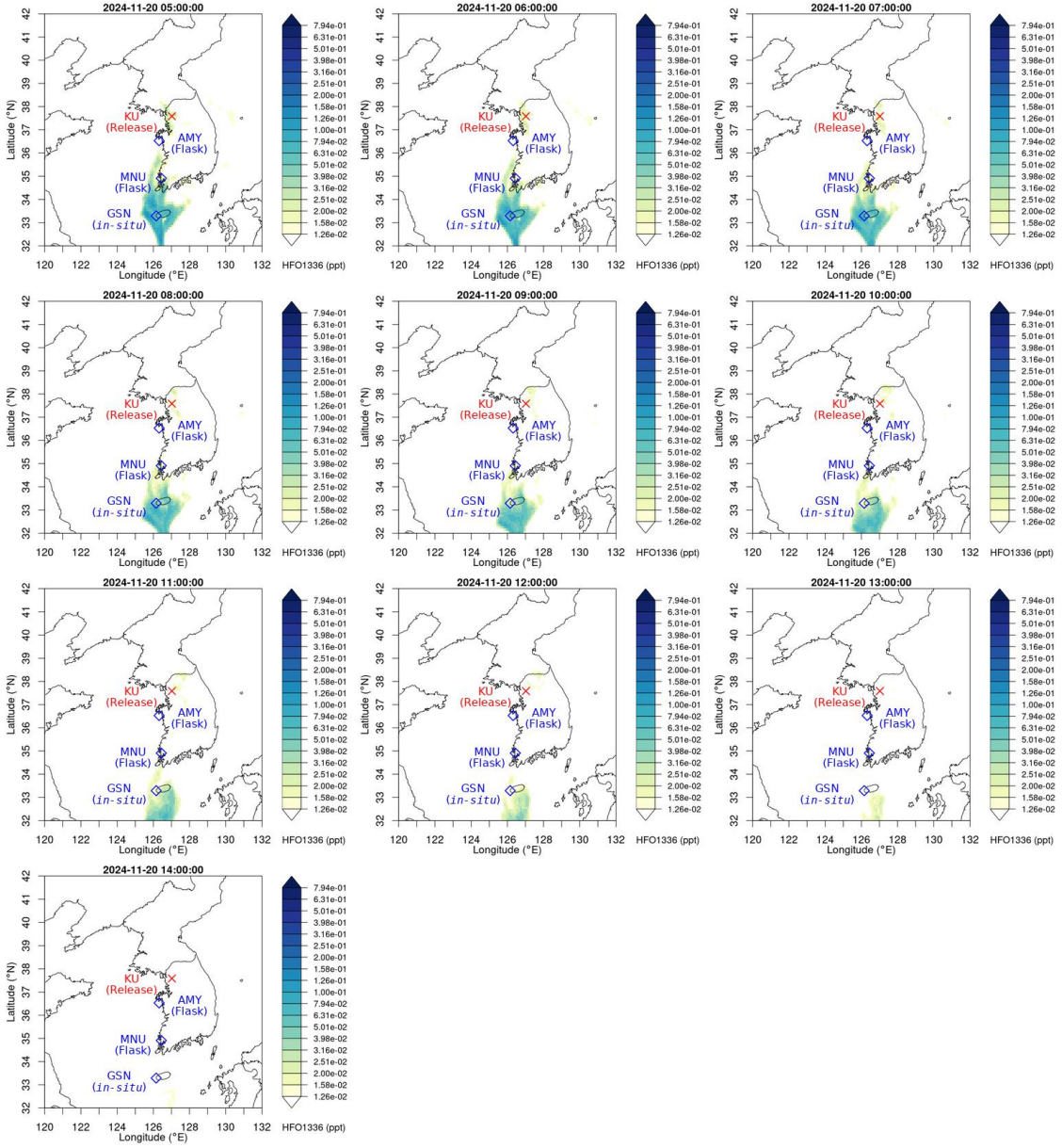


Figure S13. FLEXPART simulation for the HFO-1336mzz(E) dispersion on November 20, 2024, from 05:00 to 14:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

S5.3. HFO-1336mzz(E) Release November 22, 2024

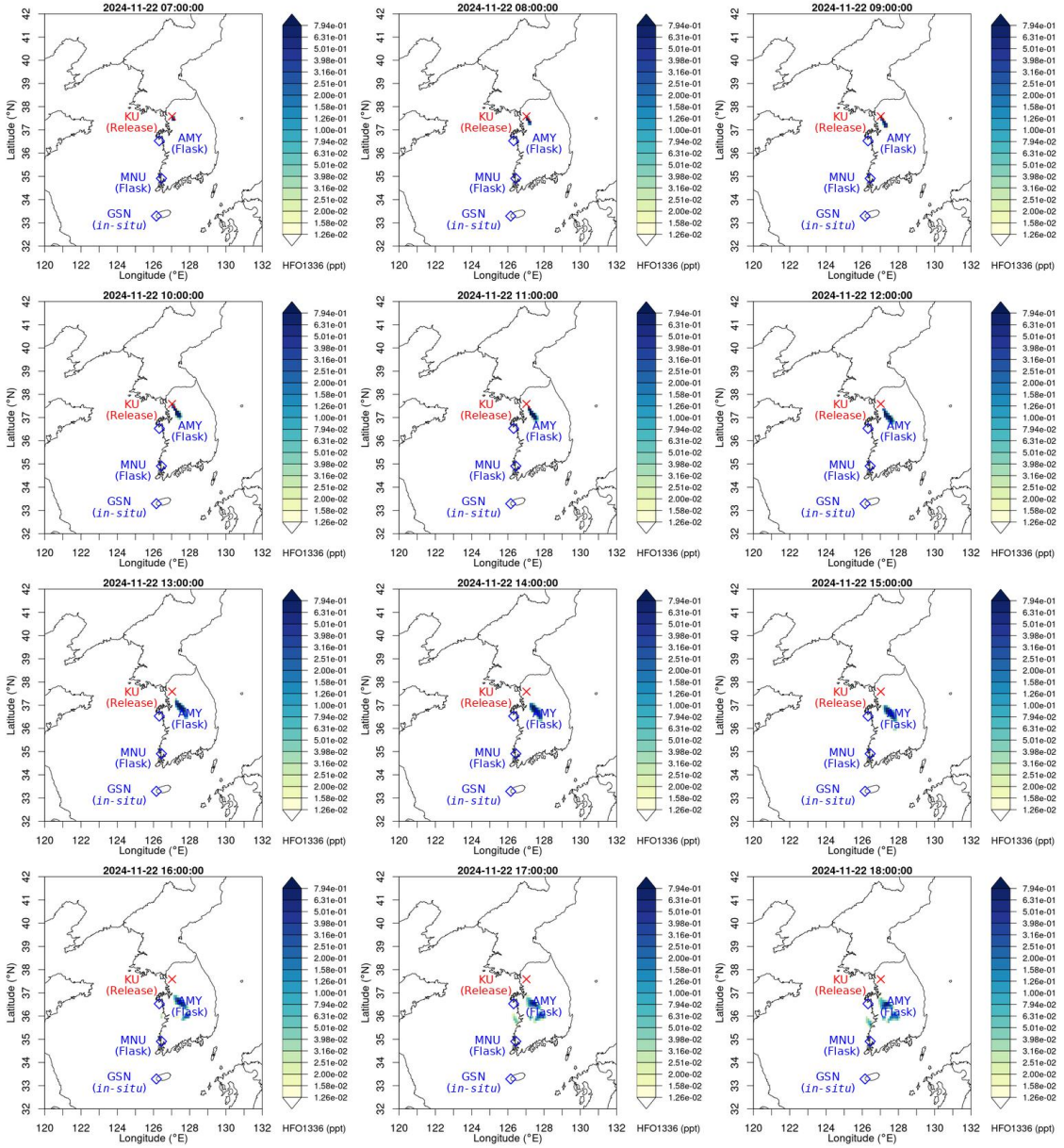


Figure S14. FLEXPART simulation for the HFO-1336mzz(E) dispersion on November 22, 2024, from 07:00 to 18:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

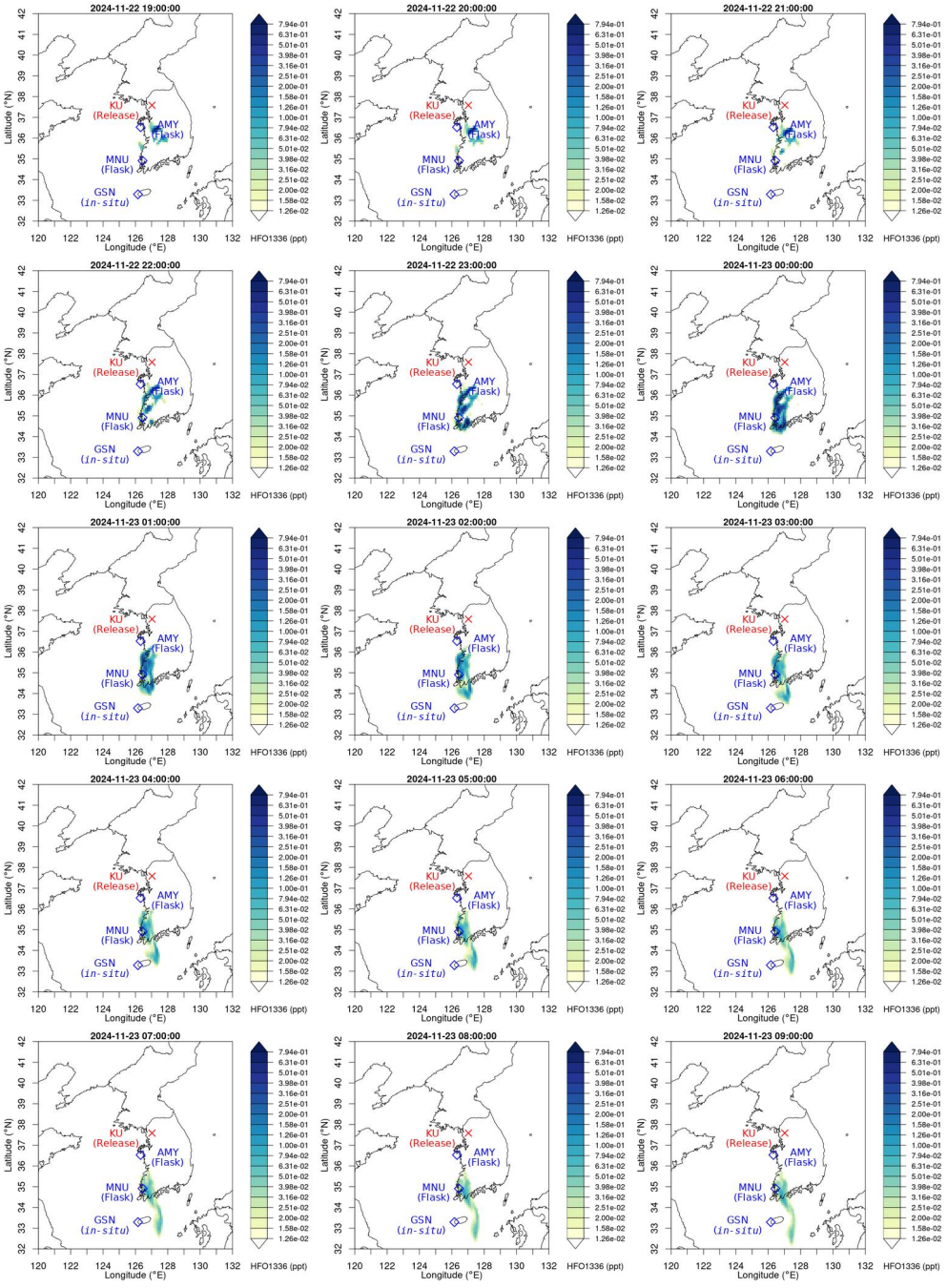


Figure S15. FLEXPART simulation for the HFO-1336mzz(E) dispersion on November 22, 2024, from 19:00 UTC to November 23, 2024, 09:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

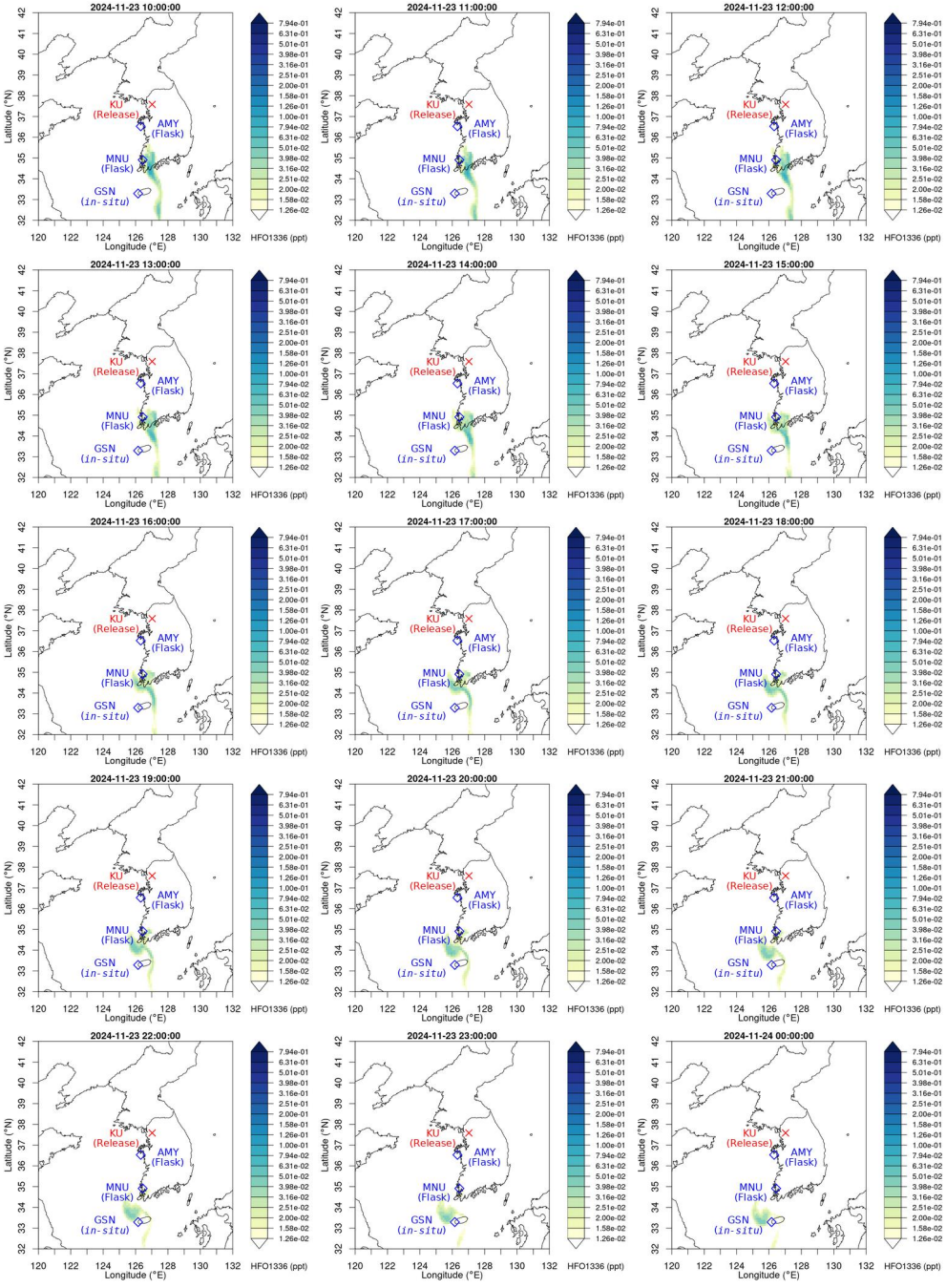


Figure S16. FLEXPART simulation for the HFO-1336mzz(E) dispersion on November 23, 2024, from 10:00 UTC to November 24, 2024, 00:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

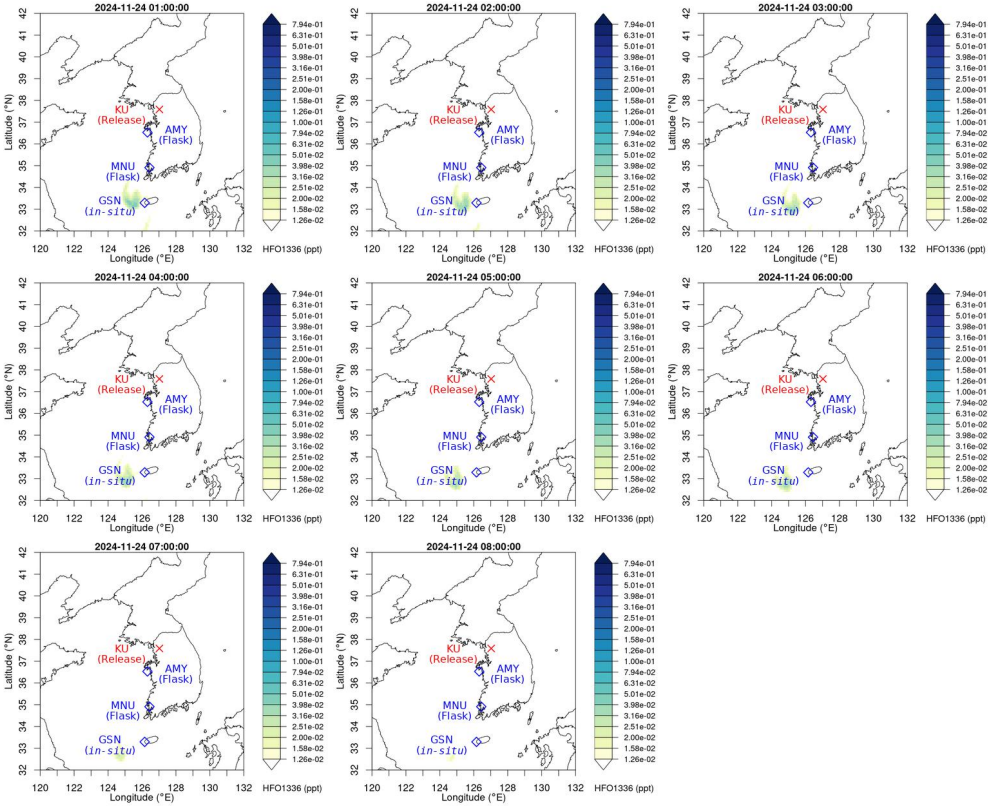


Figure S17. FLEXPART simulation for the HFO-1336mzz(E) dispersion on November 24, 2024, from 01:00 to 08:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

S5.4. HFO-1336mzz(E) Release April 22, 2025

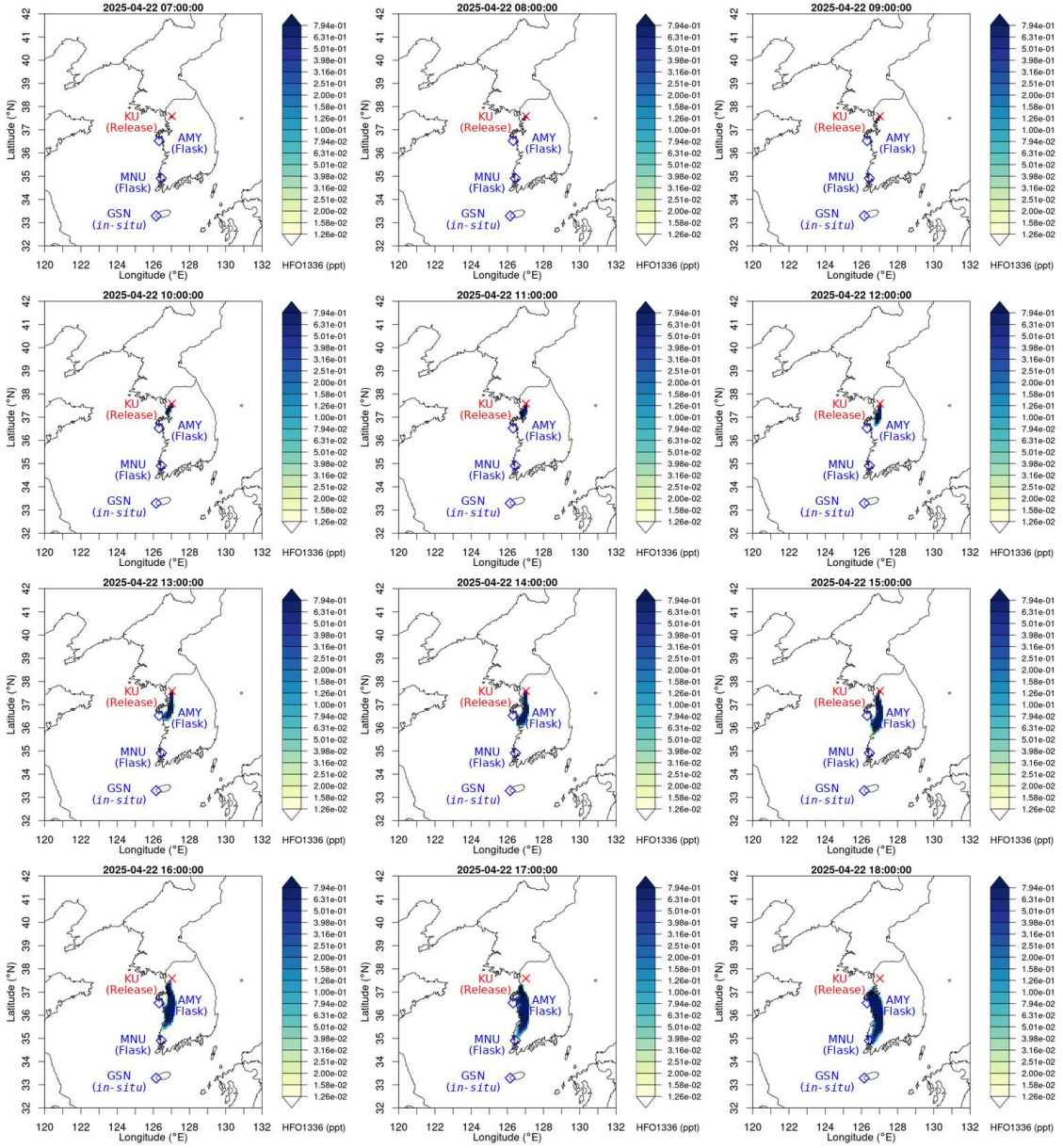


Figure S18. FLEXPART simulation for the HFO-1336mzz(E) dispersion on April 22, 2025, from 07:00 to 18:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

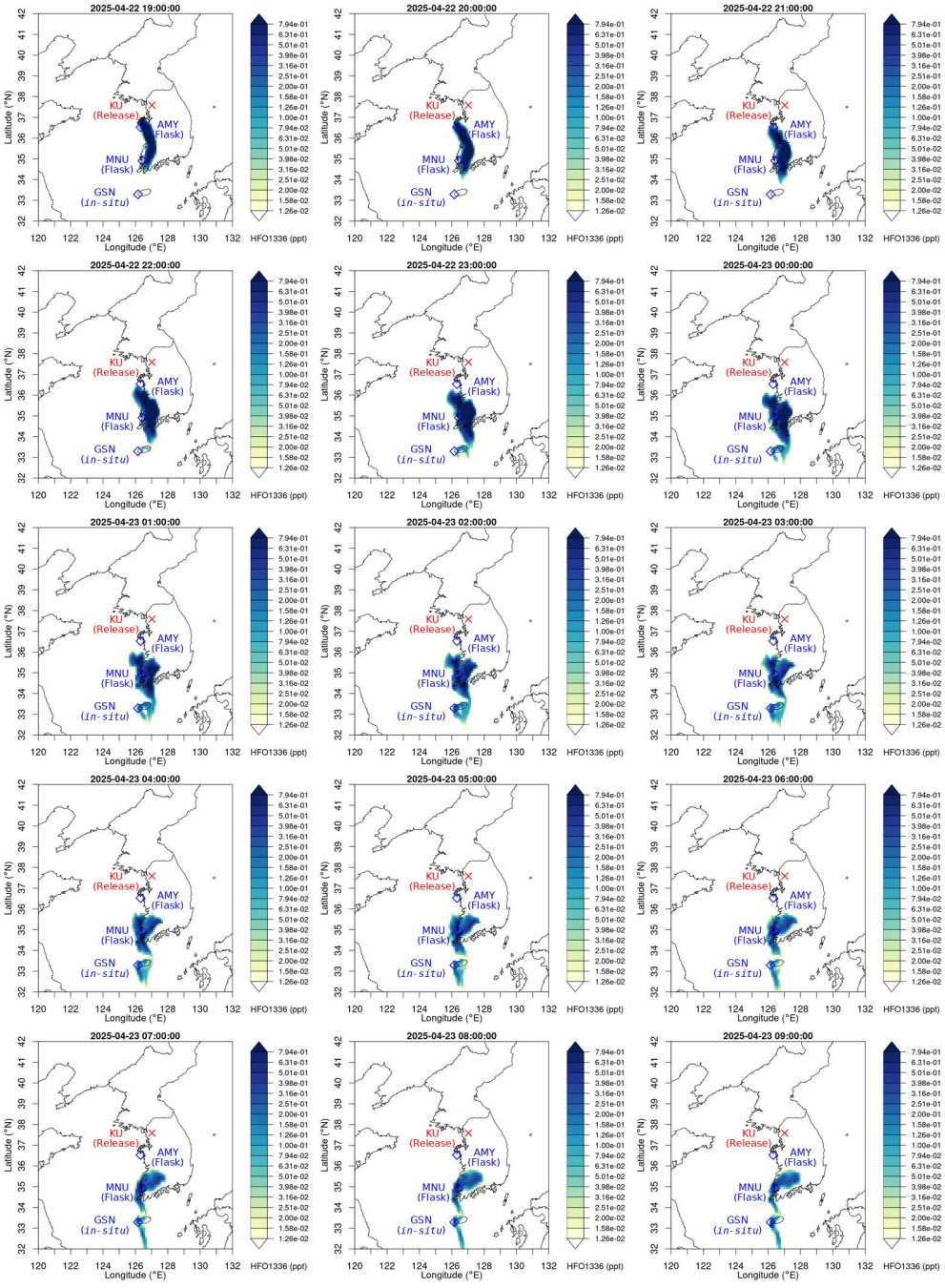


Figure S19. FLEXPART simulation for the HFO-1336mzz(E) dispersion on April 22, 2025, from 19:00 UTC to April 23, 2025, 09:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

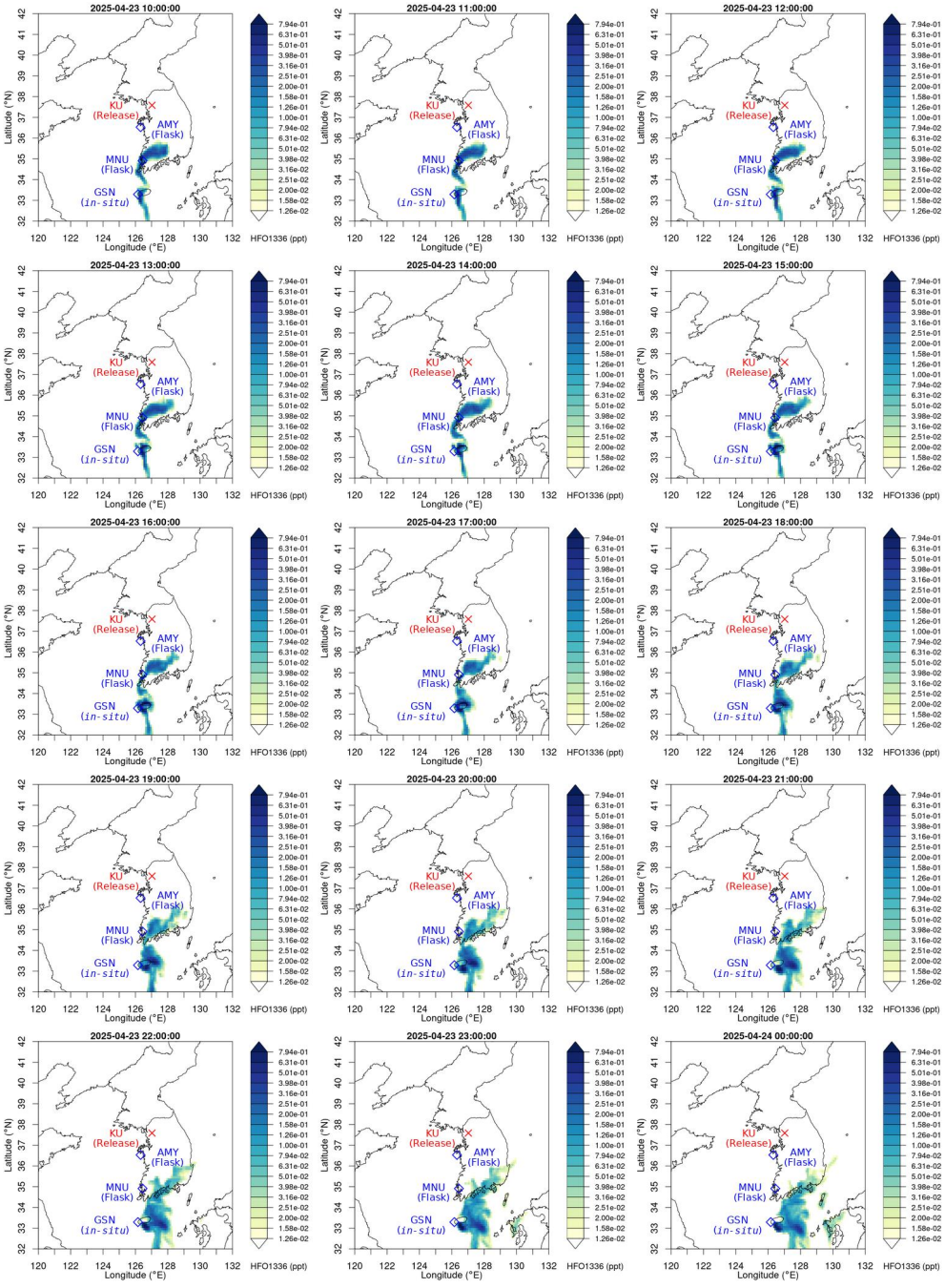


Figure S20. FLEXPART simulation for the HFO-1336mzz(E) dispersion on April 23, 2025, from 10:00 UTC to April 24, 2025, 00:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

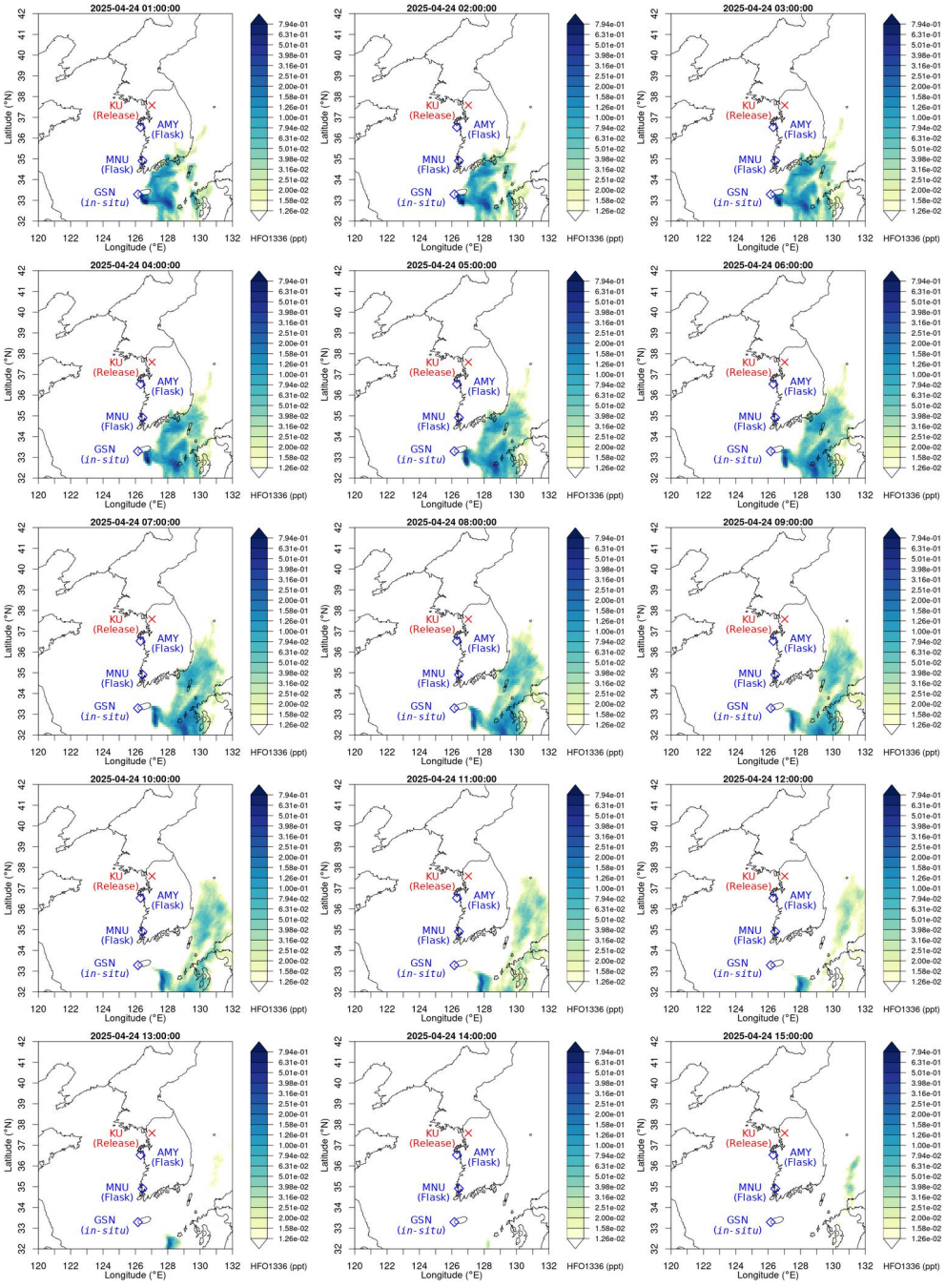


Figure S21. FLEXPART simulation for the HFO-1336mzz(E) dispersion on April 24, 2025, from 01:00 to 14:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

S5.5. HFC-161 Release May 23, 2025

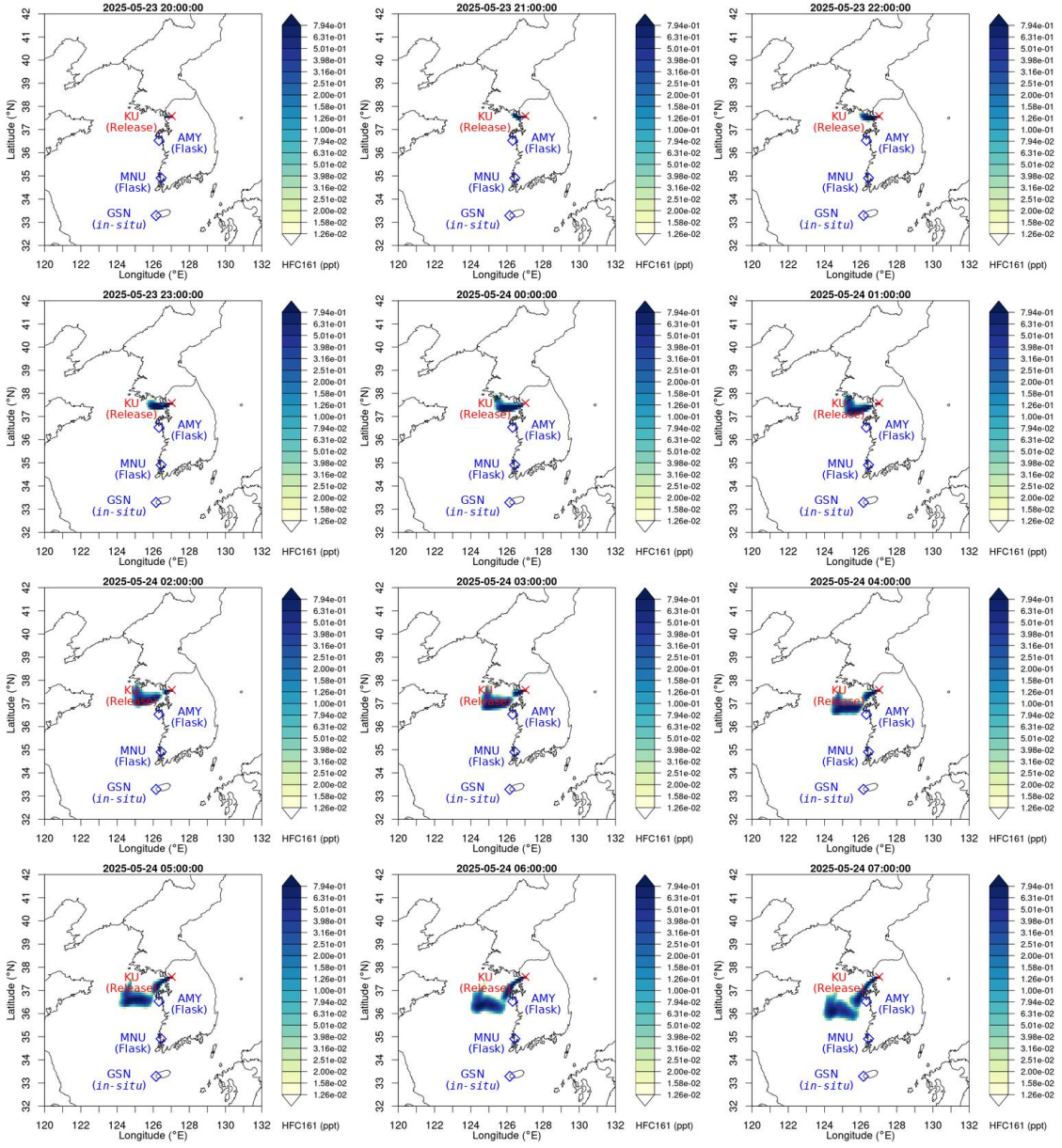


Figure S22. FLEXPART simulation for the HFC-161 dispersion on May 23, 2025, from 20:00 UTC to May 24, 2025, 07:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

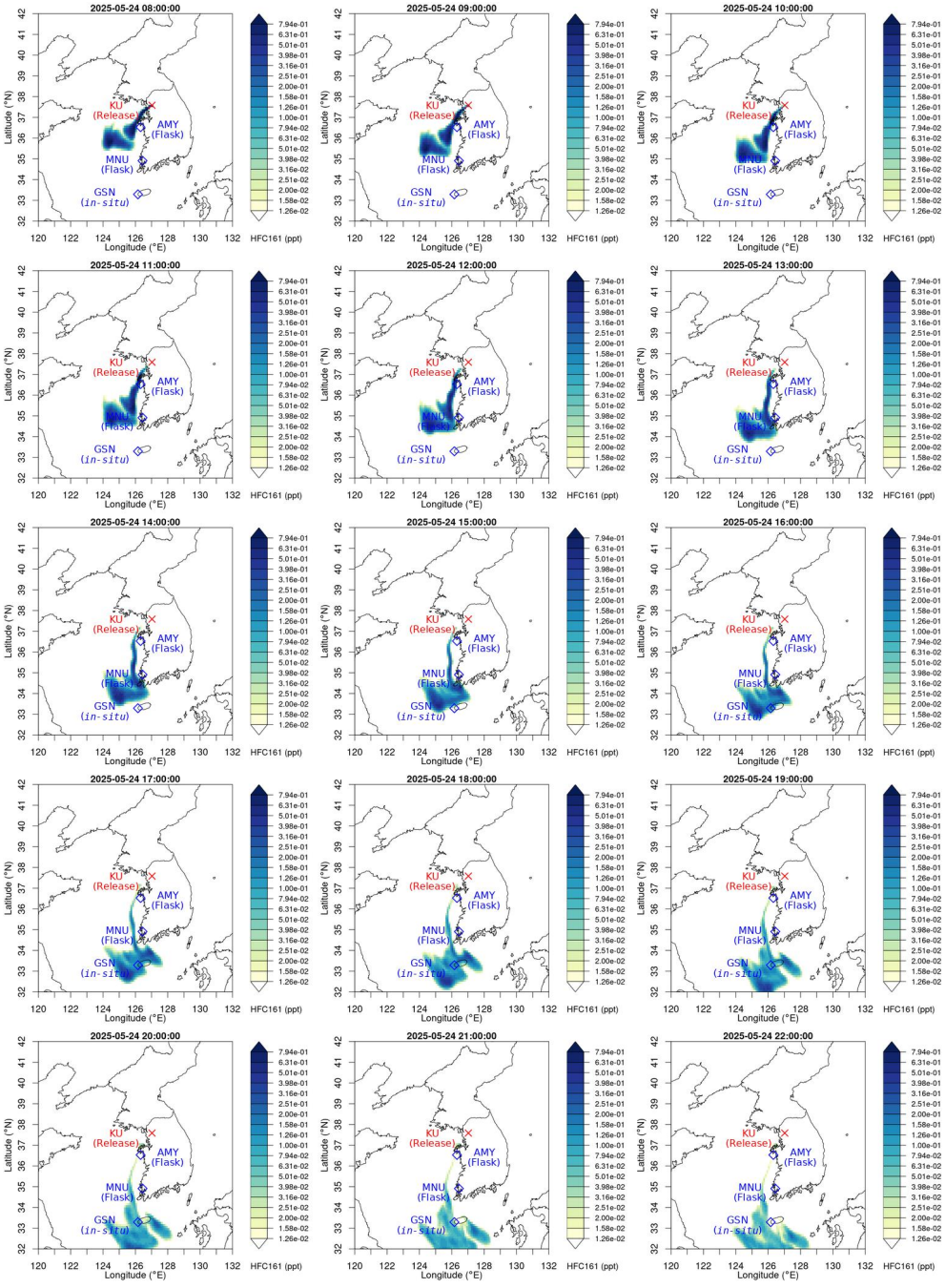


Figure S23. FLEXPART simulation for the HFC-161 dispersion on May 24, 2025, from 08:00 to 22:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

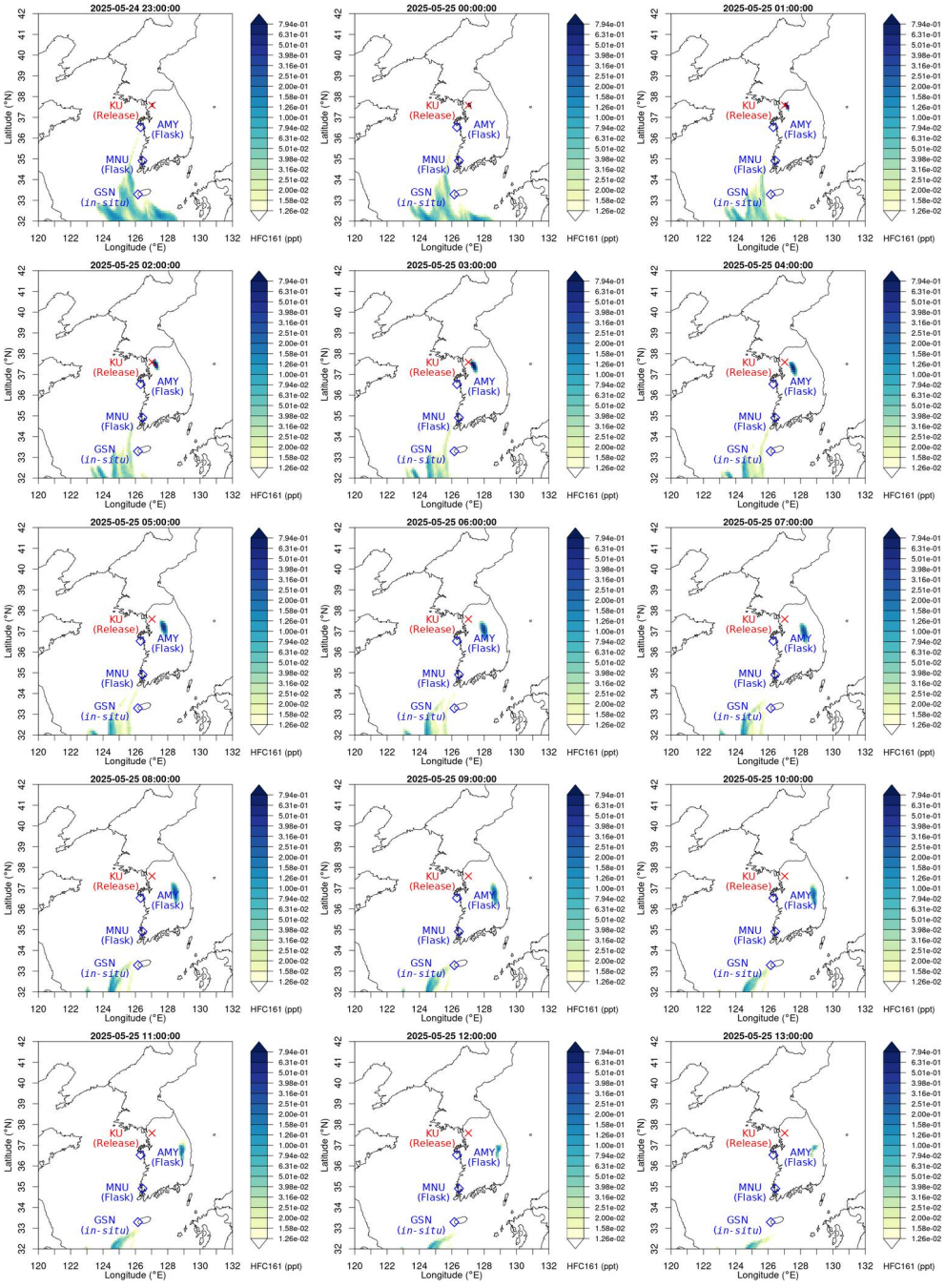


Figure S24. FLEXPART simulation for the HFC-161 dispersion on May 24, 2025, from 23:00 UTC to May 25, 2025, 13:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

S5.6. HFO-1336mzz(E) Release May 23, 2025

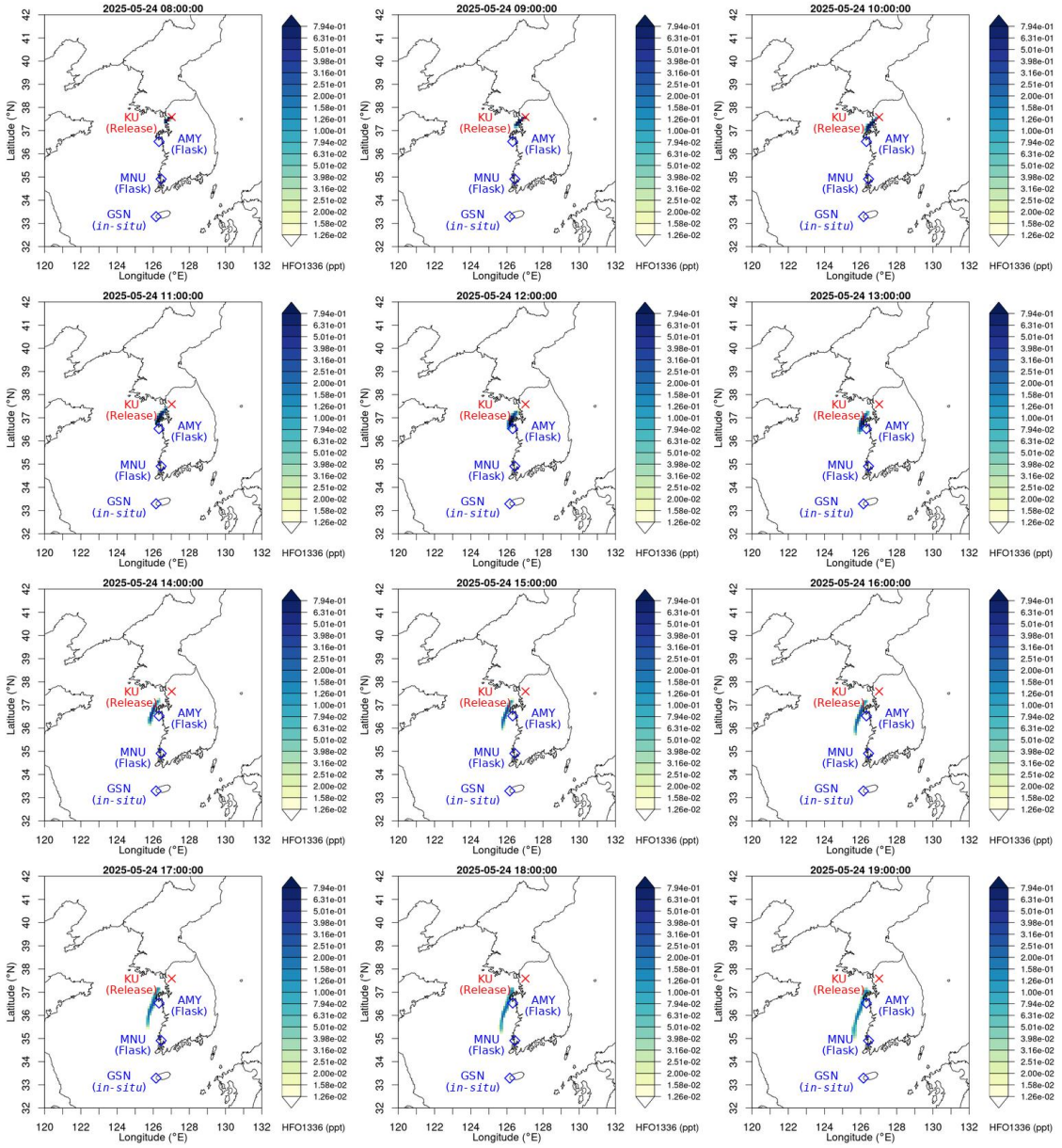


Figure S25. FLEXPART simulation for the HFO-1336mzz(E) dispersion on May 24, 2025, from 08:00 to 19:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

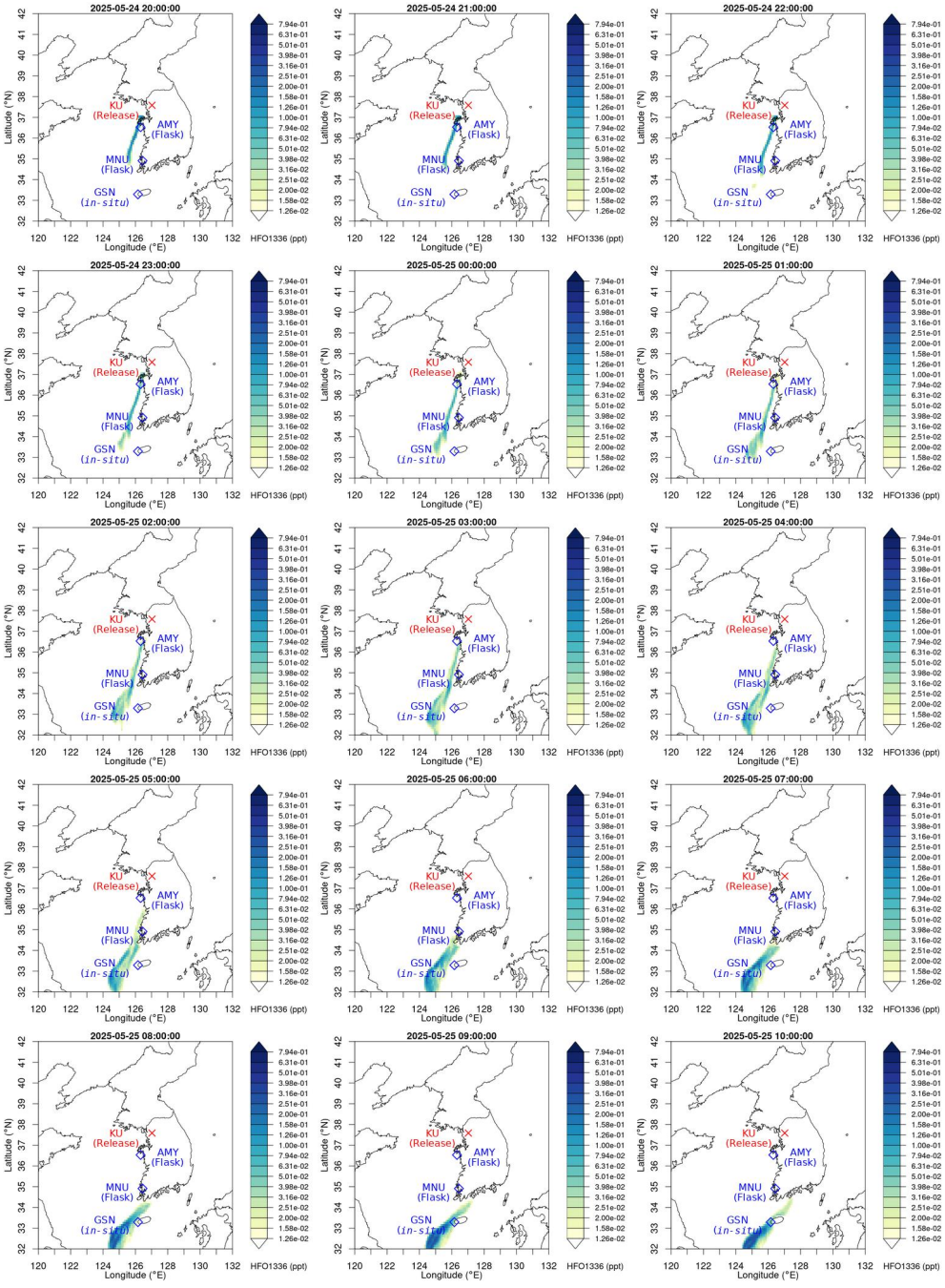


Figure S26. FLEXPART simulation for the HFO-1336mzz(E) dispersion on May 24, 2025, from 20:00 UTC to May 25, 2025, 10:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

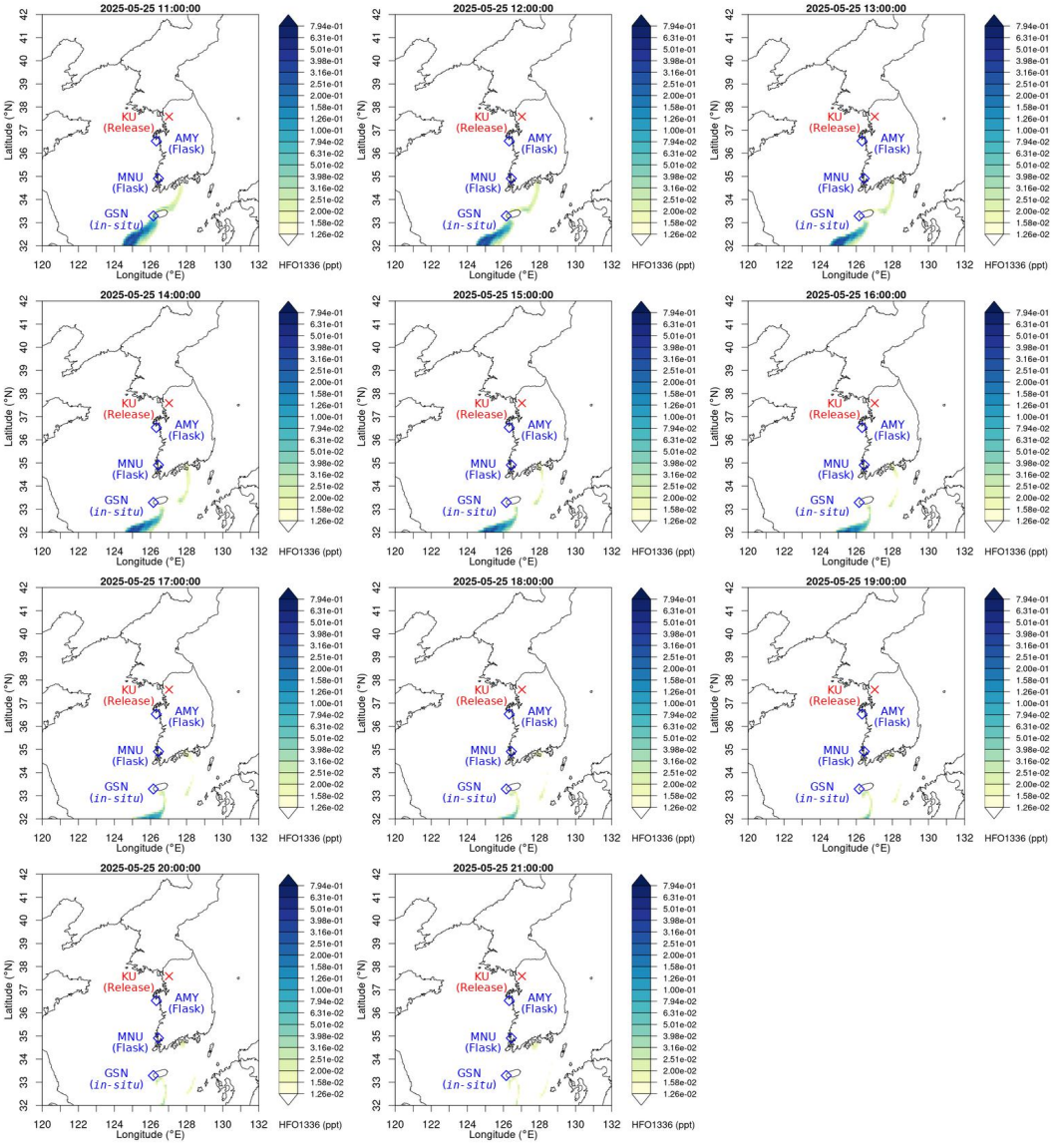


Figure S27. FLEXPART simulation for the HFO-1336mzz(E) dispersion on May 25, 2025, from 11:00 to 21:00 UTC. The tracer release site is marked in red (Korea University, KU), and the flask sampling sites Anmyeondo (AMY), Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN) are marked in blue.

S6. Time Series with Baseline

S6.1. Release November 18, 2024

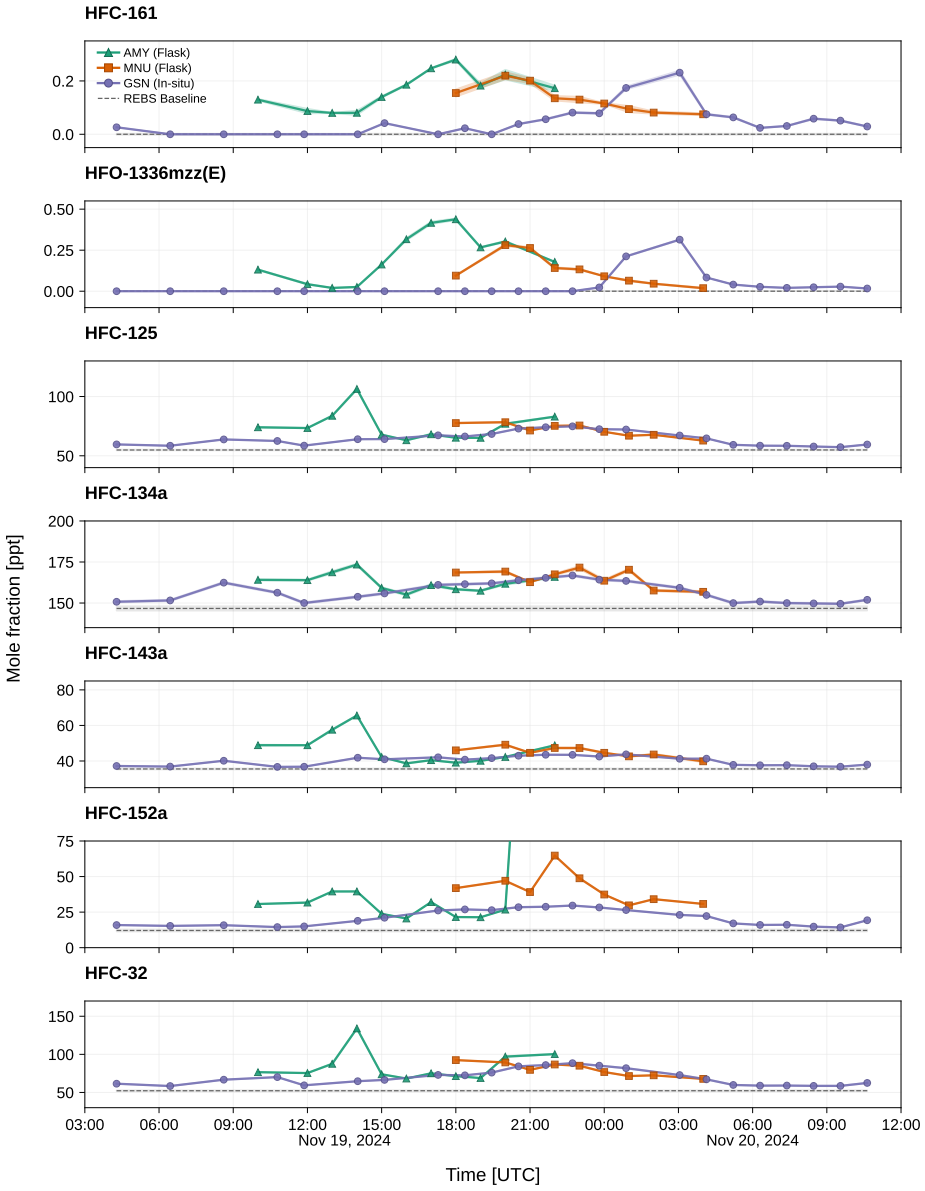


Figure S28. Time series of measured mole fractions for the release of HFC-161 and HFO-1336mzz(E) on November 18, 2024, with the flask sampling sites Anmyeondo (AMY, green) and Mokpo National University (MNU, orange), and the *in-situ* measurement station Gosan (GSN, purple), including the REBS baseline (grey). All the uncertainties are shaded in the corresponding colour.

S6.2. Release November 22, 2024

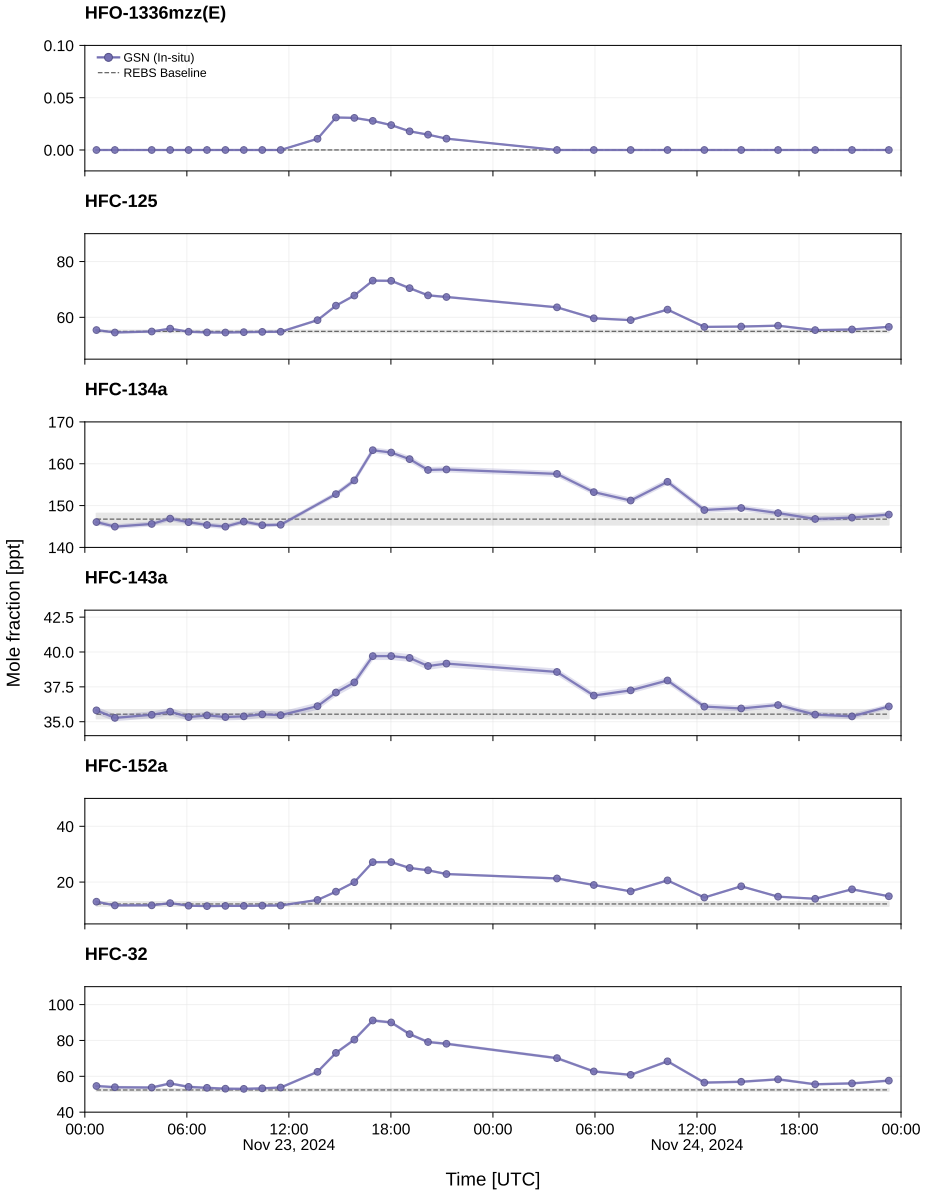


Figure S29. Time series of measured mole fractions for the release of HFO-1336mzz(E) on November 22, 2024, with the *in-situ* measurement station Gosan (GSN, purple), including the REBS baseline (grey). All the uncertainties are shaded in the corresponding colour.

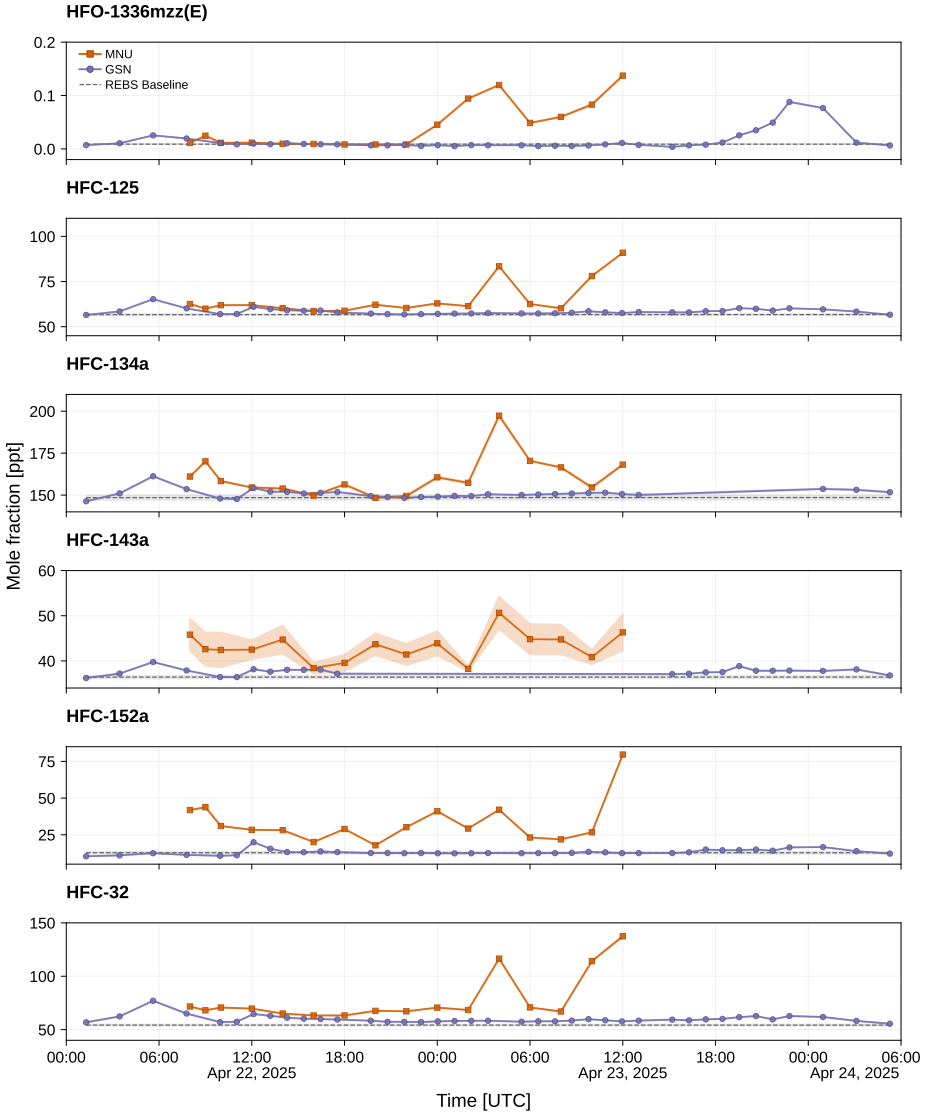


Figure S30. Time series of measured mole fractions for the release of HFO-1336mzz(E) on April 22, 2025, with the flask sampling site Mokpo National University (MNU, orange), and the *in-situ* measurement station Gosan (GSN, purple), including the REBS baseline (grey). All the uncertainties are shaded in the corresponding colour.

S6.4. Release May 23, 2025

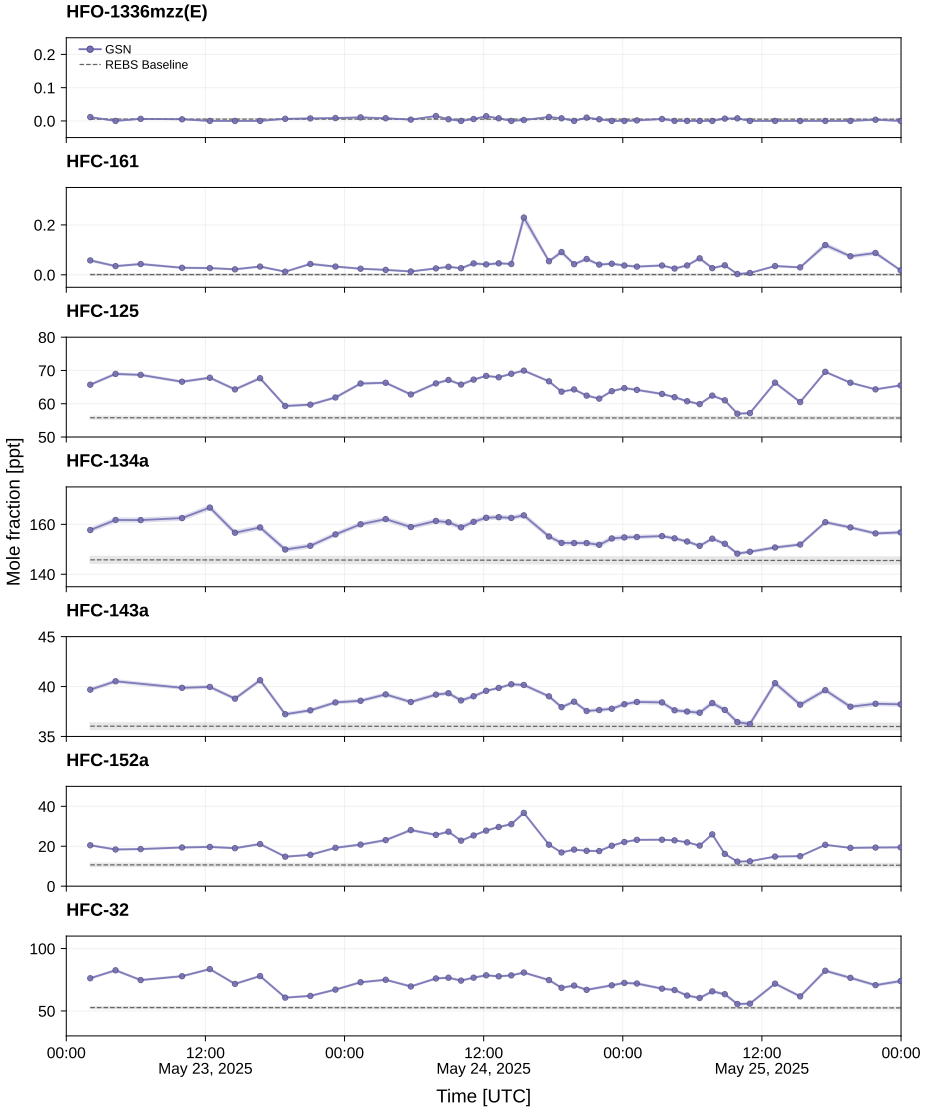


Figure S31. Time series of measured mole fractions for the release of HFC-161 and HFO-1336mzz(E) on May 23 and 24, 2024, with the *in-situ* measurement station Gosan (GSN, purple), including the REBS baseline (grey). All the uncertainties are shaded in the corresponding colour.

S7. Predicted Tracer Arrival and Air Origin

S7.1. Release November 18, 2024

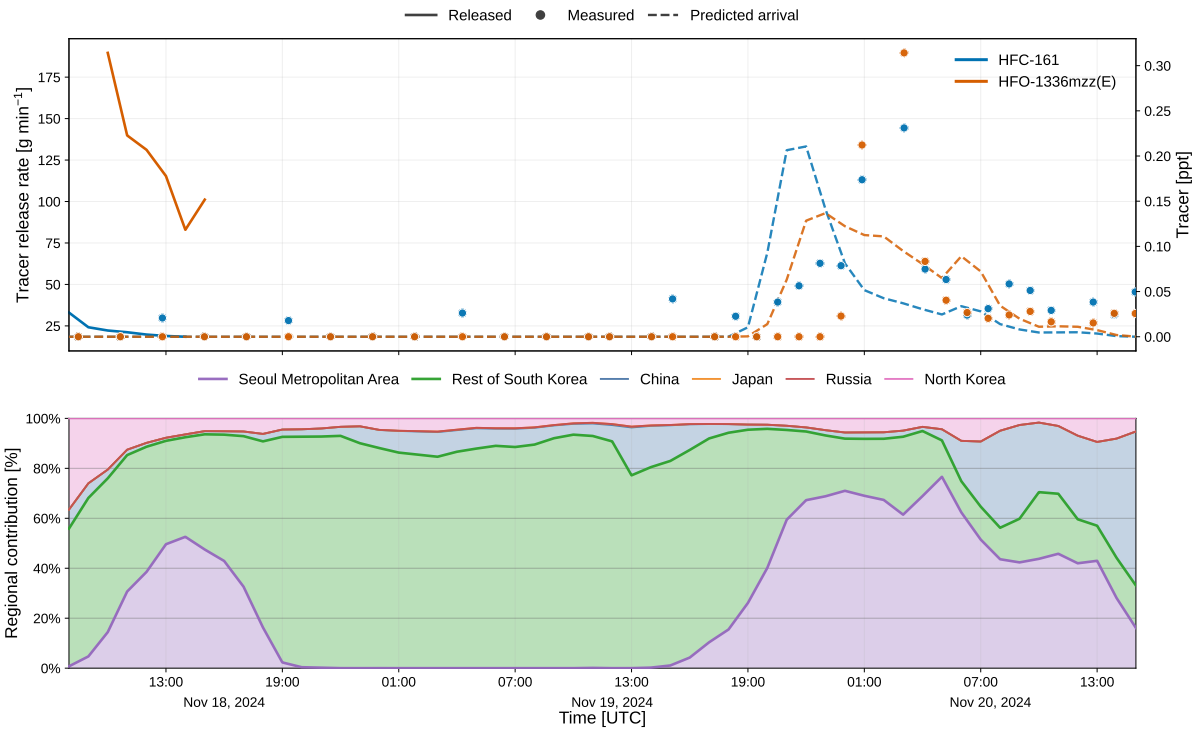


Figure S32. Both subplots are based on the *in-situ* measurement station Gosan (GSN) for the release on November 18, 2024. Top: The tracer release rates in $\mathrm{g\,min^{-1}}$ for HFC-161 (blue) and HFO-1336mzz(E) (orange) are represented as solid lines. The predicted tracer arrivals using FLEXPART are drawn as dashed lines in the corresponding colour. The measurements are displayed as solid circles. Bottom: The FLEXPART simulated origin of the measured air parcel with regional attribution, with the Seoul Metropolitan Area (SMA) in purple, South Korea in green, China in Blue, Japan in yellow, Russia in red and North Korea in pink.

S7.2. Release November 22, 2024

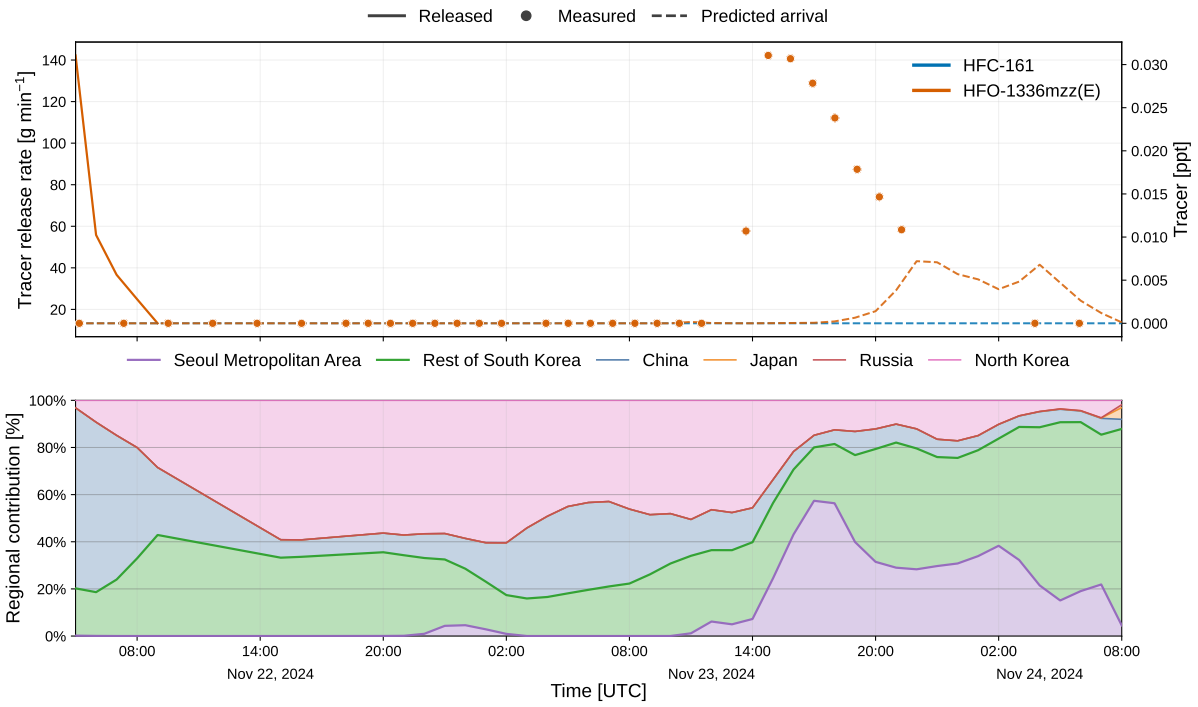


Figure S33. Both subplots are based on the *in-situ* measurement station Gosan (GSN) for the release on November 22, 2024. Top: The tracer release rates in $\mathrm{g\,min^{-1}}$ for HFC-161 (blue) and HFO-1336mzz(E) (orange) are represented as solid lines. The predicted tracer arrivals using FLEXPART are drawn as dashed lines in the corresponding colour. The measurements are displayed as solid circles. Bottom: The FLEXPART simulated origin of the measured air parcel with regional attribution, with the Seoul Metropolitan Area (SMA) in purple, South Korea in green, China in Blue, Japan in yellow, Russia in red and North Korea in pink.

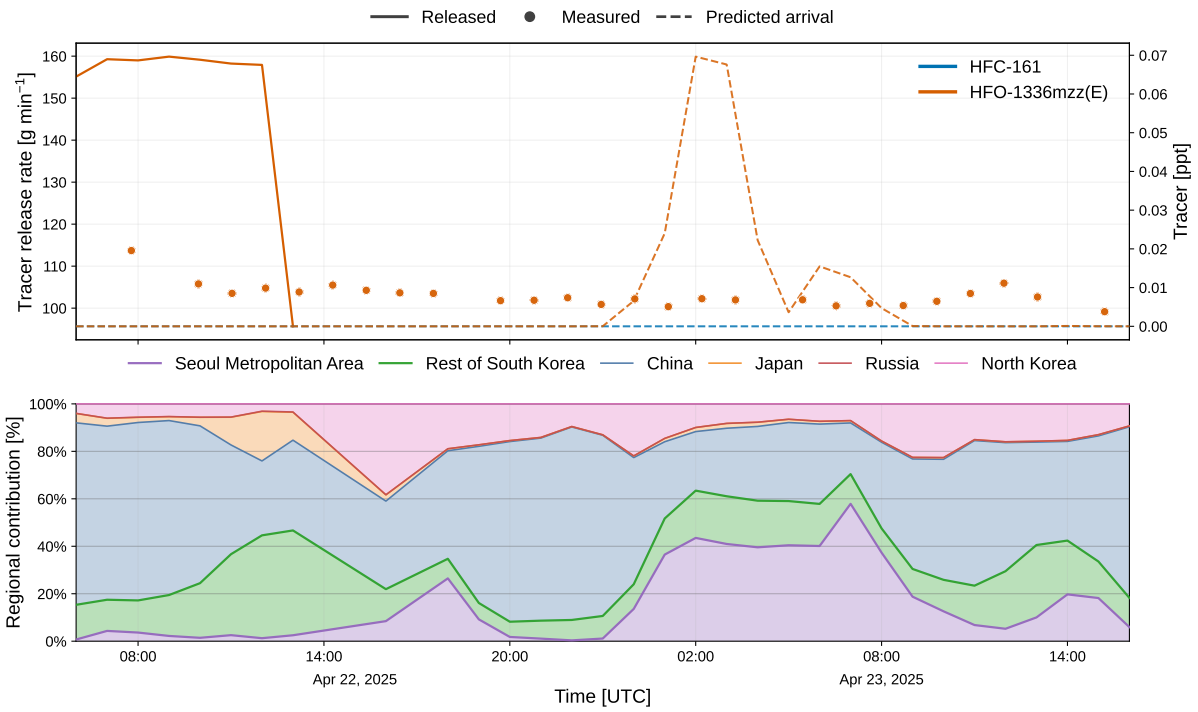


Figure S34. Both subplots are based on the *in-situ* measurement station Gosan (GSN) for the release on April 22, 2025. Top: The tracer release rates in $\mathrm{g\,min^{-1}}$ for HFC-161 (blue) and HFO-1336mzz(E) (orange) are represented as solid lines. The predicted tracer arrivals using FLEXPART are drawn as dashed lines in the corresponding colour. The measurements are displayed as solid circles. Bottom: The FLEXPART simulated origin of the measured air parcel with regional attribution, with the Seoul Metropolitan Area (SMA) in purple, South Korea in green, China in Blue, Japan in yellow, Russia in red and North Korea in pink.

S7.4. Release May 23, 2025

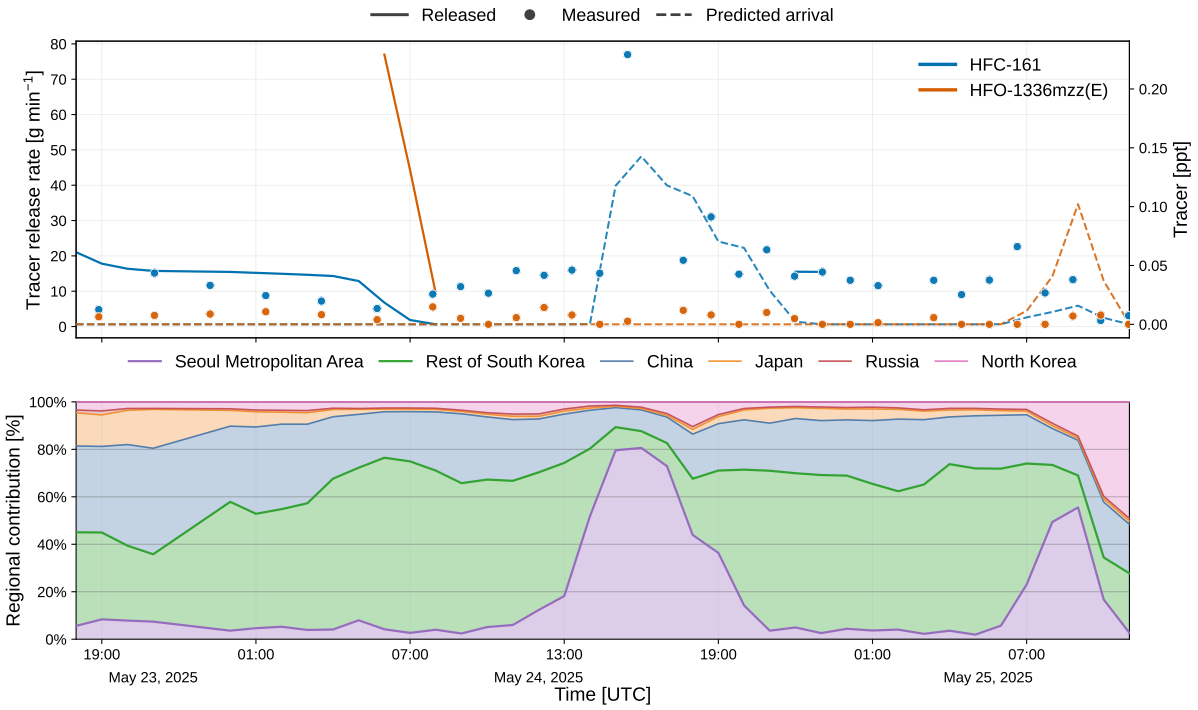


Figure S35. Both subplots are based on the *in-situ* measurement station Gosan (GSN) for the release on May 23, 2025. Top: The tracer release rates in $\mathrm{g\,min^{-1}}$ for HFC-161 (blue) and HFO-1336mzz(E) (orange) are represented as solid lines. The predicted tracer arrivals using FLEXPART are drawn as dashed lines in the corresponding colour. The measurements are displayed as solid circles. Bottom: The FLEXPART simulated origin of the measured air parcel with regional attribution, with the Seoul Metropolitan Area (SMA) in purple, South Korea in green, China in Blue, Japan in yellow, Russia in red and North Korea in pink.

S8. Data processing

S8.1. Release November 18, 2024

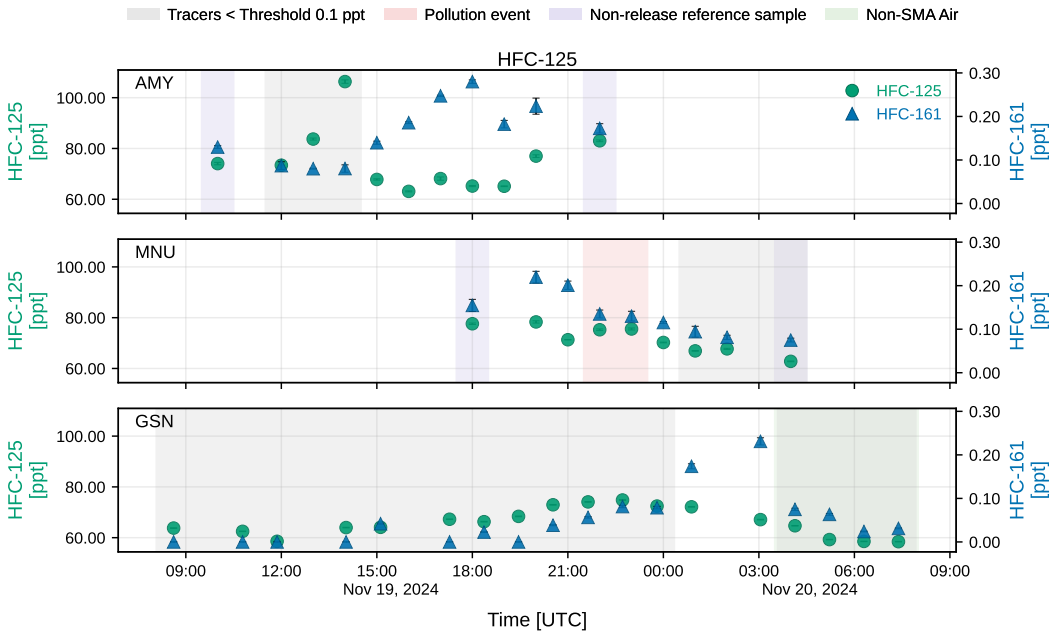


Figure S36. Quality assurance of data from the two flask sampling locations, Anmyeondo (AMY) and Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN). The exclusion criteria were a tracer threshold (0.1 ppt, grey), non-SMA pollution events (red), non-release reference flask samples (purple), and air origin based on population-impact FLEXPART simulations (green). HFC-125 (green solid circle) was used as the target compound, and HFC-161 (blue triangle) as the tracer.

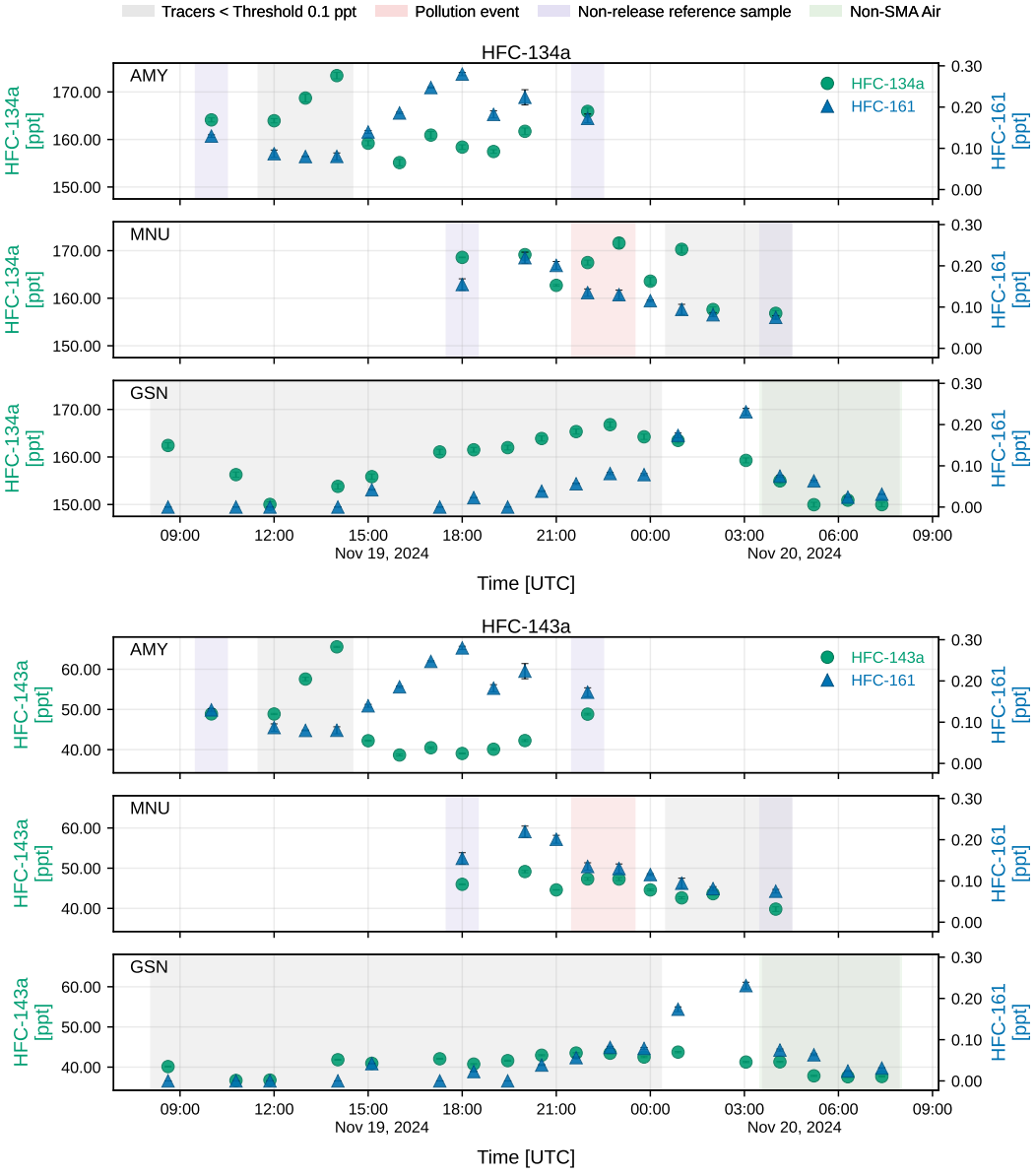


Figure S37. Quality assurance of data from the two flask sampling locations, Anmyeondo (AMY) and Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN). The exclusion criteria were a tracer threshold (0.1 ppt, grey), non-SMA pollution events (red), non-release reference flask samples (purple), and air origin based on population-impact FLEXPART simulations (green). At the top, HFC-134a and HFC-143a are the target compounds, both denoted as green solid circles, and HFC-161 (blue triangle) was used as a tracer for both.

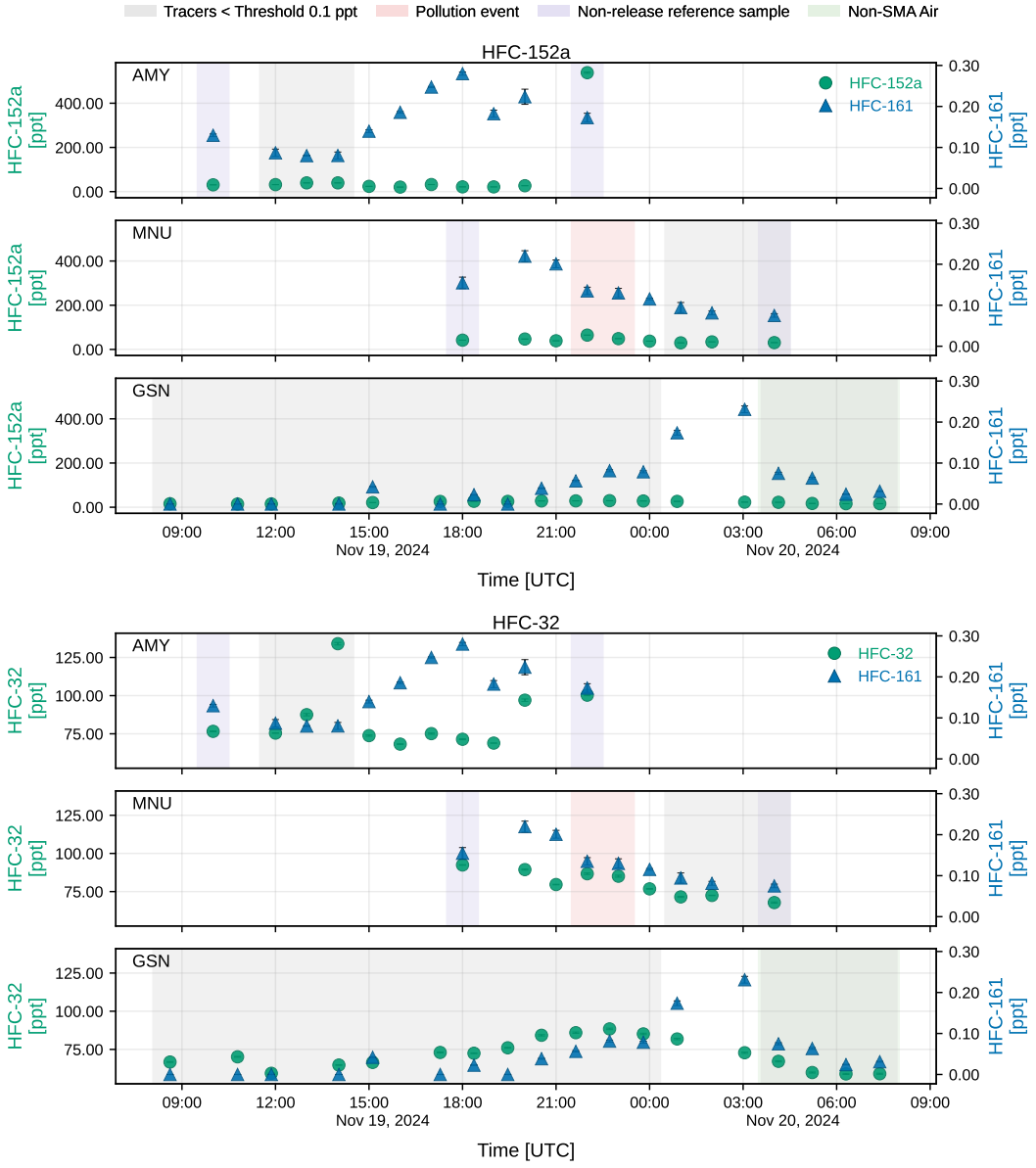


Figure S38. Quality assurance of data from the two flask sampling locations, Anmyeondo (AMY) and Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN). The exclusion criteria were a tracer threshold (0.1 ppt, grey), non-SMA pollution events (red), non-release reference flask samples (purple), and air origin based on population-impact FLEXPART simulations (green). At the top, HFC-152a and HFC-32 (green solid circle) are the target compounds, both denoted as green solid circles, and HFC-161 (blue triangle) was used as a tracer for both.

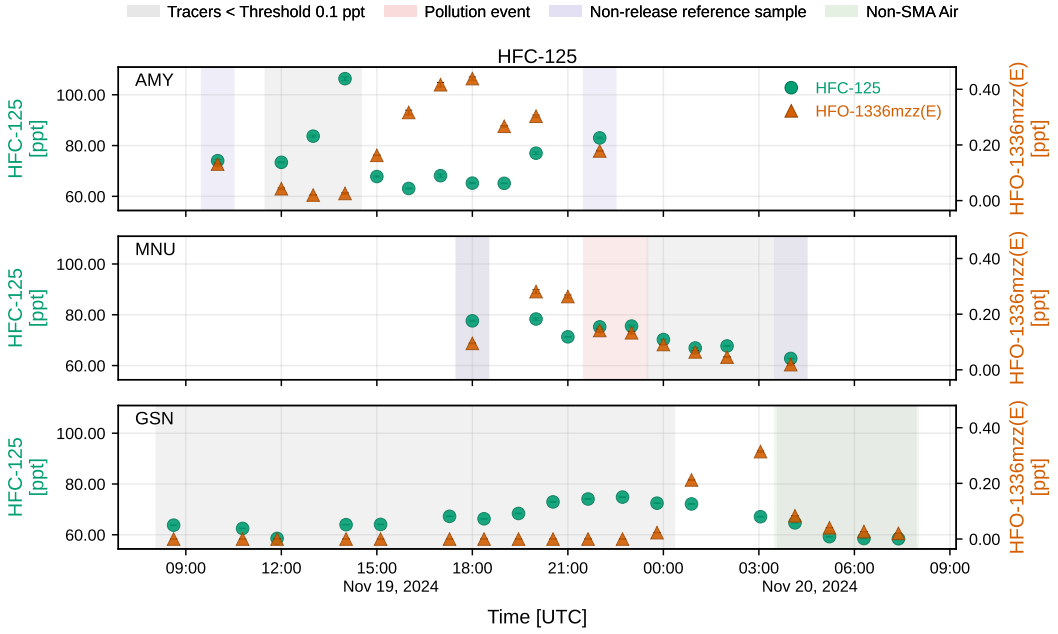


Figure S39. Quality assurance of data from the two flask sampling locations, Anmyeondo (AMY) and Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN). The exclusion criteria were a tracer threshold (0.1 ppt, grey), non-SMA pollution events (red), non-release reference flask samples (purple), and air origin based on population-impact FLEXPART simulations (green). HFC-125 (green solid circle) was used as the target compound and HFO-1336mzz(E) (orange triangle) as a tracer.

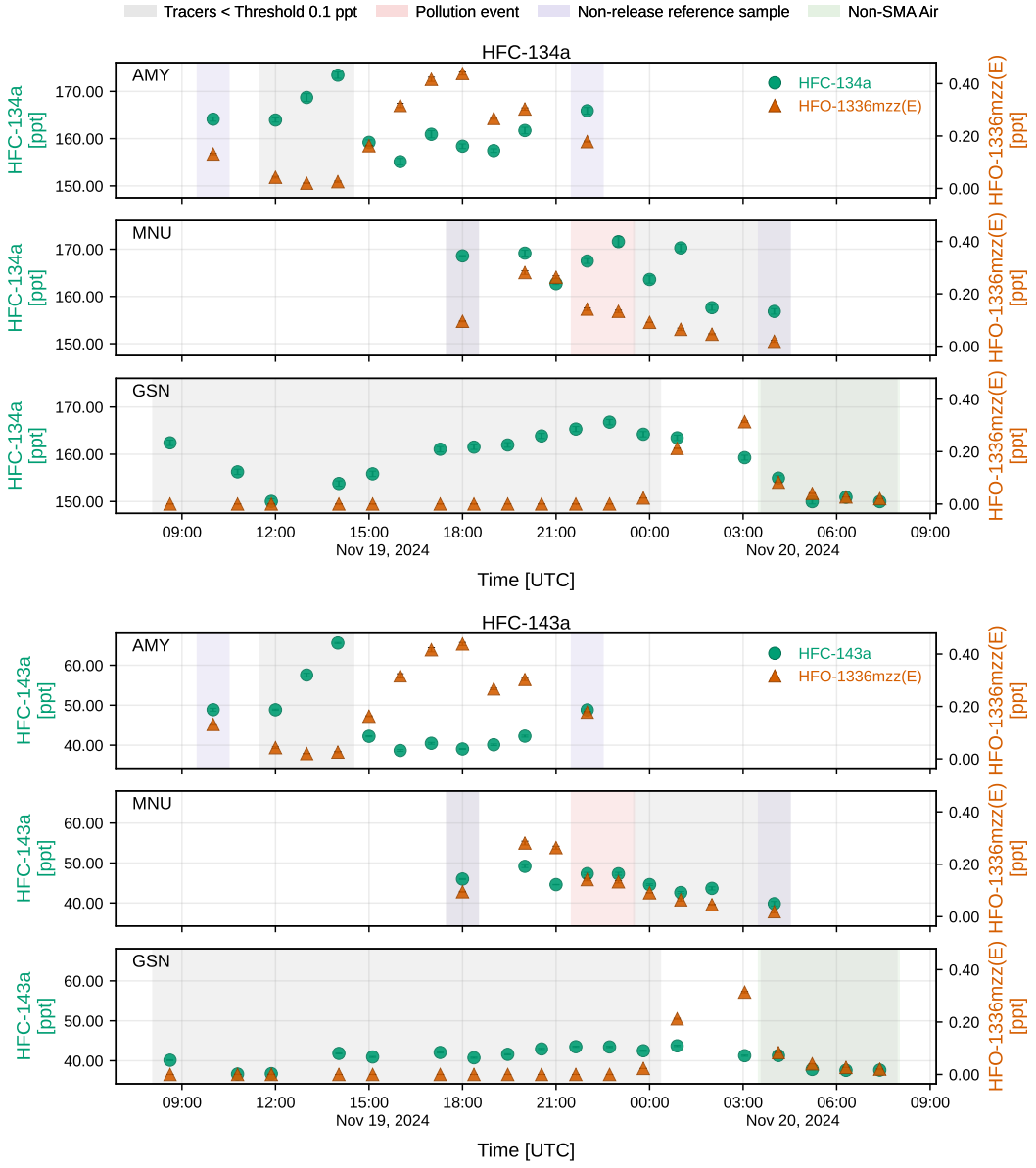


Figure S40. Quality assurance of data from the two flask sampling locations, Anmyeondo (AMY) and Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN). The exclusion criteria were a tracer threshold (0.1 ppt, grey), non-SMA pollution events (red), non-release reference flask samples (purple), and air origin based on population-impact FLEXPART simulations (green). At the top, HFC-134a and at the bottom, HFC-143a are the target compounds, both denoted as green solid circles, and HFO-1336mzz(E) (orange triangle) was used as a tracer for both.

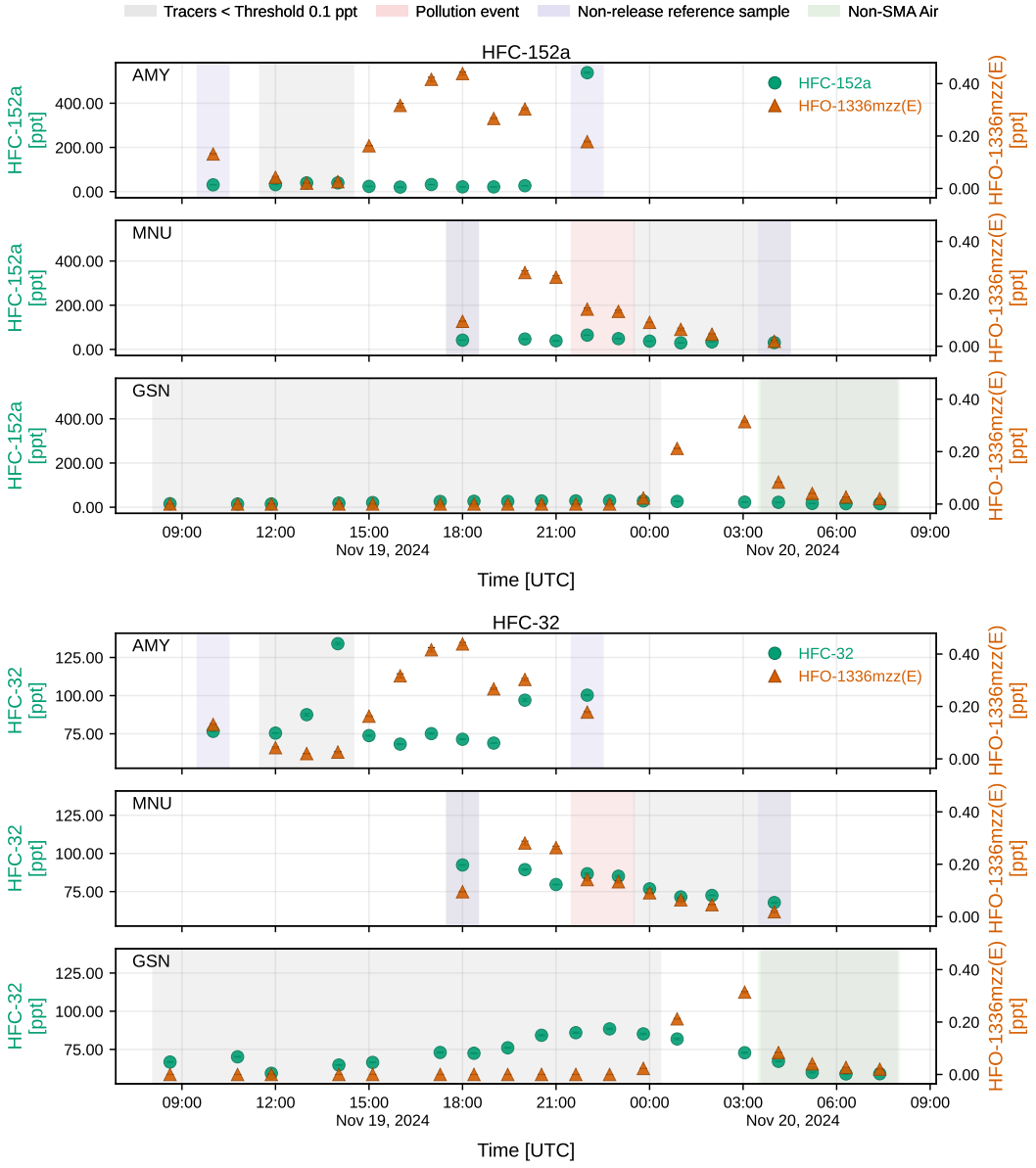


Figure S41. Quality assurance of data from the two flask sampling locations, Anmyeondo (AMY) and Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN). The exclusion criteria were a tracer threshold (0.1 ppt, grey), non-SMA pollution events (red), non-release reference flask samples (purple), and air origin based on population-impact FLEXPART simulations (green). At the top, HFC-152a and at the bottom, HFC-32 are the target compounds, both denoted as green solid circles, and HFO-1336mzz(E) (orange triangle) was used as a tracer for both.

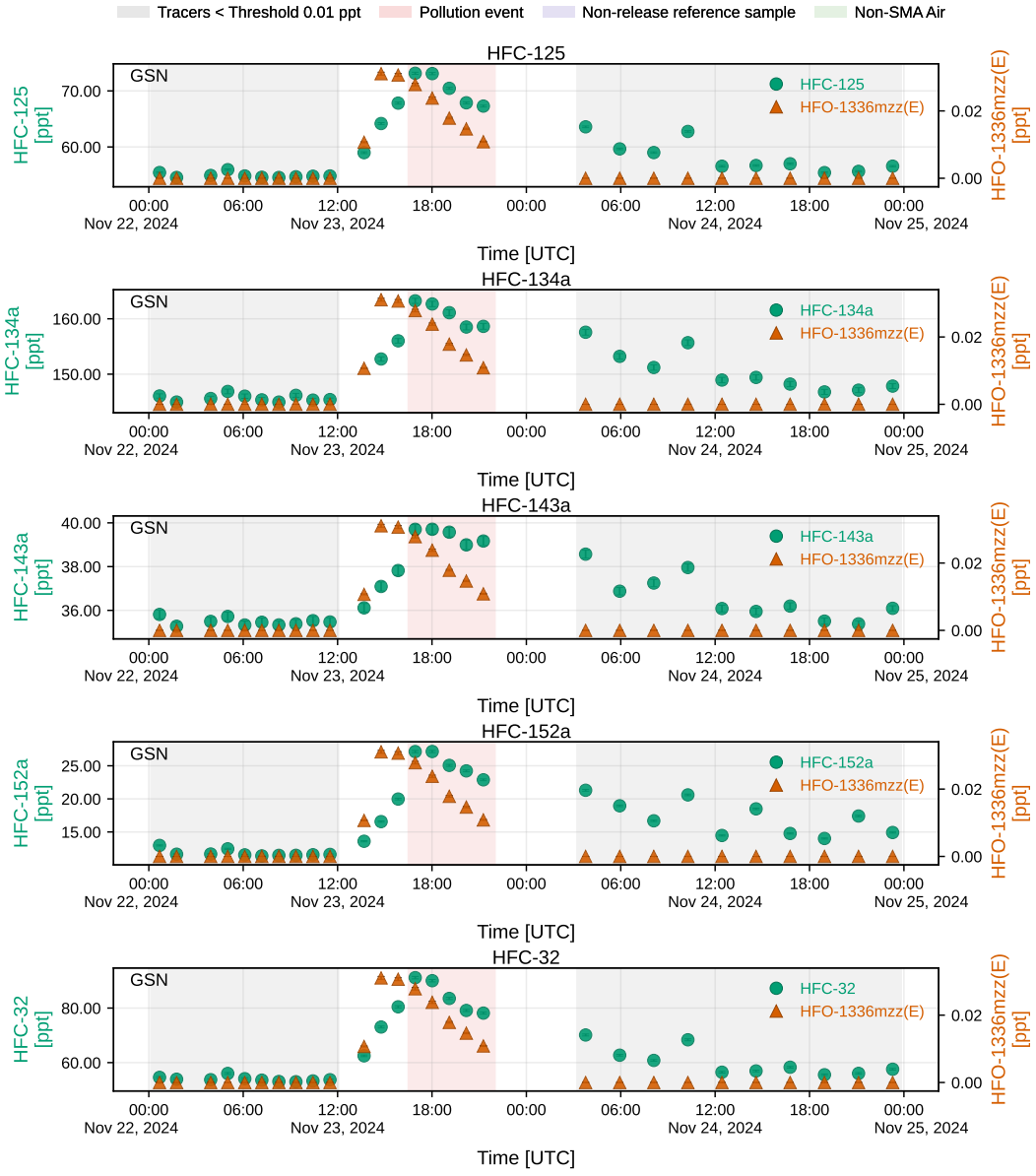


Figure S42. Quality assurance of data from the *in-situ* measurement station Gosan (GSN). The exclusion criteria were a tracer threshold (0.1 ppt, grey), non-SMA pollution events (red), non-release reference flask samples (purple), and air origin based on population-impact FLEXPART simulations (green). HFC-125, HFC-134a, HFC-143a, HFC-152a and HFC-32 are the target compounds, all denoted as green solid circles, and HFO-1336mzz(E) (orange triangle) was used as a tracer for all.

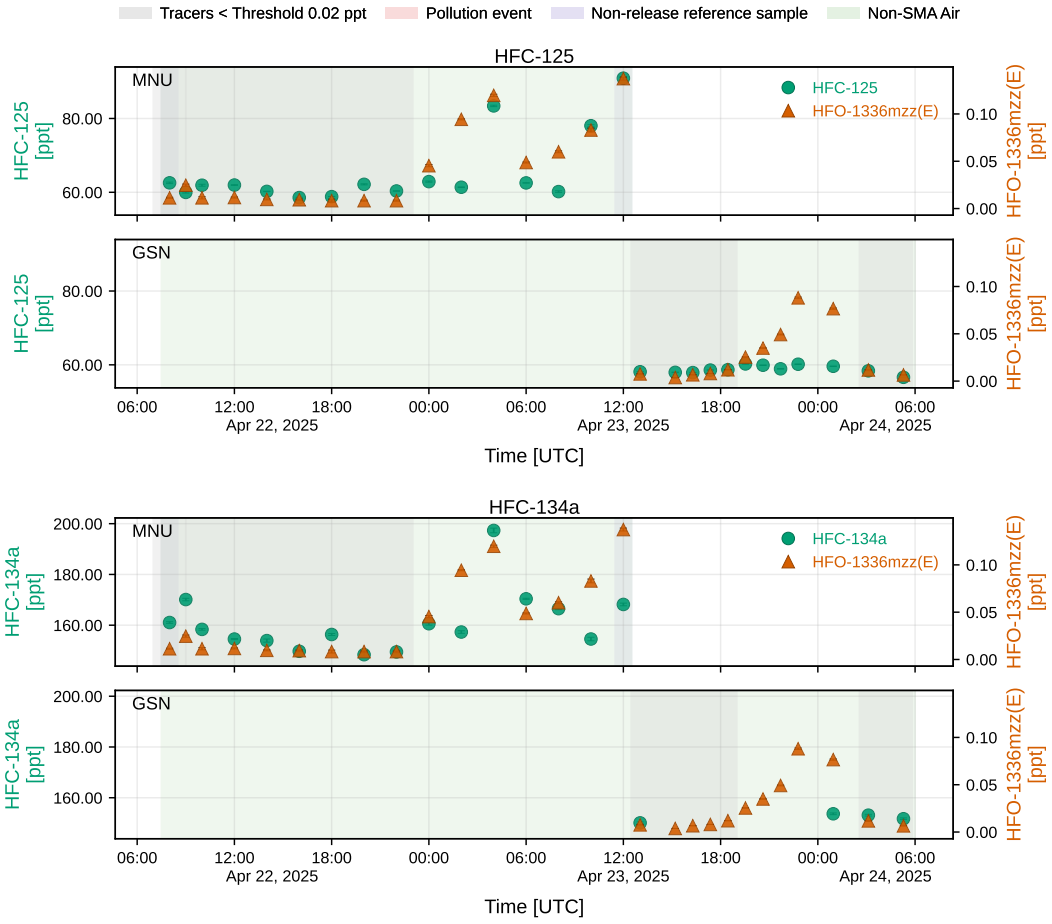


Figure S43. Quality assurance of data from the flask sampling location Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN). The exclusion criteria were a tracer threshold (0.1 ppt, grey), non-SMA pollution events (red), non-release reference flask samples (purple), and air origin based on population-impact FLEXPART simulations (green). HFC-125 and HFC-134a are the target compounds, all denoted as green solid circles, and HFO-1336mzz(E) (orange triangle) was used as a tracer for all.

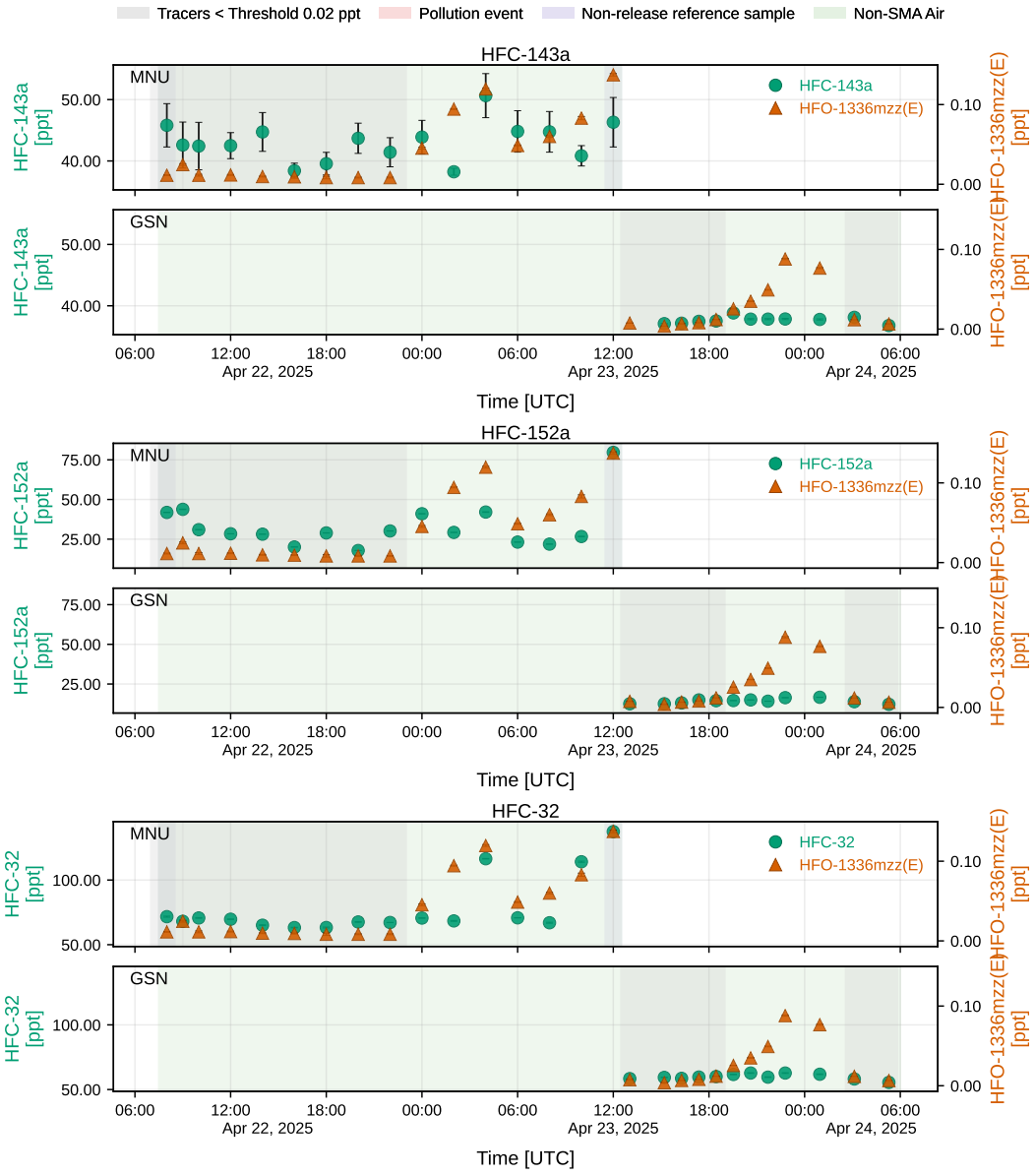


Figure S44. Quality assurance of data from the flask sampling location Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN). The exclusion criteria were a tracer threshold (0.1 ppt, grey), non-SMA pollution events (red), non-release reference flask samples (purple), and air origin based on population-impact FLEXPART simulations (green). HFC-143a, HFC-152a and HFC-32 are the target compounds, all denoted as green solid circles, and HFO-1336mzz(E) (orange triangle) was used as a tracer for all.

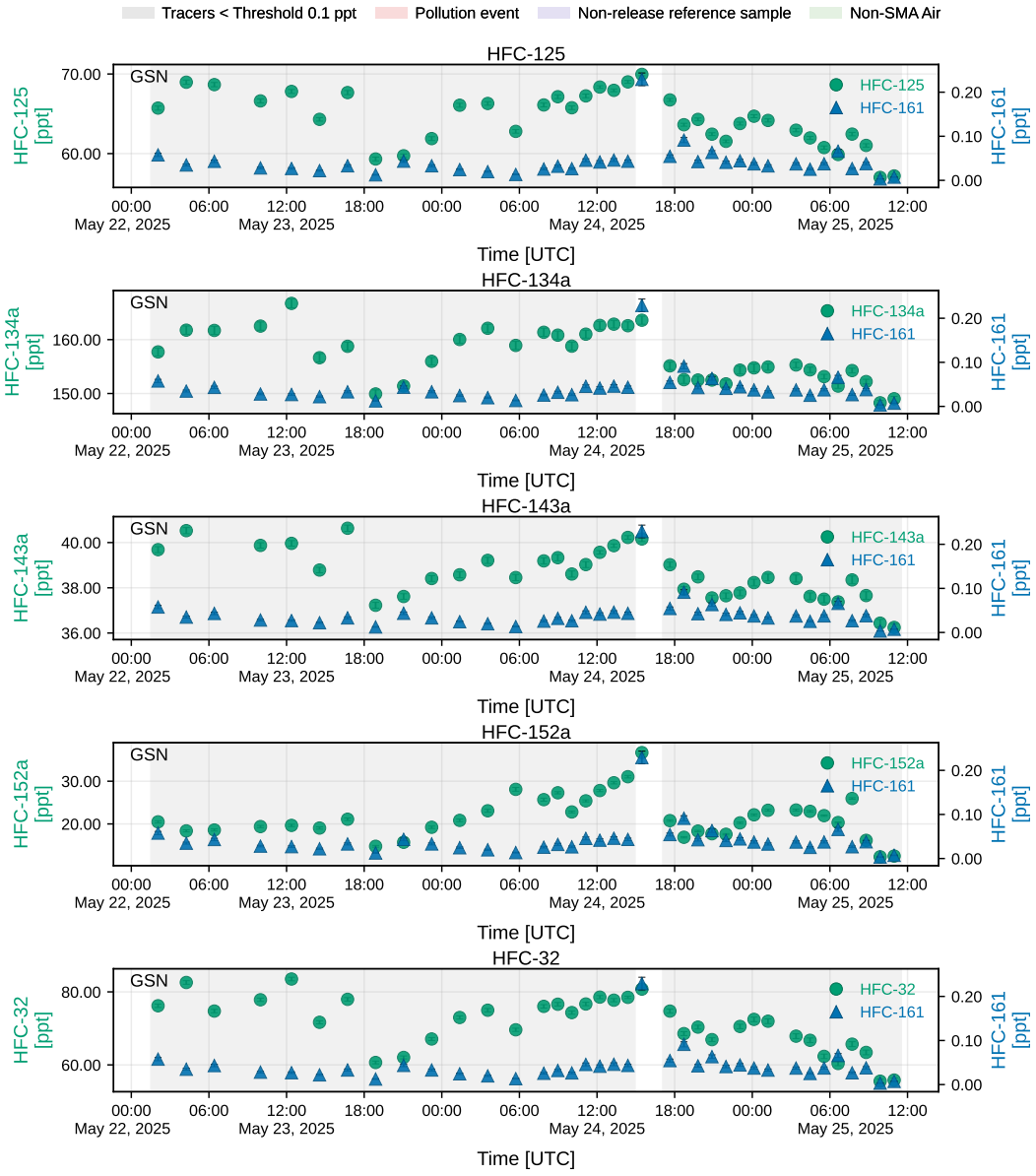


Figure S45. Quality assurance of data from the *in-situ* measurement station Gosan (GSN). The exclusion criteria were a tracer threshold (0.1 ppt, grey), non-SMA pollution events (red), non-release reference flask samples (purple), and air origin based on population-impact FLEXPART simulations (green). HFC-125, HFC-134a, HFC-143a, HFC-152a and HFC-32 are the target compounds, all denoted as green solid circles, and HFC-161 (blue triangle) was used as a tracer for all.

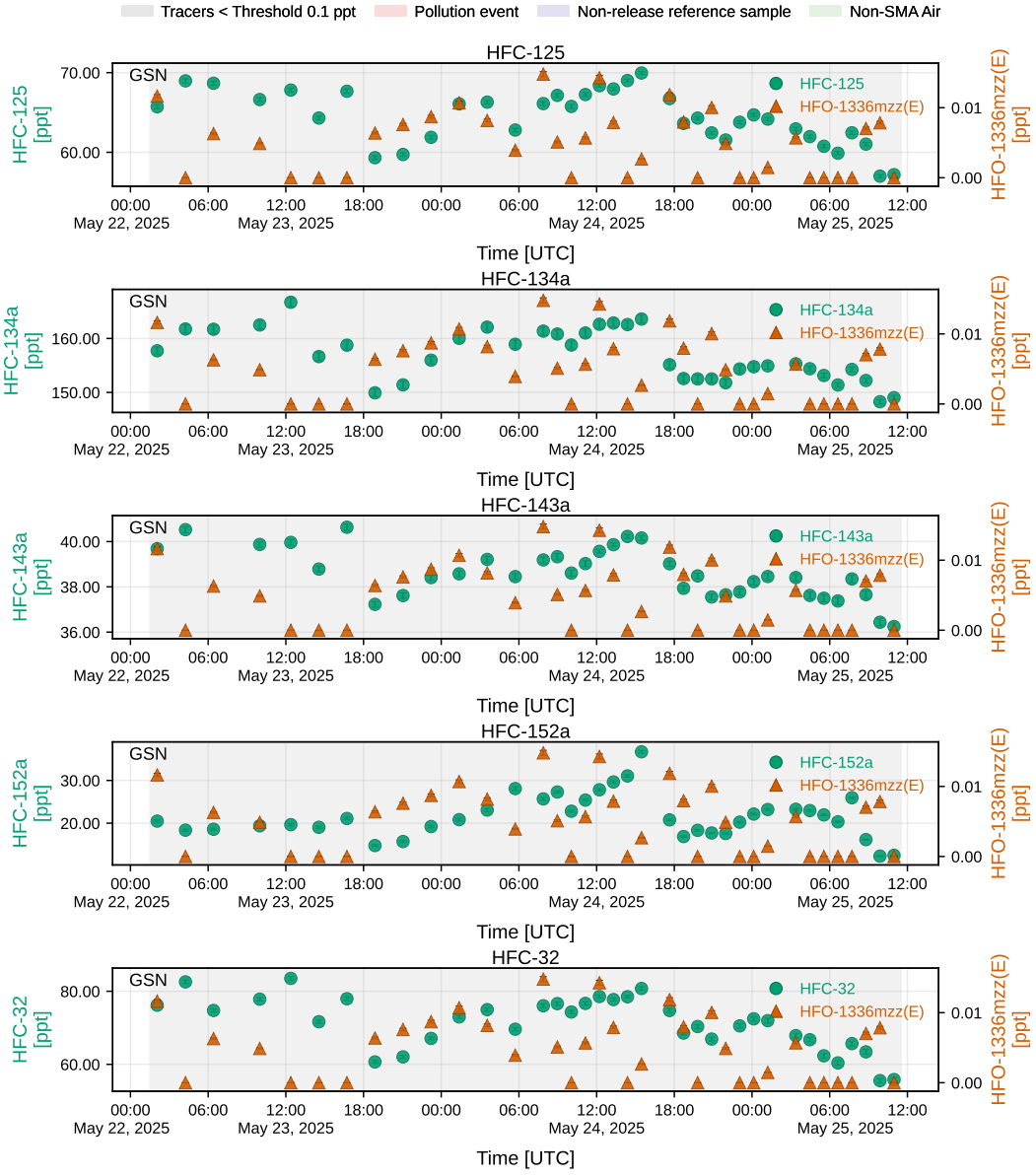


Figure S46. Quality assurance of data from the *in-situ* measurement station Gosan (GSN). The exclusion criteria were a tracer threshold (0.1 ppt, grey), non-SMA pollution events (red), non-release reference flask samples (purple), and air origin based on population-impact FLEXPART simulations (green). HFC-125, HFC-134a, HFC-143a, HFC-152a and HFC-32 are the target compounds, all denoted as green solid circles, and HFO-1336mzz(E) (orange triangle) was used as a tracer for all.

S9. Release rate assignment

S9.1. Release November 18, 2024

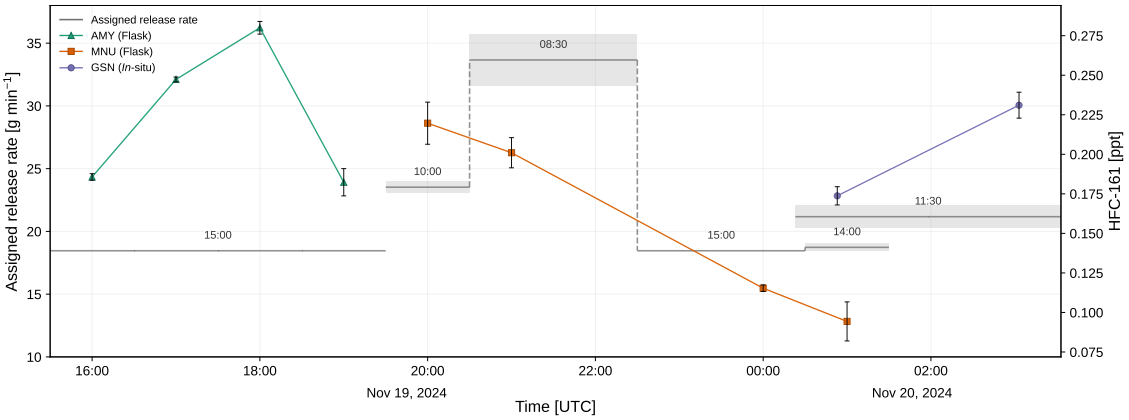


Figure S47. The measured HFC-161 mole fractions in ppt for the flask sampling sites Anmyeondo (AMY, green), Mokpo National University (MNU, orange), and the *in-situ* measurement station Gosan (GSN, purple) and the corresponding assigned release rates of HFC-161 in $\mathrm{g\,min^{-1}}$ (grey). For each measurement, the corresponding tracer release time on November 18, 2024, was assigned using FLEXPART hindcast simulations.

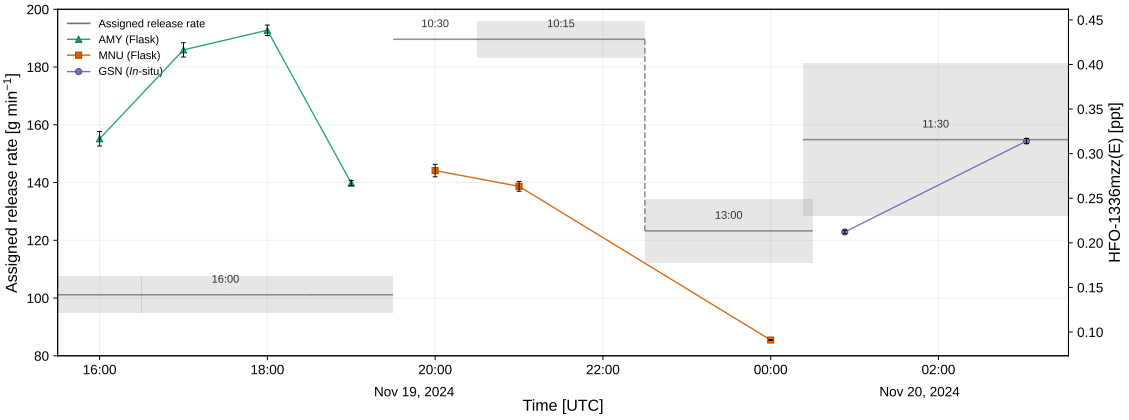


Figure S48. The measured HFO-1336mzz(E) mole fractions in ppt for the flask sampling sites Anmyeondo (AMY, green), Mokpo National University (MNU, orange), and the *in-situ* measurement station Gosan (GSN, purple) and the corresponding assigned release rates of HFO-1336mzz(E) in $\mathrm{g\,min^{-1}}$ (grey). For each measurement, the corresponding tracer release time on November 18, 2024, was assigned using FLEXPART hindcast simulations.

S9.2. Release November 22, 2024

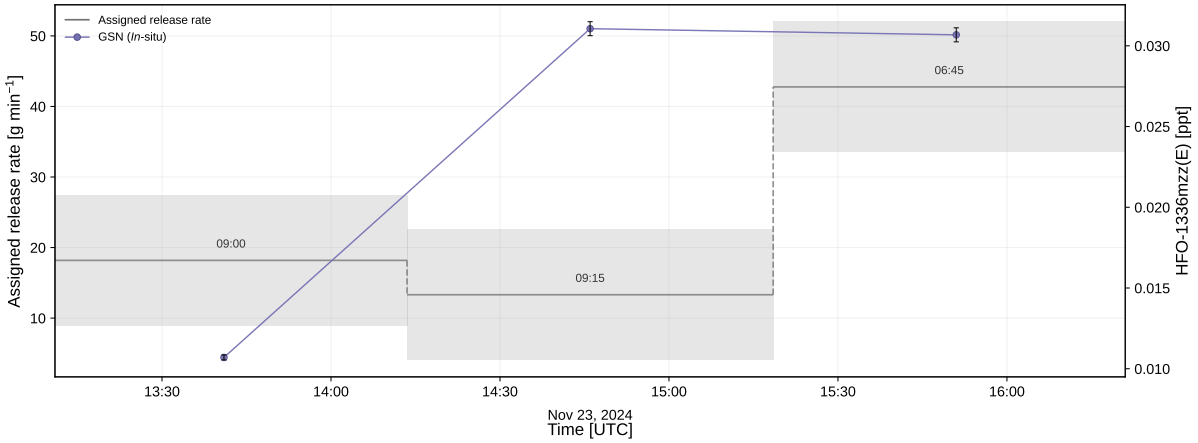


Figure S49. The measured HFO-1336mzz(E) mole fractions in ppt for the *in-situ* measurement station Gosan (GSN, purple) and the corresponding assigned release rates of HFO-1336mzz(E) in $\mathrm{g\,min^{-1}}$ (grey). For each measurement, the corresponding tracer release time on November 22, 2024, was assigned using FLEXPART hindcast simulations.

S9.3. Release May 23, 2025

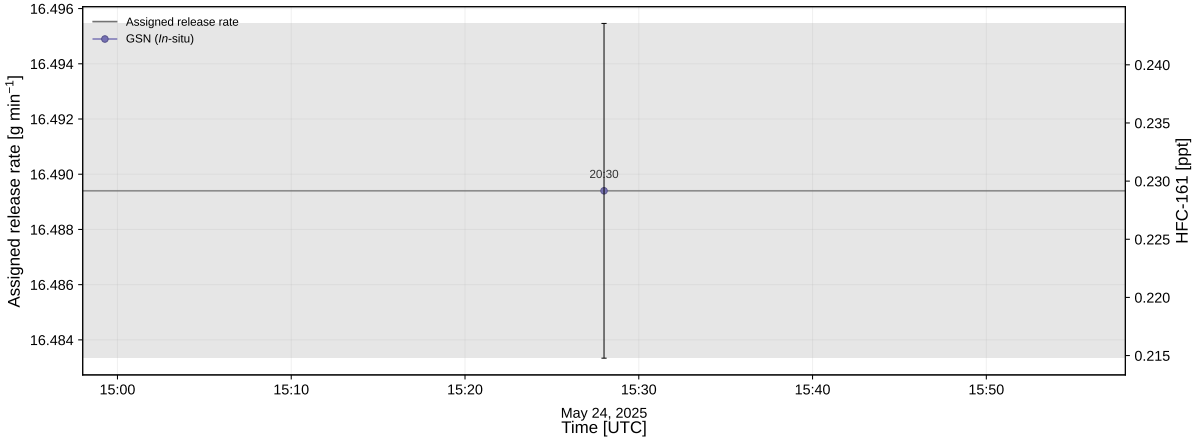


Figure S50. The measured HFC-161 mole fractions in ppt for the *in-situ* measurement station Gosan (GSN, purple) and the corresponding assigned release rates of HFC-161 in $\mathrm{g\,min^{-1}}$ (grey). For each measurement, the corresponding tracer release time on November 18, 2024, was assigned using FLEXPART hindcast simulations.

S10. Emission Estimates

S10.1. Release November 18, 2024

Table S3. Seoul Metropolitan Area (SMA) and national population-based emission estimates for the release on November 18, 2024, in $\mathrm{kt\,yr^{-1}}$ with HFC-161 as a tracer for the two flask sampling locations, Anmyeondo (AMY) and Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN).

	Station	AMY		MNU		GSN	
	Scale	SMA	South Korea	SMA	South Korea	SMA	South Korea
	HFO-1336mzz(E)	0.054±0.02	0.11±0.03	0.053±0.02	0.11±0.03	0.049±0.01	0.098±0.03
Compounds	HFC-125	1.1±0.3	2.1±0.6	3.4±1.0	6.7±2.0	2.0±0.5	4.0±1.0
	HFC-134a	0.99±0.3	2.0±0.5	2.9±0.8	5.7±2.0	1.7±0.5	3.4±0.9
	HFC-143a	0.28±0.08	0.55±0.1	1.4±0.4	2.7±0.8	0.67±0.2	1.3±0.4
	HFC-152a	0.71±0.2	1.4±0.4	2.9±0.9	5.8±2.0	0.96±0.3	1.9±0.5
	HFC-32	0.85±0.2	1.7±0.5	2.4±0.7	4.7±1.0	1.5±0.4	3.0±0.8

Uncertainties are propagated as 1σ values.

Table S4. Seoul Metropolitan Area (SMA) and national population-based emission estimates for the release on November 18, 2024, in $\mathrm{kt\,yr^{-1}}$ with HFO-1336mzz(E) as a tracer for the two flask sampling locations, Anmyeondo (AMY) and Mokpo National University (MNU) and the *in-situ* measurement station Gosan (GSN).

	Station	AMY		MNU		GSN	
	Scale	SMA	South Korea	SMA	South Korea	SMA	South Korea
	HFC-161	0.0095±0.003	0.019±0.006	0.023±0.008	0.045±0.02	0.018±0.006	0.036±0.01
Compounds	HFC-125	1.1±0.3	2.1±0.6	5.9±2.0	12±4.0	3.3±1.0	6.6±2.0
	HFC-134a	0.97±0.3	1.9±0.6	5.0±2.0	10±3.0	2.8±0.9	5.6±2.0
	HFC-143a	0.27±0.08	0.54±0.2	2.4±0.7	4.7±1.0	1.1±0.3	2.2±0.7
	HFC-152a	0.69±0.2	1.4±0.4	5.1±2.0	10±3.0	1.6±0.5	3.1±0.9
	HFC-32	0.83±0.3	1.7±0.5	4.1±1.0	8.2±2.0	2.5±0.7	4.9±1.0

Uncertainties are propagated 1σ values.

S10.2. Release November 22, 2024

Table S5. Seoul Metropolitan Area (SMA) and national population-based emission estimates for the release on November 22, 2024, in $\mathrm{kt\,yr^{-1}}$ with HFO-1336mzz(E) as a tracer for the *in-situ* measurement station Gosan (GSN).

	Station	AMY		MNU		GSN	
	Scale	SMA	South Korea	SMA	South Korea	SMA	South Korea
Compounds	HFC-125	–	–	–	–	2.8±1.0	5.5±3.0
	HFC-134a	–	–	–	–	1.6±0.8	3.2±2.0
	HFC-143a	–	–	–	–	0.33±0.2	0.65±0.3
	HFC-152a	–	–	–	–	0.80±0.4	1.6±0.7
	HFC-32	–	–	–	–	2.7±1.0	5.4±2.0

Uncertainties are propagated 1σ values.

S10.3. Release May 23, 2025

Table S6. Seoul Metropolitan Area (SMA) and national population-based emission estimates for the release on November 18, 2024, in $\mathrm{kt\,yr^{-1}}$ with HFC-161 as a tracer for the *in-situ* measurement station Gosan (GSN).

	Station	AMY		MNU		GSN	
	Scale	SMA	South Korea	SMA	South Korea	SMA	South Korea
	HFO-1336mzz(E)	–	–	–	–	0.00±0.00	0.00±0.00
Compounds	HFC-125	–	–	–	–	1.3±0.5	2.7±0.9
	HFC-134a	–	–	–	–	1.4±0.5	2.9±1.0
	HFC-143a	–	–	–	–	0.27±0.1	0.54±0.2
	HFC-152a	–	–	–	–	1.4±0.5	2.7±0.9
	HFC-32	–	–	–	–	1.2±0.4	2.3±0.8

Uncertainties are propagated 1σ values where the required inputs are available.

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