



1 Geostationary observations of atmospheric ammonia over East Asia: 2 spatio-temporal variations revealed by three years of FY-4B/GIIRS 3 measurements

4 Mengya Sheng¹, Runyi Zhou¹, Jiancong Hua¹, Shan Han¹, Shangyi Liu¹, Lin Zhang², Wei Wang³, Ruijun
5 Dang⁴, Hansen Cao⁵, Zichong Chen⁶, Yixuan Gu⁷, Mingxu Liu⁸, Lu Lee⁹, Chengli Qi⁹, Feng Lu⁹,
6 Changpei Han¹⁰, Mark W. Shephard¹¹, Nadir Guendouz¹², Camille Viatte¹², Lieven Clarisse¹³, Martin
7 Van Damme^{13,14}, Cathy Clerbaux^{12,13}, Zhao-Cheng Zeng^{1,*}

8 ¹ School of Earth and Space Sciences, Peking University, Beijing 100871, China

9 ² Laboratory for Climate and Ocean-Atmosphere Studies, Department of Atmospheric and Oceanic Sciences, School of Physics,
10 Peking University, Beijing 100871, China

11 ³ Key Laboratory of Environmental Optics and Technology, Anhui Institute of Optics and Fine Mechanics, Chinese Academy
12 of Sciences, Hefei 230031, China

13 ⁴ School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA

14 ⁵ School of Environmental Science and Engineering, Southern University of Science and Technology, Shenzhen, Guangdong
15 518055, China

16 ⁶ Hong Kong University of Science and Technology, Guangzhou 511400, China

17 ⁷ Jiangsu Key Laboratory of Atmospheric Environment Monitoring and Pollution Control, Collaborative Innovation Center of
18 Atmospheric Environment and Equipment Technology, Joint International Research Laboratory of Climate and Environment
19 Change, School of Environmental Science and Engineering, Nanjing University of Information Science and Technology,
20 Nanjing 210044, China

21 ⁸ College of Environmental Sciences and Engineering, Peking University, Beijing 100871, China

22 ⁹ Key Laboratory of Radiometric Calibration and Validation for Environmental Satellites, National Satellite Meteorological
23 Center, China Meteorological Administration, Beijing 100081, China

24 ¹⁰ Key Laboratory of Infrared Science and Technology, Shanghai Institute of Technical Physics, Chinese Academy of Sciences,
25 Shanghai 200083, China

26 ¹¹ Environment and Climate Change Canada, Toronto, Ontario M3H 5T4, Canada

27 ¹² LATMOS/IPSL, Sorbonne Université, UVSQ, CNRS, Paris 75252, France

28 ¹³ Spectroscopy, Quantum Chemistry and Atmospheric Remote Sensing (SQUARES), Brussels Laboratory of the Universe
29 (BLU-ULB), Université libre de Bruxelles (ULB), Brussels 1050, Belgium

30 ¹⁴ Royal Belgian Institute for Space Aeronomy, Brussels 1180, Belgium

31 *Correspondence to:* Zhao-Cheng Zeng (zczeng@pku.edu.cn)

32 **Abstract.** Satellite observations play a crucial role in quantifying ammonia sources by capturing large-scale variations of
33 atmospheric NH₃ concentrations. As the world's first geostationary hyperspectral infrared sounder, the Geostationary
34 Interferometric Infrared Sounder (GIIRS) on board China's FengYun-4 satellite series provides a unique opportunity to
35 monitor the diurnal cycle of NH₃. Using NH₃ retrievals between July 2022 and June 2025, this study investigates the spatio-
36 temporal variability of NH₃ columns over East Asia, with a focus on daytime variations (07:00–19:00 local time) in major
37 agricultural regions. Inter-comparison with polar-orbiting IASI and CrIS data shows that GIIRS NH₃ retrievals are consistent
38 in capturing the spatial patterns and temporal dynamics. The NH₃ peaks occur between March and July, with the timing shifting



from north to south, reflecting regional differences primarily driven by agriculture activities. Validation with ground-based FTIR measurements at Hefei in eastern China demonstrates the accuracy of GIIRS NH_3 , with a correlation coefficient of 0.77 and an RMSE of 9.67×10^{15} molec/ cm^2 , while reproducing daytime variations observed by FTIR. For major agricultural areas, the NH_3 columns generally increase from early morning to late afternoon, reaching 1.10–1.56 times morning levels in summer and spring. Compared with GEOS-CF model simulations, the results reveal pronounced discrepancies in spatial distributions over the Sichuan Basin in southwestern China and daytime variations over northern India. These findings highlight the valuable capability of FY-4B/GIIRS in identifying and tracking daytime dynamics of NH_3 sources over East Asia, offering new insights beyond current low-Earth orbit (LEO) instruments.

1 Introduction

Gaseous ammonia (NH_3), the most abundant alkaline gas and a major reactive nitrogen compound in the atmosphere, plays a critical role in the global nitrogen cycle. NH_3 is an important precursor of secondary inorganic aerosols. It rapidly reacts with atmospheric acids such as sulfuric acid (H_2SO_4) and nitric acid (HNO_3) to form ammonium sulfate ($(\text{NH}_4)_2\text{SO}_4$) and ammonium nitrate (NH_4NO_3) (Seinfeld et al., 2016). These ammonium-containing aerosols are the primary components of fine particulate matter ($\text{PM}_{2.5}$) and have been identified as key contributors to elevated $\text{PM}_{2.5}$ concentrations and haze pollution in both rural areas (Jang et al., 2025; Saraswati et al., 2019; Meng Z. et al., 2018) and megacities (Lin et al., 2020) in Asia, posing significant threats to air quality, visibility, and public health. Through aerosol-mediated processes, NH_3 also indirectly influences the formation and removal of greenhouse gases such as nitrous oxide (N_2O) and methane (CH_4) by altering the oxidative capacity of the atmosphere (Pai et al., 2021). Moreover, excessive emissions and deposition of NH_3 have adverse effects on ecosystems, causing biodiversity loss, soil acidification, and water eutrophication (Bobbink et al., 2010). Anthropogenic NH_3 emissions primarily originate from agricultural activities, particularly from synthetic fertilizer application and livestock farming, with additional contributions from industrial processes and transportation (Behera et al., 2013). Numerous studies have indicated that a relatively strong reduction in $\text{PM}_{2.5}$ and N_2O levels can be achieved by decreasing agricultural emissions (e.g., Luo et al., 2025). Therefore, comprehensive quantification and understanding of NH_3 emission sources are essential for developing effective air quality and climate mitigation strategies.

Asia is the world's most significant NH_3 emission hot spots, accounting for over 30% of global NH_3 emissions annually as reported by the EDGAR emission inventory. Due to widespread use of urea-based nitrogen fertilizers and high livestock densities, cropland areas such as the Indo-Gangetic Plain in India and the North China Plain in China are recognized as major global NH_3 emission hot spots (Van Damme et al., 2018). NH_3 volatilization is strongly controlled by surface conditions, including temperature and moisture, and irrigation-driven NH_4^+ accumulation in soils (Behera et al., 2013). The resulting atmospheric NH_3 concentrations over a region are further influenced by meteorology- and topography-induced constraints on atmospheric mixing and transport, chemical reactions dependent on the concentrations of reactive acidic gases, and dry and wet deposition (Dammers et al., 2017a). In most regions, NH_3 concentration levels in summer are significantly higher than



those in winter, driven by emissions from urea hydrolysis and livestock manure decomposition (Warner et al., 2016; Van Damme et al., 2015). However, NH_3 has a short atmospheric lifetime of a few hours to several days, resulting in large intra-day variability in concentrations from both agricultural and non-agricultural sources. Previous studies in Asia have primarily addressed the quantification of agricultural and non-agricultural sources using the bottom-up emission inventories and ground-based measurements, as well as the estimation of anthropogenic emissions inferred from NH_3 observations. Only a few studies have employed surface measurements to investigate the diurnal variability of NH_3 and its controlling mechanisms, and found that diurnal pattern of NH_3 variations in various urban and rural areas differ markedly across seasons (Chang et al., 2019; Huy et al., 2017; Meng Z. et al., 2011). Limited by the sparse spatial coverage and short temporal duration of ground-based monitoring networks, the mechanisms underlying the diurnal variation characteristics of atmospheric NH_3 in different emission source regions still remain poorly understood (Gu et al., 2022; He et al., 2020).

Satellite observations facilitate a top-down inversion method for monitoring NH_3 variations across different spatial scales. The hyperspectral infrared sounders onboard polar-orbiting satellites in low-Earth orbit (LEO), such as the Infrared Atmospheric Sounding Interferometer (IASI; Clarisse et al., 2009), the Tropospheric Emission Spectrometer (TES; Beer et al., 2008), the Atmospheric Infrared Sounder (AIRS; Warner et al., 2016), and the Cross-track Infrared Sounder (CrIS; Shephard et al., 2020), have provided global monitoring of atmospheric NH_3 column densities. Satellite-based NH_3 retrievals have been widely used to investigate the spatial distribution of NH_3 emission sources (e.g., Van Damme et al., 2018), to characterize spatiotemporal variations in atmospheric NH_3 concentrations (e.g., Van Damme et al., 2021; Shephard et al., 2020), and to constrain emission estimates (e.g., Cao et al., 2020; Dammers et al., 2019) and dry deposition estimates (e.g., Kharol et al., 2018). Van Damme et al. (2021) reported that NH_3 concentrations increased from 2008–2018 in major agricultural regions globally, including South Asia, China, the United States and some parts of Europe. Using multi-year NH_3 maps, Van Damme et al. (2018) and Clarisse et al. (2019) identified and quantified major industrial and agricultural NH_3 point sources, revealing that NH_3 emissions from approximately two-thirds of these sources were underestimated by at least one order of magnitude in the Emissions Database for Global Atmospheric Research (EDGAR) inventory. In addition, NH_3 emission estimates based on satellite observations and inverse modeling indicated that the bottom-up emission inventories underestimate NH_3 emissions, especially during summer (e.g., Xu et al., 2023; Marais et al., 2021; Zhang et al., 2018).

Accurately monitoring daily dynamics of NH_3 emissions imposes high sampling requirements in time and space on atmospheric NH_3 measurements. Polar-orbiting satellites typically measure a given location at most twice per day. For example, IASI and CrIS cross the equator at 09:30/21:30, and 01:30/13:30 local solar time (LST), respectively (Whitburn et al., 2016; Shephard et al., 2015). The above satellite-based studies mostly used morning observations from IASI and afternoon observations from CrIS, because of the lower uncertainties associated with a more favorable thermal state of the atmosphere for the remote sensing of its lowest layers. Investigations of the spatial and temporal variability of NH_3 are constrained by the limited coverage of satellite overpasses, leading to potential temporal representativeness biases and substantial uncertainties in daily NH_3 emission estimates (Clarisse et al., 2019; Van Damme et al., 2018). The Geostationary Interferometric Infrared Sounder (GIIRS) onboard the FY-4 series, the world's first hyperspectral infrared sounder in geostationary (GEO) orbit, was



105 first launched as an experimental instrument on FY-4A in 2016 and later upgraded to an operational version with enhanced
 106 sensitivity on FY-4B in 2021 (Yang et al., 2017). Compared with current LEO instruments, GIIRS provides continuous day-
 107 and-night monitoring of atmospheric NH_3 over East Asia at approximately every two-hour interval, a breakthrough in
 108 understanding and monitoring the diurnal cycle of atmospheric NH_3 variations (Zeng et al., 2023a; Clarisse et al., 2021). A
 109 recent study by Guendouz et al. (2025) investigated the correlation between GIIRS NH_3 and surface skin temperature and
 110 showed the potential of discriminating sources between temperature-driven livestock/fertilizer volatilization and urea fertilizer
 111 application.

112 With over three years of FY-4B/GIIRS geostationary observations available from July 2022 to June 2025, unprecedented
 113 opportunities have emerged to monitor the spatial and temporal variations of NH_3 concentrations and their evolution
 114 throughout the day over East Asia. In this study, we highlighted the enhanced capability of GIIRS observations to identify
 115 emission sources and capture daytime variations associated with agricultural activities, surpassing those reported by polar-
 116 orbiting satellites. The data and methodology are described in Sect.2. The spatial patterns and seasonal cycles of NH_3 observed
 117 by GIIRS are compared with observations from IASI and CrIS and estimates from the MIX Asian emission inventory in
 118 Sect.3.1. The data accuracy and temporal variations of satellite-derived NH_3 are validated against ground-based Fourier
 119 Transform Infrared (FTIR) measurements at the Hefei station in Sect.3.2. The daytime variations of NH_3 from GIIRS
 120 observations and model simulations in major agricultural regions are discussed in Sect.3.3. Conclusions are summarized in
 121 Sect.4.

122 2 Data and Methodology

123 2.1 Satellite NH_3 retrievals

124 2.1.1 GIIRS observations

125 FY-4B/GIIRS was successfully launched on 3 June 2021, and operated at 133°E from 12 April 2022 to 31 January 2024.
 126 As the FY-4A satellite approached fuel depletion, FY-4B was maneuvered from 133°E to 105°E in February 2024 to take over
 127 FY-4A's observation duties, and it has been operating nominally at 105°E since 27 February 2024. FY-4B/GIIRS observations
 128 primarily covers the regions from 3°N to 55°N and 60°E to 137°E , encompassing East Asia and parts of South and Southeast
 129 Asia (Fig. 1). The instrument performs measurements over the target region every 2 hours using a “step-stare” scanning mode.
 130 Observations are conducted along 12 scanning lines from north to south, with 27 fields of regard (FORs) arranged from west
 131 to east along each line. Within a FOR is a two-dimensional infrared detector array composed of 16×8 sparsely arranged pixels.
 132 Each Pixel has a nadir-projected size of approximately $12 \text{ km} \times 12 \text{ km}$, with a spacing of 12 km in both along-track and cross-
 133 track directions between adjacent pixels. Initially, 12 measurement cycles in a day started at 00:00, 02:00, 04:00, ..., 22:00
 134 UTC. After 6 September 2022, the start times were changed to 01:00, 03:00, 05:00, ..., 23:00 UTC, respectively.

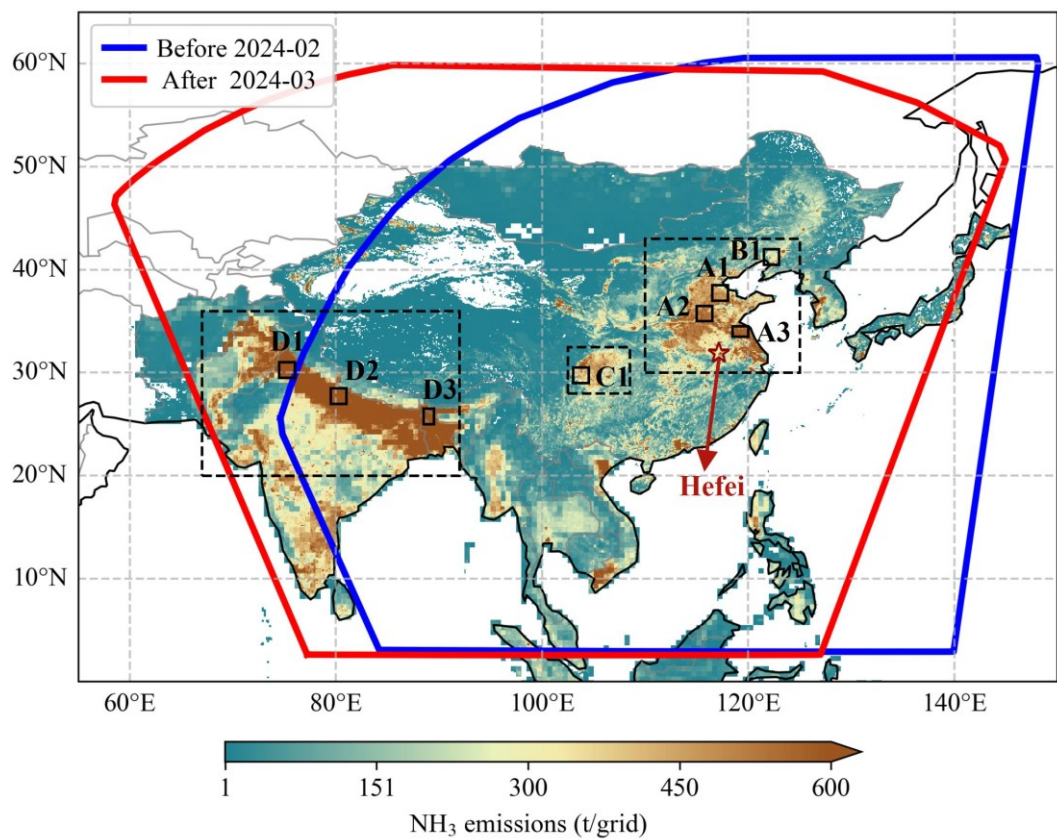


Figure 1. Spatial domain of FY-4B/GIIRS observations over East Asia. The blue and red boxes outline regions with valid NH₃ retrievals prior to and following the FY-4B orbital relocation, respectively. The background map shows total anthropogenic NH₃ emissions in 2017 from the MIX emission inventory at a 0.1° grid resolution (Li et al., 2024). The red pentagram marks the location of the Hefei station, which is further described in Sect. 3.2, and the black boxes (A1-A3, B1, C1, D1-D3) indicate major agricultural areas discussed in Sect. 3.3.

Three years of NH₃ columns from July 2022 to June 2025 are retrieved from FY-4B/GIIRS spectra using the FengYun Geostationary satellite Atmospheric Infrared Retrieval (FY-GeoAIR) algorithm, which exploits the strong NH₃ absorption features in the 955–975 cm⁻¹ spectral region. FY-GeoAIR is a full-physics retrieval algorithm that integrates a forward radiative transfer model for simulating upwelling thermal radiation and an optimal estimation-based inverse model for retrieving trace gases and auxiliary parameters from the observed spectra (Zeng et al., 2023a). In this study, the retrieval configuration and parameters are identical to those described in Zeng et al. (2023b), except that a “profile-scaling retrieval” approach was adopted instead of the “full-profile retrieval” method, which retrieves partial NH₃ columns at each atmospheric layer. In contrast, the profile-scaling retrieval applies a single, representative a priori profile (identical for all scenes) and scales this profile in the retrieval algorithm to optimize the spectra fitting. The retrieval yields the NH₃ column and the posteriori error estimate, as well as the column averaging kernel (AVK) from surface to 200 hPa (See examples in Fig. S1). This retrieval strategy is similar to the Total Carbon Column Observing Network (Wunch et al., 2011). The column AVK value at a specific atmospheric layer



152 represents the change of the retrieved total NH_3 column with respect to a perturbation of the partial NH_3 column at that
 153 atmospheric layer.

154 The observations that are cloud-contaminated or fail to converge within 10 iterations are excluded. To obtain high-quality
 155 GIIRS NH_3 observations, we also applied the following filtering criteria: (1) a root mean square error (RMSE) of the fitting
 156 residual less than 0.2 K; (2) a reduced χ^2 less than 5; (3) retrieval error below 300%; (4) the absolute difference of the a priori
 157 and retrieved surface skin temperature less than 10 K; (5) the bottom layer (from surface to $\sim$) of column AVK greater than
 158 0.1; (6) the thermal contrast (TC) greater than 0 K; (7) the retrieved NH_3 columns are positive. The retrieval error was calculated
 159 as the square root of the diagonal elements of the retrieval error covariance matrix for NH_3 , normalized by the ratio of the
 160 retrieved NH_3 column to the a priori NH_3 column. The TC is defined as the temperature difference between the surface and
 161 the lowest atmospheric layer. In this study, NH_3 retrievals from individual observations over land during daytime (7:00–19:00
 162 LST) were utilized to investigate spatial and temporal variations over East Asia (Fig. 2). To facilitate regional analysis,
 163 individual retrievals were averaged onto a $0.5^\circ \times 0.5^\circ$ grid. The strict quality filtering results in large data gaps over the Tibetan
 164 Plateau throughout the day, and over southern regions of China and India during 17:00–19:00 LST, where retrievals are
 165 frequently discarded due to low sensitivity or cloud screening. For the analysis of daytime NH_3 variations presented in Sect.
 166 3.3, we further filtered the daytime observations by requiring $\text{TC} > 5$ K to ensure sufficient sensitivity to near-surface NH_3 .

167 2.1.2 IASI observations

168 The IASI instrument, jointly developed by the Centre National d'Études Spatiales (CNES) and the European Organisation
 169 for the Exploitation of Meteorological Satellites (EUMETSAT), was specifically designed for deployment aboard the Metop
 170 series satellites. Three identical instruments were successively embarked on the Metop-A, Metop-B and Metop-C platforms,
 171 launched in 2006, 2012 and 2018, respectively. IASI operates in a sun-synchronous LEO at an altitude of approximately 800
 172 km, with a ground swath of ~ 2100 km and a spatial resolution of 12 km at nadir. It measures the Earth's emitted infrared
 173 radiation across a spectral range of $645\text{--}2760\text{ cm}^{-1}$ with an apodized resolution of 0.5 cm^{-1} (Clerbaux et al., 2009). The near-
 174 real-time NH_3 dataset is retrieved using the Artificial Neural Network for IASI (ANNI) framework. This method converts the
 175 hyperspectral signature of NH_3 , quantified by the so-called hyperspectral range index (HRI), into total column amounts
 176 (Whitburn et al., 2016). Two independent validation studies demonstrated that IASI-retrieved NH_3 columns show good
 177 consistency with both in situ and FTIR observations, exhibiting near-unity regression slopes and moderate biases (Guo et al.,
 178 2021; Wang et al., 2020). In this study, we utilized NH_3 data from IASI observations on the Metop-B and Metop-C platforms
 179 from January 2017 to June 2025 for comparison with GIIRS observations. The data products provide total NH_3 columns
 180 derived from the ANNI version 4 algorithm, which is about 15–20% larger than the previous version 3 due to the improved
 181 setup of HRI, but show very similar NH_3 distribution (Clarisse et al., 2023). Here, NH_3 columns marked as recommended by
 182 both pre-filter and post-retrieval quality flags in the data products were selected and then regridded onto a 0.5° spatial grid
 183 using arithmetic averaging. The quality flags allow some negative columns to be retained, as discussed by Clarisse et al. (2019)
 184 and Whitburn et al. (2016).



185 2.1.3 CrIS observations

186 The Cross-track Infrared Sounder (CrIS) is a Fourier transform spectrometer (FTS) jointly developed by the National
 187 Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA), provides
 188 hyperspectral infrared measurements at a spectral resolution of 0.625 cm^{-1} with a nadir spatial resolution of $\sim 14\text{ km}$. CrIS was
 189 first launched on the Suomi National Polar-orbiting Partnership (S-NPP) satellite on 28 October 2011 and subsequently
 190 deployed on NOAA-20 (JPSS-1) on 29 November 2017 and on JPSS-2 on 10 November 2022. The NH_3 retrievals from CrIS
 191 observations on S-NPP and NOAA-20 have been generated using the CrIS Fast Physical Retrieval (CFPR) algorithm
 192 developed by Environment and Climate Change Canada (ECCC), which exploits spectral features near 967 cm^{-1} . A detailed
 193 description of the CFPR algorithm can be found in [Shephard et al. \(2015, 2020\)](#). Independent validation studies against FTIR-
 194 derived total column measurements have demonstrated that CFPR (version 1.3) shows good overall consistency, with a
 195 correlation of approximately 0.8 and a slope of 1.02. For retrievals with total column values above $1 \times 10^{16}\text{ molec/cm}^2$ (ranging
 196 from moderate to high levels), the relative bias is less than 5 %. For smaller total column values ($< 1 \times 10^{16}\text{ molec/cm}^2$), there
 197 are larger differences, with CrIS retrievals about 30% higher than FTIR values ([Dammers et al., 2017a](#)). However, these
 198 validations did not account for non-detects ([White et al., 2023](#)) below the detection limit of the sensor ($\sim 4 \times 10^{15}\text{ molec/cm}^2$
 199 under typical remote sensing conditions) ([Shephard et al., 2025](#)), which could reduce potential high-biases over non-source
 200 conditions. In this study, we used CrIS NH_3 data product from NOAA-20 (version 1.6.4), spanning the period from March
 201 2019 to April 2025. The product provides geolocation information, vertically integrated ammonia total columns, retrieval
 202 uncertainties, quality flags, and additional metadata. Our analysis focuses on NH_3 retrievals over land, characterized by land
 203 fraction > 0 , quality flag ≥ 4 , cloud flag $\neq 1$, and DOFS ≥ 0.1 .

204 2.2 Ground-based FTIR measurements at Hefei

205 The Hefei station (31.91°N , 117.17°E) is located in the northwestern rural area of Hefei city, China. The surrounding
 206 region is part of the typical Jianghuai agricultural region, where wetlands and croplands are interspersed in a distinctive
 207 landscape pattern. Since July 2015, a high-resolution ground-based Fourier transform infrared spectrometry (FTIR) has been
 208 operated at the station to record mid-infrared (MIR) solar absorption spectra ($700\text{--}4000\text{ cm}^{-1}$) for the remote sensing of
 209 greenhouse gases and trace species ([Wang et al., 2017](#)). Previous studies have demonstrated that FTIR measurements at Hefei
 210 effectively capture spatiotemporal variability of NH_3 columns, with retrievals showing broadly consistent with IASI satellite
 211 data ([Wang et al., 2022](#)). In this study, FTIR-derived NH_3 column data from 2017 to 2024 were averaged to hourly means and
 212 used for the validation and cross-comparison of satellite-based NH_3 retrievals. Noted that the data primarily covers the period
 213 from 8:00 to 17:00 LST, with limited available observations between 17:00 and 18:00 LST.

214 2.3 NH_3 emission inventory

215 In this paper, the anthropogenic emission data of NH_3 in 2017 from the MIX v2.3 inventory was used for a comparison



with the NH_3 concentrations observed by satellites. MIXv2.3 is a mosaic emission inventory for Asia for the years 2010–2017, which is developed to support the Model Inter-Comparison Study for Asia Phase IV (MICS-Asia IV) project by a mosaic of up-to-date regional and national emission inventories (Li et al., 2024). MIXv2.3 provided monthly NH_3 emissions estimates for seven sectors, including agriculture, power, industry, residential, transportation, open biomass burning and shipping. The spatial domain covers 23 countries and regions in East, Southeast and South Asia, with a spatial resolution of $0.1^\circ \times 0.1^\circ$ grid.

2.4 Hourly NH_3 data from GEOS-CF model

The Goddard Earth Observing System composition forecast (GEOS-CF) system is a high-resolution global constituent prediction model developed by NASA's GMAO. It expands on the GEOS weather and aerosol modeling system by introducing the GEOS-Chem chemistry module, providing near-real-time, three-dimensional gridded information on atmospheric composition (Keller et al., 2021). The emission inputs of anthropogenic NH_3 emissions used by GEOS-CF are mainly from the Hemispheric Transport of Air Pollution emissions inventory (HTAP v2.2), which is monthly data at a 0.1° spatial resolution. The model runs at hourly intervals with $0.25^\circ \times 0.25^\circ$ horizontal resolution and 72 hybrid-eta levels from the surface to 0.01 hPa. In this study, NH_3 vertical profiles were obtained from 1-day replay simulations (referred to as “hindcast”) constrained by pre-computed meteorological analysis fields, and NH_3 total columns were calculated by combining the model’s vertical pressure levels and surface pressures from the fifth-generation ECMWF reanalysis (ERA5) (Hersbach et al., 2023).

2.5 The derivation of NH_3 variations

2.5.1. Curve-fitting Method for trend analysis

To quantify the temporal changes in NH_3 columns, we applied a curve-fitting method to obtain daily time series of satellite-based NH_3 observations. This method is widely used to extract temporal variation characteristics of atmospheric composition, such as NH_3 (Wang et al., 2022; Van Damme et al., 2015). As shown in Eq. (1), it integrates a polynomial function and a sum of harmonic function, representing long-term linear trend and seasonal cycles, respectively.

$$f(t) = a_0 + a_1 t + \sum_{n=1}^4 (\beta_n \sin(2n\pi t) + \gamma_n \cos(2n\pi t)) \quad (1)$$

where f is the daily fitting result, t is the time in decimal years, the coefficients (a_0 , a_1 , β_n , γ_n) are determined by the least squares regression. In Sect. 3.1, the fitting analysis was performed separately for each $0.5^\circ \times 0.5^\circ$ grid cell, with more than 500 data points and observation dates spanning over 100 days. Extreme values and minima of the fitted curves were then calculated to identify temporal inflection points and determine the months with peak NH_3 concentrations.

2.5.2. Gridded NH_3 enhancements

Based on the spatial distribution of NH_3 emissions and concentrations, the study domain was divided into 14 subregions (Fig. 6). Monthly variations of NH_3 columns for each subregion were obtained by aggregating the daily fitted values calculated



in Sect.2.5.1, which represent the regional background levels. NH_3 anomalies from individual measurements were then calculated by subtracting NH_3 backgrounds, as defined in Eq. (2).

$$A_i = X_i - \text{BK}_{r,m} \quad (2)$$

Where A_i is the NH_3 anomaly for the individual i -th retrieval, X_i is the observed NH_3 column, and $\text{BK}_{r,m}$ represents the NH_3 background for the region r and month m corresponding to the spatial location and observation time of retrieval i . For each grid cell, positive anomalies with occurrences of elevated concentrations ($> 1.0 \times 10^{16}$ molec/cm²) exceeding 30 days were classified as NH_3 enhancements. The frequency of such occurrences, expressed in number of days, serves as a useful indicator of enhanced emissions, such as recurring agricultural activities (Shephard et al., 2020; Warner et al., 2016).

3 Result and discussion

3.1 Spatial and temporal NH_3 distribution over East Asia

Figure 2 illustrates the three-year averaged seasonal NH_3 column concentrations retrieved from FY-4B/GIIRS observations over East Asia from July 2022 to June 2025, presented on a 0.5° by 0.5° grid at two-hour intervals. Elevated NH_3 columns, significantly above background levels, are observed over the Indo-Gangetic Plain, the North China Plain, the Sichuan Basin, and the Northeast China Plain (dashed boxes in Fig. 1). The daytime NH_3 columns reach values exceeding 4×10^{16} molec/cm², primarily driven by intensive agricultural activities and supplemented by non-negligible contributions from urban and industrial emissions. Localized weaker enhancements of NH_3 column concentrations are evident over agricultural core areas in China (including the Ningxia Irrigation Plain, the Wei River Plain, the Jiangnan Plain, and oasis agriculture in the arid regions of Xinjiang), as well as the central Deccan Plateau in India, the Mekong Delta in Vietnam, the Chao Phraya River Plain in Thailand, and the Fergana Valley in Uzbekistan (dashed boxes in Fig. S3). Most of these regions exhibit higher NH_3 columns in summer and considerable daytime variability, with large differences between morning and afternoon observations. A detailed analysis of diurnal patterns over major source regions is provided in Sect. 3.3.

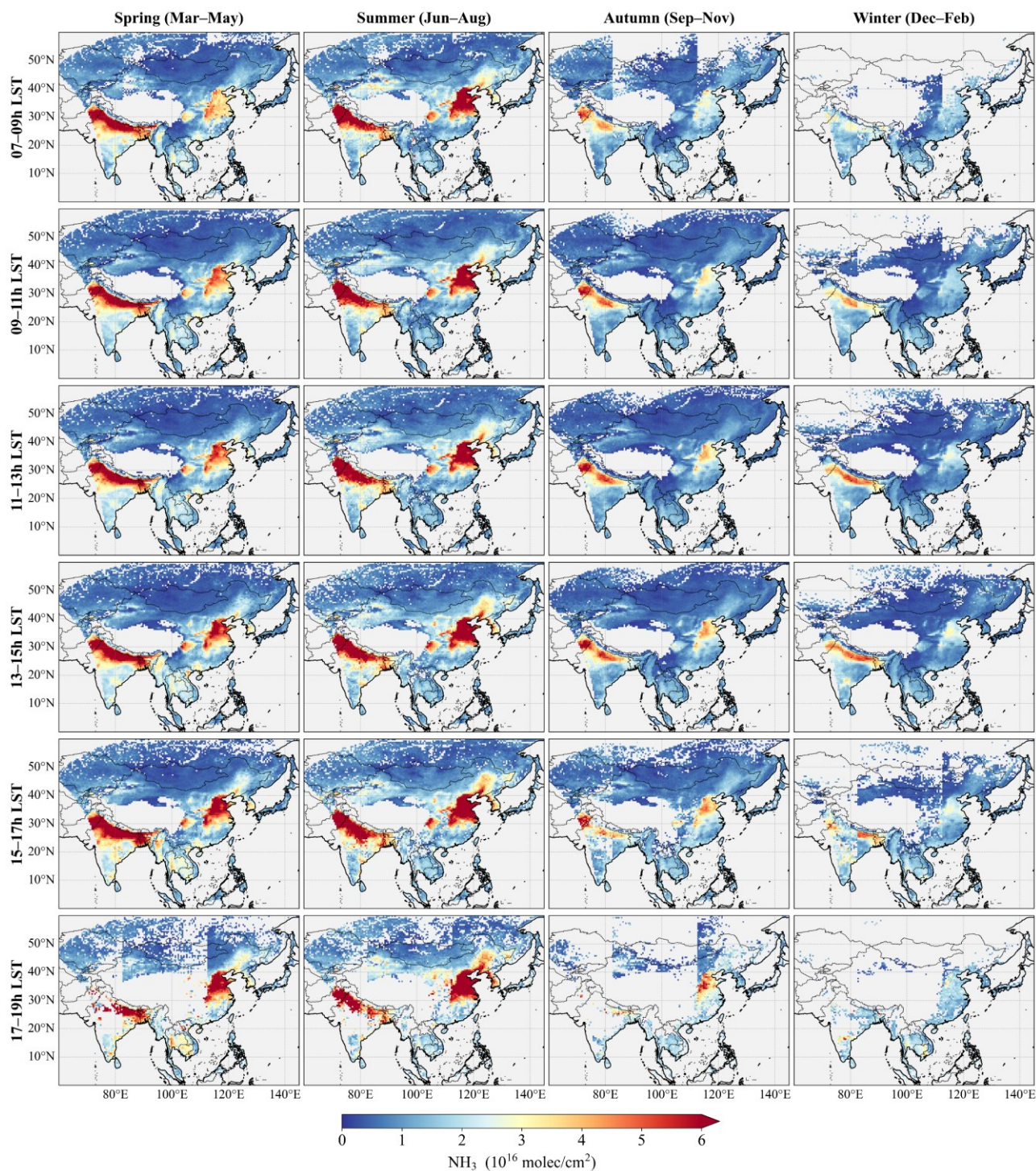


Figure 2. Seasonal maps of NH_3 columns from FY-4B/GIIRS observations from July 2022 to June 2025 averaged for every 2 hours according to local solar time (LST) on a 0.5° by 0.5° grid and for different seasons (spring: March–April–May; summer: June–July–August; autumn: September–October–November; winter: December–January–February).



270 Comparisons with the spatial distribution of NH_3 columns observed by polar-orbiting infrared sounders of IASI and CrIS
 271 show reasonable agreement, especially in regions with high NH_3 columns above 3×10^{16} molec/cm² (Fig. 3 and Fig. 4). The
 272 seasonal increases in atmospheric NH_3 are most pronounced in spring and summer. Despite generally similar seasonal and
 273 spatial patterns, inter-satellite NH_3 observations exhibit noticeable differences. Relative to the IASI observations, GIIRS
 274 typically shows very small systematic differences with fitted slopes close to unity. In contrast, GIIRS observations tend to
 275 show higher NH_3 columns than CrIS in most high-concentration regions, with mean summer differences of approximately 25–
 276 50% relative to the corresponding GIIRS values. The data point scattering in the comparison plots primarily results from
 277 spectral noise. Overall, there is good agreement between GIIRS-derived NH_3 columns and those from IASI and CrIS across
 278 different seasons.

279 To account for the effects of differing vertical sensitivities, as reflected by the AVKs, and a priori profiles among these
 280 satellites (see Fig. S1 for examples), we conducted experiments using model profile data and satellite AVKs over the North
 281 China Plain and the Northeast China Plain (30°–43°N, 110°–125°E) in June 2024 (Text S1). Model simulations of NH_3 profiles
 282 were convolved with different satellite AVKs to generate AVK-smoothed NH_3 columns, representing the NH_3 columns that a
 283 certain satellite would retrieve if the model simulations were the “truth”. We then compared AVK-smoothed NH_3 column
 284 datasets generated different satellite AVKs to evaluate the effects of different satellite vertical sensitivities. The comparison
 285 results (Fig.S5) show high correlations ($R > 0.9$) and slopes close to 1. This indicates consistency in the detection of NH_3 across
 286 different sensors, and that the effects of different AVKs and a priori profiles are small in terms of total column retrieval when
 287 comparing different satellite retrievals.

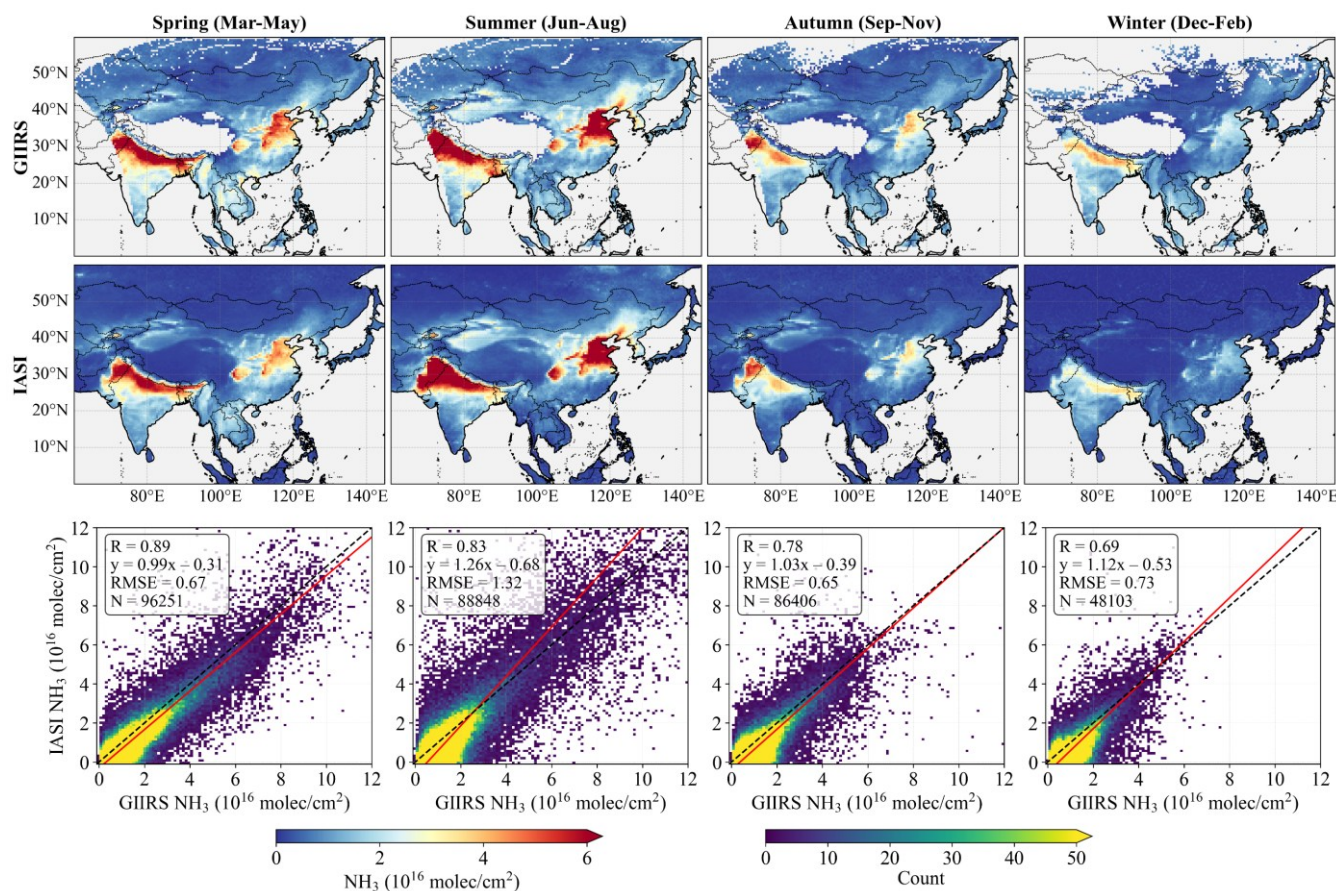


Figure 3. Comparison of NH_3 columns observed by GIIRS and IASI during morning overpasses ($\sim 09:30$ LST) from July 2022 to June 2025. Seasonal maps are presented on a $0.5^\circ \times 0.5^\circ$ grid. Scatter plots compare monthly mean NH_3 columns within the same grid cells and hourly intervals.

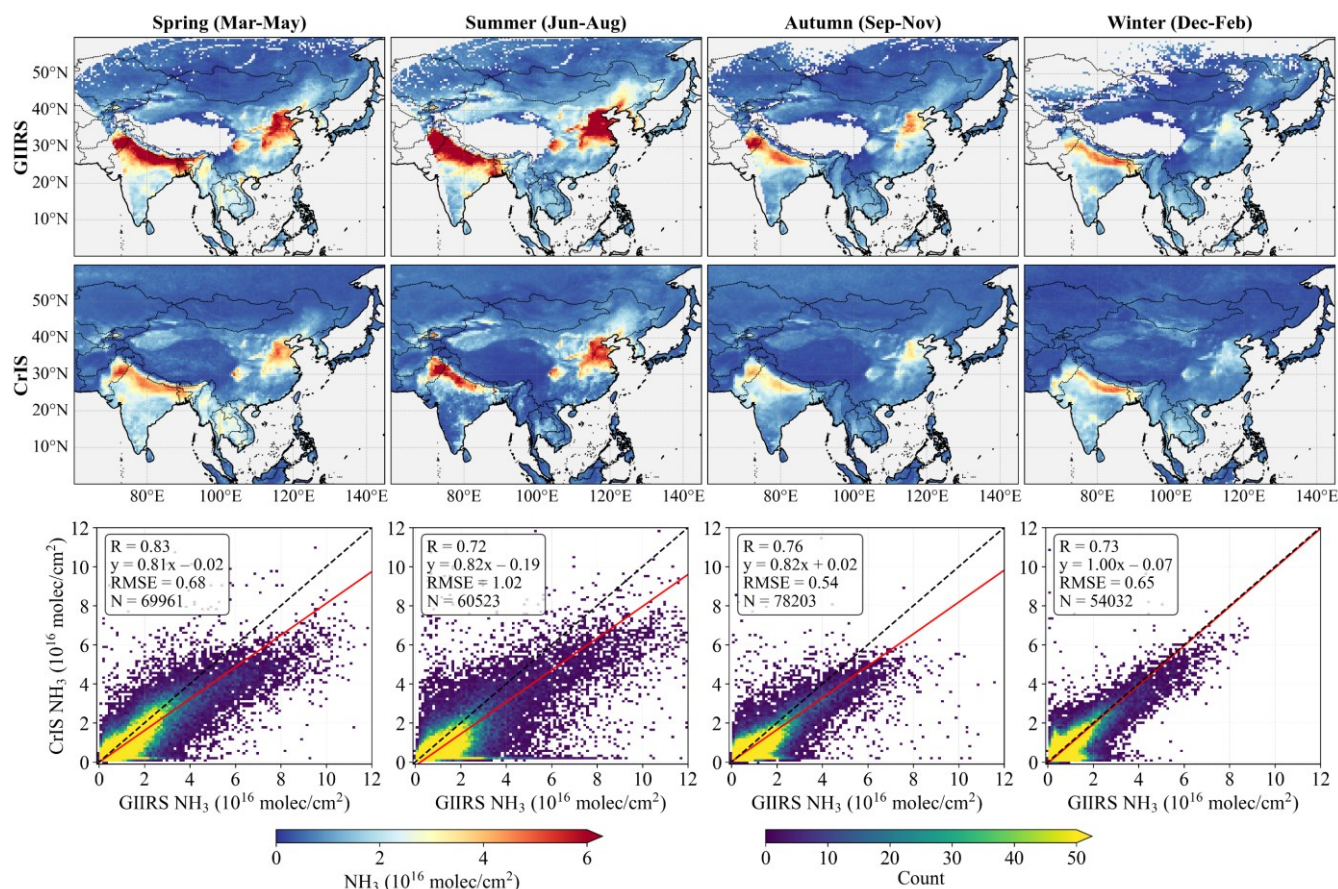


Figure 4. Comparison of NH_3 columns observed by GIIRS and CrIS during afternoon overpasses ($\sim 13:30$ LST) from July 2022 to April 2025, using the same methodology as in Fig. 3.

Figure 5 illustrates the months corresponding to the maximum NH_3 concentrations derived from GIIRS and IASI at a 0.5° grid, while the result from CrIS, which is highly scattered at this scale, is shown at 1° grid in Fig. S5. The spatial pattern shows a clear north-south gradient in the timing of NH_3 peaks. In the northern regions of East Asia, NH_3 columns generally peak in June and July, which could be attributed to enhanced volatilization from agricultural soils, livestock operations, and other sources (e.g., composting facilities and wastewater treatment plants) under high-temperature conditions (Li et al., 2024). Irrigated croplands in the North and Northeast China Plains also exhibit a secondary spring maximum (Fig. S6) associated with extensive fertilizer use and animal feeding operations. In contrast, the regions of southern China, India, and Southeast Asia, characterized by a tropical monsoon climate, exhibit earlier NH_3 peaks, generally occurring from March to May. The peak period coincides with their first cropping season, which involves intensive nitrogen fertilizer application. The warm and humid conditions in these regions further promote NH_3 volatilization from soils and livestock waste. Following the onset of the rainy season in June-July, atmospheric NH_3 concentrations decline sharply (such as R7, R8, R13, R14 in Fig. 6), primarily due to enhanced wet scavenging processes. This seasonal pattern aligns with findings from multiple studies reporting a distinct



“late dry season-early wet season” NH_3 maximum in tropical regions (e.g., [Chen et al., 2020](#); [Liu et al., 2019](#)). In addition, bimodal local maxima, with peaks of comparable magnitude, are also observed in regions such as central India (from May to September), Guangdong in southern China (typically in April and August), and the transboundary region between the Mekong Delta in Vietnam and Yunnan in China (March-April and June-July). The consistent spatial distribution of NH_3 observed by GIIRS and IASI over Southeast Asia also reflects the influence of biomass burning associated with fires on its seasonal variations. In general, the spatial and temporal distributions largely agree with the previous studies of [Van Damme et al. \(2015\)](#) and [Shephard et al. \(2020\)](#). Minor discrepancies between GIIRS and IASI result from differences in observational accuracy and retrieval algorithms, as discussed above. The results indicate that satellite-observed NH_3 seasonal cycles are driven by the interplay of agricultural activities and climatic conditions, leading to deviations from seasonal patterns of anthropogenic emissions ([Fig. 6](#)).

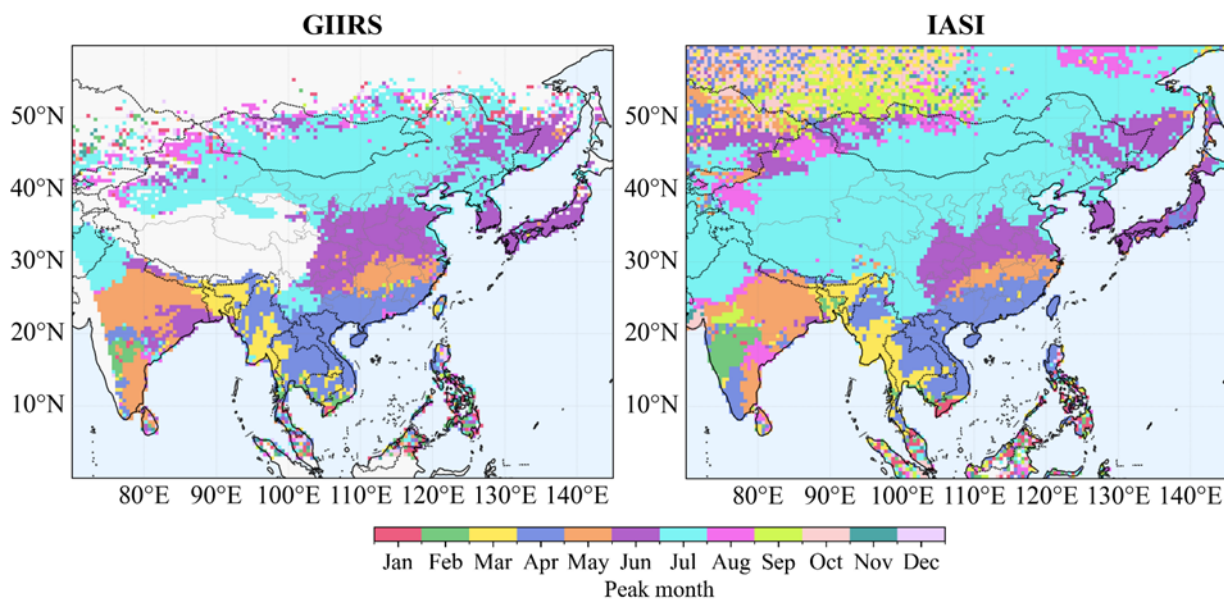


Figure 5. The months with NH_3 column peaks observed by FY-4B/GIIRS from July 2022 to June 2025 and IASI from January 2022 to June 2025 at a $0.5^\circ \times 0.5^\circ$ grid. GIIRS results for the full daytime period (07:00–19:00 LST) are presented here for clarity, as morning and afternoon observations show consistent seasonal patterns (not shown).

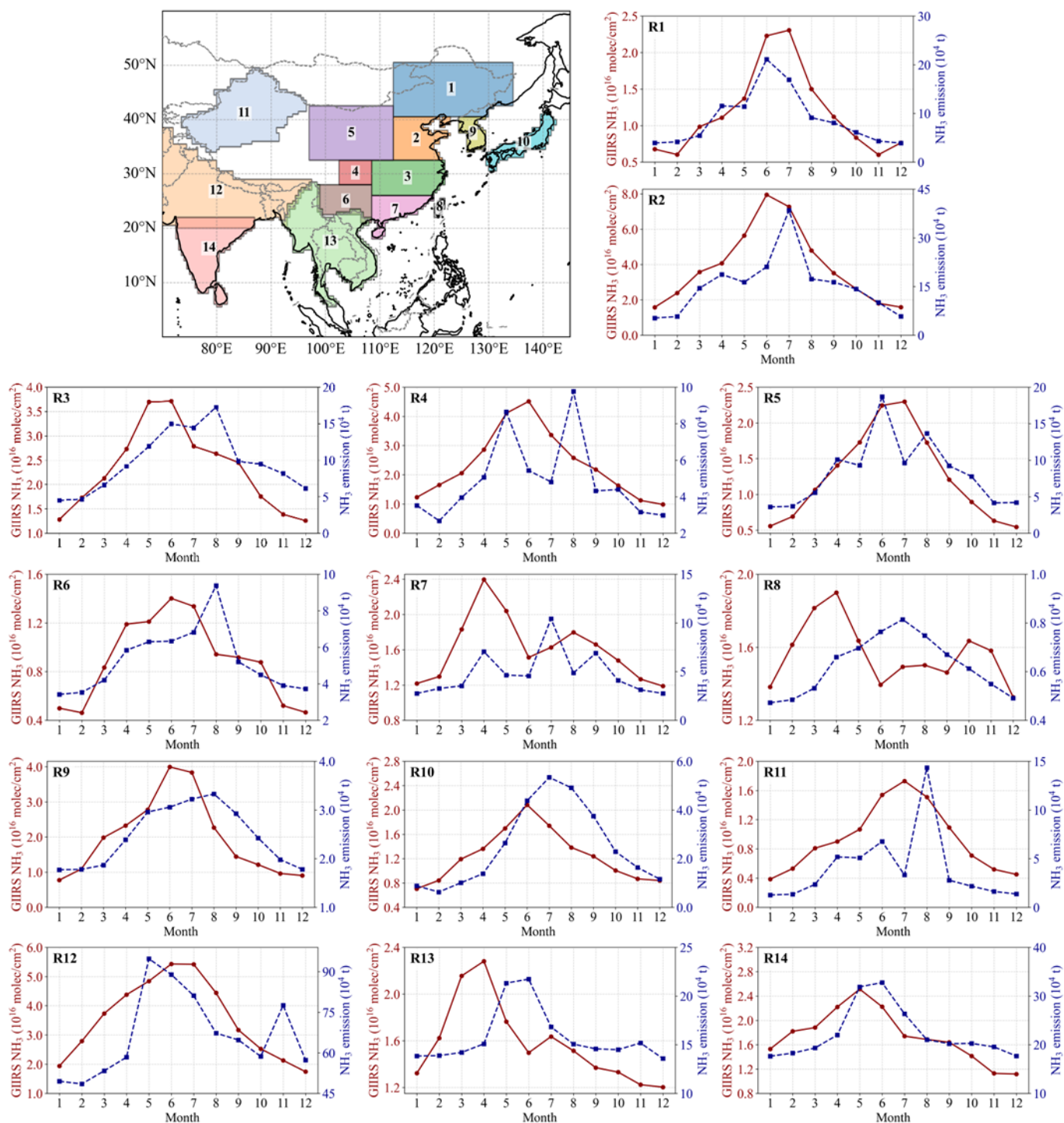


Figure 6. Monthly variations of GHIRS-derived NH_3 columns from July 2022 to June 2025 and NH_3 total emissions from the MIX inventory in 2017. Coloured boxes specify domains of 14 subregions (Sect. 2.5.2).



After removing monthly backgrounds derived from predefined regions (Fig. S7), satellite-observed NH_3 enhancements (Fig. 7) reveal a spatial pattern of anthropogenic emissions that is highly consistent with the MIX emission inventory (Fig. 1). Due to data discrepancies, the enhancement values detected by CrIS are 0.50 ± 0.64 and $0.74 \pm 0.90 \times 10^{16}$ molec/cm² lower than those detected by GIIRS and IASI, respectively. Apart from the major agricultural emission regions mentioned above, some regions (e.g. Hyderabad and Vijayawada in India) also show elevated NH_3 levels compared to the background during autumn and winter, likely influenced by dense urban and industrial activities. Differences in local overpass times and sensor sensitivities among the polar-orbiting and geostationary satellites can lead to inconsistencies in the observed NH_3 concentrations across various source regions, particularly in the Sichuan Basin, the Ningxia Irrigation Plain, and the urban and biomass-burning regions of Southeast Asia. Compared with IASI and CrIS observations at different local times, GIIRS provides consistent and reliable measurements throughout the full daytime, enabling accurate characterization of spatial and temporal variations in NH_3 concentrations across distinct emission source regions.

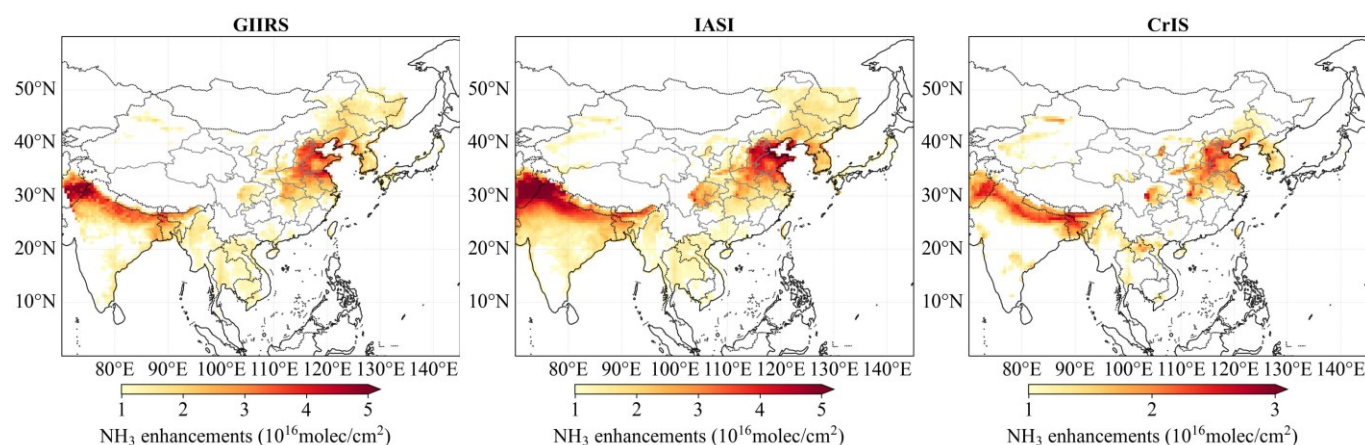


Figure 7. Spatial distribution of NH_3 enhancements derived from satellite observations (GIIRS, IASI, and CrIS). Note that the color bar for CrIS differs from those for GIIRS and IASI, and abnormal NH_3 enhancements over the Tibetan Plateau and Tibet have been excluded.

3.2 Inter-comparison of NH_3 variations at the Hefei station

To evaluate the data accuracy of GIIRS-derived NH_3 columns and assess the consistency of temporal variations with polar-orbiting satellite measurements, we compared the satellite-based observations with ground-based FTIR measurements at the Hefei station. Satellite data within a 0.25° latitude/longitude radius around the Hefei station (Fig. S8) were selected and averaged on an hourly scale. A linear regression through the origin was applied to evaluate the proportional agreement between the datasets.

Figure 8 shows scatter plots comparing NH_3 columns retrieved from satellite observations and FTIR measurements during their overlapping periods. Overall, the satellite-derived NH_3 columns show good agreement with the FTIR data, with Pearson correlation coefficients (R) exceeding 0.70, although satellite values are generally slightly higher. Among the satellites, GIIRS agrees best with FTIR in terms of highest correlation and the low root mean square error (RMSE). However, GIIRS exhibits a



relative systematic bias toward overestimating NH_3 columns, as indicated by its regression slope (1.12) being notably larger than those of IASI and CrIS. When measurement uncertainties were taken into account, regression analysis using the orthogonal distance regression (ODR) method yielded a further improvement in correlation ($R = 0.80$), while the regression slope increased to 1.24 (Fig. S9), demonstrating that GIIRS tends to produce consistently higher NH_3 columns than IASI and CrIS.

Although the overestimation of GIIRS becomes more pronounced in afternoon observations (Fig. S10), the corresponding data conversely show improved consistency, which is characterized by higher R and lower RMSE values. This is related to the fact that the inversion accuracy of GIIRS observations is affected by TC and boundary layer conditions. High NH_3 columns and significant TC represent favorable conditions for retrieving NH_3 from satellite observations (Zeng et al. 2023a; Clarisse et al., 2010). As illustrated in Fig. S11, large positive TC between 11:00 and 15:00 LST enhances measurement sensitivity, leading to lower retrieval errors. GIIRS NH_3 column retrievals are most reliable during daytime hours (07:00–19:00 LST), particularly in summer when TC exceeds 5 K.

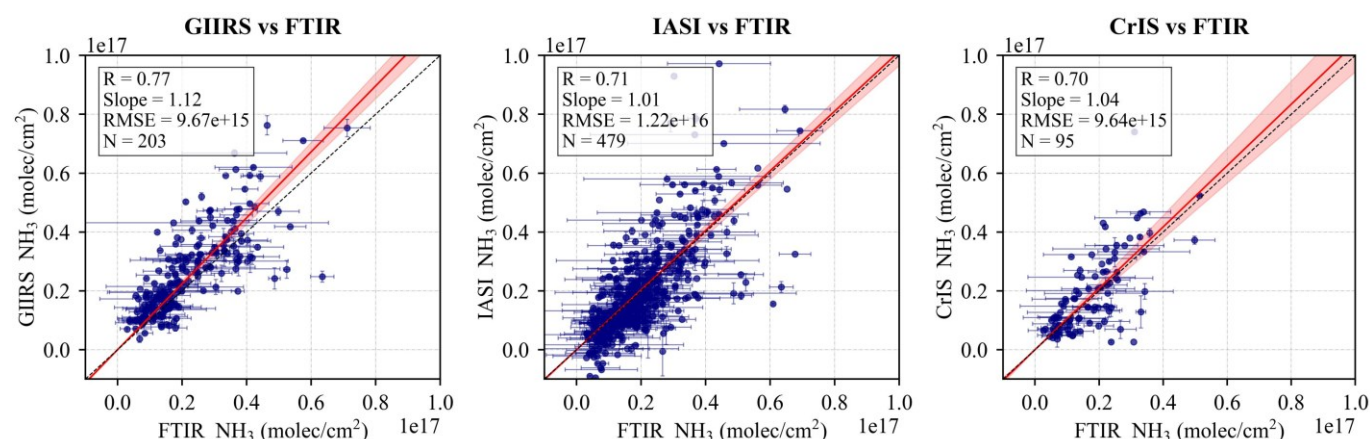


Figure 8. Cross-validation of hourly NH_3 columns from GIIRS, IASI, and CrIS with FTIR measurements at the Hefei station. The overlapping periods span January 2017 (IASI), March 2019 (CrIS), and July 2022 (GIIRS) to December 2024.

The Hefei station and its surrounding regions predominantly adopt a rice–wheat rotation, with rice and winter wheat typically sown in spring (around May) and autumn (around October), respectively. According to the MIX emission inventory, agricultural ammonia emissions in this region exhibit two primary peaks in June and August, which are associated with local agricultural practices including livestock waste management, nitrogen fertilizer application and irrigation activities during the rice growing season (Hou et al., 2020). Smaller peaks occur in October–November and April, corresponding to the rice harvest/wheat sowing period and the wheat regreening fertilization stage, respectively. Driven jointly by agricultural emission intensity and meteorological conditions such as high temperatures, atmospheric NH_3 concentrations observed by satellites and ground-based FTIR show consistent seasonal cycles, peaking in summer (June–August) and reaching a minimum in winter (November–January). Figure 9 shows the monthly NH_3 time series observed by satellites and FTIR at different local overpass times. GIIRS and IASI show closely matched NH_3 peaks in June. The systematic overestimation of peak values by GIIRS



relative to CrIS and FTIR is consistent with an inherent data bias as shown in Fig. 8.

Notably, GHIRS-derived NH_3 columns in June 2024 were significantly higher than those in the same month of 2023 and 2025, with increases of 1.46- and 1.67-times during morning overpass time ($\sim 9:30$ LST), and 1.35- and 2.15-times during afternoon overpass time ($\sim 13:30$ LST), respectively. Such pronounced variability is likely linked to extreme weather events reported in the region, such as persistent heatwaves and abrupt drought–flood transitions (Zhou et al., 2025; Ding et al., 2024). Morning observations from IASI align with GHIRS data, showing that NH_3 concentrations in June 2024 reached 1.43 to 2.62 times the levels recorded in the years 2017–2025 (specifically, 1.59 times that of 2023 and 1.53 times that of 2025). Similar interannual changes were also captured by CrIS and FTIR in June 2024, showing that NH_3 levels increased by factors of 1.17–1.53 for CrIS and 1.40–2.28 for FTIR compared to earlier years, despite data gap in June 2023 for FTIR. Similar interannual changes were observed by CrIS and FTIR in June 2024, with NH_3 levels increasing by factors of 1.17–1.53 and 1.40–2.28 compared with previous years, respectively, despite a data gap in June 2023 for FTIR.

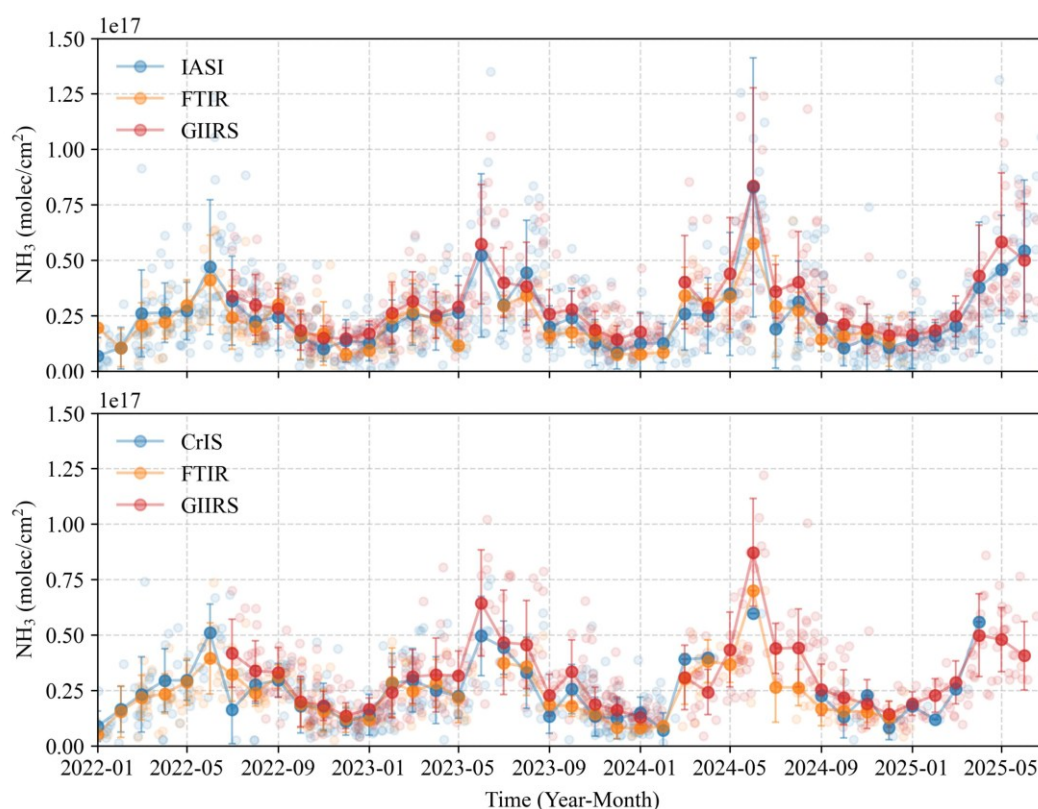
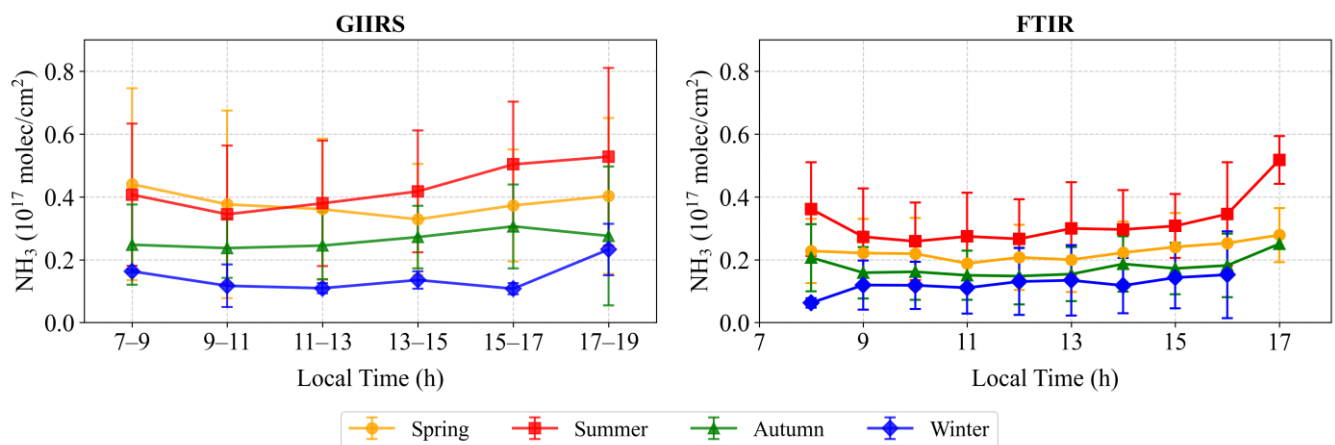


Figure 9. Timeseries of monthly NH_3 columns at the Hefei station from satellite-based and ground-based observations at different local overpass times of polar-orbiting satellites for morning ($\sim 9:30$ LST) and afternoon ($\sim 13:30$ LST). The light-colored, semi-transparent points represent daily mean values at different local times.

Comparing GHIRS-based NH_3 columns at different local times, afternoon concentrations are generally higher than those in the morning, with the largest differences observed in summer (July–August) and the smallest in autumn and winter. To more



392 accurately characterize daytime NH_3 variations, we further applied strict data filtering criteria by retaining only retrievals with
393 $\text{TC} > 5 \text{ K}$, to ensure the data have high sensitivity to the surface layer NH_3 . Over the three-year period, 37 high-quality
394 observation days were identified, each providing six consecutive two-hour interval observations from 07:00 to 19:00 LST (Fig.
395 S12). The maximum diurnal amplitude occurs in summer, reaching over $1.5 \times 10^{16} \text{ molec/cm}^2$. Except for autumn, all three
396 other seasons exhibit relatively high NH_3 concentrations around 7:00 and 17:00 LST, a pattern that aligns well with the diurnal
397 variations reported by Wang et al. (2022) based on FTIR measurements (Fig. 10). However, NH_3 retrievals from FTIR lack
398 sufficient valid observations within a single day, making it difficult to consistently capture the intra-day variability in NH_3
399 across different dates.



400
401 **Figure 10. Daytime NH_3 variations observed by GIIRS and FTIR in different seasons. The seasonal mean NH_3 from GIIRS are**
402 **calculated based on 37 high-quality days in Fig. S12.**

403 Moreover, the FTIR station is situated in a transitional zone between the urban and suburban areas. A spatial domain with
404 a radius of 0.25° used in this study encompasses GIIRS sampling points from both urban and agricultural regions (Fig. S8). To
405 assess spatial variability of NH_3 , GIIRS retrievals with $\text{TC} > 5\text{K}$ within this spatial domain were classified into urban and non-
406 urban categories, and their daytime variations were statistically analyzed across seasons over three years. As shown in Fig.
407 S13, NH_3 concentrations in non-urban areas are consistently and significantly higher than those in urban areas during spring
408 and summer, indicating the strong contribution of agricultural activities to ambient NH_3 levels. Particularly in spring,
409 statistically significant differences are most pronounced during 7:00–9:00 and 17:00–19:00 LST, corresponding to time
410 windows of fertilizer application and livestock activity. During winter, higher NH_3 levels in the morning and late afternoon are
411 mainly observed in urban areas, likely reflecting the impact of traffic emissions. These findings highlight the importance of
412 high-frequency satellite observations for the dynamic monitoring of NH_3 variations, and the contribution of agricultural activity
413 in shaping the diurnal NH_3 variability.

414 3.3 Daytime NH_3 variations in major agricultural regions

415 We focused on eight major agricultural source areas with a high proportion of irrigated cropland, located in the North



China Plain and the Northeast China Plain, the Sichuan Basin, and the Indo-Gangetic Plain (black boxes in Fig. 1), to further investigate daytime variations in NH_3 columns. To ensure sufficient measurement sensitivity to near-surface NH_3 , only GIIRS observations with TC greater than 5 K were retained, thereby excluding cases with low information content. Compared to the dataset used in Sect. 3.1, the fractions of valid observations remaining in the three study regions were about 83 %, 88 %, and 73 %, respectively. During autumn and winter, available observations are sparse in the early morning and late afternoon. Here, GIIRS-observed daytime variations of NH_3 columns across different seasons (Fig. 11) and the corresponding spatial distributions for each study region (Figs. 12–14) are presented, with comparisons to anthropogenic NH_3 emissions (Fig. S14) and GEOS-CF model simulations (Figs. S15–18). Despite significant differences of NH_3 columns between the model-simulated data and satellite-based observations, we focused on analyzing the daytime variations and their spatial distributions in representative months of May–June (NH_3 peak months) in 2025.

The North China Plain is characterized by extensive irrigated croplands under winter wheat–maize rotation and widespread small-scale livestock farming concentrated in east-central provinces, including Henan, Shandong, and Hebei. Due to intensive agricultural and livestock activities, dense industrial emissions and heavy urban traffic, the region ranks among the most polluted regions in China. The spatial distribution of local NH_3 high values across different seasons shows considerable variations, especially during the late afternoon in the spring and summer, which may indicate a change in emission hotspots (Fig. 12). Across the three selected areas (A1–A3), GIIRS observations reveal a consistent temporal pattern of NH_3 columns, with values increasing from early morning to late afternoon in summer but generally declining after 15:00 in other seasons. In summer, the mean variations in GIIRS NH_3 column amplitudes for the afternoon and morning are 22%, 27%, and 29%, respectively, while in May and June 2025, these variations increased to 56%, 38%, and 32 %, respectively.

The Northeast China Plain is a key grain production region, particularly for maize, soybeans, and rice. Agriculture is highly mechanized, and livestock farming is carried out on a large scale. Due to concentrated emissions and fixed locations, the spatial pattern of NH_3 enhancements shows little variation at different local times (Fig. 12). The B1 area is located in the estuarine delta, with large cities such as Shenyang and Anshan to the east. Due to low population density and limited industrial activity, NH_3 emissions in this area are primarily associated with fertilizer application and animal husbandry, resulting in relatively low levels than other areas. GIIRS observations show that NH_3 columns are at markedly reduced levels, approximately 52% of those in the North China Plain, but follow a similar diurnal cycle, with the variation amplitude in summer being comparable (25% for 3 years, 43% for May–June 2015). The difference is that in winter, the diurnal variation also shows higher NH_3 columns in the morning (7:00–9:00 LST), which may be related to traffic emissions and the effects of meteorological conditions (such as temperature and humidity changes) in the early morning. Ground-based studies have reported that the peak atmospheric NH_3 concentration typically occurs in the morning, as observed in the urban area of Beijing (Gu et al., 2022) and in the rural areas of Xianghe (He et al., 2020), Xinxiang (Teng et al., 2017), Shanghai (Wang S. et al., 2015), and Hefei (Wang et al., 2022).

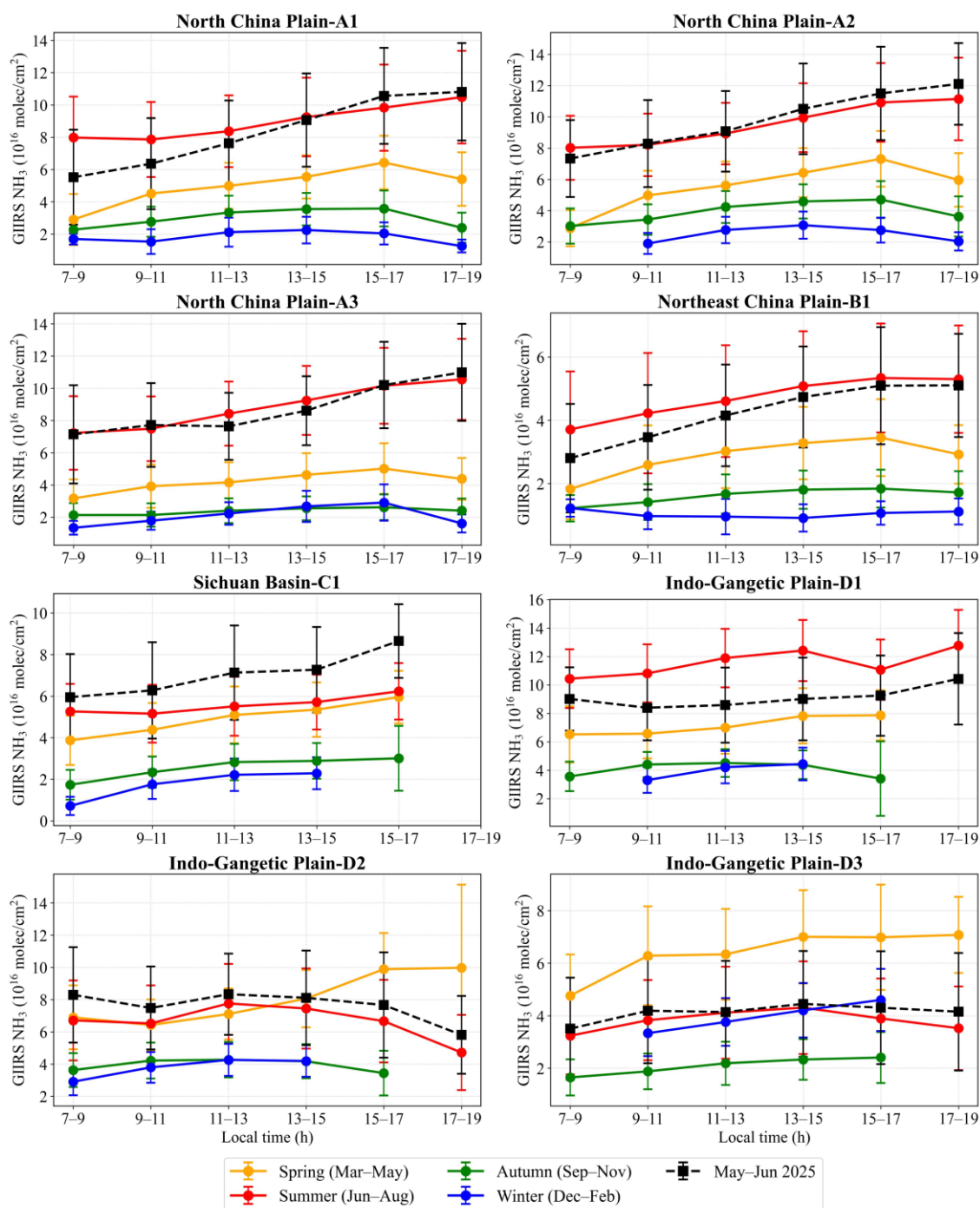


Figure 11. Daytime NH_3 variations for major agricultural emission areas observed by GIIRS in different seasons.

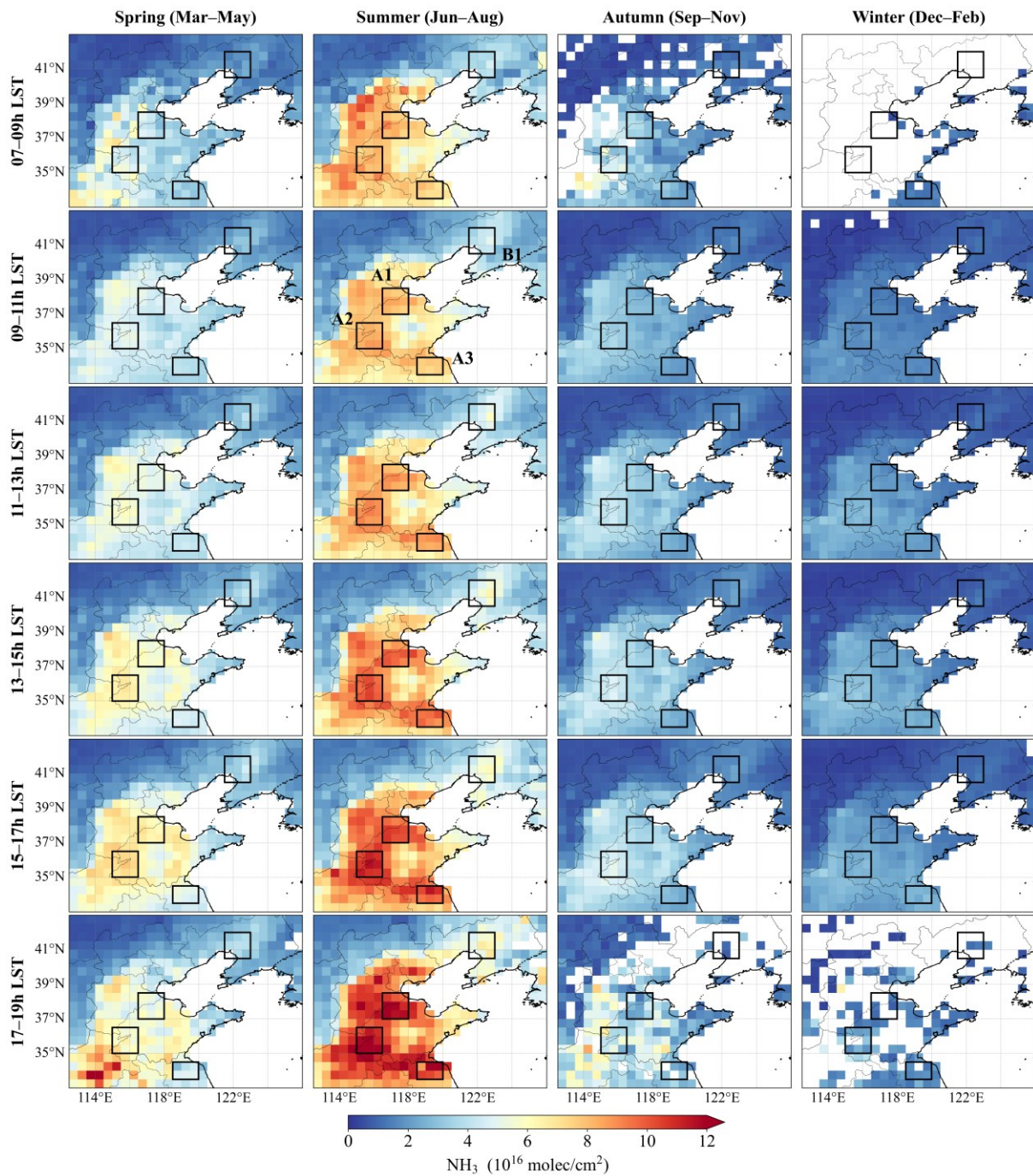


Figure 12. Daytime NH_3 variations observed by GIRS from July 2022 to June 2025 in the North China Plain and the Northeast China Plain.

The Sichuan Basin, located in southwestern China, is an important agricultural region, producing rice, rapeseed, vegetables, and citrus fruits, with intensive irrigation and high crop density. Satellite observations show that NH_3 is



significantly enhanced in the western regions, particularly along the Mianyang-Deyang-Chengdu-Meishan-Leshan corridor (Fig. 7 and Fig.13), reflecting both intensive agricultural activity and urban-industrial emissions. The basin's unique topography and meteorological conditions such as frequent temperature inversions result in very few valid NH_3 observations after 17:00 LST. Across different seasons, NH_3 columns generally exhibit an increasing trend from morning to afternoon. In spring and summer, seasonal mean NH_3 concentrations show relatively small differences because agricultural sources dominate and vertical mixing is enhanced by changes in boundary layer height, with daytime NH_3 variations of 27% and 23%, respectively. The largest daytime variation occurs in winter, when afternoon values are 1.46 times higher than those in the morning.

The Indo-Gangetic Plain, South Asia's most extensive alluvial plain, spans Pakistan, northern India, and Bangladesh. The region is densely populated and intensively farmed, producing rice, wheat, sugarcane, and vegetables, often under irrigated and mechanized conditions. Fertilizer application, livestock excretion, industrial activities, and high population density lead to significant NH_3 and reactive nitrogen emissions, reaching their maximum over the Punjab, Pakistan. We selected three areas that are located in Punjab, Uttar Pradesh, and Bangladesh, respectively (Fig.14). Differences in NH_3 emission sources and climatic conditions across these regions lead to pronounced seasonal variations in NH_3 concentrations (Fig. S3). The daytime variation amplitudes of NH_3 columns are highest in spring, which are 17%, 32%, and 21% for D1, D2, and D3, respectively. However, under the coupled conditions of abundant precipitation and strong solar radiation in summer, NH_3 columns in the D2 and D3 areas reach their peak around 13:00 LST.

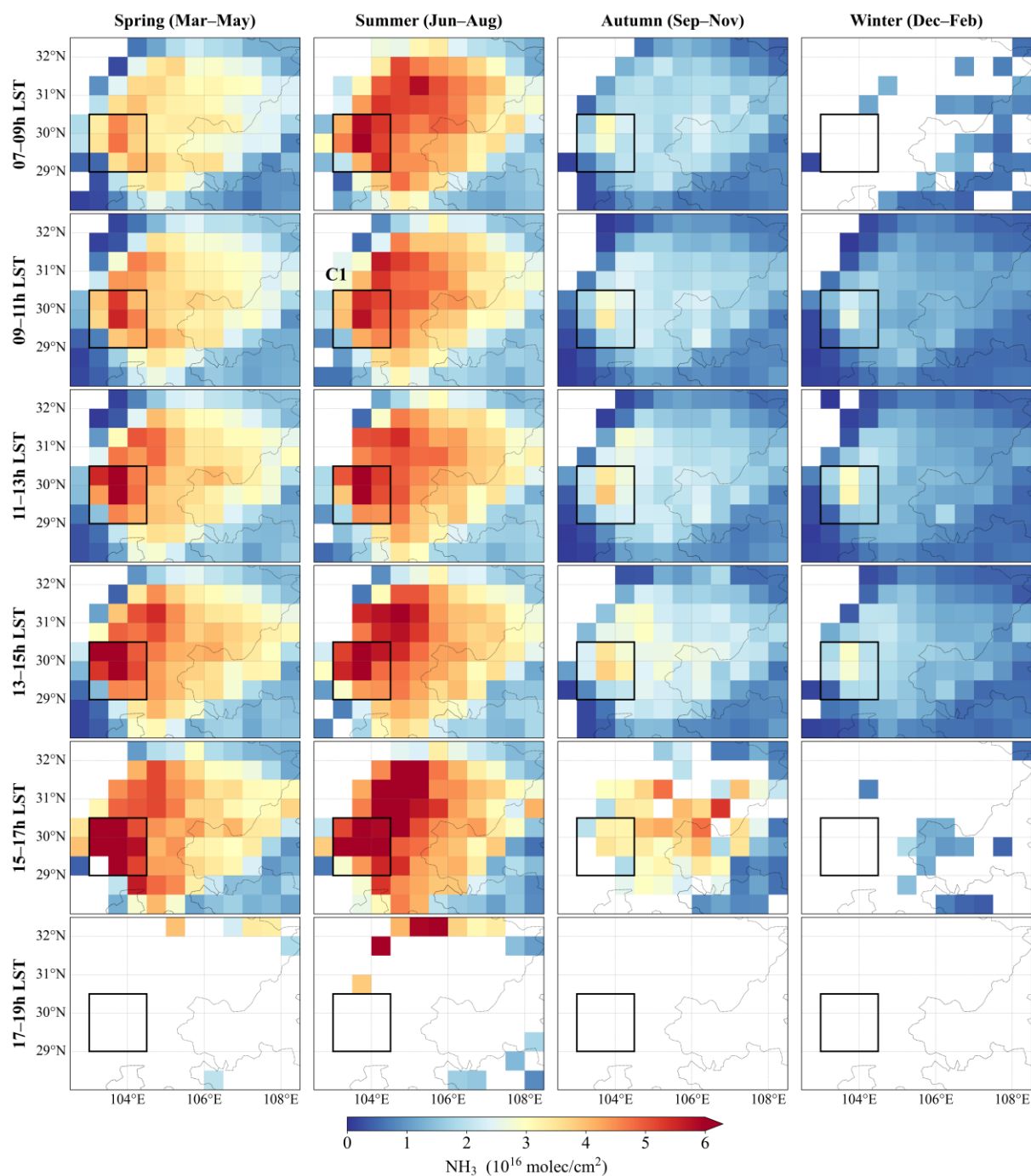


Figure 13. Daytime NH_3 variations observed by GHIRS from July 2022 to June 2025 in the Sichuan Basin.

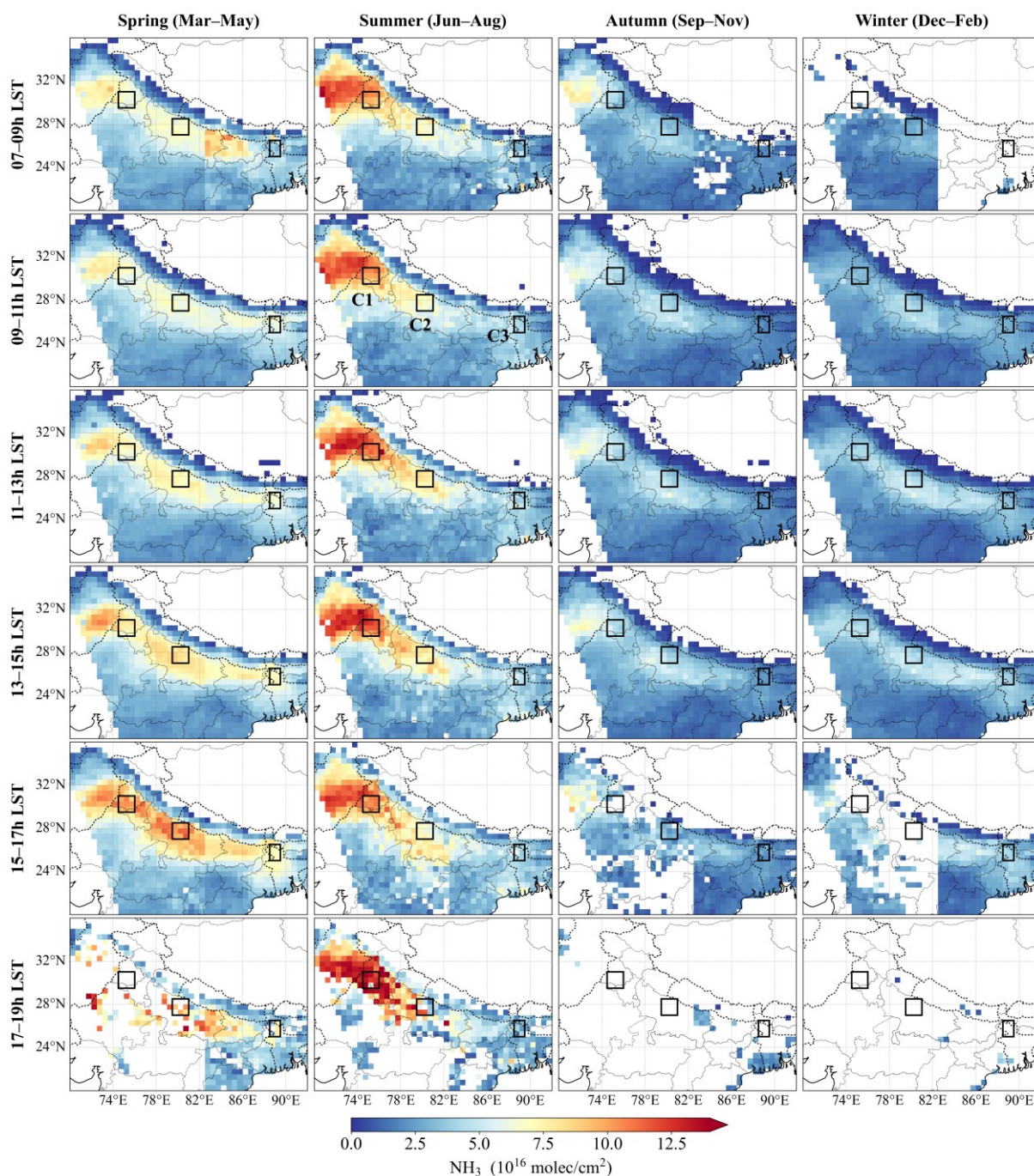


Figure 14. Daytime NH_3 variations observed by GHIRS from July 2022 to June 2025 in the Indo-Gangetic Gangetic Plain.

The diurnal variation of atmospheric NH_3 column concentrations is primarily influenced by surface emissions, boundary layer dynamics, and gas-particle partitioning associated with meteorological conditions (Behera et al., 2013; Lan et al., 2024). In these main agricultural source areas, NH_3 concentrations generally rise from morning to afternoon, which is driven by



diurnal variations in temperature and humidity that shift the gas-particle equilibrium toward the gaseous phase. The daytime NH_3 variations simulated by the GEOS-CF model for May-June 2025 range from 7% to 36%, which is slightly lower than the variations observed by GIIRS (10% to 56%). However, the GEOS-CF model was unable to accurately reproduce the spatial pattern of NH_3 enhancements in the Sichuan Basin (Fig. S17), which can be largely attributed to the influence of complex topography and local climatic conditions. After considering about the vertical sensitivities of satellite retrievals, the AVK-smoothed model data resulted in an overall reduction of $12 \pm 38\%$ in the model NH_3 columns over the Sichuan Basin. However, considerable discrepancies in the spatial distribution remain relative to the satellite observations. Figure 15 presents a cross-comparison between the satellite-derived NH_3 columns and the AVK-smoothed model data in May-June 2025. Over the North China Plain and the Northeast China Plain, the model underestimates NH_3 columns by 62% on average, with a standard deviation of 45%, whereas over the Sichuan Basin, the underestimation reaches 65%, with a standard deviation of 30%. In contrast, the model generally overestimates NH_3 columns over the Indo-Gangetic Plain. Regarding spatial and temporal pattern of diurnal variations (Figs. 19–22), the largest discrepancies are observed in the areas of C1 in the Sichuan Basin and D1 in the Indo-Gangetic Plain, suggesting that the model has limited capability to simulate NH_3 in these areas and may require improvements through satellite-observed constraints to improve simulation accuracy.

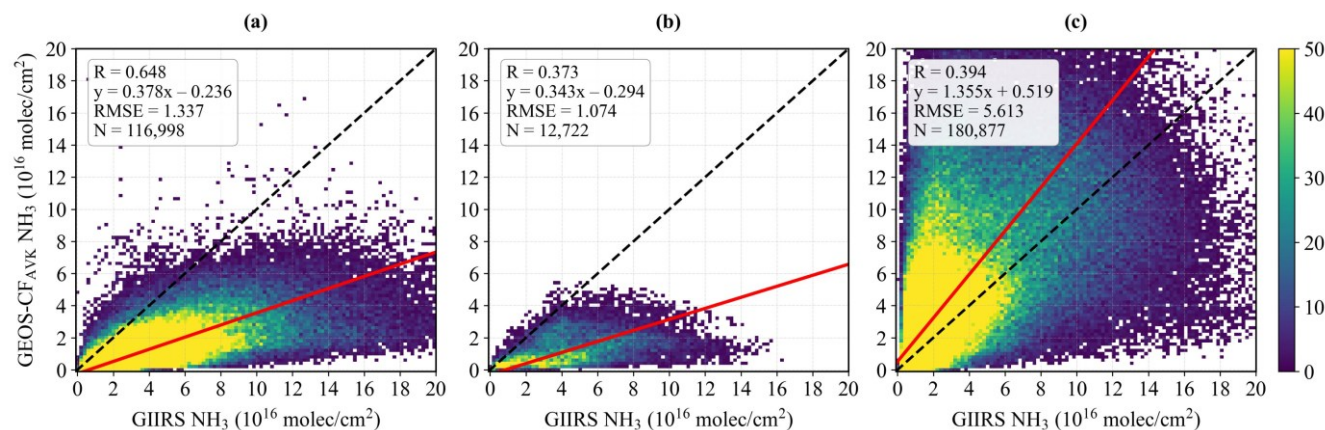


Figure 15. Comparison of NH_3 columns in May and June 2025 from GIIRS observations and GEOS-CF AVK-smoothed model simulations for (a) the North China Plain and the Northeast China Plain, (b) the Sichuan Basin, and (c) the Indo-Gangetic Plain. The model data is calculated by applying the AVKs from satellite retrievals to NH_3 profile (see Text S1).

4 Conclusions and Perspectives

The geostationary satellite observations from FY-4B/GIIRS provide a unique opportunity to monitor the diurnal variations of atmospheric NH_3 over East Asia, yet current research on this topic remains limited. In this study, we present a comprehensive analysis of three years of FY-4B/GIIRS observations from July 2022 to June 2025, revealing the spatiotemporal variations of NH_3 across East Asia and the distinctive daytime variations in agricultural emission regions.

NH_3 column concentrations from GIIRS observations exhibit pronounced local enhancements over major emission regions, particularly flat agricultural plains (e.g. the North China Plain, Northeast China Plain, the Indo-Gangetic Plain, the



506 Ningxia Irrigation Plain, the Wei River Plain, the Jiangnan Plain, the Mekong Delta in Vietnam, the Chao Phraya River Plain
 507 in Thailand) with intensive crop cultivation and animal husbandry, and smaller-scale accumulation in topographically confined
 508 areas such as valleys and basins (e.g. the Sichuan Basin, oasis agriculture in the arid regions of Xinjiang in China, the Fergana
 509 Valley in Uzbekistan). After removing background levels derived from predefined reference regions, NH_3 enhancements show
 510 a consistent spatial pattern with anthropogenic emissions from the bottom-up MIX Asia emission inventory, and highlight
 511 these major emission source regions. The spatial distribution of NH_3 derived from GIIRS matches well with polar-orbiting
 512 satellite observations from IASI and CrIS.

513 The timing of peak NH_3 in the seasonal cycle primarily reflects agricultural activities related to fertilizer application, and
 514 is modulated by climatic factors such as temperature. For example, NH_3 columns generally exhibit a summer maximum (June-
 515 July) and a secondary spring maximum (April) in the North China Plain and Northeast China Plain. In southern regions of
 516 China, India, and Southeast Asia, NH_3 peaks during the late dry season (March-May) and declines sharply in the early wet
 517 season (June-July). Overall, regional differences in the timing of peak months follow a north-south gradient. Comparison with
 518 ground-based FTIR measurements and satellite-based IASI and CrIS observations show generally good agreement, yielding a
 519 correlation coefficient of 0.77 and an RMSE of 9.67×10^{15} molec/cm² relative to FTIR, while also consistently capturing the
 520 temporal variability of NH_3 columns.

521 This study reports the detailed daytime variations of NH_3 columns observed by FY-4B/GIIRS over the North China Plain,
 522 the Northeast China Plain, the Sichuan Basin, Hefei, and the Indo-Gangetic Plain. The NH_3 columns during the day generally
 523 increase from early morning to late afternoon, showing similar temporal variations to those observed by ground-based FTIR
 524 measurements at Hefei and simulated by GEOS-CF model in main agricultural source areas. Crucially, GIIRS provides
 525 substantial advantages by accurately characterizing spatial distributions and enabling continuous daily observations. GIIRS in
 526 the infrared is complementary to the Geostationary Environment Monitoring Spectrometer (GEMS; Kim et al., 2020), which
 527 operates in the ultraviolet/visible (UV/VIS) spectral range and provides hourly observations of trace gases such as NO_2 and
 528 SO_2 over East Asia. The synergy between GIIRS and GEMS enables joint investigations of NH_3 and NO_2 , offering new
 529 opportunities to better quantify reactive nitrogen budgets and assess their impacts on air quality and climate. The planned
 530 launch of FY-4C/GIIRS in late 2025, together with FY-4B, will further enhance observational capabilities by providing broader
 531 spatial coverage and higher-frequency measurements. This emerging satellite constellation will offer unprecedented
 532 opportunities for monitoring diurnal cycles and emission processes across East and South Asia, thereby improving our
 533 understanding of atmospheric chemistry and supporting the development of more effective air pollution mitigation strategies.

534
 535



536 **Data availability.**

537 The GIIRS NH₃ data (July 2022 to June 2025) used in this study is publicly available on Zenodo
538 (<https://doi.org/10.5281/zenodo.17193848>). Further updates on the data will be provided on the project website
539 (<https://fengyunair.github.io/>). The IASI L2 ammonia satellite observations are available from the AERIS data infrastructure
540 (<https://iasi.aeris-data.fr/>, last access: 16 September 2025). The CrIS Fast Physical Retrieval (CFPR) ammonia dataset is
541 created by the Environment and Climate Change Canada is publicly available
542 (https://hpfx.collab.science.gc.ca/~mas001/satellite_ext/cris/). The Hefei FTIR data are retrieved by Key Laboratory of
543 Environmental Optics and Technology, Anhui Institute of Optics and Fine Mechanics, Chinese Academy of Sciences (Wang
544 et al., 2022). The MIX emission inventory can be requested from the MEIC team (http://meicmodel.org.cn/?page_id=2721).
545 The GEOS-CF model data are available from High Performance Computing for Science, NASA Center for Climate Simulation
546 (<https://portal.nccs.nasa.gov/datashare/gmao/geos-cf/v1/das/Y2025/>, last access: 10 August 2025).

547 **Author contributions.**

548 MS and ZZ designed the study. MS carried out the result analysis and prepared the manuscript. ZZ and JH developed the
549 GIIRS NH₃ retrieval algorithm. MS, RZ, SH, and SL collected and analyzed the emission sets. WW provided the FTIR data.
550 RD, LZ, HC, ZC, and YG provided guidance on interpreting the satellite data and model simulations. ML provided guidance
551 on analyzing emission inventory. NG, LC, MVD, and CC provided the IASI data and guided the interpretation. MWS provided
552 the CrIS data and guidance. LL, CQ, FL, and CH provided guidance on analyzing GIIRS spectra. All authors reviewed and
553 proofread the paper. LC is a senior research associate supported by the Belgian F.R.S.-FNRS.

554 **Competing interests.** The contact author has declared that none of the authors has any competing interests.

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